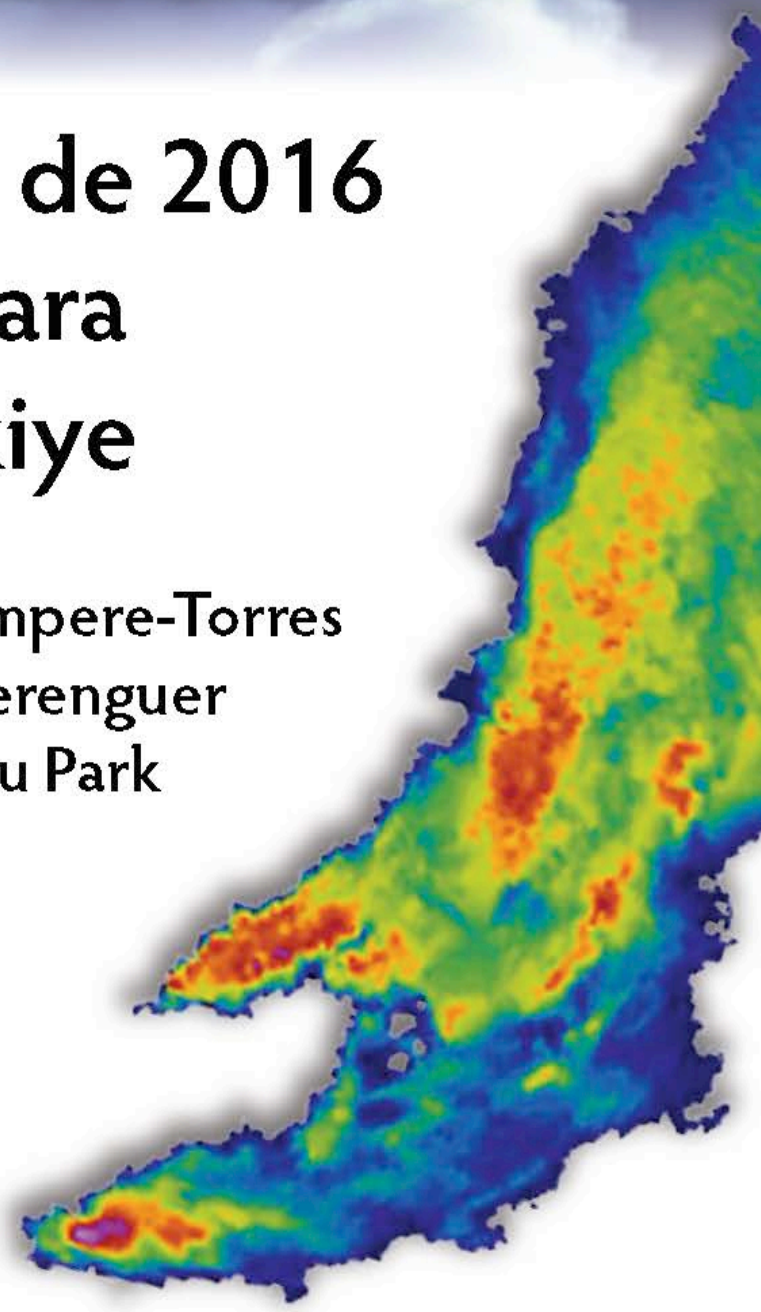


TRAINING PROGRAM ON METEOROLOGICAL RADARS AND ADVANCED QUANTITATIVE APPLICATIONS

4 - 8 April de 2016
Ankara
Türkiye

Prof. Daniel Sempere-Torres
Dr. Marc Berenguer
Dr. Shinju Park



Centre de Recerca Aplicada en Hidrometeorologia
UNIVERSITAT POLITÈCNICA DE CATALUNYA

T.C.
Orman ve Su İşleri Bakanlığı
Meteoroloji Genel Müdürlüğü

VAISALA



Ankara, 4-8 April 2016

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VAISALA

PROGRAM

FIRST DAY	
09:30 – 09:45	Introduction to the course.
09:45 – 10:30	Introduction to the meteorological radar and its applications.
10:30 – 11:00	*Coffee-break*
11:00 – 12:00	How meteorological radars work: from the radar signal to radar measurements.
12:00 – 14:00	*Lunch*
14:00 – 15:00	Introduction to the software and visualisation tool for the course
15:00 – 15:30	**Practice on computer:** Visualisation of radar data. Analysis of case studies. Exercises
15:30 – 16:00	*Coffee-break*
16:00 – 16:30	Ground clutter and non-meteorological echoes. Basic and advanced processing.
16:30 – 17:00	**Practice on computer:** Ground clutter recognition and beam blocking correction.

SECOND DAY

09:30 – 11:00	The challenge of using meteorological radars for quantitative purposes: Quantitative Precipitation Estimation (QPE).
10:30 – 11:00	*Coffee-break*
11:00 – 12:00	Attenuation by intense rain: the problem and possibilities of correction (using differential phase and other advanced algorithms).
12:00 – 12:30	Effects with the distance to the radar.
12:30 – 14:00	*Lunch*
14:00 – 14:30	**Practice on computer:** Path and radome attenuation. Effects with the distance to the radar.
14:30 – 15:30	Vertical structure of the precipitation and representativeness of radar measurements at ground: Bright Band (BB) and Vertical Profile of Reflectivity (VPR) correction.
15:30 – 16:00	*Coffee-break*
16:00 – 17:00	**Practice on computer:** BB identification and VPR correction.

THIRD DAY	
09:30 – 10:00	Reminding basic concepts.
10:00 – 10:30	*Coffee-break*
10:30 – 12:00	Dual-polarization radars: the added value of polarimetric variables.
12:00 – 12:30	**Practice on computer:** Visualisation of polarimetric data and hydrometeor classification examples. Analysis of case studies.
12:30 – 13:30	*Lunch*
13:30 – 15:00	Case Study: The Colorado flood of 2013.
15:00 – 15:30	*Coffee-break*
15:30 – 16:30	Network of radars: methodologies to compose multiple radars. Basic methodologies and advanced 3D composite products.

FOURTH DAY	
09:30 – 10:15	Comparison of radar QPE with raingauge network estimates. Basic methodologies and corrections.
10:15 – 11:00	**Practice on computer:** Radar and raingauge comparison and blending.
11:00 – 11:30	*Coffee-break*
11:30 – 12:00	Blending radar and raingauge data. Advanced geostatistical techniques.

12:00 – 12:30	Radar and raingauge blending: Case studies.
12:30 – 13:30	*Lunch*
13:30 – 14:15	Rainfall forecasting and nowcasting: state of the art on Quantitative Precipitation Forecasting (QPF).
14:15 – 15:00	Methodologies for precipitation nowcasting using radar observations.
15:00 – 15:30	*Coffee-break*
15:30 – 16:00	**Practice on computer:** Nowcasting based on radar observations.
16:00 – 16:30	Rainfall nowcasting at European scale: the EDHIT project.

FIFTH DAY	
09:30 – 10:45	Hydrological applications of radar and early warnings at basin scale using radars.
10:45 – 11:15	*Coffee-break*
11:15 – 11:45	Flash flood early warnings: Agramunt case study.
11:45 – 12:30	Debris Flows early warnings using radar.
12:30 – 13:45	*Lunch*
13:45 – 14:45	Dealing with uncertainties in radar products.
14:45 – 15:15	*Coffee-break*
15:15 – 15:45	Advanced products and services using radar: Flood alert for cities and aviation products.
15:45 – 16:15	Open discussion.
16:15 – 16:30	Quality questionnaire and delivery of Diplomas.

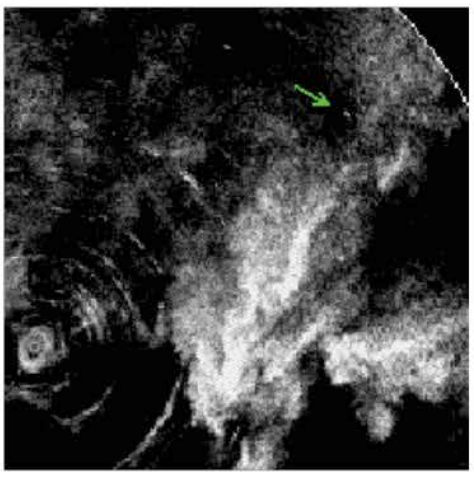
Introduction to the course. Introduction to the meteorological radar and its applications.

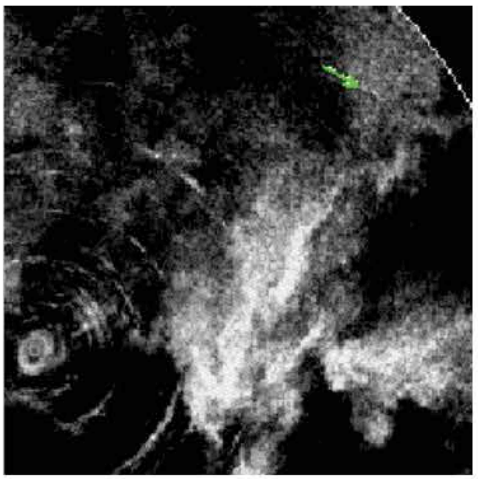
Centre for Applied Research in Hydrometeorology
CRAHI
Universitat Politècnica de Catalunya
Barcelona (Spain)

T.C.
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Meteoroloji Genel Müdürlüğü

Meteorological Radar

- Acronym for "RAdio Detection And Ranging"
  The invention that changed the world; R. Buderi, 1996.
- Start used for METEOROLOGICAL PURPOSES just after WW II



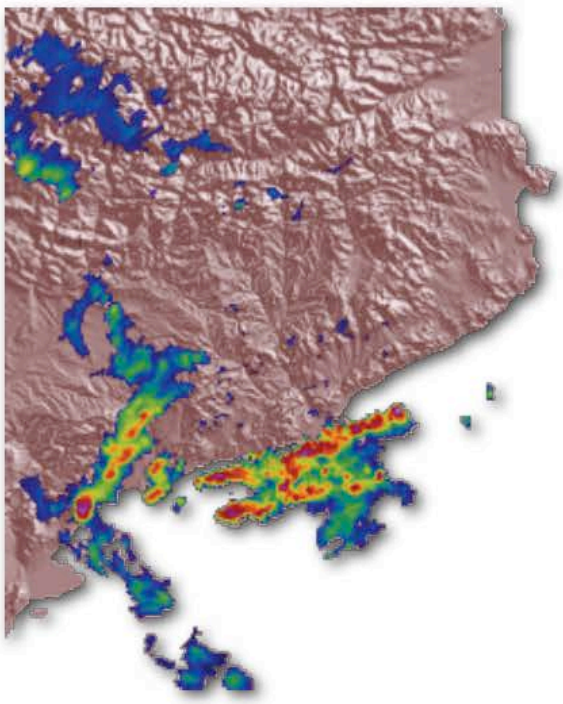


Meteorological Radar

- Acronym for "RAdio Detection And Ranging"
  The invention that changed the world; R. Buderi, 1996.
- Start used for METEOROLOGICAL PURPOSES just after WW II
- First Meteorological Radar Conference in **1947** (AMS)

Considered as a **KEY TOOL FOR HYDROLOGY** from the very beginning

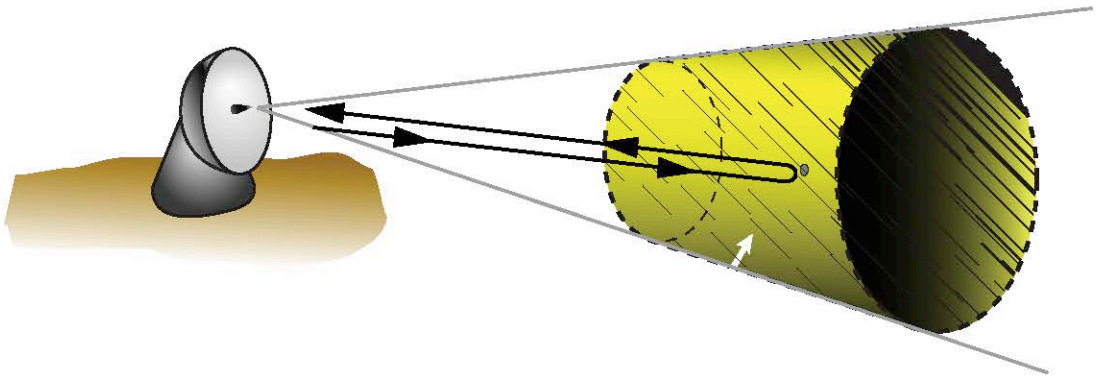
Meteorological Radar



- **Remote indirect measurement** of precipitation
- Measurement of **high spatial and temporal resolution**
  $\Delta t \approx$ **5 - 10 minutes**
  $\Delta x \approx$ **1km²**
- Resolution able to fulfill **hydrological requirements**
- Covering **large areas** from a central site (200 x 200 km²)

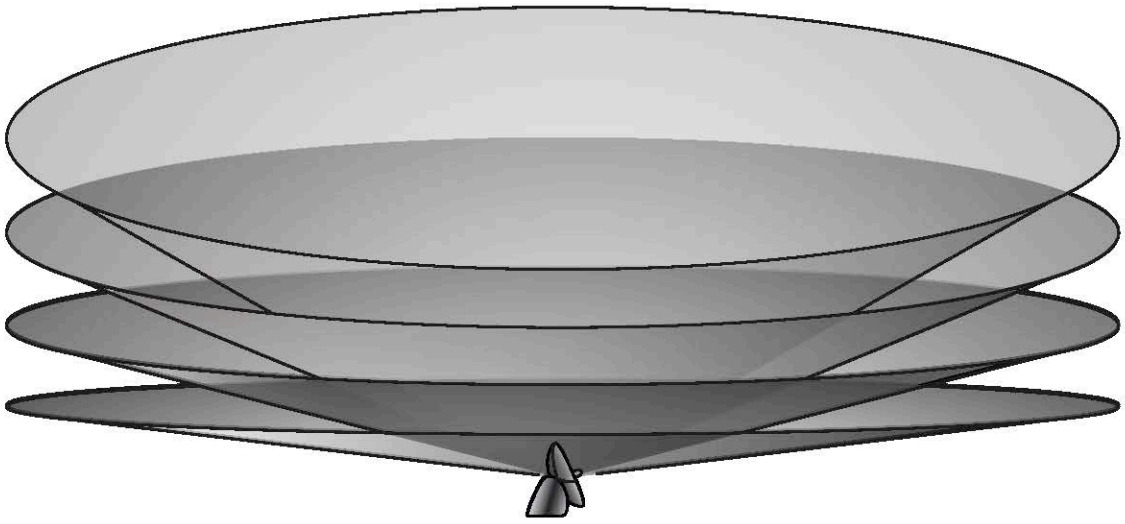
considered as **KEY TOOL FOR HYDROLOGICAL APPLICATIONS**

Radar measurements

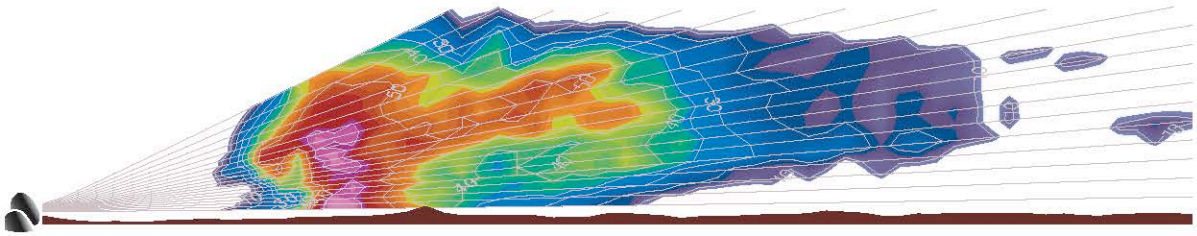


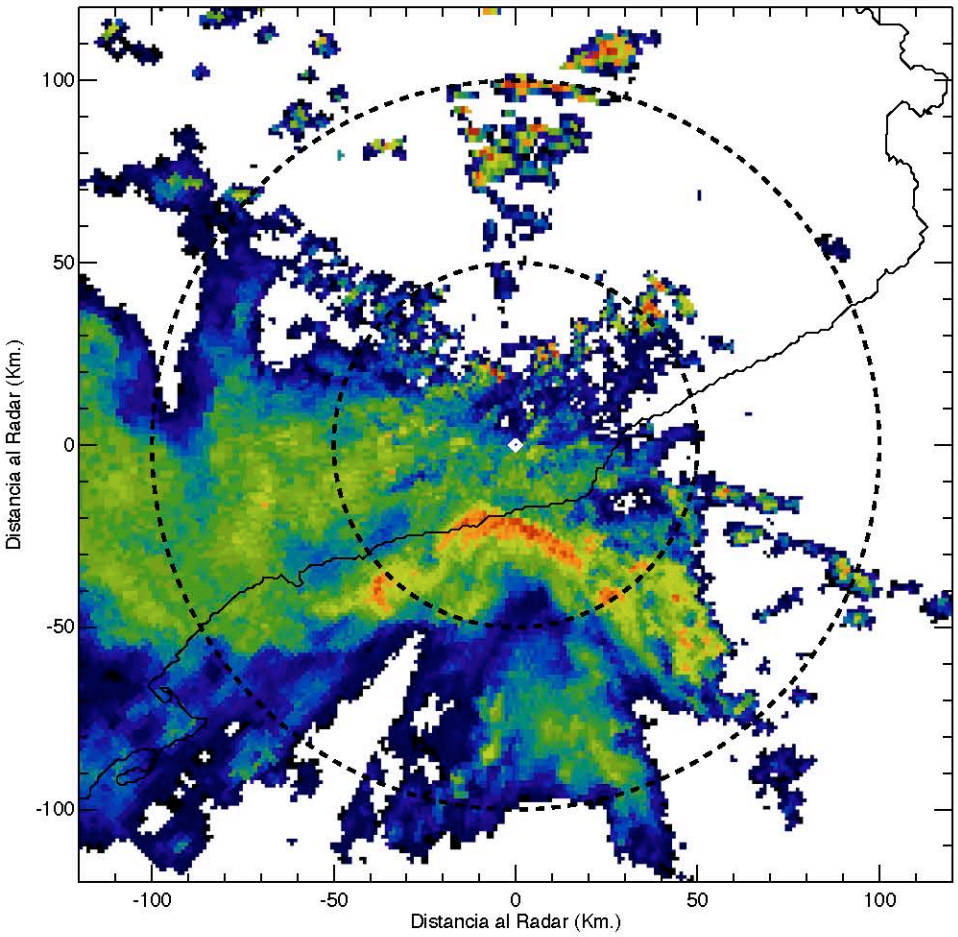
Weighted average precipitation measurement on a volume
(It measures reflectivity (Z) instead of intensity (R))

Radar measurements



Radar measures conical surfaces at different elevation angles
obtaining atmosphere volumes

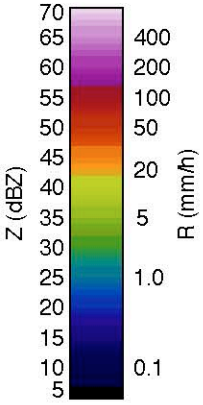


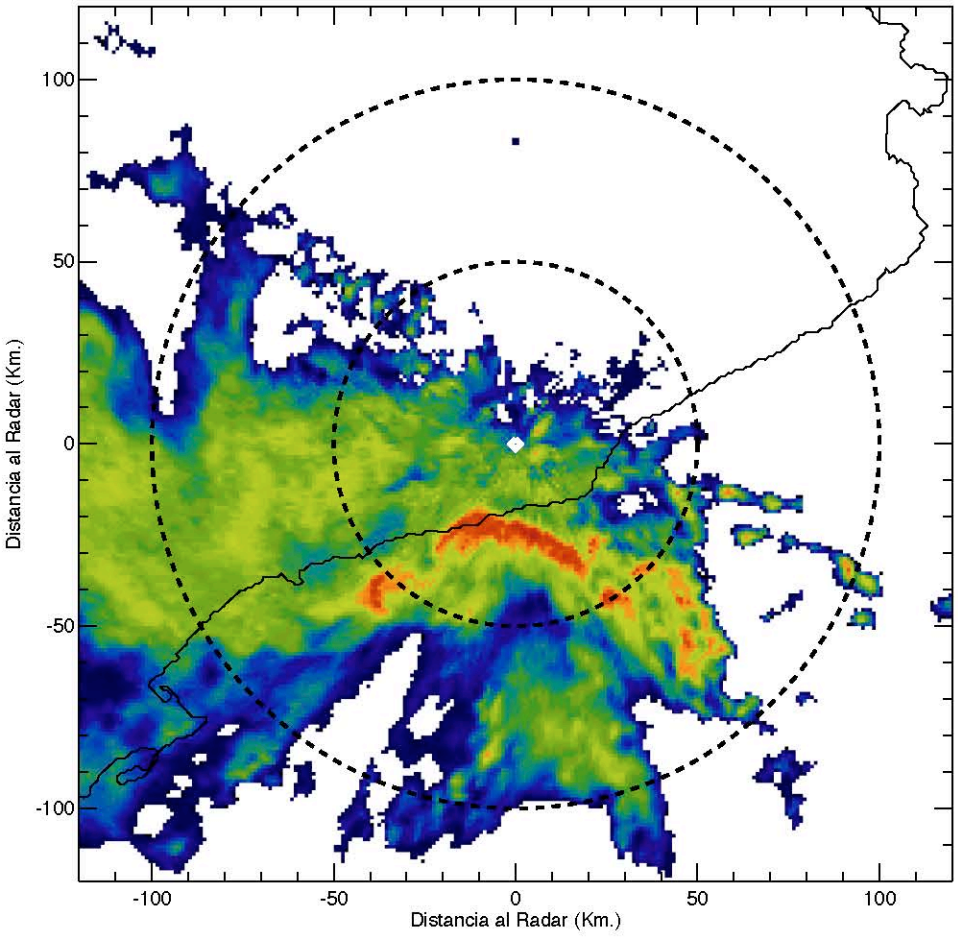


Raw Radar field

Polar Coordinates

Processing required



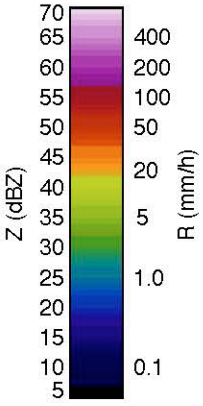


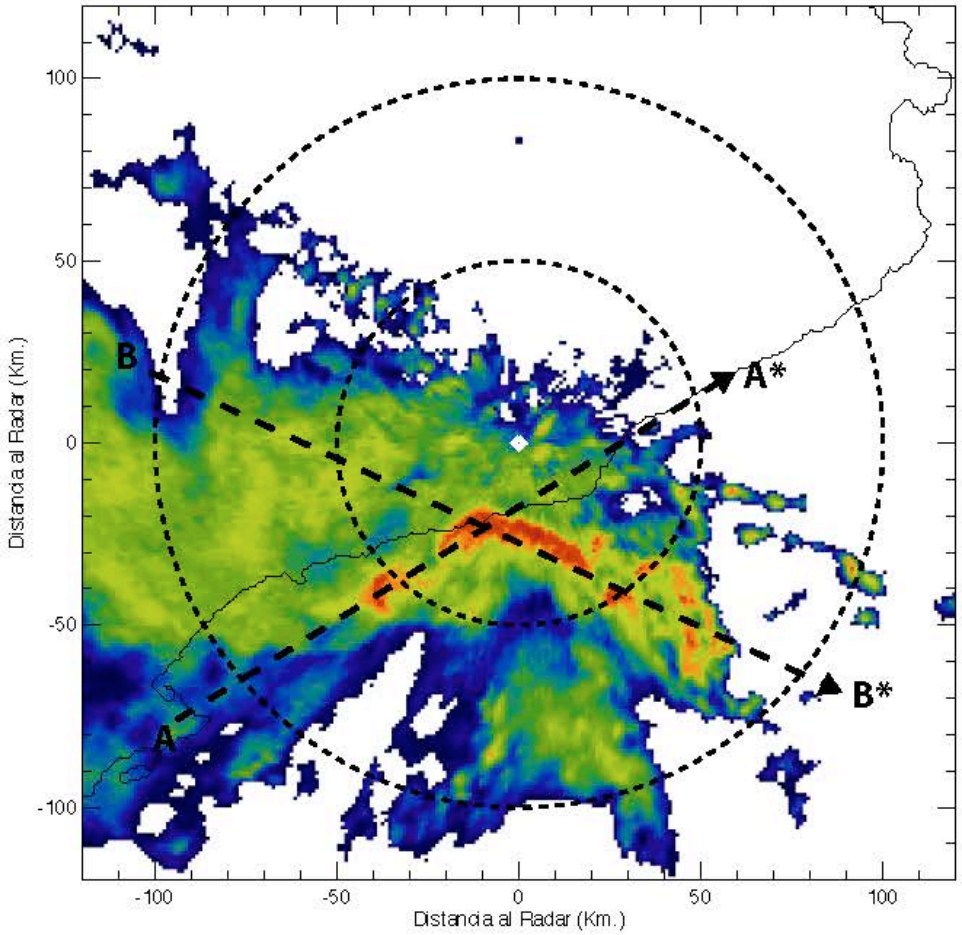
Processed Radar rainfall field

Cartesian Coordinates

Processing applied

Groundclutter
Attenuation
Signal stability



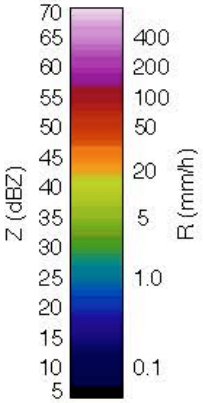


Processed Radar rainfall field

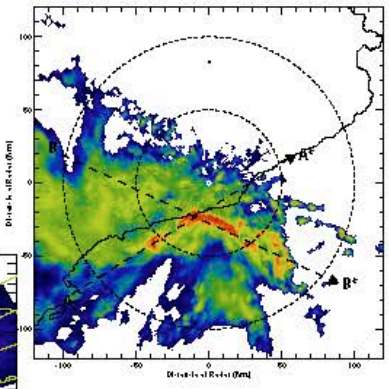
Cartesian Coordinates

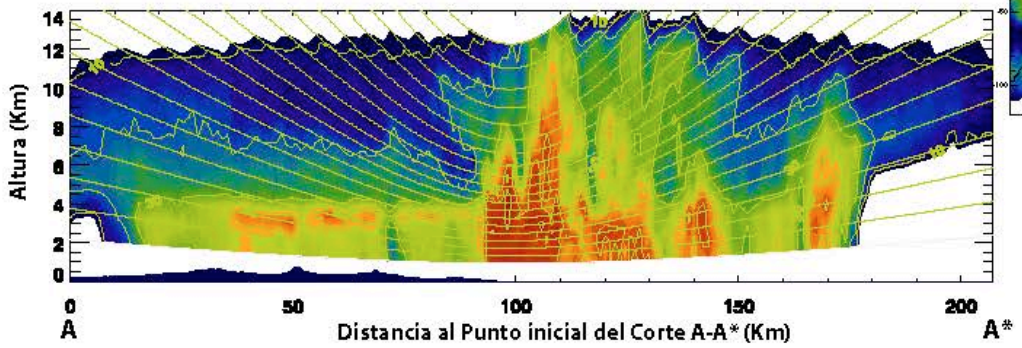
Processing applied

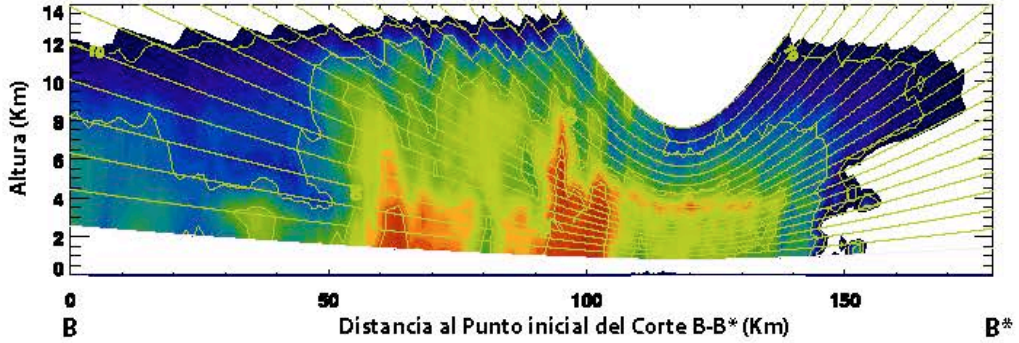
Groundclutter
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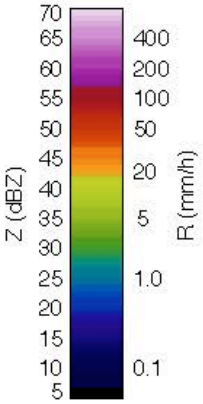


The radar provides a 3D measurement of the precipitation field structure



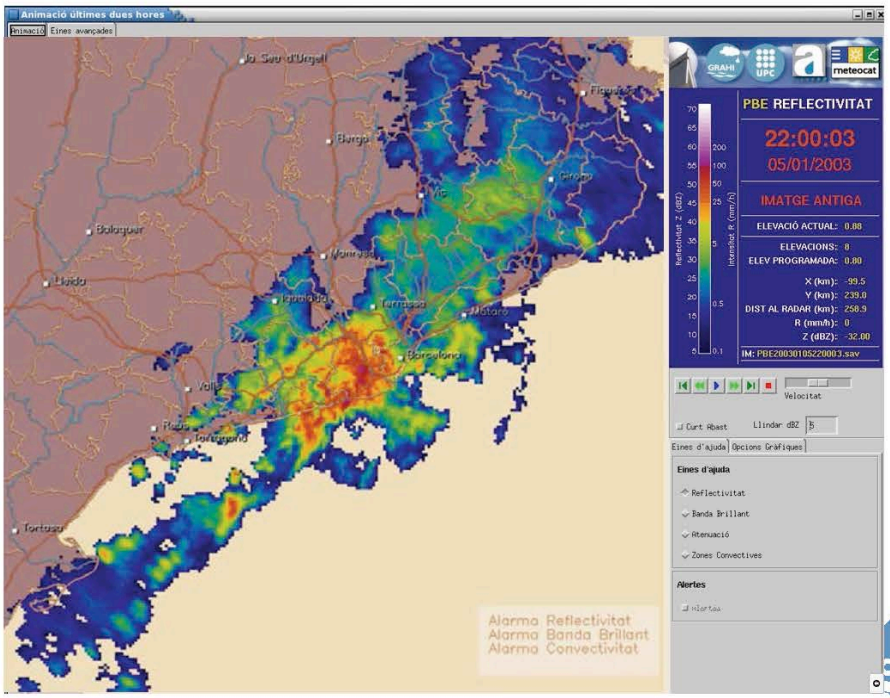






Advantages of weather radar

- HIGH spatial and temporal resolution measurements
- Covering large areas



Usually in hydrology: Raingauge network



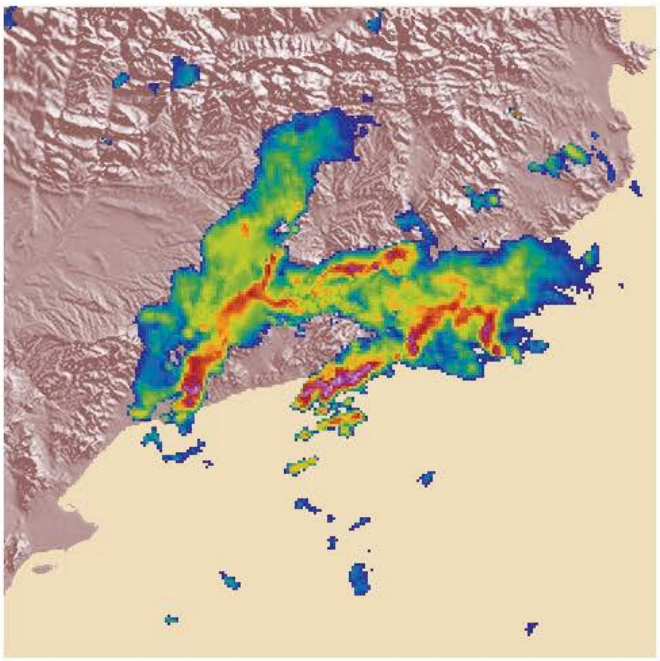
- **Point measurements** (200 cm²)
- **Irregularly widespread** over the land
- **Low spatial** density
  usually 1 raingauge per 200-300 km²

Unable to fulfill the requirements for
hydrological modelling
1 raingauge per 5-10 km²

NEED INTERPOLATION

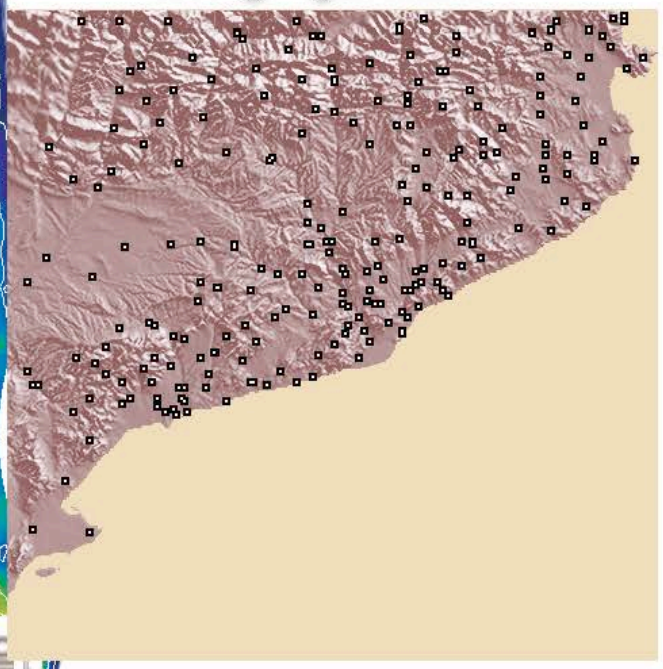
Comparison radar/raingauge interpolation

Radar

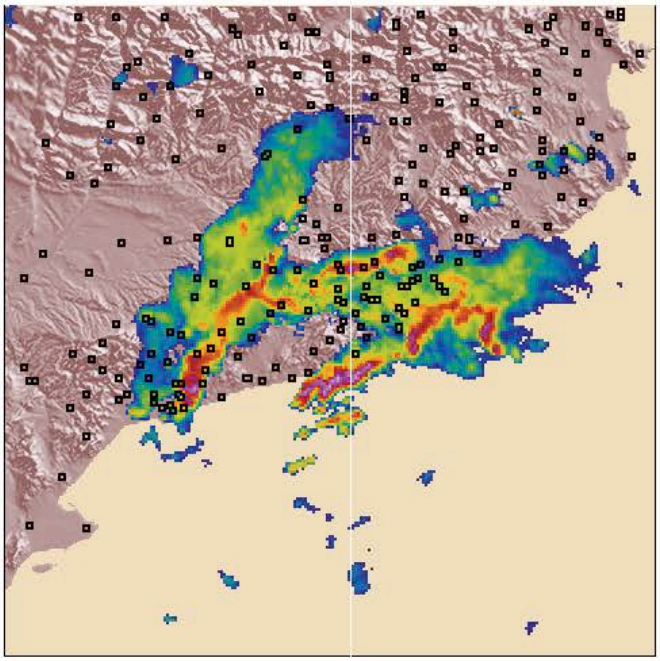


Comparison radar/raingauge interpolation

Raingauge network

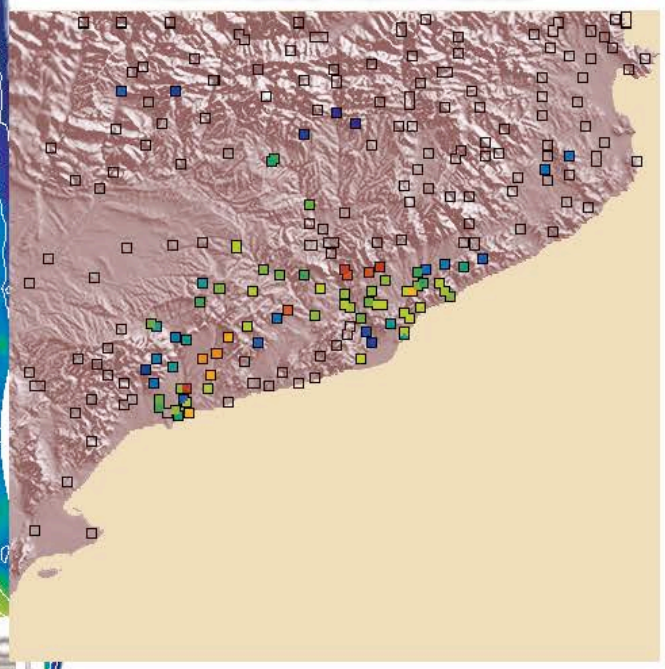


Radar

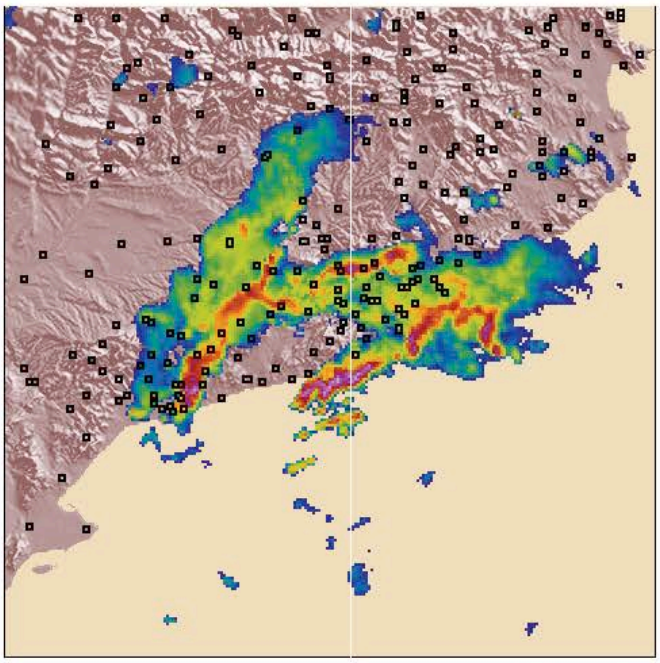


Comparison radar/raingauge interpolation

Rain rates from Radar

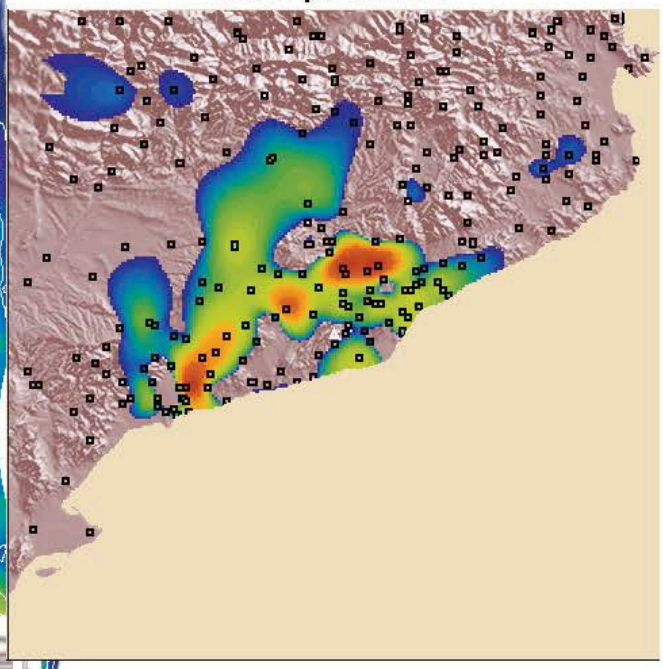


Radar

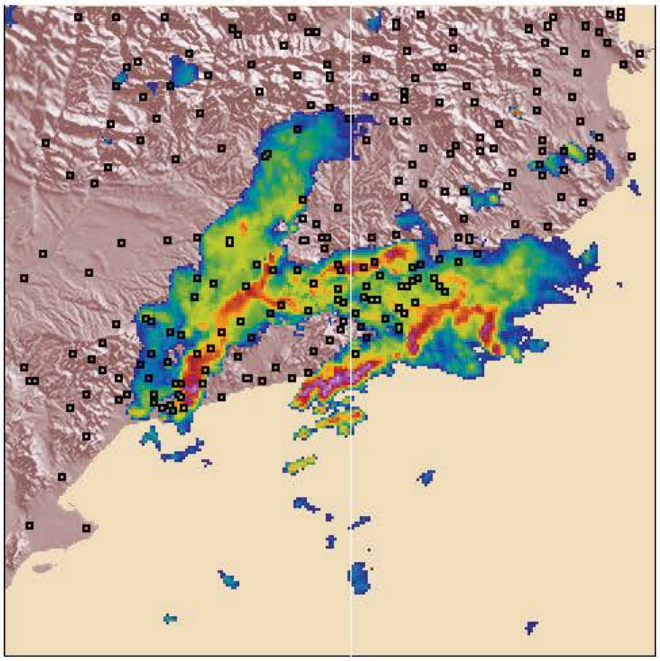


Comparison radar/raingauge interpolation

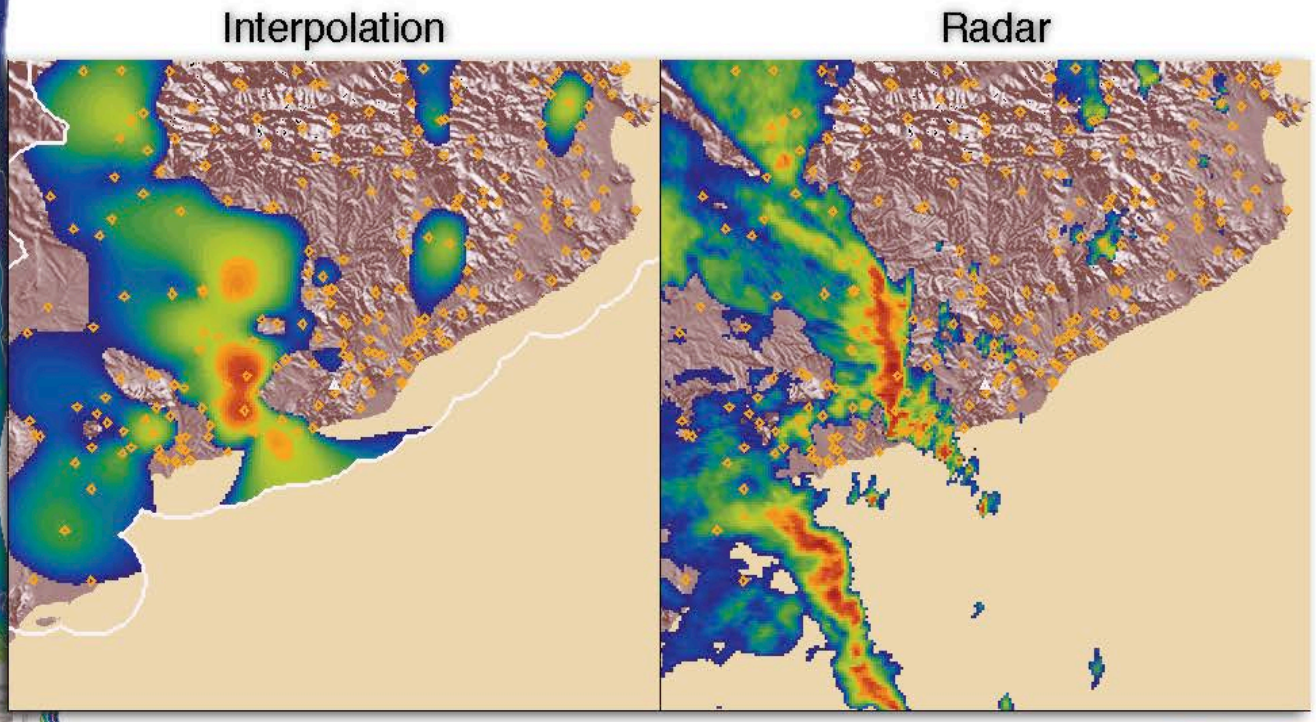
Interpolation



Radar



Comparison radar/raingauge interpolation



A unique tool for Hydrometeorology

Radars can help us to
describe and **understand** the
high VARIABILITY of PRECIPITATION

provide **better estimates of rainfall**

IMPROVE HYDROLOGICAL MODELING and FORECASTING

However, after 75 years of radar meteorology

- Meteorological radar use is **essentially QUALITATIVE** (support to Meteorological vigilance and forecasting)
- There are very **few QUANTITATIVE** applications
- **HYDROLOGICAL APPLICATIONS** are still **to BE DEVELOPED**

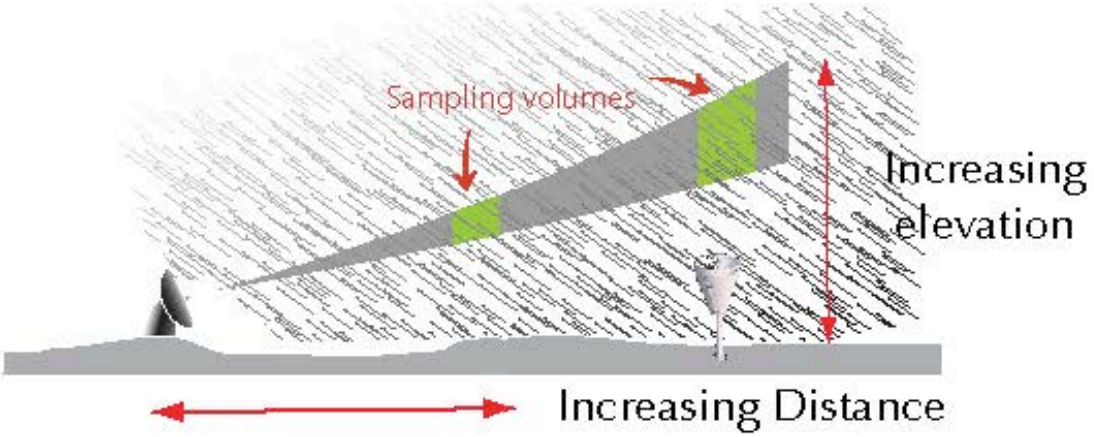
WHY?

Indirect measure of the rainrate

Reflectivity $Z = \int_0^\infty N(D) D^6 dD$

Rain rate $R = \frac{\pi}{6} \int_0^\infty V(D) N(D) D^3 dD$

Related by the Drop Size Distribution



weighted average on a 1-km³ volume

QPE is possible, but a VERY careful processing is needed

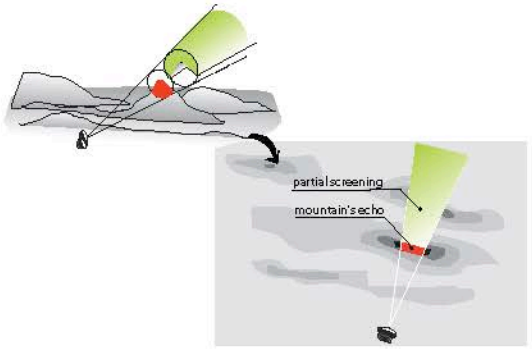
(Extremely "painful")

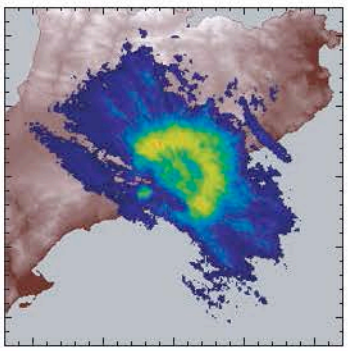
- Started only in the last 25 years
- New Mentality in Radar studies: Need to **understand the physics** of the radar measurement **before doing anything else**

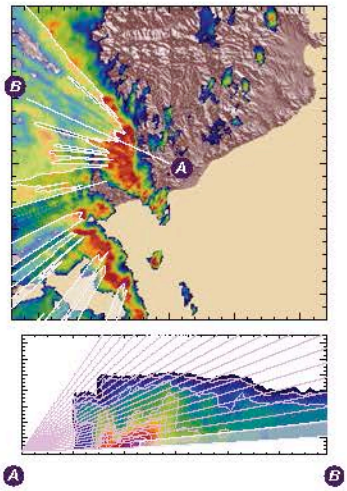
MILESTONE: Zawadzki 1984

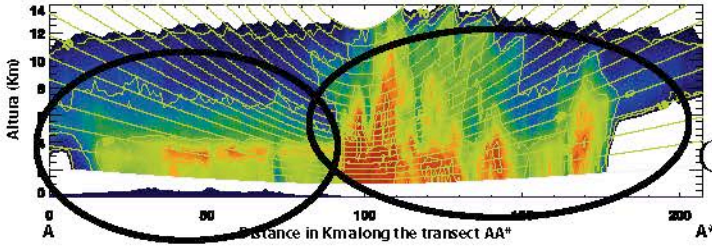
Factors affecting the precision of radar measurement of rain

QPE is only possible if a VERY careful processing is carried out









Convective rain

Stratiform rain

QPE Radar processing chain

Signal and ground clutter processing

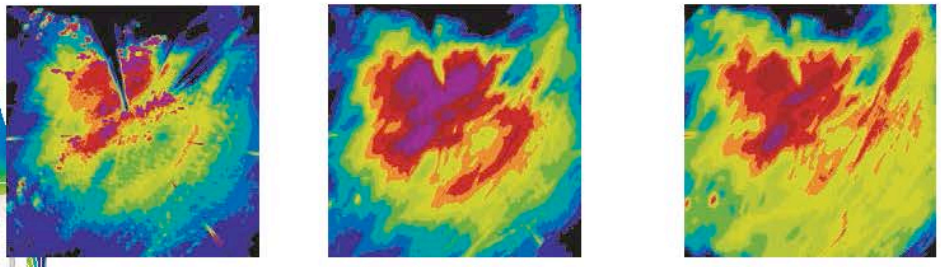
Precipitation type classification VPR and Z-R per types

RAW

Stage 2
Corrected data

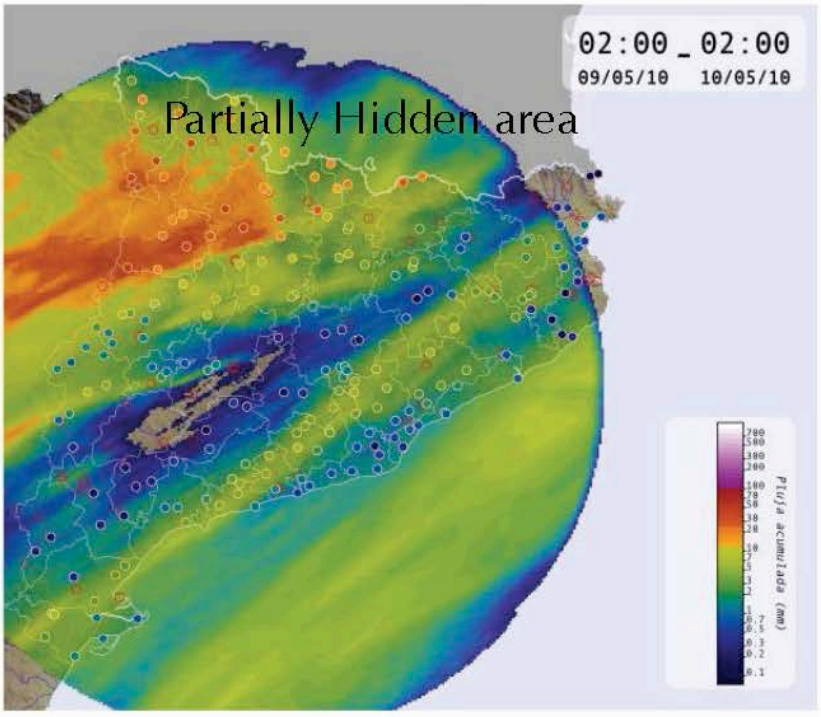
Stage 3
R at ground

RAINGAUGE NETWORK

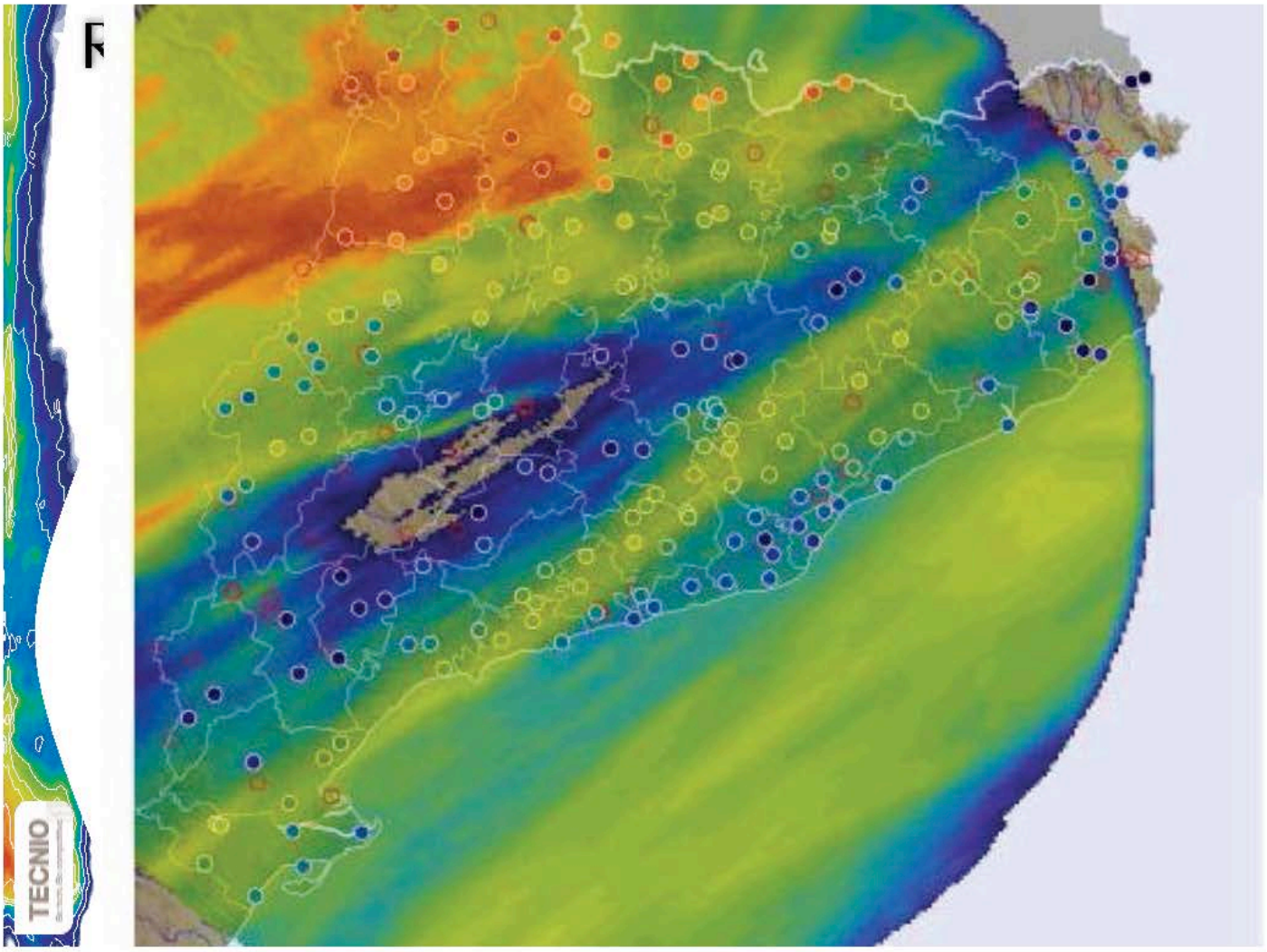


Rain accumulation for a whole event

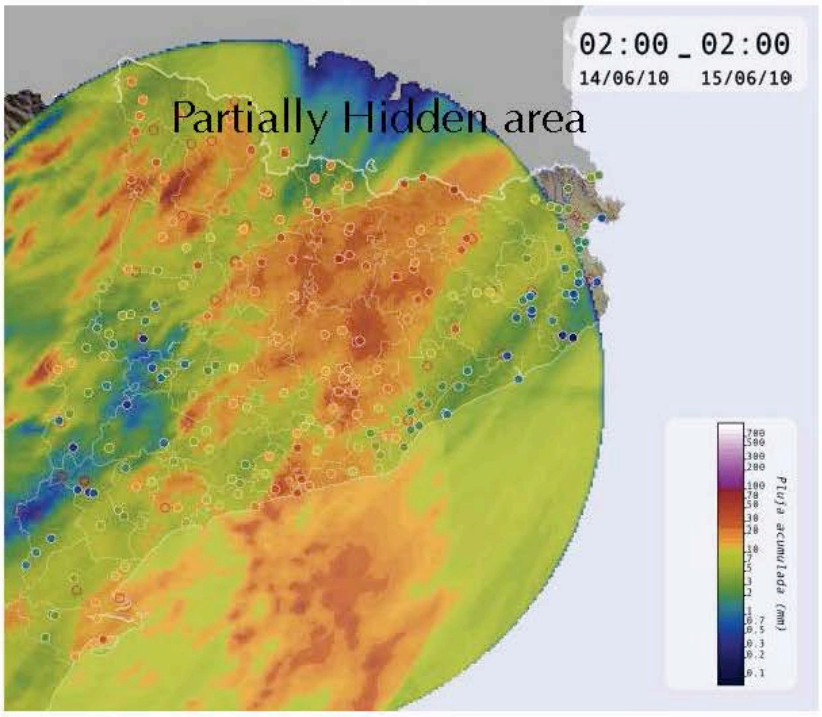
Rainfall estimation by radar



Radar-raingauge daily accumulation comparison

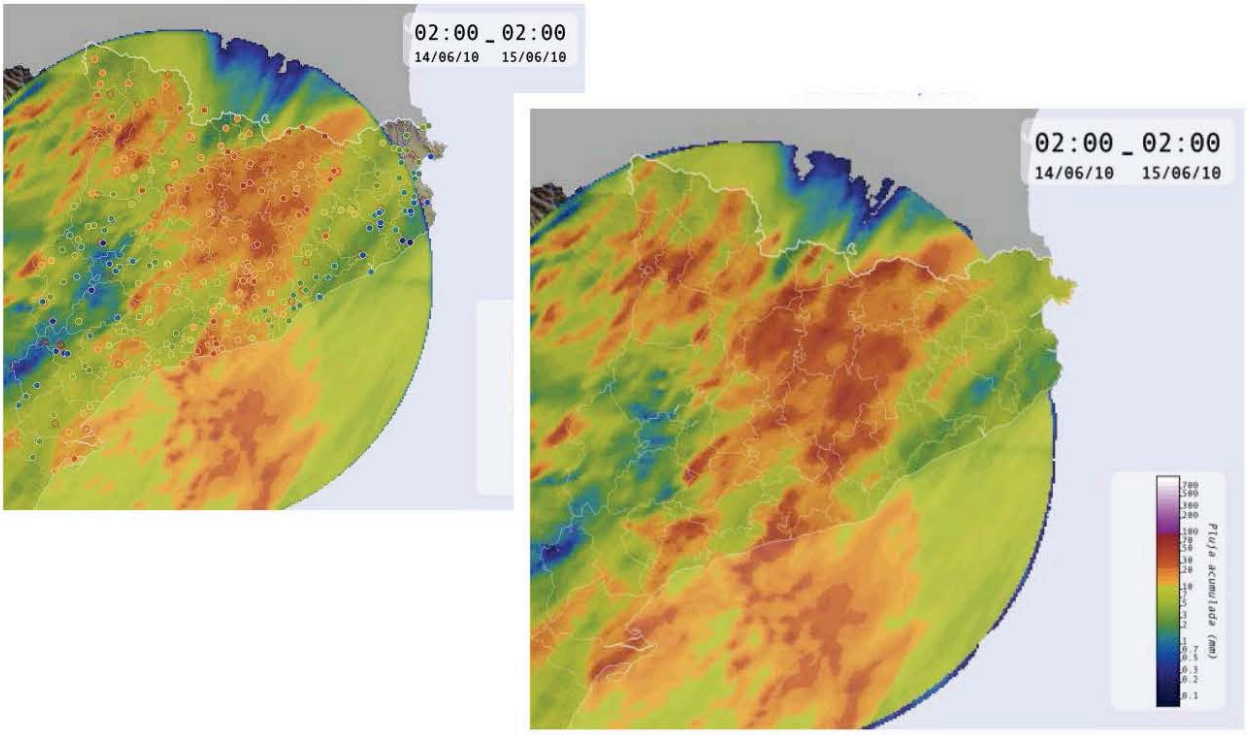


Rainfall estimation by radar



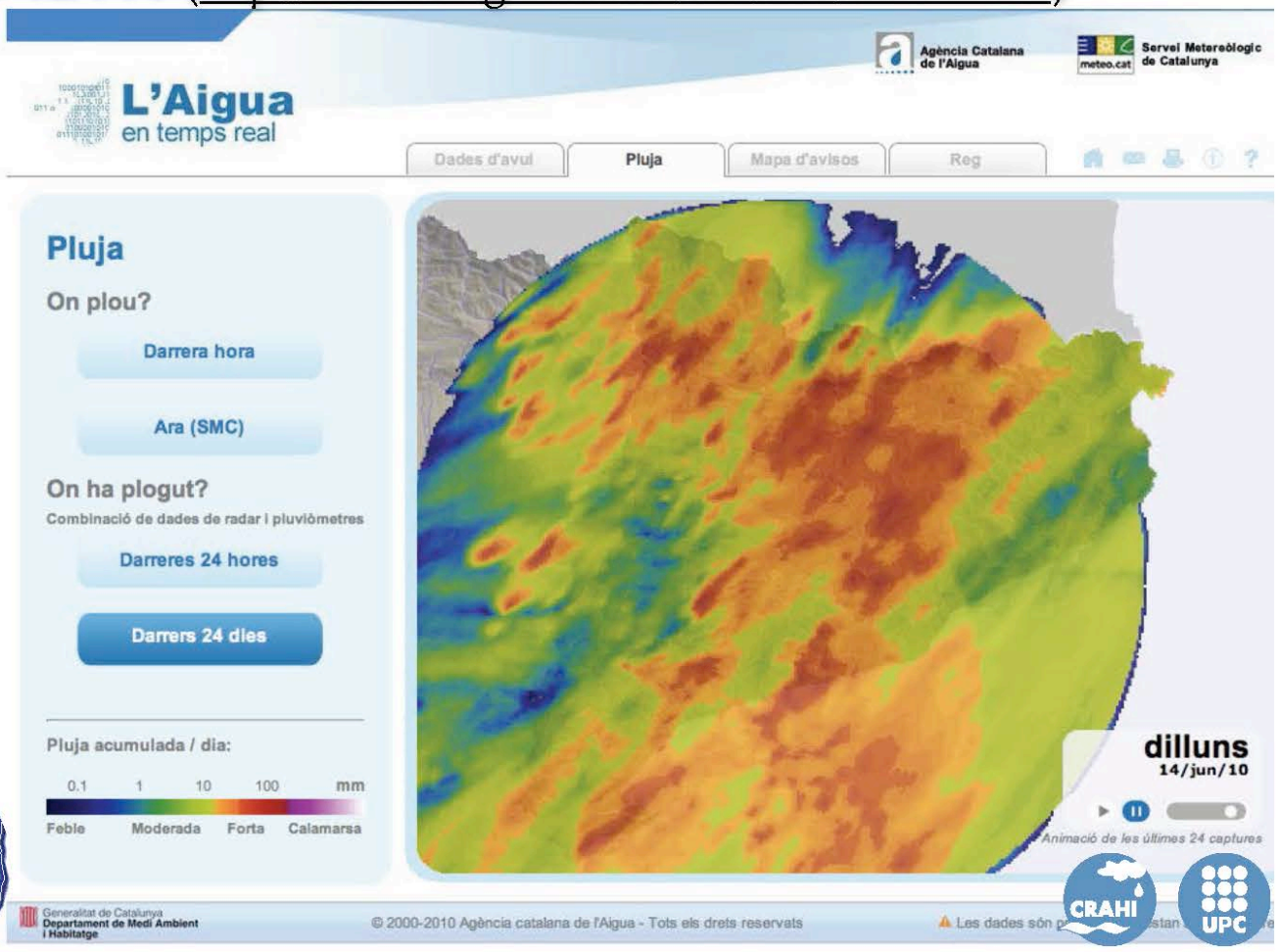
Radar-raingauge daily accumulation comparison

Rainfall estimation by radar

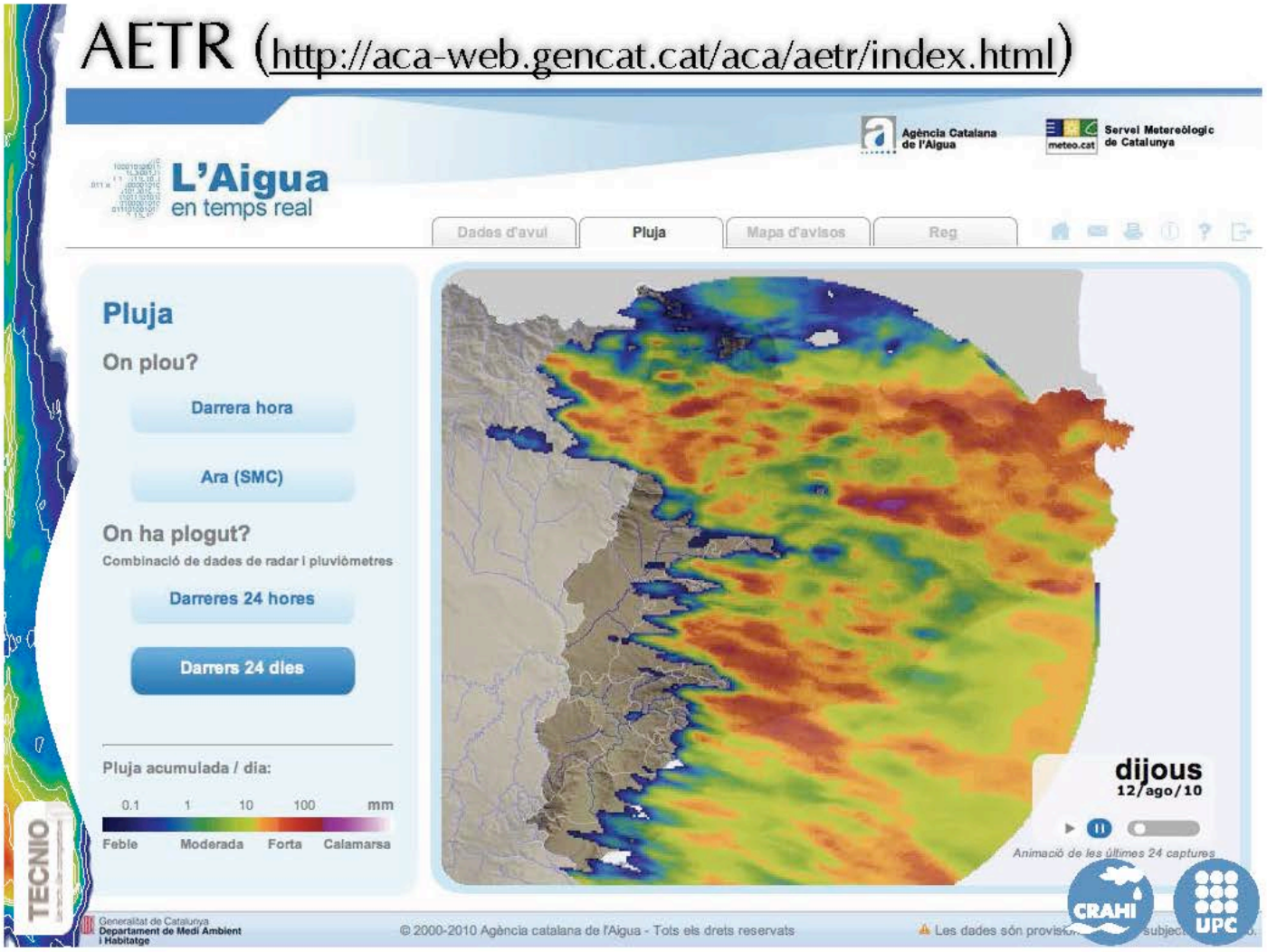


Combination Radar-raingauge

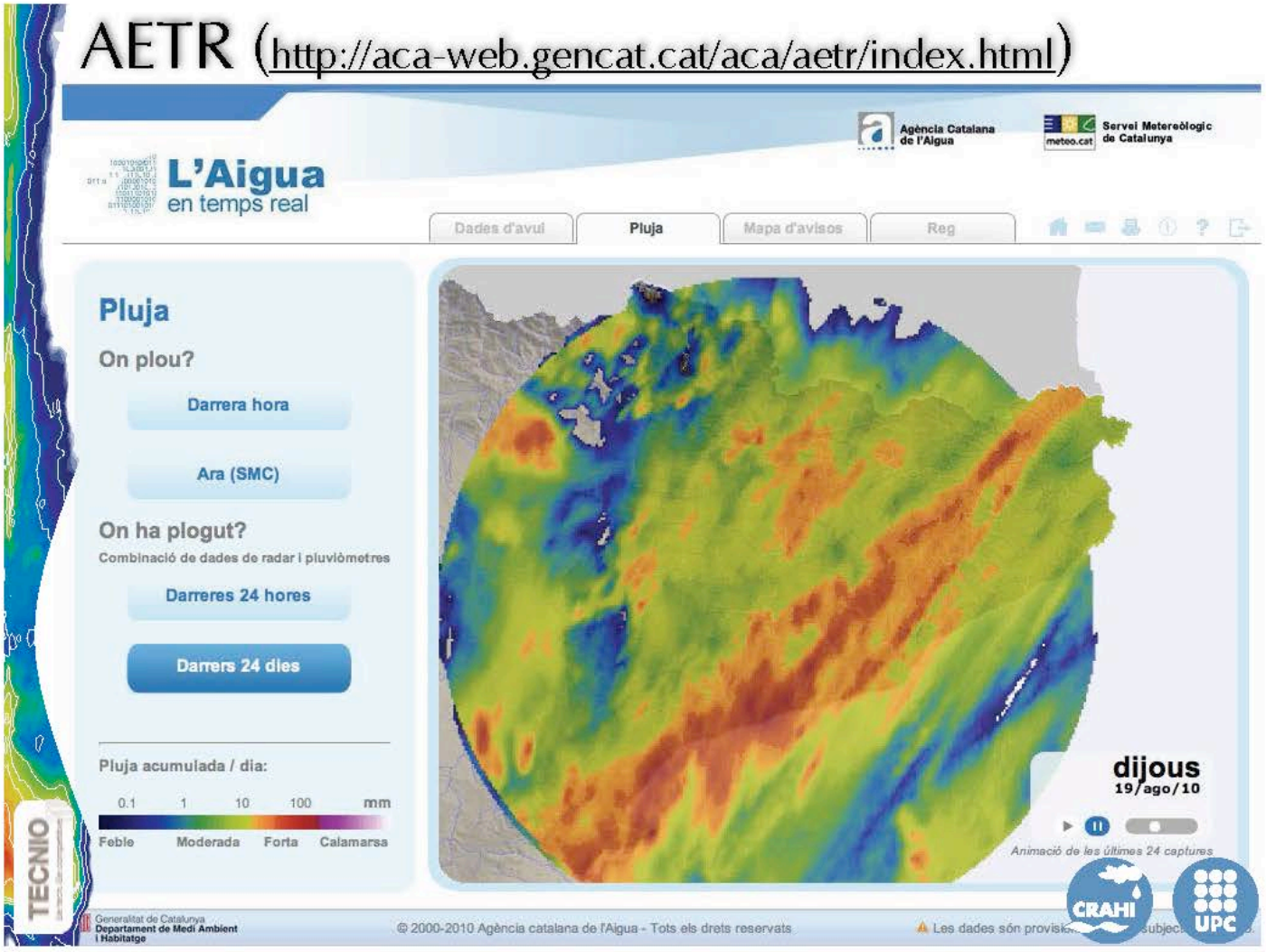
AETR (http://aca-web.gencat.cat/aca/aetr/index.html)



AETR (http://aca-web.gencat.cat/aca/aetr/index.html)



AETR (http://aca-web.gencat.cat/aca/aetr/index.html)





RADAR Quantitative Applications

Studies, analysis, processing algorithms to deal with the different sources of errors

QUANTITATIVE ESTIMATES from radar

Lot of work and advancements have been done,
but **very few operational radars** are taking full profit of it

Understanding the main concepts through case studies

CRAHI UPC

TRAINING PROGRAM ON METEOROLOGICAL AND ADVANCED QUANTITATIVE APPLICATIONS

How meteorological radars work:
From the radar signal to radar measurements

Centre de Recerca Aplicada en Hidrometeorologia
UNIVERSITAT POLITÈCNICA DE CATALUNYA



How weather radars work

- The **transmitter** generates a strong microwave signal concentrated into a pulse.
- The **antenna** focuses the signal in one direction.
- The **receiver** measures the (very weak) signal returned from the intercepted targets.
- **Processing** the received signal permits measuring the radar variables (distance of the target, power intensity and radial velocity).
- Further processing to produce and disseminate **radar products**.



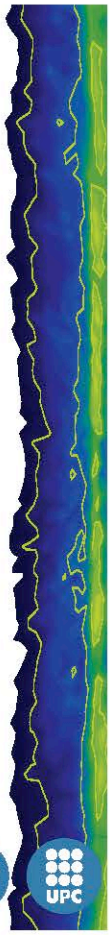


How weather radars work

The radar transmitter generates a pulse of energy with a given wavelength

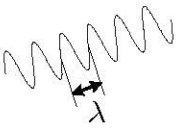






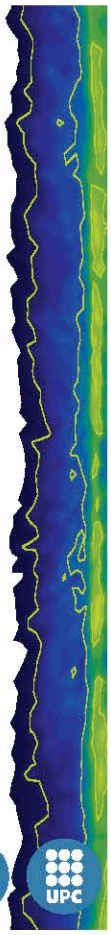
How weather radars work

The radar transmitter generates a pulse of energy with a given wavelength



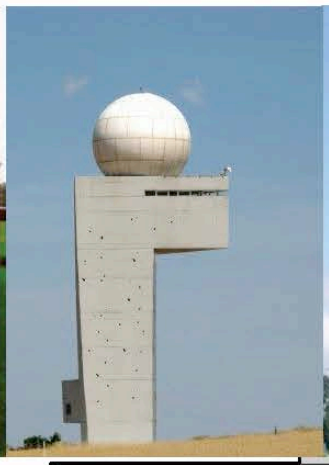


	X	C	S
wavelength [cm]	3	5	10
frequency [GHz]	10	6	3
Size of the antenna for a 1° beamwidth [m]	3	5	10



How weather radars work





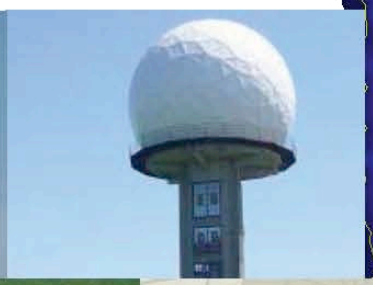


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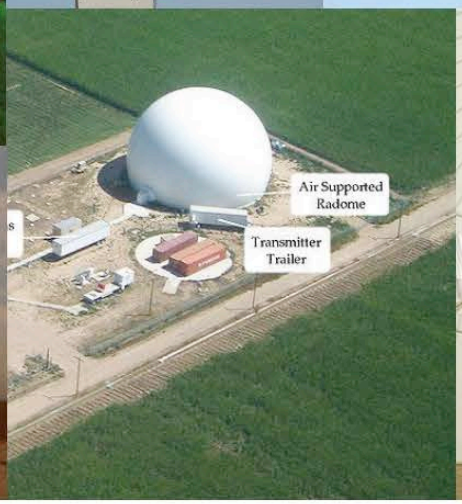
How weather radars work







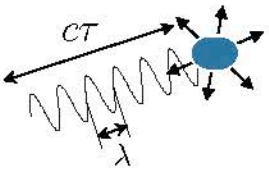






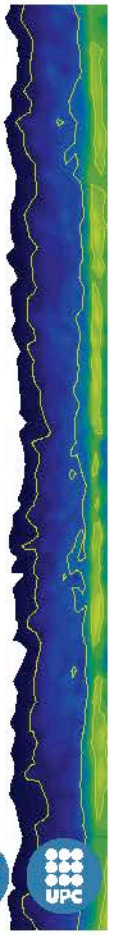
How weather radars work

pulse duration: τ





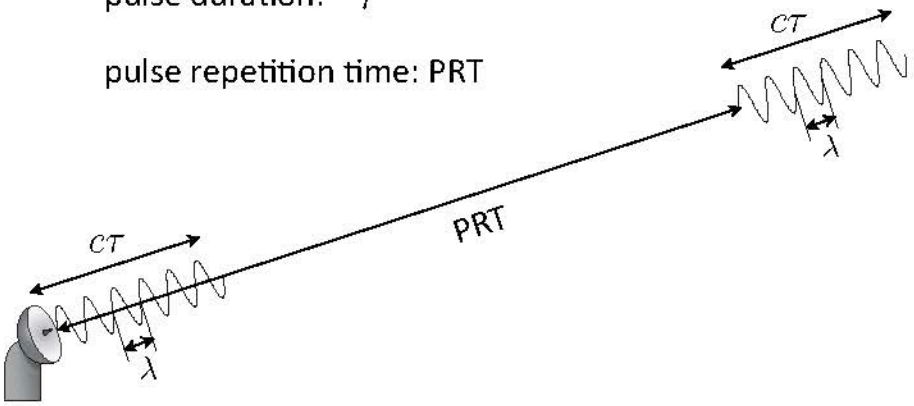
determines the resolution of the radar data: $\Delta r = \frac{c\tau}{2}$



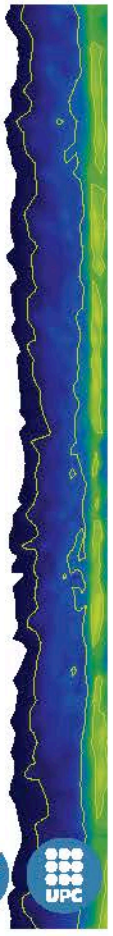
How weather radars work

pulse duration: τ

pulse repetition time: PRT



determines the maximum radar range: $r_{max} = PRT \cdot c/2$



How weather radars work

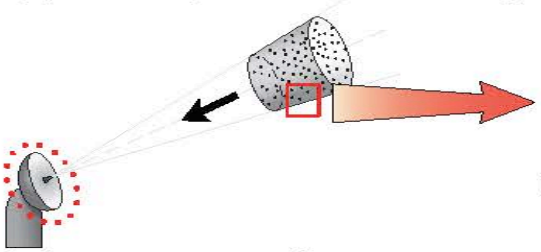
Received power: $\overline{P}(r_0) = \frac{\pi^3 c}{1024 ln2}\left[\frac{P_t \tau G^2 \theta^2}{\lambda^2}\right]\left[|\kappa|^2 \frac{Z}{r_0^2}\right] L^{-2}(r_0)$

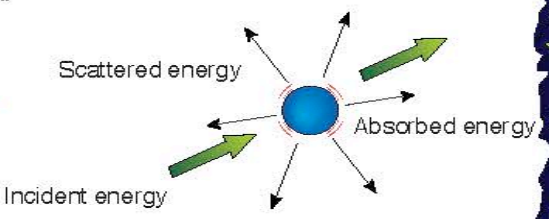
radar target

C: depends on the characteristics of the radar (antenna, wavelength,...).

Z(r_0): reflectivity factor. How much power is backscattered: $Z_e(r_0) = \frac{1}{\Delta V}\sum_i \sigma_{b,i}$

L(r_0): losses. Depend on the radar wavelength.

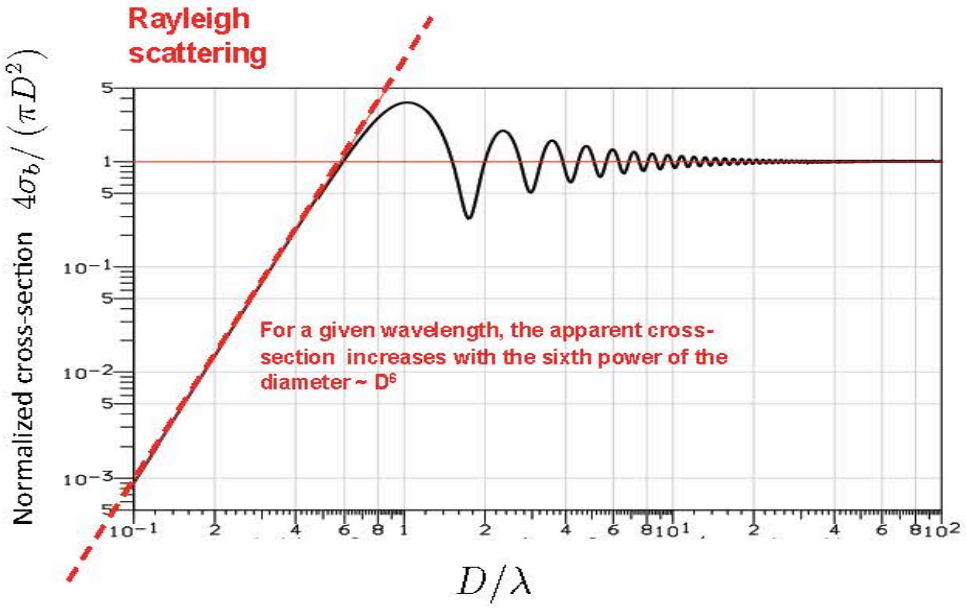




location: $r_0 = \frac{t_0}{2c}$

How weather radars work

Hydrometeors (rain, snow, hail...). For most radars, they are **Rayleigh scatterers** for which scattering is proportional to $D^6\lambda^{-4}$

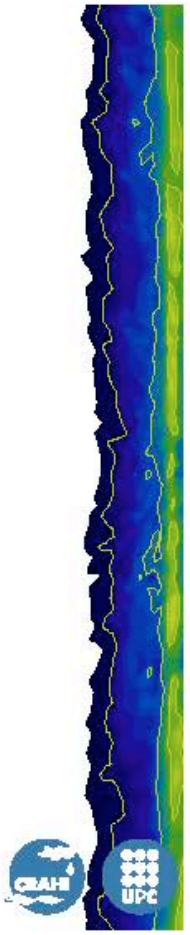


Radar reflectivity

Received power: $\overline{P}(r_0) = \frac{\pi^3 c}{1024 ln2}\left[\frac{P_t \tau G^2 \theta^2}{\lambda^2}\right]\left[|\kappa|^2 \frac{Z}{r_0^2}\right] L^{-2}(r_0)$

radar target

$$Z_e(r_0) = \frac{1}{\Delta V}\sum_i \sigma_{b,i} = \frac{1}{\Delta V}\sum_i D_i^6$$



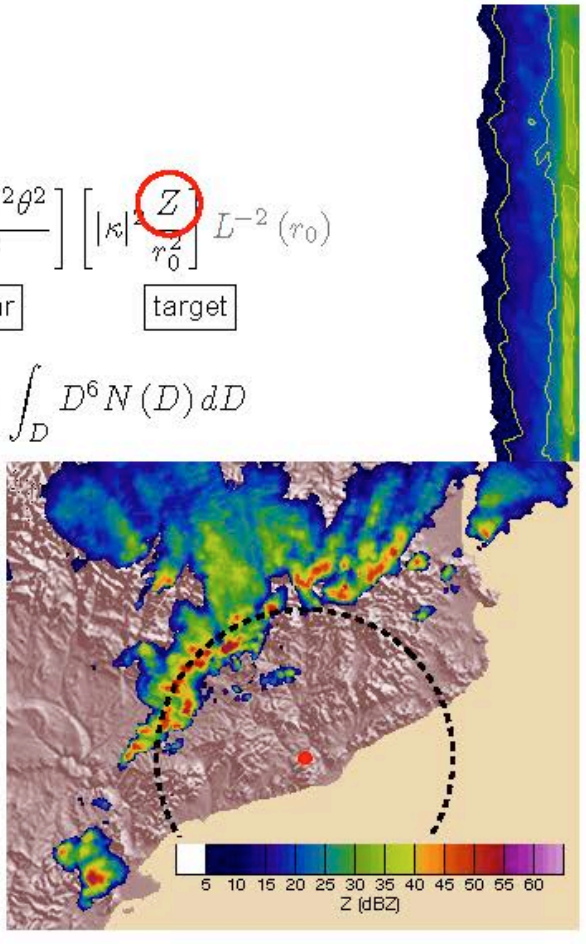
Radar reflectivity

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radar target

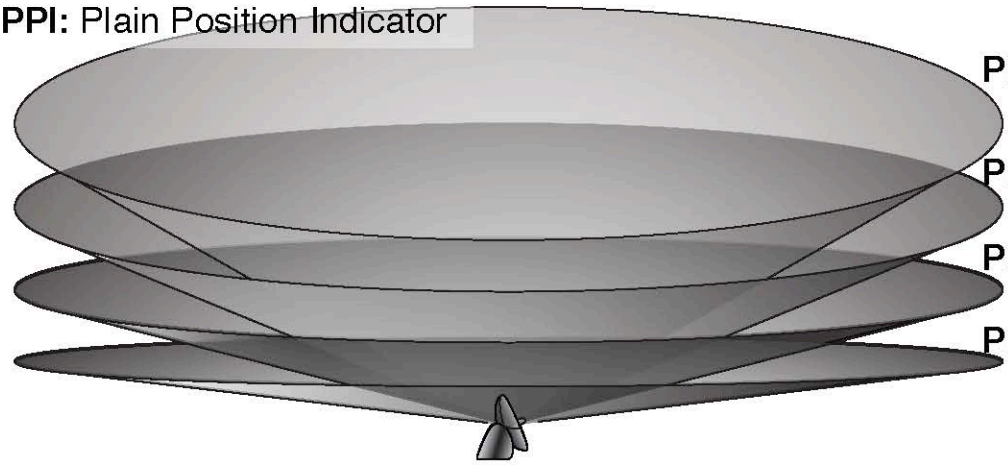
$$Z_e(r_0) = \frac{1}{\Delta V}\sum_i \sigma_{b,i} = \frac{1}{\Delta V}\sum_i D_i^6 = \int_D D^6 N(D)\, dD$$

$$Z[\mathrm{dBZ}] = 10\log\left(Z[\mathrm{mm^6 m^{-3}}]\right)$$

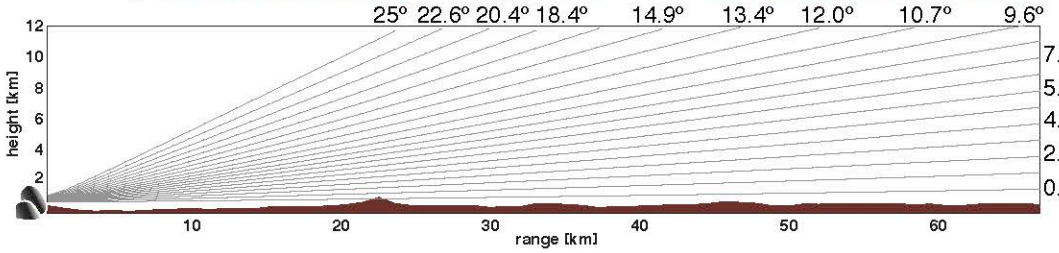


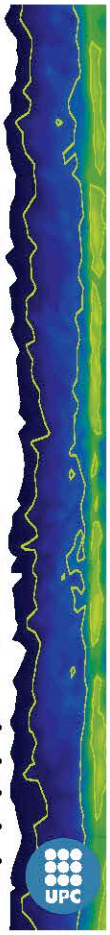
Weather radar measurements

PPI: Plain Position Indicator



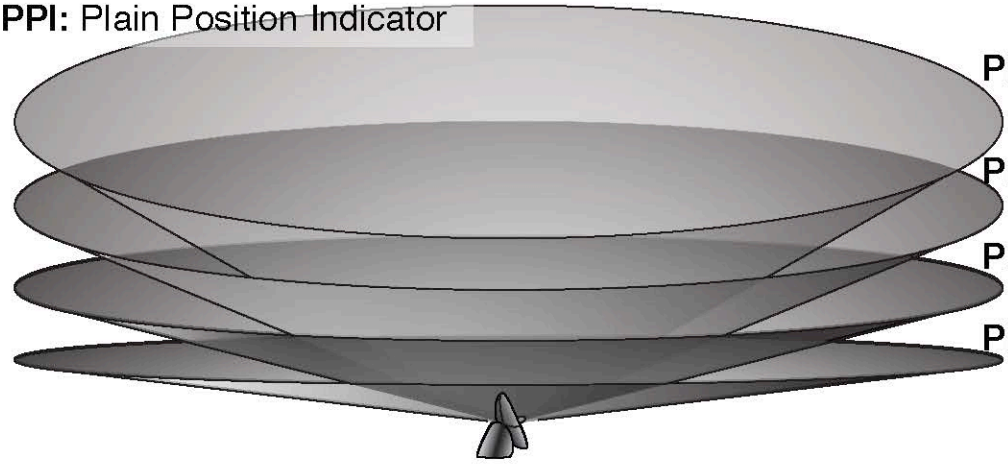
Radar measures conical surfaces at different **elevation angles** obtaining **volumetric observations** of the **precipitation field**



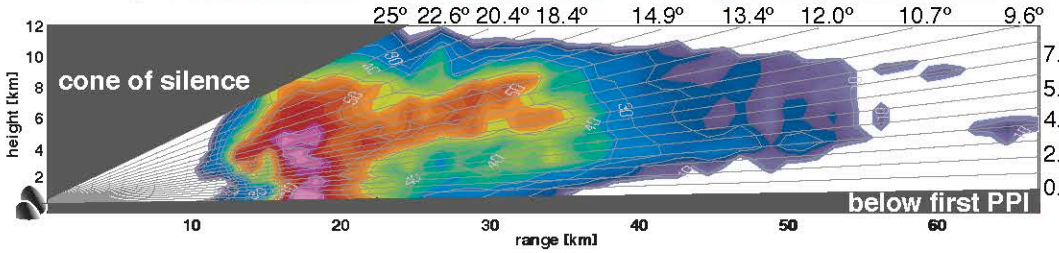


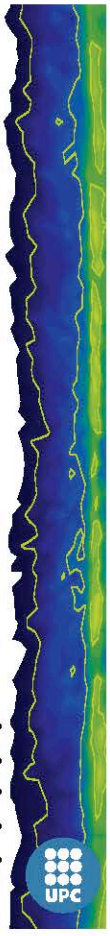
Weather radar measurements

PPI: Plain Position Indicator

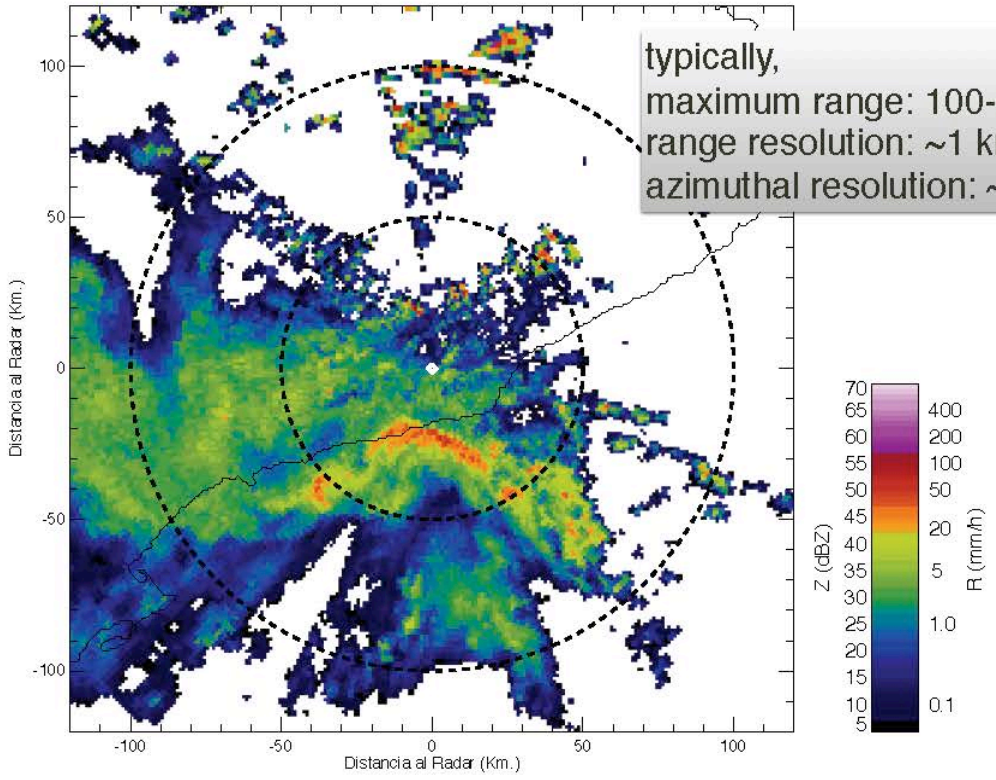


Radar measures conical surfaces at different **elevation angles** obtaining **volumetric observations** of the **precipitation field**



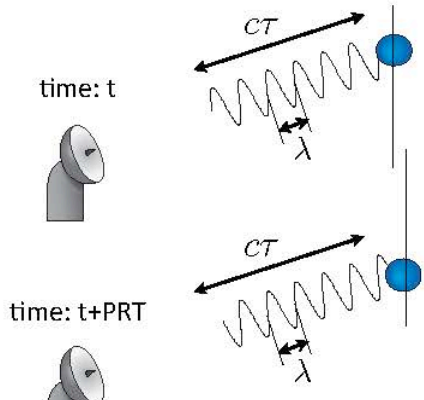


Weather radar measurements



How weather radars work

pulse repetition time: PRT



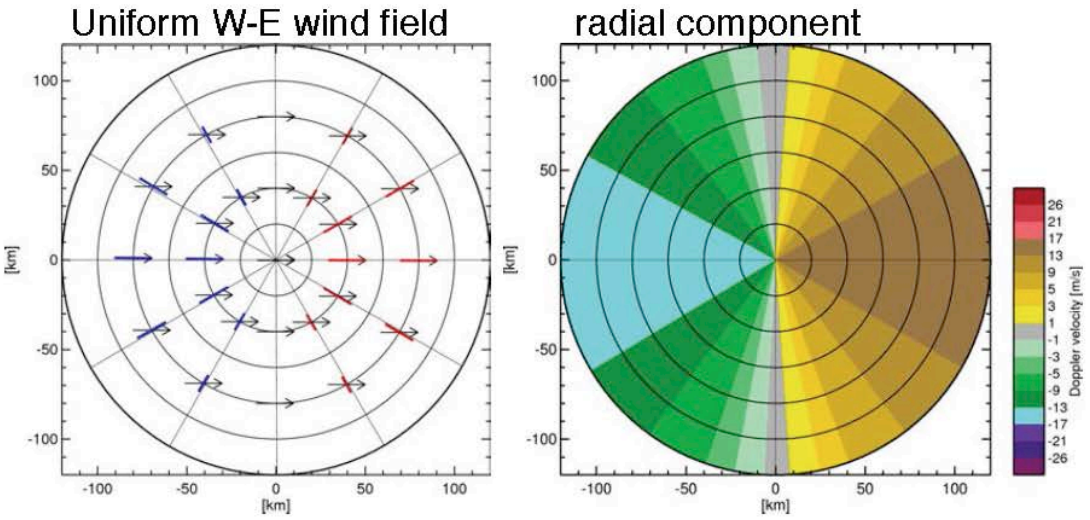
$$\varphi(t) = \frac{4\pi r(t)}{\lambda} \qquad r(t) = \frac{\varphi(t)\,\lambda}{4\pi}$$

$$\varphi(t + PRT) = \frac{4\varphi\left[r(t) + \Delta r\right]}{\lambda}$$

Doppler velocity

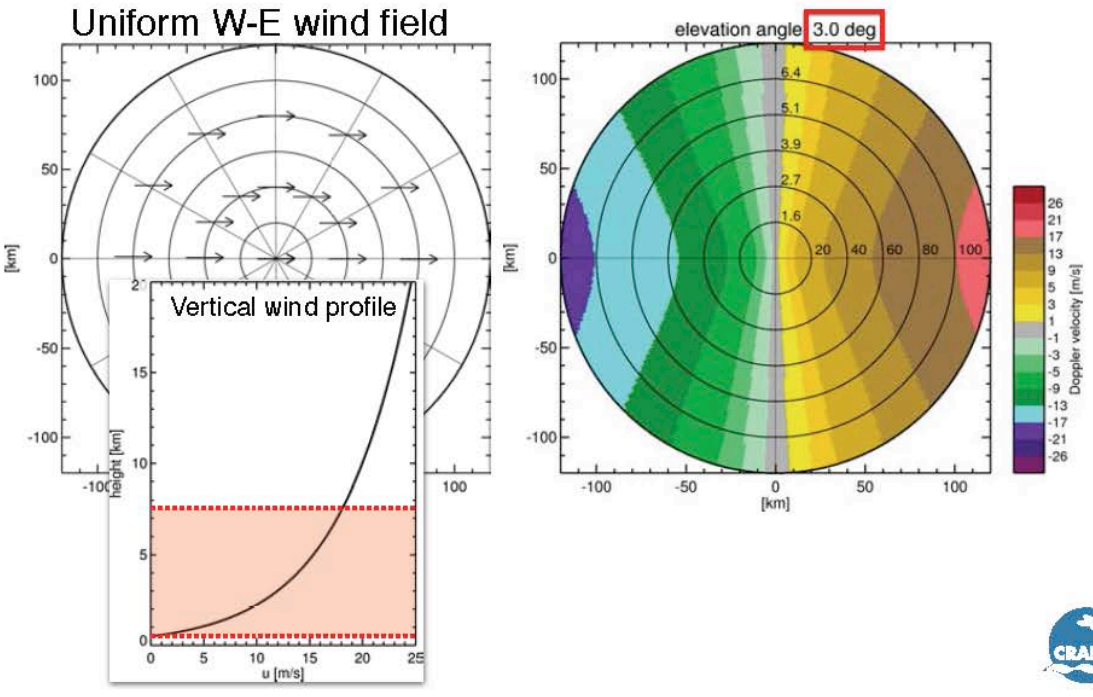
$$\frac{\Delta r(t)}{\Delta t} = \frac{\lambda}{4\pi}\frac{\Delta\varphi(t)}{\Delta t} = \frac{\lambda}{4\pi PRT}\Delta\varphi(t) = v_r(t)$$

Doppler velocity



Doppler velocity

The effect of height



Doppler velocity

To interpret Doppler velocity data:

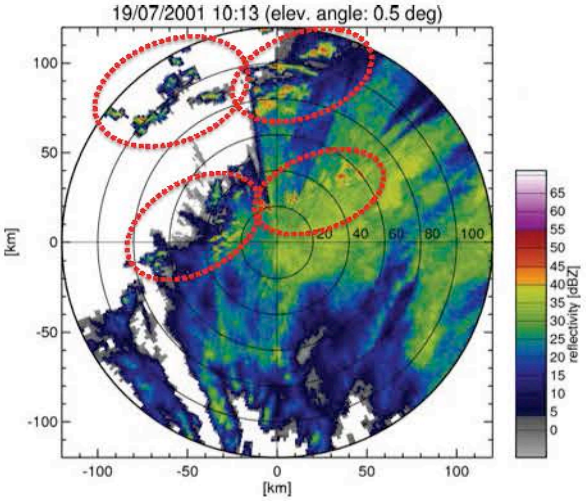
1- Radial component of the wind.

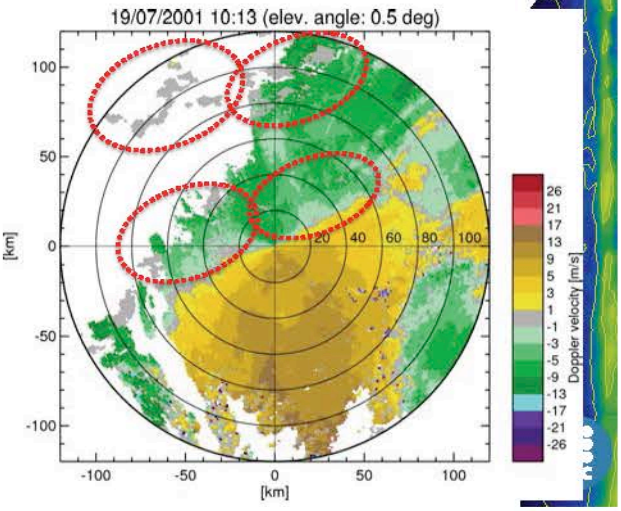
2- The wind is rarely uniform.

3- Measurements can only be made where there are targets.

4- The height of the observations changes with range.

5- In general, ground targets do not move.





Doppler velocity

To interpret Doppler velocity data:

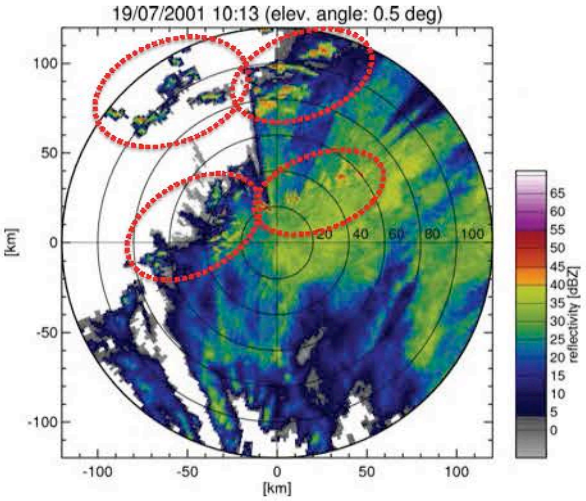
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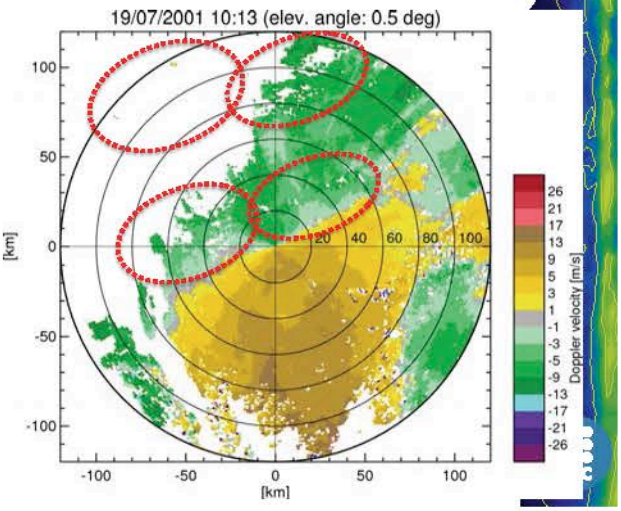
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Doppler velocity

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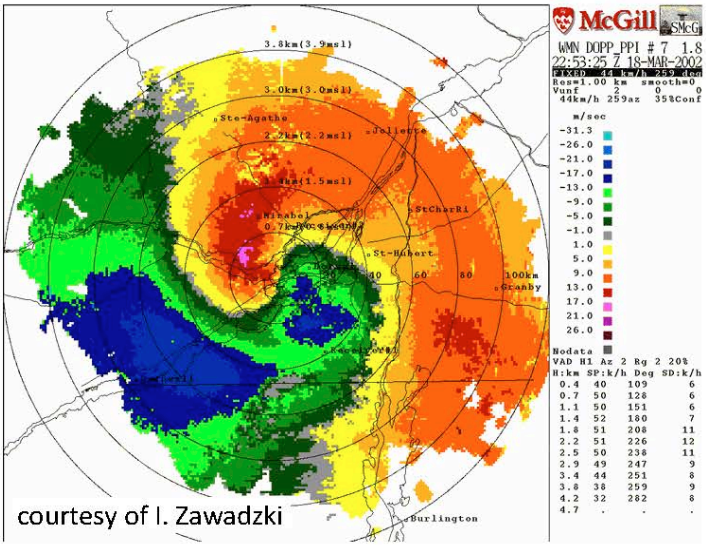
1- Radial component of the wind.

2- The wind is rarely uniform.

3- Measurements can only be made where there are targets.

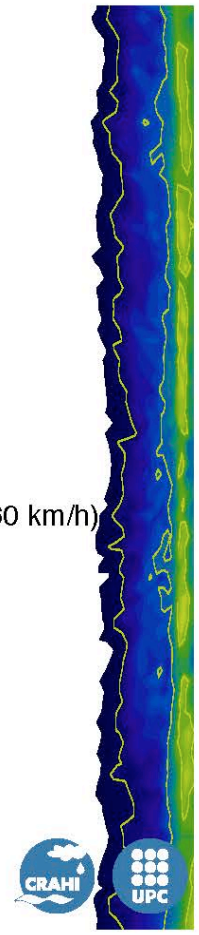
4- The height of the observations changes with range.

5- In general, ground targets do not move.



SE low level jet (nearly 60 km/h) at a height of ~0.6 km.

SW winds aloft.



Doppler velocity

To interpret Doppler velocity data:

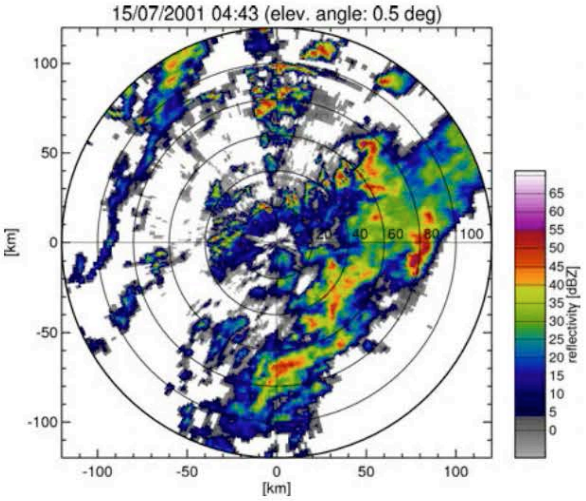
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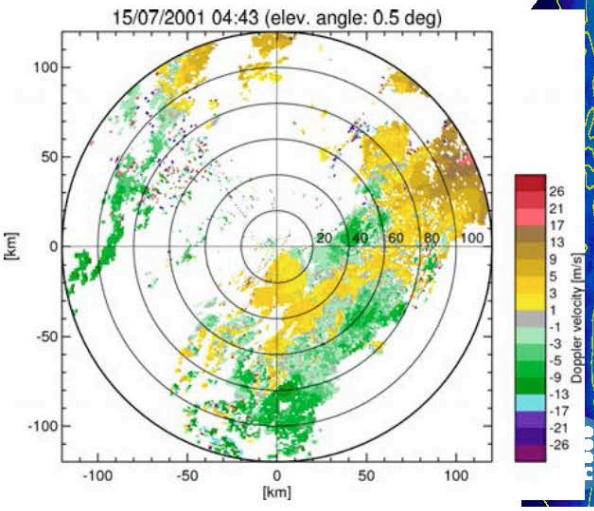
2- The wind is rarely uniform.

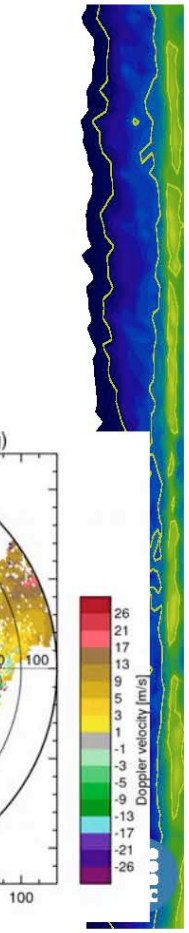
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Doppler velocity

To interpret Doppler velocity data:

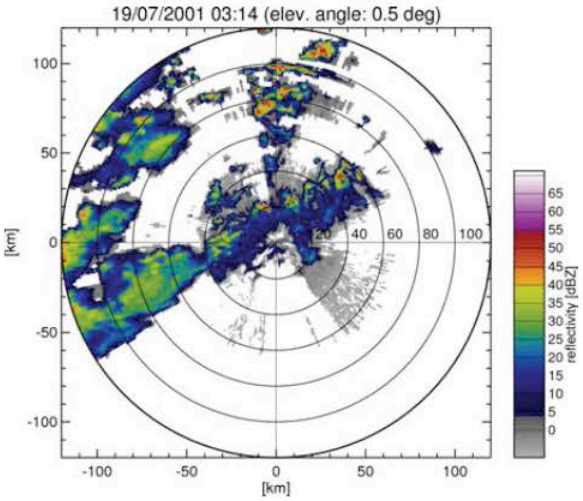
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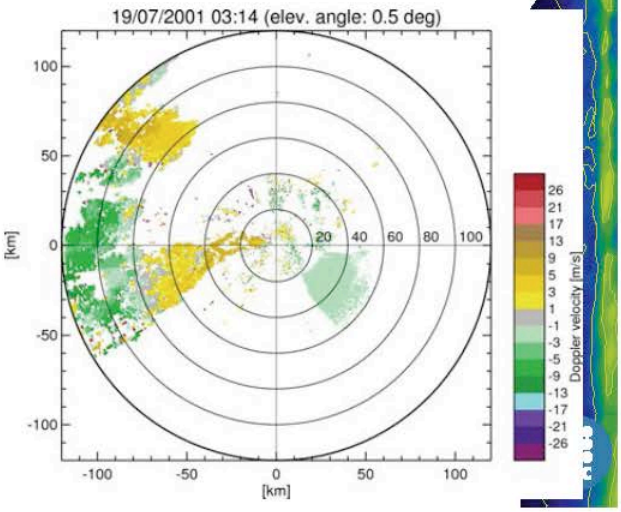
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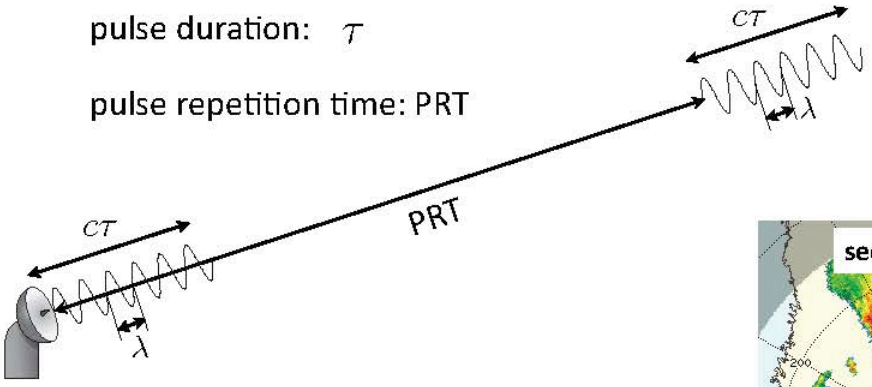




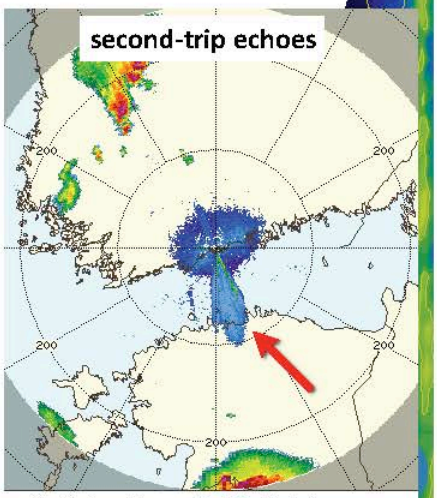
How weather radars work

pulse duration: τ

pulse repetition time: PRT



• determines the maximum range: $r_{max} = \frac{c \cdot PRT}{2}$

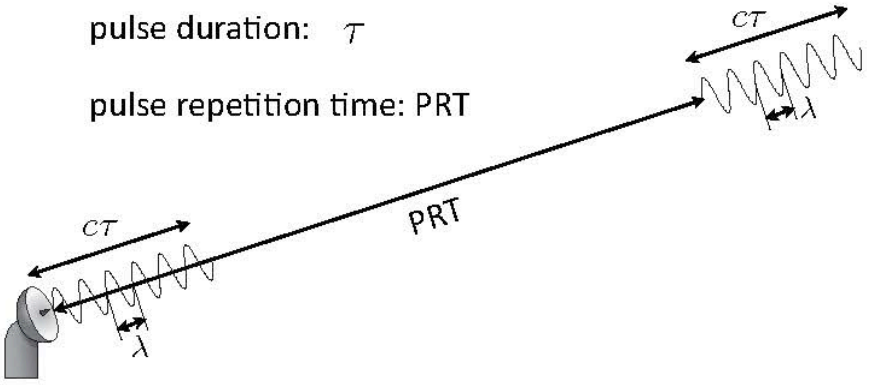


Matti Leskinen (U. Helsinki)

How weather radars work

pulse duration: τ

pulse repetition time: PRT



- determines the maximum range: $r_{max} = \frac{c \cdot PRT}{2}$
- determines the maximum velocity: $v_{r,max} = \frac{\lambda \Delta\varphi_{max}}{4\pi PRT} = \frac{\lambda}{4 \cdot PRT}$

$$v_{r,max} \cdot r_{max} = \frac{c \cdot \lambda}{8}$$ **dilemma**

How weather radars work

maximum unambigous range: $r_{max} = \frac{c \cdot PRT}{2}$

Nyquist velocity: $v_{r,max} = \frac{\lambda \Delta\varphi_{max}}{4\pi PRT} = \frac{\lambda}{4 \cdot PRT}$

	X	C	S
wavelength [cm]	3	5	10
r_{max} [km]	240 / 120	240 / 120	240 / 120
v_{max} [m/s]	4.7 / 9.4	7.8 / 15.6	15.6 / 31.2

PRT = $1.6 \cdot 10^{-3}$ sec (PRF = 625 Hz)

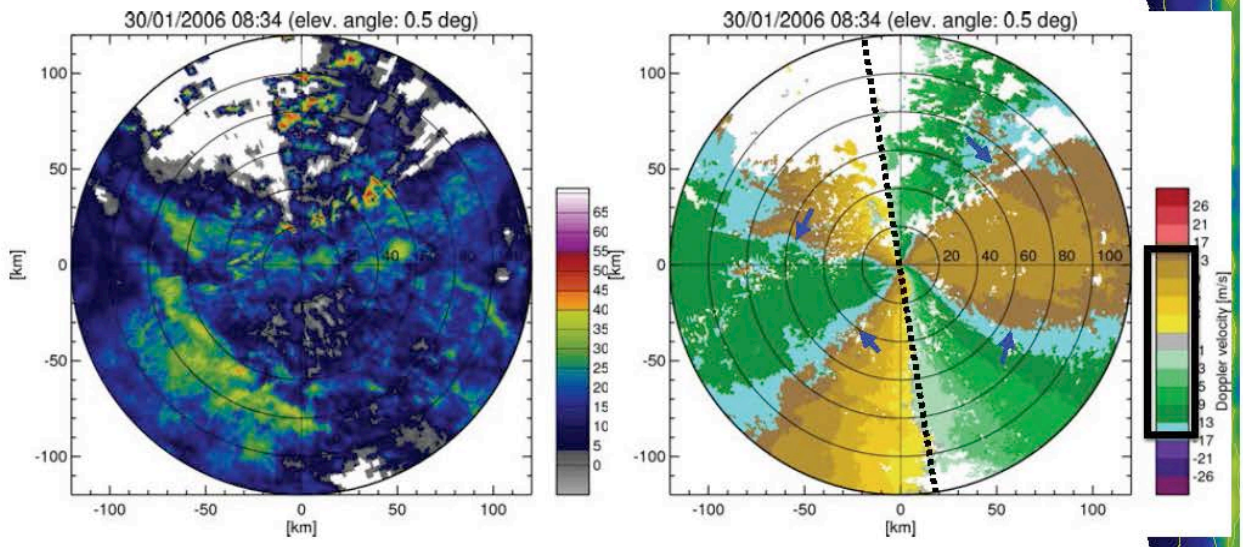
PRT = $0.8 \cdot 10^{-3}$ (PRF = 1250 Hz)

Doppler velocity

Velocity aliasing (v > v_{nyq})

$$v_{r,max} = \frac{\lambda \Delta \varphi_{max}}{4\pi PRT} = \frac{\lambda}{4 \cdot PRT}$$

= 15.6 m/s



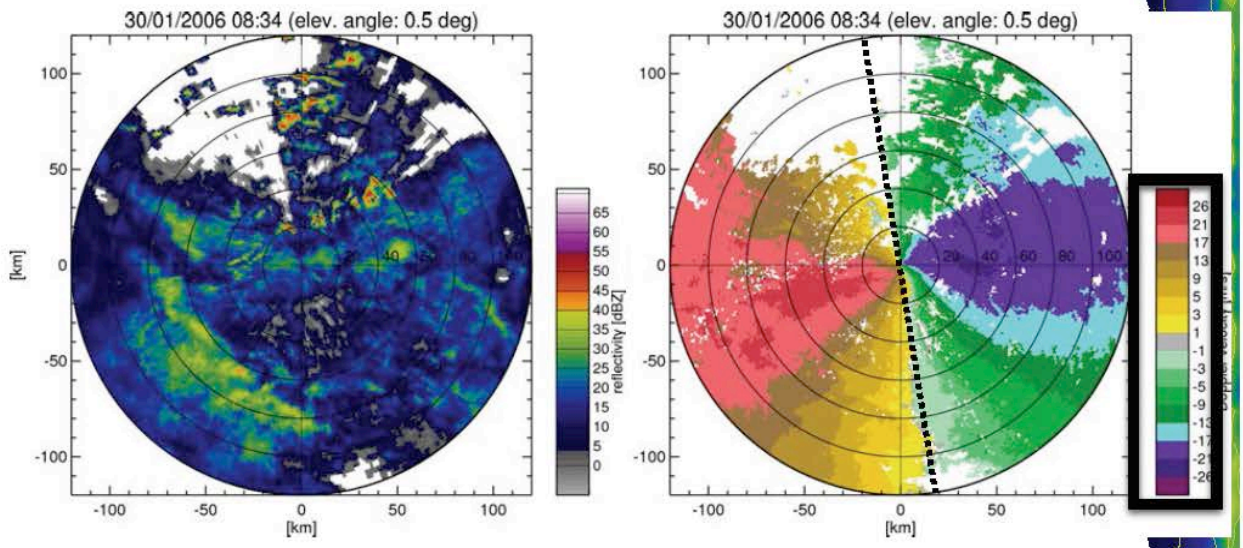
corrected by using multiple PRFs (PRTs).

Doppler velocity

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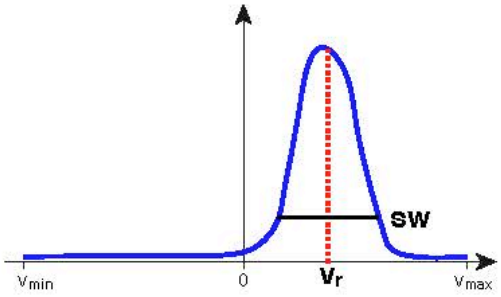


corrected by using multiple PRFs (PRTs).

Doppler velocity

From the analysis of multiple pulses, the **Doppler spectrum** is calculated:

the contribution to the measured power as a function of Doppler velocity at each radar bin.



Moments of the power spectrum:

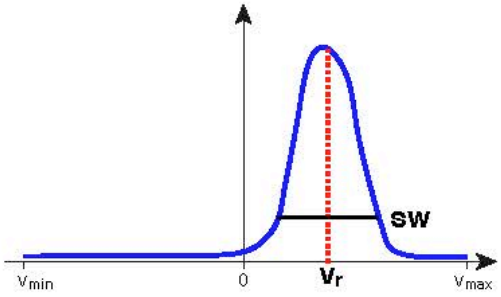
Doppler velocity: mean.

Spectral width: standard deviation.

Doppler velocity

From the analysis of multiple pulses, the **Doppler spectrum** is calculated:

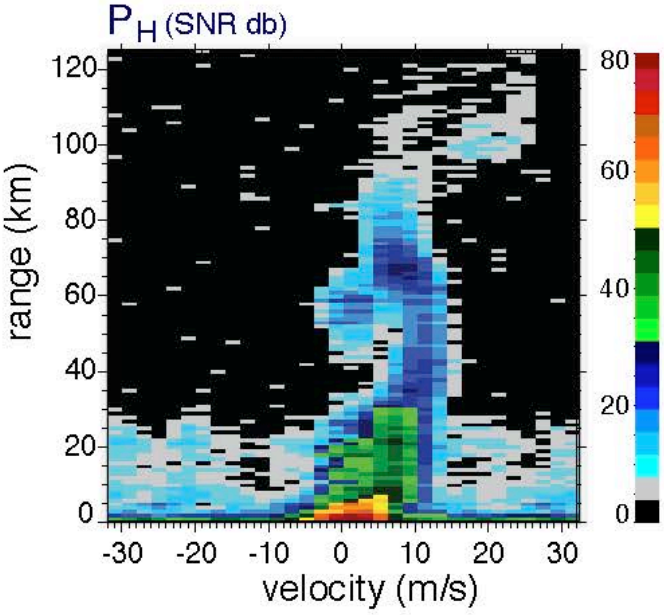
the contribution to the measured power as a function of Doppler velocity at each radar bin.



Moments of the power spectrum:

Doppler velocity: mean.

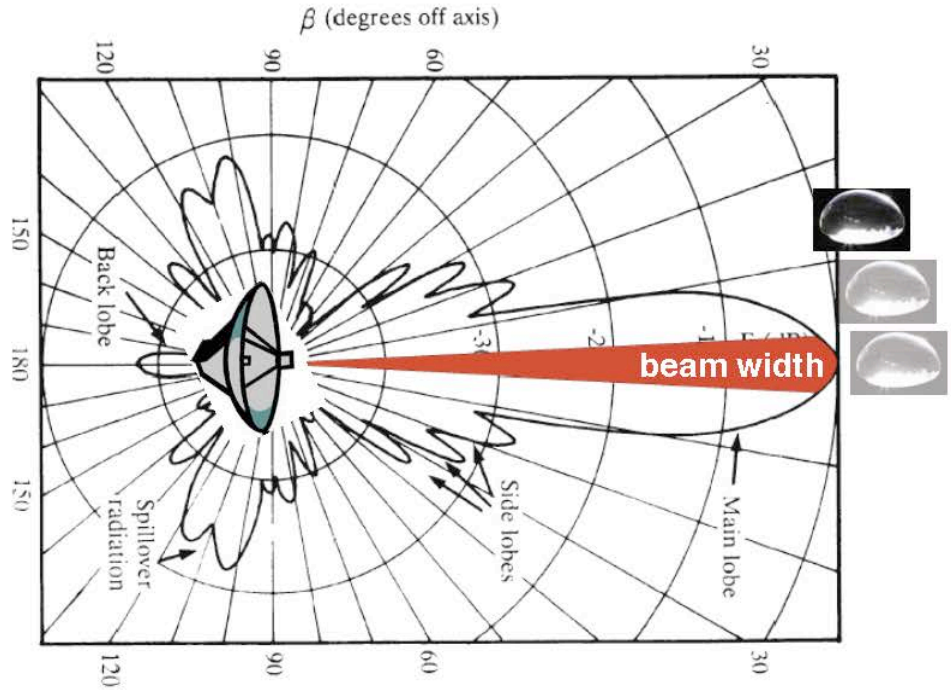
Spectral width: standard deviation.



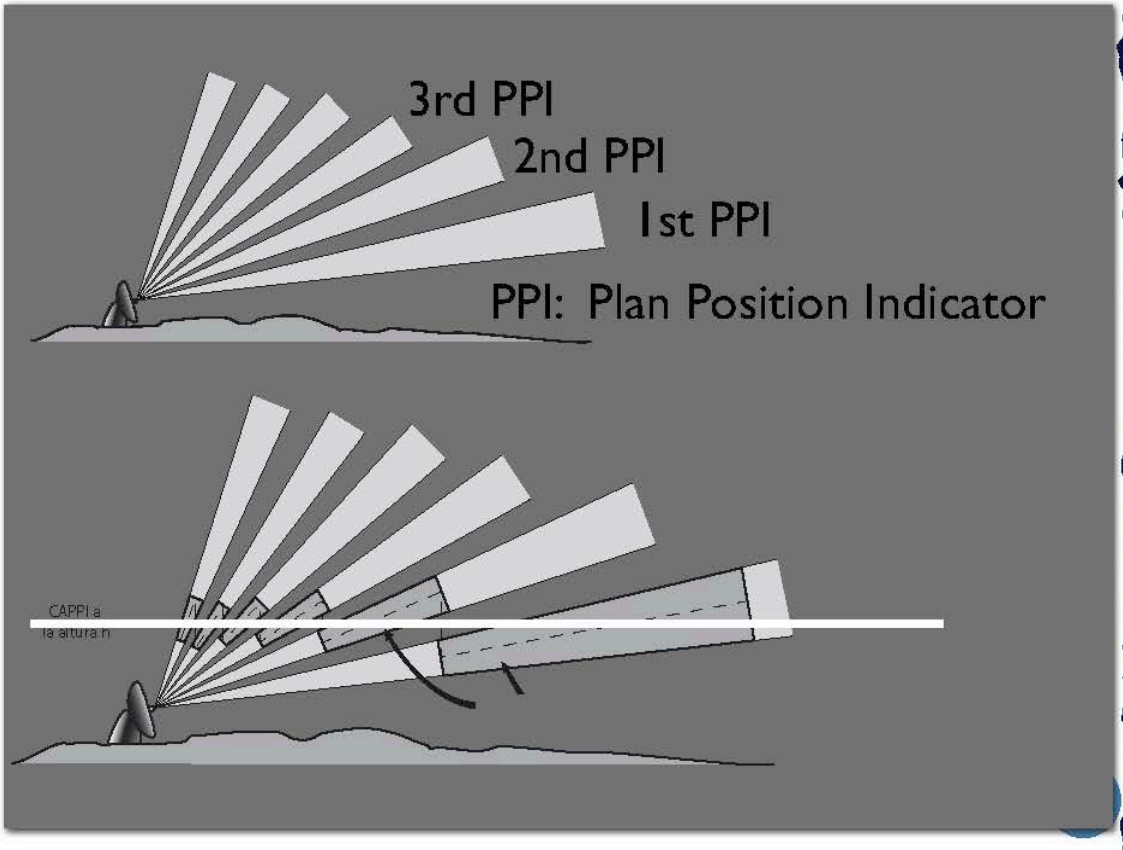
courtesy of I. Zawadzki

The radar beam pattern

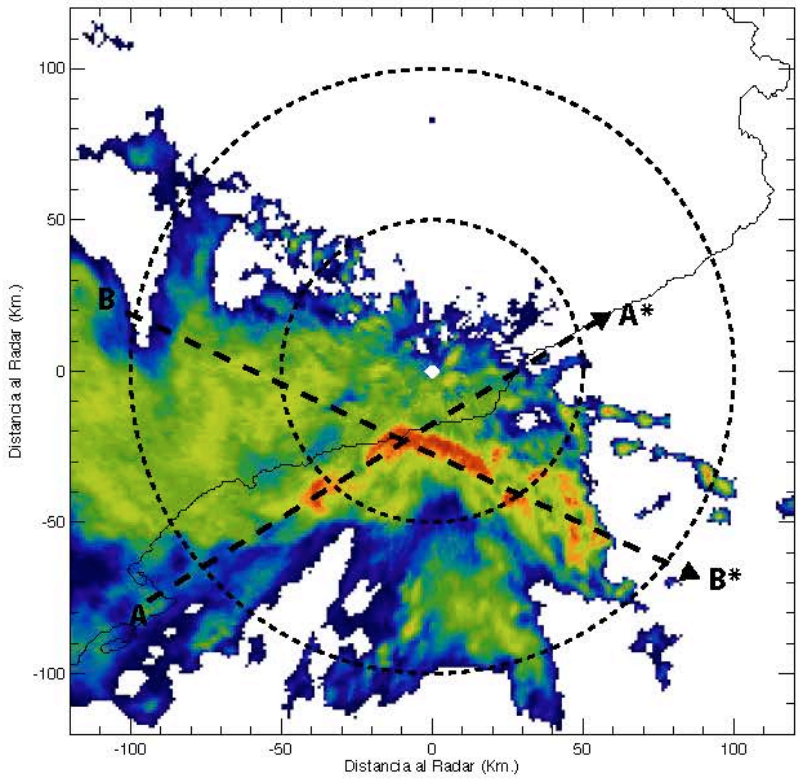
The measured power is the integral of the returns from the different targets taking into account the power density distribution.



Weather radar measurements

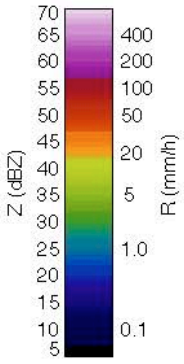


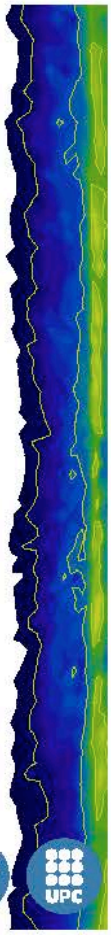
Weather radar measurements - Processed radar data



Cartesian Coordinates

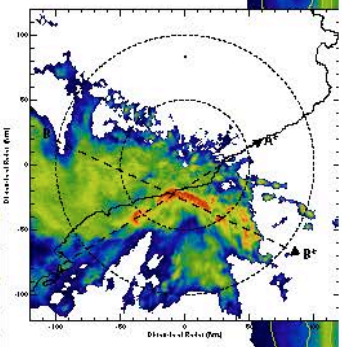
Processing applied

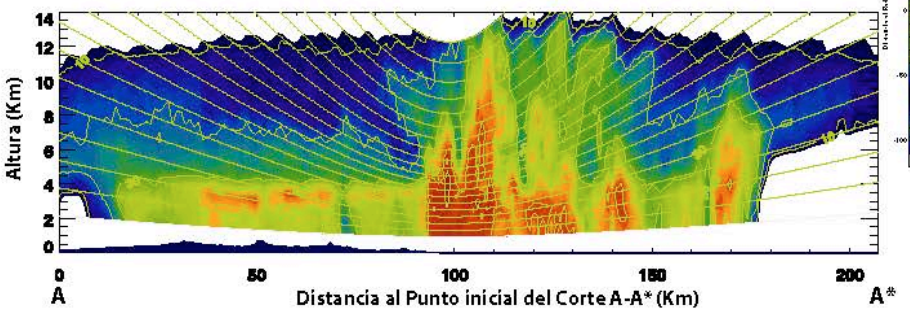


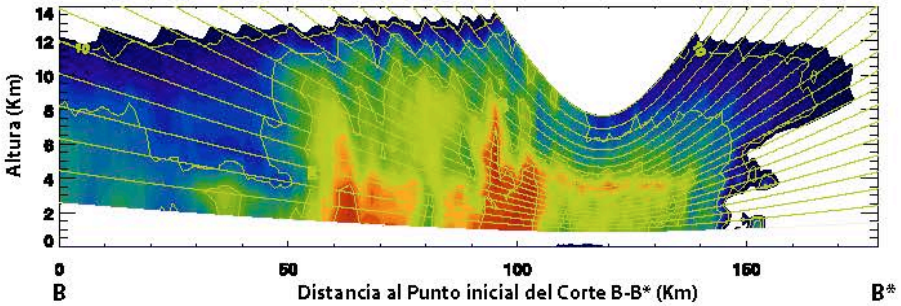


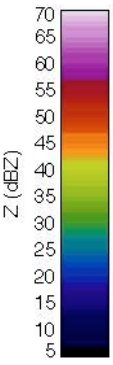
Weather radar measurements - Processed radar data

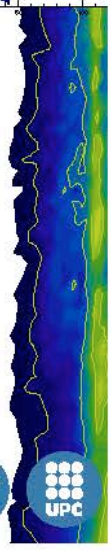
Radars provide 3D measurements of the precipitation field structure





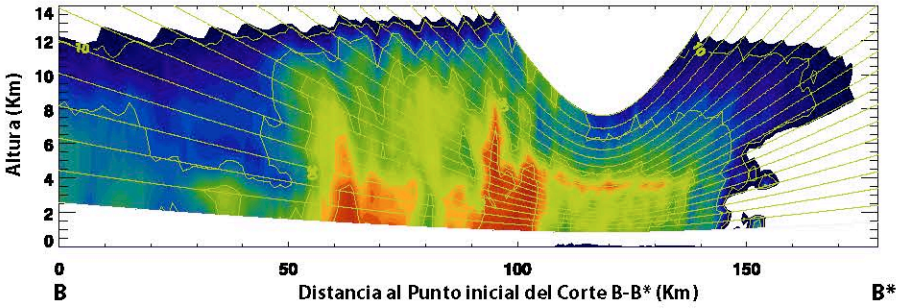


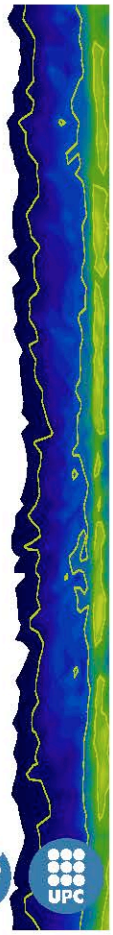




Conclusions

- Radar is the best instrument for monitoring the occurrence, intensity and movement of precipitation at the scales that are relevant for the population.
- Volumetric observations.
- Observations are available immediately.
- Quantitative Precipitation Estimation requires careful processing of these observations.





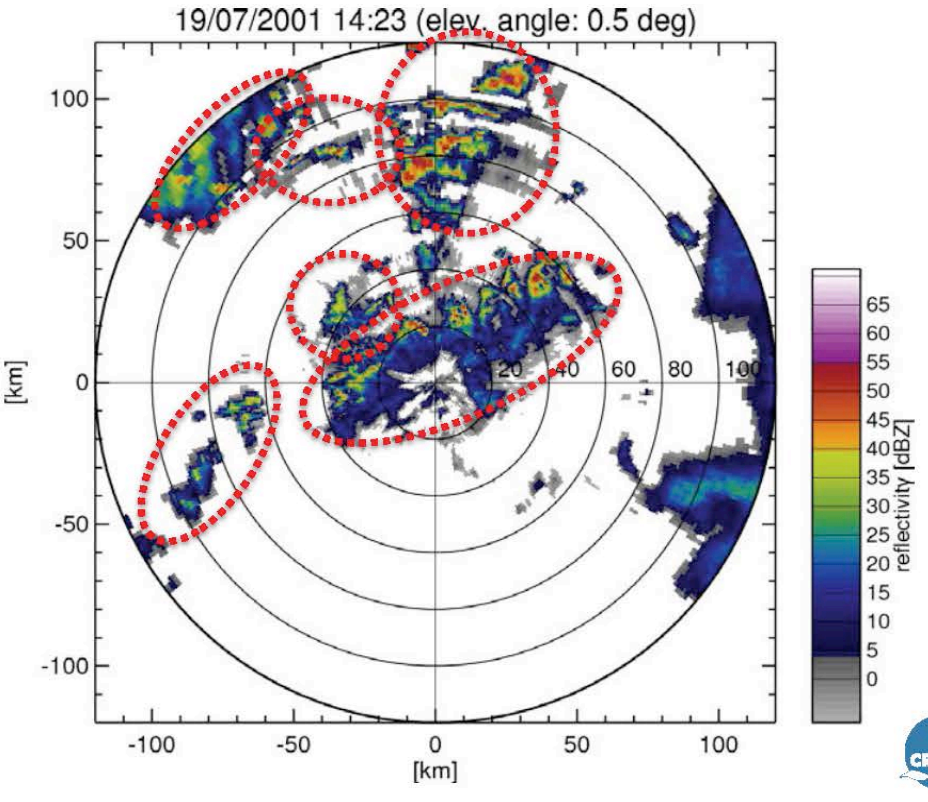


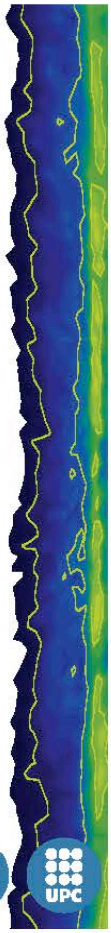
TRAINING PROGRAM ON METEOROLOGICAL AND ADVANCED QUANTITATIVE APPLICATIONS

Ground clutter and non-meteorological echoes.
Basic and advanced processing

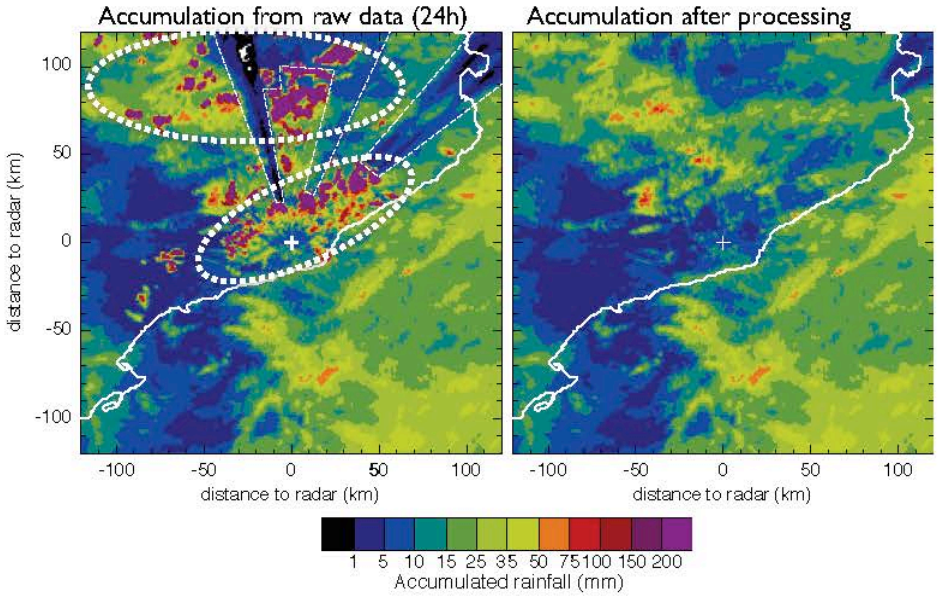


Beam interception with the terrain

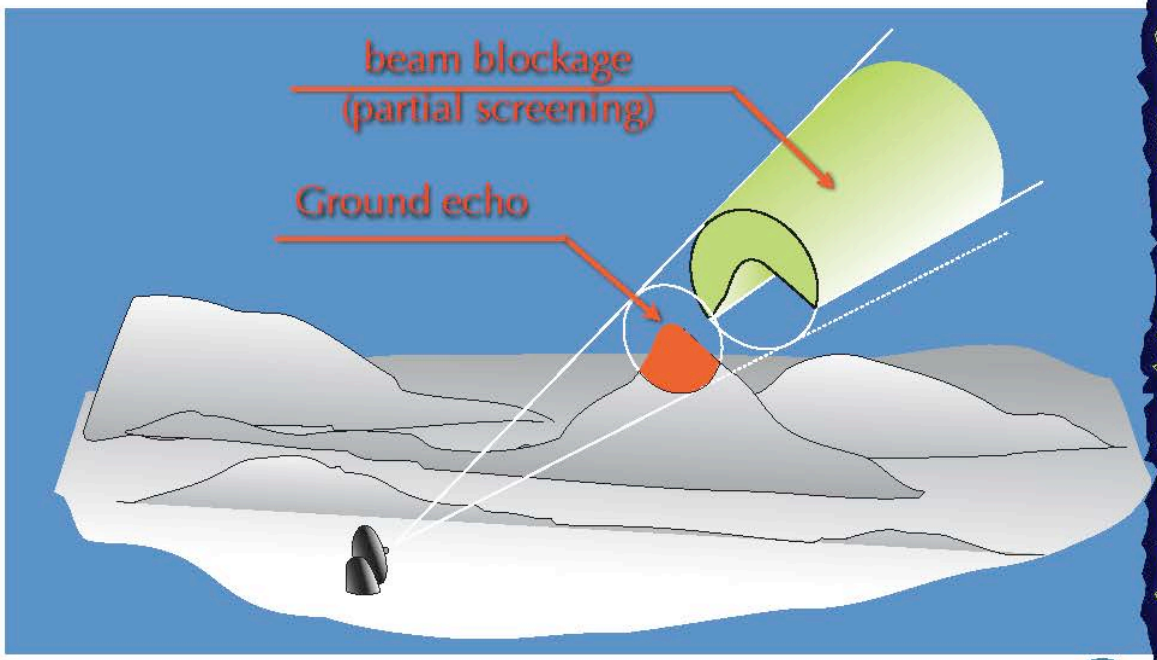




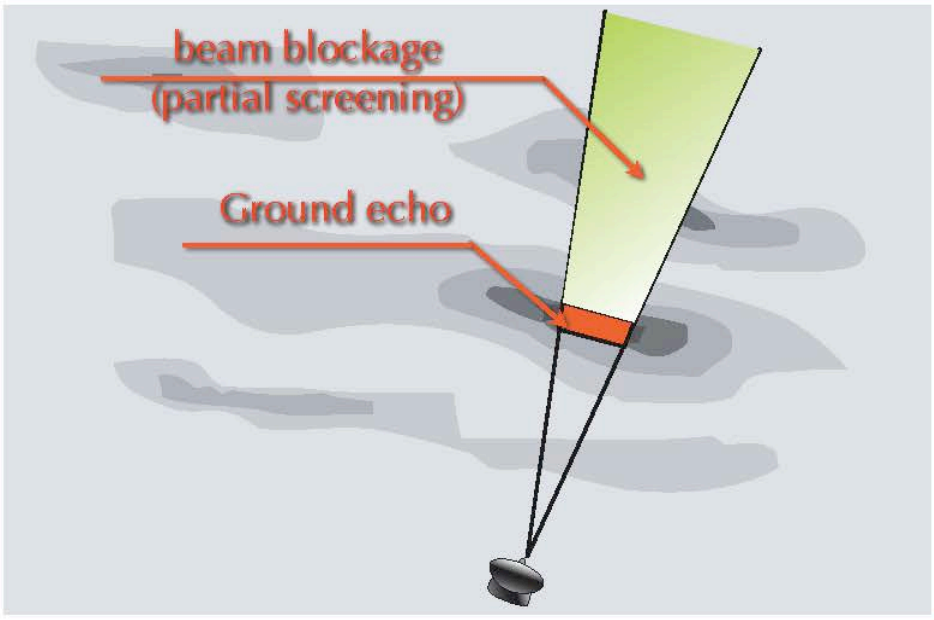
Beam interception with the terrain



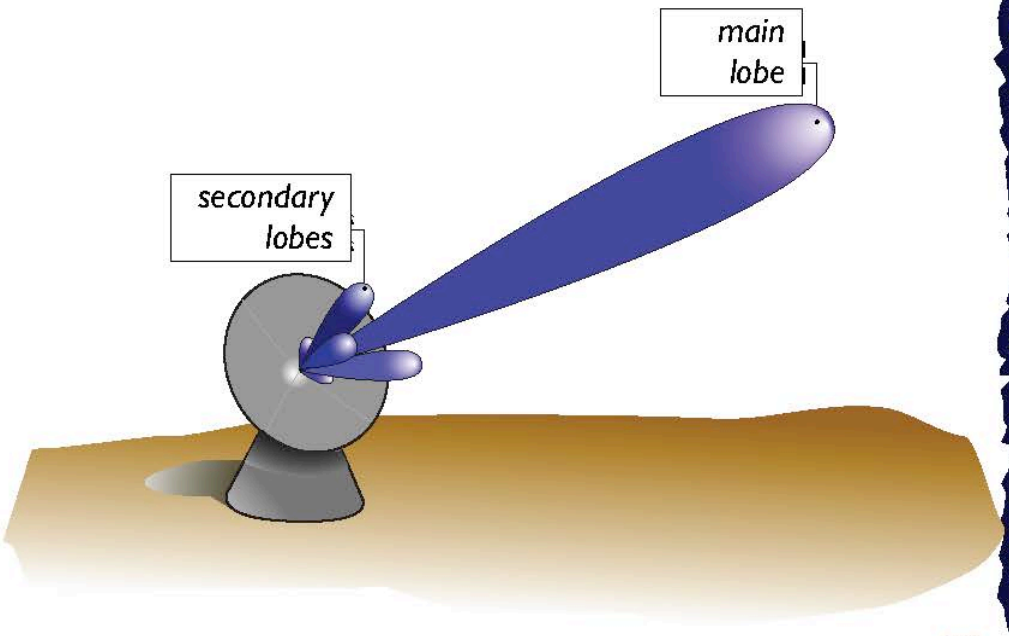
Beam interception with the terrain



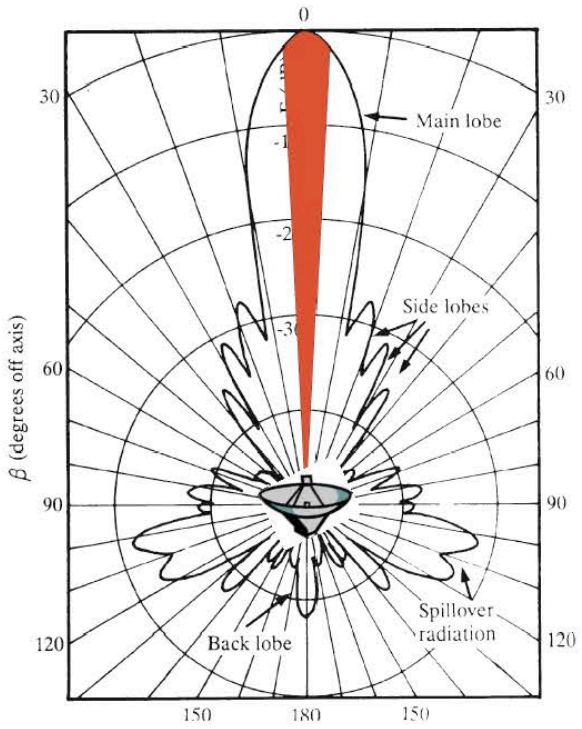
Beam interception with the terrain



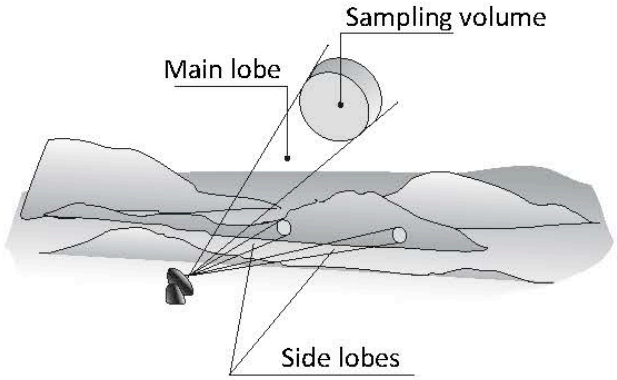
Side lobes

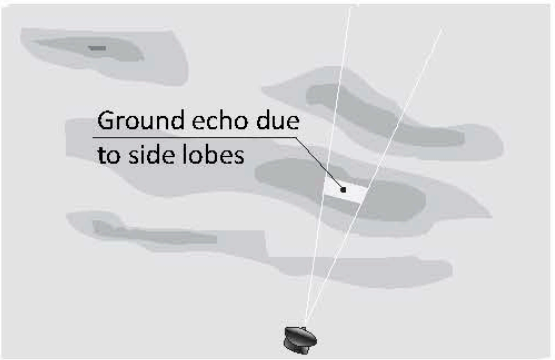


Side lobes

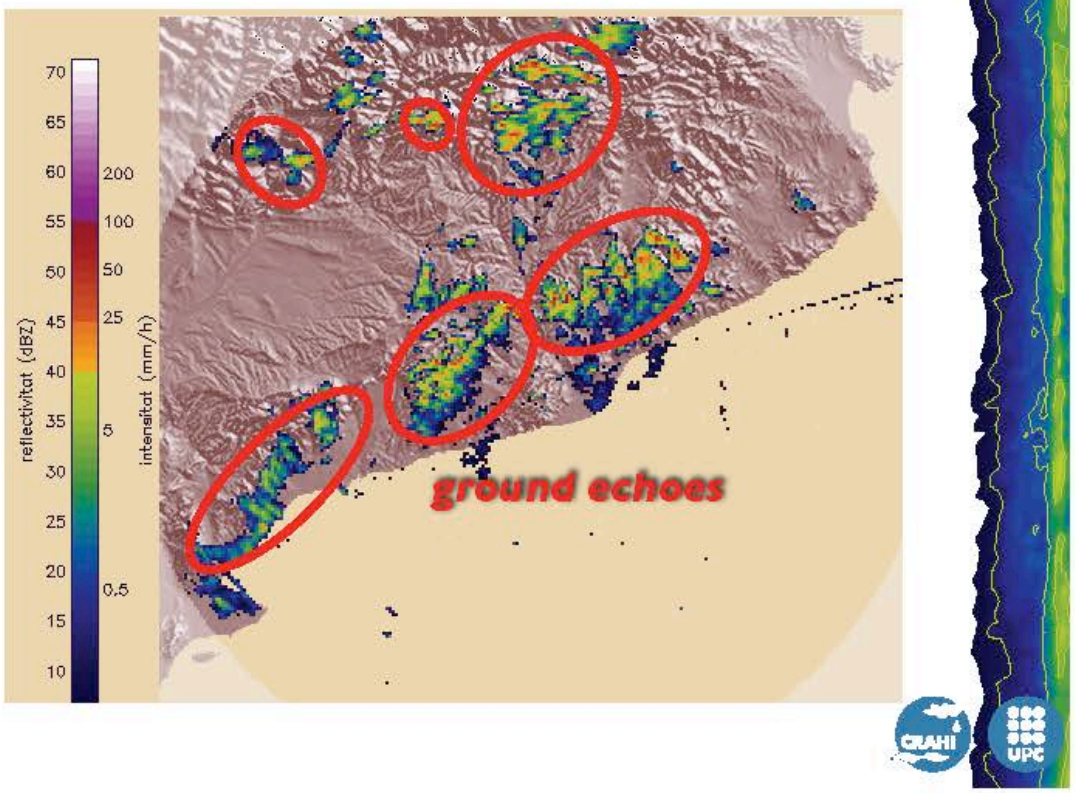


Side lobes

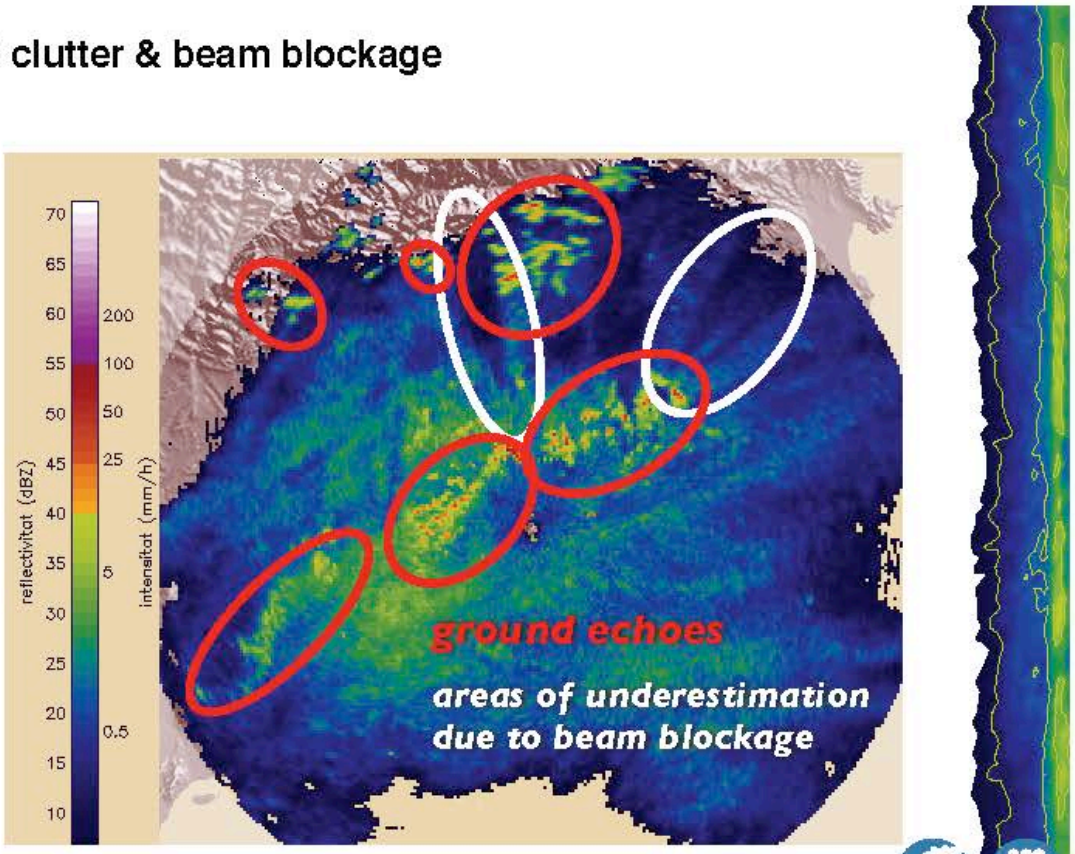




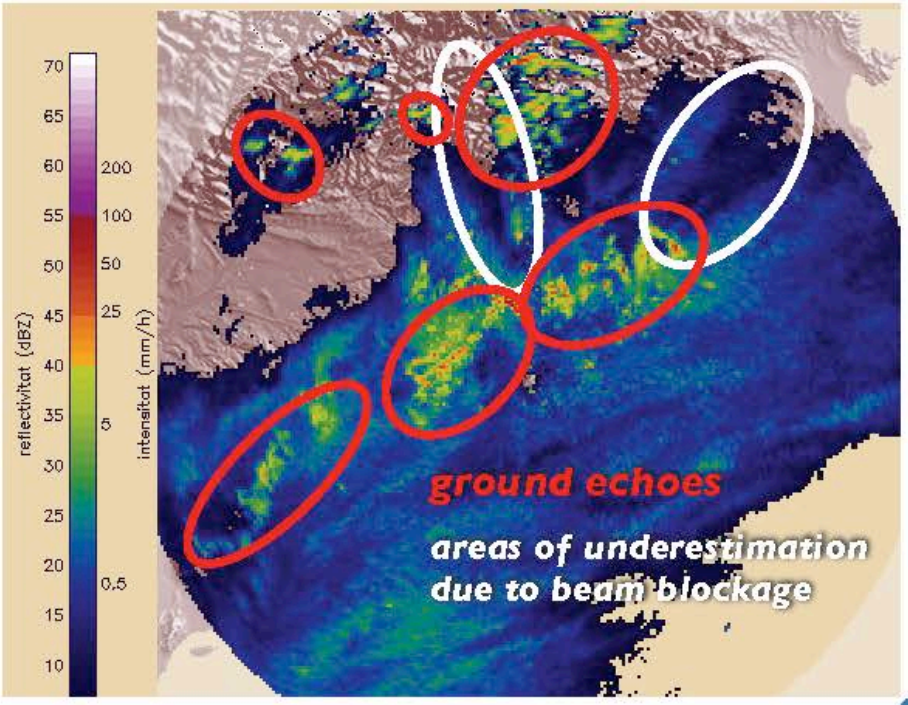
Ground clutter



Ground clutter & beam blockage



Ground clutter & beam blockage

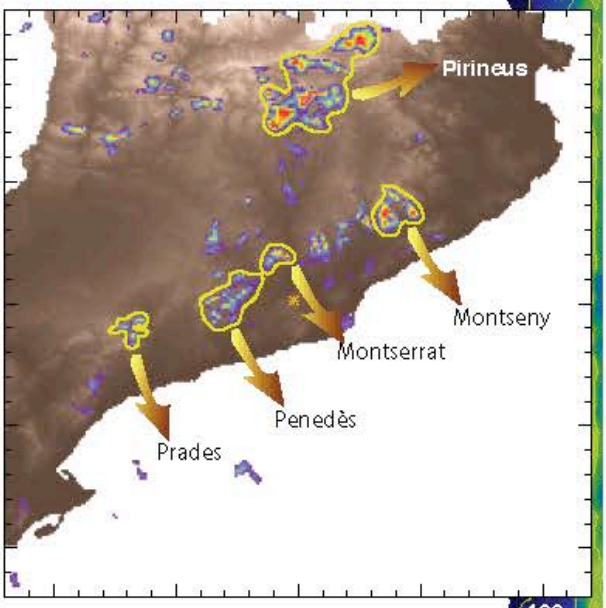


Ground clutter identification

1 - Clutter identification: mean clutter mask

PROS:
- Simplicity.
- Requires reconstruction of the fields in the clutter-contaminated areas.

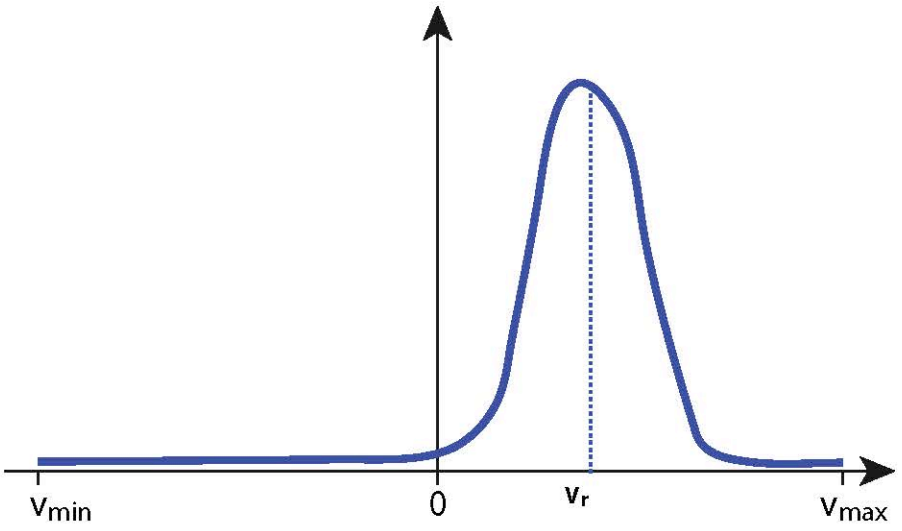
CONS:
- Not flexible.
- Anomalous propagation
- Sea clutter.



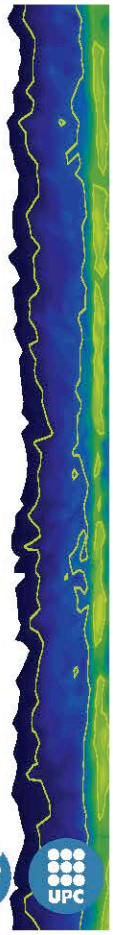
Ground clutter identification

2 - Doppler spectrum filtering

Applied in most operational systems for ground clutter removal and reconstruction.



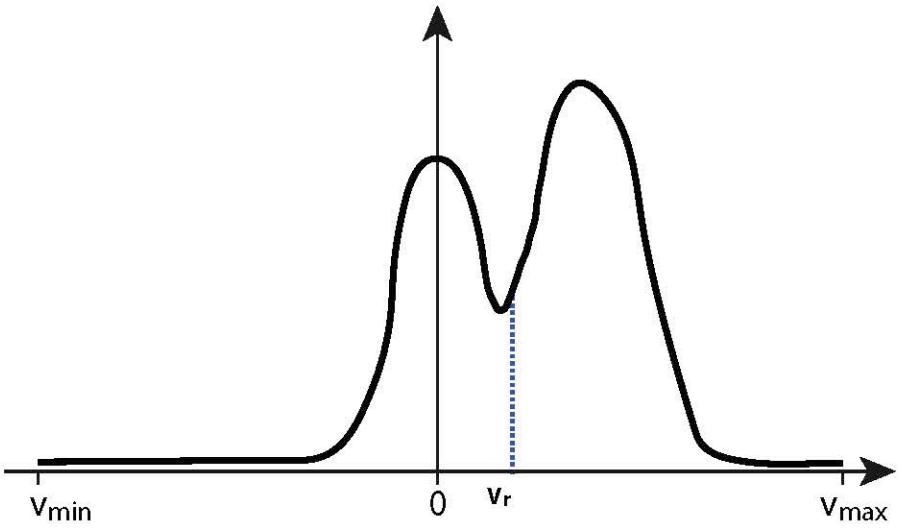
PS in a clutter-fee bin



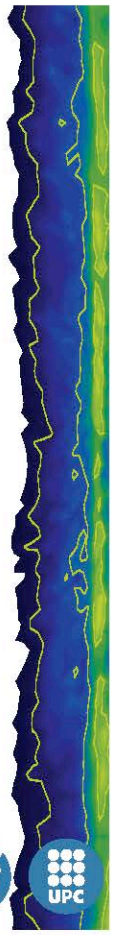
Ground clutter identification

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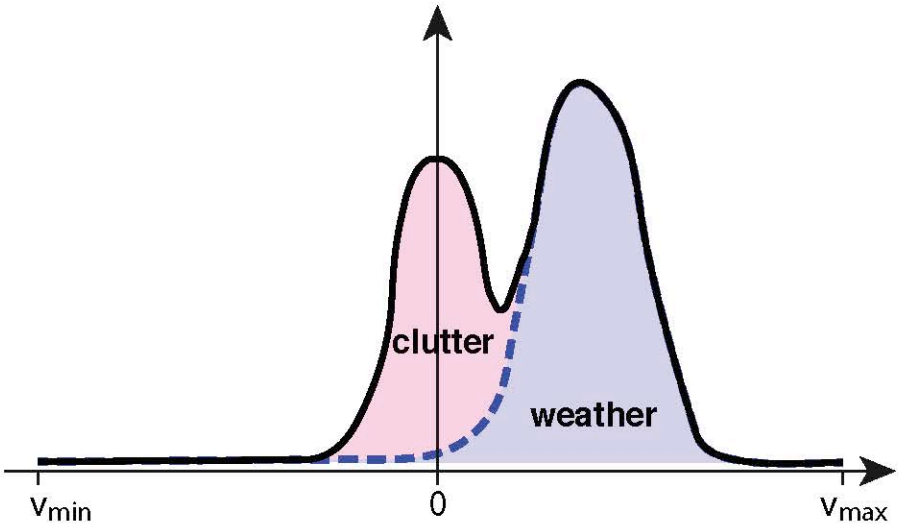
PS in a clutter-contaminated bin



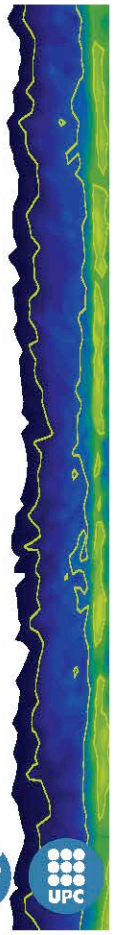
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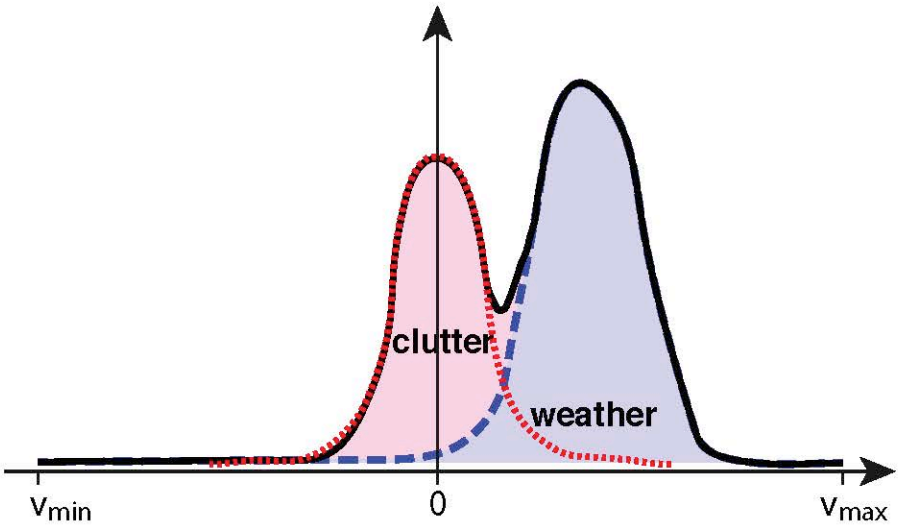
PS in a clutter-contaminated bin



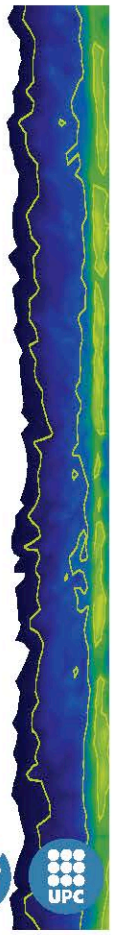
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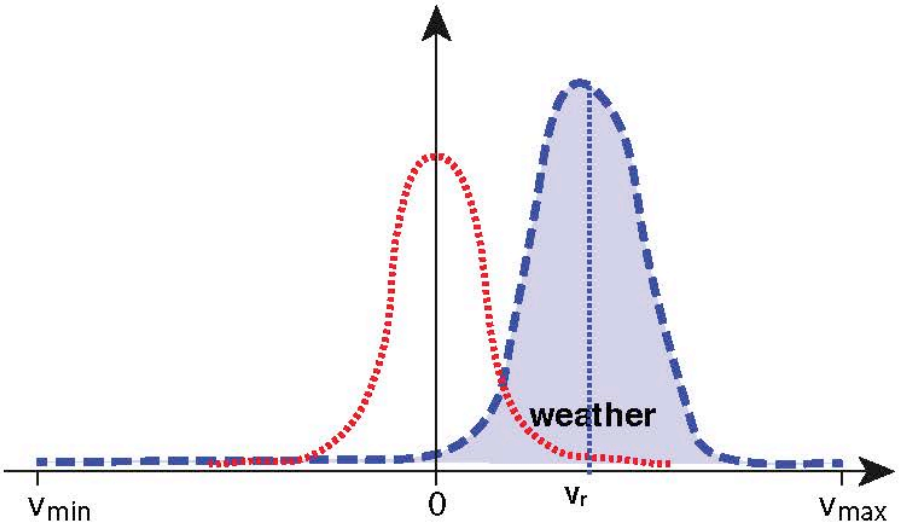
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Ground clutter identification

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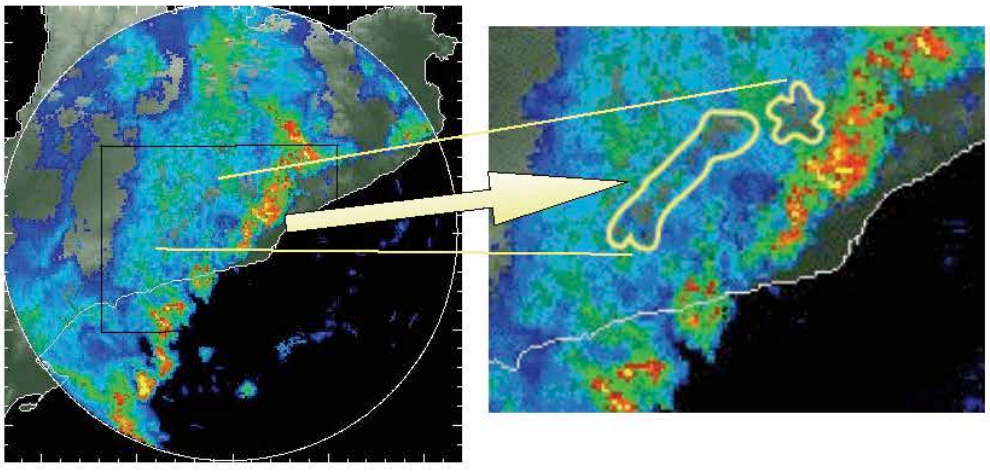


PS in a clutter-contaminated bin

Ground clutter identification

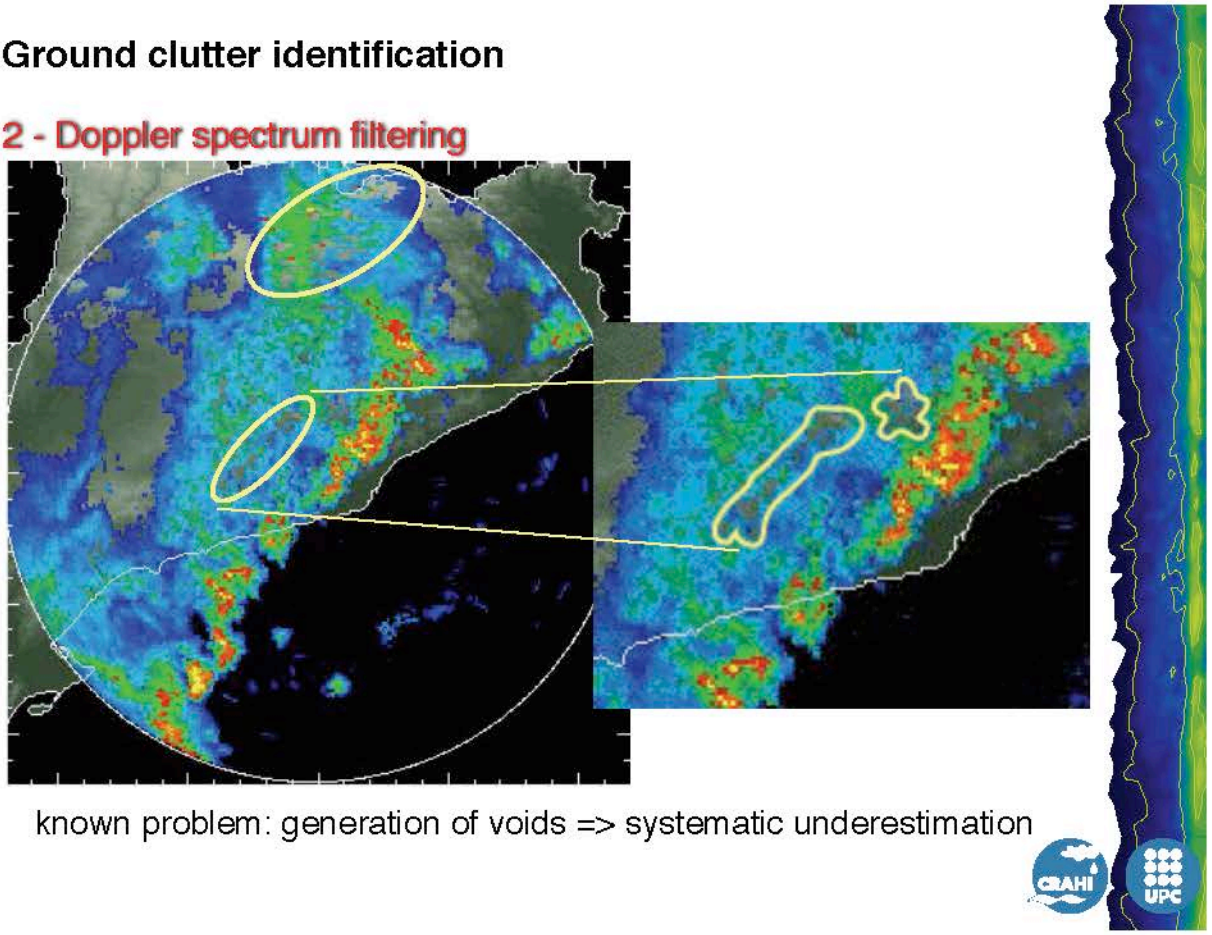
2 - Doppler spectrum filtering

- Applied in most operational systems for ground clutter removal and reconstruction.



Ground clutter identification

2 - Doppler spectrum filtering



known problem: generation of voids => systematic underestimation

Ground clutter identification

2 - Doppler spectrum filtering

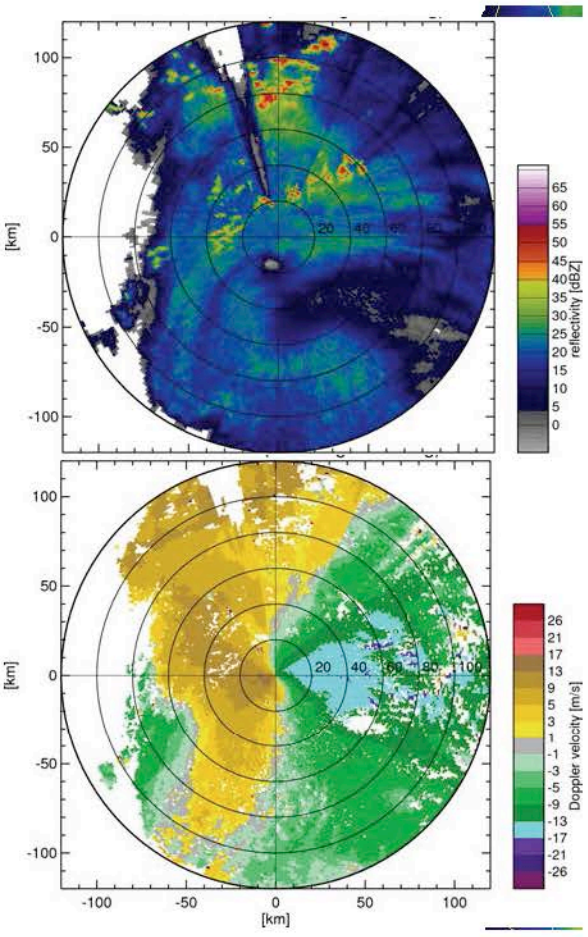
PROS:

- Done at the processing level.

CONS:

- Strong clutter signal -> poor reconstruction of the reflectivity.
- Tangential velocity areas.
- Sea clutter

(*) Some of them can be mitigated with fine tuning of the algorithm.



Ground clutter identification

2 - Doppler spectrum filtering

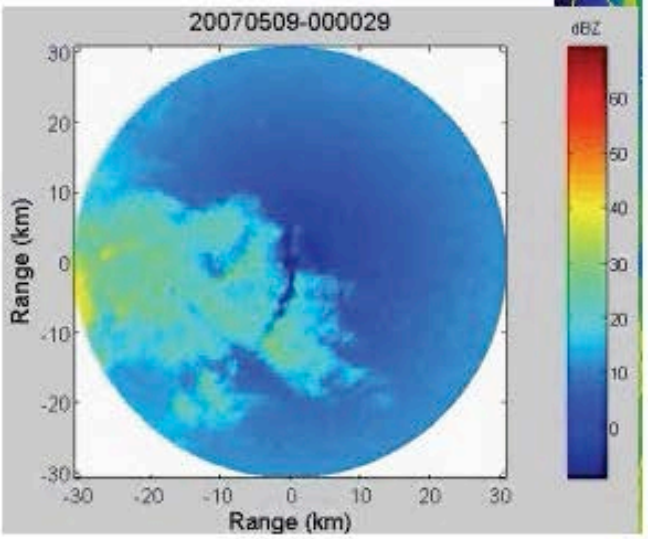
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Ground clutter identification

3 - Clutter identification based on statistical features

Identification of clutter bins based on the ***combined*** use of statistics that characterize the properties of ground echoes:

- Low vertical development: *echotop, vertical gradient of reflectivity*
- Low velocities: *Doppler velocity*
- High spatial variability: *Texture of reflectivity, spin change*
- Polarimetric variables: *rho_{HV}, texture of Z_{dr}, texture of Phi_{dp}*

Ground clutter identification

3 - Clutter identification based on statistical features

Identification of clutter bins based on the ***combined*** use of statistics that characterize the properties of ground echoes:

- Low vertical development: *echotop, vertical gradient of reflectivity*
- Low velocities:
- High spatial variabilit
- Polarimetric variable

Combination?

Decision trees: Joss et al. (1995); Bellon et al. (1999); Steiner et al. (2002)

Fuzzy logic: Kessinger et al. (2003); Berenguer et al. (2006); Cho et al. (2006); Gourley et al. (2007); Rico-Ramirez et al. (2008); Moiseev et al. (2009); Hubbert et al. (2010)…

Ground clutter - Reconstruction of observations

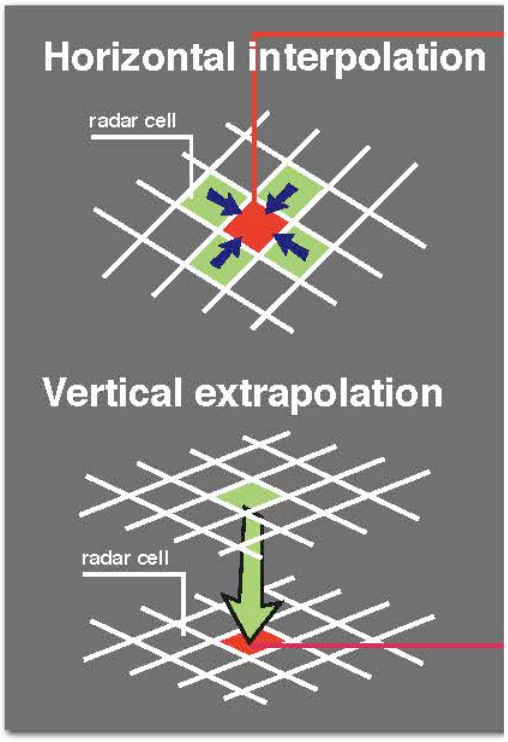
3 - Clutter identification based on statistical features

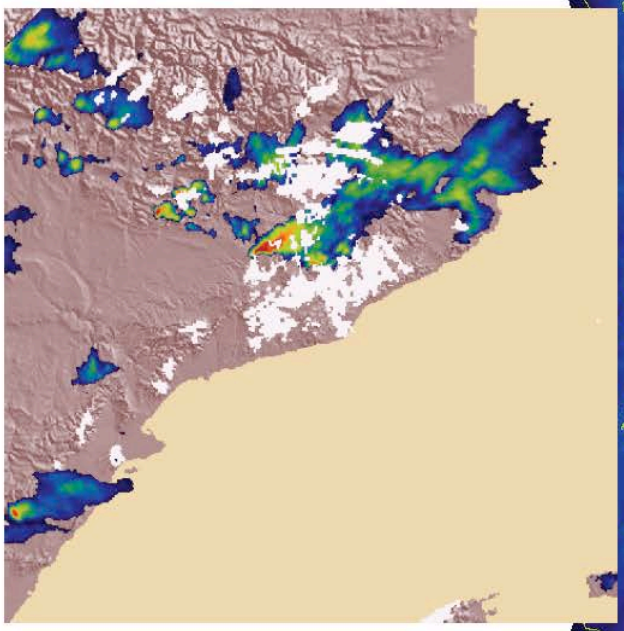
PROS:
- Take benefit from multiple variables (not only Doppler information).
- Tangential velocity areas.
- Sea clutter.
- Can include information from the past ("clutter climatology").

CONS:
- Reconstruction done a posteriori.
- Ad-hoc?

Ground clutter & beam blockage

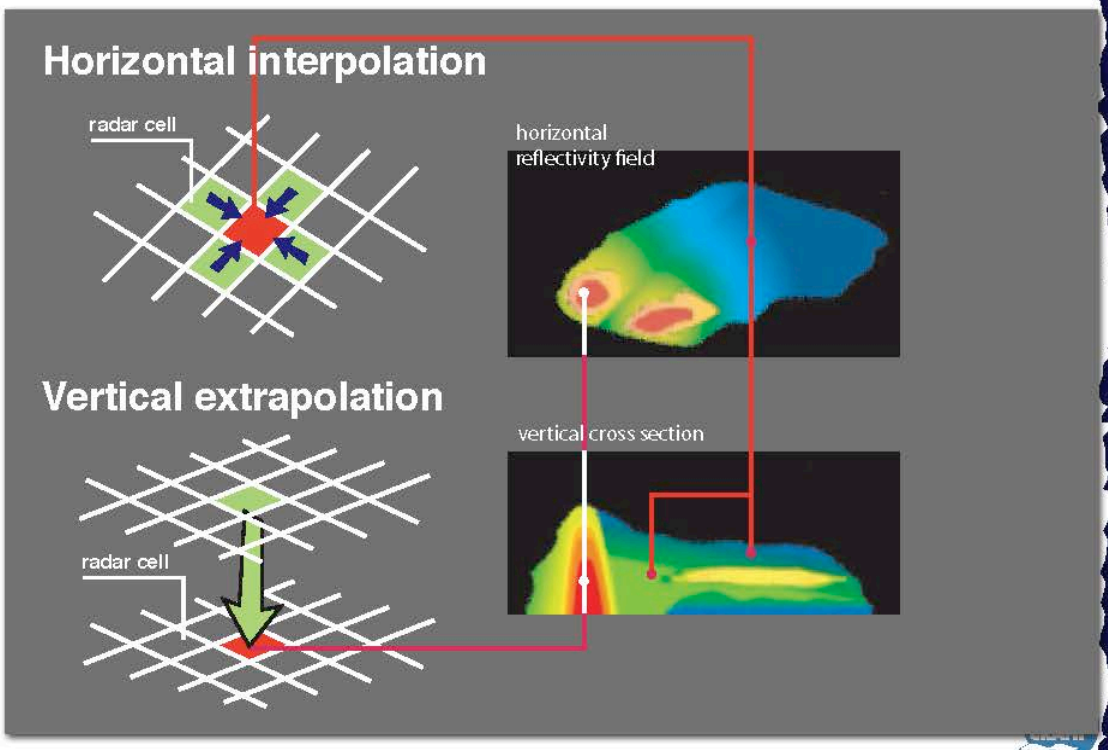
Reconstruction of the precipitation signal in clutter areas





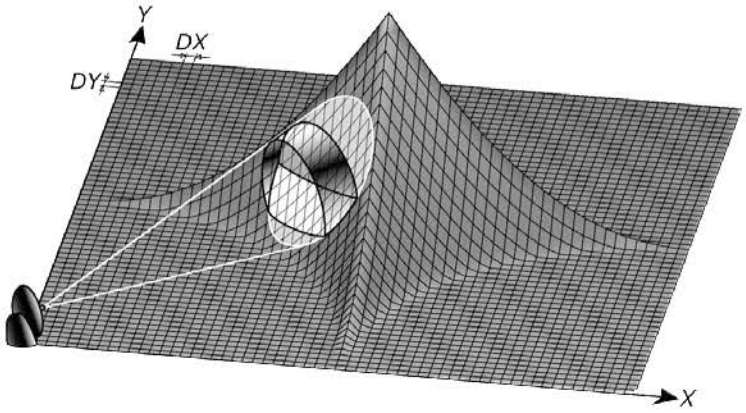
Ground clutter & beam blockage

Reconstruction of the precipitation signal in clutter areas

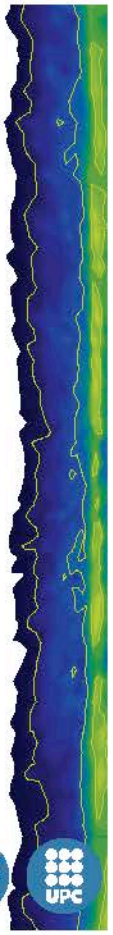


Beam blockage correction

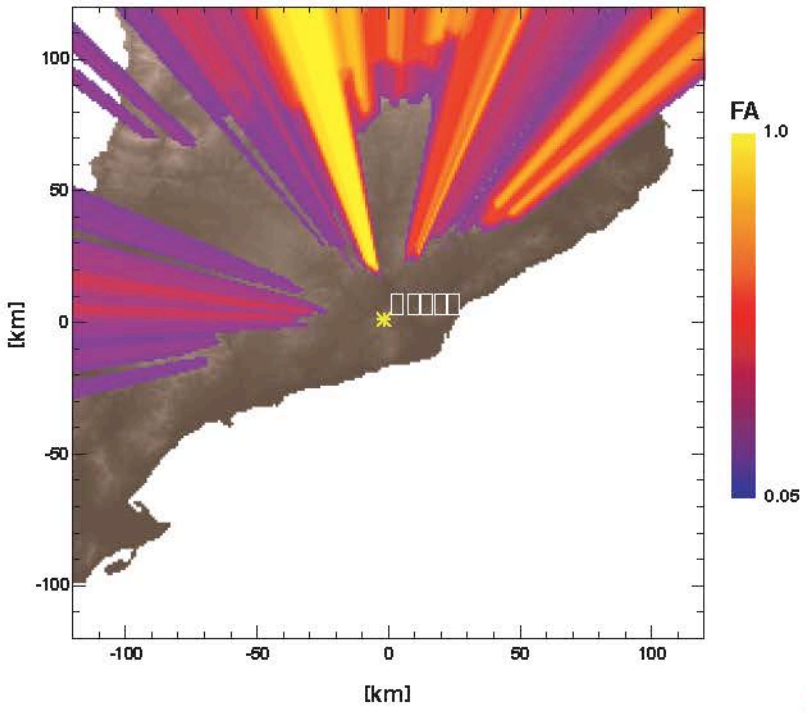
Illuminated surfaces computed by simulation with a DEM

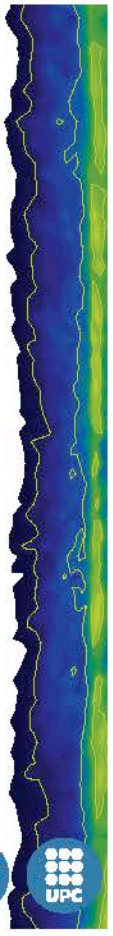


Delrieu and Creutin, 1995, JTECH, Simulation of radar mountain returns using a digitized terrain model.

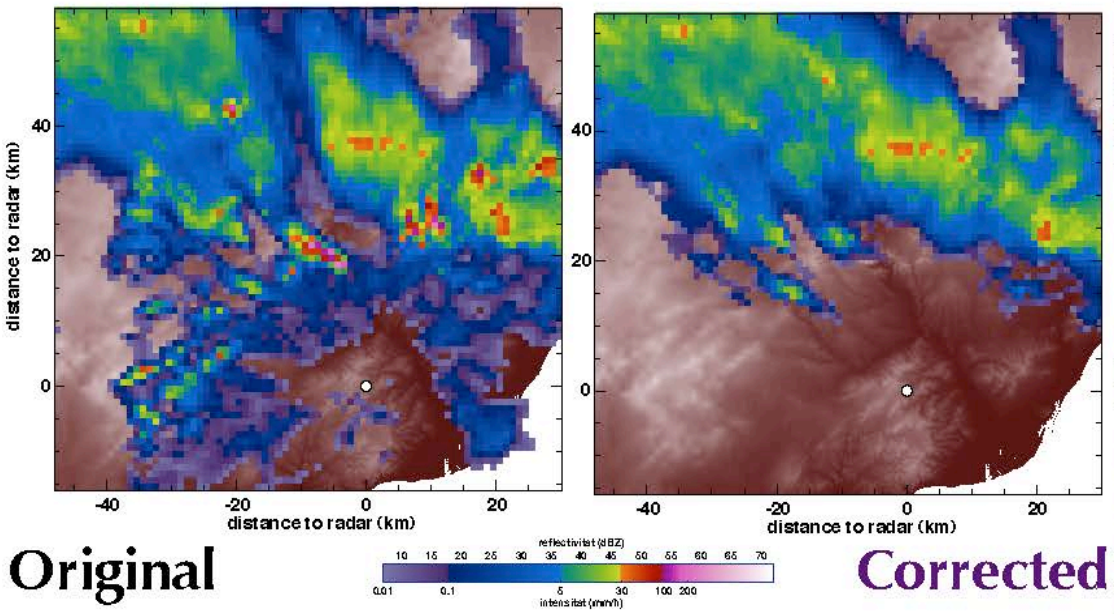


Beam blockage correction





Ground clutter & beam blockage

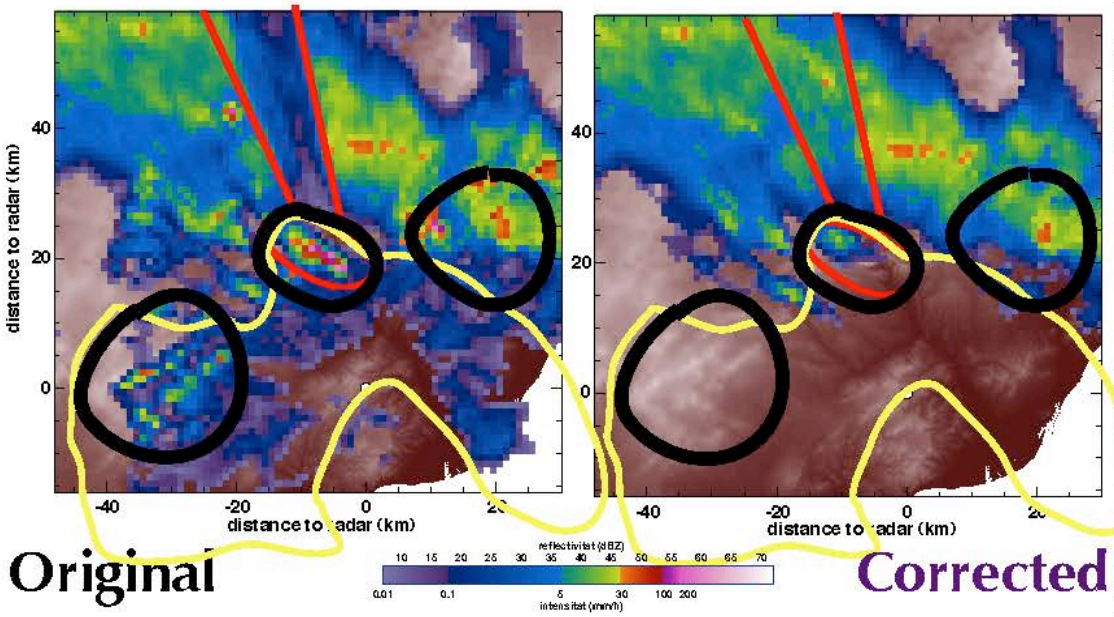


Original

Corrected

Ground clutter suppression, beam blockage correction and substitution.

Ground clutter & beam blockage



Original

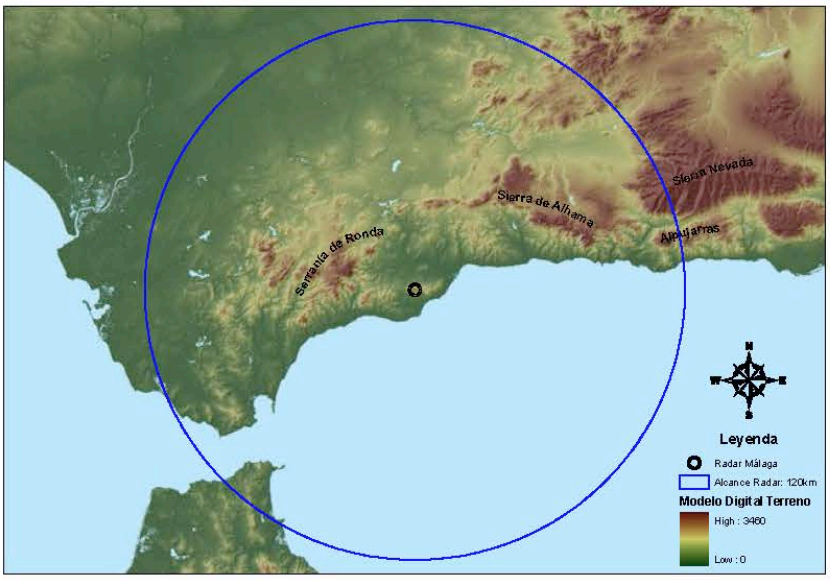
Corrected

Ground clutter suppression, beam blockage correction and substitution.

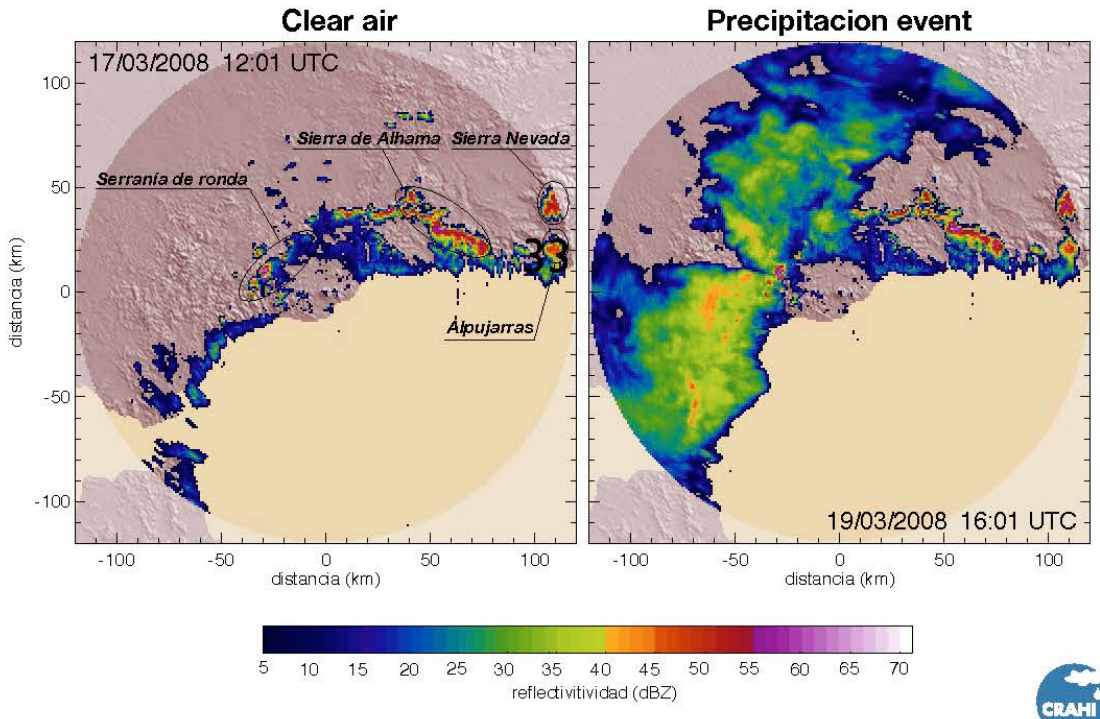
Ground clutter & beam blockage

Case study: Málaga Radar (AEMET), Spain

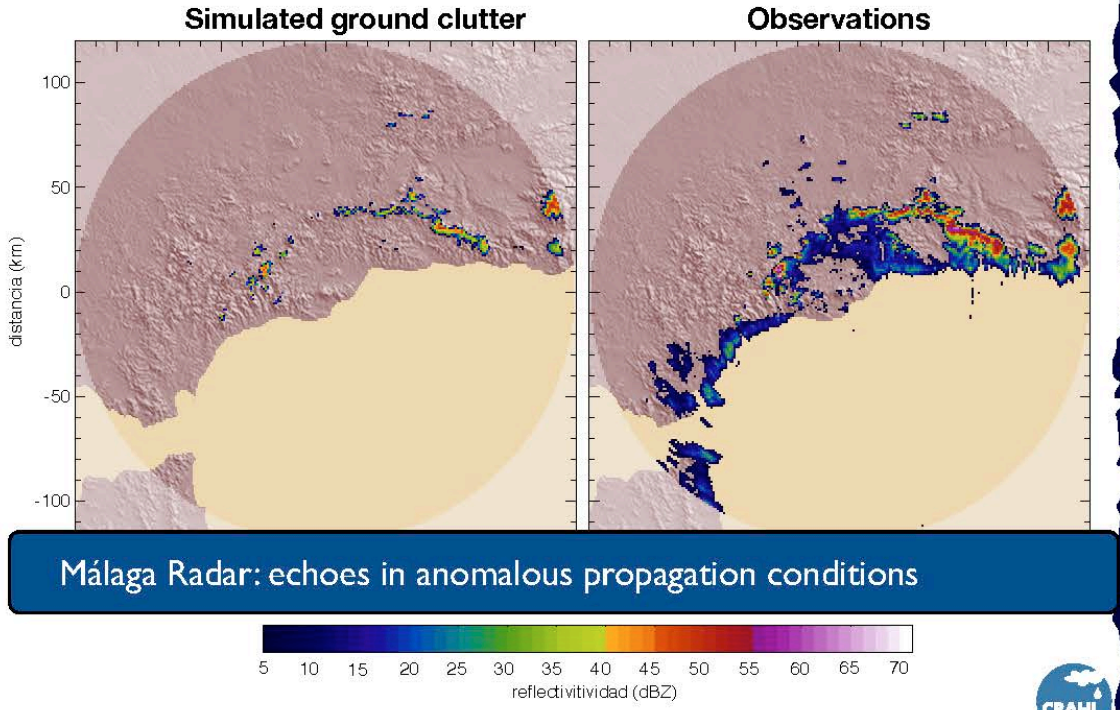
Very complex orography, area prone to anomalous propagation: usual processing is not enough



Ground clutter & beam blockage



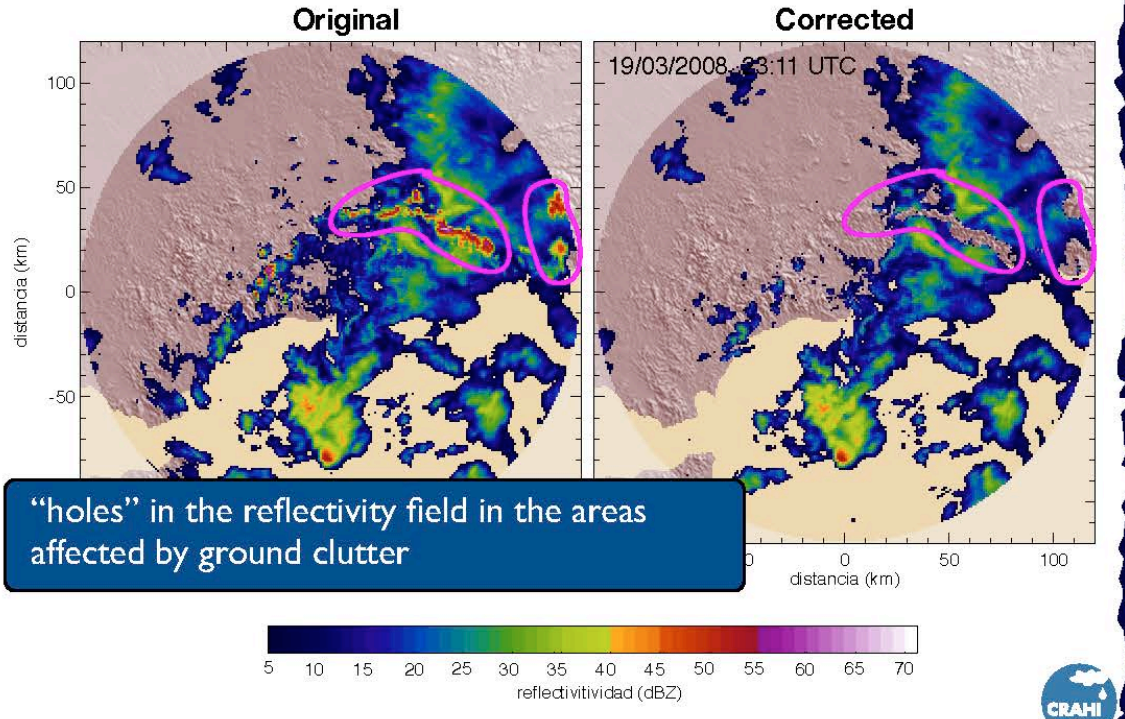
Ground clutter & beam blockage



Málaga Radar: echoes in anomalous propagation conditions

Ground clutter & beam blockage

Classical Doppler processing



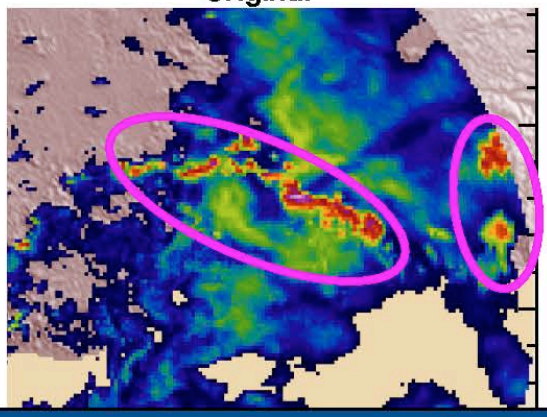
"holes" in the reflectivity field in the areas affected by ground clutter

Ground clutter & beam blockage

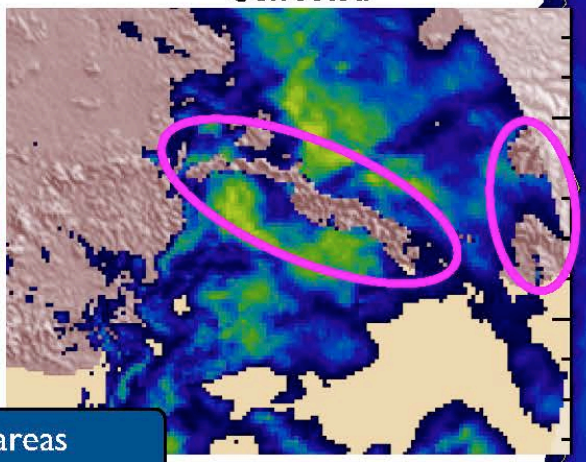
Classical Doppler processing

Limitation 1

Original



Corrected

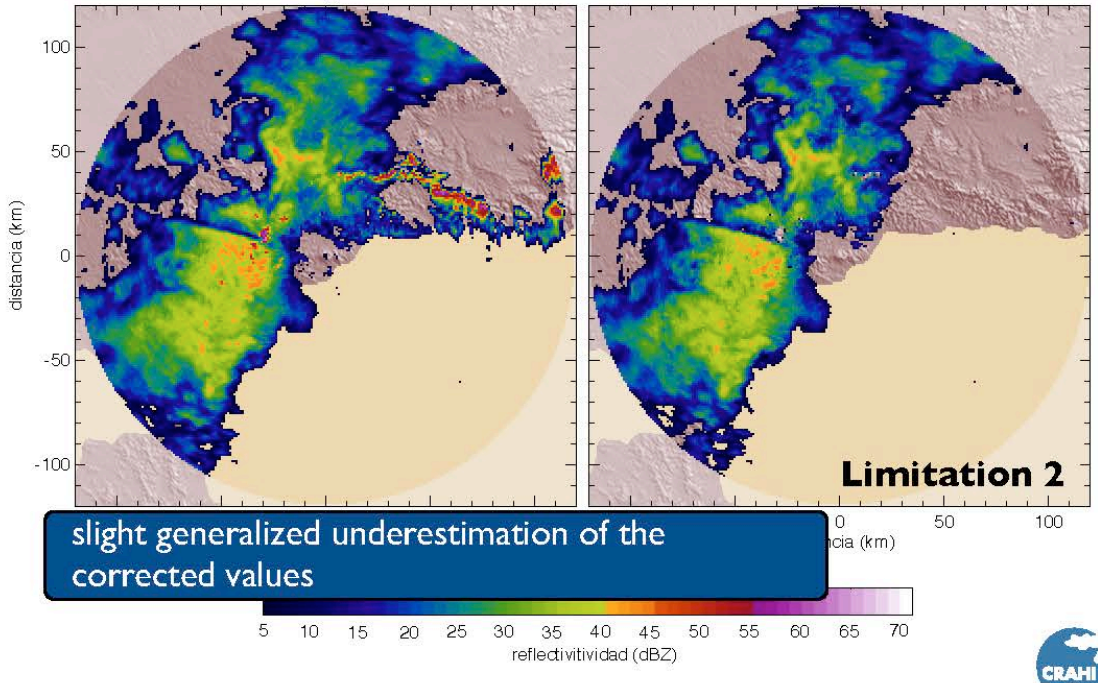


"holes" in the reflectivity field in the areas affected by ground clutter

Ground clutter & beam blockage

Classical Doppler processing

Original



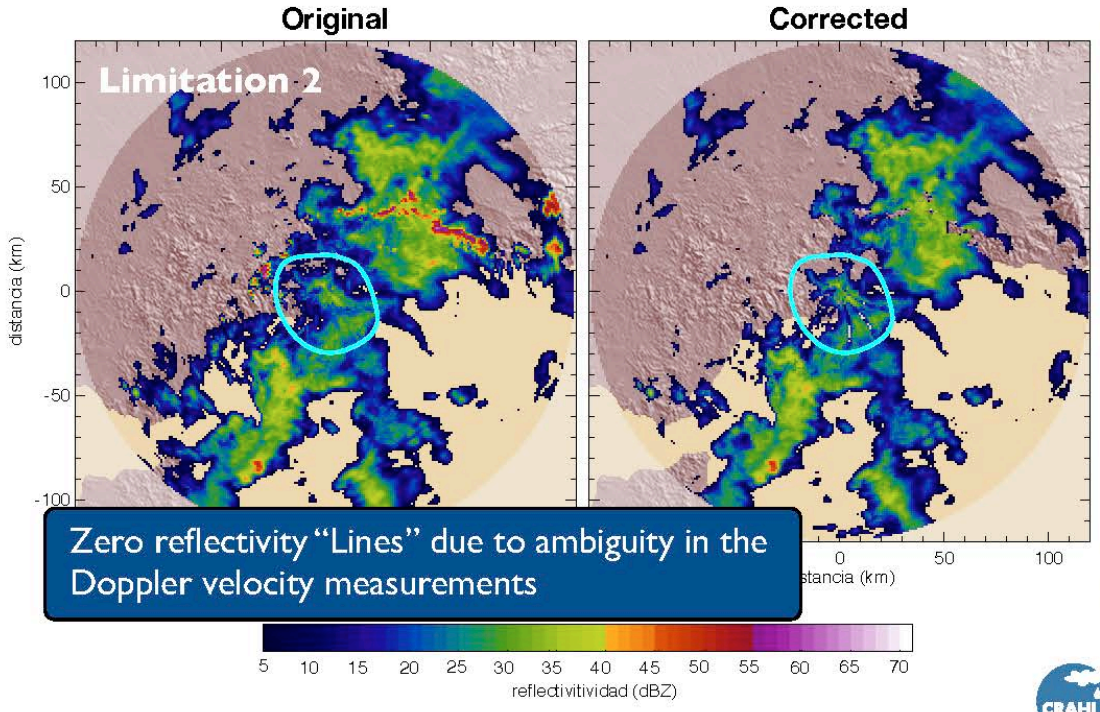
Corrected

Limitation 2

slight generalized underestimation of the corrected values

Ground clutter & beam blockage

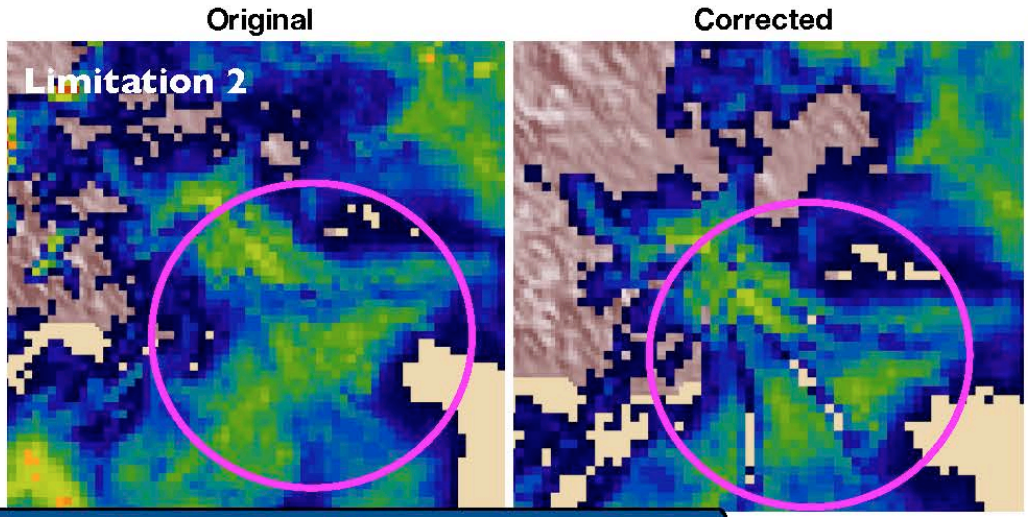
Classical Doppler processing



Zero reflectivity "Lines" due to ambiguity in the Doppler velocity measurements

Ground clutter & beam blockage

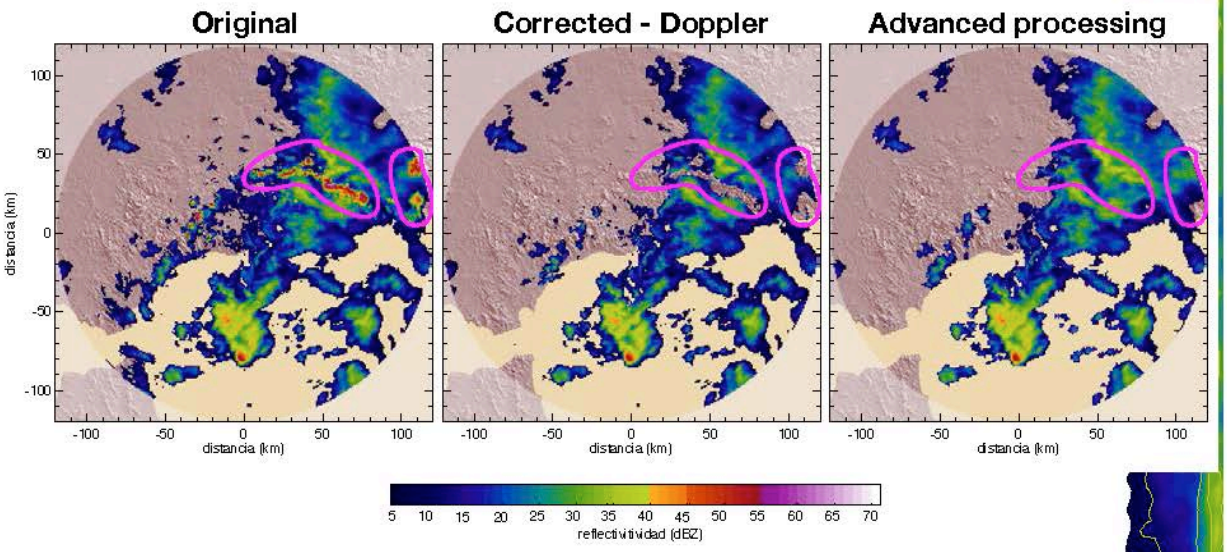
Classical Doppler processing



Zero reflectivity "Lines" due to ambiguity in the Doppler velocity measurements

Ground clutter & beam blockage

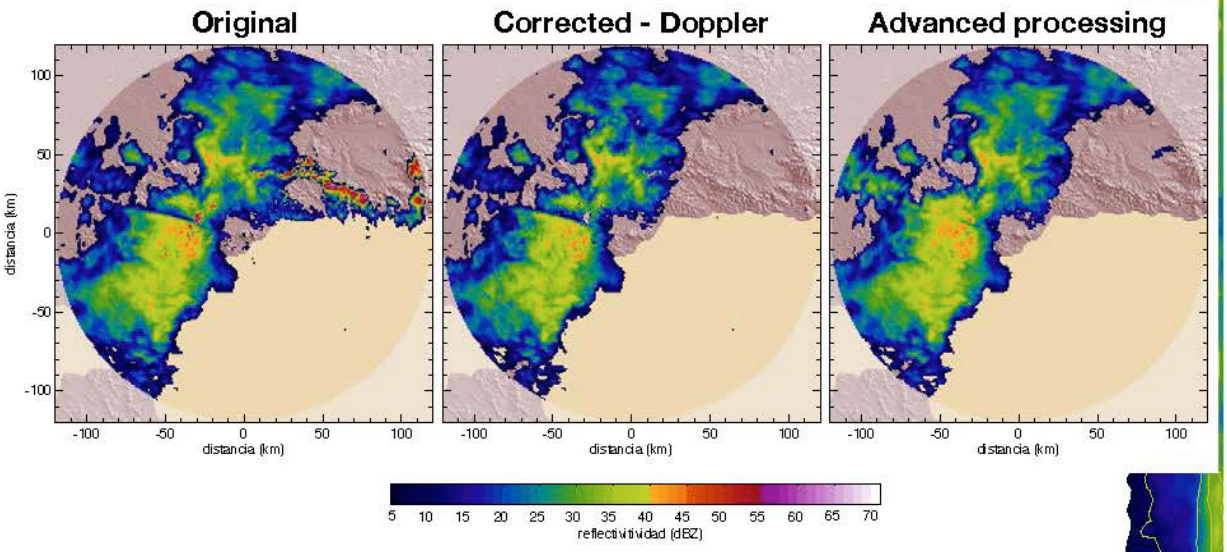
Advanced processing



Proper value estimation in the areas originally affected by ground clutter

Ground clutter & beam blockage

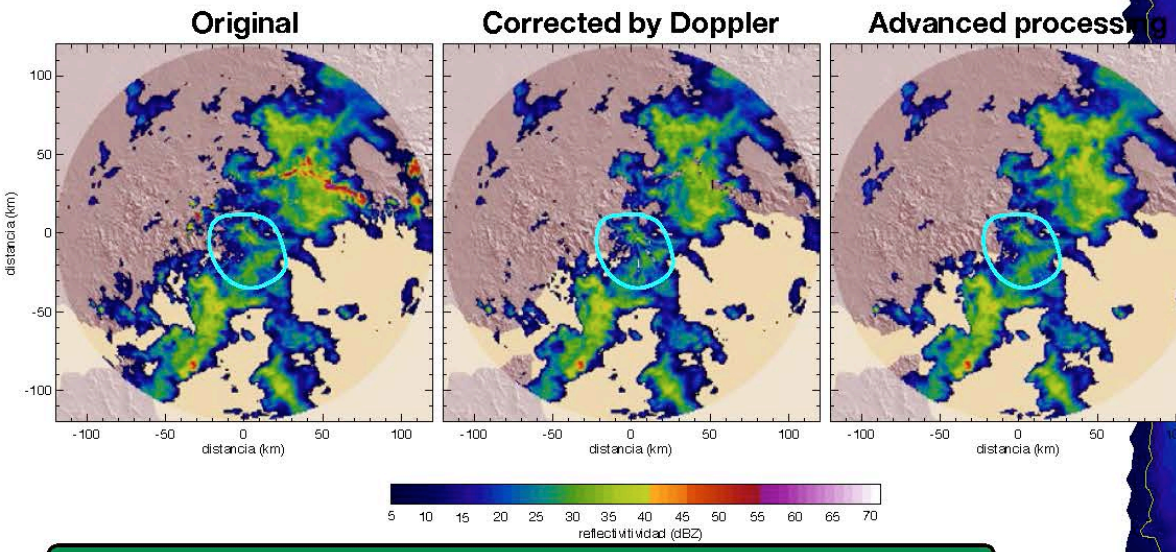
Advanced processing



Not affected by the generalized underestimation due to the Doppler filter

Ground clutter & beam blockage

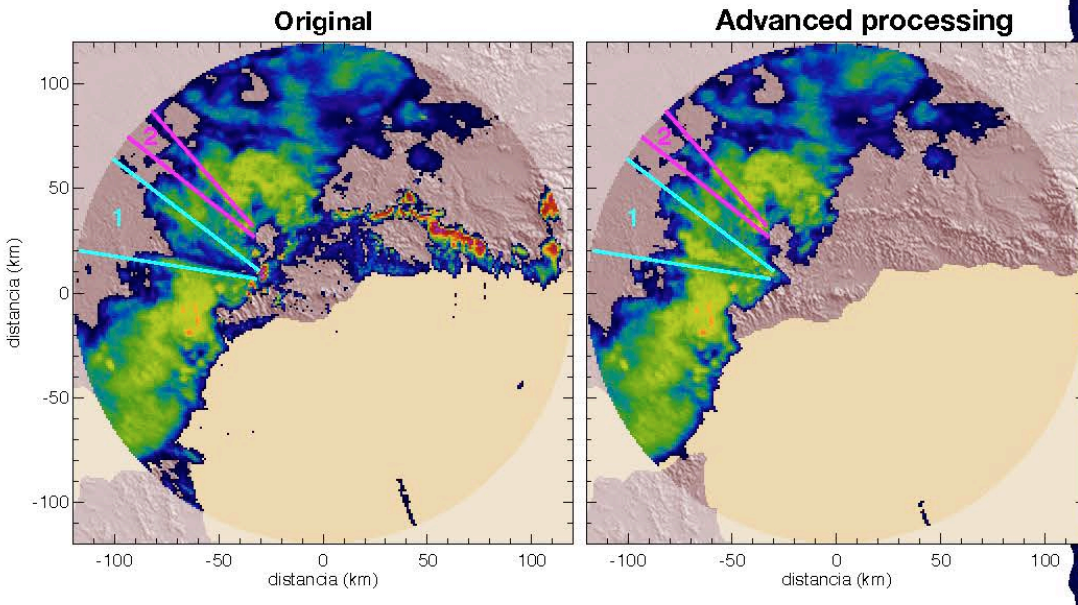
Advanced processing



Fixes the Zero reflectivity "Lines" due to ambiguity in the Doppler velocity measurements

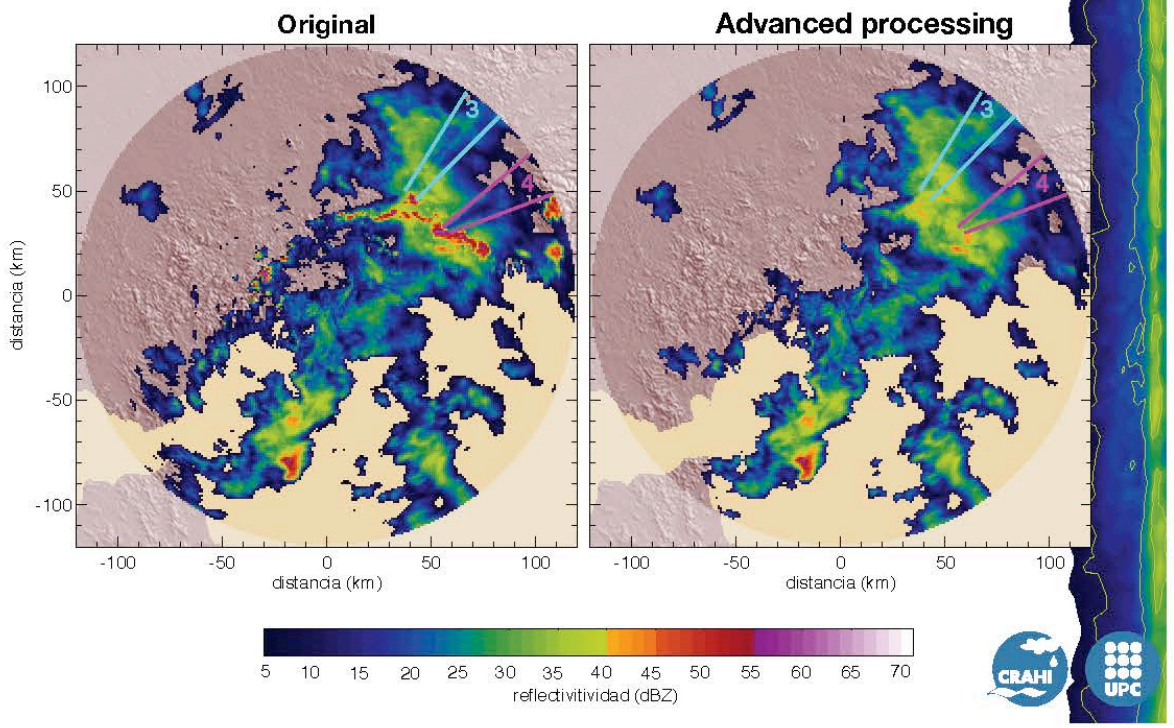
Ground clutter & beam blockage

Beam blockage correction



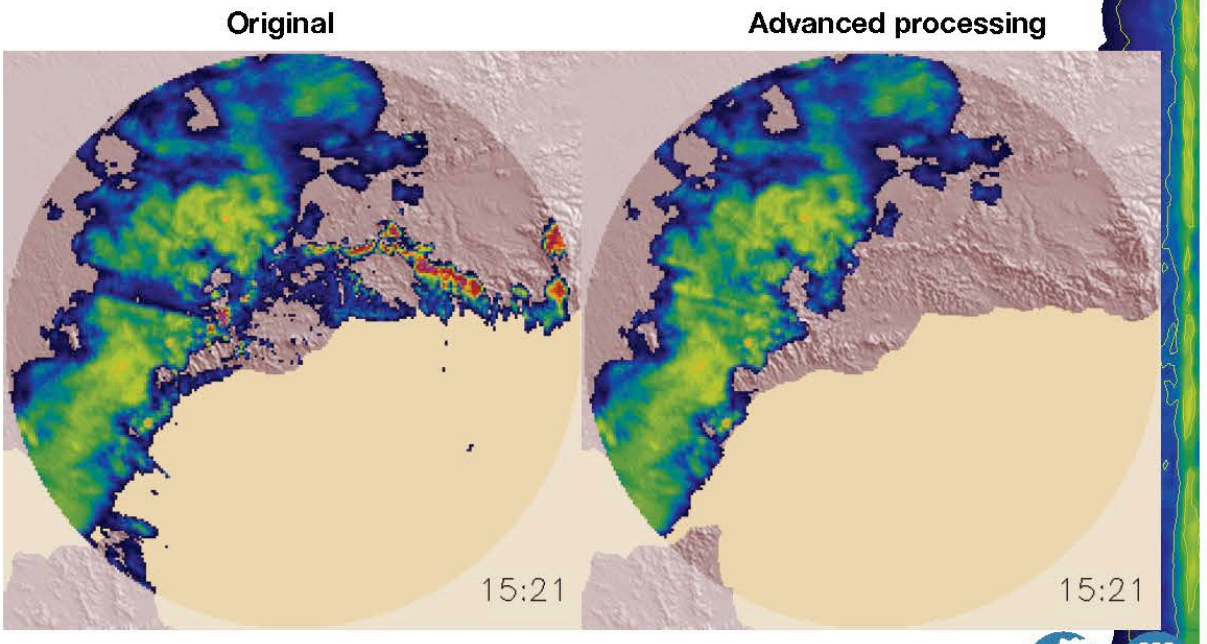
Ground clutter and beam blockage

Beam blockage correction



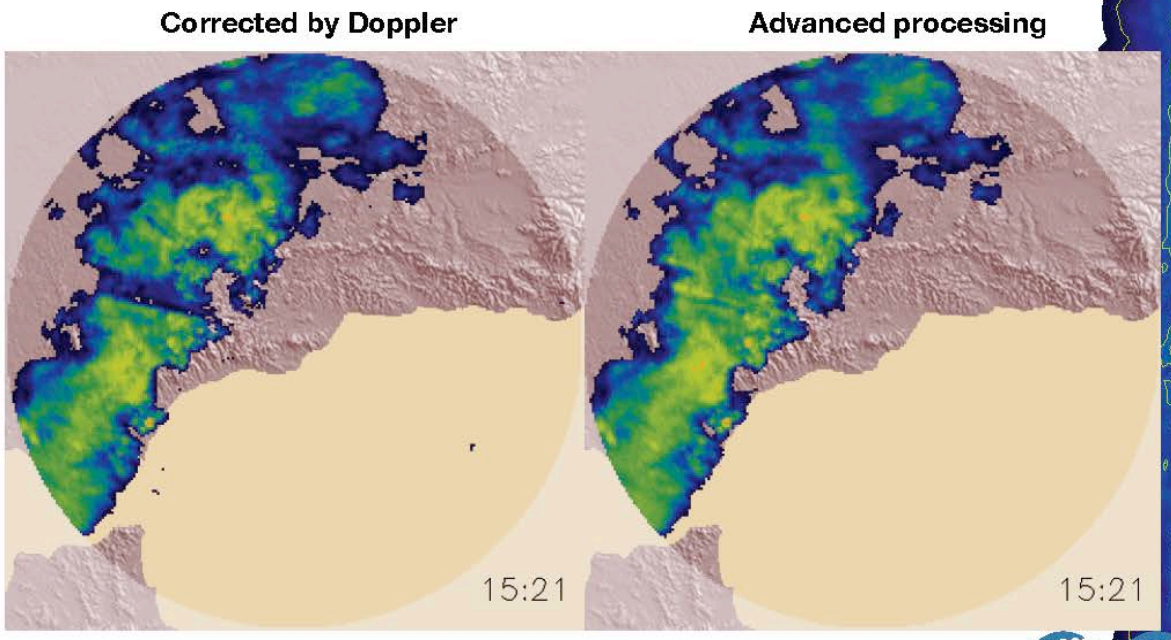
Ground clutter and beam blockage

Beam blockage correction



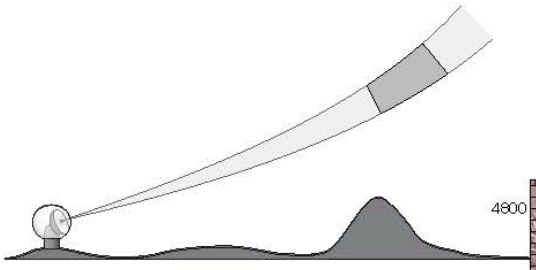
Ground clutter and beam blockage

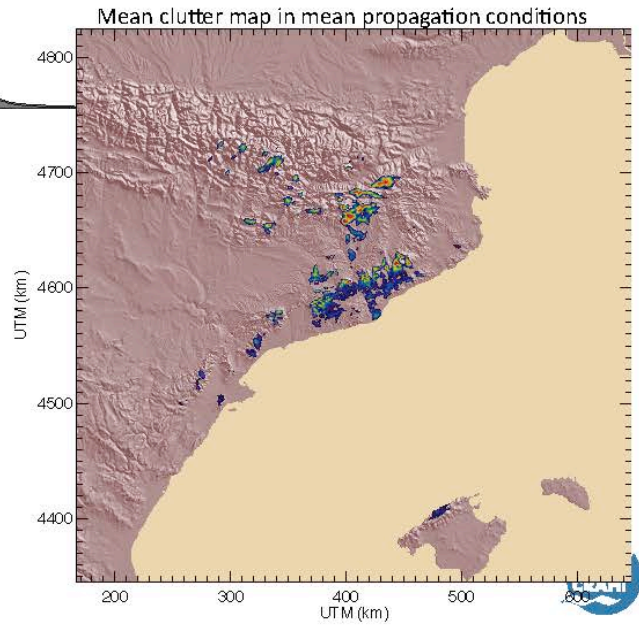
Doppler spectrum correction vs. advanced correction



Propagation conditions

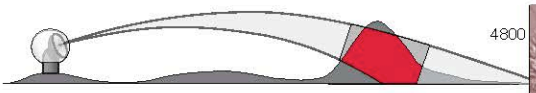
The beam path is controlled by the atmospheric refractivity gradient





Propagation conditions

The beam path is controlled by the atmospheric refractivity gradient

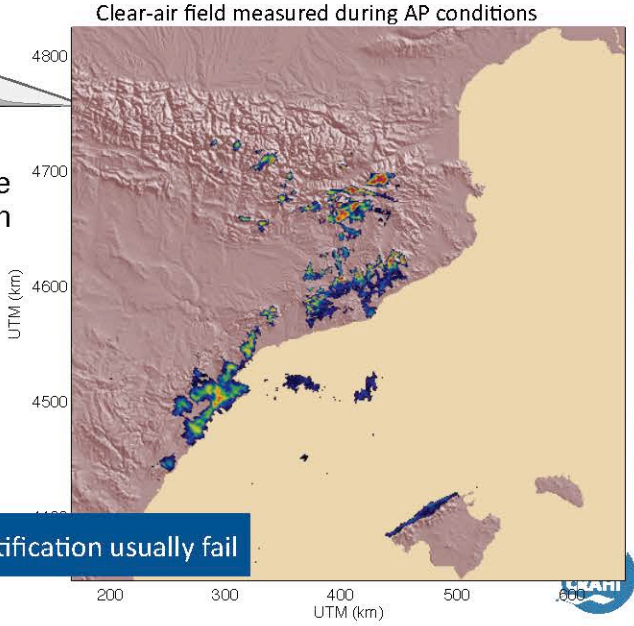


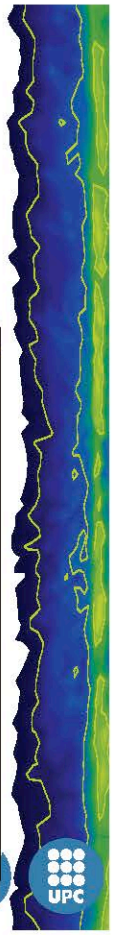
Clutter identification becomes more difficult in anomalous propagation (AP) conditions

- echo intensity varies
- echo size varies
- appear in "new" locations

traditional techniques for clutter identification usually fail

Clear-air field measured during AP conditions

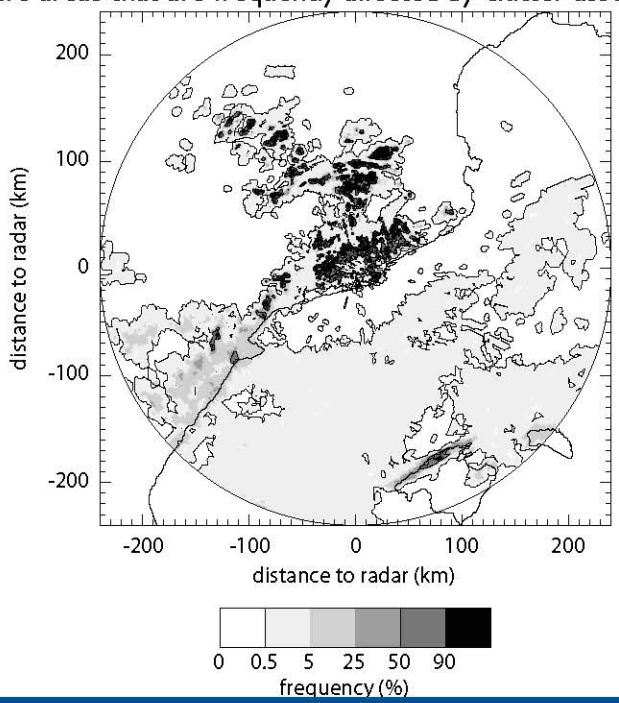




Operational Radar Networks & Data Calibration

Clutter climatology

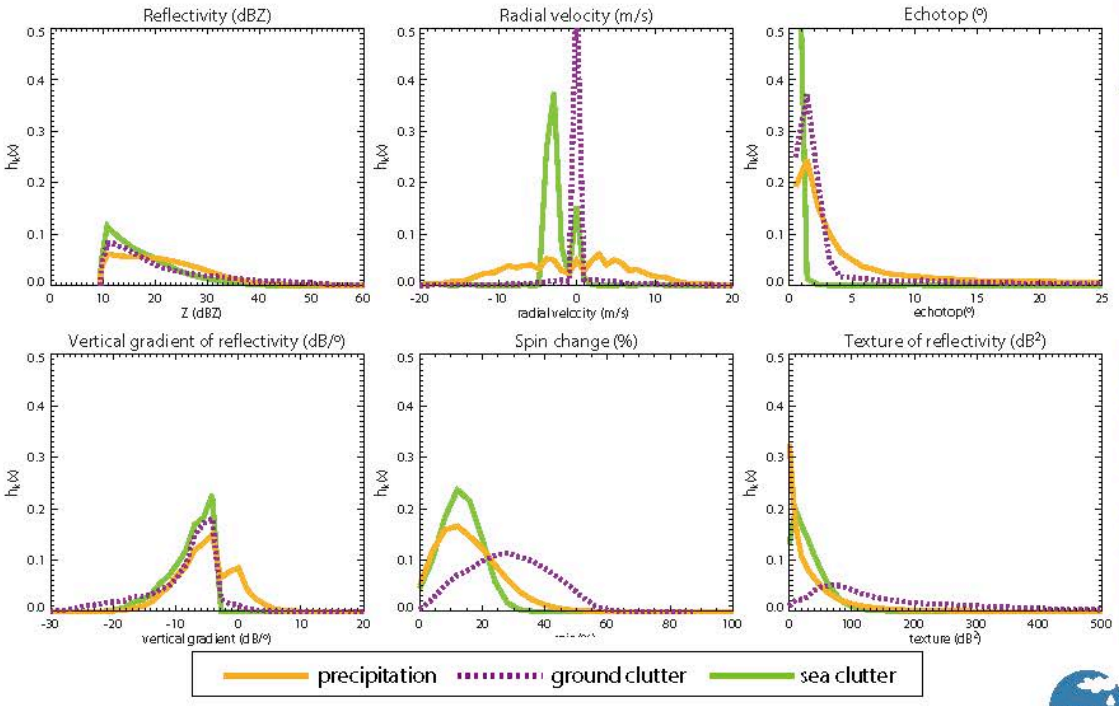
There are areas that are frequently affected by clutter associated to AP.



from 200 manually analyzed radar scans

Characterization of clutter echoes

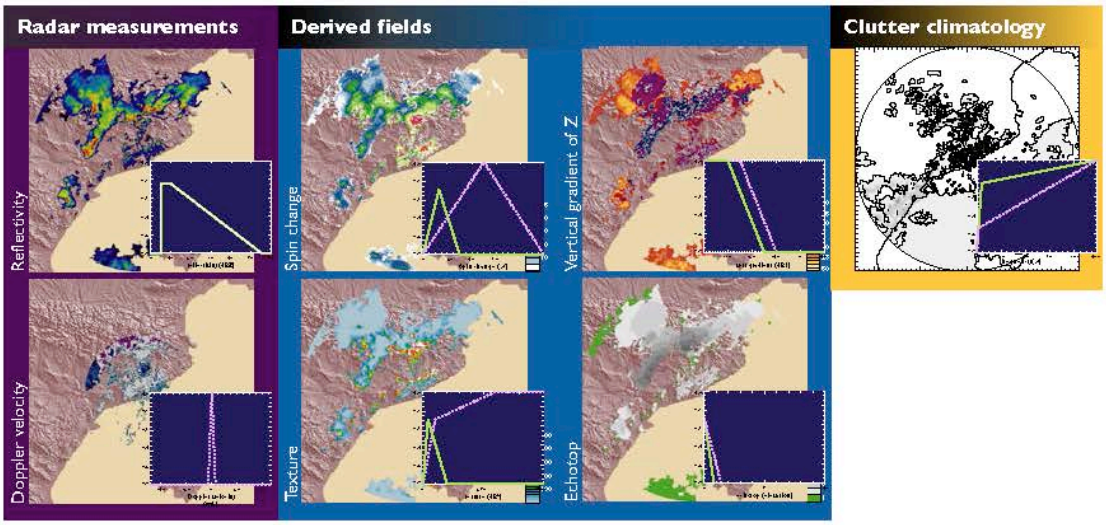
Features that discriminate clutter from precipitation



The developed technique

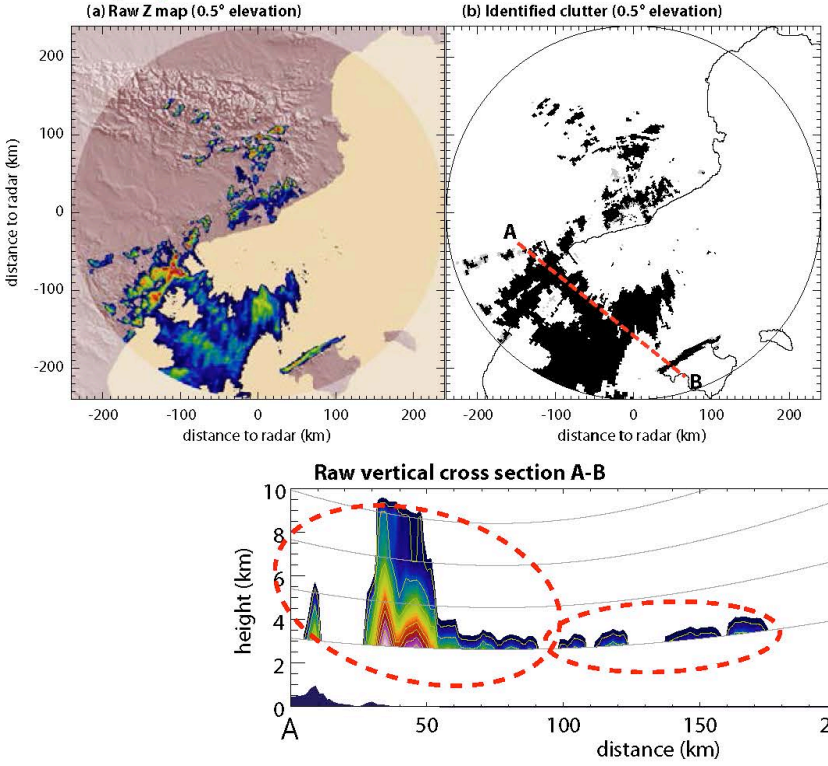
Fuzzy logic algorithm

Berenguer et al. 2006 (JTECH)



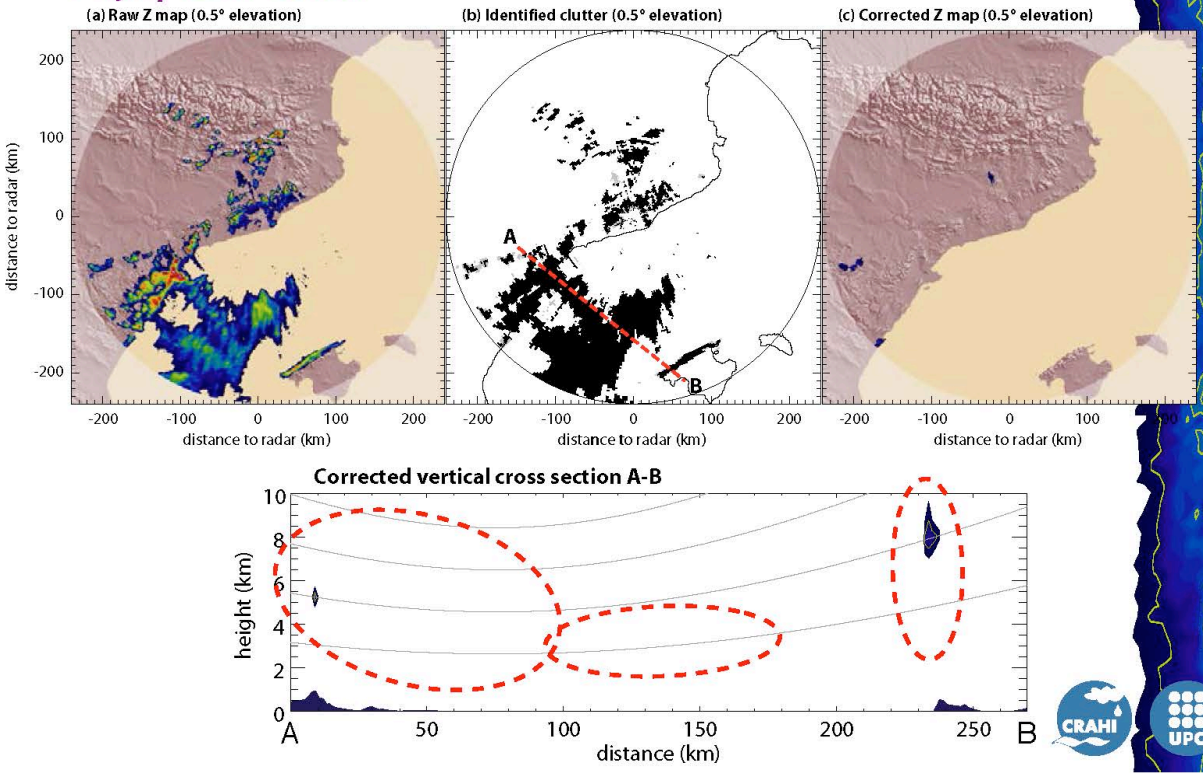
Selected cases

17 July 2001 20:10: clear-air scan measured in severe AP conditions.



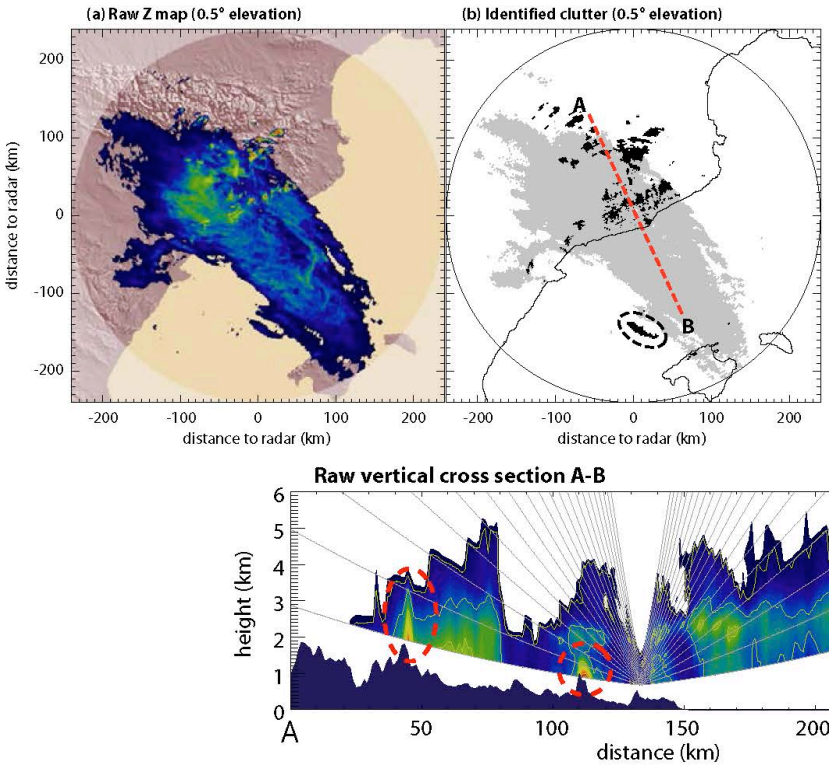
Selected cases

17 July 2001 20:10: clear-air scan measured in severe AP conditions.



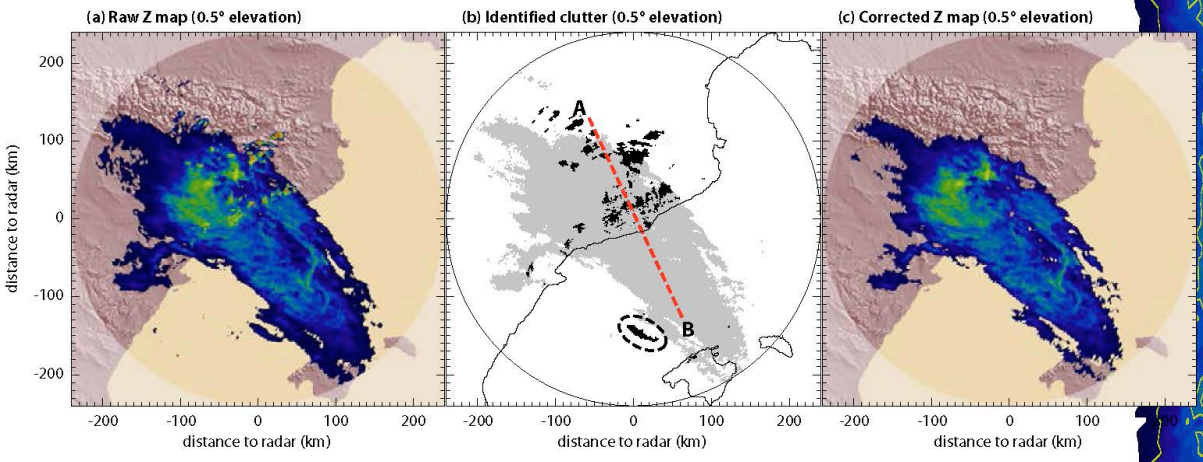
Selected cases

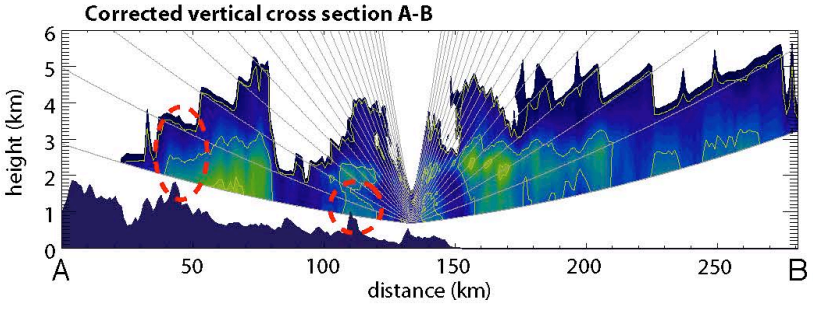
01 February 2001 12:30: stratiform situation measured in MP conditions



Selected cases

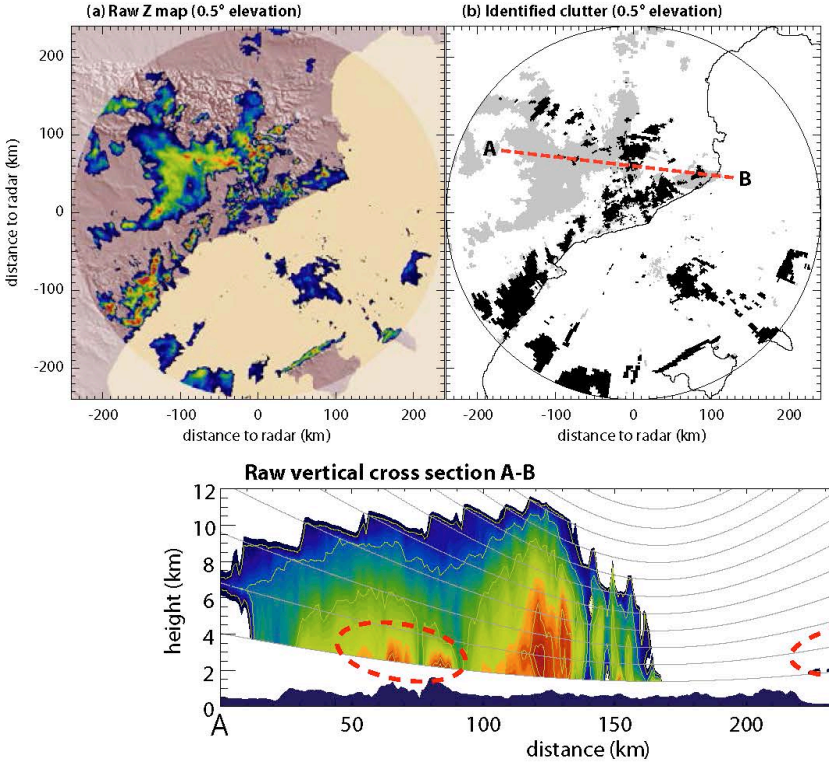
01 February 2001 12:30: stratiform situation measured in MP conditions

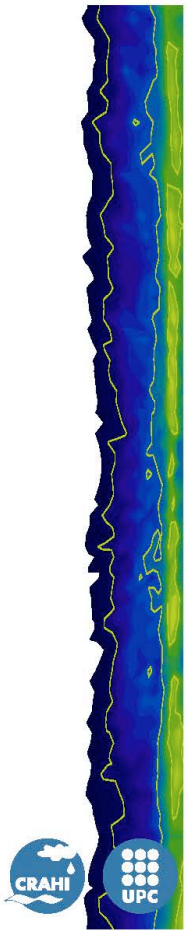




Selected cases

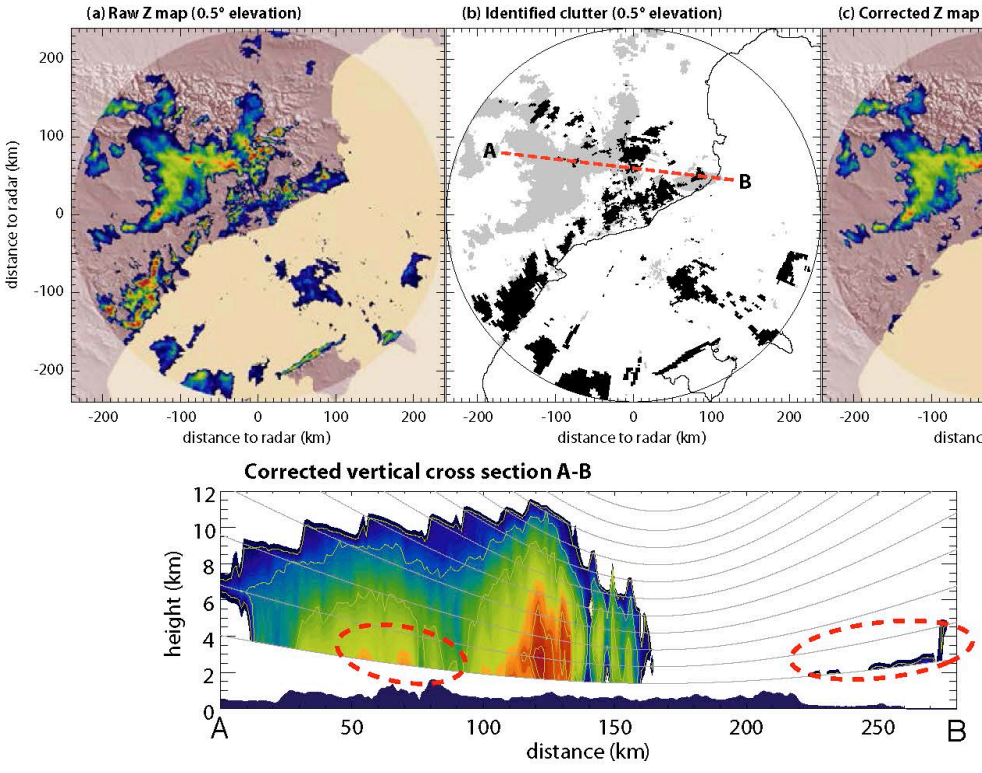
14 July 2001 20:10: convective situation with significant AP clutter

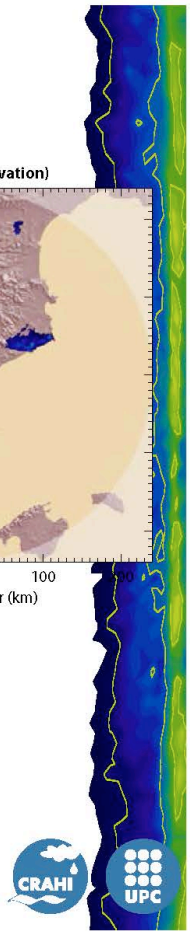




Selected cases

14 July 2001 20:10: convective situation with significant AP clutter





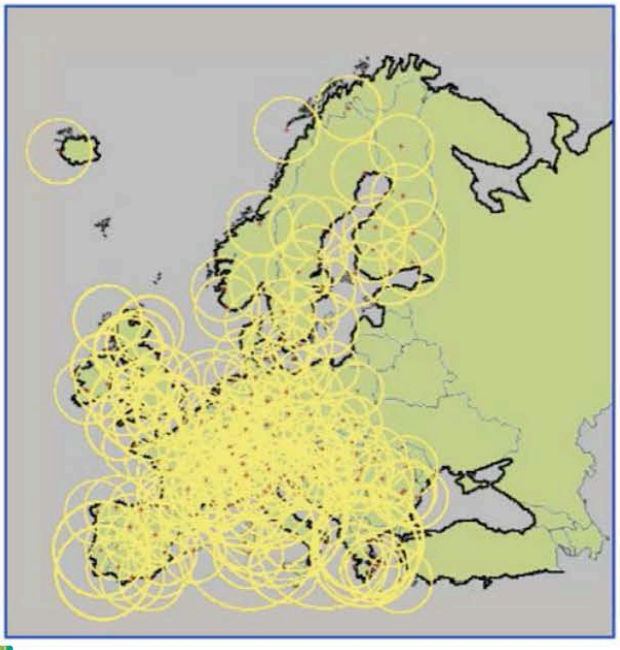
The challenge of using meteorological radars for quantitative purposes: Quantitative Precipitation Estimation (QPE)

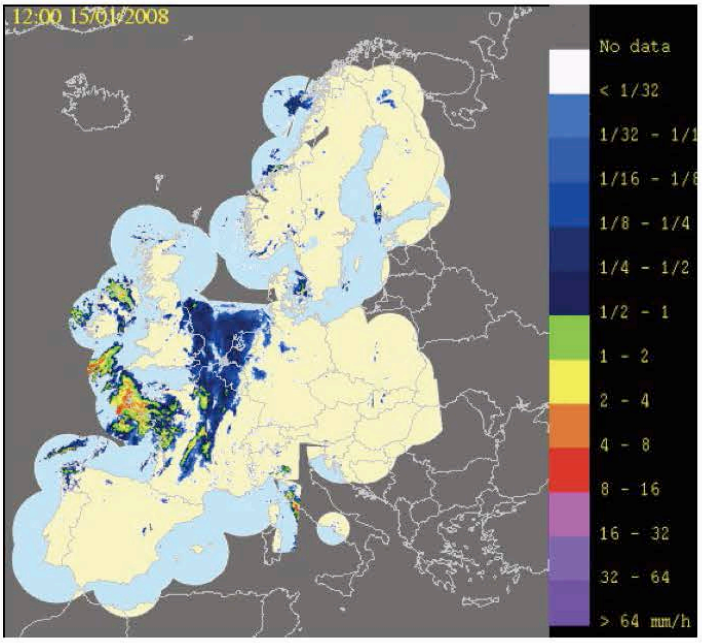
Centre for Applied Research in Hydrometeorology
CRAHI
Universitat Politècnica de Catalunya
Barcelona (Spain)

T.C.
Orman ve Su İşleri Bakanlığı
Meteoroloji Genel Müdürlüğü

The "Challenge":

To improve QPE in operational radars





OPERA : Operational Programme for the Exchange of weather RAdar information in Europe

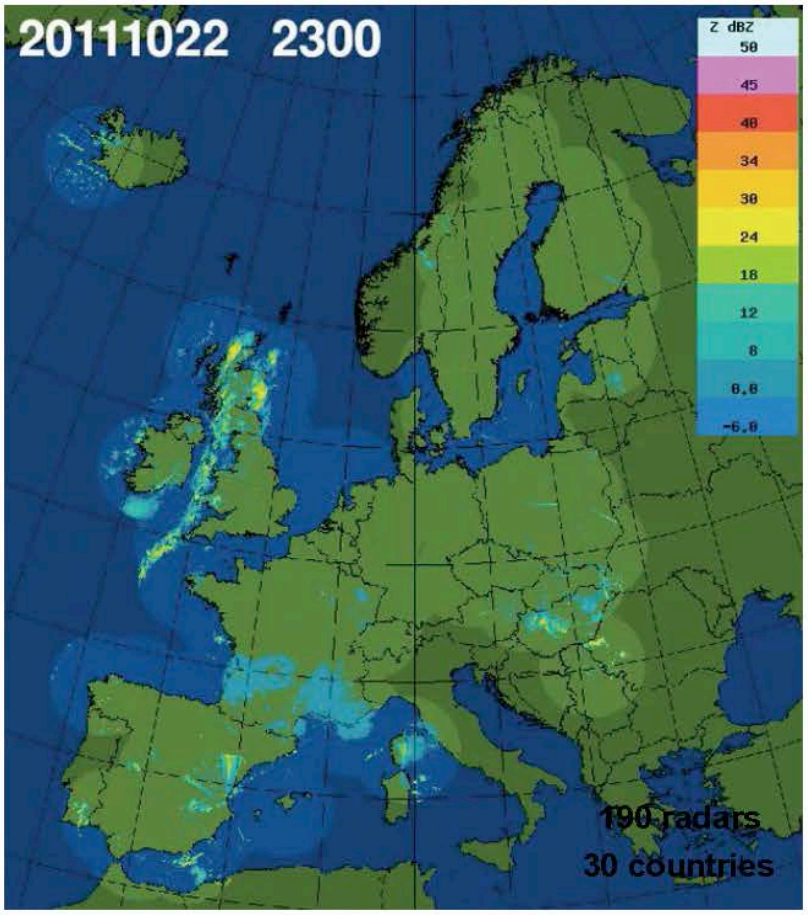
EU radar mosaic

OPERA radar mosaic:

- Precipitation observations over Europe @2 km and every 15 minutes.
- Operationally produced since mid 2011.
- First nowcasting demonstration (HAREN project): June 2012-September 2013
- Second demonstration: **June 2014-July 2015**

EDHIT

European Civil Protection

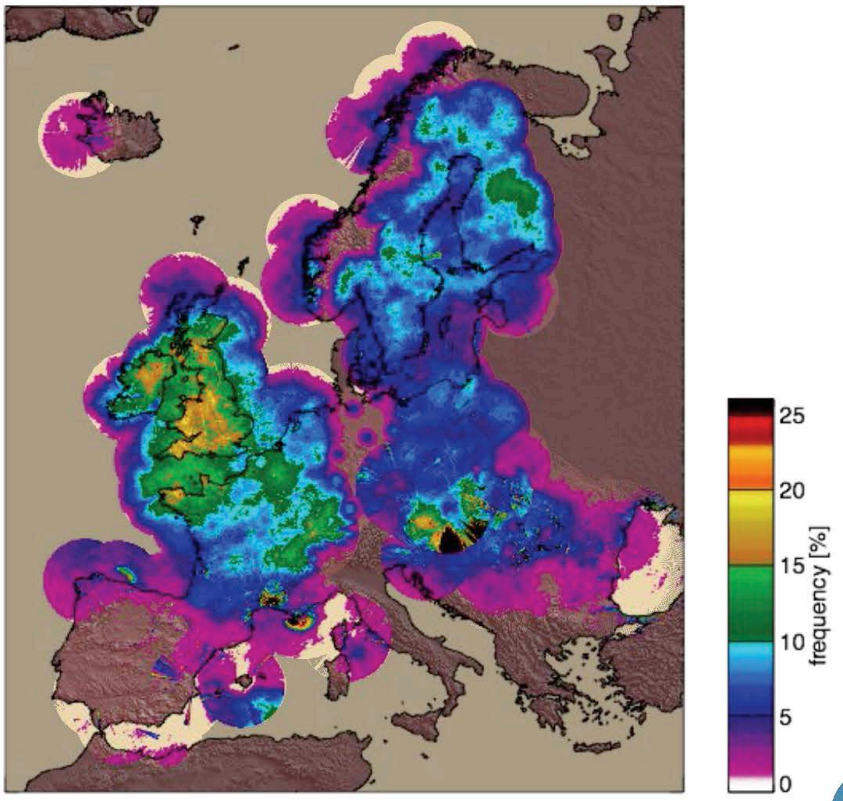


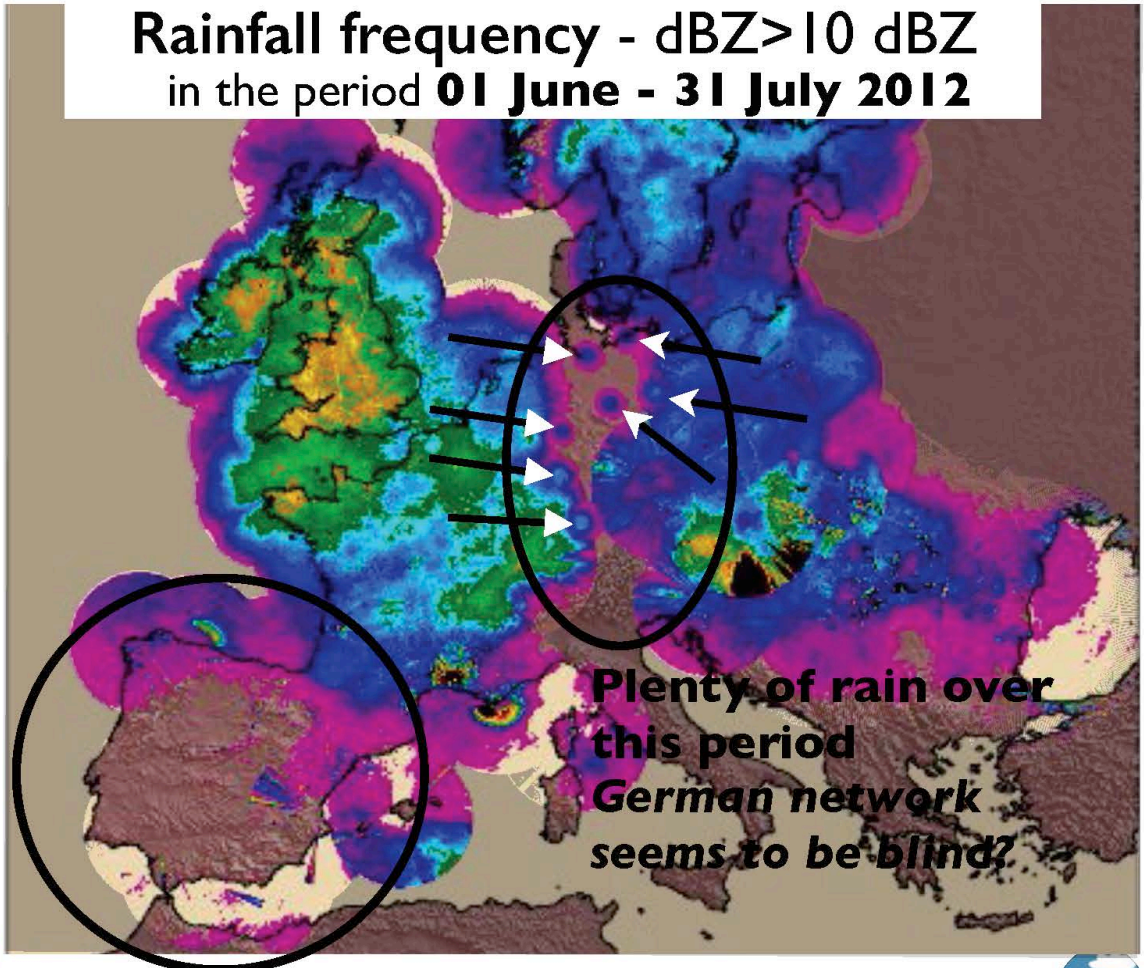
OPERA COMPOSITES
Quality depends on location

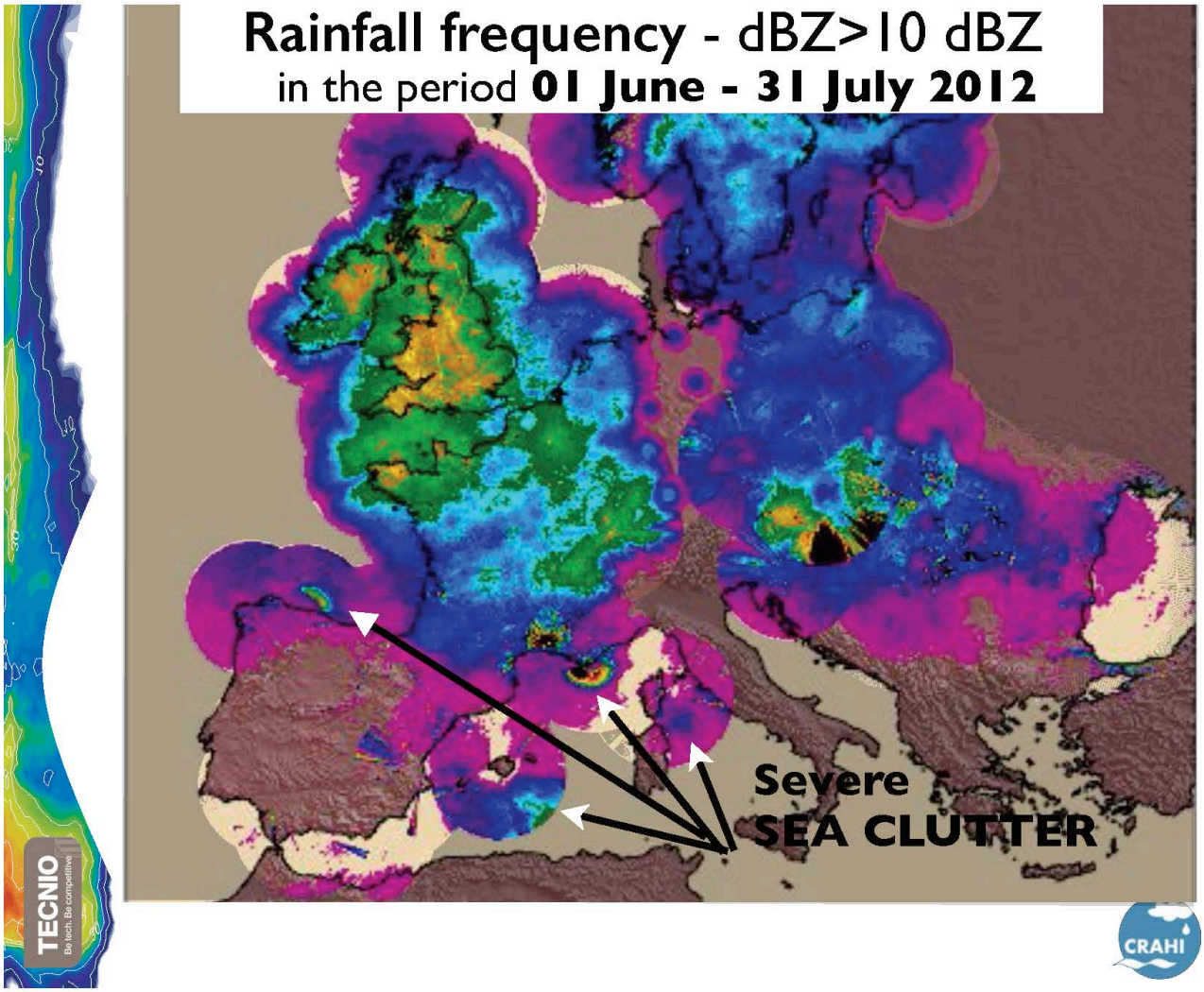
- Composites integrate different NATIONAL NETWORKS
  - Any National Network follow **its own QC criteria**
  - Any National Network has a **different processing**
- The EU composite is not homogeneous in quality

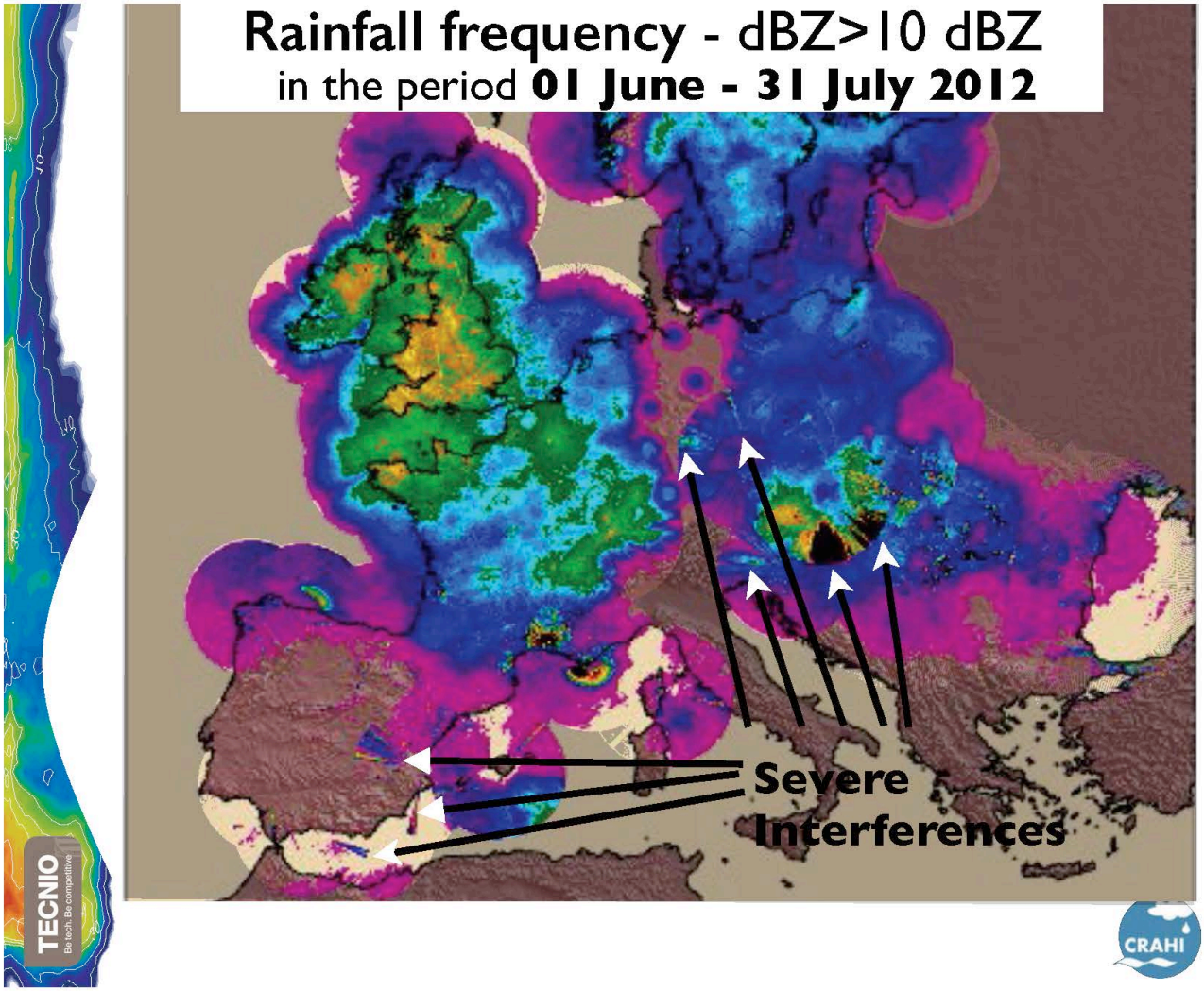
Rainfall frequency - dBZ>10 dBZ

in the period **01 June - 31 July 2012 (5856 images)**



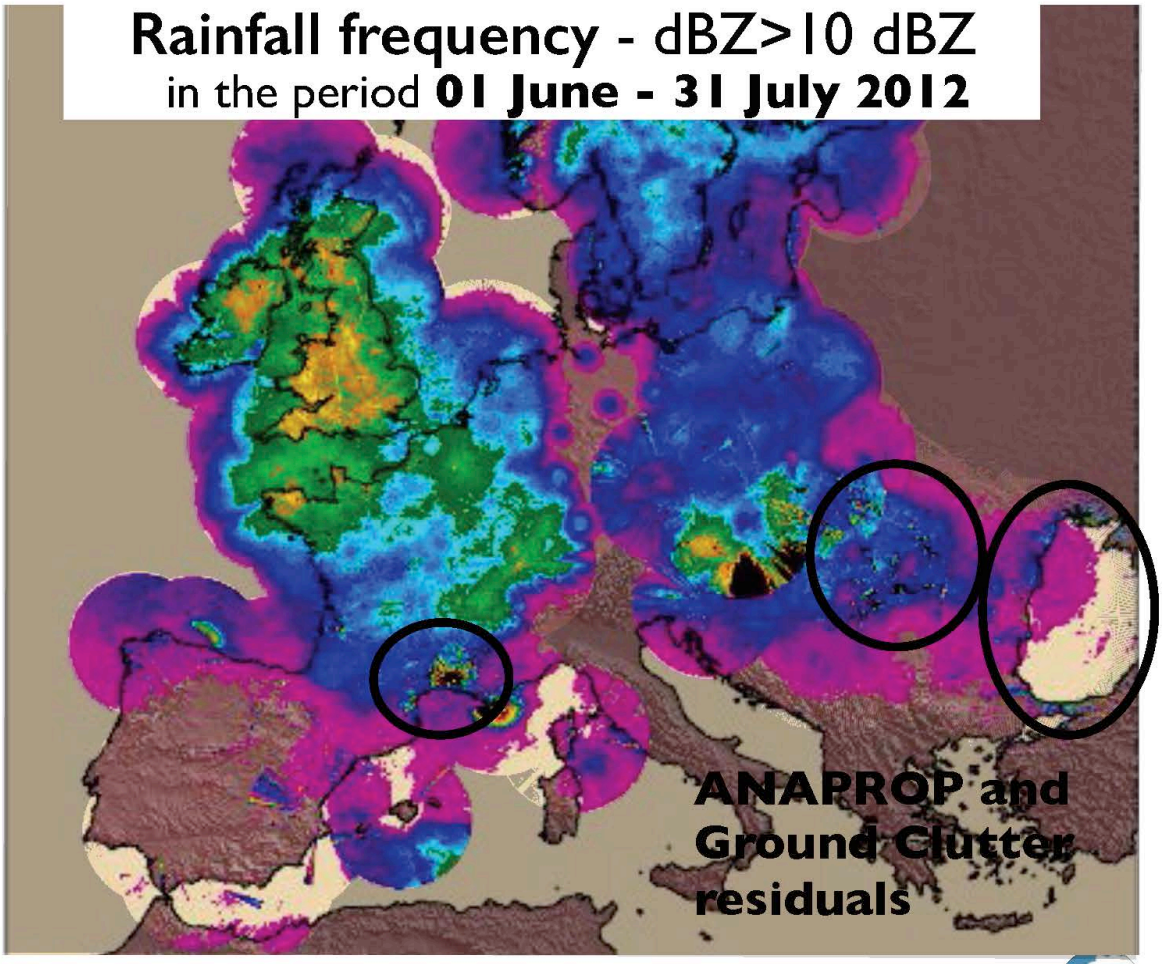



Rainfall frequency - dBZ>10 dBZ
in the period 01 June - 31 July 2012
Severe
SEA CLUTTER


Rainfall frequency - dBZ>10 dBZ
in the period 01 June - 31 July 2012
Severe
Interferences

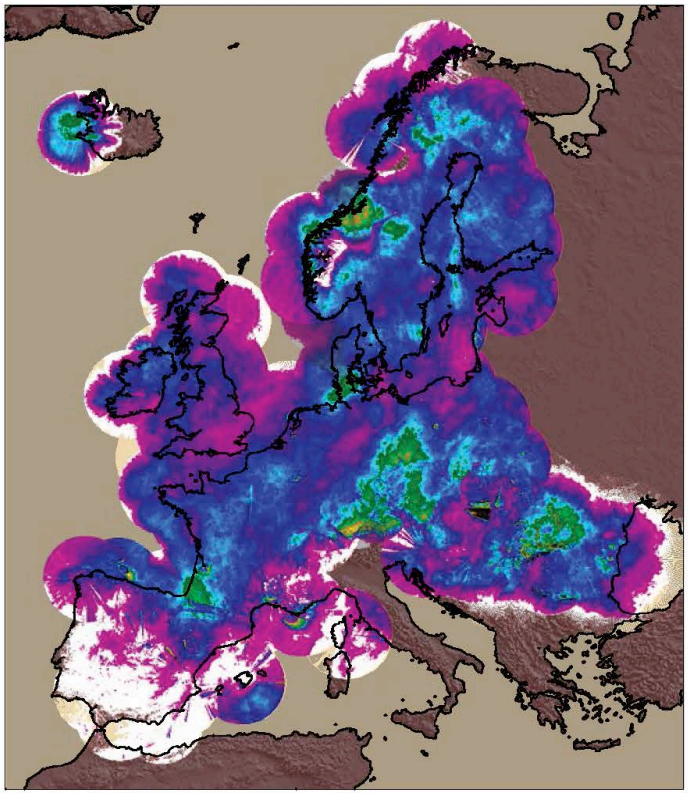
Rainfall frequency - dBZ>10 dBZ

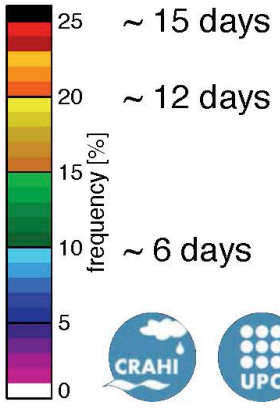
in the period **01 June - 31 July 2012**

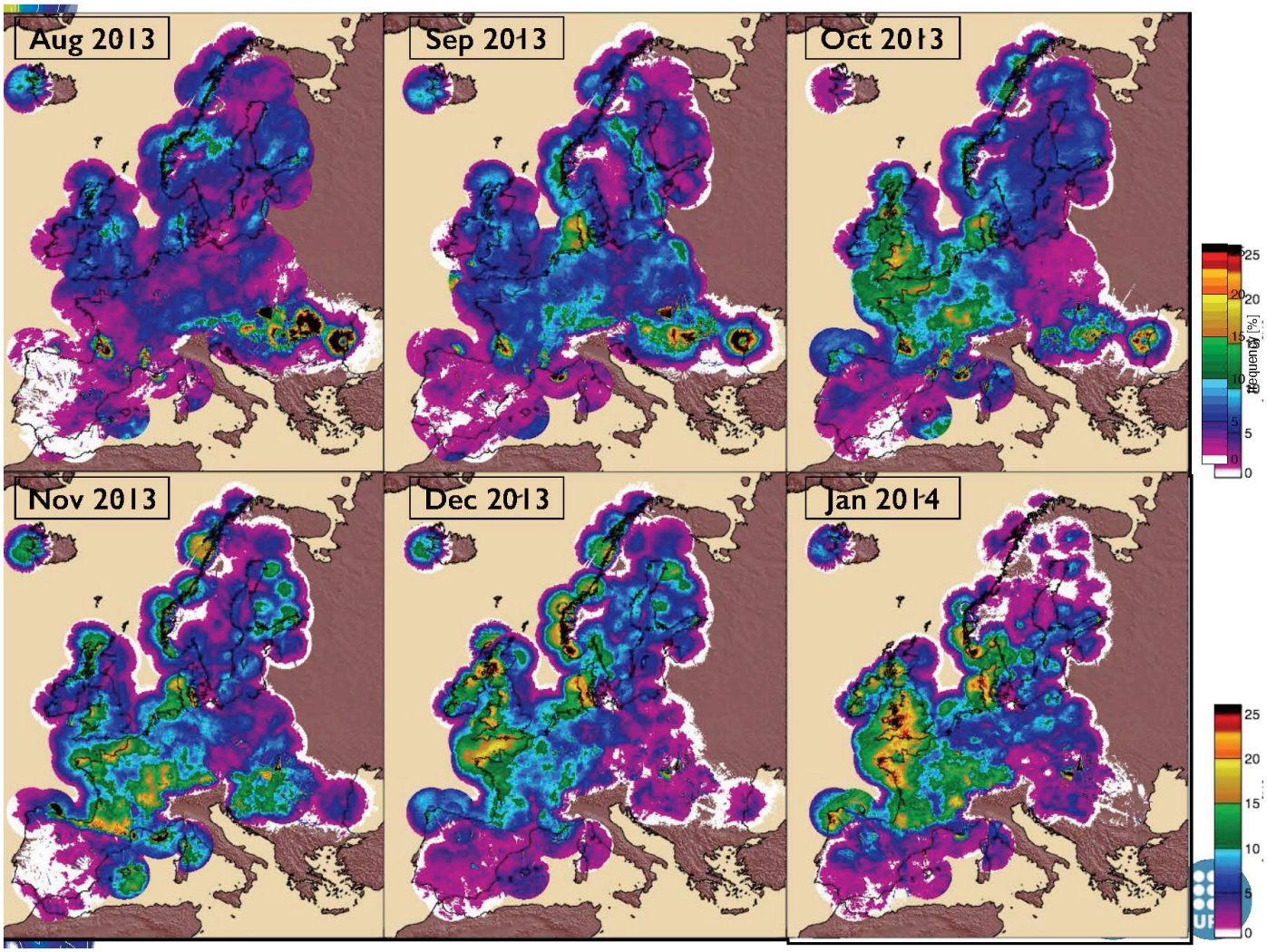


Frequency of rain (dBZ > 10 dBZ)

in the period **01 June - 30 June 2013**

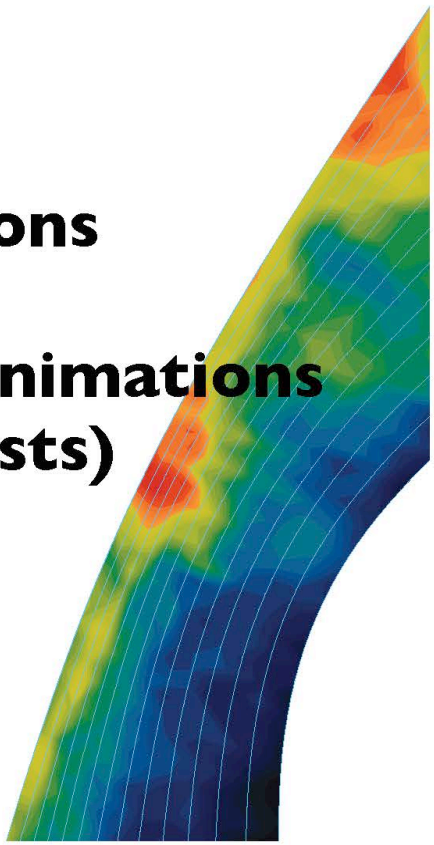




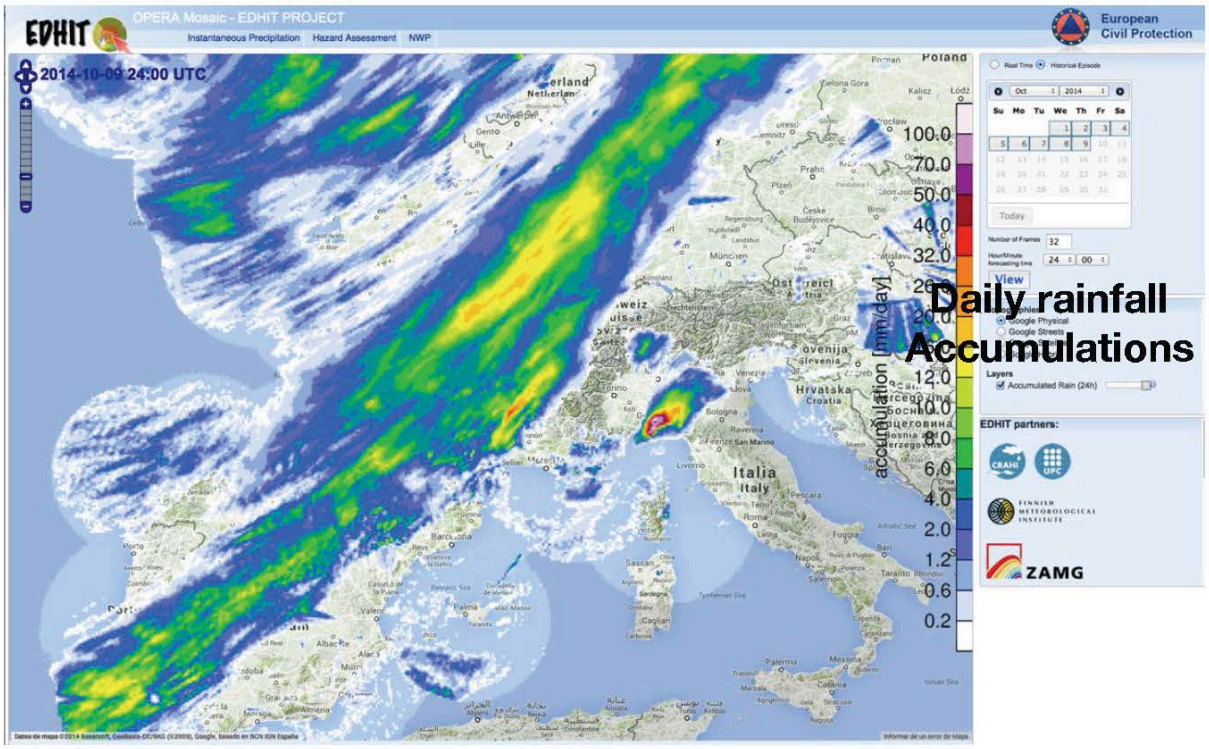


Rainfall Accumulations

(Daily accumulations and animations are severe quality tests)



Genova (Italy) on 10th of October 2014

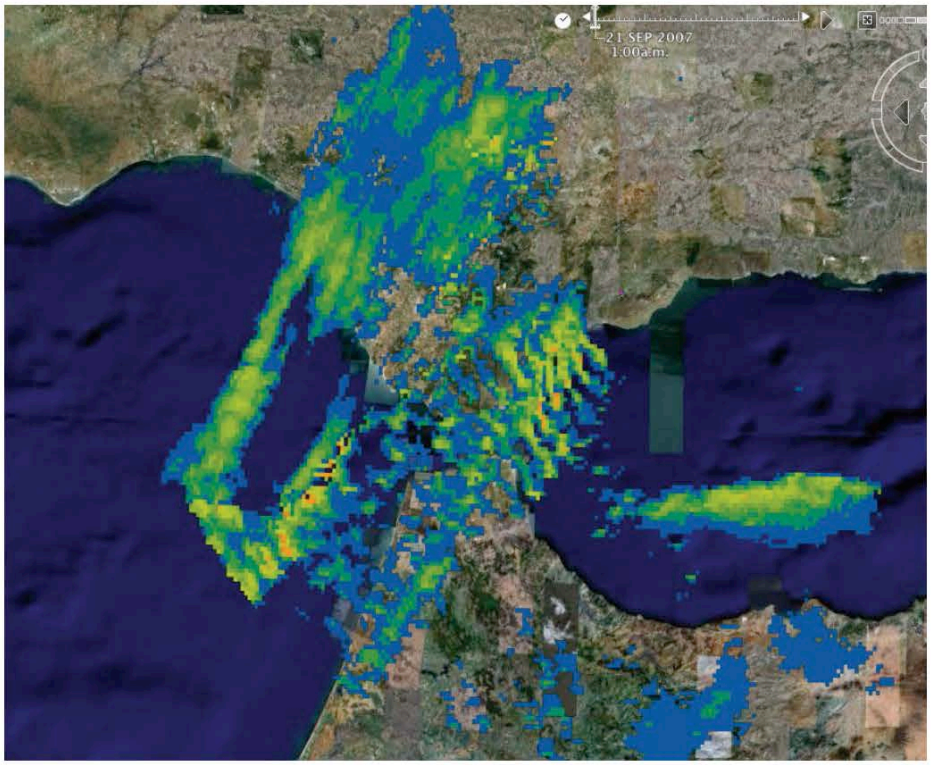


Accumulation algorithm using motion vector



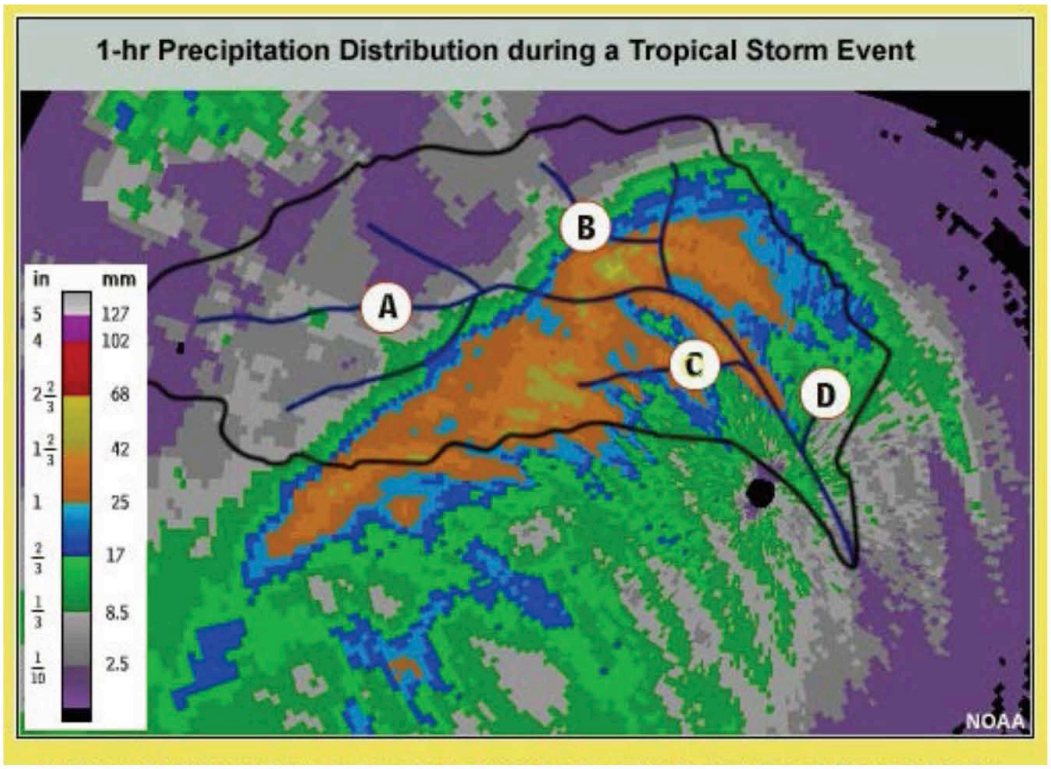
CLASSIC PROBLEM: Accumulation as addition of CAPPIS

Accumulation product for the National composite of AEMET



CLASSIC PROBLEM: Accumulation as addition of CAPPIS

Accumulation product for NEXRAD (USA)



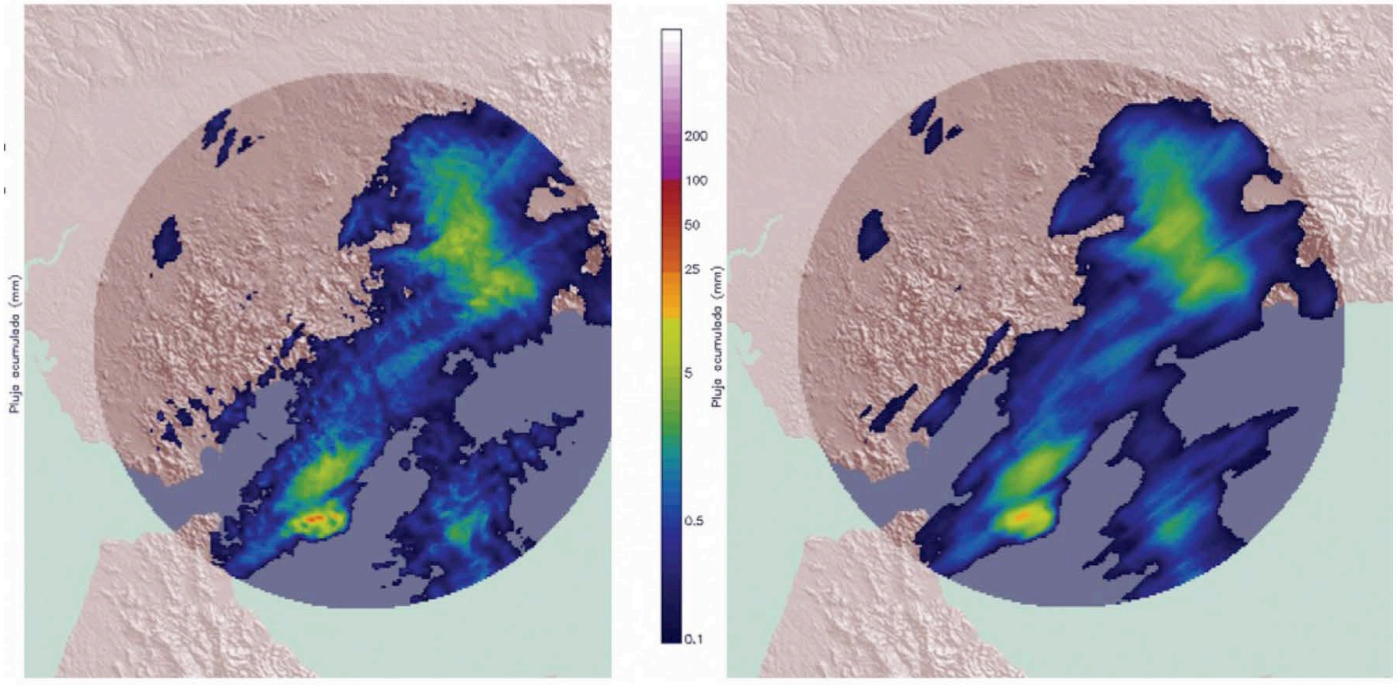
Meteorological Radars and advanced applications

Rainfall accumulation

19/03/2008 22:50 UTC

Accumulation as addition of CAPPIS

Accumulation with motion vector



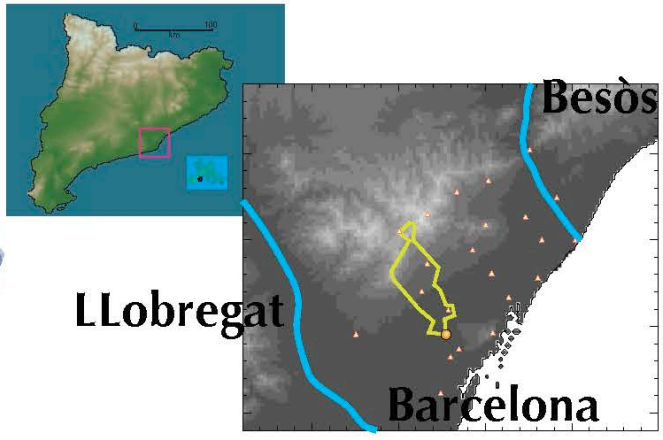
QPE Processing (CRAHI)

Volumetric data (raw polar reflectivity)

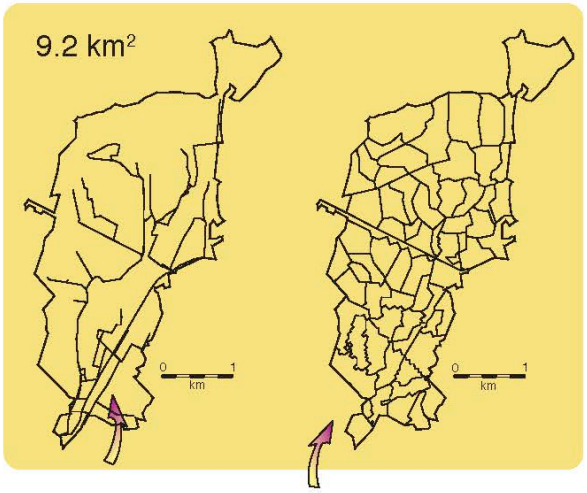
Signal recovering and Z correction	Calibration control	(Sempere-Torres et. al., AMS Radar 2001, 2003)
	Radom attenuation and signal stability	(Delrieu et. al., JTECH 1995, Sánchez-Diezma, 2001)
	Partial radar beam screening	(Berenguer et. al., AMS Radar 2003, ERAD 2004, Roca 2013)
	Rainfall attenuation	(Sanchez-Diezma et. al., AMS Radar 2001) (Berenguer et al. JTECH 2006)
	Ground clutter substitution	(Steiner et. al., JAM 1995) (Sánchez-Diezma, JGR 2001) (Franco et al., AMS Radar 2007, ERAD 2002, ERAD 2004, ERAD 2006, Met. Z. 2007, JTH 2008)
Rainfall at ground	VPR correction	(Franco et al., ERAD 2006, AMS Radar 2007, JTH 2008)
	Z-R relationship	(Sempere-Torres et. al., JAM 1994; JGR 1997; AMS Radar 1999; ERAD 2000)
Network composite	3D advanced composite of multiple radars	(Roca-Sancho et. al., J. of Hydrology, 2014)
Raingauge blending	Kriging with External Drift and Radar correlogram	(Velasco-Forero et. al., Ad. Water Res., 2009; AMS Radar 2007; ERAD 2006; Schiemann et al., HESS 2011)

Pre-classification of rainfall types

Aplicacion Hidrológica

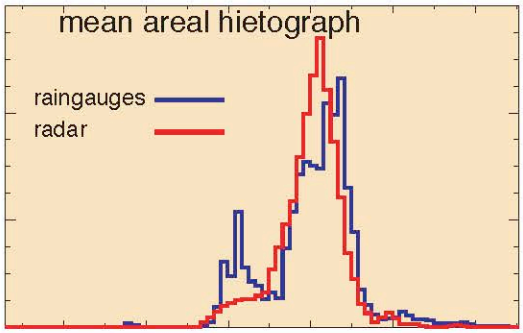


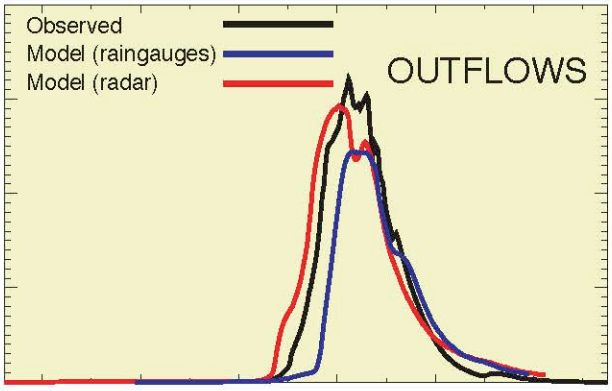
Riera Blanca
Impervious urban basin
managed by CLABSA



Hydrological model:
MOUSE (DHI)

Case study Riera Blanca





T.C.
Orman ve Su İşleri Bakanlığı
Meteoroloji Genel Müdürlüğü

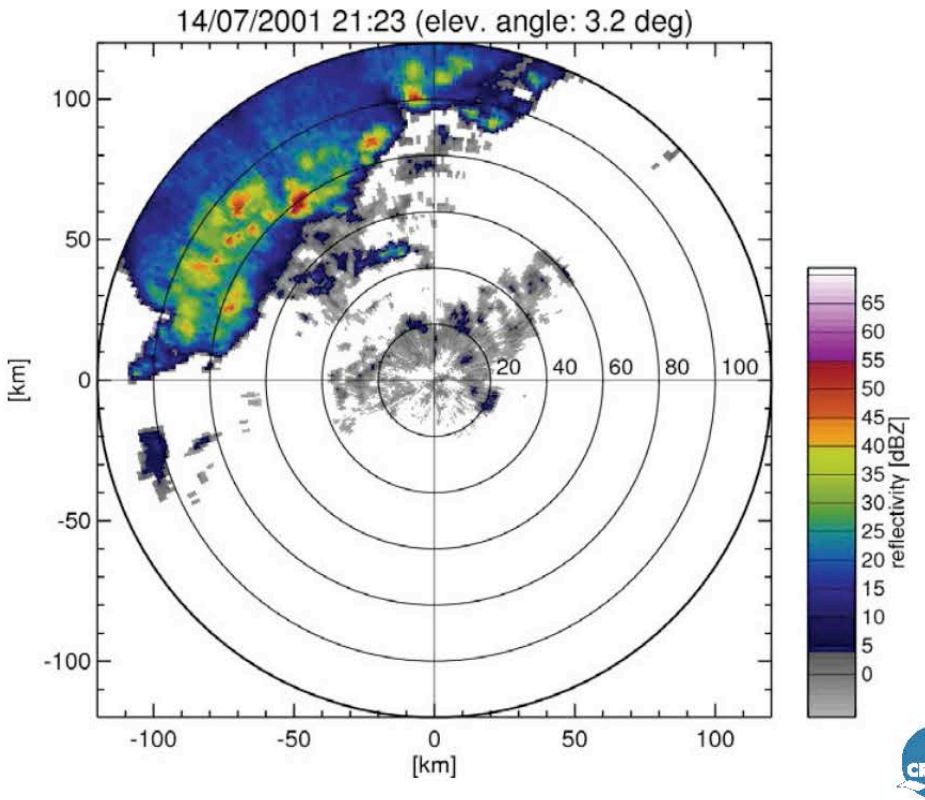
TRAINING PROGRAM ON METEOROLOGICAL AND ADVANCED QUANTITATIVE APPLICATIONS

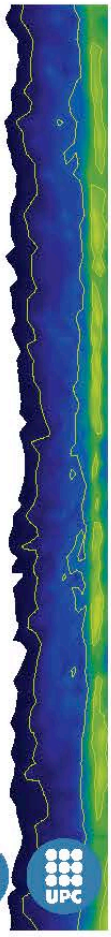
Attenuation by intense rain:
The problem and possibilities of correction

Centre de Recerca Aplicada en Hidrometeorologia
UNIVERSITAT POLITÈCNICA DE CATALUNYA

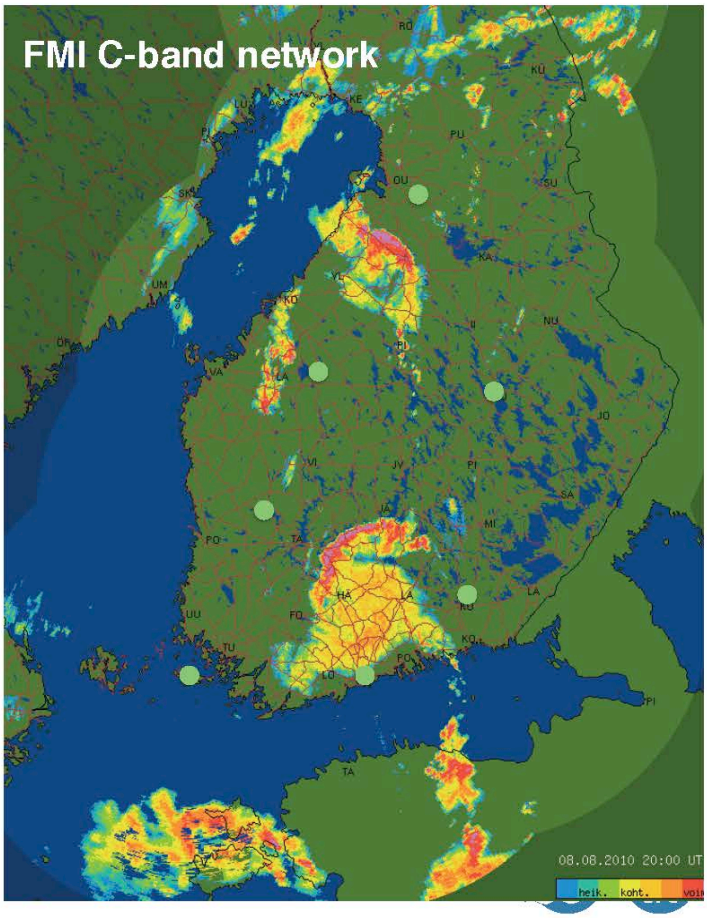


Signal attenuation by rain



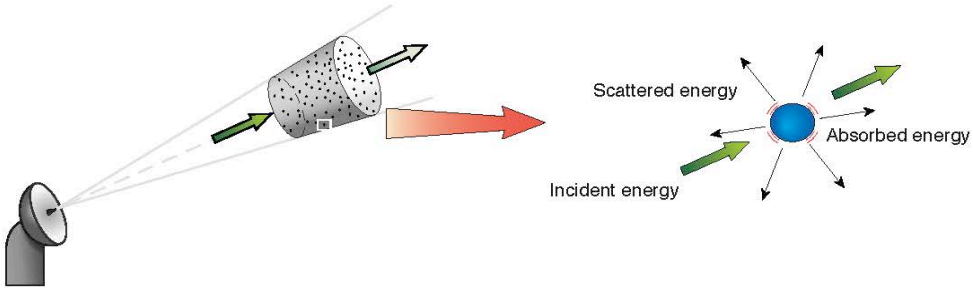


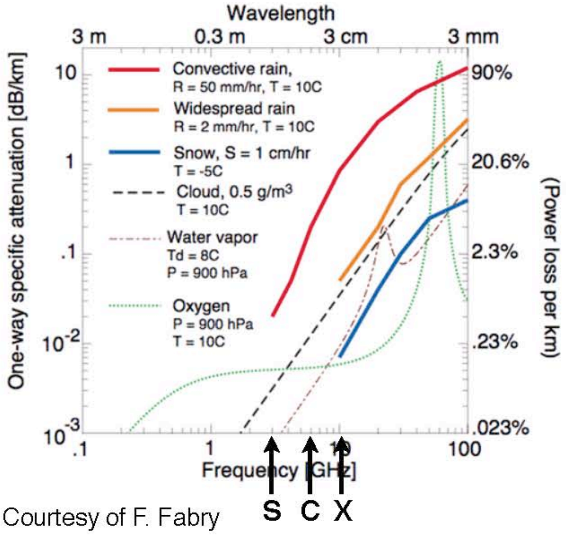
Signal attenuation by rain



Courtesy of P. Rossi (FMI)

Signal attenuation by rain - L(r)





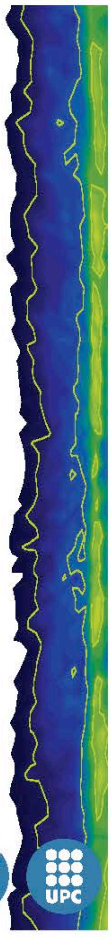
Courtesy of F. Fabry

Specific attenuation (dB/km)

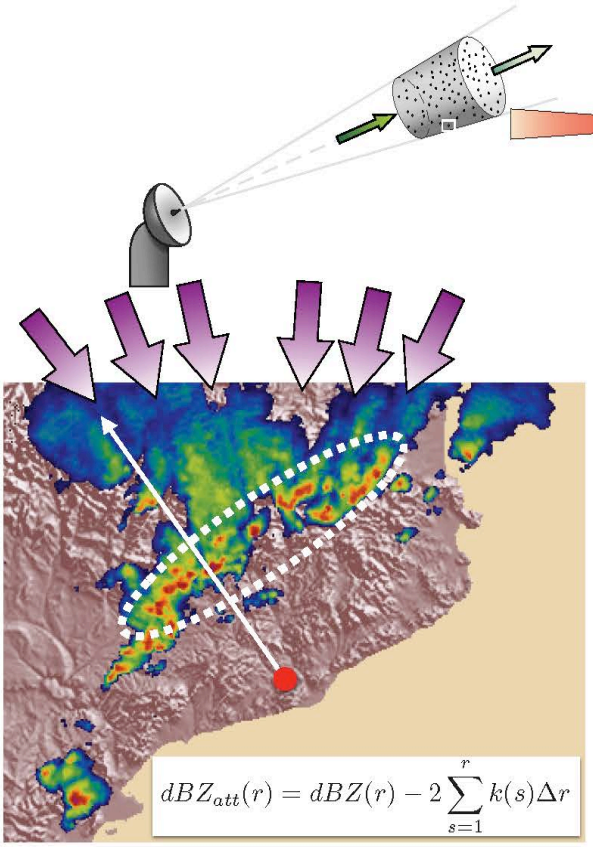
$$k = \int_0^\infty \sigma_e(D) N(D)\, dD$$

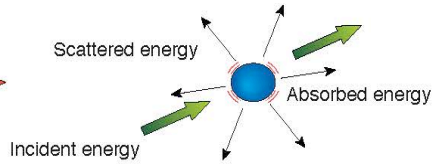
Depends on:

- Rainfall intensity
- $\sigma_e(D)$: extinction cross section
  - radar wavelength
  - temperature
- Drop Size Distribution (DSD)



Signal attenuation by rain - L(r)





Specific attenuation (dB/km)

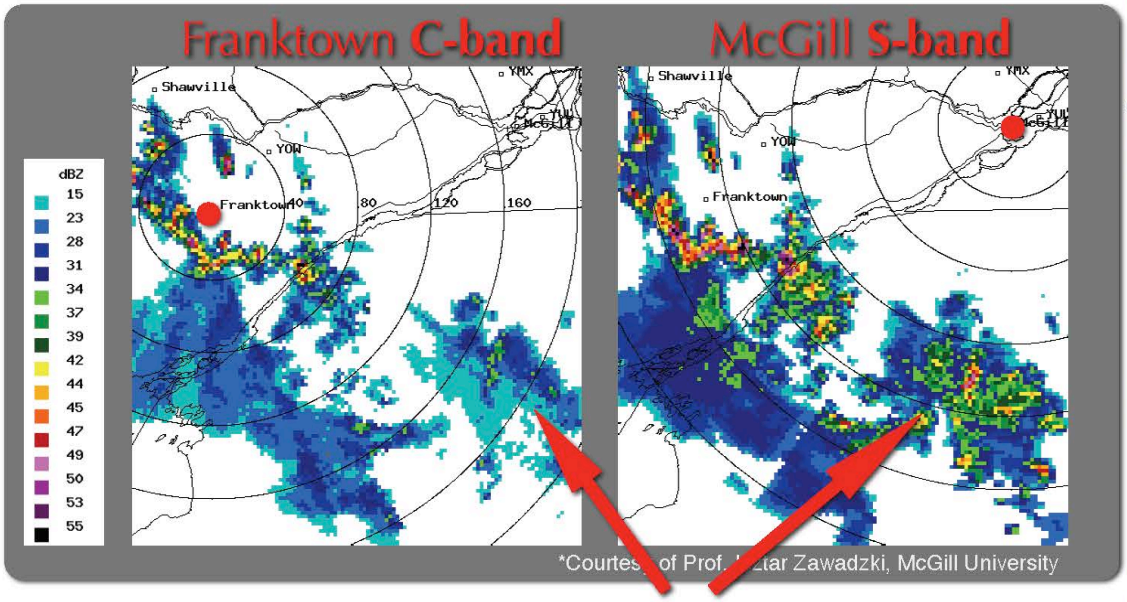
$$k = \int_0^\infty \sigma_e(D) N(D)\, dD$$

Depends on:

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  - radar wavelength
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Signal attenuation by rain

Comparison of C-band and S-band observations

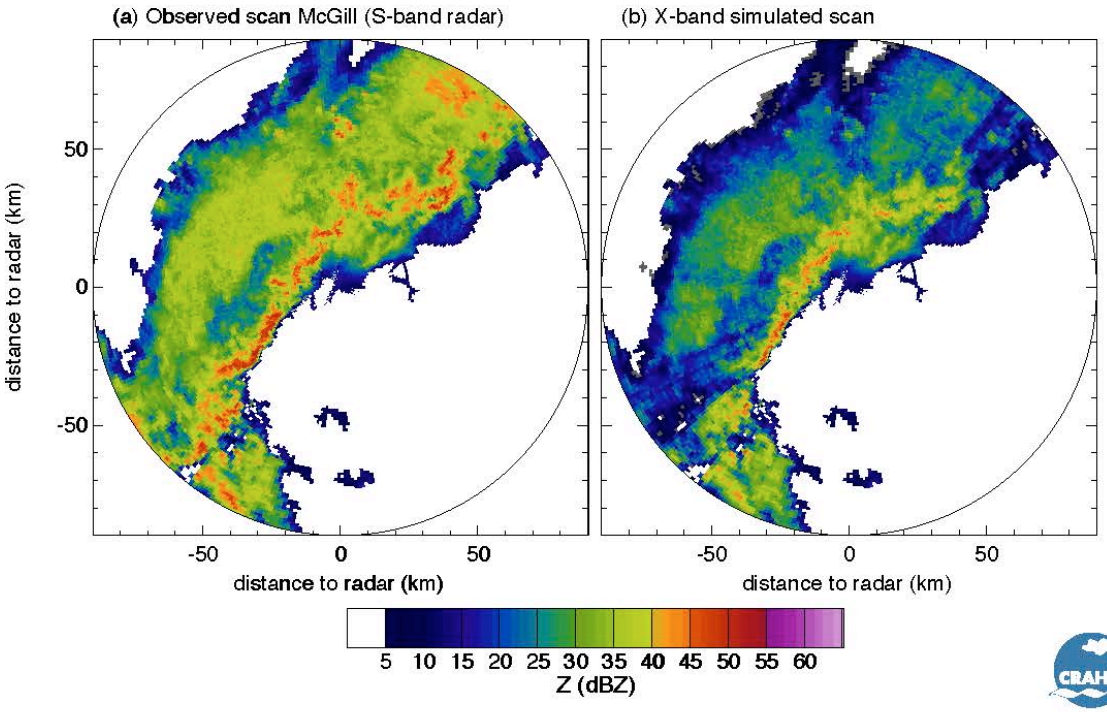


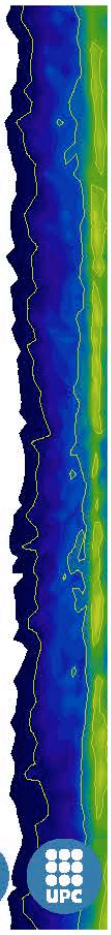
11 dB in equidistant weather due to in-rain attenuation

Could be additional **dBs** due to radome attenuation

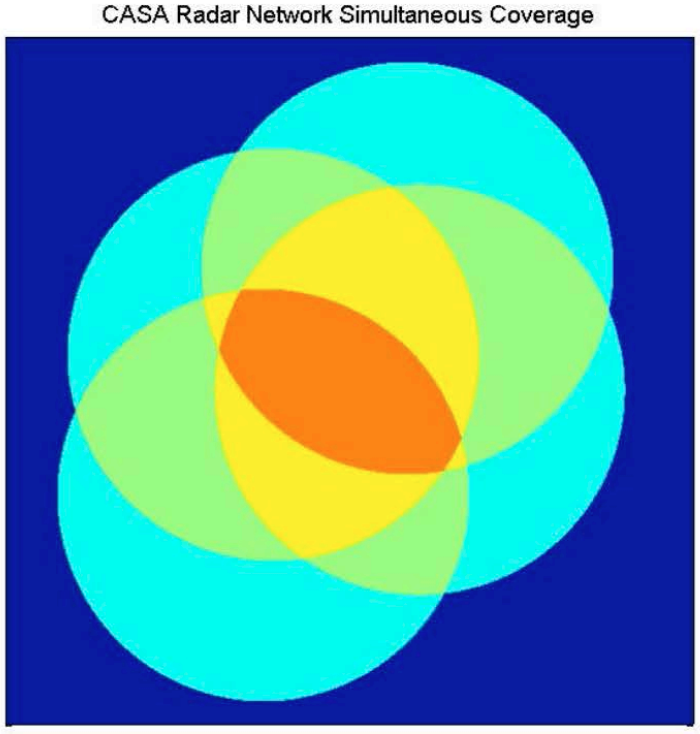
Signal attenuation by rain

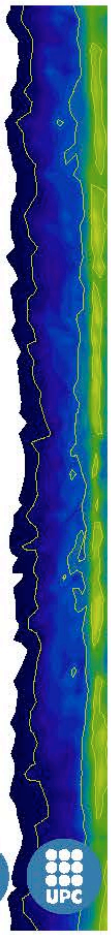
Simulation of X-band measurements





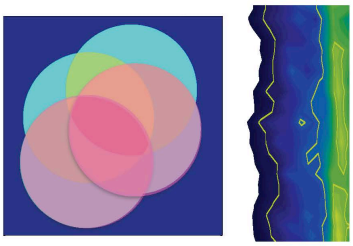
Signal attenuation by rain

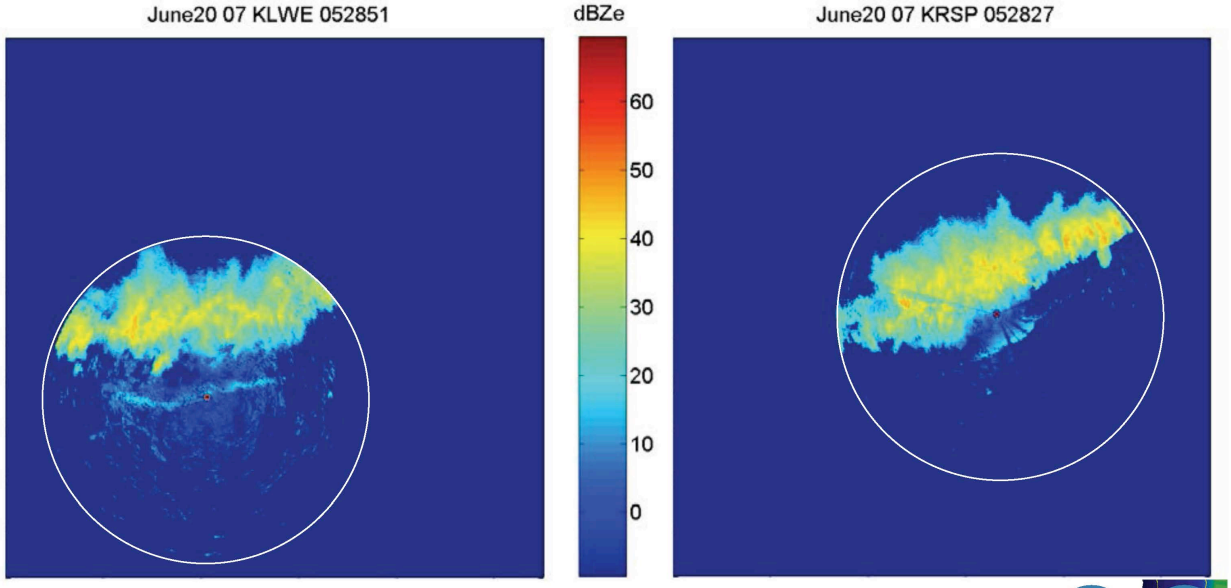




Signal attenuation by rain

X-band loop





courtesy of I. Zawadzki (McGill University)

Signal attenuation by rain - L(r)

$$Z_m(r) = Z_e(r)\,A(r) \qquad A(r) = exp\Big[-0.2\,ln(10)\int_0^r k(s)\,ds\Big]$$

$$k(r) = \alpha\,Z_e(r)^{\beta}$$

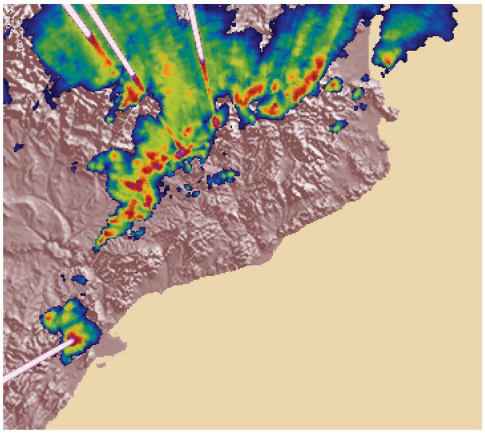
The analytical solution

$$Z_e(r) = \frac{Z_m(r)}{\Big[1 - 0.2\,ln(10)\,\beta\int_0^r \alpha\,Z_m^{\beta}(s)\,ds\Big]^{1/\beta}}$$

Hitschfeld & Bordan (1954)

Highly unstable!

HB-corrected field



with errors in the radar measurements

- radar calibration (Hitschfeld & Bordan, 1954)
- intrinsic errors in the reflectivity measurements

with other sources of uncertainty

- errors in the selected k-Z parameters
- DSD natural variability (Berne & Uijlenhoet 2005)
- non-uniform beam-filling (Berne & Uijlenhoet 2005)

Signal attenuation by rain - L(r)

$$Z_m(r) = Z_e(r)\,A(r) \qquad A(r) = exp\Big[-0.2\,ln(10)\int_0^r k(s)\,ds\Big]$$

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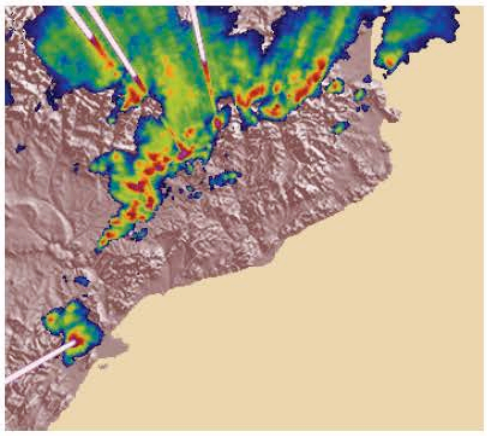
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Hitschfeld & Bordan (1954)

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with errors in th

- radar calibrat
- intrinsic error

with other sourc

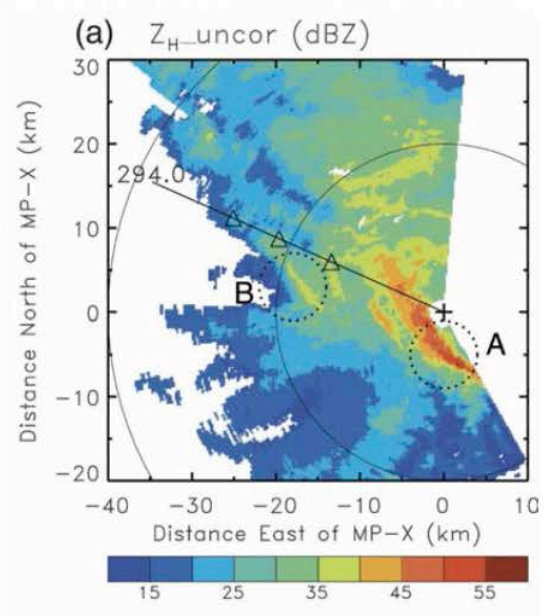
- errors in the
- DSD natural
- non-uniform

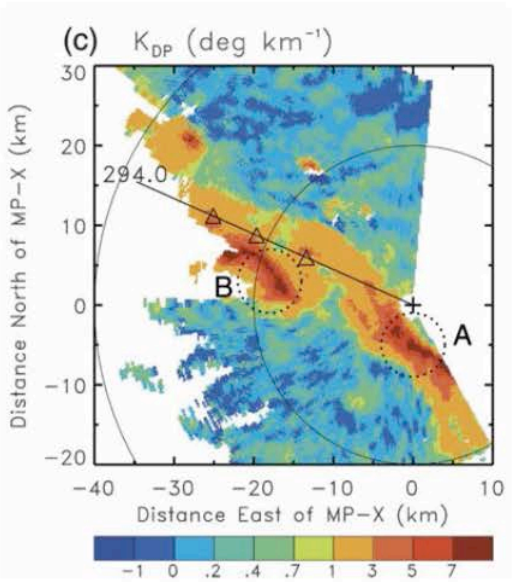
correction techniques **constrain** the model with **extra information**

- clutter echoes
- dual-frequency measurements
- dual-radar systems
- dual-polarization measurements

Signal attenuation by rain - dual-polarization correction

The correction uses dual-pol variables to correct for attenuation.



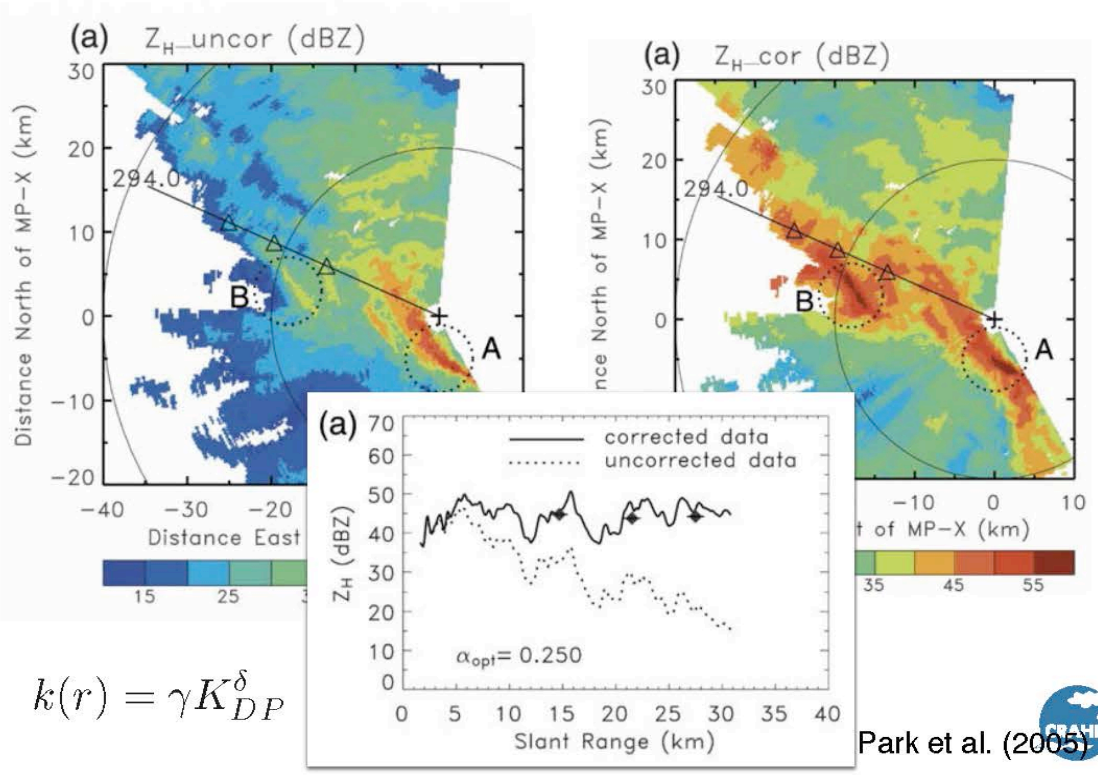


$$k(r) = \gamma K_{DP}^{\delta} \qquad (\delta \approx 1)$$

Source: Park et al. (2005)

Signal attenuation by rain - dual-polarization correction

The correction uses dual-pol variables to correct for attenuation.

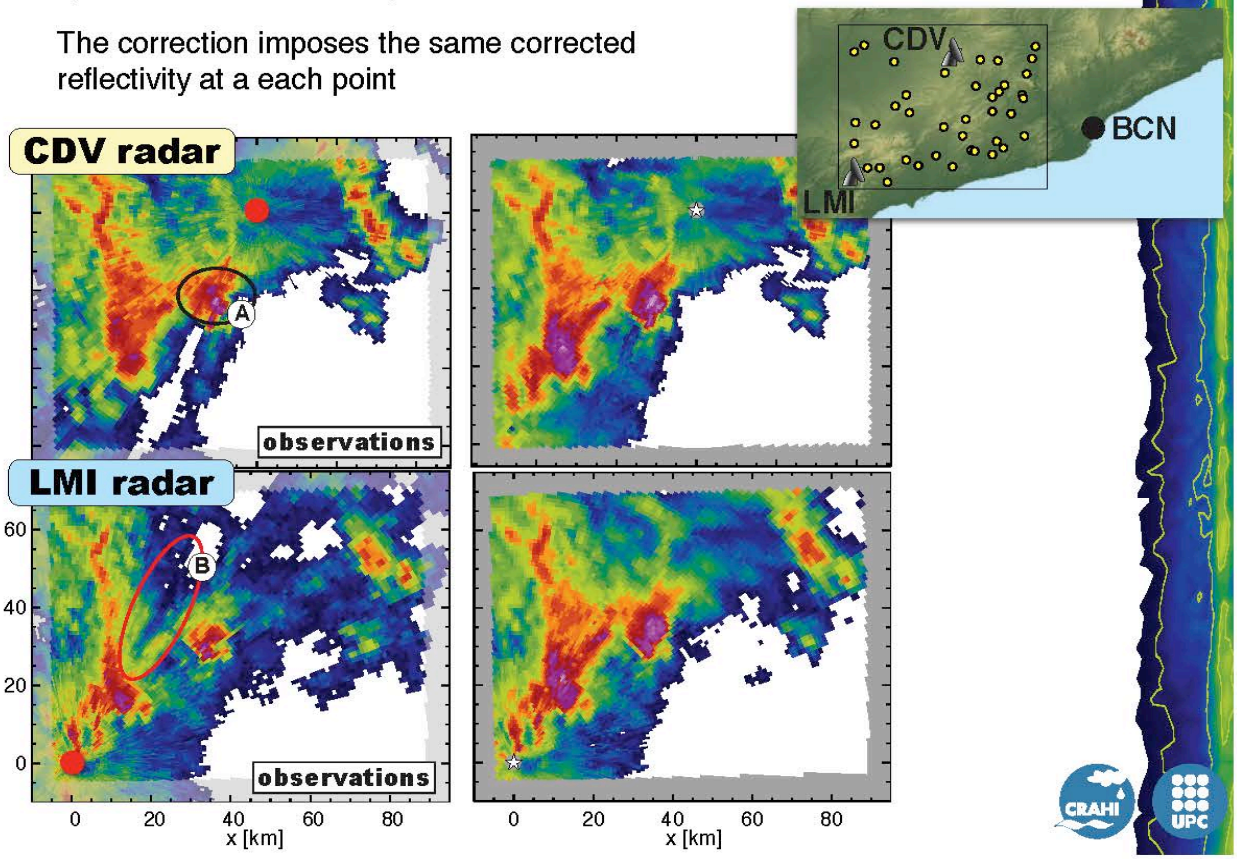


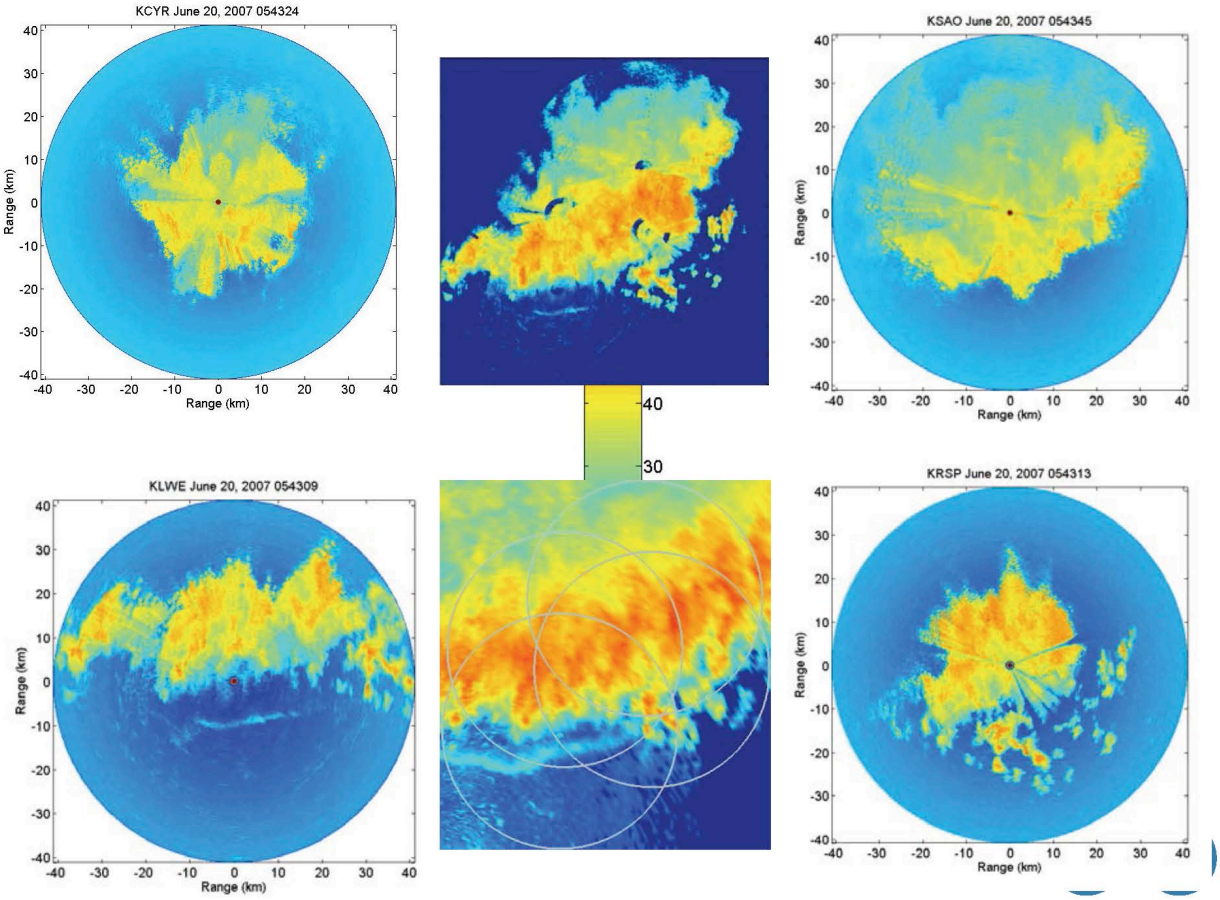
$$k(r) = \gamma K_{DP}^{\delta}$$

Park et al. (2005)

Signal attenuation by rain - dual-radar correction

The correction imposes the same corrected reflectivity at a each point





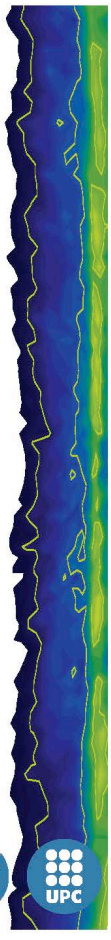
Radome attenuation

Signal **attenuation** caused by rain over the **radome due to:**

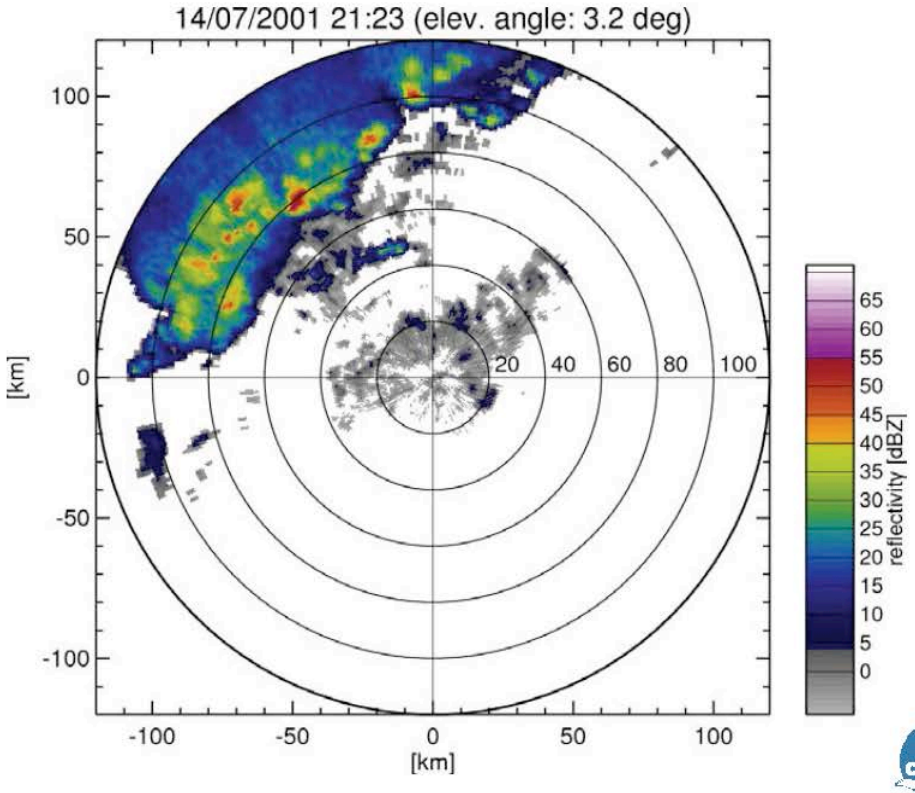
- Heavy rainfall
- Radomes not well maintained





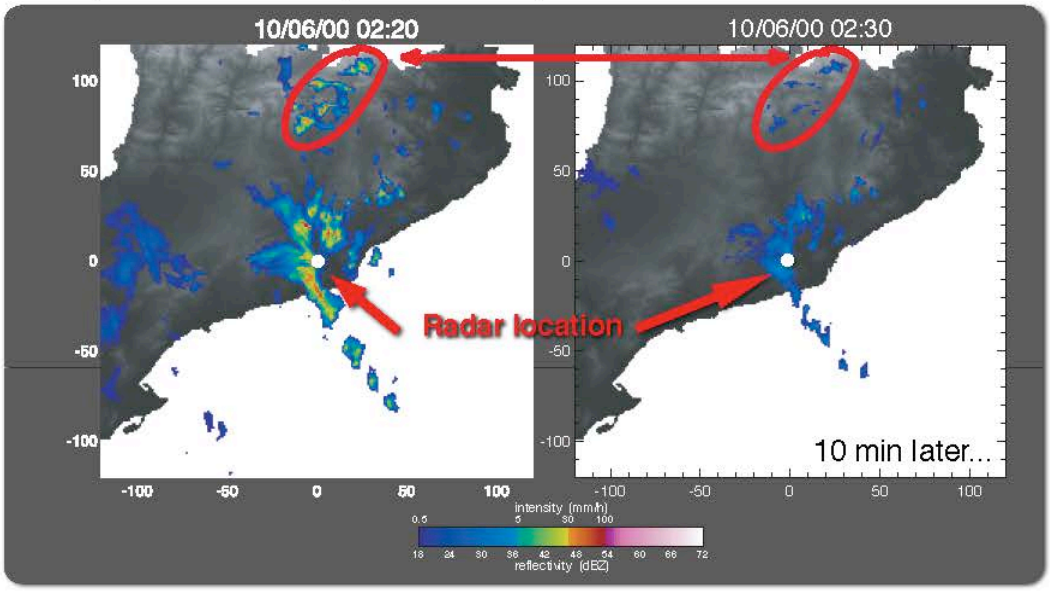


Signal attenuation by rain



Radome attenuation

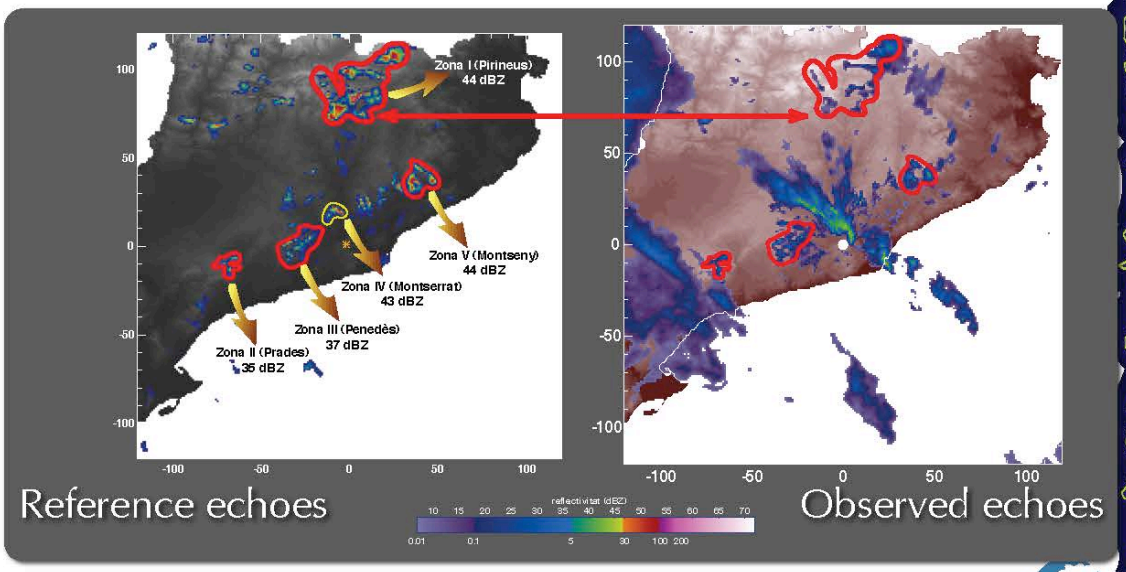
Example: 10 June 2000 (Corbera radar)



Sudden subdetection due to heavy rain over the radome

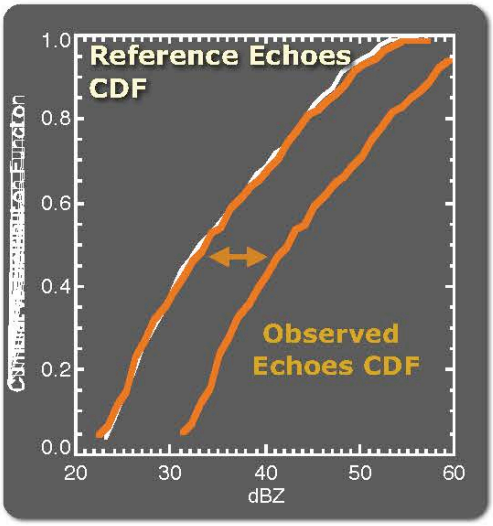
Radome attenuation

- **Attenuation and Stability Control using MOuntain REturns (ASCMORE Algorithm)**



Radome attenuation

- **Attenuation and Stability Control using MOuntain REturns (ASCMORE Algorithm)**



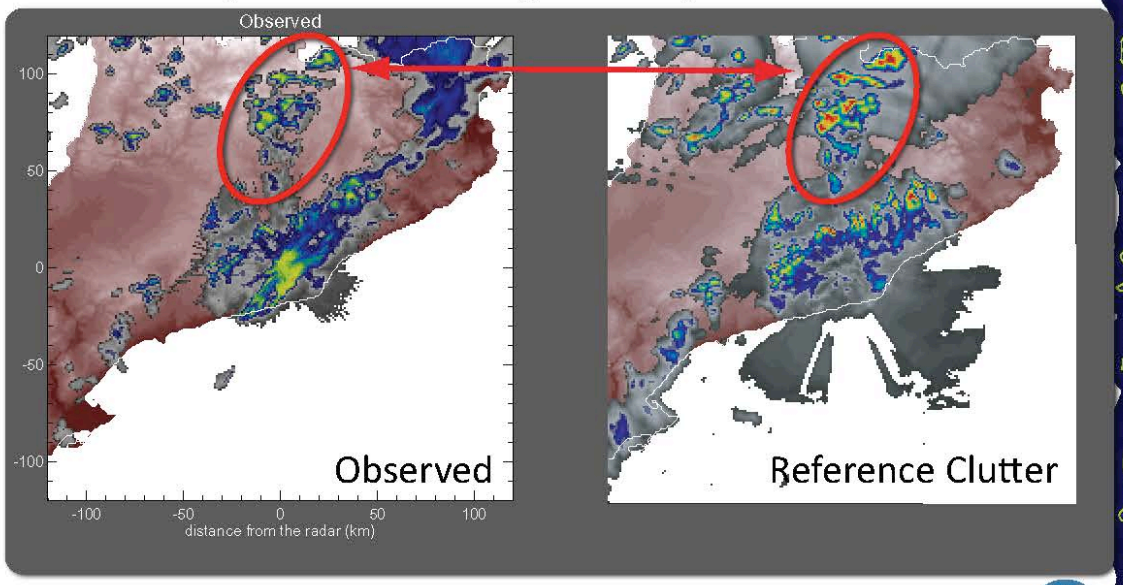
- The shape of the **mountan returns cdf** is not affected, but just **biased by a constant factor**.
- Correction Factor calculated by difference between observed and reference echoes CDF means.

Real Time warning

Real Time correction if possible

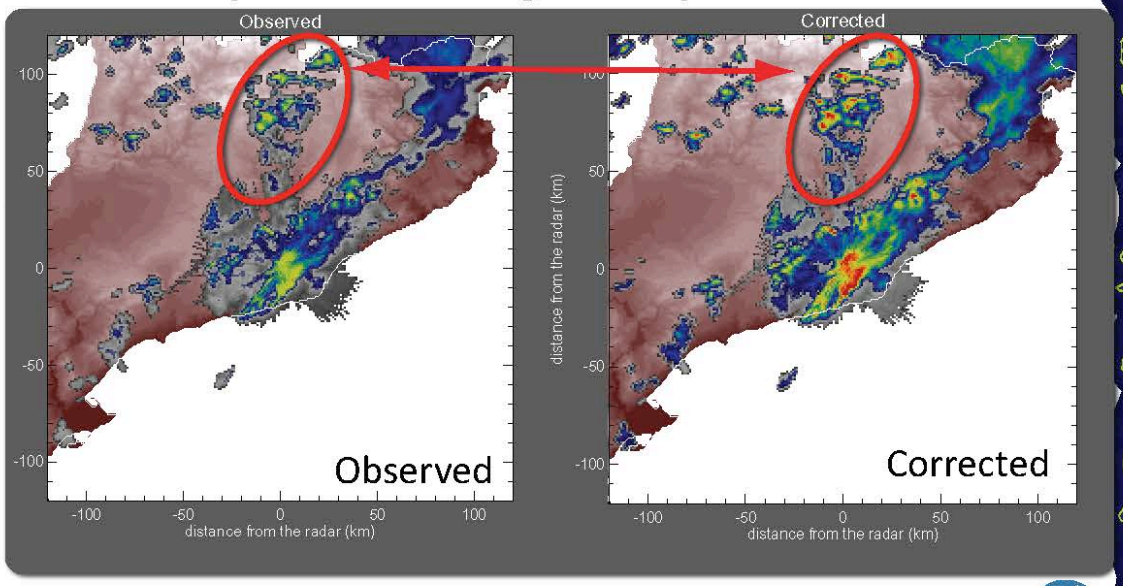
Radome attenuation

- **Attenuation and Stability Control using MOuntain REturns (ASCMORE Algorithm)**



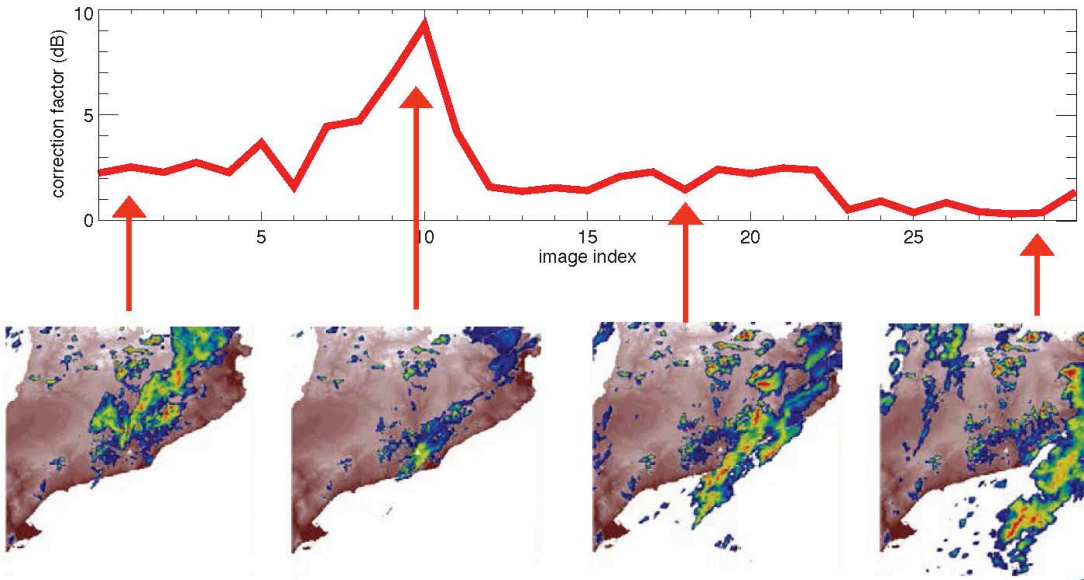
Radome attenuation

- **Attenuation and Stability Control using MOuntain REturns (ASCMORE Algorithm)**



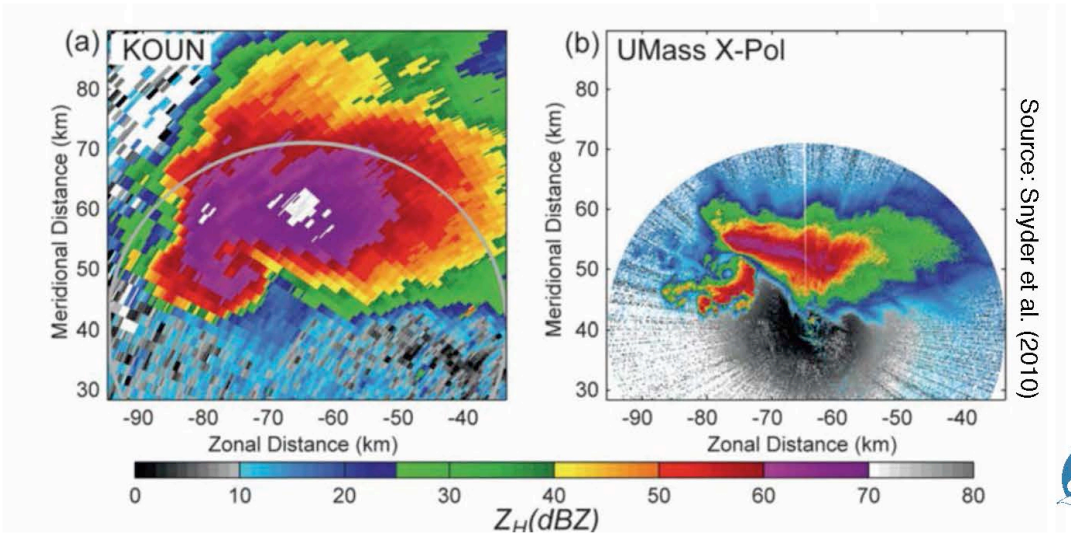
Radome attenuation

- **Attenuation and Stability Control using MOuntain REturns (ASCMORE Algorithm)**



Signal attenuation by rain

- Path attenuation is severe at X-band, but it can also be very serious at C-band (extinction can occur).
- For quantitative uses in intense rain, needs to be corrected.
- Unstable correction -> Requires using additional information.

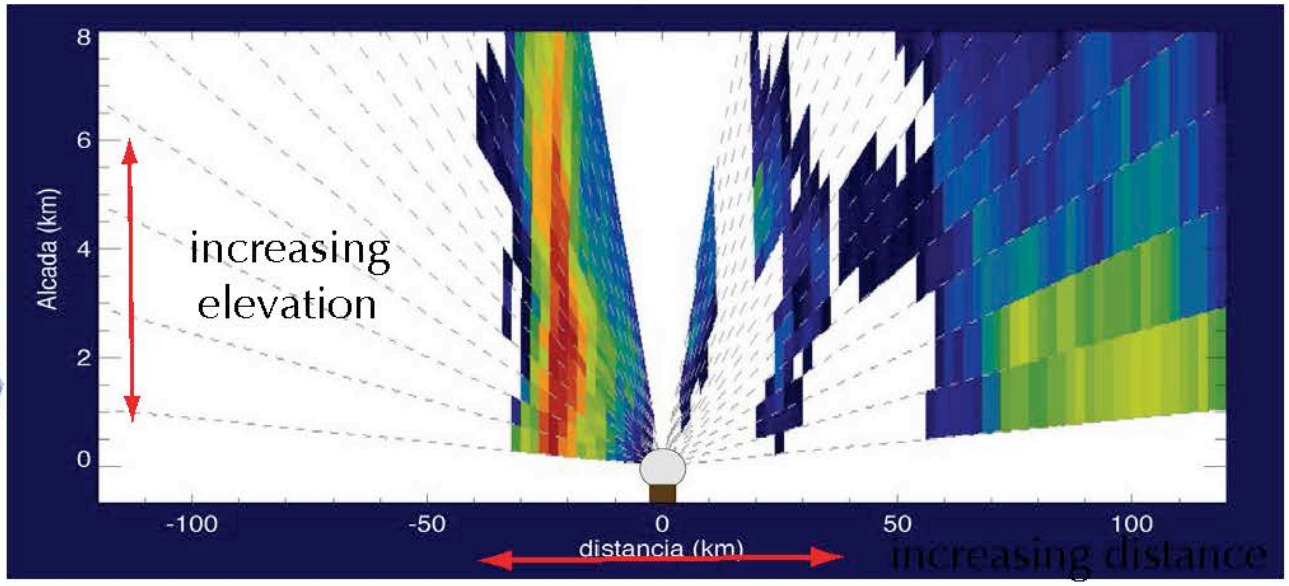


Effects with the distance to the radar

Centre for Applied Research in Hydrometeorology
CRAHI
Universitat Politècnica de Catalunya
Barcelona (Spain)

T.C.
Orman ve Su İşleri Bakanlığı
Meteoroloji Genel Müdürlüğü

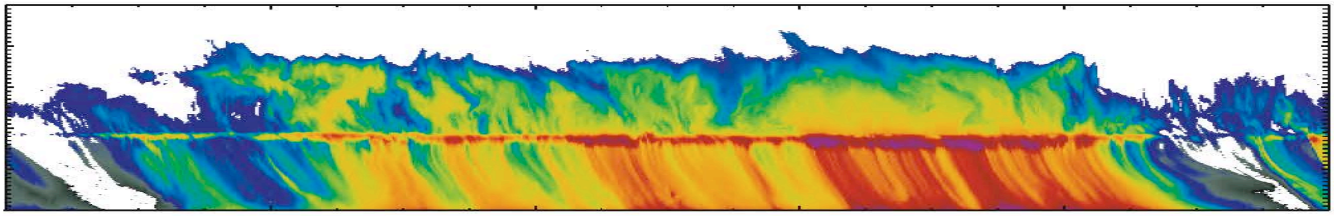
Errors induced by the Distance

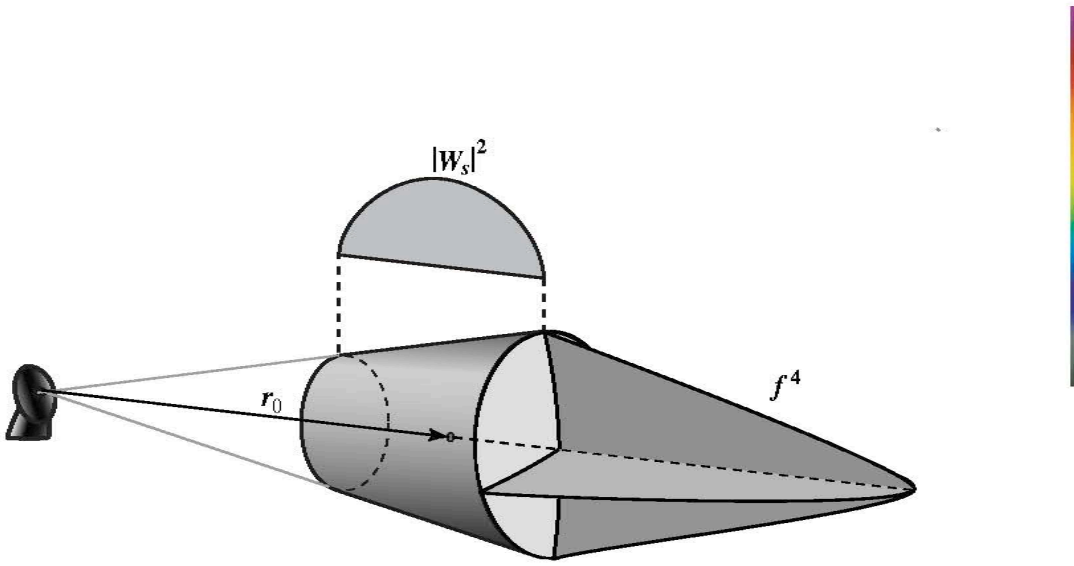


The elevation increases with distance
The sampling volume becomes bigger
The estimated value decreases

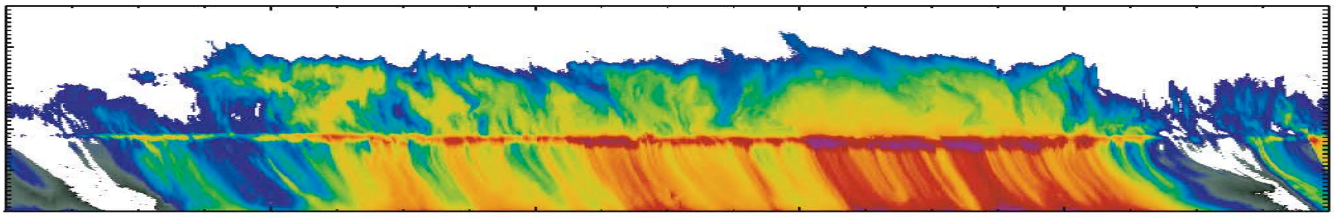
The measurement is less representative of the precipitation at the surface

Errors induced by the Distance

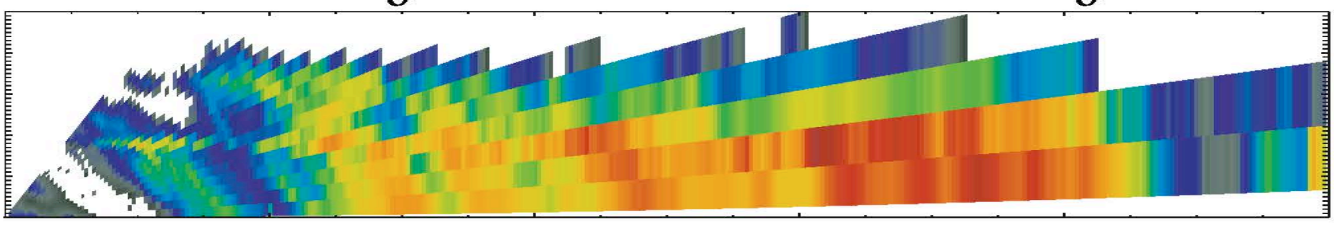




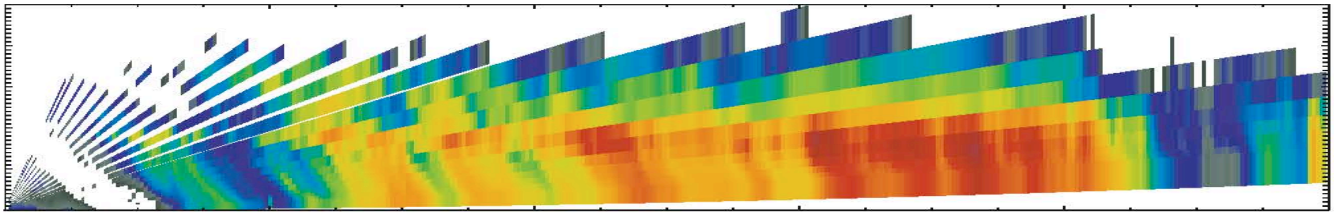
Errors induced by the Distance



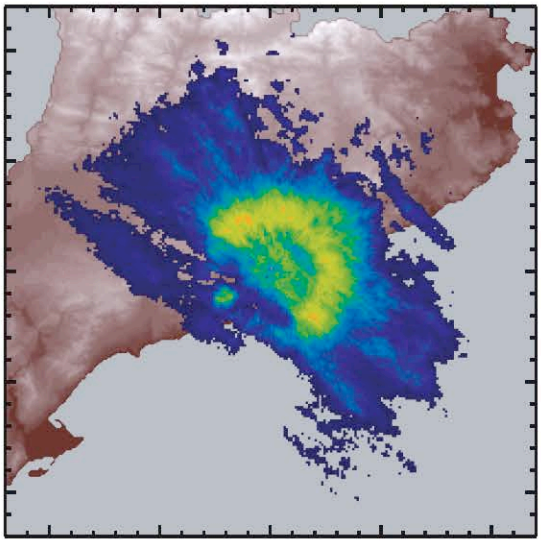
Antenna Program: linear increase of elevation angles



Antenna Program: geometrical increase of elevation angles



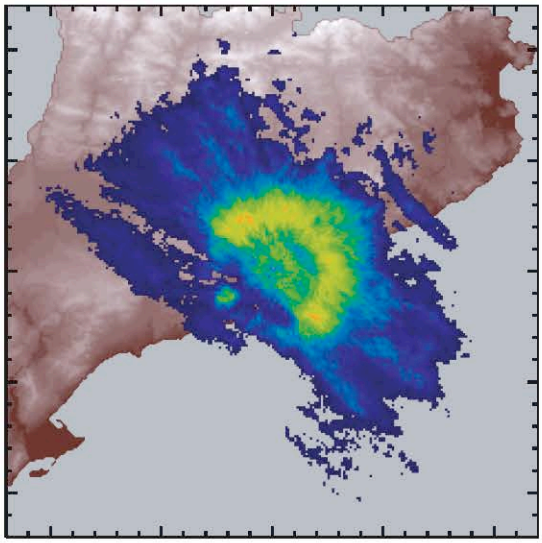
Bright Band: the problem

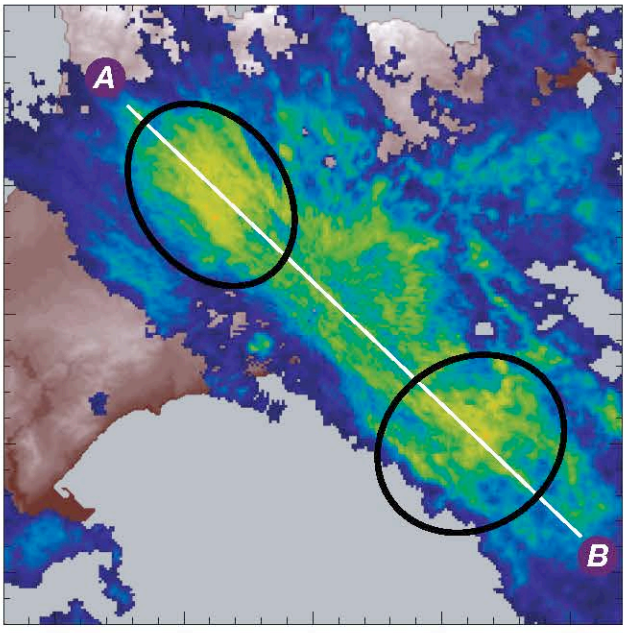


- Fictive reflectivity enhancement due to the melting layer
- Need to be corrected
- Sometimes very clear

Membre de:
CIDEM
XARXA DE CENTRES DE SUPORT A LA INNOVACIÓ TECNOLÒGICA

Bright Band: the problem



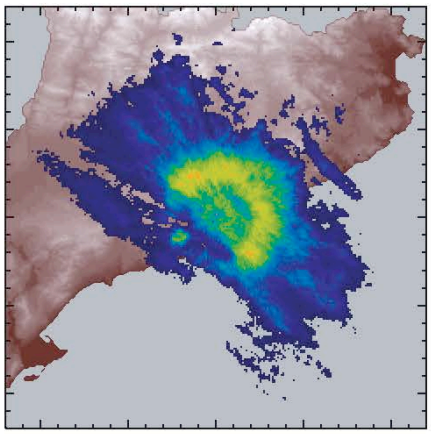


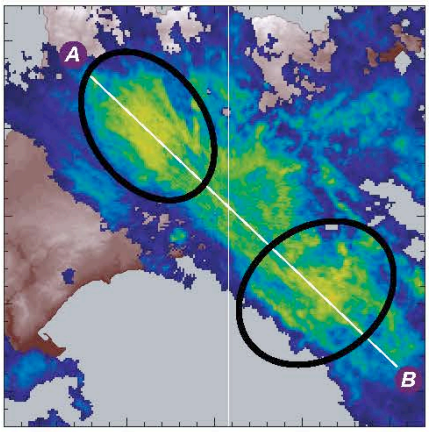
Third PPI

First PPI

Enhancements due to Bright Band

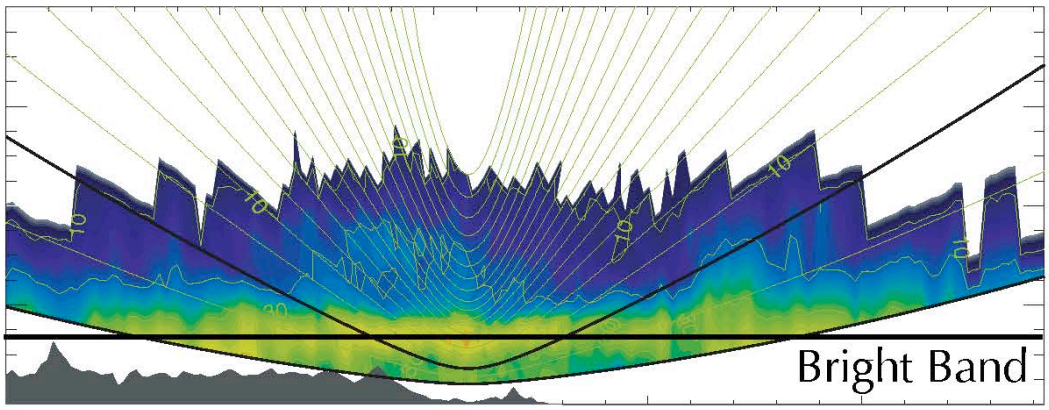
Membre de:
CIDEM
XARXA DE CENTRES DE SUPORT A LA INNOVACIÓ TECNOLÒGICA





Third PPI

First PPI

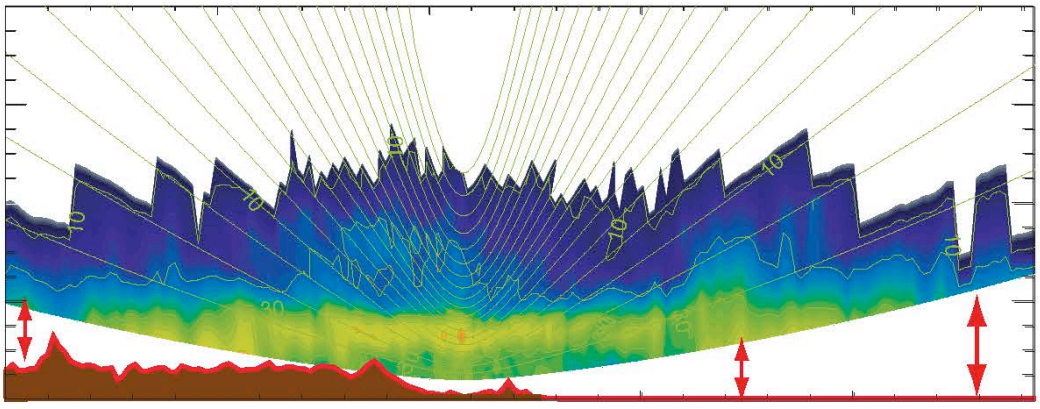


A

B

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XARXA DE CENTRES DE SUPORT A LA INNOVACIÓ TECNOLÒGICA
CRAHI
UPC

VPR correction

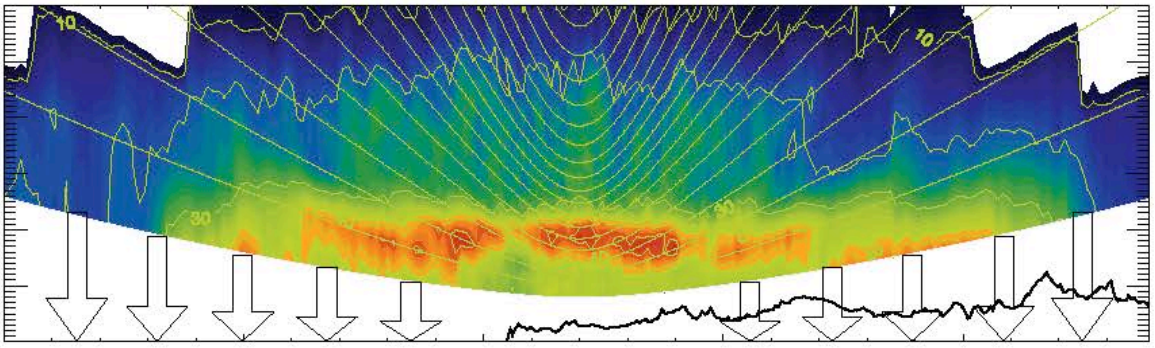


Extrapolate reflectivities to ground

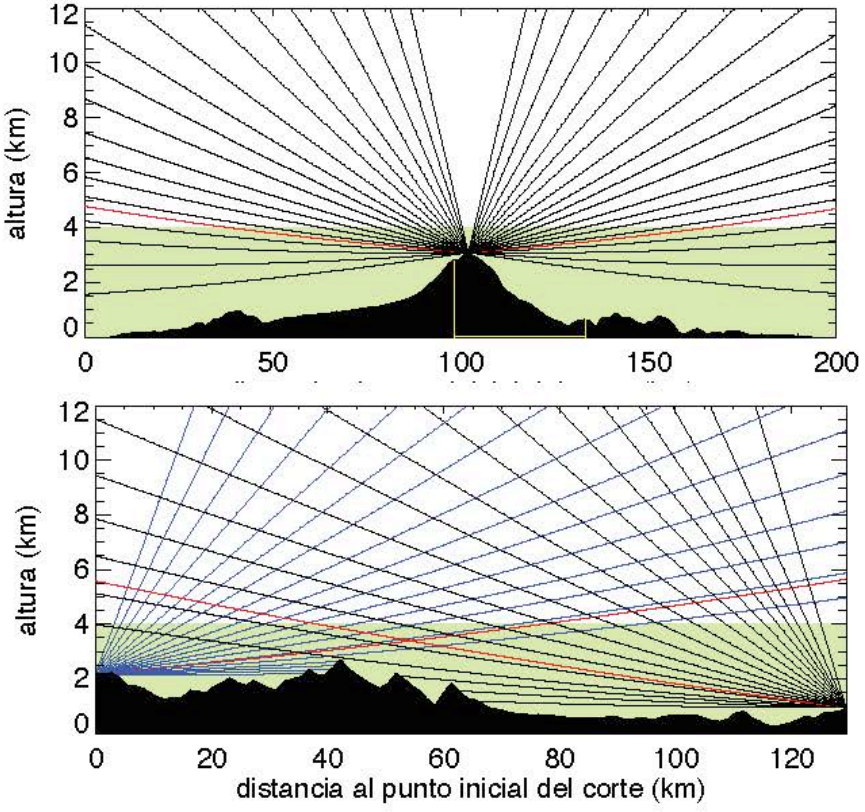
taking extra care of Bright Band contamination

Membre de:
CIDEM
XARXA DE CENTRES DE SUPORT A LA INNOVACIÓ TECNOLÒGICA
CRAHI
UPC

Vertical Profile of Reflectivity: distance effects and Bright Band correction

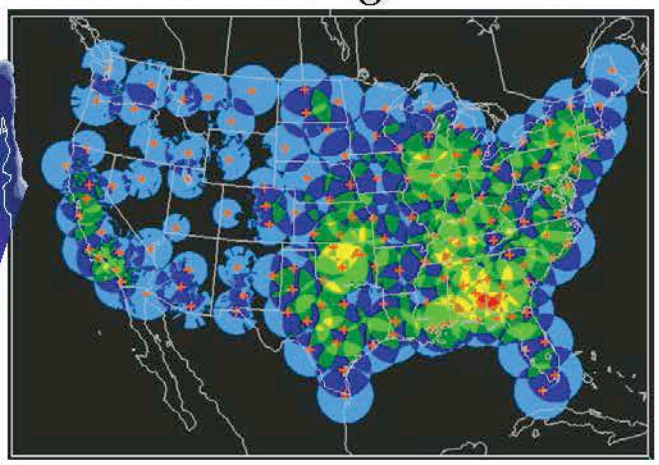


Design of the Antena program taking into account the climatological height of the Isotherm 0°



Radar Visibility

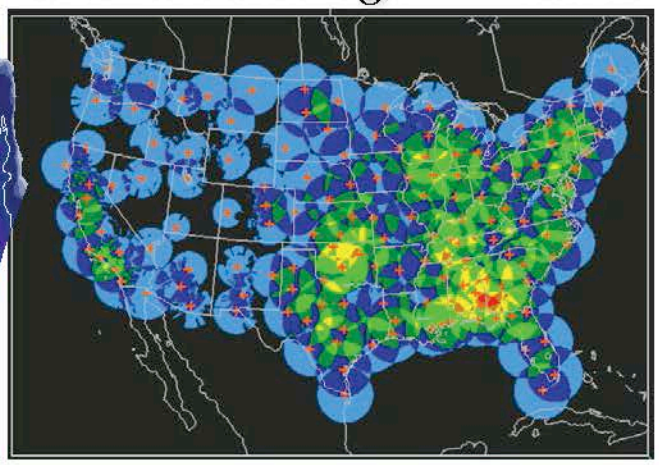
NEXRAD coverage @5km



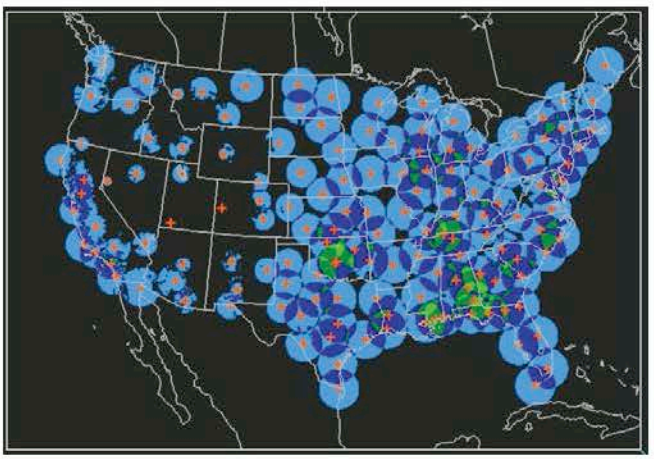
Membre de:
CIDEM

Radar Visibility

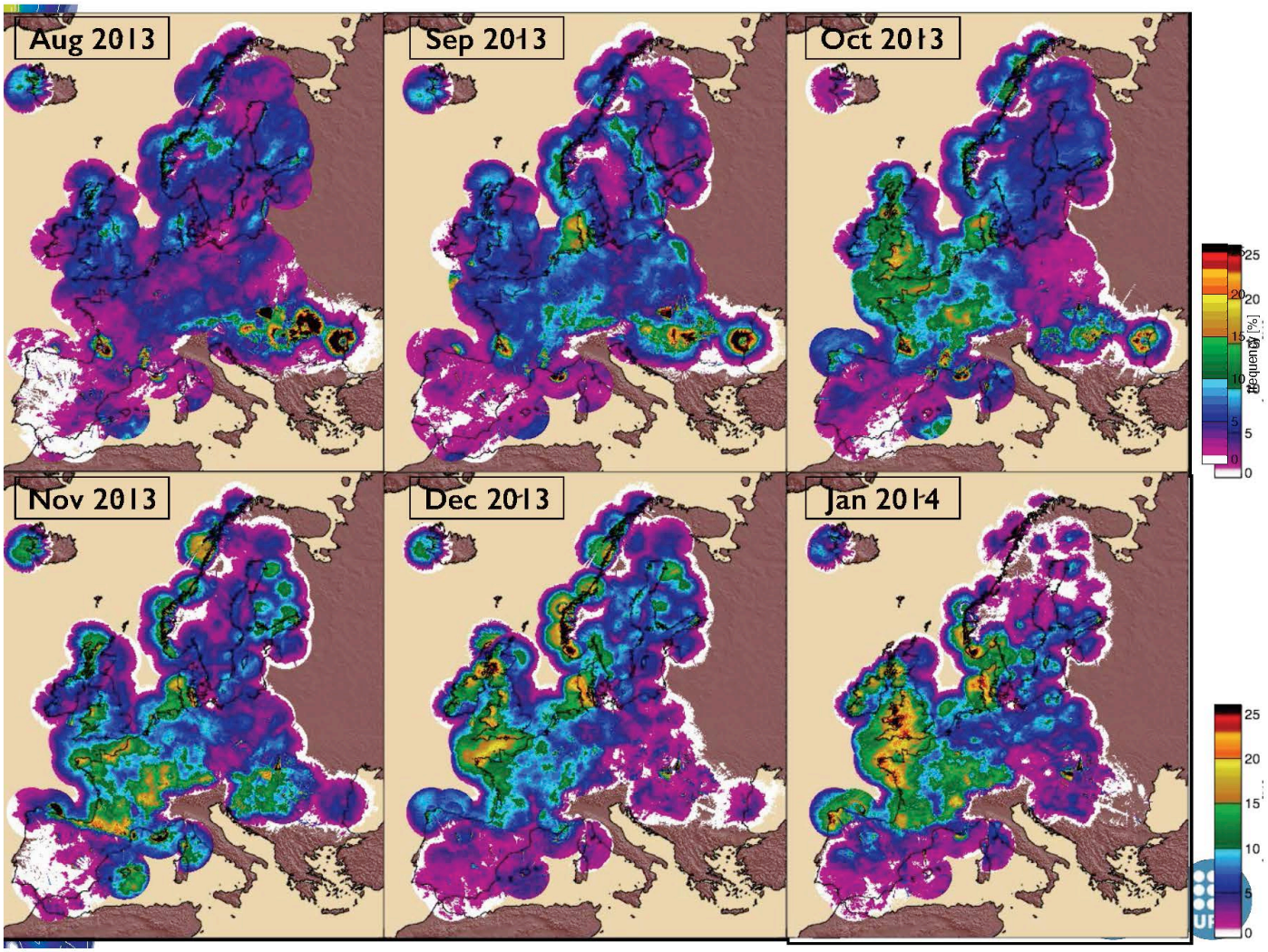
NEXRAD coverage @5km



@3km

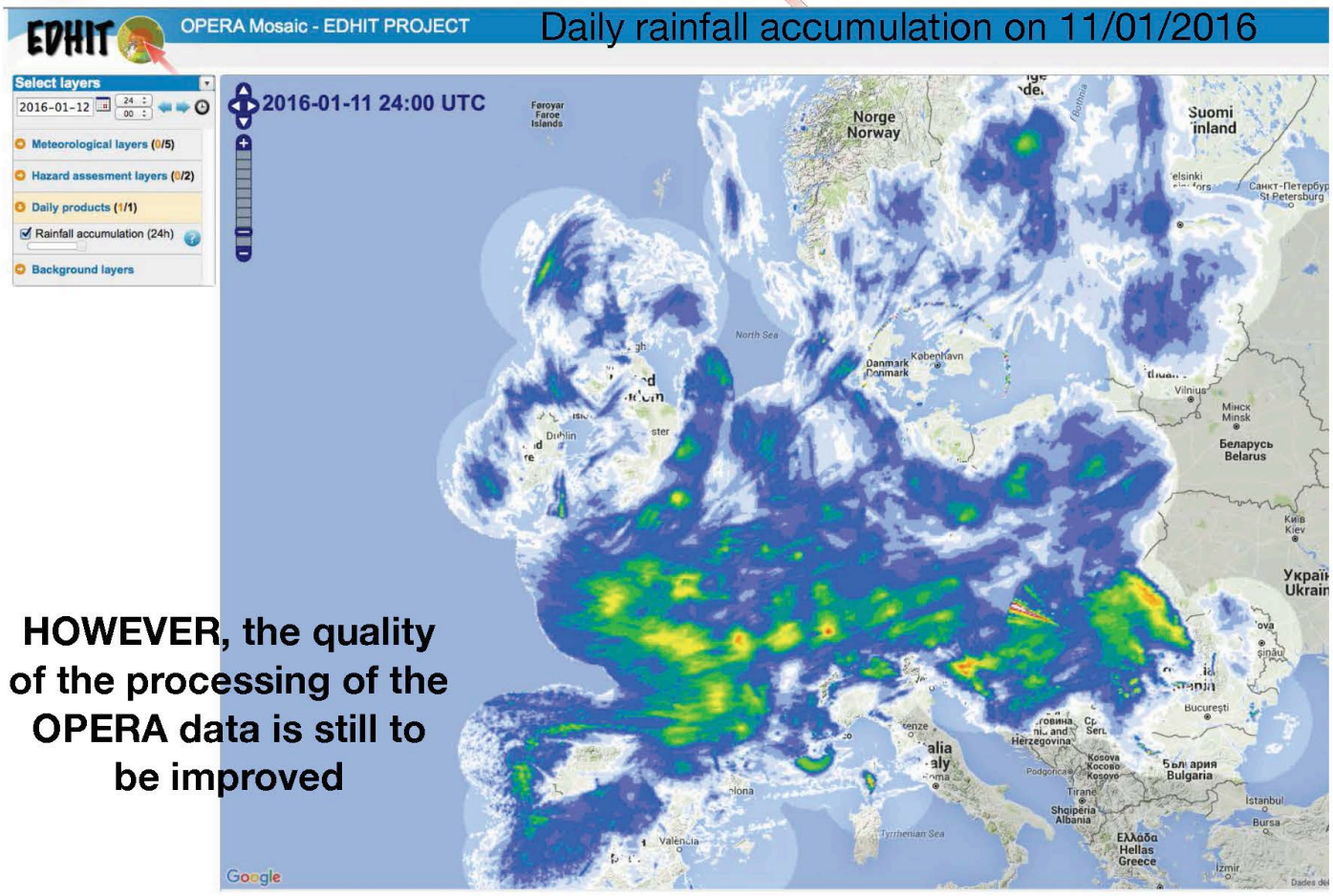


Membre de:
CIDEM



European Civil Protection

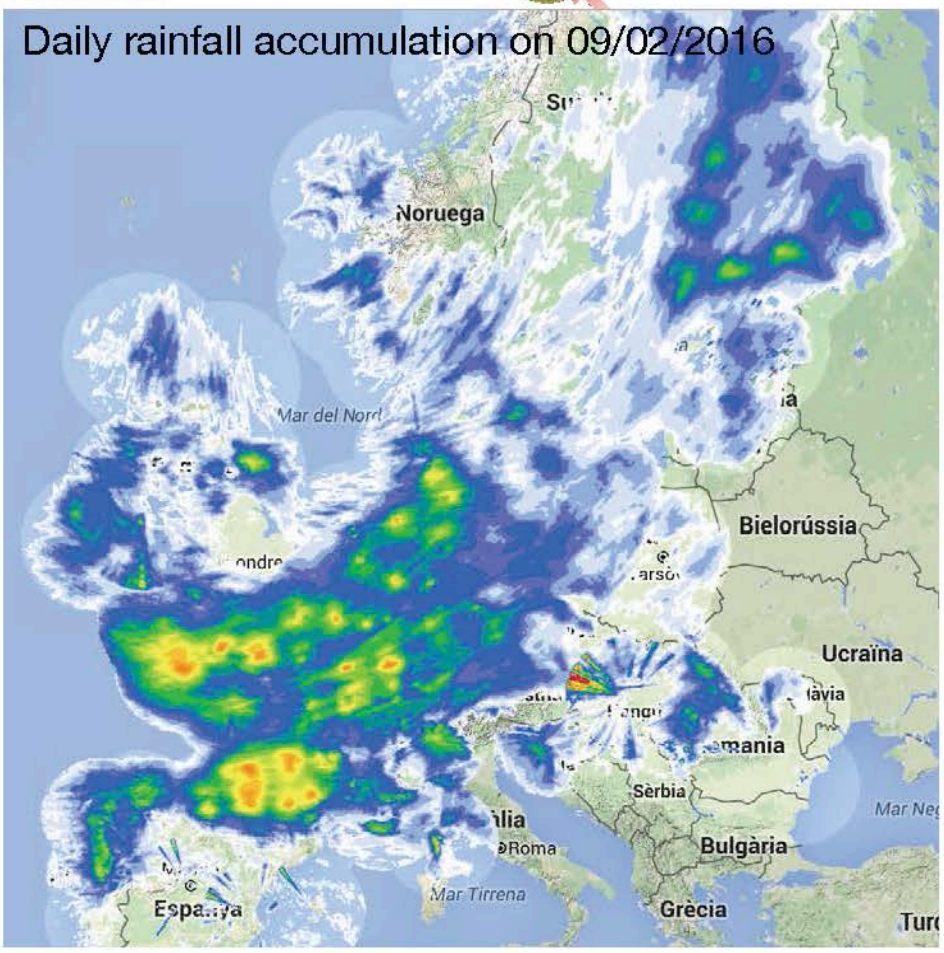
EDHIT



HOWEVER, the quality of the processing of the OPERA data is still to be improved

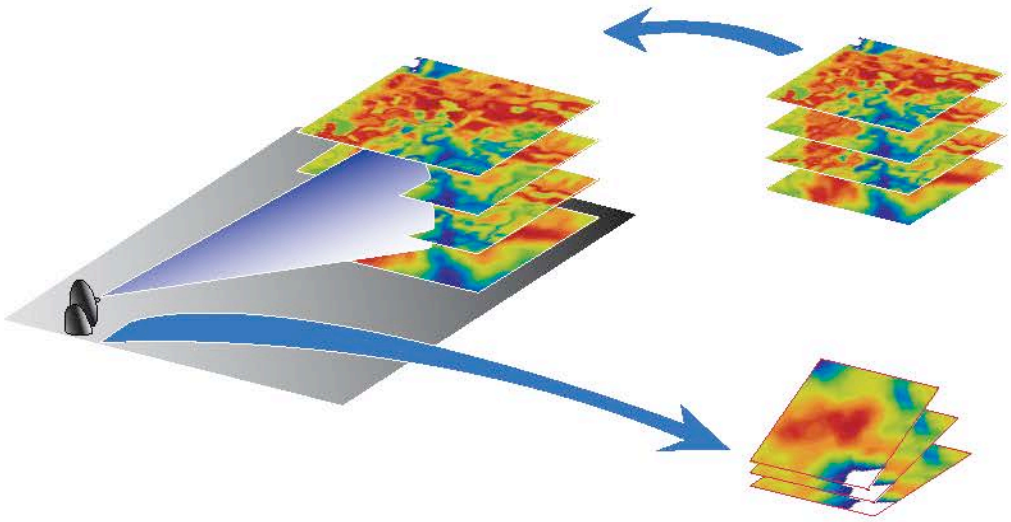
European Civil Protection

EDHIT



Errors induced by the Distance

Generation of radar estimates at different distances

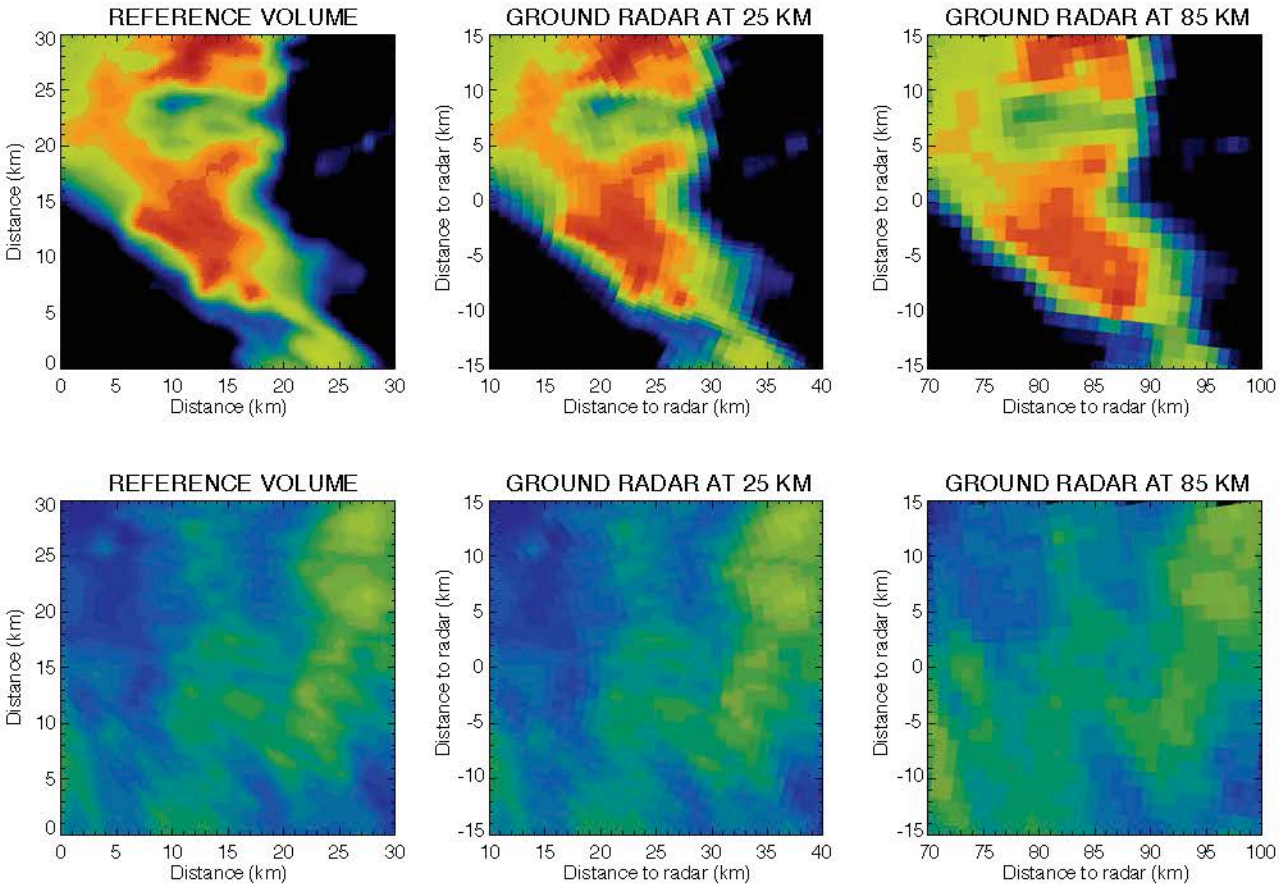


TECNIO

CRAHI

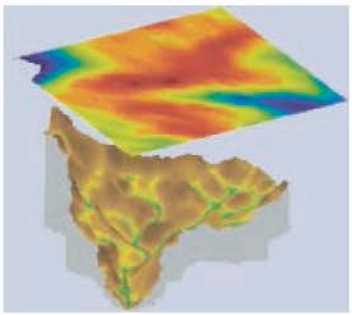
UPC

Errors induced by the Distance

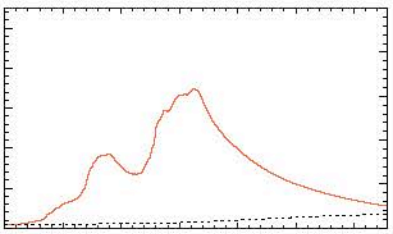


Hydrological Validation

Analysis of the effects on the outflows of a basin, using a hydrological modeling.



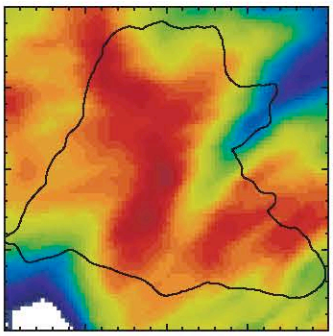
Associated outflows



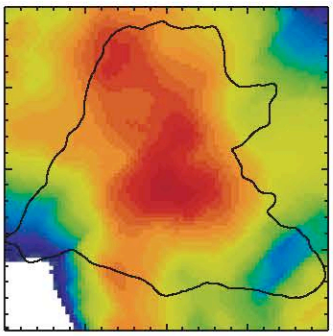
Assessment of the hydrological effect of errors

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XARXA DE CENTRES DE SUPORT A LA INNOVACIÓ TECNOLÒGICA
CRAHI
UPC

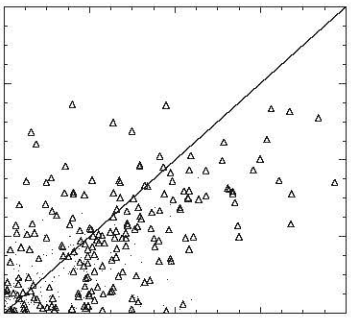
Convective case study



Reference field

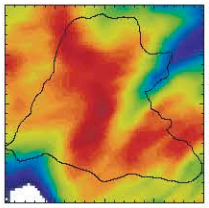


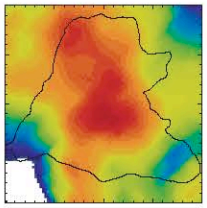
Seen by radar
at 100 km

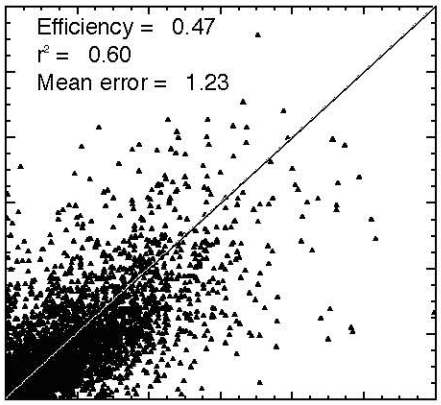


Membra de:
CIDEM
XARXA DE CENTRES DE SUPORT A LA INNOVACIÓ TECNOLÒGICA

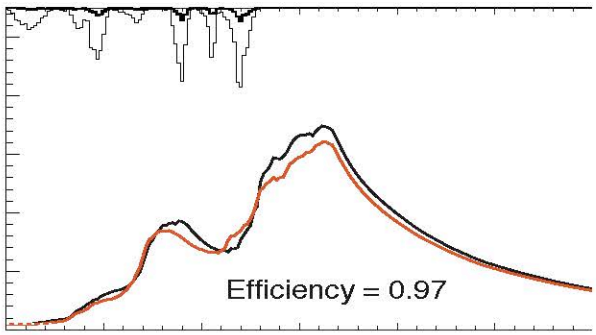
Convective case study







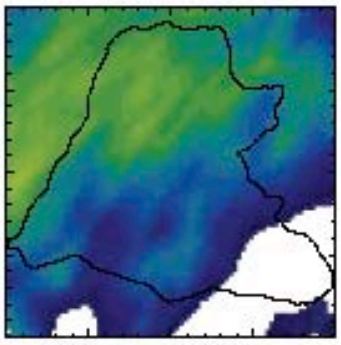
Reference field



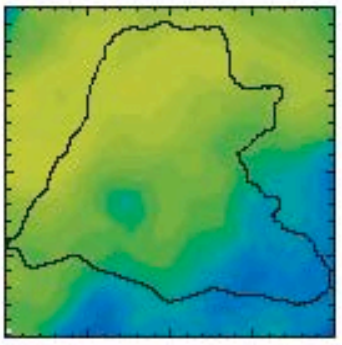
Outflow from degraded field
Outflow from reference field

Membra de:
CIDEM
XARXA DE CENTRES DE SUPORT A LA INNOVACIÓ TECNOLÒGICA

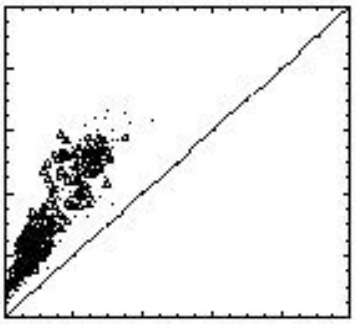
Stratiform case study



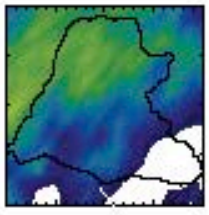
Reference field

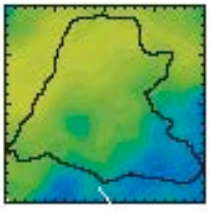


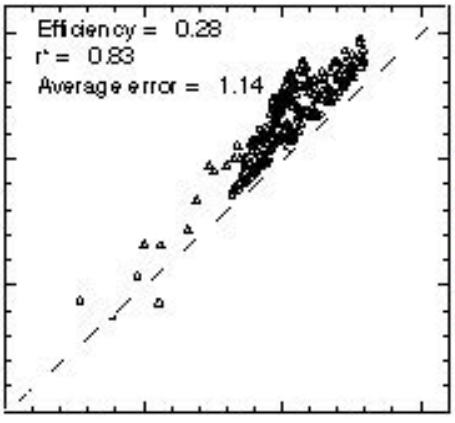
Seen by radar
at 50 km

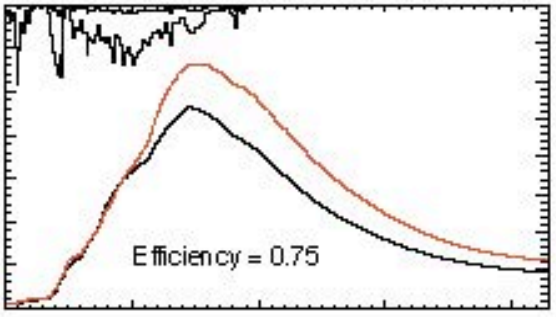


Convective case study



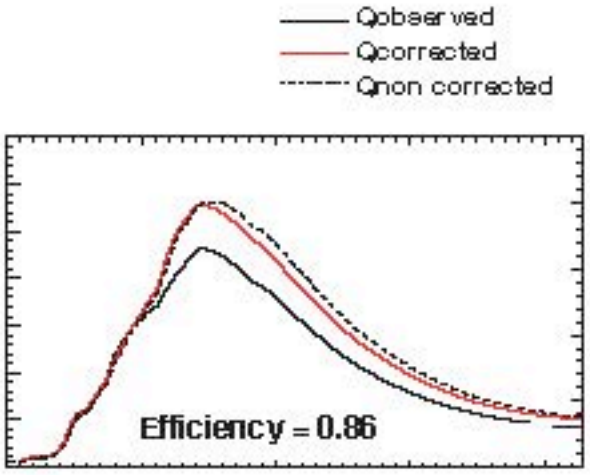


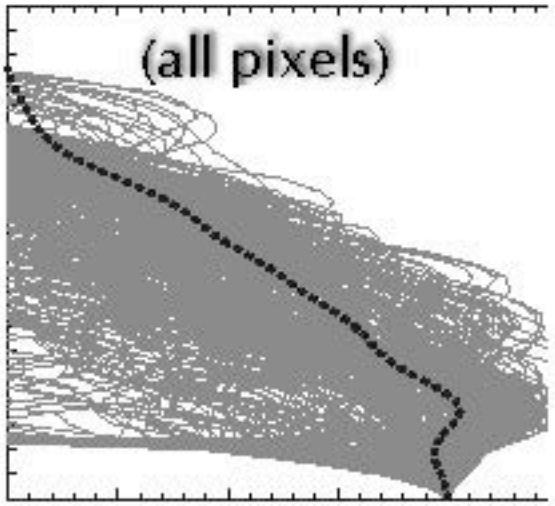




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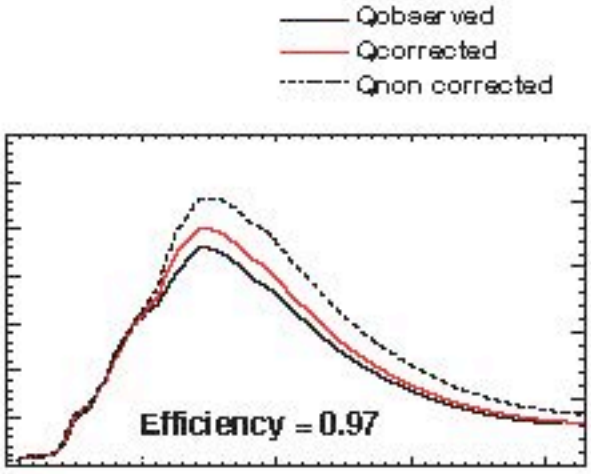
El efecto de la corrección por PVR

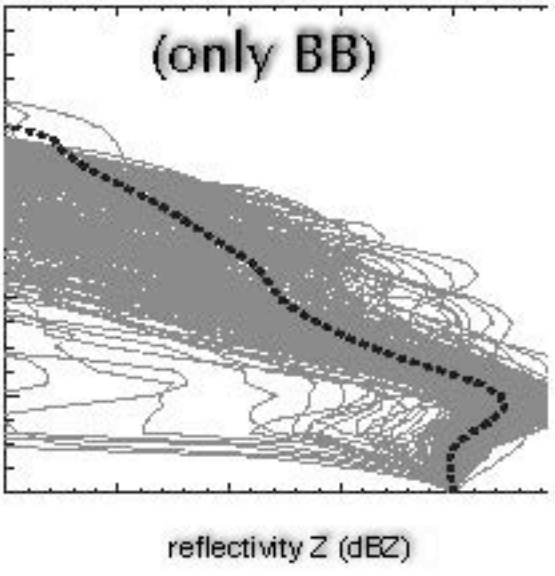




PVR medio

El efecto de la corrección por PVR





PVR medio

TRAINING PROGRAM ON METEOROLOGICAL AND ADVANCED QUANTITATIVE APPLICATIONS

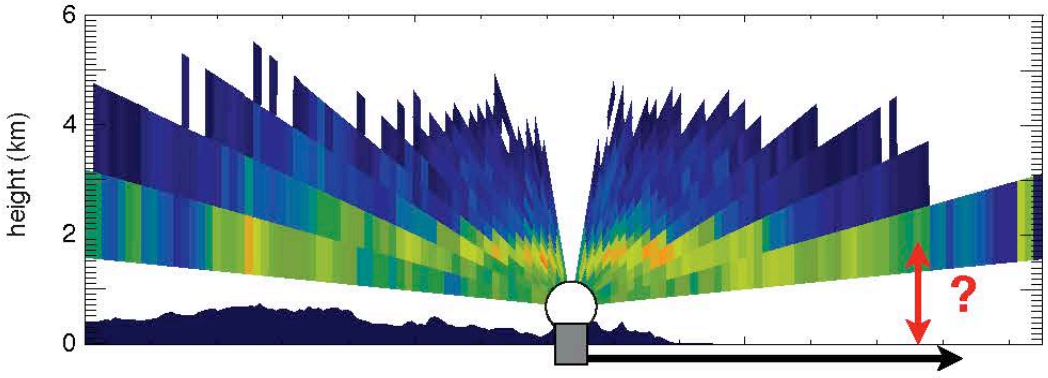
Vertical structure of the precipitation & representativeness of radar measurements at ground: Bright Band and Vertical Profile of Reflectivity correction.

Centre de Recerca Aplicada en Hidrometeorologia
UNIVERSITAT POLITÈCNICA DE CATALUNYA

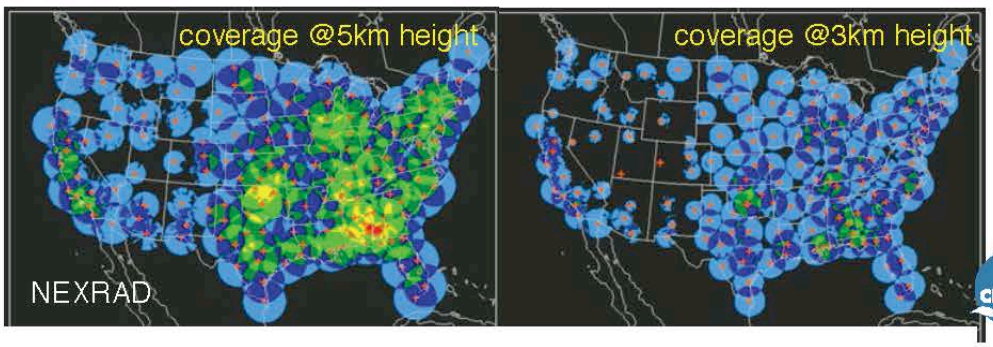


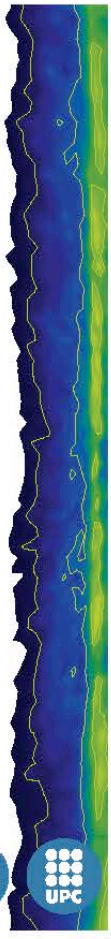
Errors with range

Representativeness of radar observations



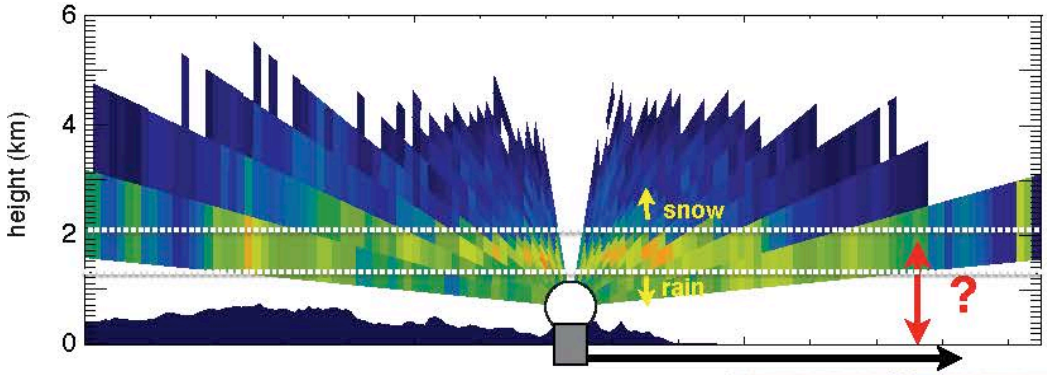
•Sampling height increases with distance



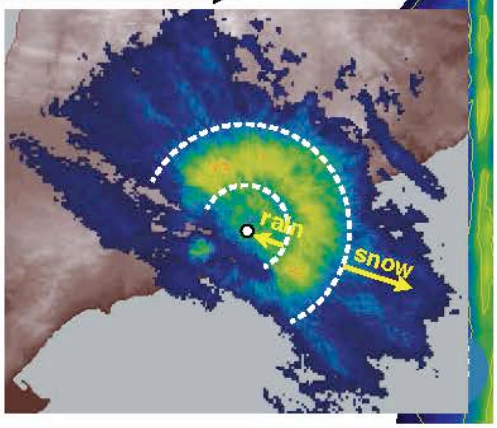


Errors with range

Representativeness of radar observations

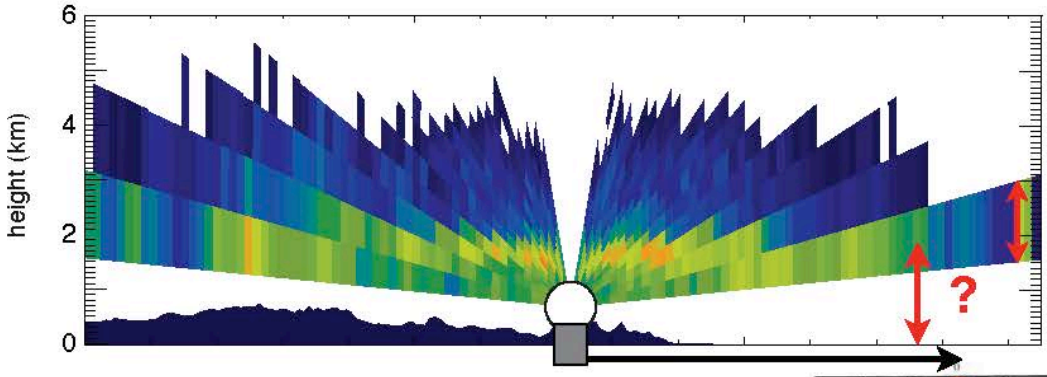


•Sampling height increases with distance



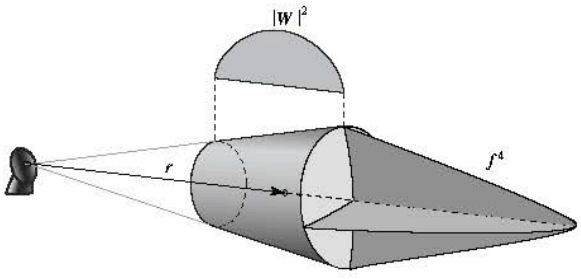
Errors with range

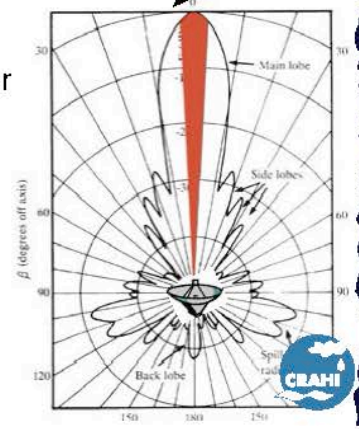
Representativeness of radar observations



•Sampling height increases with distance

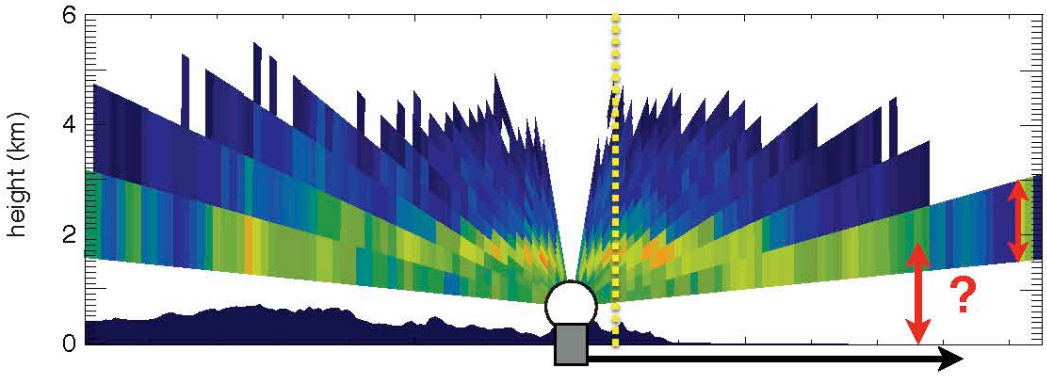
•With range, the sampling volume becomes larger



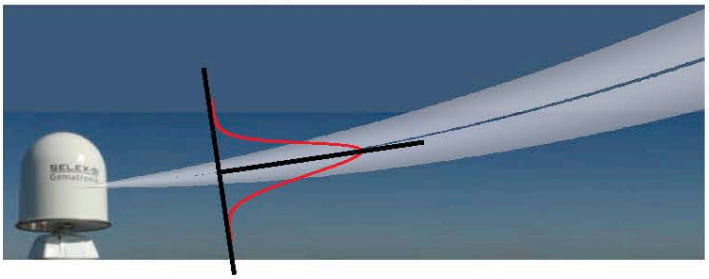


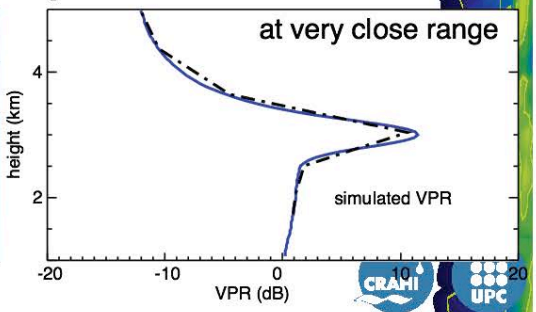
Errors with range

Representativeness of radar observations



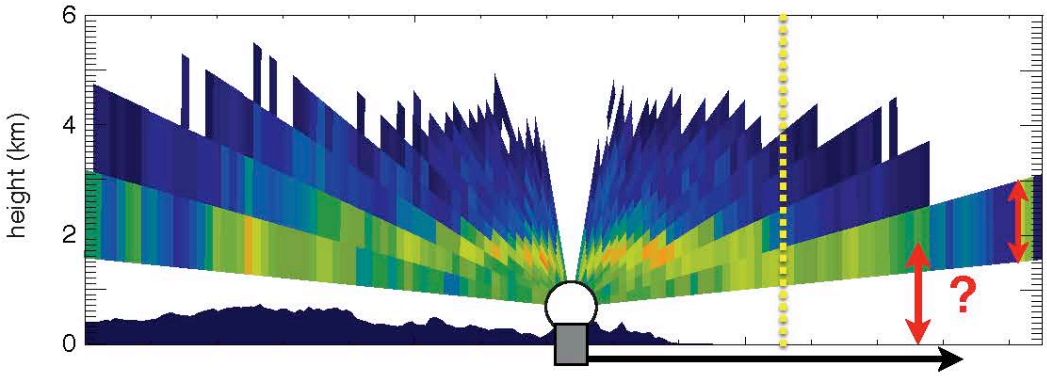
- Sampling height increases with distance
- With range, the sampling volume becomes larger



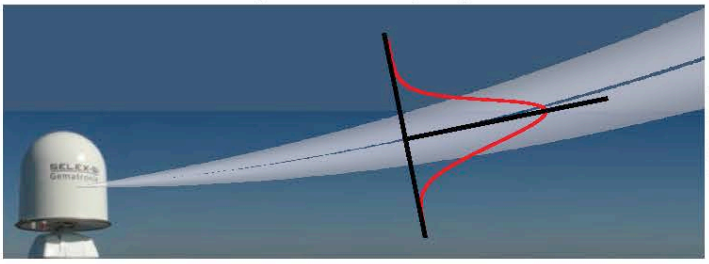


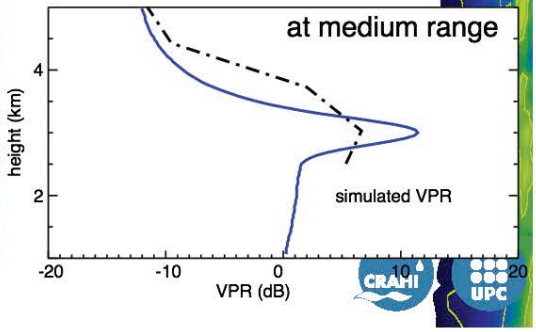
Errors with range

Representativeness of radar observations



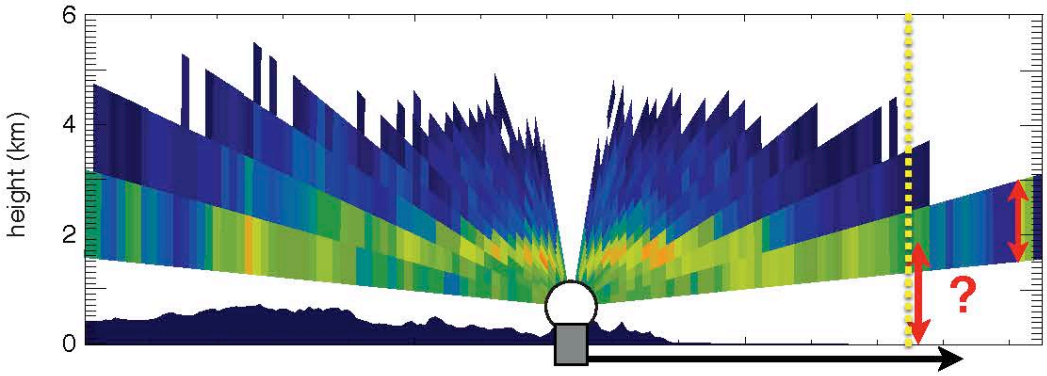
- Sampling height increases with distance
- With range, the sampling volume becomes larger



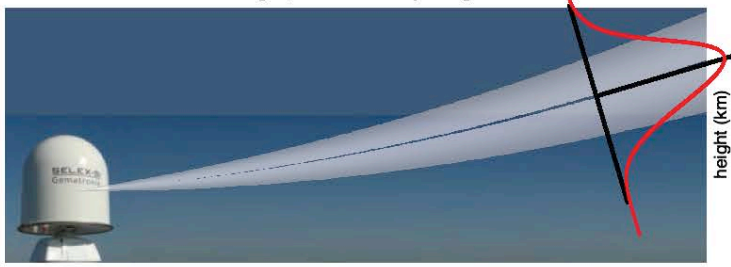


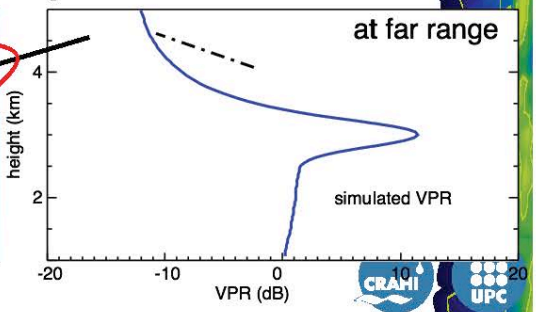
Errors with range

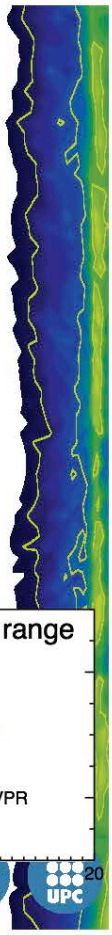
Representativeness of radar observations



- Sampling height increases with distance
- With range, the sampling volume becomes larger

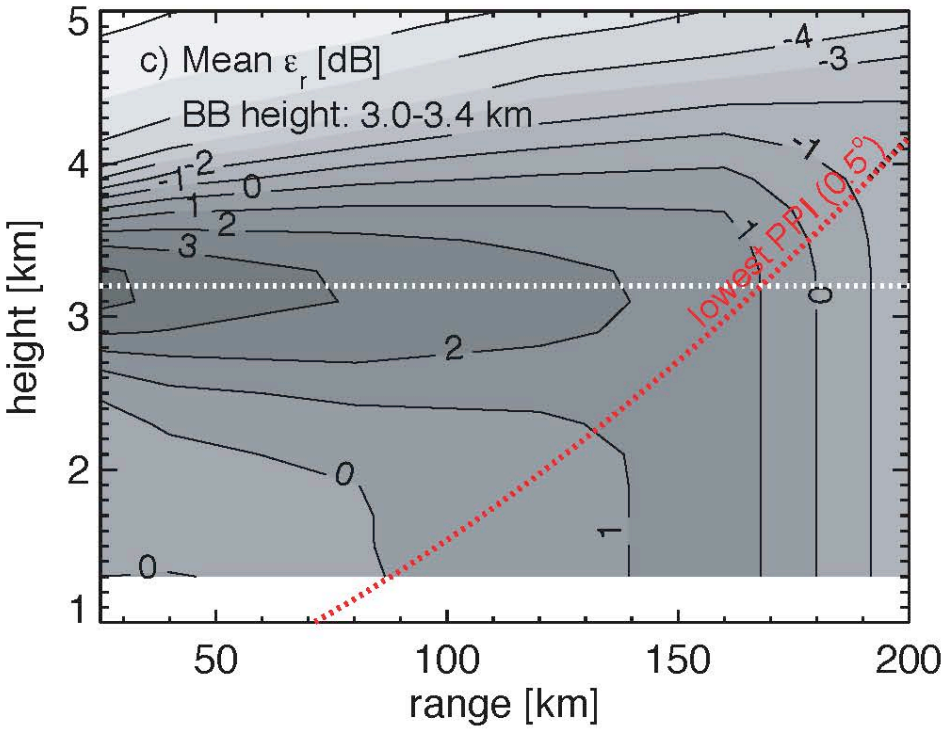


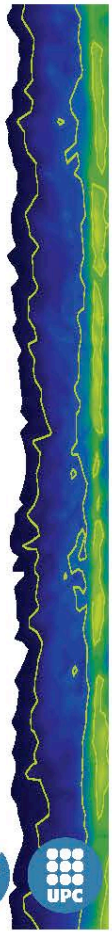




Errors with range

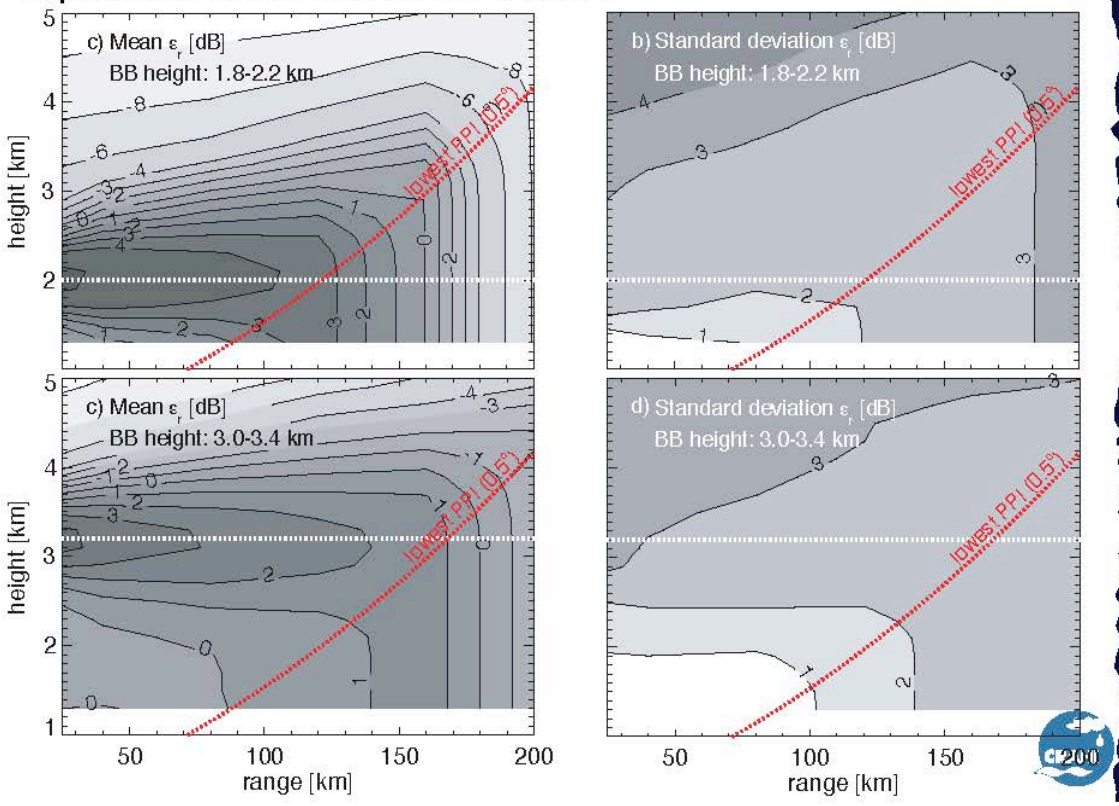
Representativeness of radar observations



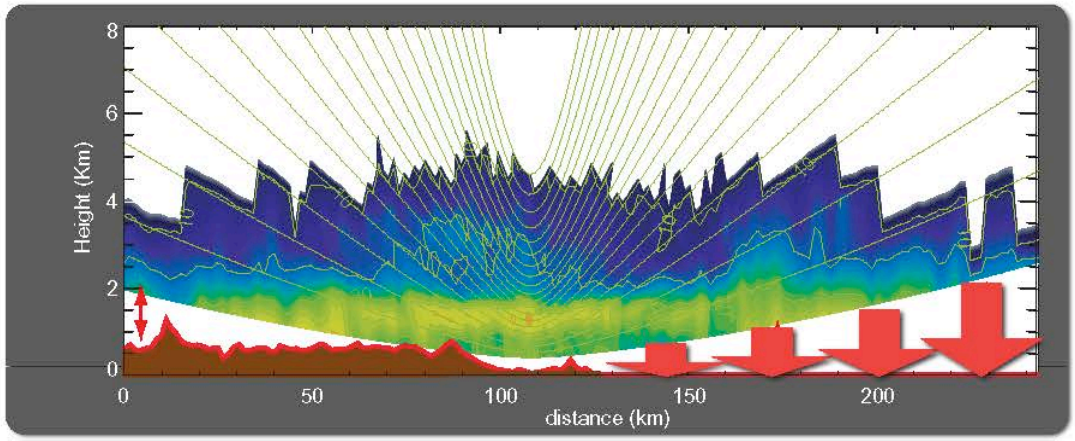


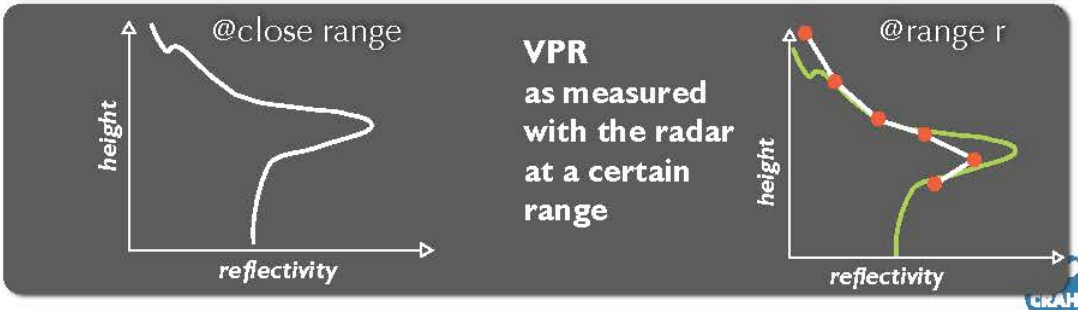
Errors with range

Representativeness of radar observations



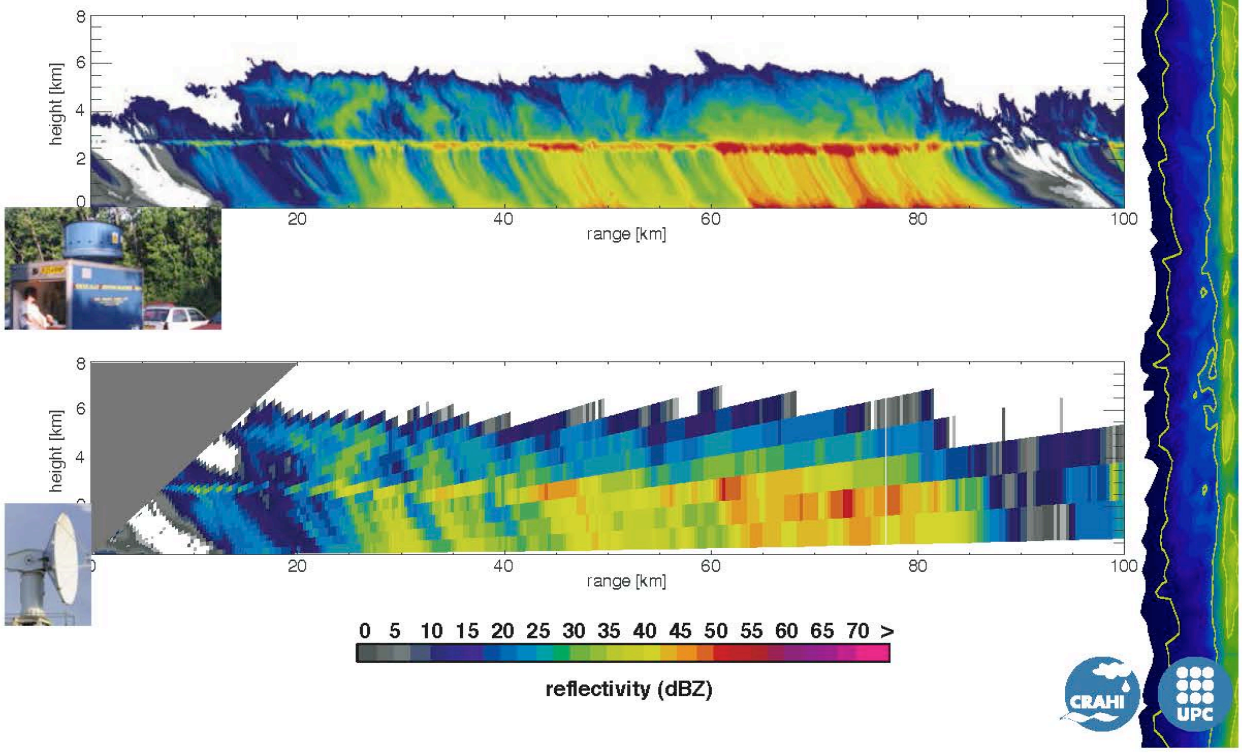
Vertical Profile of Reflectivity





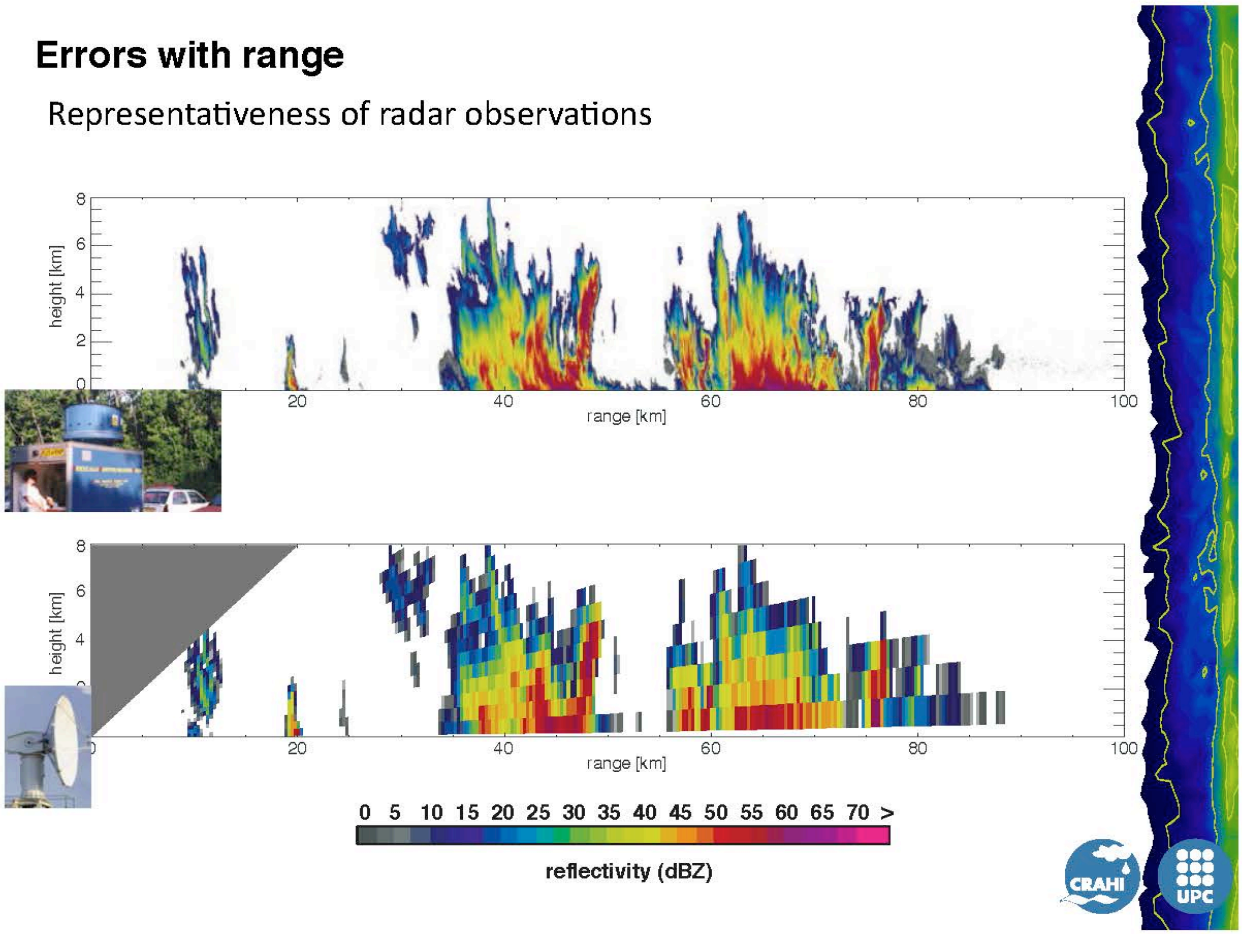
Errors with range

Representativeness of radar observations

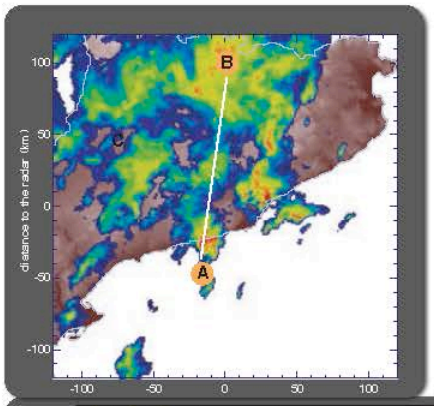


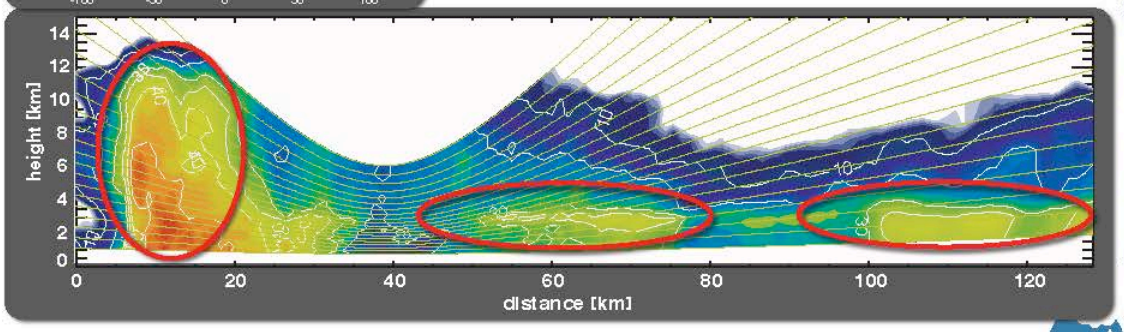
Errors with range

Representativeness of radar observations



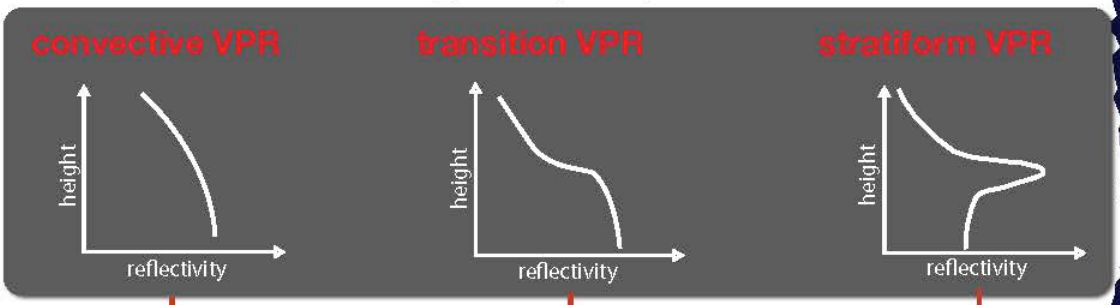
Vertical Profile of Reflectivity

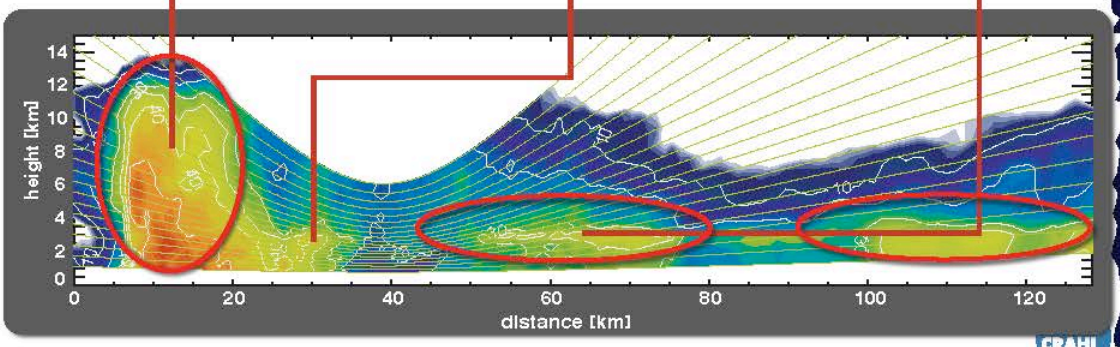




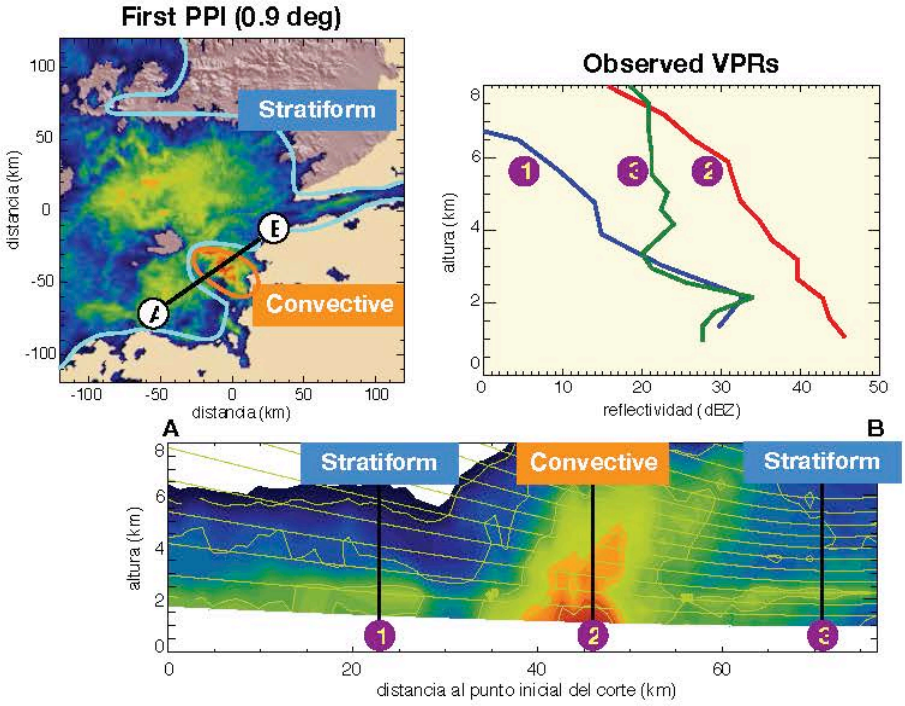
Vertical Profile of Reflectivity

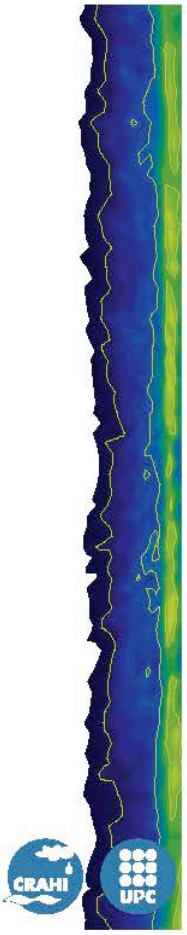
Different types of precipitation





Space time variability of the VPR







VPR correction

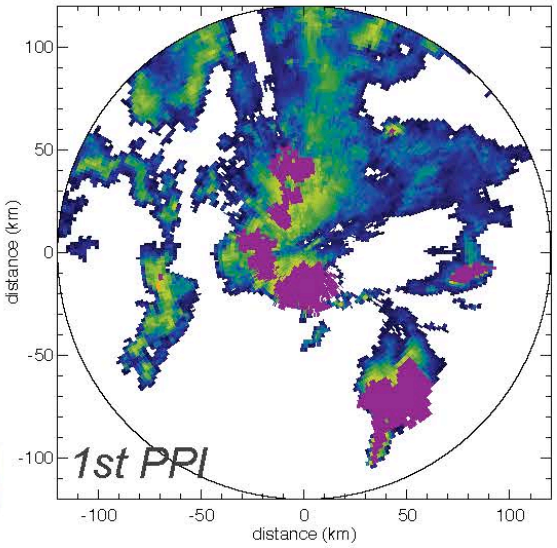
STEP 1: Classification

STEP 2: Identification of a representative VPR

STEP 3: Extrapolation of the observations to the surface

The classification algorithm - **Ingredients**

1) Identification of convective areas [Steiner et al., 1995].



Detecting on 1st PPI :

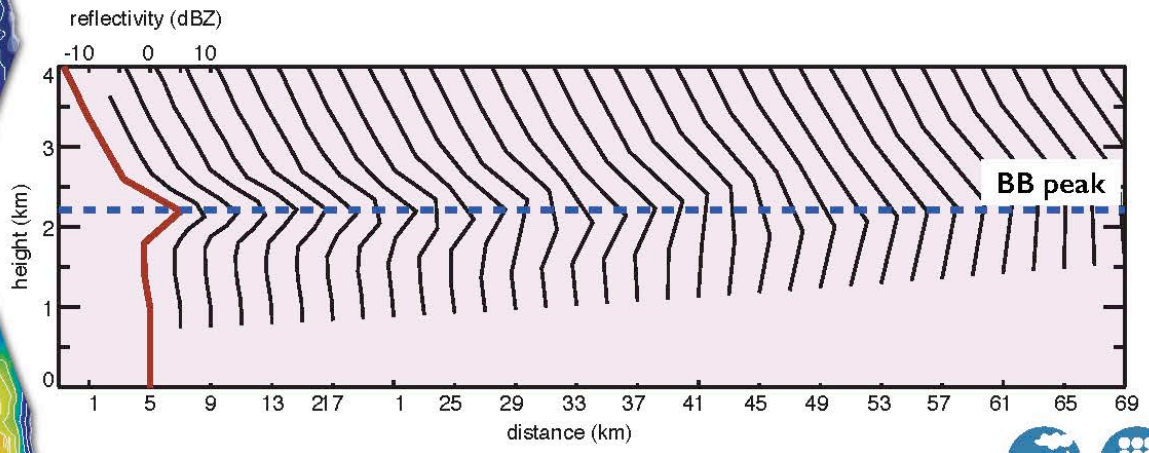
$Z \uparrow$

$grad_H Z \uparrow$

The classification algorithm - **Ingredients**

1) Identification of convective areas [Steiner et al., 1995].

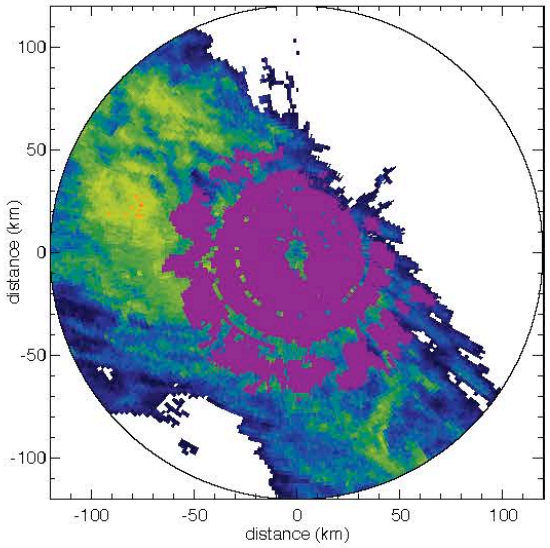
2) Height of the bright band peak, and identification of the BB areas [Sánchez-Diezma et al. 2000].



The classification algorithm - **Ingredients**

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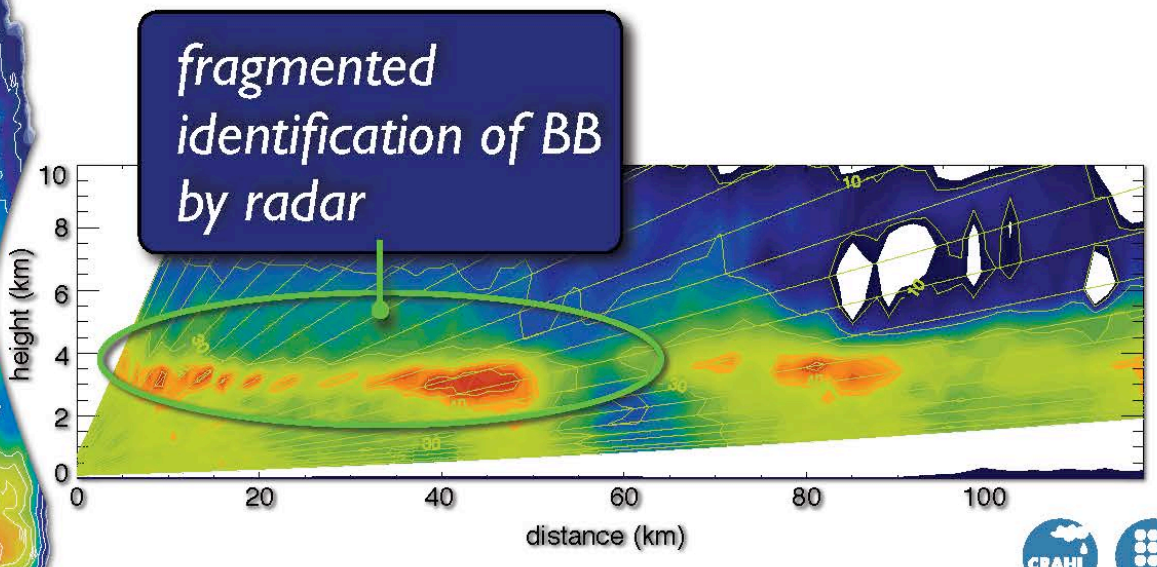
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The classification algorithm - **Ingredients**

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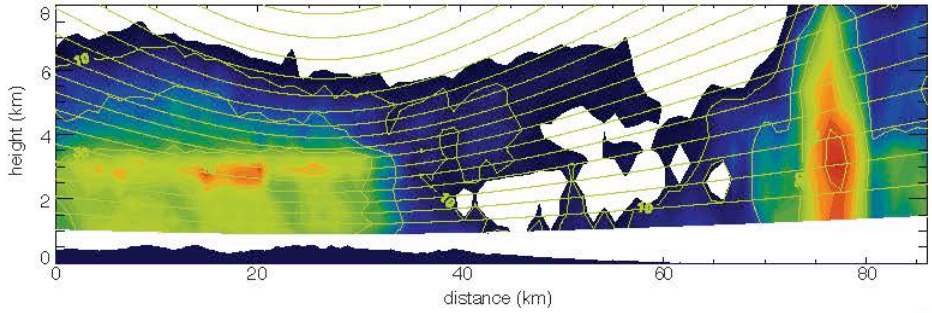
The classification algorithm - **Ingredients**

1) Identification of convective areas [Steiner et al., 1995].

2) Height of the bright band peak, and identification of the BB areas [Sánchez-Diezma et al. 2000].

3) Height of the BB top (as a function of range).

4) 30-dB echotop.





The classification algorithm - **Ingredients**

1) Identification of convective areas [Steiner et al., 1995].

2) Height of the bright band peak, and identification of the BB areas [Sánchez-Diezma et al. 2000].

3) Height of the BB top (as a function of range).

4) 30-dB echotop.

5) DVIZ [$mm^6 \cdot m^{-3} \cdot km^{-1}$] above the BB top.

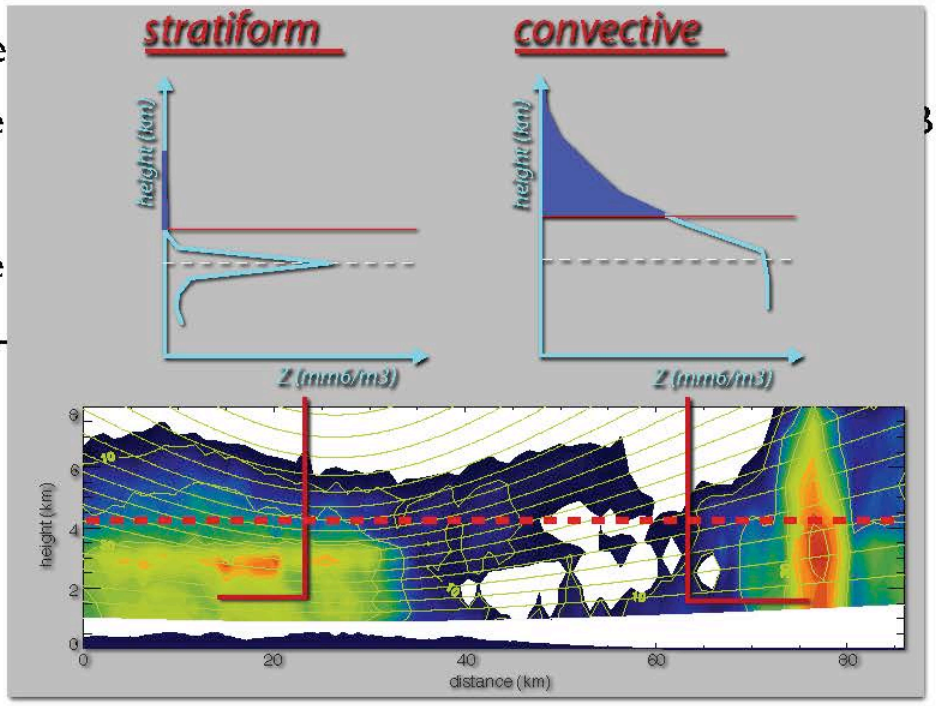
The classification algorithm - **Ingredients**

1) Ide

2) He BB areas

3) He

4) 30-



5) DVIZ [$mm^6 \cdot m^{-3} \cdot km^{-1}$] above the BB top.

The classification algorithm - **Ingredients**

Class:

0) it does not rain.

1) unknown.

2) Light rain (5 dBZ < dBZ < 15 dBZ).

3) Shallow convection: DVIZ < th3.

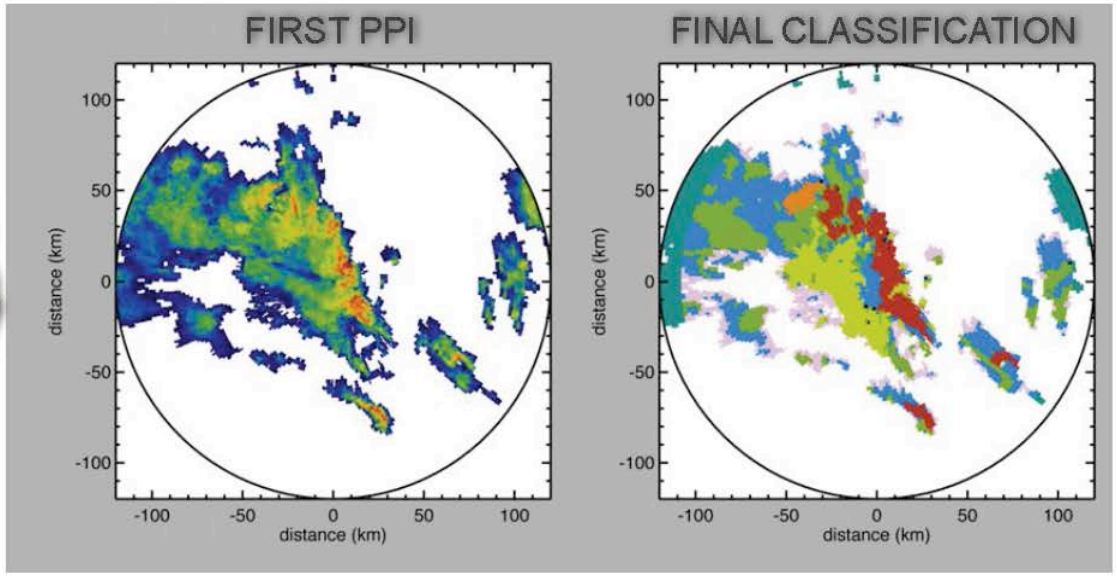
4) Deep convection: DVIZ > th3.

5) Stratiform, with BB peak not found near the radar.

6) Stratiform, with BB peak found near the radar.

7) Stratiform with BB peak NOT found far from the radar.

Example



LIGHT RAIN | BB PEAK | BB GRAD$_V$ | TRANS. | SH CONV. | DEEP CONV. | STRAT. FAR

VPR correction

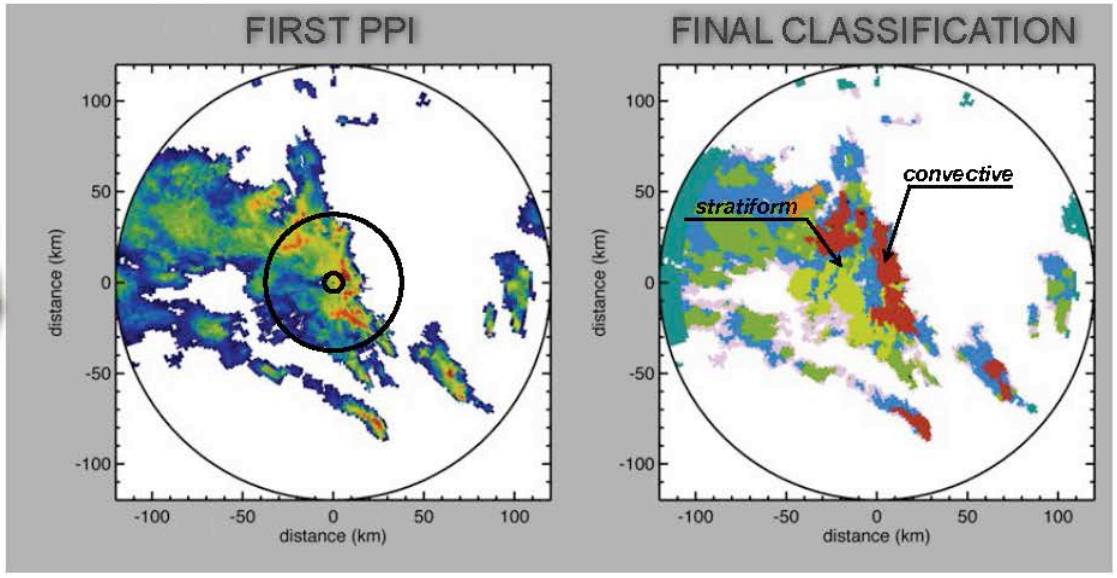
STEP 1: Classification

STEP 2: Identification of a representative VPR

STEP 3: Extrapolation of the observations to the surface

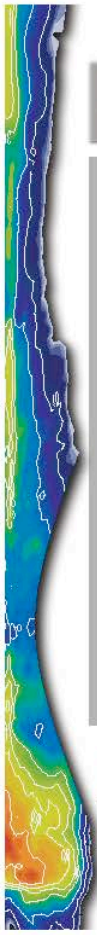


Example

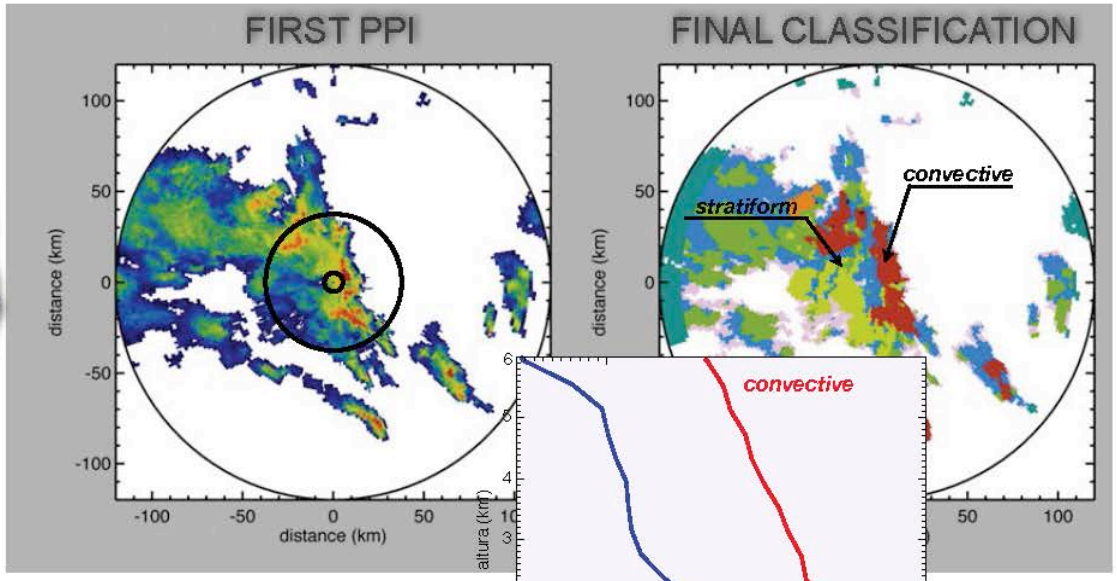


LIGHT RAIN | BB PEAK | BB GRAD$_V$ | TRANS. | SH CONV. | DEEP CONV.

STRAT. FAR



Example



LIGHT RAIN | BB PEAK | BB GR | DEEP CONV.

STRAT. FAR

* PVRs observaded near the radar



VPR correction

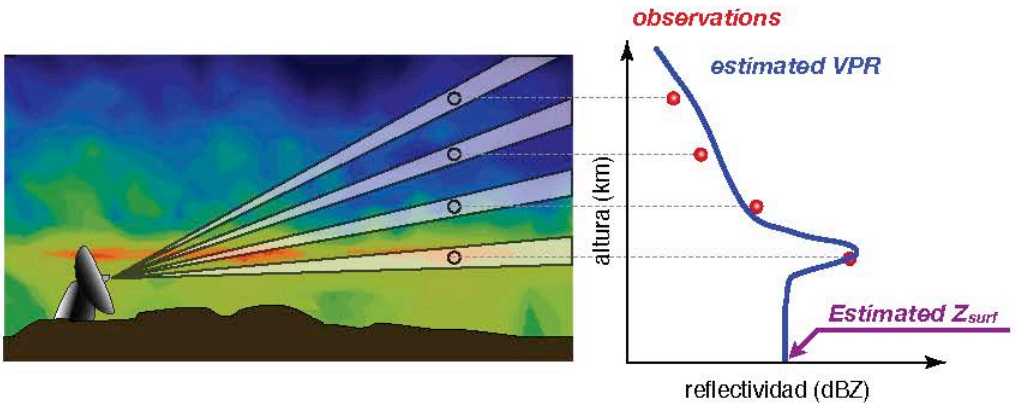
STEP 1: Classification

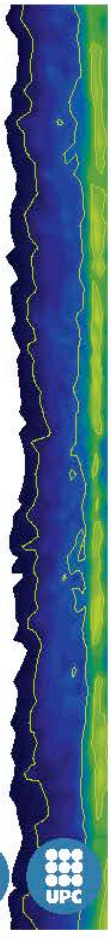
STEP 2: Identification of a representative VPR

STEP 3: Extrapolation of the observations to the surface

Extrapolation to the ground with a representative VPR

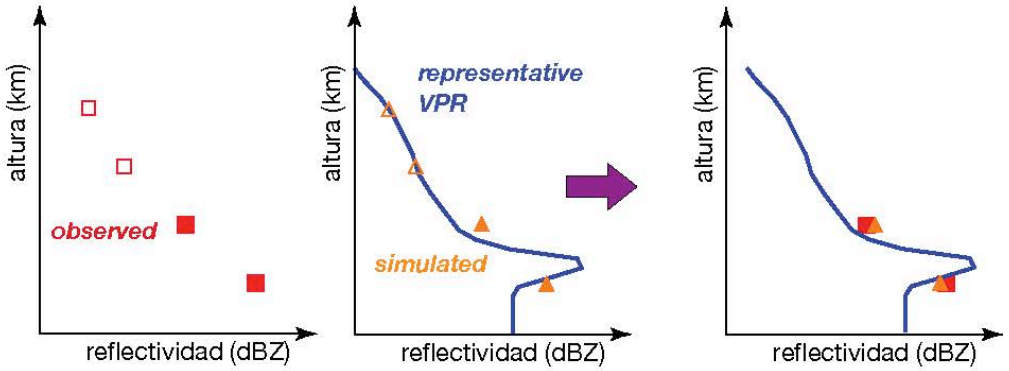
Fit the representative VPR to the radar observations





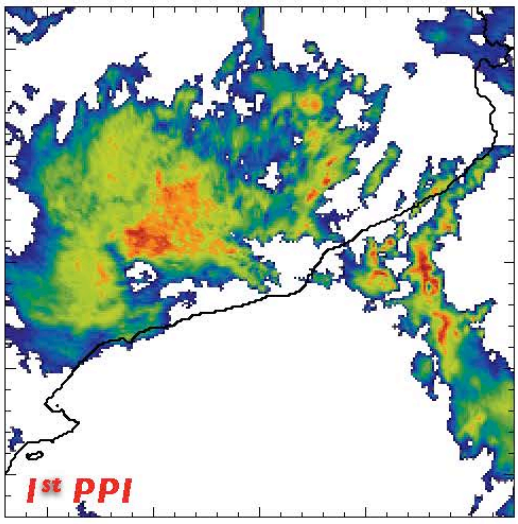
Extrapolation to the ground with a representative VPR

The best alternative: use only the observations below and right above the melting layer **(but not those in the BB).**

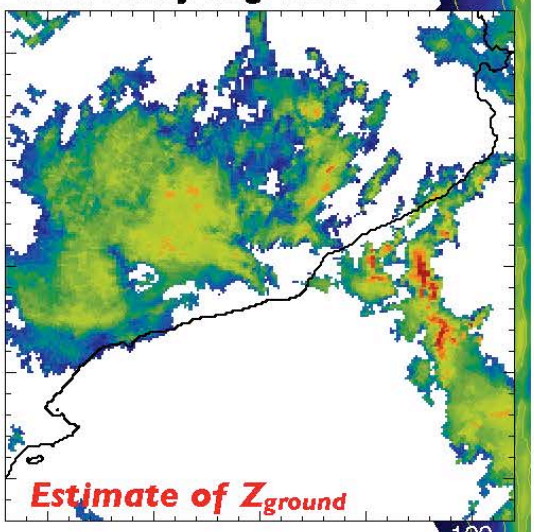


VPR correction

By extrapolating the observations at each grid point to the surface with the representative VPR,

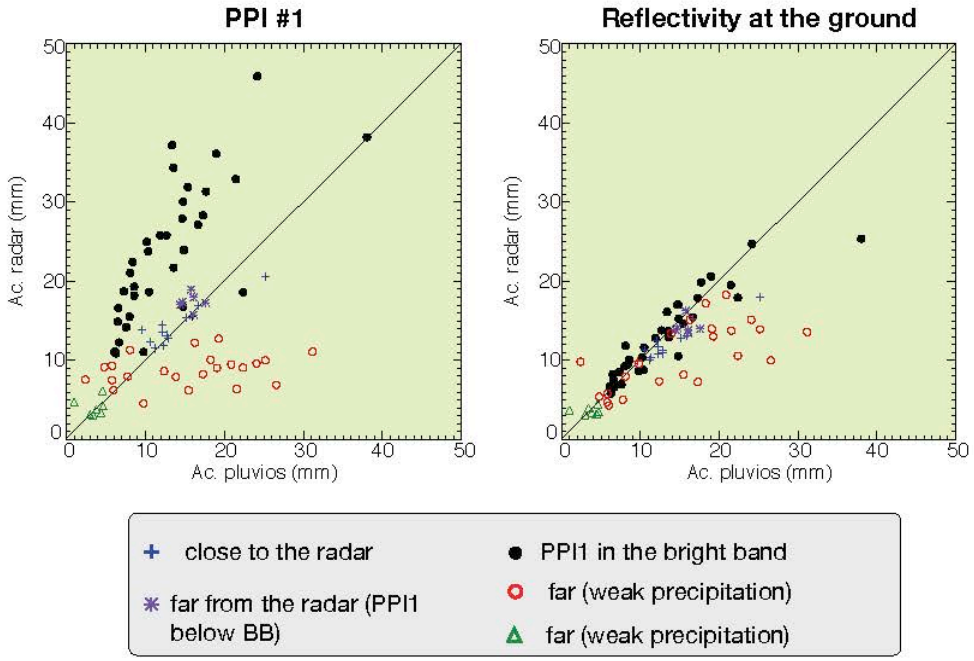


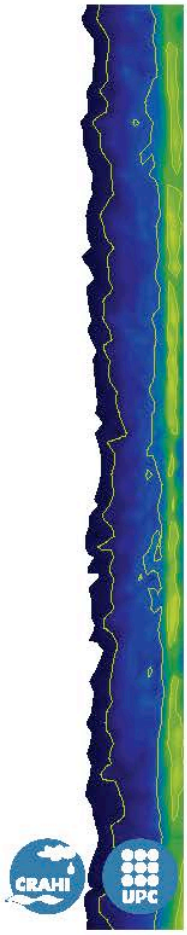
Reflectivity at ground



Extrapolation to the ground with a representative VPR

Comparison with rain gauge observations





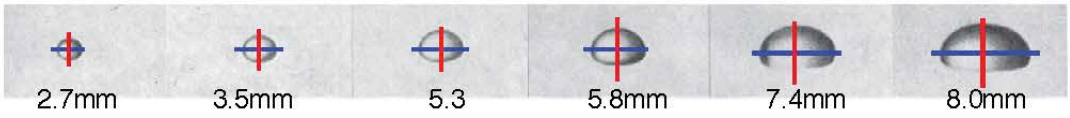
TRAINING PROGRAM ON METEOROLOGICAL AND ADVANCED QUANTITATIVE APPLICATIONS

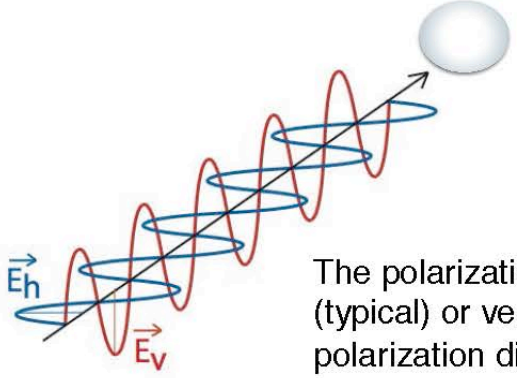
Dual-polarization radars:
The added value of polarimetric variables

Centre de Recerca Aplicada en Hidrometeorologia
UNIVERSITAT POLITÈCNICA DE CATALUNYA

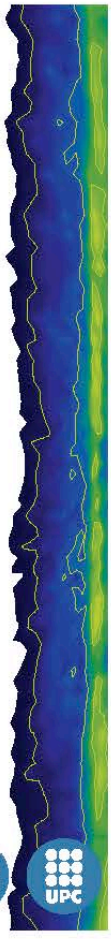


The concept of dual-polarization





The polarization of the waves can be horizontal (typical) or vertical (rare) or both (as in polarization diversity)



Dual-polarization - Observed variables

Z_e • Equivalent reflectivity (horizontal and vertical).

$$Z_{DR} = 10\log\left(\frac{Z_H}{Z_V}\right)$$

• It is zero for spherical particles; positive (negative) for oblate (prolate) particles. Measures the average deformation of targets.

$$\phi_{DP} = \phi_V - \phi_H$$

• Phase difference between E_H and E_V produced by the anisotropy of the optical density of the propagation medium. It is zero for spherical particles; positive for oblate, and negative for prolate, particles. Measures mass*deformation It is independent of radar calibration.

$$\rho_{HV} = \overline{\left(Z_H - \overline{Z_H}\right) * \left(Z_V - \overline{Z_V}\right)}$$

• The overbar indicates the average over several consecutive pulses.

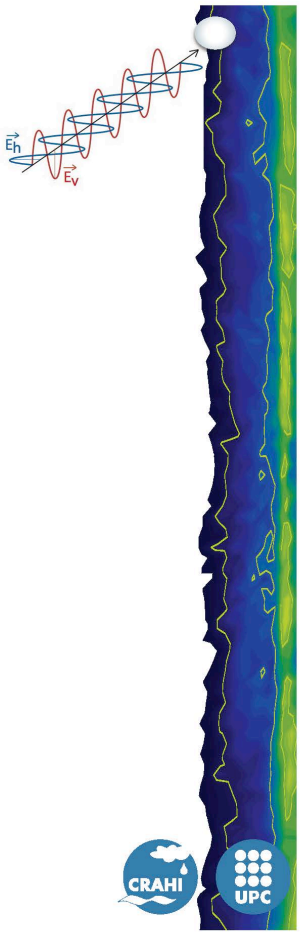
If the shapes, orientations and distributions of targets do not change in time ρ_{HV}=1; if there is a complete reshufflings at every pulse ρ_{HV}=0. Measures the time change in the variety of particles, their shapes and their orientations

Dual-polarization - APPLICATIONS

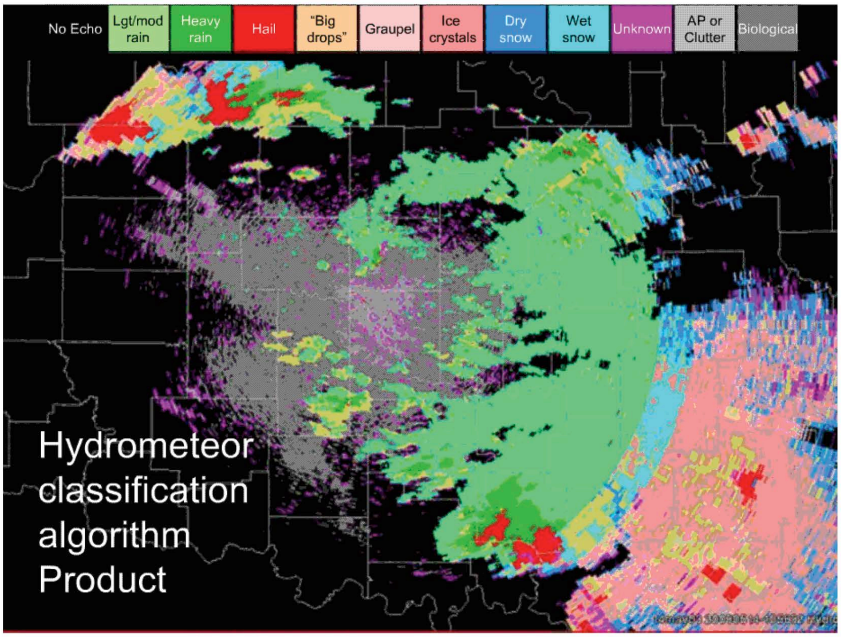
1 - Hydrometeor classification

2 - Rainfall estimation

3 - Radar calibration

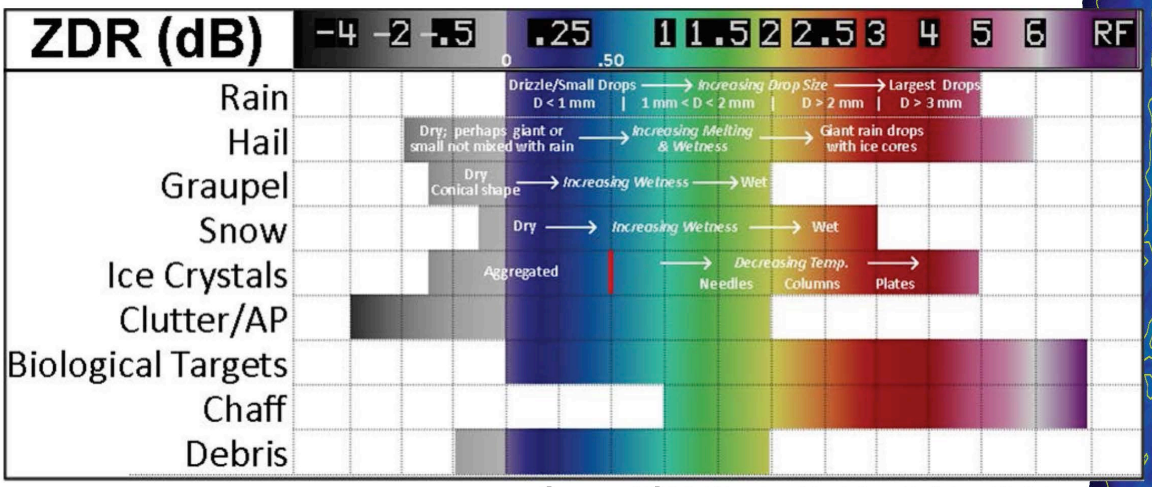


1 - Hydrometeor classification



Source: N. Marsili

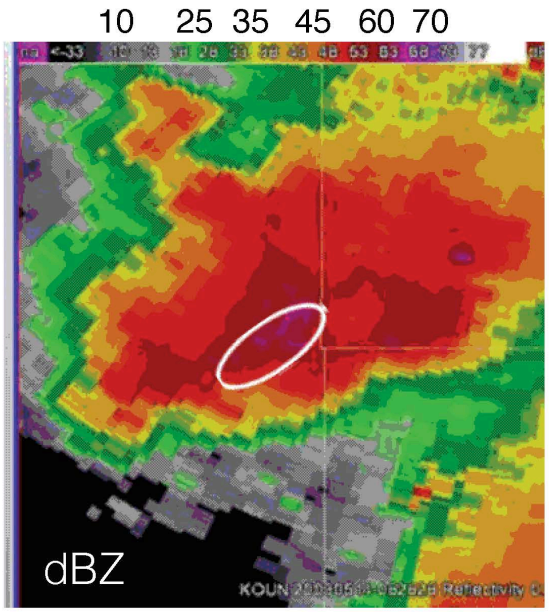
Dual-polarization variables

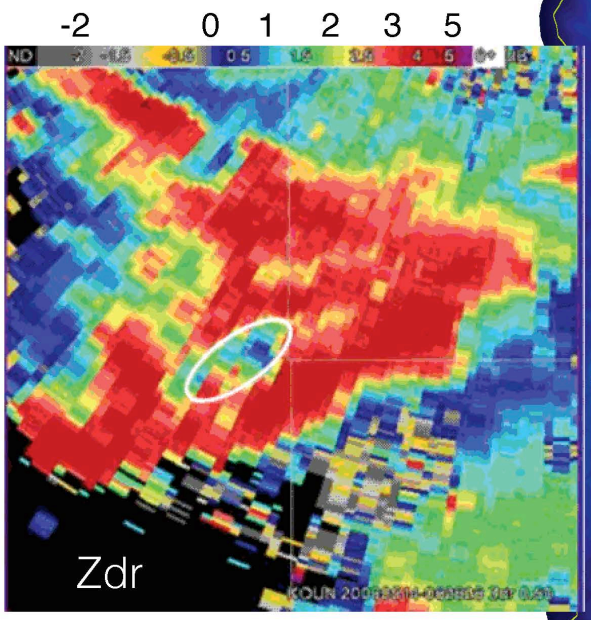


Source: NOAA Warning Decision Training Division

1 - Hydrometeor classification

Zdr in convective situations

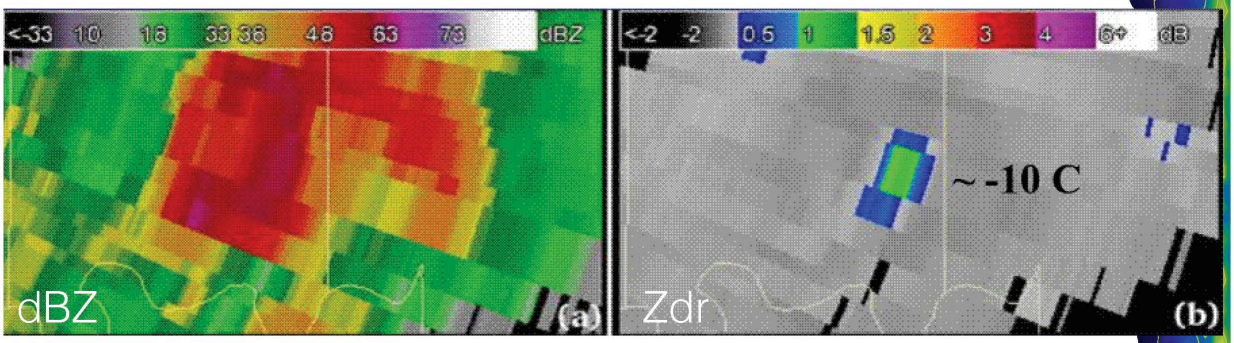




Source: N. Marsili

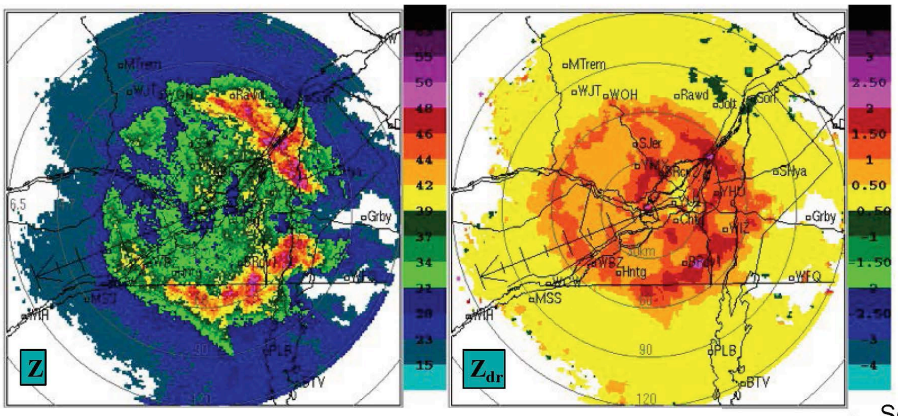
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Zdr in convective situations

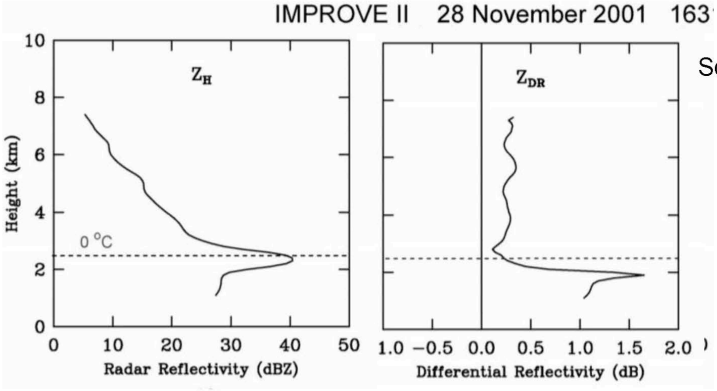


Source: N. Marsili

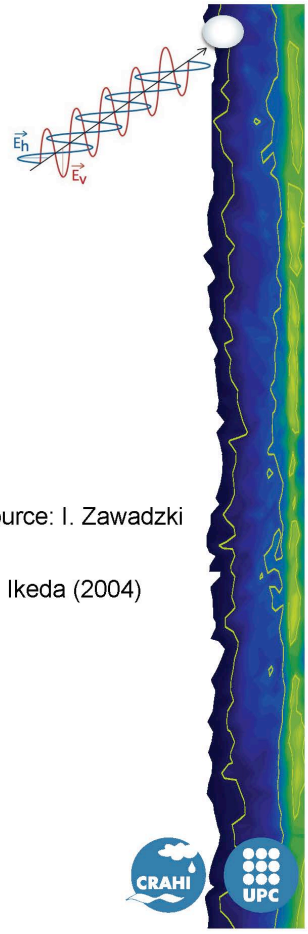
1 - Hydrometeor classification



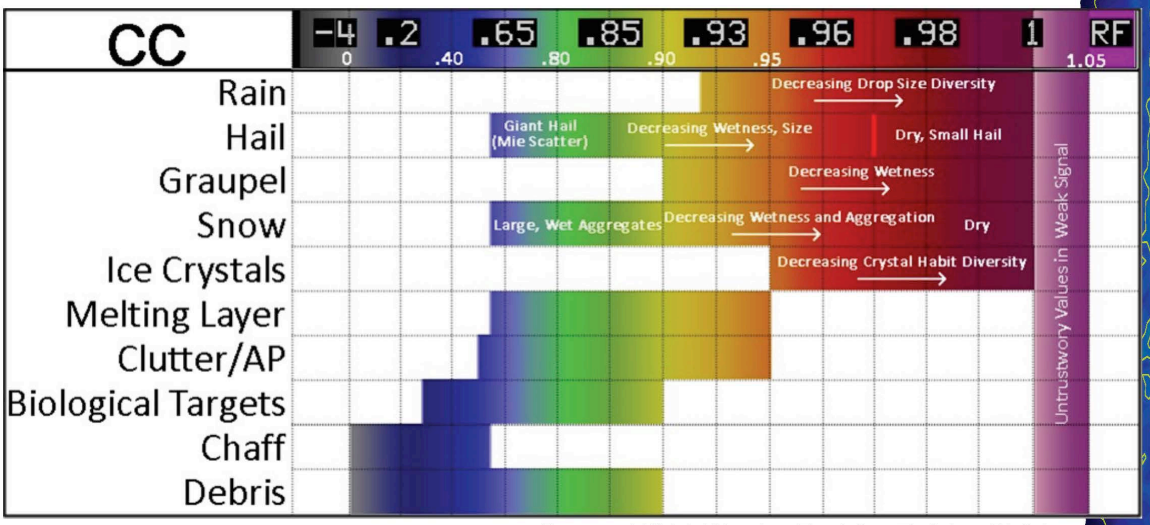
Source: I. Zawadzki



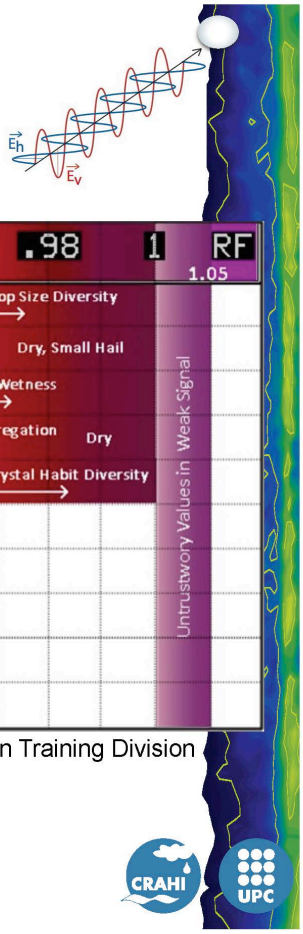
Source: Brandes & Ikeda (2004)



Dual-polarization variables

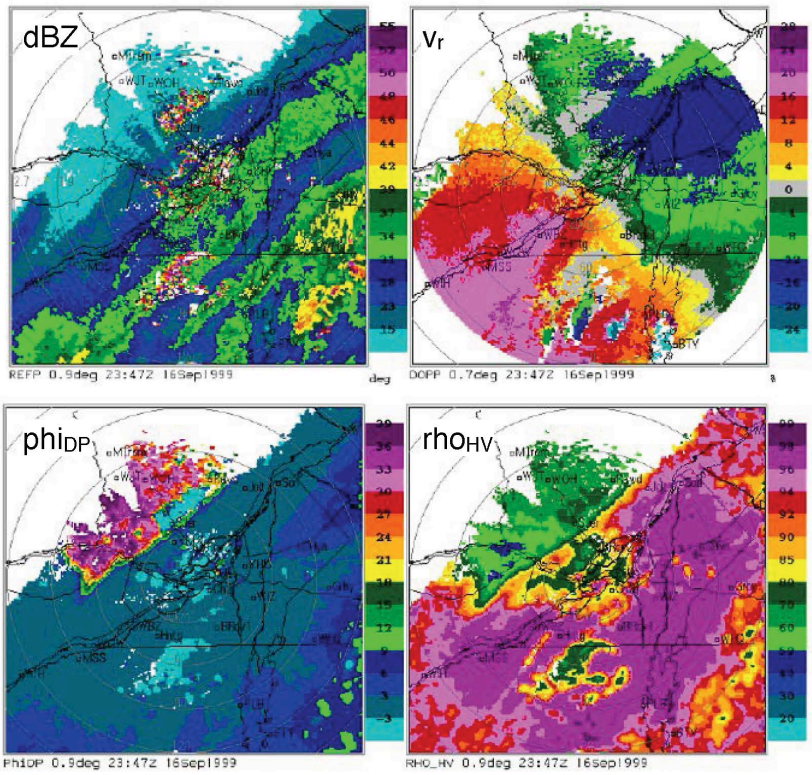


Source: NOAA Warning Decision Training Division

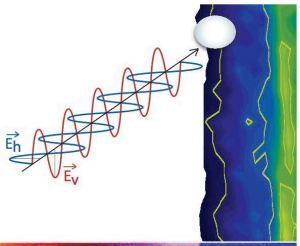


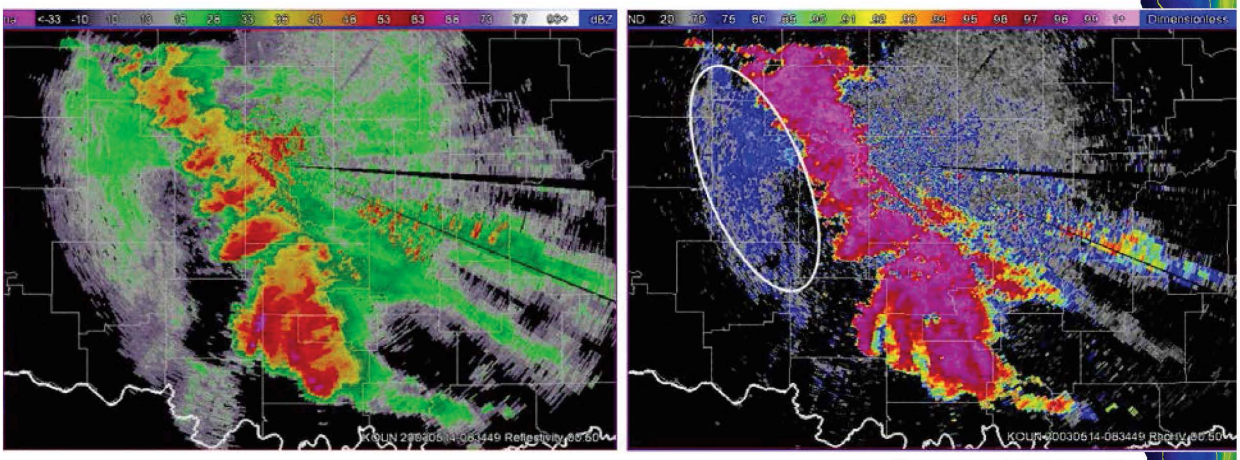
Dual-polarization variables

Source: I. Zawadzki



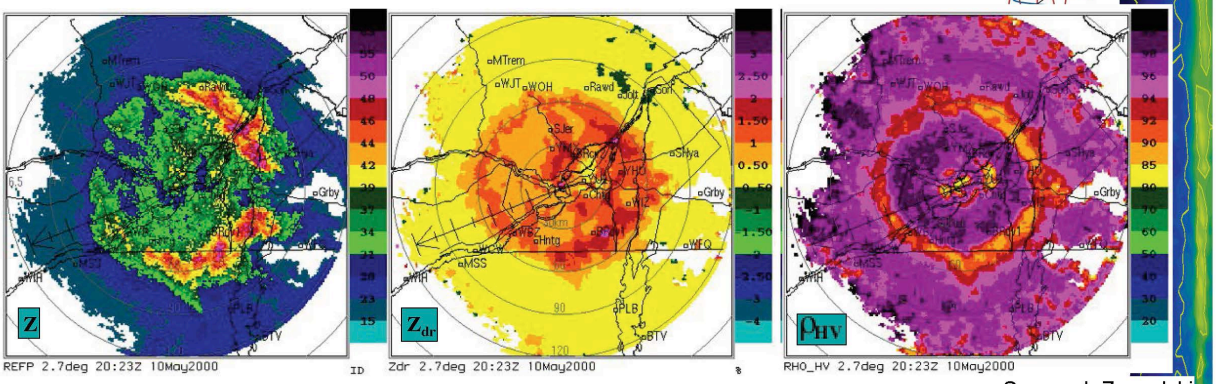
1 - Hydrometeor classification



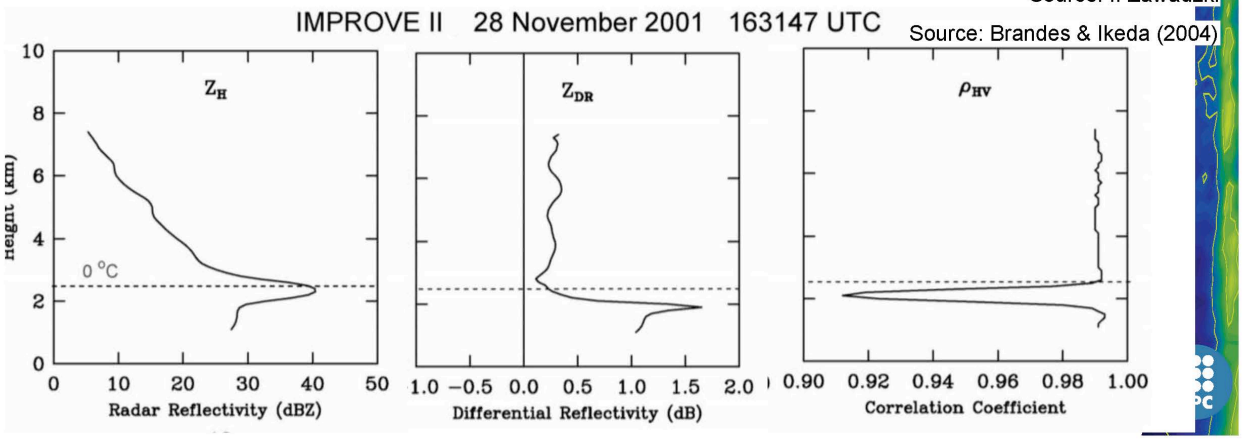


Source: N. Marsili

1 - Hydrometeor classification

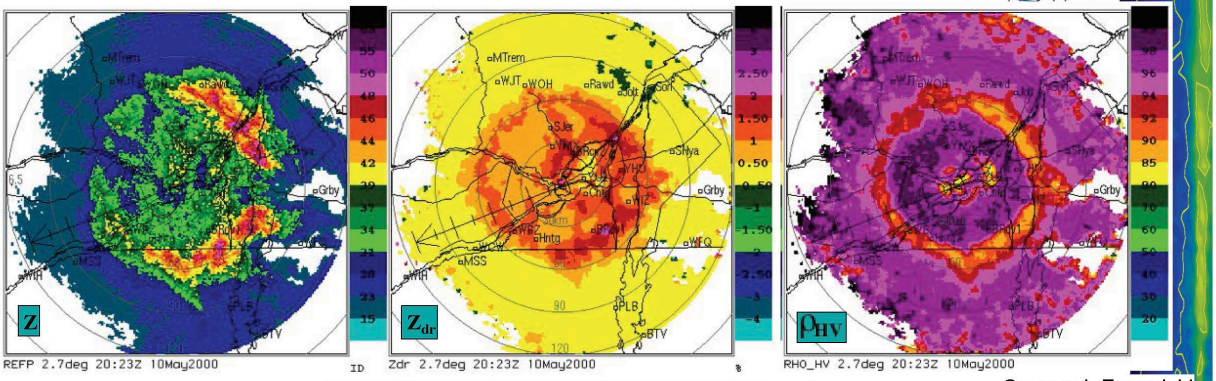


Source: I. Zawadzki

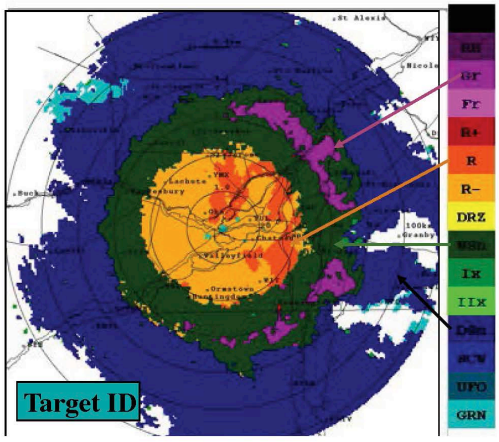


Source: Brandes & Ikeda (2004)

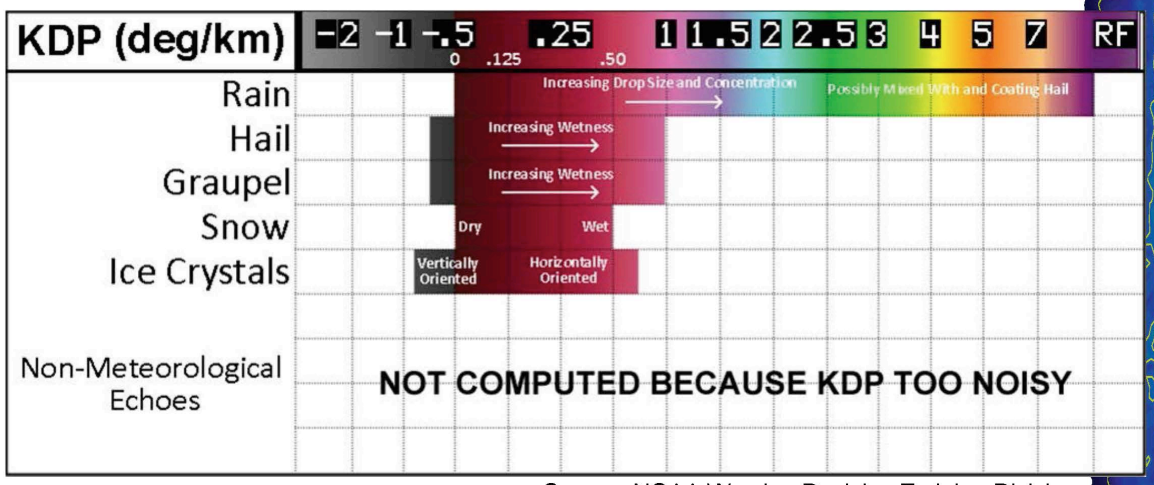
1 - Hydrometeor classification



Source: I. Zawadzki



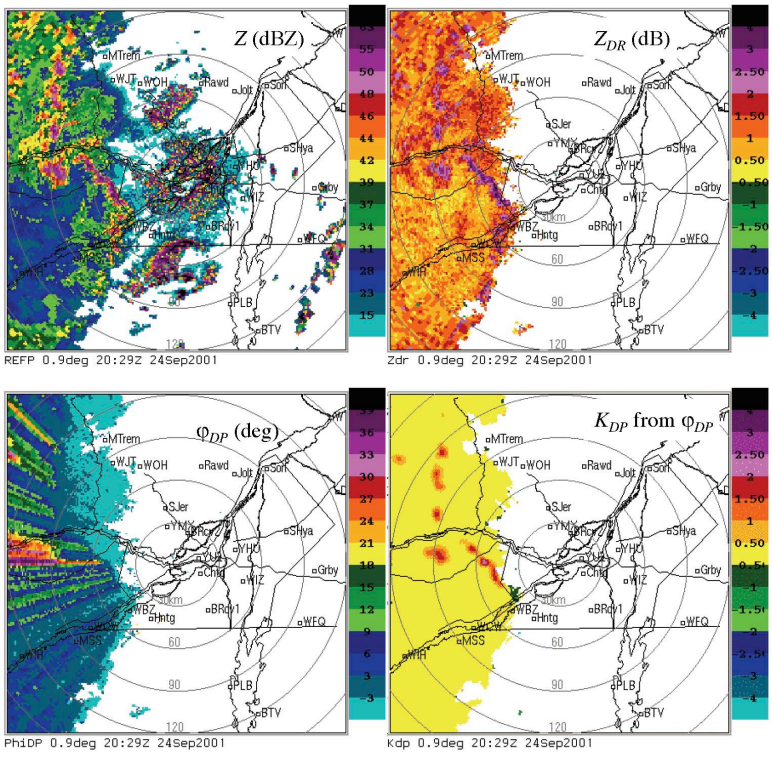
Dual-polarization variables



Source: NOAA Warning Decision Training Division

Dual-polarization variables

Source: I. Zawadzki



Rainfall estimation (Z-R and type of rainfall)

For single-polarization radars,

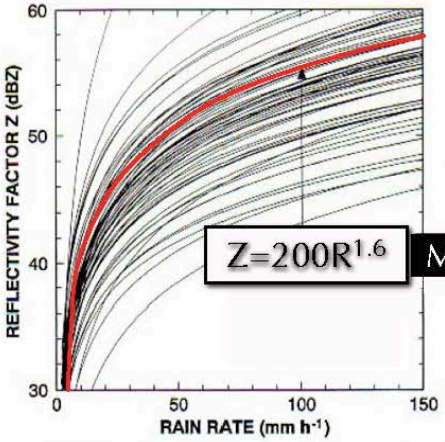
Reflectivity: $Z = \int_0^\infty D^6 N(D) dD$

Rain rate: $R = \frac{\pi}{6} \int_0^\infty v(D) N(D) D^3 dD$

$Z = aR^b$

↓

Related to the Drop Size Distribution



$Z=200R^{1.6}$ Marshall & Palmer (1948)

Fig. 8.6 Sixty-nine R, Z relationships from Battan (1973).

Rainfall estimation (Z-R and type of rainfall)

For single-polarization radars,

Reflectivity: $Z = \int_0^\infty D^6 N(D) dD$

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↓

Related to the Drop Size Distribution

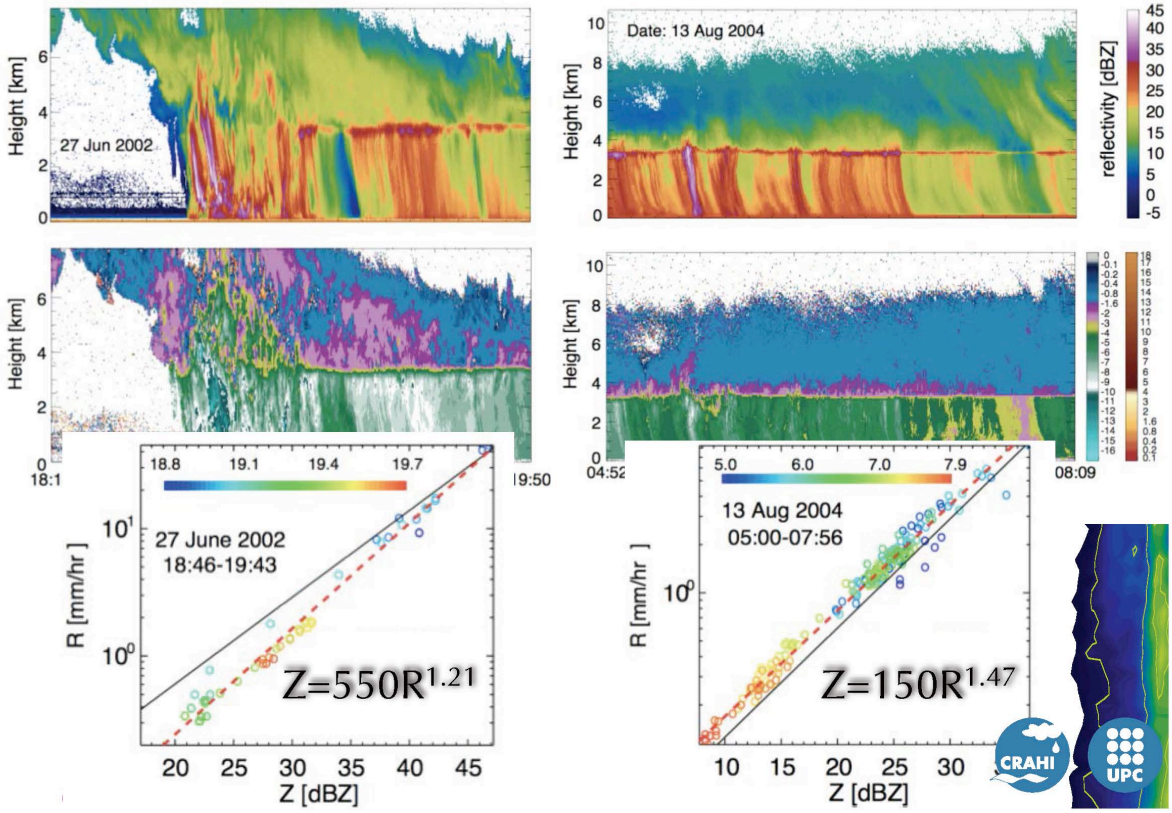
DSD depends upon the **predominant microphysical mechanism** controlling drop growth

Z-R conversion depends on the **type of rainfall**

Radar processing algorithms should be different **depending on the type of rainfall**

Case-to-case Z-R variability

Courtesy of Isztar Zawadzki



2 - Rainfall estimation

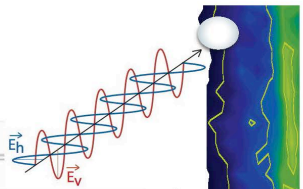


TABLE 1. List of different polarimetric algorithms used for rainfall estimation.

$R(K_{DP}) = a|K_{DP}|^b \text{ sign}(K_{DP})$

	a	b	Assumptions	Source
1	50.7	0.85	Simulated DSD, equilibrium shape	BC01
2	54.3	0.806	Measured DSD (FL), Brandes' shape	BZV02
3	51.6	0.71	Simulated DSD, Goddard's shape	IB02
4	44.0	0.822	Measured DSD (OK), equilibrium shape	NSSL
5	50.3	0.812	Measured DSD (OK), Bringi's shape	NSSL
6	47.3	0.791	Measured DSD (OK), Brandes' shape	NSSL

$R(Z, Z_{DR}) = a\, Z^b Z_{dr}^c$

	a	b	c	Assumptions	Source
7	6.70×10^{-3}	0.927	−3.43	Simulated DSD, equilibrium shape	BC01
8	7.46×10^{-3}	0.945	−4.76	Measured DSD (FL), Brandes' shape	BZV02
9	7.11×10^{-3}	1.0	*	Simulated DSD, Goddard's shape	IB02
10	1.42×10^{-2}	0.770	−1.67	Measured DSD (OK), equilibrium shape	NSSL
11	1.59×10^{-2}	0.737	−1.03	Measured DSD (OK), Bringi's shape	NSSL
12	1.44×10^{-2}	0.761	−1.51	Measured DSD (OK), Brandes' shape	NSSL

$R(K_{DP}, Z_{DR}) = a|K_{DP}|^b Z_{dr}^c \text{ sign}(K_{DP})$

	a	b	c	Assumptions	Source
13	90.8	0.93	−1.69	Simulated DSD, equilibrium shape	BC01
14	136	0.968	−2.86	Measured DSD (FL), Brandes' shape	BZV02
15	52.9	0.852	−0.53	Measured DSD (OK), equilibrium shape	NSSL
16	63.3	0.851	−0.72	Measured DSD (OK), Bringi's shape	NSSL

Ryzhkov et al. (2005)

2 - Rainfall estimation

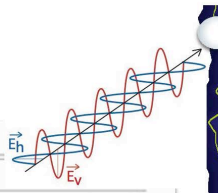


TABLE 1. List of different polarimetric algorithms used for rainfall estimation.

$R(K_{DP}) = a|K_{DP}|^b \text{ sign}(K_{DP})$

	a	b	Assumptions	Source
1	50.7	0.85	Simulated DSD, equilibrium shape	BC01
2	54.3	0.806	Measured DSD (FL), Brandes' shape	BZV02
3	51.6	0.71	Simulated DSD, Goddard's shape	IB02
4	44.0	0.822	Measured DSD (OK), equilibrium shape	NSSL
5	50.3	0.812	Measured DSD (OK), Bringi's shape	NSSL
6	47.3	0.791	Measured DSD (OK), Brandes' shape	NSSL

$R(Z, Z_{DR}) = a\, Z^b Z_{dr}^c$

	a	b	c	Assumptions	Source
7	6.70×10^{-3}	0.927	−3.43	Simulated DSD, equilibrium shape	BC01
8	7.46×10^{-3}	0.945	−4.76	Measured DSD (FL), Brandes' shape	BZV02
9	7.11×10^{-3}	1.0	*	Simulated DSD, Goddard's shape	IB02
10	1.42×10^{-2}	0.770			
11	1.59×10^{-2}	0.737			
12	1.44×10^{-2}	0.761			

very sensitive to small errors in Z_{DR}

$R(K_{DP}, Z_{DR}) = a|K_{DP}|^b Z_{dr}^c \text{ sign}(K_{DP})$

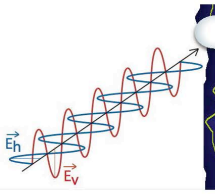
	a	b	c	Assumptions	Source
13	90.8	0.93	−1.69	Simulated DSD, equilibrium shape	BC01
14	136	0.968			
15	52.9	0.852			
16	63.3	0.851			

very sensitive to small errors in Z_{DR}

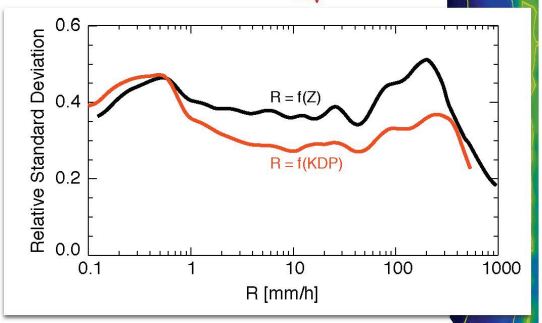
In the end, in many cases, a combination of R(Z) and R(K_{dp})

Ryzhkov et al. (2005)

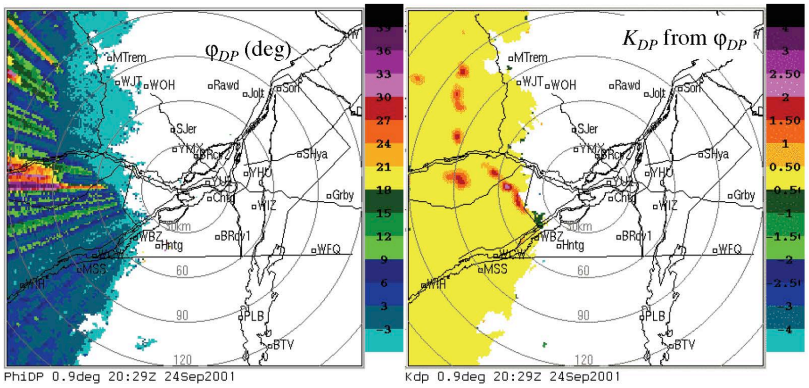
2 - Rainfall estimation R(K_{DP})



- It has a better relationship with rain rate: the relative error of the conversion of K_{DP} into R is smaller than that of the Z-R relationship
- It is not affected by attenuation.
- It is not affected by partial beam blocking.
- The disadvantages is that it is difficult to measure values below 1°/km

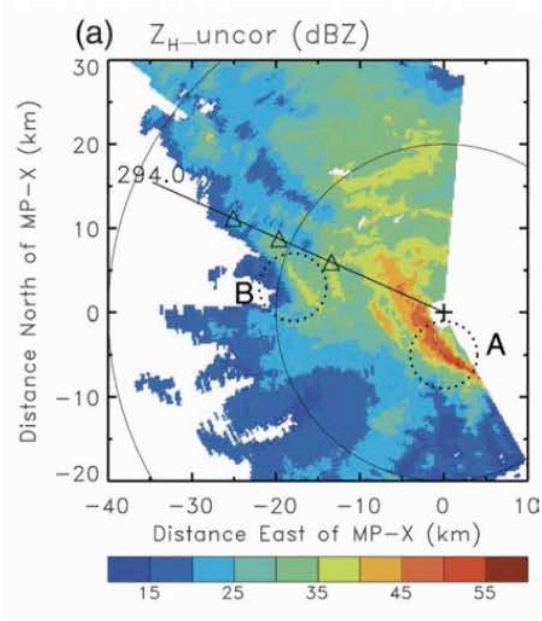


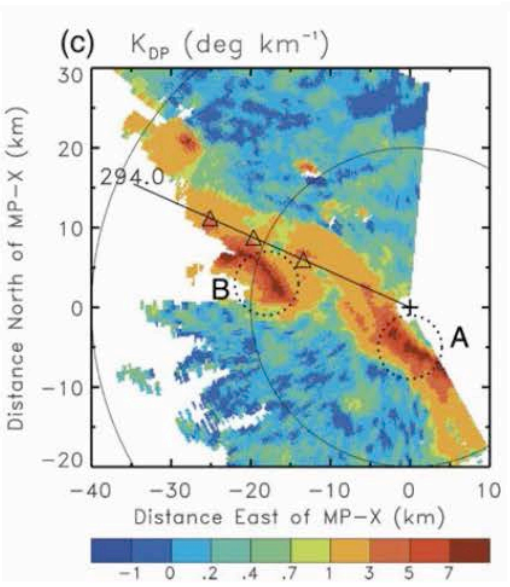
Source: I. Zawadzki



Signal attenuation by rain - dual-polarization correction

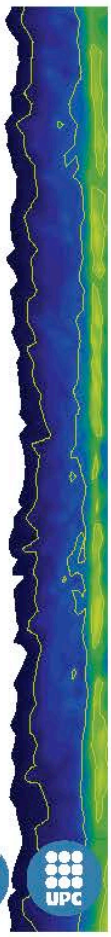
The correction uses dual-pol variables to correct for attenuation.





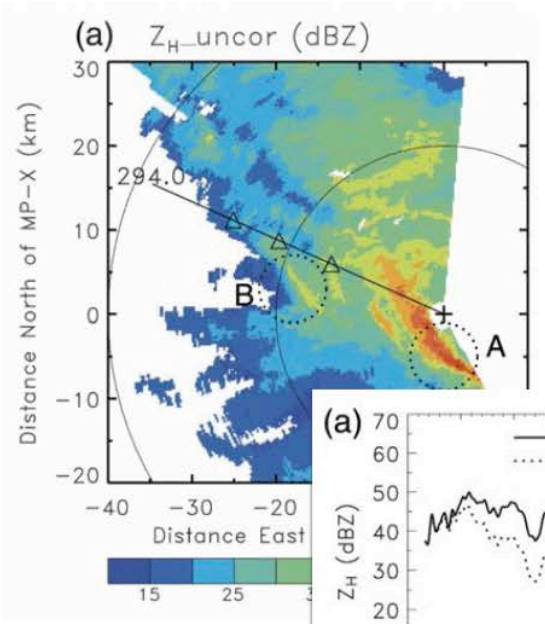
$$k(r) = \gamma K_{DP}^{\delta} \qquad (\delta \approx 1)$$

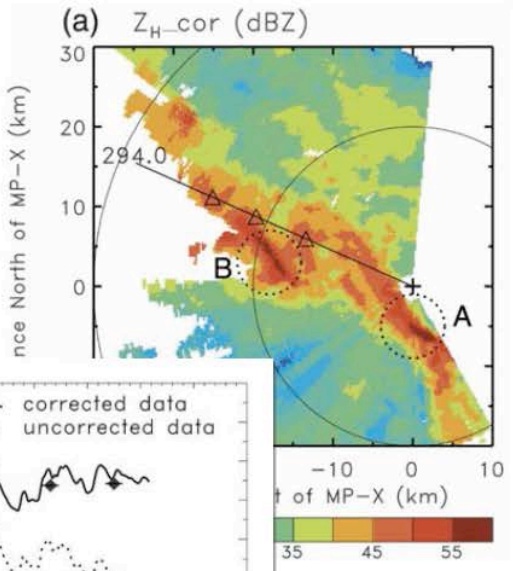
Source: Park et al. (2005)

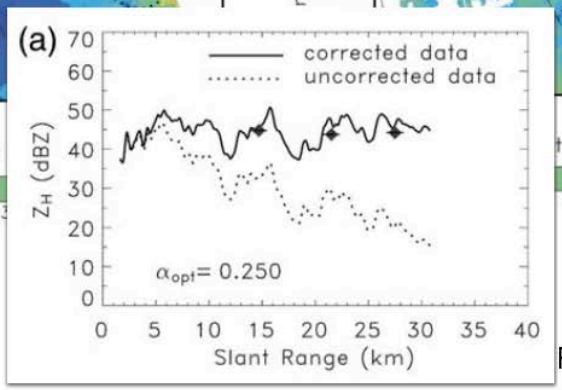


Signal attenuation by rain - dual-polarization correction

The correction uses dual-pol variables to correct for attenuation.

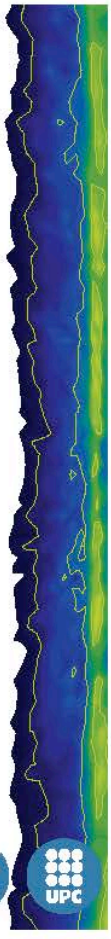




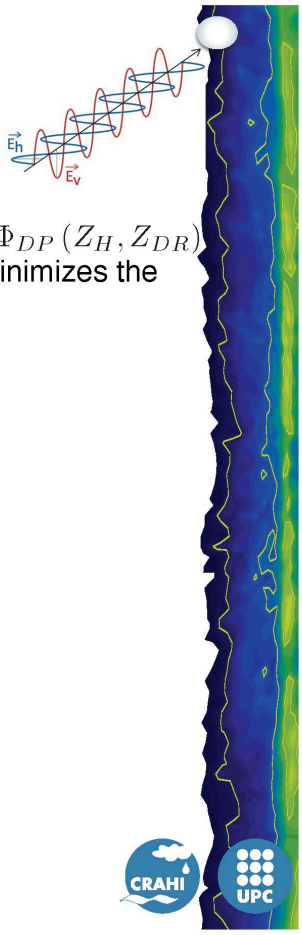


$$k(r) = \gamma K_{DP}^{\delta}$$

Park et al. (2005)



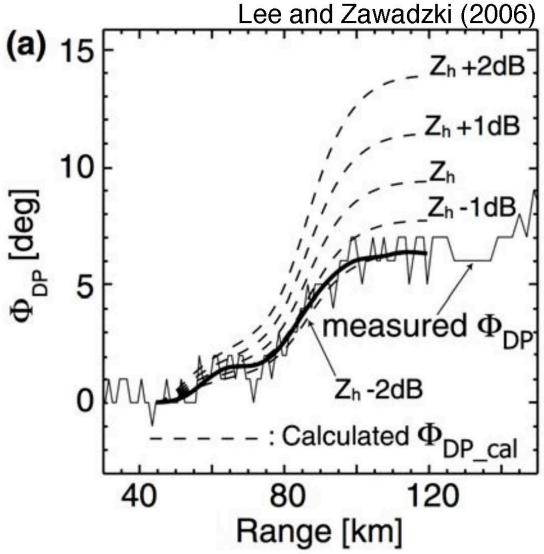
3 - Radar calibration



Based on the fact that Φ_{DP} is not affected by calibration

The calibration method is based on comparing observed Φ_{DP} and $\Phi_{DP}(Z_H, Z_{DR})$ estimated from Z_H (and Z_{DR}). The dBZ calibration error is that that minimizes the differences between the two.

Lee and Zawadzki (2006)



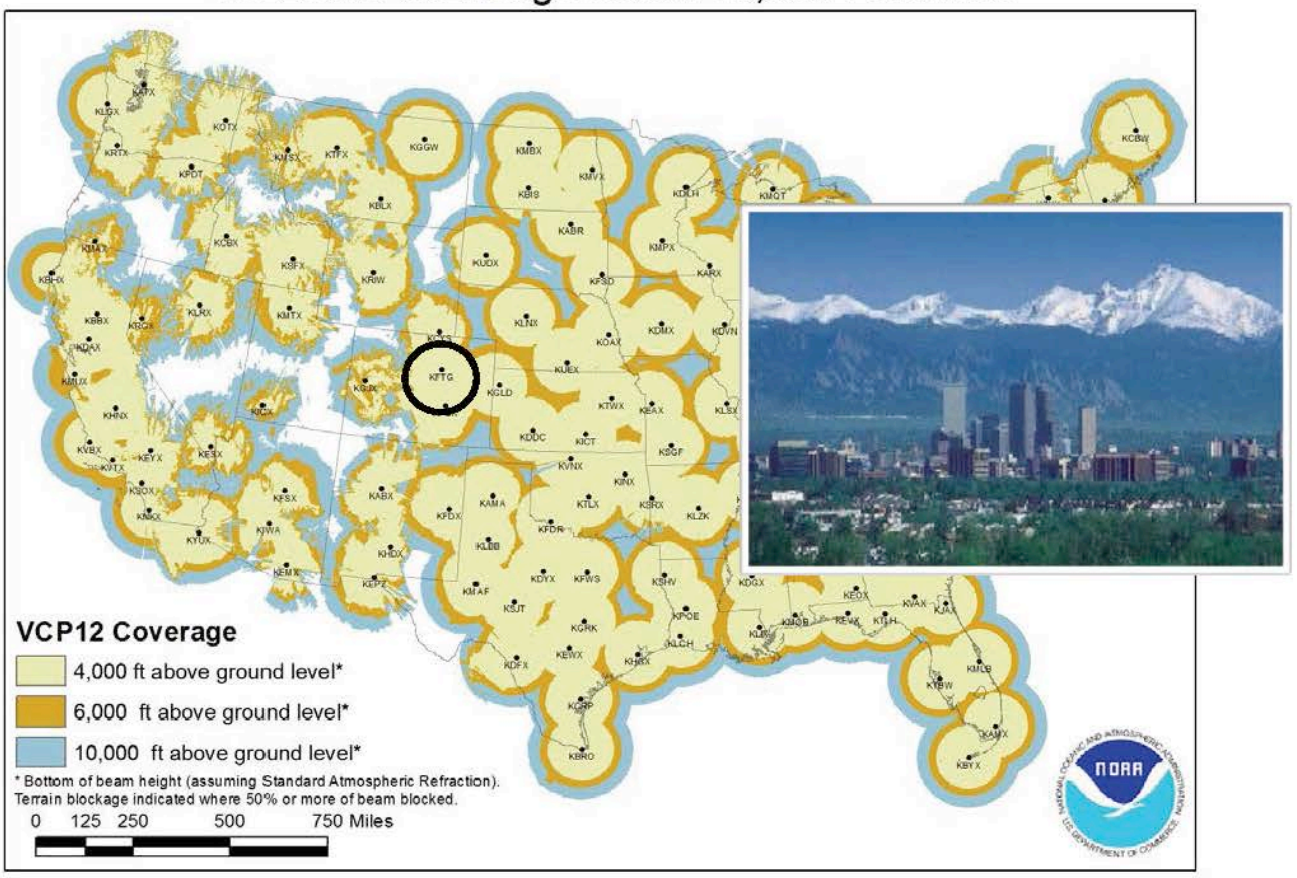
Case Study:
The Colorado flood of 2013

Centre for Applied Research in Hydrometeorology
CRAHI
Universitat Politècnica de Catalunya
Barcelona (Spain)

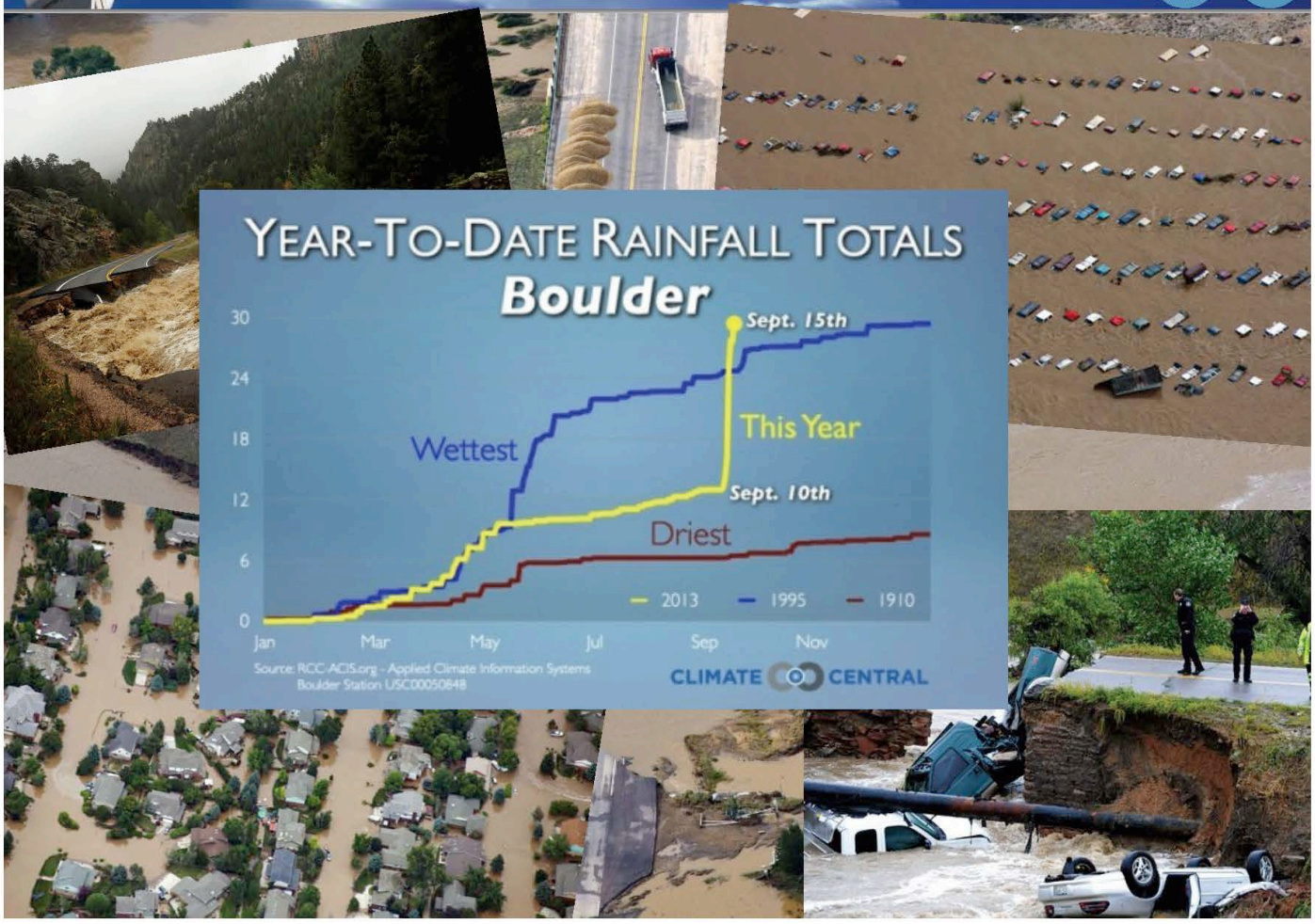
T.C.
Orman ve Su İşleri Bakanlığı
Meteoroloji Genel Müdürlüğü

Meteorological Radars and advanced applications

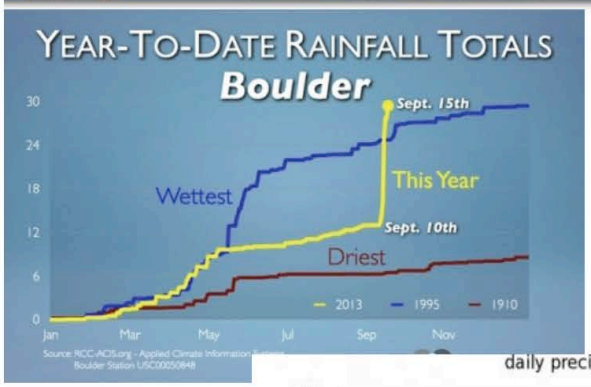
NEXRAD Coverage Below 10,000 Feet AGL

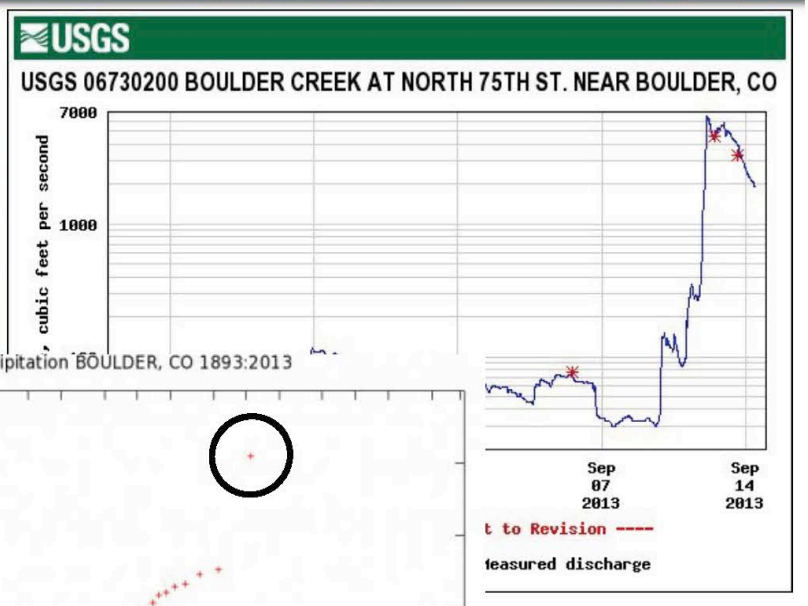


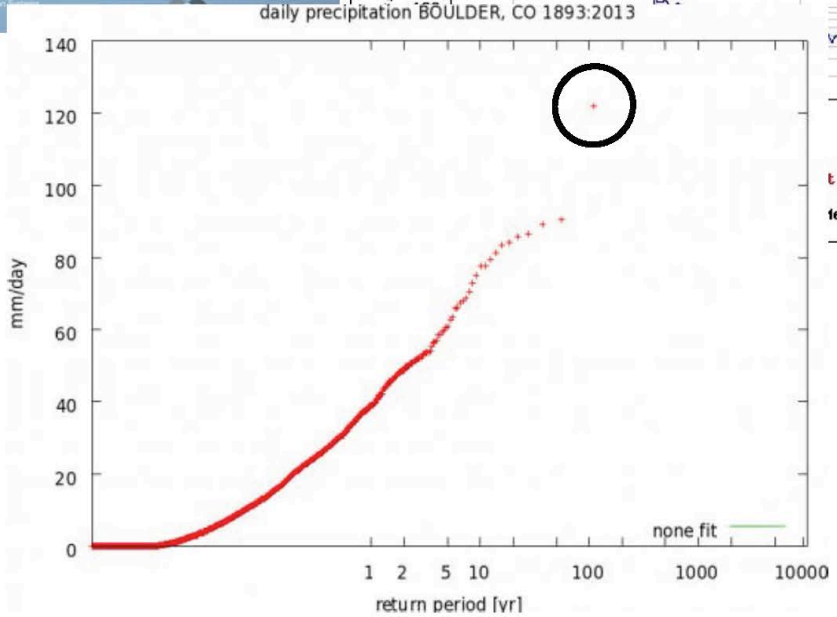
Meteorological Radars and advanced applications



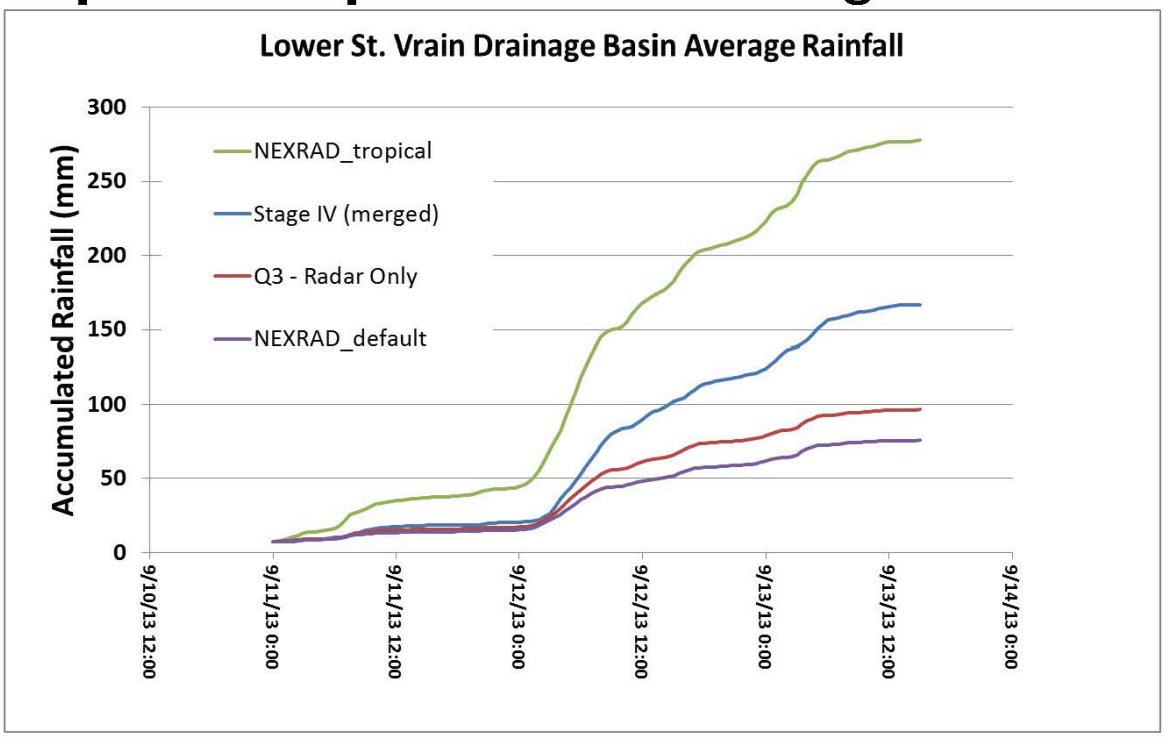
Meteorological Radars and advanced applications







QPE operational products showed large uncertainties

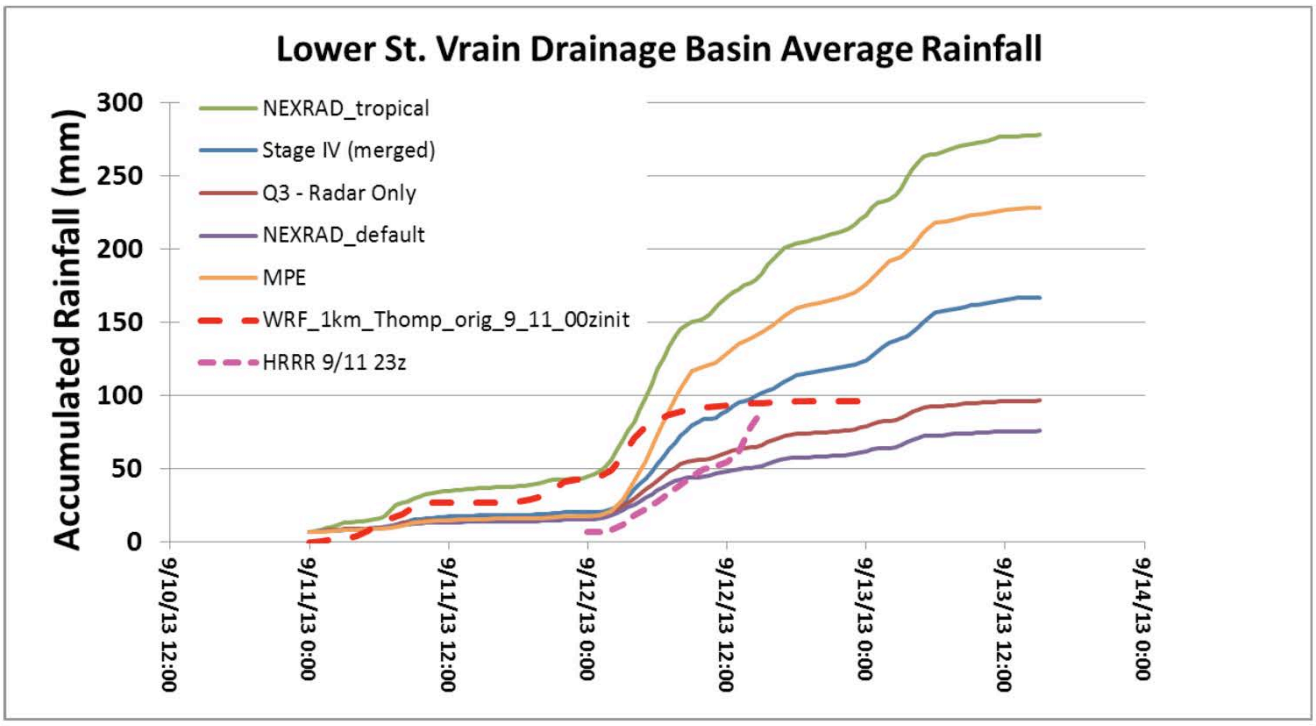


Courtesy of Dr. David Gochis, RAL-NCAR

QPE Rainfall Uncertainty Basin Accumulations:
Ex: Lower St. Vrain basin

QPE at the Colorado Flood of September 2013

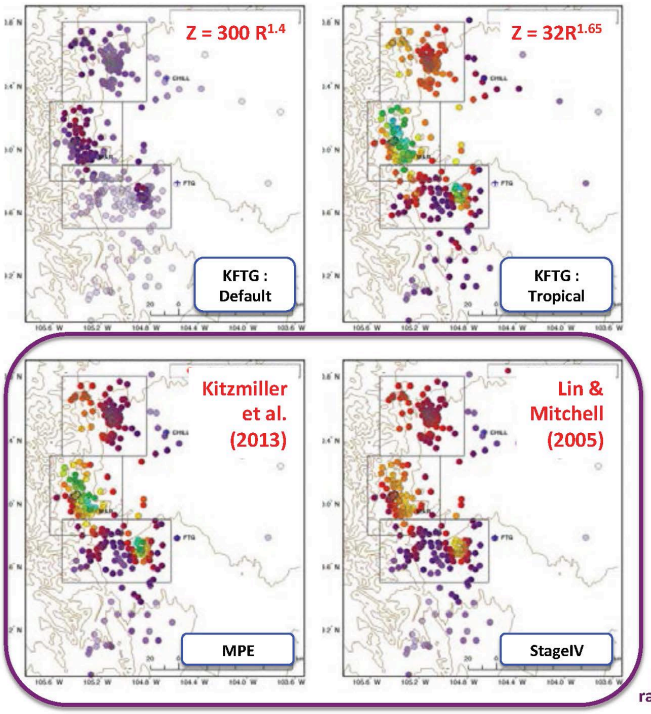
QPE operational products showed large uncertainties

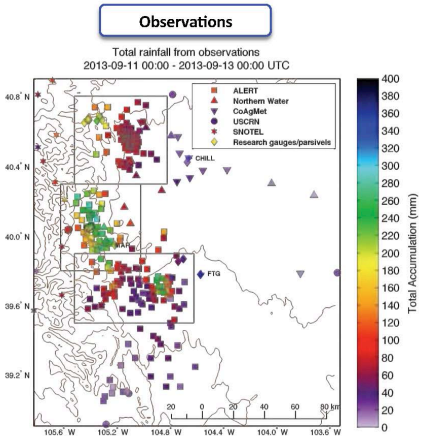


Courtesy of Dr. David Gochis, RAL-NCAR

Can we understand them?

2-day (00 UTC 11 through 00 UTC 13 September) observed and estimated rainfall accumulation





1 – 2 day latency, raingauge adjusted

MPE product seems to be the best QPE available

- Simplified orographic blocking occultation
- Simplified VPR correction
- Radar calibration factor (by raingauges comparison)

Meteorological Radars and advanced applications

Signal stability and non meteorological clutter processing

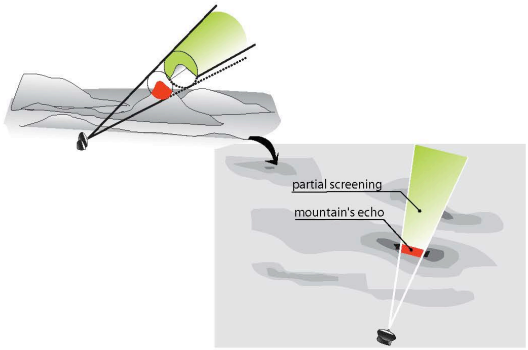
Precipitation type classification VPR and Z-R per types

RAW

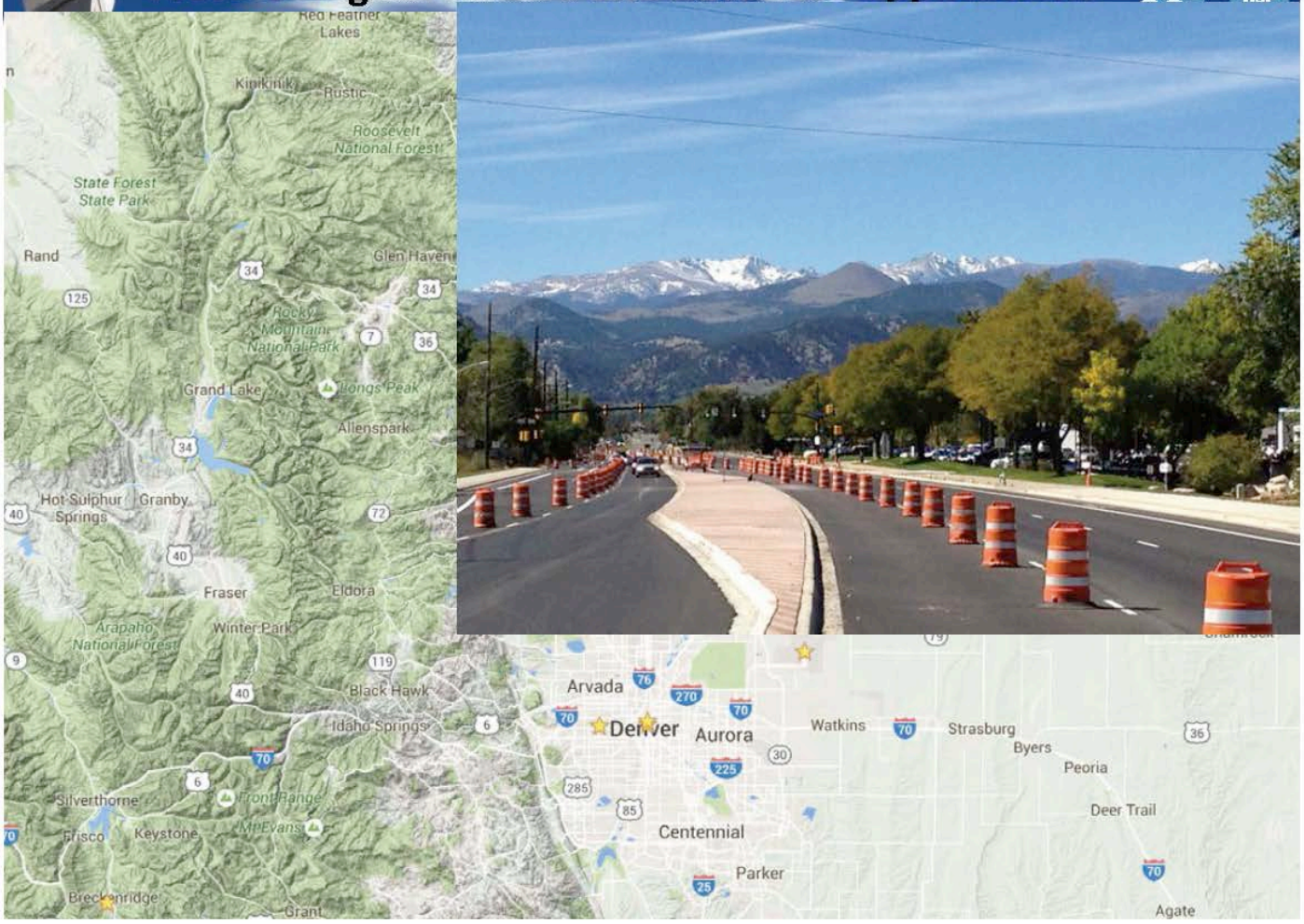
Stage 2 Corrected data

Stage 3 R at ground

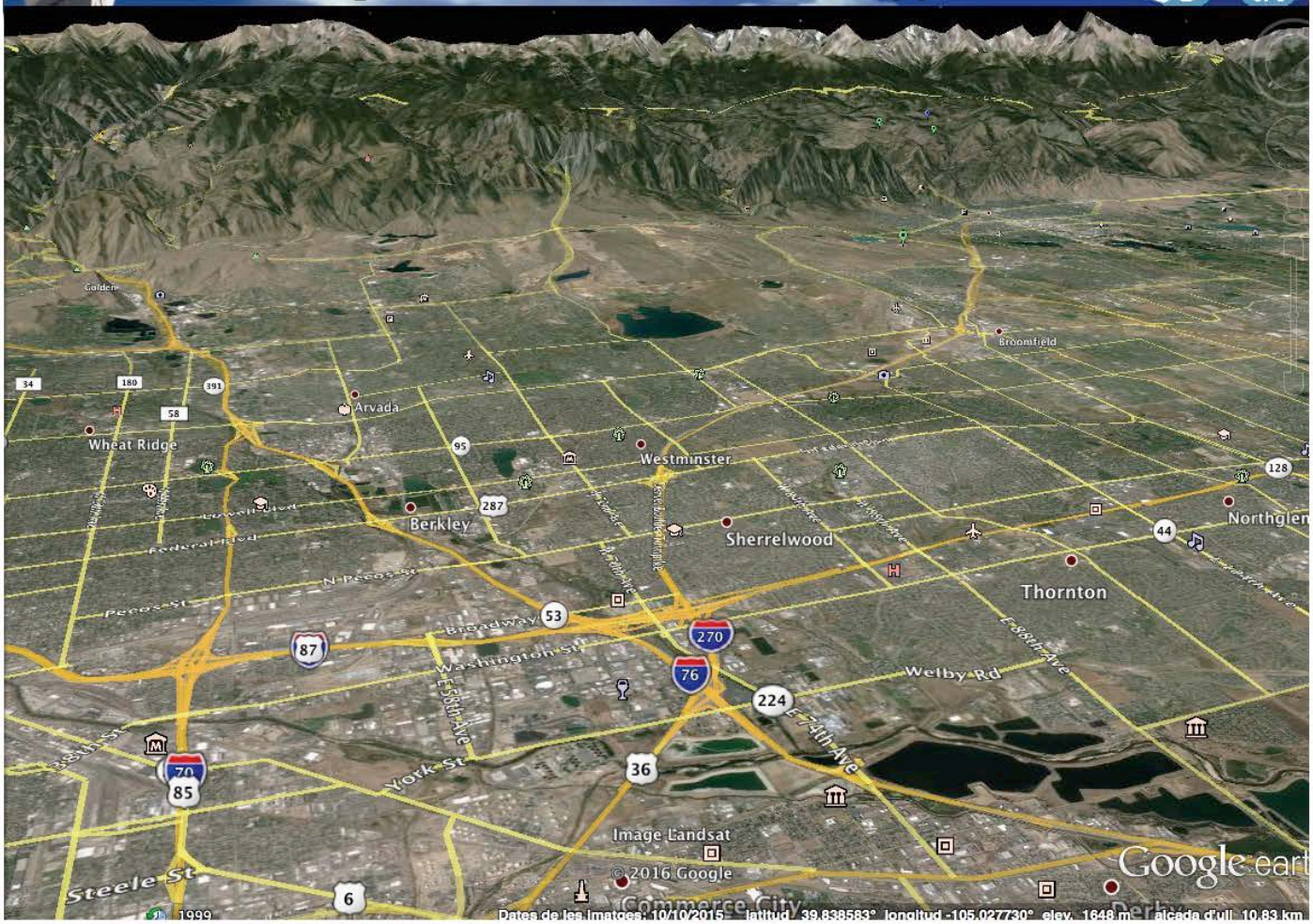
RAINGAUGE NETWORK



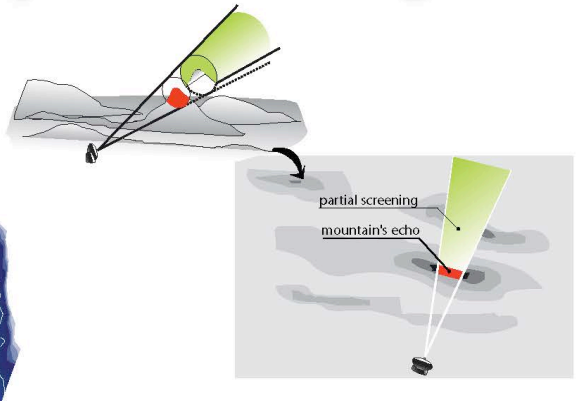
Meteorological Radars and advanced applications



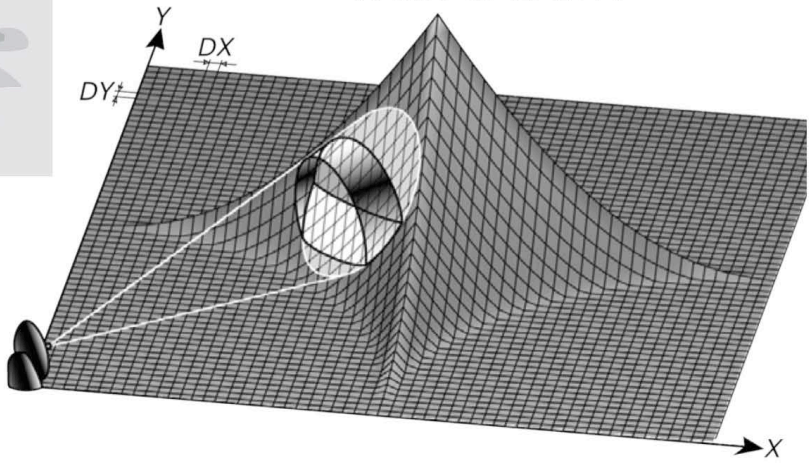
Meteorological Radars and advanced applications



Errors due to the beam interception with the terrain: **partial screening**

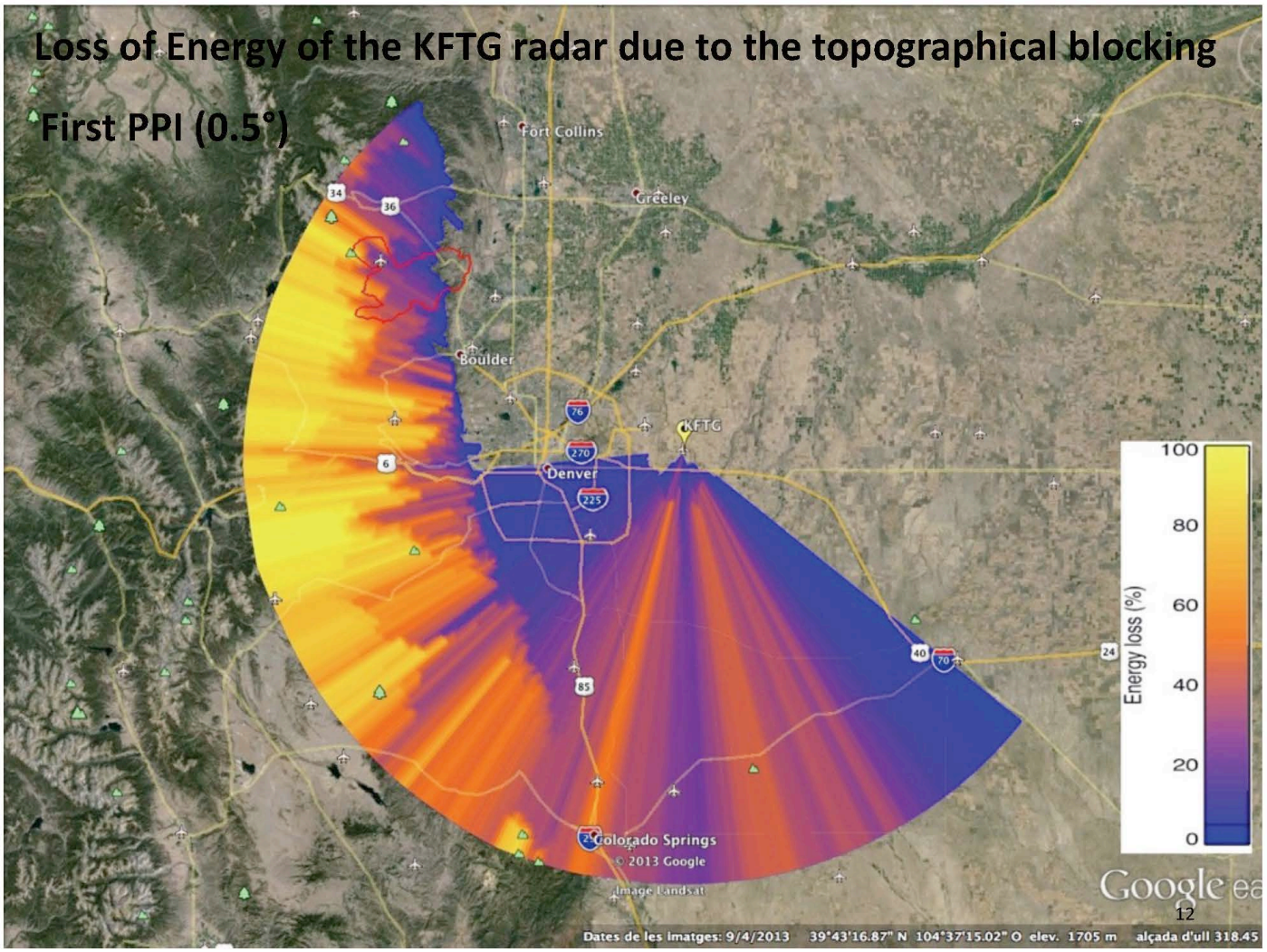


Illuminated surfaces computed by simulation with a DEM

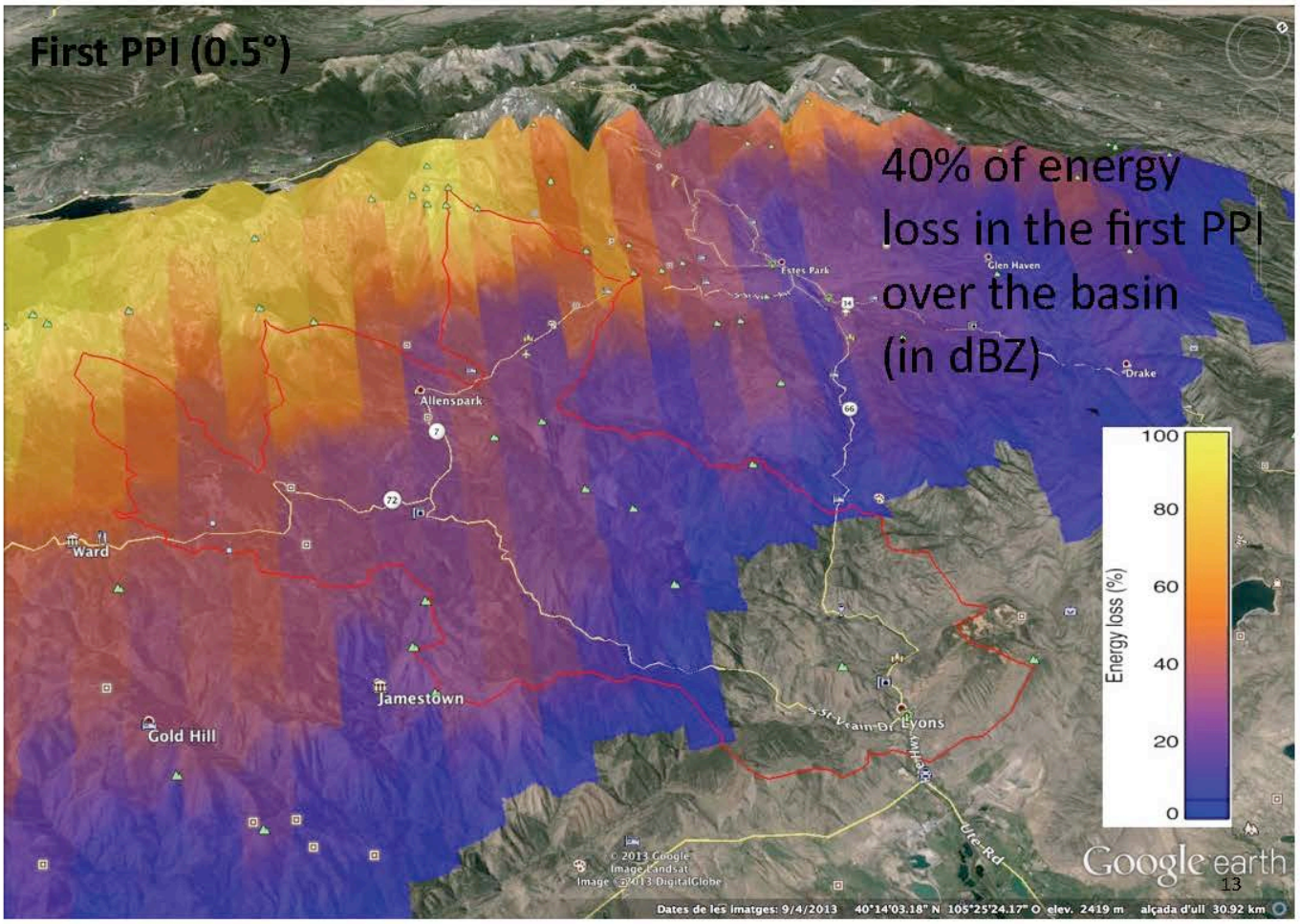


loss of energy due to beam blocking

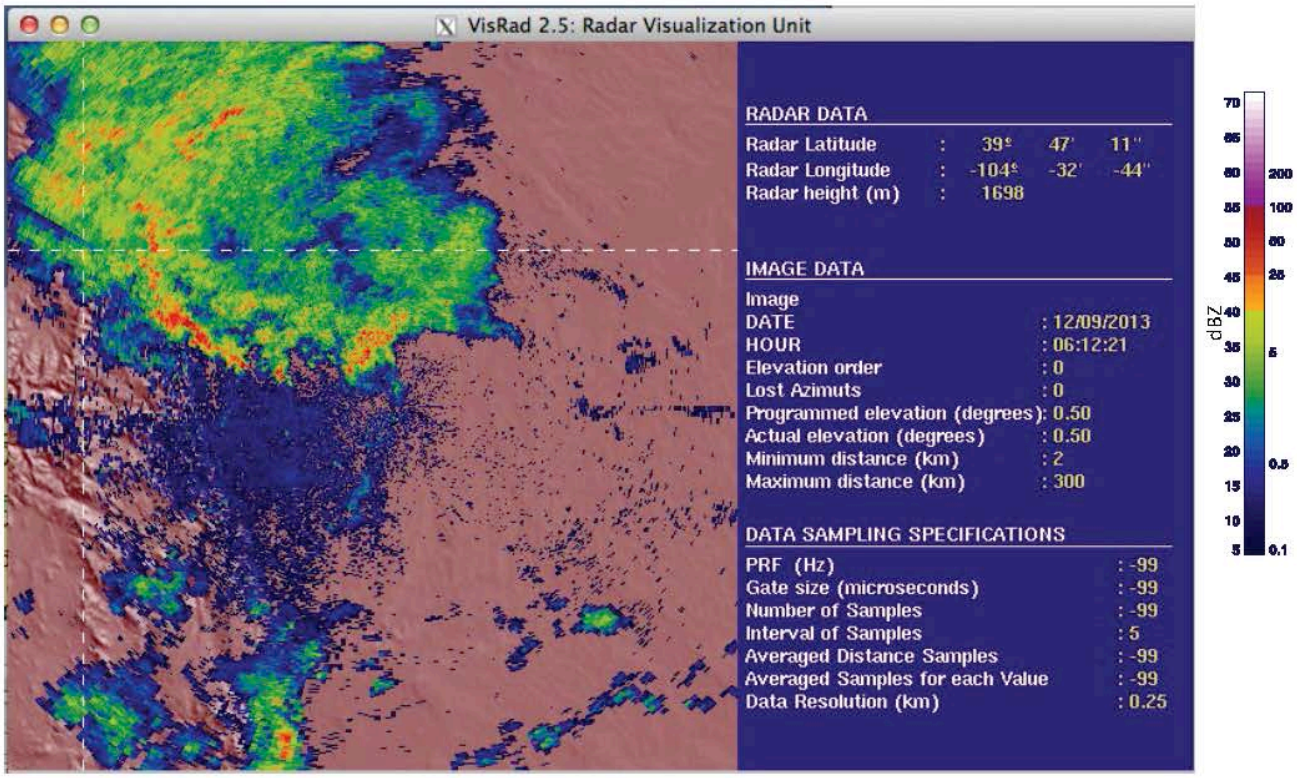
Delrieu and Creutin, 1995, JTECH, Simulation of radar mountain returns using a digitized terrain model.



Loss of Energy of the KFTG radar due to the topographical blocking

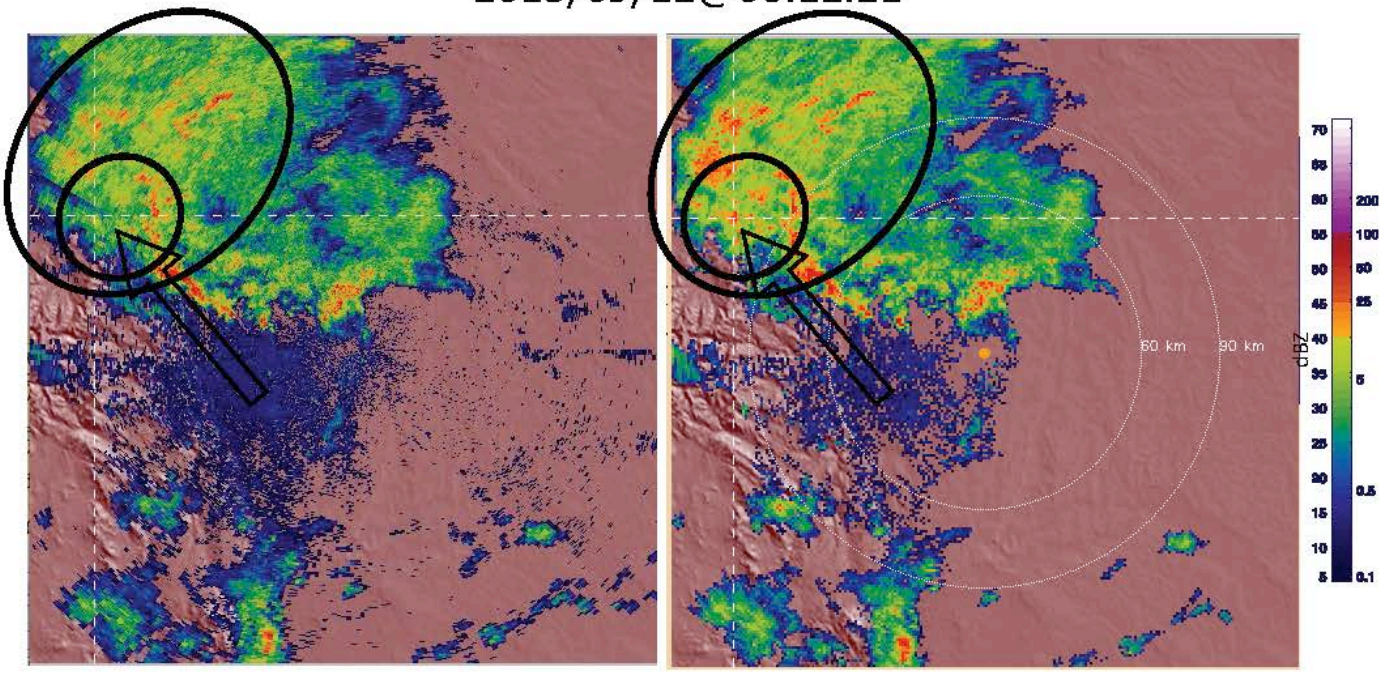


2013/09/12@06:12:21



ORIGINAL DATA

2013/09/12@06:12:21

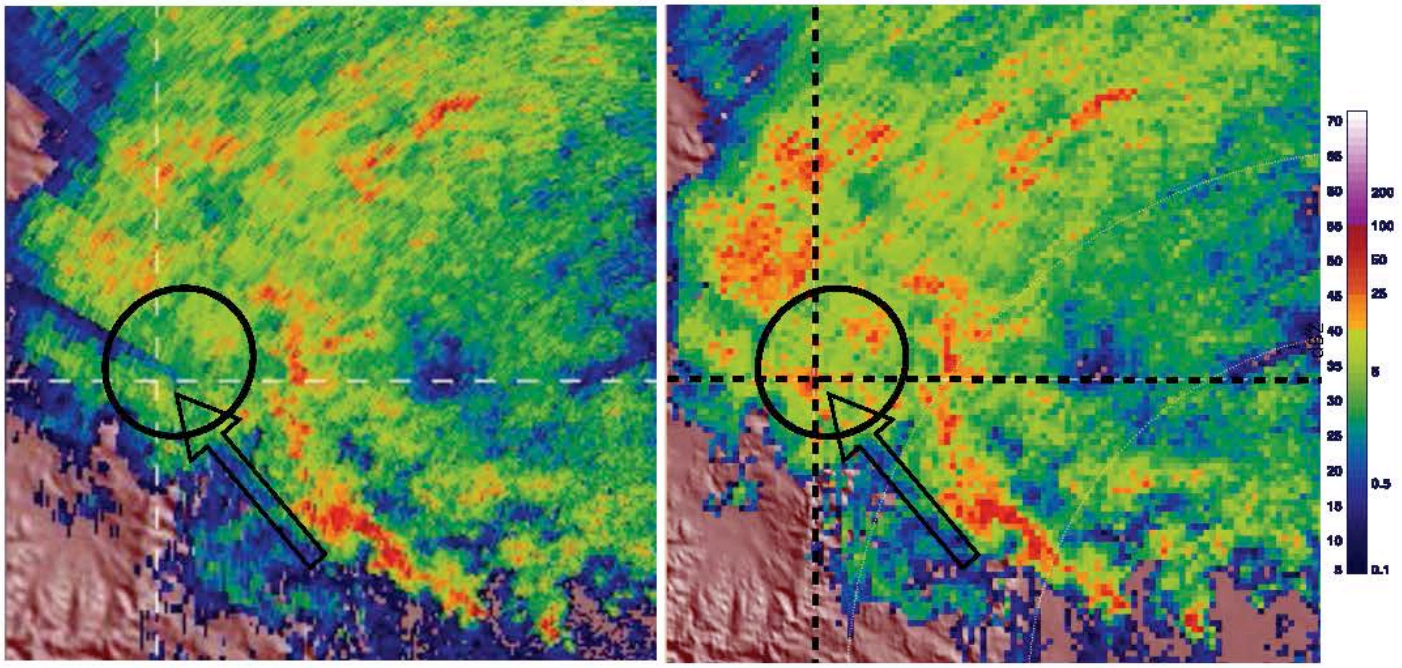


ORIGINAL DATA

BEAM BLOCKING CORRECTED

Meteorological Radars and advanced applications

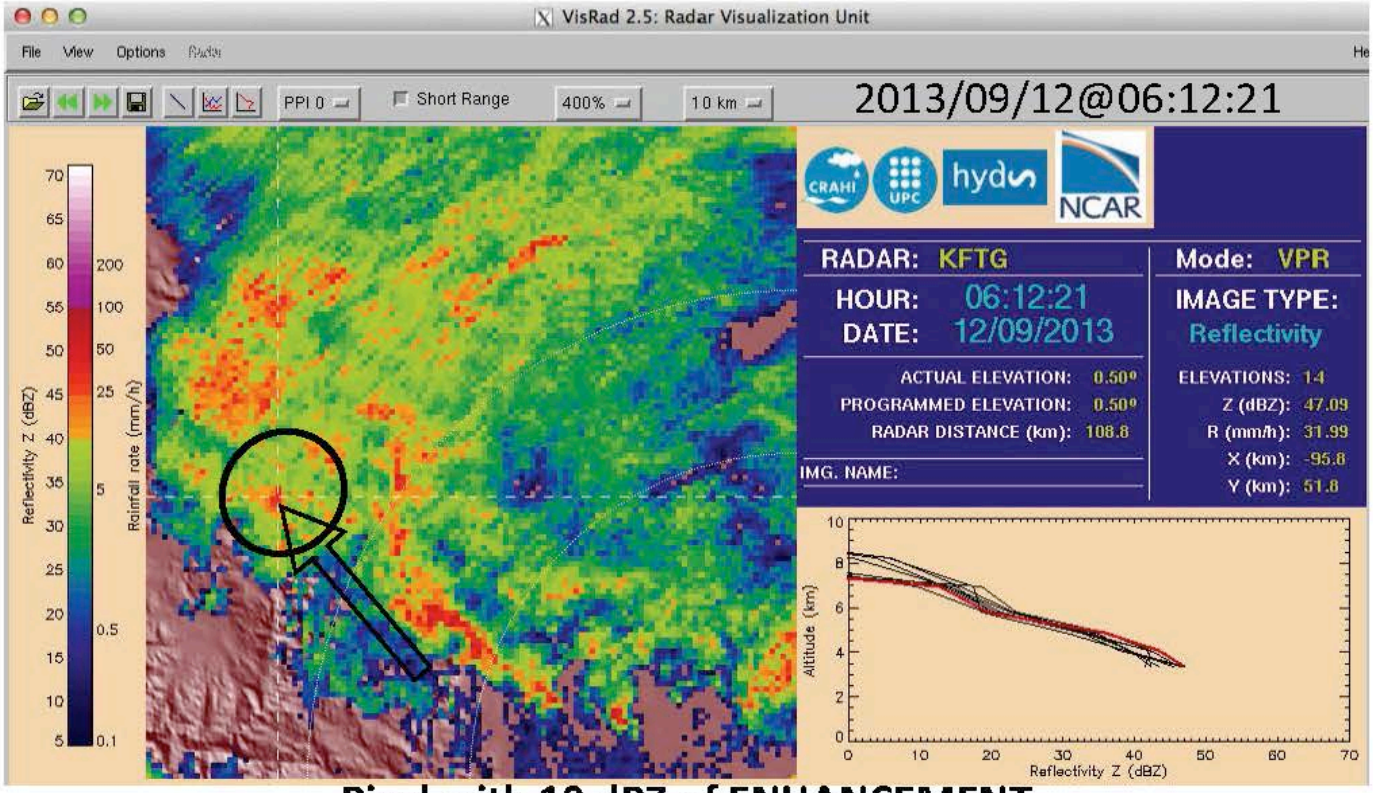
2013/09/12@06:12:21



ORIGINAL DATA

BEAM BLOCKING CORRECTED

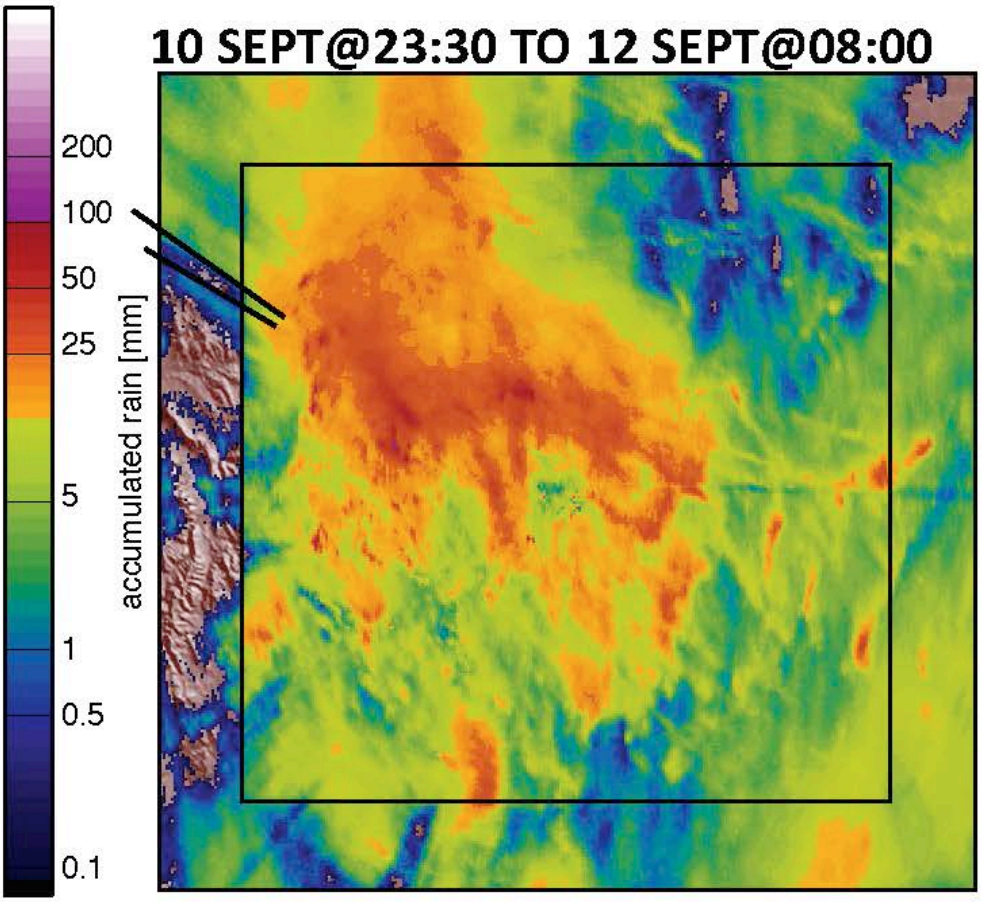
Area with 5-10 dBZ of ENHANCEMENT i.e. underestimation of factor 2 - 4 in Rainfall intensities



Pixel with 10 dBZ of ENHANCEMENT
(from 37 to 47 dBz)
i.e. underestimation of factor 4 in R intensities

Meteorological Radars and advanced applications

Rainfall Accumulation from
10 SEPT@23:30 TO 12 SEPT@08:00



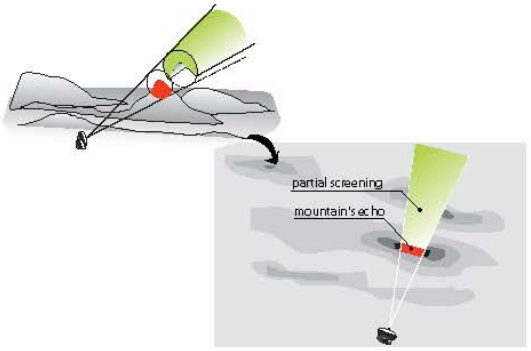
Signal stability and non meteorological clutter processing

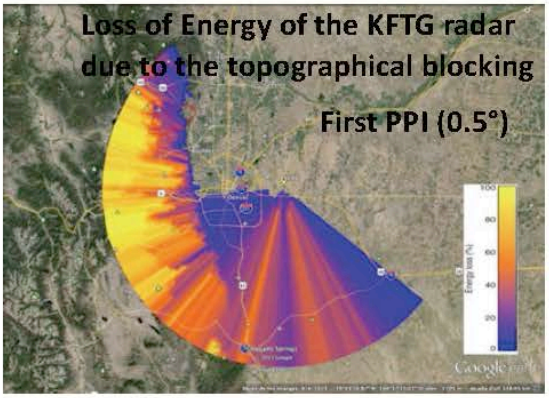
RAW

Stage 2
Corrected data

Stage 3
R at ground

RAINGAUGE NETWORK





Meteorological Radars and advanced applications

Signal stability and non meteorological clutter processing

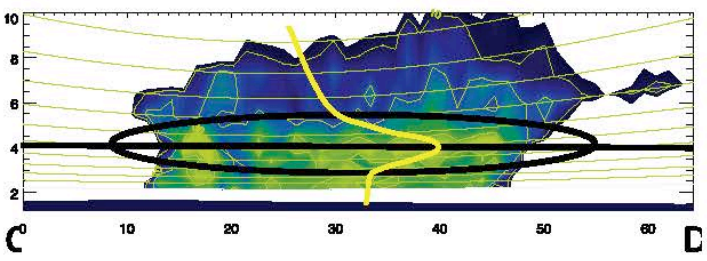
Precipitation type classification VPR and Z-R per types

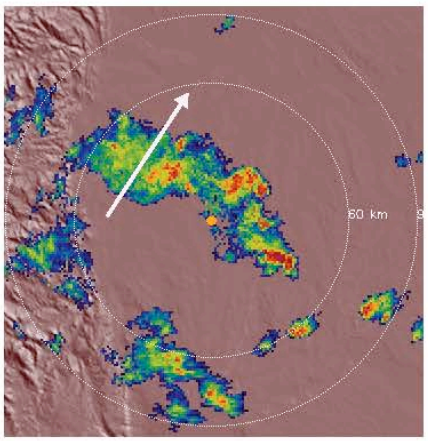
RAW

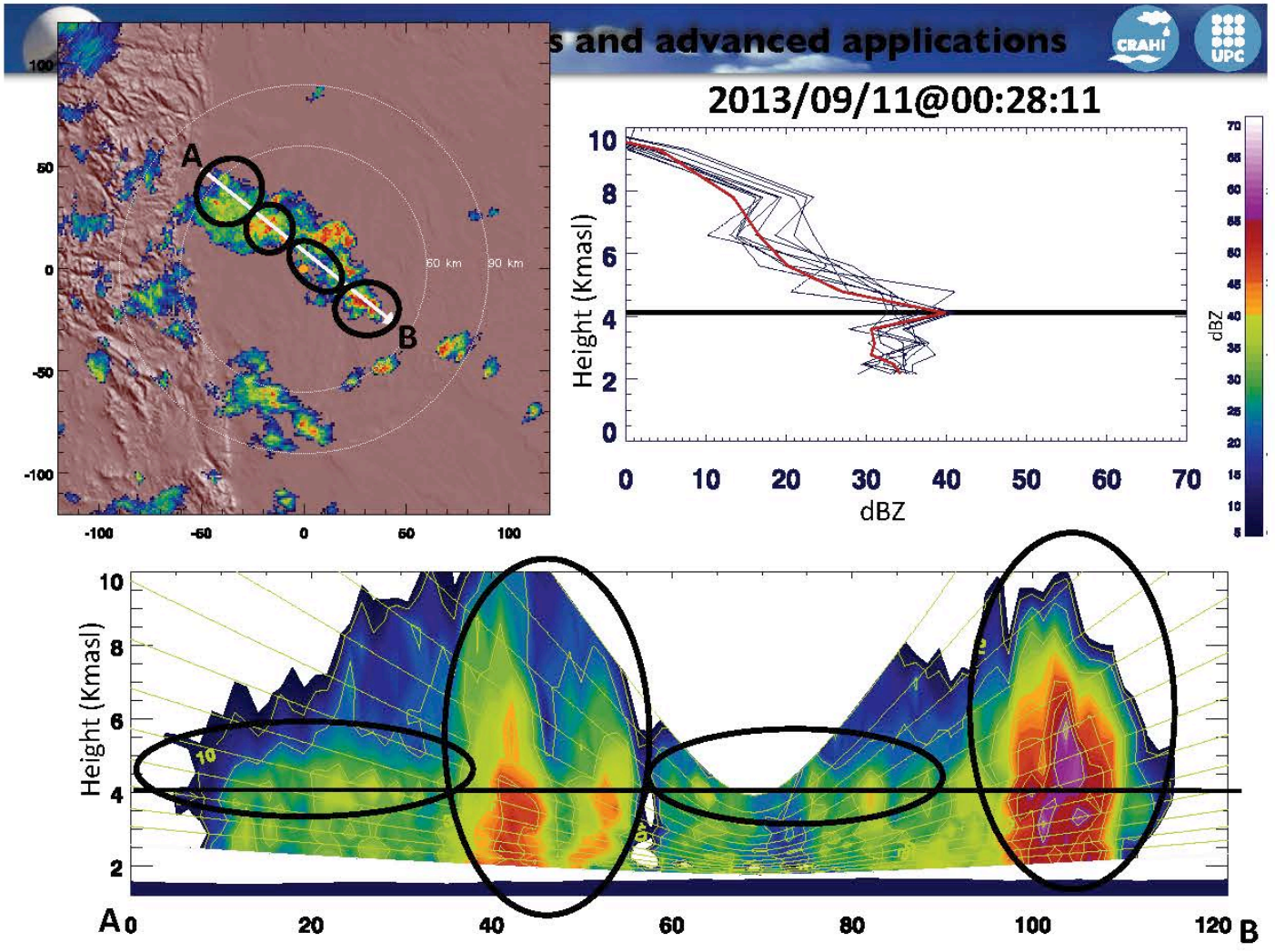
Stage 2
Corrected data

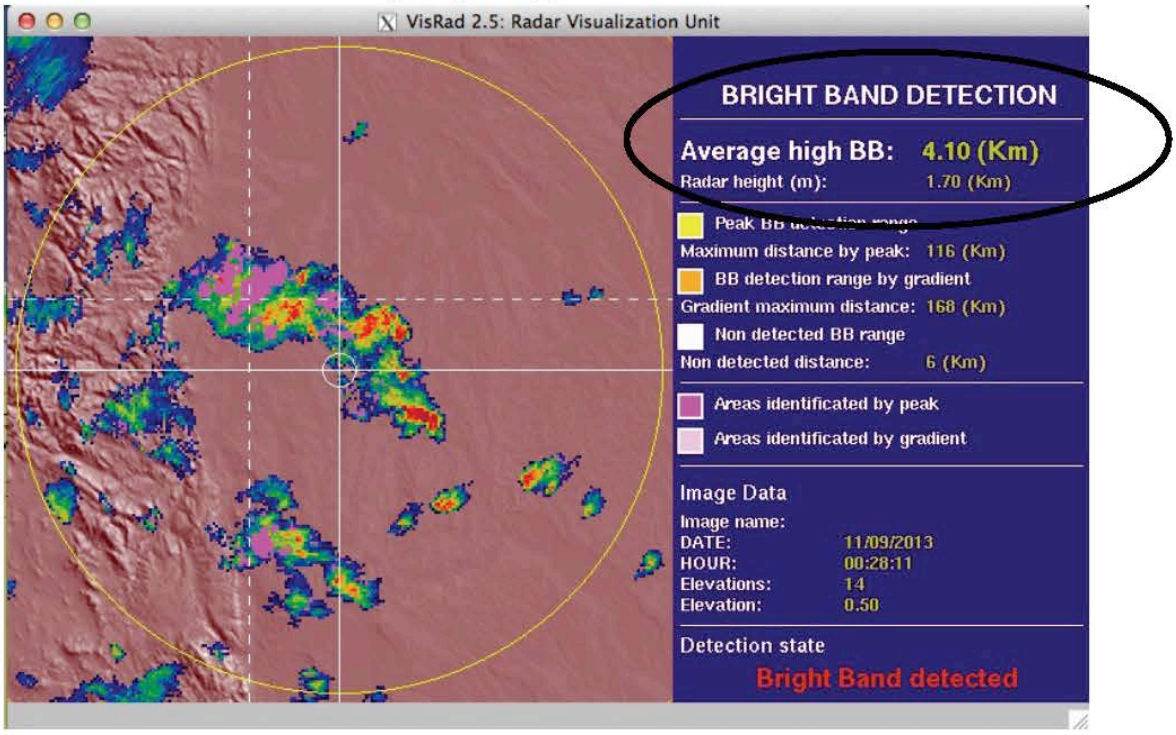
Stage 3
R at ground

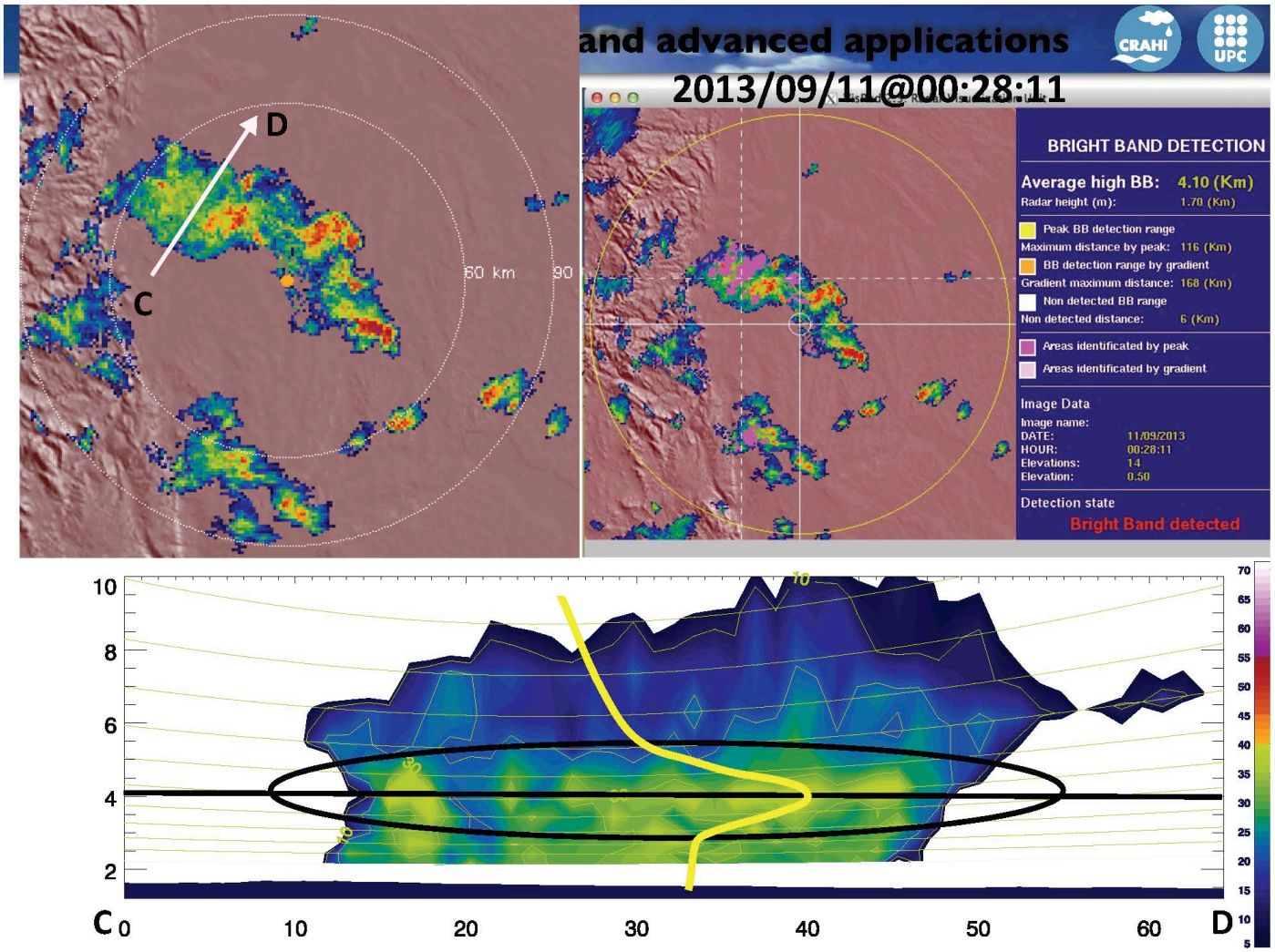
RAINGAUGE NETWORK



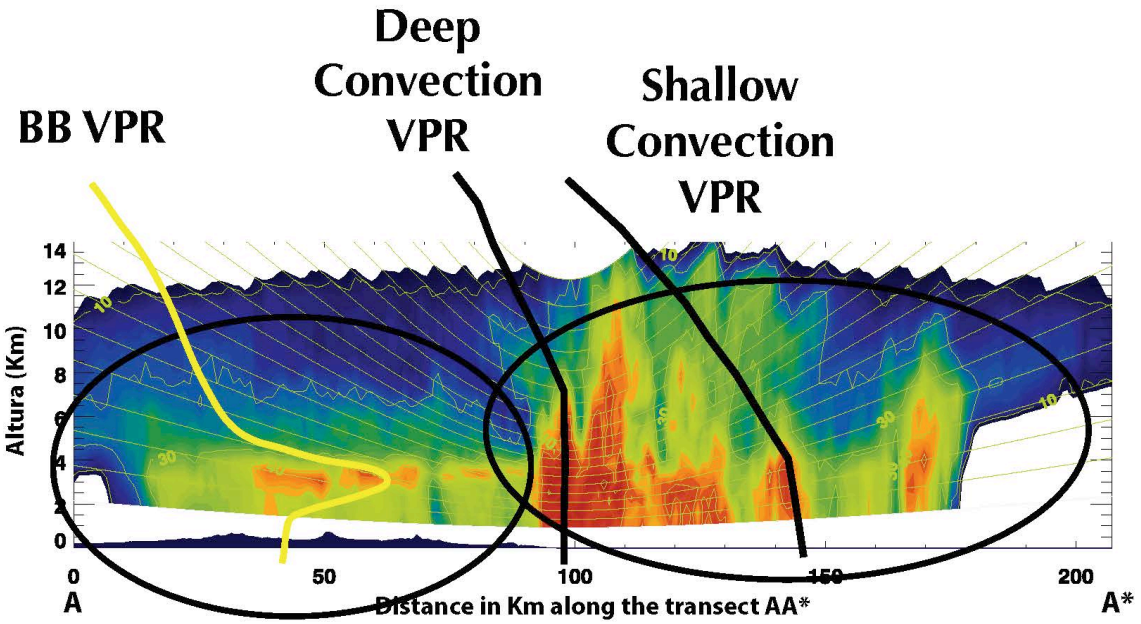



2013/09/11@00:28:11
A
B
60 km
90 km
Height (Kmasl)
dBZ
A
B

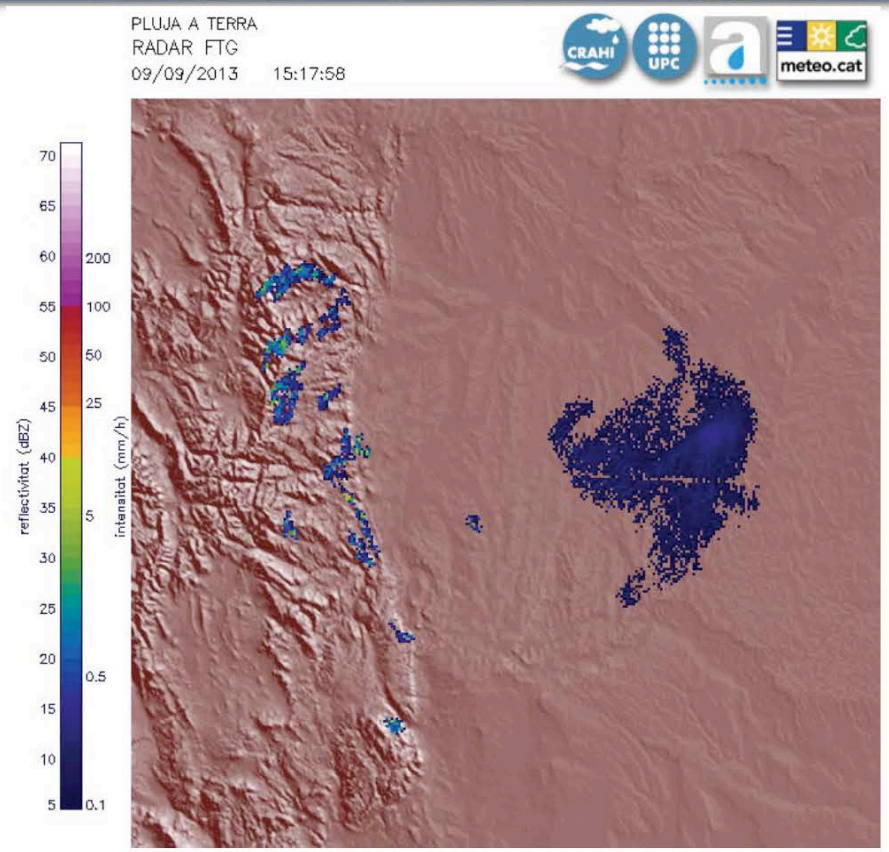

2013/09/11@00:28:11
VisRad 2.5: Radar Visualization Unit
BRIGHT BAND DETECTION
Average high BB: 4.10 (Km)
Radar height (m): 1.70 (Km)
Maximum distance by peak: 116 (Km)
BB detection range by gradient
Gradient maximum distance: 168 (Km)
Non detected BB range
Non detected distance: 6 (Km)
Areas identificated by peak
Areas identificated by gradient
Image Data
Image name:
DATE: 11/09/2013
HOUR: 00:28:11
Elevations: 14
Elevation: 0.50
Detection state
Bright Band detected



THE SEPARATION IN AREAS OF HOMOGENEOUS RAIN PROCESSES IS **EXTREMELY IMPORTANT** FOR **EFFICIENT VPR CORRECTION**



QPE at the Colorado Flood of September 2013

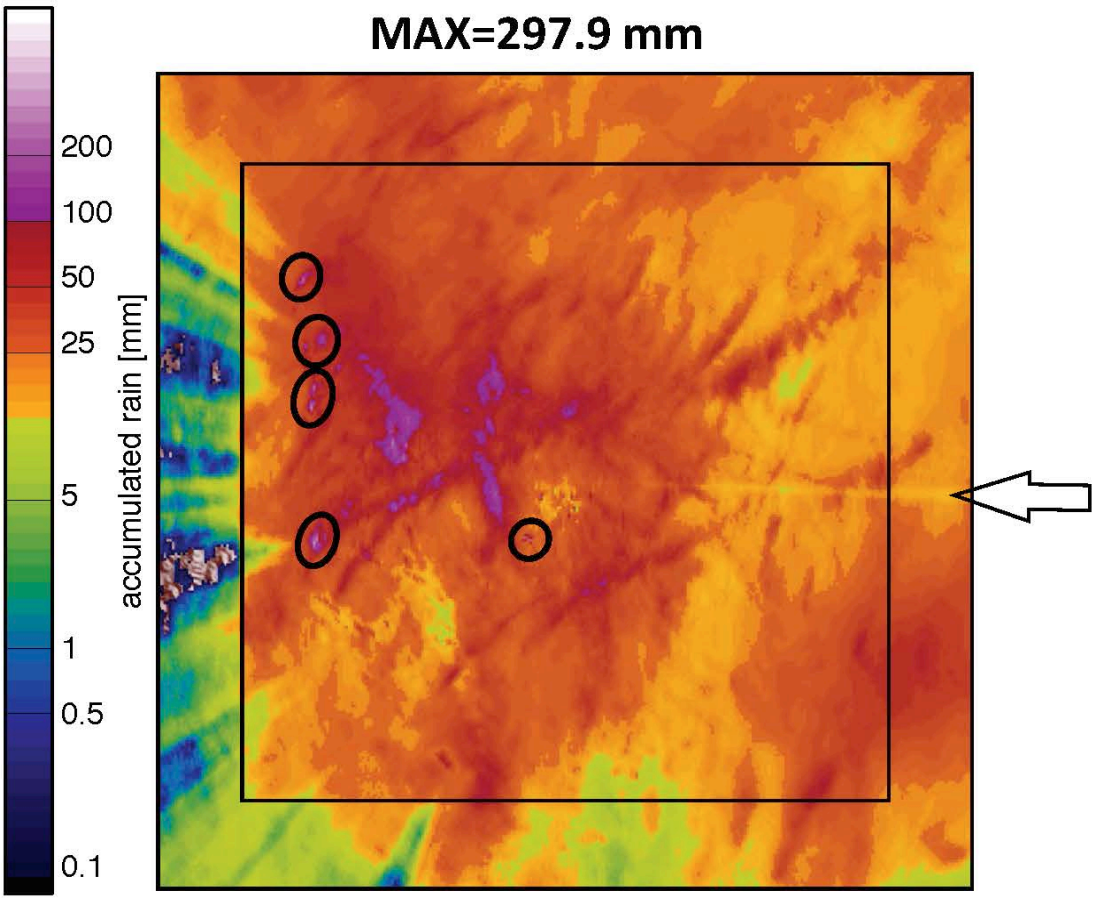


QPE at ground

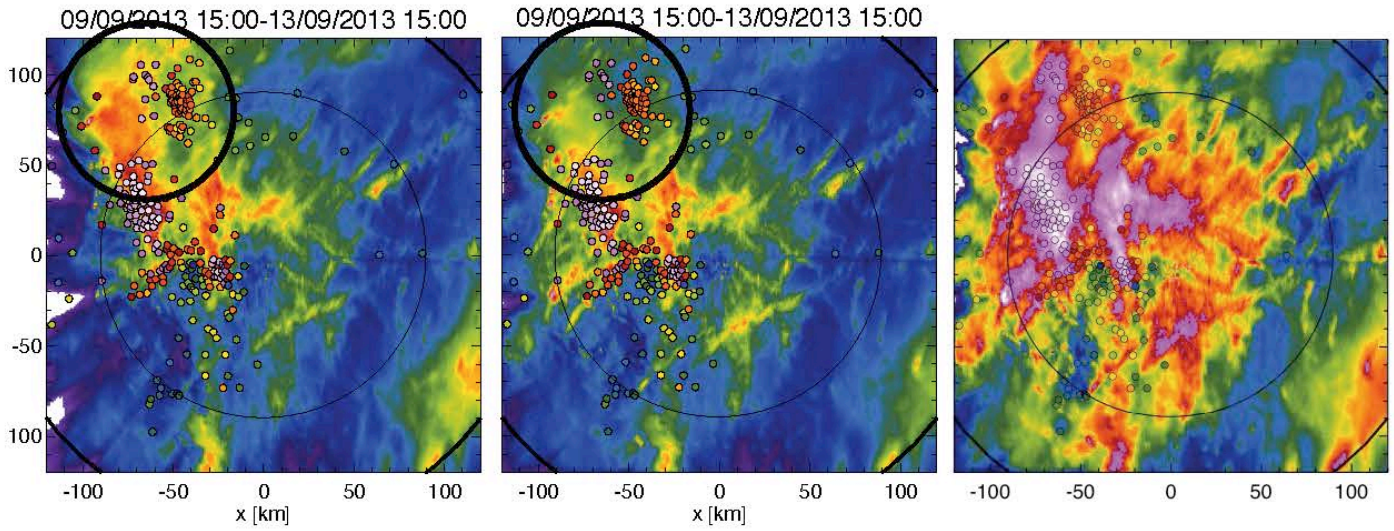
Meteorological Radars and advanced applications

Rainfall Accumulation from 09 SEPT@15:10 TO 13 SEPT@15:40

MAX=297.9 mm



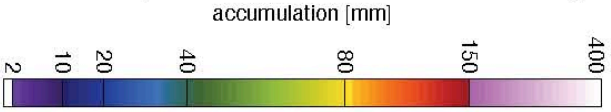
RESULTS



4-day rainfall accumulation ORIGINAL DATA (NEXRAD as IT IS)

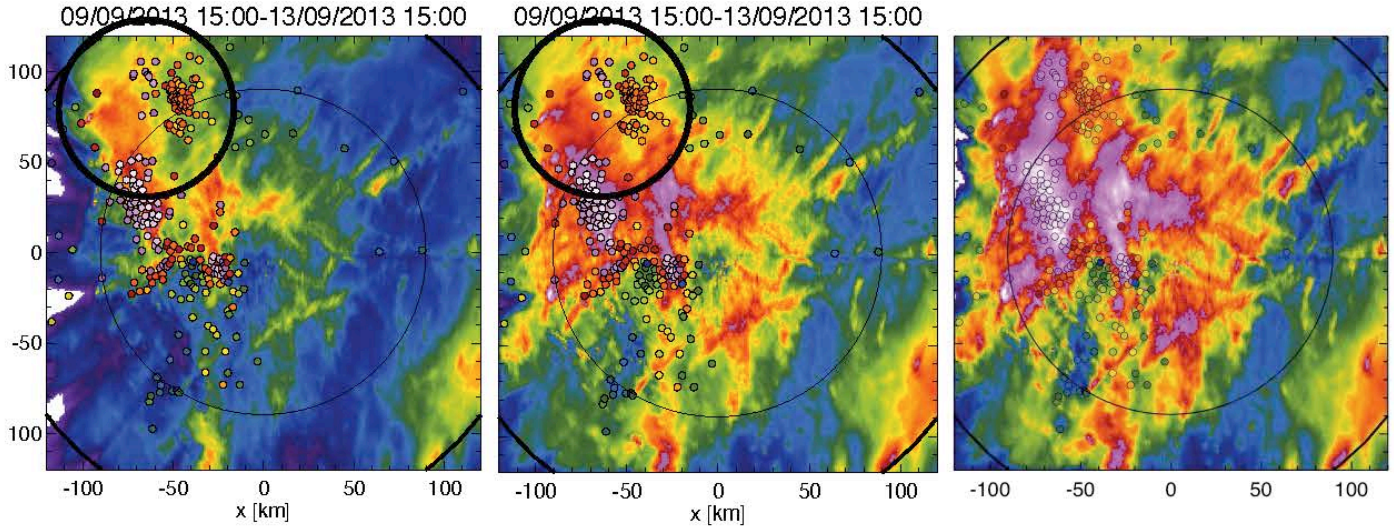
4-day rainfall accumulation CORRECTED DATA (partial blocking + VPR + double ZR)

4-day rainfall accumulation Radar and raingauge blending



Meteorological Radars and advanced applications

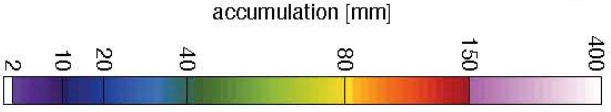
RESULTS: Partial failure of the algorithms due to of a RADAR BIAS of around 4 dB



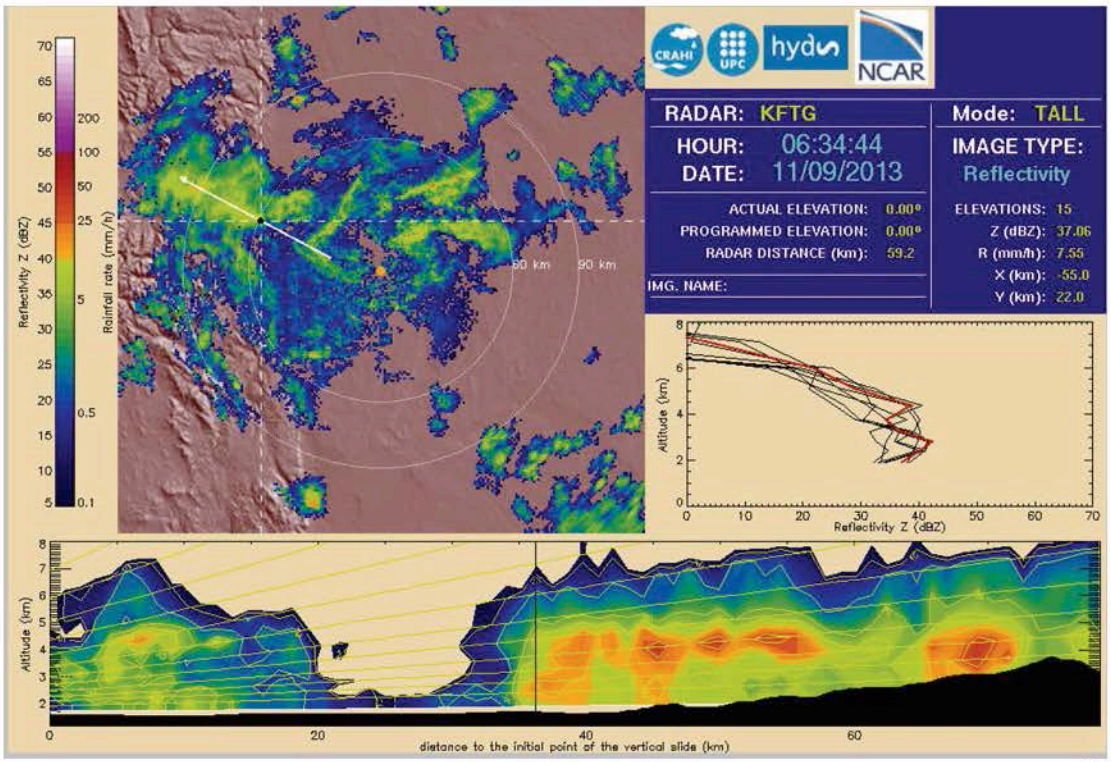
4-day rainfall accumulation UNCORRECTED DATA (NEXRAD as IT IS)

4-day rainfall accumulation CORRECTED DATA **with + 4dB of bias correction**

4-day rainfall accumulation Radar and raingauge blending

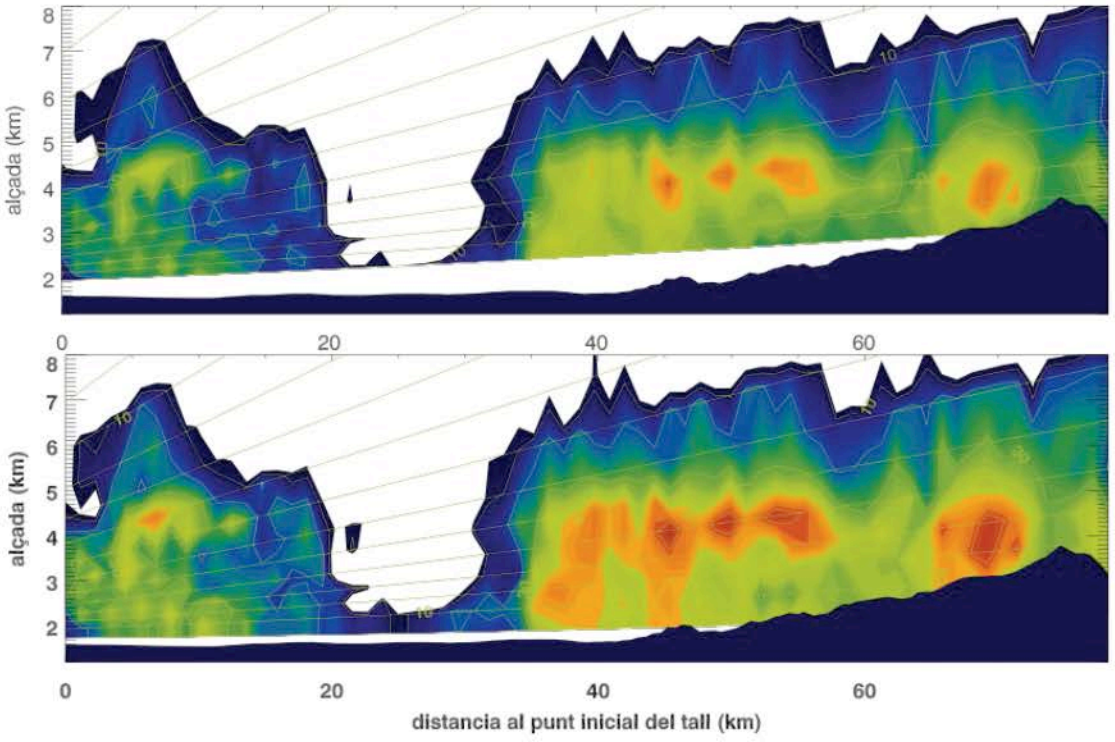


+4 dB calibration + occultation correction + vertical profile correction



Meteorological Radars and advanced applications

RESULTS: Partial failure of the algorithms due to of a RADAR BIASof around 4 dB



+ 4 dB of Radar Bias

Is this 4 dB of radar bias realistic?

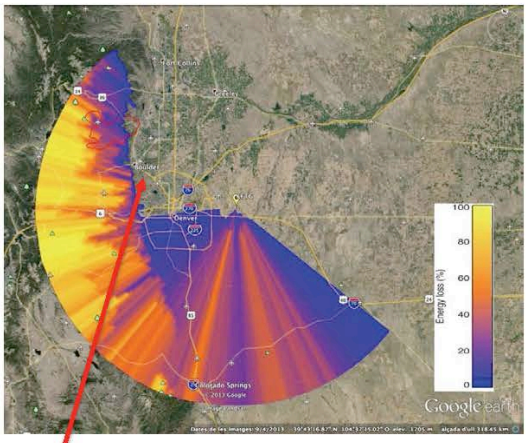
Can we improve the classification algorithm?

Can we derive an adapted ZR conversion to the evolution of rainfall types?

Meteorological Radars and advanced applications

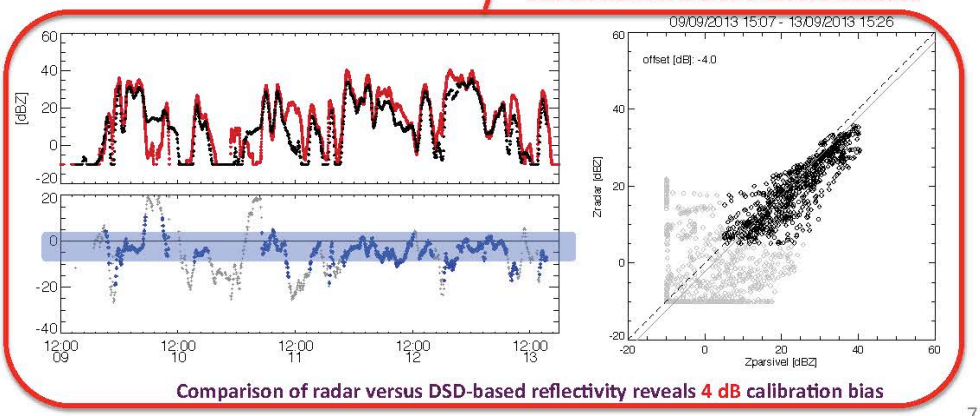
Diagnosis of Radar Rainfall Errors

- **Basic Signal Processing**
  - radar occultation (partial beam blockage)
  - radar calibration (bias removal)
- **Advanced Data Processing**
  - precipitation type classification
  - vertical profile correction (extrapolation to ground level & bright band correction)
  - reflectivity to rainfall conversion (DSD variation)
- **Adjustment**
  - comparison to raingauges
  - merging radar & raingauge information (e.g., kriging)



Loss of energy for KFTG radar due to occultation of 0.5 deg PPI

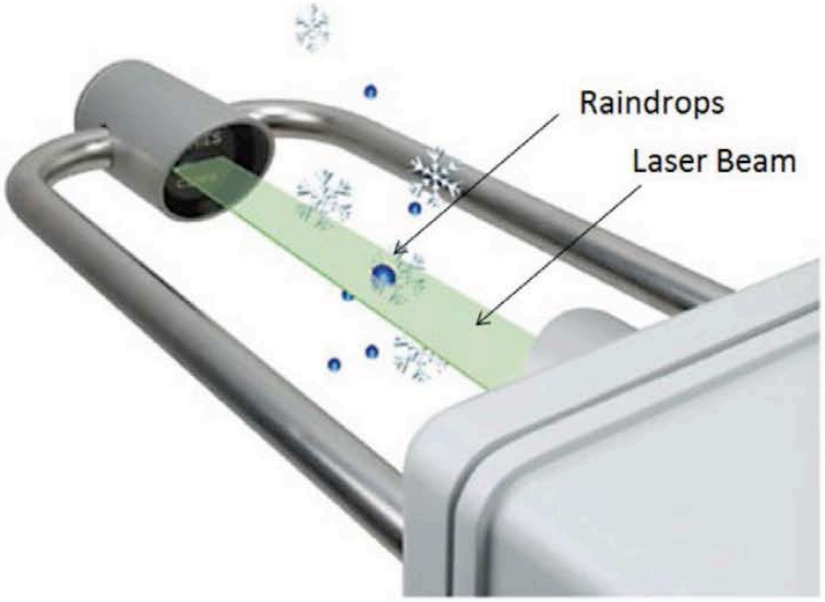
Bias assessment in area without occultation



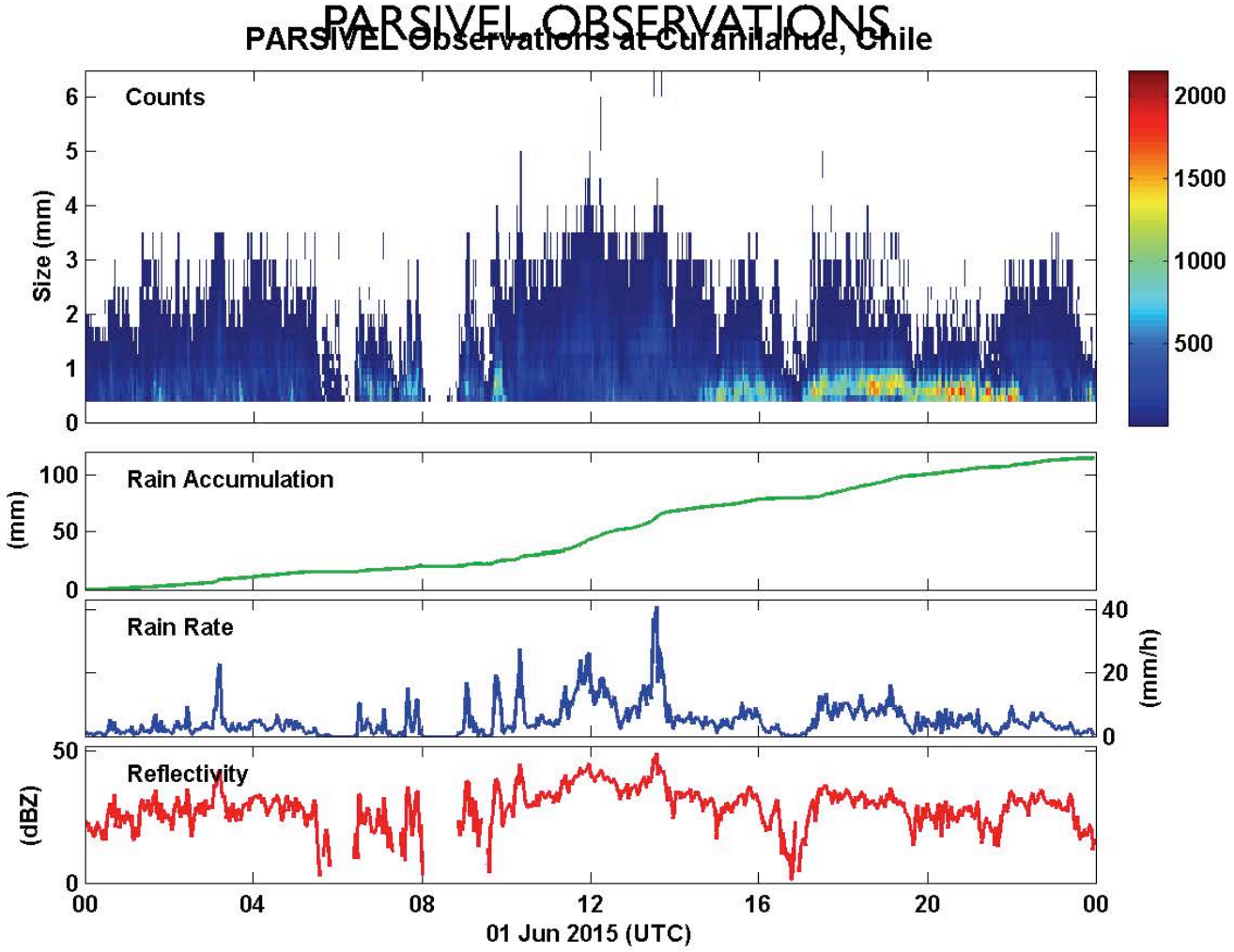
Comparison of radar versus DSD-based reflectivity reveals 4 dB calibration bias

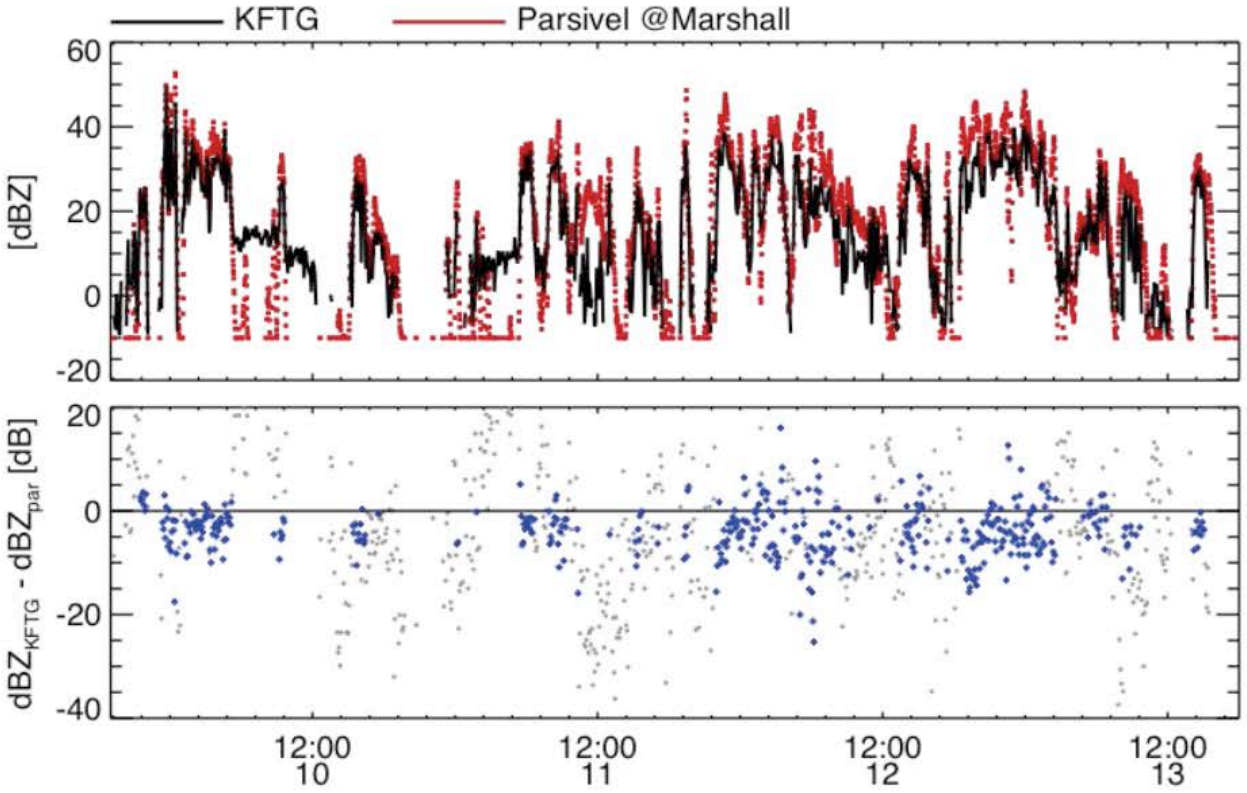


PARSIVEL Optical Disdrometer



PARSIVEL OBSERVATIONS

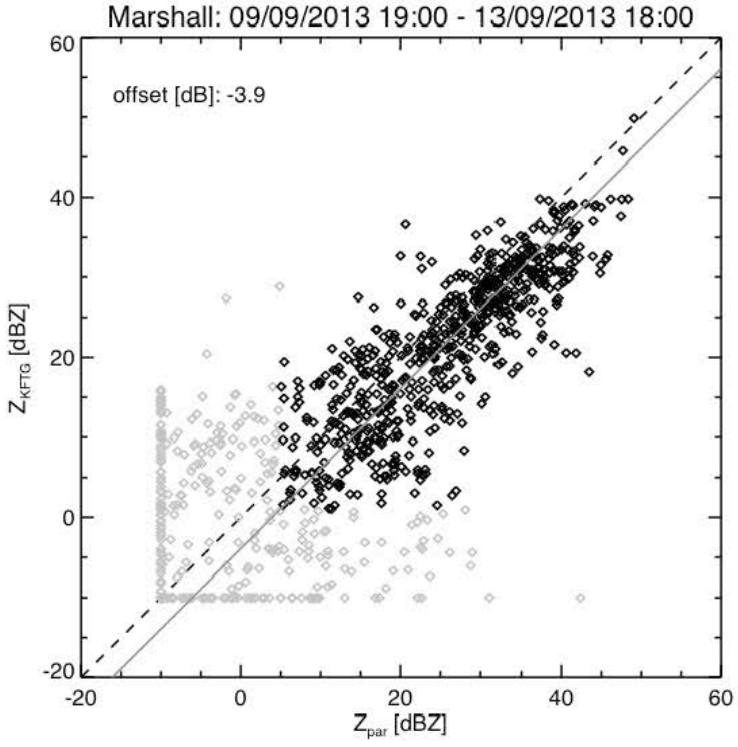




Z comparison between Marshall Parsivel2 and KFTG radar

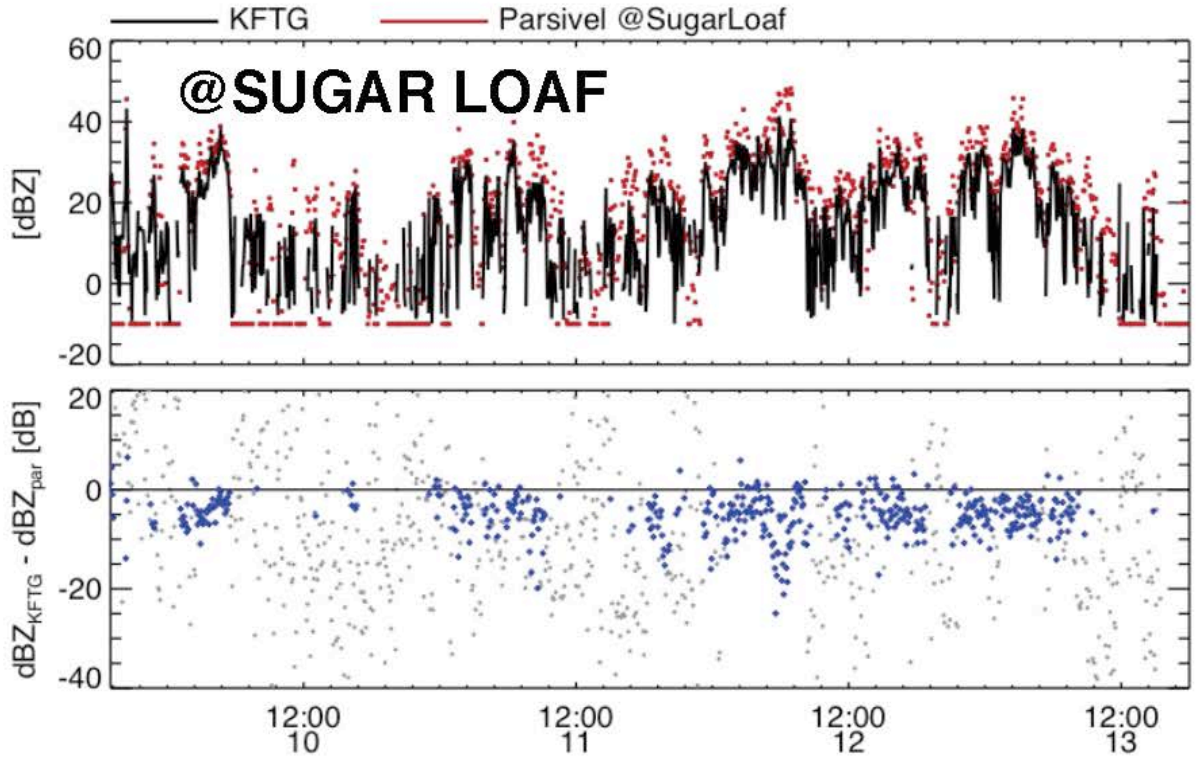
Blue dots: Both instruments measure > 5 dBz

Meteorological Radars and advanced applications

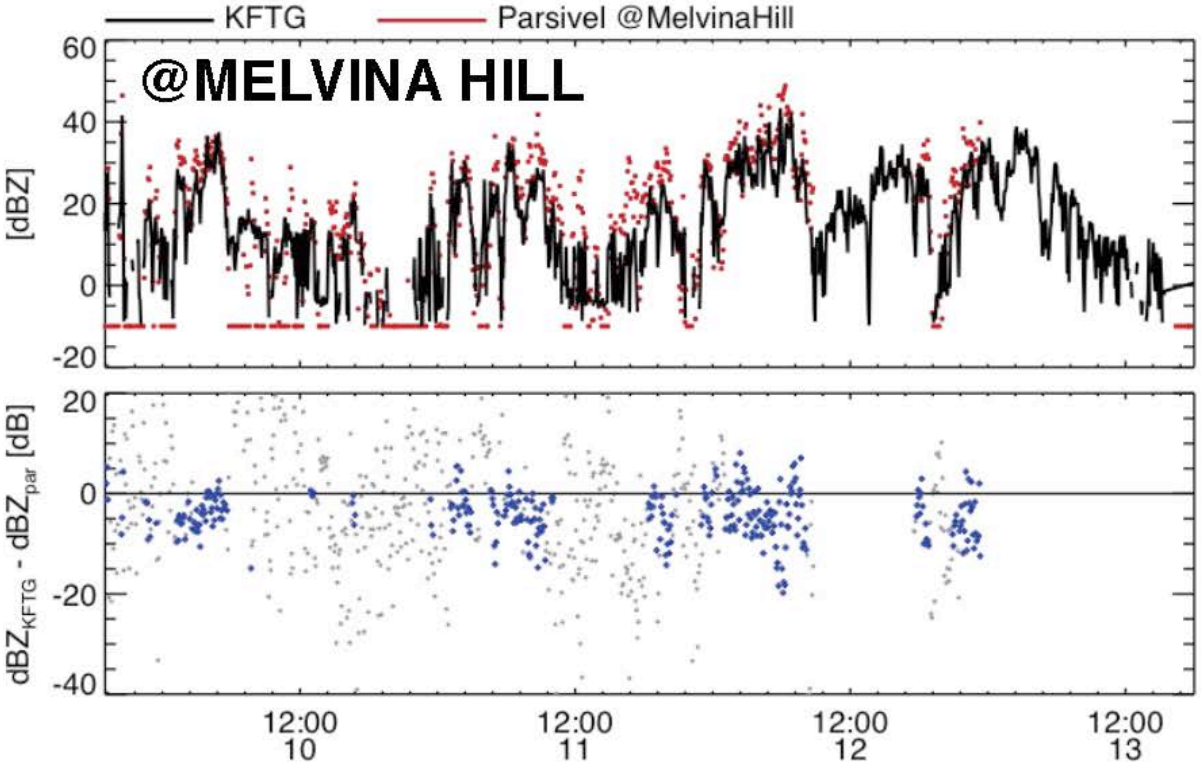


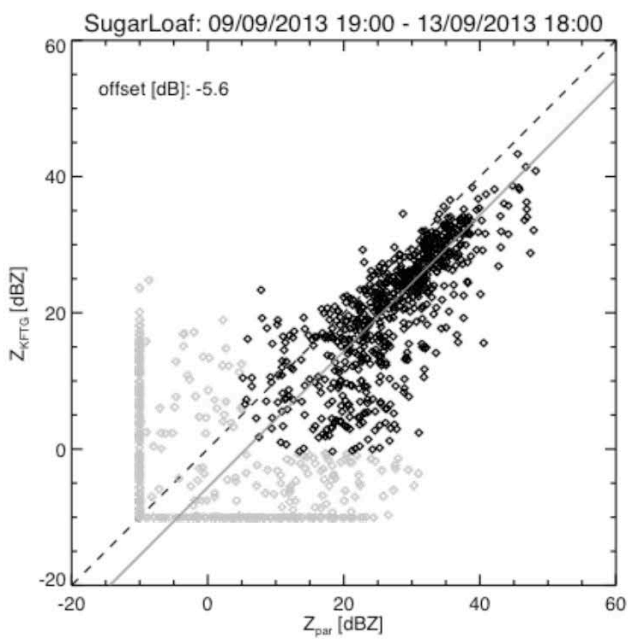
Confirms 4 dB of radar bias in Z

Z comparison between Marshall Parsivel2 and KFTG radar

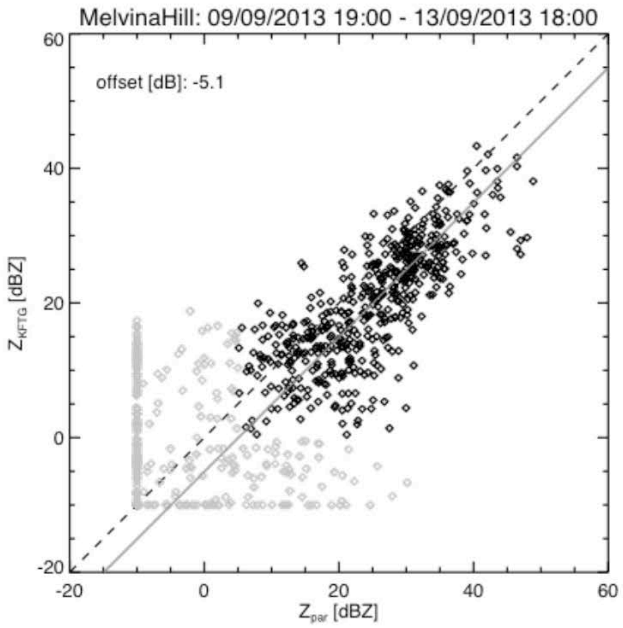


Meteorological Radars and advanced applications





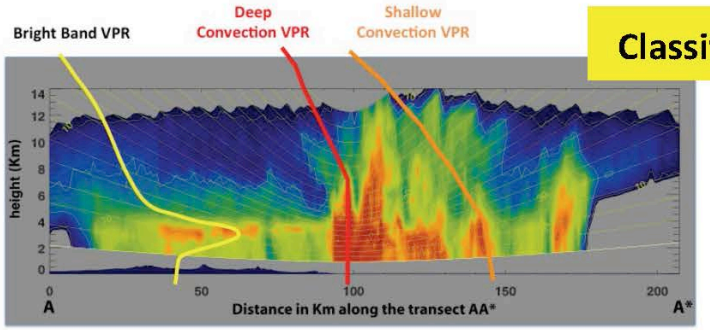
@SUGAR LOAF

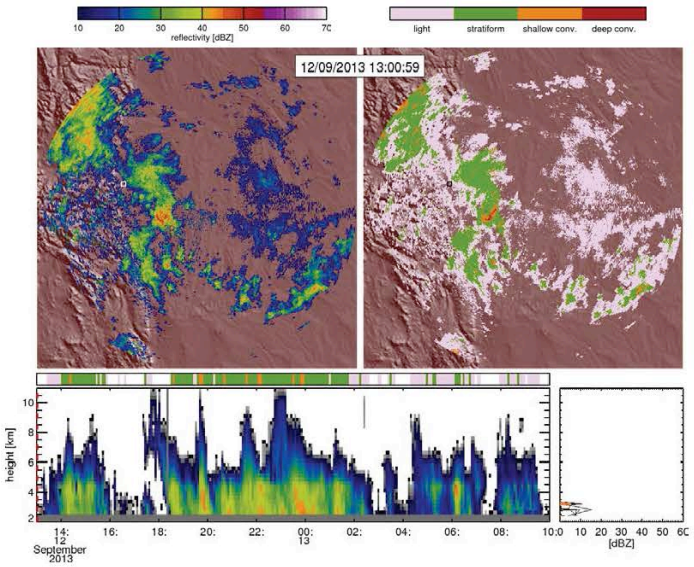


@MELVINA HILL

Confirms 4 dB of radar bias in Z

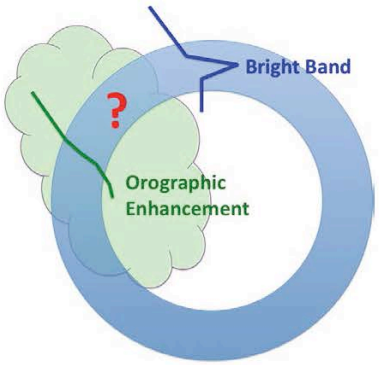
Meteorological Radars and advanced applications

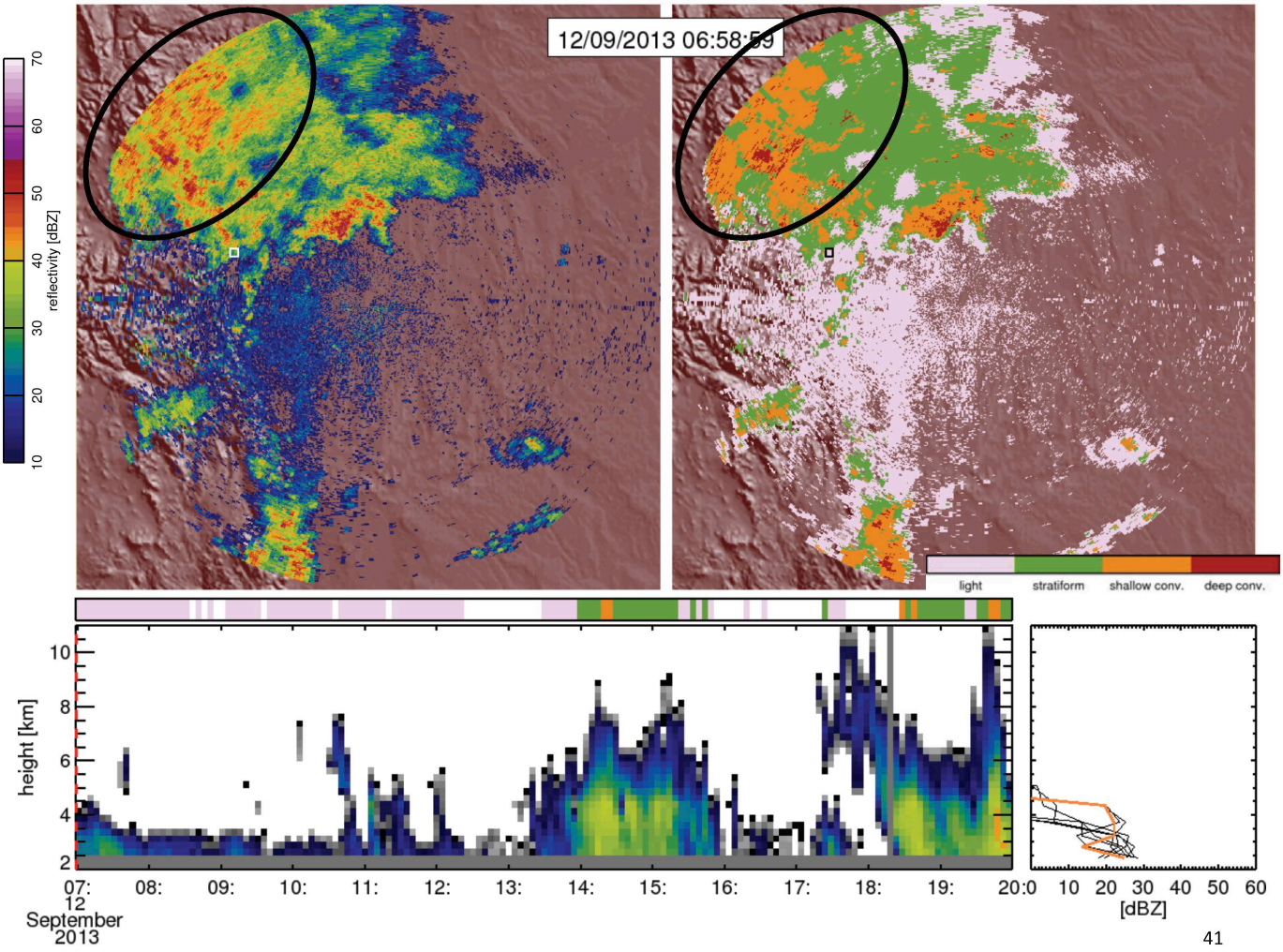




Classification of Precipitation Type

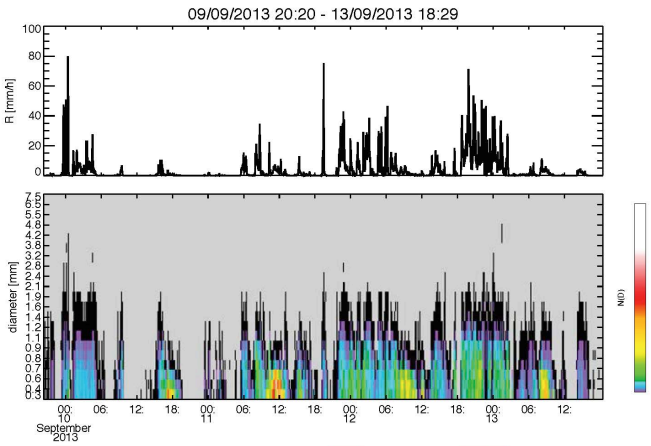
- **Ingredients for Algorithm**
  - intensity threshold
  - cloud depth
  - horizontal & vertical gradients
  - freezing level height
  - intensity above freezing level
- **Challenges**
  - bright band versus orographic enhancement

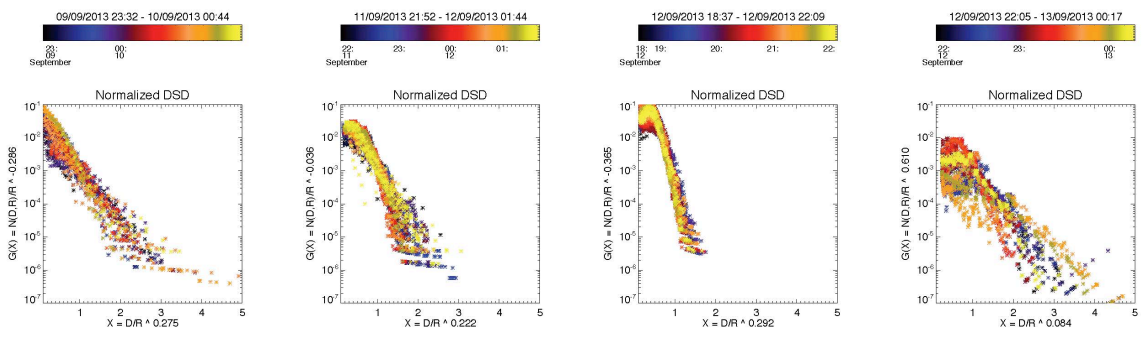




Raindrop Size Distribution

- **Precipitation Type**
  - differences in physical growth processes (dynamics & microphysics)
  - raindrop size spectra variability
- **Analysis Framework**
  - scaling analysis
  - variability controlled by size, number concentration or mixture thereof
- **Z – R Relationships**
  - classified by type (future)





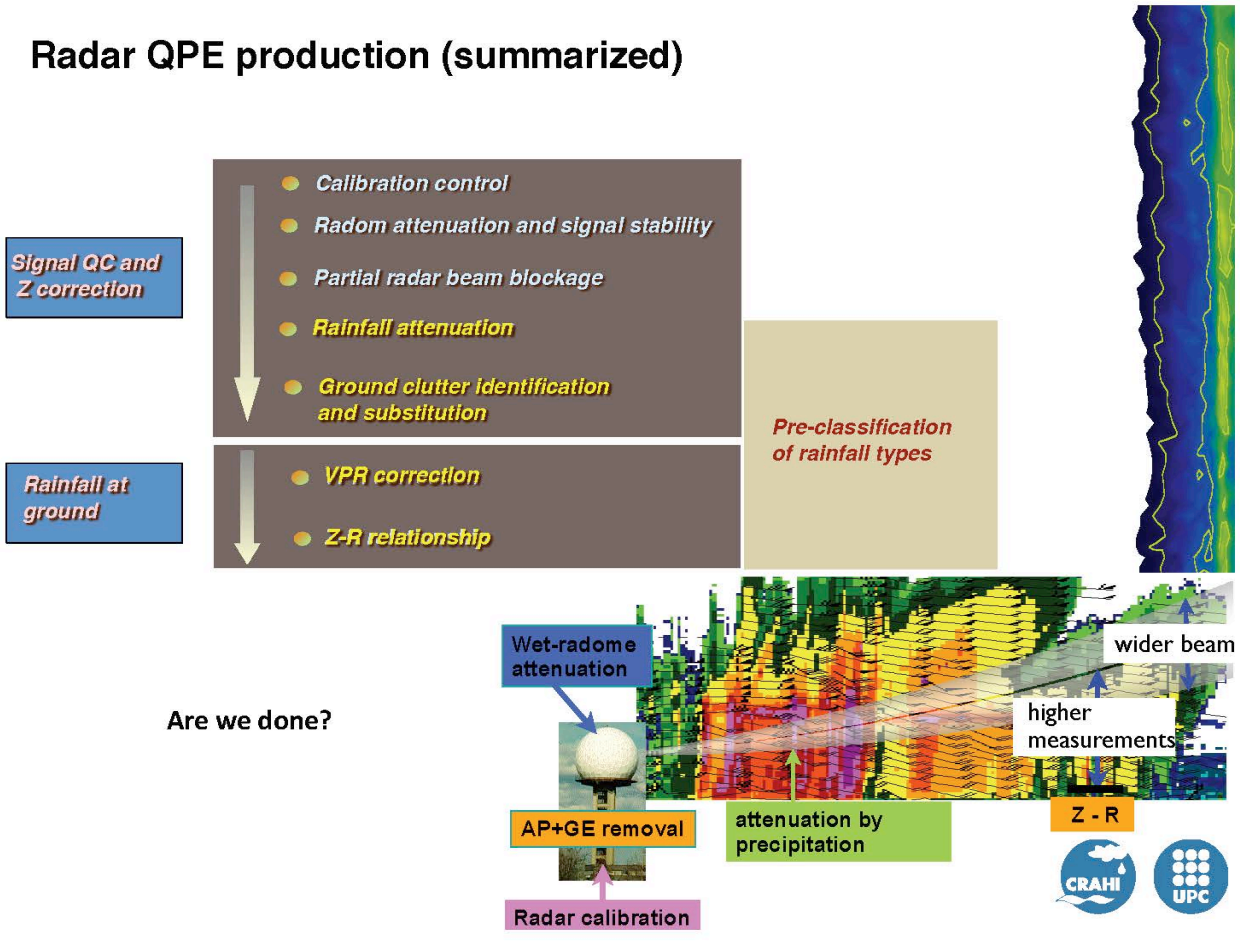
TRAINING PROGRAM ON METEOROLOGICAL AND ADVANCED QUANTITATIVE APPLICATIONS

Methodologies to mosaic radar networks.
Basic methodologies & advanced 3D composite products.

Centre de Recerca Aplicada en Hidrometeorologia
UNIVERSITAT POLITÈCNICA DE CATALUNYA



Radar QPE production (summarized)



Are we done?

Improved QPE from radar compositing

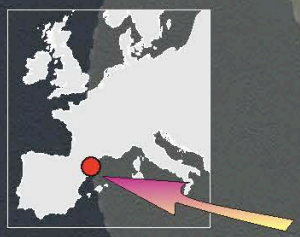
SAIH telemetered network

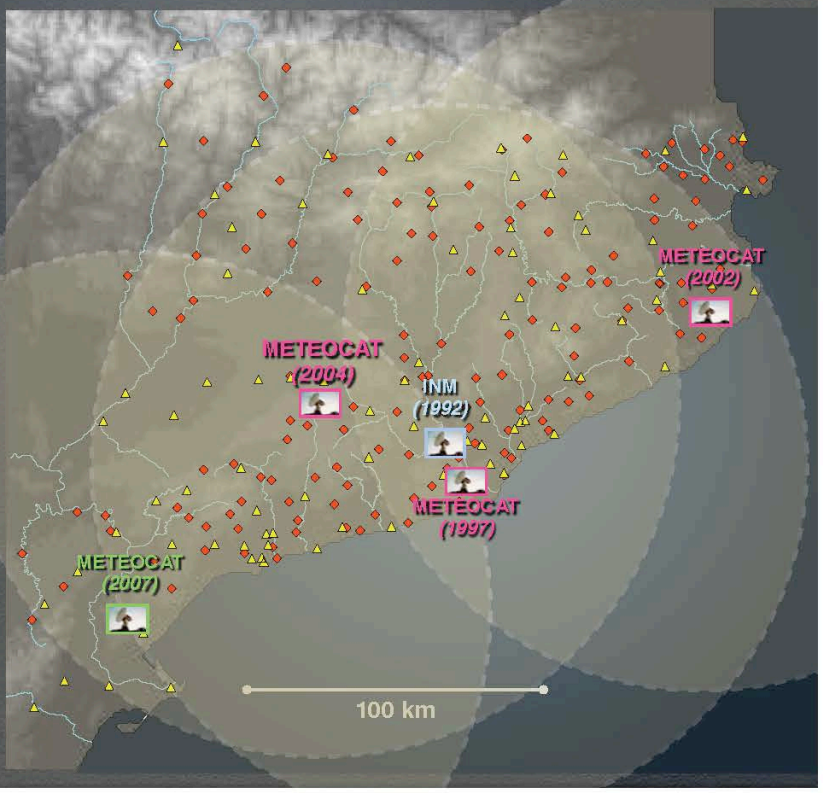
- *stage level*
- *raingauges*

METEOCAT network

- *raingauges*

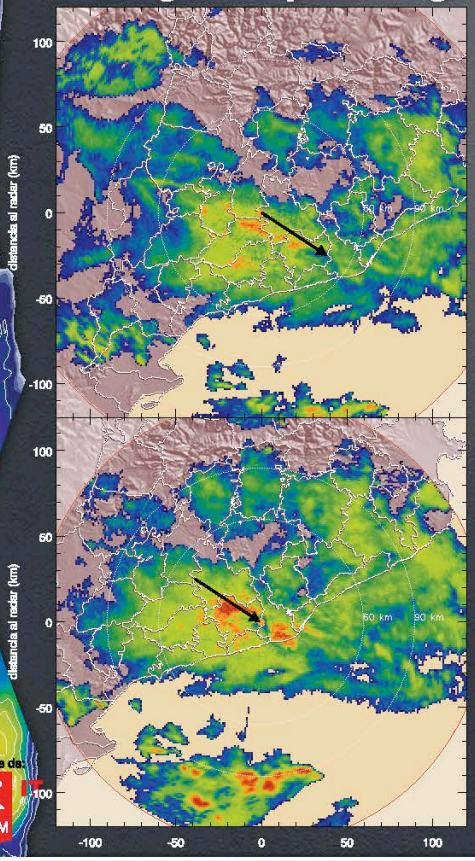
C-band, Doppler Radar network

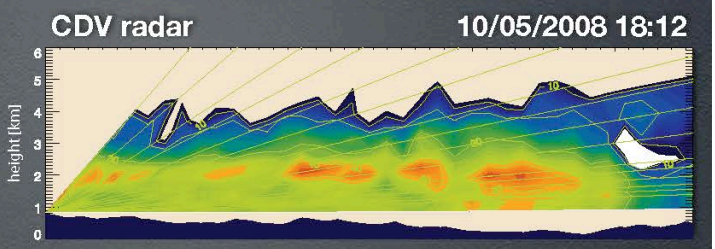


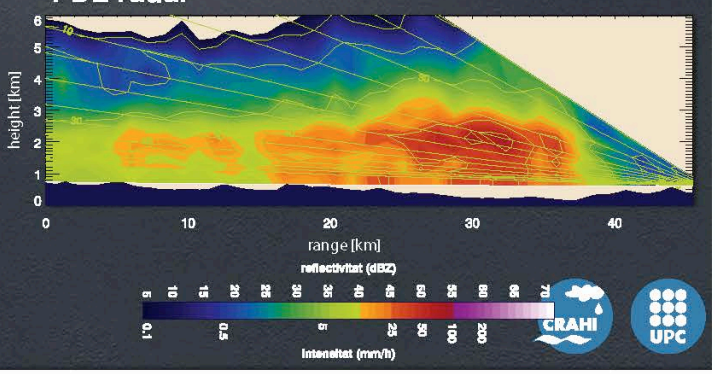


Membre de:
CIDEM

Existing compositing methods



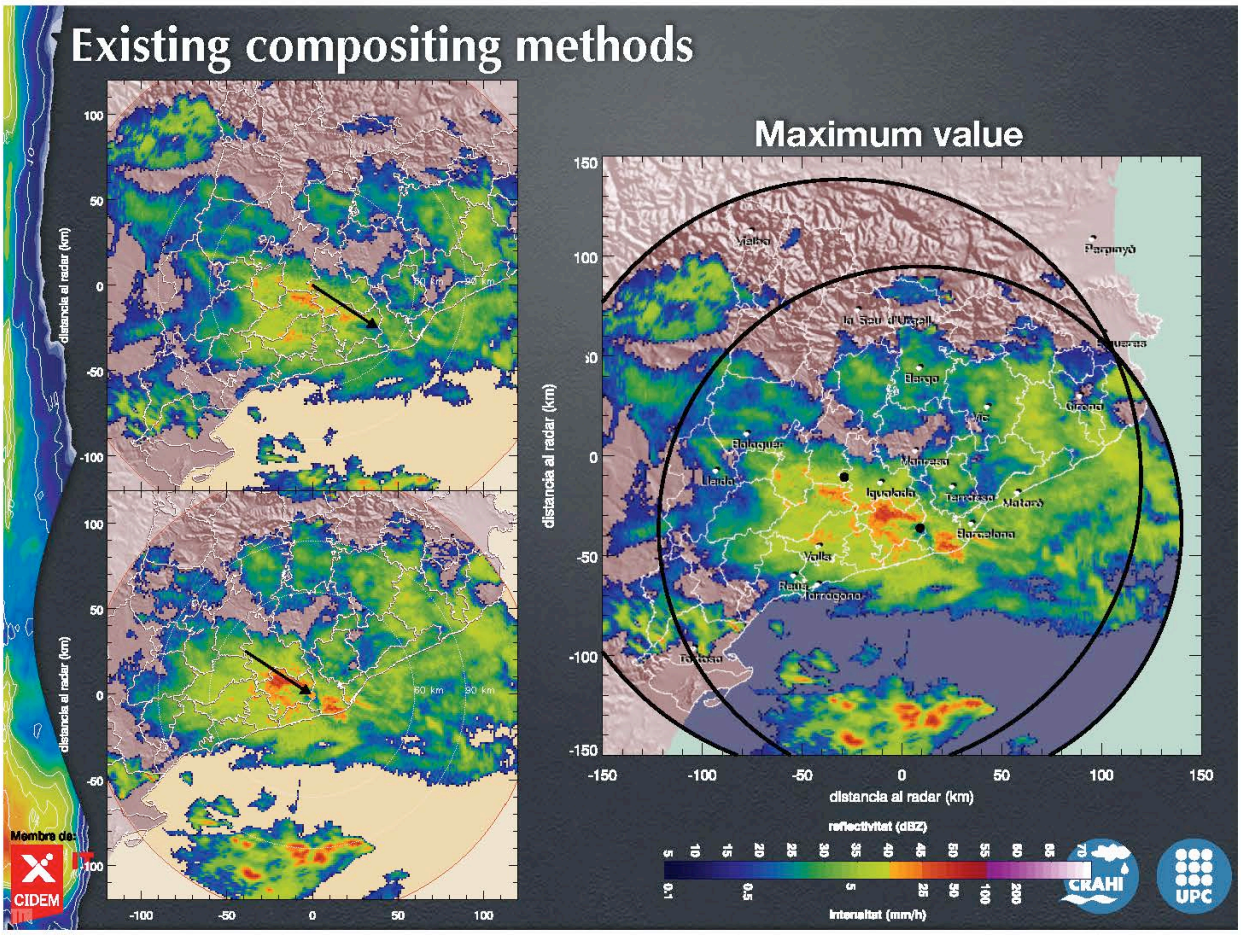


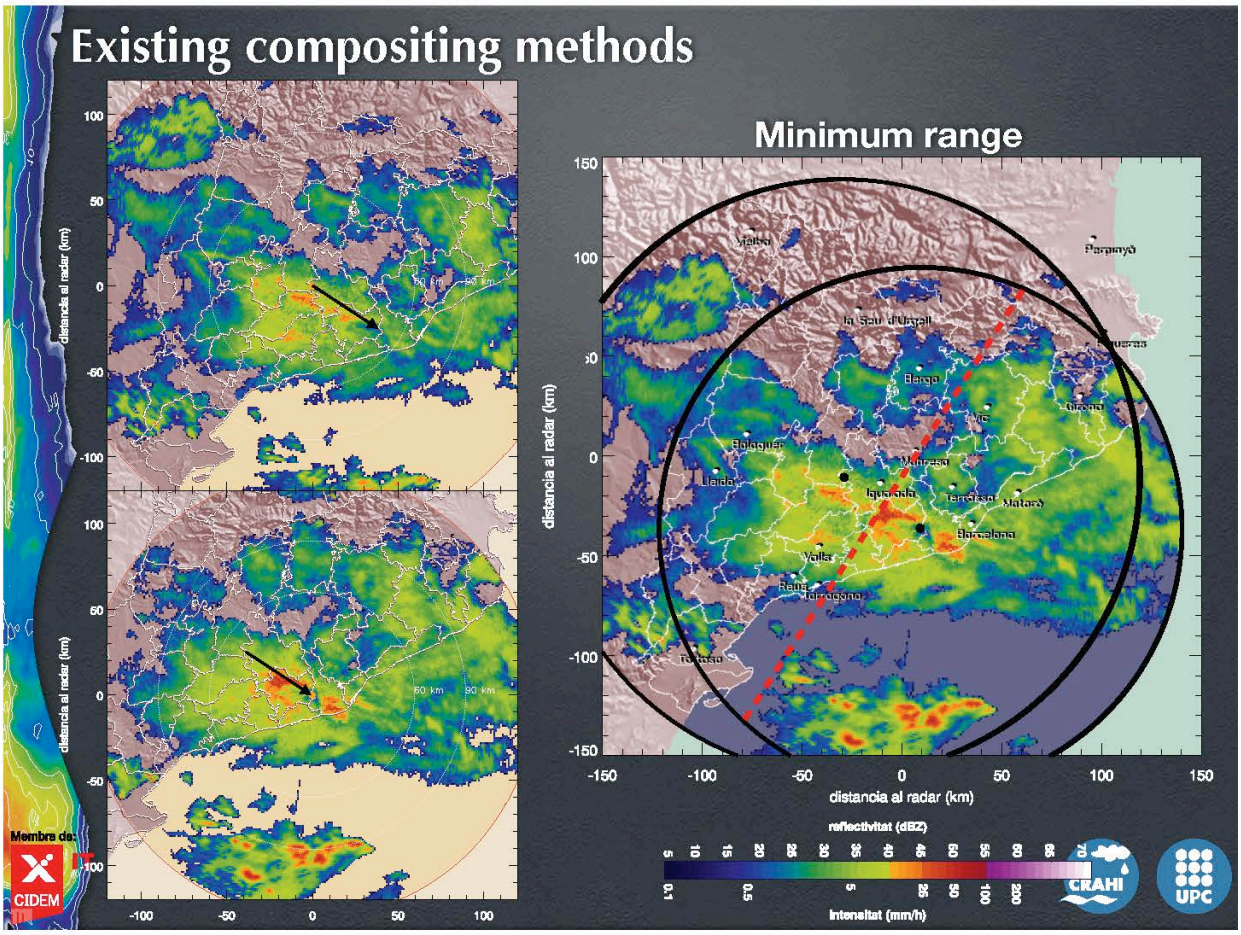


Membre de:
CIDEM

CRAHI

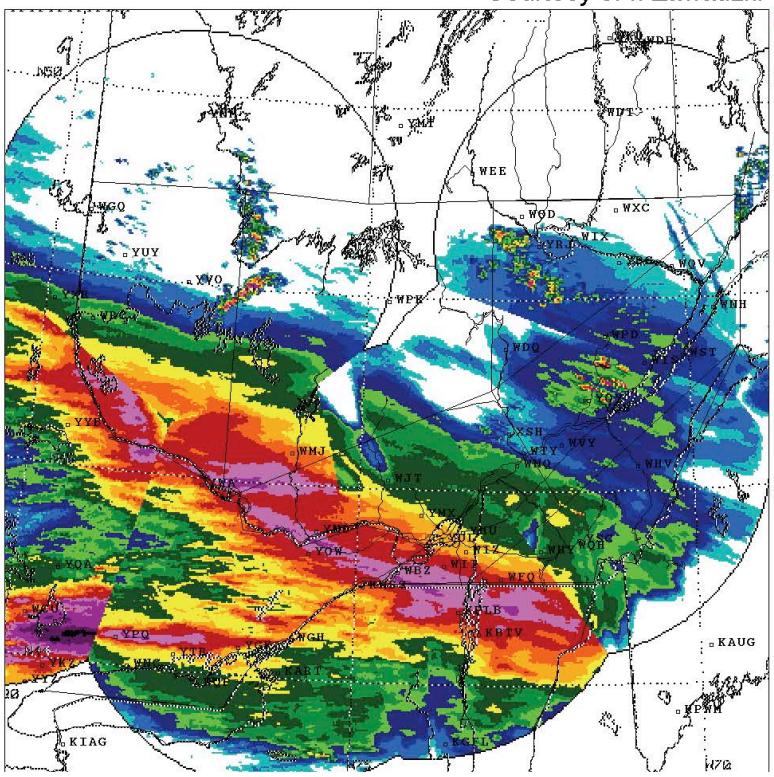
UPC

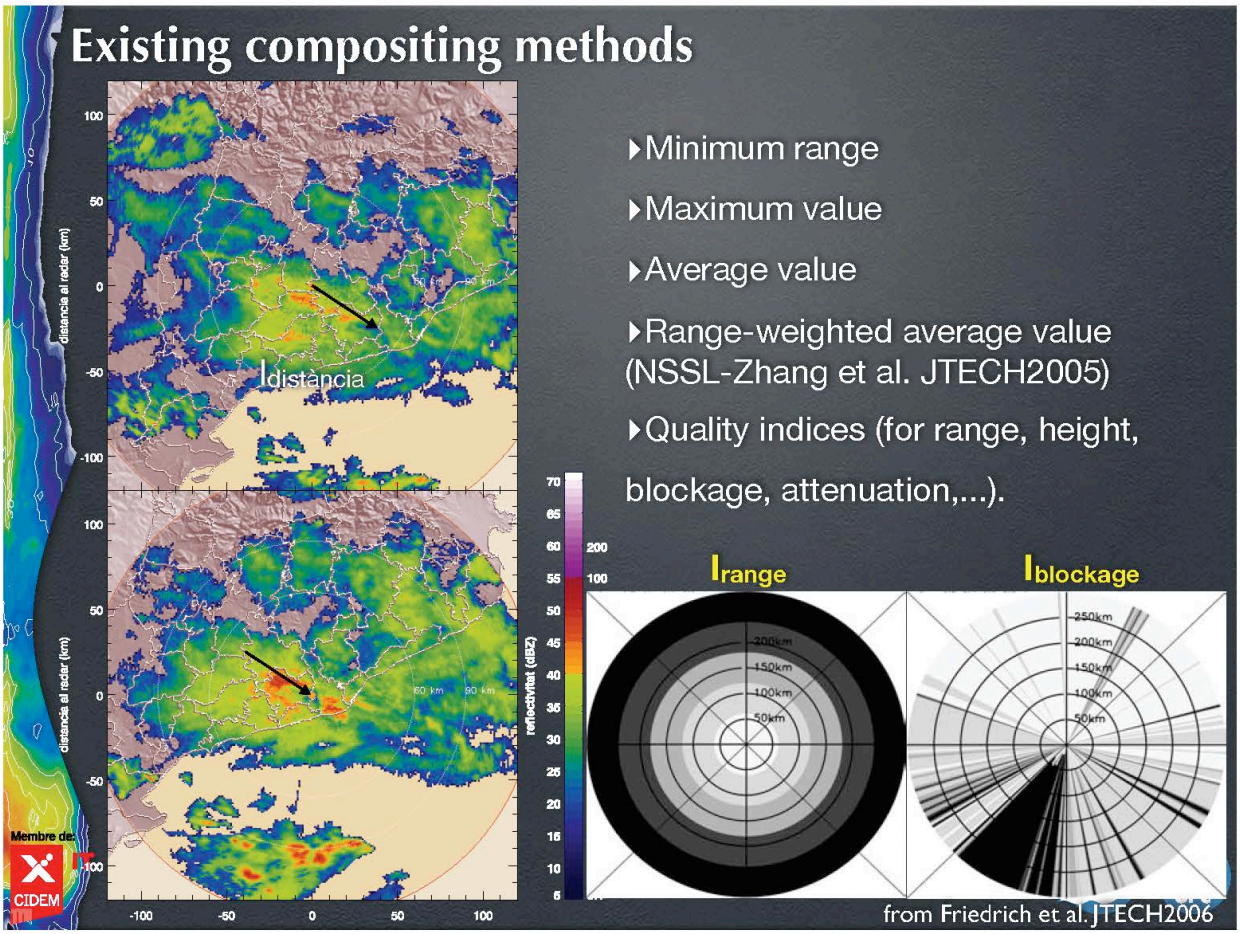

Existing compositing methods
Maximum value
distancia al radar (km)
reflectivitat (dBZ)
intensitat (mm/h)
Membre de:
CIDEM
CRAHI
UPC

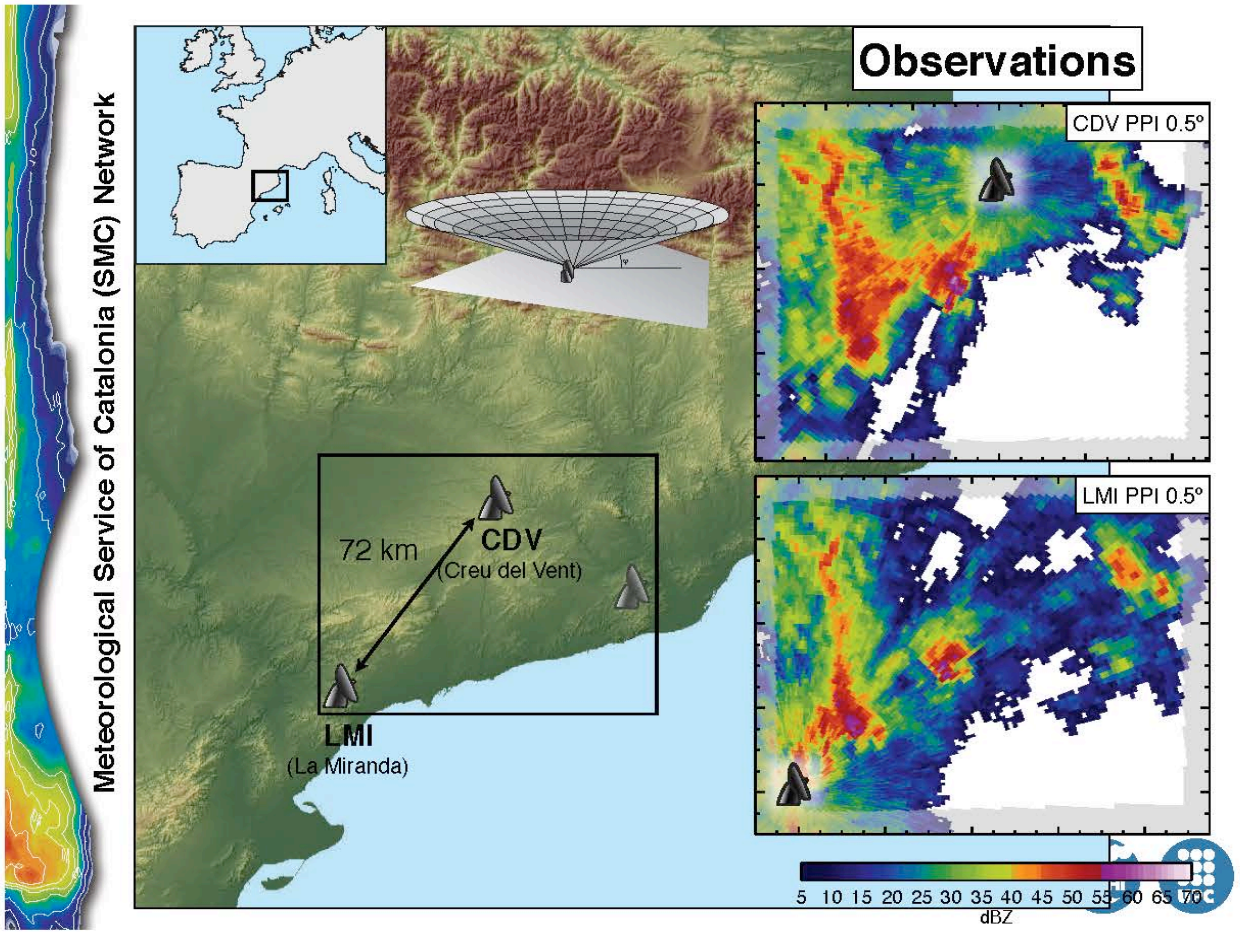

Existing compositing methods
Minimum range
distancia al radar (km)
reflectivitat (dBZ)
intensitat (mm/h)
Membre de:
CIDEM
CRAHI
UPC

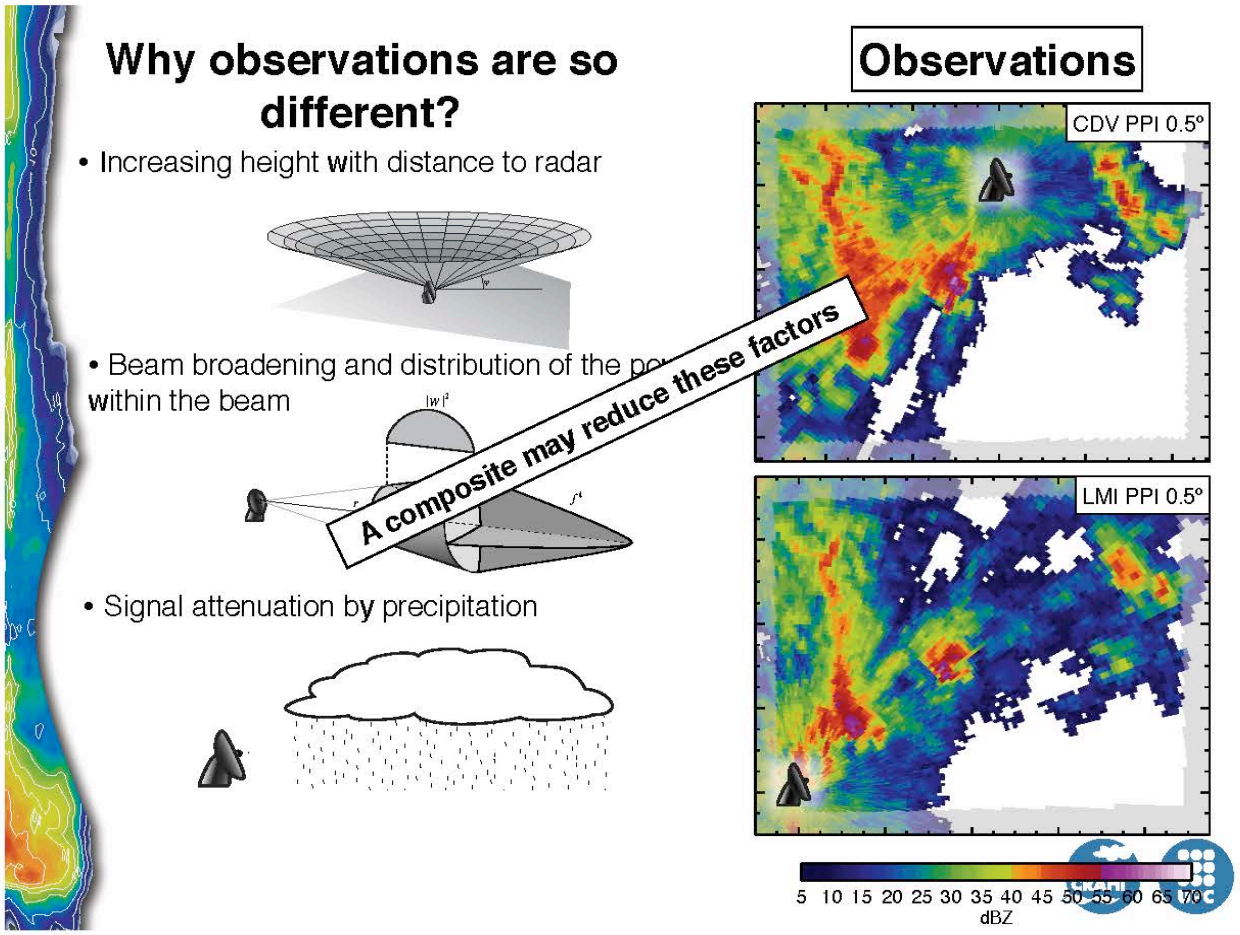
Existing compositing methods

Courtesy of I. Zawadzki

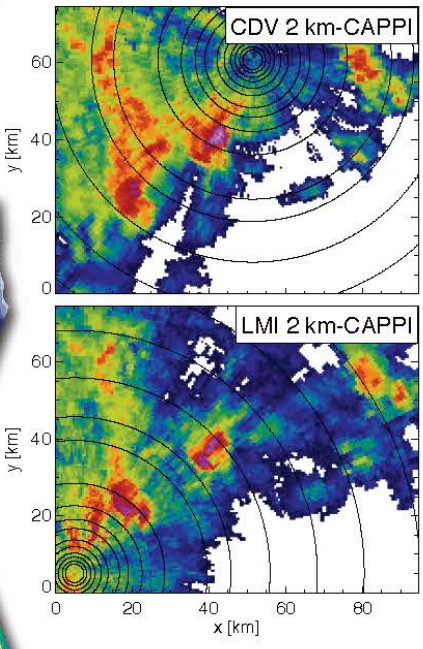





Meteorological Service of Catalonia (SMC) Network
Observations
CDV PPI 0.5º
LMI PPI 0.5º
72 km
CDV
(Creu del Vent)
LMI
(La Miranda)
5 10 15 20 25 30 35 40 45 50 55 60 65 70
dBZ


Why observations are so different?
• Increasing height with distance to radar
• Beam broadening and distribution of the po
within the beam
• Signal attenuation by precipitation
A composite may reduce these factors
Observations
CDV PPI 0.5º
LMI PPI 0.5º
5 10 15 20 25 30 35 40 45 50 55 60 65 70
dBZ

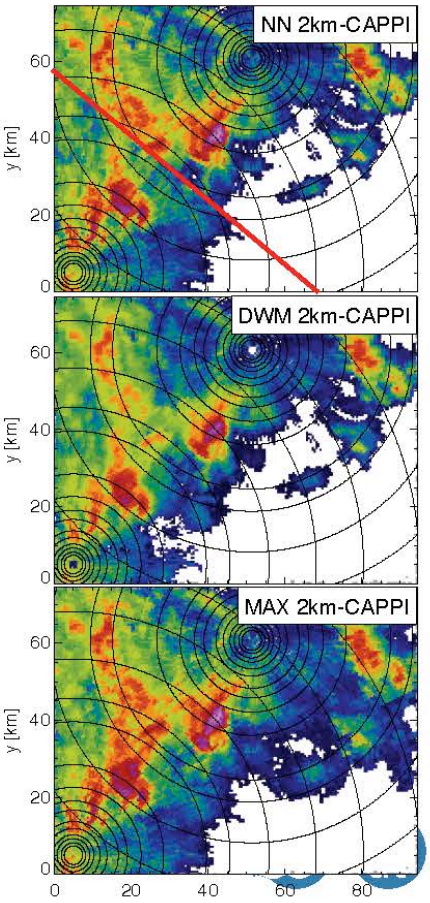
Common compositing methods



Nearest Neighbour

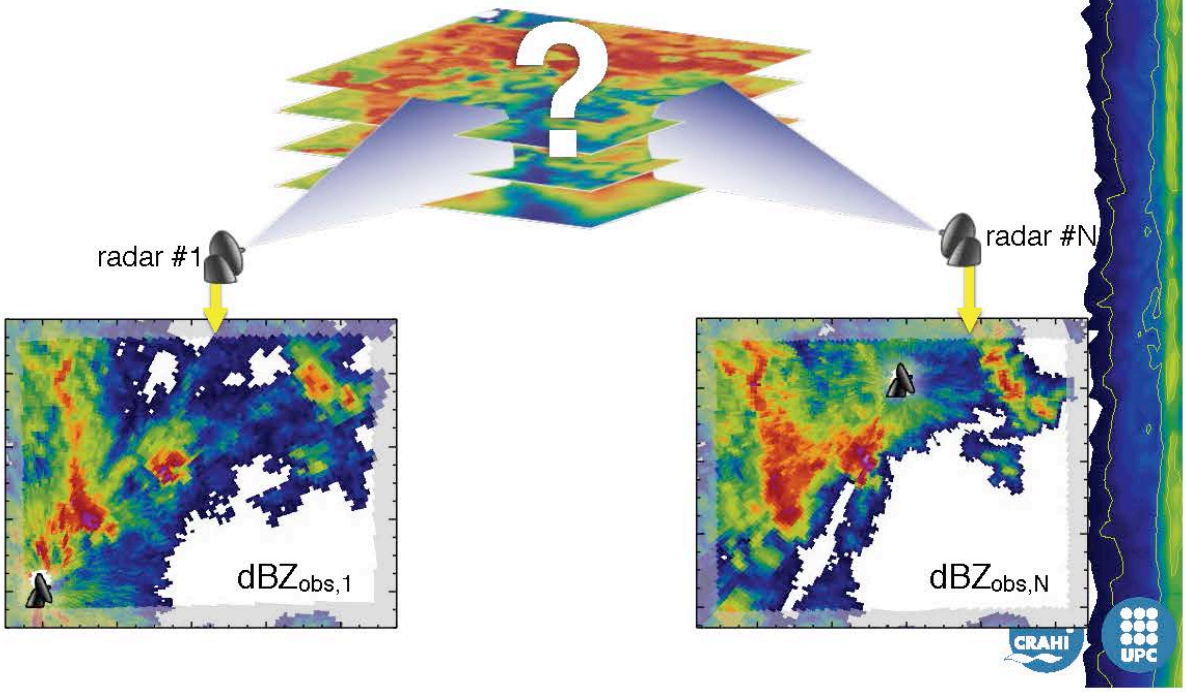
Distance-weighted mean

Maximum value



An inverse compositing method

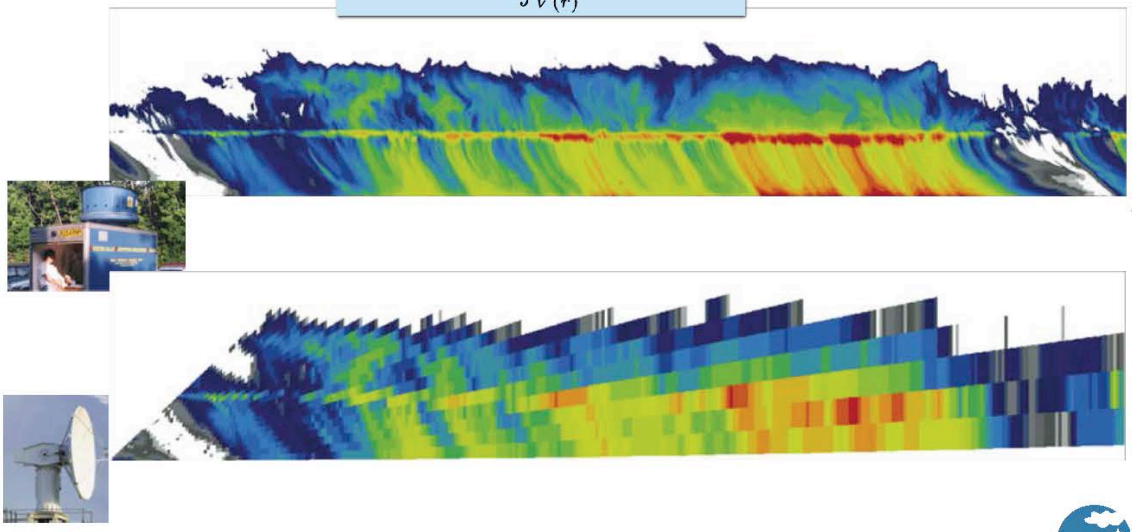
INV: Retrieves the most likely composite compatible with observations considering how the radar samples the atmosphere



An inverse compositing method

INV: Retrieves the most likely composite compatible with observations considering how the radar samples the atmosphere

- Range effects: $Z_{sim}(r) = C \cdot \int_{V(r)} |W|^2 f^4 z \, dV$

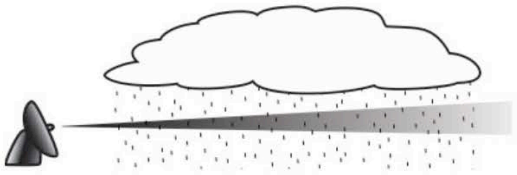


An inverse compositing method

INV: Retrieves the most likely composite compatible with observations considering how the radar samples the atmosphere

- Range effects:

- Path attenuation:



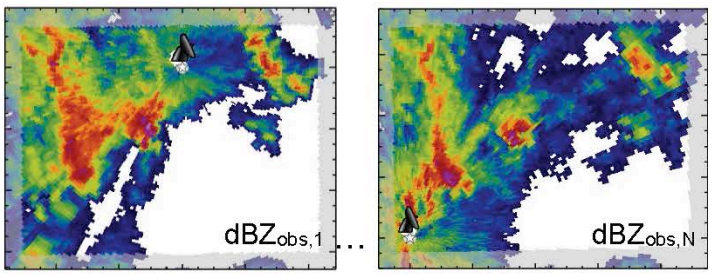
$$A(r) = \exp\left[-2 \cdot \ln(10) \int_0^r K(s,z) ds\right]$$

$$Z_{sim}(r) = C \cdot \int_{V(r)} |W|^2 f^4 z \, dV \cdot A(r)$$

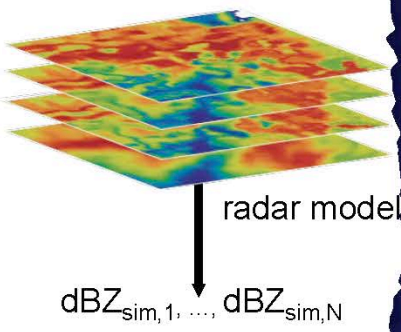
the radar operator

INV mosaicking algorithm – structure

Inputs: 1) Observations (N radars)



2) A good first guess (M2)



Optimization: (conjugate gradient method).

Cost function:

$$J(z) = \| dBZ_{sim,1}(z) - dBZ_{obs,1}(z) \|^2 + \ldots + \| dBZ_{sim,N}(z) - dBZ_{obs,N}(z) \|^2$$

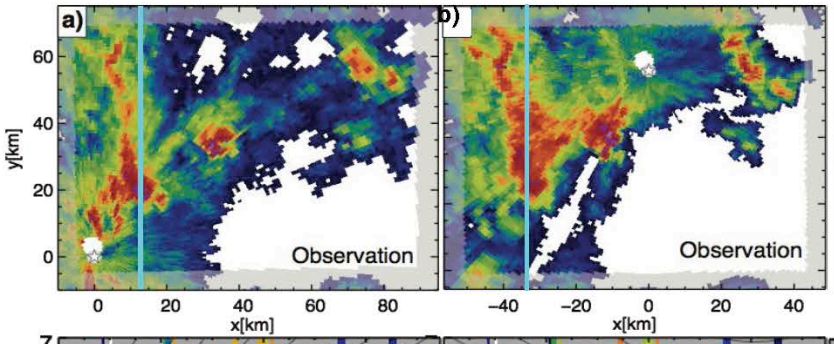
Result: 3-D high-resolution dBZ mosaic (500 x 500 x 250 m^3).

$$z_{ret} = \arg\min J(z)$$



INV mosaicking algorithm – first guess

NSSL: Distance-weighted mean (Zhang et al. JTECH 2005).



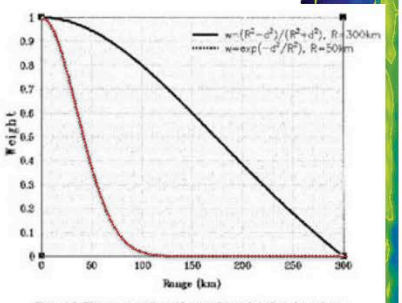
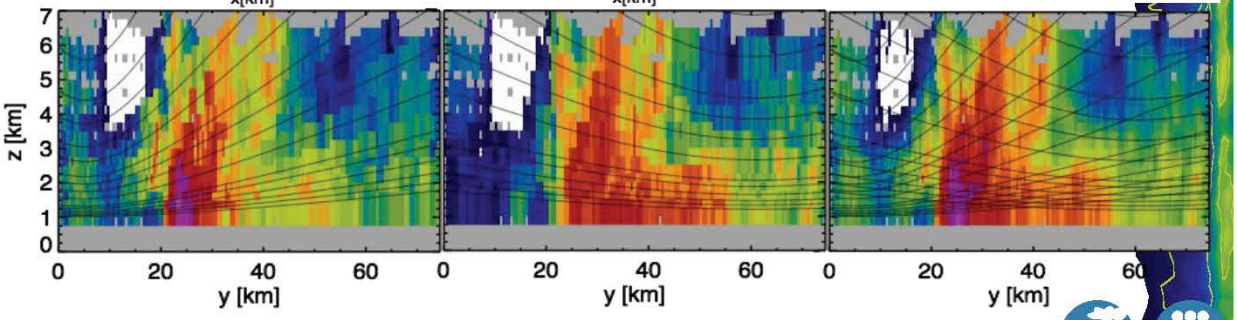
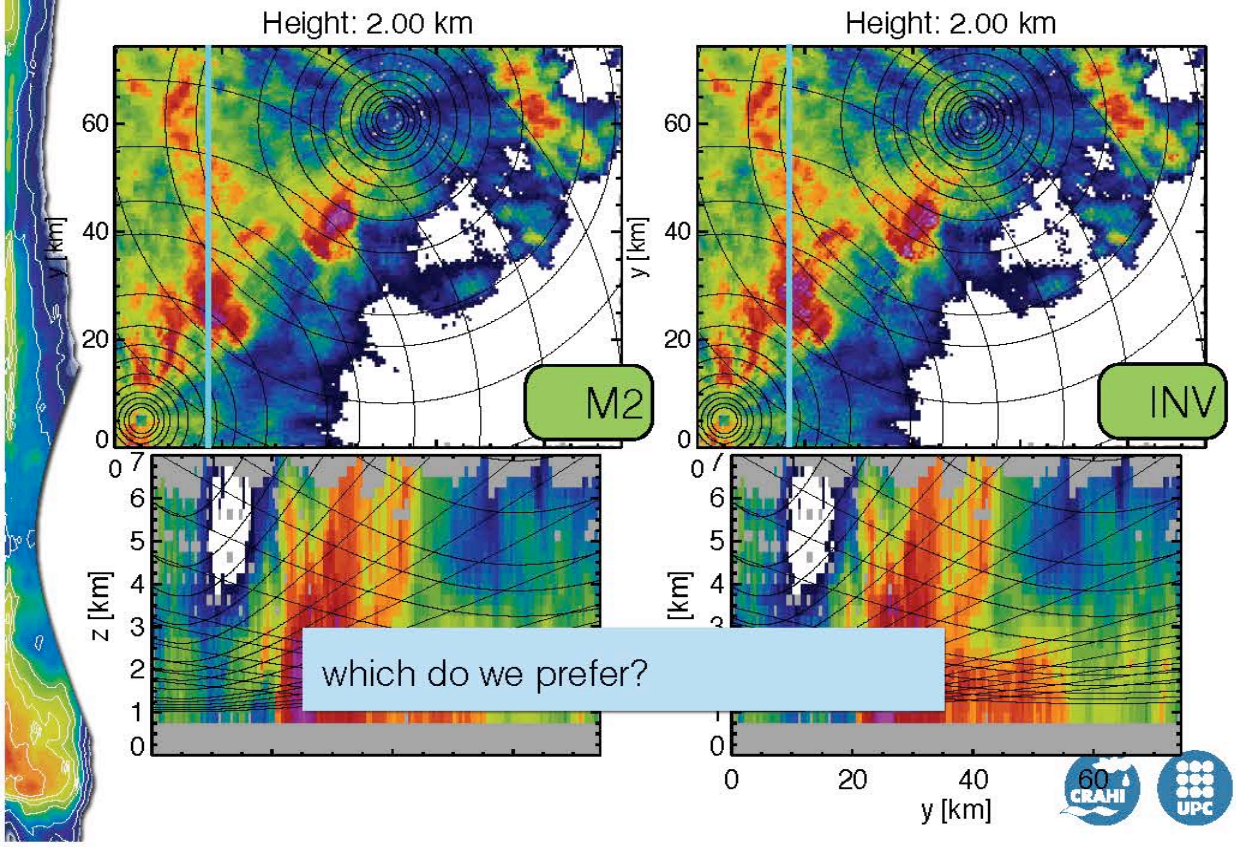


FIG. 15. Two examples of mosaic weighting functions.

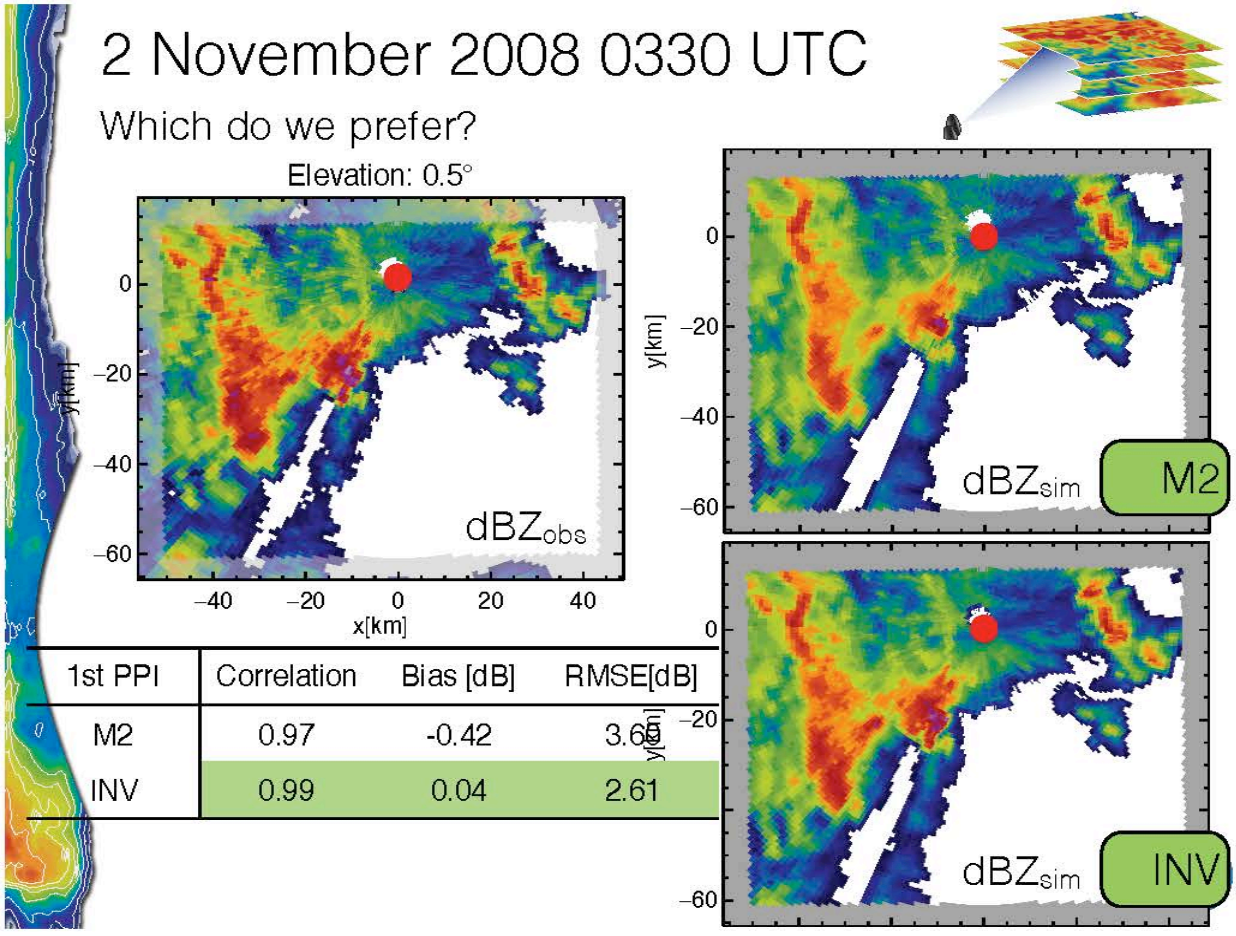


2 November 2008 0330 UTC



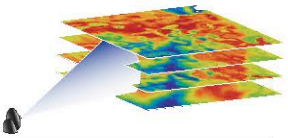
2 November 2008 0330 UTC

Which do we prefer?



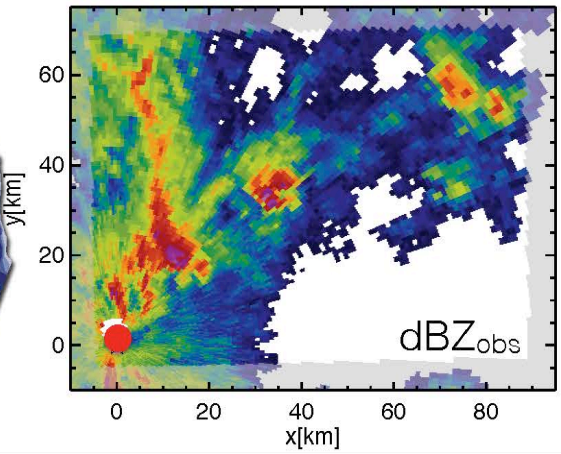
1st PPI	Correlation	Bias [dB]	RMSE[dB]
M2	0.97	-0.42	3.66
INV	0.99	0.04	2.61

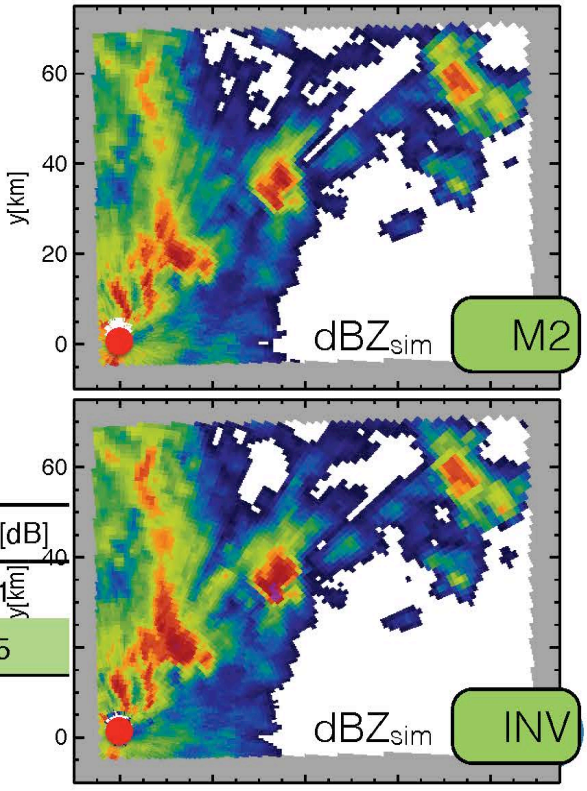
2 November 2008 0330 UTC



Which do we prefer?

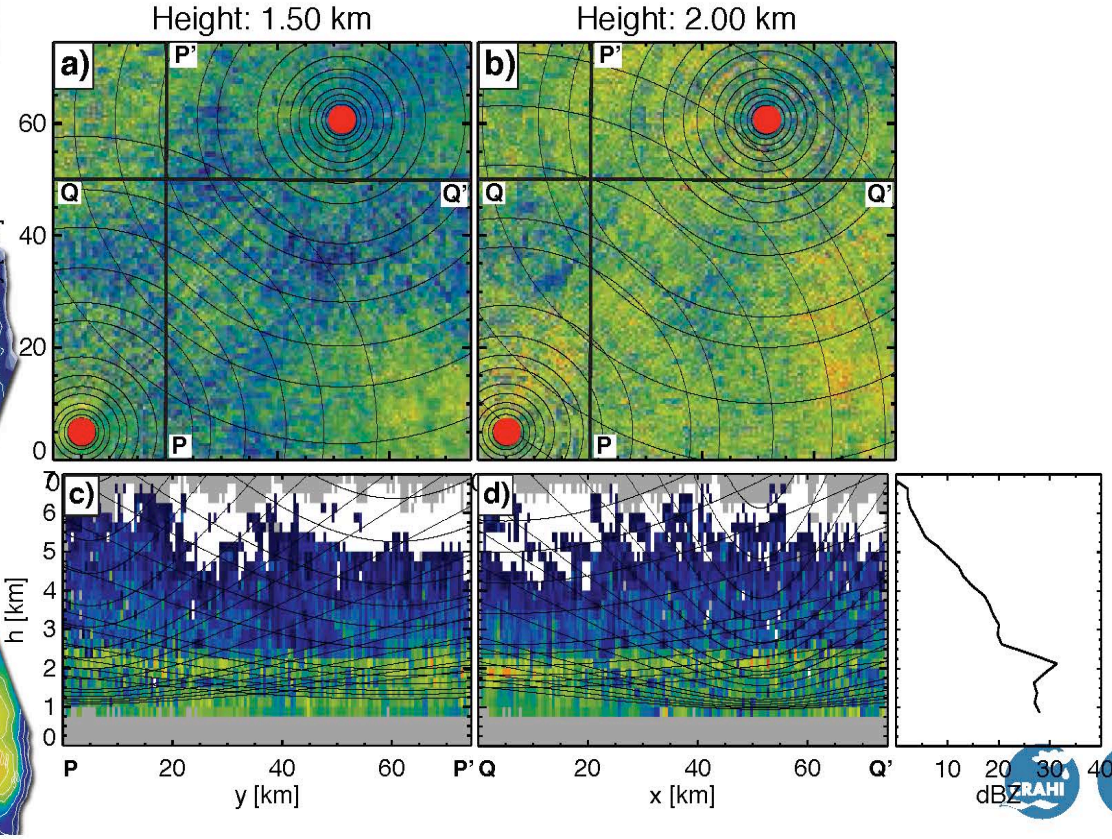
Elevation: 0.5°

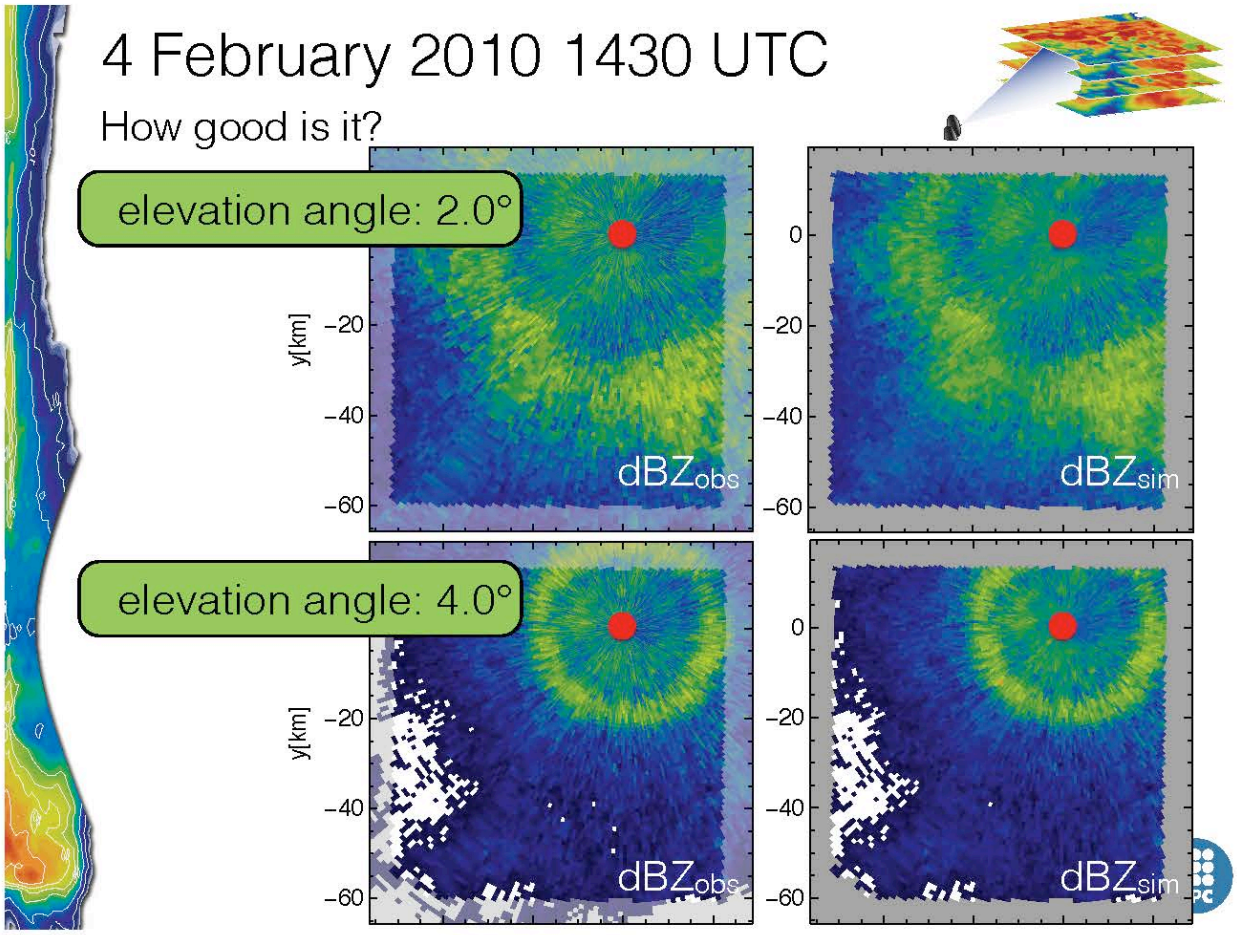


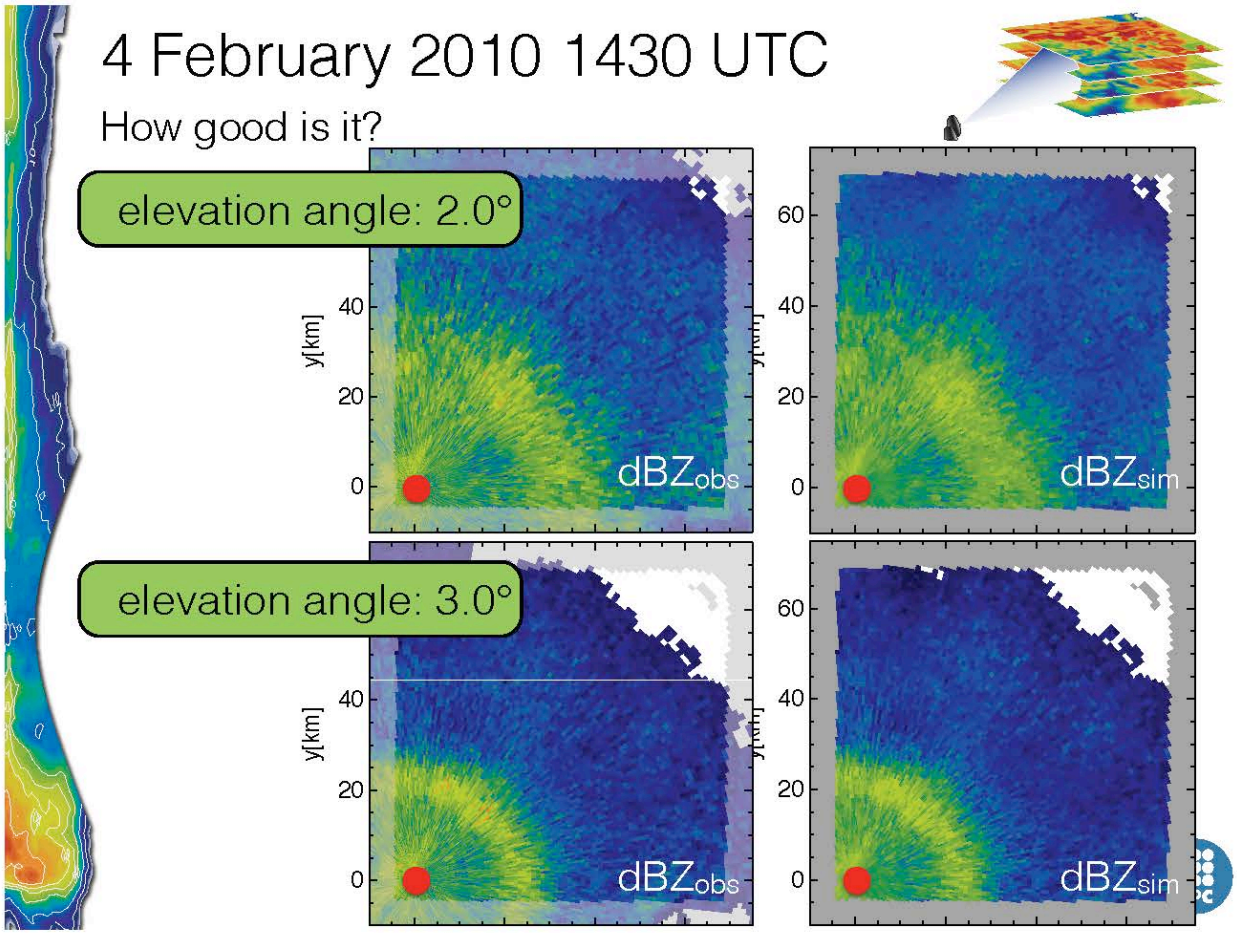


1st PPI	Correlation	Bias [dB]	RMSE[dB]
M2	0.93	0.10	4.61
INV	0.94	0.13	4.45

4 February 2010 1430 UTC

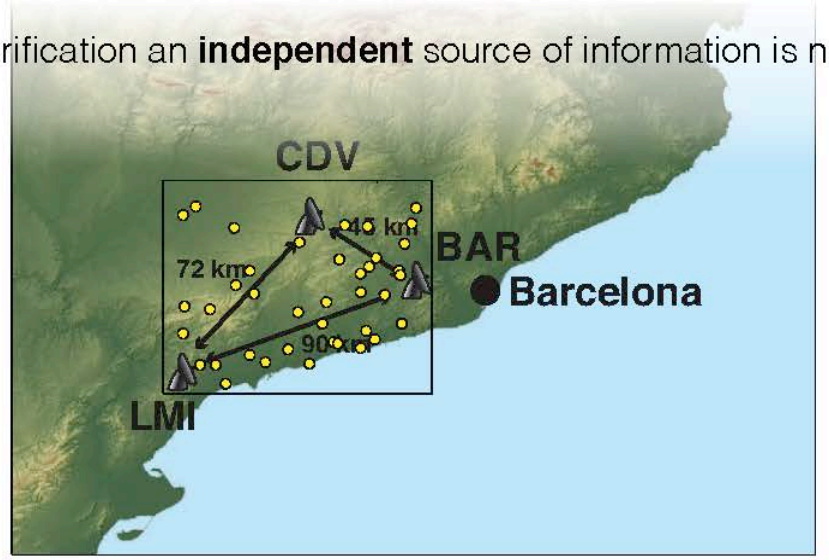



4 February 2010 1430 UTC
How good is it?
elevation angle: 2.0°
elevation angle: 4.0°
y[km]
−20
−40
−60
0
dBZobs
dBZsim


4 February 2010 1430 UTC
How good is it?
elevation angle: 2.0°
elevation angle: 3.0°
y[km]
0
20
40
60
dBZobs
dBZsim

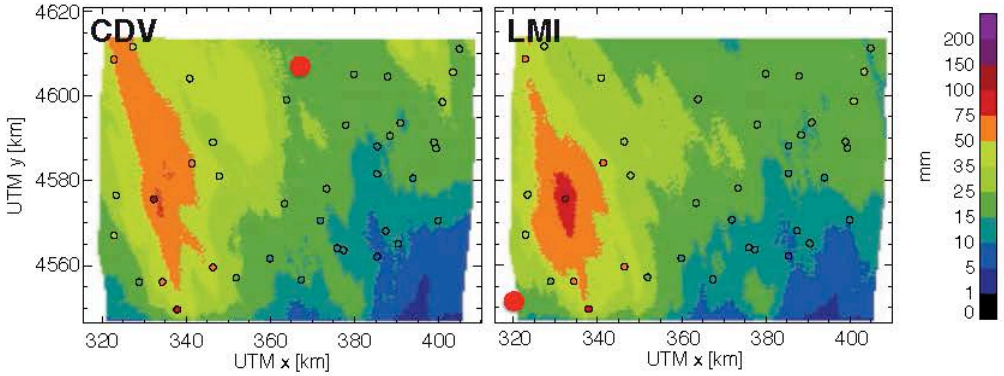
Evaluation

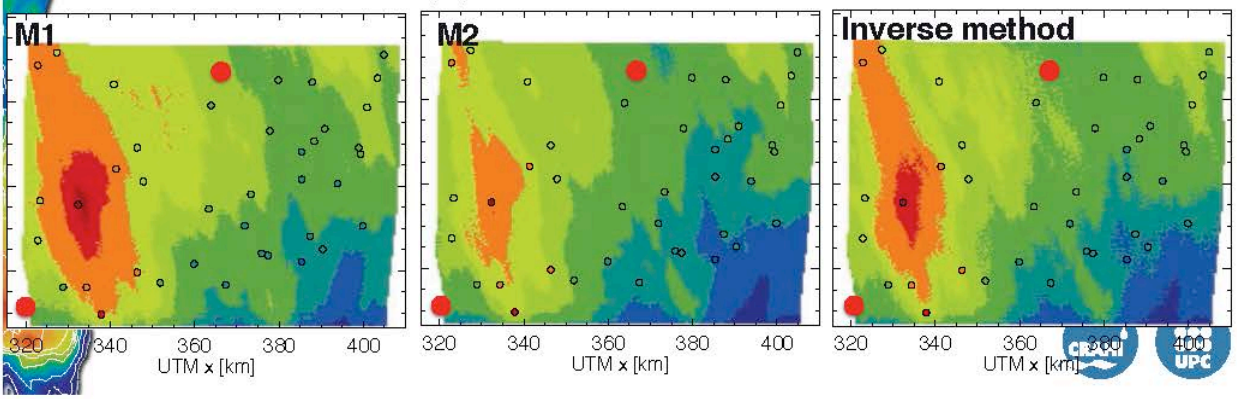
- The inverse method has been applied with LMI and CDV radars
- Similarity between simulations and observations for these radars only show the **consistency** of the method
- For verification an **independent** source of information is needed



2 November 2008

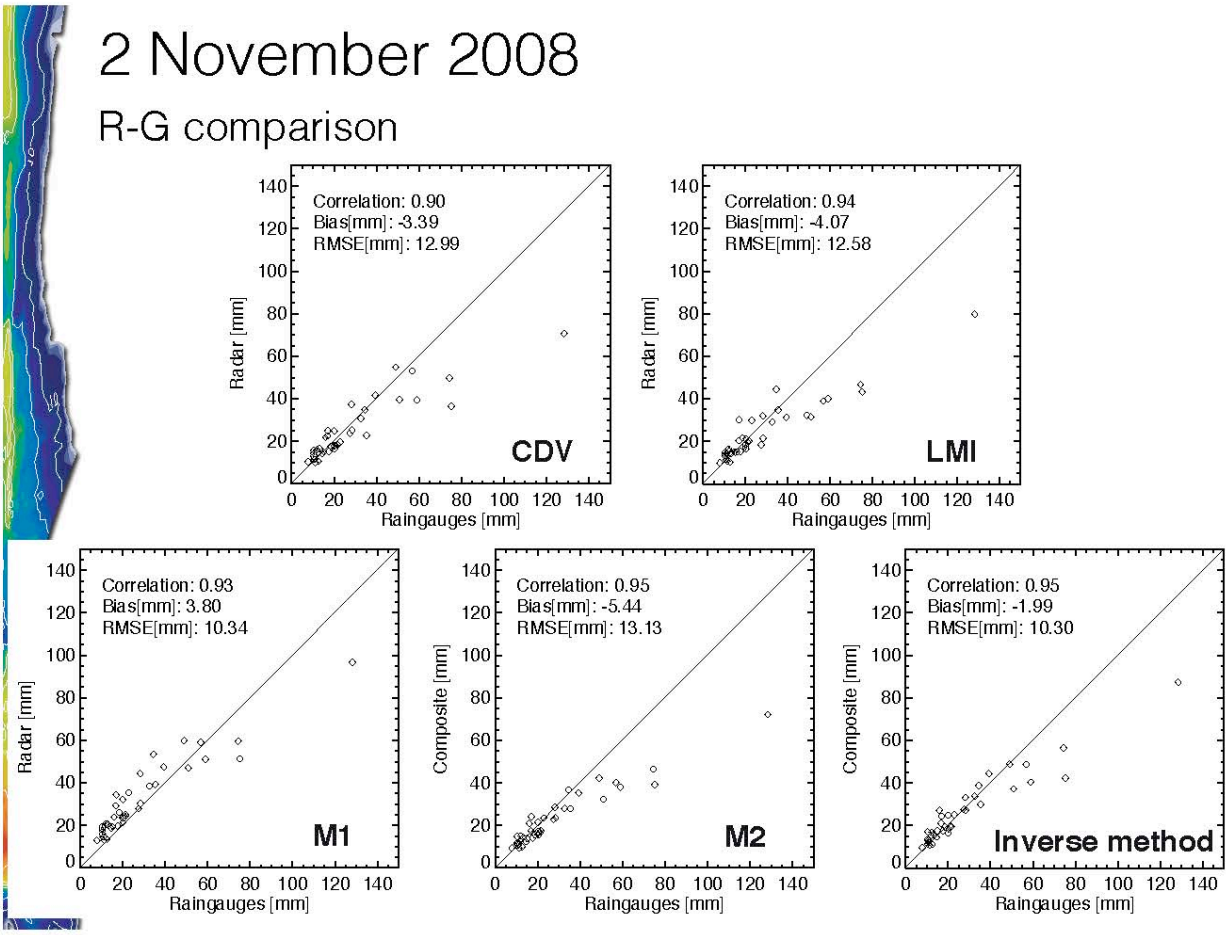
R-G comparison





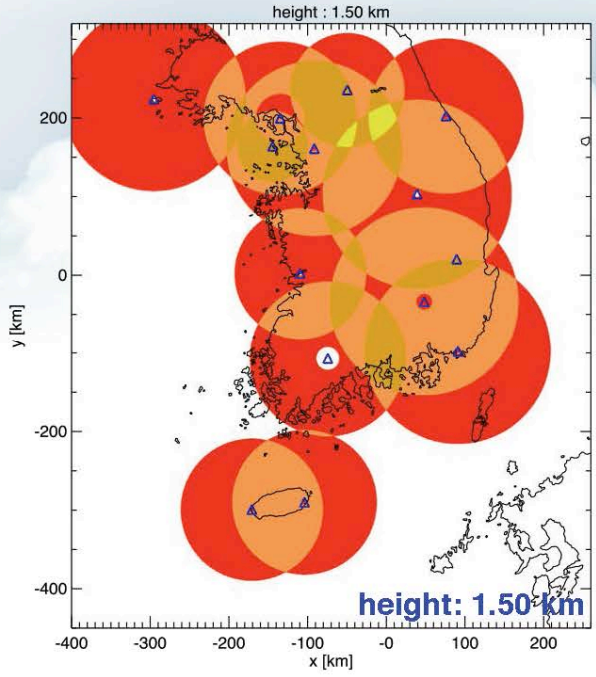
2 November 2008

R-G comparison



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NSSL mosaicking algorithm – Korean mosaic



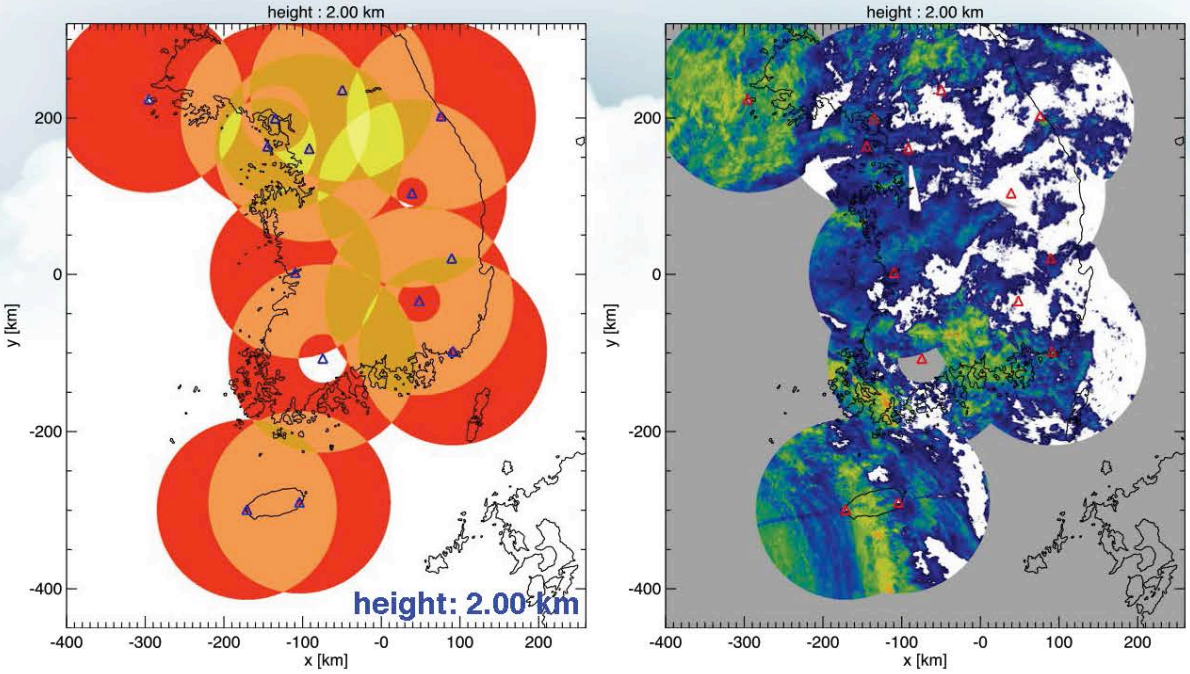
- 14 S-band radars (almost no attenuation).
- 2 C-band radars
- Various scanning protocols
- Beam width: ~1 °
- Resolution: 1° x 250 m.
- Maximum range: 120 km

Grid:

- Domain: 660km x 770km x 7.5km
- Resolution: 0.5km x 0.5 km x 0.25km

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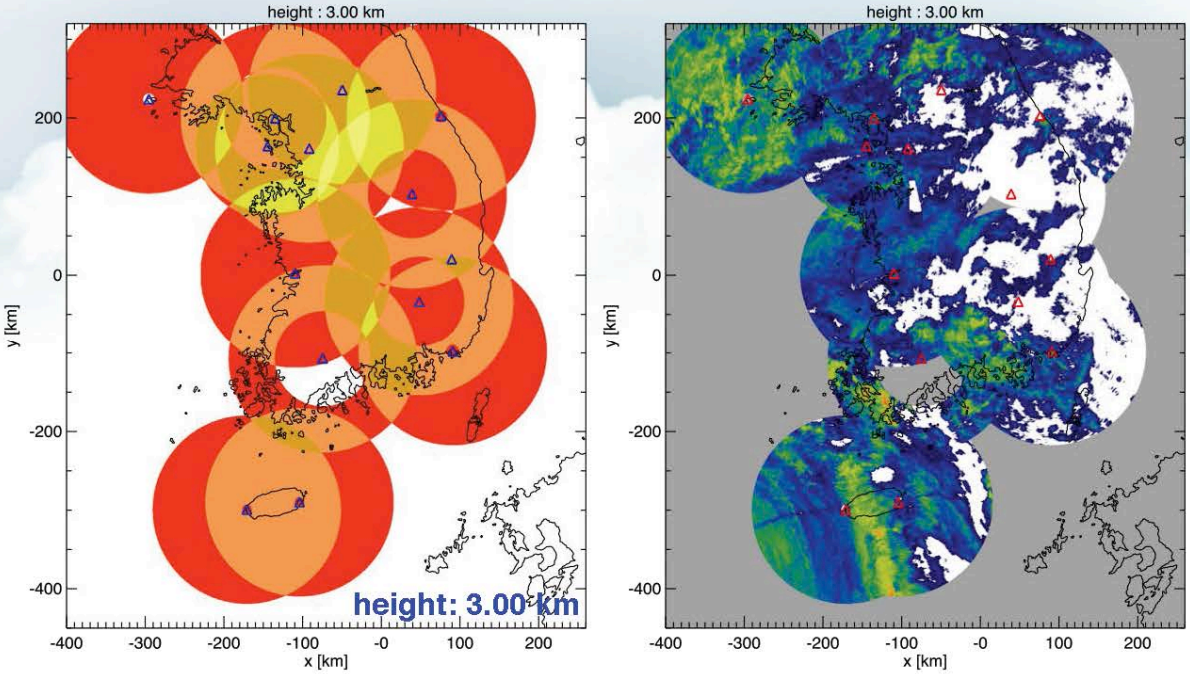
NSSL mosaicking algorithm – Korean mosaic



II. Research details and performance (for Year 1)
4. Research details and performance

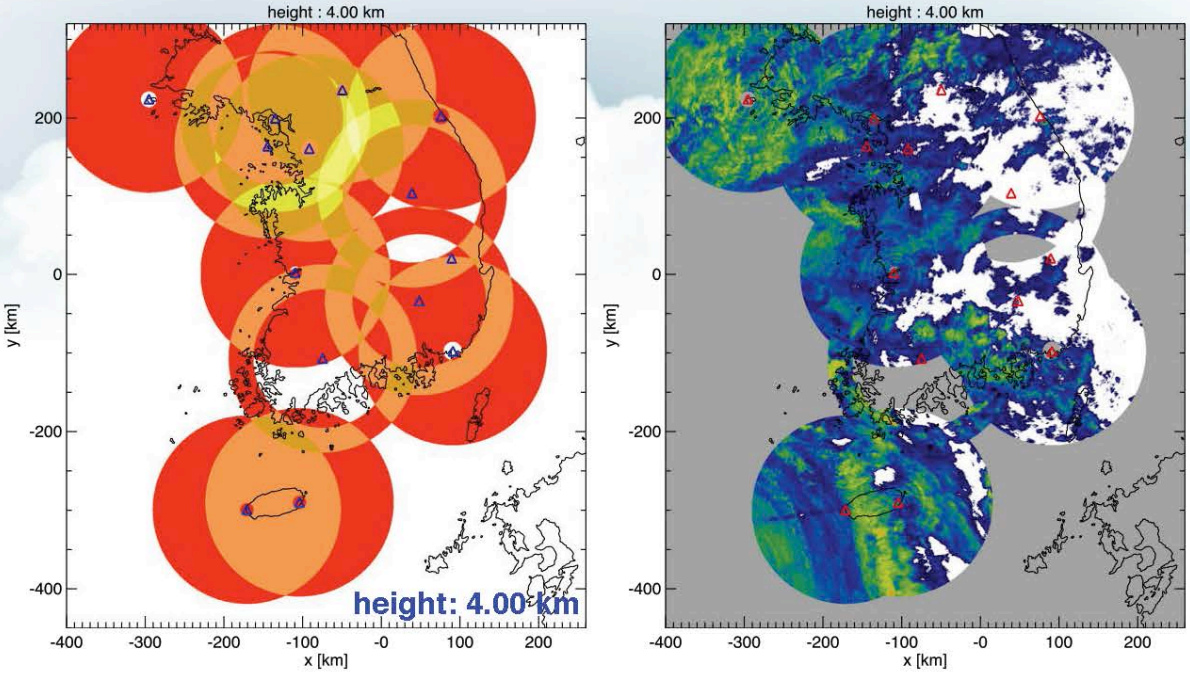
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NSSL mosaicking algorithm – Korean mosaic



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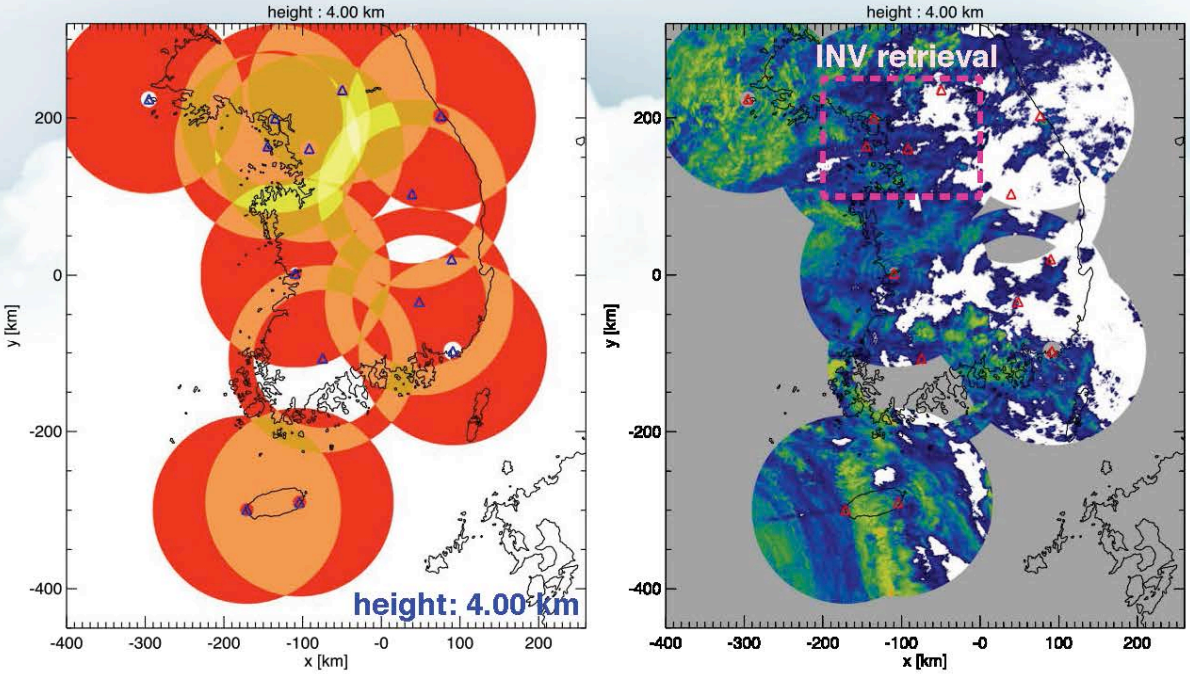
NSSL mosaicking algorithm – Korean mosaic



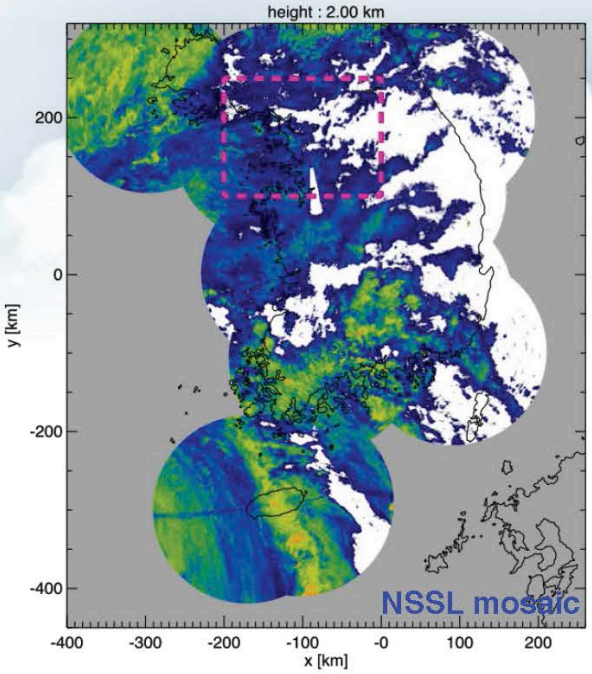
II. Research details and performance (for Year 1)
4. Research details and performance

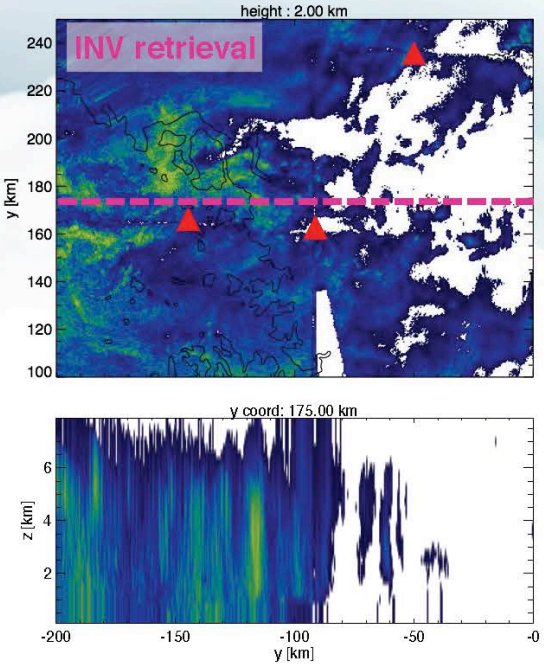
Centre de Recerca Aplicada en Hidrometeorologia
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NSSL mosaicking algorithm – Korean mosaic



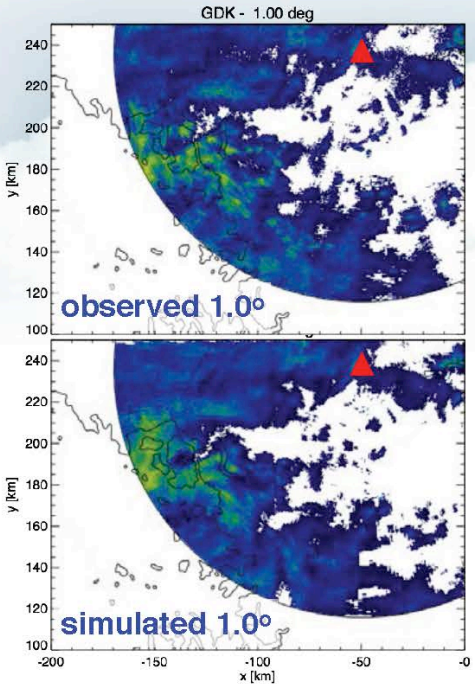
INV mosaicking algorithm – Case #1: 12 July 2015 0800 UTC

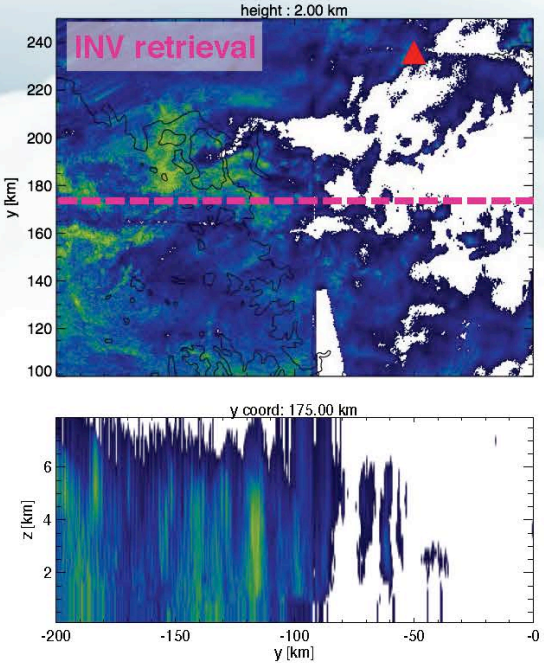




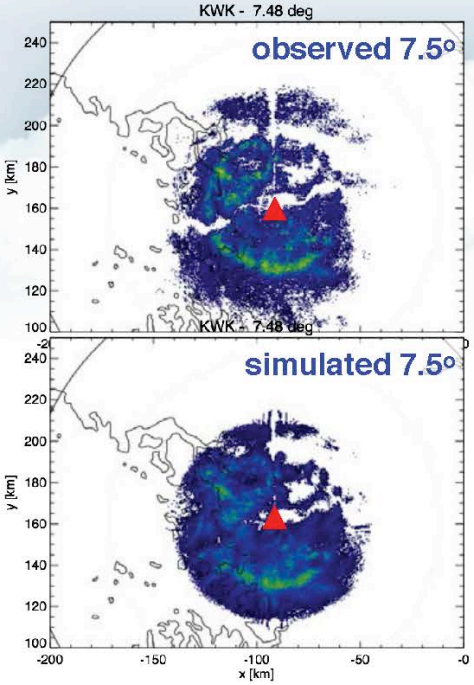
II. Research details and performance (for Year 1)
4. Research details and performance
Centre de Recerca Aplicada en Hidrometeorologia
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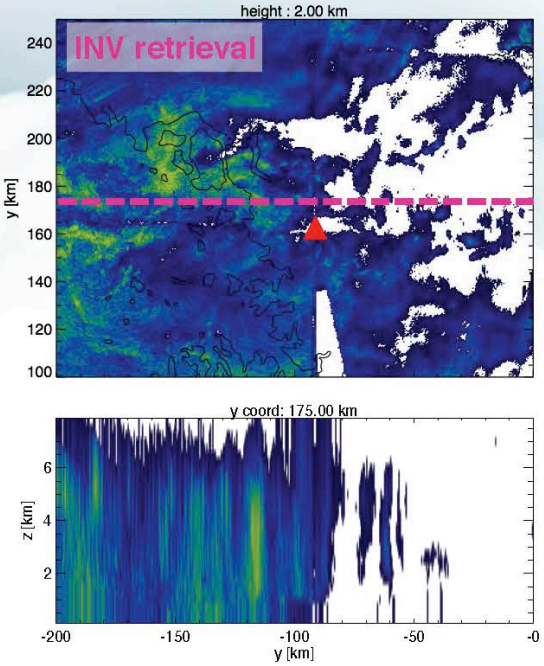
INV mosaicking algorithm – Case #1: 12 July 2015 0800 UTC





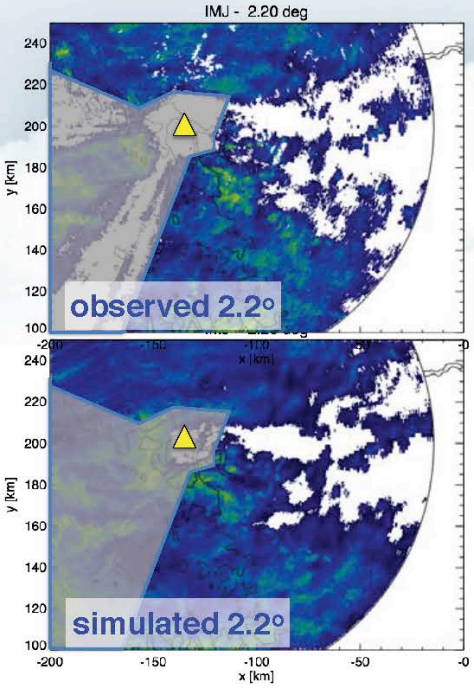
INV mosaicking algorithm – Case #1: 12 July 2015 0800 UTC

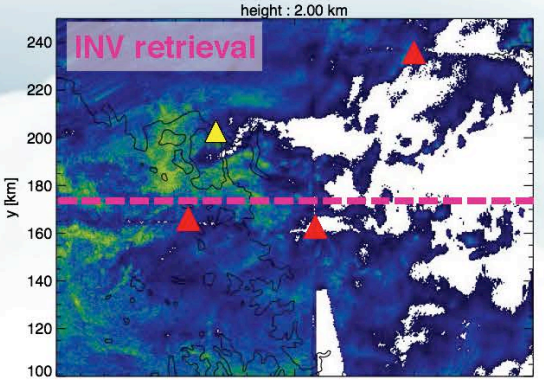


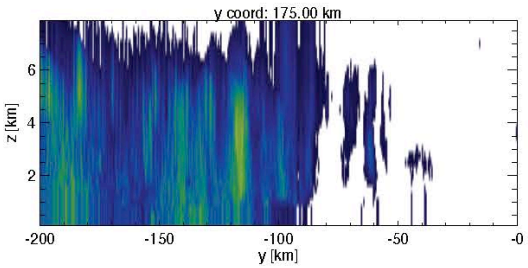


II. Research details and performance (for Year 1)
4. Research details and performance
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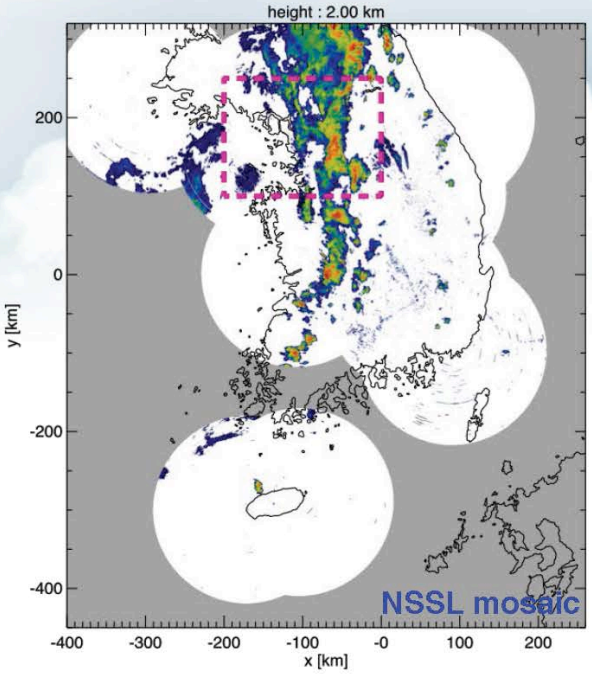
INV mosaicking algorithm – Case #1: 12 July 2015 0800 UTC

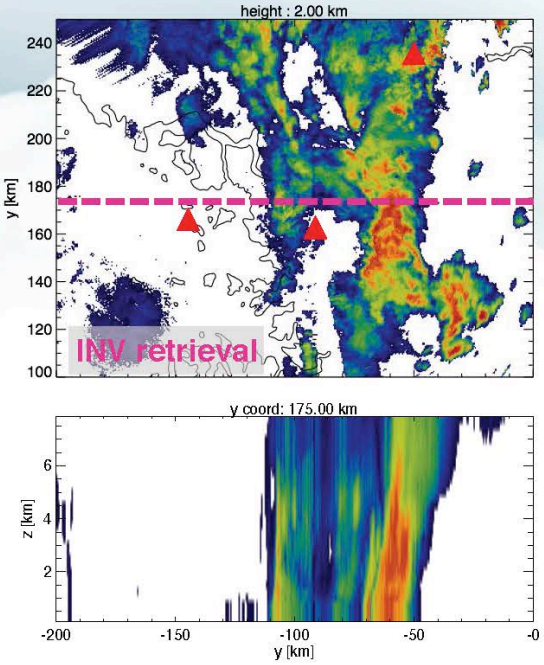






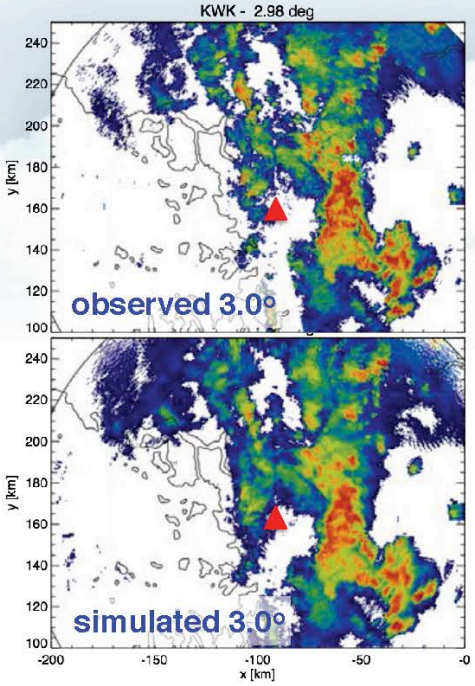
INV mosaicking algorithm – Case #2: 08 Aug 2015 1430 UTC

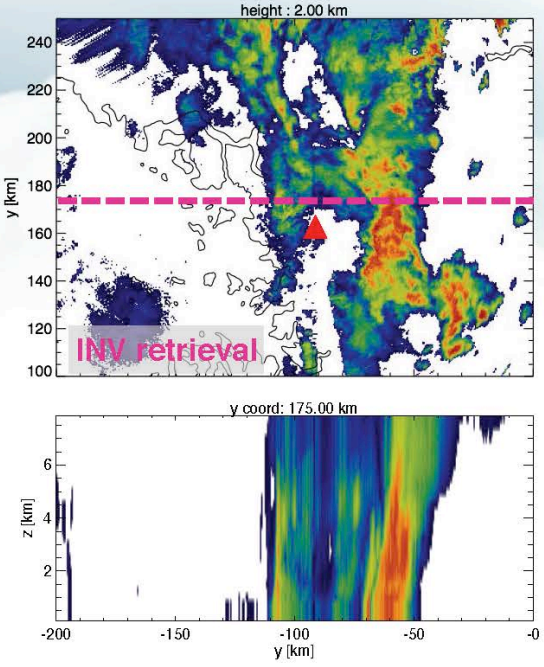




II. Research details and performance (for Year 1)
4. Research details and performance
Centre de Recerca Aplicada en Hidrometeorologia
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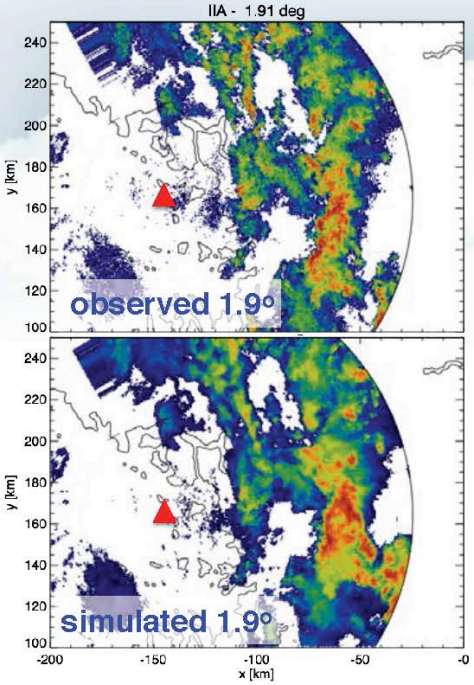
INV mosaicking algorithm – Case #2: 08 Aug 2015 1430 UTC

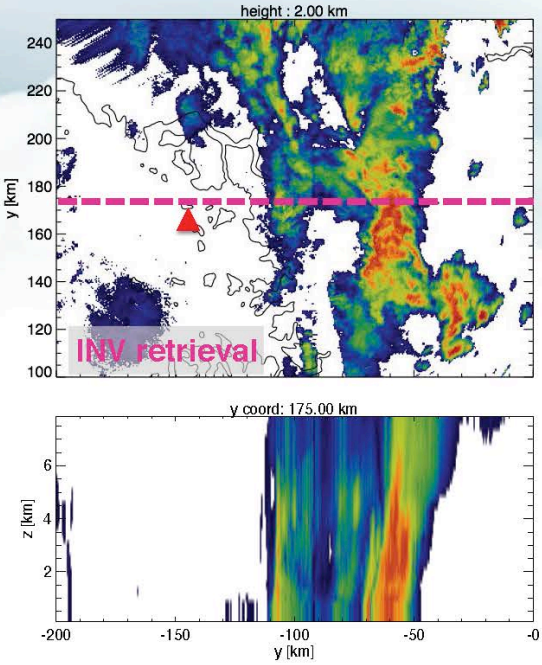




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INV mosaicking algorithm – Case #2: 08 Aug 2015 1430 UTC

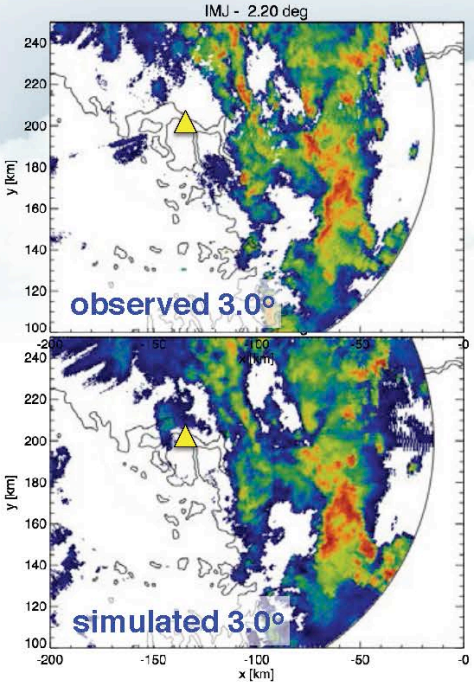


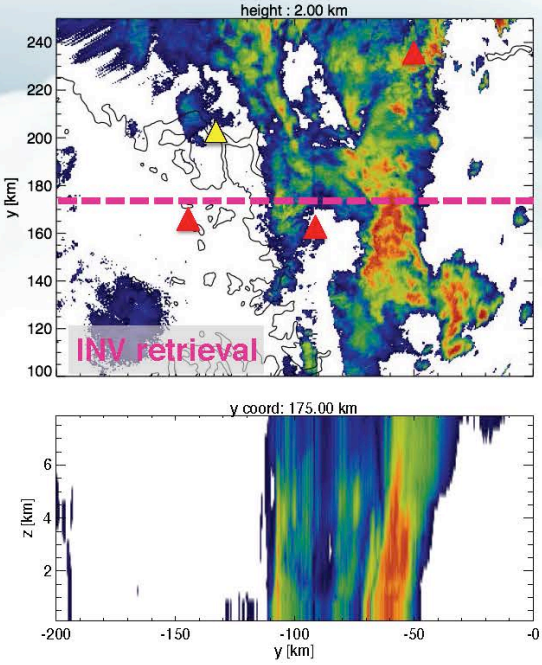


II. Research details and performance (for Year 1)
4. Research details and performance

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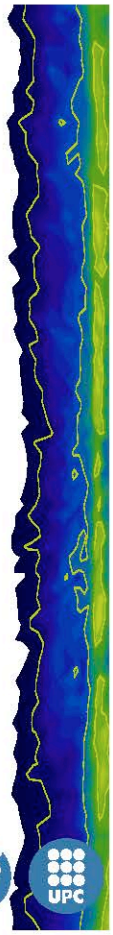
INV mosaicking algorithm – Case #2: 08 Aug 2015 1430 UTC





Conclusions

- The INV technique accounts for the knowledge of how the radar scans the atmosphere through a radar operator (beam broadening and path attenuation).
- It supposes an improvement to other existing methods based on simpler criteria (such as weighted distance), thanks to the retrieval of a mosaic that is coherent with the observations of the multiple radars.
- Can work with non-homoegeneous radar networks.

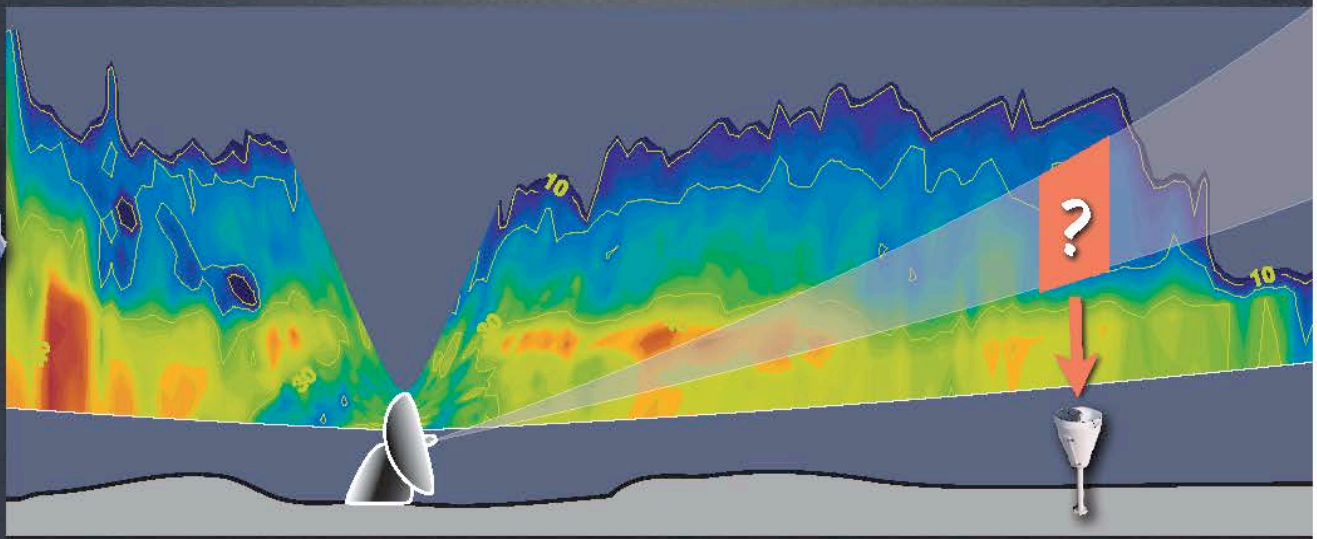


Comparison of radar QPE with raingauge network estimates. Basic methodologies and corrections

Centre for Applied Research in Hydrometeorology
CRAHI
Universitat Politècnica de Catalunya
Barcelona (Spain)

T.C.
Orman ve Su İşleri Bakanlığı
Meteoroloji Genel Müdürlüğü

The first thing hydrologists want to do when getting radar data is to compare them with raingauges...



weighted average on 1-km³ volume aloft in relation with estimates over 200 cm² at ground?

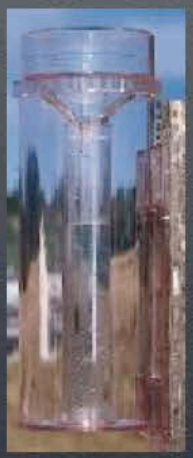
How to merge radar data with ground measurements?

- Correction factors Radar/Raingauge
- Probabilistic methodologies
- Geostatistical methodologies

Precipitation at ground?

- **Raingauges**







Measuring the precipitation at ground on 200 cm^2

Precipitation at ground?

- Disdrometers



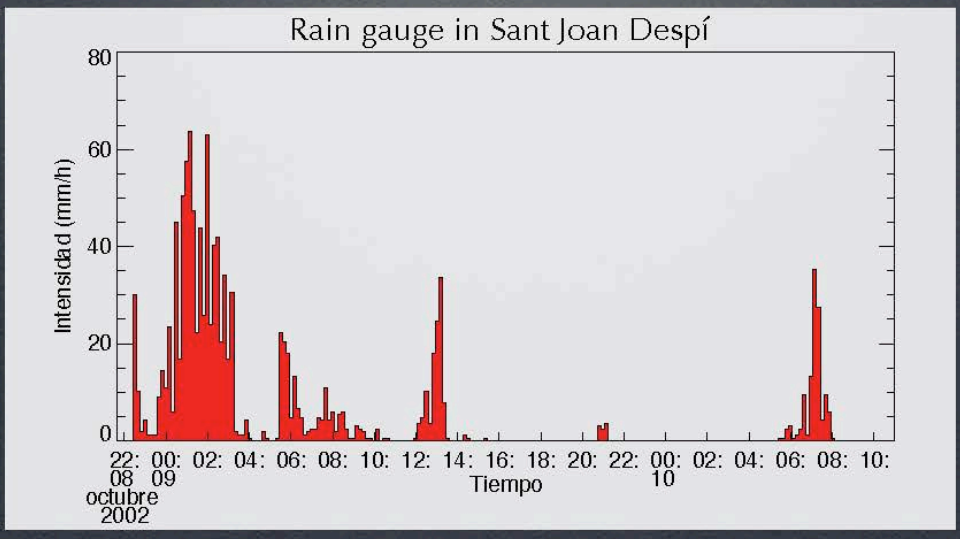


Measuring the number and the drop size distribution

Precipitation at ground?

Raingauges and disdrometers:

Very good temporal description of precipitation



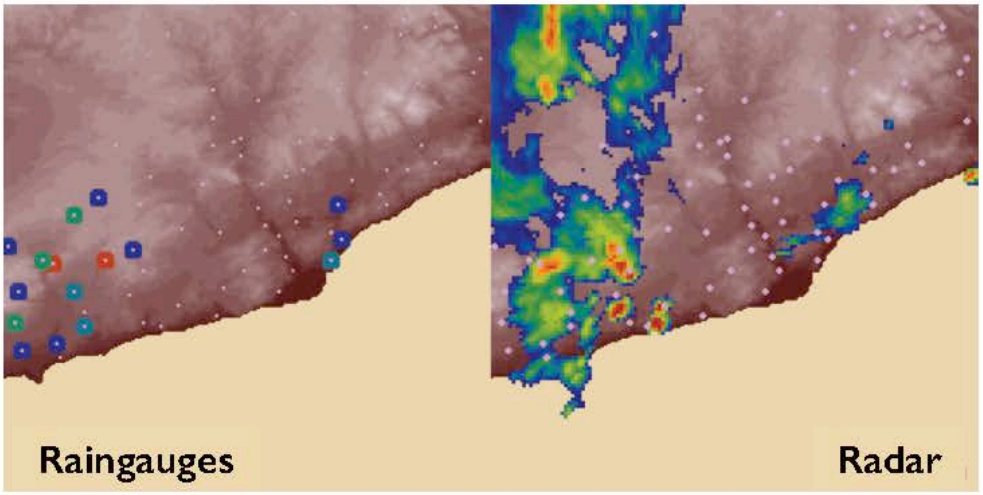
Provide a limited spatial description of the rainfall field

REQUIRE SPATIAL INTERPOLATION

How estimate an "enhanced" rainfall field that combine the best characteristics of each one of these tools?

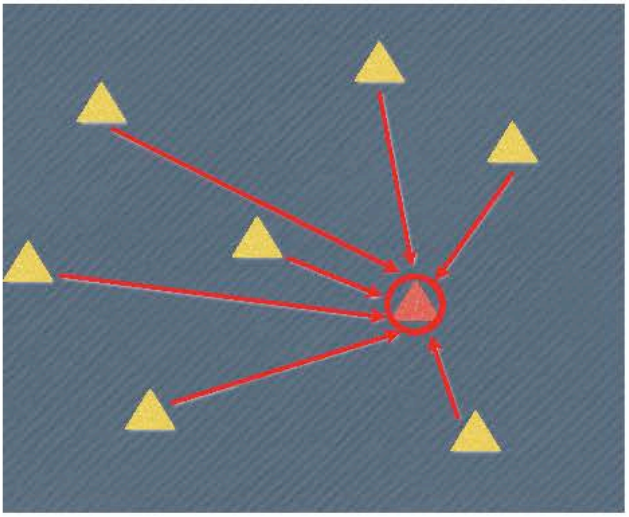
Raingauges: DIRECT measures of rainfall made on a tiny area

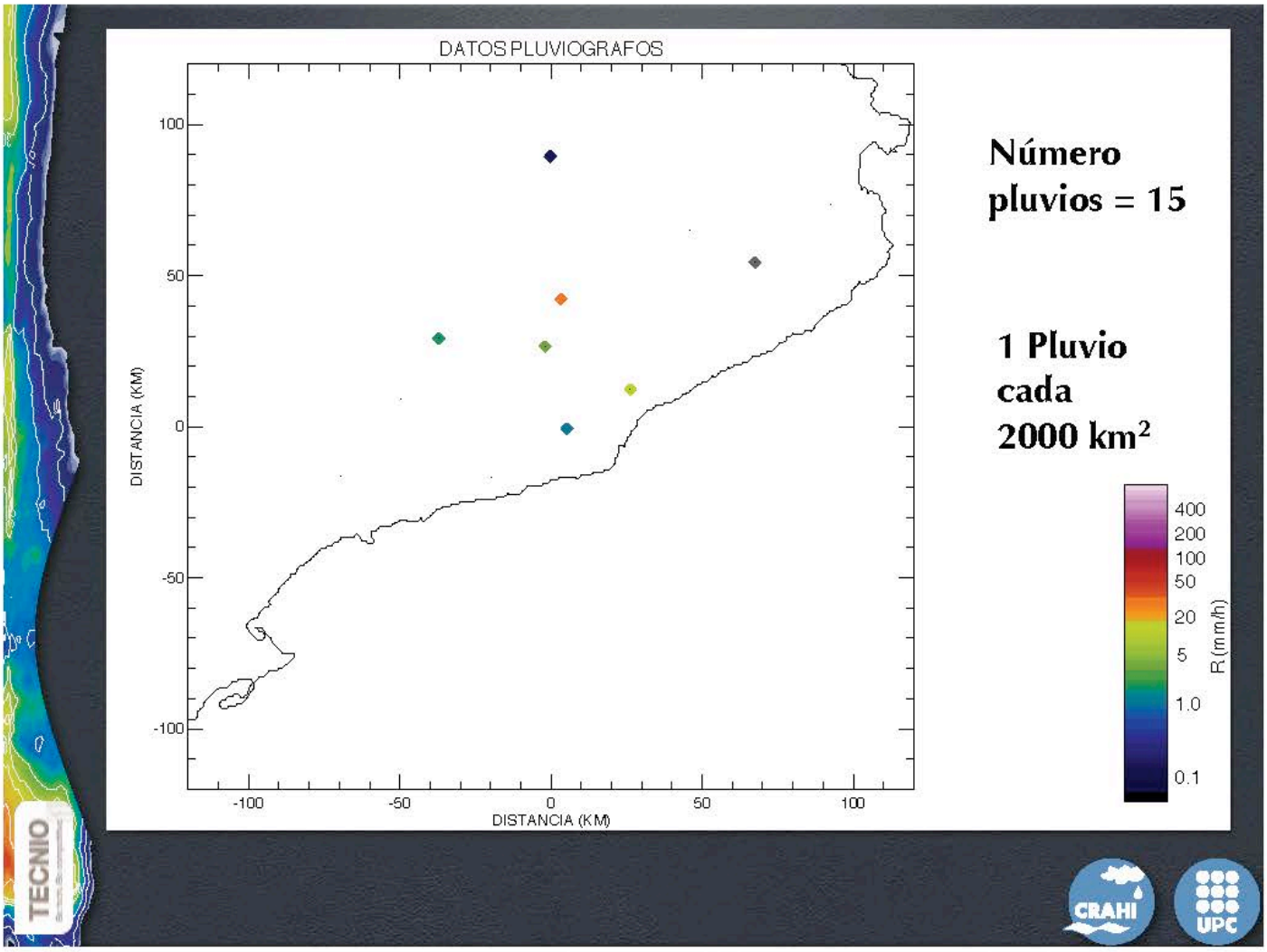
Radar: HIGH temporal and spatial resolutions of an INDIRECT measure of rainfall

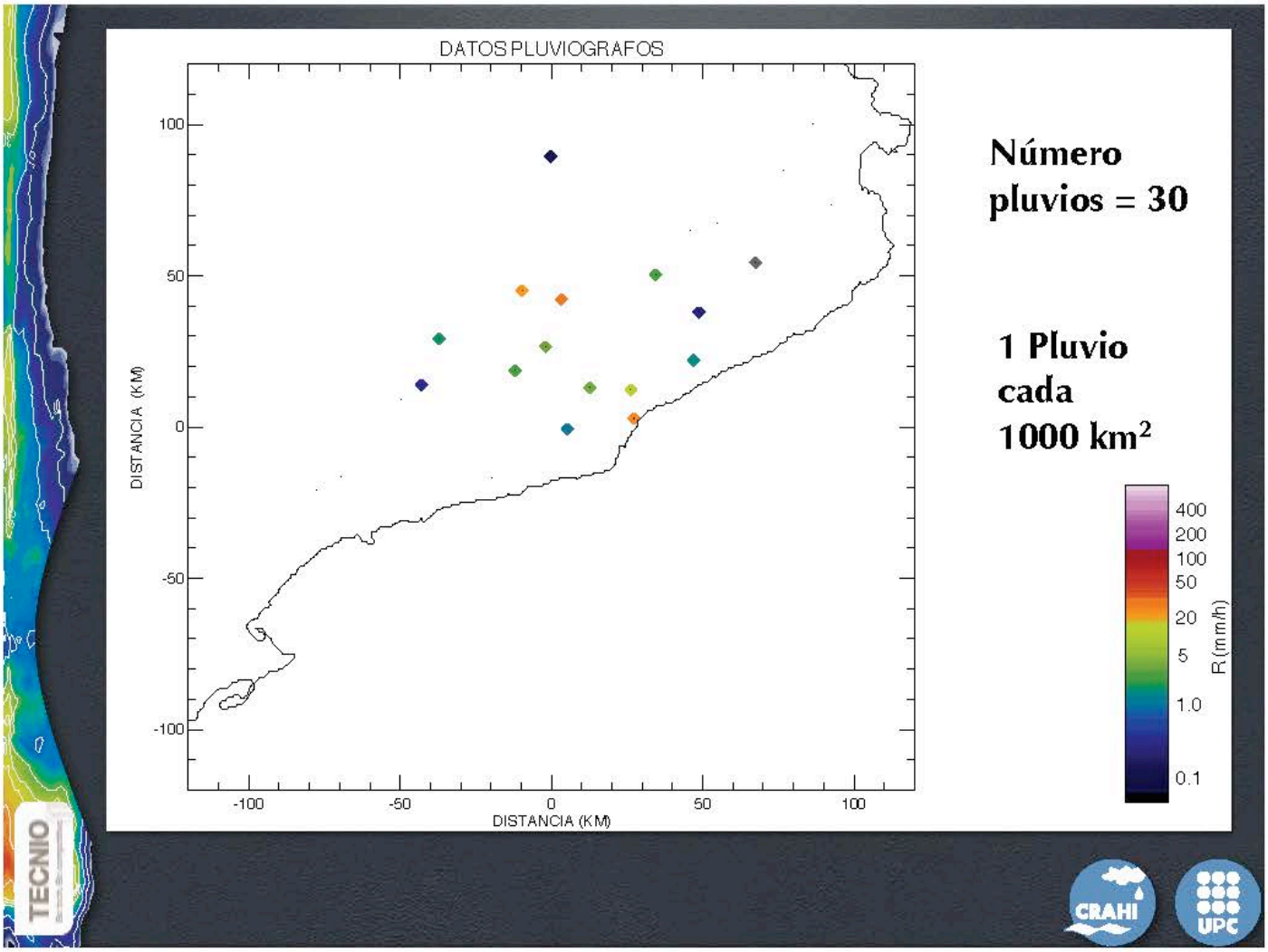


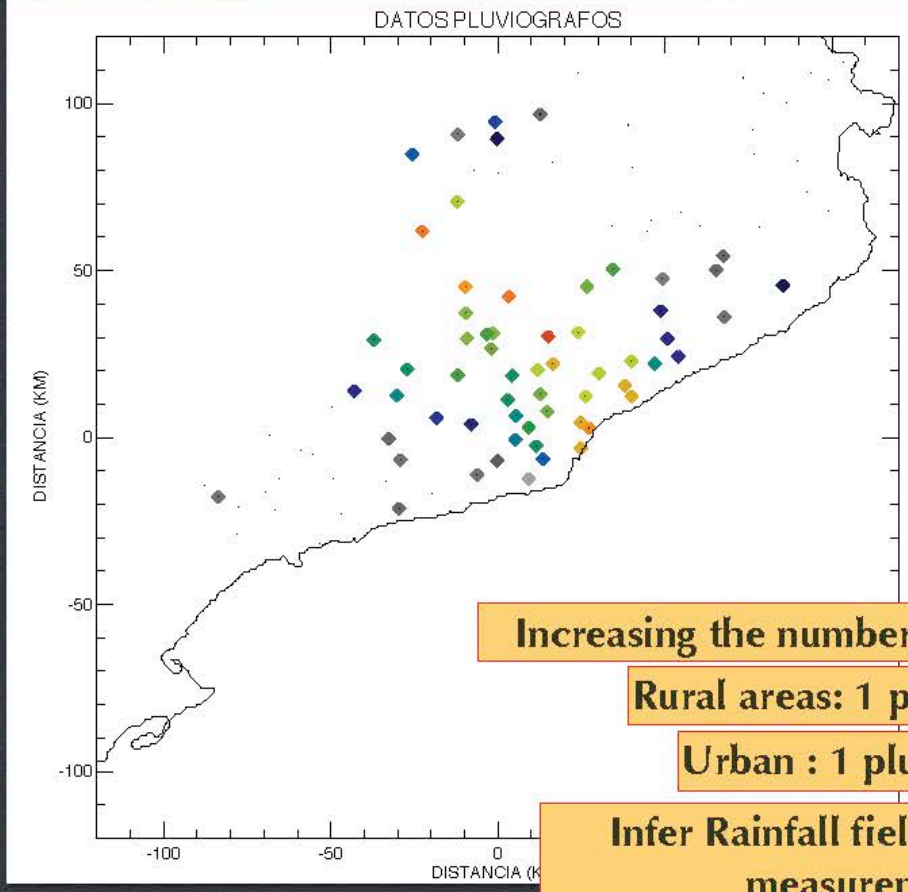


Spatial Interpolation




DATOS PLUVIOGRAFOS
DISTANCIA (KM)
DISTANCIA (KM)
100
50
0
-50
-100
-100
-50
0
50
100
Número pluvios = 15
1 Pluvio cada 2000 km²
400
200
100
50
20
5
1.0
0.1
R (mm/h)
TECNIO
CRAHI
UPC


DATOS PLUVIOGRAFOS
DISTANCIA (KM)
DISTANCIA (KM)
100
50
0
-50
-100
-100
-50
0
50
100
Número pluvios = 30
1 Pluvio cada 1000 km²
400
200
100
50
20
5
1.0
0.1
R (mm/h)
TECNIO
CRAHI
UPC



Número pluvios = 125

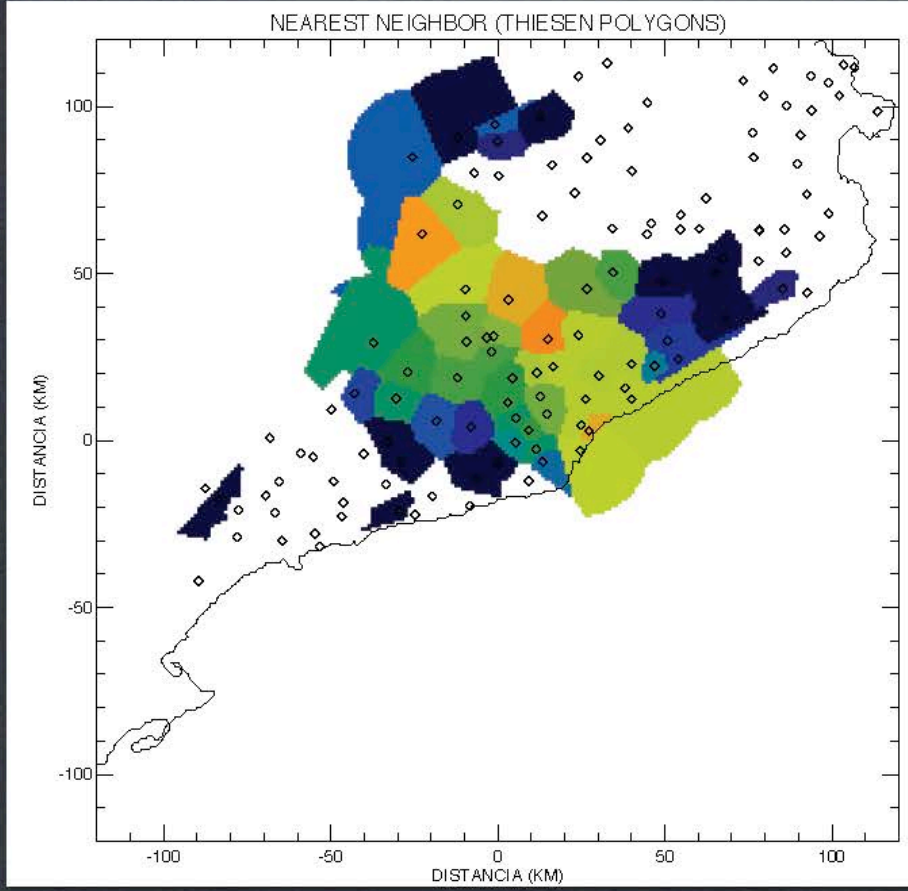
1 Pluvio cada 200 km²

Increasing the number of raingauges?

Rural areas: 1 pluvio per 50 km²

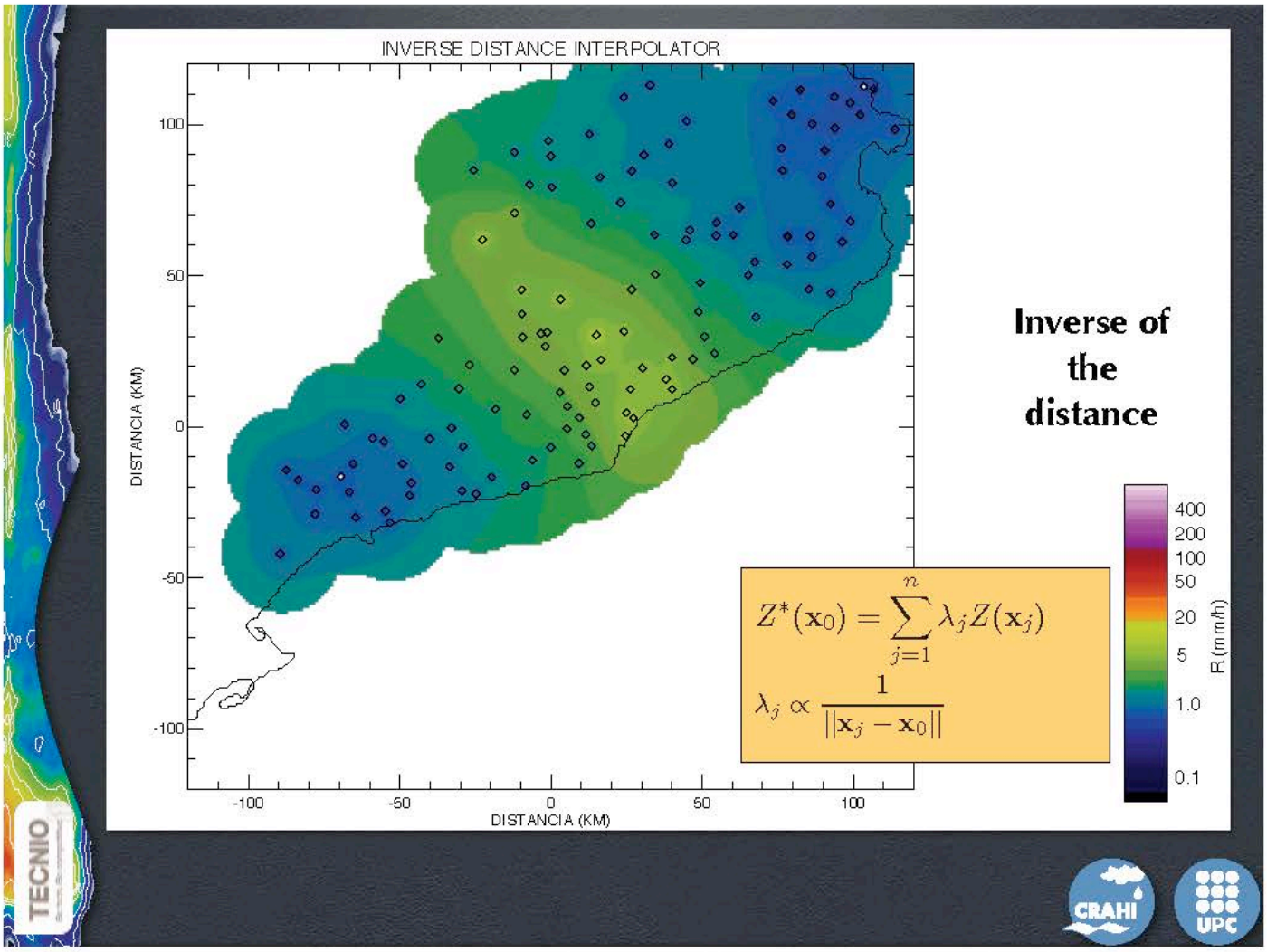
Urban : 1 pluvio per 2 km²

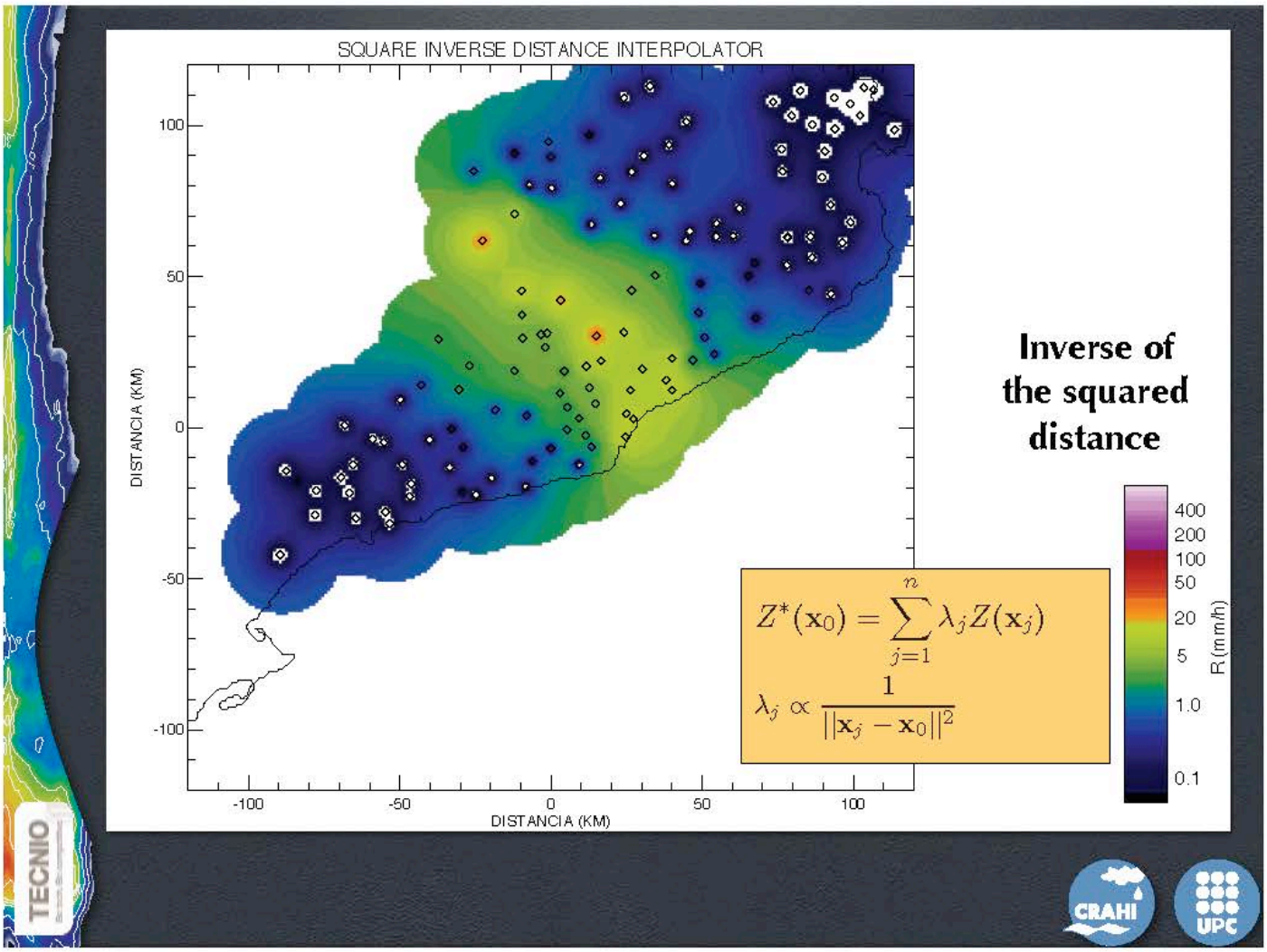
Infer Rainfall fields from point measurements. (INTERPOLATION)

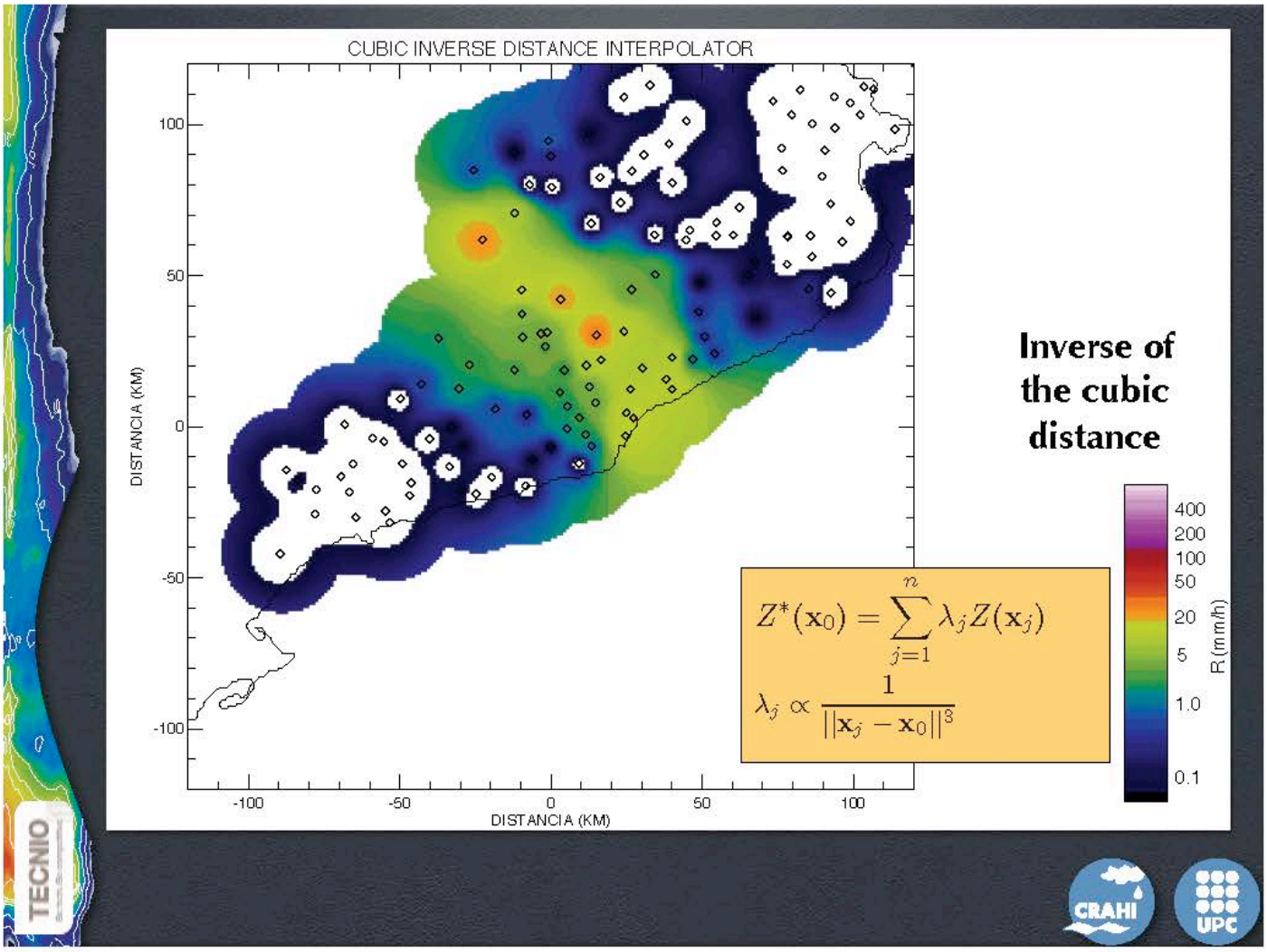


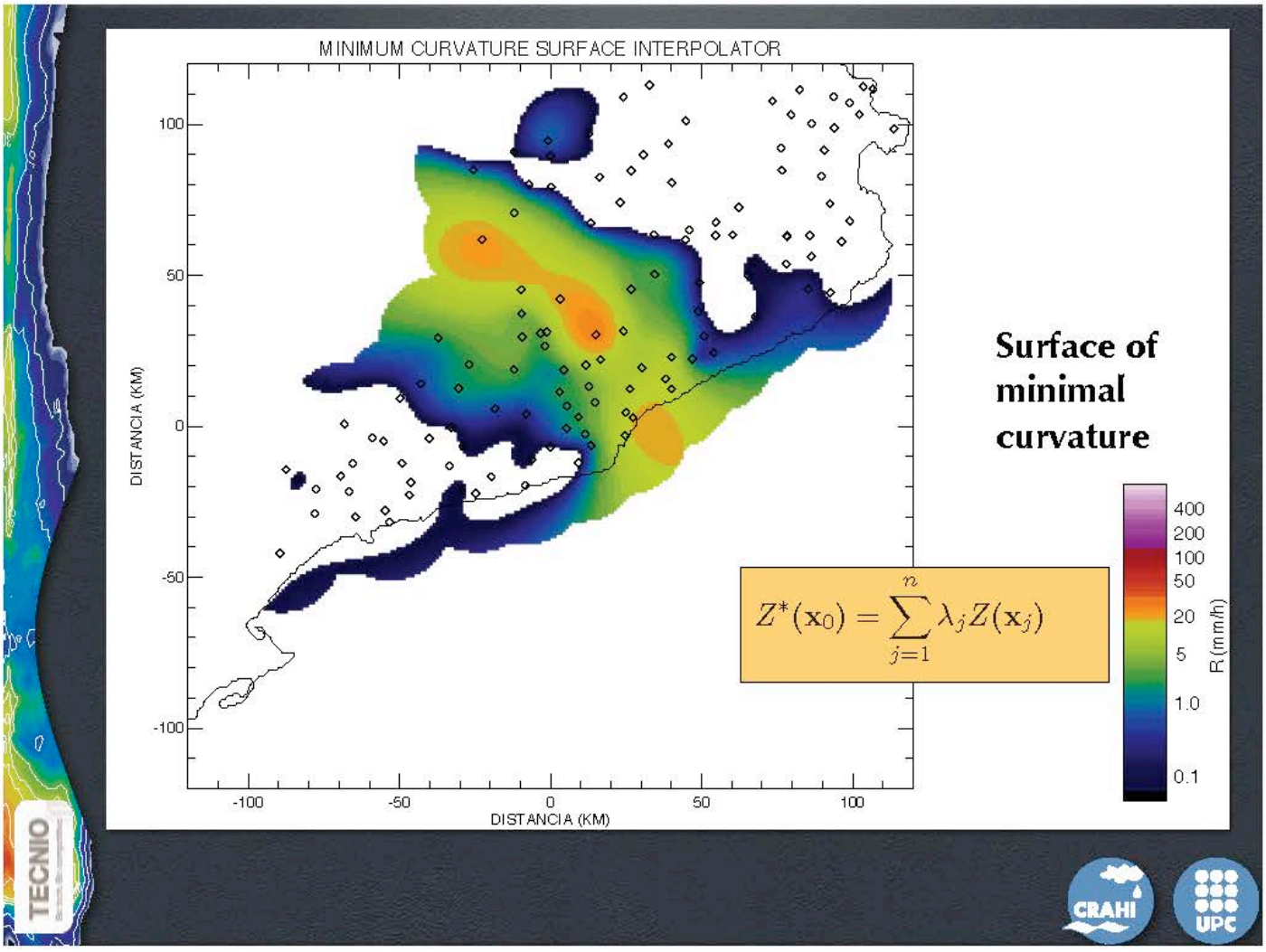
Thiessen, 1911

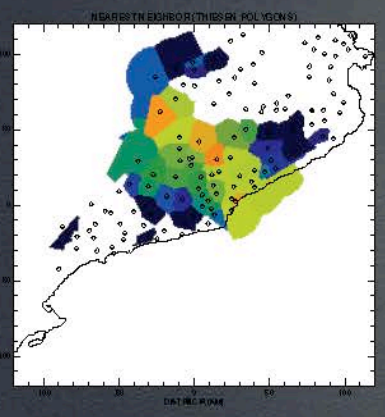
Nearest neighboor

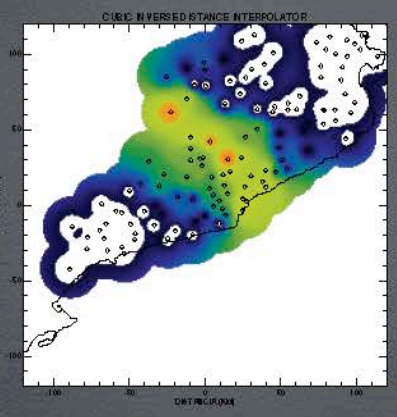

INVERSE DISTANCE INTERPOLATOR
DISTANCIA (KM)
DISTANCIA (KM)
100
50
0
-50
-100
-100
-50
0
50
100
Inverse of the distance
$Z^*(\mathbf{x}_0) = \sum_{j=1}^{n} \lambda_j Z(\mathbf{x}_j)$
$\lambda_j \propto \frac{1}{||\mathbf{x}_j - \mathbf{x}_0||}$
400
200
100
50
20
5
1.0
0.1
R (mm/h)
TECNIO
CRAHI
UPC

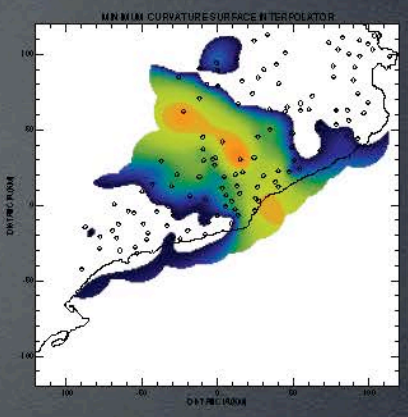

SQUARE INVERSE DISTANCE INTERPOLATOR
DISTANCIA (KM)
DISTANCIA (KM)
100
50
0
-50
-100
-100
-50
0
50
100
Inverse of the squared distance
$Z^*(\mathbf{x}_0) = \sum_{j=1}^{n} \lambda_j Z(\mathbf{x}_j)$
$\lambda_j \propto \frac{1}{||\mathbf{x}_j - \mathbf{x}_0||^2}$
400
200
100
50
20
5
1.0
0.1
R (mm/h)
TECNIO
CRAHI
UPC


CUBIC INVERSE DISTANCE INTERPOLATOR
DISTANCIA (KM)
DISTANCIA (KM)
100
50
0
-50
-100
-100
-50
0
50
100
Inverse of the cubic distance
$Z^*(\mathbf{x}_0) = \sum_{j=1}^{n} \lambda_j Z(\mathbf{x}_j)$
$\lambda_j \propto \frac{1}{||\mathbf{x}_j - \mathbf{x}_0||^3}$
400
200
100
50
20
5
1.0
0.1
R (mm/h)
TECNIO
CRAHI
UPC


MINIMUM CURVATURE SURFACE INTERPOLATOR
DISTANCIA (KM)
DISTANCIA (KM)
100
50
0
-50
-100
-100
-50
0
50
100
Surface of minimal curvature
$Z^*(\mathbf{x}_0) = \sum_{j=1}^{n} \lambda_j Z(\mathbf{x}_j)$
400
200
100
50
20
5
1.0
0.1
R (mm/h)
TECNIO
CRAHI
UPC







¿Wich one represents better the spatial variability of rainfall fields?

The usual density of raingauge networks DON'T ALLOW US to characterize adequately the spatial variability of the rainfall field

Critical aspect in SHORT TIME INTERVALS (in REAL TIME)

TECNIO

CRAHI

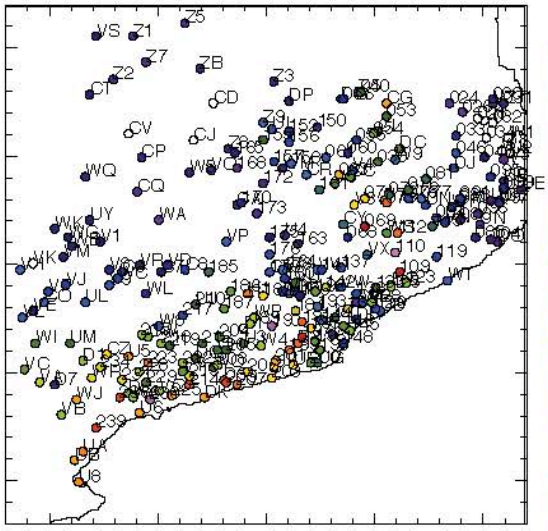
UPC



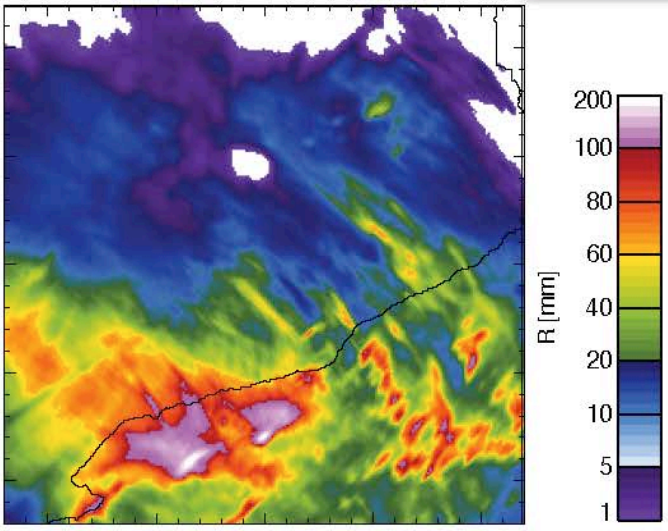
Raingauges vs. radar



07/09/2005 00:00 - 07/09/2005 23:00



07/09/2005 00:00 - 07/09/2005 23:00



Direct rainfall measurements

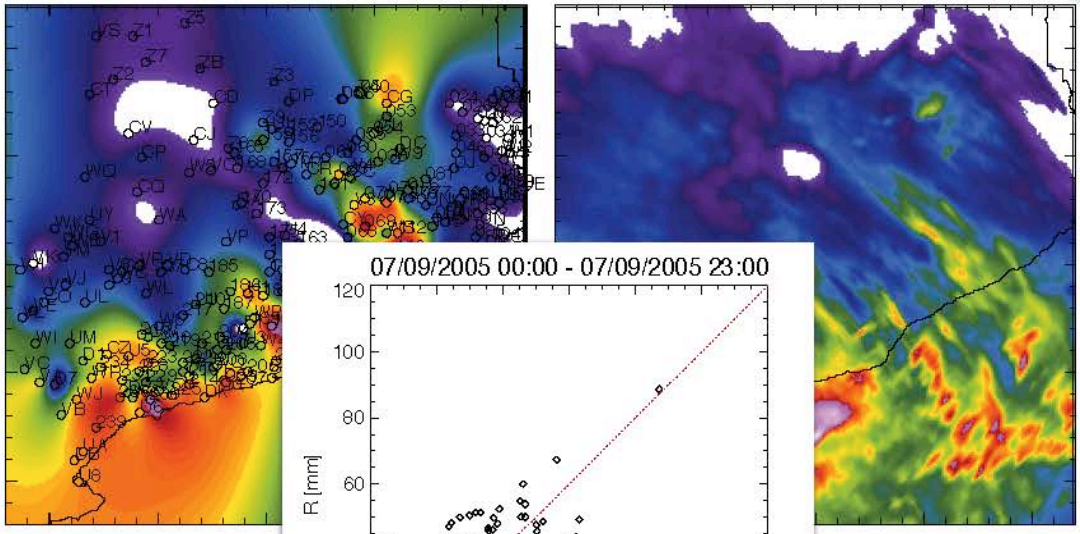
Space-time variability of the field

TECNIO

Raingauges vs. radar



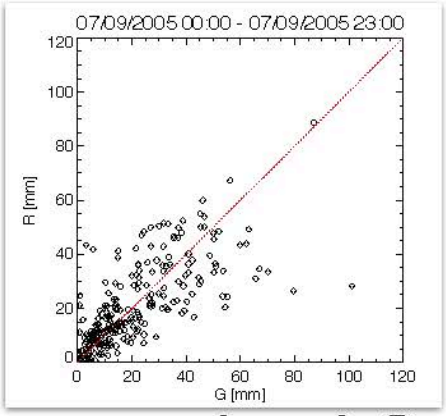




Direct rainfall measurements

Space-time variability of the field







How to compare them? Quality index

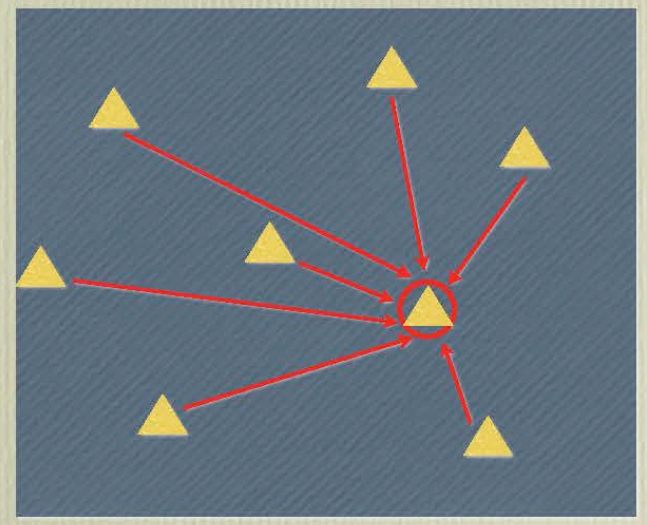
Correlation Coefficient R

$$r = \frac{\sum_{i=1}^{n}\left(\left(x_i - \bar{x}\right)\left(y_i - \bar{y}\right)\right)}{\sqrt{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2 \sum_{i=1}^{n}\left(y_i - \bar{y}\right)^2}}$$

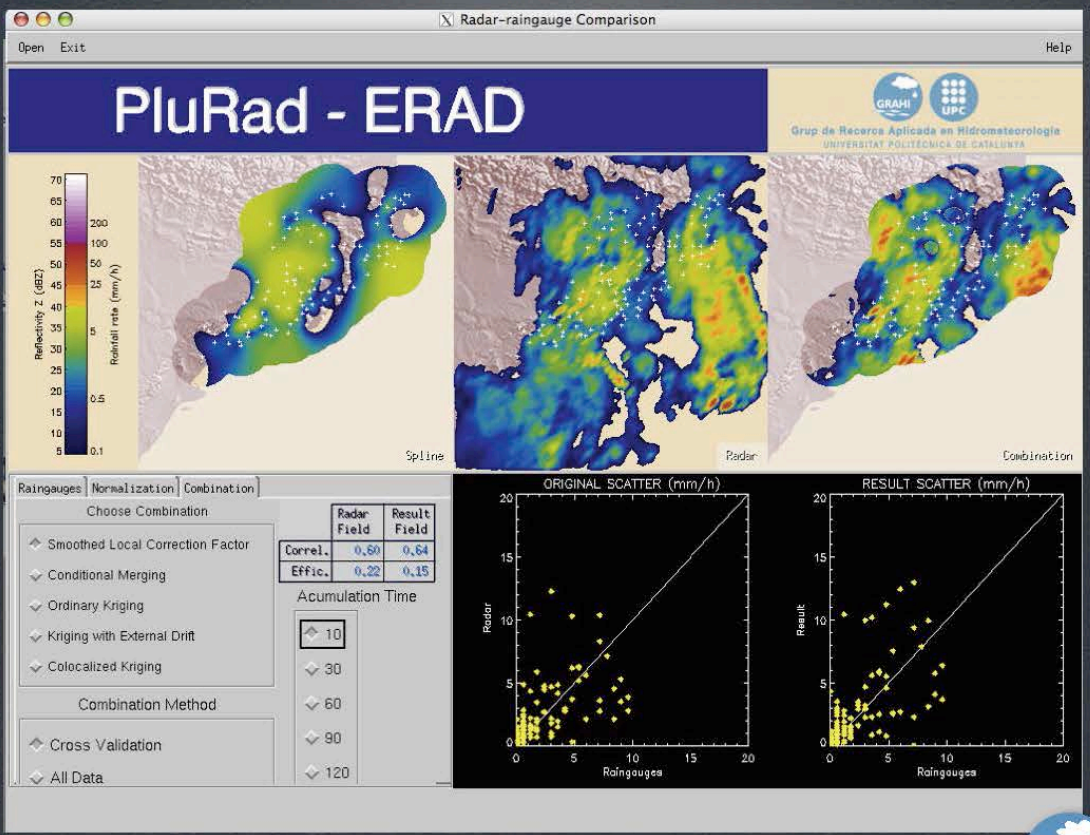
Nash and Sutcliffe Efficiency

$$E = 1 - \frac{\sum_{i=1}^{n}\left(\mathrm{EST}_i - \mathrm{OBS}_i\right)^2}{\sum_{i=1}^{n}\left(\mathrm{OBS}_i - \overline{\mathrm{OBS}}\right)^2}$$

Cross Validation



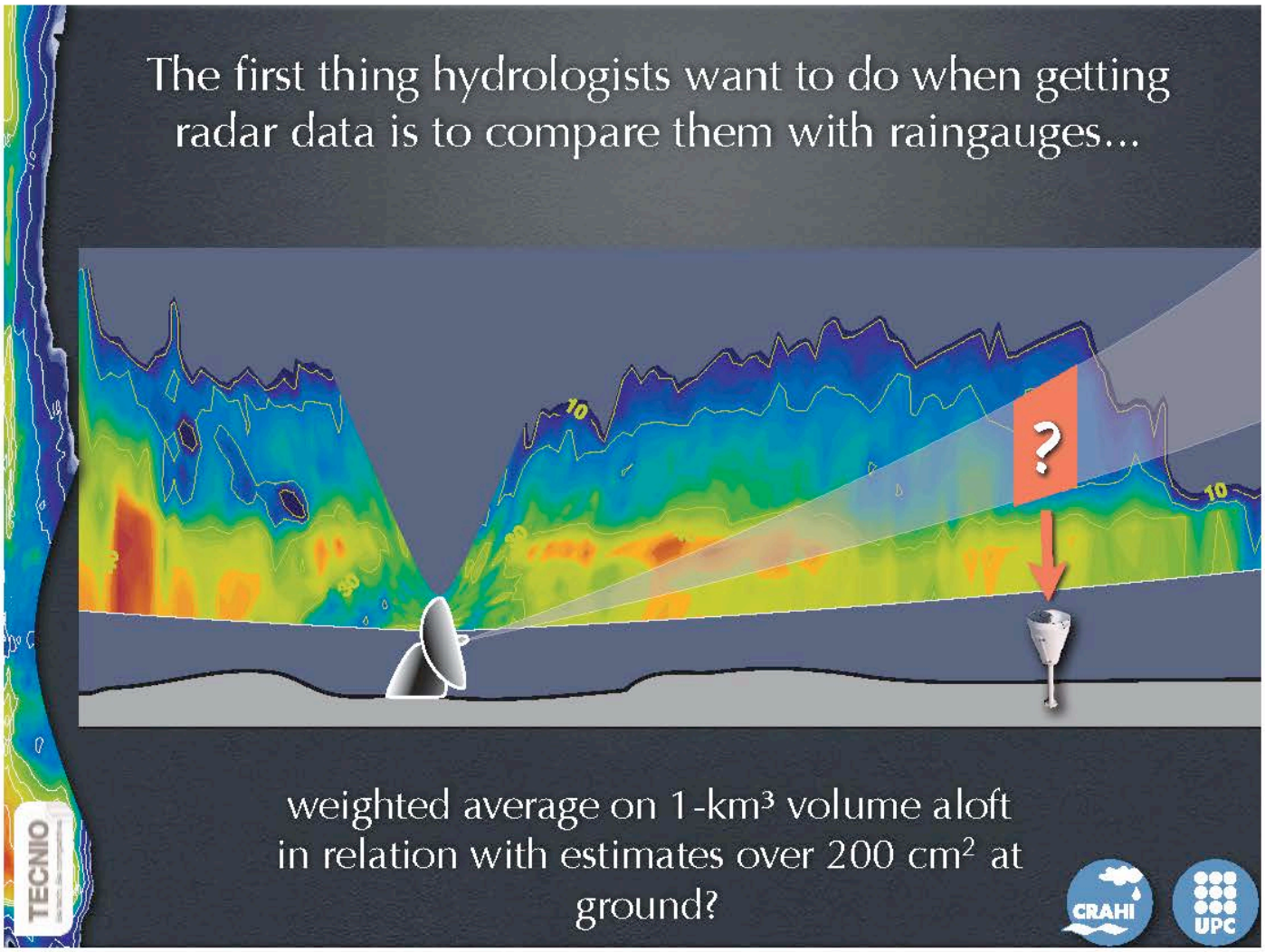
Radar-raingauge combination

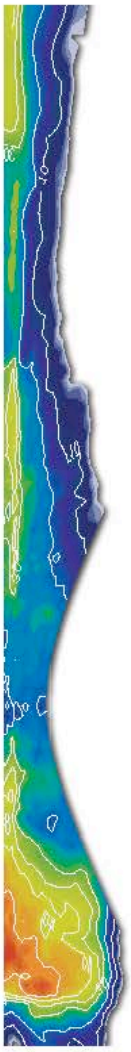


Blending radar and raingauge data. Advanced geostatistical techniques

Centre for Applied Research in Hydrometeorology
CRAHI
Universitat Politècnica de Catalunya
Barcelona (Spain)

T.C.
Orman ve Su İşleri Bakanlığı
Meteoroloji Genel Müdürlüğü





Merging radar and raingauge estimates

- Fitting an adjustment factor between Radar and Raingauge estimates (e.g. Wilson & Brandes 1979).
- Geostatistical techniques (kriging): Krajewski (1987), Creutin et al. (1988), Sinclair & Pegram (2005),...

Velasco-Forero, C. A., D. Sempere-Torres, E. F. Cassiraga, and J. J. Gómez-Hernández, 2009: A non-parametric automatic blending methodology to estimate rainfall fields from rain gauge and radar data. *Advances in Water Resources*, 32, 986-1002.

Schiemann, R., R. Erdin, M. Willi, C. Frei, M. Berenguer, and D. Sempere-Torres, 2011: Geostatistical radar-raingauge combination with nonparametric correlograms: methodological considerations and application in Switzerland. Hydrology and Earth System Sciences, 15, 1515-1536.

Geostatistical methods

Linear estimators: $$\widehat{R}(\mathbf{u_0}) = \sum_{i=1}^{n} \lambda_i(\mathbf{u_0}) R_G(\mathbf{u_i})$$



Geostatistical methods

Linear estimators: $$\widehat{R}(\mathbf{u_0}) = \sum_{i=1}^{n} \lambda_i(\mathbf{u_0}) R_G(\mathbf{u_i})$$

How is λ_i found?

Under certain hypotheses, we minimize those that make the error of $\widehat{R}(\mathbf{u_0})$ minimum.

$$\sum_{i=1}^{n} \lambda_i(\mathbf{u_0}) = 1$$

$$\sum_{j=1}^{n} \lambda_j(\mathbf{u_0}) \gamma(\Delta_{ij}) + \mu = \gamma(\Delta_{i0})$$

Ordinary kriging

The semi-variogram

$$\gamma(\Delta_{ij}) = \frac{1}{2} E\left\{ [R(\mathbf{u_i}) - R(\mathbf{u_j})]^2 \right\}$$

Information about the spatial variability of the field

Theoretical model methods

When information is scarce.

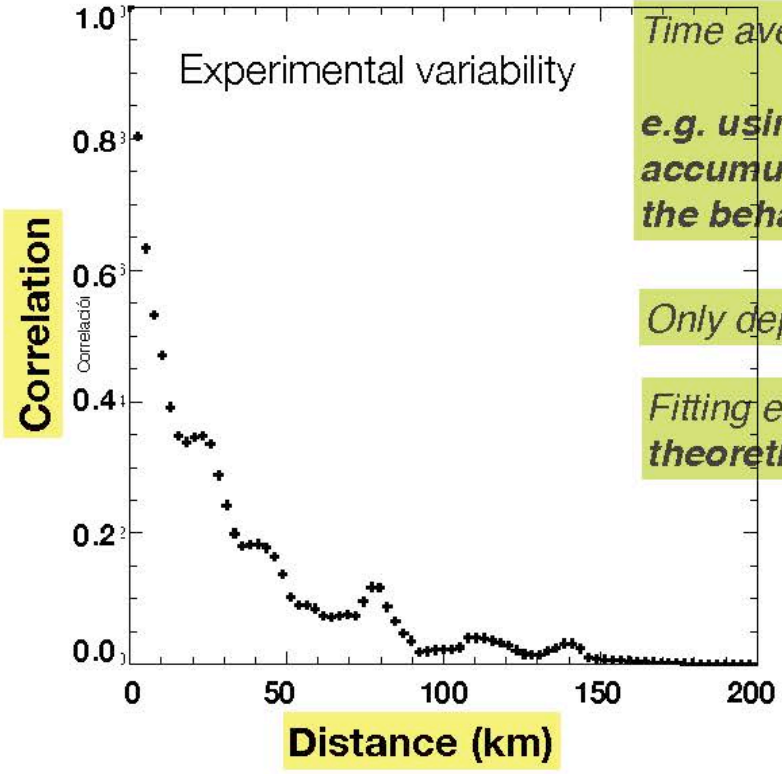
Sample semi-variograms

From rain gauge measurements

From radar rainfall

Estimation of Rainfall Fields

Computing Spatial variability models



*Time averaged: **"climatological"***

e.g. using several hourly accumulated records to characterise the behaviour of hourly rainfall fields

*Only dependant of distance: **Isotropic***

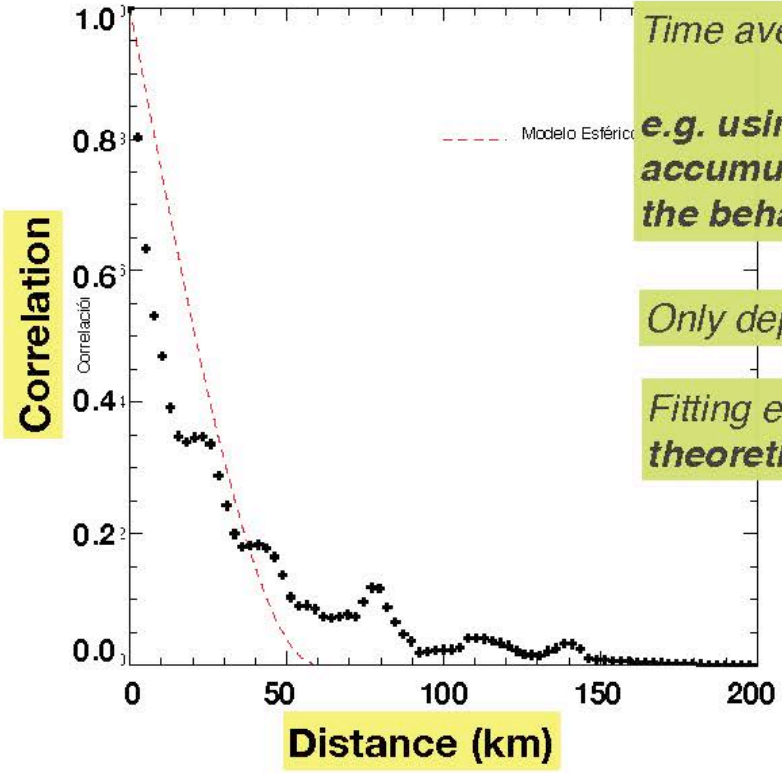
*Fitting experimental variability to **theoretical models***

The use of radar in flood Early Warning Systems

Estimation of Rainfall Fields

Previously ...

Computing Spatial variability models



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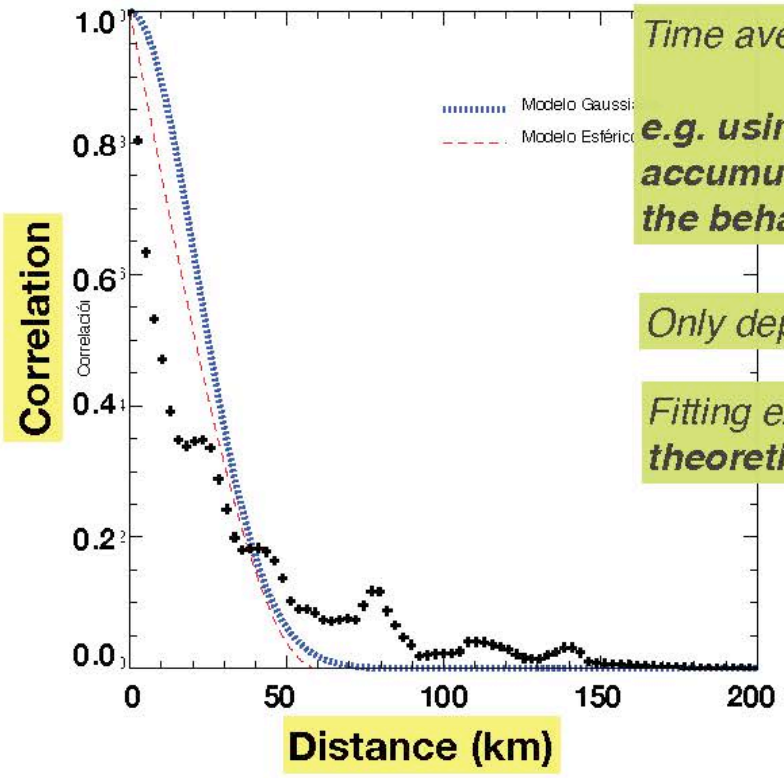
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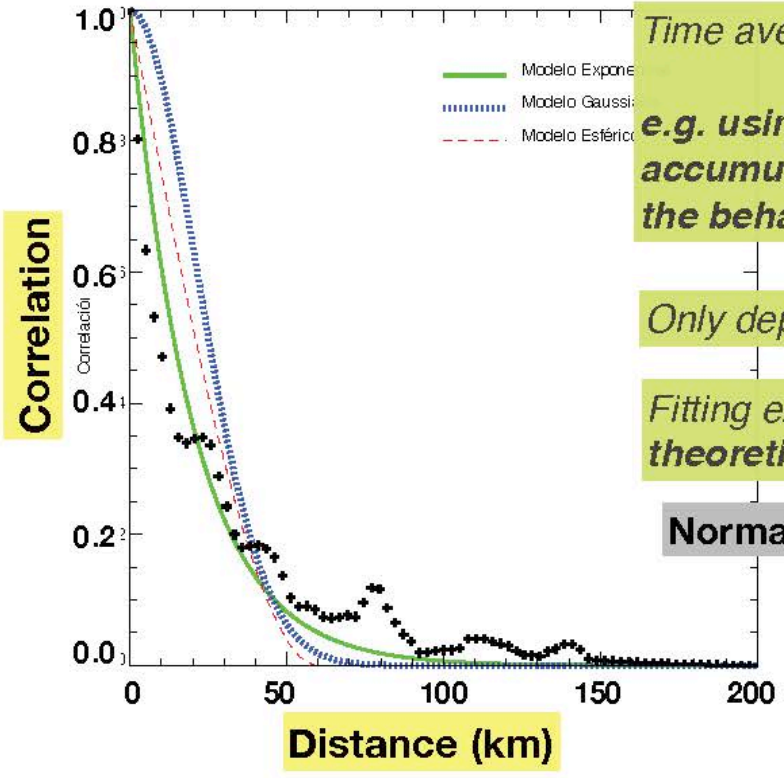
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The use of radar in flood Early Warning Systems

Estimation of Rainfall Fields

Previously ...

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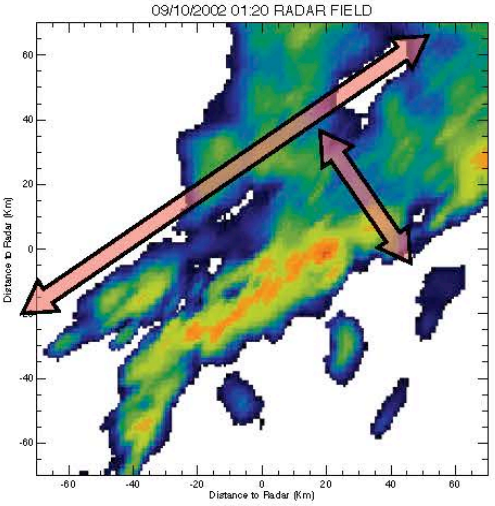
*Fitting experimental variability to **theoretical models***

Normal Geostatistical Analysis

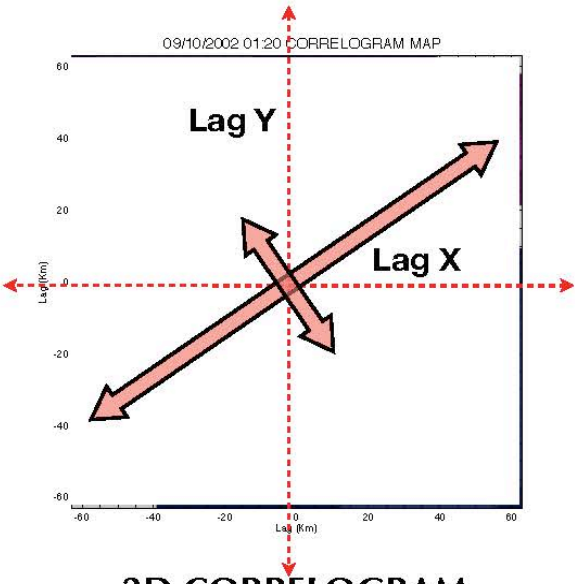
... but ...

... but ...

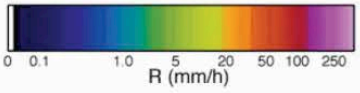
SPATIAL VARIABILITY OF RAINFALL IS NOT ISOTROPIC



RADAR



2D CORRELOGRAM

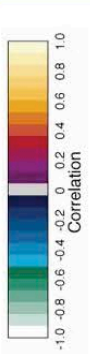


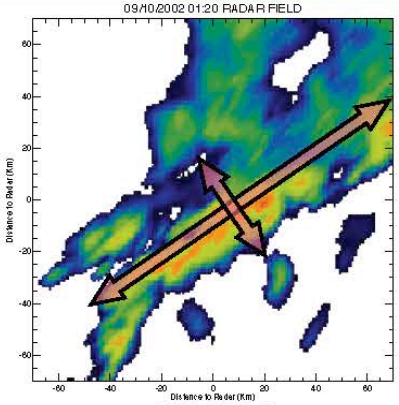


The use of radar in flood Early Warning Systems

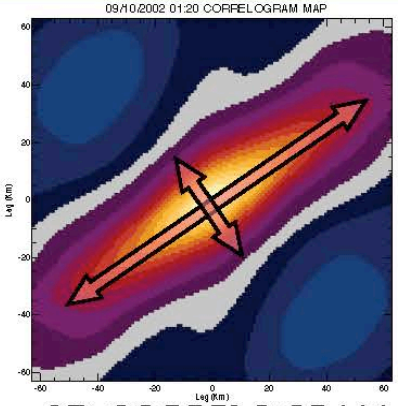
... but ...

SPATIAL VARIABILITY OF RAINFALL IS ANISOTROPIC

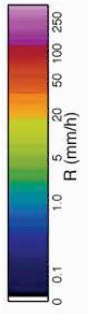


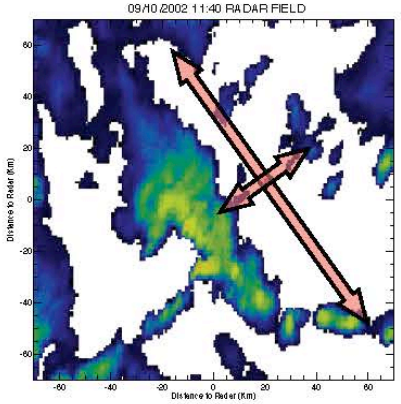


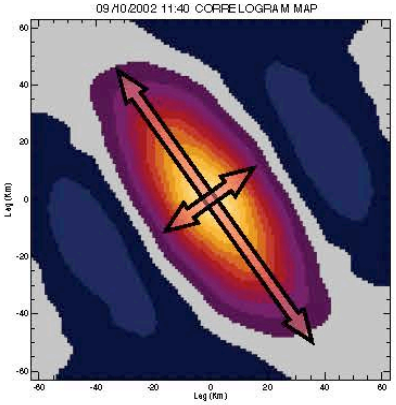
RADAR



2D CORRELOGRAM



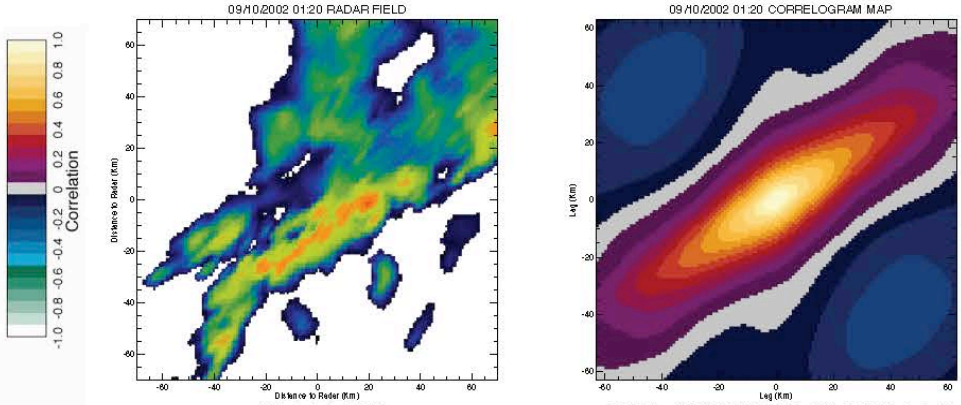




The use of radar in flood Early Warning Systems

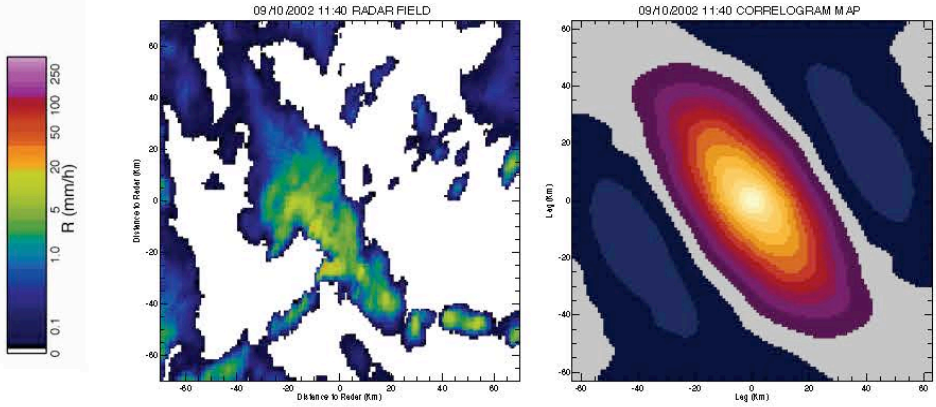
... and also ...

SPATIAL CORRELATION OF RAINFALL CHANGES WITH TIME



RADAR 2D CORRELOGRAM

01:20 AM
09/10/2002

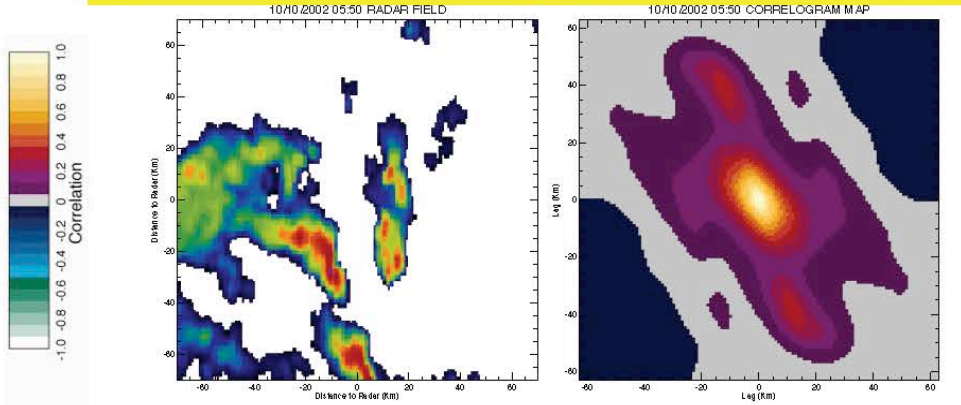


11:40 AM
09/10/2002

The use of radar in flood Early Warning Systems

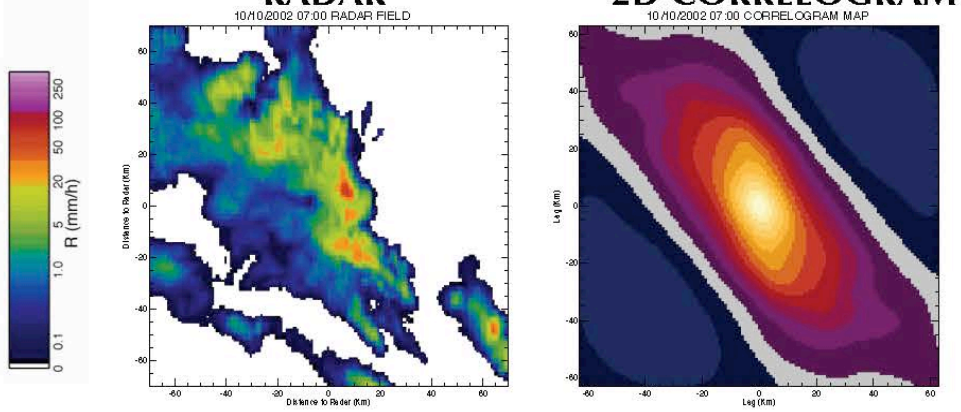
... and also ...

SPATIAL CORRELATION OF RAINFALL CHANGES WITH TIME



RADAR 2D CORRELOGRAM

05:50 AM
10/10/2002



07:00 AM
10/10/2002

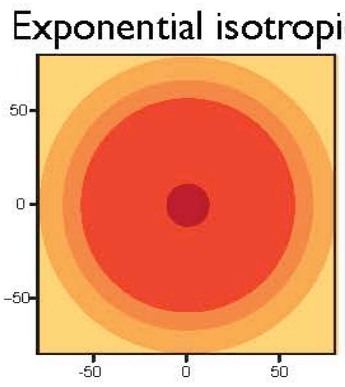
SPATIAL VARIABILITY OF RAINFALL CHANGES WITH DIRECTION AND TIME

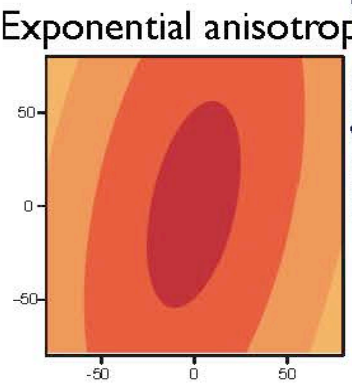


Typhoon Nangka hitting Hong Kong - June 26 / 2009
One imagen each 20 seconds

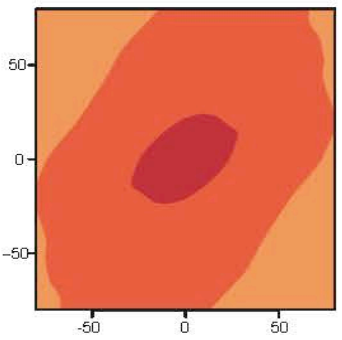
The semi-variogram

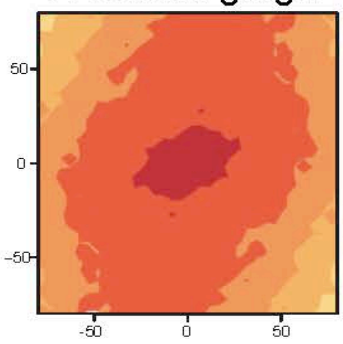
Parametrical model





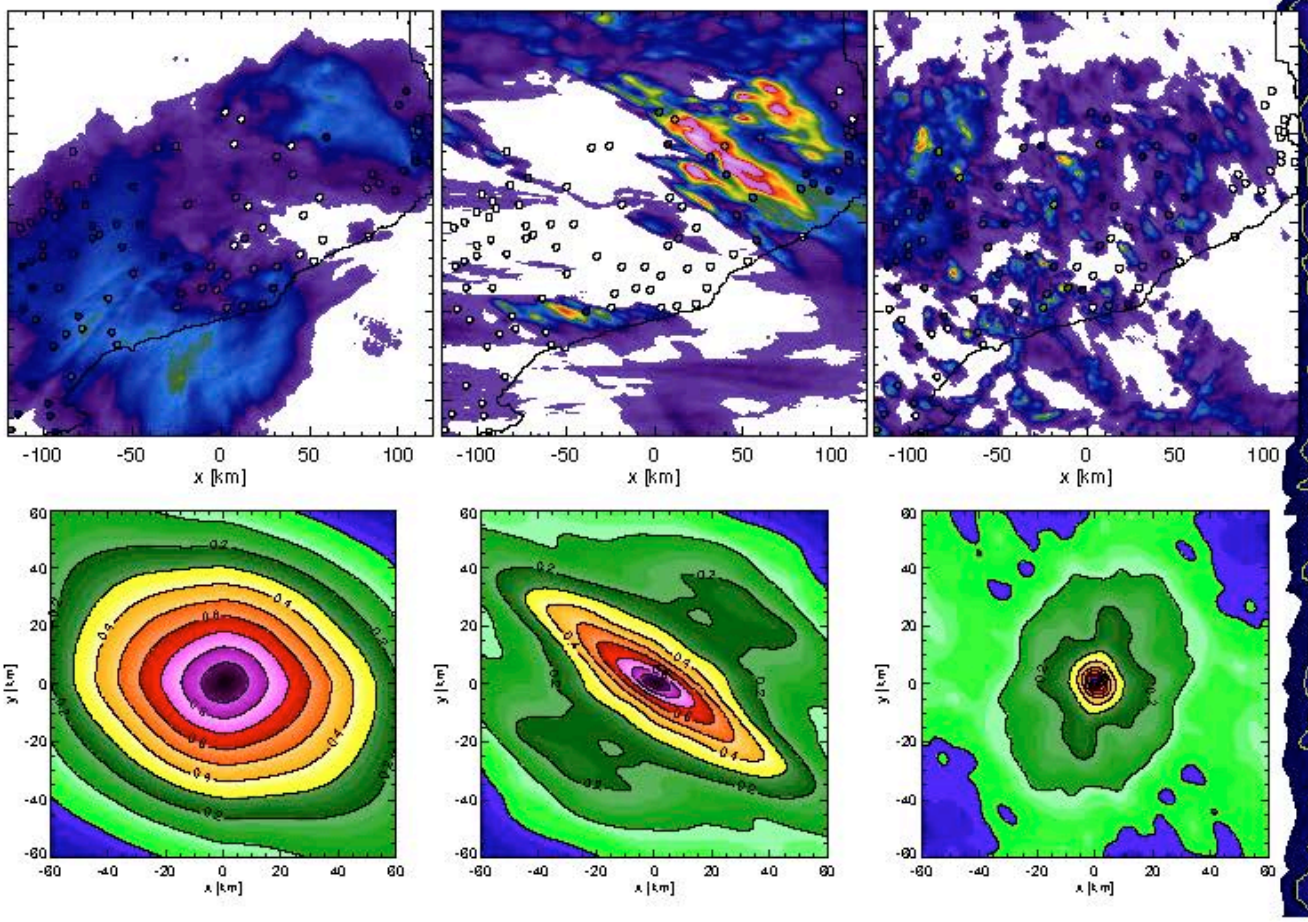
Sample (from observations)



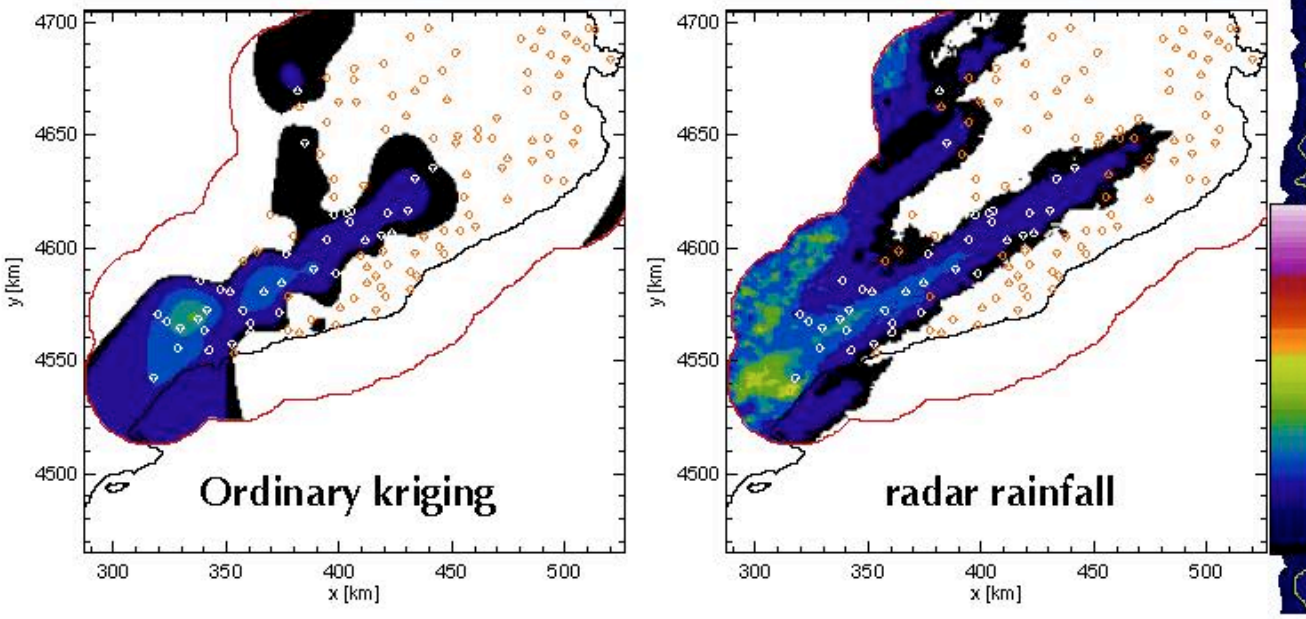


Schiemann et al. **HESS2011**

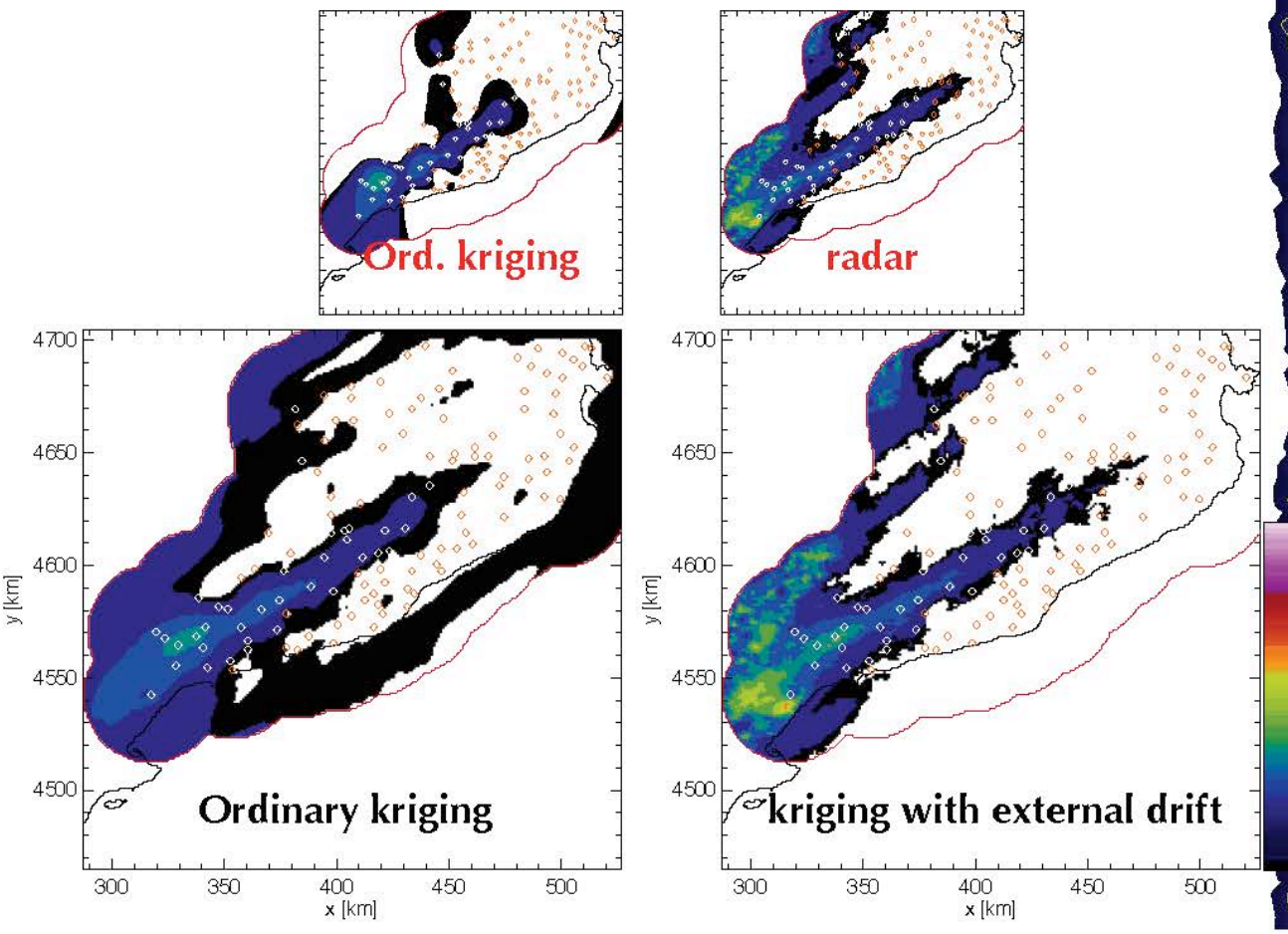
Sample semi-variogram



How can we add radar information?



How can we add radar information?



Kriging with an external drift

Linear estimator $$\widehat{R}(\mathbf{u_0}) = \sum_{i=1}^{n} \lambda_i(\mathbf{u_0}) R_G(\mathbf{u_i})$$

But now, a **secondary variable Y** is used, such that, on average, explains the field R at every point.

How is λ_i obtained?

$$\sum_{i=1}^{n} \lambda_i(\mathbf{u_0}) = 1$$

$$\sum_{j=1}^{n} \lambda_j(\mathbf{u_0}) \gamma(\Delta_{ij}) + \mu = \gamma(\Delta_{i0})$$

Ordinary kriging

$$\sum_{i=1}^{n} \lambda_i(\mathbf{u_0}) = 1$$

$$\sum_{i=1}^{n} \lambda_i(\mathbf{u_0}) Y(x_i) = Y(\mathbf{u_0})$$

$$\sum_{j=1}^{n} \lambda_j(\mathbf{u_0}) \gamma(\Delta_{ij}) + \mu_1 + \mu_2 Y(x_i) = \gamma(\Delta_{i0})$$

kriging with an external drift

Use of weather radar in flood risk management

Kriging with an external drift

Linear estimator $$\widehat{R}(\mathbf{u_0}) = \sum_{i=1}^{n} \lambda_i(\mathbf{u_0}) R_G(\mathbf{u_i})$$

But now, a **secondary variable Y** is used, such that, on average, explains the field R at every point.

Y: radar rainfall

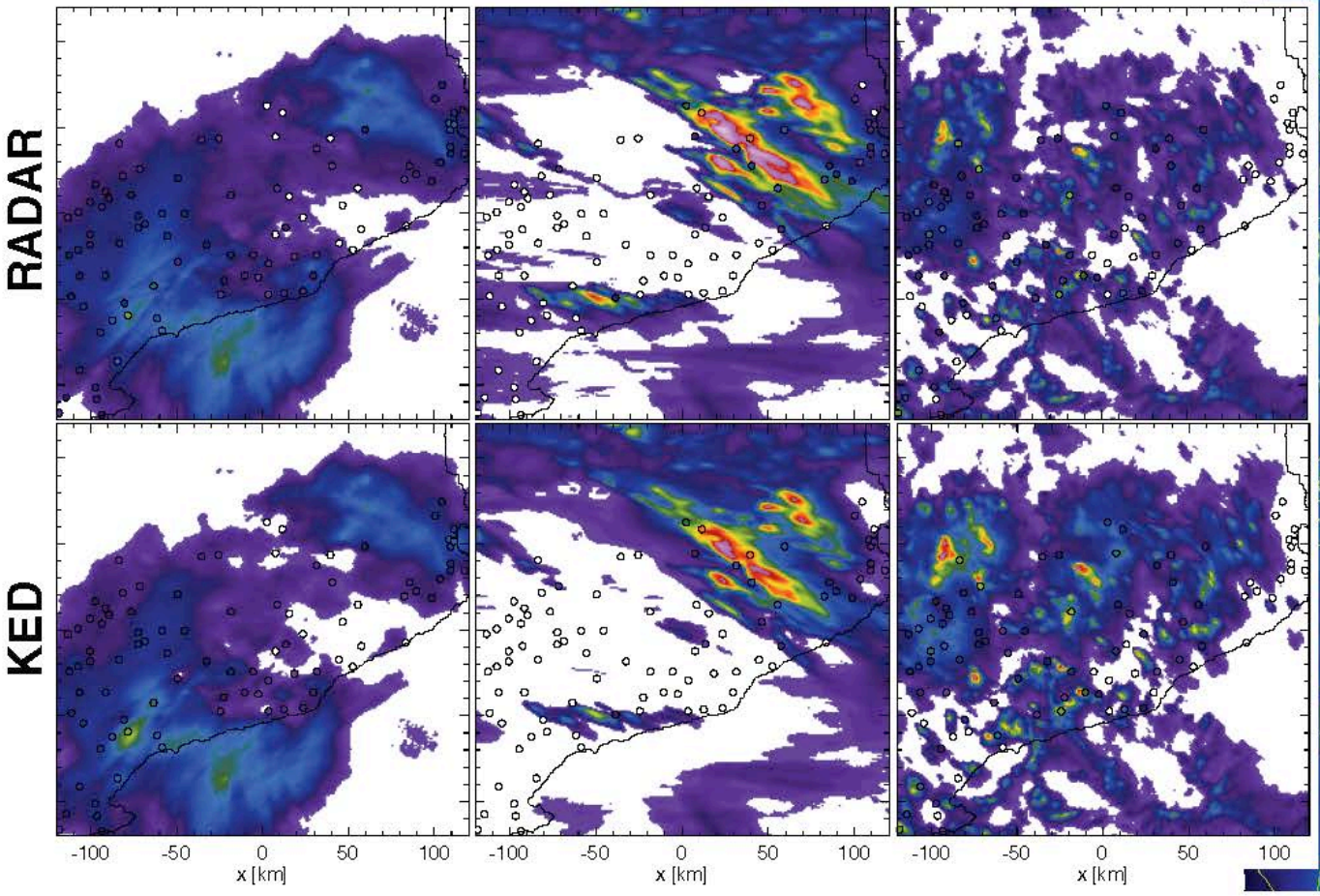
What do we get?

1) Better rainfall estimates than OK

2) Better depiction of the spatial variability of the field.

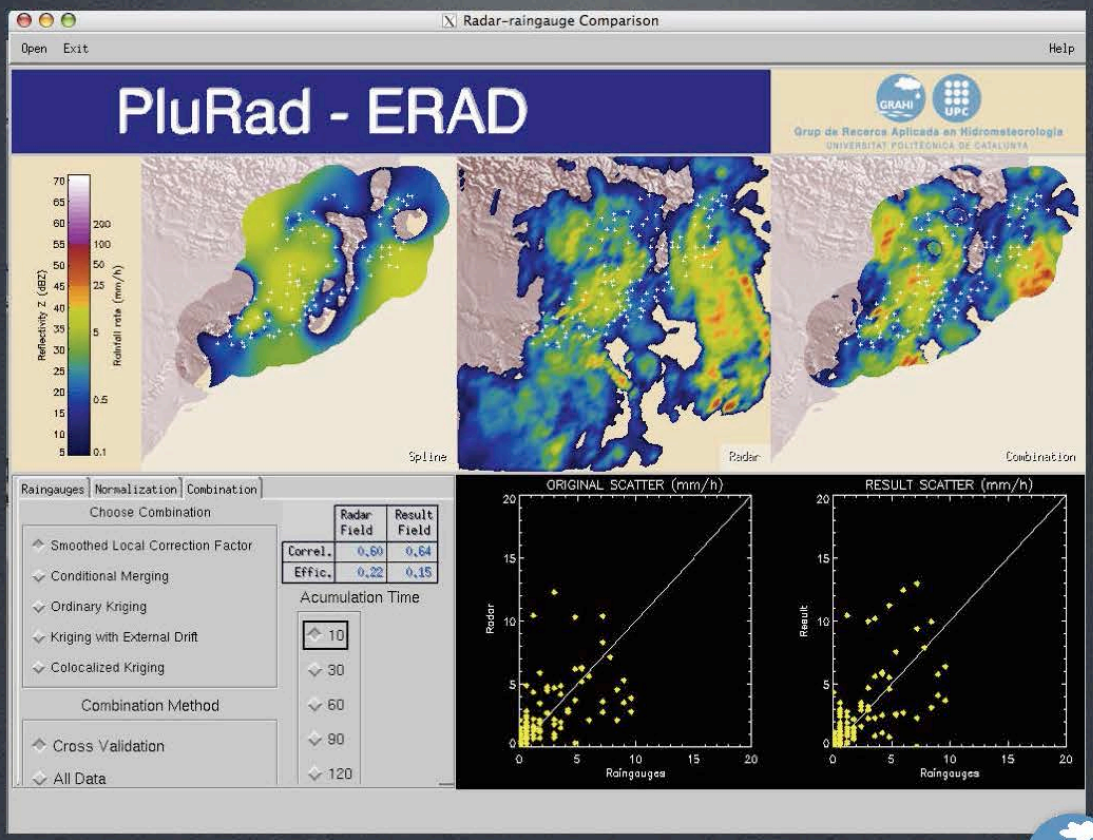
Velasco-Forero et al. AWR2009

Radar vs KED

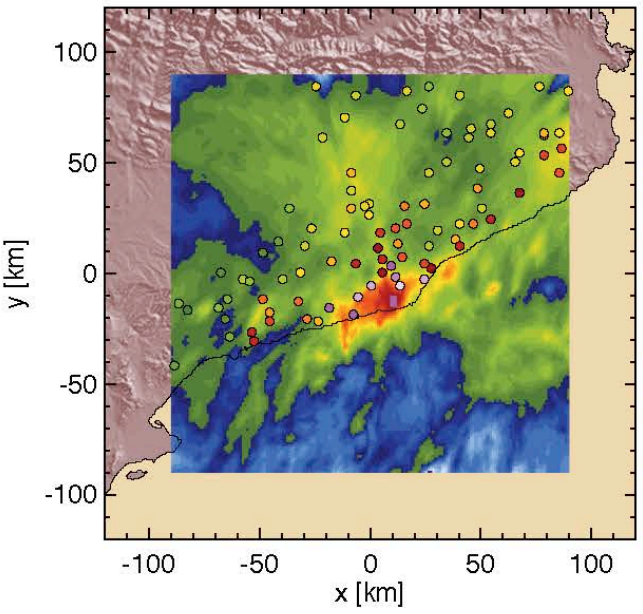


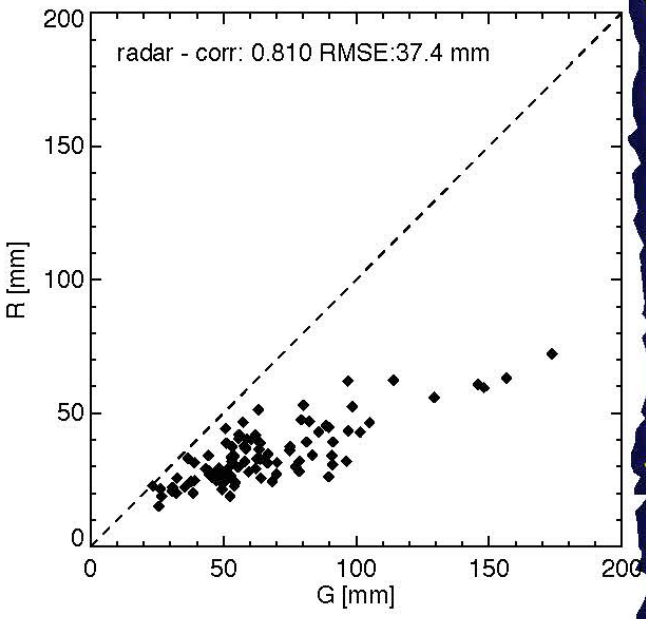
Use of weather radar in flood risk management

Radar-raingauge combination



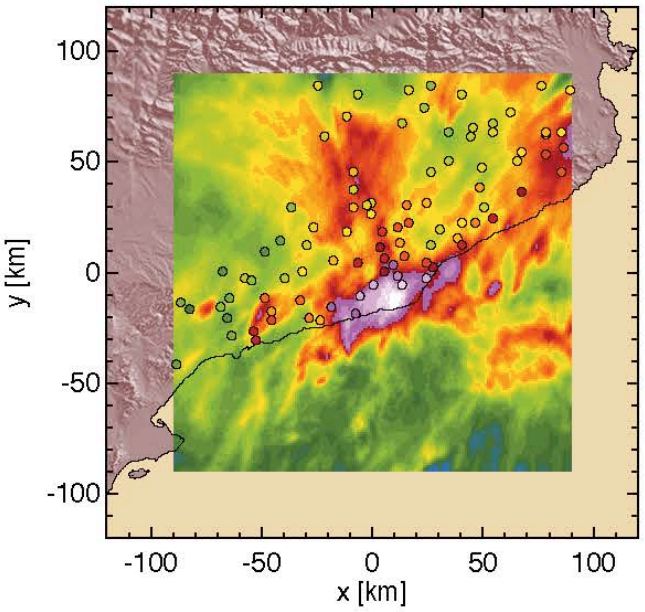
Basic corrections

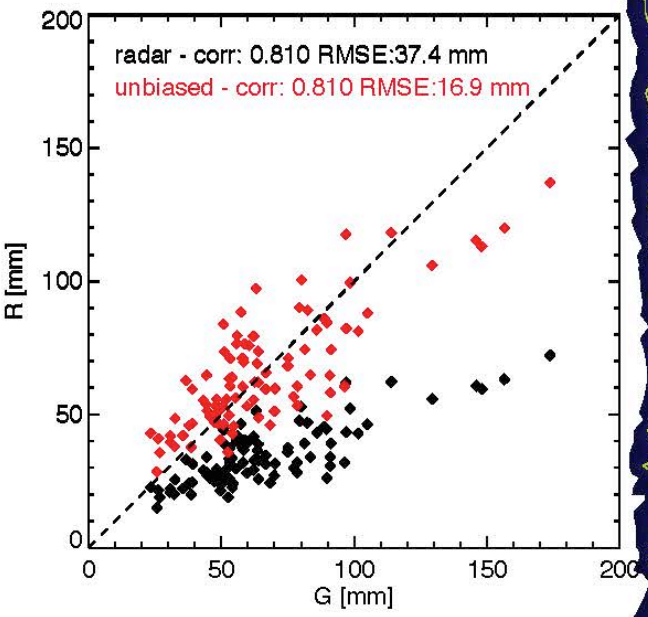




- Ground clutter
- Beam blockage

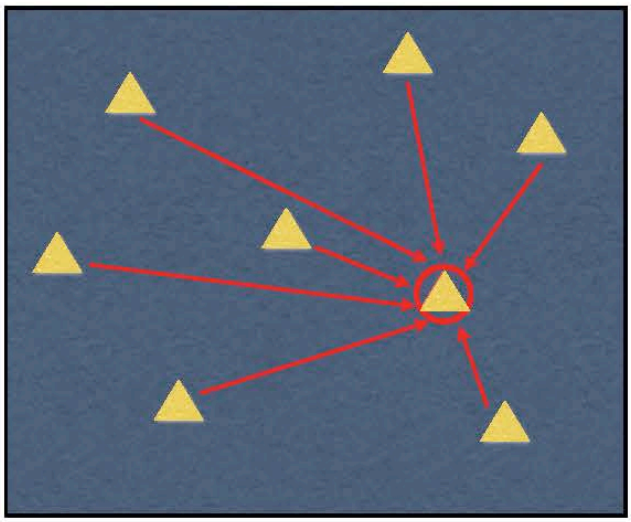
Basic corrections





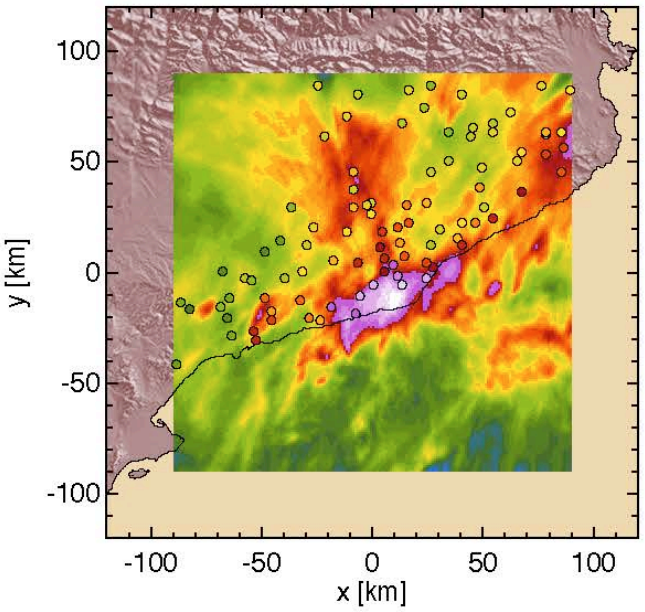
- Ground clutter.
- Beam blockage.
- Radar-rain gauge adjustment (Wilson & Brandes 1979).

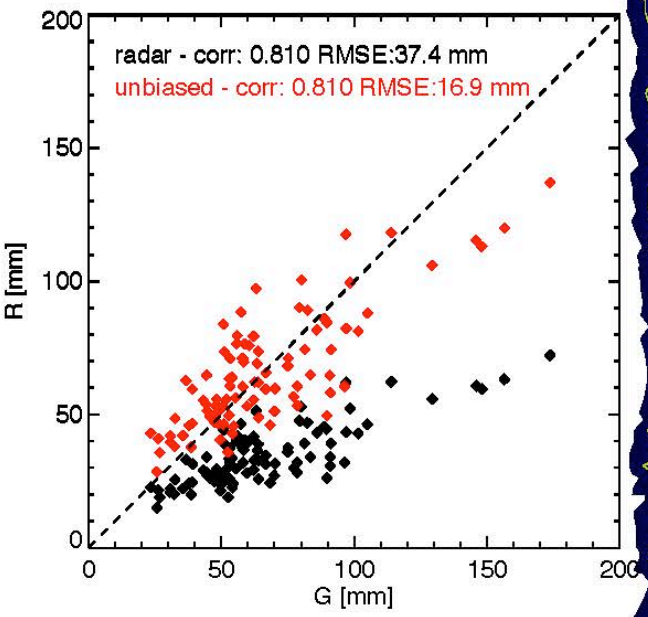
Performance Comparison by leave-one-out cross-validation of different Estimators



Use of weather radar in flood risk management

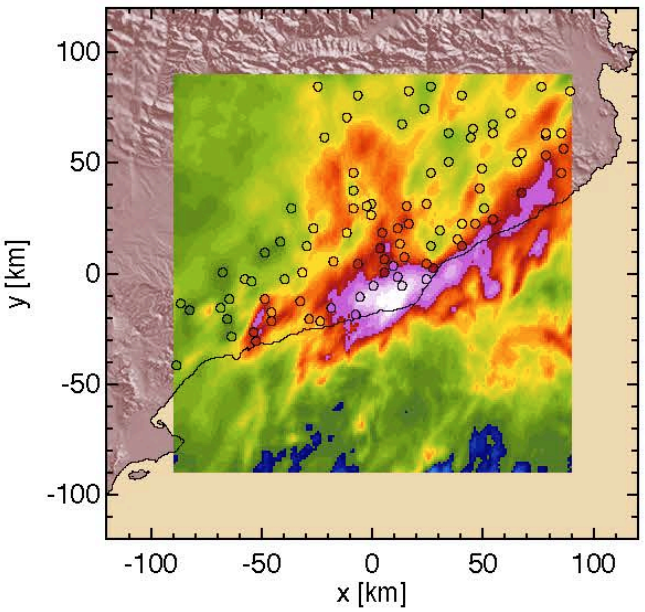
Basic corrections

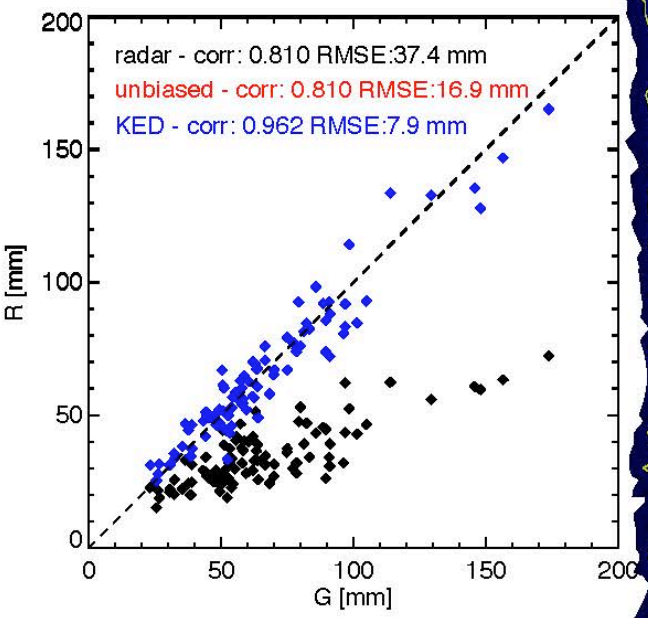




- Ground clutter.
- Beam blockage.
- Radar-rain gauge adjustment (Wilson & Brandes 1979).

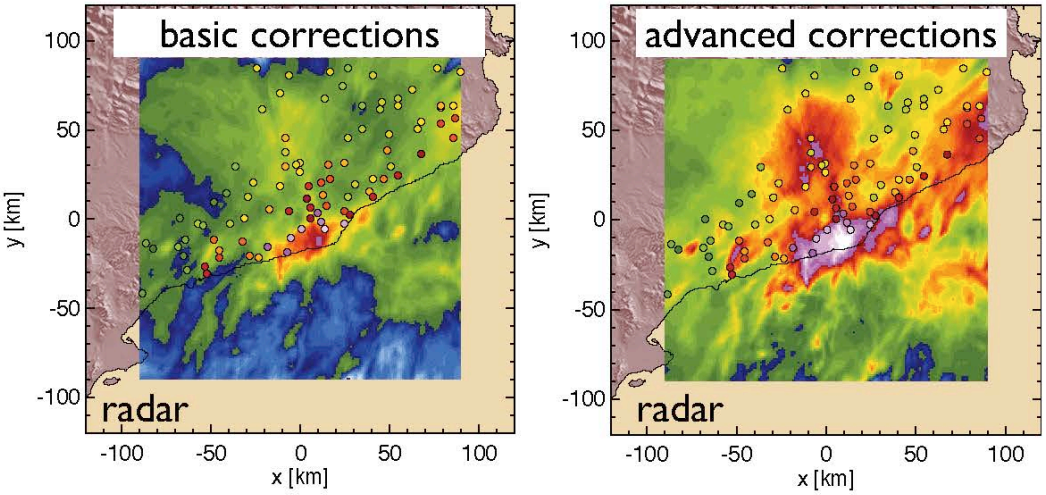
Basic corrections





- Ground clutter.
- Beam blockage.
- Radar-rain gauge adjustment (Wilson & Brandes 1979).
- KED

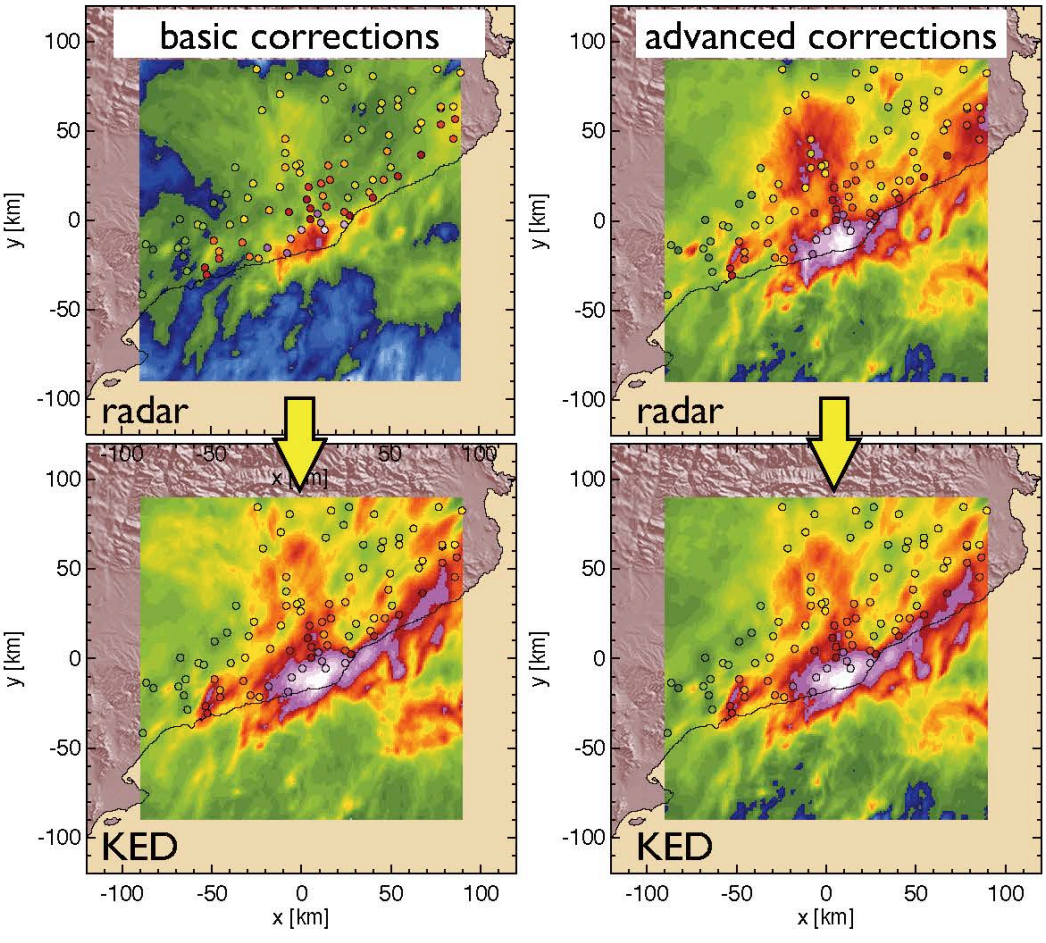
Advanced corrections



- Ground clutter
- Beam blockage.

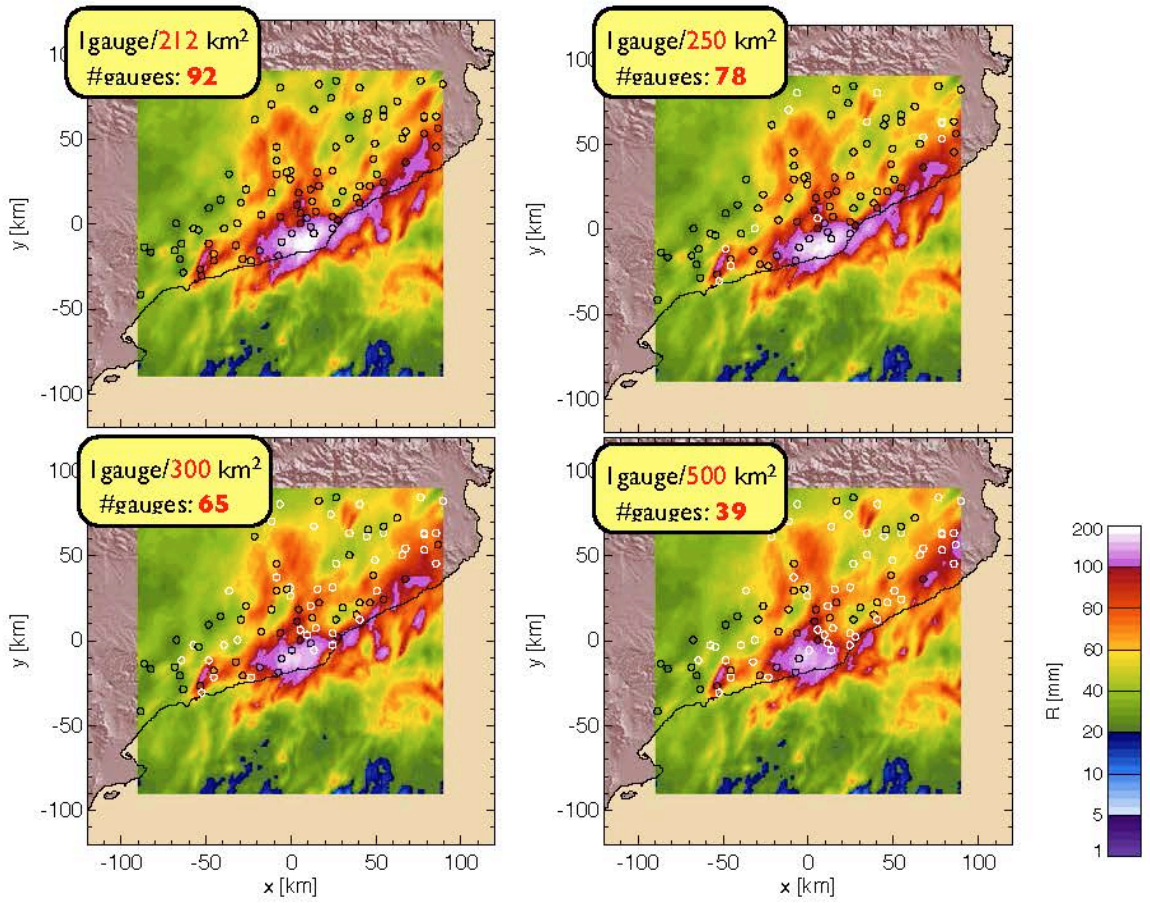
- Basic corrections
- Calibration and stability
- Precipitation type.
- VPR
- Multiple Z-R.

Advanced corrections

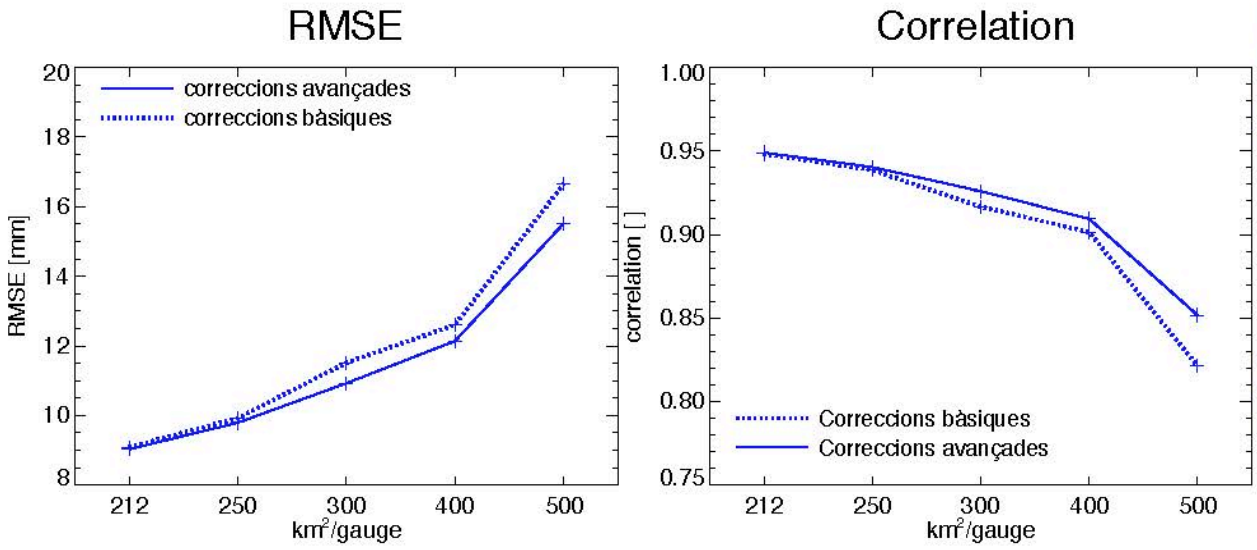


Use of weather radar in flood risk management

Rain gauge density



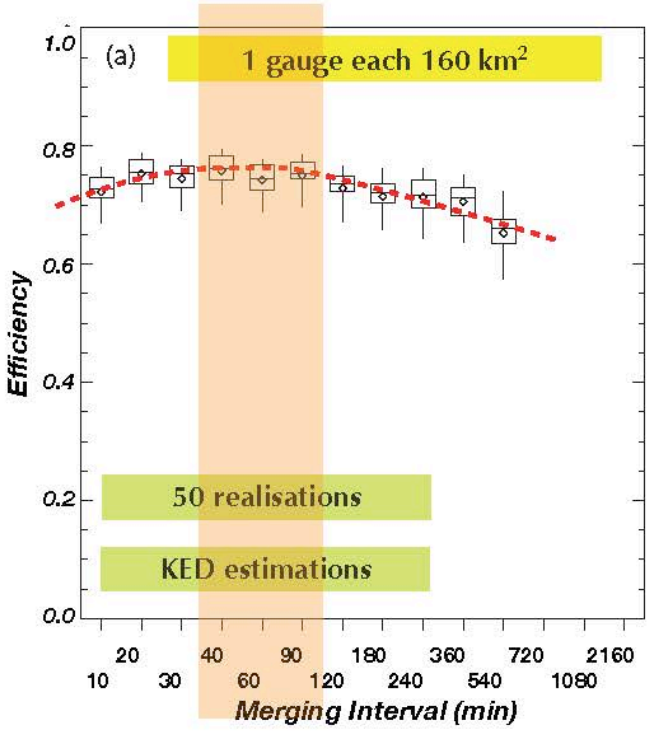
The effect of rain gauge density and radar QPE



Use of weather radar in flood risk management

Impact of aggregation period and gauges density

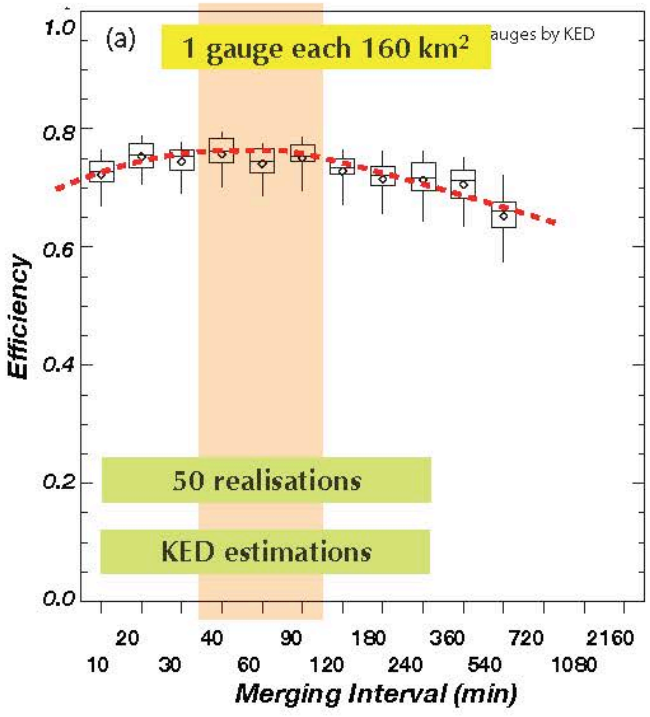
2002-10-08 Event
AEMET Radar

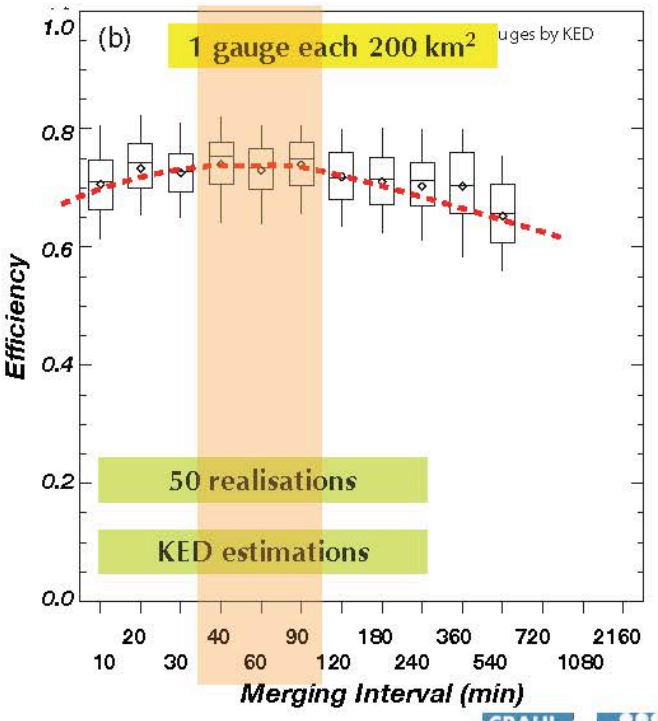




Impact of aggregation period and gauges density

2002-10-08 Event
AEMET Radar





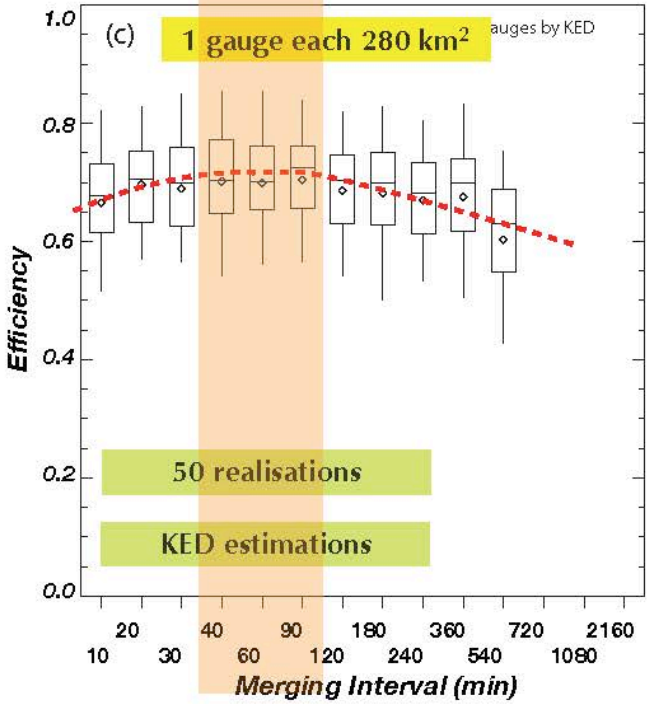


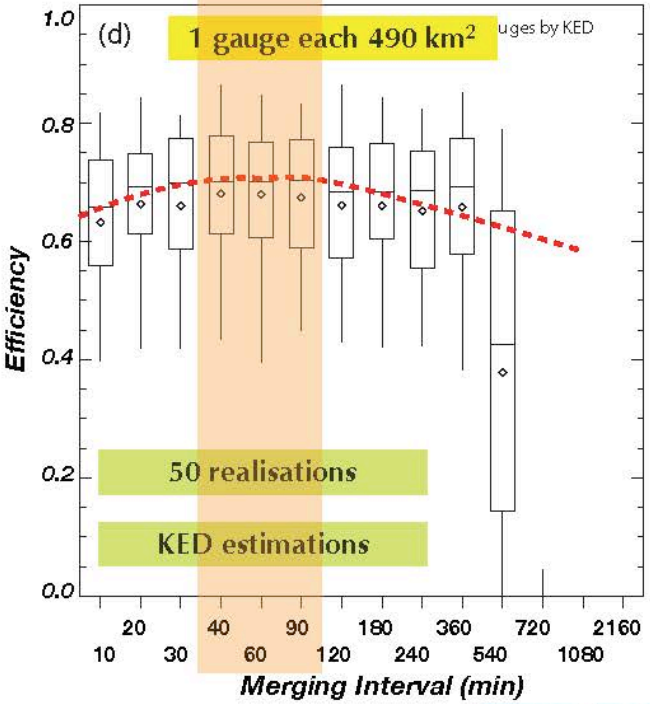
Impact of aggregation period and gauges density

36-hr Accum

2002-10-08 Event
AEMET Radar

Case Study 1





CRAHI UPC

TRAINING PROGRAM ON METEOROLOGICAL AND ADVANCED QUANTITATIVE APPLICATIONS

Rainfall forecasting and nowcasting:
State of the art on very-short term QPF.

Centre de Recerca Aplicada en Hidrometeorologia
UNIVERSITAT POLITÈCNICA DE CATALUNYA

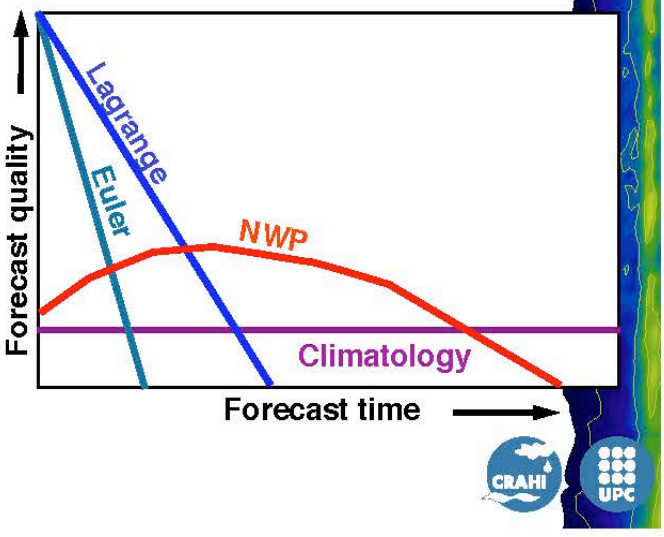


Precipitation forecasting

The types of meteorological forecasting outputs which are potentially useful include:

Quantative Preciptiation Forecasts (QPF).
And other variables such as temperature, wind, humidity,...

- ***Nowcasting***: short/range based on recent and current observations.
- ***Numerical Weather Prediction*** (NWP): three-dimensional models of the atmosphere.
- ***Statistical methods.***

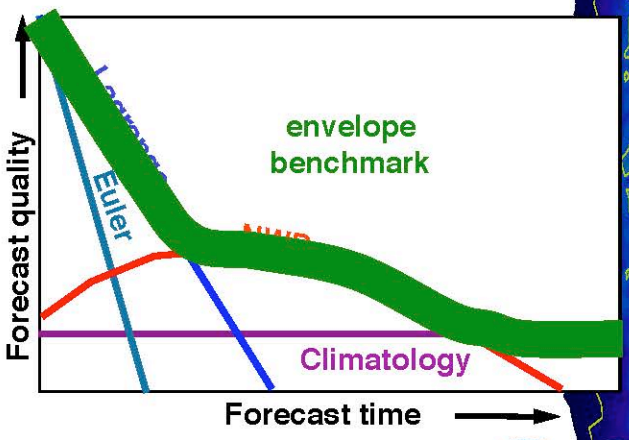


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Precipitation forecasting

The World Meteorological Organisation defines:

- nowcasting: current conditions and < 2 h.
- very short-range: < 12 h.
- short-range: 12 - 72 h.
- medium-range: 72 - 240 h.
- extended range: 10 - 30 days.
- long range: 30 days - 2 years.

NWP ensembles: probabilistic approach to consider that uncertainties can lead to significantly different outcomes (e.g. differences in Initial Conditions cause the butterfly effect).

Example: When the spread is small or significant clustering of ensemble members occurs, the forecaster will often be more confident in the forecast.

Precipitation forecasting

Typical lead time and resolution characteristics of QPF techniques.

Table 3.1 Some typical lead time and resolution characteristics for meteorological forecasting techniques (typical values in the period 2005–2010)

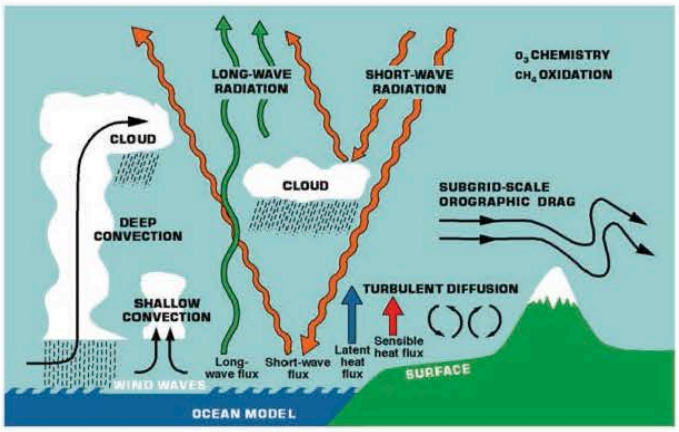
Method	Lead time	Horizontal/grid resolution (km)	Time step for model outputs (h)	Comments
Nowcasting	0–6 h (rainfall)	1–5 km	5 or 15 min	Maximum lead times may be only 0–2 h or less for thunderstorms and some other types of event
	0–10 days (tropical cyclones)	100–1,000 km	Hourly or more	Typical values for tropical cyclone, typhoon and hurricane forecasting
Numerical Weather Prediction	0–3 days	1–25 km	1–6 h	Higher resolution models may have limited spatial extent (e.g. limited area models, mesoscale models)
	3–10 days	25–100 km	6–12 h	Models are typically global in extent
	10 days+	25–100 km	12 h to monthly	May be operated for lead times of several months or more ahead
Statistical methods	Weeks to months ahead	Depends on application	Depends on application	Probabilistic estimates of timing, magnitude and location

Source: Sene, 2009: Hydrometeorology. Forecasting and applications.

Precipitation forecasting - NWP

Numerical Weather Prediction (NWP) models are based on:

- 3-D equations for mass, momentum and energy conservation in the atmosphere.
- Initial fields of the forecasted variables are needed.



Schematic diagram of the different physical processes represented in the IFS model.

Source: ECMWF (2009).

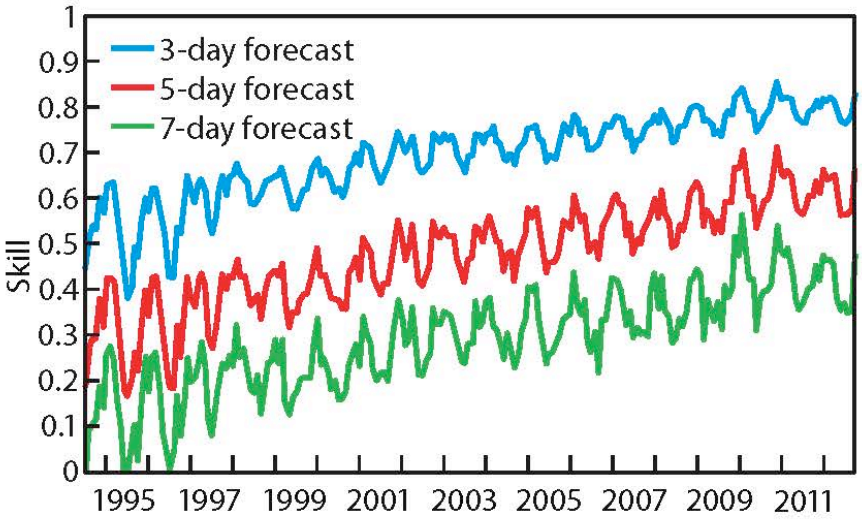
Steps in forecasting by NWP:

1. Data collection and validation.
2. Data assimilation.
3. Model runs.
4. Post-processing (downscaling, analogue methods,...).

Precipitation forecasting - NWP

NWP skill - ECMWF

- Computing power.
- Data assimilation.
- Better knowledge of atmospheric processes.



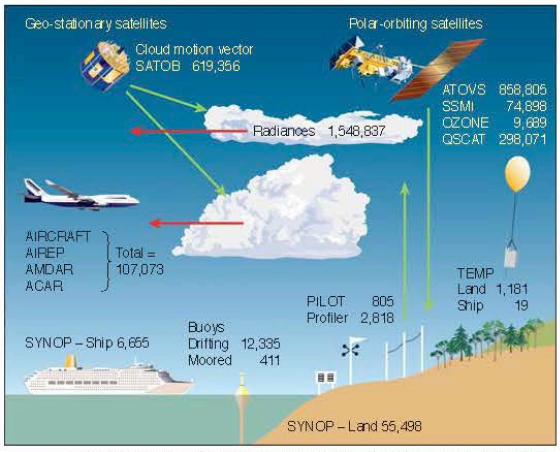
Source: ECMWF annual report (2012).

Precipitation forecasting - NWP

Data assimilation

- Allows better description of the initial conditions.
- Hypothesis: better initial conditions would result in better forecasts.

Large scale models



24h summary of observations received at ECMWF, 5 July 2004.

Source: ECMWF (2009).

At smaller scales (mesoscale),



What do we assimilate?

Doppler velocity - one component of the wind.

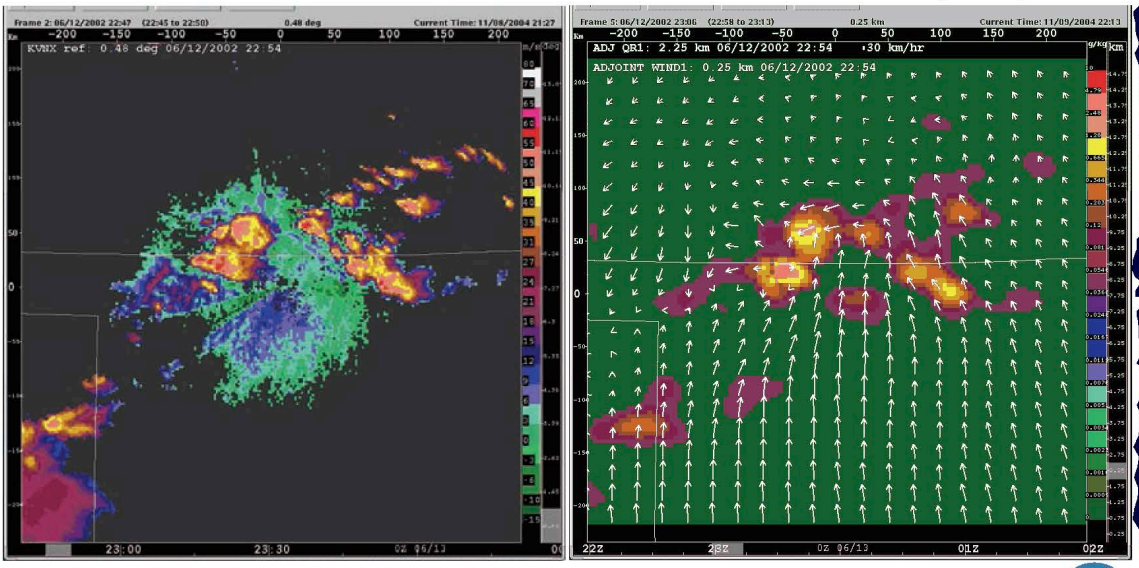
Reflectivity - liquid water content

Precipitation forecasting - data assimilation at convective scale

IHOP case, June 12, 2002

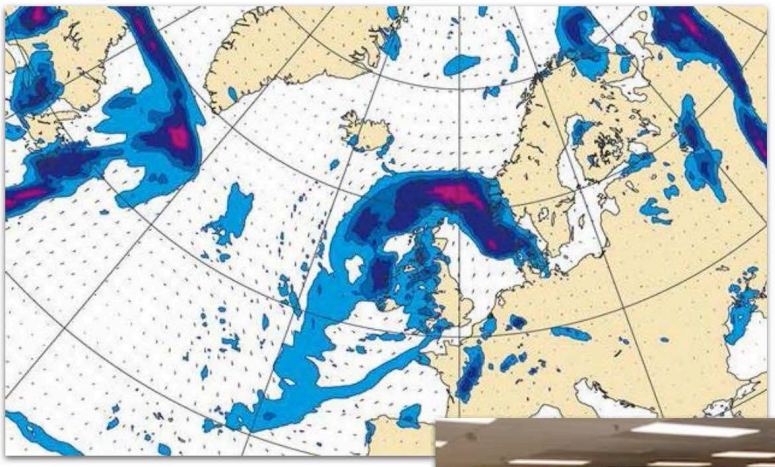
Observations

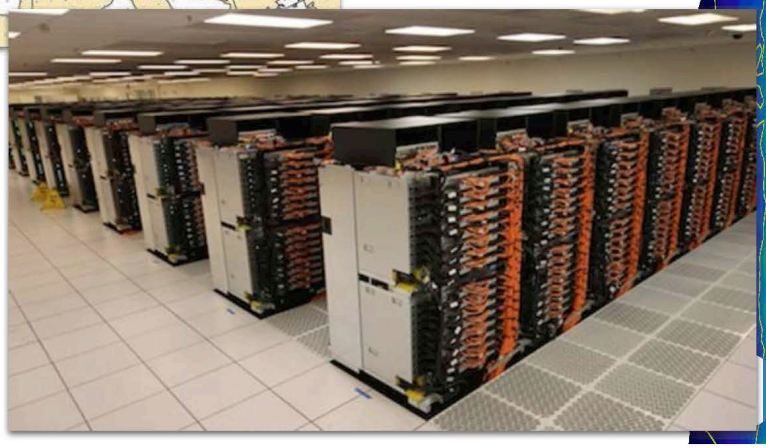
3-h forecast
(4DVar data assimilation system)



Source: A. Crook (NCAR).

Precipitation forecasting

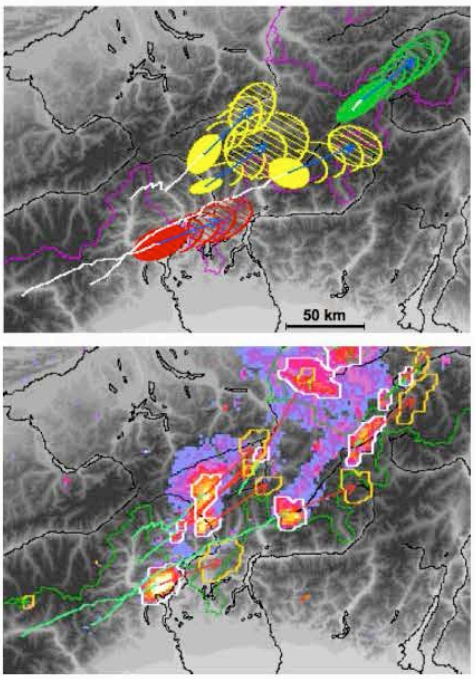




Nowcasting of severe weather - convective cell tracking

A well-established tool for severe weather nowcasting

1. Detection of storm objects from weather radar volume scans
2. Organizing the objects in consecutive radar images into tracks
3. Nowcasting is typically based on the extrapolation of the storms using their history.

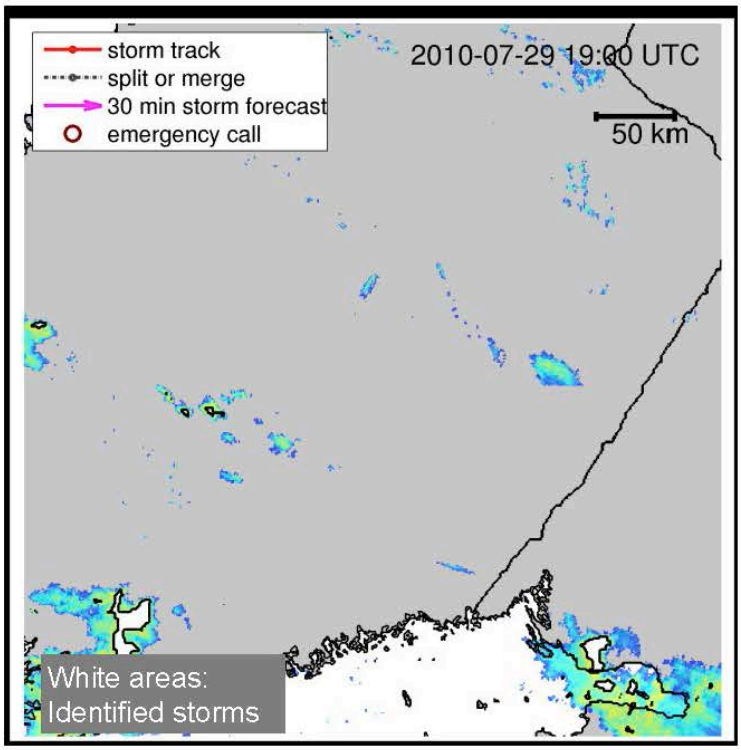


Source: Hering et al. 2006

Nowcasting of severe weather - convective cell tracking

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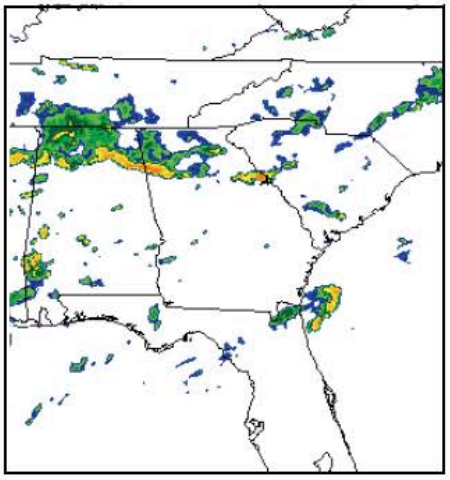


Courtesy of P. Rossi (FMI)

Rainfall nowcasting - Convective initiation

NCAR Auto-nowcaster (Mueller et al. 2003)

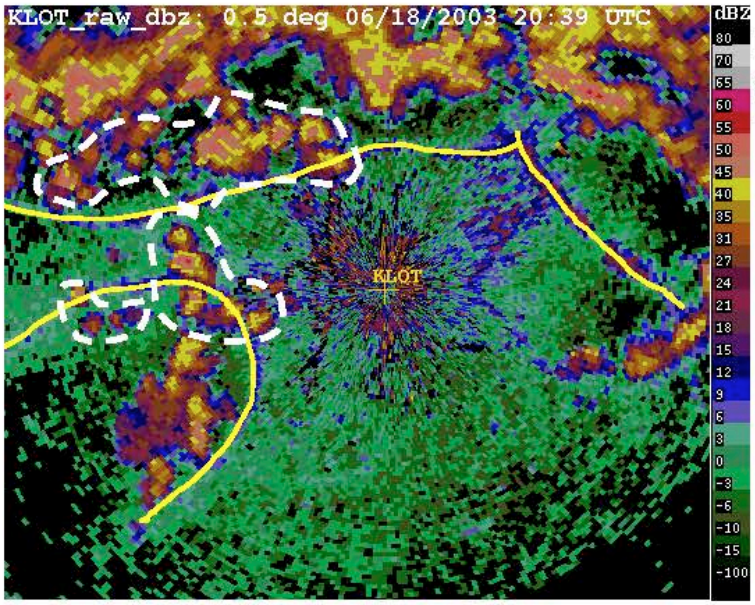




Source: C. Mueller.

Rainfall nowcasting - Authonowcaster

is unique in its ability to provide ***nowcasts of storm initiation*** by…..



Detection and extrapolation of surface convergence boundaries ….

….that trigger thunderstorm initiation and impact storm evolution.

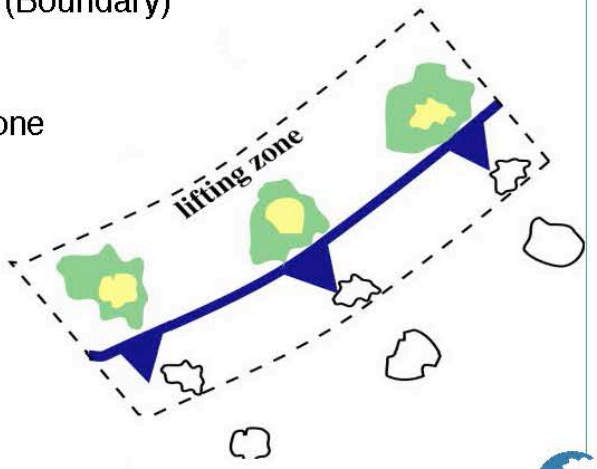
Source: C. Mueller.

Rainfall nowcasting - Atuonowcaster

Based on our present knowledge of storm evolution, the following parameters are used to forecast storm initiation, growth and dissipation.

Factors Associated With Storm Initiation:

- Presence of convergence line (Boundary)
- Lifted index < 0 in lifting zone
- Cu in lifting zone
- Rapid growth of Cu in lifting zone
- Colliding boundaries
- Low boundary relative cell speeds



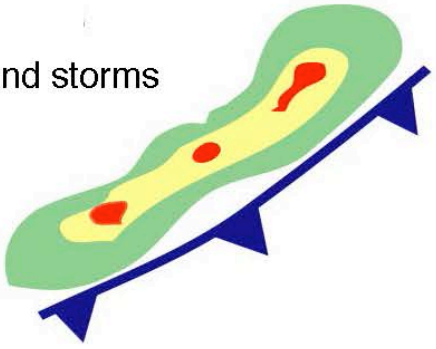
Source: C. Mueller.

Rainfall nowcasting - Atuonowcaster

Based on our present knowledge of storm evolution, the following parameters are used to forecast storm initiation, growth and dissipation.

Factors Associated With Storm Growth:

- Boundary motion = storm motion
- Convergence strong and deep
- Erect updrafts
- Merging of storms
- Boundary intercepting cumulus and storms



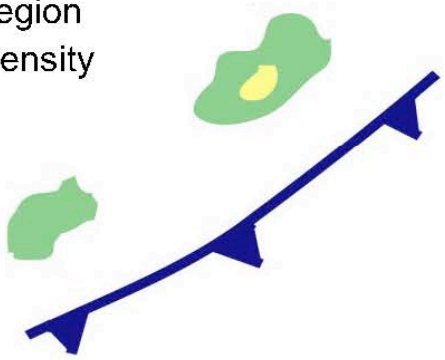
Source: C. Mueller.

Rainfall nowcasting - Atuonowcaster

Based on our present knowledge of storm evolution, the following parameters are used to forecast storm initiation, growth and dissipation.

Factors Associated With Storm Dissipation:

- Boundary moving away from storms
- Boundary moving into a stable region
- Storm decreasing in size and intensity and no boundary present .

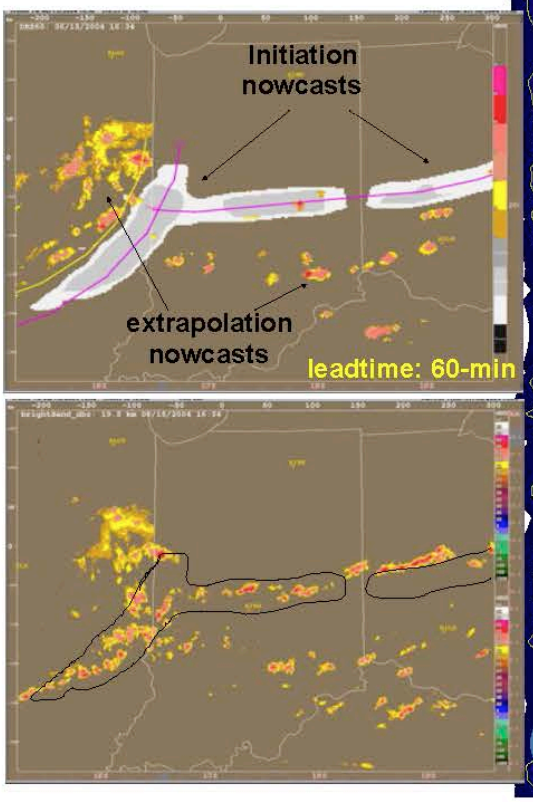


Source: C. Mueller.

Rainfall nowcasting - Atuonowcaster

Predictor Fields used for Combined Likelihood of Initiation

- **Environmental conditions (RUC)**
  - Frontal likelihood
  - Layered stability
  - CAPE (max between 900 and 700 mb)
  - Mean 875 to 725 mb Relative Humidity
- **Boundary-layer**
  - Convergence
  - LI (based on METARS)
  - Vertical velocity along boundary (maxW)
  - Boundary-relative steering flow
  - New storm development along boundary
- **Clouds**
  - Clear or Cumulus
  - Vertical develop as observed by drop in IR temperatures

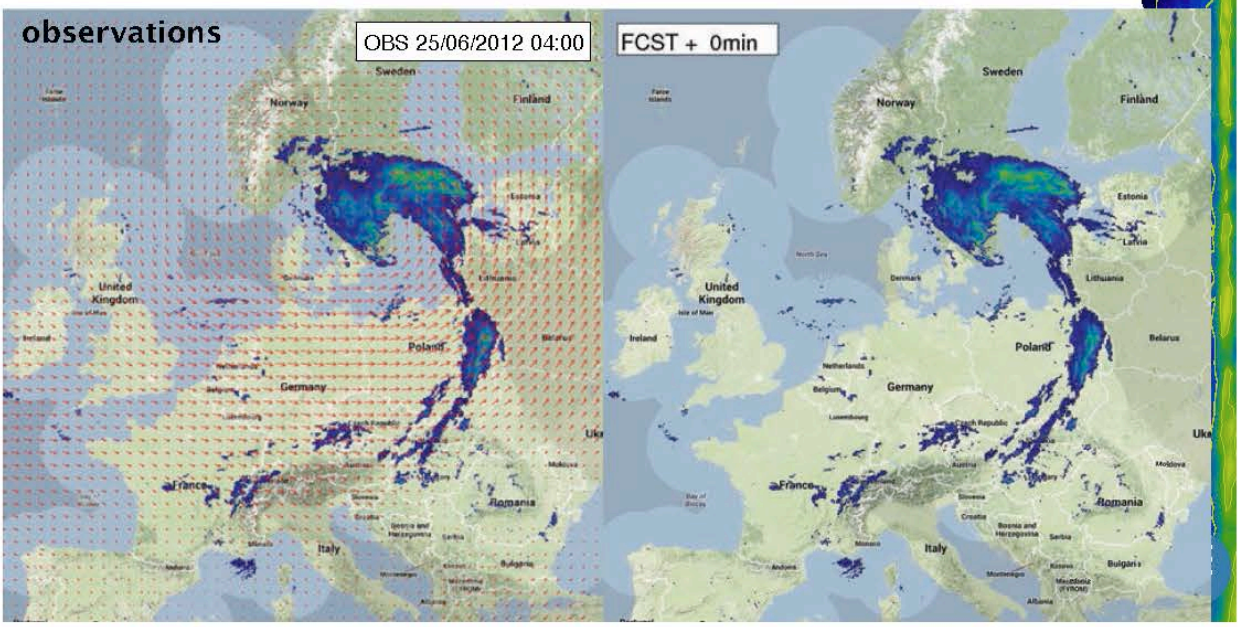


Source: C. Mueller.

Rainfall nowcasting

Very short-term forecasting by extrapolation of radar observations.

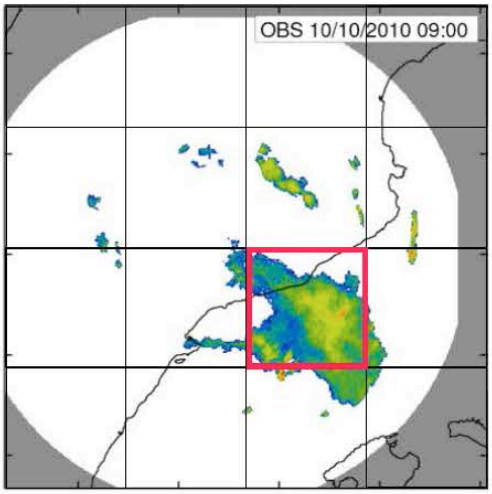
1. **Tracking:** The motion field of rainfall is estimated from observations.
2. **Extrapolation**: The most recent field is extrapolated accordingly.

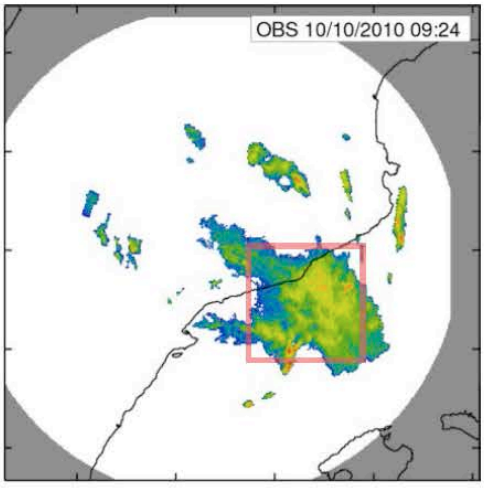


Rainfall nowcasting - Tracking

Most of the methods were "inspired" by:

•TREC (Rinehart & Garvey, 1978)

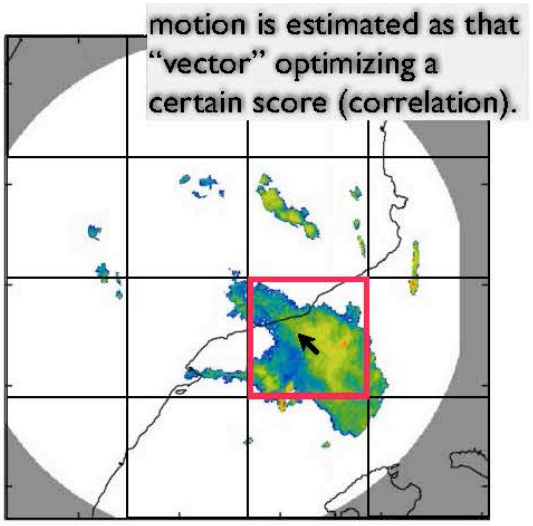


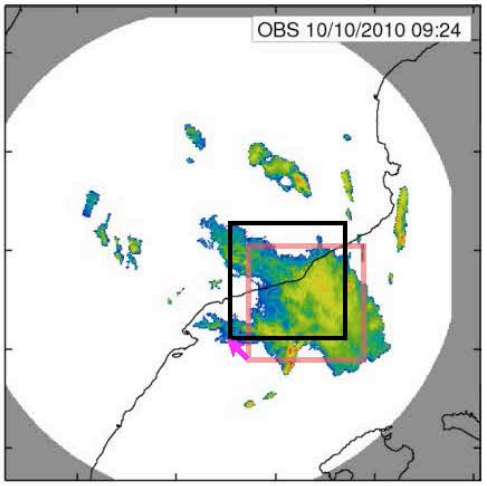


Rainfall nowcasting - Tracking

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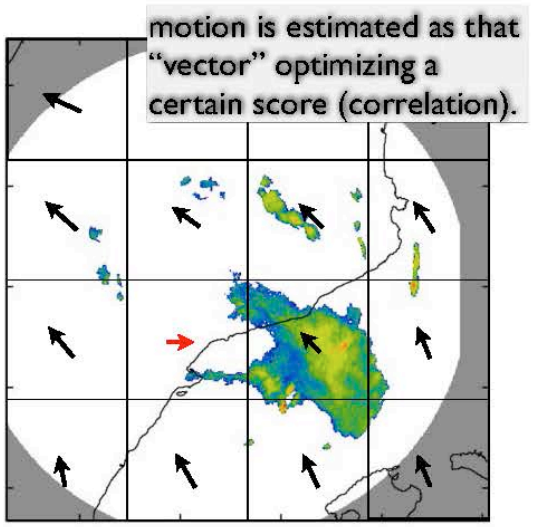




Rainfall nowcasting - Tracking

Most of the methods were "inspired" by:

•TREC (Rinehart & Garvey, 1978)



• Smoothing:

CO-TREC (Li et al. 1995). Imposed the Boussinesq mass continuity equation to the motion field.

VET (Laroche and Zawadzki 1994). Introduce a weak constraint that penalizes non-smooth fields.

Bowler et al. (2004). Using optical flow techniques.

•…

The tracking algorithm

Smoothing is achieved by different approaches:

- CO-TREC (Li et al. 1995).

Imposed the Boussinesq mass continuity equation to the motion field.

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$$

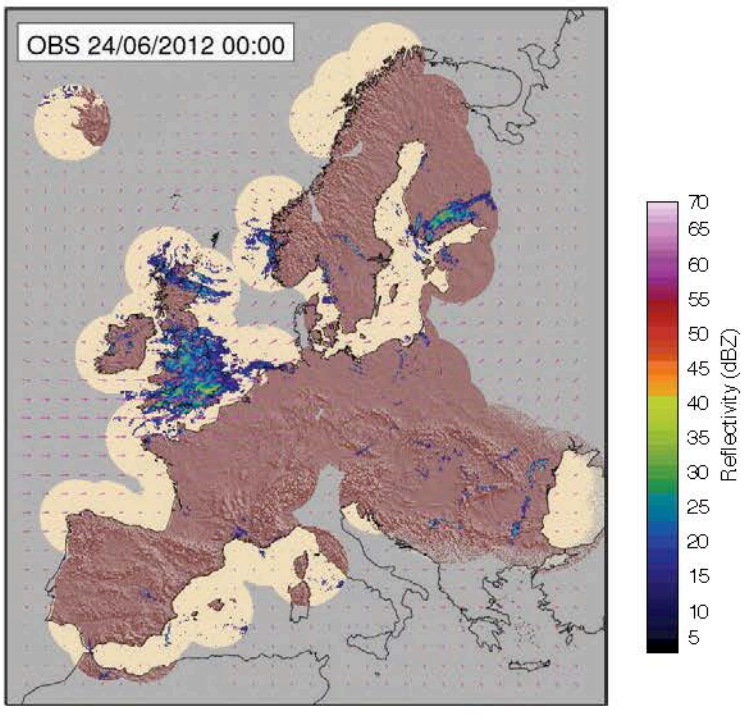
- VET (Laroche and Zawadzki 1994). Introduce a weak constraint that penalizes non-smoothed fields.

- Bowler et al. (2004). Using optical flow techniques.

- ...

Rainfall nowcasting - Tracking

Evolution of the motion field - 24 June 2012.



Rainfall nowcasting - Extrapolation

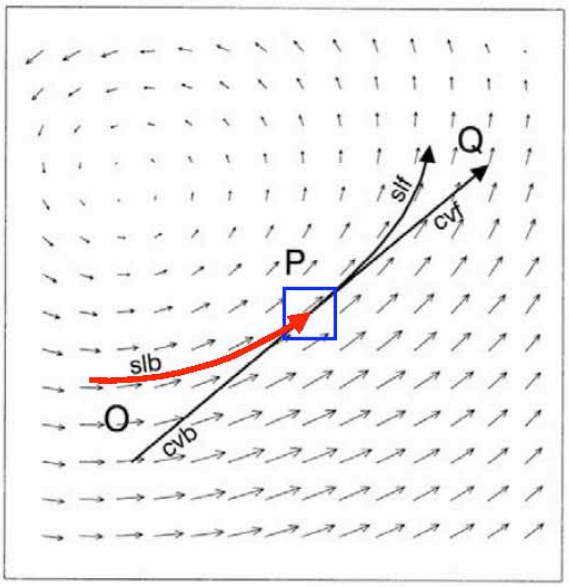


FIG. 8. Displacement vectors of four advection schemes: semi-Lagrangian forward (slf), semi-Lagrangian backward (slb), constant-vector forward (cvf), and constant-vector backward (cvb). *P* is the grid point of a parcel for which one wants to find out where it comes from (backward), or where it goes (forward).

From: Germann & Zawadzki (2002).

Semi-Lagrangian backward scheme.

$$dBZ^*(x,y,t) = dBZ(x - \Delta x, y - \Delta y, t_0)$$

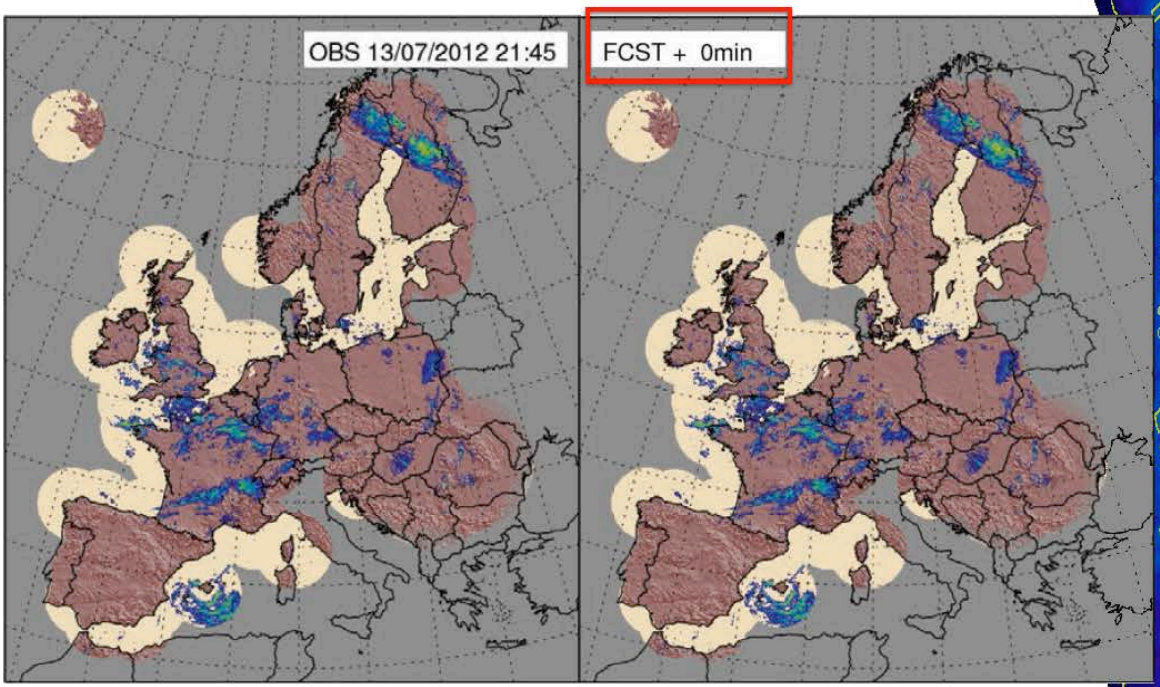
$$\Delta x = \sum_{k=0}^{N} u(x,y) \cdot \Delta t \text{ and } \Delta y = \sum_{k=0}^{N} v(x,y) \cdot \Delta t$$

where N=(t-t_0)/Dt.

the motion field is integrated backwards with small intervals (Dt~1 min).

Rainfall nowcasting

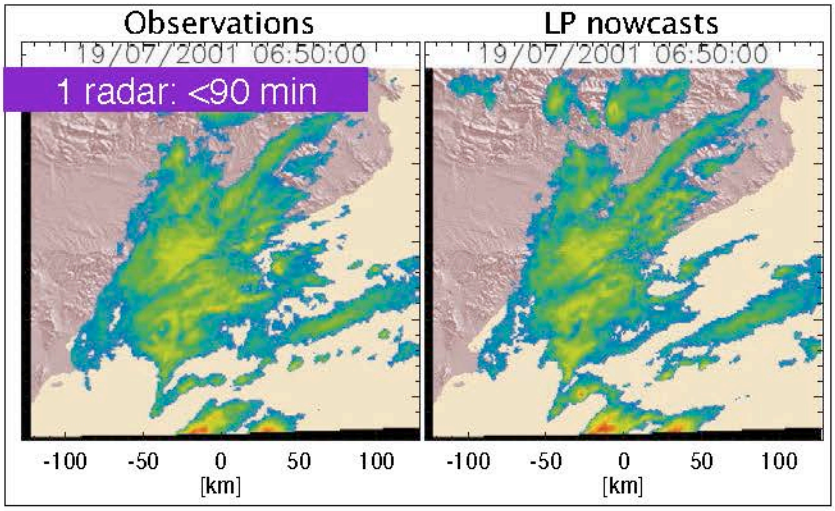
13 July 2012 - 4h forecasts



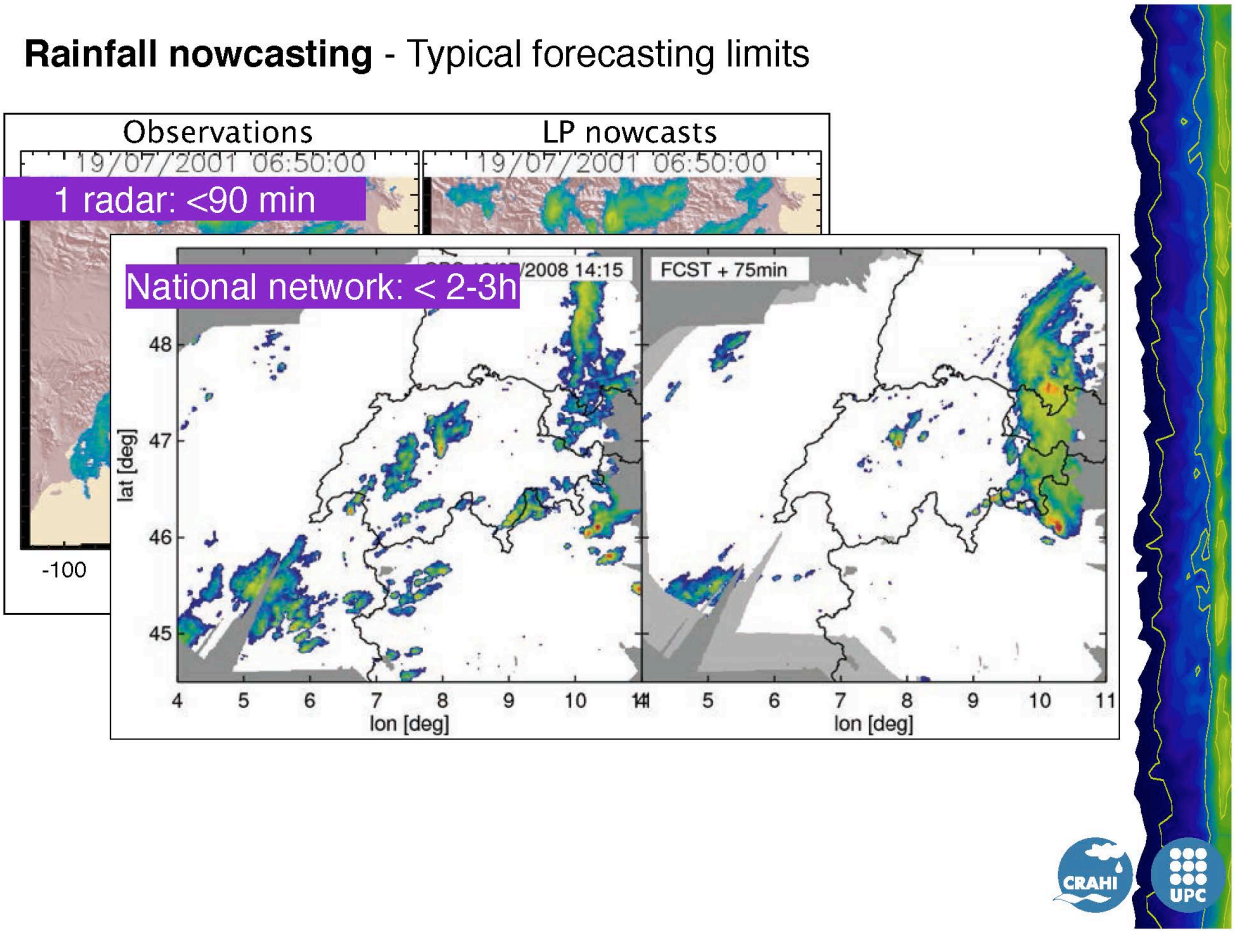
How does it work?

-performance of nowcasting-

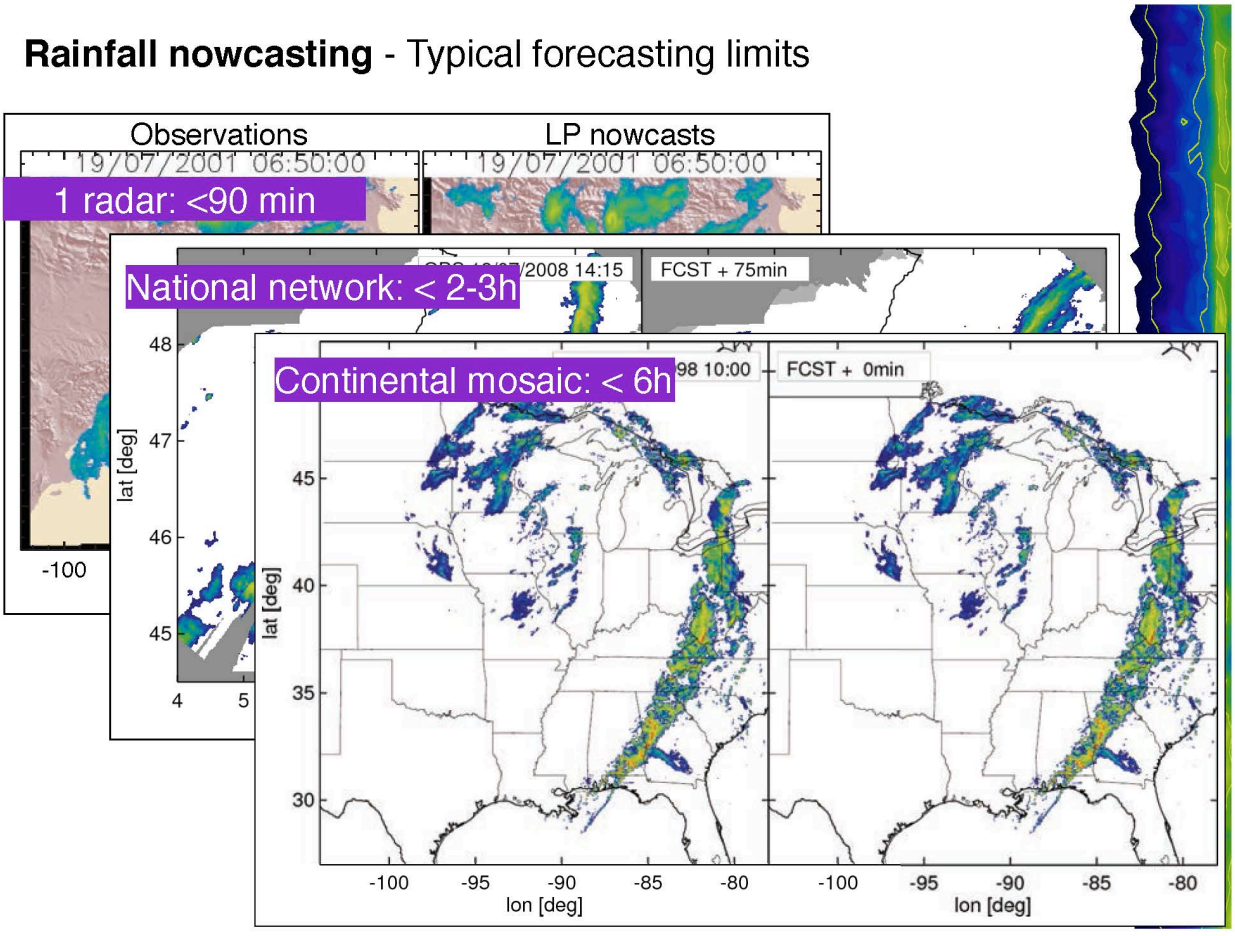
Rainfall nowcasting - Typical forecasting limits



Rainfall nowcasting - Typical forecasting limits

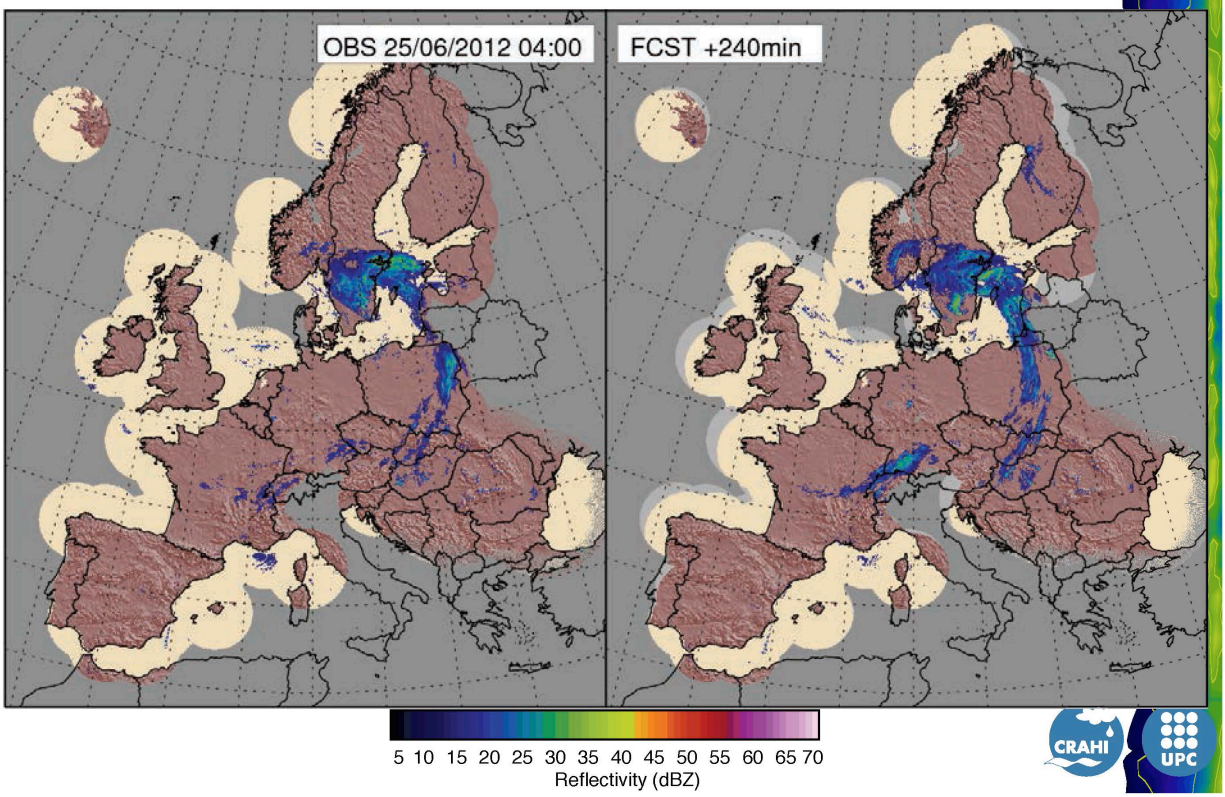


Rainfall nowcasting - Typical forecasting limits

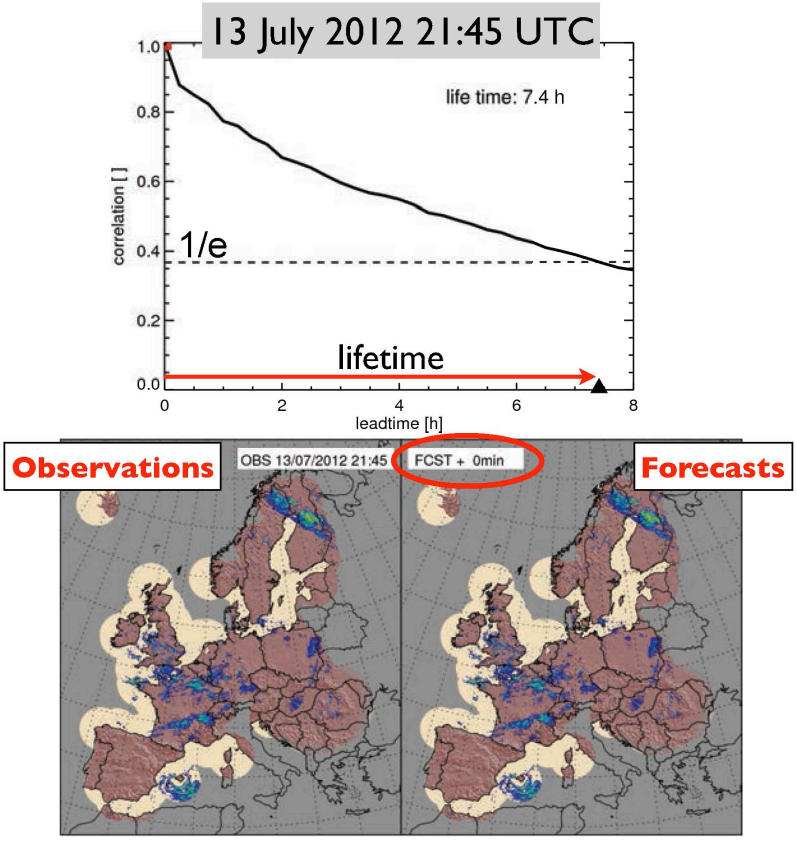


Rainfall nowcasting

13 June 2012 - 4h forecasts

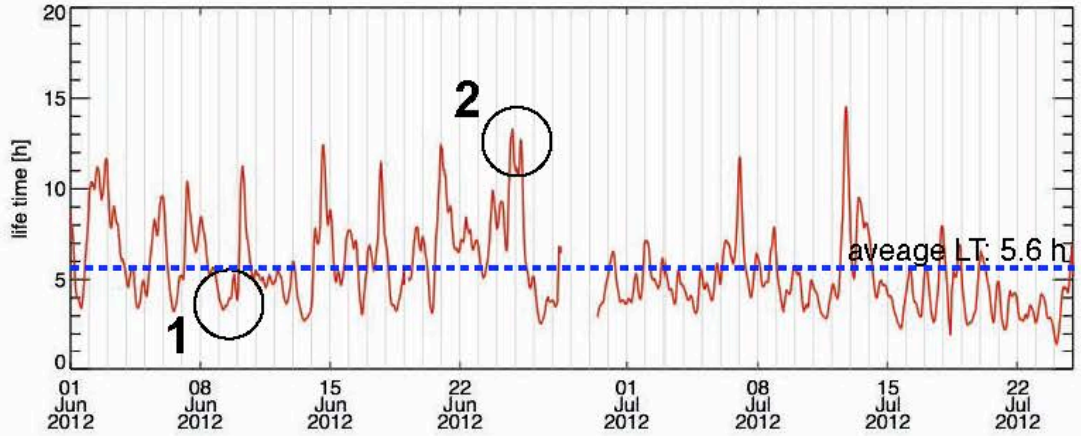


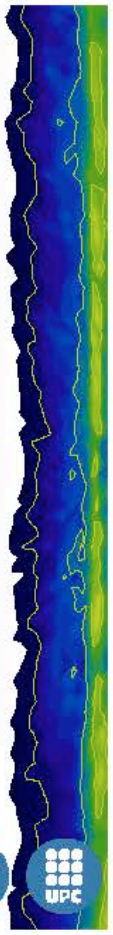
Rainfall nowcasting - Evaluation



Rainfall nowcasting - Lifetime variability

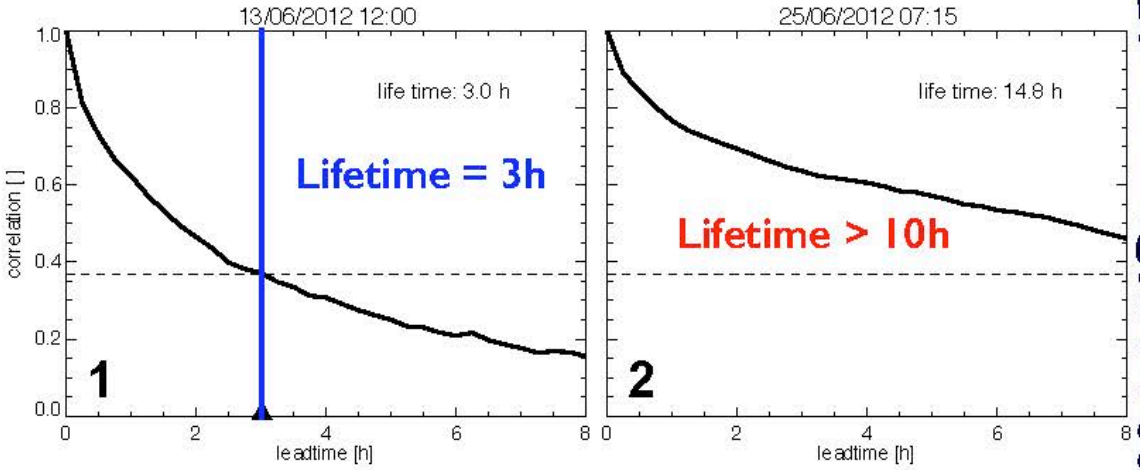
In the period **01 June - 31 July 2012**

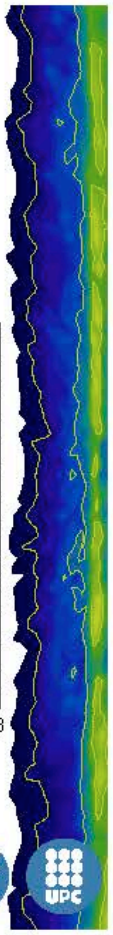




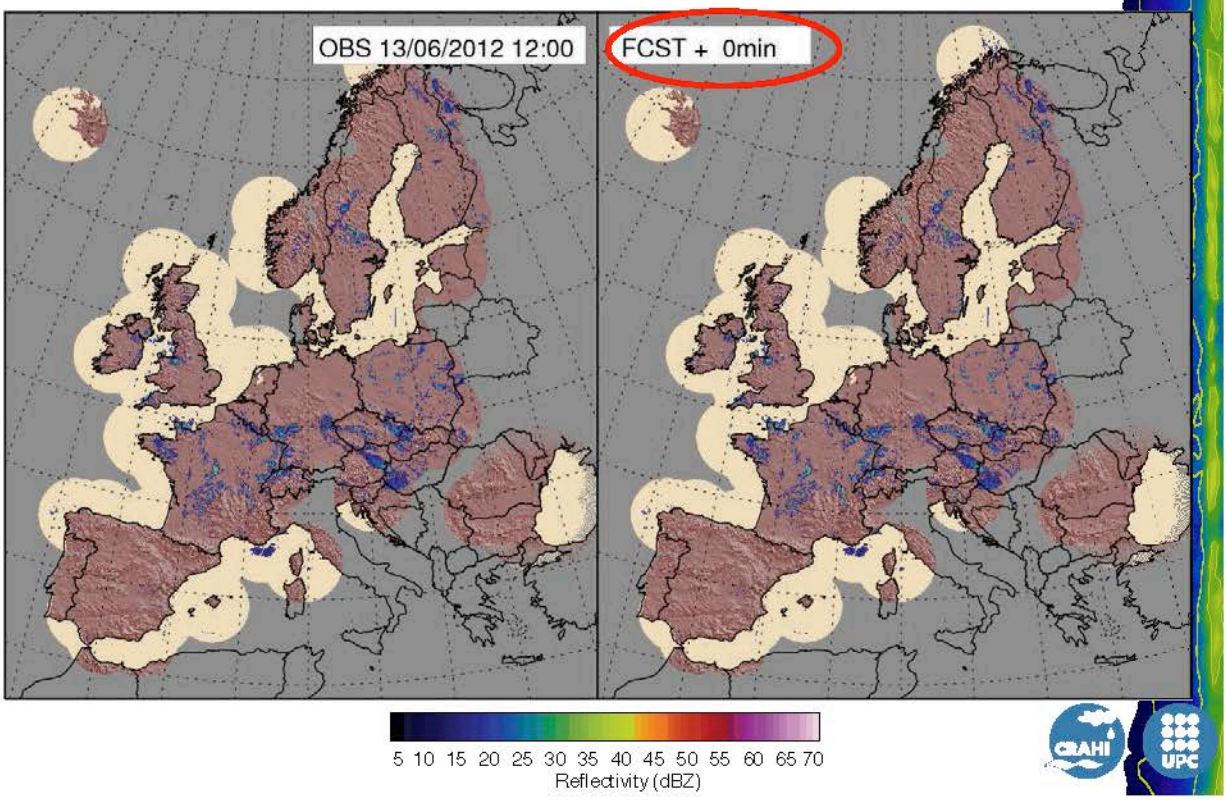
Rainfall nowcasting - Lifetime variability

In the period **01 June - 31 July 2012**

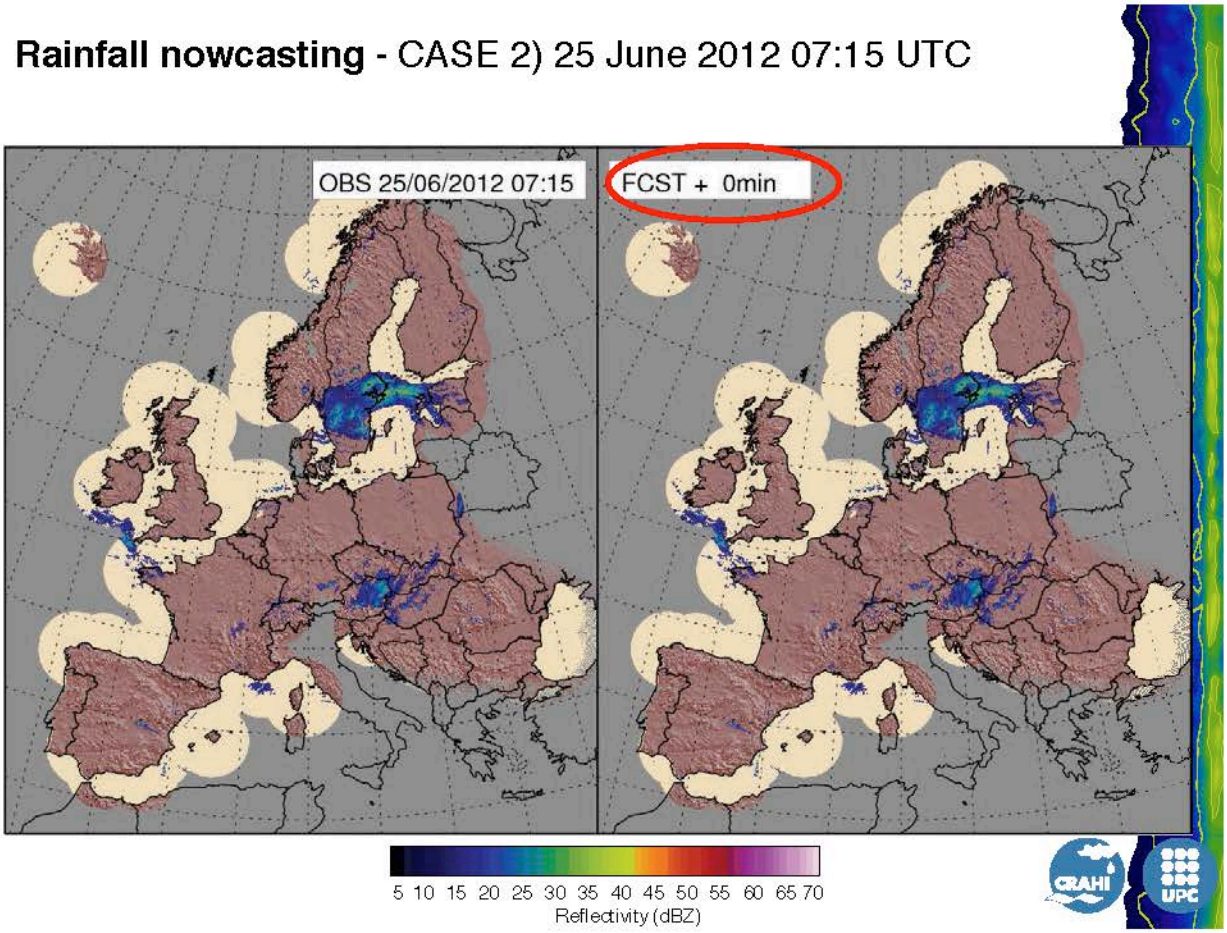


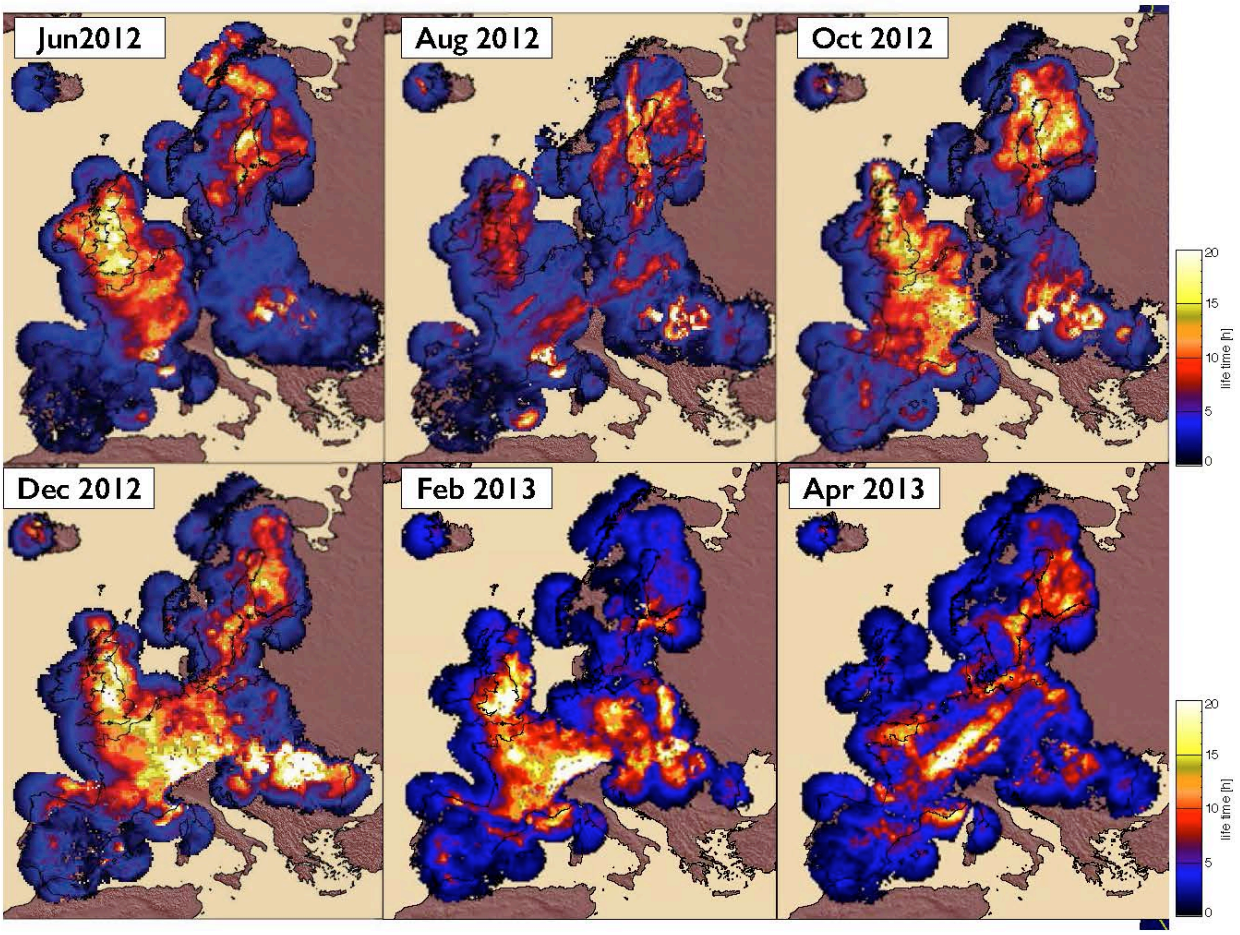


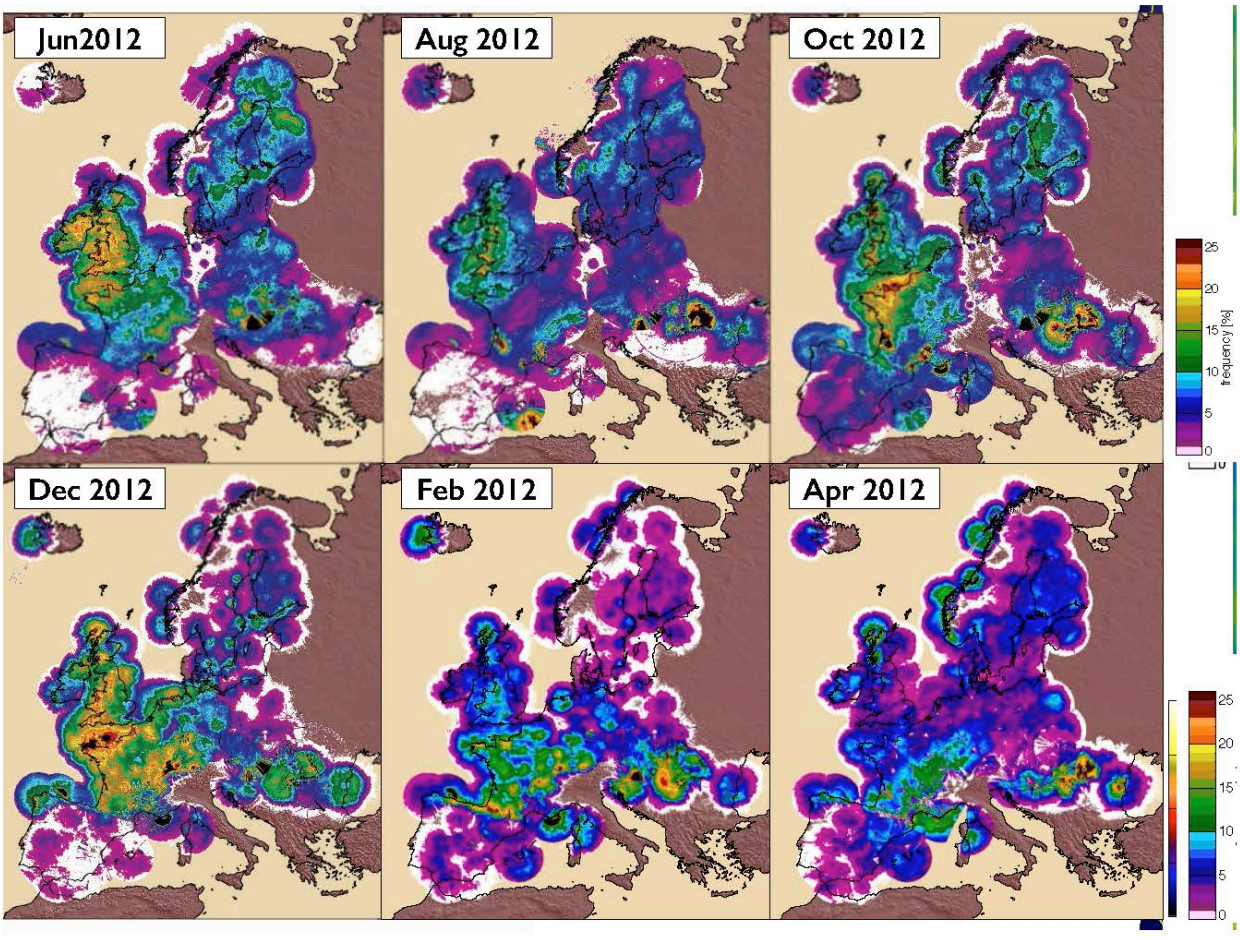
Rainfall nowcasting - CASE 1) 13 June 2012



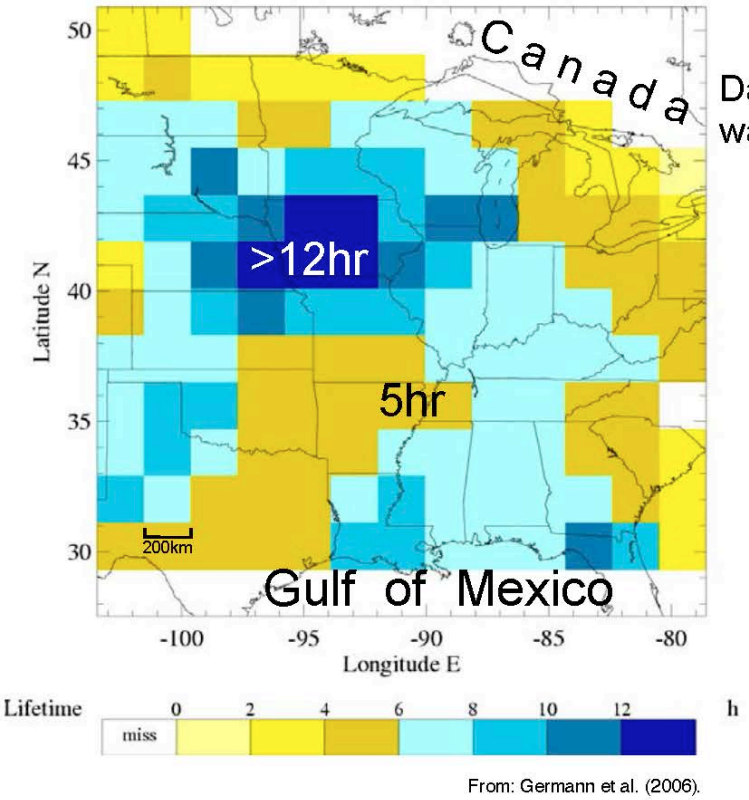
Rainfall nowcasting - CASE 2) 25 June 2012 07:15 UTC




Jun2012
Aug 2012
Oct 2012
Dec 2012
Feb 2013
Apr 2013
20
15
10
5
0
life time [h]


Jun2012
Aug 2012
Oct 2012
Dec 2012
Feb 2012
Apr 2012
25
20
15
10
5
0
frequency [%]

Rainfall nowcasting - Lifetime spatial variability



Data: 464 hours of warm season rainfall.

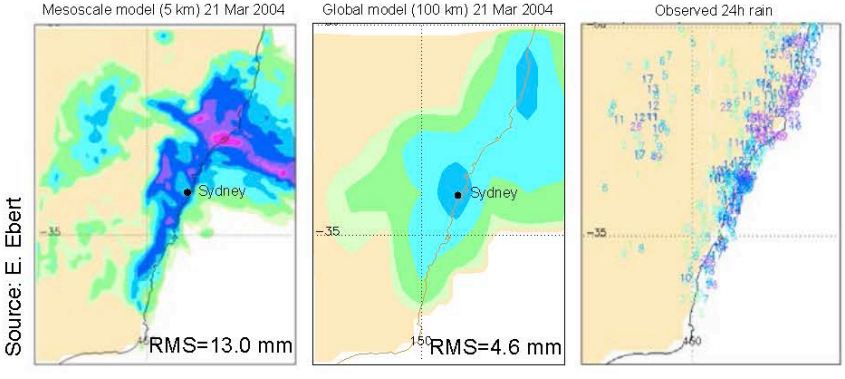
From: Germann et al. (2006).

Precipitation forecasting - Verification of precipitation fcsts

Point-to-point comparison of forecasts with precipitation measurements.

Statistical studies: do NWP models reproduce overall the statistical properties of observations? (as a proxy of how realistic are the simulated physical processes).

Which rain forecast would you rather use?



Precipitation forecasting - Verification of precipitation fcsts

What makes a useful forecast?

- Resembles the observations on the broader scale.
- Predicts an event somewhere near where it was observed.
- Predicts the event over the same area (i.e., with the same frequency) as observed.
- Has a similar distribution of intensities as the observations.
- Looks like what a forecaster would have predicted if he had had knowledge of the observations.

many approaches

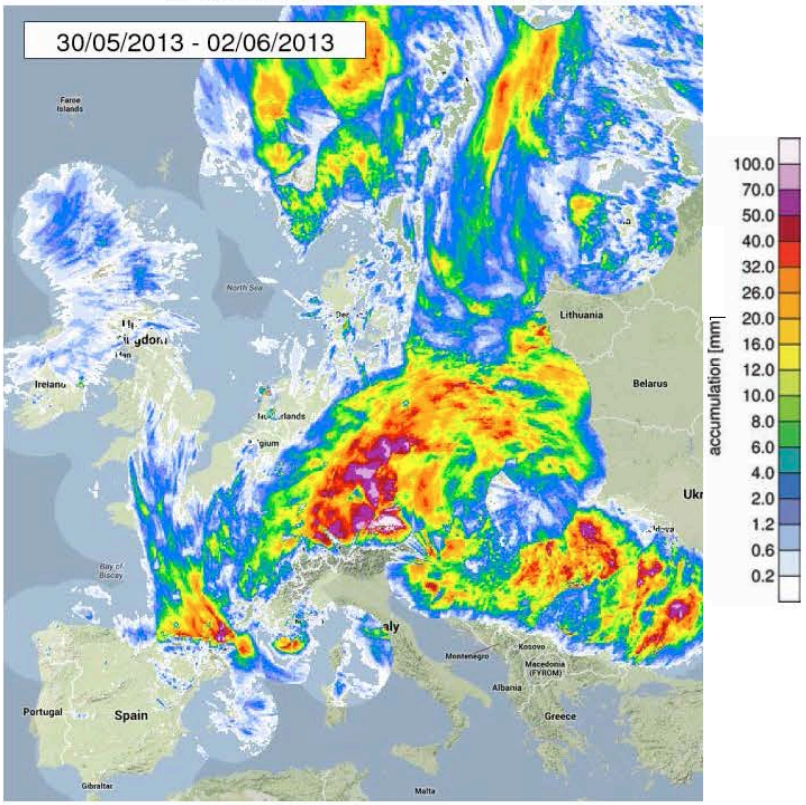
many scores

Fuzzy method	Matching strategy*	Decision model for useful forecast	Metrics
Upscaling (Zepeda-Arce et al. 2000; Weygandt et al. 2004)	NO-NF	Resembles obs when averaged to coarser scales	BIAS, CSI, ETS
Minimum coverage (Damrath 2004)	NO-NF	Predicts event over minimum fraction of region	POD, FAR, ETS
Fuzzy logic (Damrath 2004), joint probability (Ebert 2002)	NO-NF	More correct than incorrect	POD, FAR, ETS
Fractions skill score (Roberts and Lean 2005)	NO-NF	Similar frequency of forecast and observed events	FSS
Pragmatic (Theis et al. 2005)	SO-NF	Can distinguish events and non-events	BS, BSS
CSRR (Germann and Zawadzki 2004)	SO-NF	High probability of matching observed value	CSRR
Multi-event contingency table (Atger 2001)	SO-NF	Predicts at least one event close to observed event	ROC, value
Practically perfect hindcast (Brooks et al. 1998)	SO-NF	Resembles forecast based on perfect knowledge of observations	TS_p, TS_c
Intensity-scale (Casati et al. 2004)	NO-NF	Lower error than random arrangement of obs	SS
Area-related RMSE (Rezacova et al. 2005)	NO-NF	Similar intensity distribution as observed	RMSE

Source: E. Ebert

Precipitation forecasting - Evaluation of nowcasts and NWP

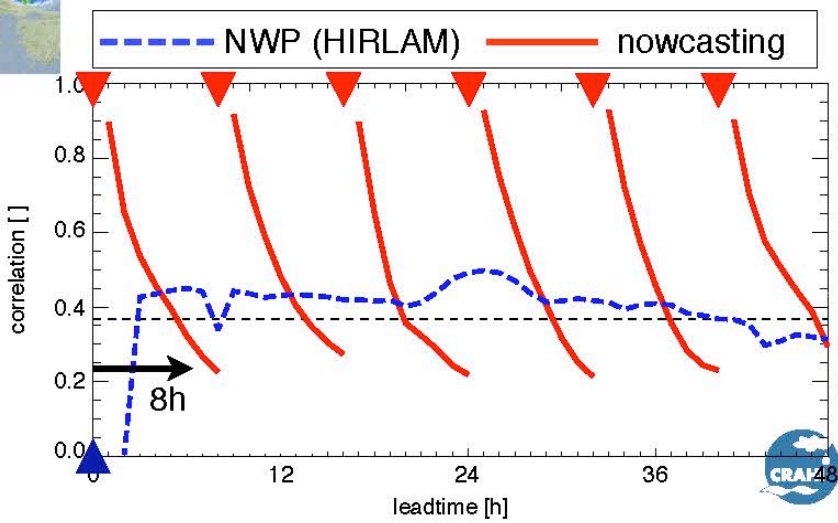
01 June 2013 - 48 hour evaluation

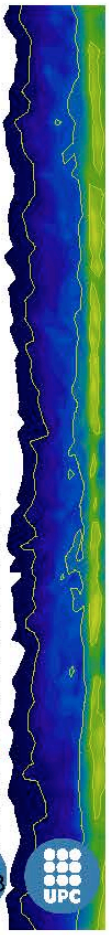


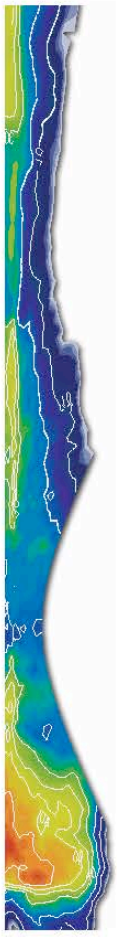
Precipitation forecasting - Evaluation of nowcasts and NWP



Comparison between rainfall forecasts and observations

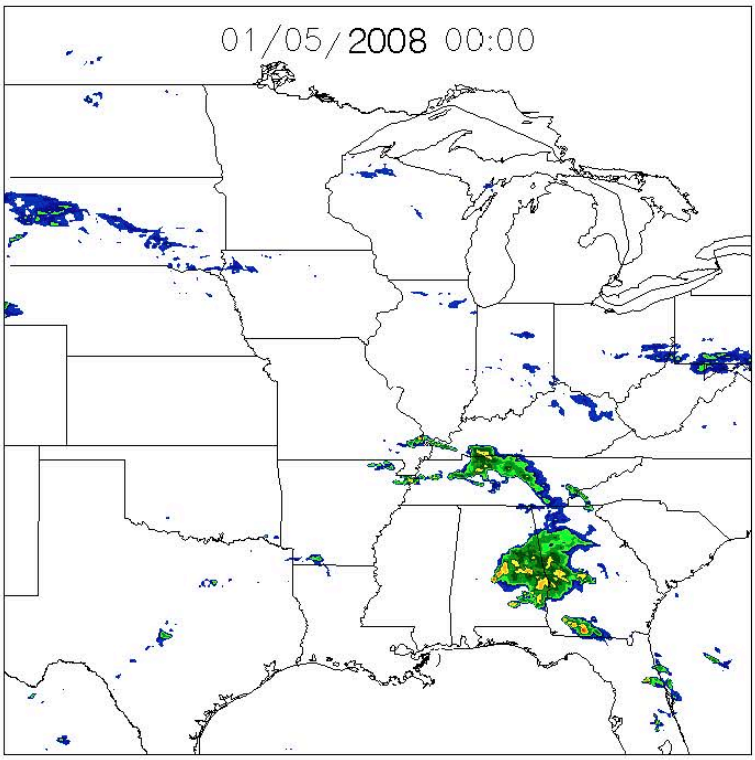






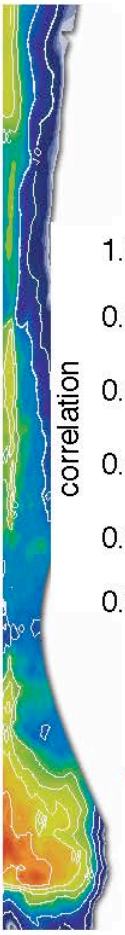
Nowcasting vs NWP

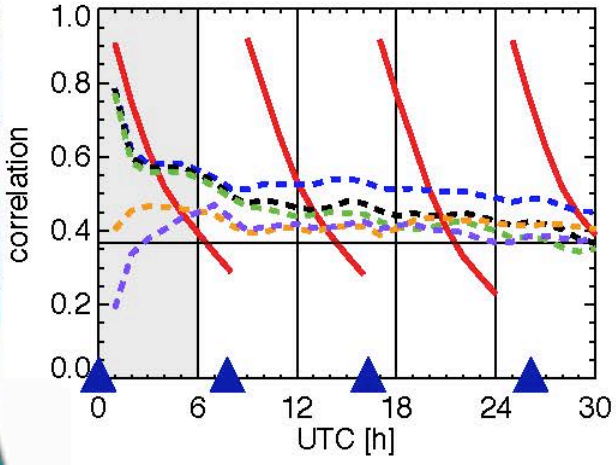
Performance to forecast rainfall - spring 2008



Nowcasting vs NWP

Performance to forecast rainfall - spring 2008





Radar-based nowcasting still better than NWP:

- Models not assimilating radar: ~5 h
- Radar-assimilating models for ~3h

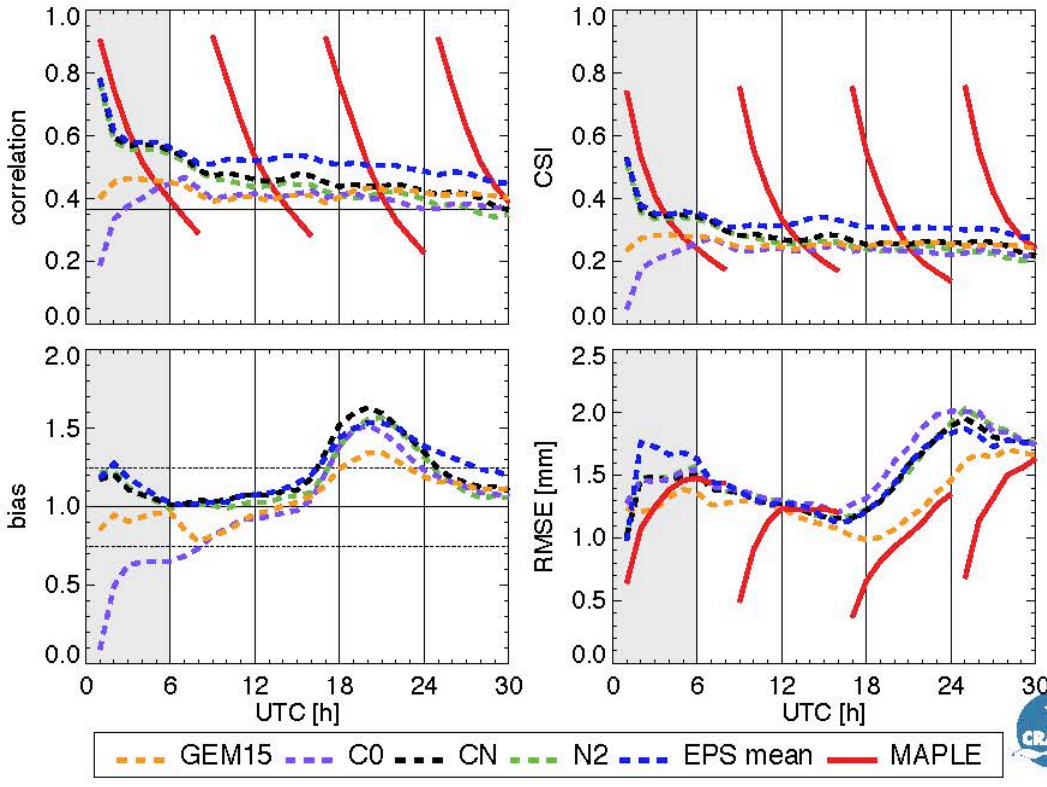
Cheaper to run: nowcasts can be updated every 15 minutes.

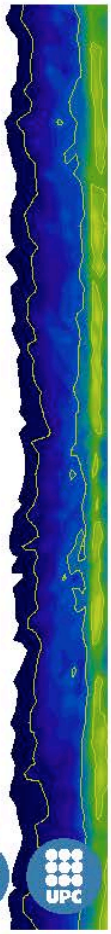
nowcasting — GEM15 — C0 — CN — N2 — EPS mean

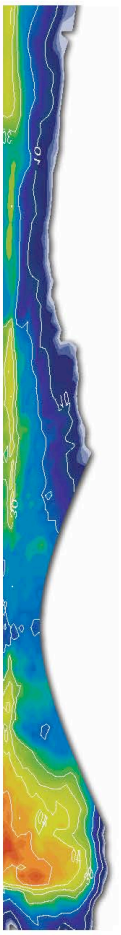
with radar data assimilation

OU Storm-Scale Ensemble Forecast (10 members)

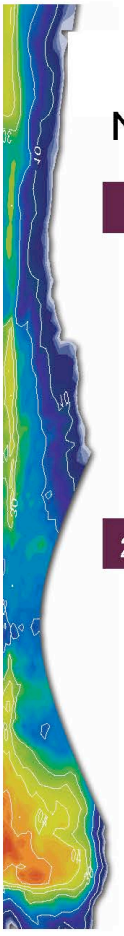
Skill of NWP for QPF - Spring 2008







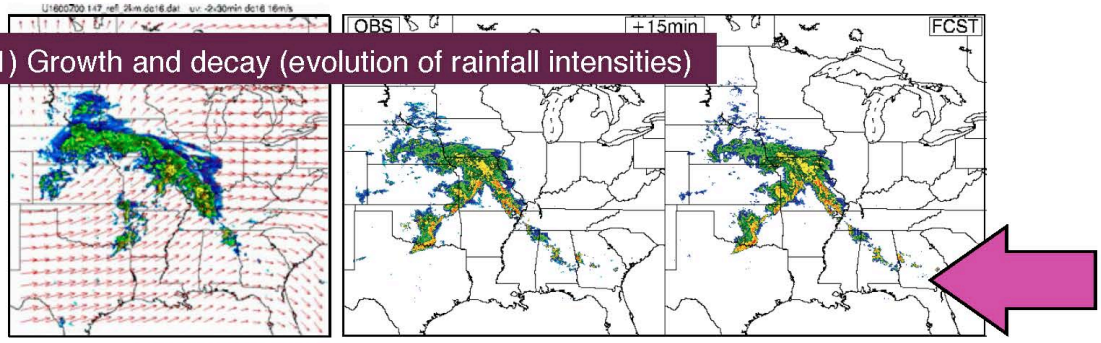
describing errors in rainfall nowcasting



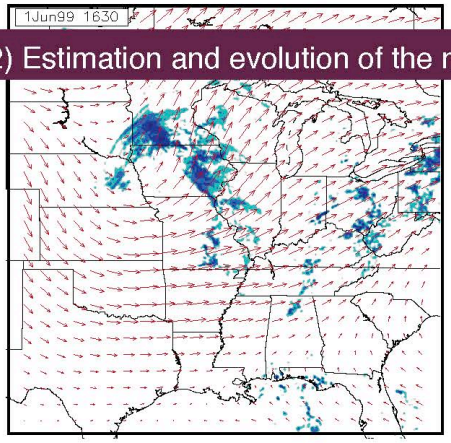
Errors affecting radar-based nowcasting

Main sources of errors in LP forecasts(1)

1) Growth and decay (evolution of rainfall intensities)



2) Estimation and evolution of the motion field



+

Errors affecting radar-based QPE (clutter, VPR, Z-R,...).

(1) Germann et al. (MWR2006)

Description of forecasting errors

Developing a **stochastic nowcasting technique** that describes the uncertainty in nowcasting by extrapolation.

And adapted to **probabilistic rainfall-runoff modeling.**

IMPRINTS

The technique - SBMcast(1)

An **ensemble approach** based on the hypotheses of the *String of Beads*(2) model for the evolution of the rainfall field:

- Simulation at 2 levels: global and pixel scale.
- Model for spatial and temporal correlation.
- Moving coordinates.

(1) Berenguer et al. (JOH2011) (2) Pegram & Clothier (JOH2001).

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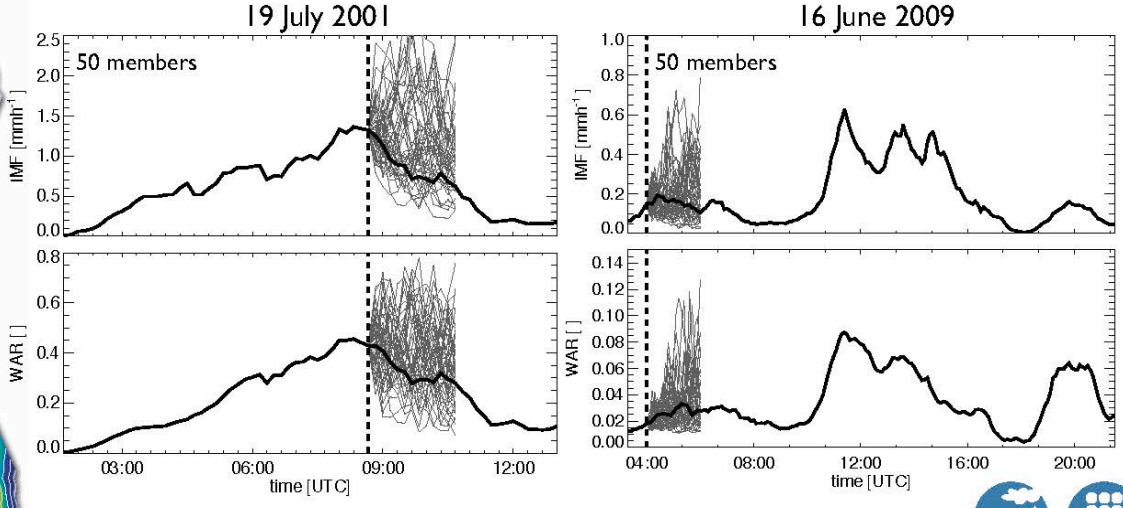
SBMcast

Global variables:

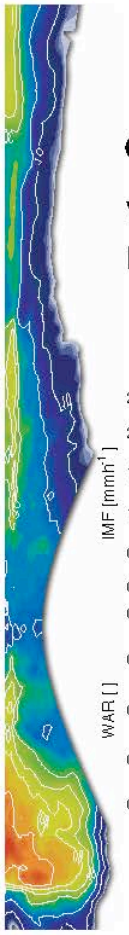
WAR: wet area ratio
IMF: image mean flux

IMF*, WAR* modeled as a bivariate AR(5) process:

$$\begin{bmatrix} WAR'^{*}[t,n\cdot\Delta t] \\ IMF'^{*}[t,n\cdot\Delta t] \end{bmatrix} = \sum_{i=1}^{5} \Phi_i \begin{bmatrix} WAR'^{*}[t,(n-1)\cdot\Delta t] \\ IMF'^{*}[t,(n-1)\cdot\Delta t] \end{bmatrix} + Z[t,n\cdot\Delta t]$$



CRAHI UPC



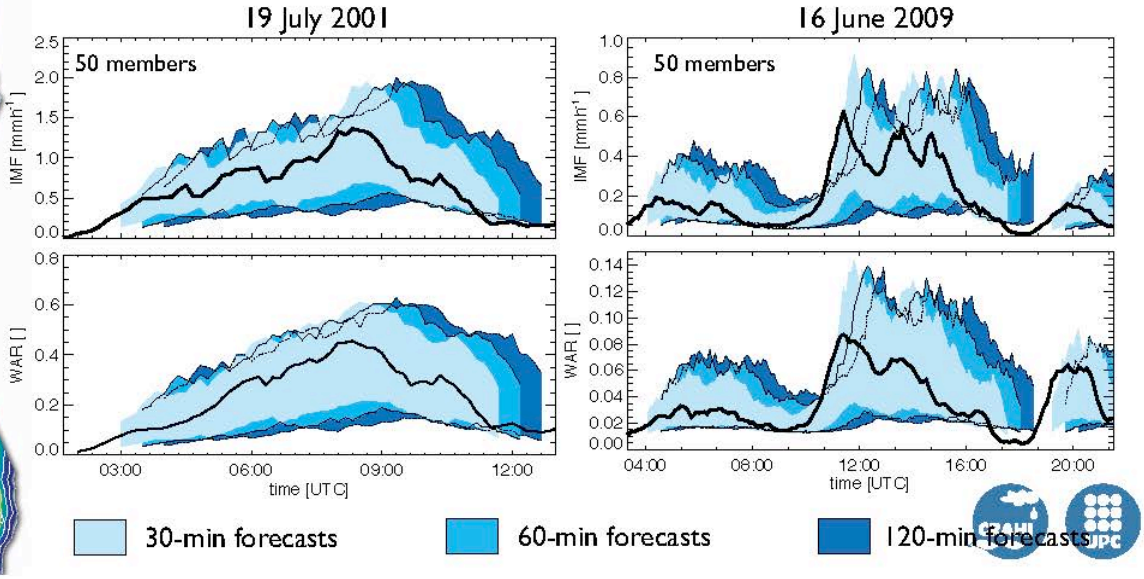
SBMcast

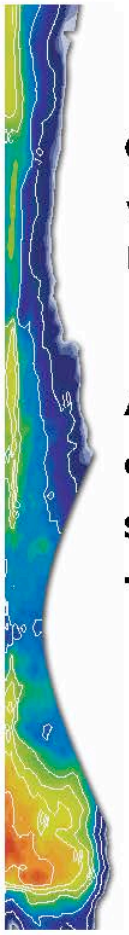
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SBMcast

Global variables:

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IMF*, WAR* modeled as a bivariate AR(5) process:

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At pixel scale:

dBZ: truncated Gaussian distribution (fitted through IMF and WAR).

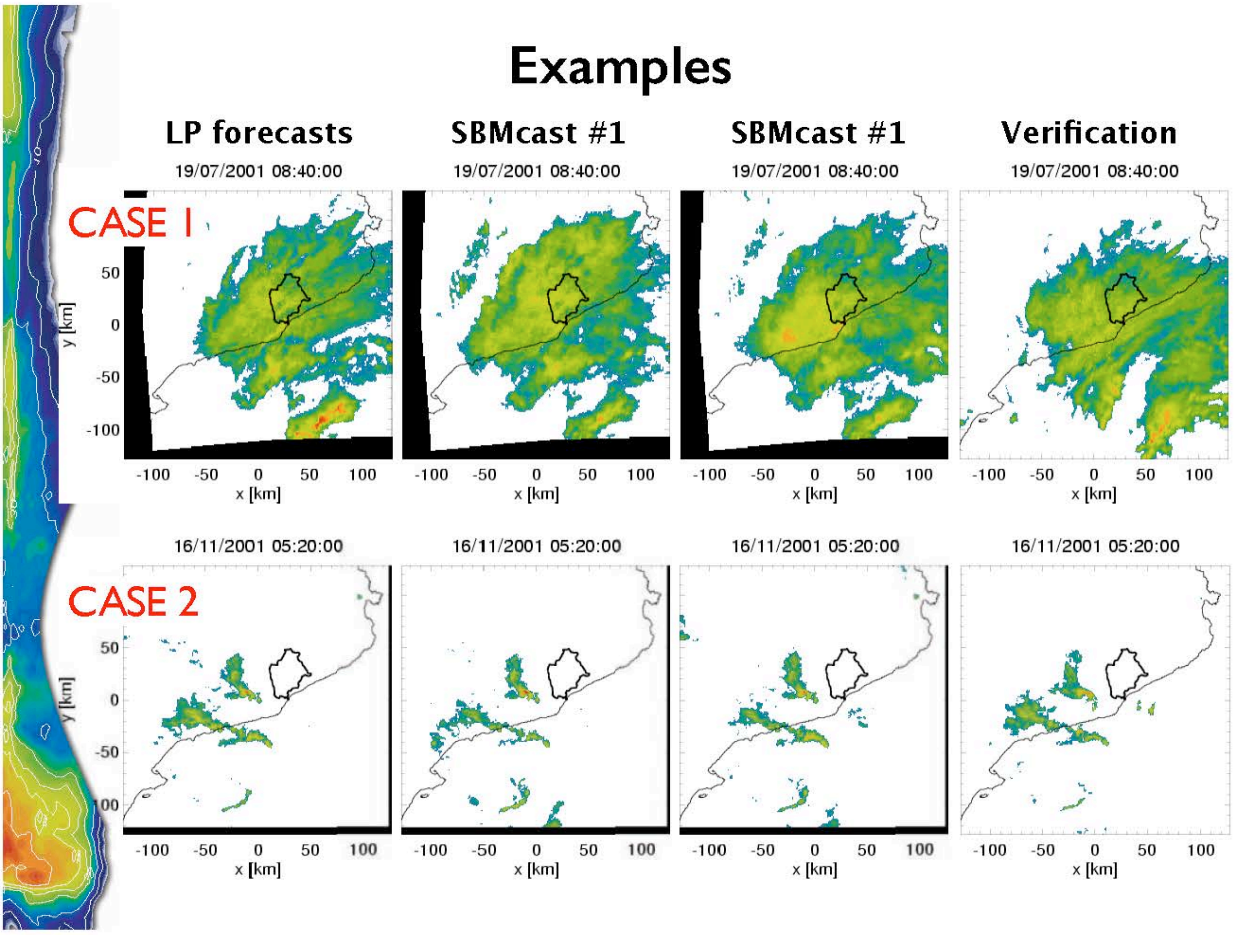
Spatial power spectrum: $P(w)=cw^{-\beta}$ (constant along the forecast).

Time correlation in Lagrangian coords modeled as an AR(2):

$$X^{*}[t,n\Delta t] = \phi_1(t)\cdot X^{*}[t,(n-1)\cdot\Delta t] + \phi_2(t)\cdot X^{*}[t,(n-2)\cdot\Delta t] + \xi[t,n\cdot\Delta t]$$

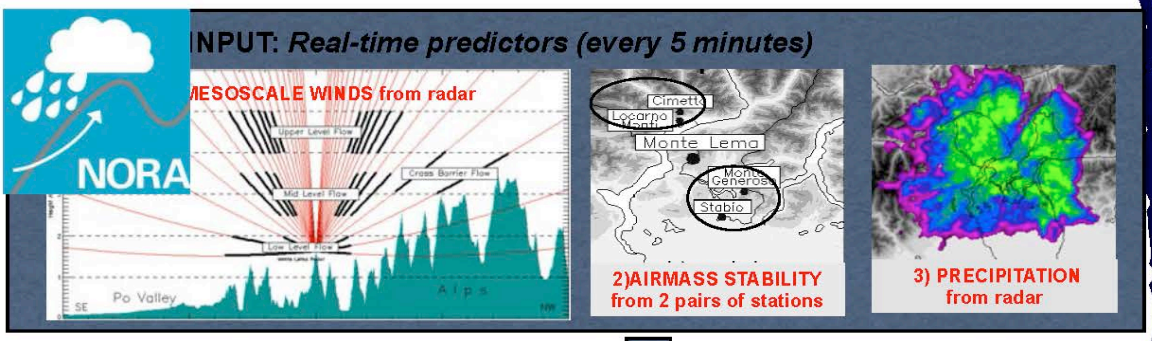
where $X(t) = \dfrac{dBZ(t)-\mu(t)}{\sigma(t)}$

Examples



Rainfall nowcasting - NORA

NORA: Nowcasting Orographic Rainfall by means of Analogues



BASIC IDEA

Search in the historical database for analogs: the situations with the most similar mesoscale winds, air mass stability and precipitation field.

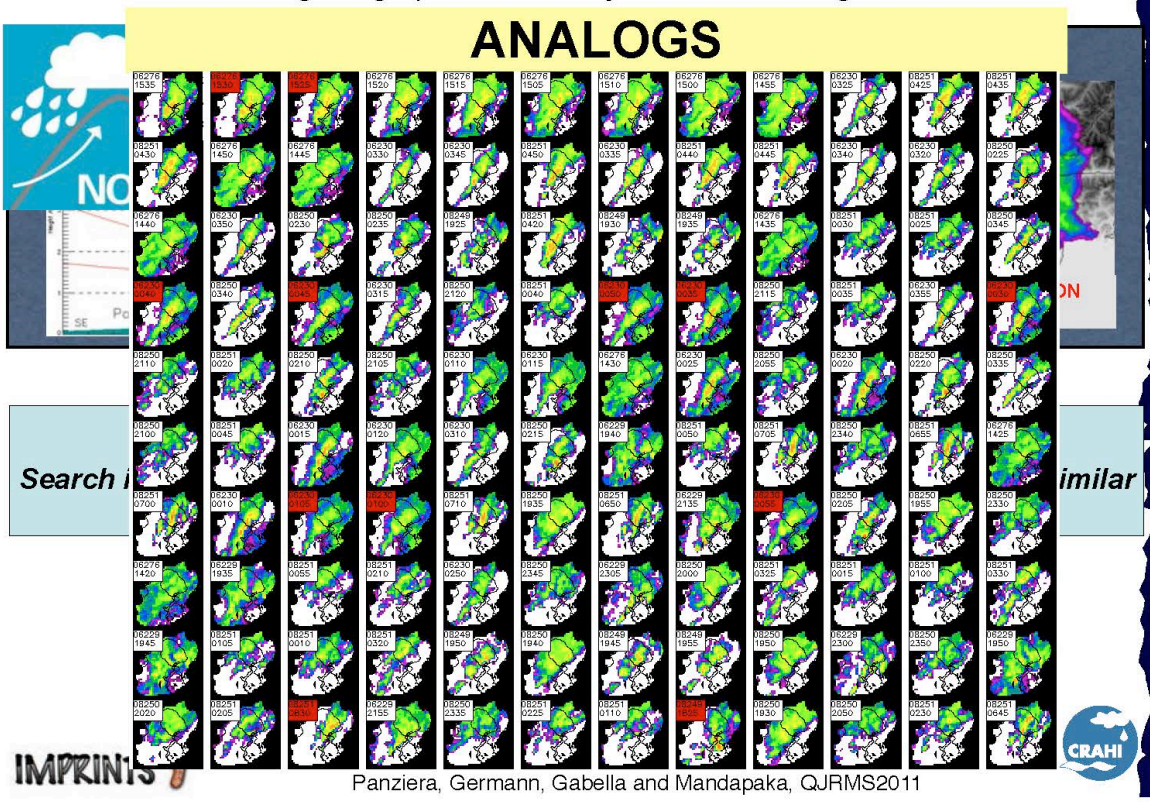
IMPRINTS

Panziera, Germann, Gabella and Mandapaka, QJRMS2011

CRAHI UPC

Rainfall nowcasting - NORA

NORA: Nowcasting Orographic Rainfall by means of Analogues

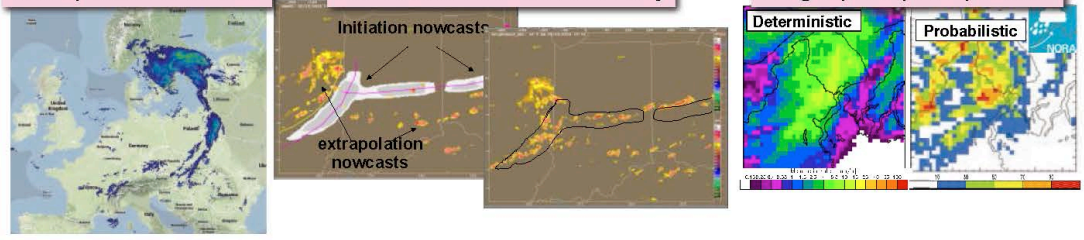


Panziera, Germann, Gabella and Mandapaka, QJRMS2011

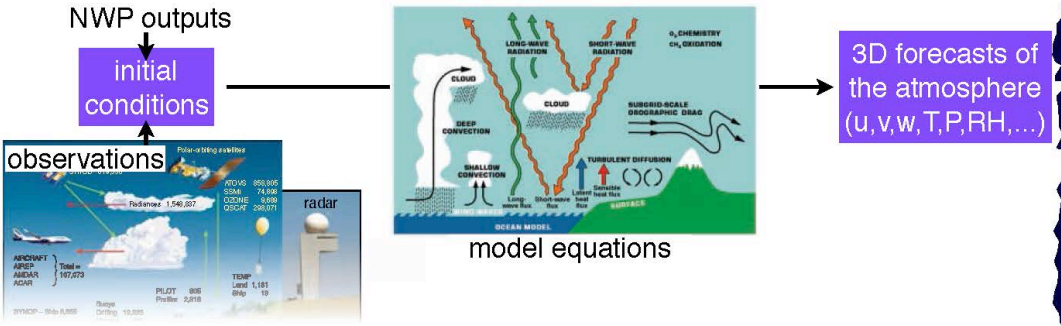
Precipitation forecasting

- ***Nowcasting***: short/range based on recent and current observations.

extrapolation of obs | convection initiation/decay | orographic precipitation



- ***Numerical Weather Prediction*** (NWP): three-dimensional models of the atmosphere.



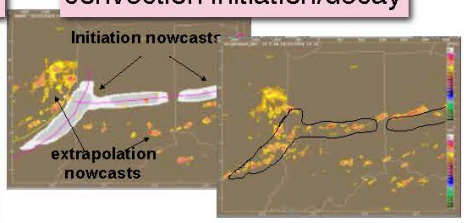
Precipitation forecasting

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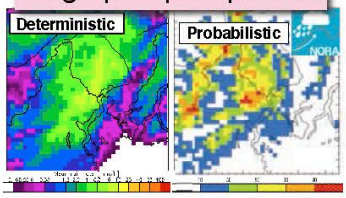
extrapolation of obs



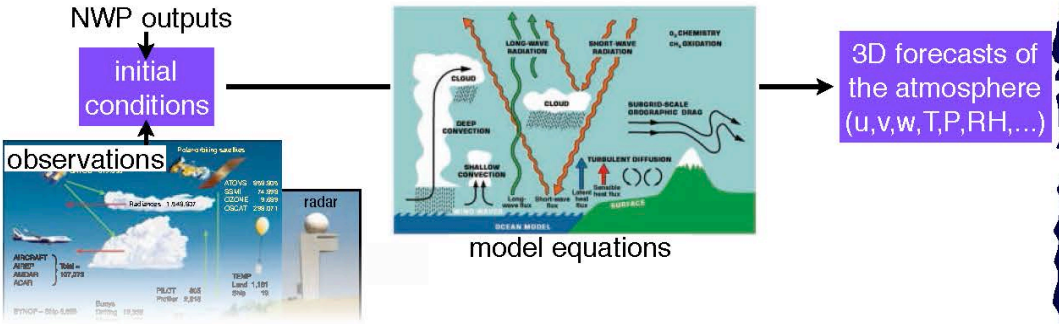
convection initiation/decay



orographic precipitation



- ***Numerical Weather Prediction*** (NWP): three-dimensional models of the atmosphere.



- ***Statistical methods.*** More focused on seasonal forecasting of large-scale phenomena (El Niño Southern Oscillation, North Atlantic Oscillation,...).

Hydrological applications of radar and early warnings at basin scale using radars

Centre for Applied Research in Hydrometeorology
CRAHI
Universitat Politècnica de Catalunya
Barcelona (Spain)

T.C.
Orman ve Su İşleri Bakanlığı
Meteoroloji Genel Müdürlüğü

Genova (Italy)
on 4th of November 2011



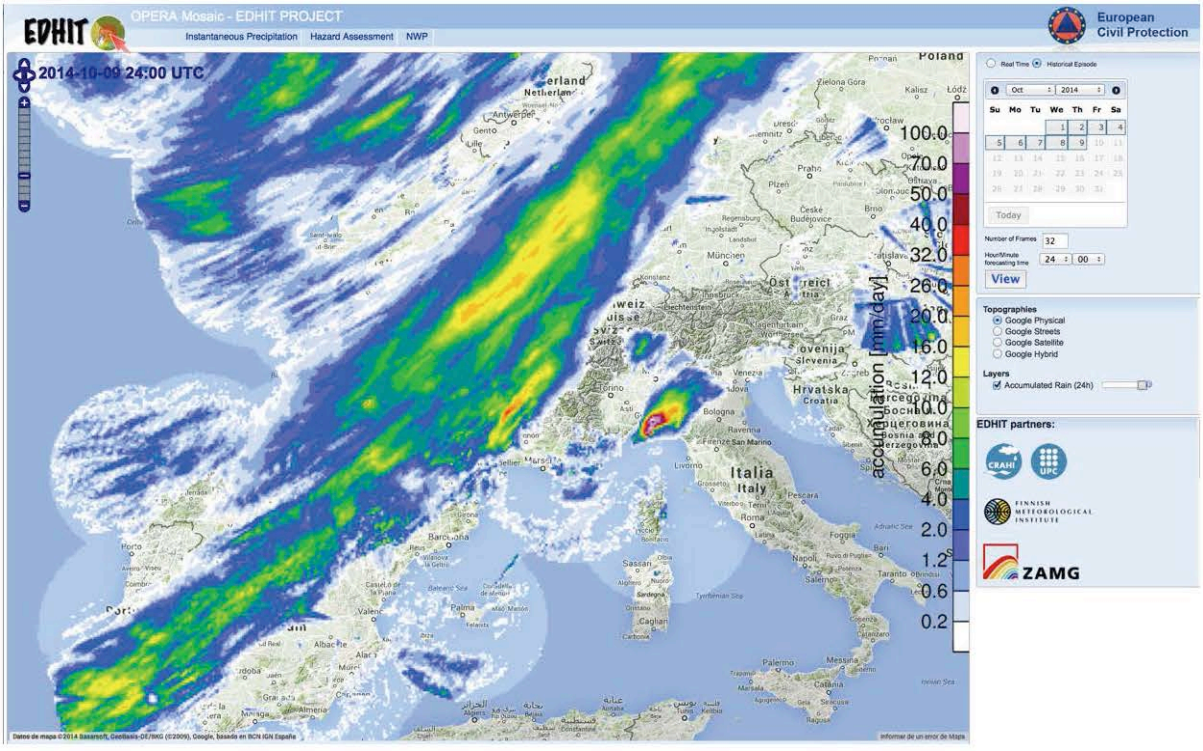
after > 300 mm of accumulated rain in less than 24h

Genova (Italy)
on 10th of October 2014



after > 300 mm of accumulated rain in few hours

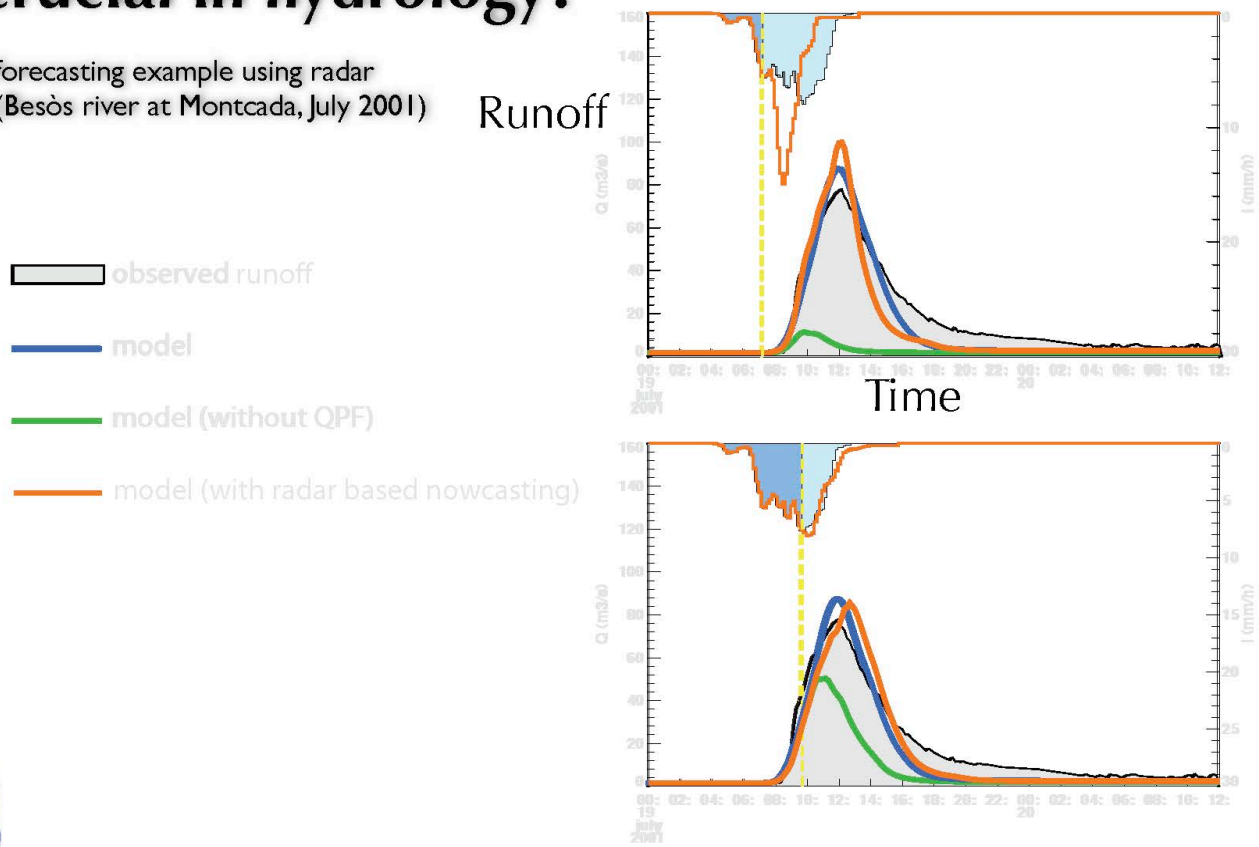
Genova (Italy)
on 10th of October 2014



after > 500 mm of accumulated rain in few hours

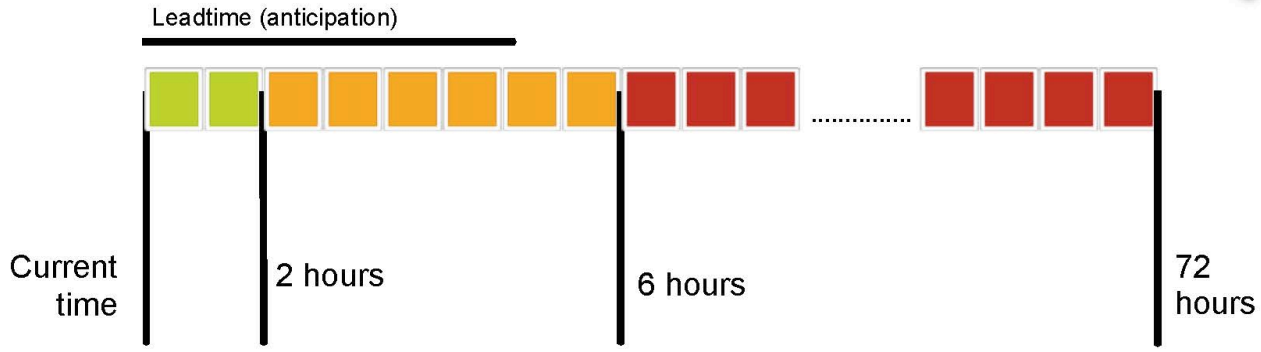
Why precipitation nowcasting is crucial in hydrology?

forecasting example using radar
(Besòs river at Montcada, July 2001)



Increasing anticipation of heavy rainfalls

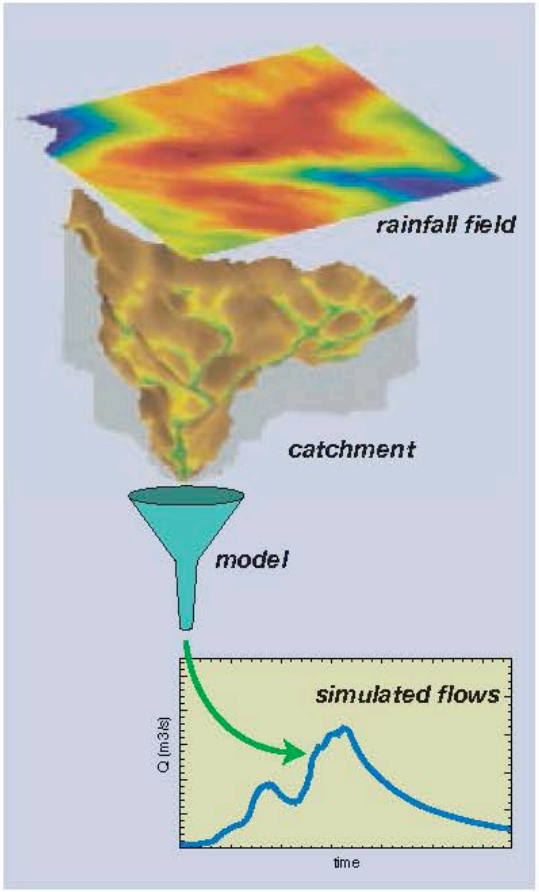
IMPRINTS



Ensemble Radar Nowcasting | **Blending Radar-NWP** | **Meteorological rainfall forecasting (NWP)**

- **High resolution radar nowcasting probabilistic outputs** (ensembles) for FF & DF forecasting (**up to 2 h**)
- **Combining (blending) radar rainfall nowcasting with probabilistic NWP products (between 2h and 6h)**
- **Adapting high-resolution meteorological model forecasts** to FF & DF early warnings (**from 6h to 72 h**)

Coupled hydrometeorological forecasting



Hydrological Modeling approaches in EWS

- **LEVEL 1: Simplified Hydrological Warnings (Flood Guidance Systems)**

The rainfall forecast is directed transformed in Warnings based on rainfall accumulation in the drainage system.

- **LEVEL 2: Simplified Modelling**

The rainfall forecast is transformed into estimated runoff Q by a simplified lumped model in limited outputs of the cacthment. Regionalisation of parameters when ungagged

- **LEVEL 3: Full Hydrological modeling**

A full distributed model is adjusted to the basin characteristics through the analysis of past events and the calibration on high quality data (rainfall, runoff, evapotranspiration, snow water equivalent....)

Required Data + Computational Cost +

Flood Guidance System

- **Methodology**:
  The basin-aggregated accumulated rainfall over the upstream drainaged area of every river cell is calculated considering 1 km space resolution and 30 minutes time resolution.
- **Reference thresholds** based on available rainfall statistics (IDF data at every cell) asociated to probability of ocurrence (Hazard)
- **Hazard-based Warning**: The warnings are issued by comparing basin-aggregated accumulated rainfall at every river cell against reference thresholds selected. The output is excedence probability of basin-aggregated rainfall for the basin Tc

Not an hydrologic model ¡¡¡
(but with an hydrologic component)

Experience from Four European projects coordinated by CRAHI

2009-2012

FP 7 Cooperation Work Programme: Environment
Collaborative Project
IMproving Preparedness and RIsk maNagemenT for flash floods and debriS flow events
IMPRINTS
FP7-ENV-2008-1-226555
January 2009 - November 2012
FC FP7 PROJECT COORDINATED BY
ERICHA

2012-2013

Hazard Assessment based on Rainfall European Nowcasts
HAREN
http://www.haren-project.eu/
European Civil Protection

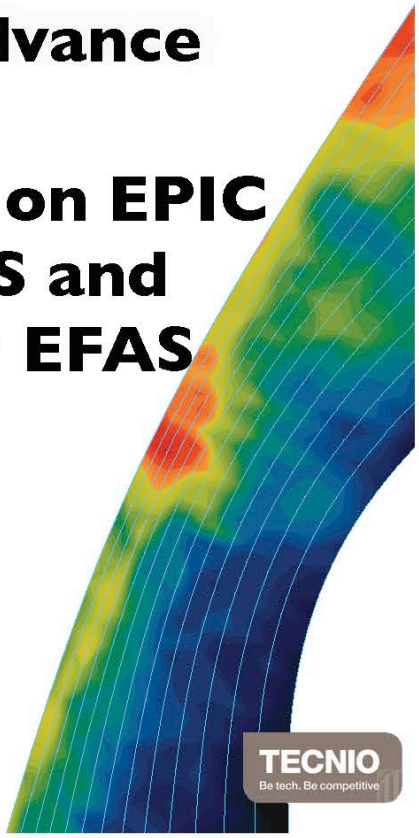
2014-2015

European Demonstration of a rainfall and lightning induced Hazard Identification nowcasting Tool
EDHIT
Coordinator:
Stakeholders:
http://www.edhit.eu

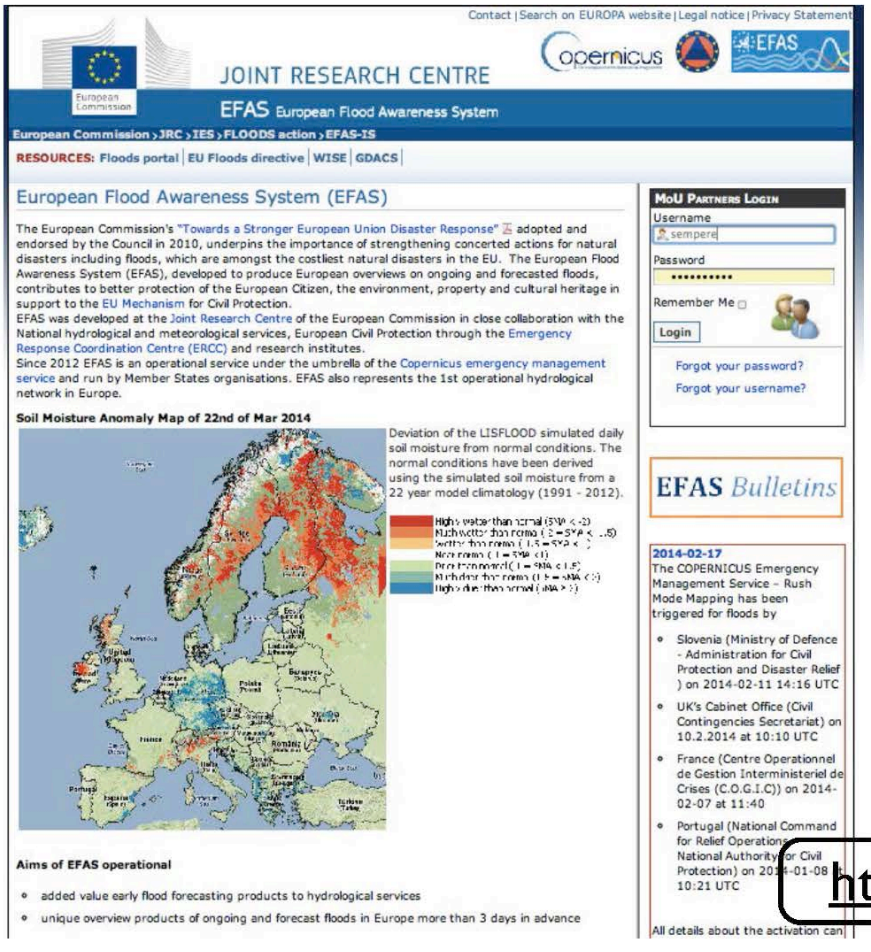
TECNIO
Be tech. Be competitive

From 6h to few days in advance

Flash Flood Module based on EPIC developed in IMPRINTS and operationally running in EFAS



EUROPEAN FLOOD AWARENESS SYSTEM (EFAS)

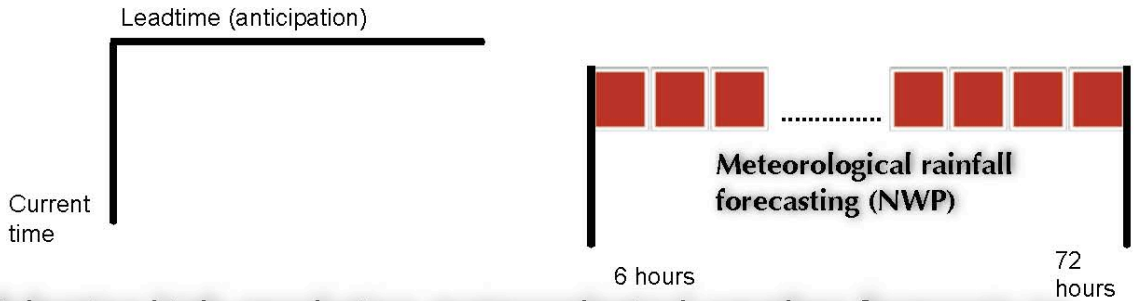


IMPRINTS

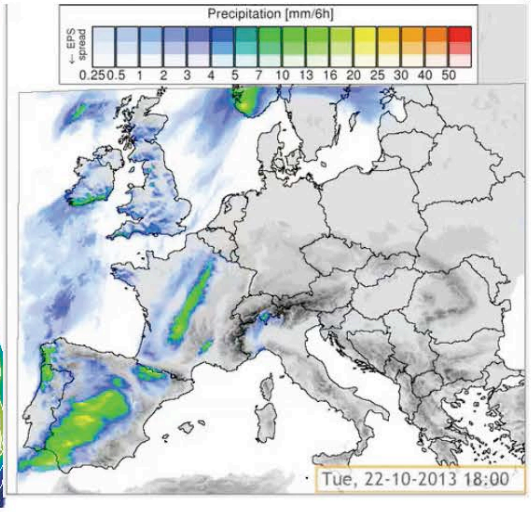
Flash Flood FF-EWS module

http://www.efas.eu/

Increasing anticipation of heavy rainfalls



- Adapting high-resolution meteorological weather forecasts to their use for FF & DF early warnings (from 6h to 72 h)



Initialisation with ECMWF-VAREPS
(15 days, 51 members, 32 km resolution)

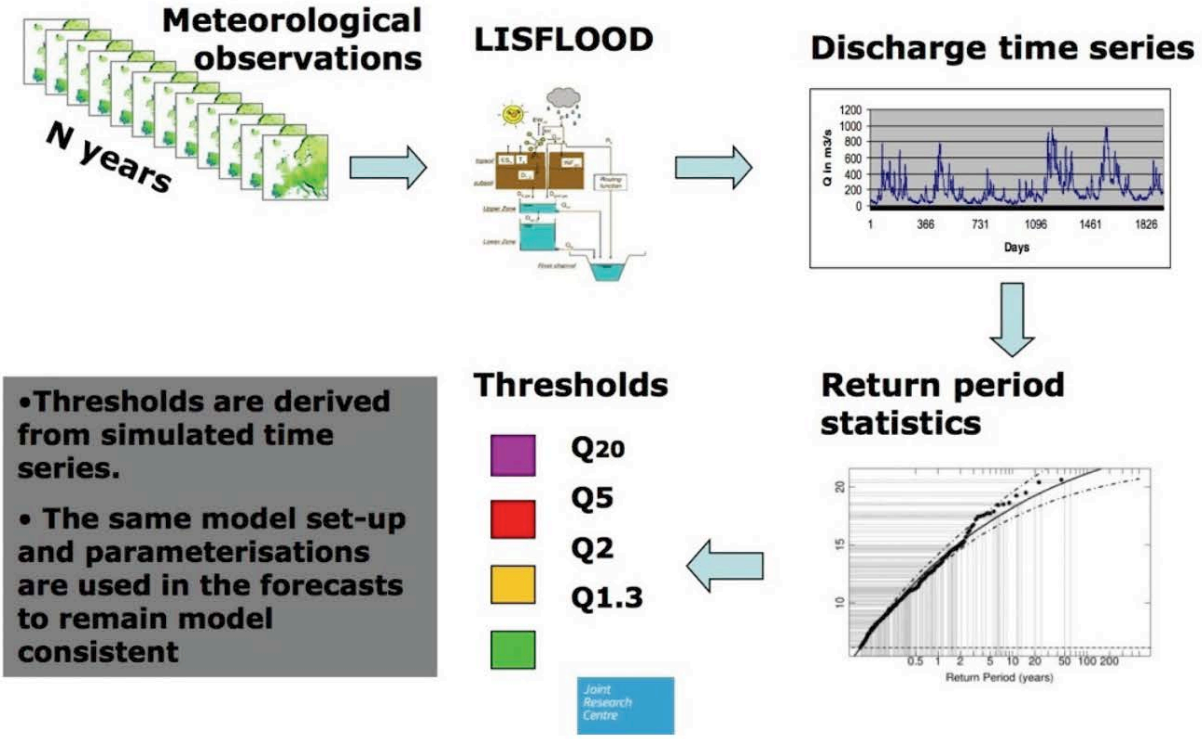
Operational COSMO-LEPS 7
7 km spatial resolution
since Dec 2009

Probabilistic Forecast COSMO-LEPS
16 Ensembles

Source: MeteoSwiss-COSMO Consortium

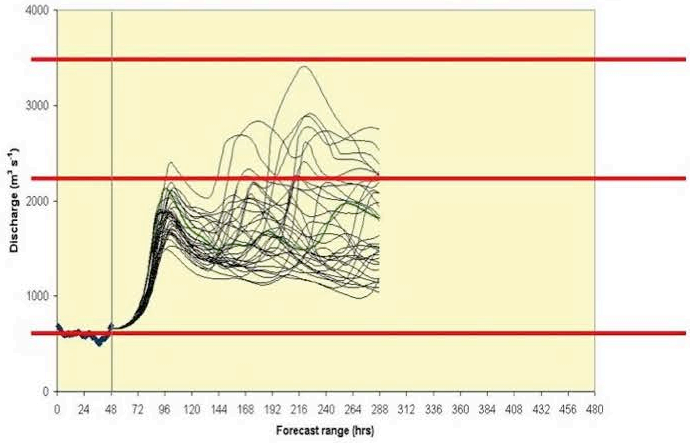
EUROPEAN FLOOD AWARENESS SYSTEM (EFAS)

Establish thresholds – from model climatology



Concept of threshold exceedance

For flood early warning we want to know if critical discharges are exceeded – not necessarily the discharges themselves



If the threshold for flooding is here, there is no problem

If the threshold for flooding is here, there might be a problem

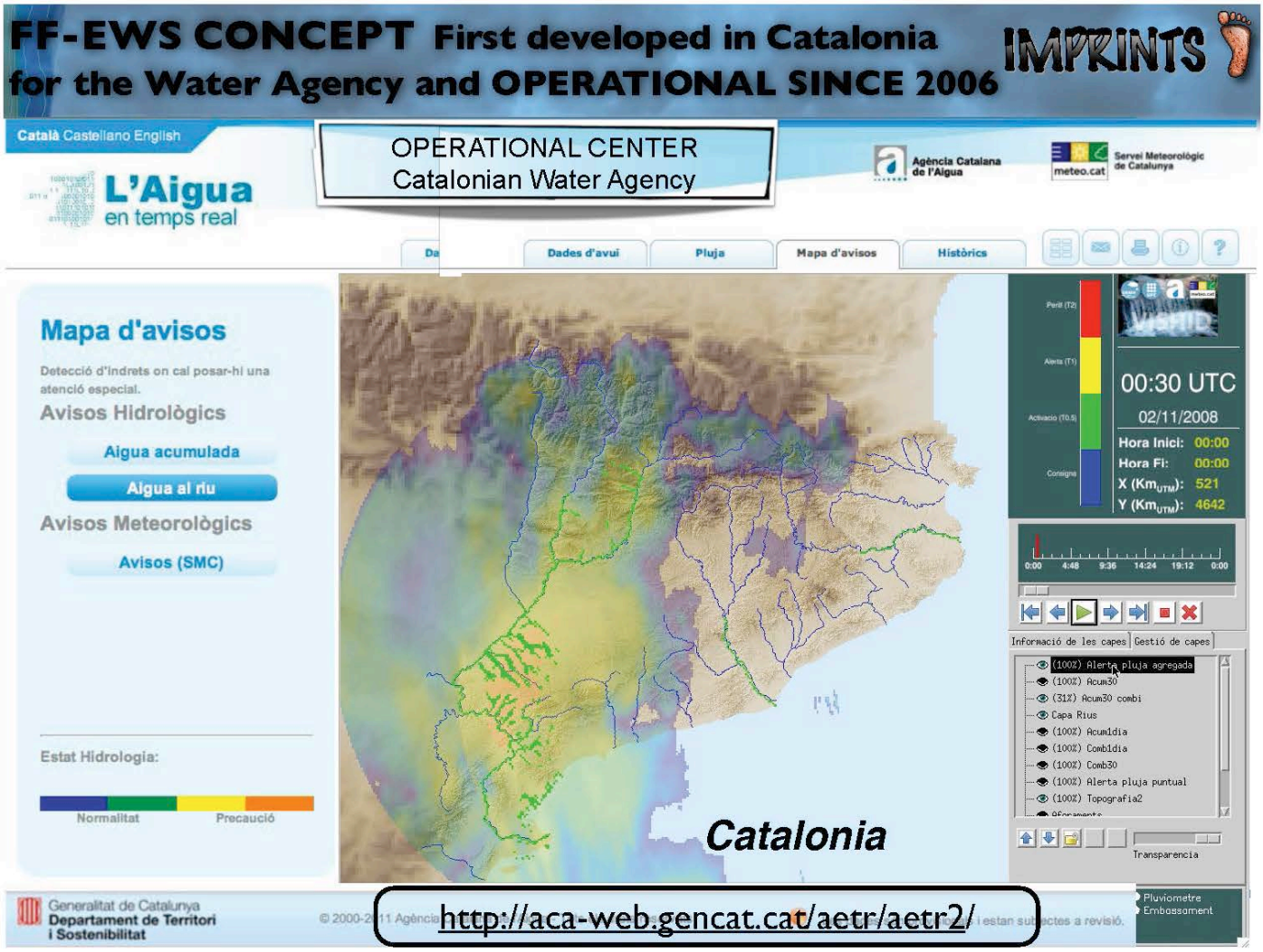
If the threshold for flooding is here, there is almost certain a problem

FF & DF early warning systems

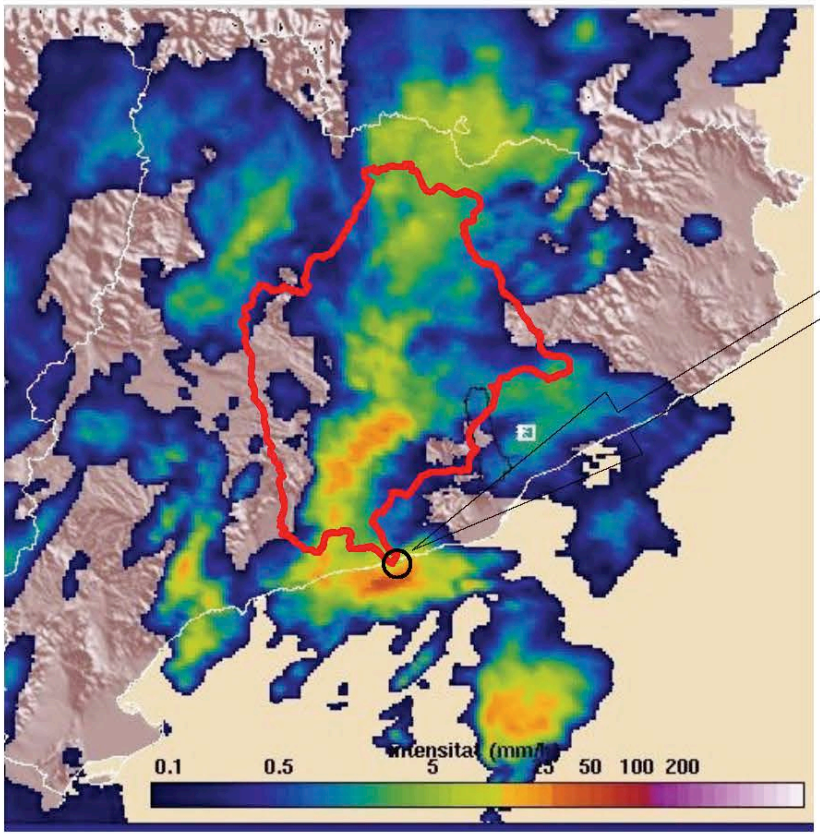
IMPRINTS

In Flash Floods, the basins affected are small (tenths of Km^2) and show very quick responses (from 1/2 hour to few hours)





Flash Flood Indicator: Basin aggregated rainfall exceedances

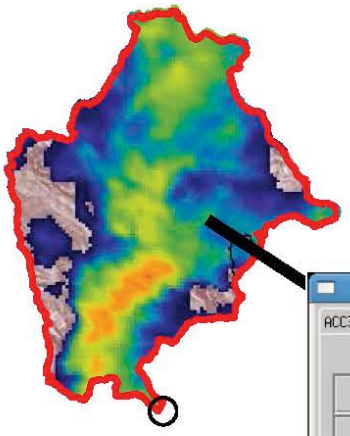


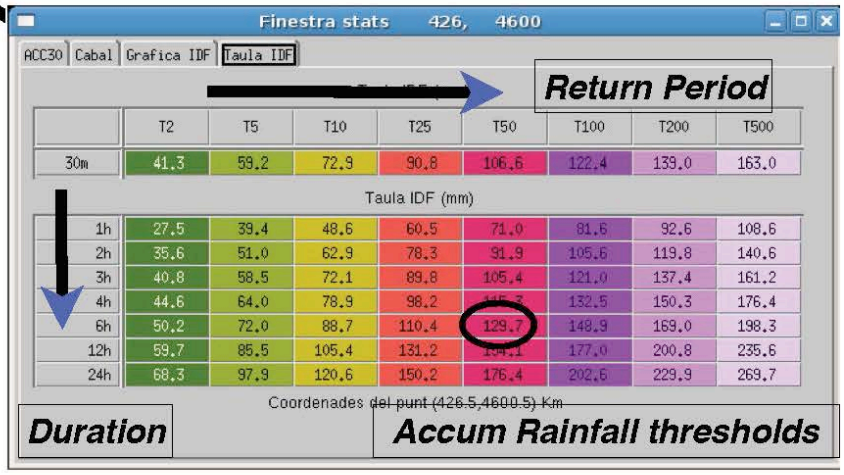
Given a point in the drainage system,

We can define the associated basin, and calculate the rainfall that will be collected by the selected point

Flash Flood Indicator:
Basin aggregated rainfall exceedances

This basin aggregated rainfall is accumulated over the hydrological characteristic time of the basin





	T2	T5	T10	T25	T50	T100	T200	T500
30m	41.3	59.2	72.9	90.8	106.6	122.4	139.0	163.0
1h	27.5	39.4	48.6	60.5	71.0	81.6	92.6	108.6
2h	35.6	51.0	62.9	78.3	91.9	105.6	119.8	140.6
3h	40.8	58.5	72.1	89.8	105.4	121.0	137.4	161.2
4h	44.6	64.0	78.9	98.2	[illegible]	132.5	150.3	176.4
6h	50.2	72.0	88.7	110.4	129.7	148.9	169.0	198.3
12h	59.7	85.5	105.4	131.2	[illegible]	177.0	200.8	235.6
24h	68.3	97.9	120.6	150.2	176.4	202.6	229.9	269.7

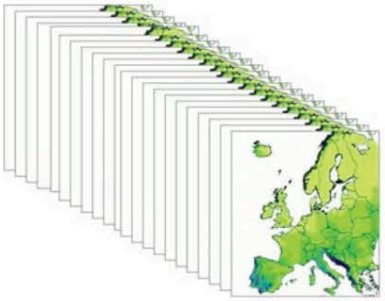
And a **probability of Exceedance** is associated (return period in years)



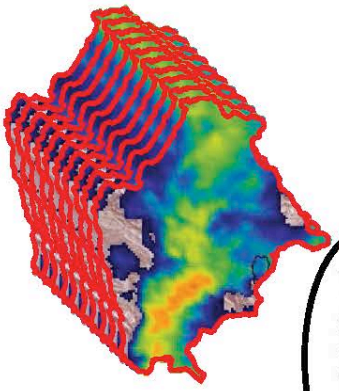
EPIC: European Precipitation Index Climatology

- **30 Years of COSMO-LEPS** reanalysis have been generated.
- For any point in the river system (1 km^2) a **Climatology of its basin aggregated rainfall** is calculated.
- A Precipitation Index based on Climatology is thus calculated at European scale (**EPIC**).
- For any new event the rainfall forecasted is used to calculate the **basin aggregated rainfall, and compared against the EPIC CLIMATOLOGY.**

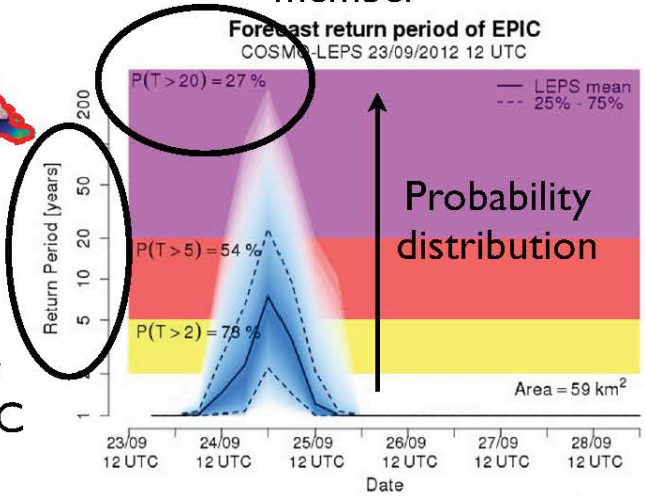
COSMO-LEPS Probabilistic Rainfall forecasts



Probabilistic basin aggregated rainfall forecasts



Warning code associated to the 75% percentile member

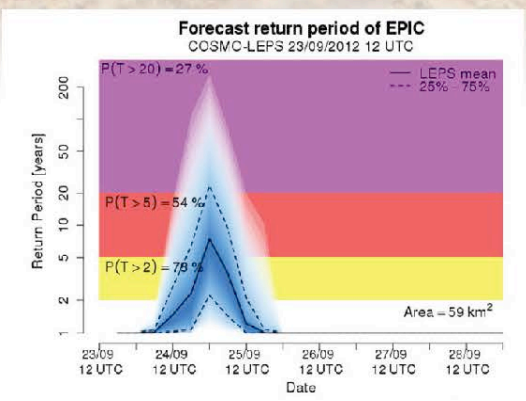


Return Period of any member calculated by comparison against EPIC climatology

FF & DF early warning systems

IMPRINTS

Event of 2012-09-25 in Newcastle Upon Time (UK)



EPIC 2012-09-23 12:00



Forecast 48h in advance

Top story



Floods hit 300 homes in north England

26 Sep 2012: River defences under pressure in downpours, while fishing village is left covered in sea foam

Most recent

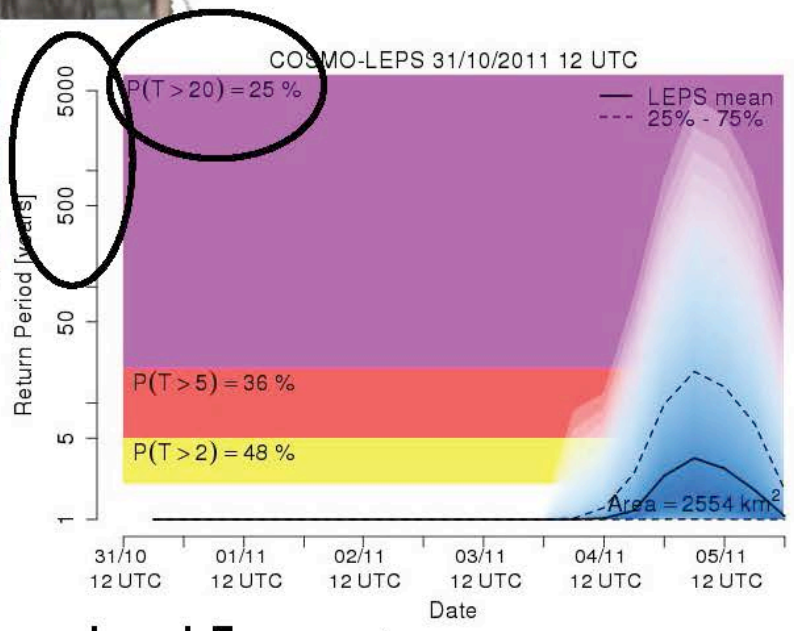


Looters of flooded shop condemned by police

26 Sep 2012: Newcastle upon Tyne cycle shop targeted as swollen rivers cause havoc in northern England

Genova (Italia) 4/11/2011

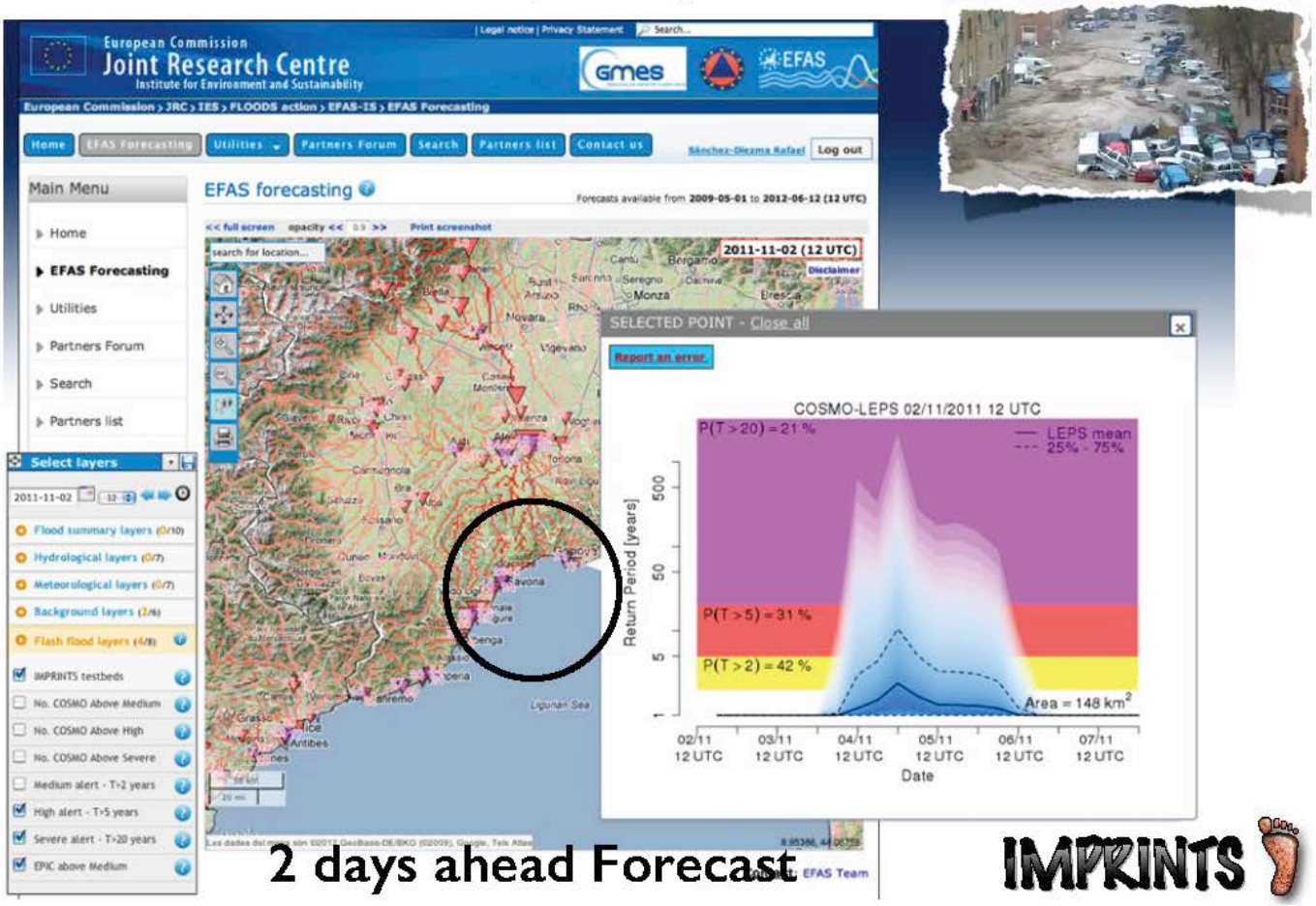




4 days ahead Forecast

IMPRINTS

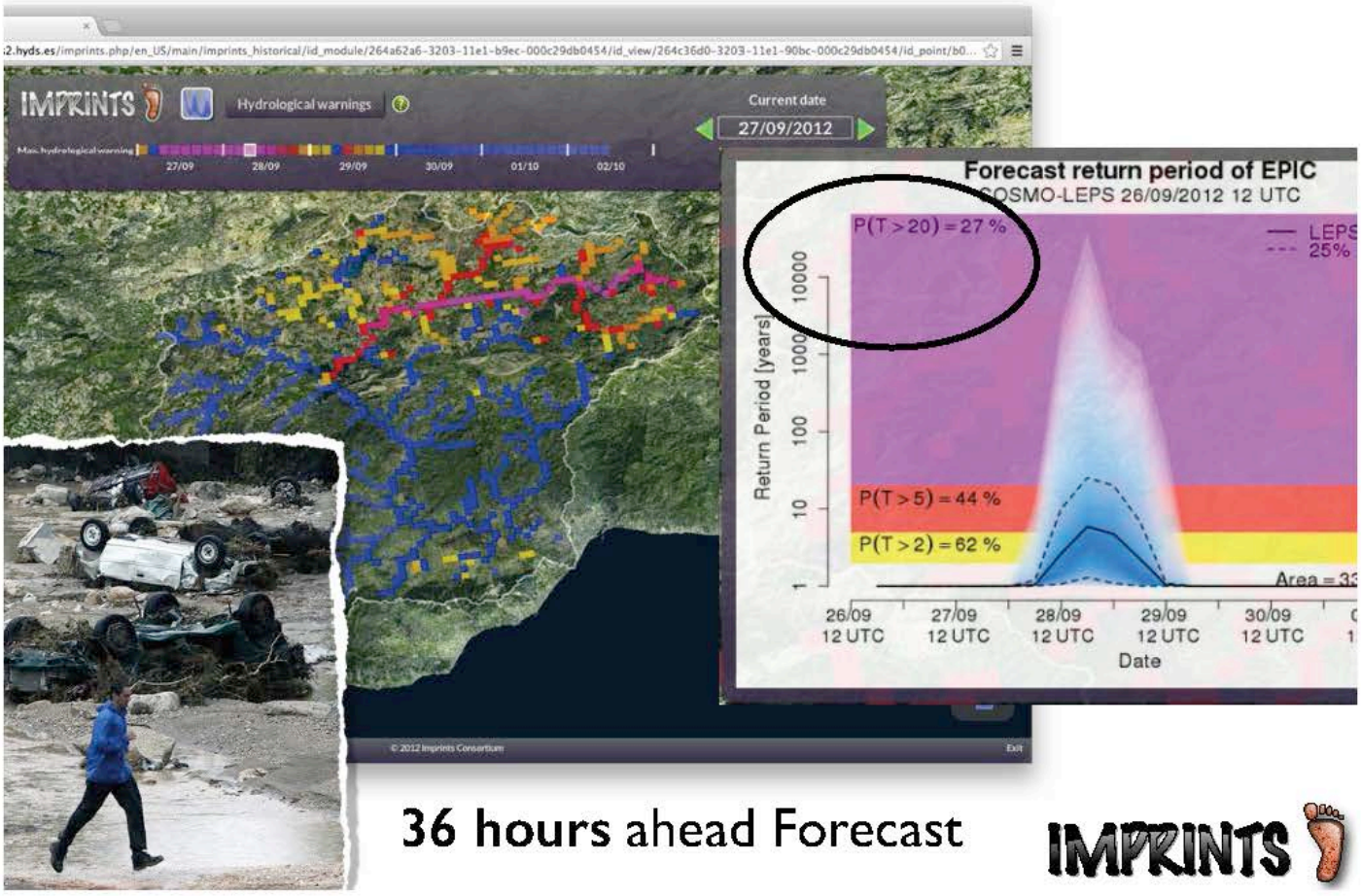
Genova (Italia) 4/11/2011



2 days ahead Forecast

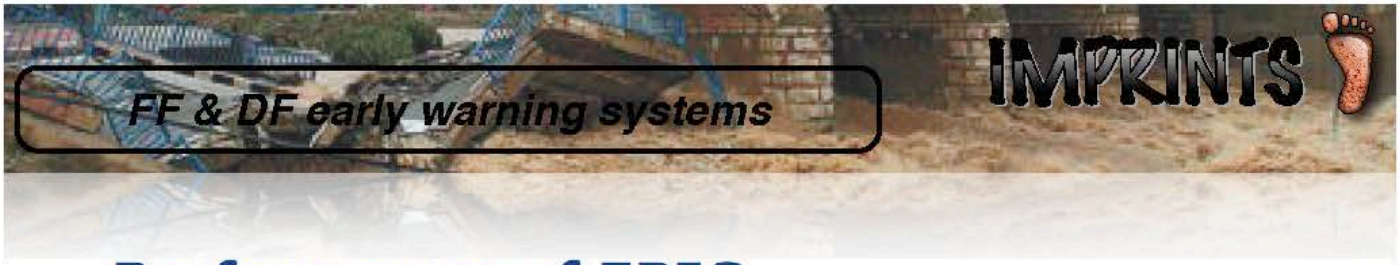
IMPRINTS

Guadalhorce 28/09/2012



36 hours ahead Forecast

IMPRINTS



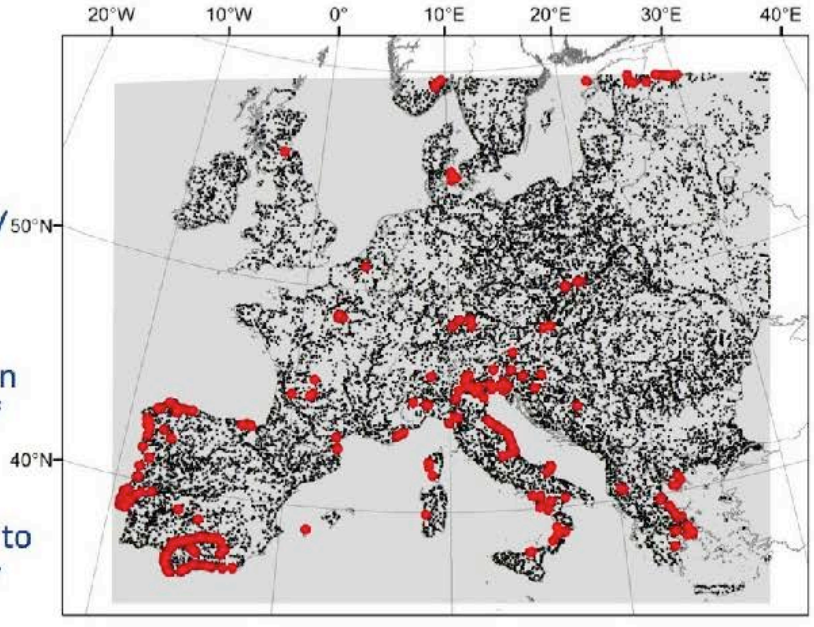
Performance of EPIC

22 months data starting on 1/12/2009.

We derived an alert criterion for extreme events of 60% probability of exceeding the 5-year return period.

363 points above the alert criterion were clustered in 50 events, 42 of which were confirmed events.

Out of 8 false alarms, 3 were due to boundary issues and can be easily recognized and removed

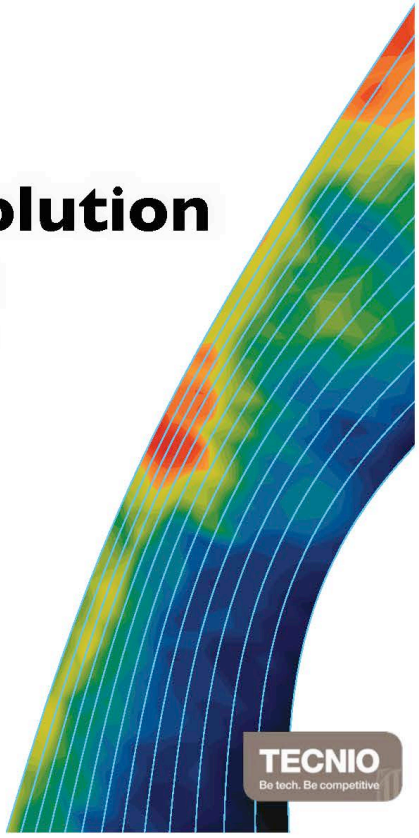


IMPRINTS

EDHIT

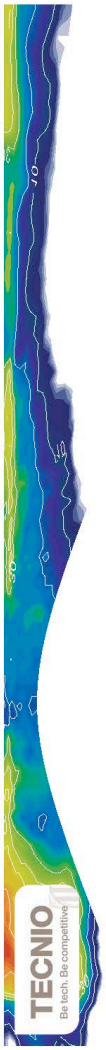
European Civil Protection

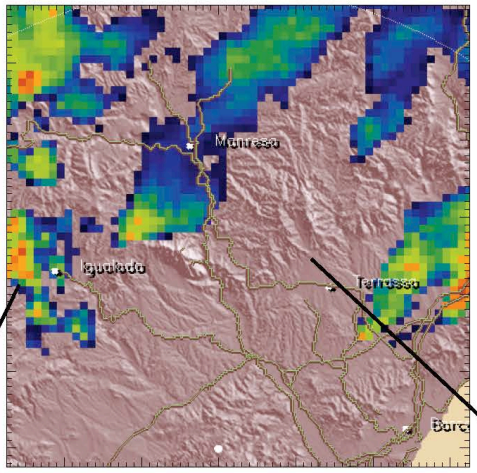
Can we increase the resolution in time and space using radar data?



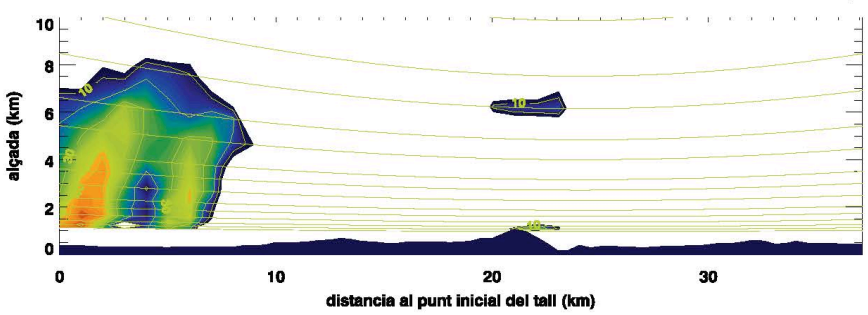
CRAHI

UPC





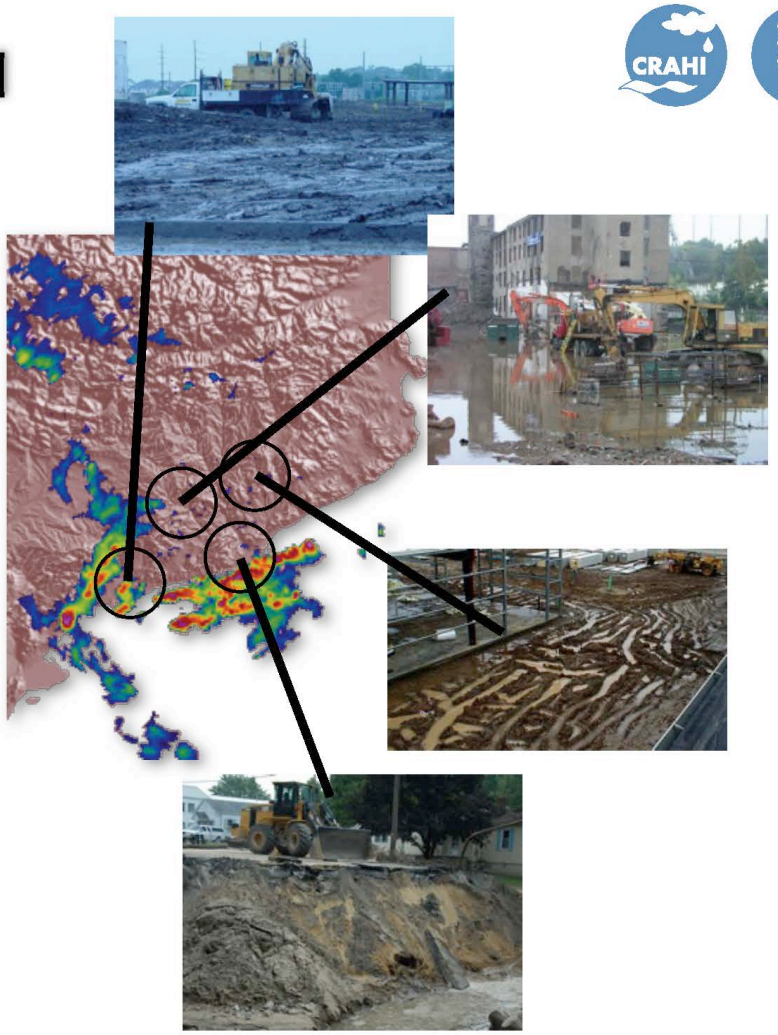
21:30



CRAHI

UPC

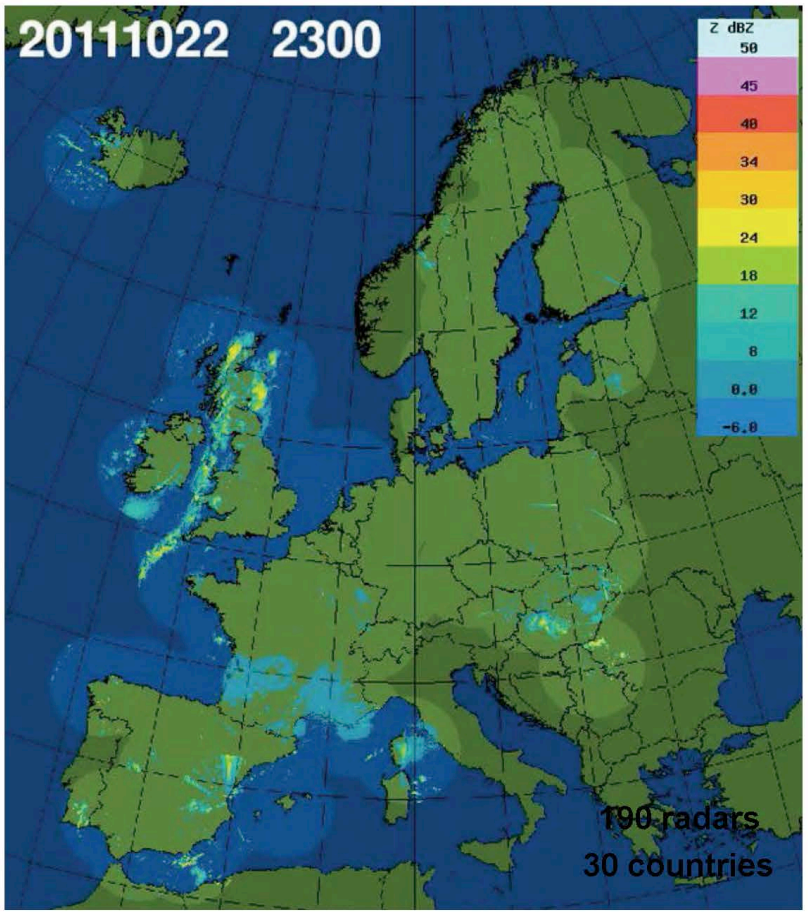
Warnings based on rainfall forecasts



EU radar mosaic

OPERA radar mosaic:

- Precipitation observations over Europe @2 km and every 15 minutes.
- Operationally produced since mid 2011.
- First nowcasting demonstration (HAREN project): June 2012-September 2013
- Second demonstration: **June 2014-July 2015**



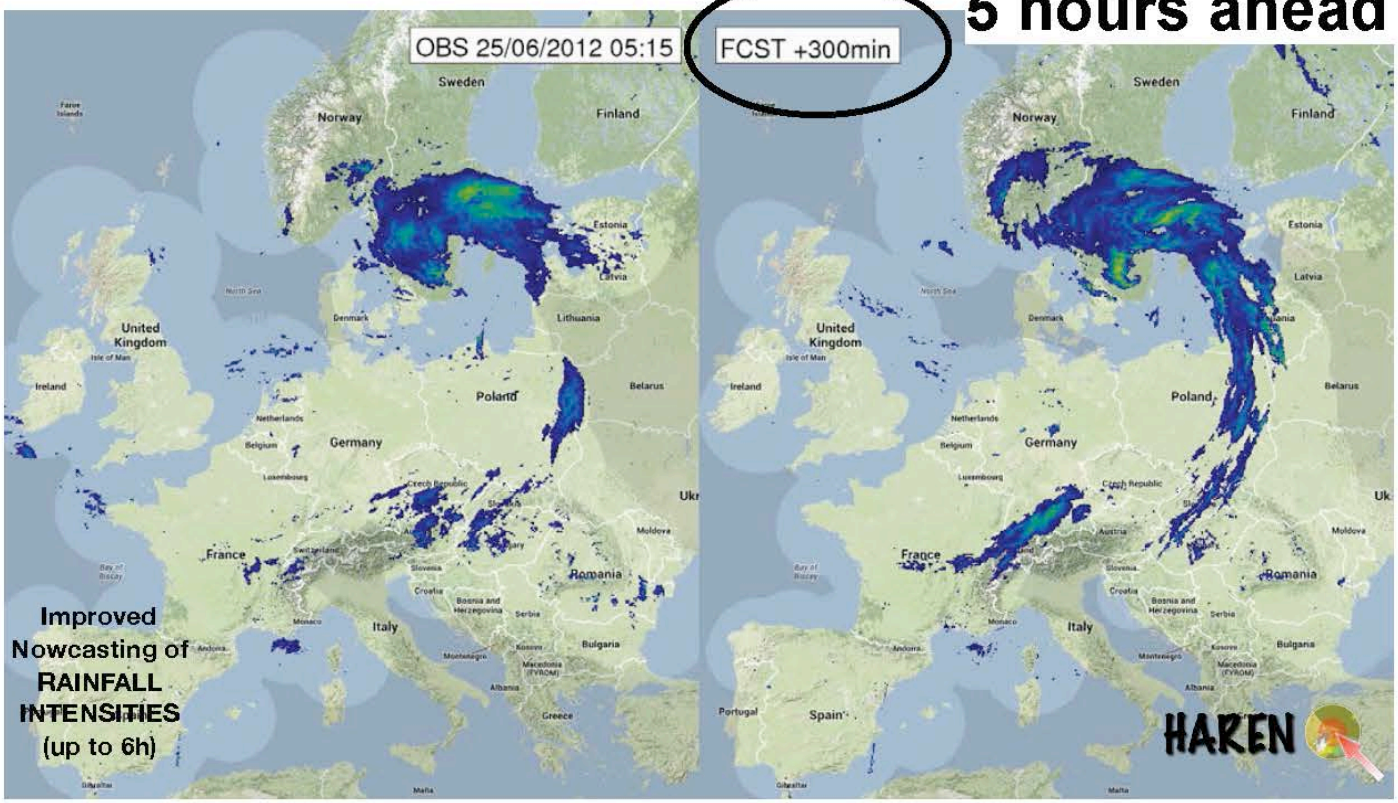
EDHIT

European Civil Protection

European Radar Nowcasting - OPERA mosaics

Over a network of 150+ radars.

5 hours ahead



CRAHI Algorithm of nowcasting by lagrangian persistence

Berenguer et al. J. Hydrometeorology, 2005; J. of Hydrology, 2011

European Civil Protection

EDHIT

Radar-based rainfall nowcasting at European Scale based in OPERA EDHIT products

Improved Nowcasting of RAINFALL INTENSITIES (up to 6h)

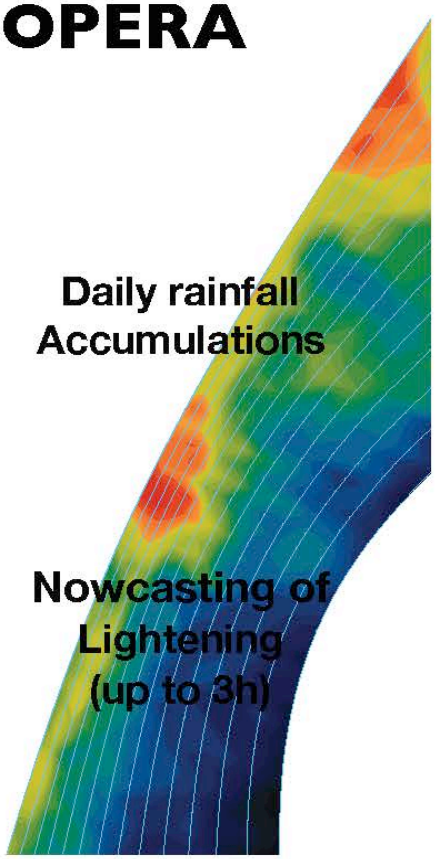
Rainfall hourly Accumulations forecasts (up to 6h)

Daily rainfall Accumulations

Hydrological Hazard forecasts (up to 6h)

Hourly HAZARD IDENTIFICATION forecasts (up to 6h)

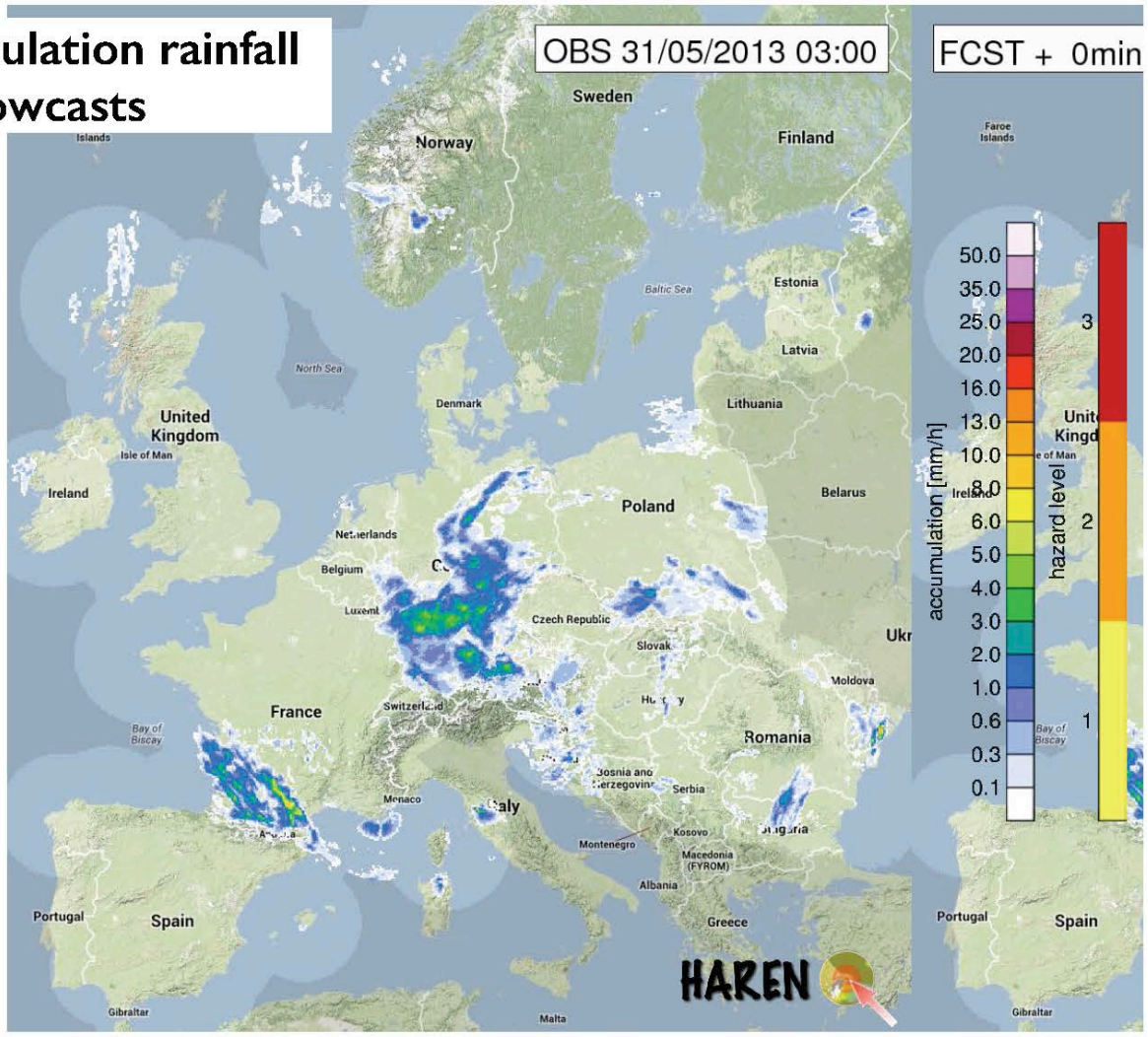
Nowcasting of Lightening (up to 3h)



JRC EUROPEAN COMMISSION

EFAS

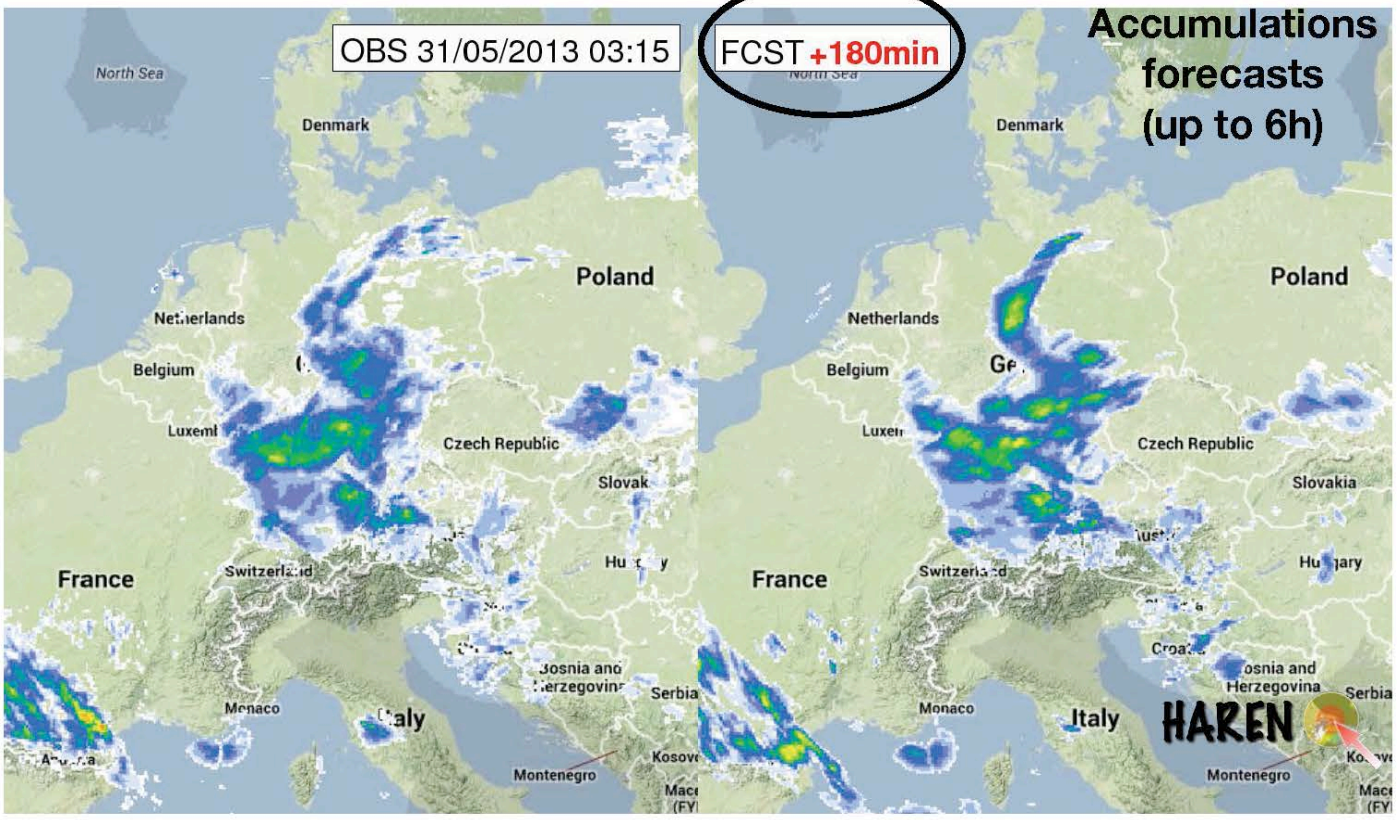
1h-accumulation rainfall nowcasts



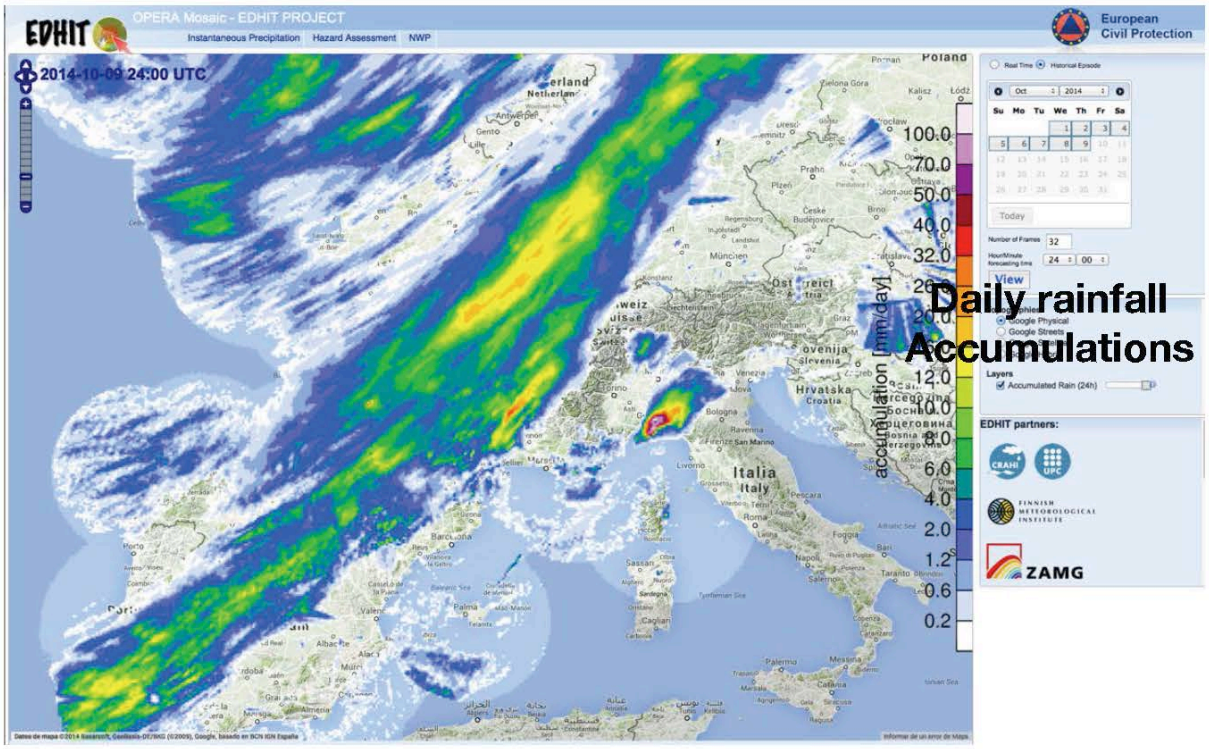
1h-accumulation rainfall nowcasts

Nowcasts @ 31 May 2013 3h ahead

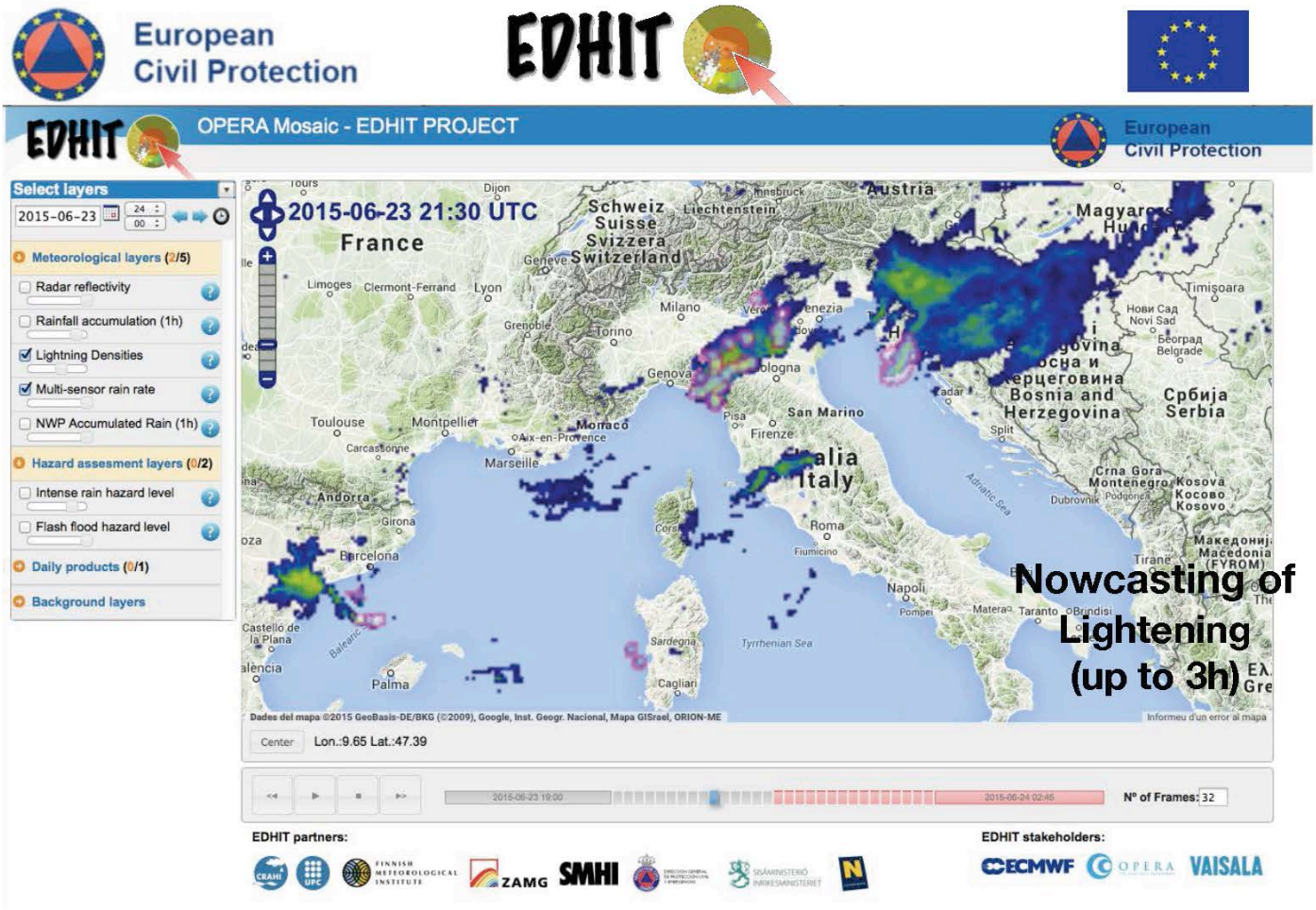
Rainfall hourly Accumulations forecasts (up to 6h)



Genova (Italy) on 10th of October 2014

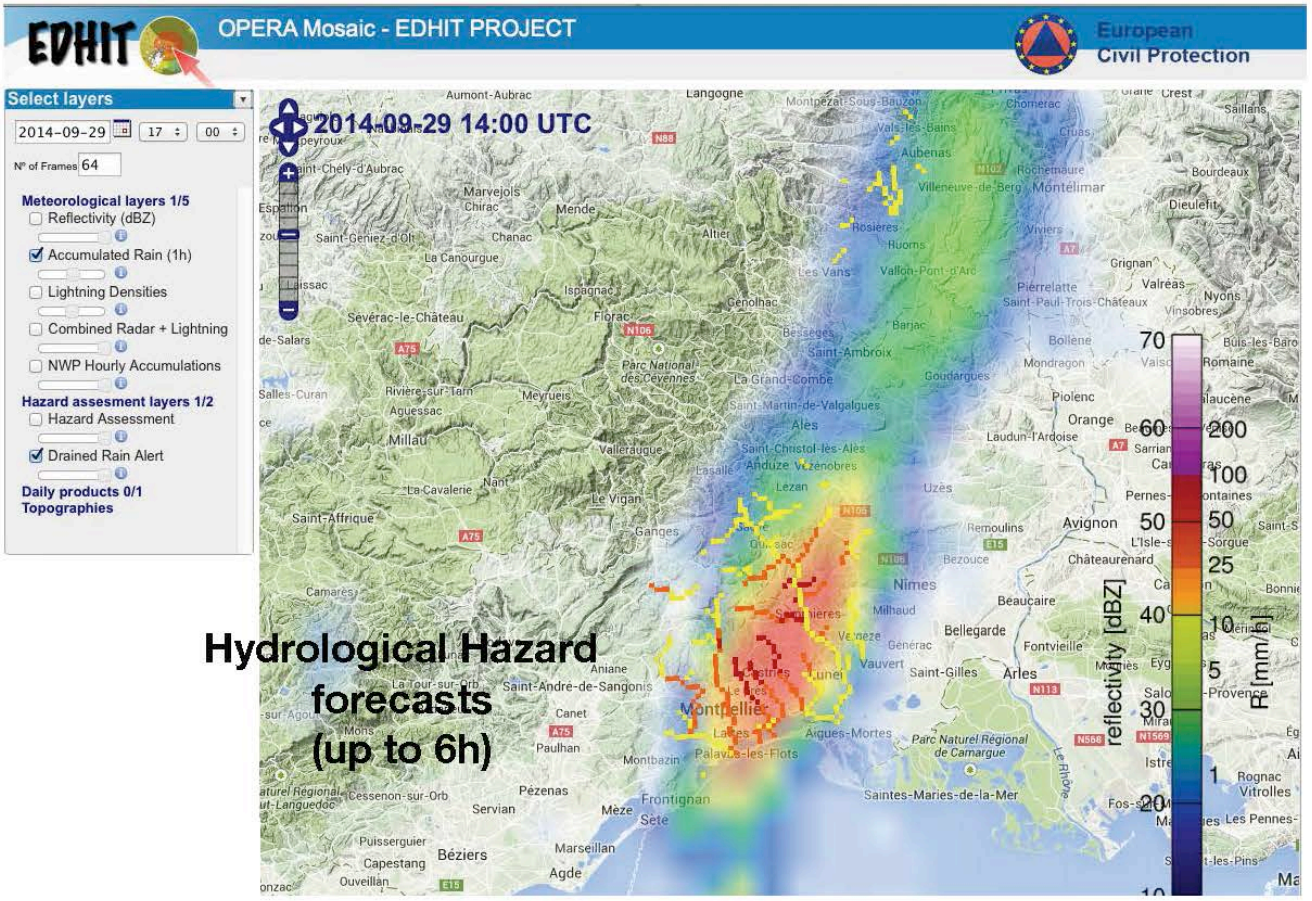


after > 300 mm of accumulated rain in few hours

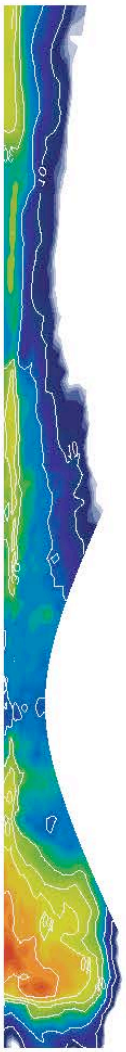


European Civil Protection

EDHIT



Hydrological Hazard forecasts (up to 6h)

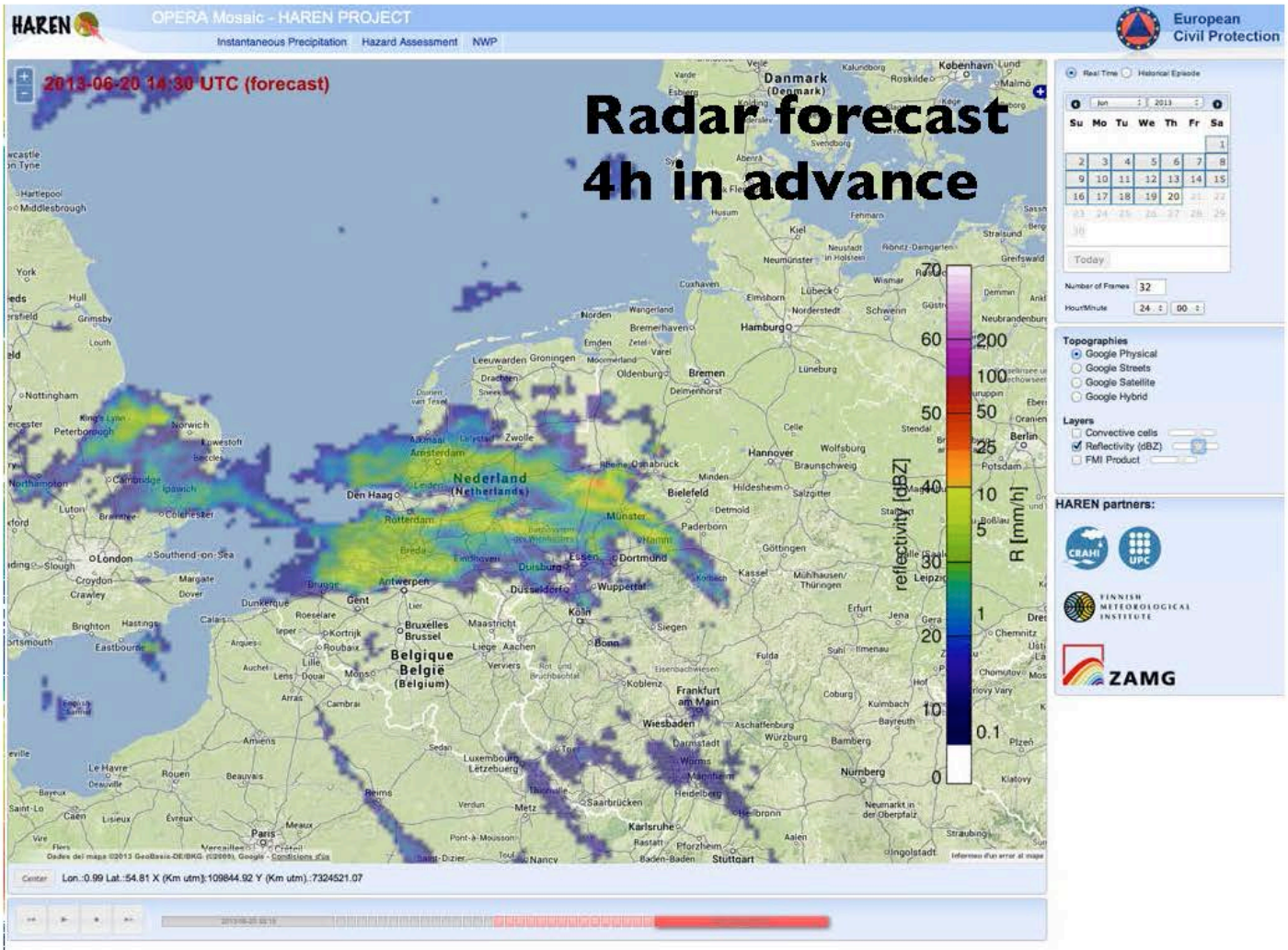


CASE STUDY in The Netherlands (20 June 2013)

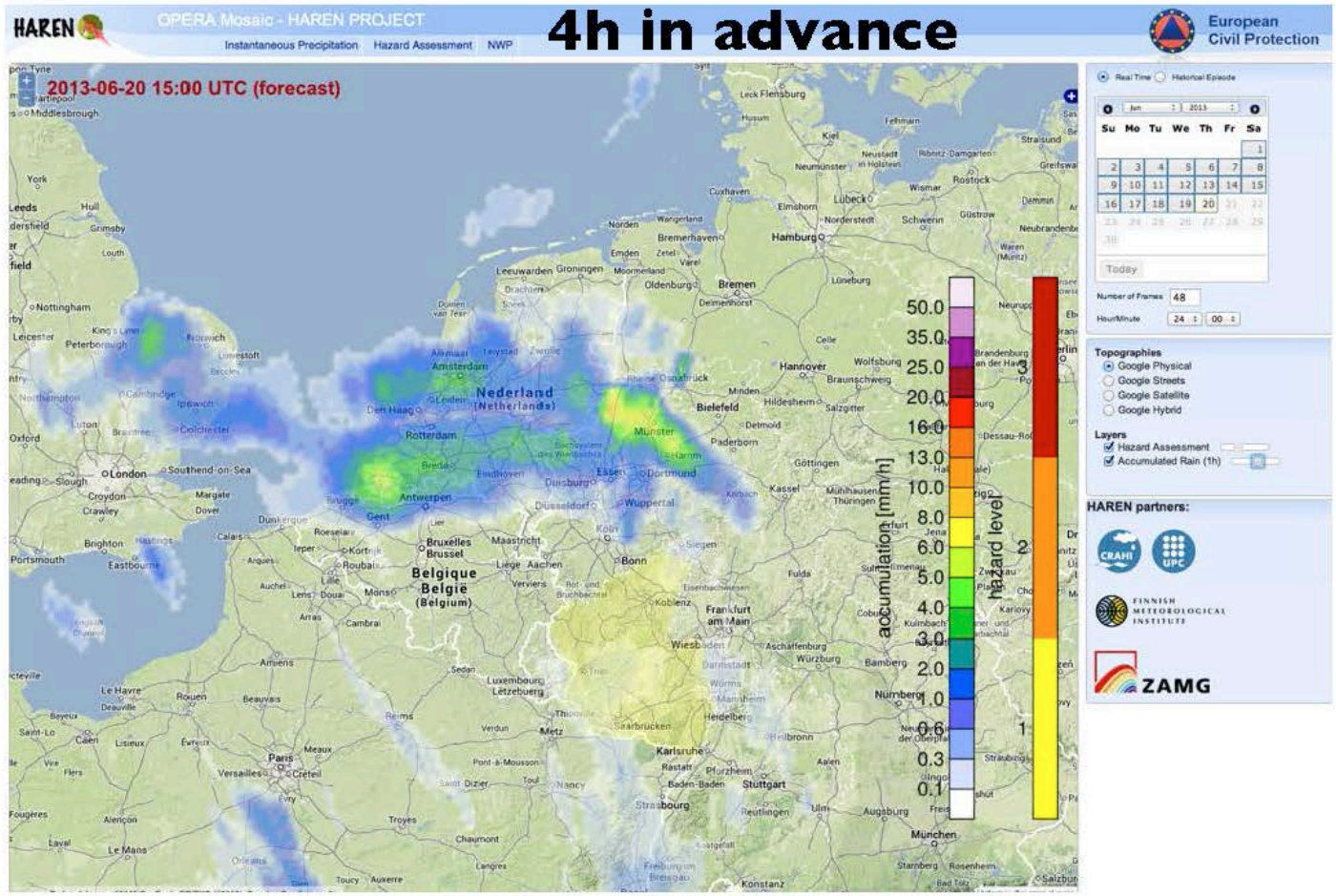
Ondertussen in het oosten van het land: zandzakken en rubberbootjes



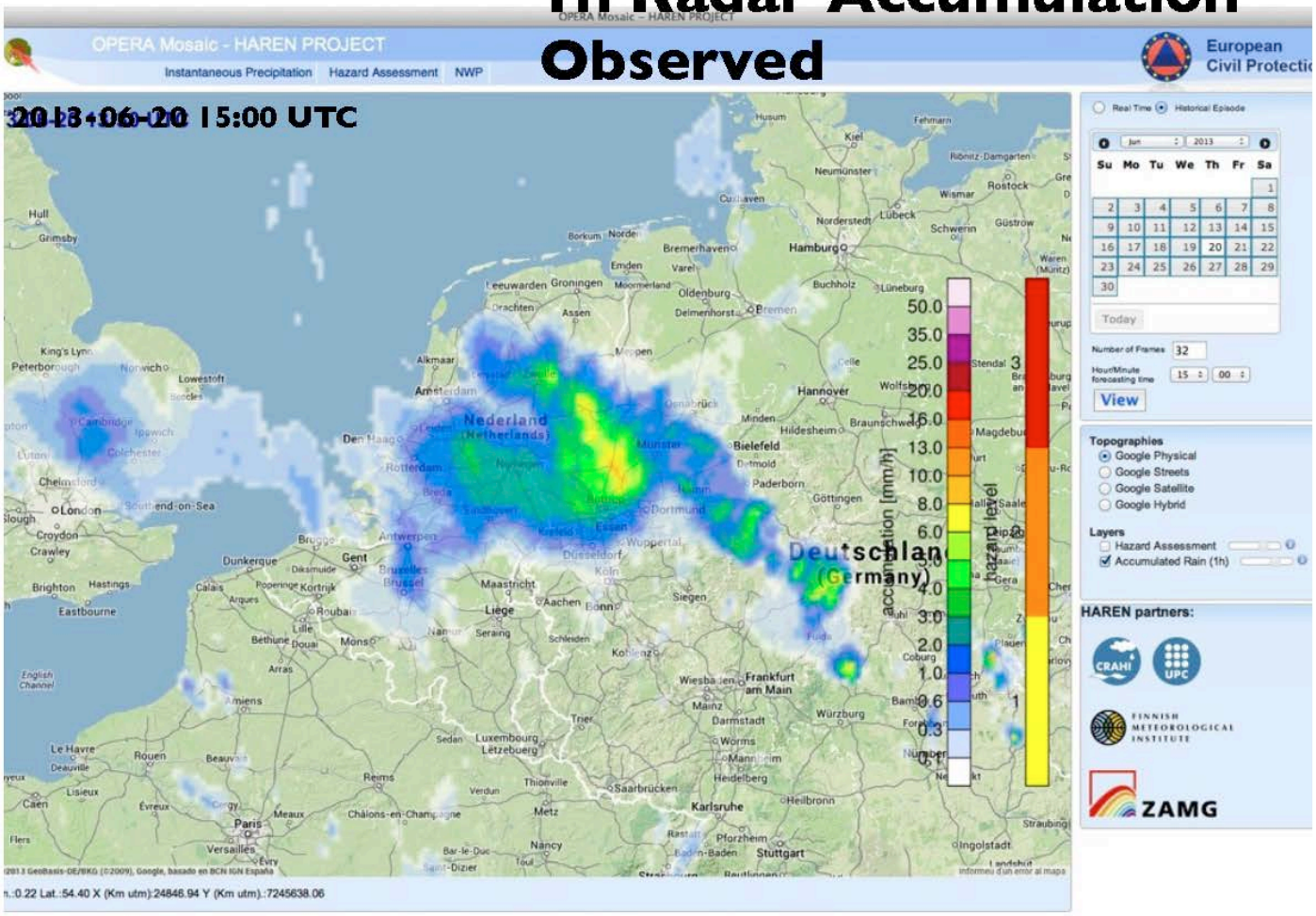
Noodweer in Enschede. Screenshot van WeerGroningen.



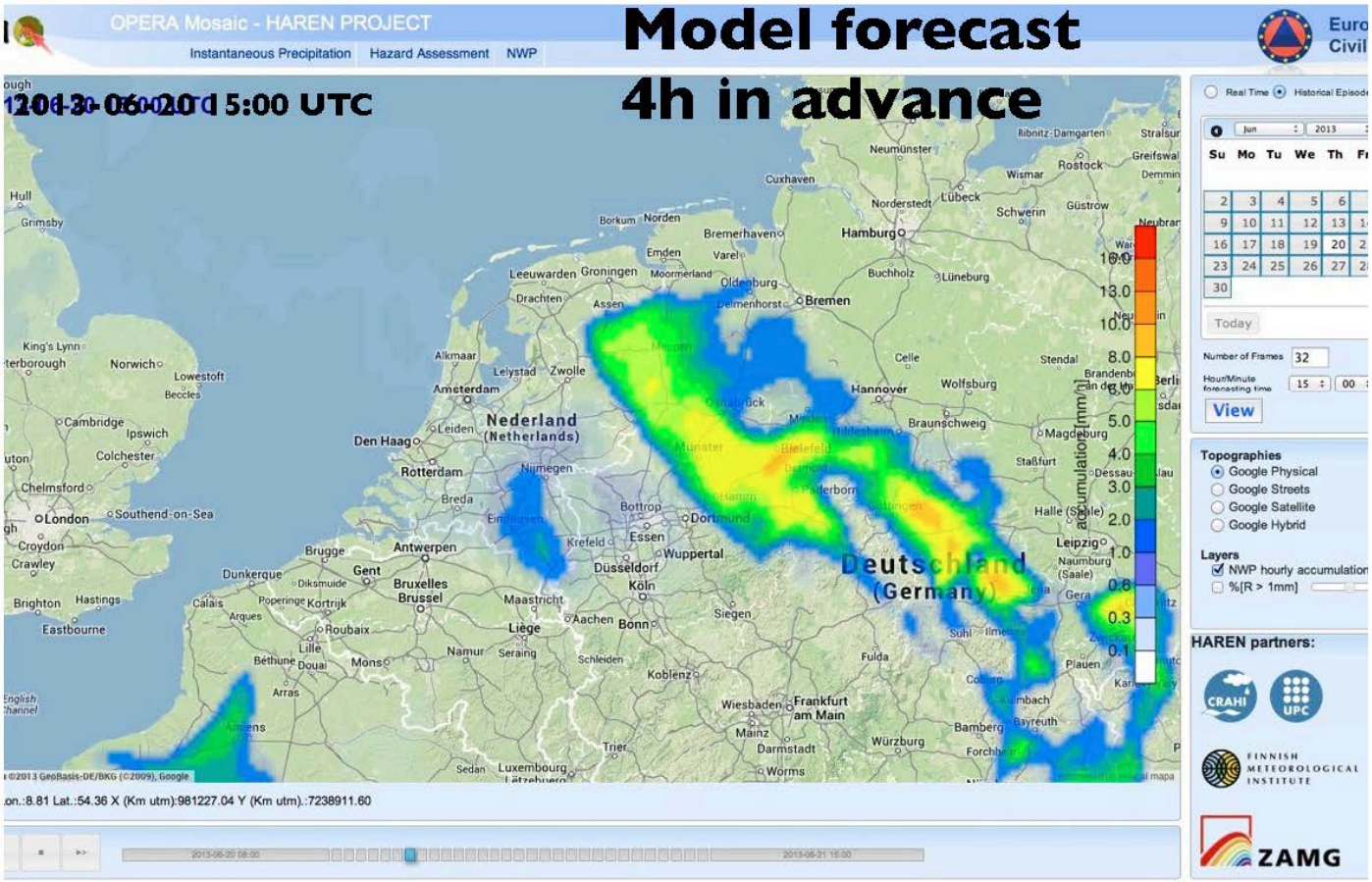
1h Radar Accumulation
4h in advance



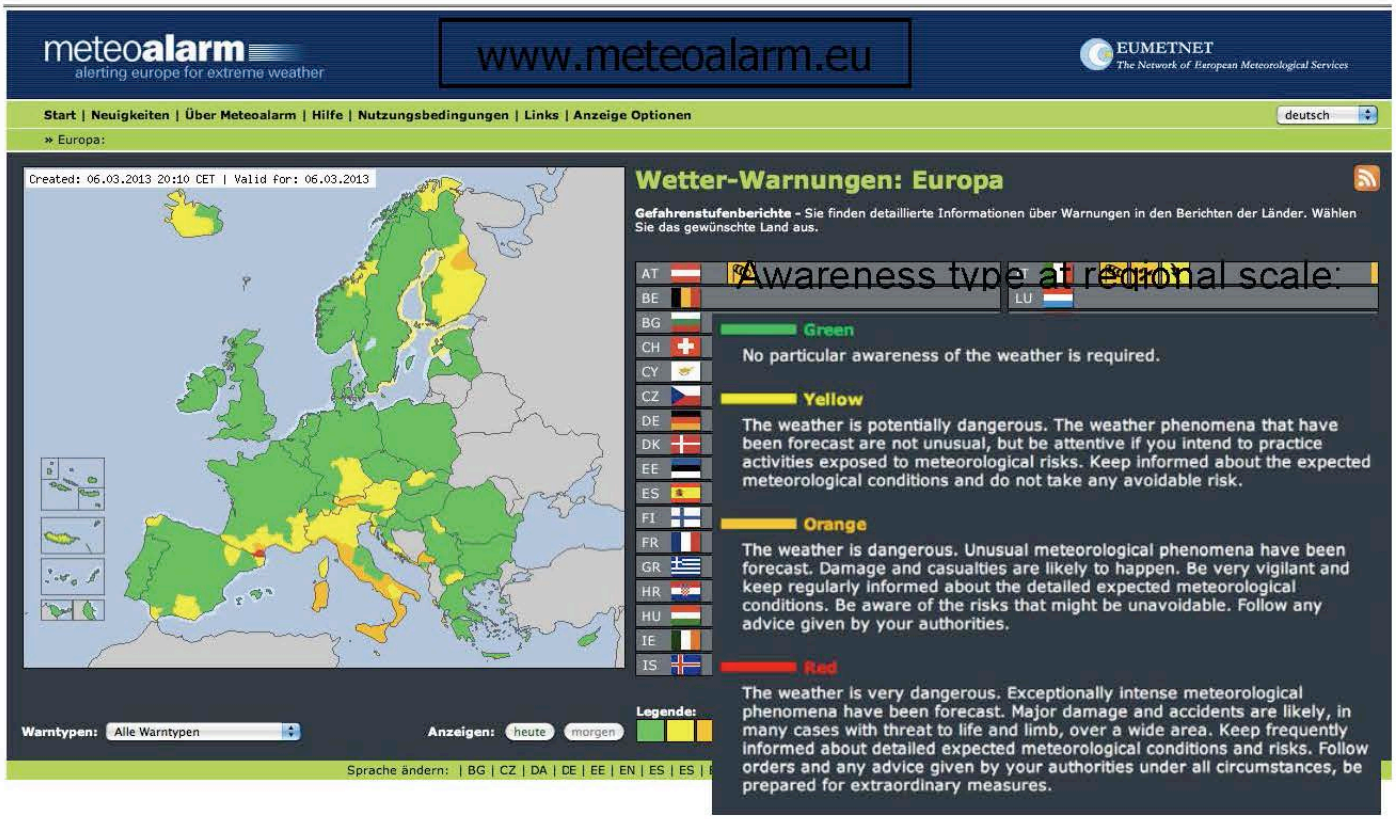
1h Radar Accumulation Observed



Model forecast 4h in advance



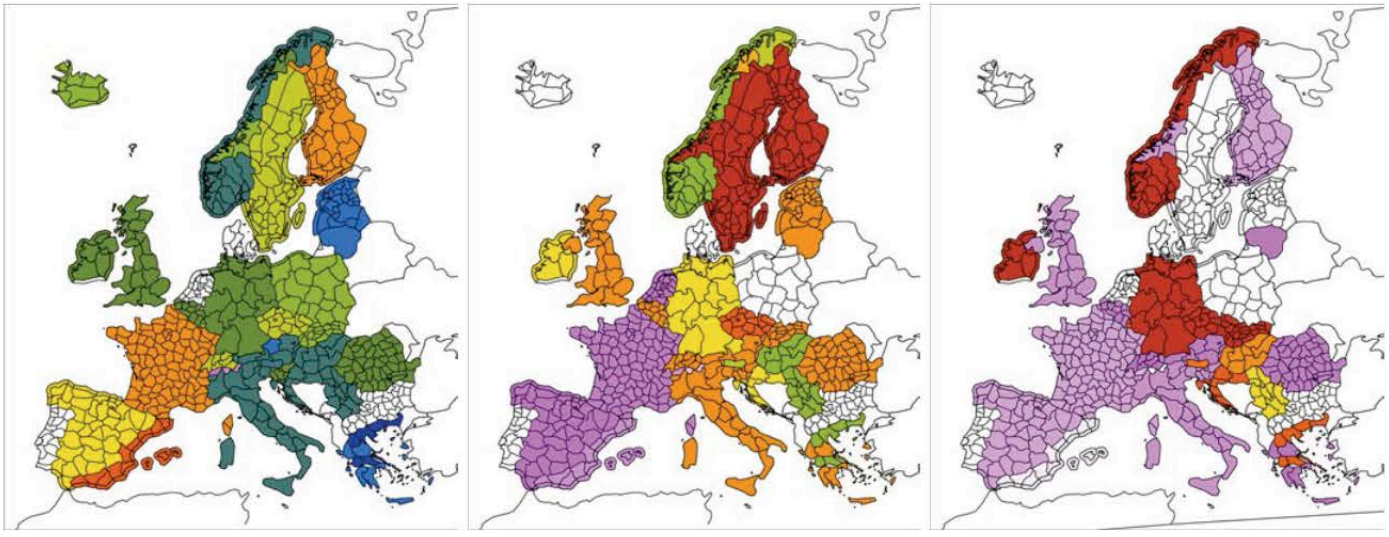
Hazard identification related to Meteoalarm EU regional thresholds

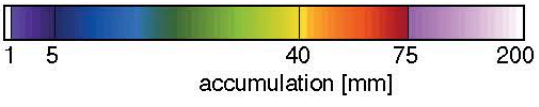


HAZARD ASSESSMENT

regional thresholds for 12-h accumulations defined by METEOALARM

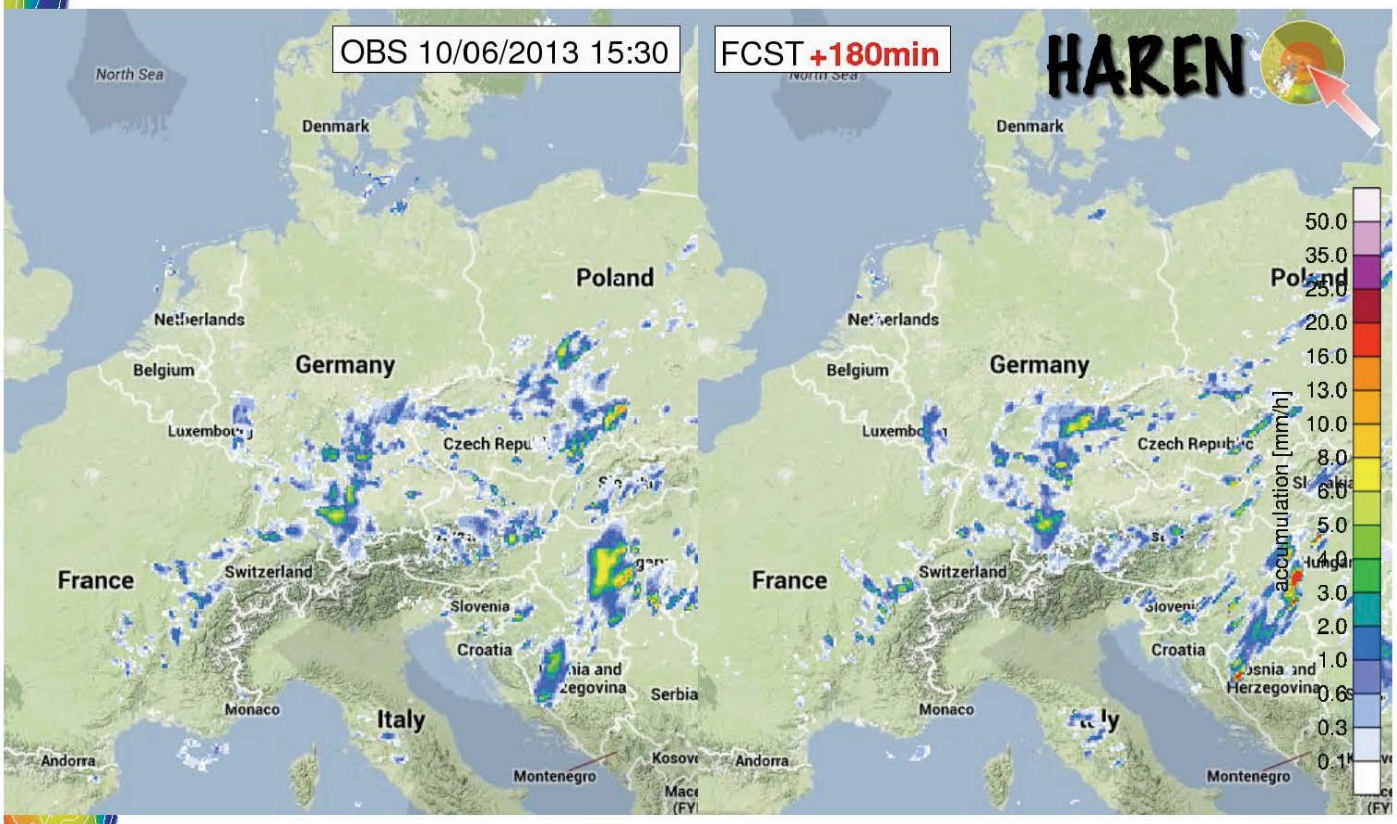
hazard level 1 | hazard level 2 | hazard level3



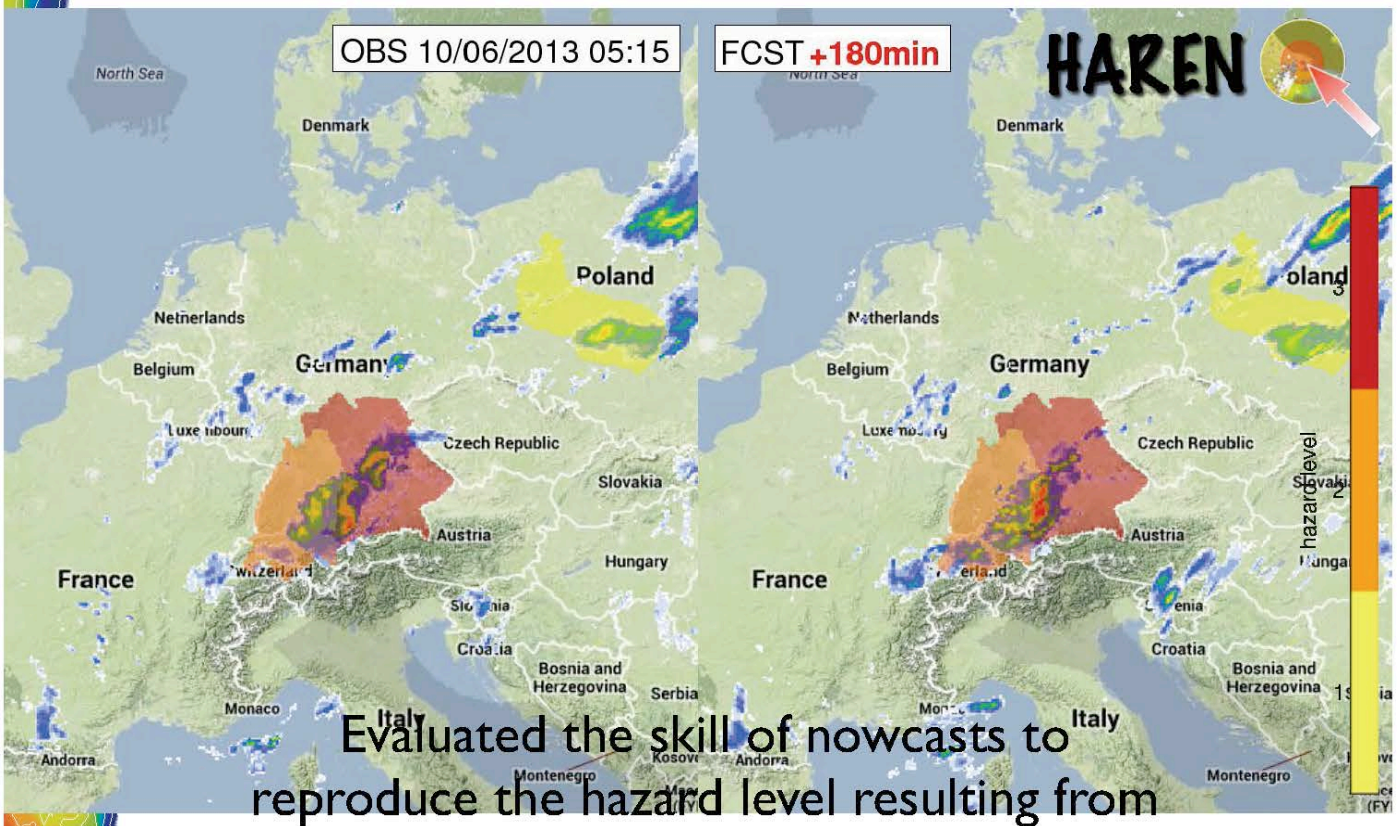


HAREN

HAZARD ASSESSMENT - Intense rain



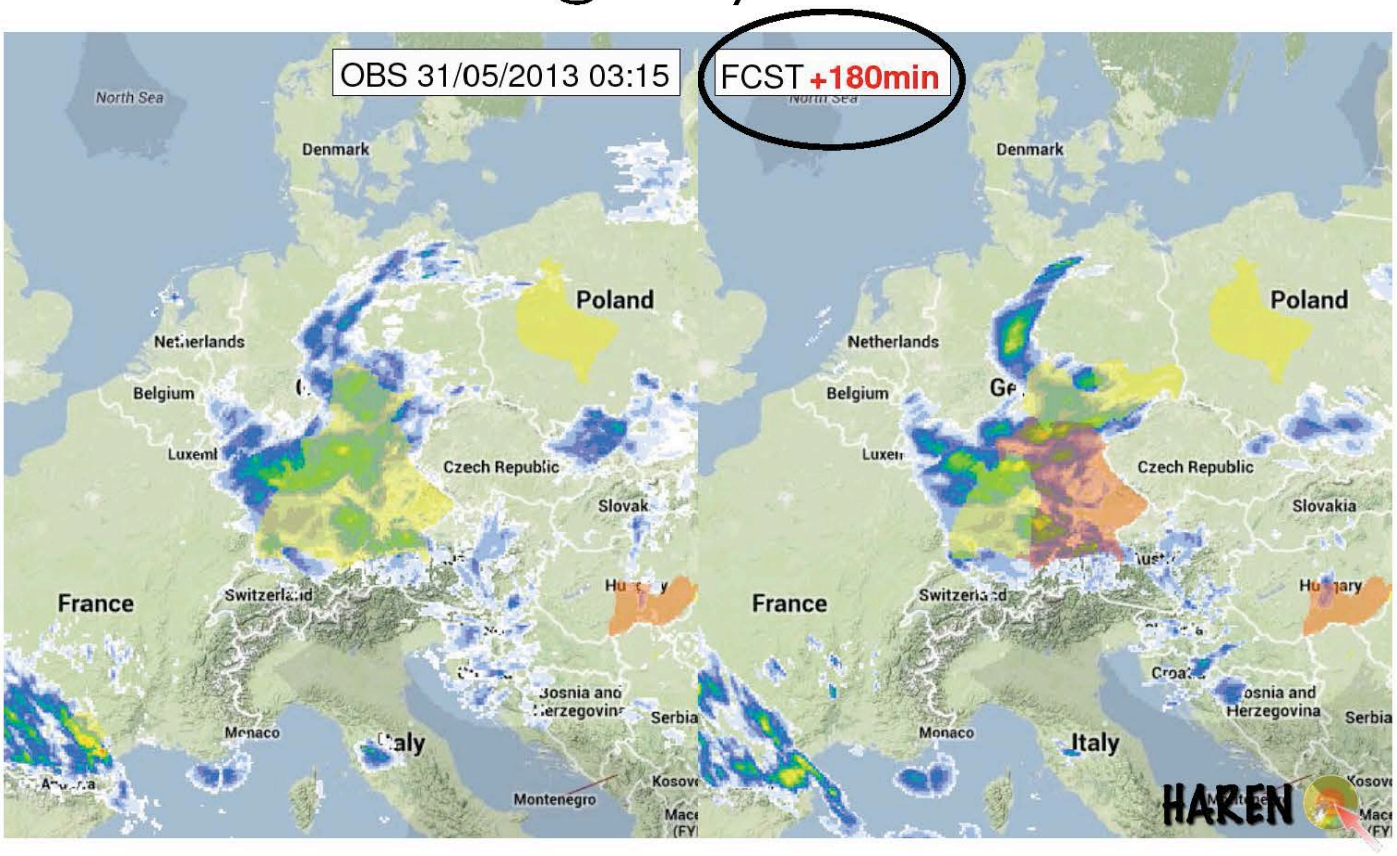
HAZARD ASSESSMENT - Intense rain



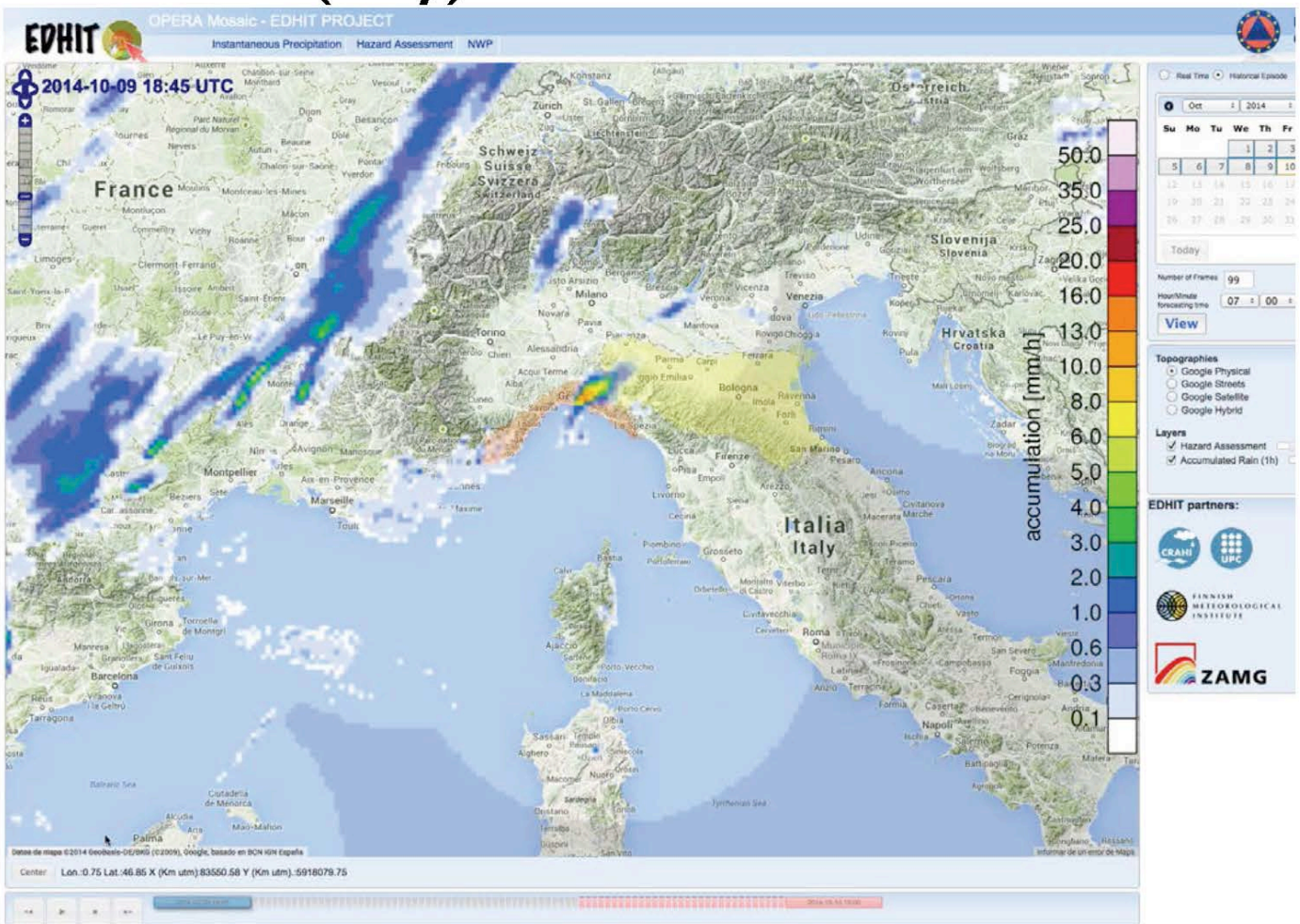
Evaluated the skill of nowcasts to reproduce the hazard level resulting from observations

Hazard assessment based on 1h rainfall accumulations

Nowcasts @ 31 May 2013 3h ahead



Genova (Italy) on 10th of October 2014



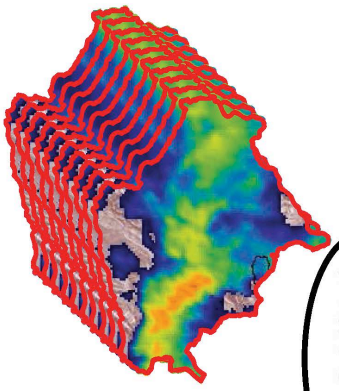
EFAS Flash Flood module based on IMPRINTS

IMPRINTS

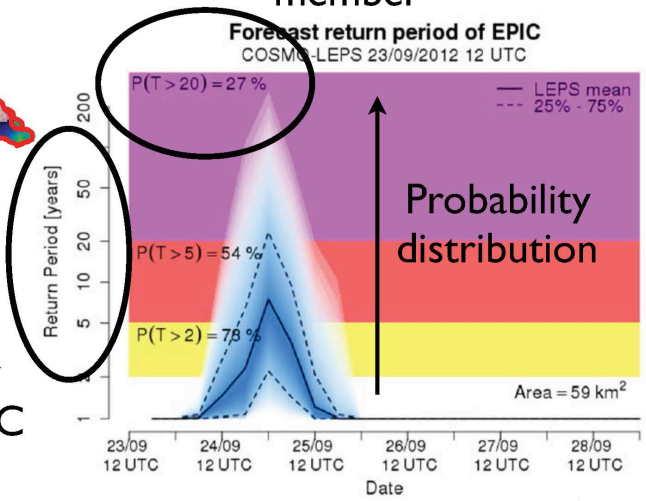
COSMO-LEPS Probabilistic Rainfall forecasts



Probabilistic basin aggregated rainfall forecasts



Warning code associated to the 75% percentile member

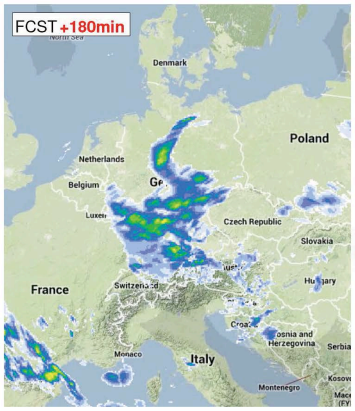


Return Period of any member calculated by comparison against EPIC climatology

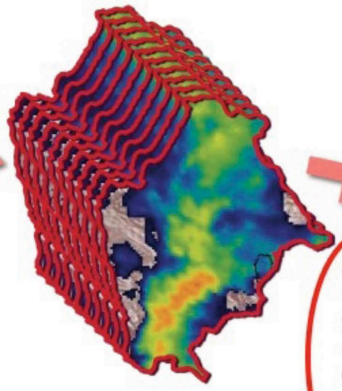
EFAS Flash Flood Module based on EDHIT up to 6h ahead

EDHIT Flash Flood Index up to 6h ahead

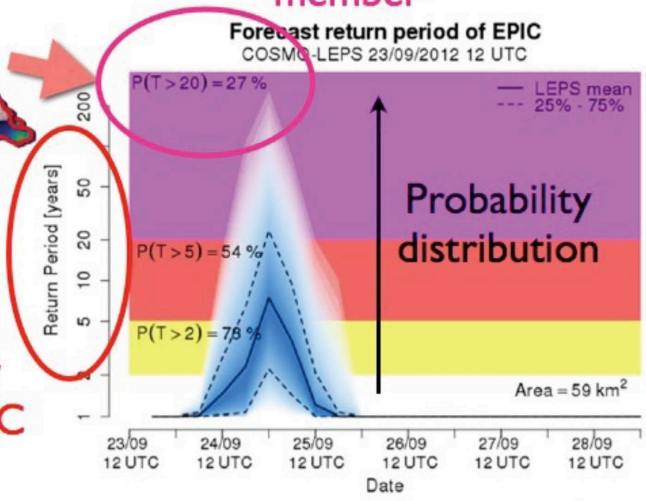
EDHIT Radar Rainfall forecasts



Probabilistic basin aggregated rainfall forecasts



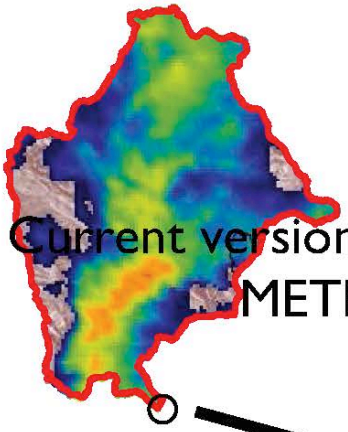
Warning code associated to the 75% percentile member



Return Period of any member calculated by comparison against EPIC climatology

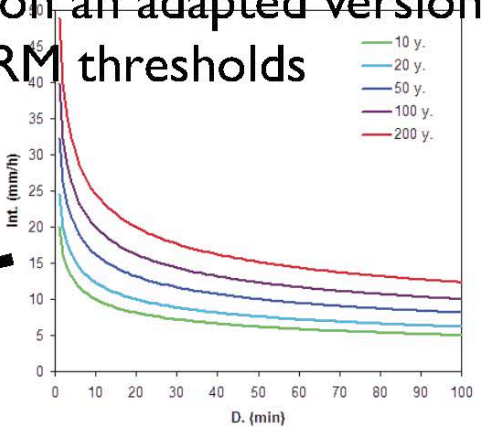
FF-EWS: Critical improvement

Build a basin-aggregated rainfall Climatology



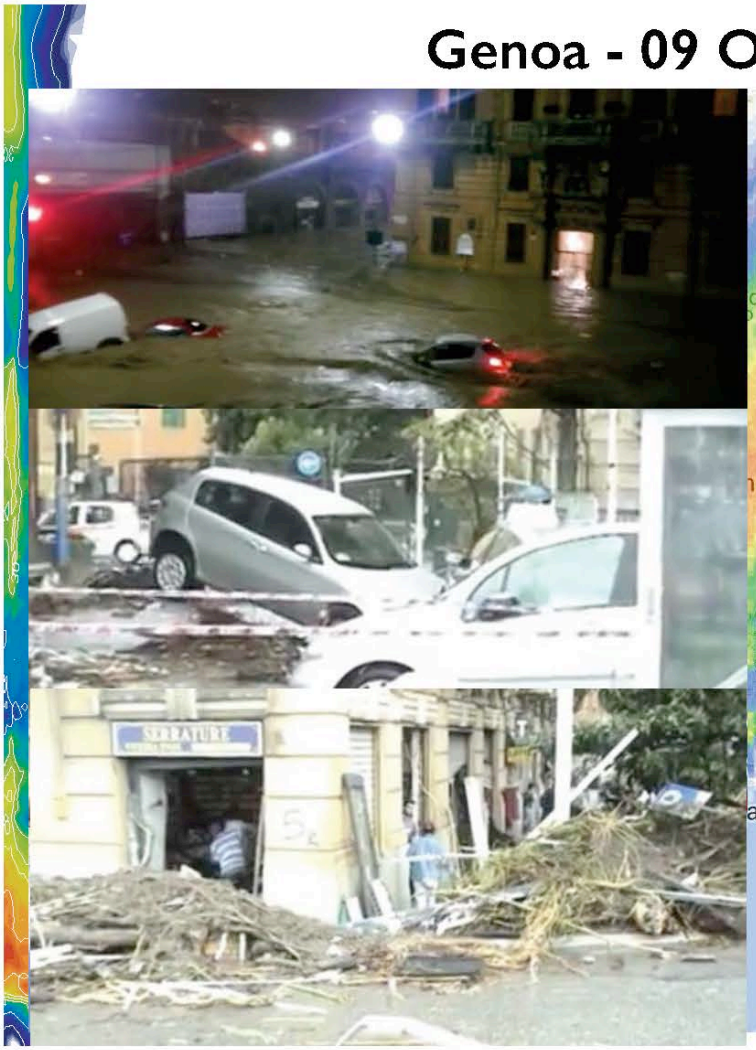
Statistical analysis of the **probability of Exceedance** of the bassin-agregated rainfall

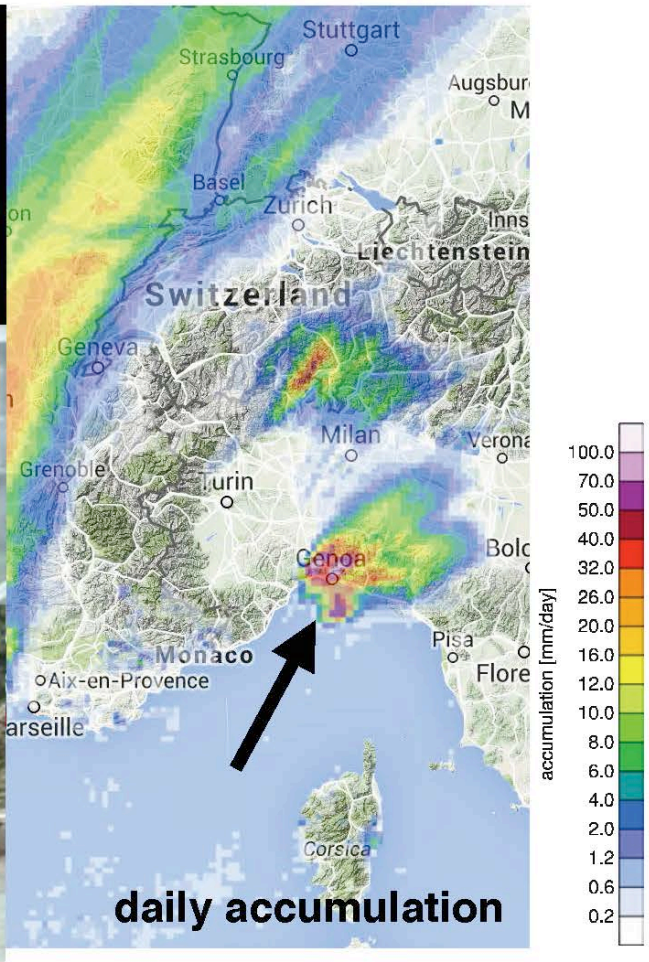
Current version: based on an adapted version of METEOALARM thresholds



Thresholds for the **Warning levels**

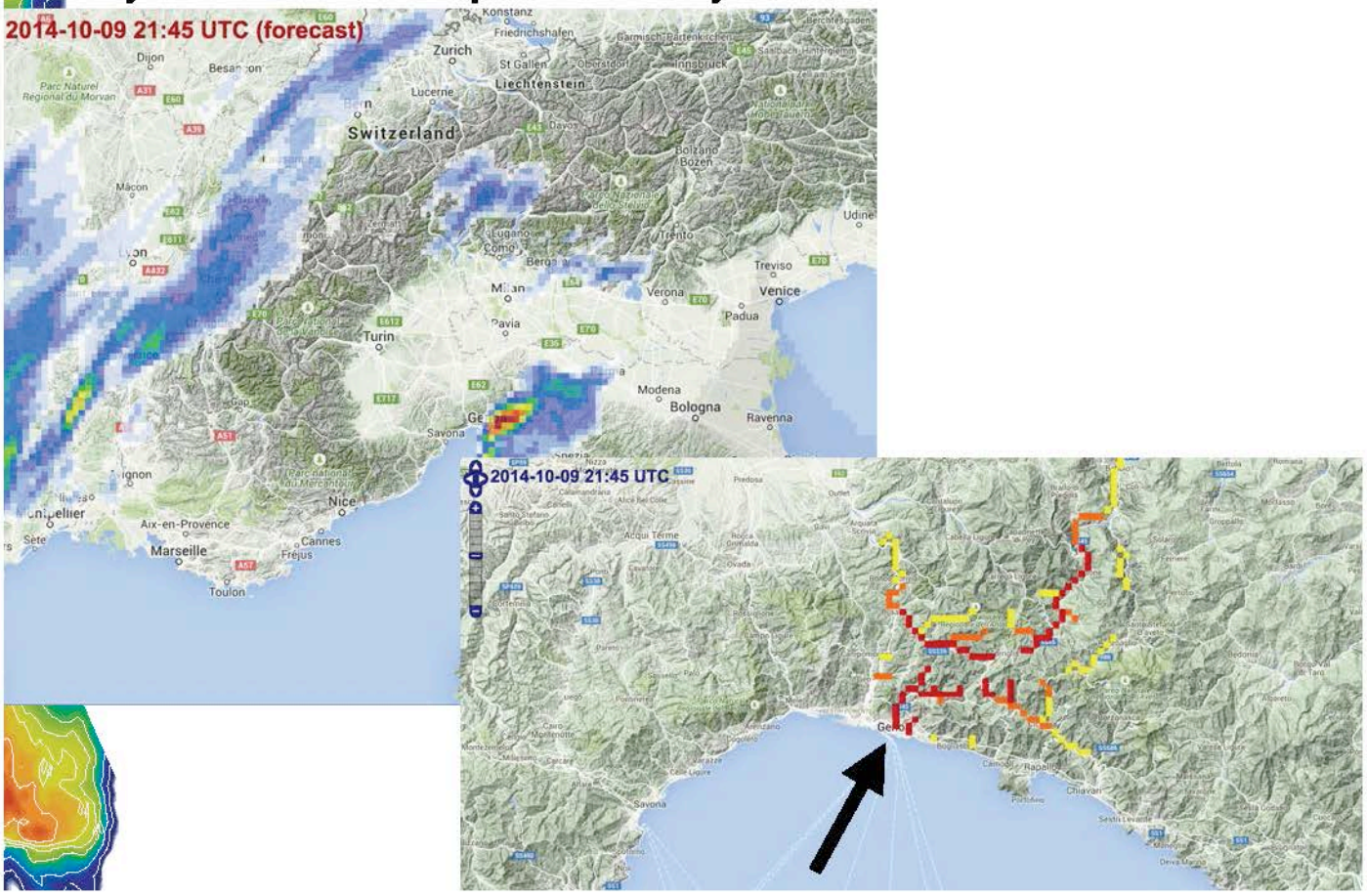
Genoa - 09 Oct 2014



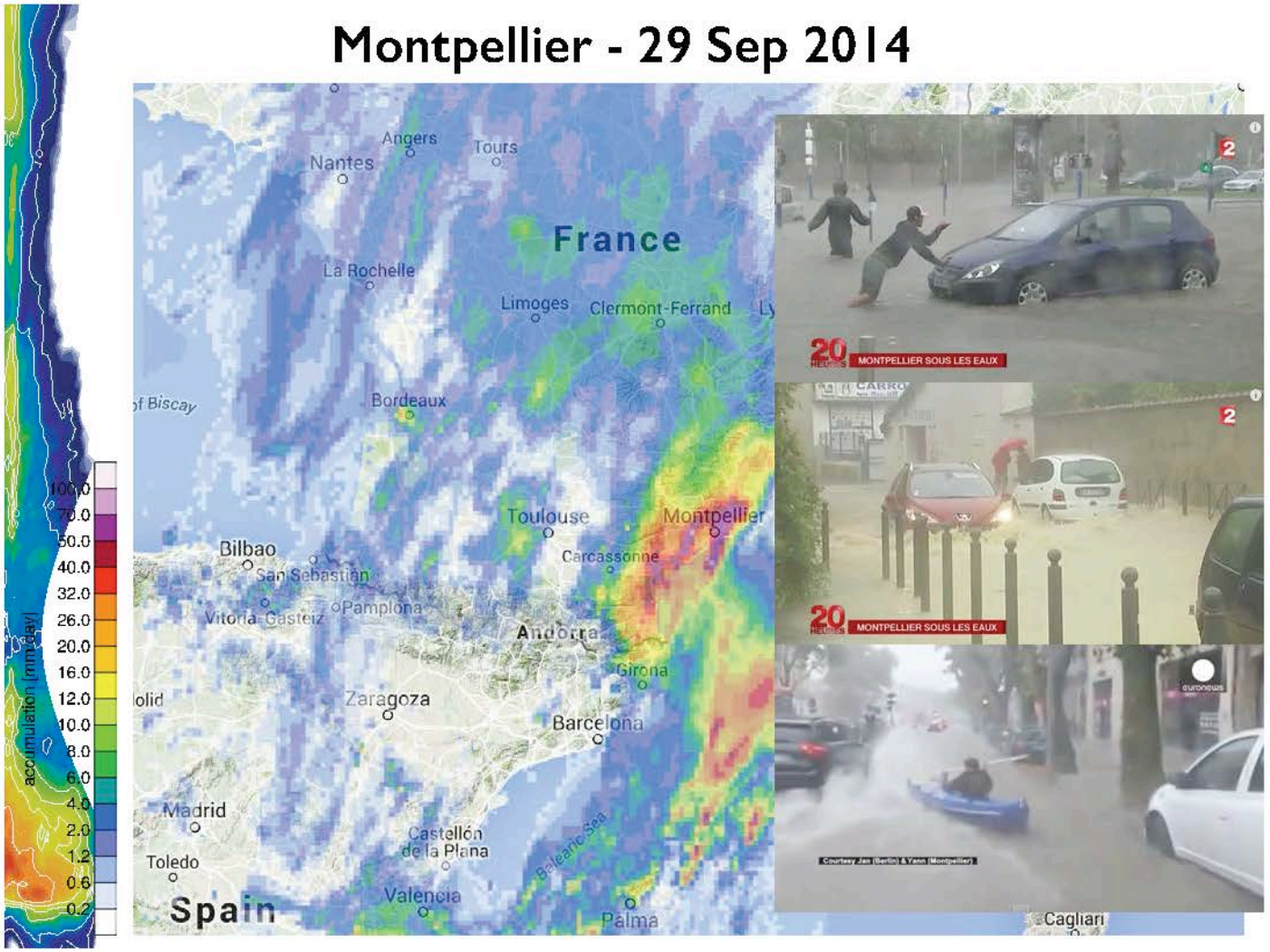


Genoa - 09 Oct 2014

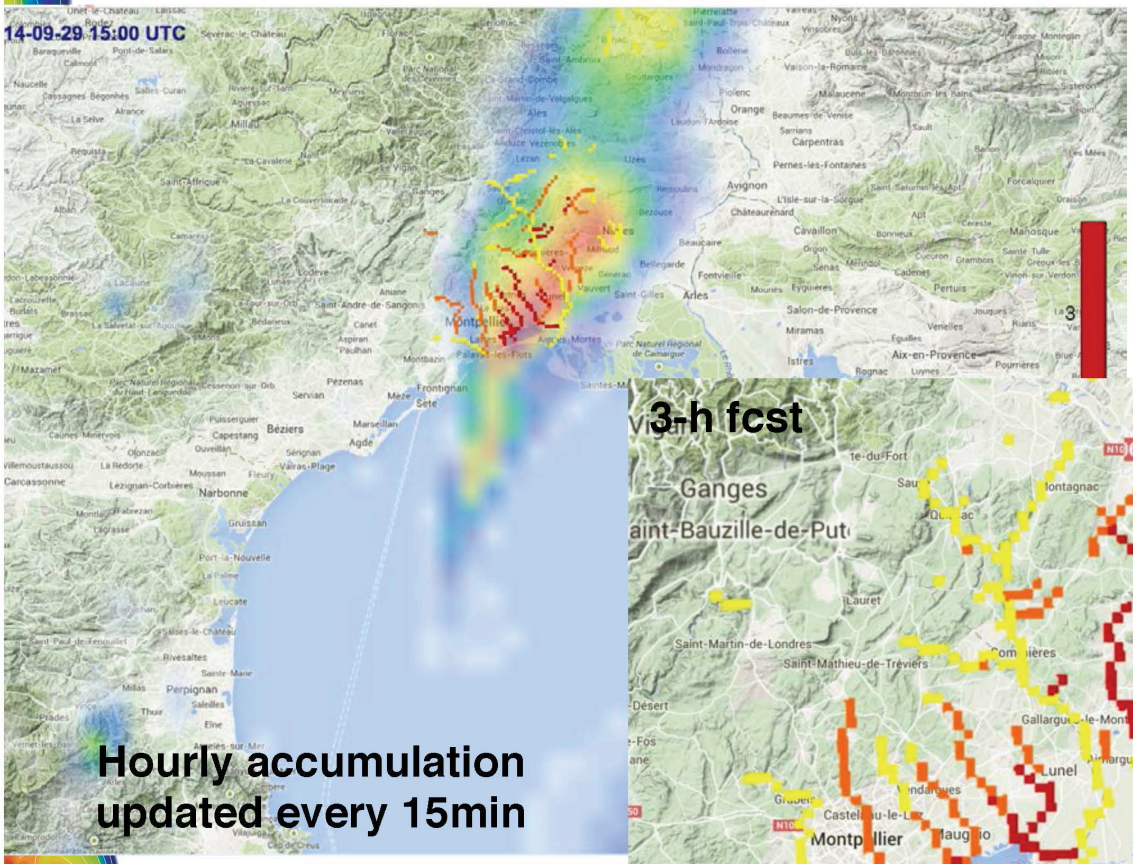
Hourly accumulation updated every 15min



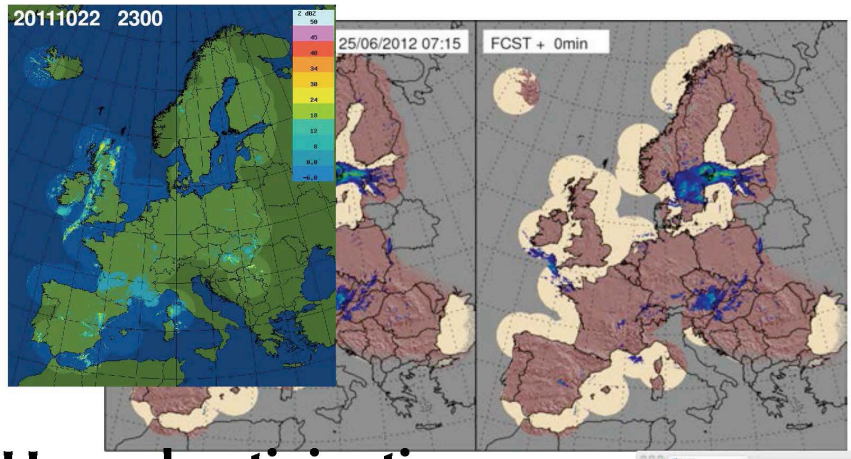
Montpellier - 29 Sep 2014



Montpellier - 29 Sep 2014



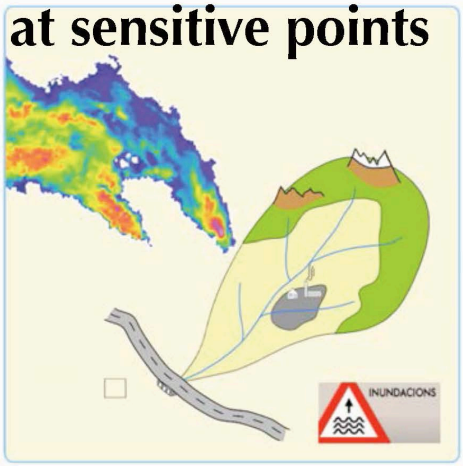
From observations

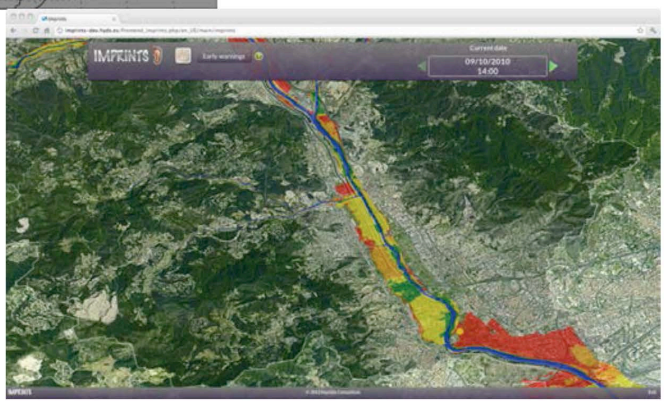


EDHIT

High resolution rainfall nowcastings over Europe @2km every 15 minutes

Hazard anticipation at sensitive points

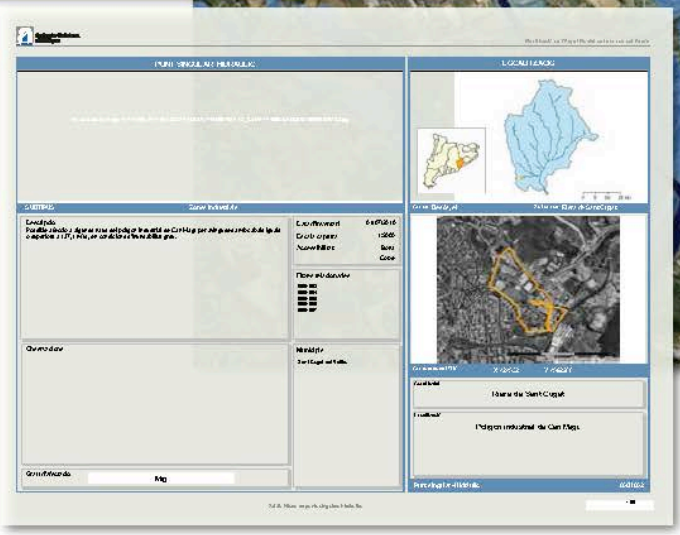




Cross them with vulnerability maps

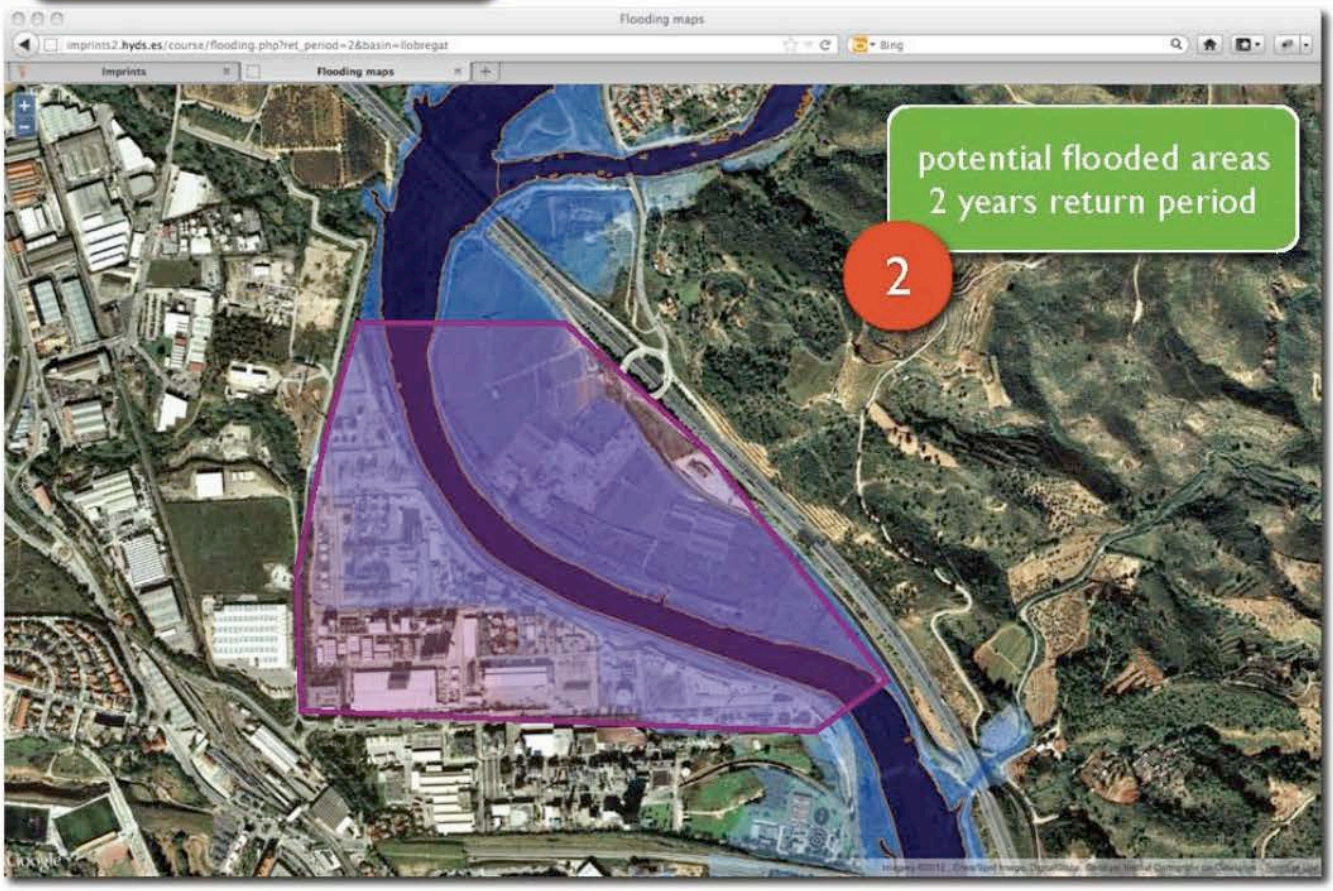
- Detailed information about flooded areas for different return periods

- Detailed information about critical points and impact of flooding

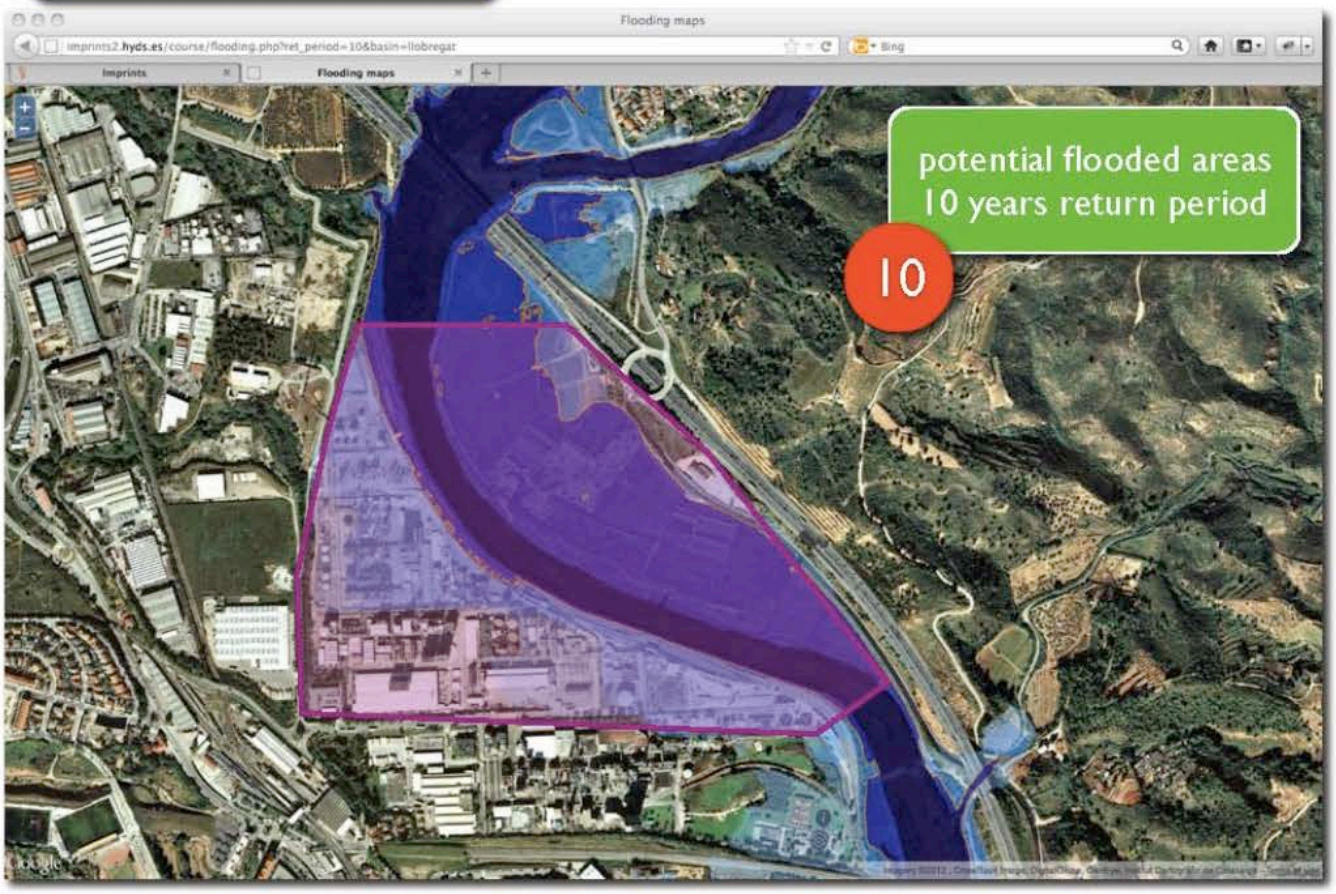


IMPRINTS

Critical points



Critical points







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Hidrometeorological Early Warnings

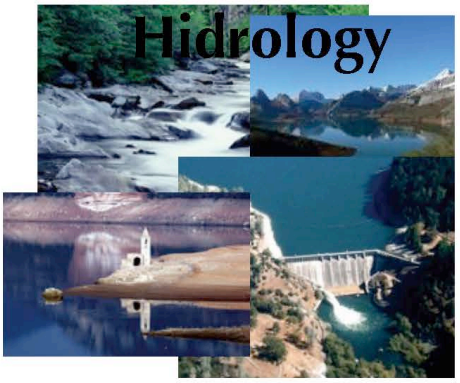
CRAHI

UPC

Transportation



Hidrology



Leisure and sports





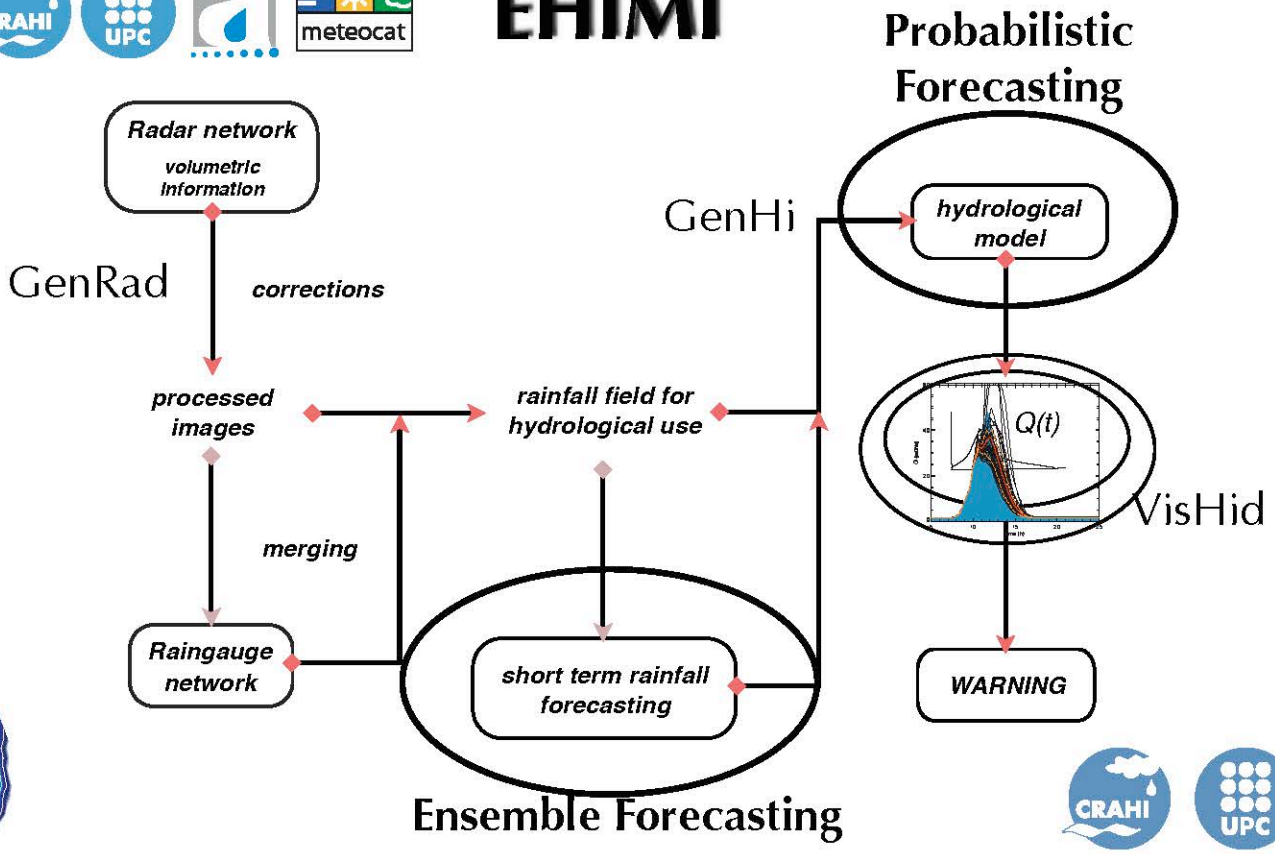
Outdoor activities



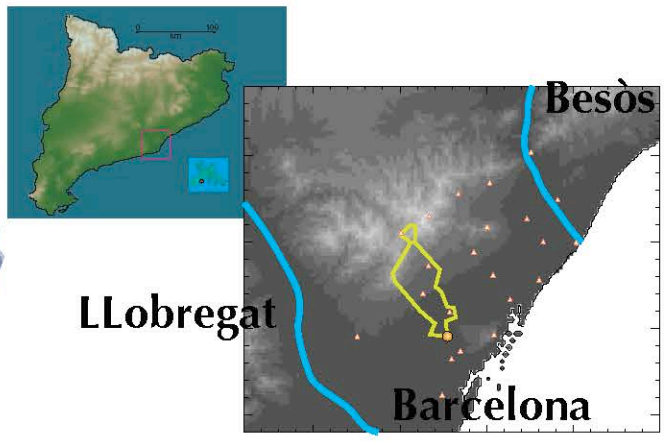


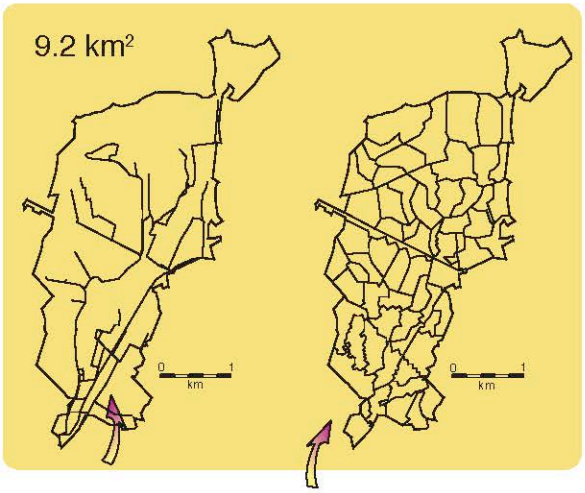
Integrated system for operational hydrological forecasting in Catalunya

EHIMI



Hydrological application:
Case study of Riera Blanca



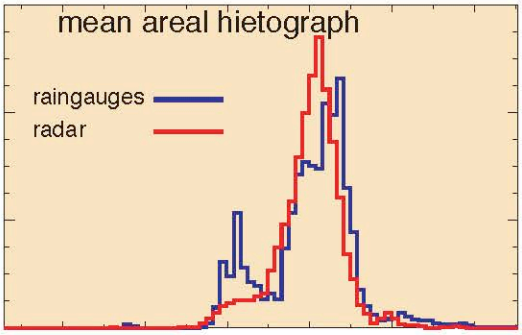


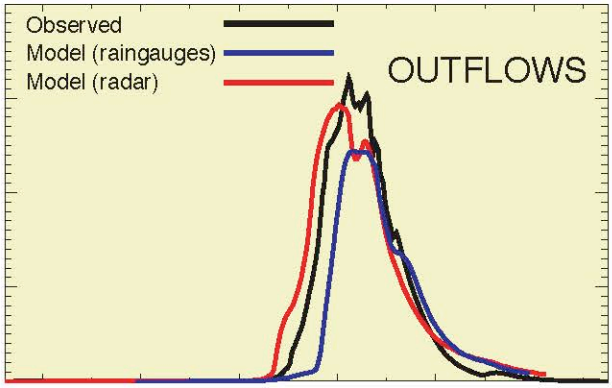
Riera Blanca
Impervious urban basin
managed by CLABSA

Hydrological model:
MOUSE (DHI)

Sempere-Torres, et al. ***J. Environmental Eng. (ASCE), 1999:*** *372-385*

Case study Riera Blanca





Sempere-Torres, et al. ***J. Environmental Eng. (ASCE), 1999:*** *372-385*

T.C.
Orman ve Su İşleri Bakanlığı
Meteoroloji Genel Müdürlüğü

TRAINING PROGRAM ON METEOROLOGICAL AND ADVANCED QUANTITATIVE APPLICATIONS

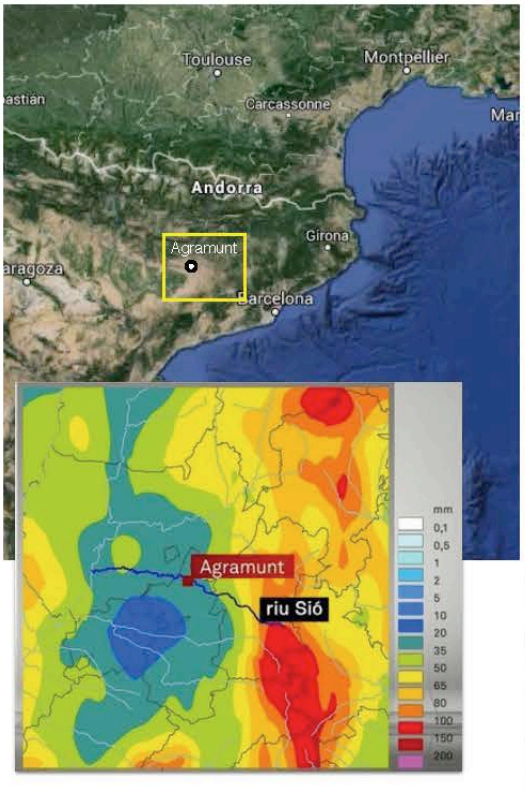
Heavy rain and flash flood early warnings at basin scale using radars.

Centre de Recerca Aplicada en Hidrometeorologia
UNIVERSITAT POLITÈCNICA DE CATALUNYA



The flood event of 02 November 2015

Agramunt



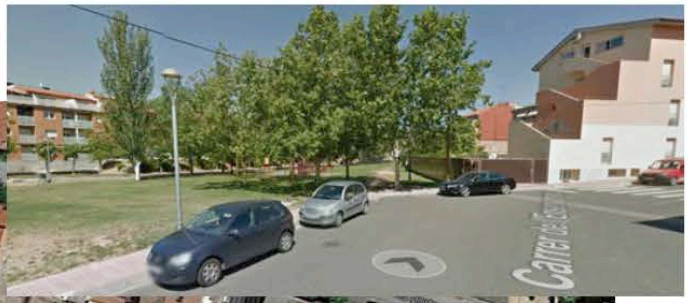


The flood event of 02 November 2015



4 casualties in a semi-basement

The flood event of 02 November 2015



The flood event of 02 November 2015

Reduced circulation capacity





The flood event of 02 November 2015

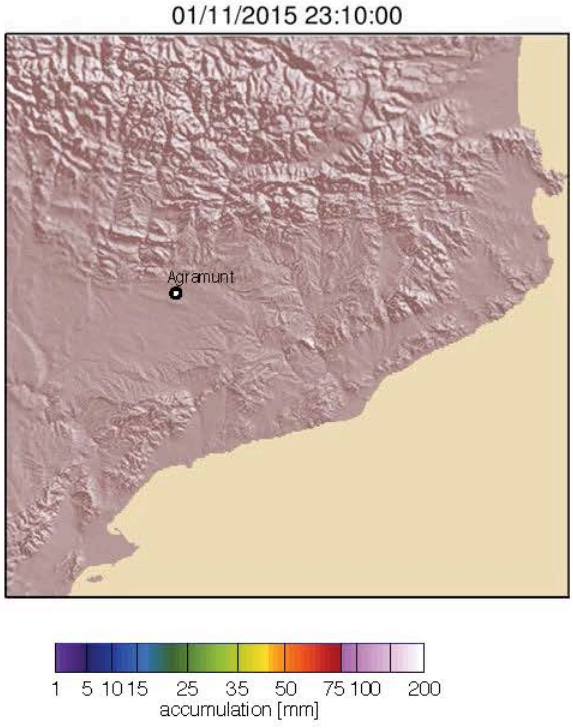


The flood event of 02 November 2015



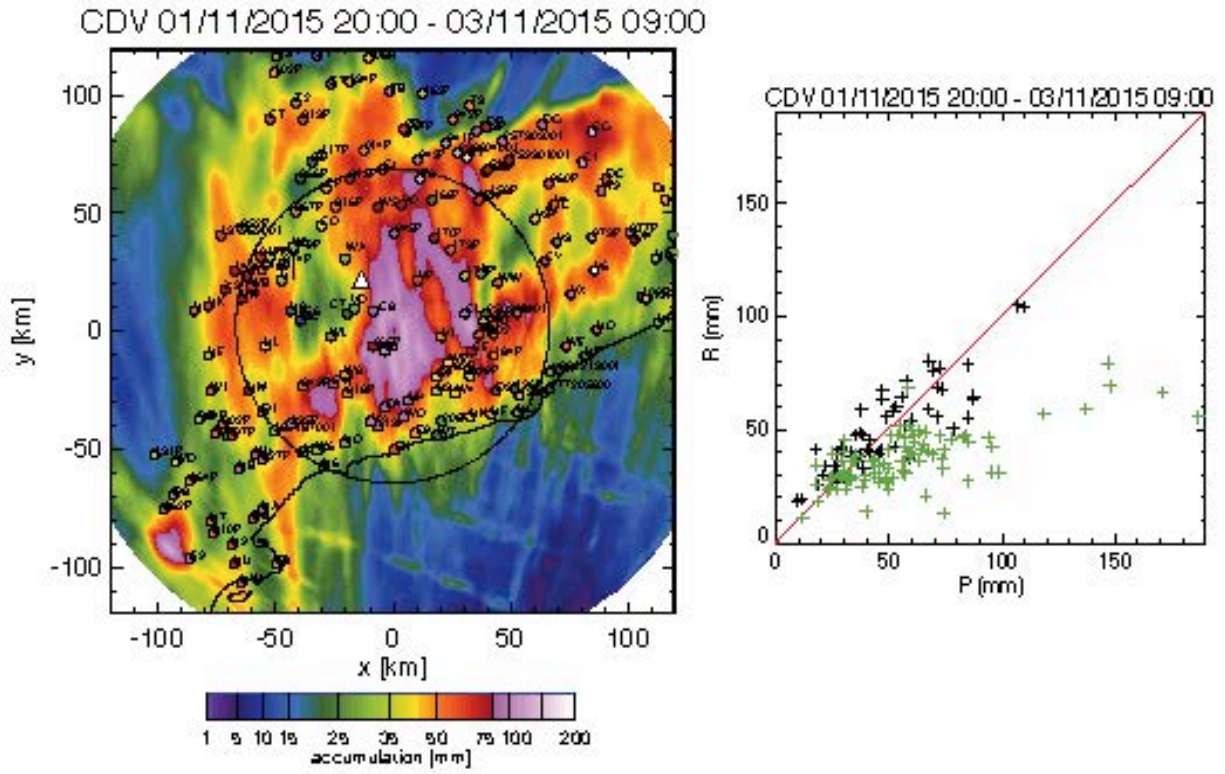
The flood event of 02 November 2015

Radar QPE



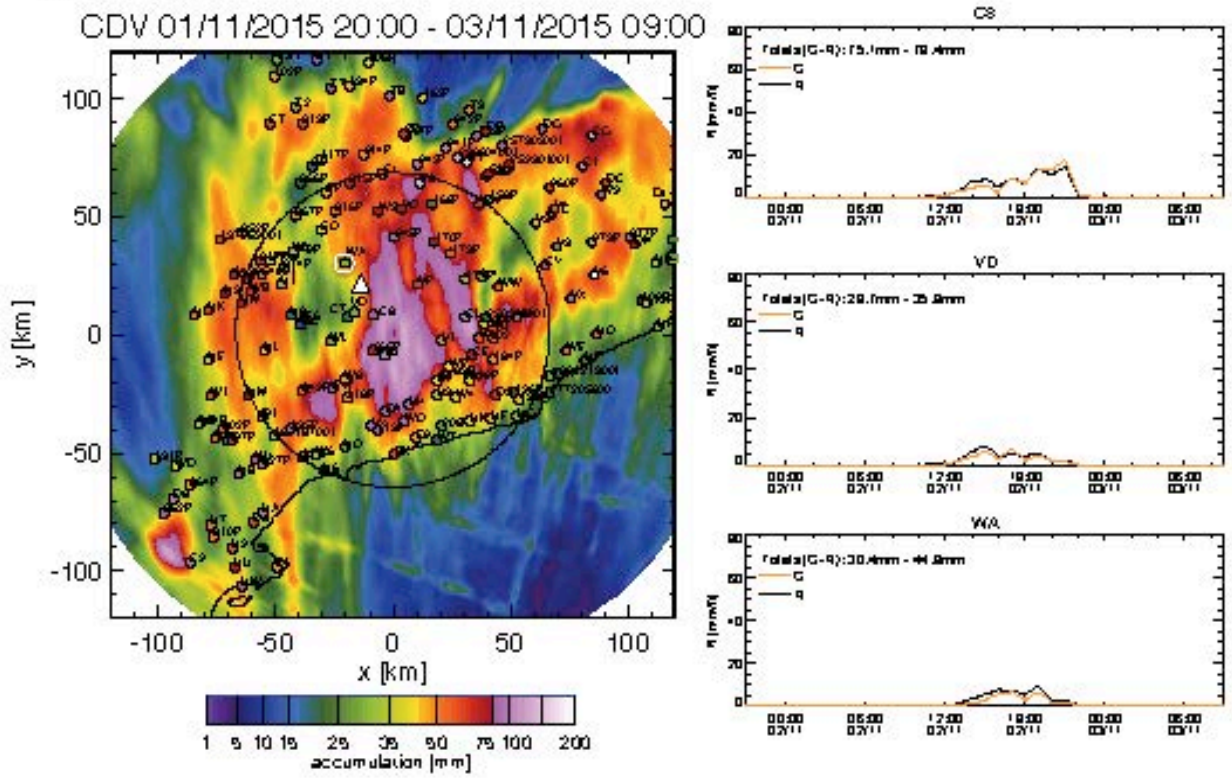
The flood event of 02 November 2015

Radar QPE



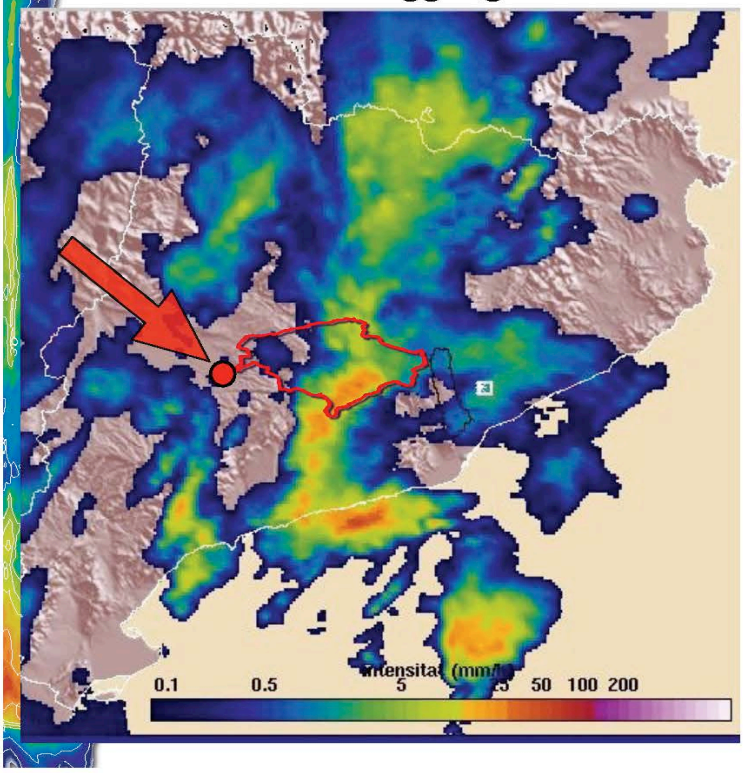
The flood event of 02 November 2015

Radar QPE



HAZARD ASSESSMENT - Flash floods

Based on basin-aggregated rainfall

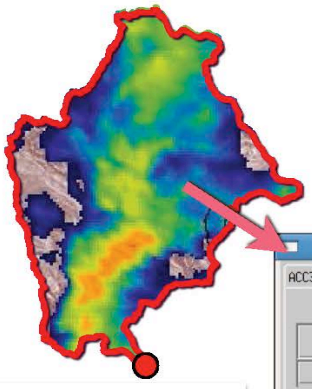


Given a point in the drainage system,

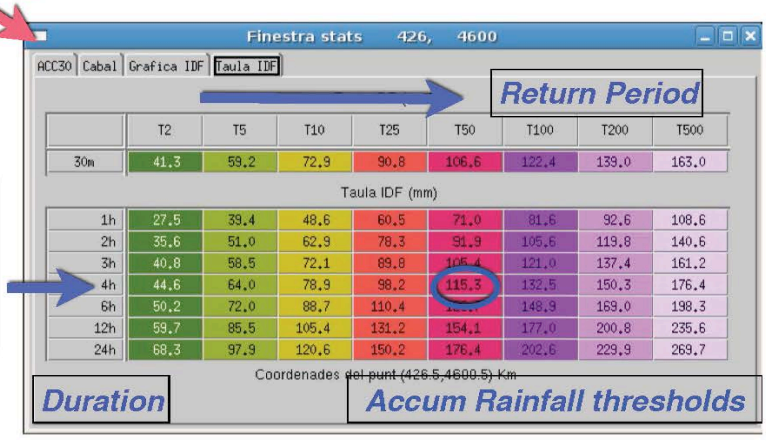
We can define the associated basin, and calculate the rainfall that will be collected by the selected point

HAZARD ASSESSMENT - Flash floods

The **basin-aggregated** rainfall is accumulated over the hydrological characteristic time of the basin

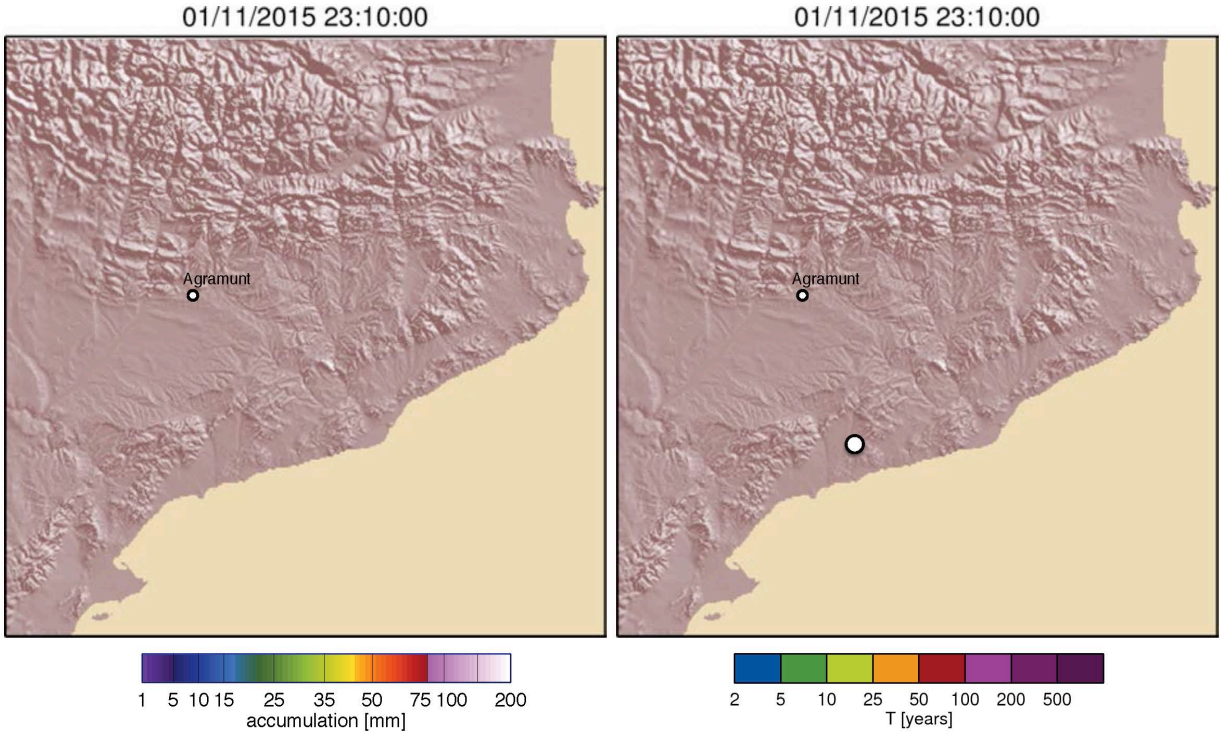


And a **probability of exceedance** is estimated (return period in years)



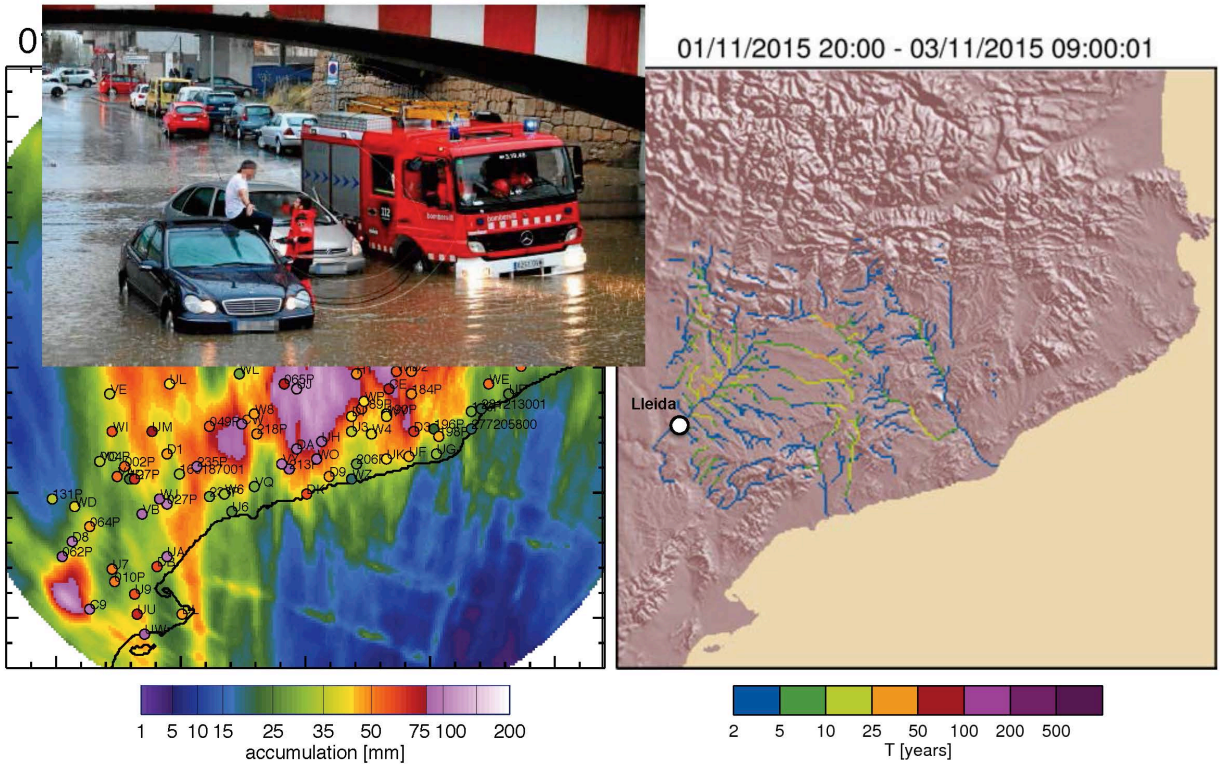
The flood event of 02 November 2015

Flash flood hazard assessment



The flood event of 02 November 2015

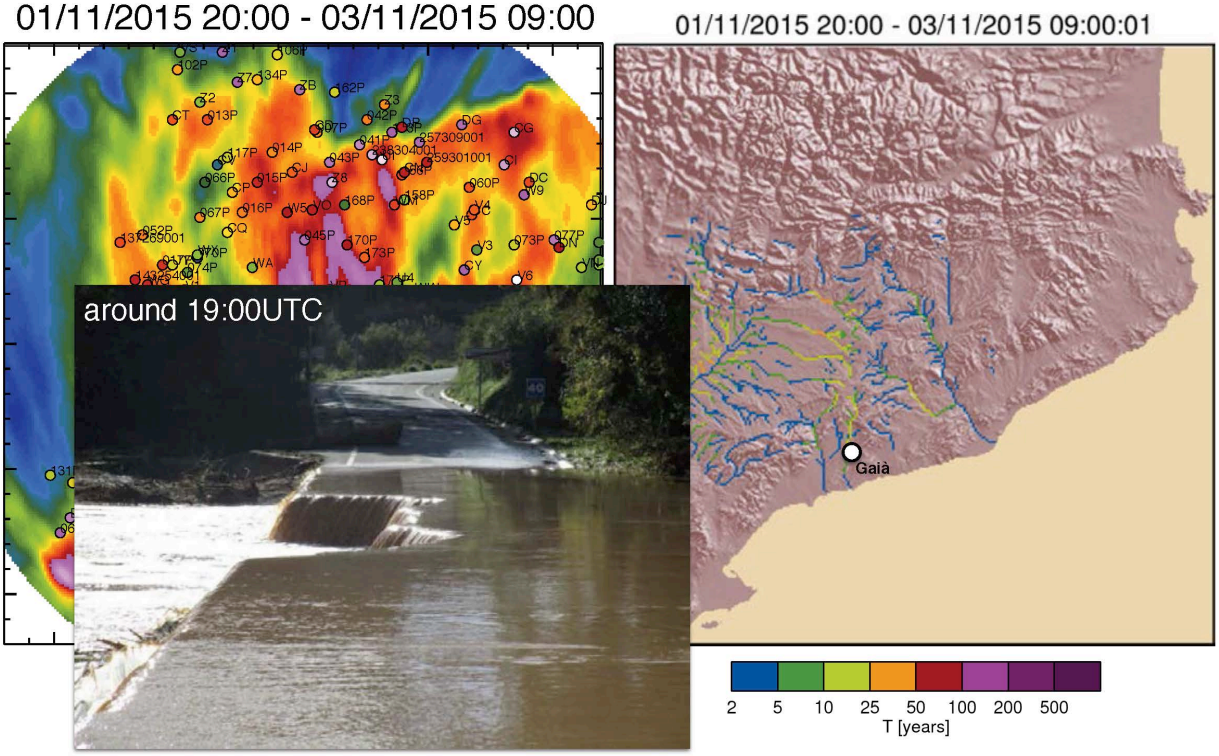
Flash flood hazard assessment



The flood event of 02 November 2015

Flash flood hazard assessment

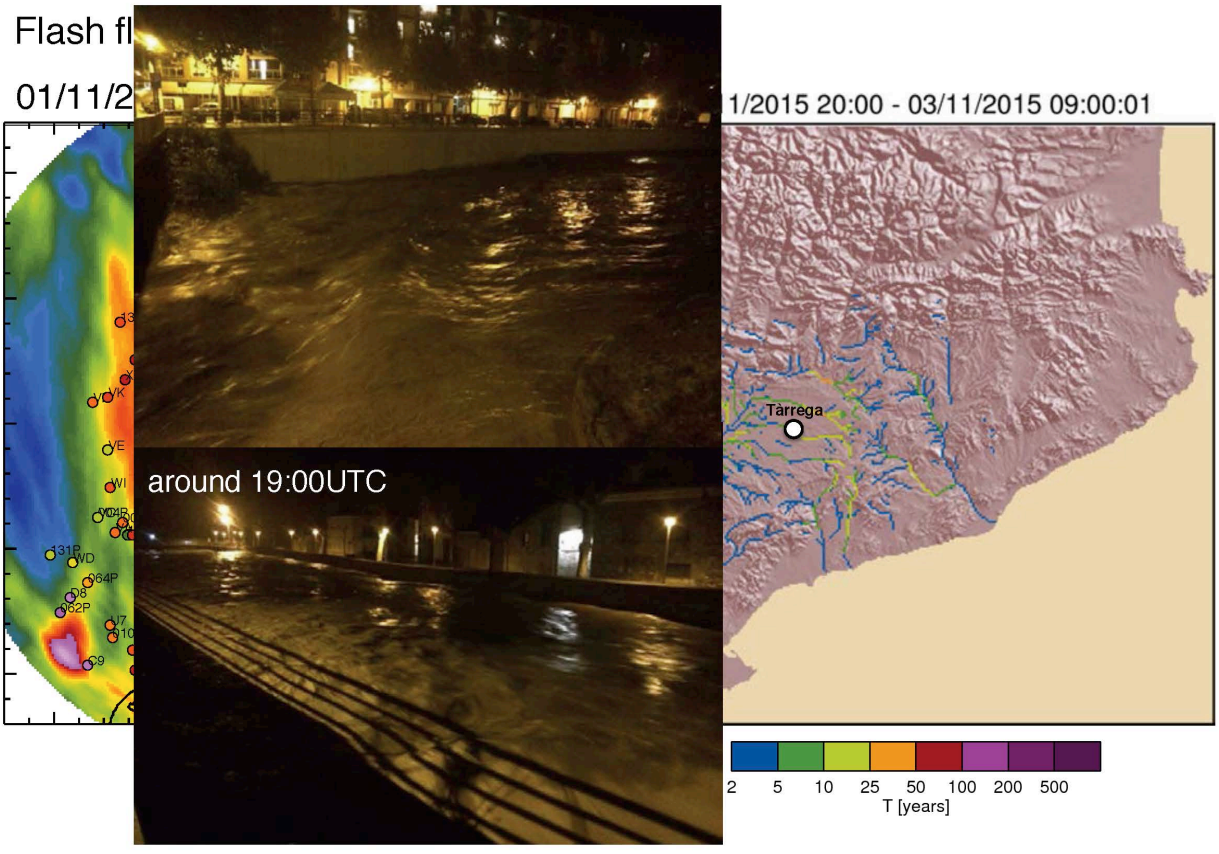
01/11/2015 20:00 - 03/11/2015 09:00



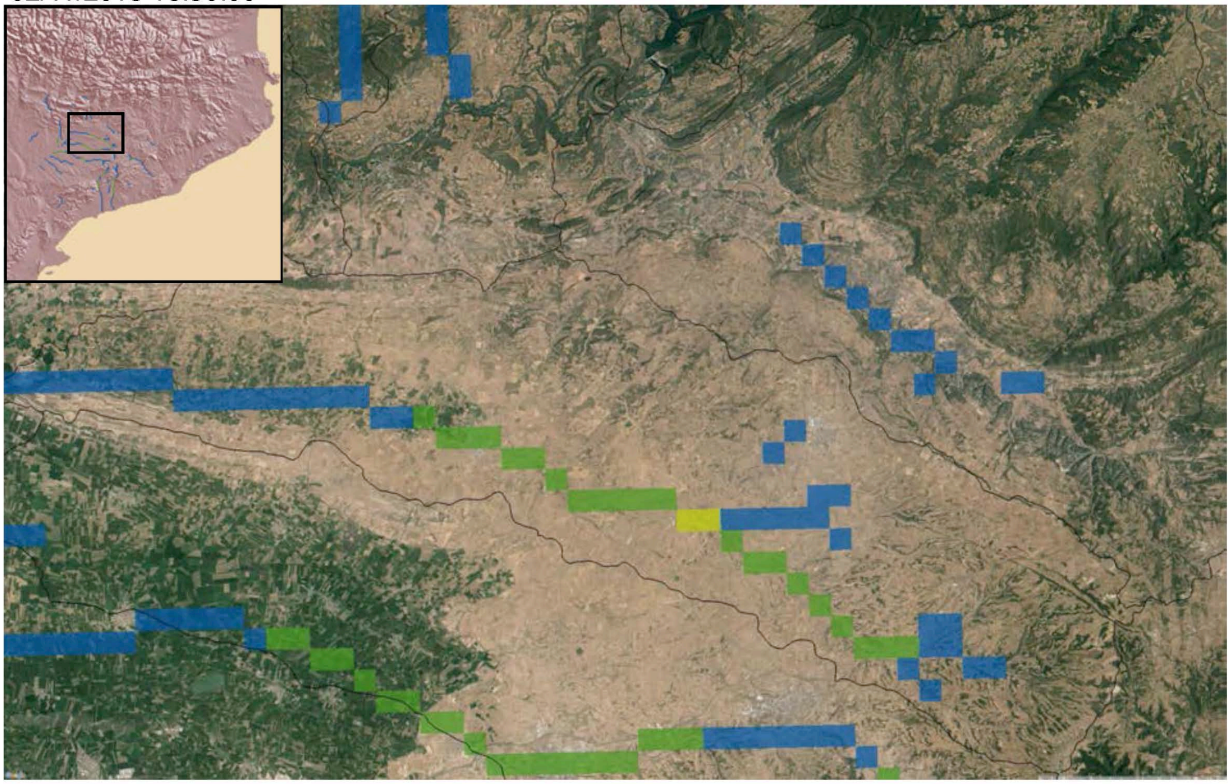
The flood event of 02 November 2015

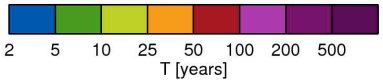
Flash fl

01/11/2



02/11/2015 18:30:00



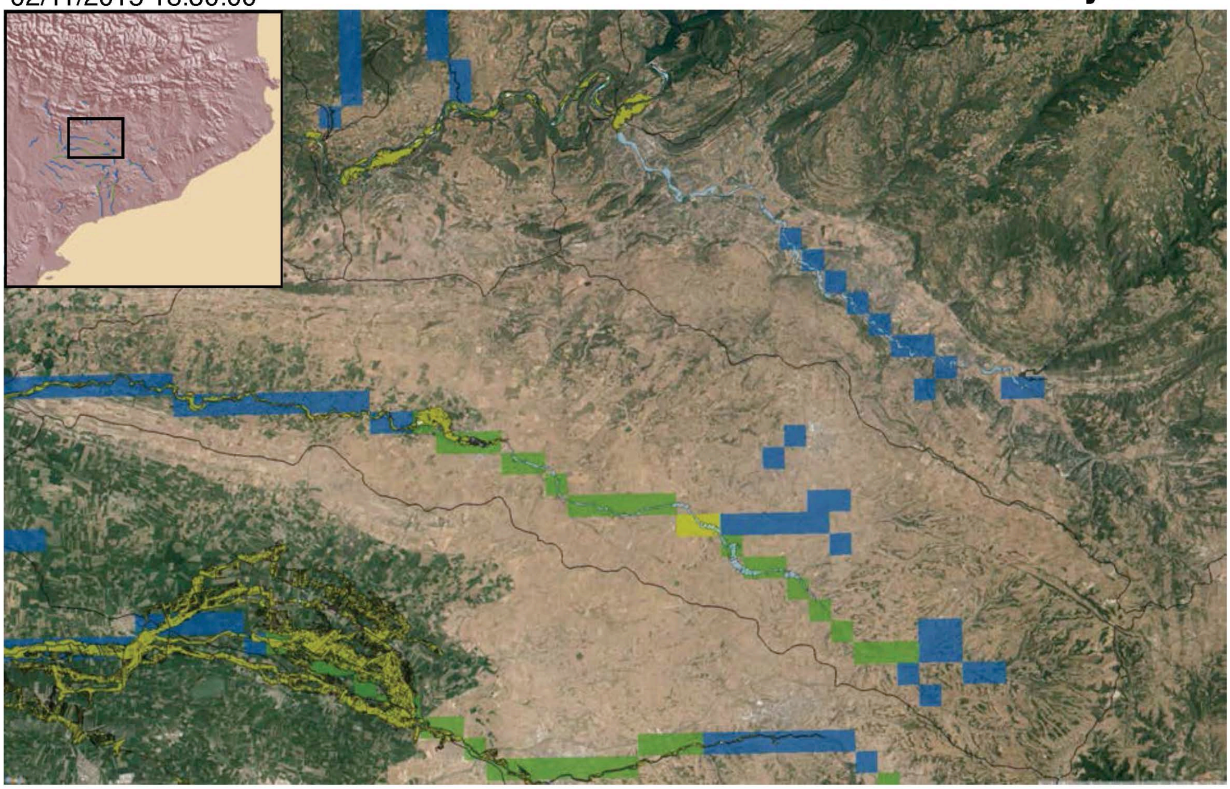


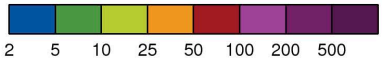


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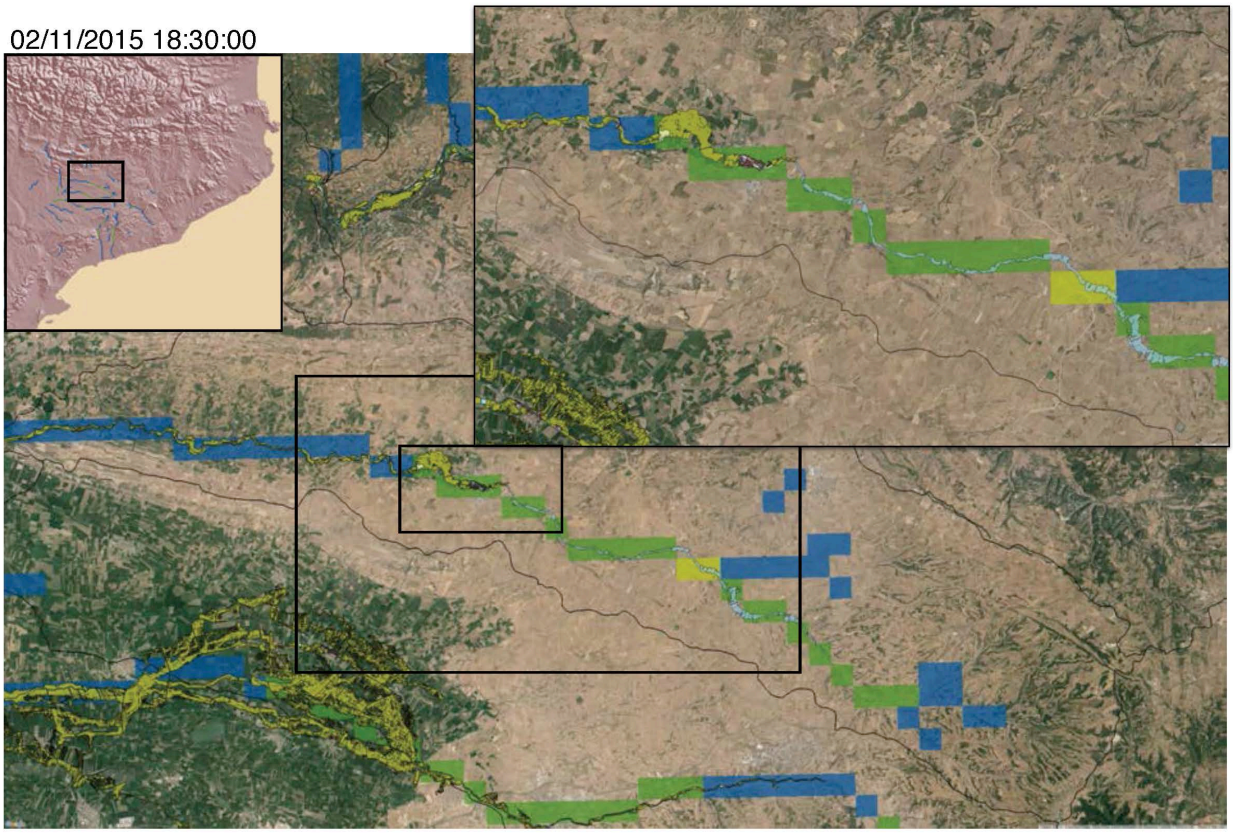
02/11/2015 18:30:00

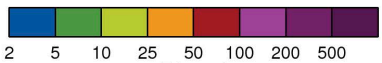
Flood risk for T=10 years

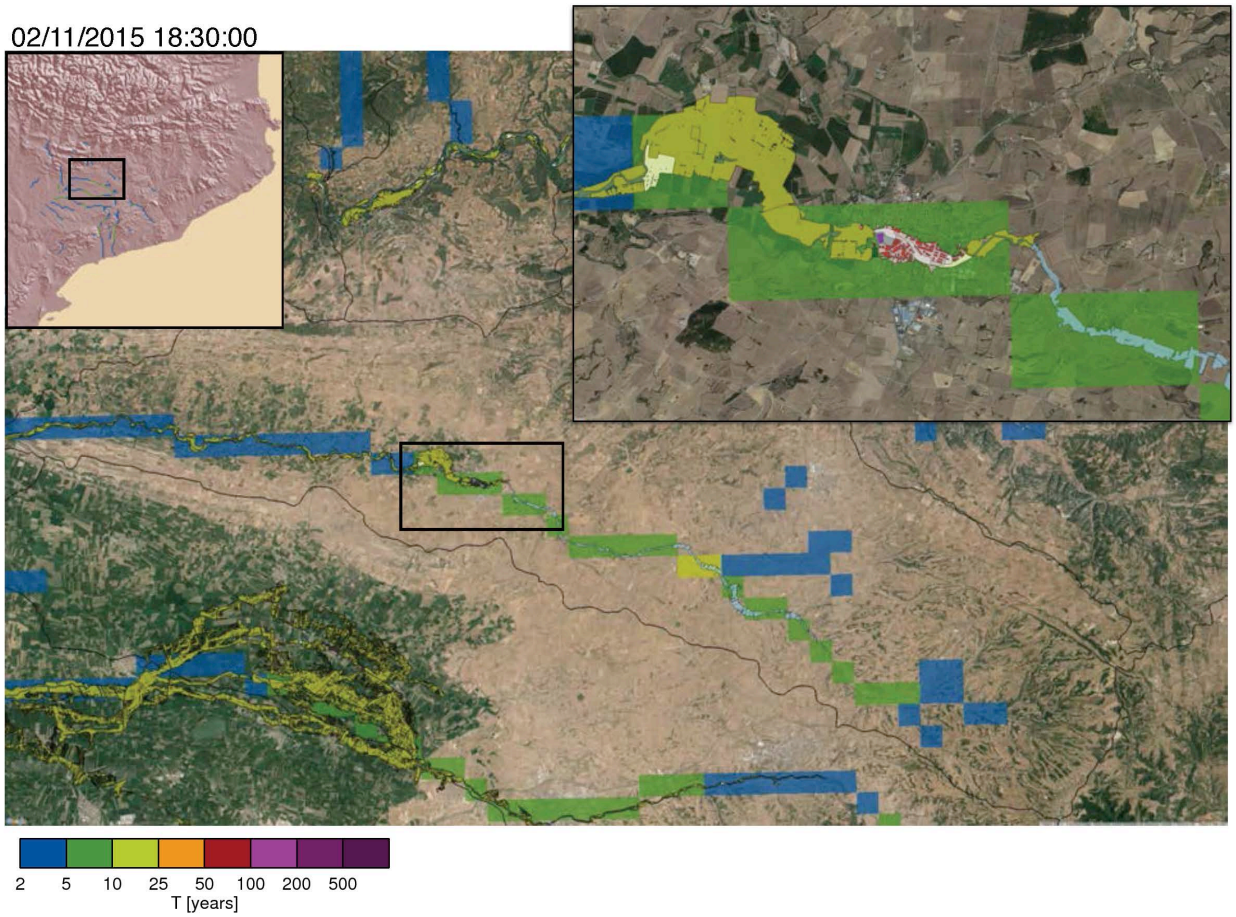




02/11/2015 18:30:00



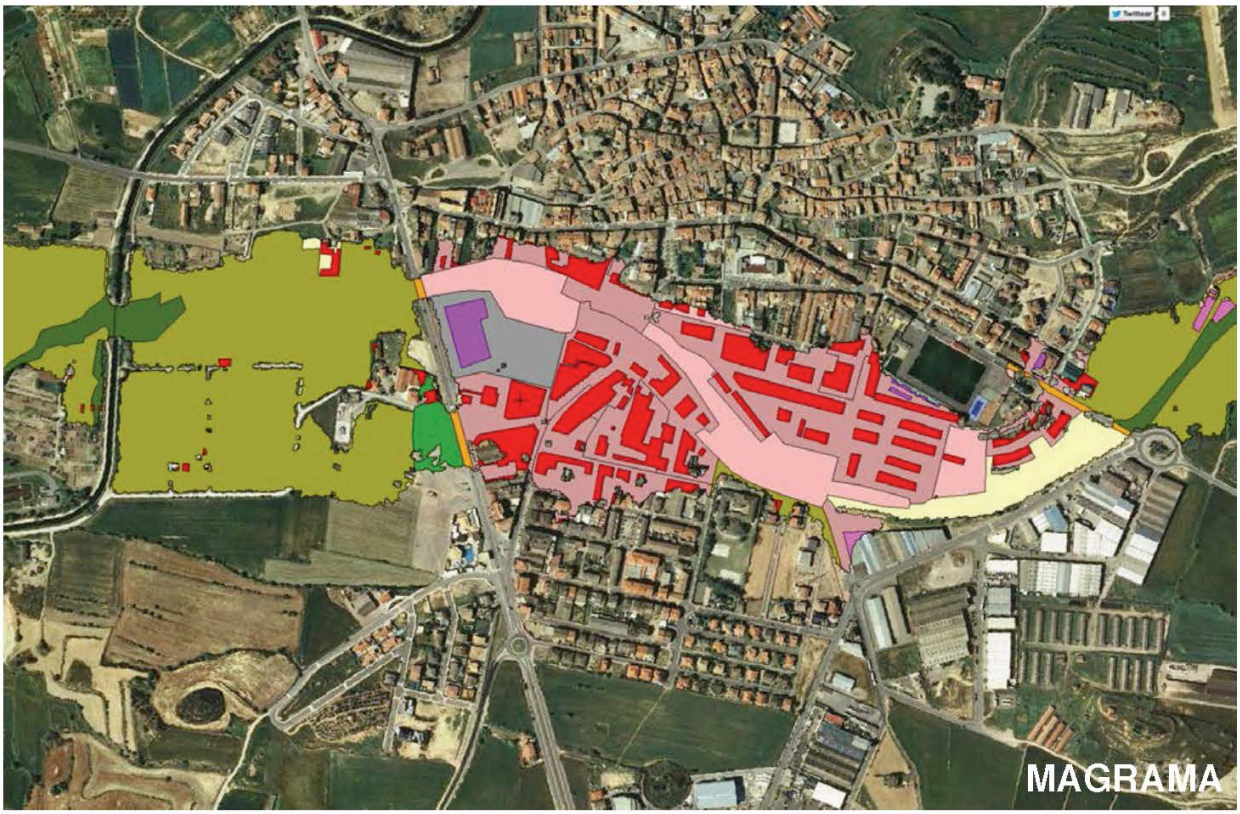




SNCZI: Sistema Nacional de Cartografia de Zonas Inundables



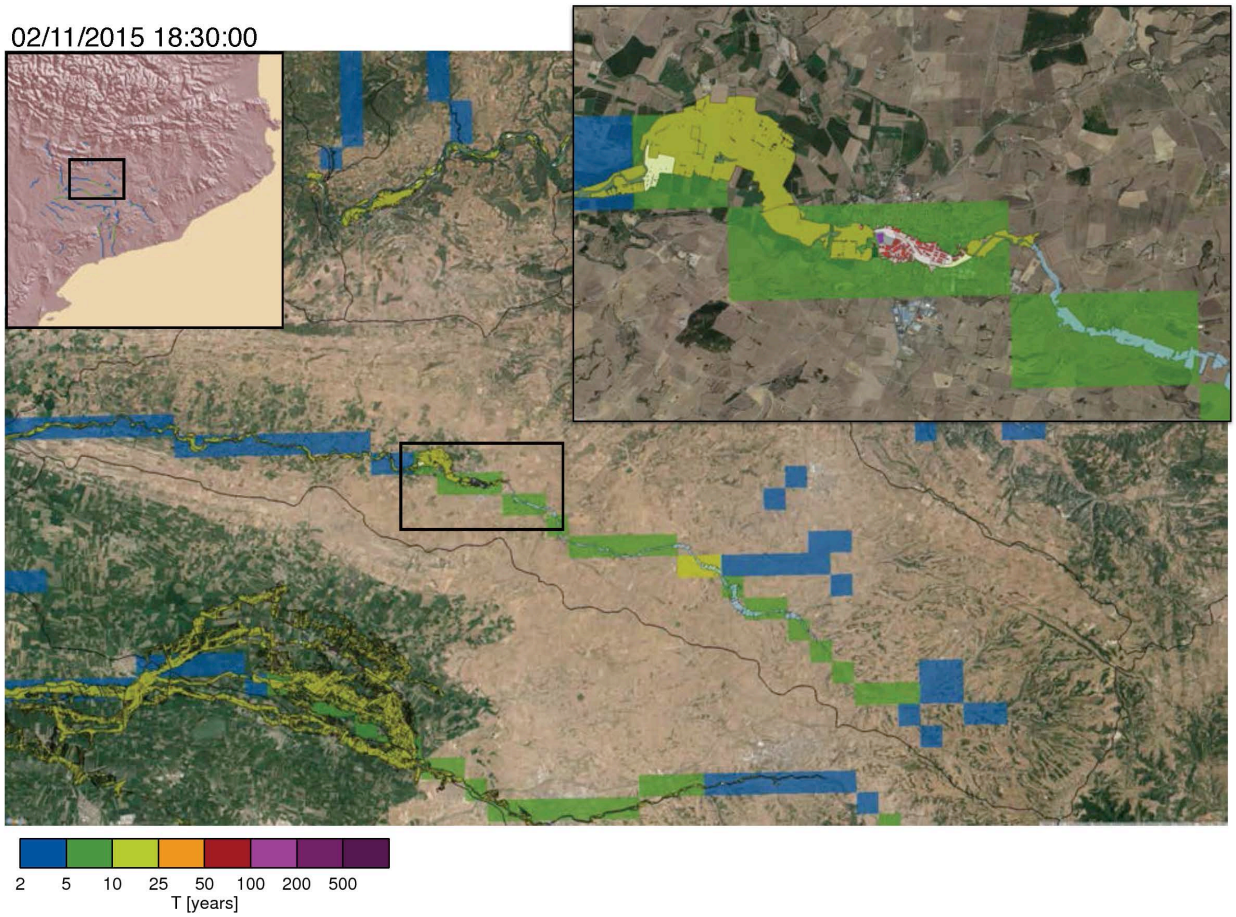
SNCZI: Sistema Nacional de Cartografia de Zonas Inundables



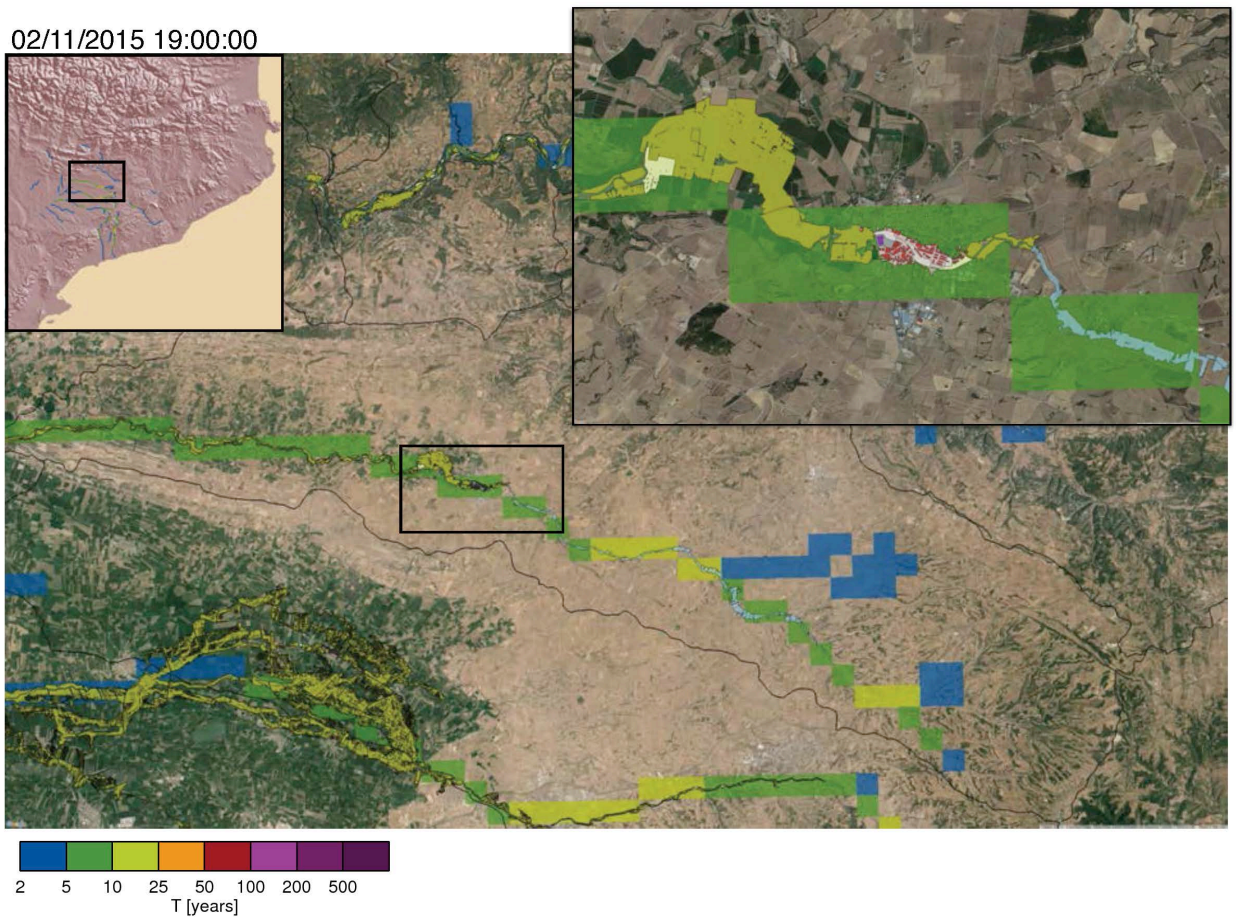
SNCZI: Sistema Nacional de



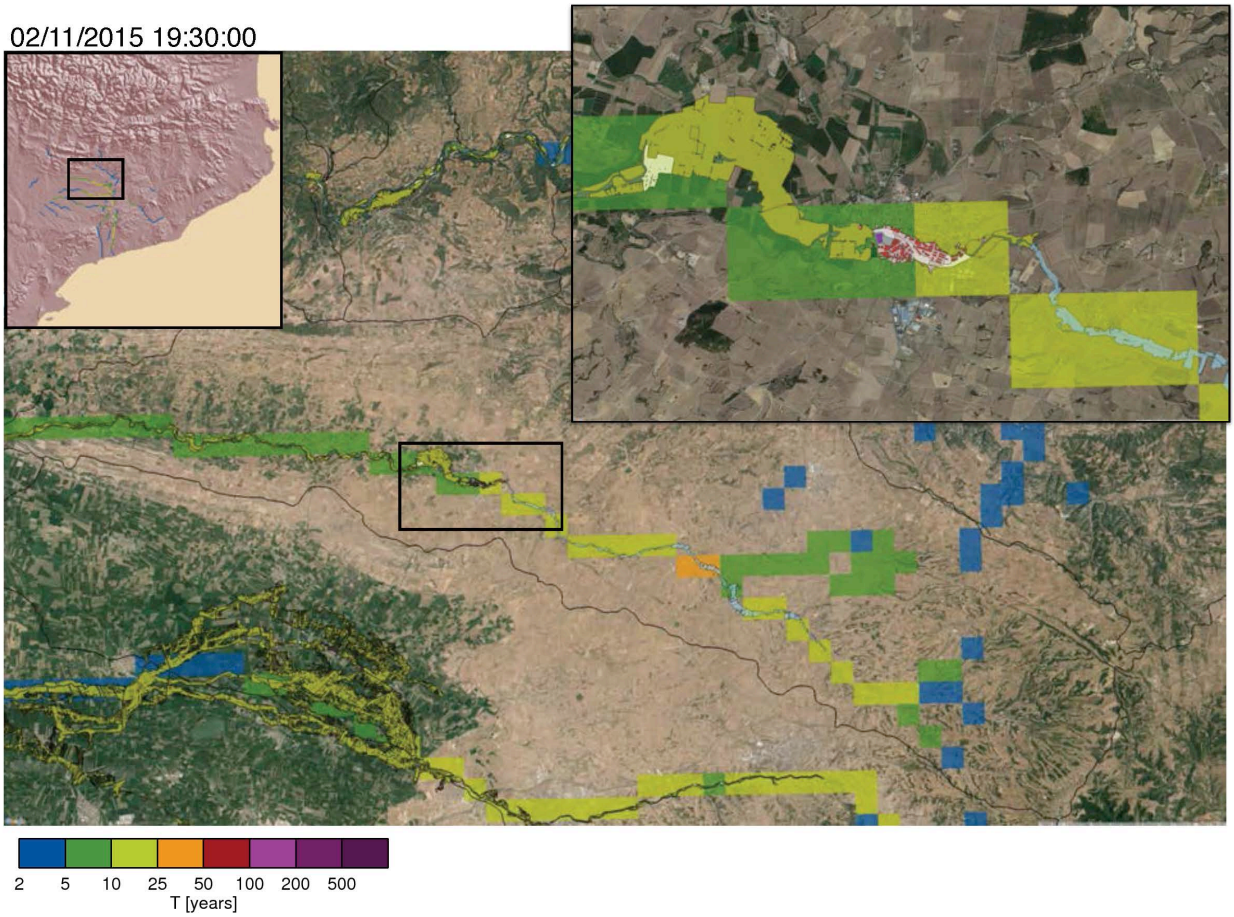
02/11/2015 18:30:00



02/11/2015 19:00:00

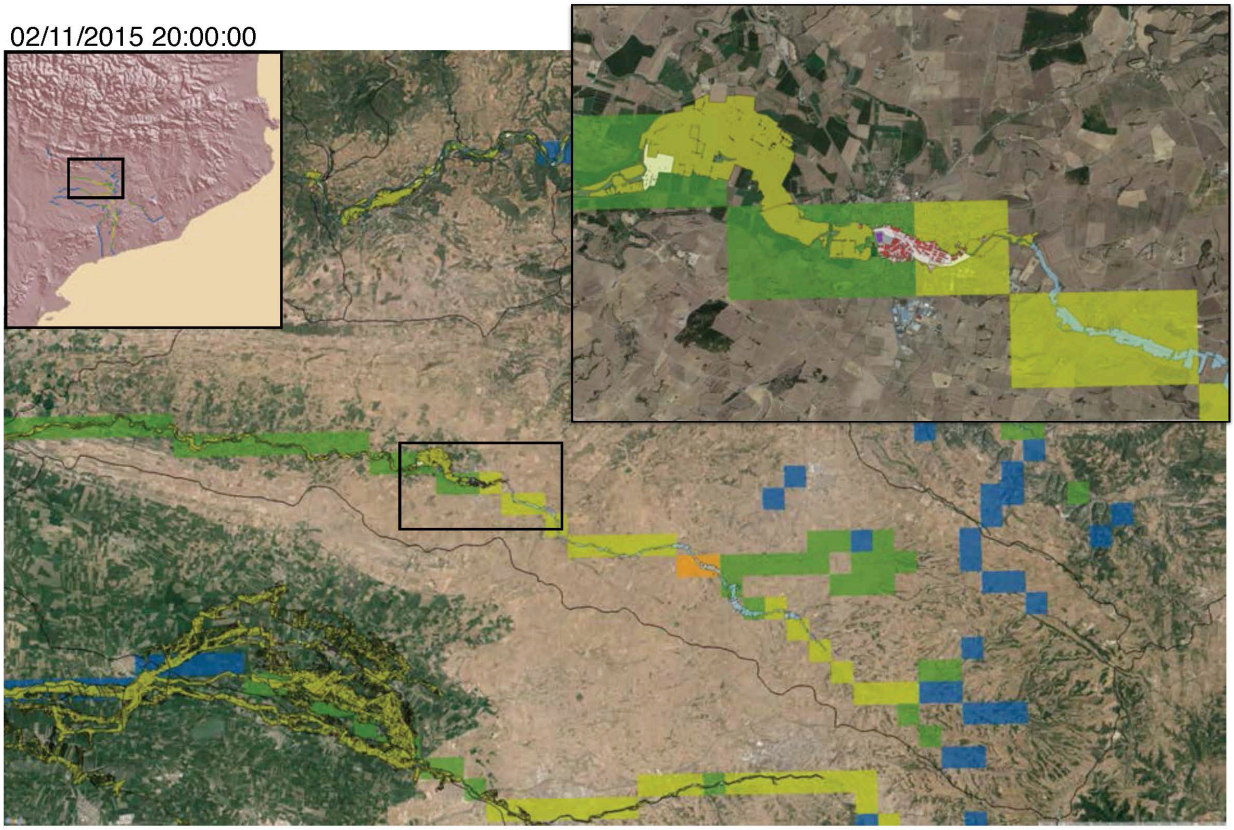


02/11/2015 19:30:00

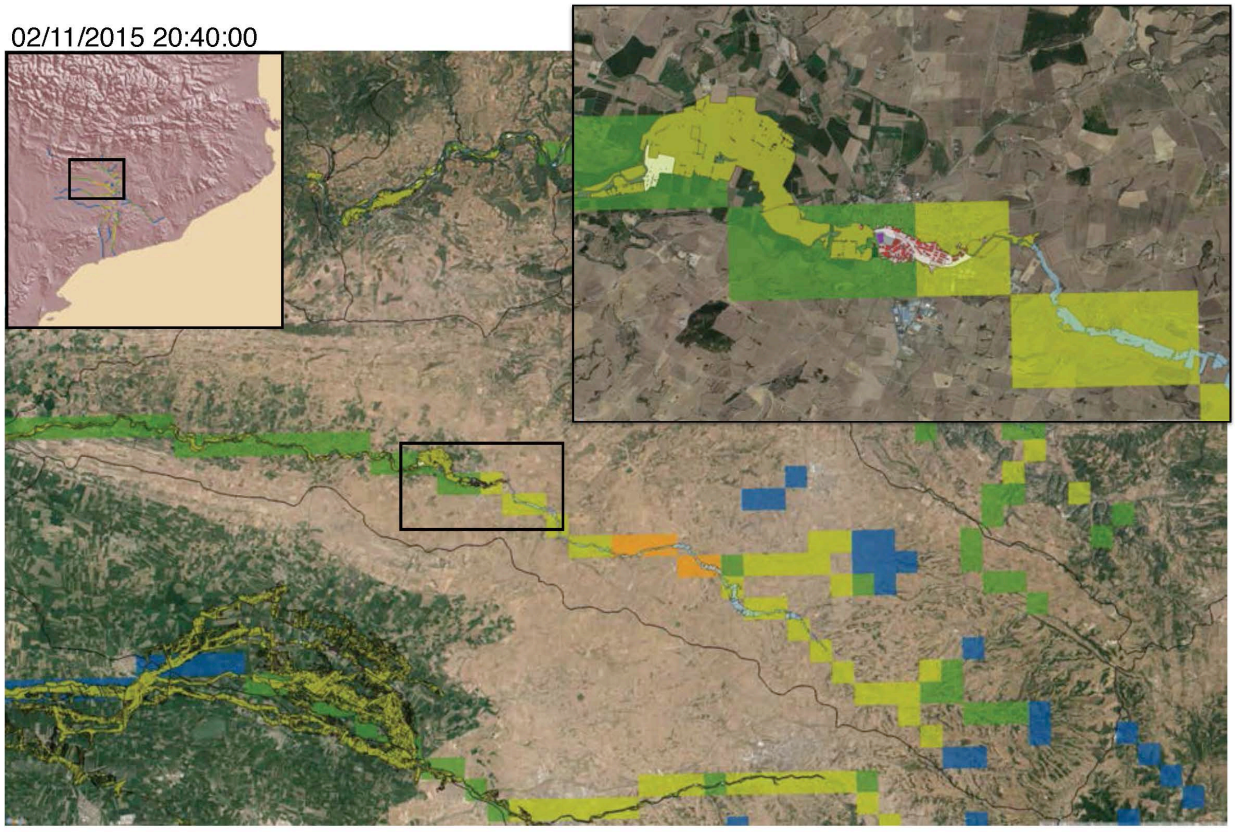


2 5 10 25 50 100 200 500
T [years]

02/11/2015 20:00:00



2 5 10 25 50 100 200 500
T [years]

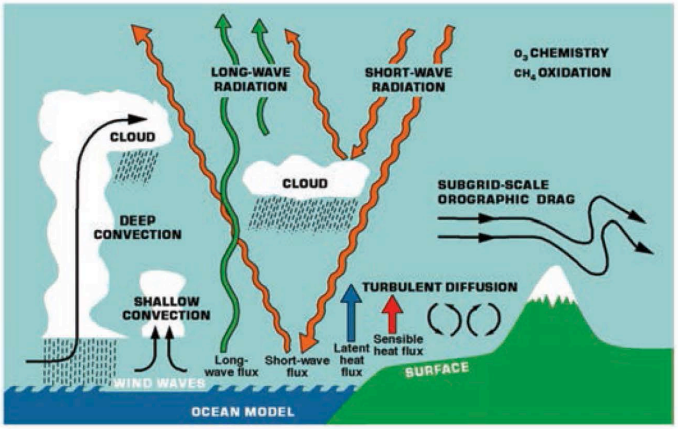


… and stayed T>5years until 24:00.

Precipitation forecasting - NWP

Numerical Weather Prediction (NWP) models are based on:

- 3-D equations for mass, momentum and energy conservation in the atmosphere.
- Initial fields of the forecasted variables are needed.

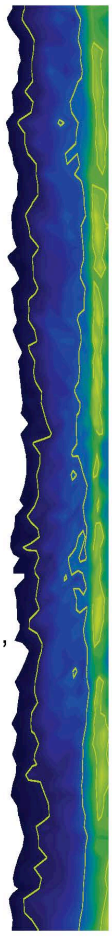


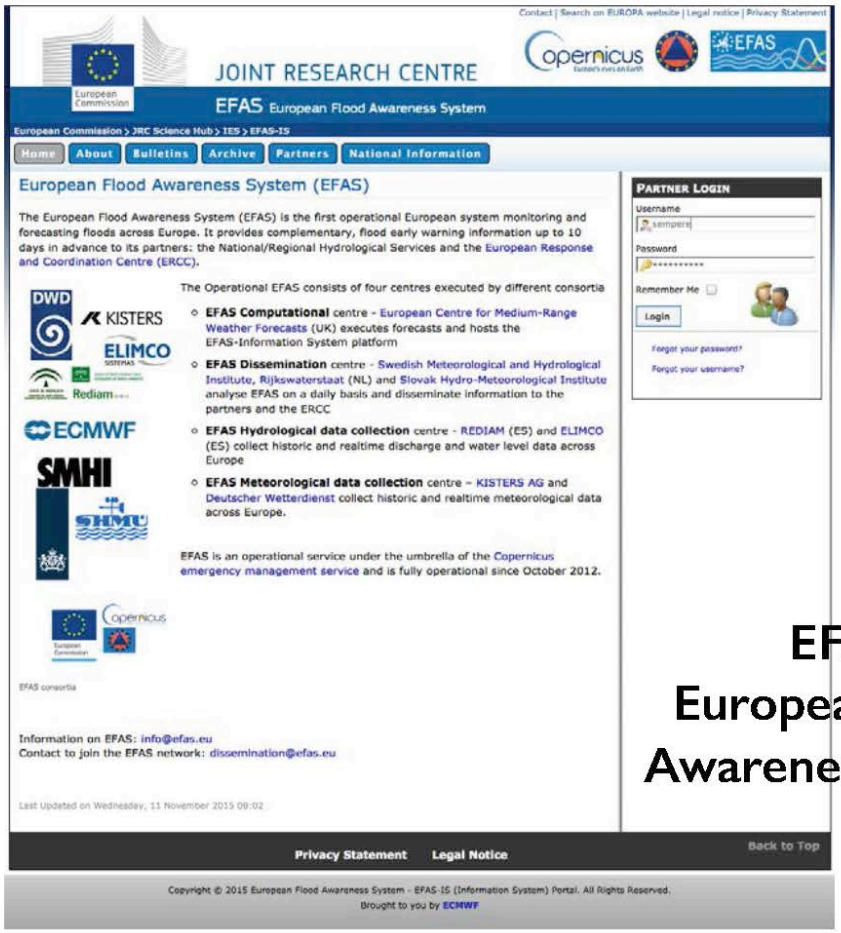
Schematic diagram of the different physical processes represented in the IFS model.

Source: ECMWF (2009).

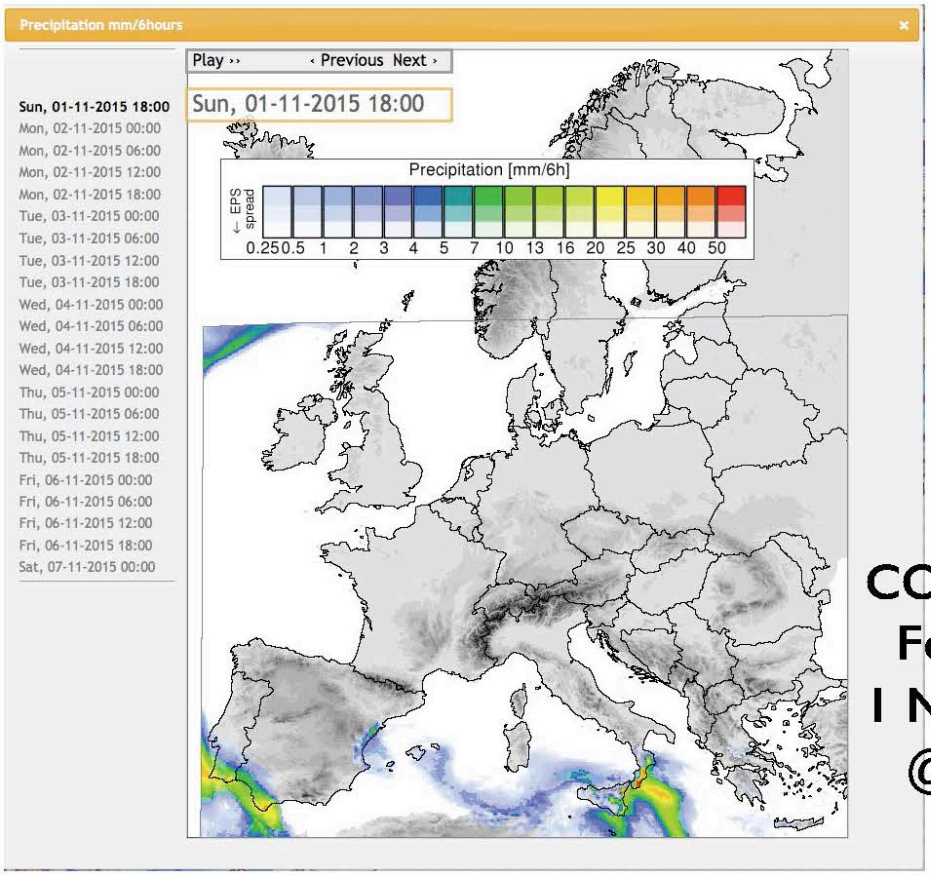
Steps in forecasting by NWP:

1. Data collection and validation.
2. Data assimilation.
3. Model runs.
4. Post-processing (downscaling, analogue methods,...).

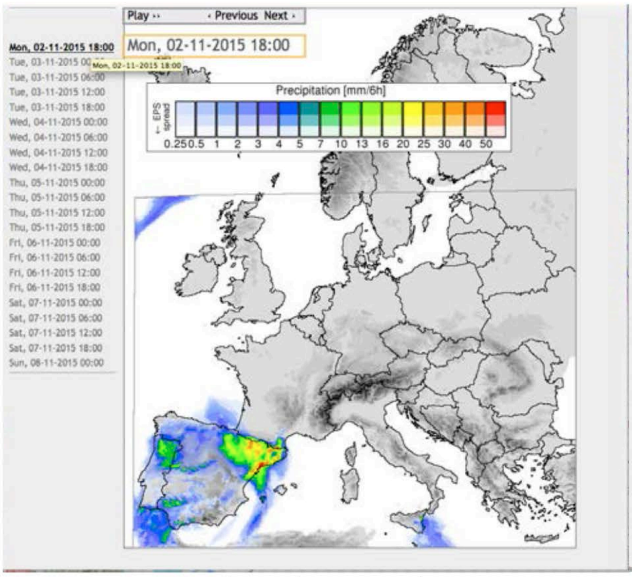




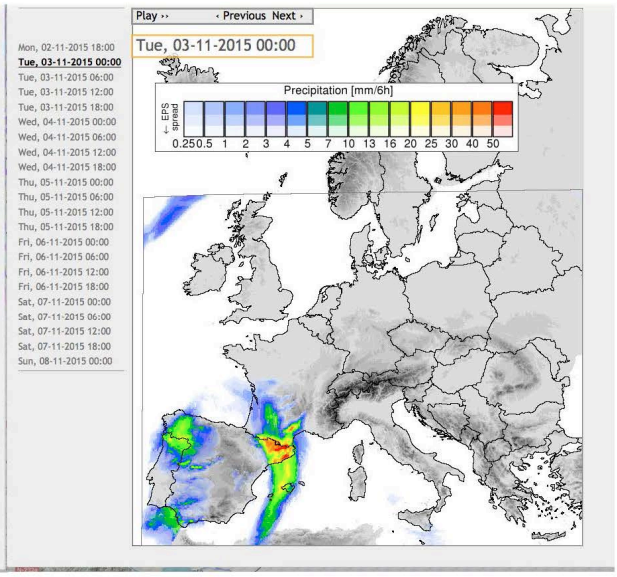
EFAS
European Flood Awareness System



COSMO-LEPS
Forecast on
1 NOVEMBER
@ 12 UTC

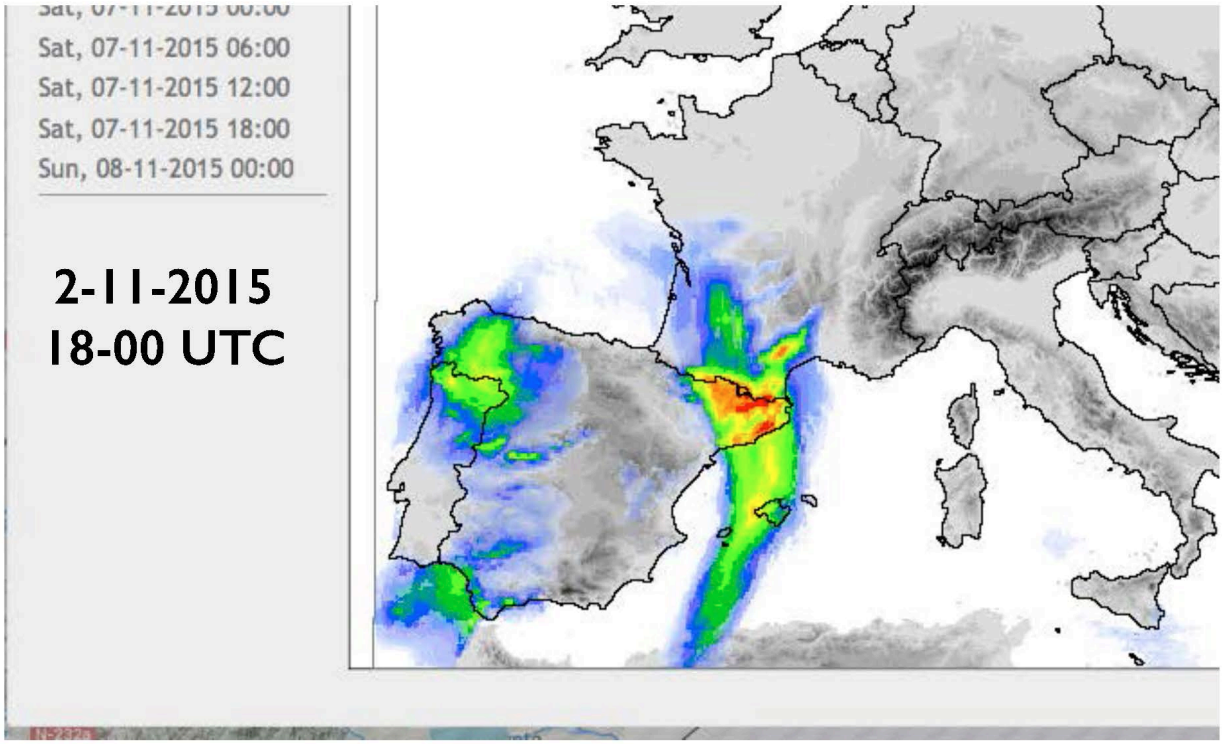


12-18 UTC

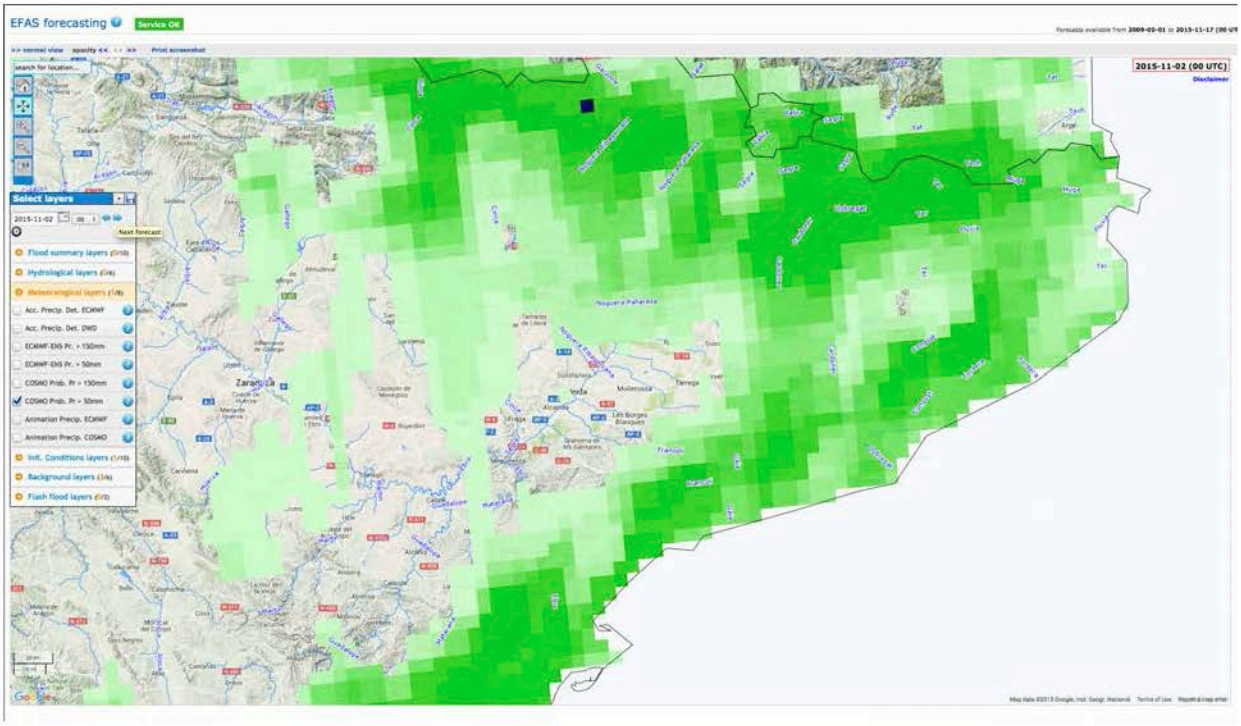


18-00 UTC

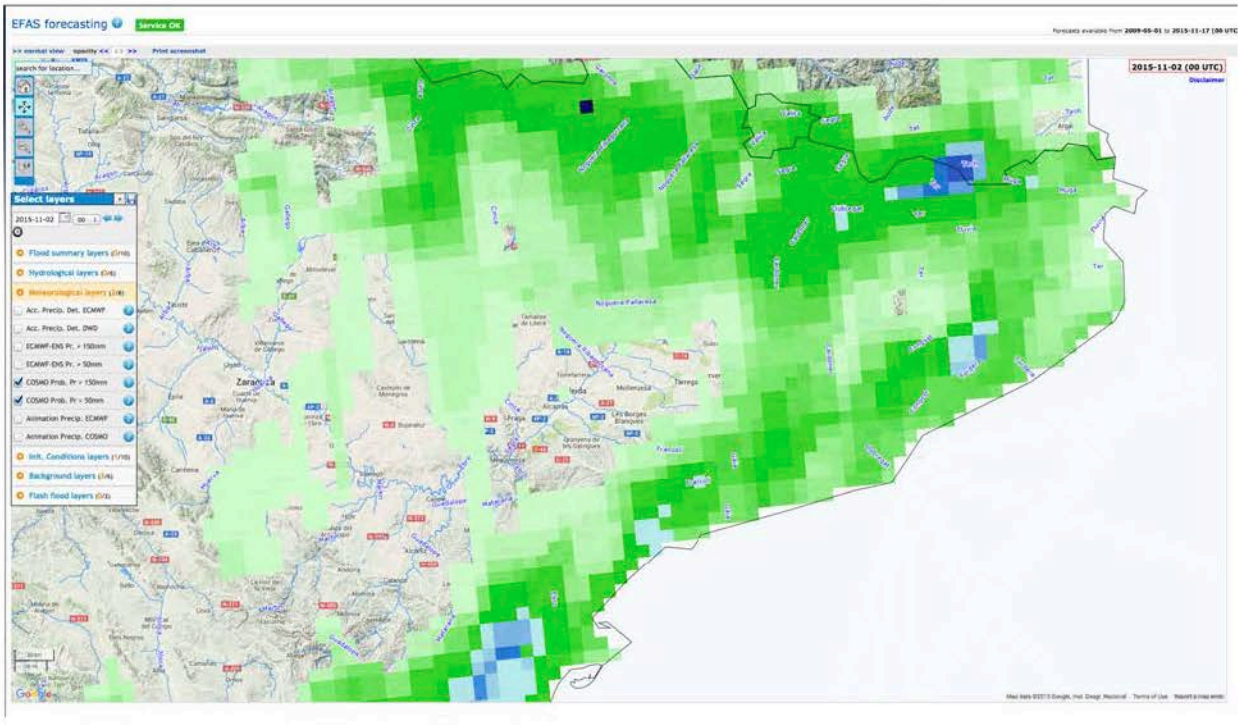
COSMO-LEPS
Forecast on 2 NOVEMBER@ 12 UTC



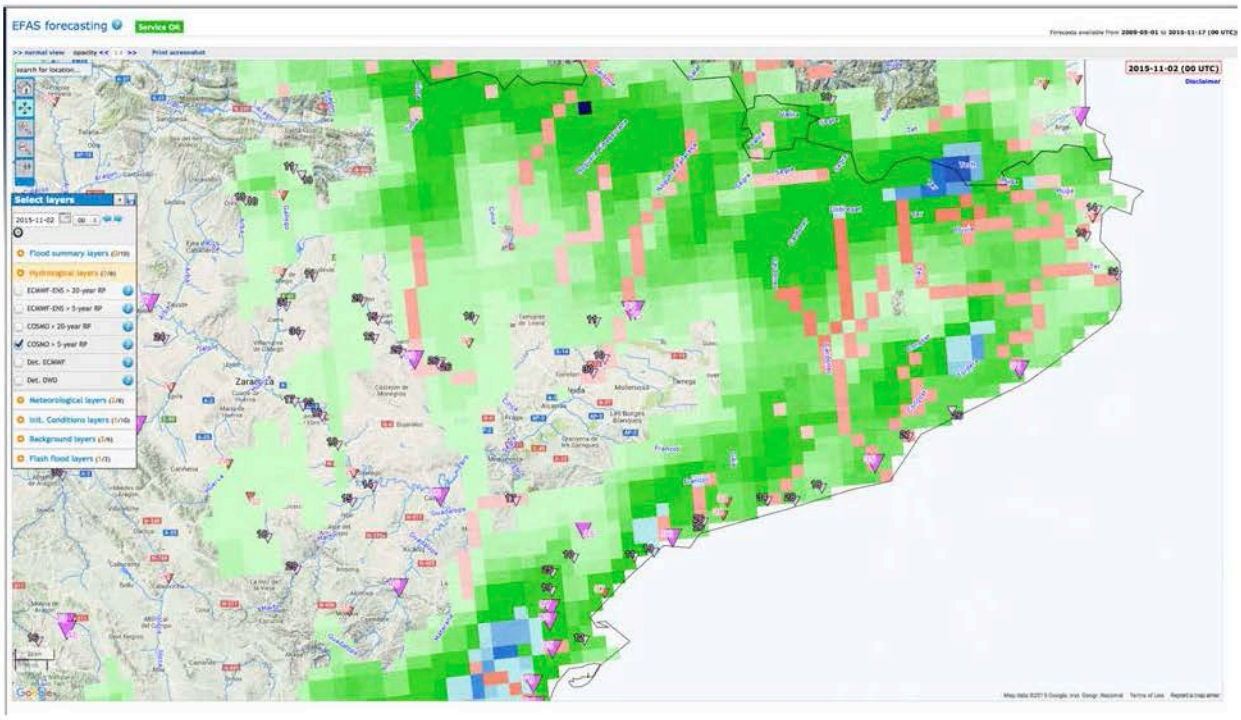
COSMO-LEPS
Forecast on 2 NOVEMBER@ 12 UTC



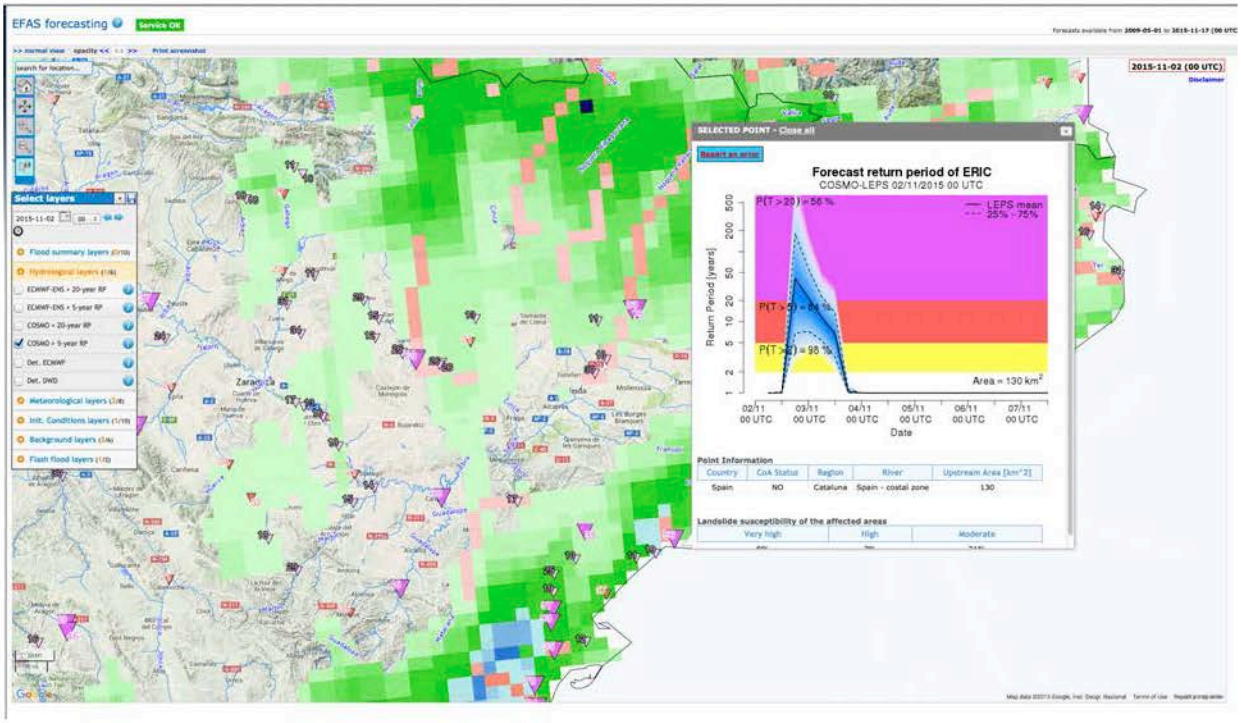
Forecast on 2 NOVEMBER@ 00 UTC



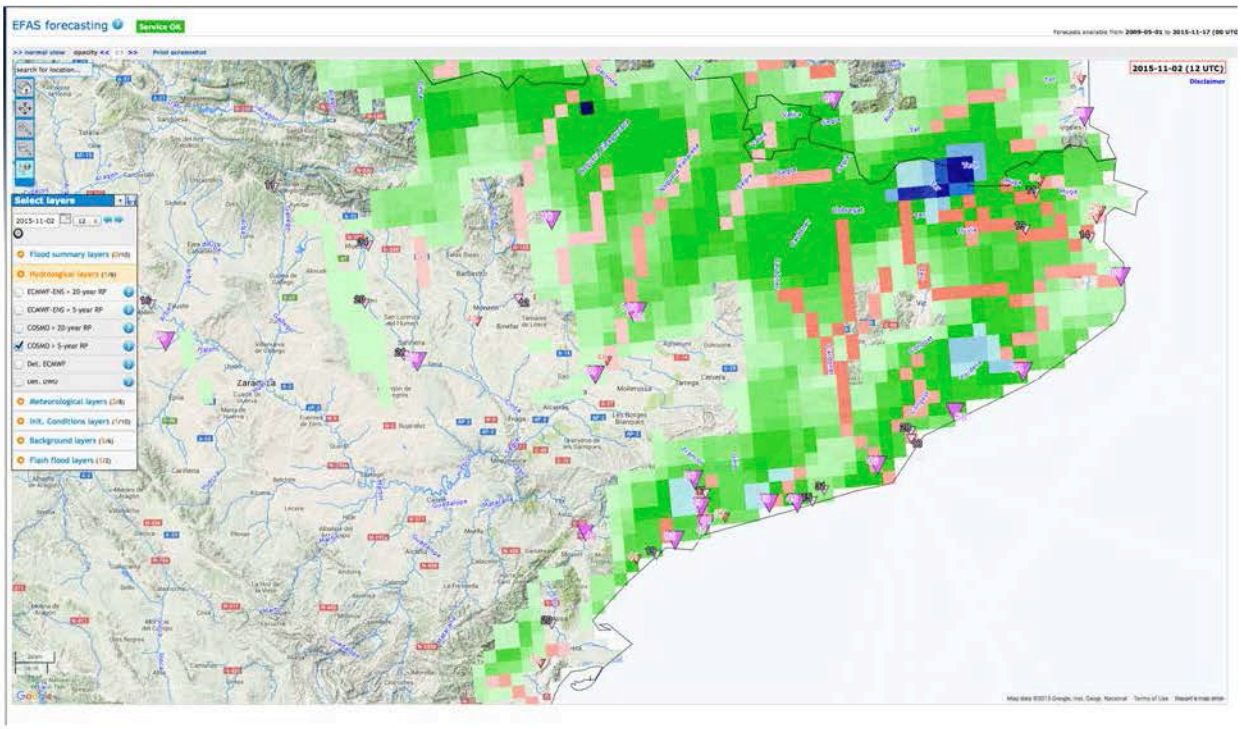
Forecast on 2 NOVEMBER@ 00 UTC



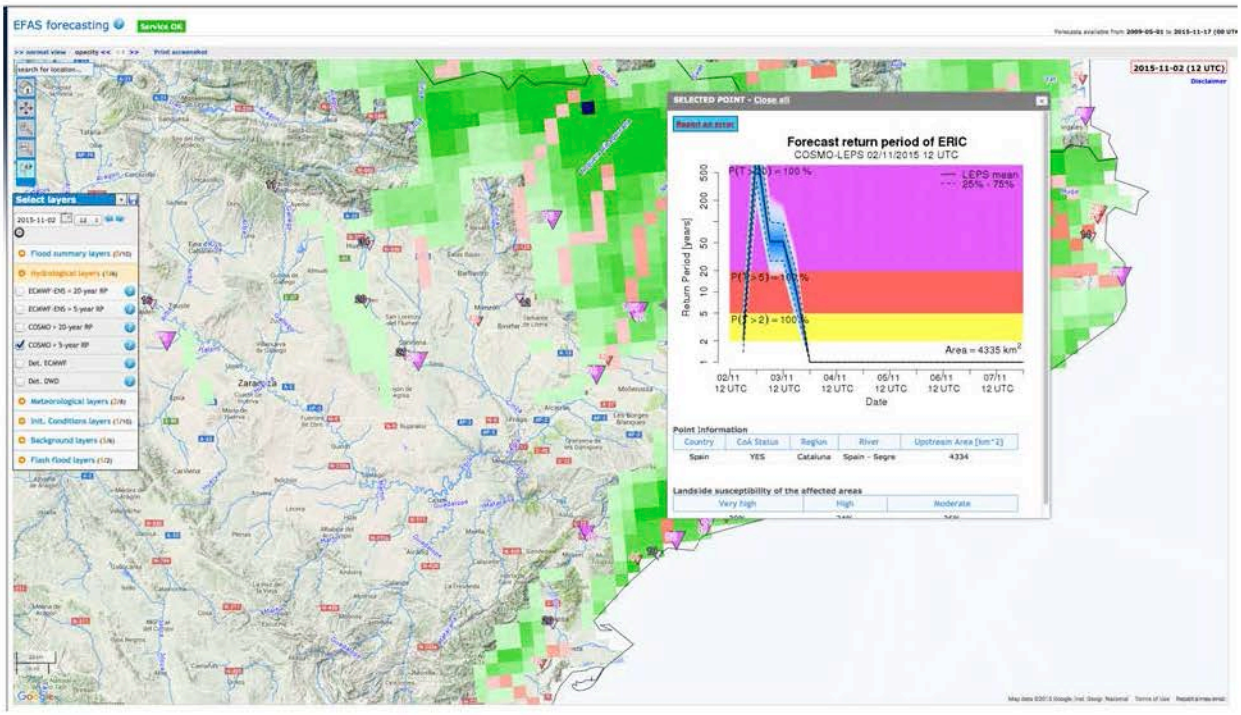
Forecast on 2 NOVEMBER@ 00 UTC



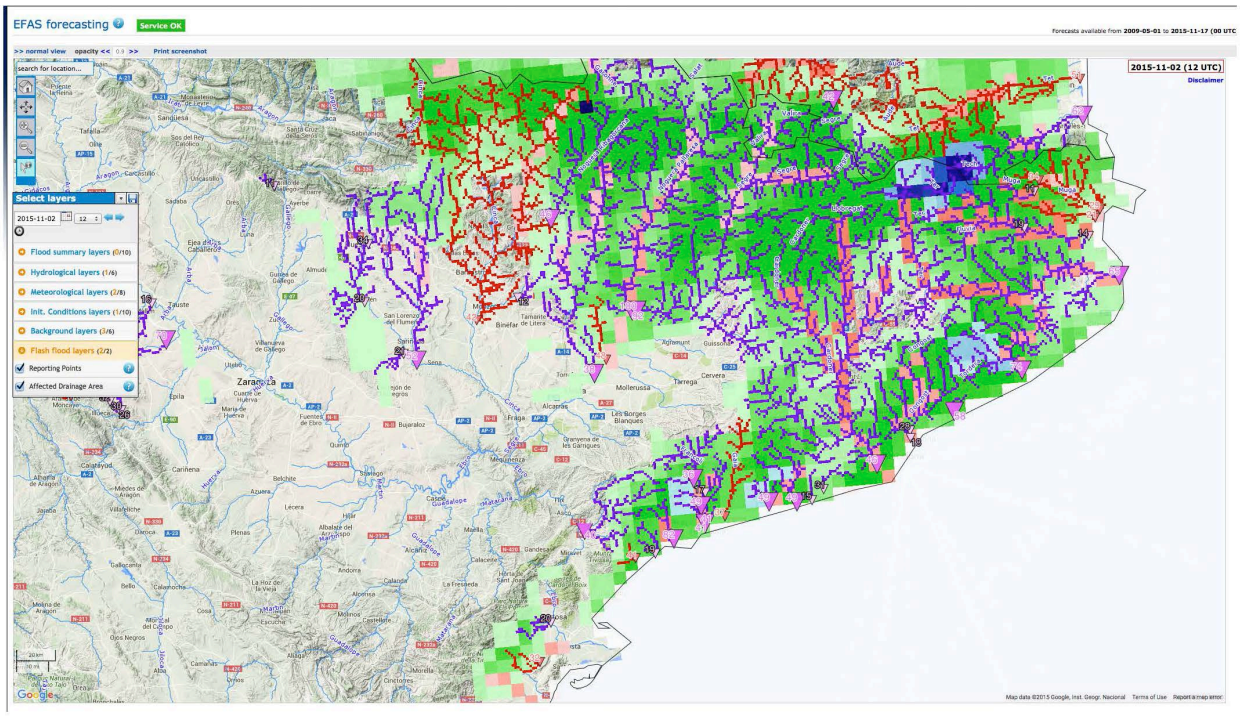
Forecast on 2 NOVEMBER@ 00 UTC



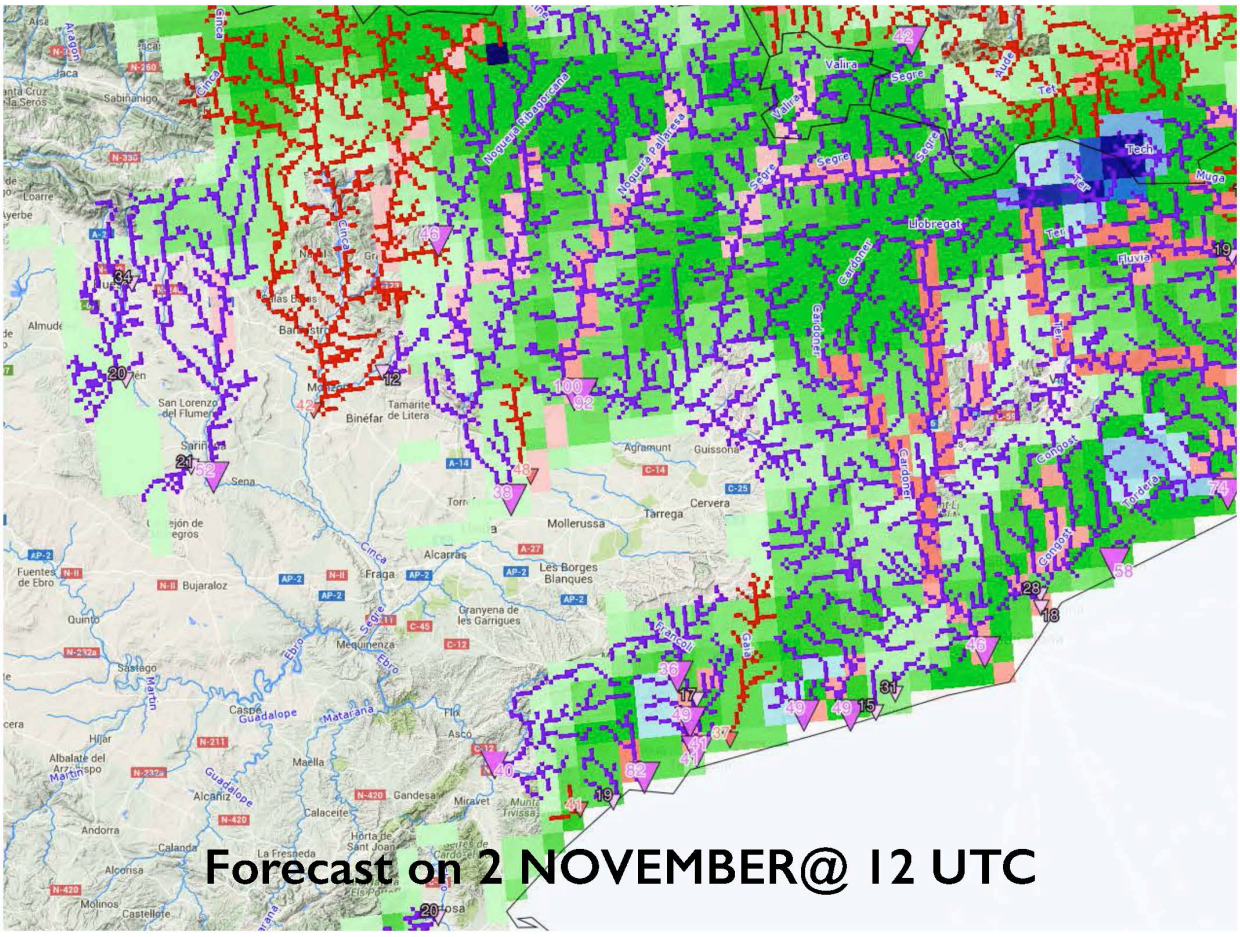
Forecast on 2 NOVEMBER@ 12 UTC



Forecast on 2 NOVEMBER@ 12 UTC



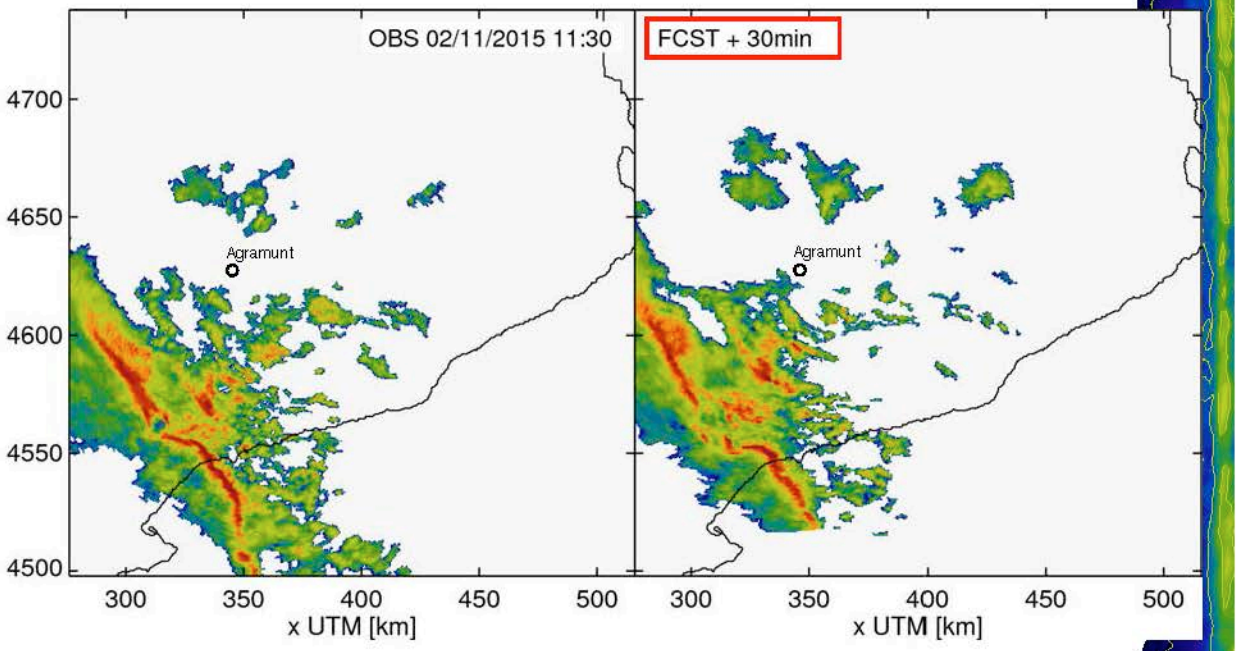
Forecast on 2 NOVEMBER@ 12 UTC



Forecast on 2 NOVEMBER@ 12 UTC

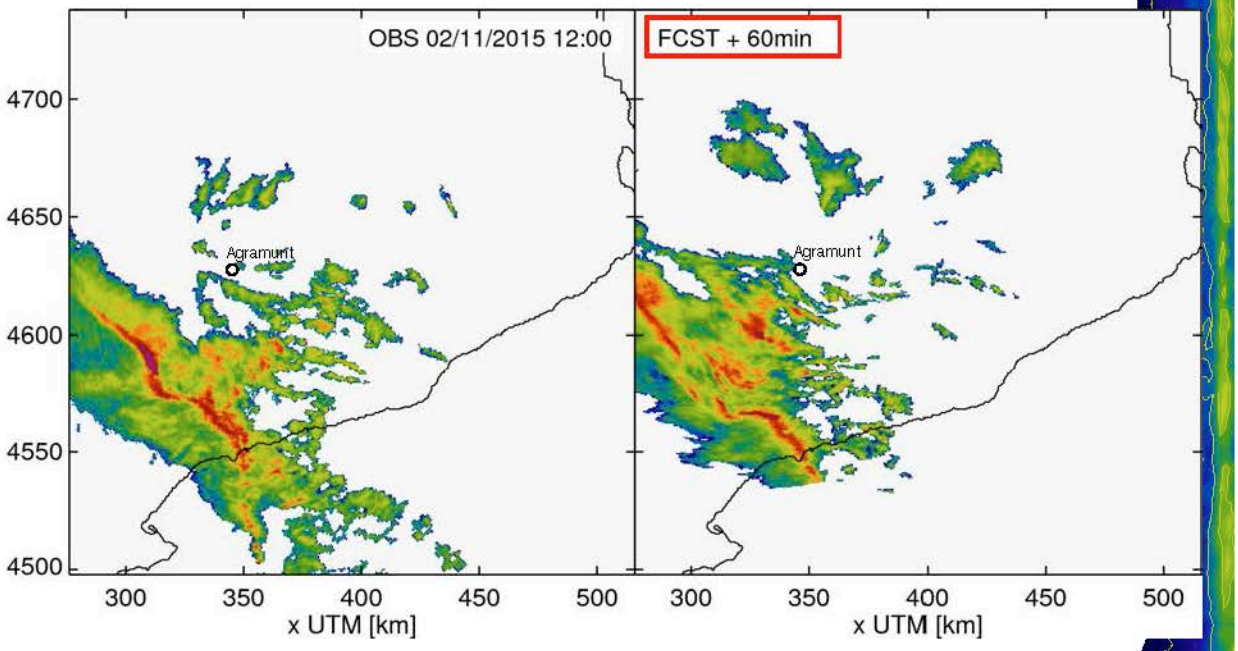
The flood event of 02 November 2015

Rainfall nowcasting

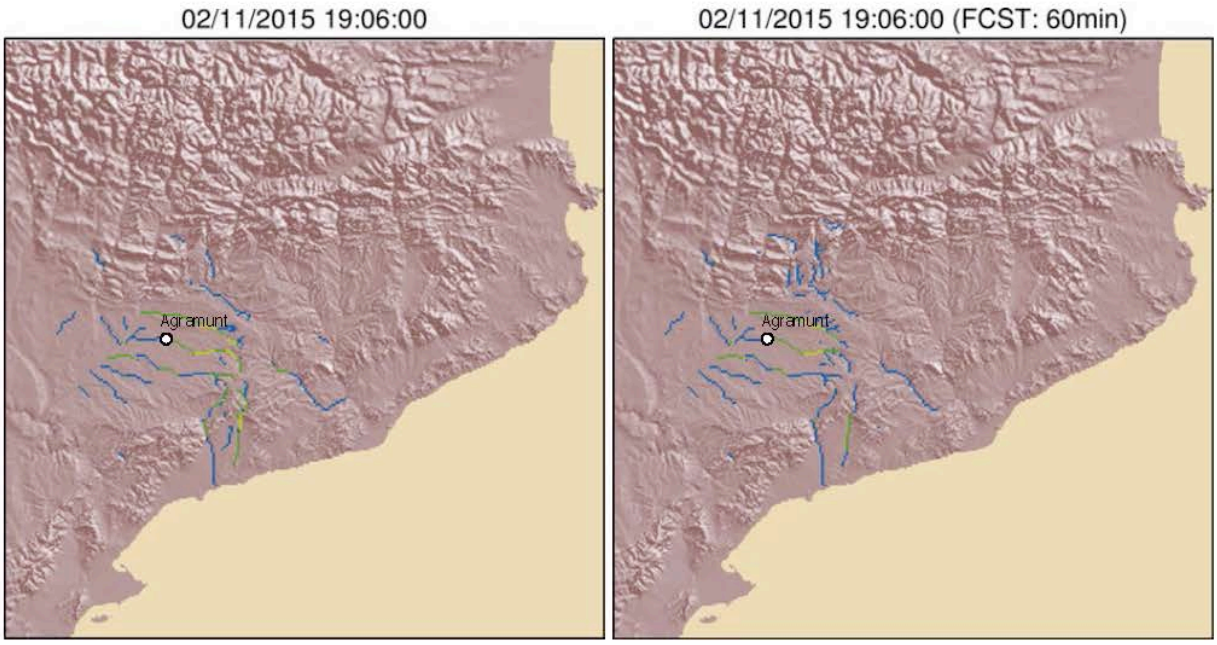


The flood event of 02 November 2015

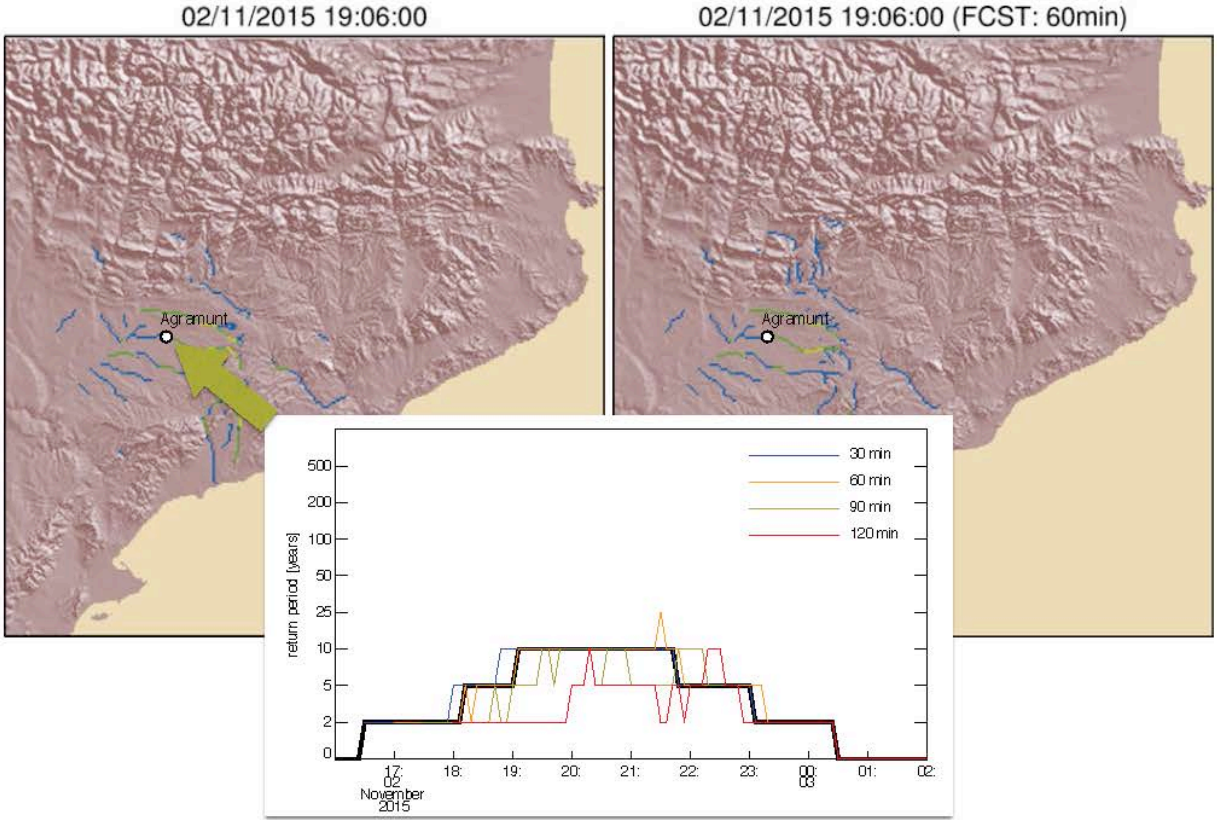
Rainfall nowcasting



60min-fcsts



60min-fcsts



TRAINING PROGRAM ON METEOROLOGICAL AND ADVANCED QUANTITATIVE APPLICATIONS

Debris Flows early warnings using radar.

Centre de Recerca Aplicada en Hidrometeorologia
UNIVERSITAT POLITÈCNICA DE CATALUNYA



Landslides

Triggering agents:

- **Precipitation:** heavy or prolonged rainfall causes the build up of water pressure into the ground. Groundwater conditions responsible for slope failures are related to rainfall through infiltration, soil characteristics, antecedent moisture content, and rainfall history.

  trigger of landslides that produced ~90% of worldwide casualties (Petley 2008).



Photo: J. Corominas



Photo: www.commissario2994.it

Landslides

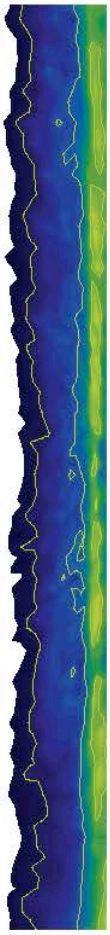
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  trigger of landslides that produced ~90% of worldwide casualties (Petley 2008).

- **Rapid snow melt:** when sudden increases in temperature lead to rapid melting of the snow pack. This water can then infiltrate into the ground, which may have impermeable layers below the surface due to still-frozen soil or rock, leading to rapid increases in pore water pressure.

- **Earthquakes and volcanic eruptions:** due to seismic shaking and pore water pressure generation.

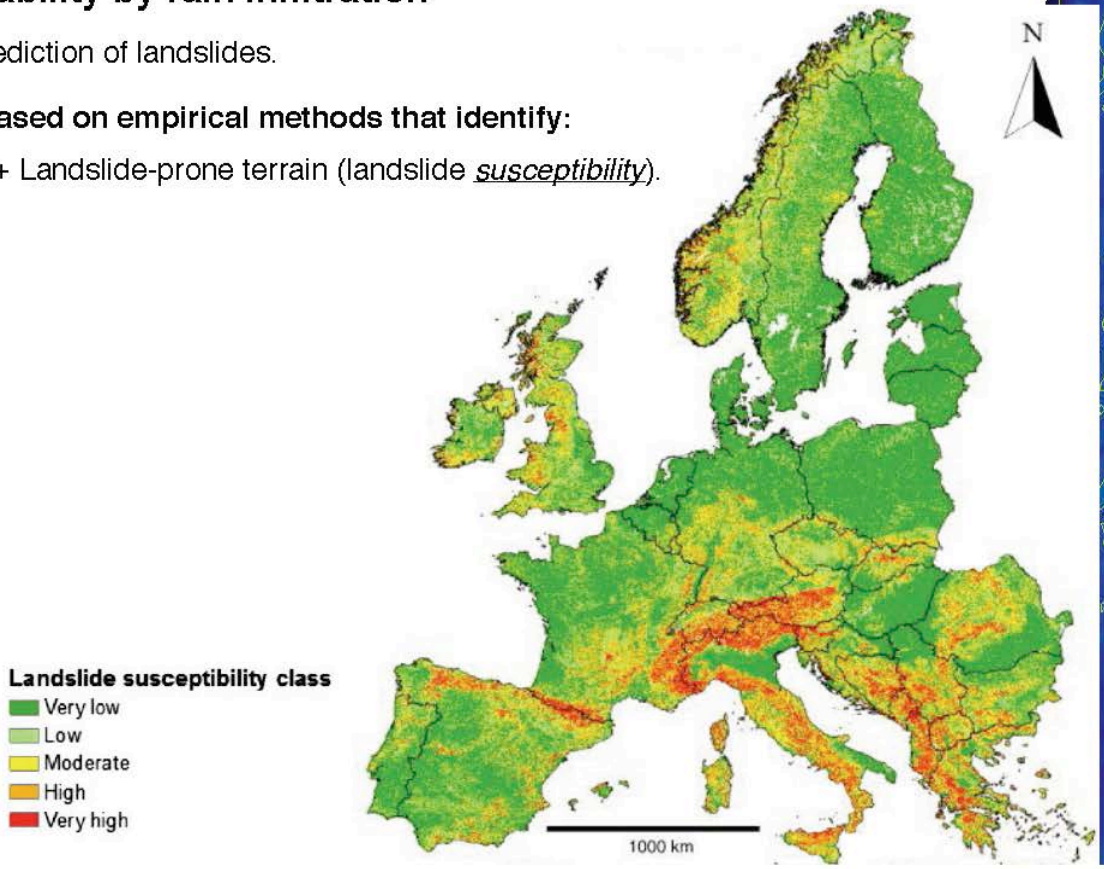


Instability by rain infiltration

Prediction of landslides.

- **Based on empirical methods that identify:**

  + Landslide-prone terrain (landslide *susceptibility*).



Instability by rain infiltration

Prediction of landslides.

- **Based on empirical methods that identify:**
  - + Landslide-prone terrain.
  - + Rainfall intensity-durations that cause slopes to fail.

- **Theoretical methods:**
  - + Based on the infinite-slope stability analysis. Landslide potential related to groundwater pressures in discrete landscape cells.

Factor of Safety to characterize slope stability:

$$FS = \frac{\text{shear strength}}{\text{shear stress}}$$



Debris flows

A debris flow is a moving mass of loose mud, sand, soil, rock, water and air that travels down a slope under the influence of gravity. To be considered a debris flow the moving material must be loose and capable of flow, and, at least 50% of the material must be sand-size particles or larger.





Debris flows

Initiation: the volume of of sediments starts moving, with or without external water. Main initiation mechanisms (Takahashi 2007):

- Landslide-induced debris flows: the landslide block transforms into debris flow while in motion by the effects of stored water or by the supply of water from outside.
- Due to the erosion of the gully bed: the sediments on the stream bed are eroded by the water from outside and the concentration of solids in the surface water flow becomes dense to be called DF.
- Due to the collapse of natural dams: the collapse of a debris dam suddenly makes up debris flow.

Propagation: The volume evolves along a fix channel or the hillslope. As it evolves, the flow erodes the channel and grows until it reaches equilibrium.

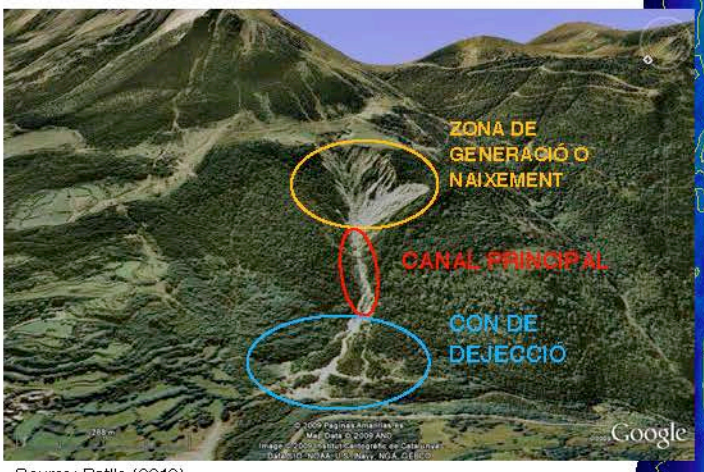
Deposition: Occurs when there is no energy left, either because of smaller slopes or because the channel is less well defined.

Debris flows

Source area: usually steep (25º-40º) and with little vegetation. Detritic soils or with significant meteororization.

Main channel: In many cases, debris flows through a channel (torrents or erosion guills). The channel collects water and incorporates it to the debris flow, and it maintains the depth of the flow,

Accumulation zone: is where the transported material is deposited. The flow is no longer confined by the channel, frequently coinciding with a change in slope.



Source: Batlle (2010)

Debris flows - Conditioning and triggering factors

Slope and terrain shape: Relevant for the initialization and propagation.

Soil characteristics and lithology: determine the availability of material, cohesion and friction, composition, resistance, deformability, alteration, fraction, porosity, permeability,... most favorable materials are colluvial, glacial, fluvial and volcanic deposits.

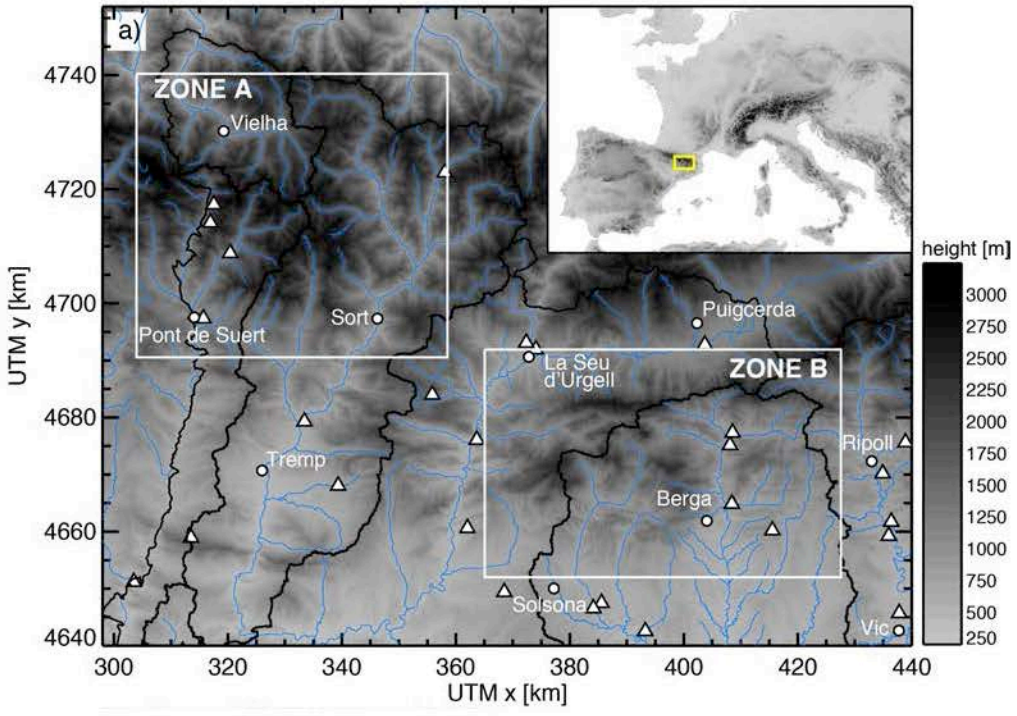
Climate: affects the alteration of the materials and the position of the water table. Also, rainfall is the main agent triggering debris flows.

Susceptibility: does not include the role of the triggering agent.

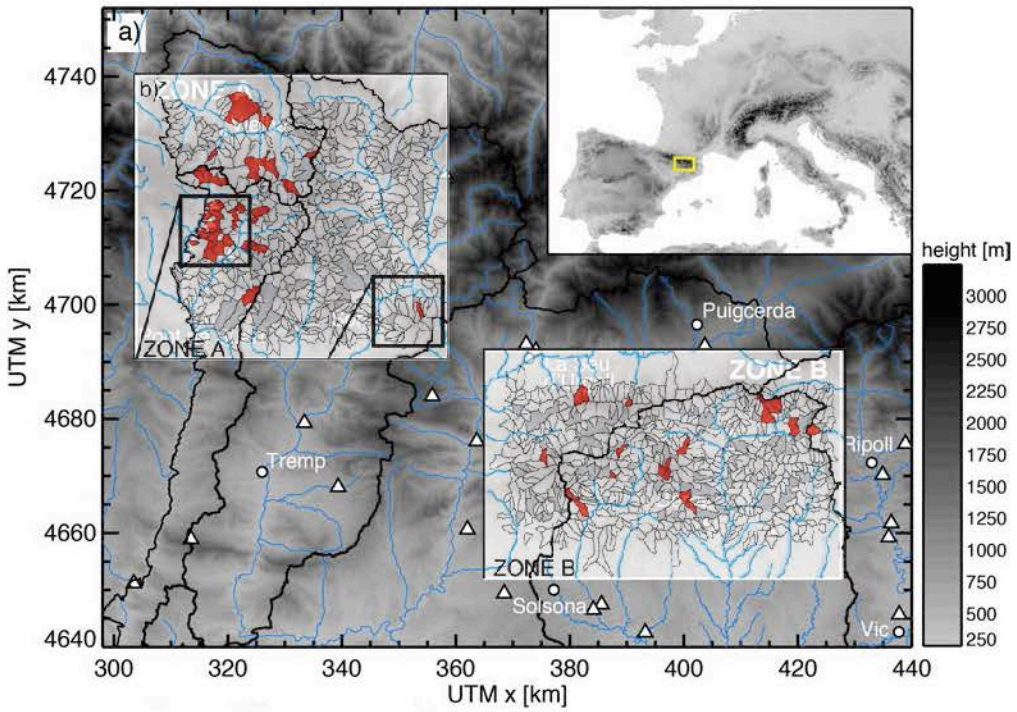
	Alta permeabilitat	Baixa permeabilitat
Tipus de material	Sòls granulars (graves, sorres), terrenys poc consolidats, dipòsits morrènics o massissos rocosos molt fissurats.	Terrenys cohesius, pobrament drenats! argiles o margues.
Pluja antecedent significativa?	No	Si
Per què?	Alta capacitat de drenatge del propi terreny ! l'aigua no queda retinguda durant gaire temps.	Infiltració lenta i circulació pel sòl durant més temps.
Temps necessari per a que les pressions d'aigua intersticials desestabilitzin	Curt	Gran
Resposta a pluja caiguda en 24 hores (P(24h))	Alta	Baixa
Susceptibilitats	Altes intensitats de precipitacions en breus períodes de temps.	Períodes prolongats de pluja de moderada intensitat.

Source: Batlle (2010)

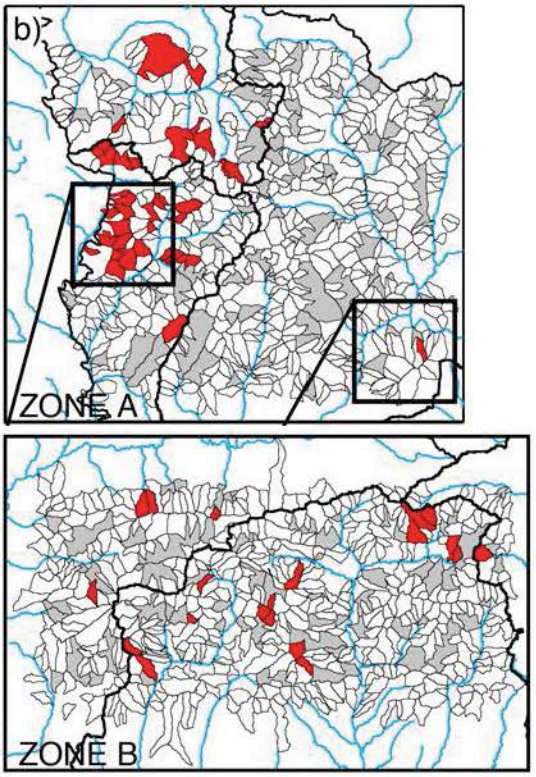
Analysis domain



Analysis domain

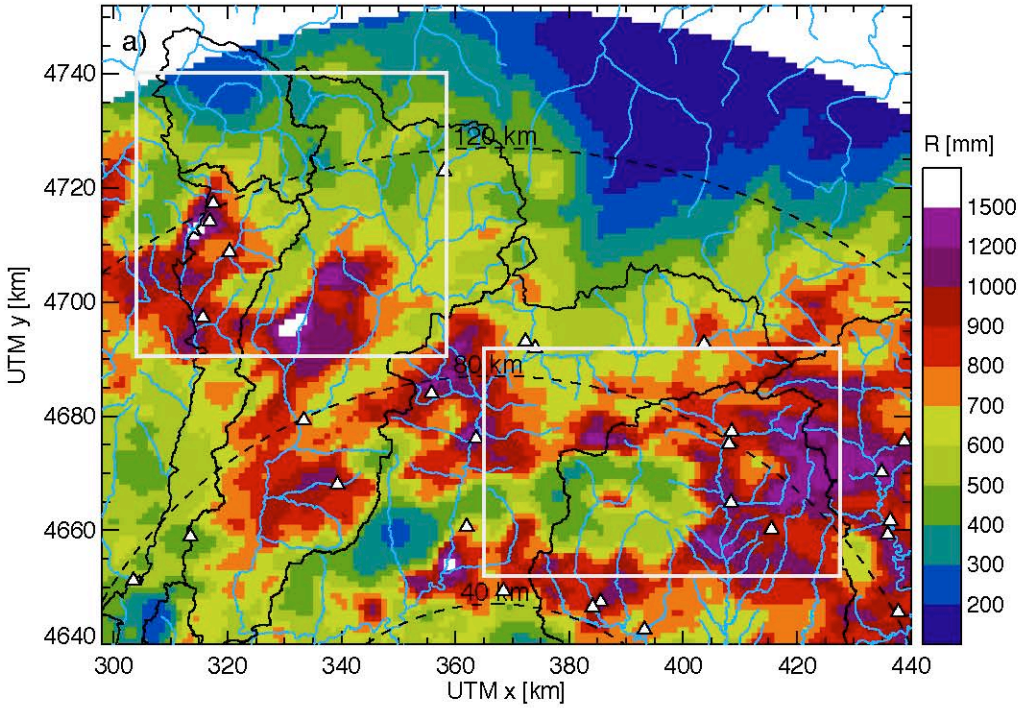


Analysis domain

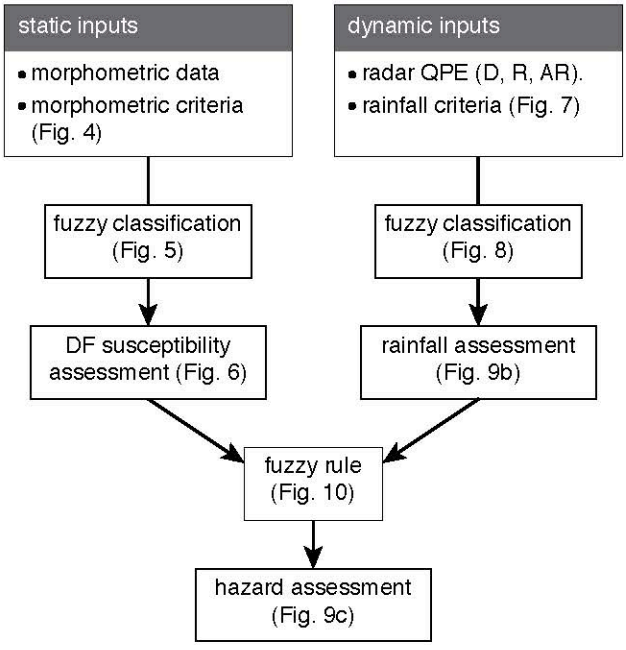


- 2 C-band radars (affected by attenuation)
- 16 PPIs (0.6-25°).
- Beamwidth: 1.1 °
- Resolution 1°x1km.
- Maximum range: 130 km

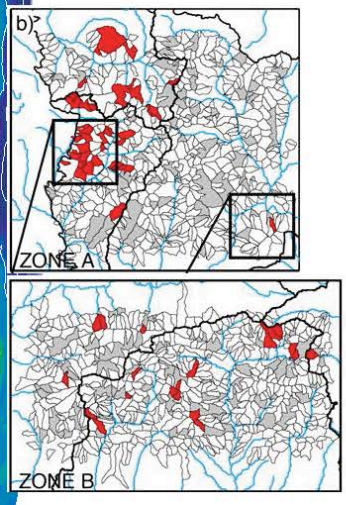
Rainfall accumulation - May-October 2010



Scheme of the method

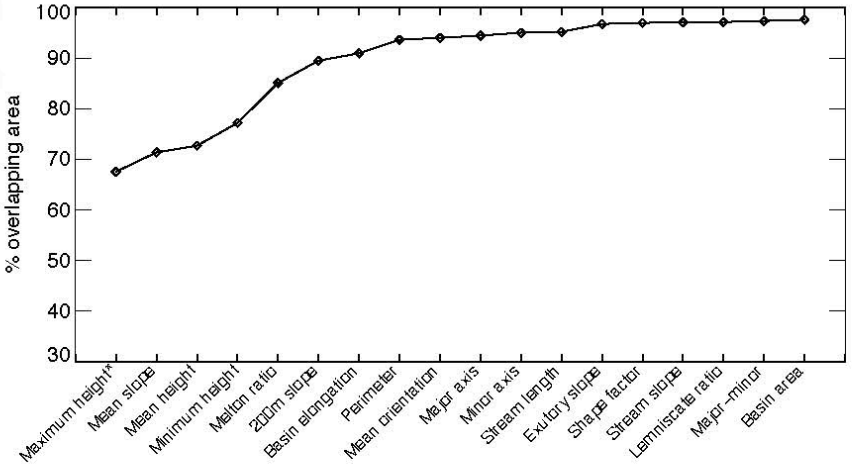


DF susceptibility assessment

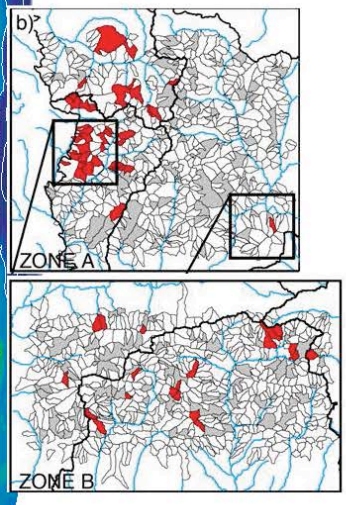


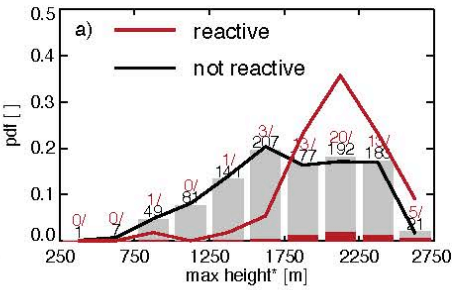
Based on the work of Chevalier et al. (NH2014)

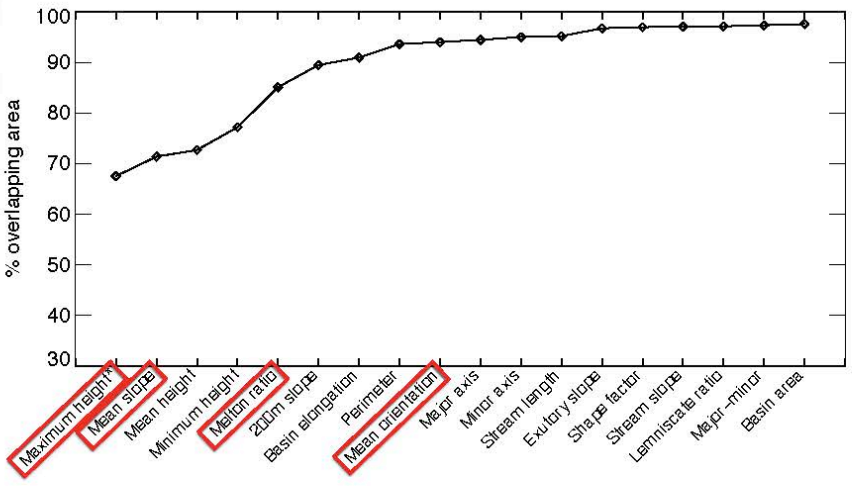
- Applied to 1st and 2nd order subbasins.
- Identified 56 reactive subbasins form aerial photographs.
- Using geomorphological variables that can be retrieved from DEM analysis.



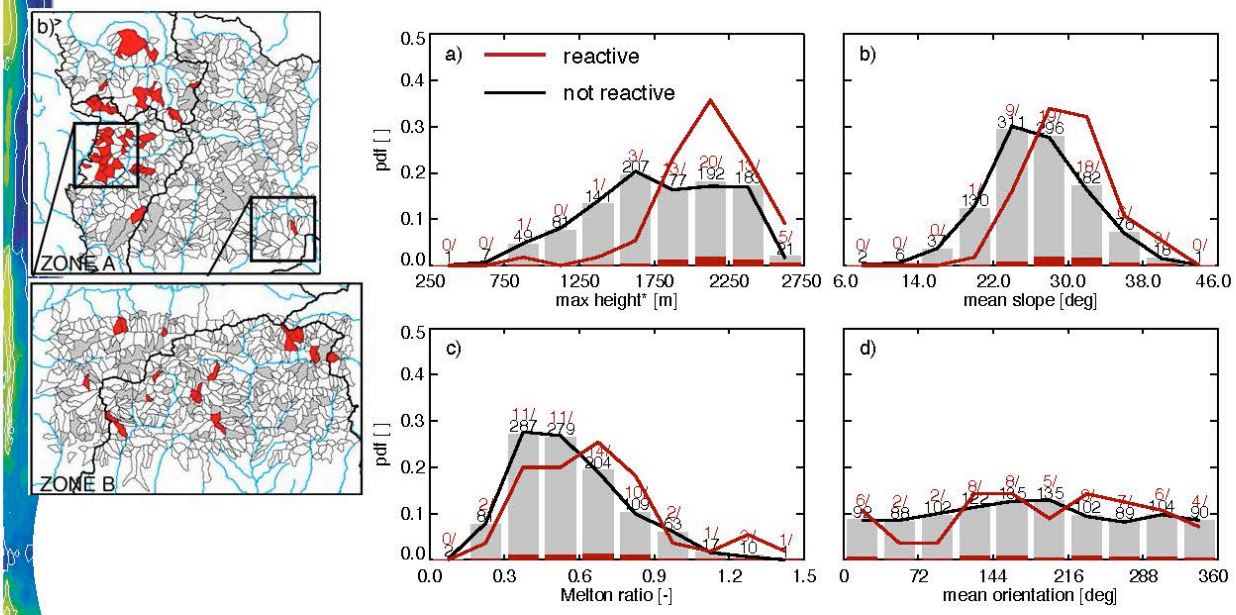
DF susceptibility assessment



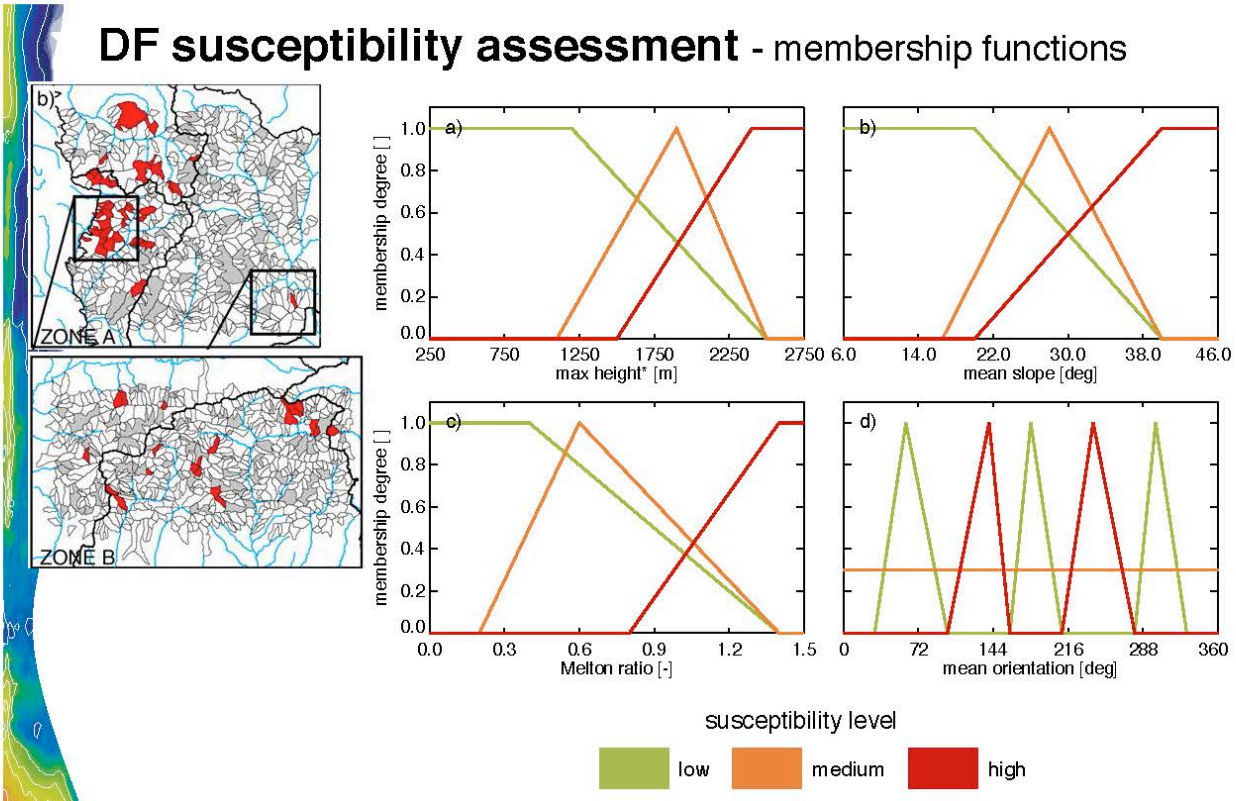




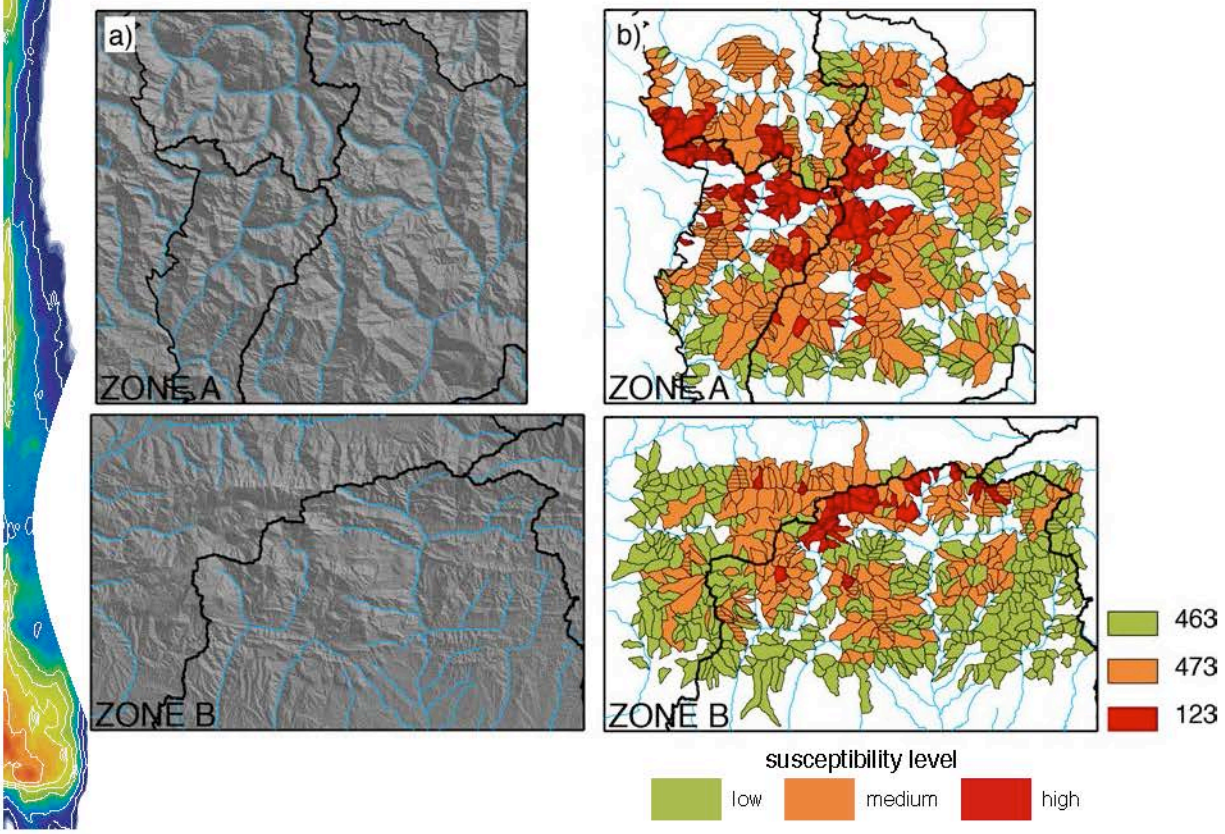
DF susceptibility assessment



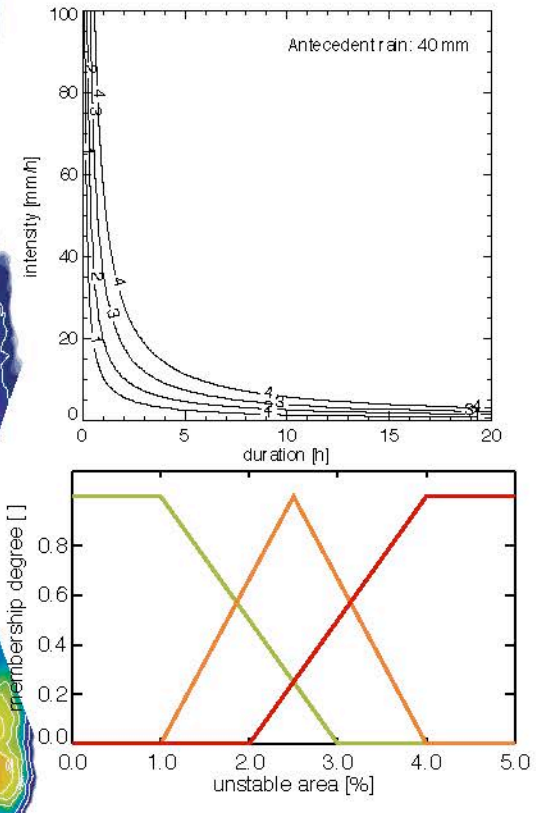
DF susceptibility assessment - membership functions



DF susceptibility assessment



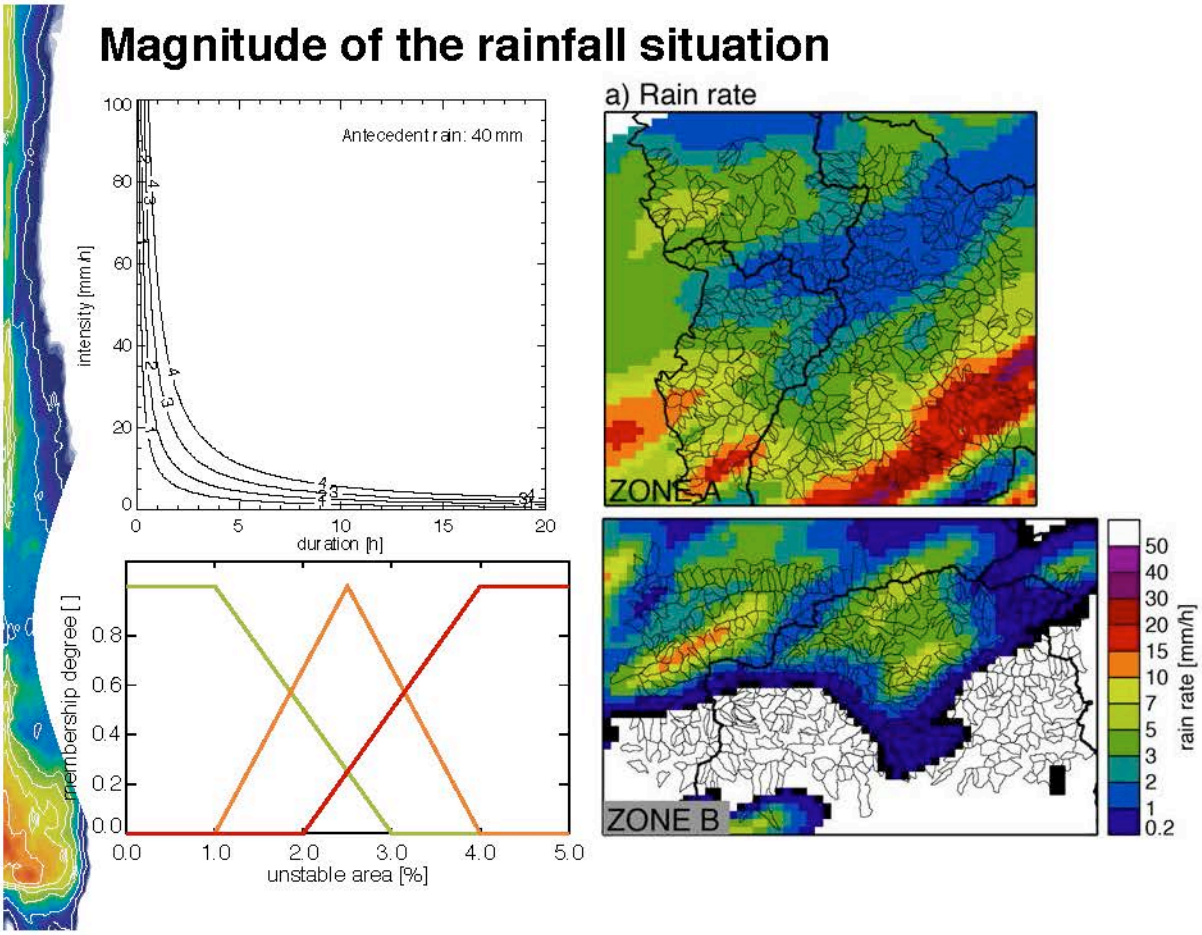
Magnitude of the rainfall situation



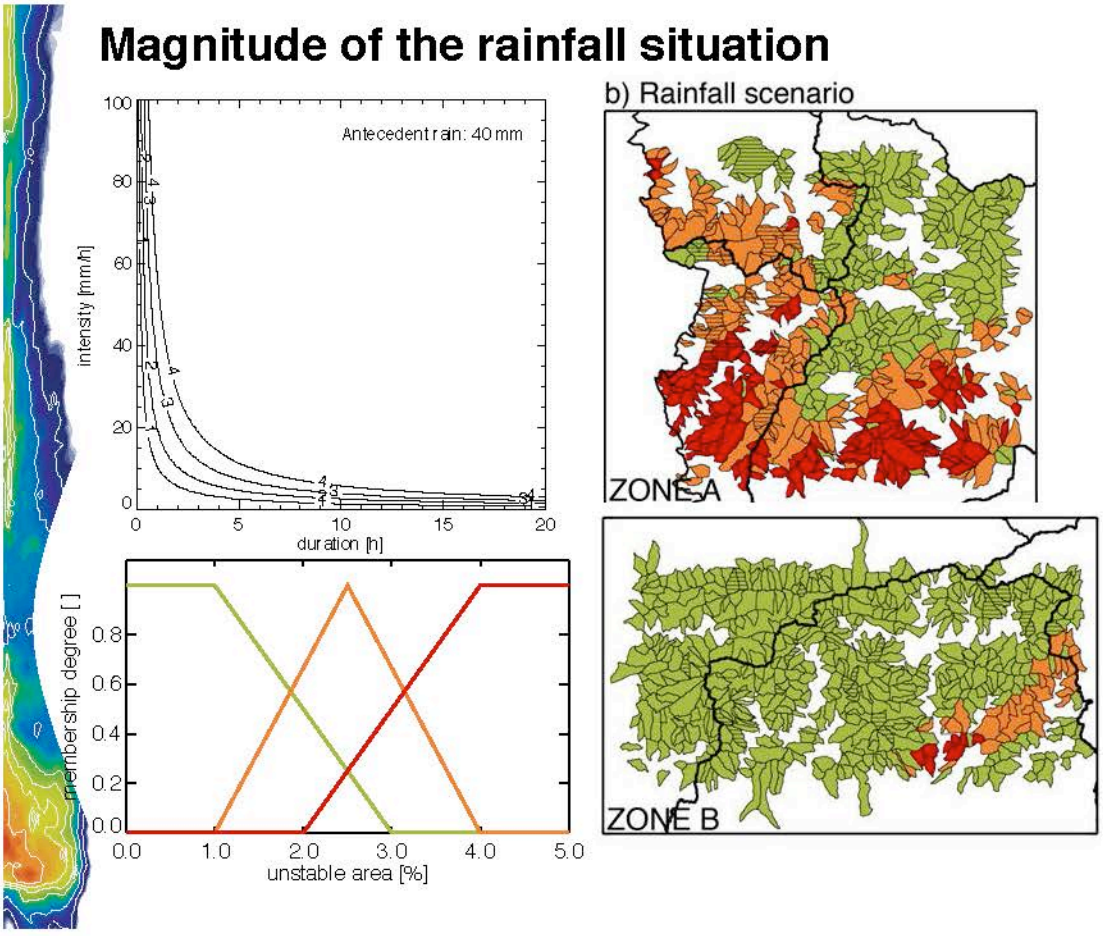
Based on the stability model proposed by Papa et al. (HESS2012):

- It models shallow landslide triggering by rain infiltration.
- Based on infinite slope analysis.
- The effect of rainfall infiltration on groundwater pressure head assumes vertical flow.
- The effect of antecedent rain assumes steady-state conditions.

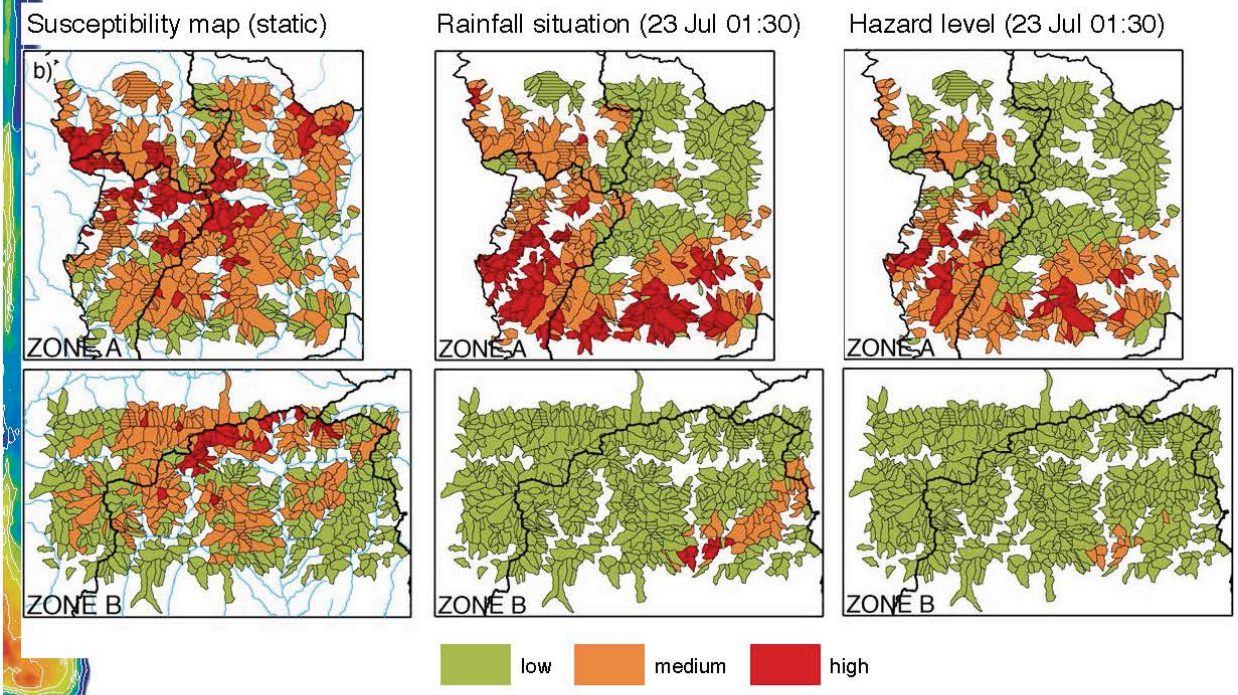
Magnitude of the rainfall situation



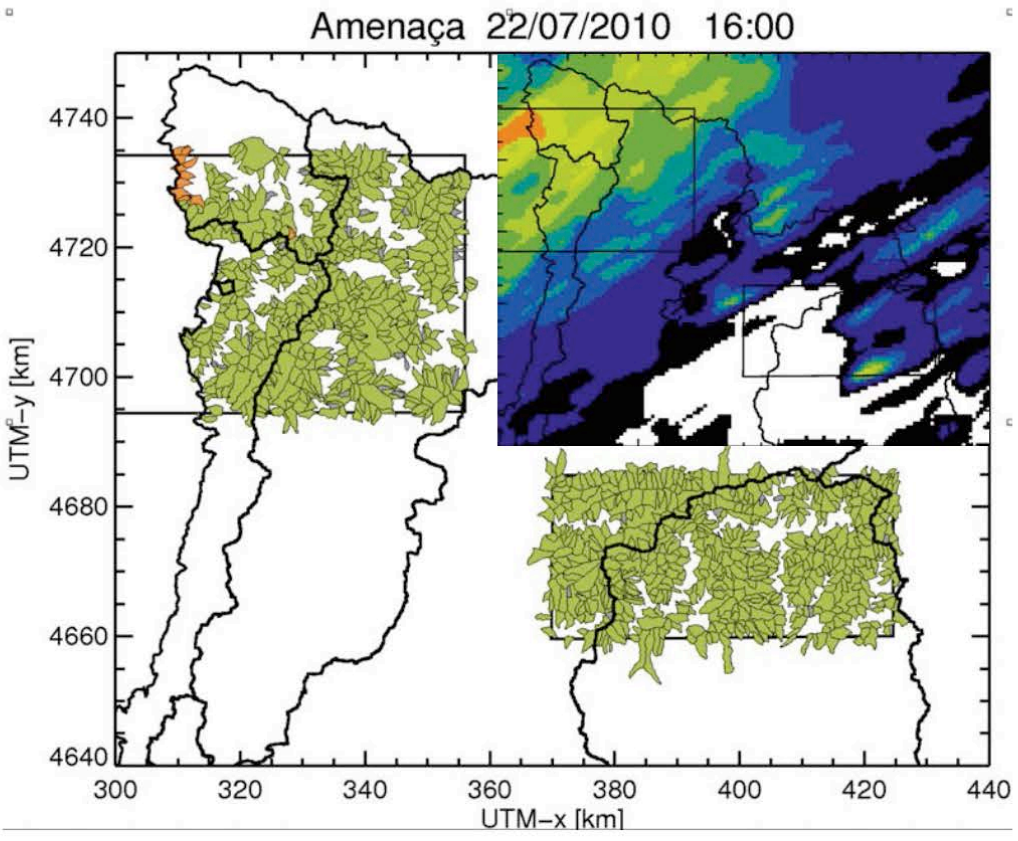
Magnitude of the rainfall situation



Hazard assessment - example of 23 Jul 2010 @01:30



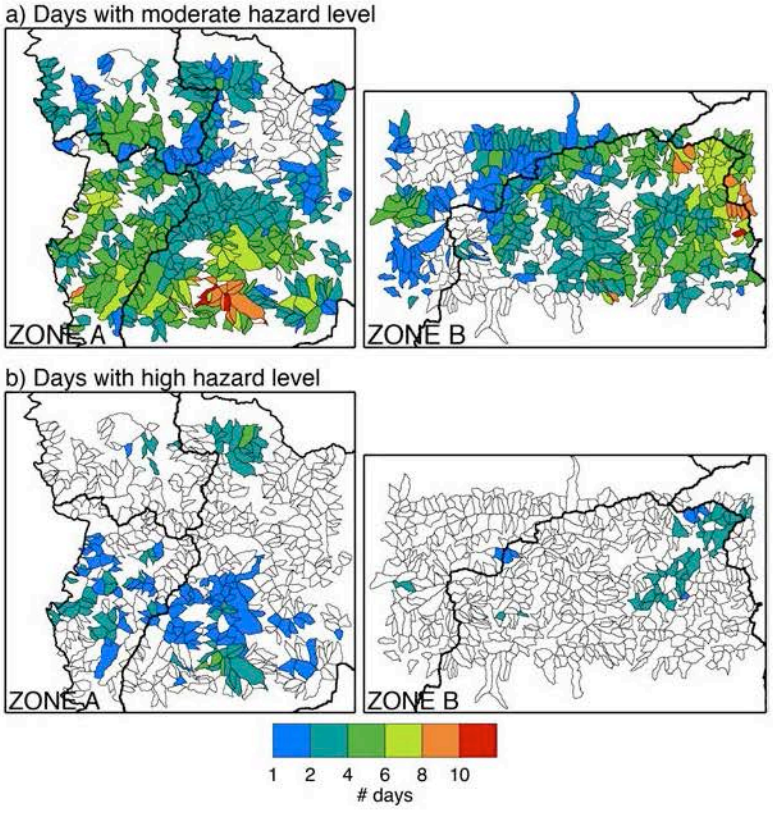
Hazard assessment - example of 22-23 Jul 2010



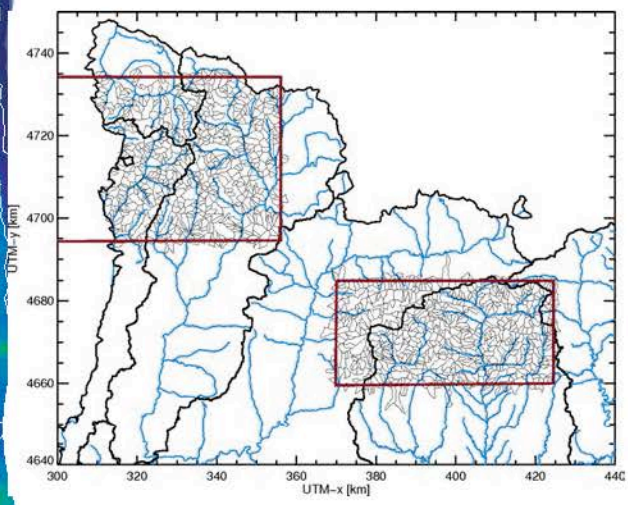
Hazard assessment (fuzzy rule)

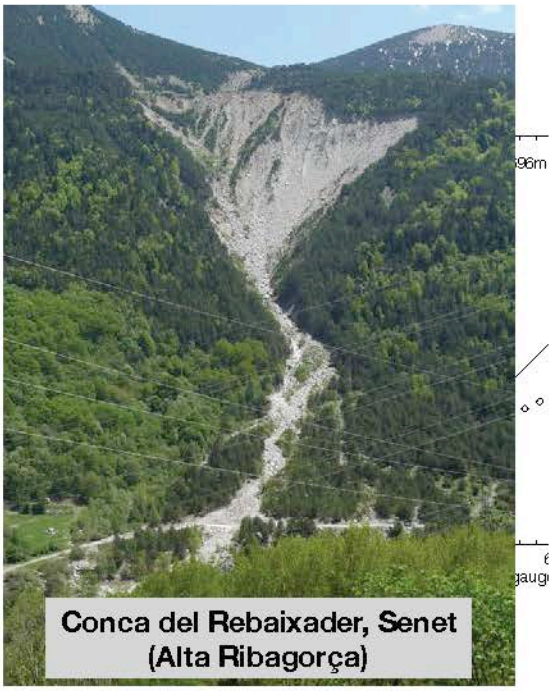
Rainfall situation	DF susceptibility (S_1)		
	Low (S_1)	Moderate (S_2)	High (S_3)
Weak (R_1)	Low (H_1)	Low (H_1)	Low (H_1)
Moderate (R_2)	Low (H_1)	Moderate (H_2)	Moderate (H_2)
Severe (R_3)	Moderate (H_2)	High (H_3)	High (H_3)

Hazard assessment - May-October 2010

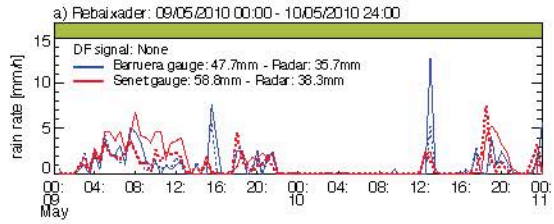


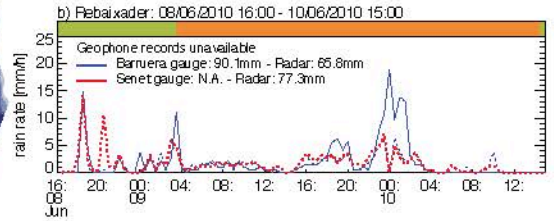
Evaluation of the technique in Rebaixader

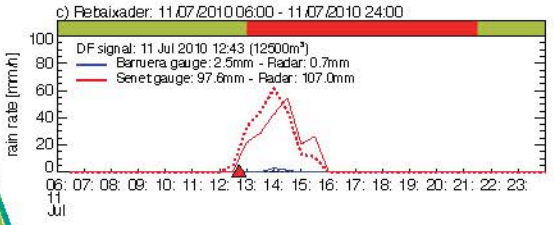


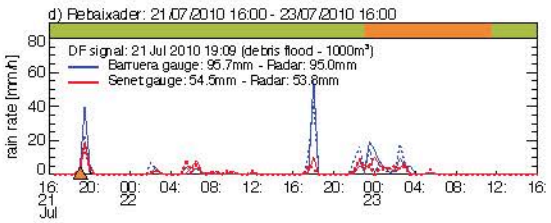


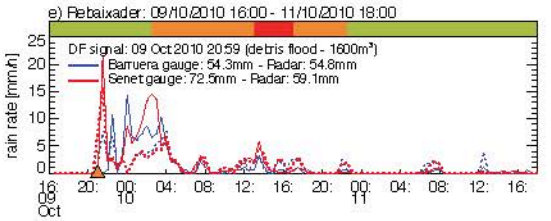
Rainfall accumulation (May-October 2010)





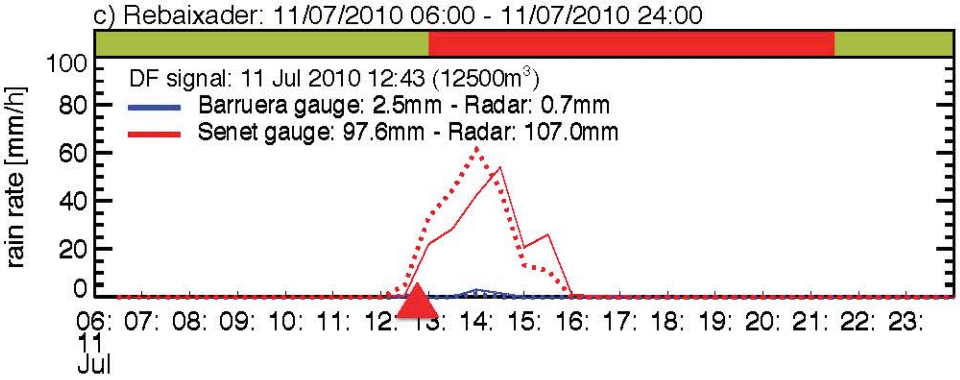






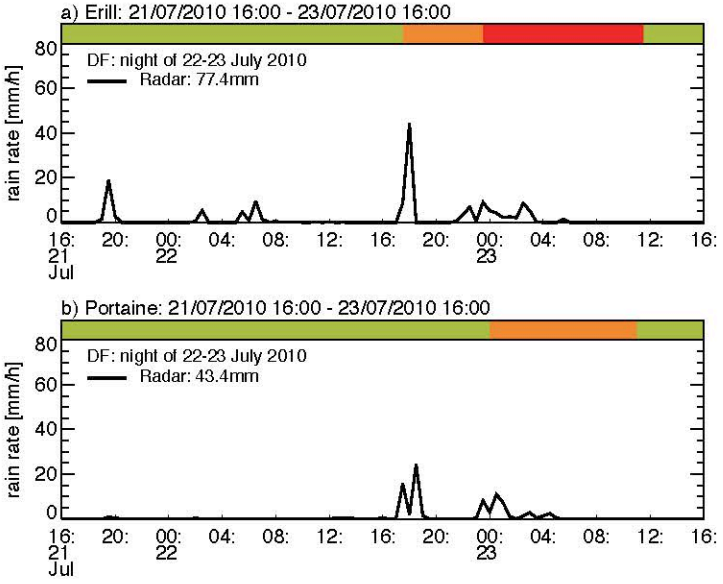


Event of 11 July 2010





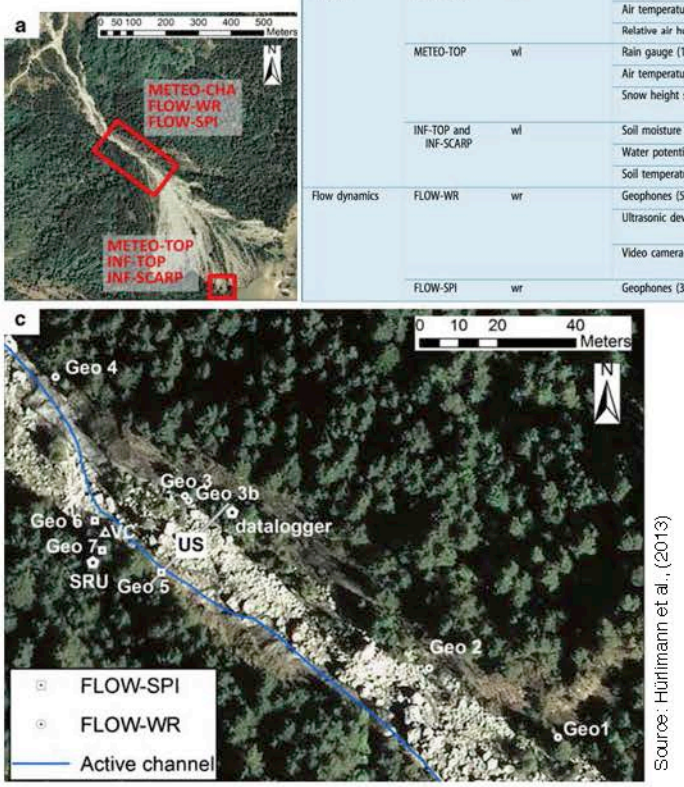
Events in Erill and Portainé



What else?

Table 1 Stations and sensors installed in the Rebaïxader monitoring system

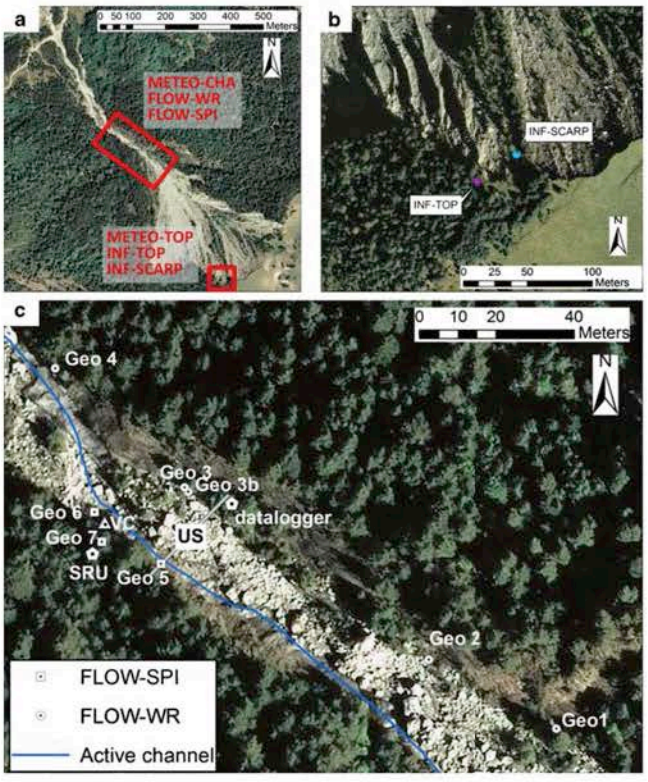
	Abbreviation of station	Wired–wireless*	Sensors (number of sensors installed)	Model	Installation year
Initiation	METEO-CHA	wr	Rain gauge (1)	RM YOUNG S2203	2009
			Air temperature sensor (1)	Campbell Scientific CS215	2009
			Relative air humidity sensor (1)		2012
	METEO-TOP	wl	Rain gauge (1)	Decagon ECRN-100	2012
			Air temperature sensor (1)	Decagon PASSECT	2012
			Snow height sensor (1)	Campbell Scientific SR50A/AT	2012
	INF-TOP and INF-SCARP	wl	Soil moisture sensor (3 and 3)	Decagon 10HS	2012
			Water potential sensor (2 and 2)	Decagon MPS-2	2012
			Soil temperature sensor (2 and 2)		
Flow dynamics	FLOW-WR	wr	Geophones (5)	Geospace 20 DX	2009
			Ultrasonic device (1)	Pepperl+Fuchs UC6000-30GM-IUR2-V15	2009
			Video camera (1)	Mobotix MX-M12D-Sec-DNight-D43N43	2011
	FLOW-SPI	wr	Geophones (3)	Geospace 20 DX	2012



Source: Hürlimann et al., (2013)

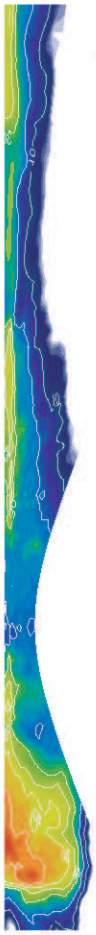
Fig. 2 **a** Map of the six monitoring stations installed in the Rebaïxader site (see Table 1 for abbreviations). **b** Close-up of the two infiltration stations located at the lateral moraine. **c** Location of the sensors measuring the flow behavior at station FLOW-WR and FLOW-SPI. *Geo* geophone, *US* ultrasonic device, *VC* video camera, *SRU* seismic recording unit

What else?

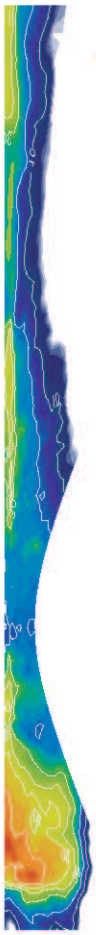


Source: Hürlimann et al., (2013)

Fig. 2 **a** Map of the six monitoring stations installed in the Rebaïxader site (see Table 1 for abbreviations). **b** Close-up of the two infiltration stations located at the lateral moraine. **c** Location of the sensors measuring the flow behavior at station FLOW-WR and FLOW-SPI. *Geo* geophone, *US* ultrasonic device, *VC* video camera, *SRU* seismic recording unit



Summary



Summary

- Radar QPE is useful for monitoring the rainfall field at high space and time resolution (reliable after complex processing of the measurements).
- Integrated radar rainfall estimates with susceptibility mapping for hazard assessment.
- Demonstration during the period May-Oct 2010.
- Evaluation of the performance of the system is a challenge (lack of data).
- In Rebaixader, no missings or false alarms. Delayed response for the cases with triggering high rainfall intensities at the beginning of the event.

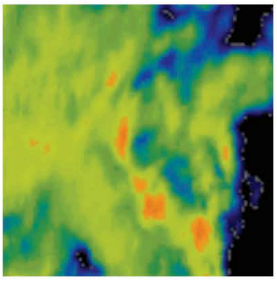
Dealing with uncertainties in radar products

Centre for Applied Research in Hydrometeorology
CRAHI
Universitat Politècnica de Catalunya
Barcelona (Spain)

T.C.
Orman ve Su İşleri Bakanlığı
Meteoroloji Genel Müdürlüğü

Quantifying Ucertainties in radar QPE?

Associate to any estimated radar field (QPE, QPF...) an uncertainty measurement



Precipitation Estimate



Associated uncertainty (dB)

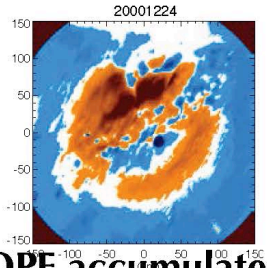
Ucertainties in radar QPE

The errors are **SPACE AND TIME DEPENDENT**, and have **SPACE AND TEMPORAL STRUCTURE**

Radar estimate errors are NOT RANDOM NOISE



Random noise



QPE accumulated error (mm)

They are spatial and temporal correlated

How to calculate them?

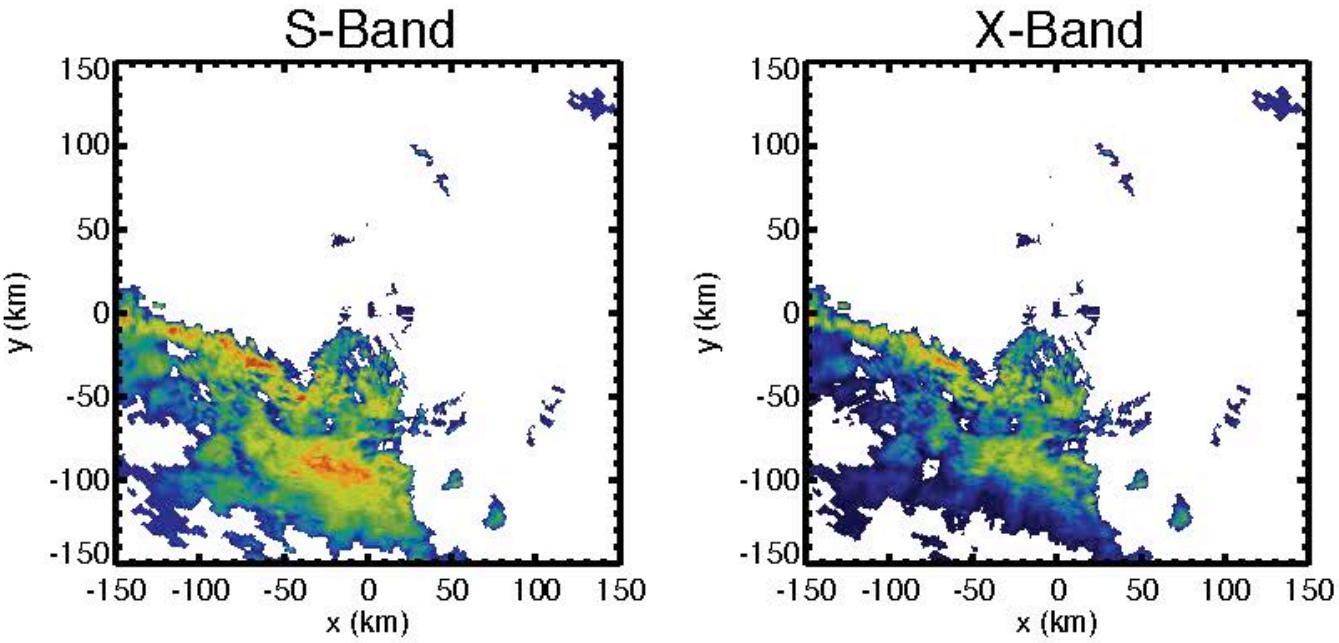
Two main ways (Germann et al. ERAD 2006):

PHYSICAL APPROACH

- Estimate uncertainty due to a given **source of error**
- Characterize its **spatial and temporal structure**
- Provide a **climatological description of the error structure**
- **Repeat** for any source of error
- **Study the cross-correlation** between different sources of error
- Infere the **joint error structure**

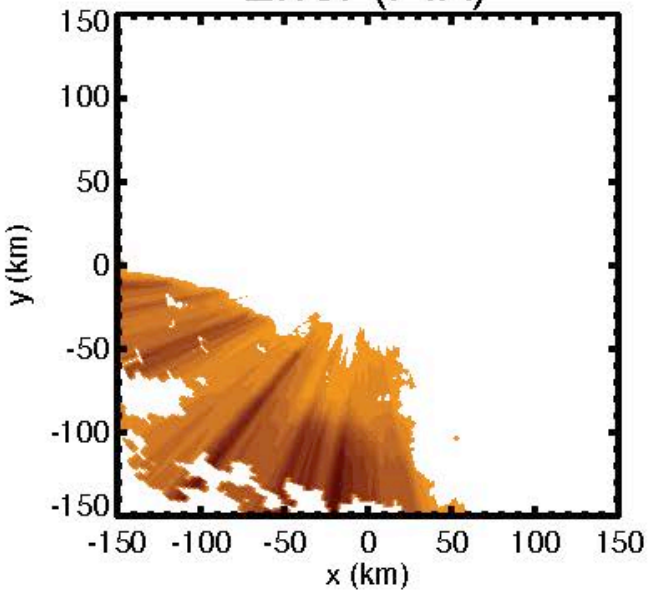
Example: Attenuation

Simulation of attenuation



Example: Attenuation

Simulation of attenuation Error (PIA)

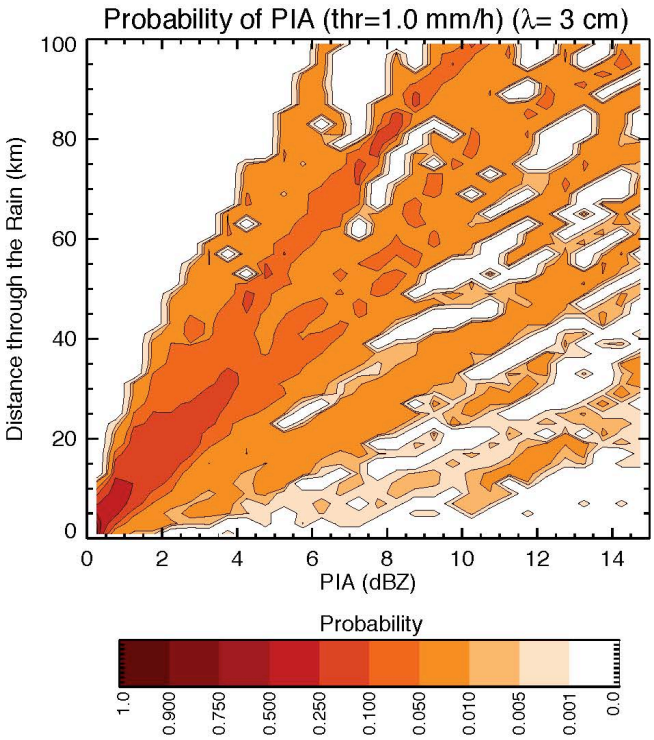


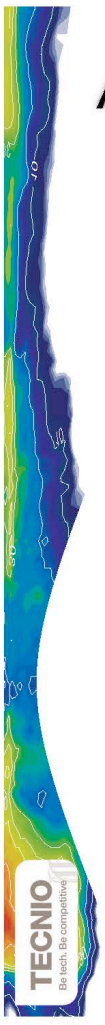
Location dependent!

Space-Time correlated!

Attenuation

X band (3cm) **~200 Events**





Alternative: Operational approach

COMPARE AGAINST A REFERENCE

We need **"the reference"** field

We need to build a benchmark

Establishing a BENCHMARK

Usually the reference to assess the precipitation uncertainty have been the raingauges

- Uncertainty = raingauge - radar estimates, at different locations
- Study the spatial & temporal structure

Several approaches....

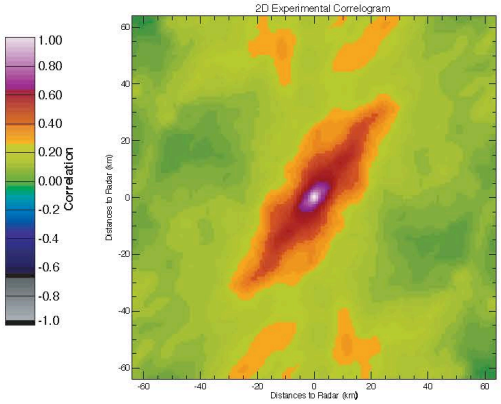
BUT

- Raingauges are point measurements
- Different nature of estimates (200 cm^2 against 1km^3)

Alternative: 2D BENCHMARK

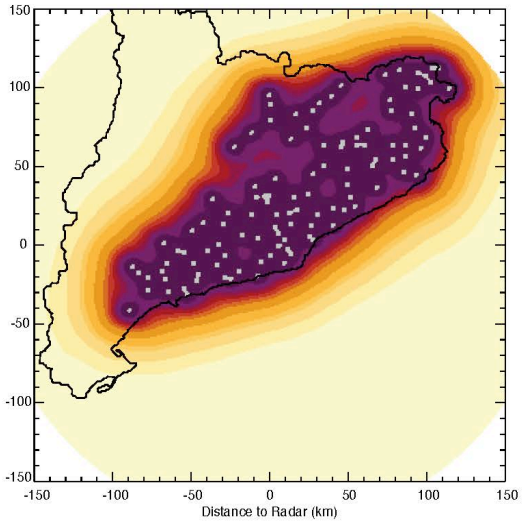
BENCHMARK = 2D precipitation field estimate obtained by **intelligent interpolation** of raingauges (Velasco, *Adv. Water Res. 2009*)

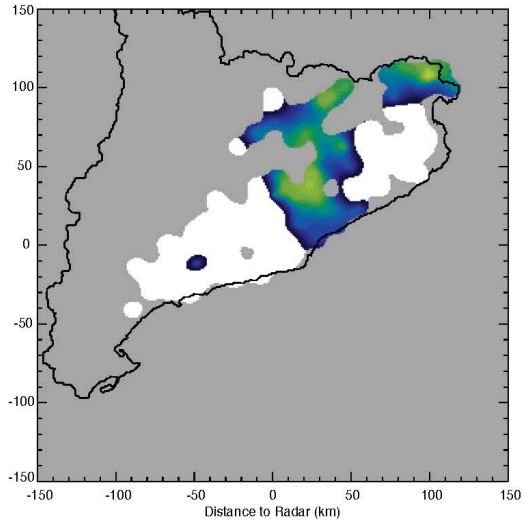
- Dense raingauge network
- Interpolate by kriging using the radar field to compute the variogram (spatial structure)



Alternative: 2D BENCHMARK

- Select the area in which you can be confident (use the error estimation provide by kriging)

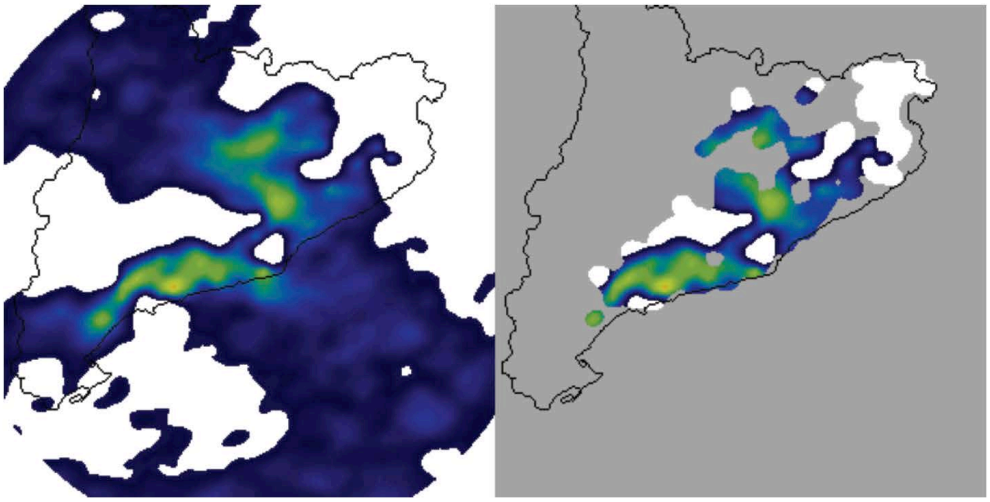




Only use the area in which interpolation explains 80% of the field variance (see Velasco Forero et al., 2008)

Alternative: 2D BENCHMARK

- Automatic procedure
- Evolves in time (as precipitation) depending on the precipitation structure and the available raingauges



Second step: Defining the 2D uncertainty field

If in a given pixel
Benchmark and Radar Data > Threshold

$$Error = 10 \cdot Log_{10}\left(\frac{Benchmark}{RadarData}\right)$$

Error = 0 Otherwise

Applications

- Better understand the nature of uncertainties
- Provide Quality Control of the algorithms
- Allow performances intercomparison of different algorithms
- Allow generation of radar ensembles

Case study: Catalunya hydrometeorological testbed

Servei Meteorològic de Catalunya

Agència Catalana de l'Aigua

CRAHI

UPC

Operational instrumentation at Catalunya

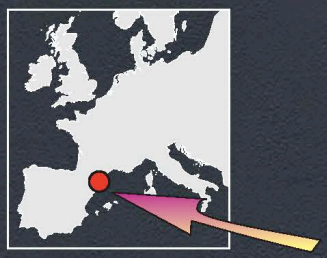
SAIH telemetered network

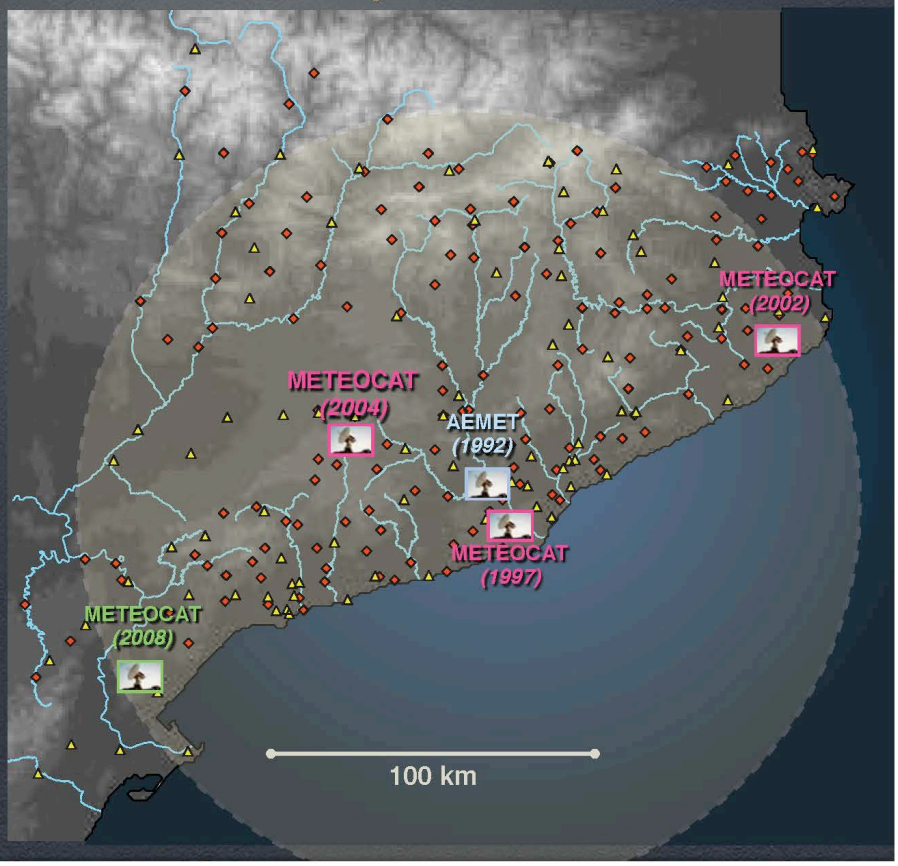
- *stage level*
- *raingauges*

METEOCAT network

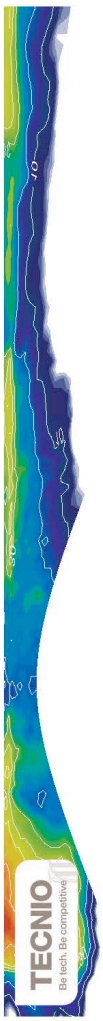
- *raingauges*

C-band, Doppler Radar network

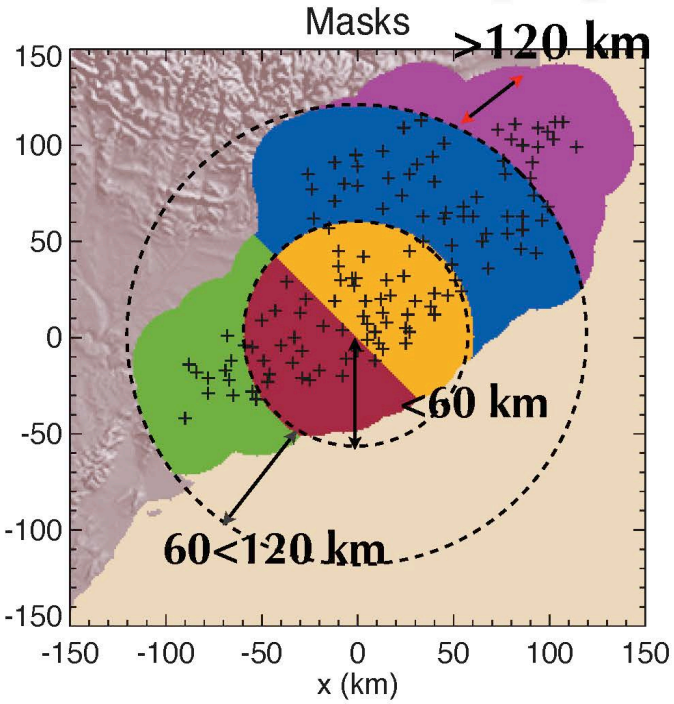




Case Study: Catalunya Hydrometeorological Test-bed



Subset of 125 raingauges



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QPE Radar processing chain

Signal and ground clutter processing

Precipitation type classification VPR and Z-R per types

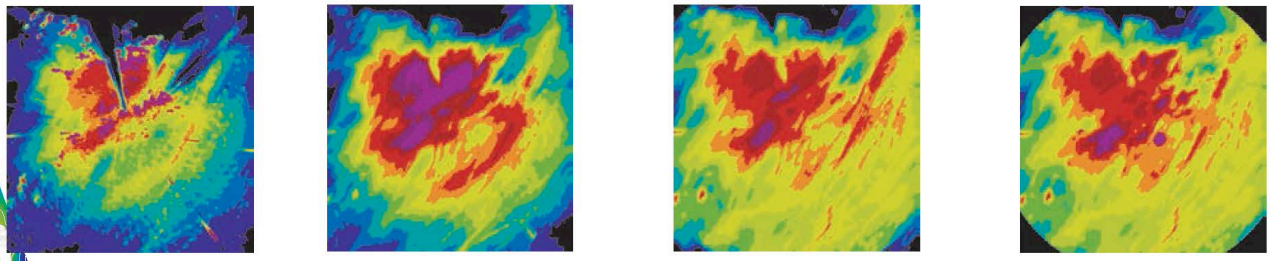
Finest Raingauges Blend

RAW

Stage 2 Corrected data

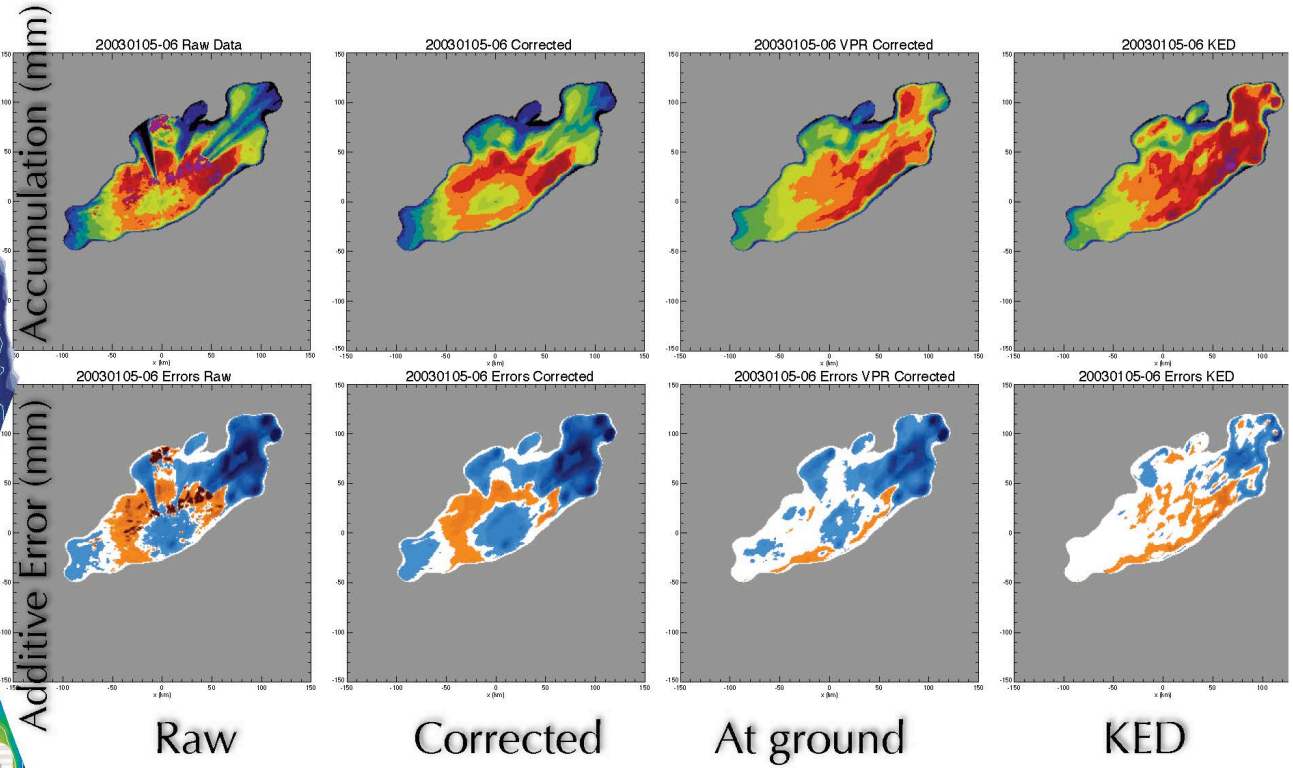
Stage 3 R at ground

Stage 4 KED

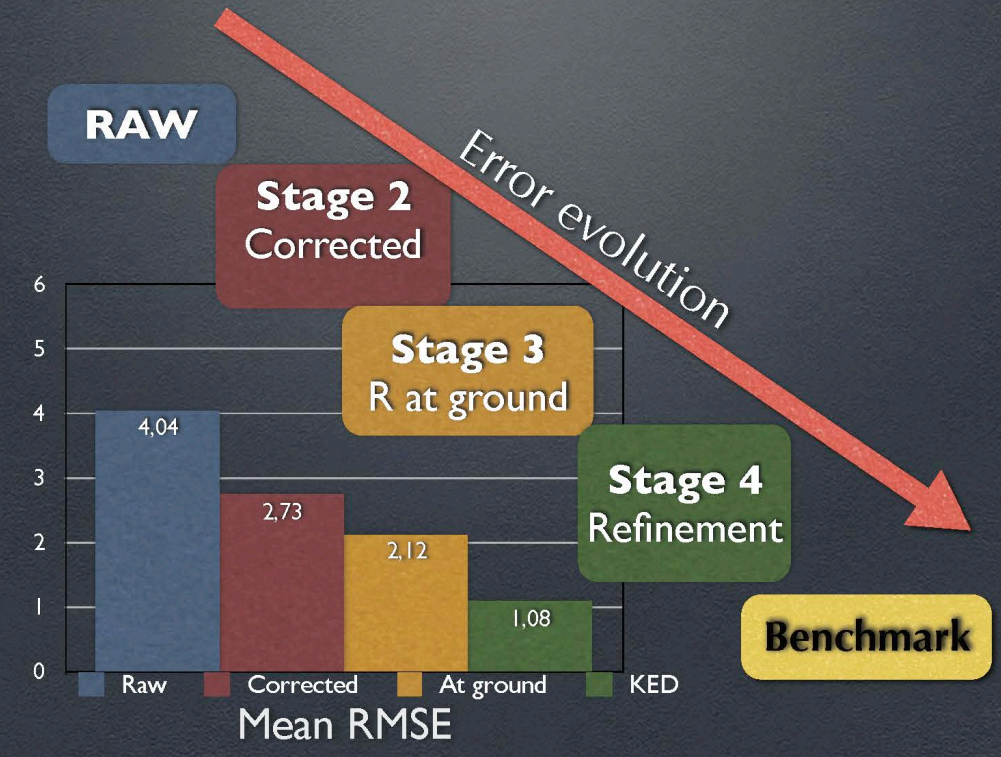


Rain accumulation for a whole event

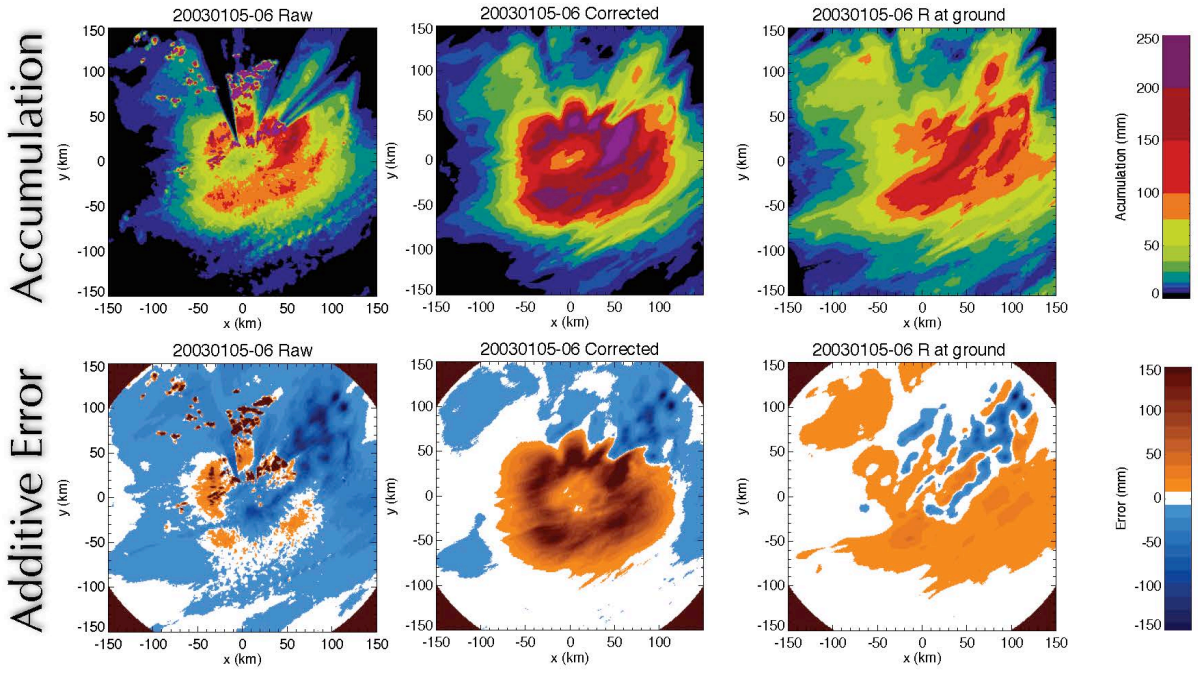
1) Understanding nature of the errors



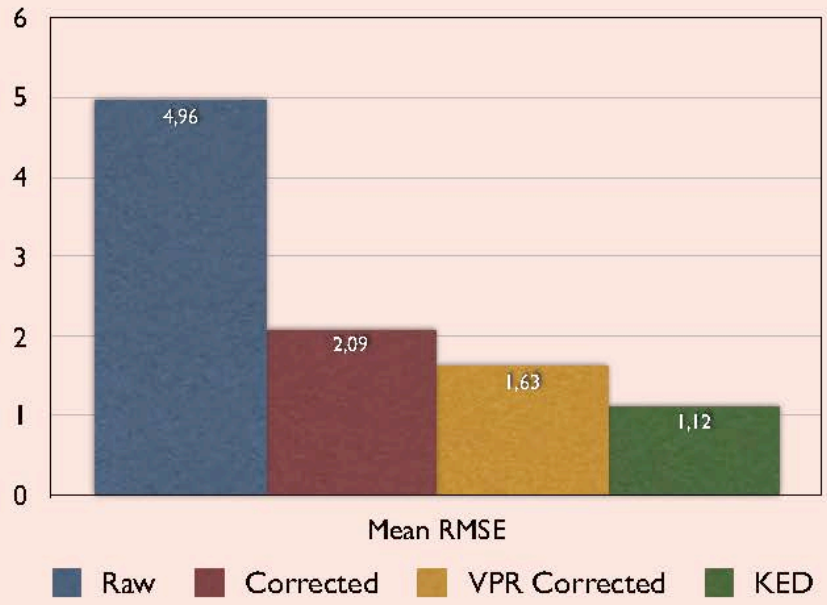
2) Assessing the quality at any step of the processing chain



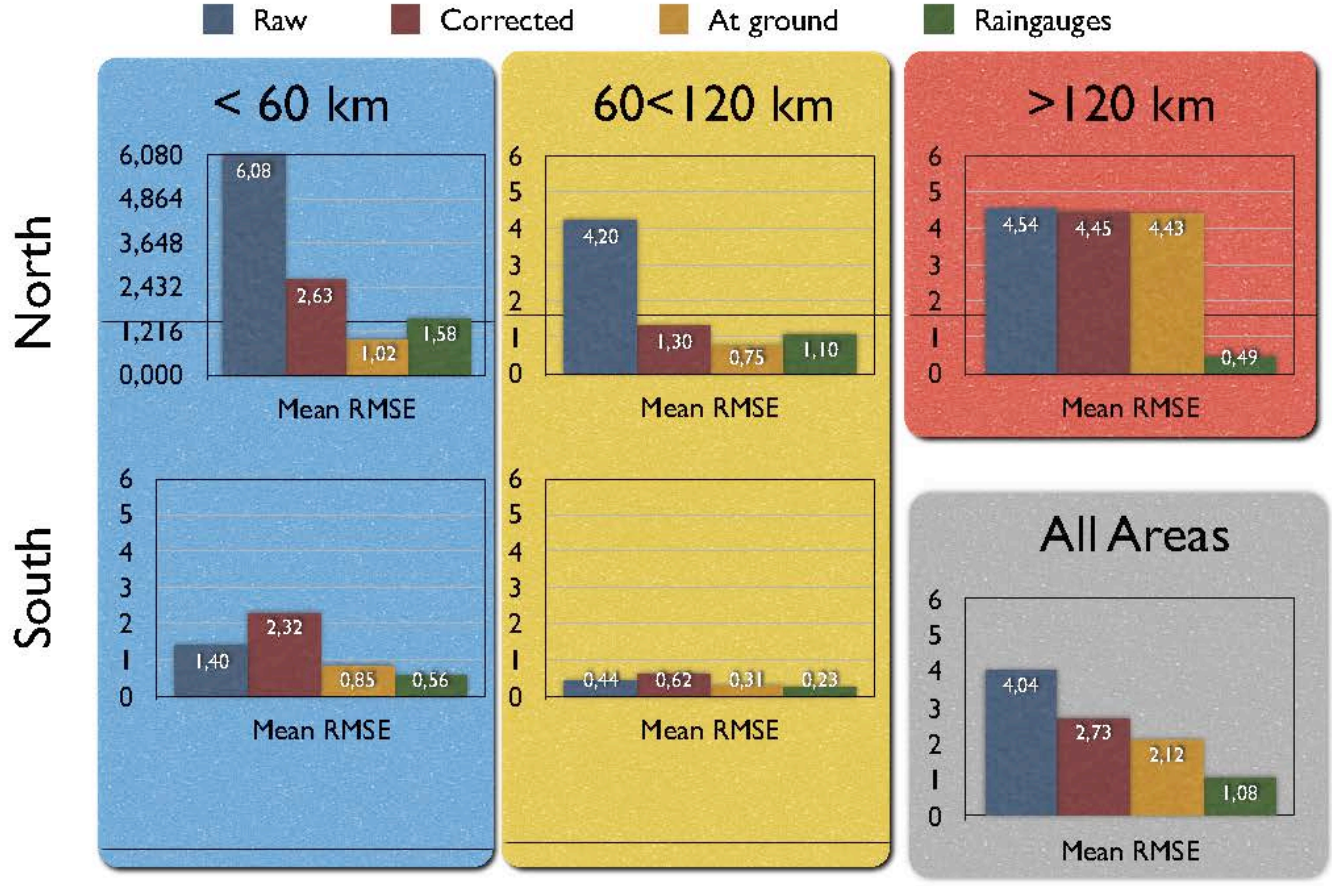
Control the nature of the errors



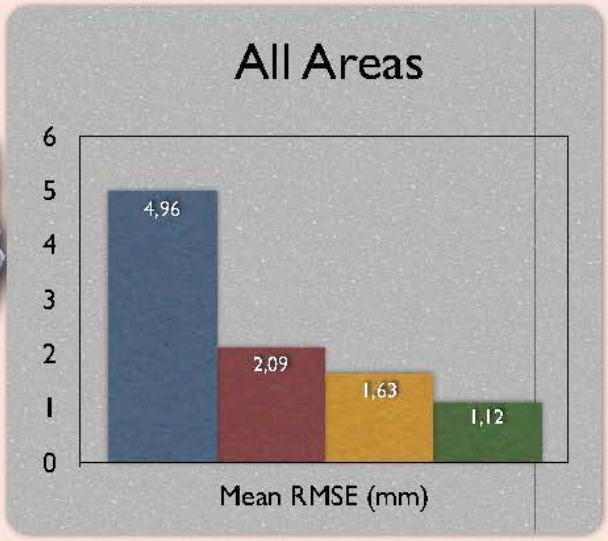
Quantifying the error: 2003-01-05

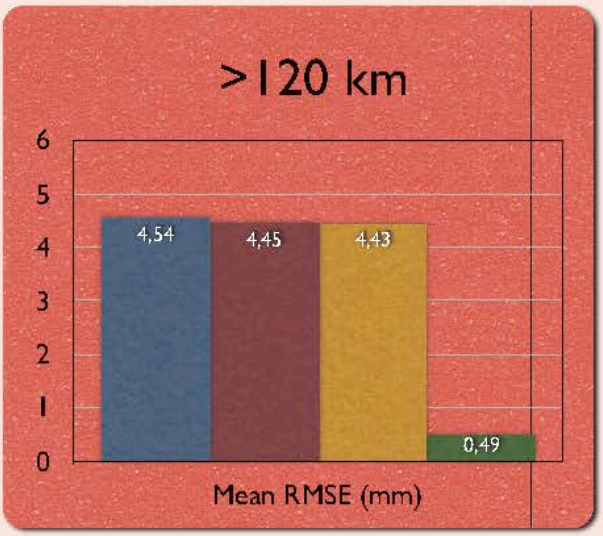


Explore distance effect: 2003-01-05



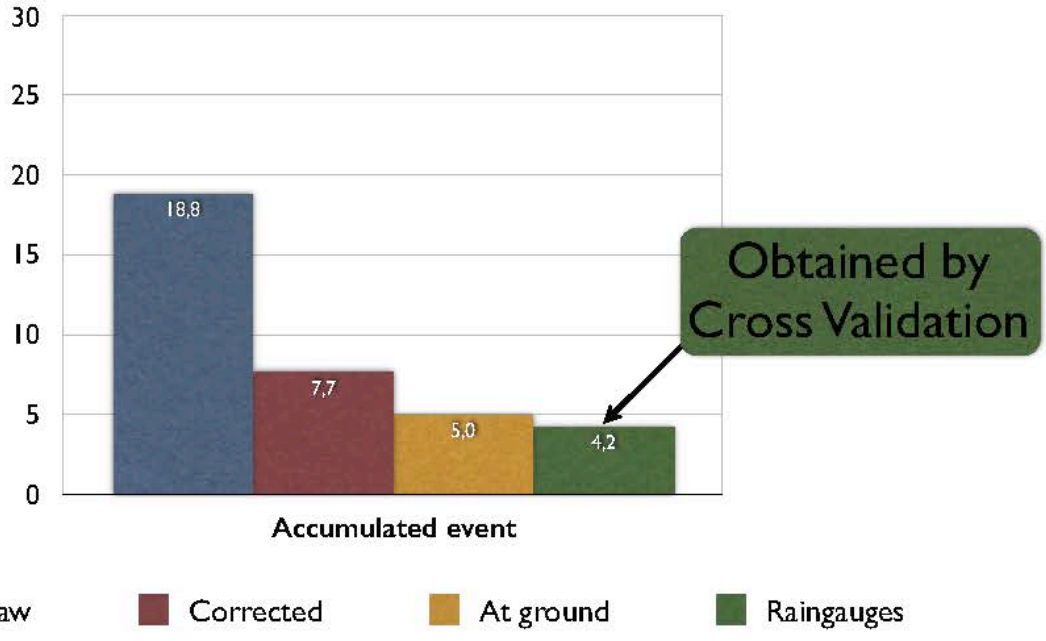
Explore distance effect



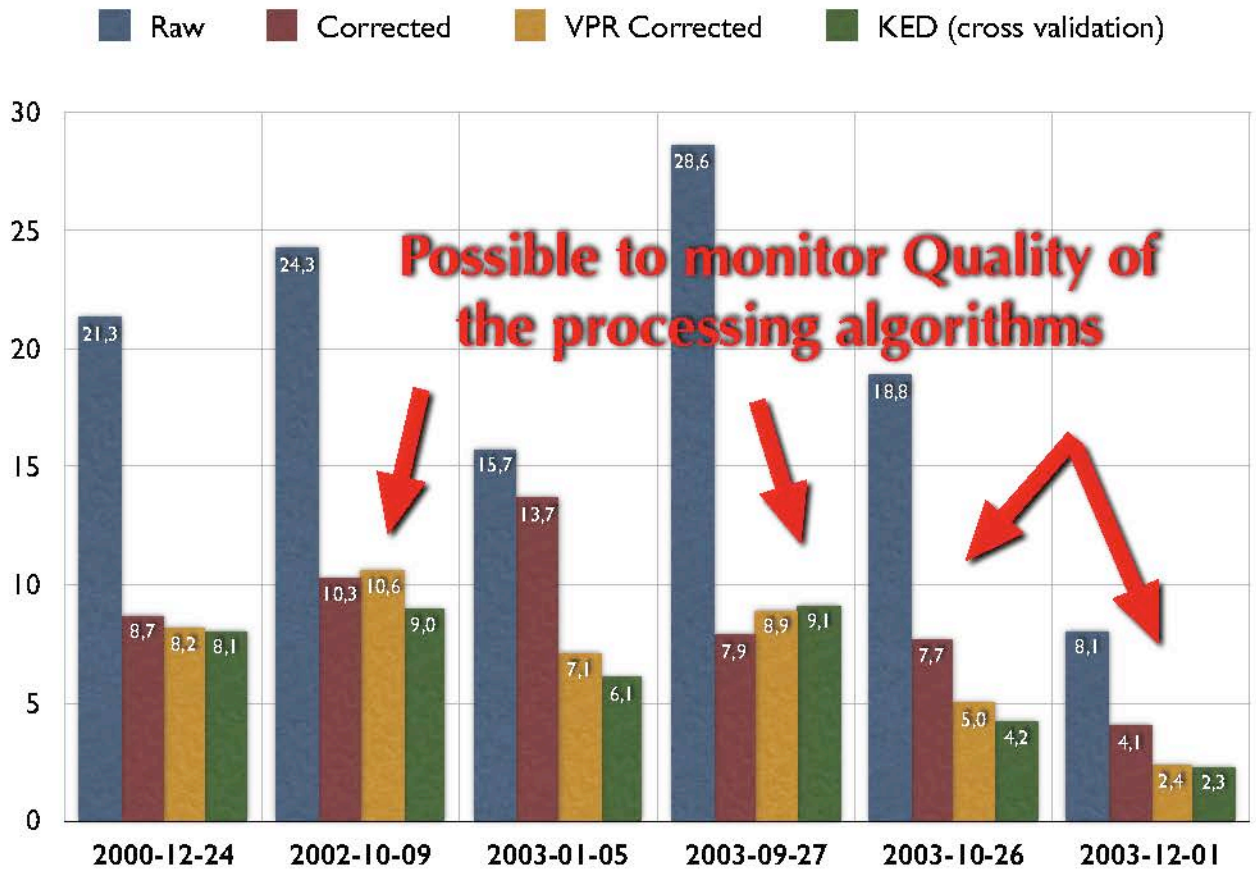


Raw Corrected VPR Corrected KED

RMSE against Raingauges (only at raingauge locations)



RMSE against Raingauges (only at raingauge locations)

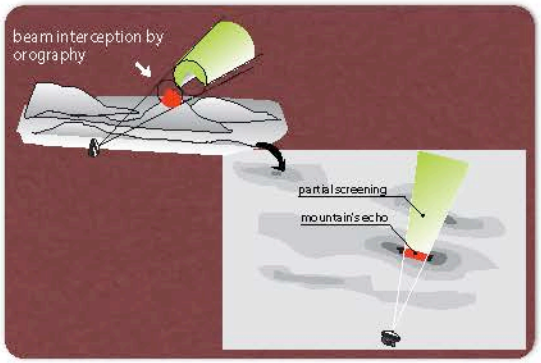


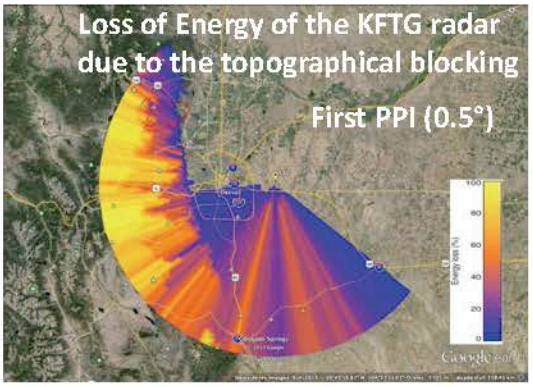
Meteorological Radars and advanced applications

Signal stability and non meteorological clutter processing

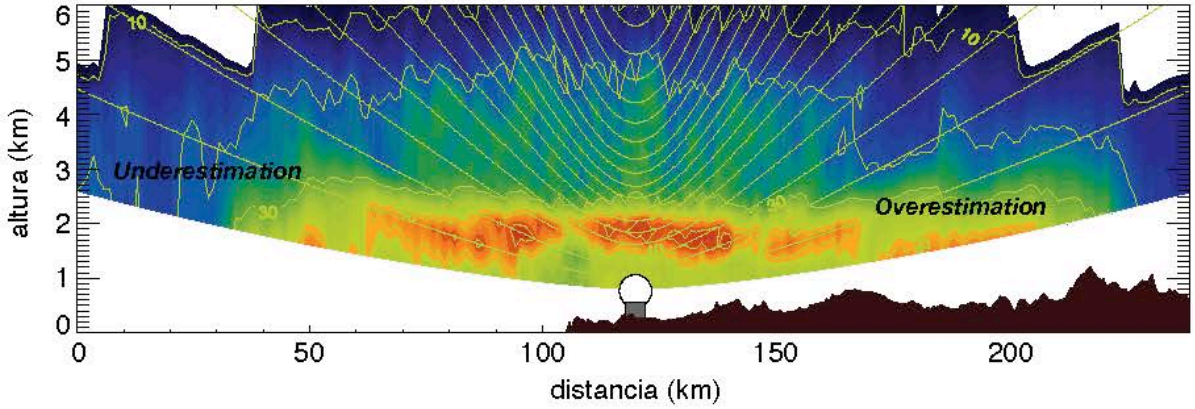
Precipitation type classification VPR and Z-R per types

RAW → **Stage 2** Corrected data → **Stage 3** R at ground ↔ **RAINGAUGE NETWORK**





Vertical Profile of Reflectivity
Extrapolation of elevated reflectivity

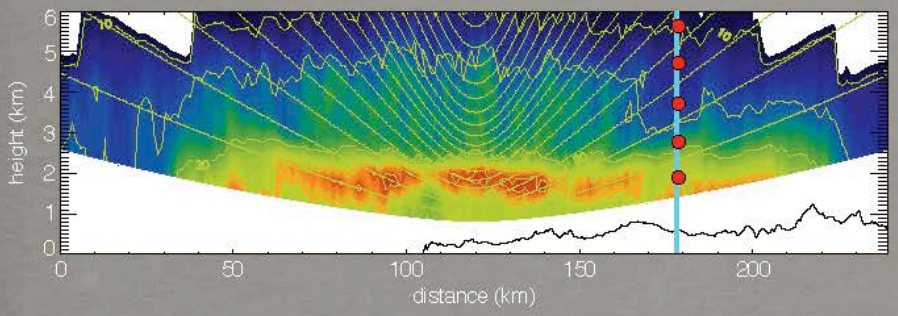


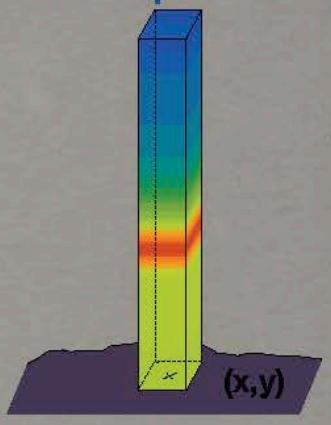
Extrapolate the reflectivity profile to the ground

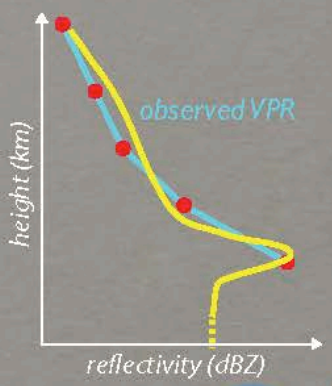
taking extra care of Bright Band contamination

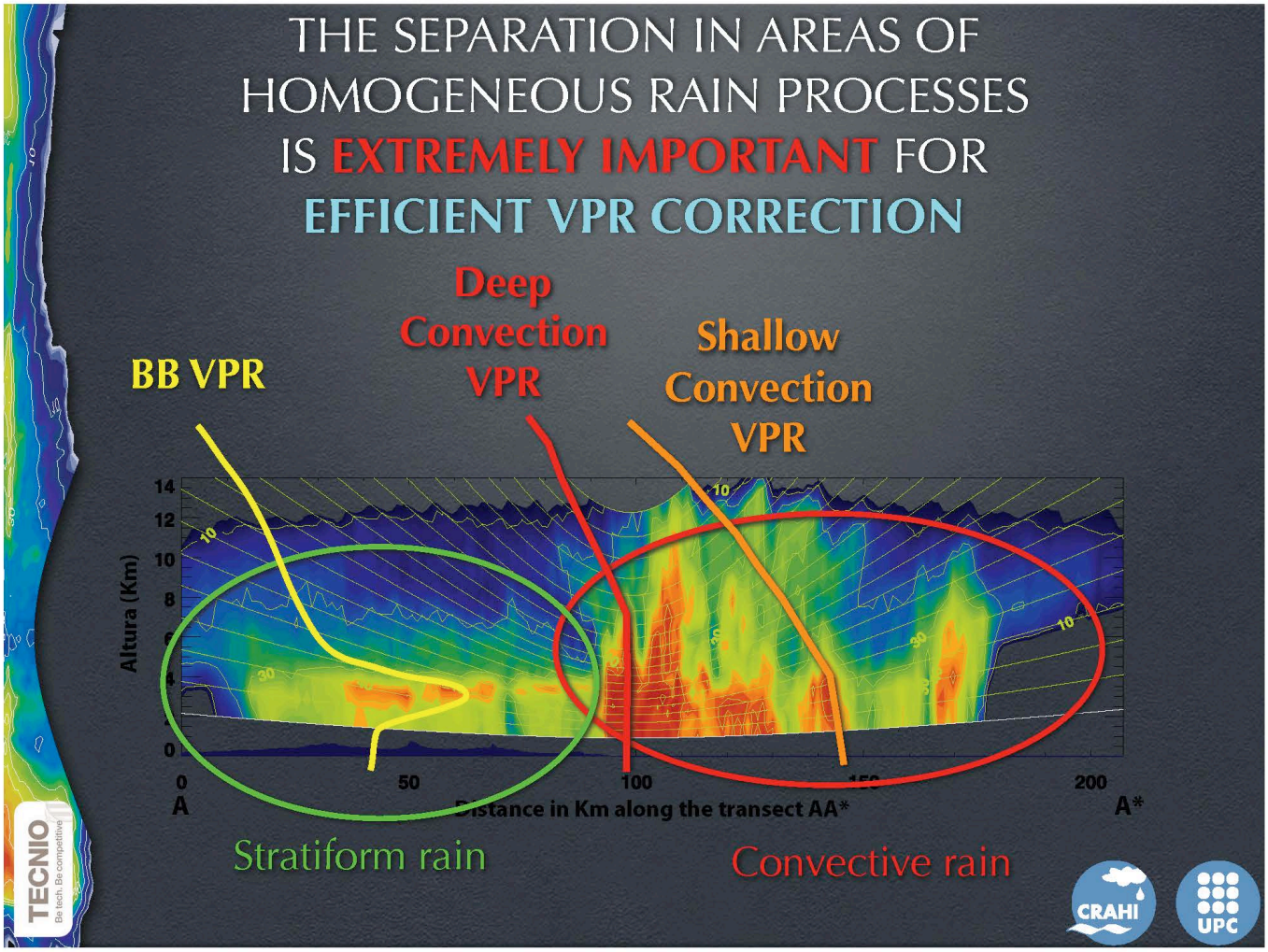
Rainfall estimate at Ground by VPR extrapolation

We need to infere a representative VPR



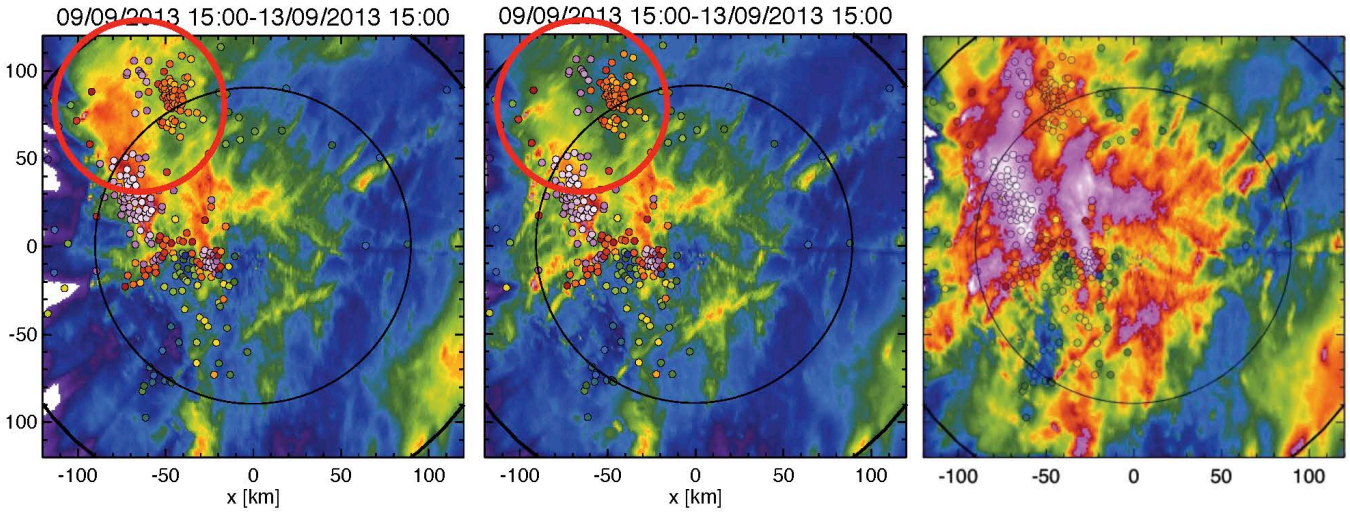








RESULTS

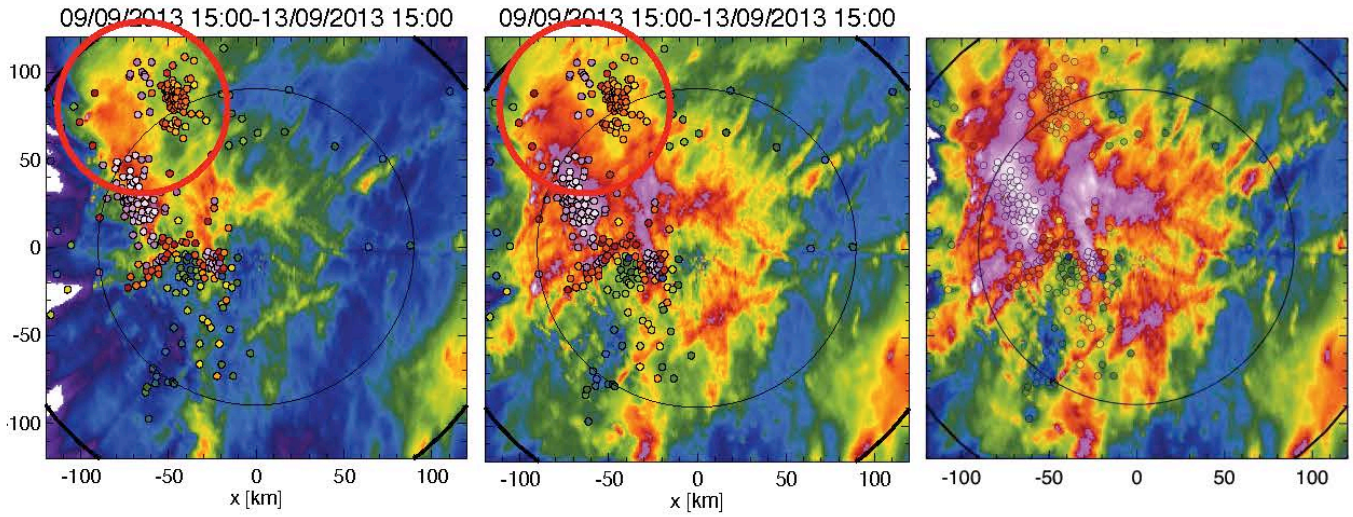


4-day rainfall accumulation UNCORRECTED DATA (NEXRAD as IT IS)

4-day rainfall accumulation CORRECTED DATA (partial blocking + VPR + double ZR)

4-day rainfall accumulation Radar and raingauge blending

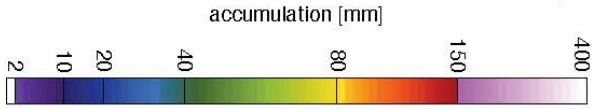
RESULTS: Partial failure of the algorithms due to of a RADAR BIASof around 4 dB



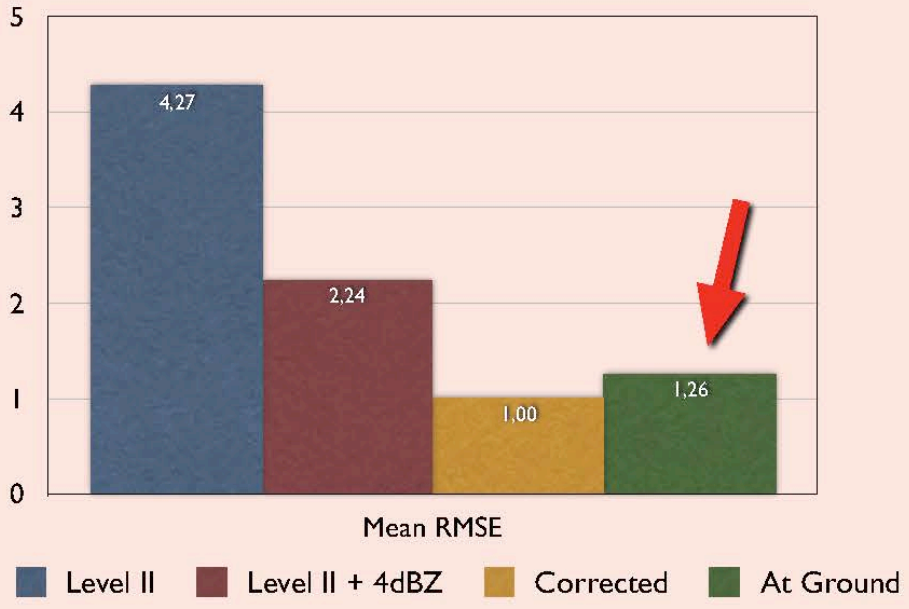
4-day rainfall accumulation UNCORRECTED DATA (NEXRAD as IT IS)

4-day rainfall accumulation CORRECTED DATA **with + 4dB of bias correction**

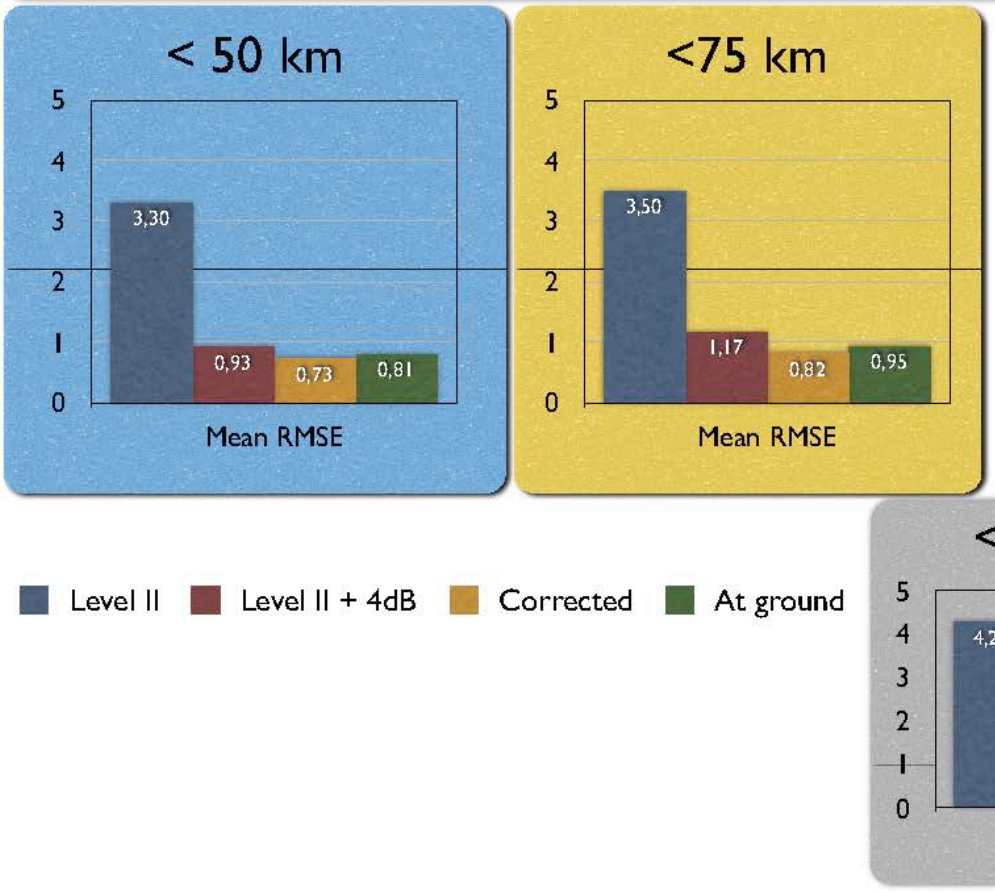
4-day rainfall accumulation Radar and raingauge blending



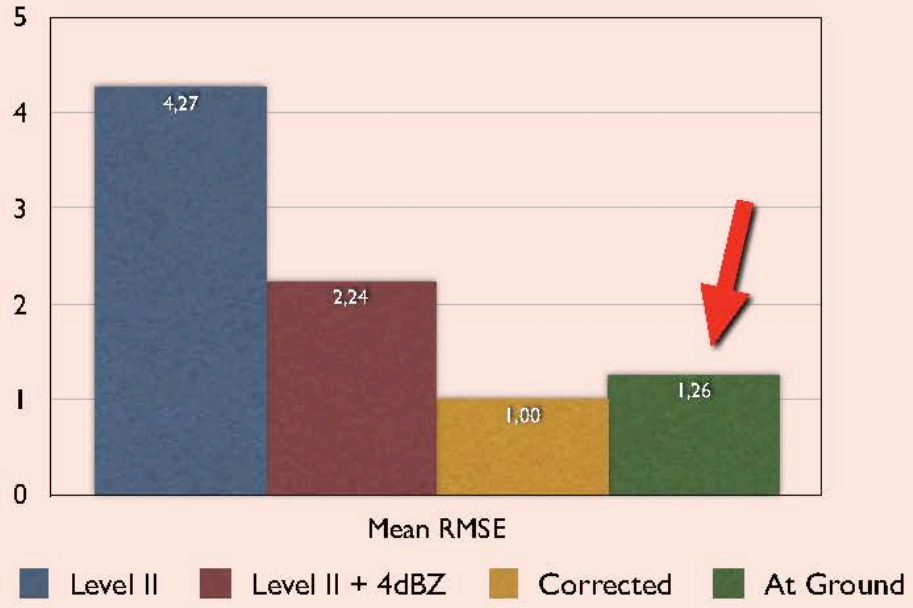
Quantifying the error at the Colorado Flood of September 2013



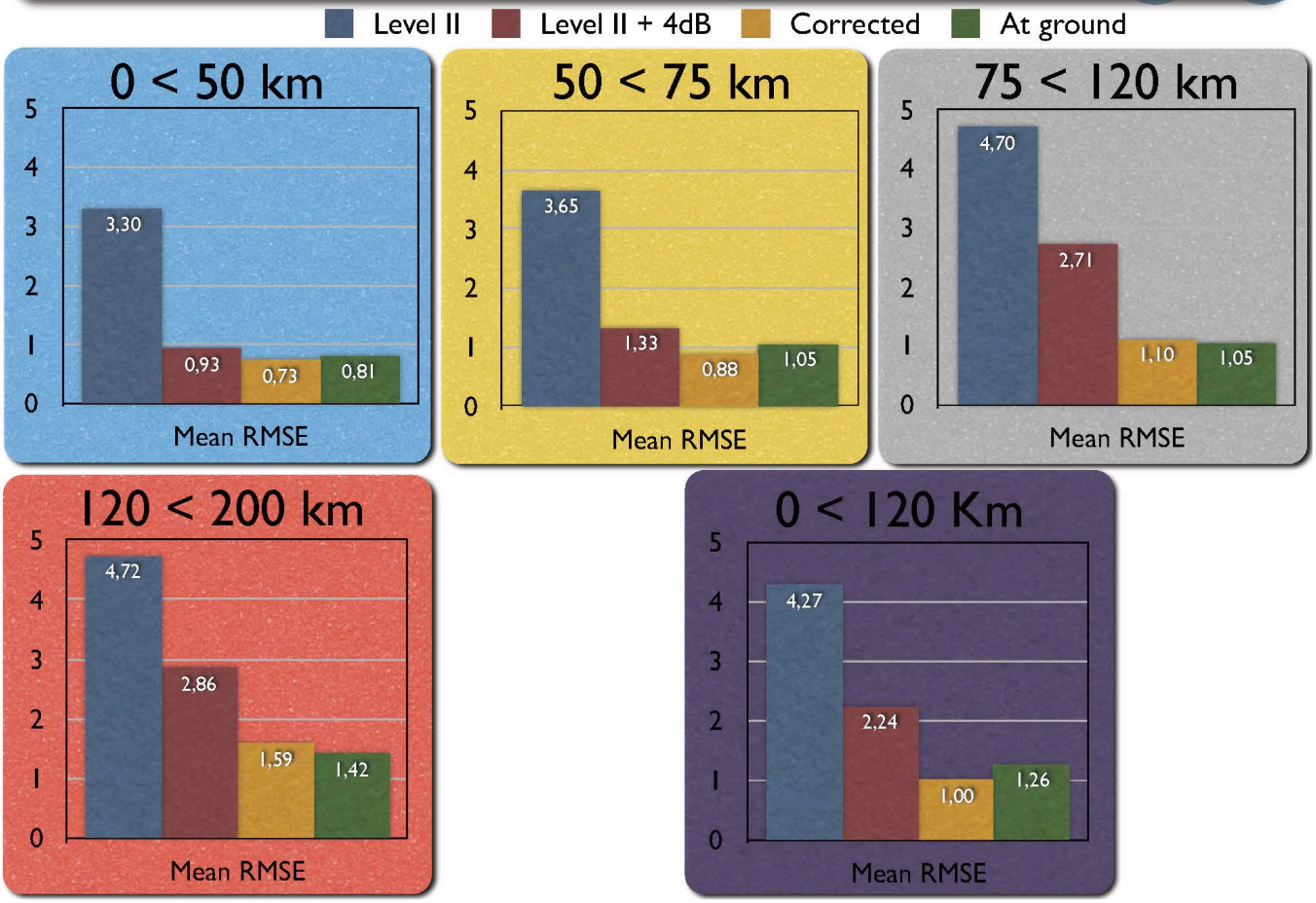
Explore distance effect:



Quantifying the error at the Colorado Flood of September 2013

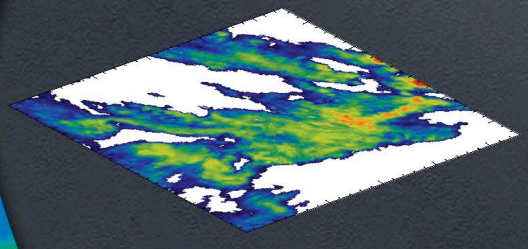


Explore distance effect:



3) Providing uncertainty in a useful way: Producing Radar QPE ensembles

- Compatible with observed fields
- Adding fluctuations/errors **CORRELATED IN SPACE AND TIME**

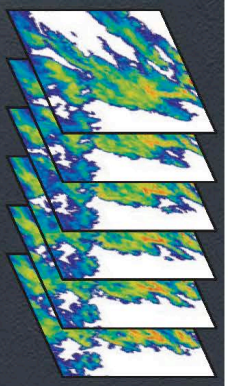


QPE estimate

+

FLUCTUATIONS WITH SPATIAL AND TEMPORAL STRUCTURE

=



TECNIO Be tech. Be competitive

CRAHI

UPC

SIMULATION OF FLUCTUATIONS WITH SPATIAL AND TEMPORAL CORRELATION

Fluctuation without structure

+

Model of spatial and temporal structure

→

F′
Fluctuation field with spatial and temporal structure

TECNIO Be tech. Be competitive

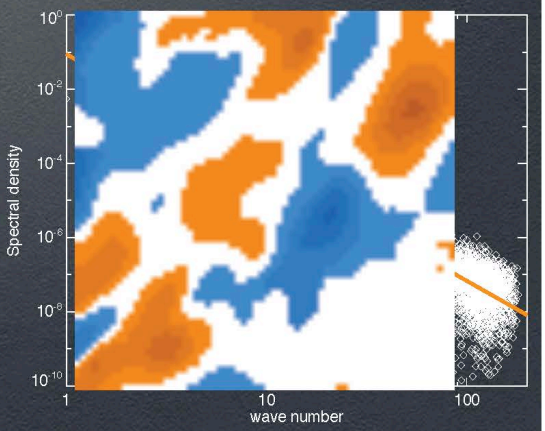
CRAHI UPC

SIMULATION OF FLUCTUATIONS WITH SPATIAL AND TEMPORAL CORRELATION

Fourier Spectrum (3D)

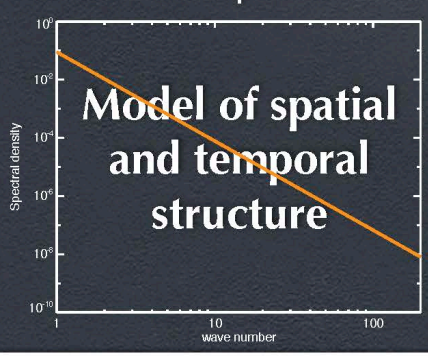


FFT



F′

+

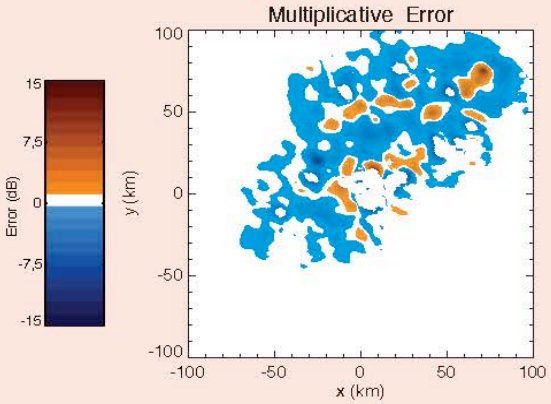


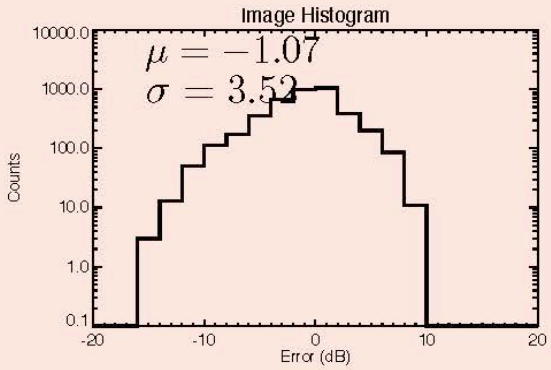
TECNIO Be tech. Be competitive

CRAHI UPC

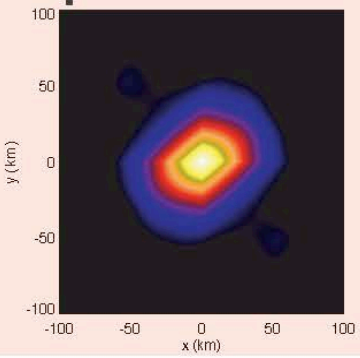
Multiplicative Error analysis

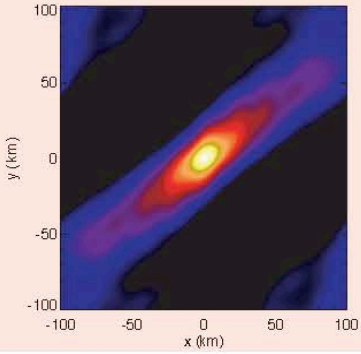
Frequency Distribution of errors (1 time step)



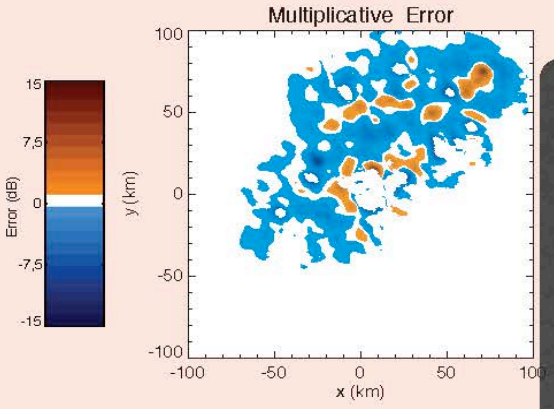


Spatial Correlation (different time steps)

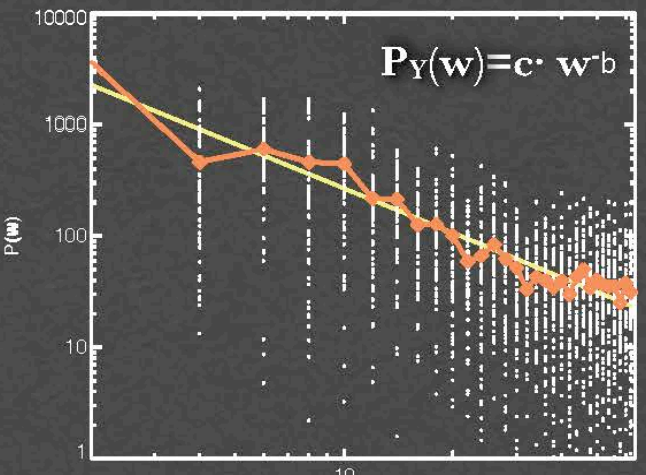




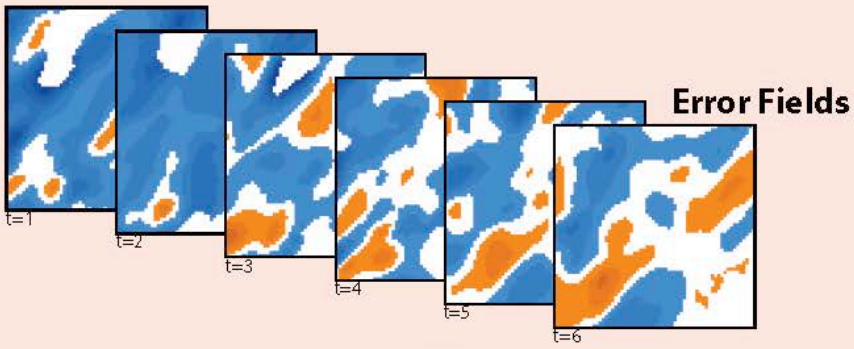
Multiplicative Error analysis

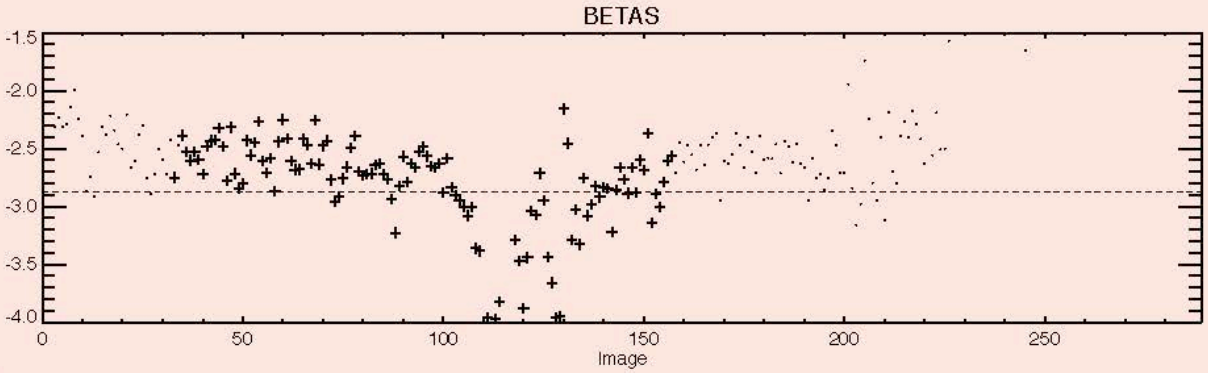


Power Spectrum in space



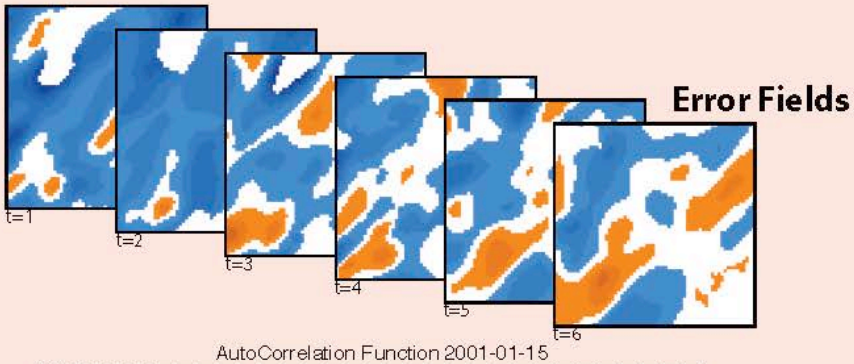
Multiplicative Error analysis

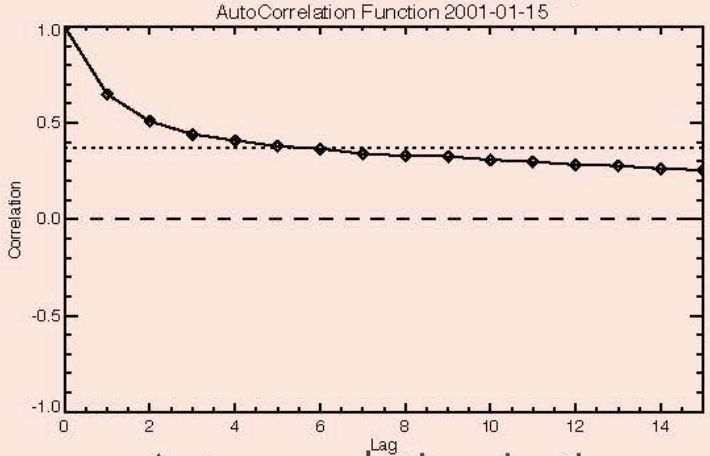




Evolution of the BETA in time

Multiplicative Error analysis

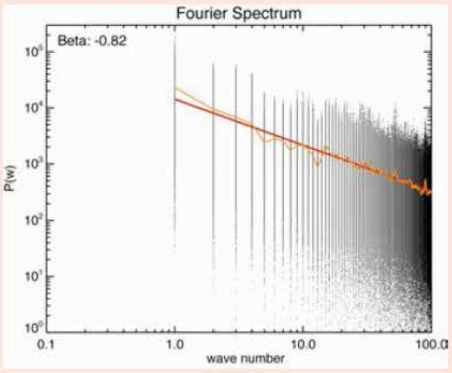


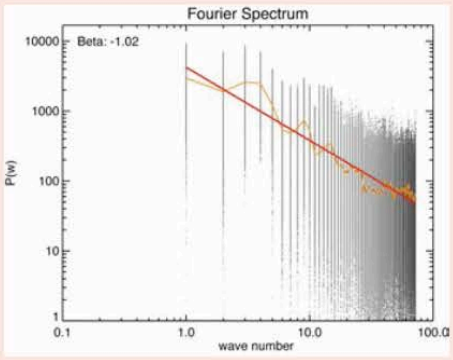


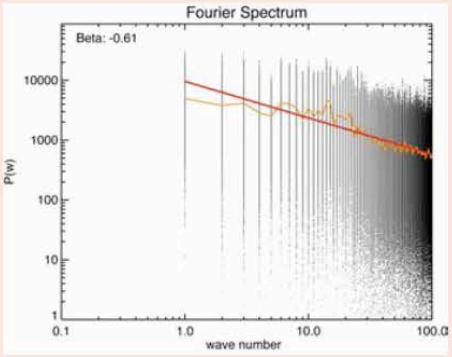
Autocorrelation in time

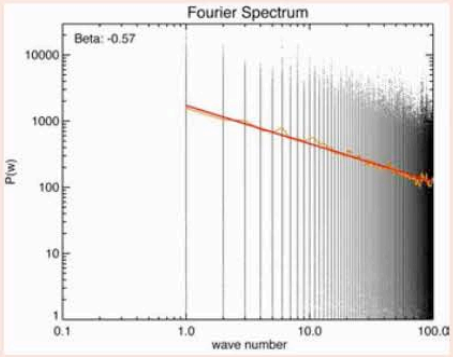
Assessment of temporal structure of errors

Average and pixel-based temporal spectra of errors (dB)



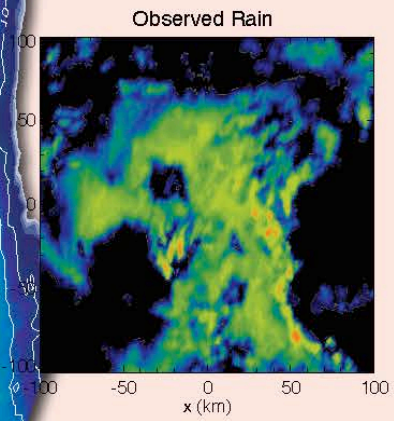


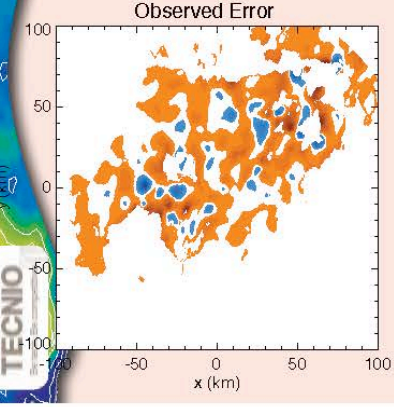


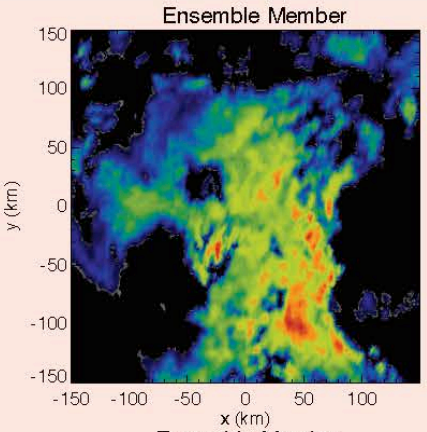


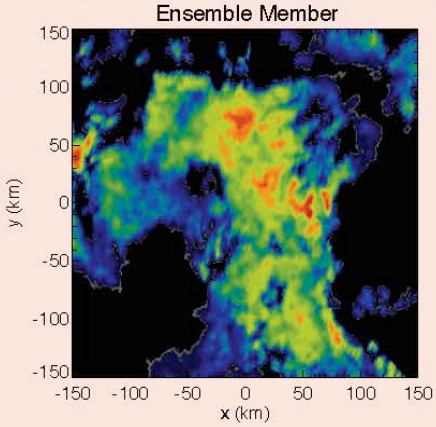
Application: Generation of radar ensembles

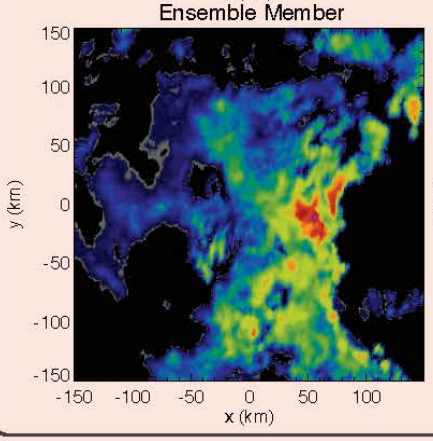
4 equiprobable precipitation fields

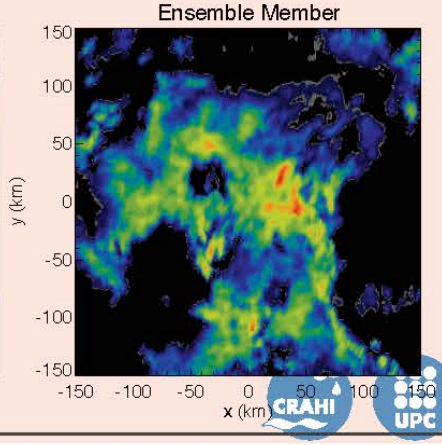




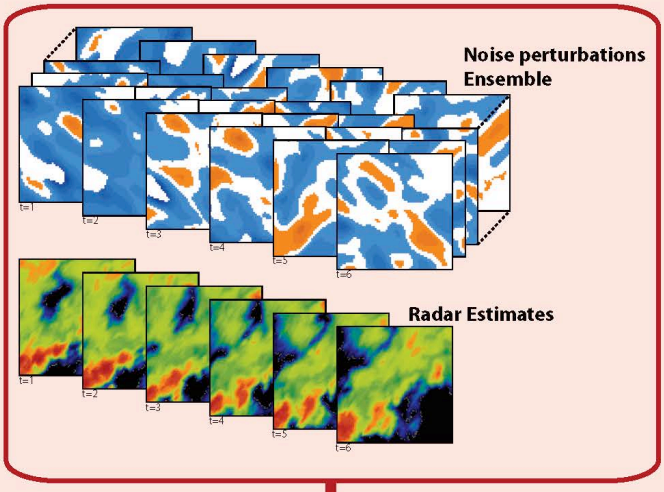




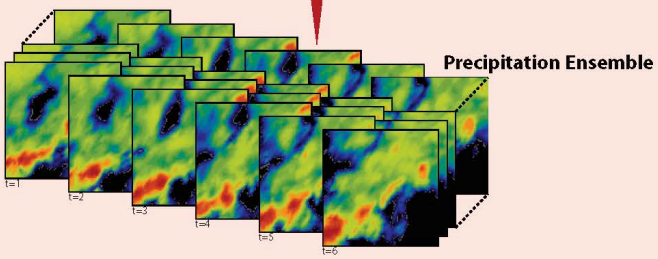


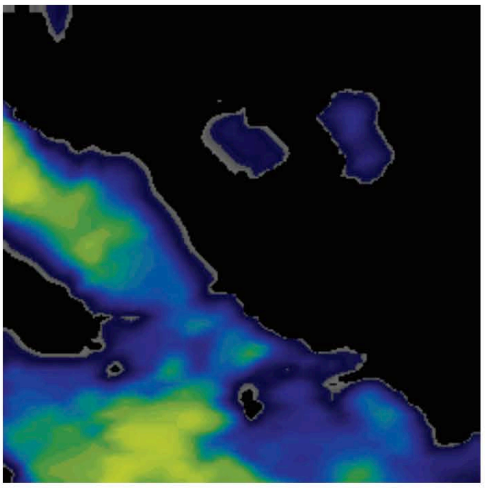


Application: Generation of radar ensembles

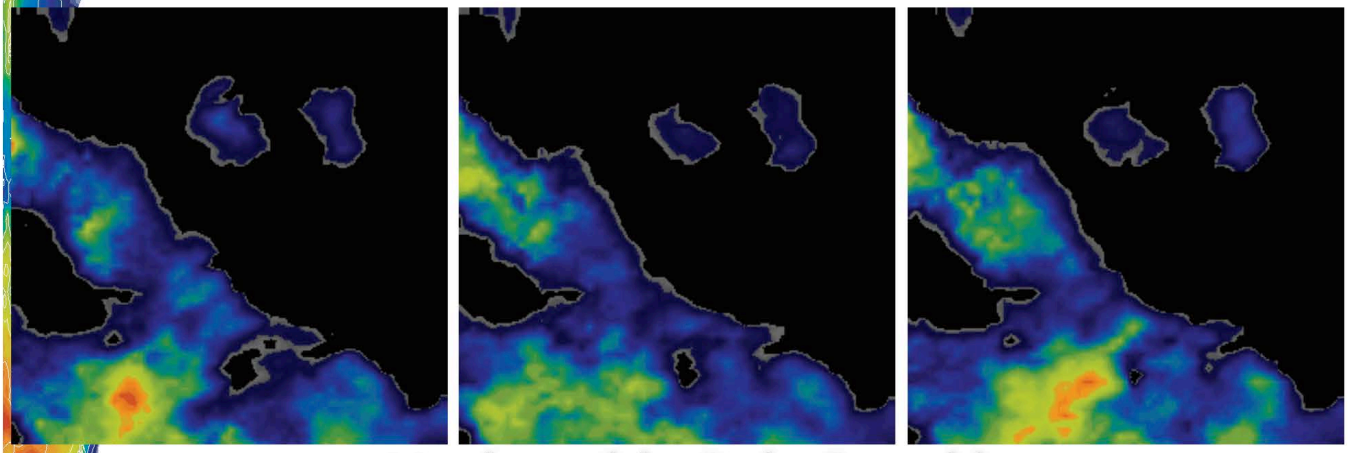


$$\mathcal{E}(t) = R_{rad}(t) \cdot 10^{\delta(t)/10}$$



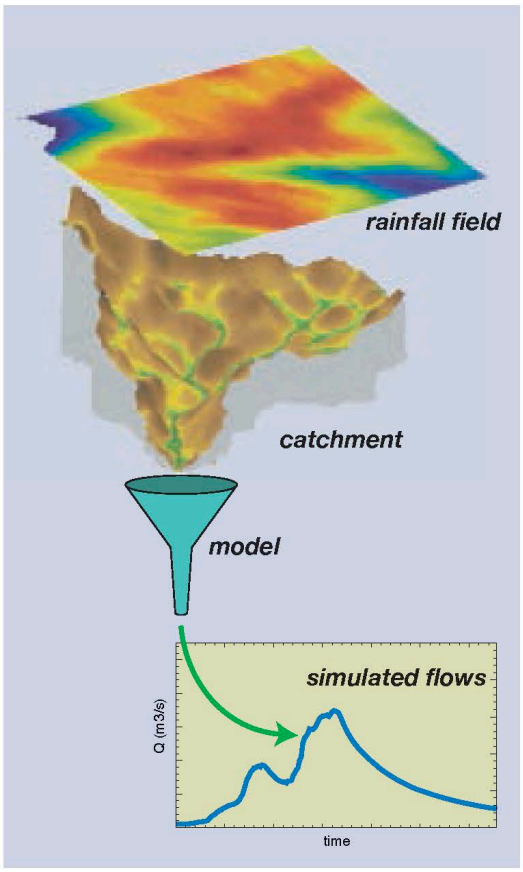


Radar Observed



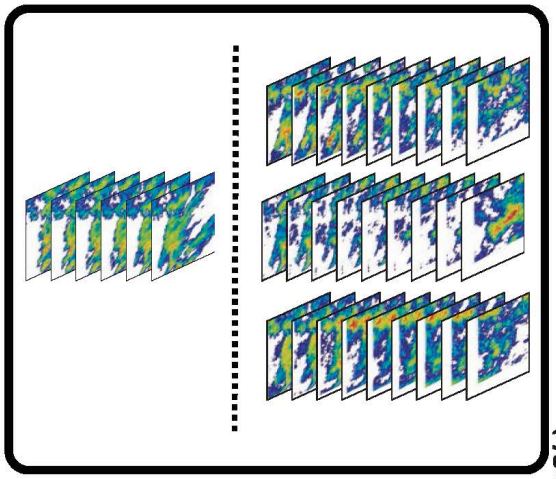
Members of the Radar Ensemble

Hydrological application

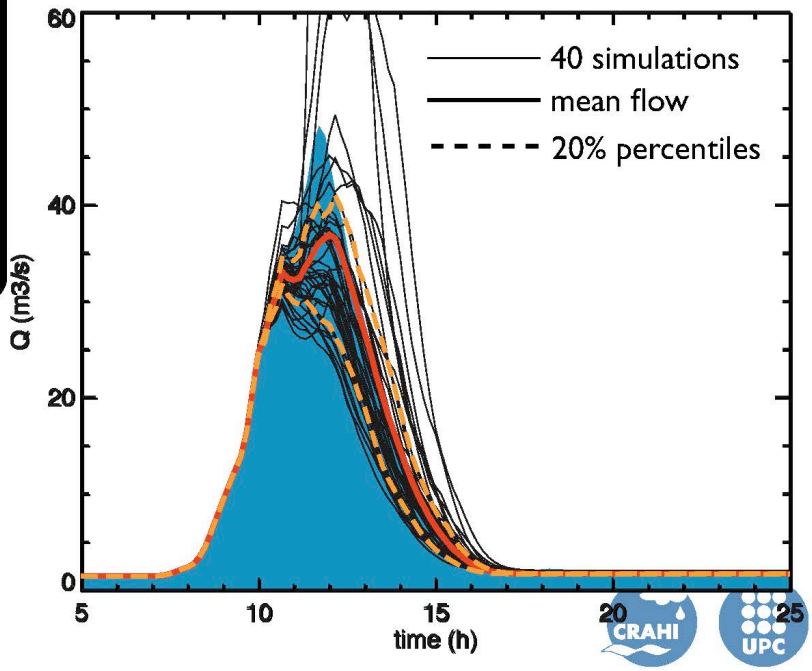


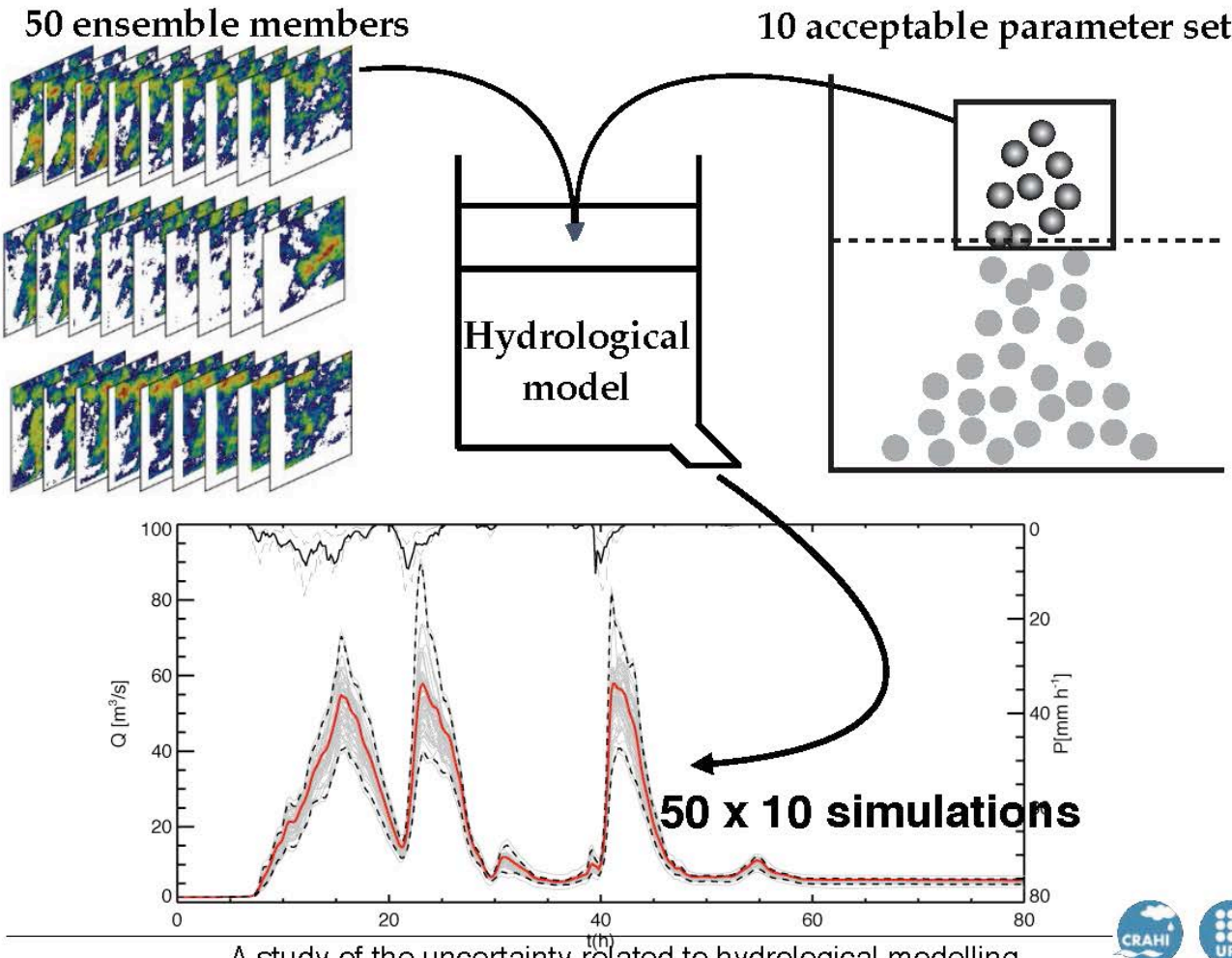
Application

Uncertainty in flow forecasts

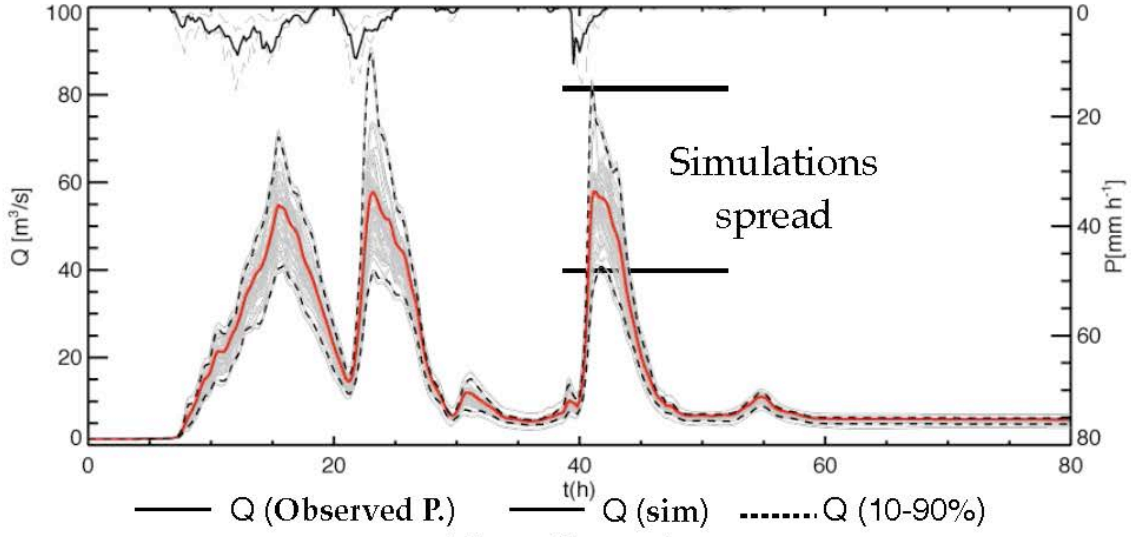


Hydrological model





Quantifying the effect of uncertainty



Mean Spread

$$\bar{D}_Q = \frac{\bar{Q}_{90} - \bar{Q}_{10}}{\bar{Q}_{Pobs}}$$

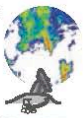
hydrometeorological
innovative solutions

Advanced products and services using radar: Flood-EWS for cities and Aviation products

8th April 2016

Data

Weather Radar Data



NWP Data



Raingauges Sensors



Aditional Data

background information



users information

EWS

Autoprotection Plans.

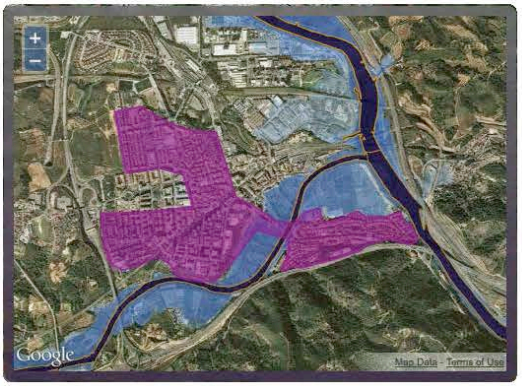
Protocols.

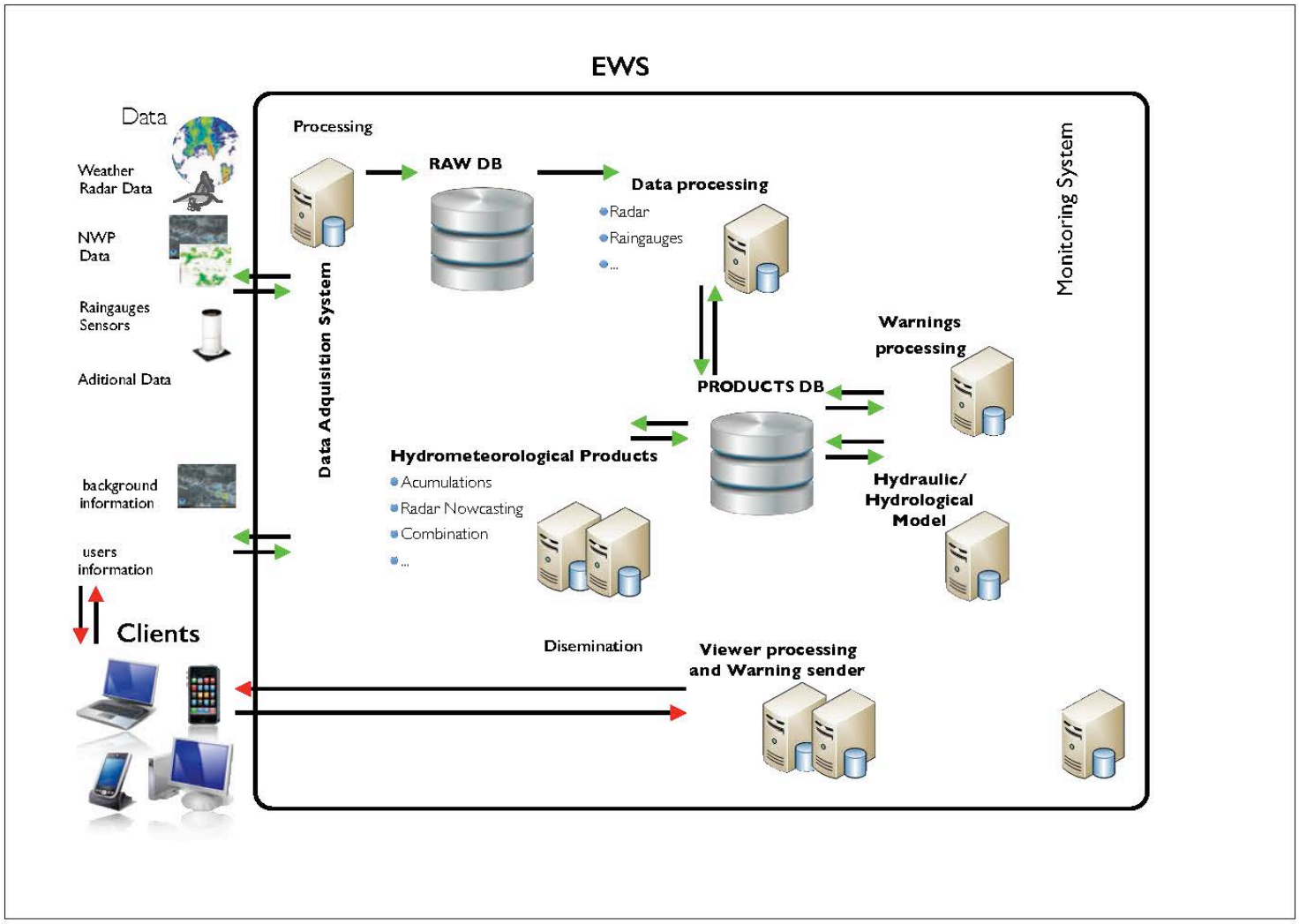
Impact: costs, etc.

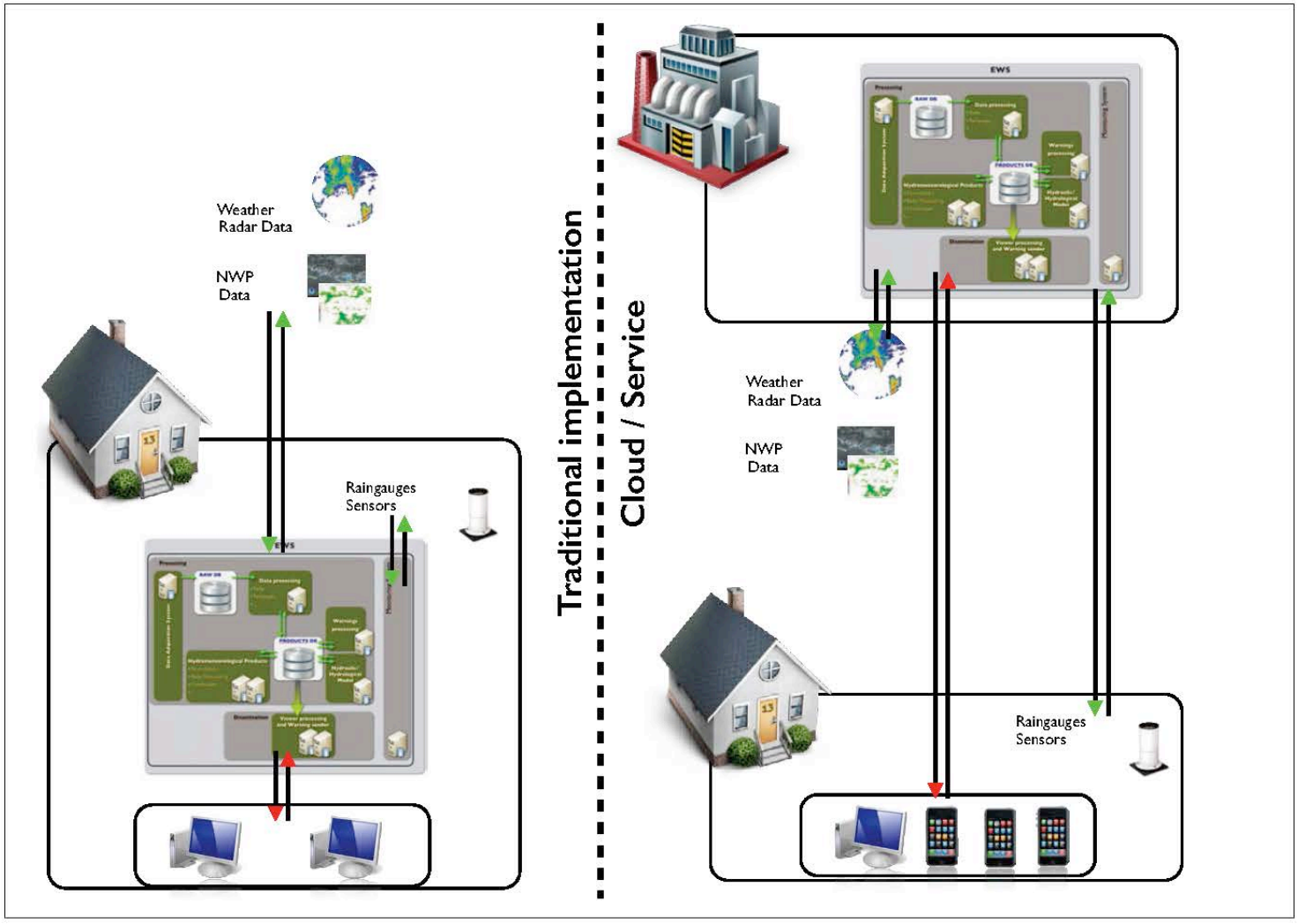
Parametrizations.

User profiles.

...




EWS
Data
Weather Radar Data
NWP Data
Raingauges Sensors
Aditional Data
background information
users information
Clients
Processing
RAW DB
Data processing
Radar
Raingauges
...
Data Adquisition System
Monitoring System
Warnings processing
PRODUCTS DB
Hydrometeorological Products
Acumulations
Radar Nowcasting
Combination
...
Hydraulic/ Hydrological Model
Disemination
Viewer processing and Warning sender


Traditional implementation
Cloud / Service
Weather Radar Data
NWP Data
Raingauges Sensors
EWS
Weather Radar Data
NWP Data
Raingauges Sensors

Services for Urban Flood EWS

- Scalable system
  - Adaptable to user needs
  - Base on modules for different purposes

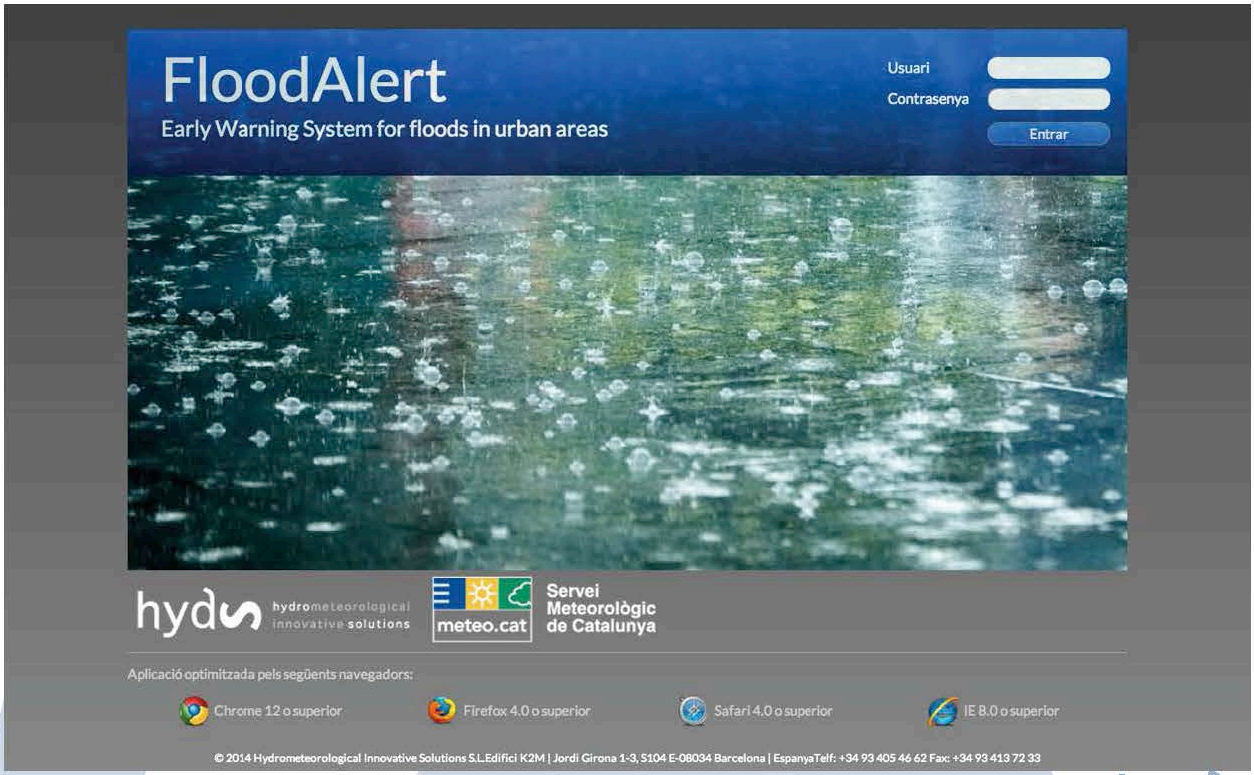
Hidromet

FloodAlert

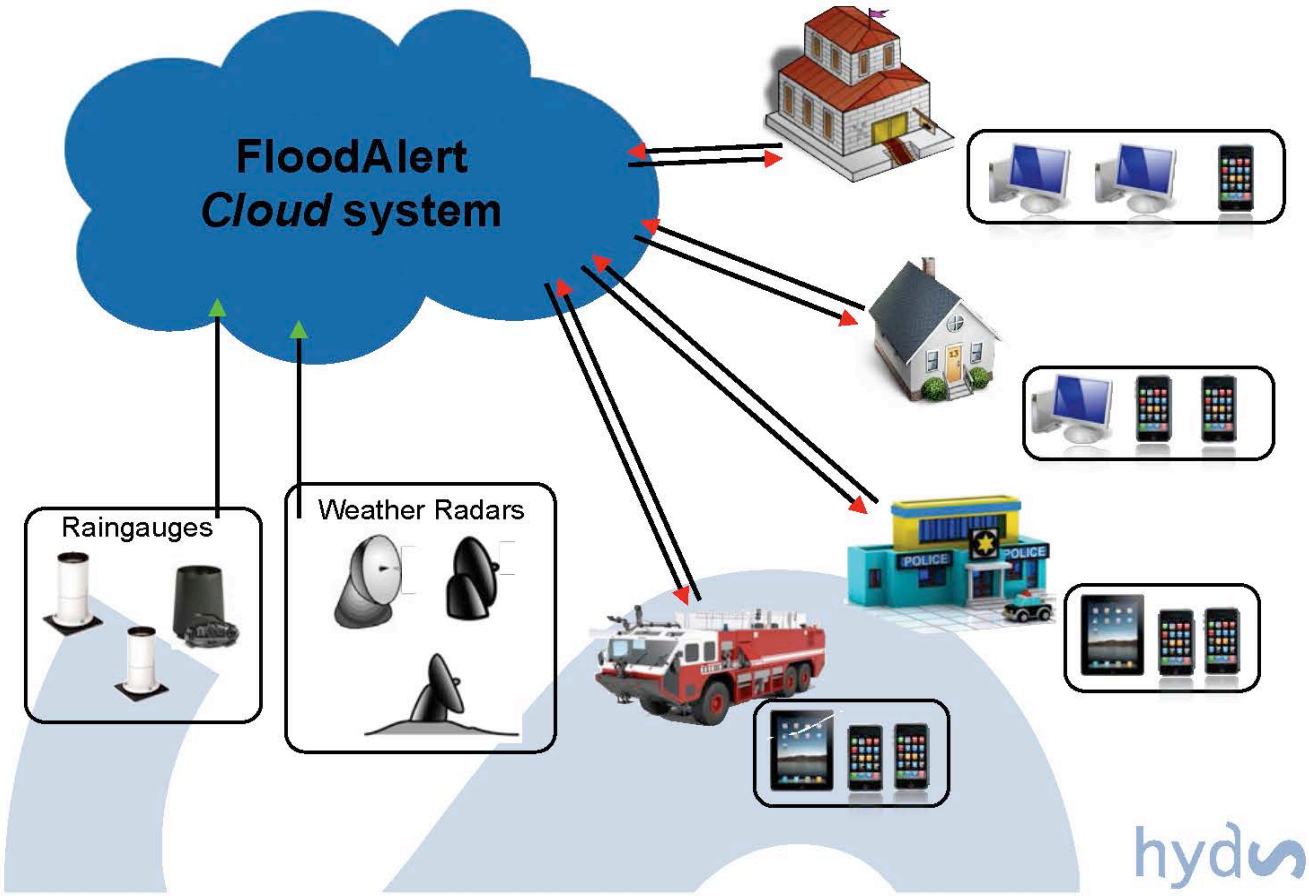
WiCast

- WiCast: Radar Nowcasting + NWP models forecasts
- FloodAlert: WiCast + Intelligent area accumulation
- Hidromet: FloodAlert + Hydraulic/hydrological model

FloodAlert: EWS for urban flood warning



FloodAlert: EWS for urban flood warning



FloodAlert: EWS for urban flood warning

Weather radar process

Past

Raw:

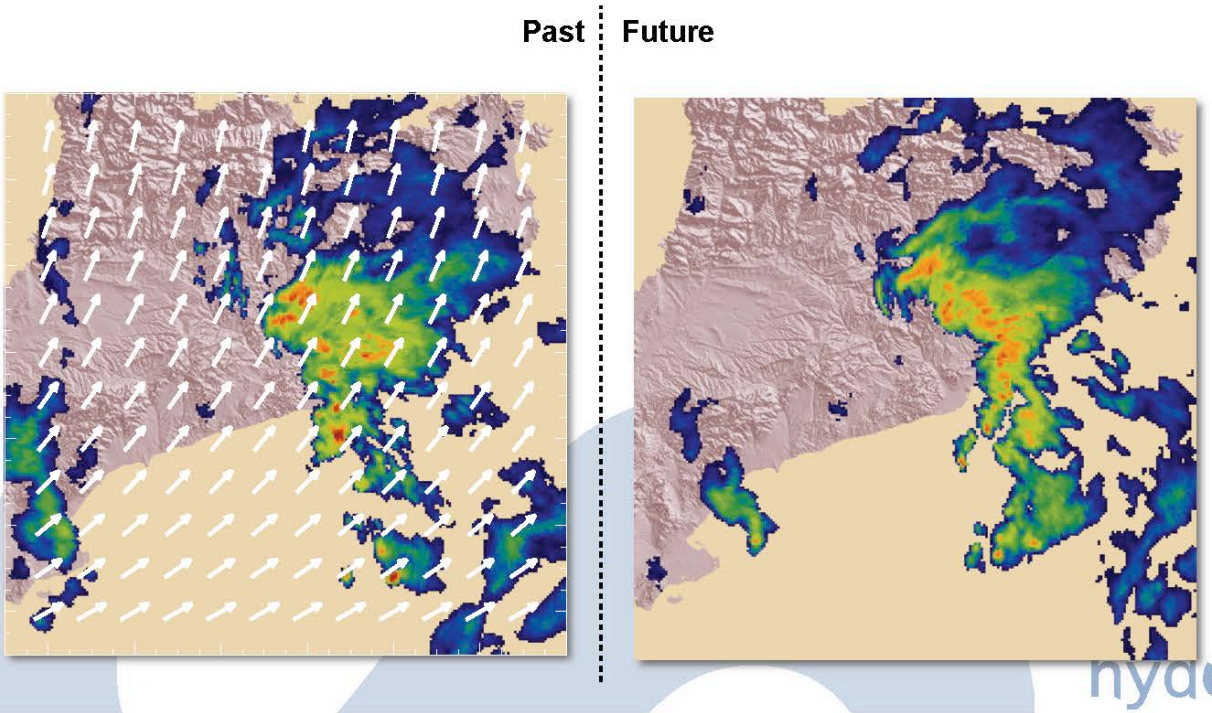
Calibration
Quality Control

Instantaneous:

FloodAlert: EWS for urban flood warning

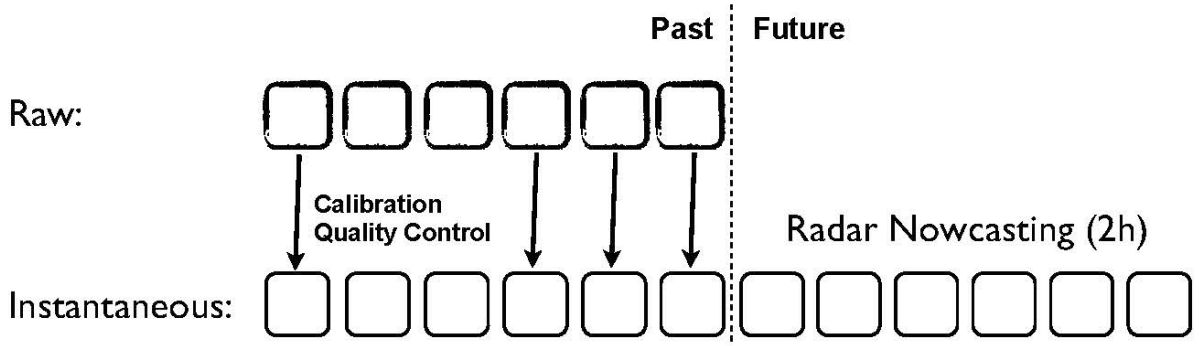
Based on radar rainfall estimations and short term radar-nowcasting

Nowcasting Technique (2h forecast)



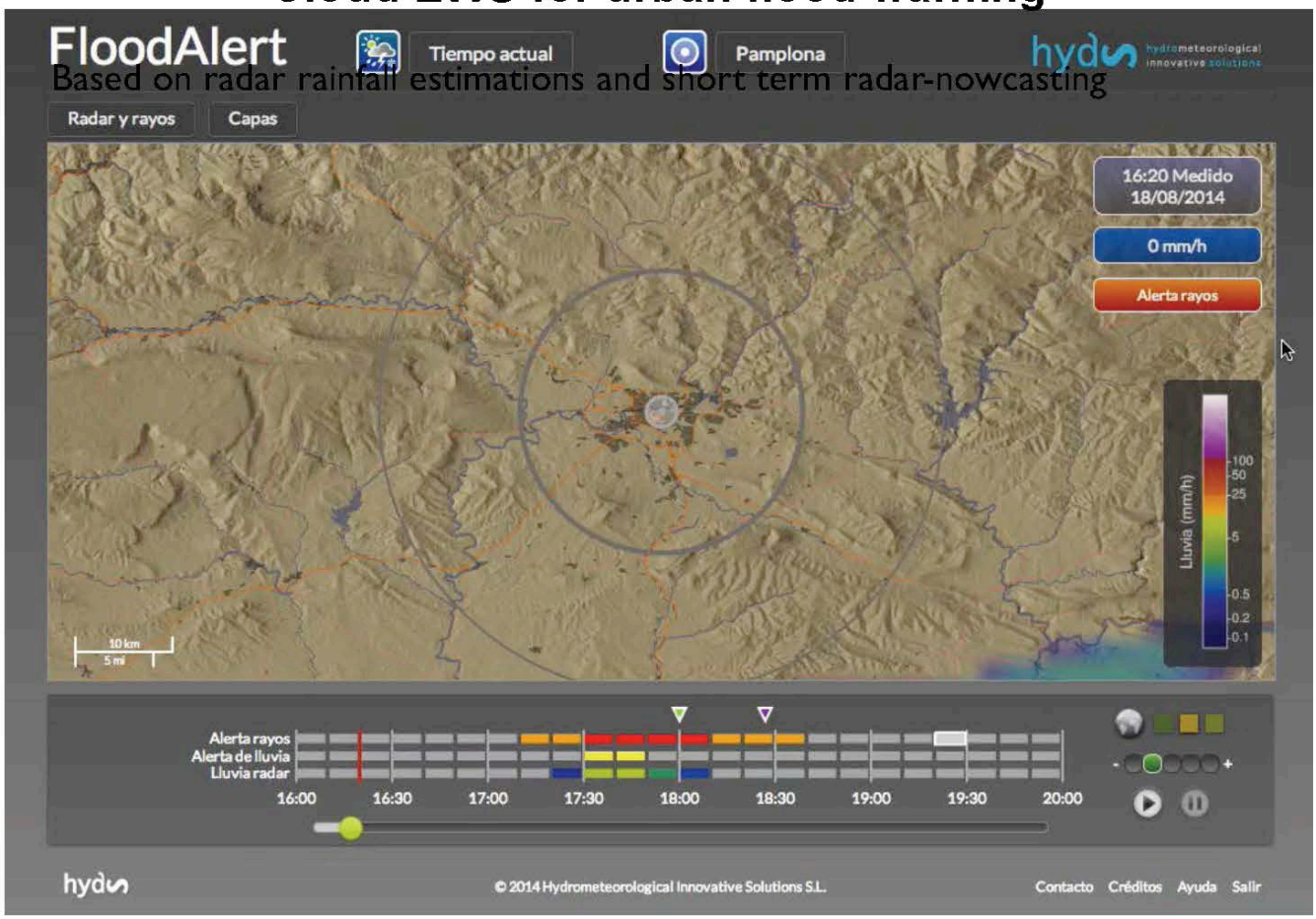
FloodAlert: EWS for urban flood warning

Weather radar process

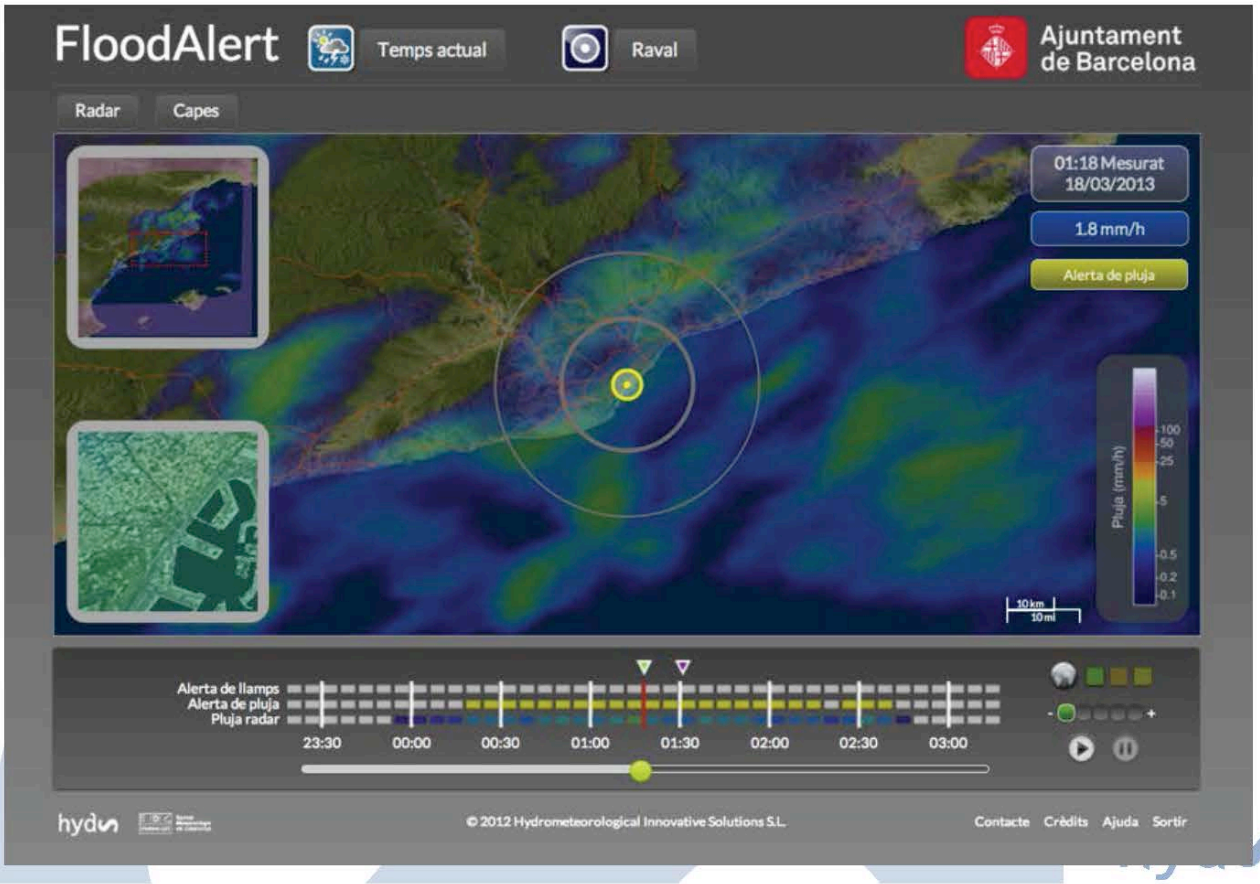


Cloud EWS for urban flood warning

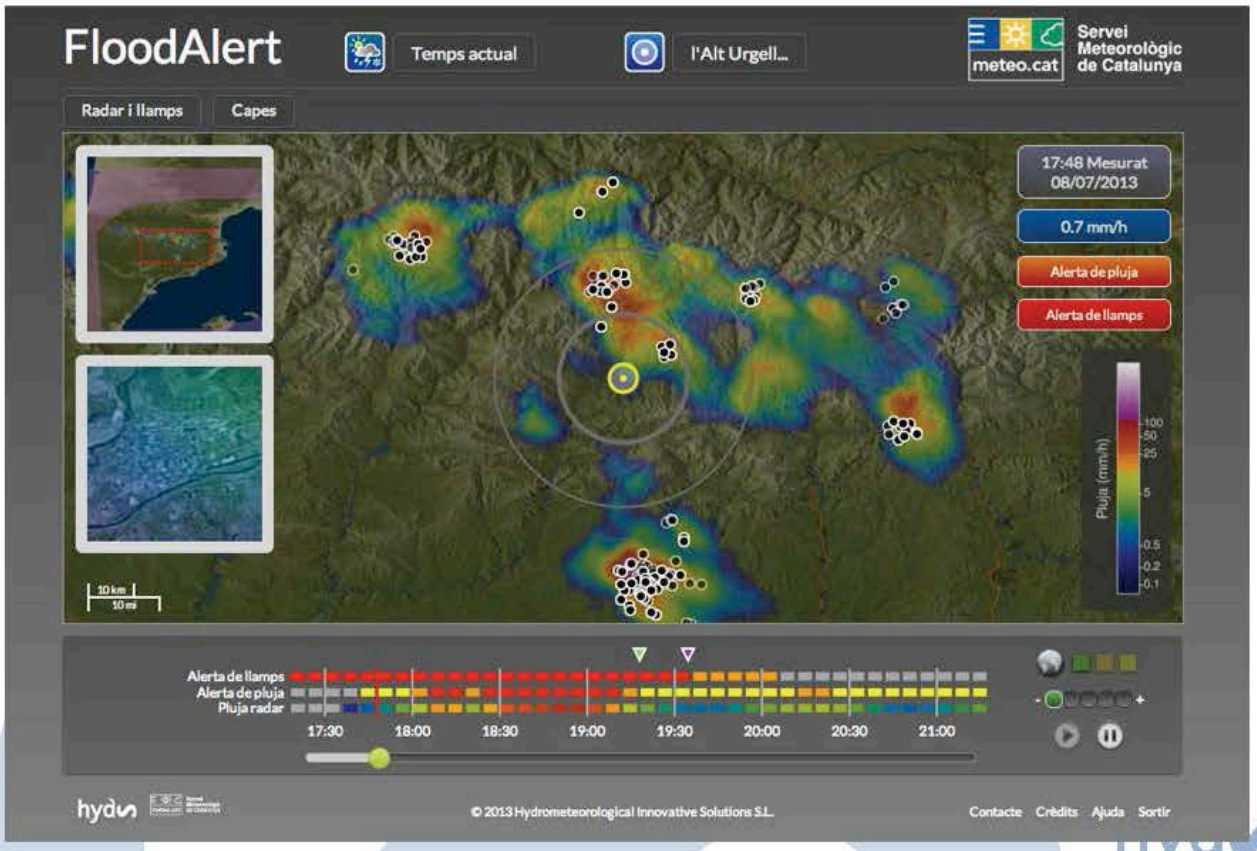
Based on radar rainfall estimations and short term radar-nowcasting



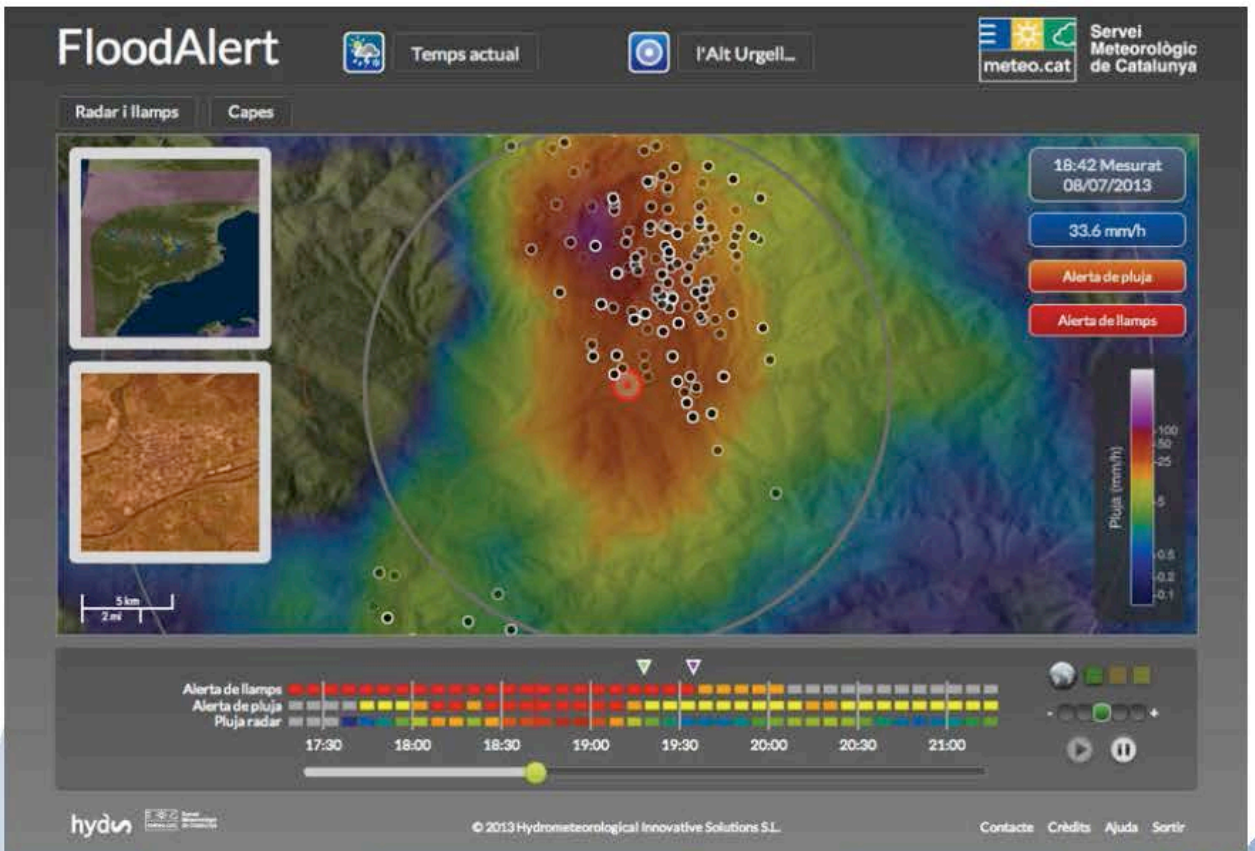
FloodAlert: EWS for urban flood warning



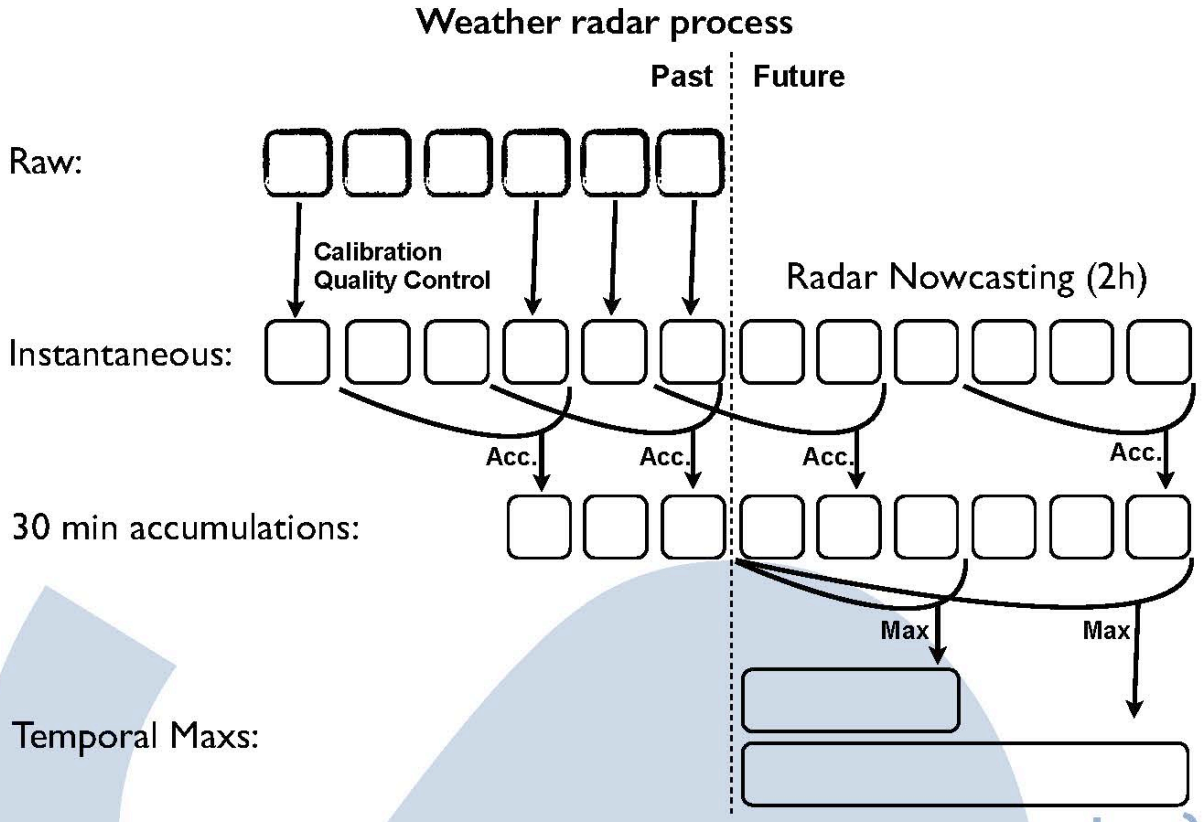
FloodAlert: EWS for urban flood warning



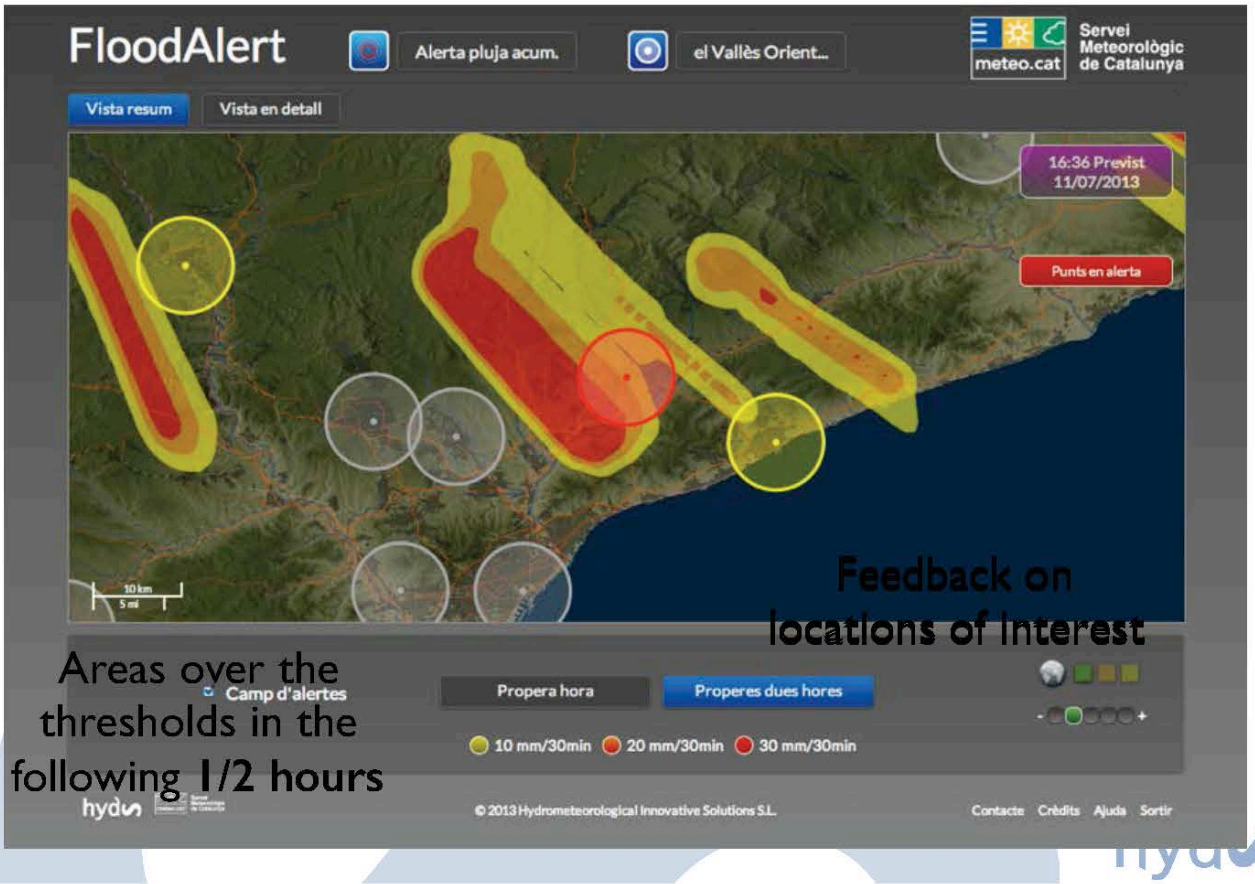
FloodAlert: EWS for urban flood warning



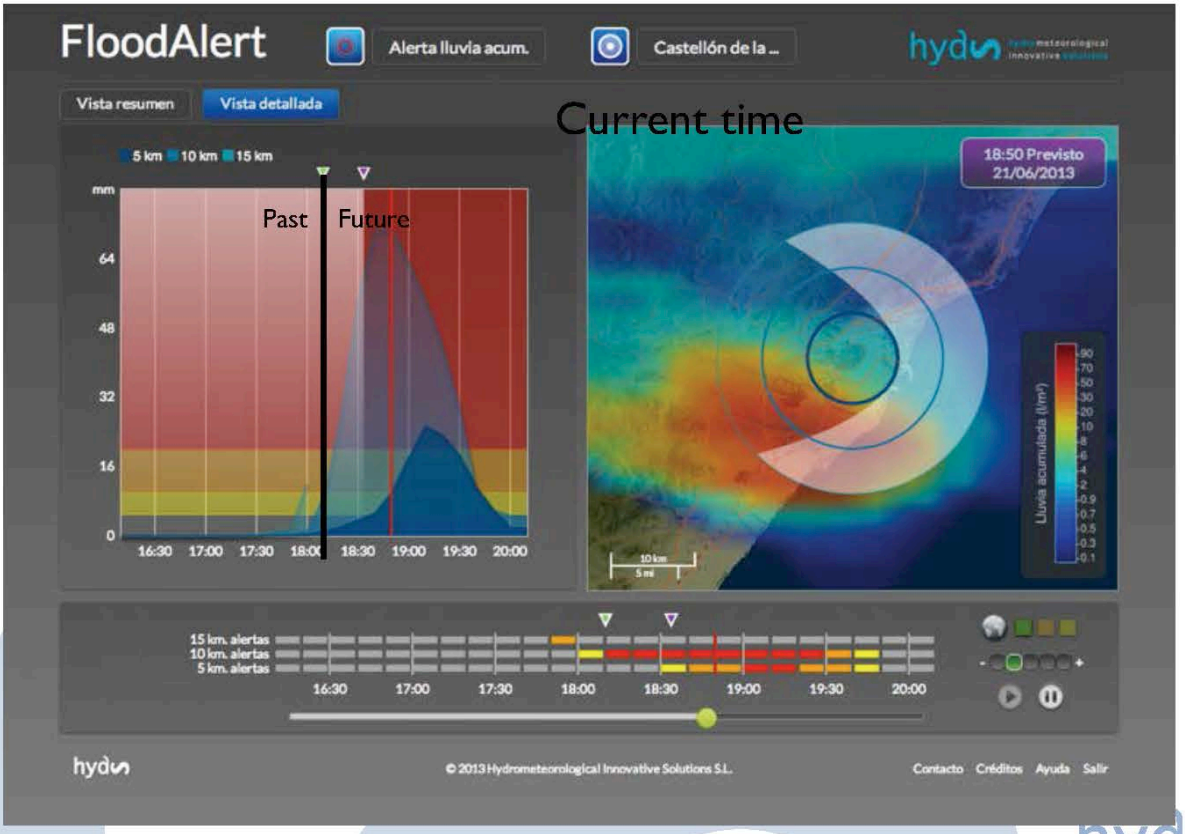
FloodAlert: EWS for urban flood warning



FloodAlert: EWS for urban flood warning



FloodAlert: EWS for urban flood warning



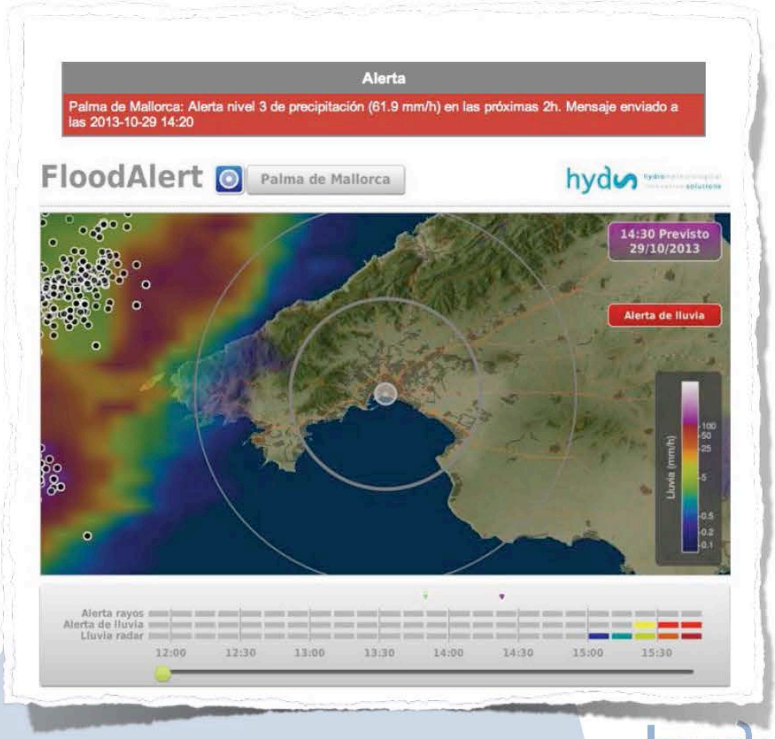
FloodAlert: EWS for urban flood warning



- Mail and SMS warnings acording to user-defined profiles
- Warnings in case of no availability and when service recovers

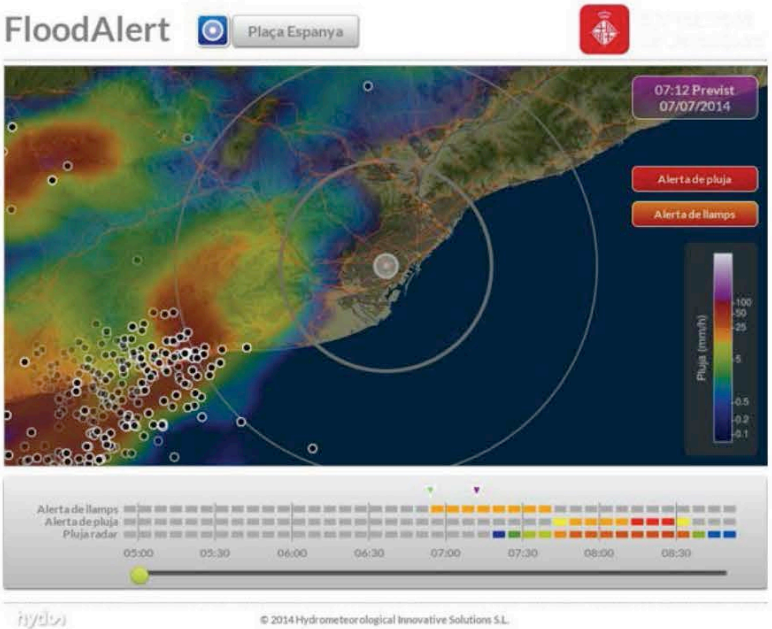
FloodAlert: EWS for urban flood warning





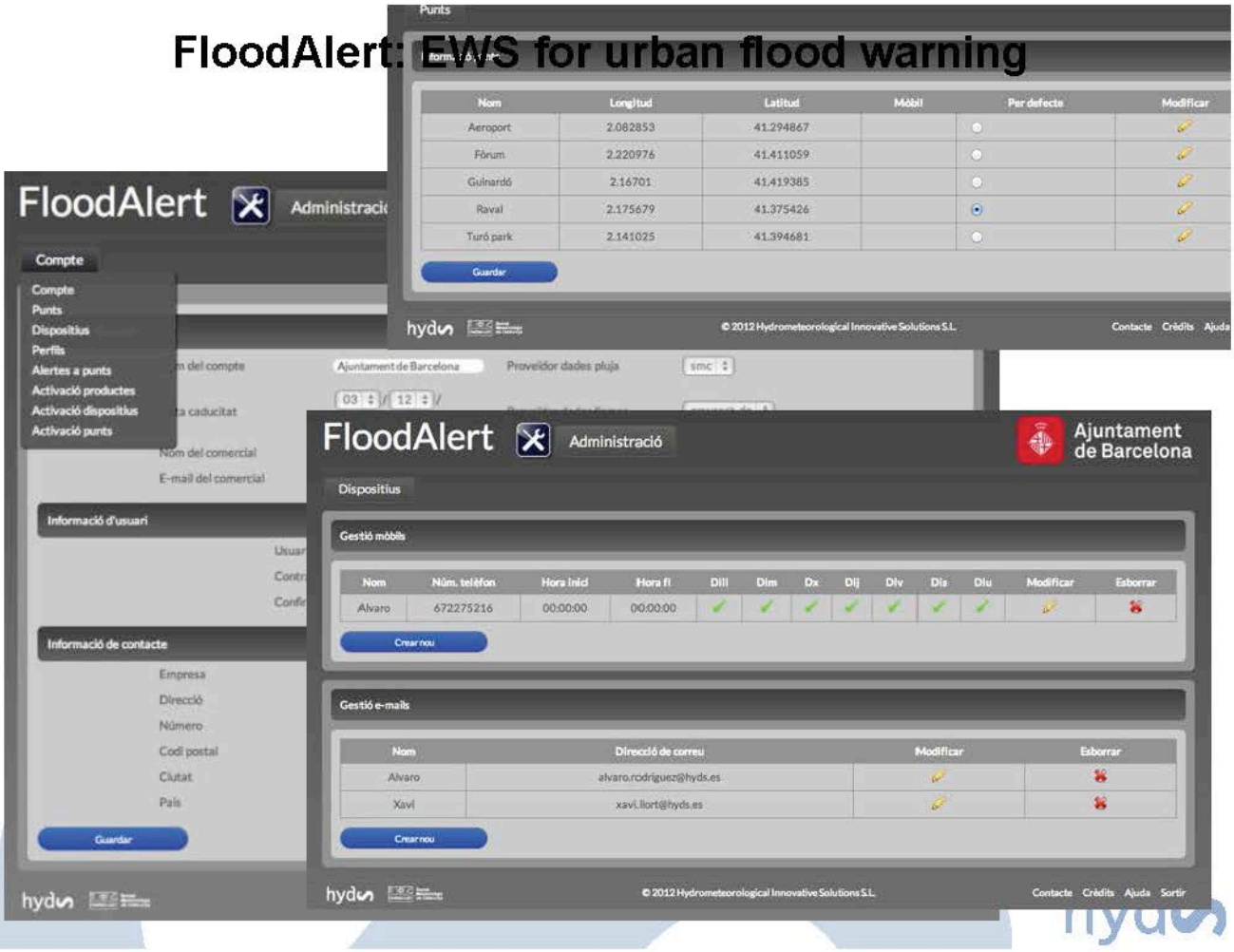
FloodAlert: EWS for urban flood warning



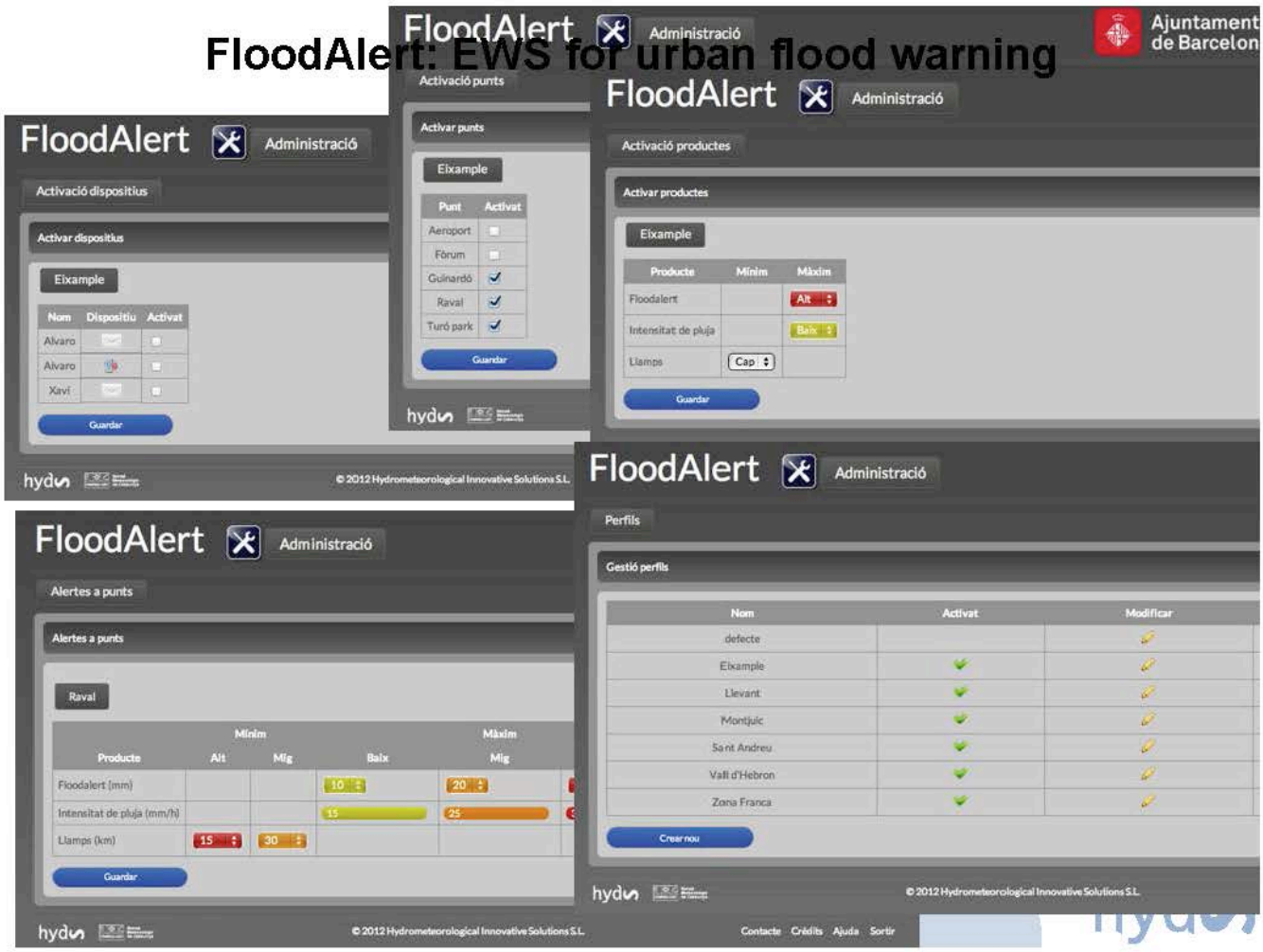




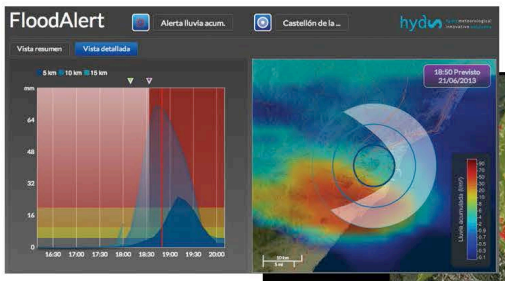
FloodAlert: EWS for urban flood warning



FloodAlert: EWS for urban flood warning



FloodAlert dynamic link with pre-calculated maps

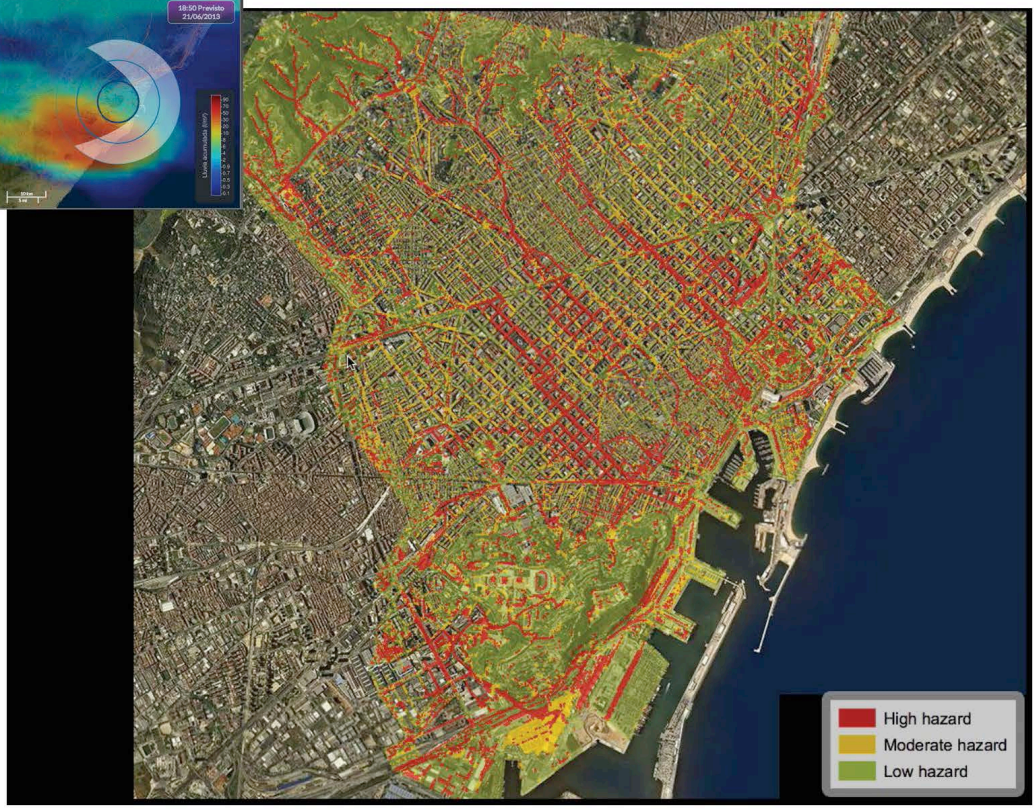


Linked dynamically in real time according to return periods

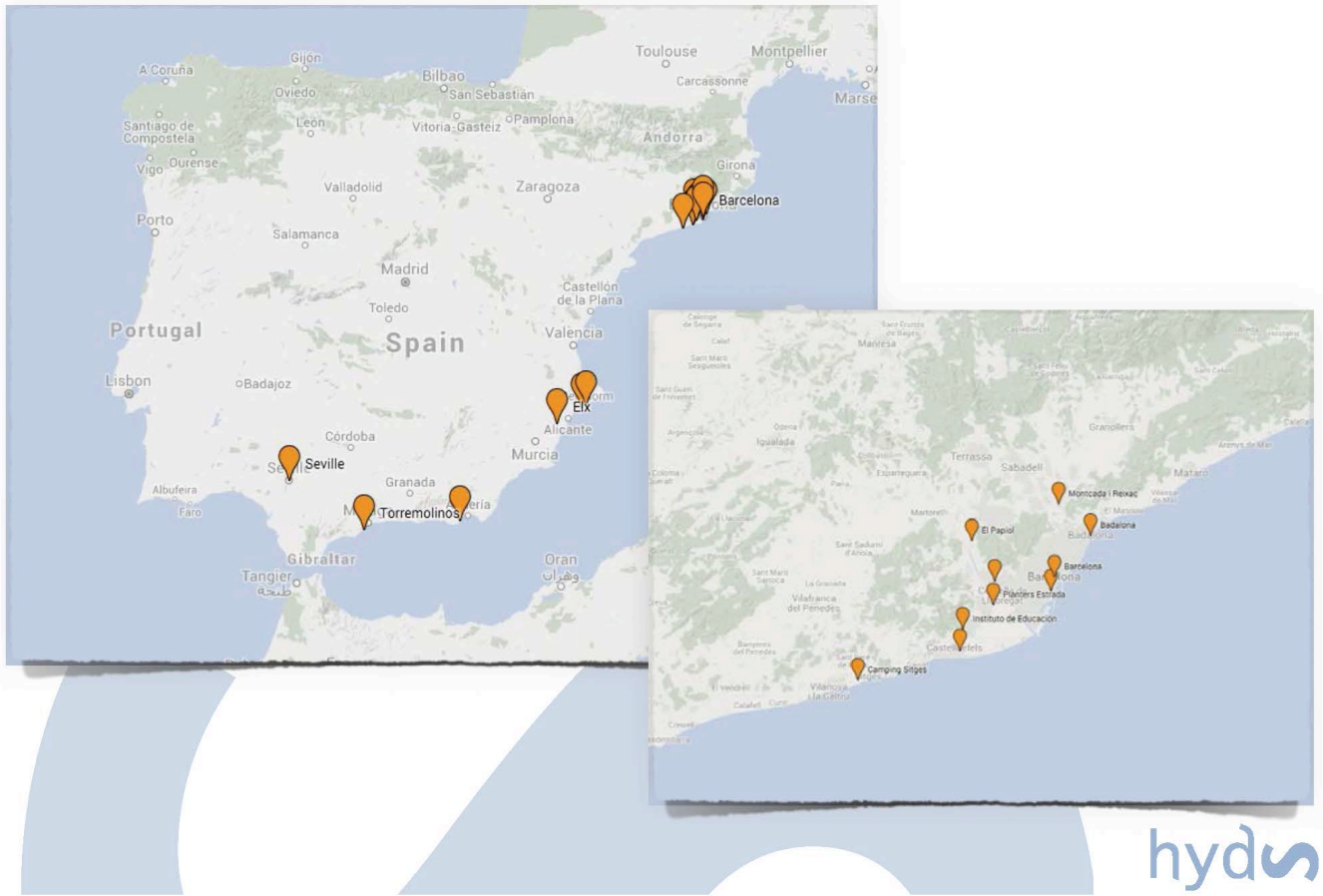
Maps on a WMS to be examined

*Thanks to B.Russo for the Barcelona Maps

AQUALOGY



FloodAlert Current implementations



FloodAlert: Success Case

October 29th, 2013
Mallorca

Una tromba de agua provoca el caos en la isla con cientos de incidentes

La lluvia cayó con una violencia inusitada; hasta 20 litros por metro cuadrado en diez minutos se registraron en Palma - Las centralitas de los organismos de emergencia se vieron desbordadas por la avalancha de llamadas, la mayoría por inundaciones - Un falso techo de una nave del polígono de Son Castelló cayó sobre un operario - Diez personas heridas por caídas o accidentes de tráfico

Xavier Peris / Lorenzo Marina. Palma Una fortísima tromba de agua descargó ayer por la tarde unos 45 litros en apenas una hora y dejó Palma y amplias zonas de Mallorca sumidas en el caos. Los distintos organismos de emergencia se vieron desbordados por la avalancha de llamadas –más de trescientas a las cuatro y media de la tarde– referidas sobre todo a inundaciones y caída de árboles. En el polígono de Son Castelló se desplomó el falso techo de una nave industrial y los cascotes cayeron sobre un trabajador, aunque no sufrió lesiones graves. Las ambulancias del 061 tuvieron que intervenir durante el tiempo de la tormenta a una decena de personas heridas en accidentes de tráfico o

Cuatro personas rescatadas in extremis en Santanyí

Dos patrullas de la Guardia Civil resultaron cruciales para auxiliar a los ocupantes de tres vehículos que eran arrastrados por las riadas al cruzar dos torrentes en el sur de la isla. En uno de los casos, los agentes tuvieron que meterse en el agua para sacar a las víctimas, y acabaron vestidos con ropas que les prestaron los bomberos

La tormenta dejó 43 litros en Portopí, veinte de ellos en 10 minutos

30.10.2013 | 00:39



La tormenta dejó 43 litros en Portopí, veinte de ellos en 10 minutos

La fuerte tormenta que, procedente de Eivissa, entró a las dos y media de la tarde por Andratx, evacuó hasta 43 litros por metro cuadrado en la estación meteorológica de la AEMET en Portopí. Y veinte de esos litros cayeron en tan solo diez minutos, resal… máxima responsable de la A… é Guerrero, para ilustrar la …ero.

Una fuerte tormenta azota Balears dejando lluvia, viento y miles de rayos

…ya se detectó a las once de la …ana al norte de Eivissa y al oeste de Mallorca y que ya empezó a afectar a la mitad norte de la pitiusa mayor en torno a la una de la tarde. En la localidad de San Carlos dejó veintinueve litros por metro cuadrado mientras que en Santa Eulària arrojó hasta 25 litros en tan solo veinte minutos.

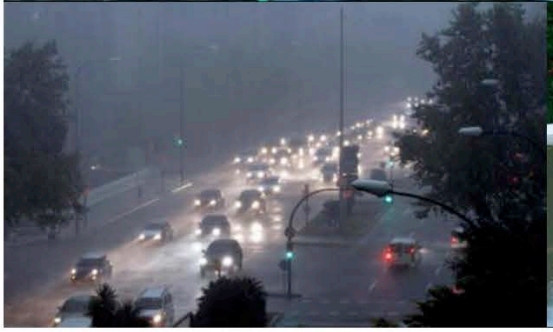
Tras llegar a Mallorca, en Andratx ocasionó precipitaciones de gran intensidad con granizo y rayos que superaron los 51 litros por metro cuadrado. Pero el récord de agua caída se registró en Galilea, con 66 litros en apenas 35 minutos. Felanitx fue otra de las localidades más afectadas por la tromba de agua ya que allí se recogieron hasta 45 litros en quince minutos. Portocolom padeció inundaciones de bajos por la fuerte intensidad de la lluvia, con 18 litros recogidos en solo diez minutos de chaparrón. La

FloodAlert: Success Case

October 29th, 2013
Mallorca





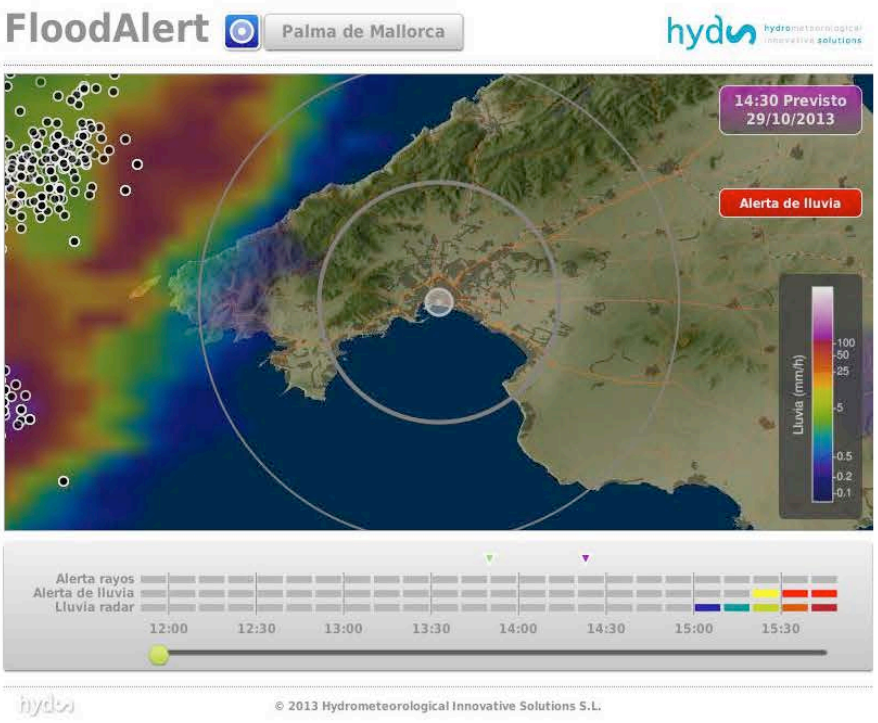


hydrometeorological innovative solutions

14:25h: ~60 min before...

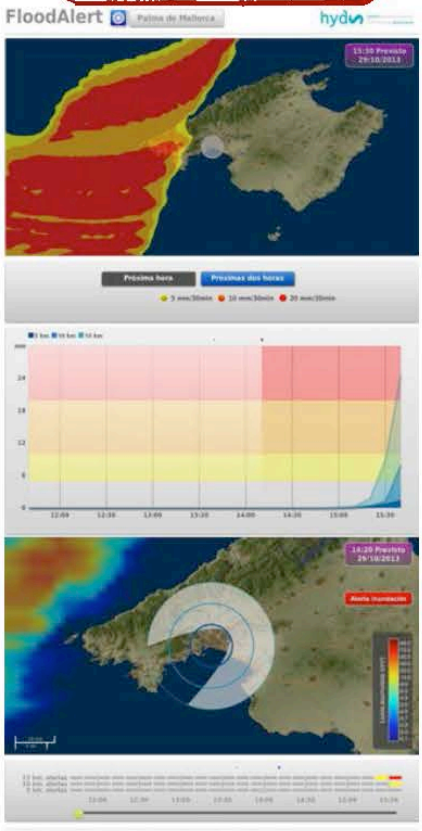
Alerta

Palma de Mallorca: Alerta nivel 3 de precipitación (61.9 mm/h) en las próximas 2h. Mensaje enviado a las 2013-10-29 14:20

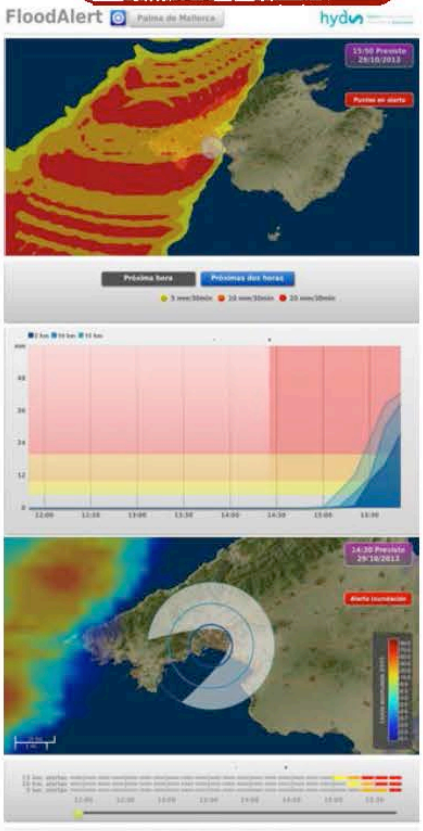


FloodAlert: Success Case

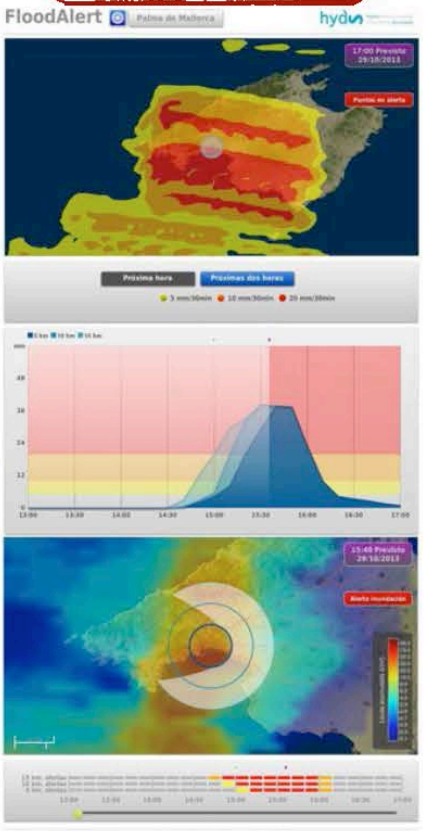
14:00h: ~90 min before...



14:25h: ~60 min before...

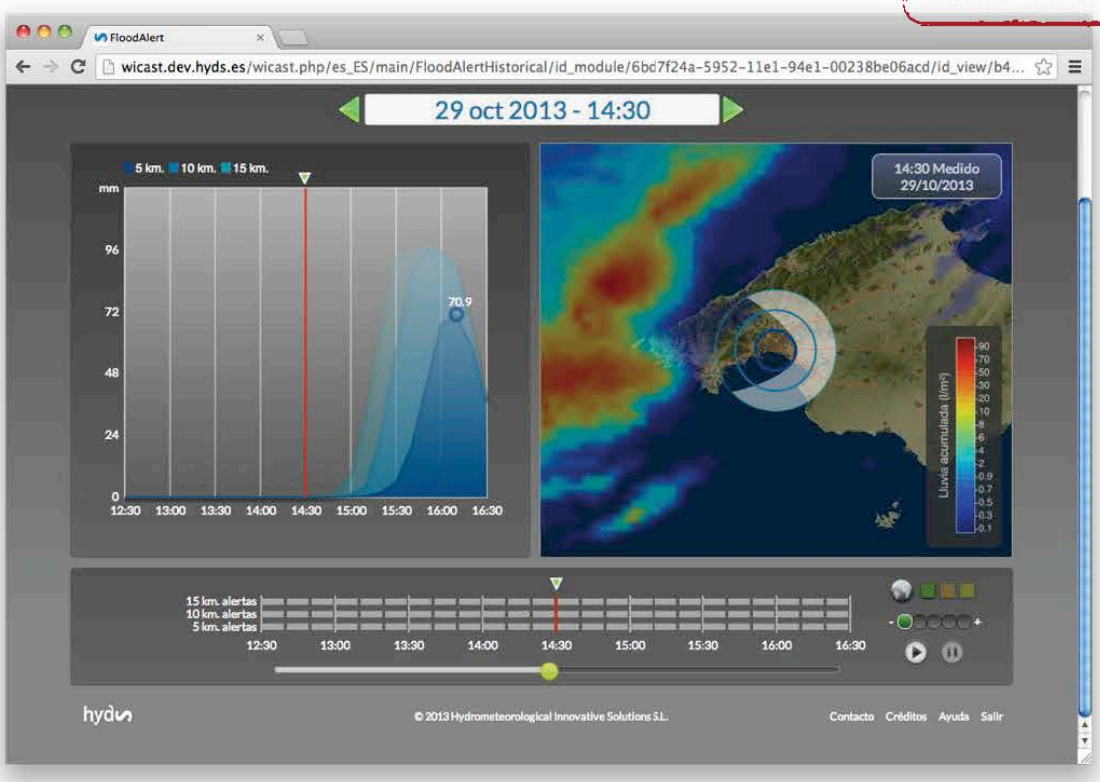


15:30h: ~0 min before...



FloodAlert: Success Case

14:30h: ~70 min before...



FloodAlert: Success Case

July 13th, 2013
Lleida

La lluvia causa inundaciones en Lleida y 200 salidas de los Bomberos

Lleida | 14/07/2013 - 17:19h

L'aigua manté tallada una via a l'estació de Lleida i afecta tres línies de trens regionals

Els passos inferiors s'han inundat i els usuaris no

Lleida | 14/07/2013 - 11:45h

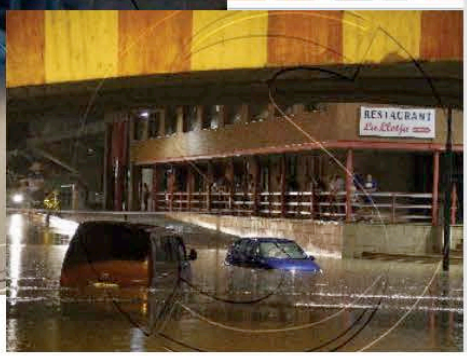
ACN

La tempesta de Lleida va deixar una quantitat rècord de 57 litres en 30 minuts

A Lladurs (Solsonès) van arribar a caure 3,1 litres en tan sols un minut

Lleida | 14/07/2013 - 16:58h





El PP insta l'Ajuntament de Lleida a renovar el clavegueram de les zones inundables de la ciutat

Lleida ciutat - Societat

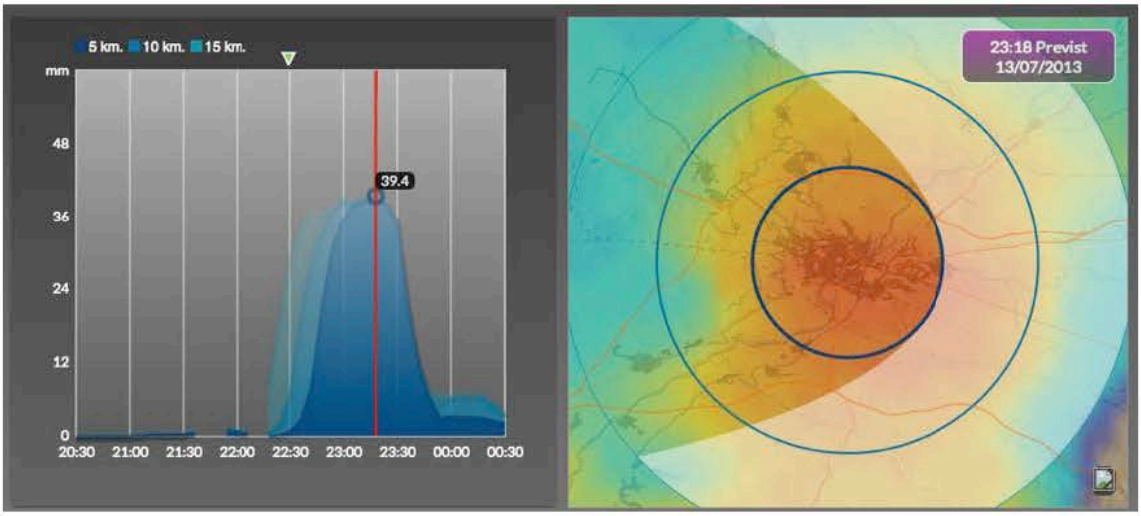
Escrit per Bondia.cat

Dilluns 15, Juliol de 2013 15:40



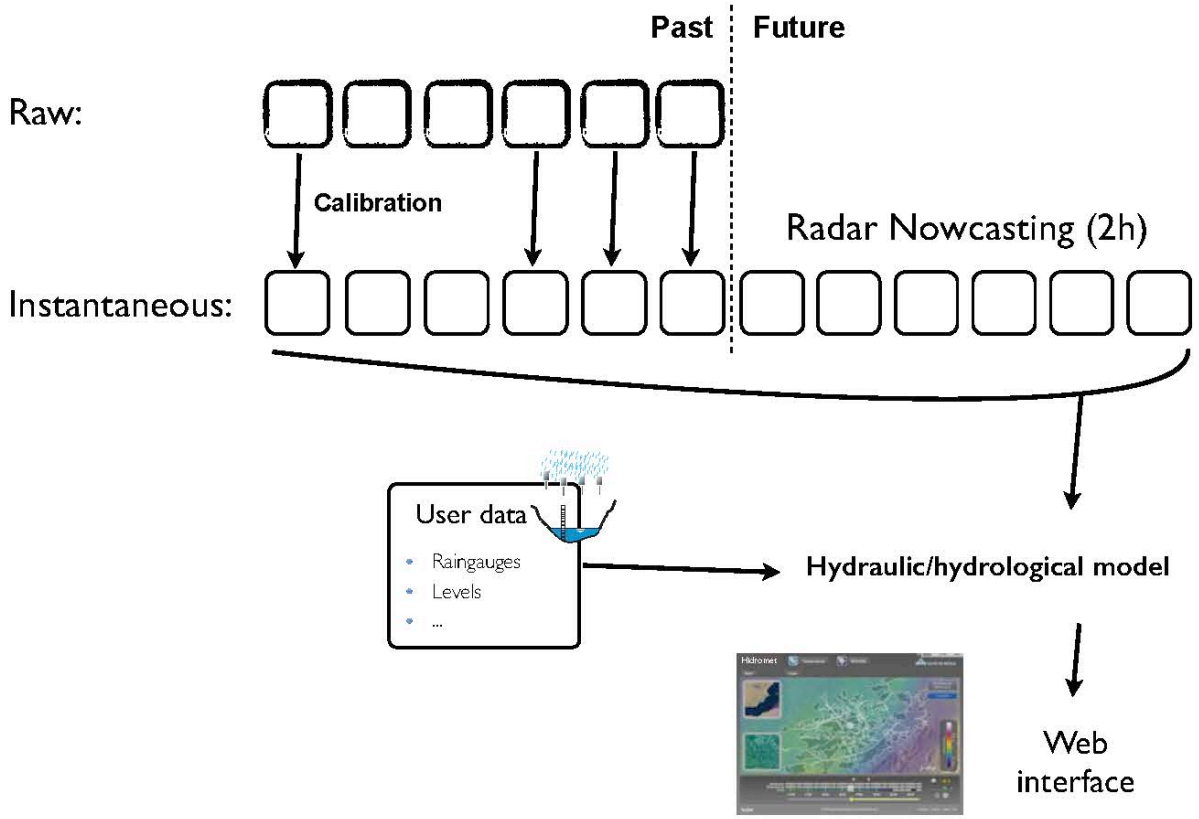
FloodAlert: Success Case

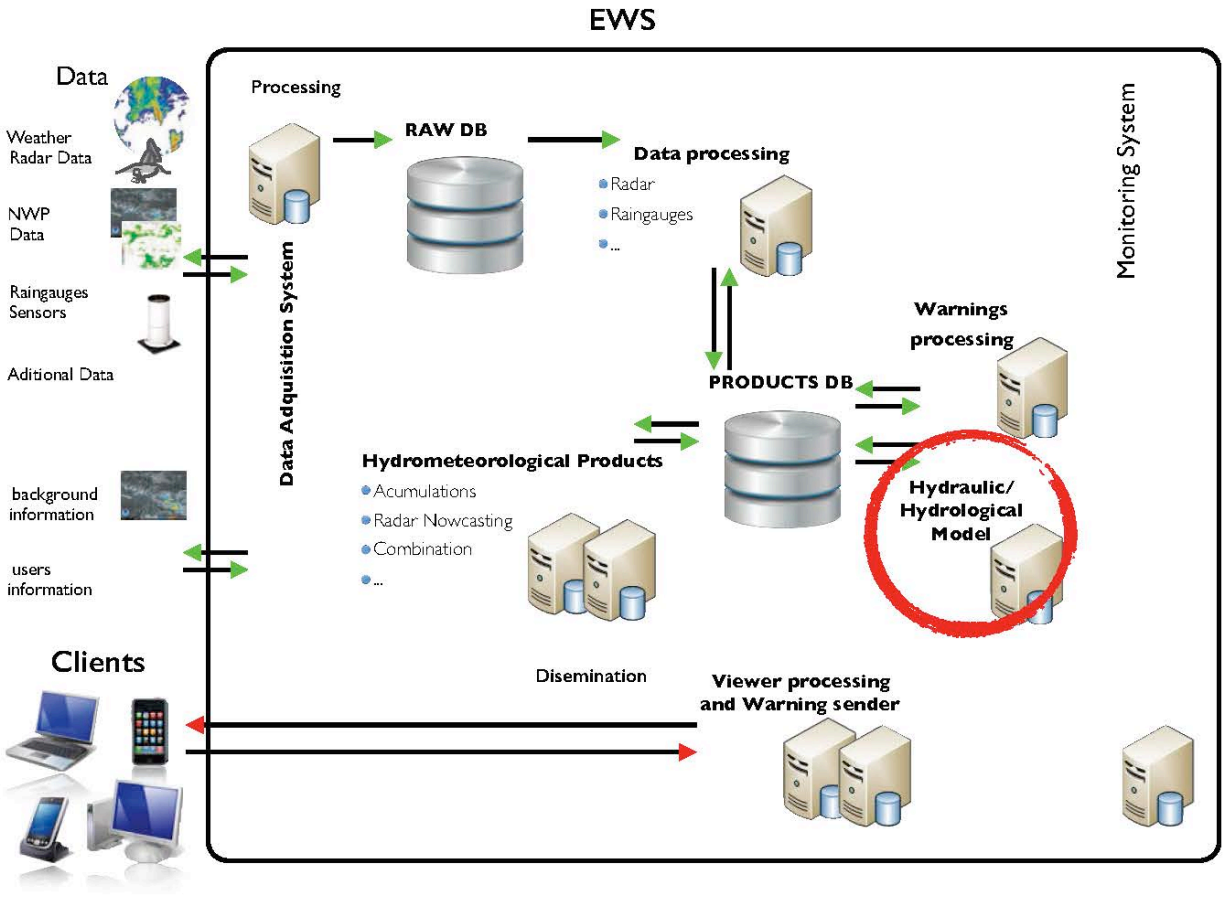
~40 min before...





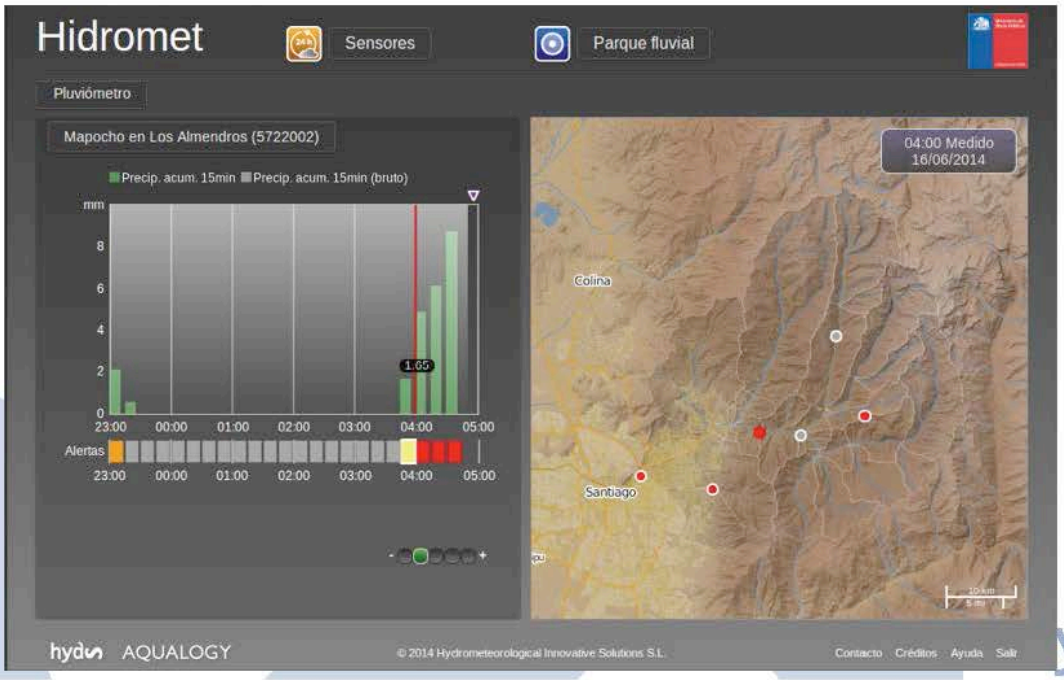
Cloud EWS for urban flood warning





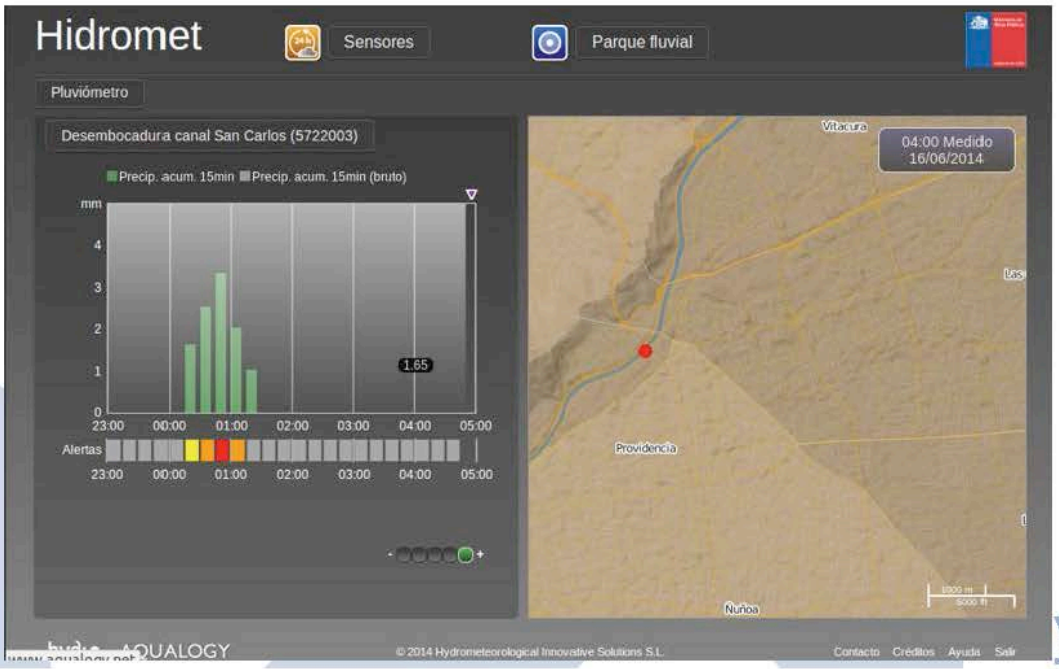
Cloud EWS for urban flood warning

- Sensors integrated
  - Quality control
  - Visualization



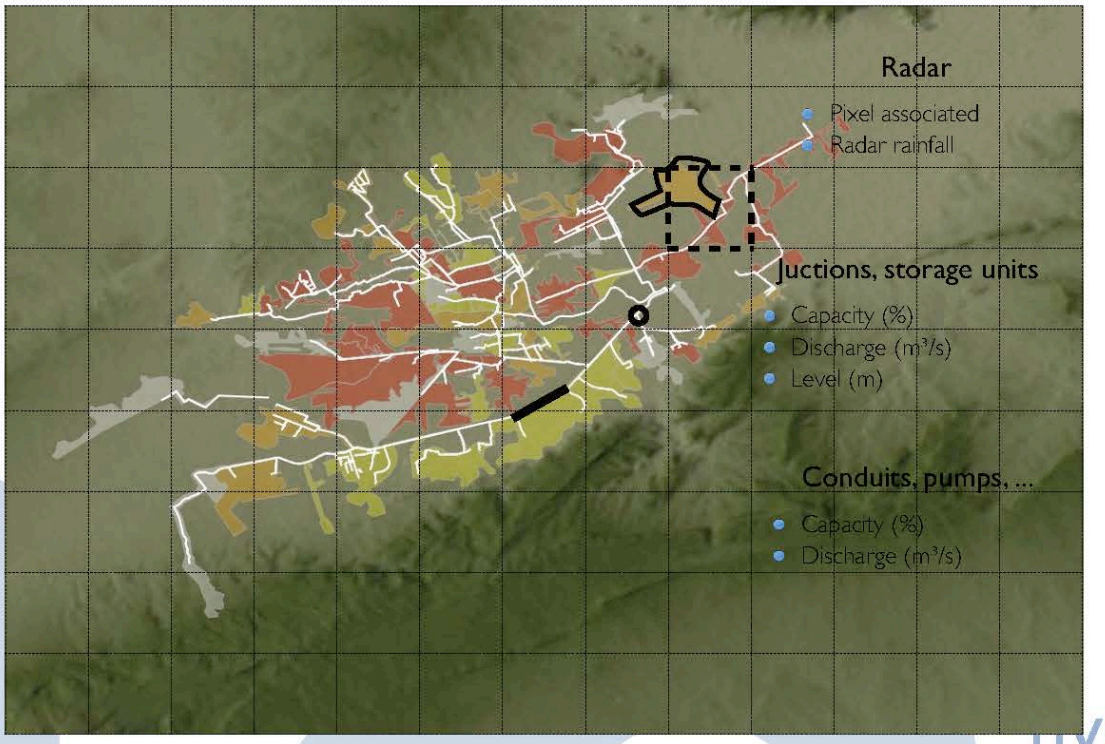
Cloud EWS for urban flood warning

- Sensors integrated
  - Quality control
  - Visualization
  - Warnings



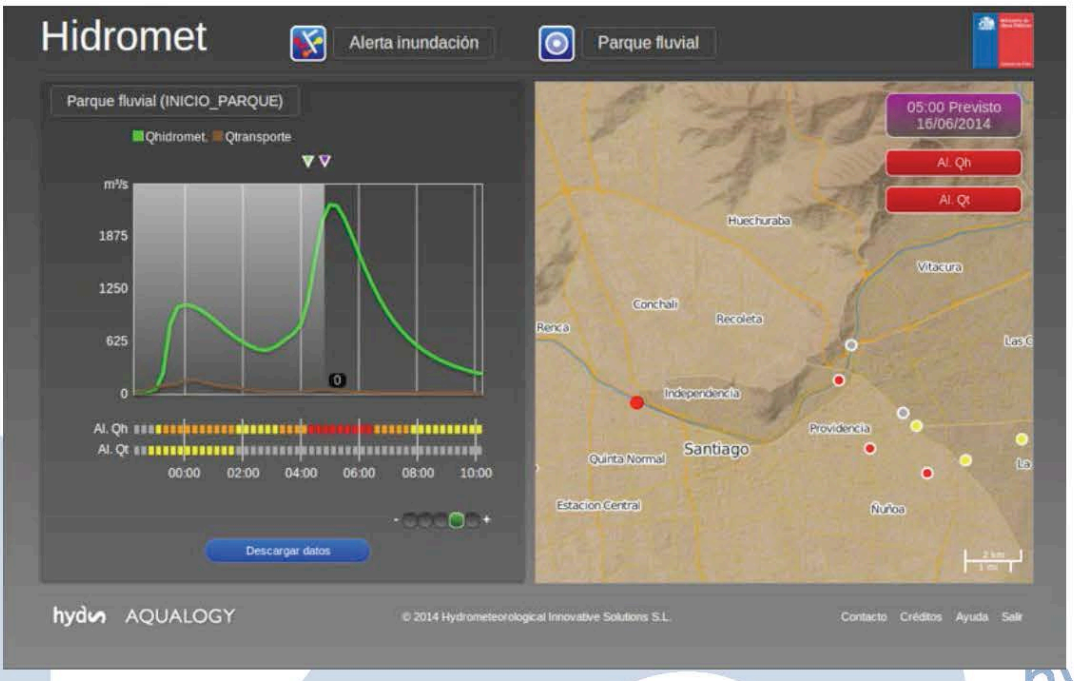
Cloud EWS for urban flood warning

- Elements of the model integrated



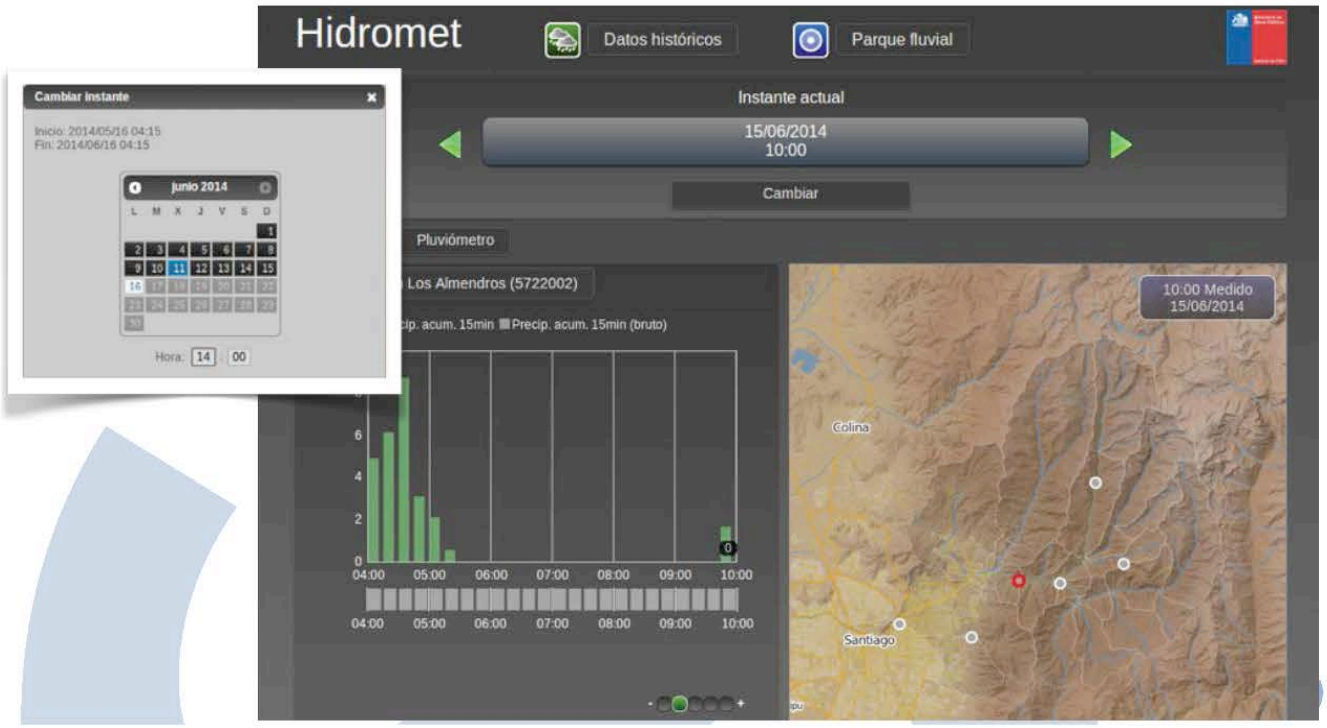
Cloud EWS for urban flood warning

- Real Time simulations available



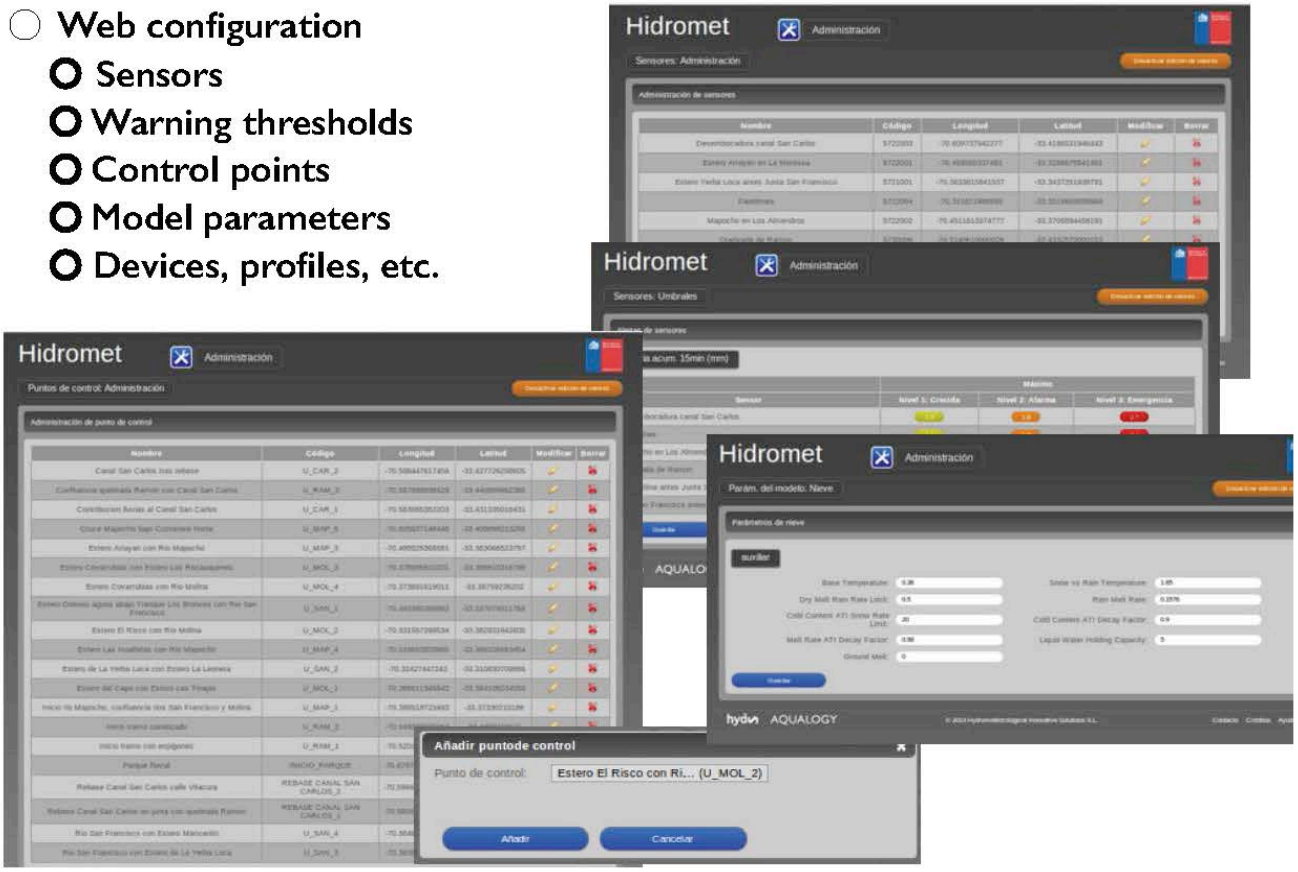
Cloud EWS for urban flood warning

- Historical records



Cloud EWS for urban flood warning

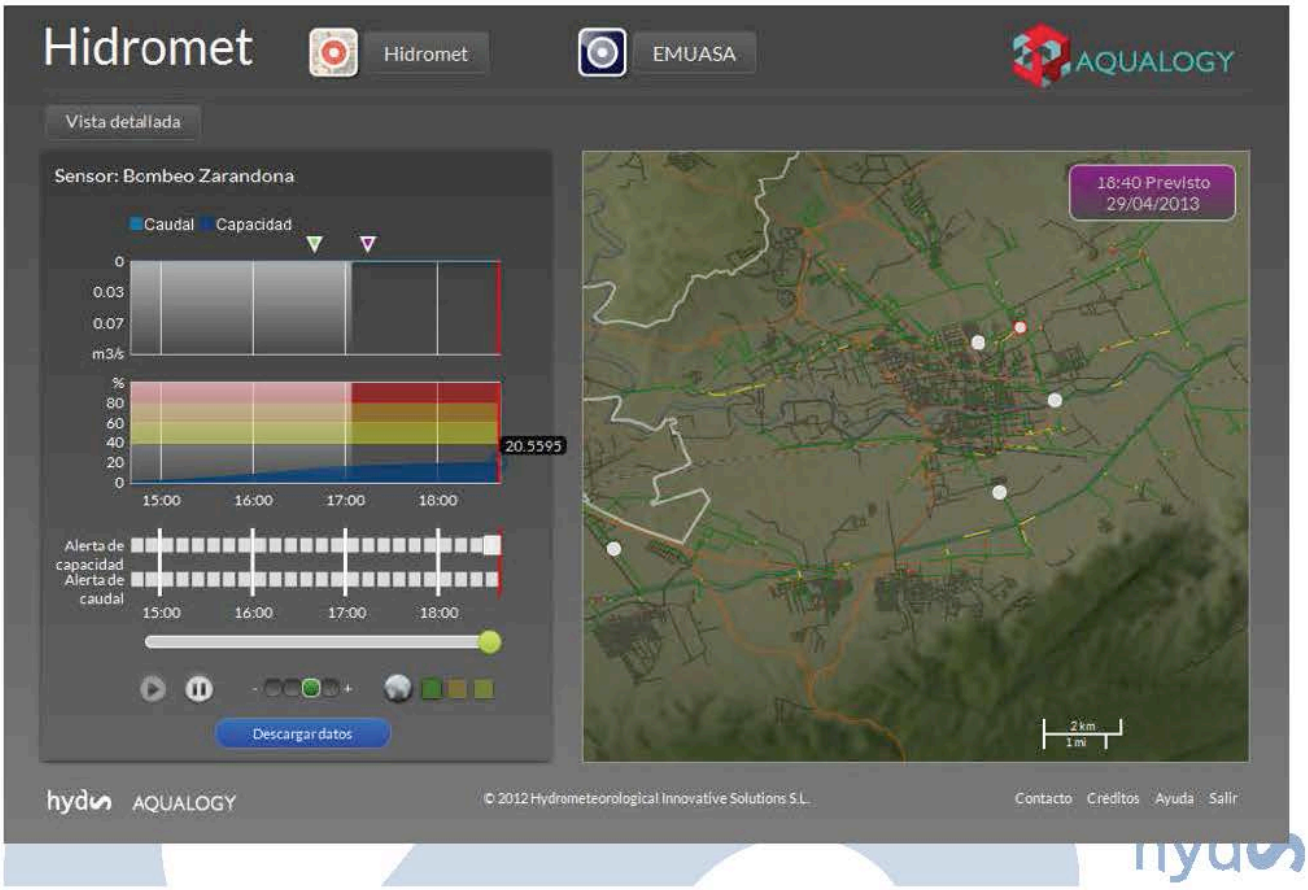
- Web configuration
  - Sensors
  - Warning thresholds
  - Control points
  - Model parameters
  - Devices, profiles, etc.



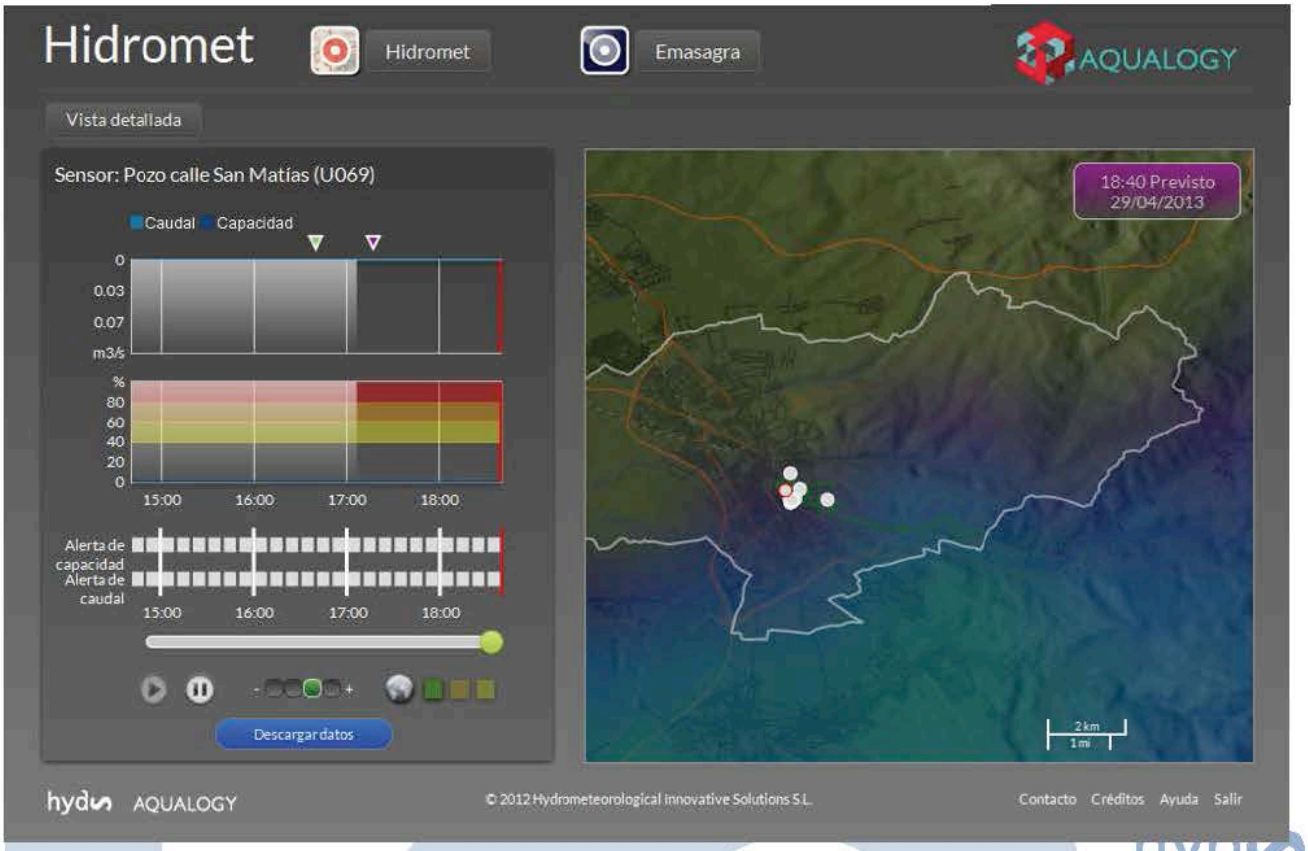
Implementations: Laguna (SWMM)



Implementations: Murcia (SWMM)

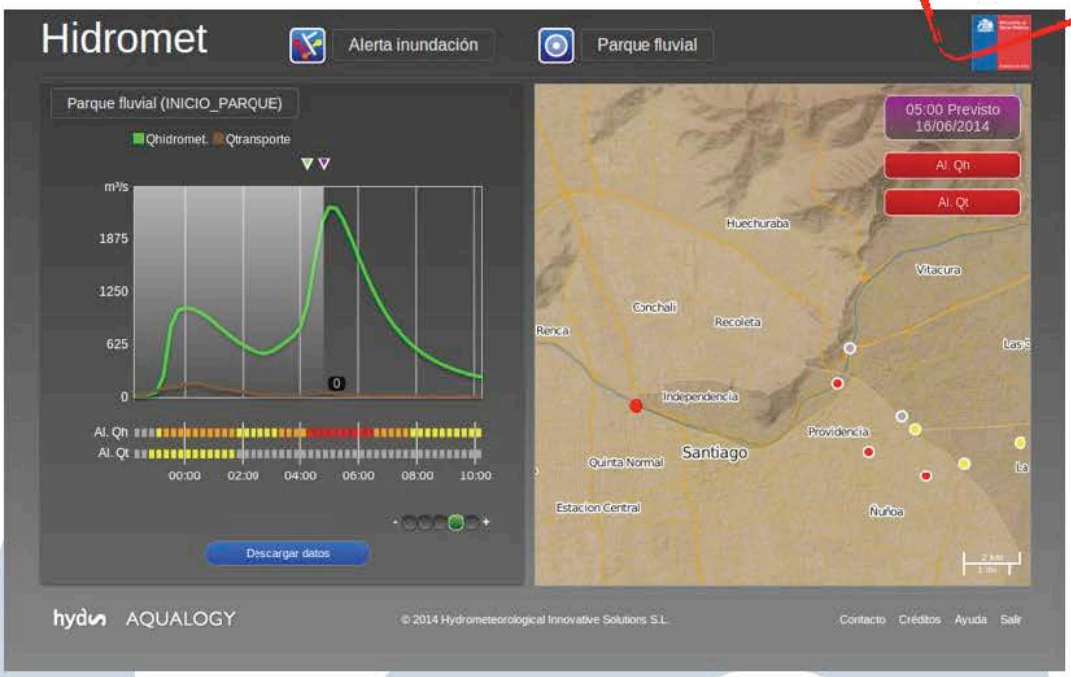


Inplementations: Granada (SWMM)



Inplementations: Santiago de Chile (HEC-HMS)

Currently under implementation



Hidromet Current implementations





hydrometeorological innovative solutions

DLR Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft

Aeroports de Catalunya

meteo.cat Servei Meteorològic de Catalunya

MEDUSA DEMONSTRATION

Meteorological Decision Support System for Aviation

Algorithms

Medusa algorithms thunderstorm weather

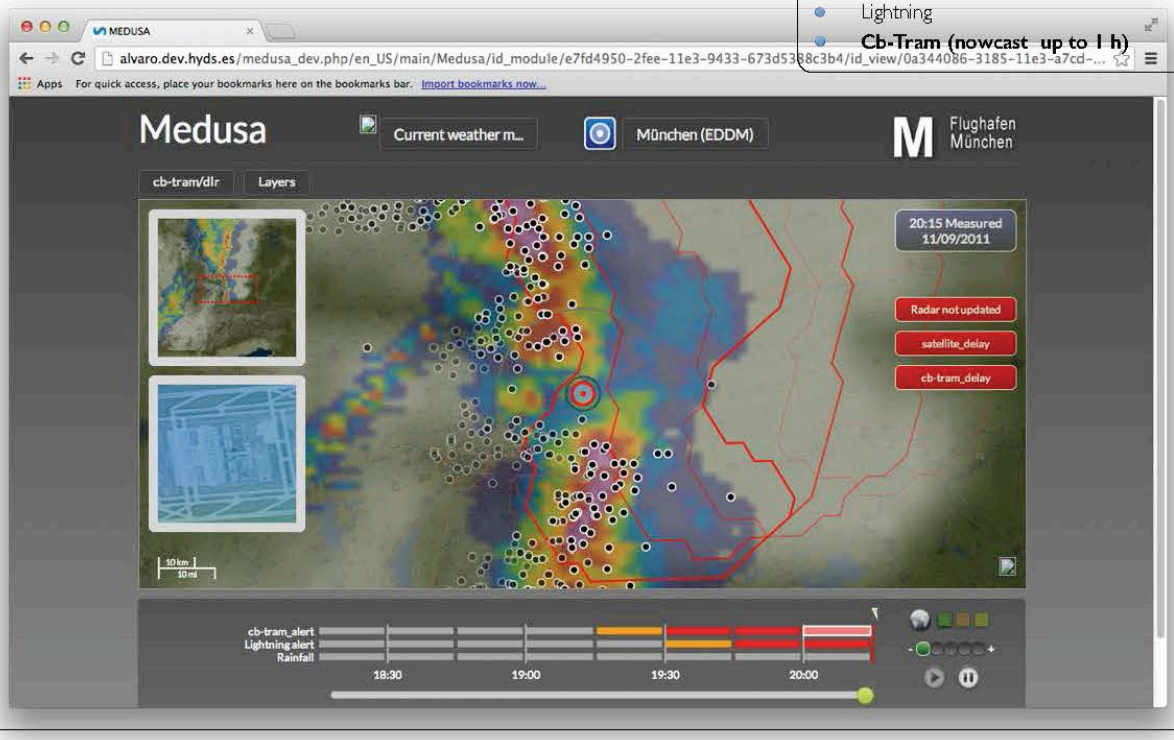
- Cb - Tram (DLR)
- Rad - Tram (DLR)
- Cb -Like (DLR)
- Radar nowcasting (HYDS)
- Radar&NWP blending (HYDS)
- Flood Warning (HYDS)

Medusa algorithms winter weather

- WHITE: nowcast of snow, freezing rain, icing and ground condition (DLR)
- Potential Snow Areas (HYDS)

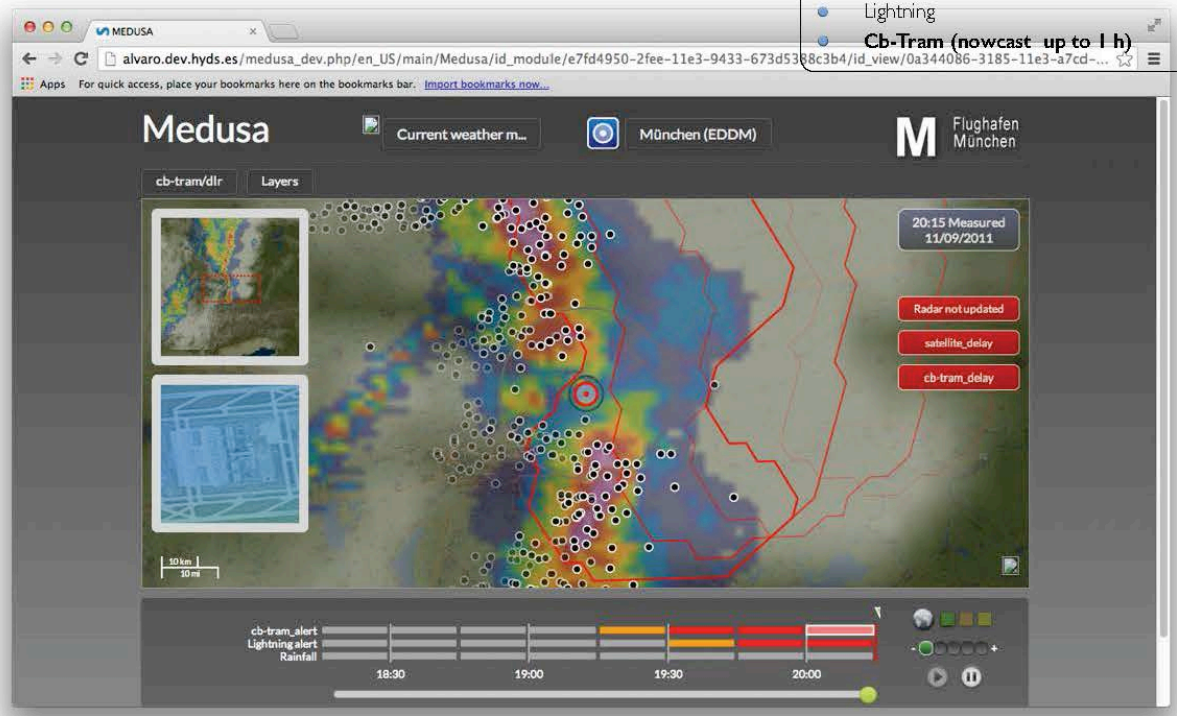
Examples MEDUSA display MUC airport

- Radar data
- Satellite data
- Lightning
- **Cb-Tram (nowcast up to 1 h)**



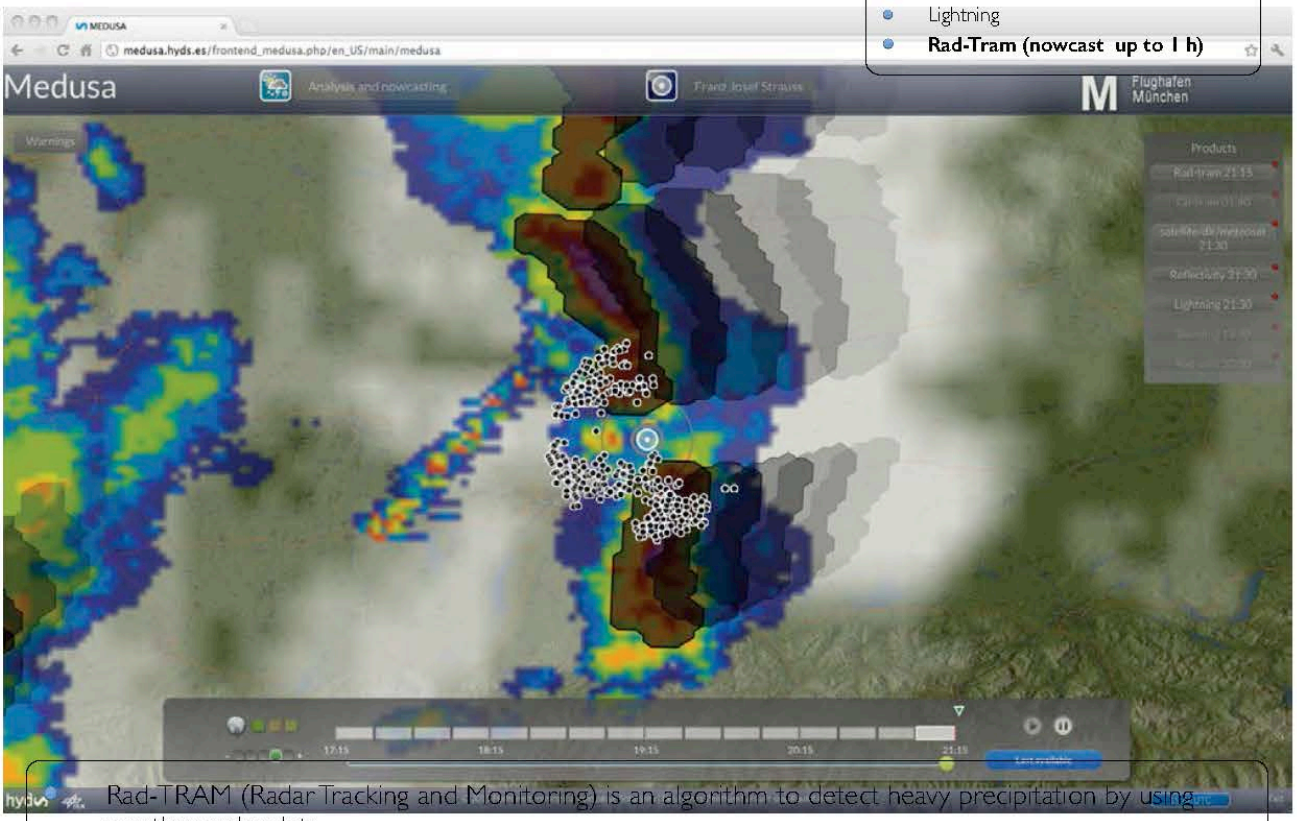
- Cb-TRAM (Cumulonimbus Tracking and Monitoring) is an algorithm to detect, track, and forecast up to one hour (= nowcast) thunderstorm clouds from space by using METEOSAT SEVIRI data

- Radar data
- Satellite data
- Lightning
- **Cb-Tram (nowcast up to 1 h)**



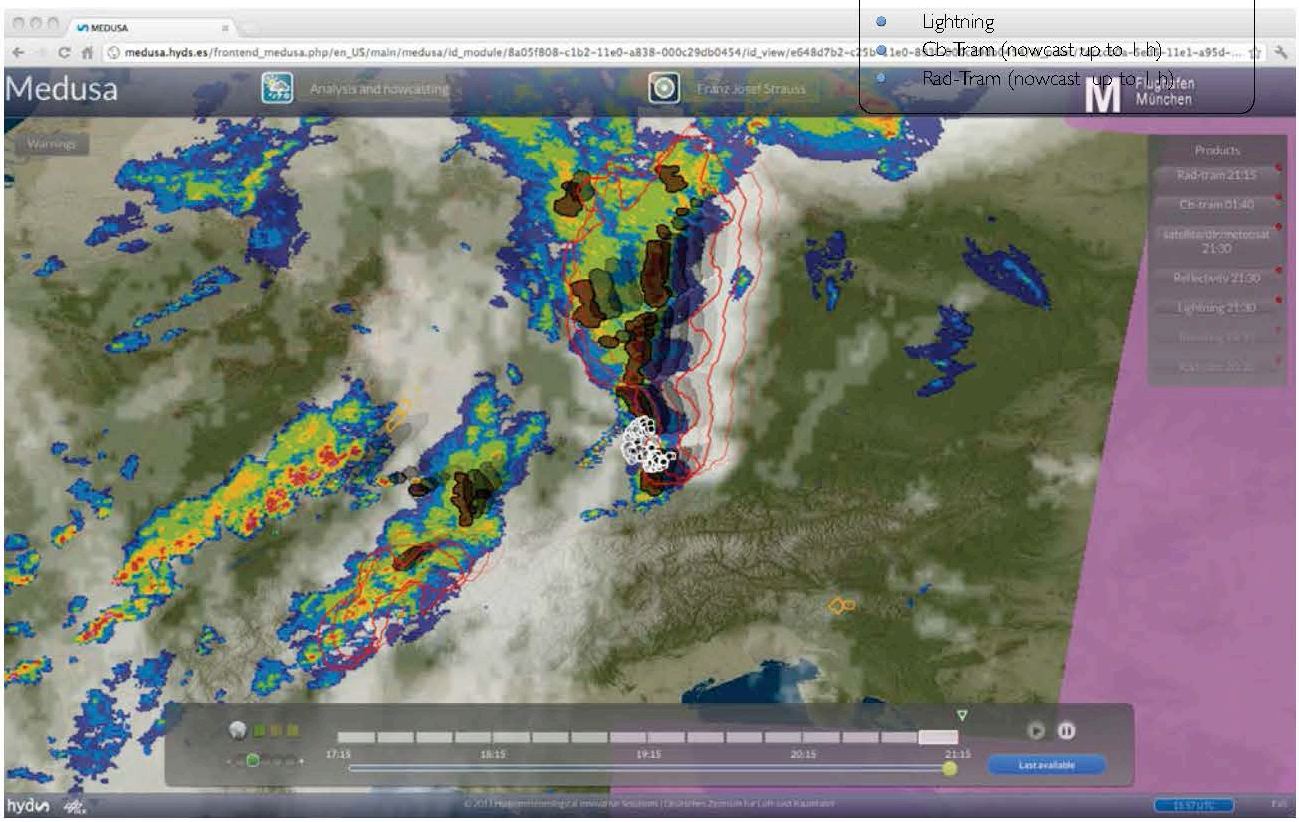
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- Radar data
- Satellite data
- Lightning
- **Rad-Tram (nowcast up to 1 h)**



- Rad-TRAM (Radar Tracking and Monitoring) is an algorithm to detect heavy precipitation by using weather radar data

- Radar data
- Satellite data
- Lightning
- Cb-Tram (nowcast up to 1 h)
- Rad-Tram (nowcast up to 1 h)



Examples MEDUSA Cb-Tram La Seu

