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OBSERVE TO PREDICT, PREDICT TO PREVENT

Predictability and predictive ability of severe rainfall processes

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in cooperation with:

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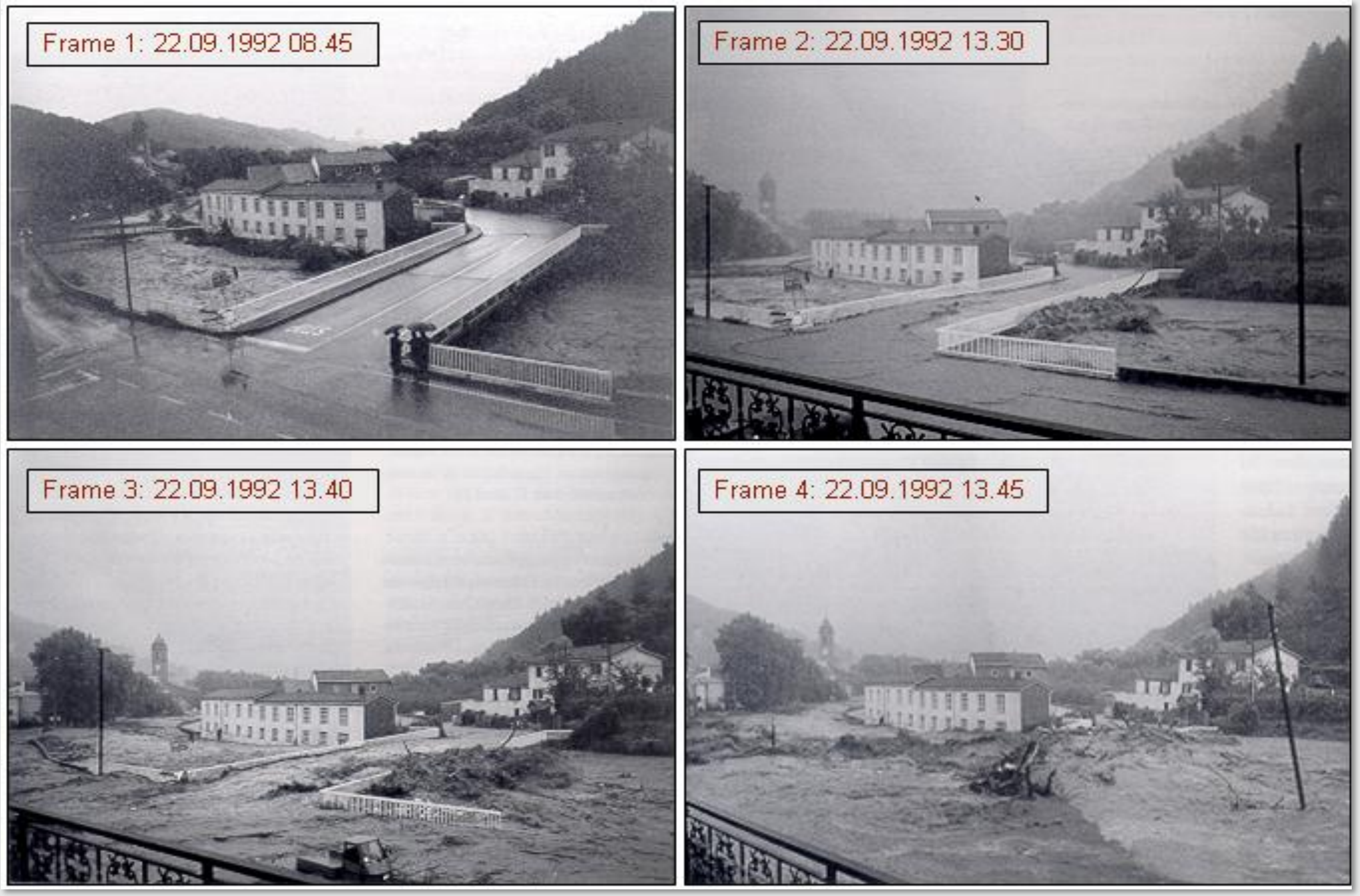
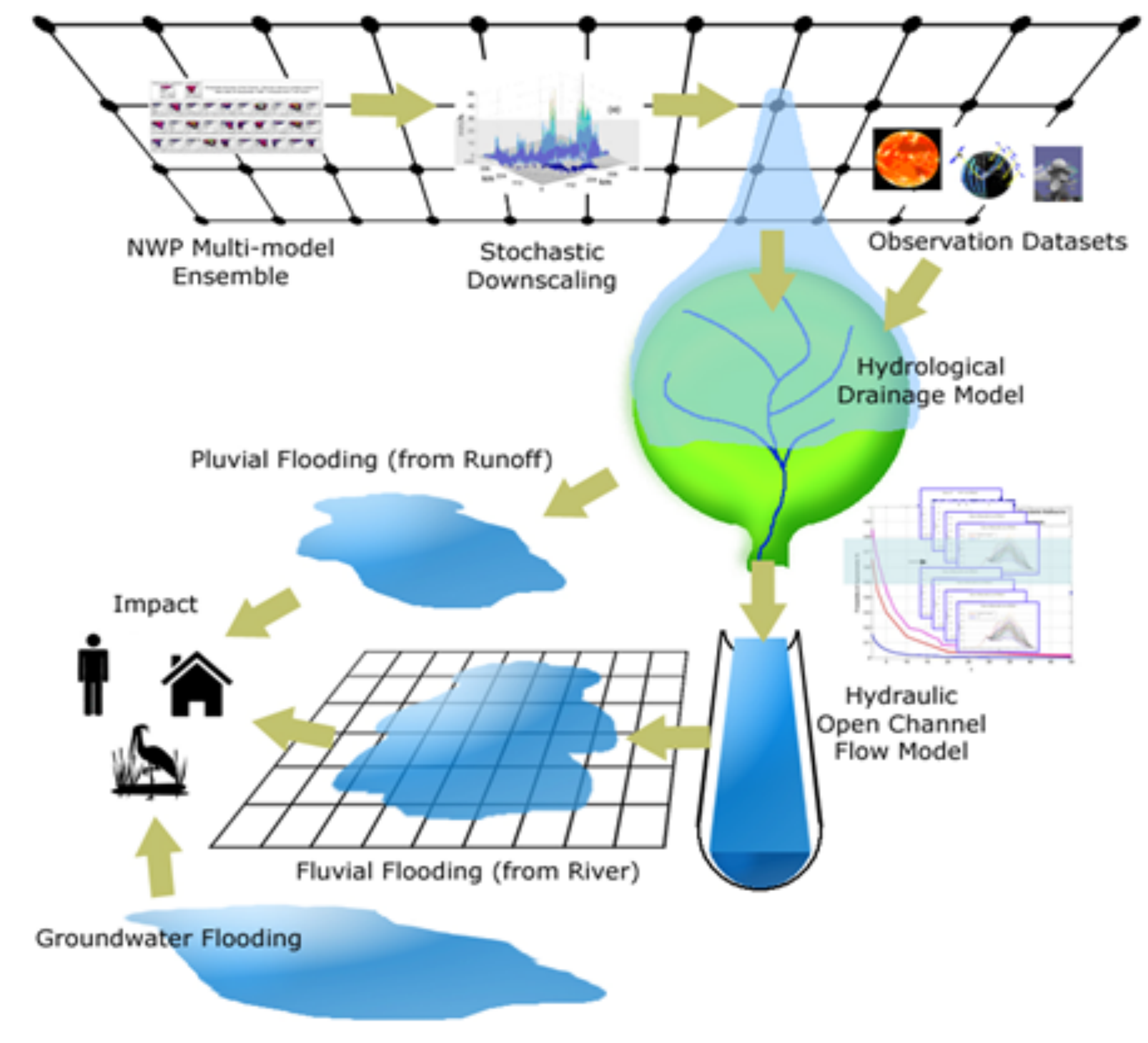
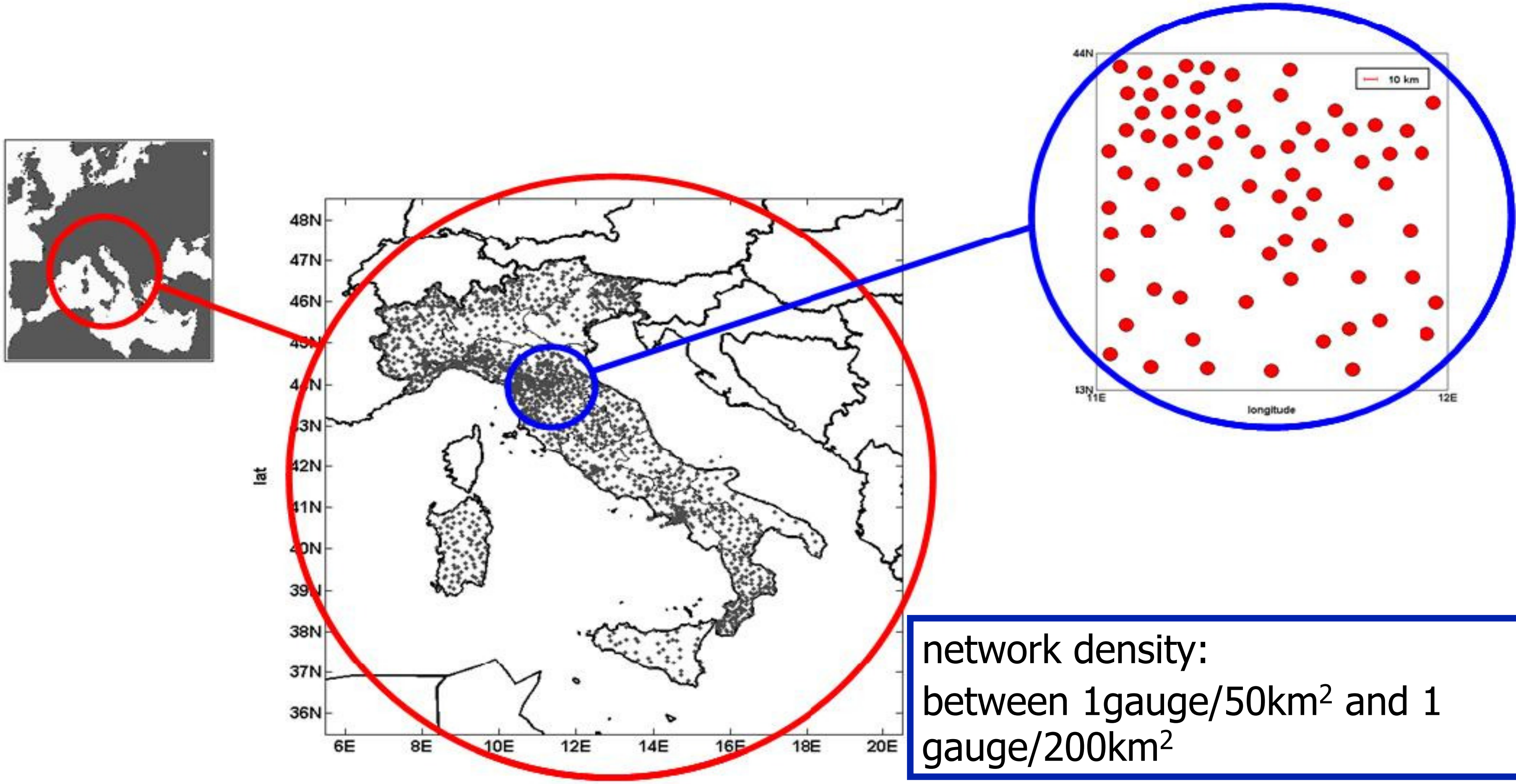
Flash-flood events in the Mediterranean area



Need for a full hydro-meteorology forecasting chain



Italian raingauge network: about 3000 sensors

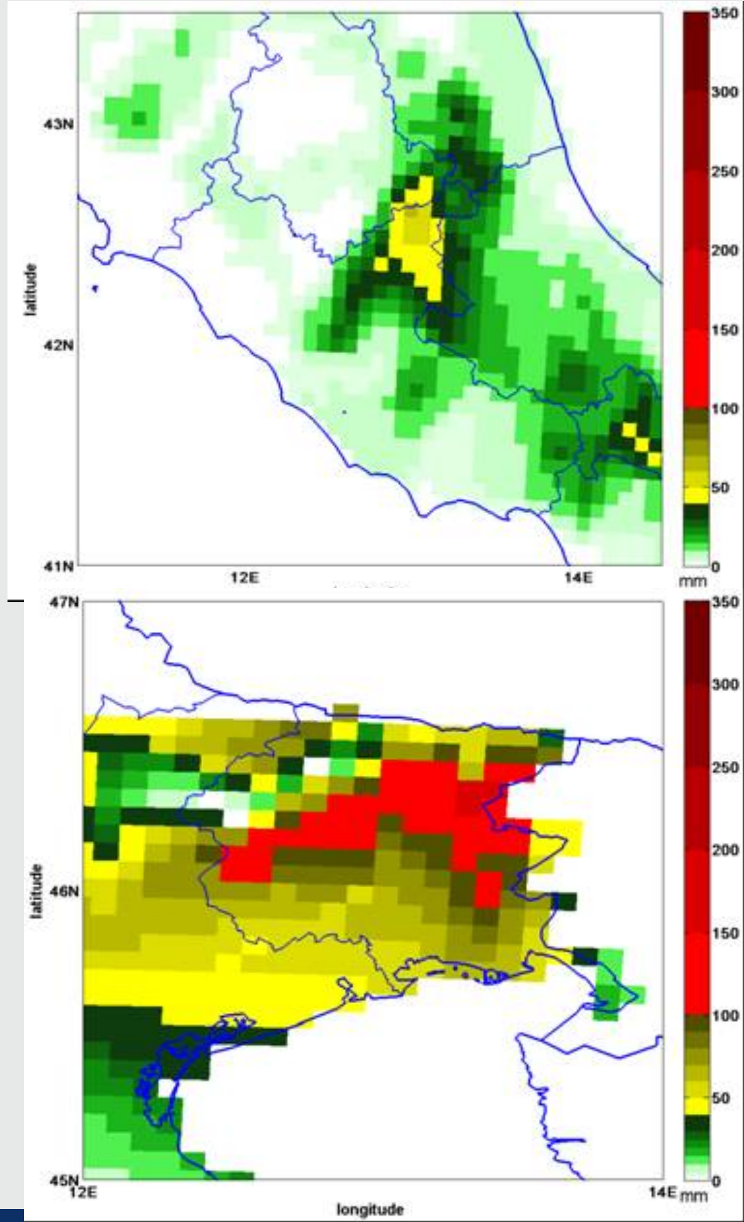


network density:
between 1gauge/50km^2 and 1 gauge/200km^2

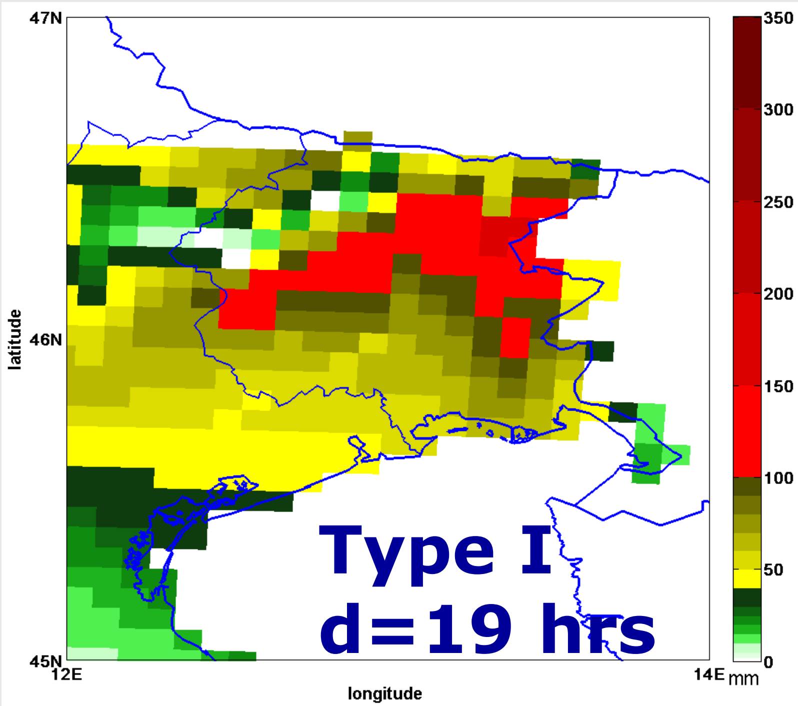
Severe rainfall events classification

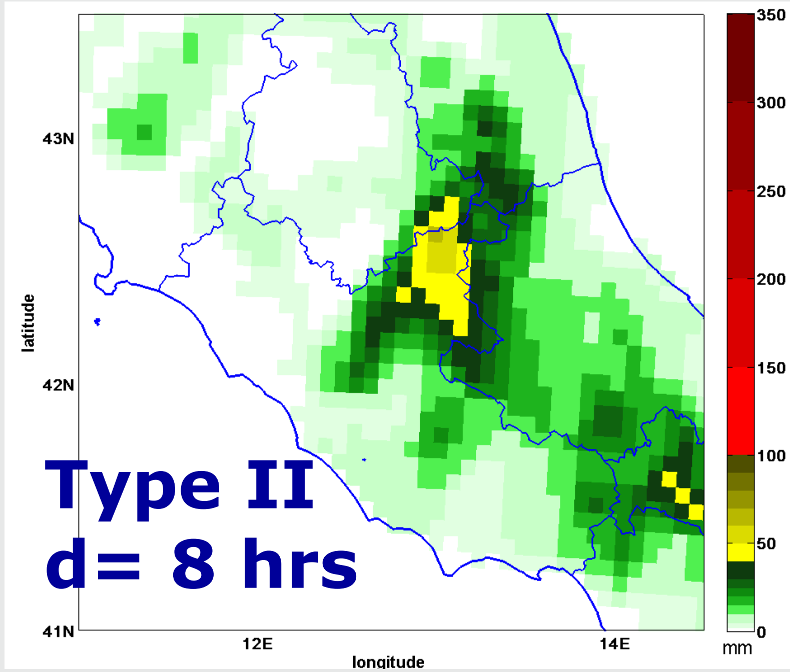
Molini et al. (2009, NHESS) developed a procedure to single out heavy rainfall events and to classify them on the basis of:

1. Duration
2. Spatial extent
3. Large/small-scale triggering



Severe rainfall events classification





Type I events:

- Long-lived (lasting more than 12 hours)
- Spatially distributed (more than 50x50 km^2)

Type II events:

- Brief and localized (lasting less than 12 hours)
- Spatially concentrated (less than 50x50 km^2)

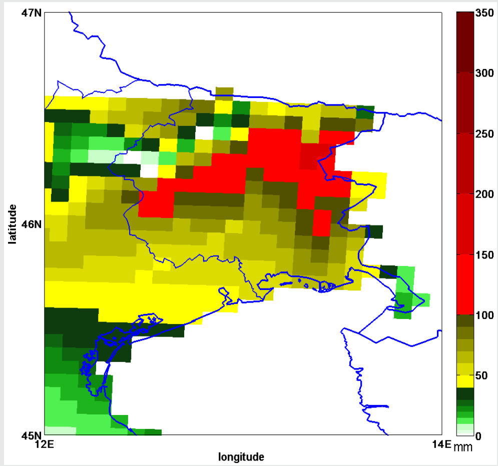
Severe rainfall events classification

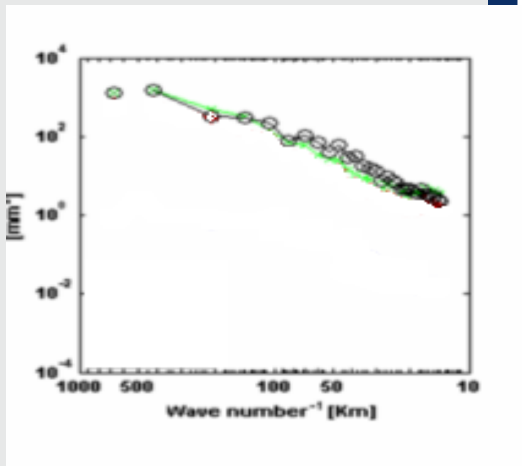
Type I events:

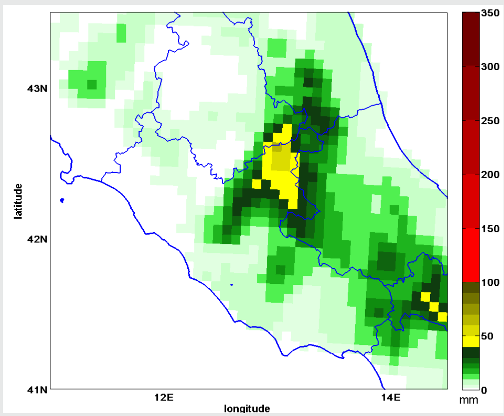
- no characteristic length scale, constant-slope spectrum

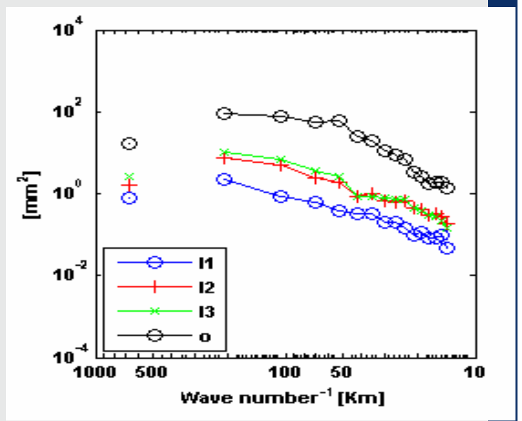
Type II events:

- 'two-component' spectrum









Severe rainfall events classification

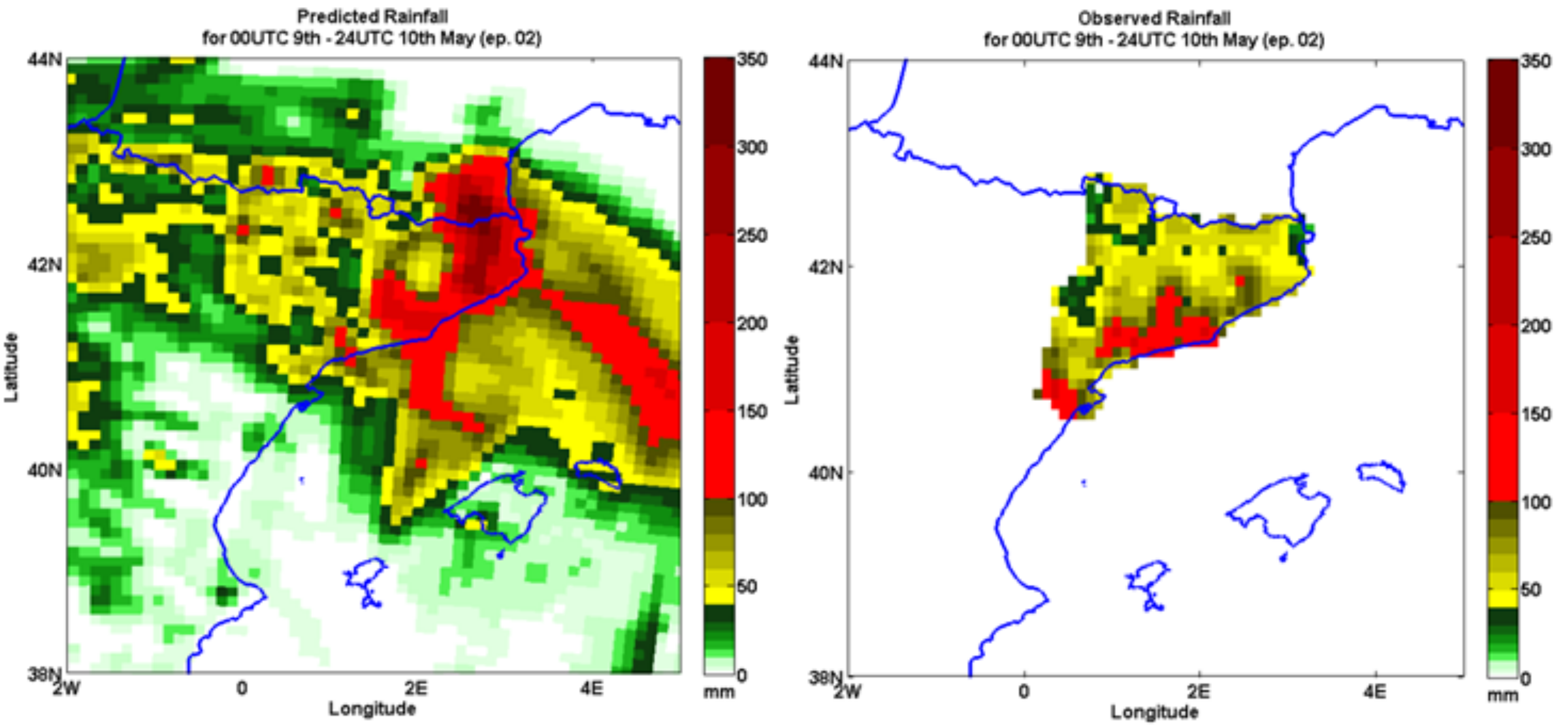
We started applying the event classification procedure to the Italian Raingauge Network observations in January 2006***.

139 severe events:

- **88** events **Type I** events lasting more than 12 hours and striking an area bigger than 50x50 km^2;
- **51** events **Type II** events lasting less than 12 hours and striking an area smaller than 50x50 km^2.

*******last update May 2011.***

Severe rainfall events classification



Similar results were found on Catalonia's 2008 rainfall severe events (Comellas's master thesis; Comellas et al, 2011, NHESS)

SEVERE HYDRO-METEOROLOGICAL EVENTS: classification features

morphological analyses

1. Duration
2. Extent
3. Characteristic spectral length scale

triggering factors / microphysics

- Quasi equilibrium / non equilibrium triggering conditions
- Gross Moist Stability / Saturated fractions
- 3D microphysical structure of severe storms

Equilibrium conditions

Large scale forcing determines the statistical properties of convection and the spatio-temporal behavior of the corresponding severe rainfall events

The rate of creation of CAPE by forcing is balanced by its consumption by convection

Non-Equilibrium conditions

Triggering condition determines the spatio-temporal behavior of the corresponding severe rainfall events

CAPE is build up from large scale processes over long timescales and removed by sudden triggering of deep moist convection

$$\frac{dCAPE}{dt} = \begin{pmatrix} Rate\ of\ creation \\ by\ forcing \end{pmatrix} - \begin{pmatrix} Rate\ of\ destruction \\ by\ convection \end{pmatrix}$$

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A convective time scale for equilibrium e non-equilibrium conditions

A convective adjustment timescale τ_C is estimated from the rate at which instability (measured by CAPE) is being removed by convective heating (Done et al., 2006)

Convective timescale

$$\tau_c = \frac{CAPE}{dCAPE/dt} \sim \frac{CAPE}{Precip.\ rate}$$

Equilibrium expected when τ_c small compared to forcing timescale

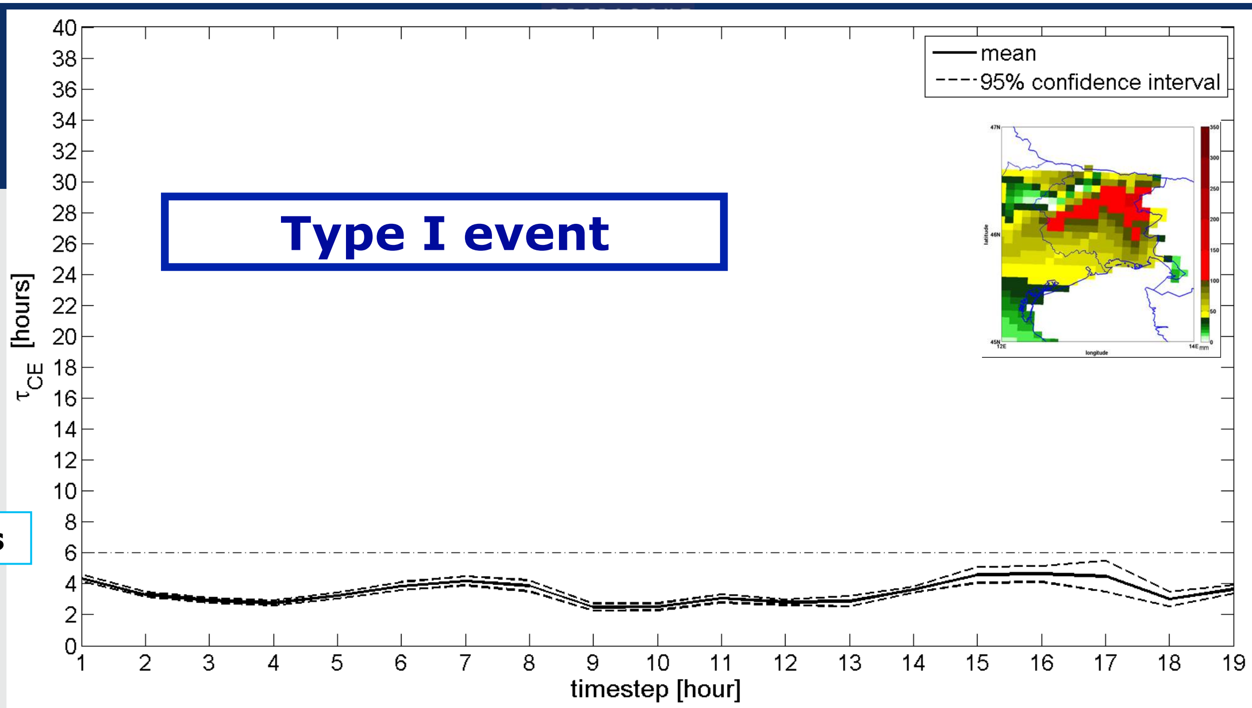
$$\tau_C = \frac{CAPE}{\frac{dCAPE}{dt}} = \frac{CAPE}{0.045 \cdot i_R}$$

Equilibrium conditions

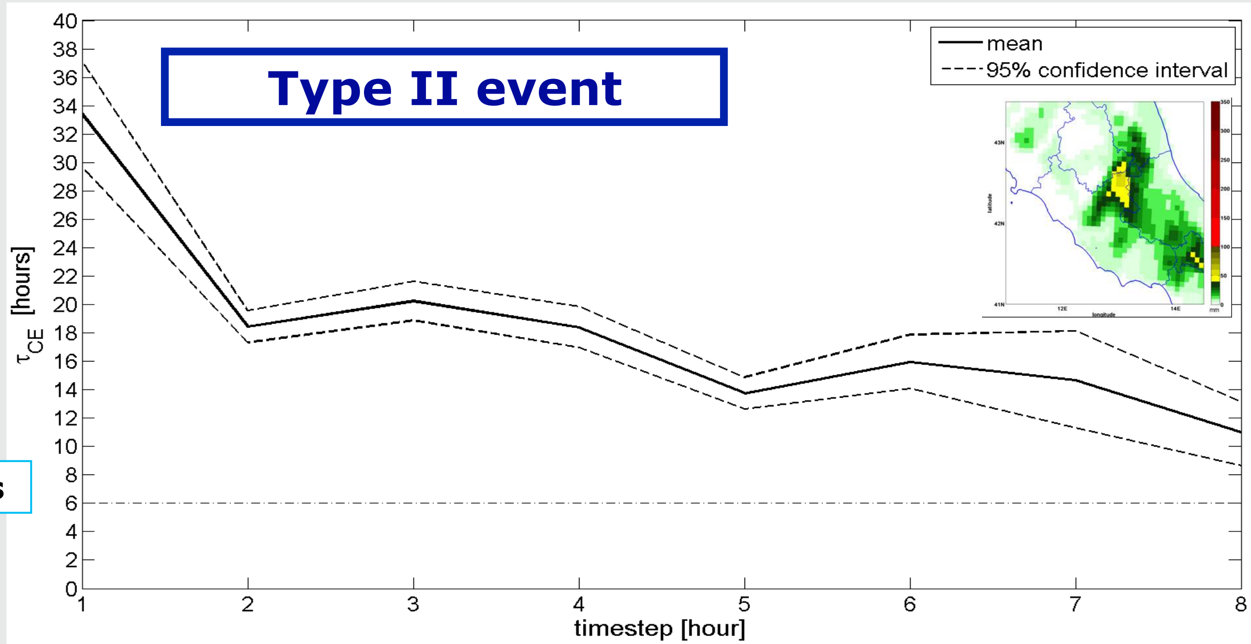
Non-Equilibrium conditions

τ_{CS} ~6 hours

t_{CS}= 6 hrs



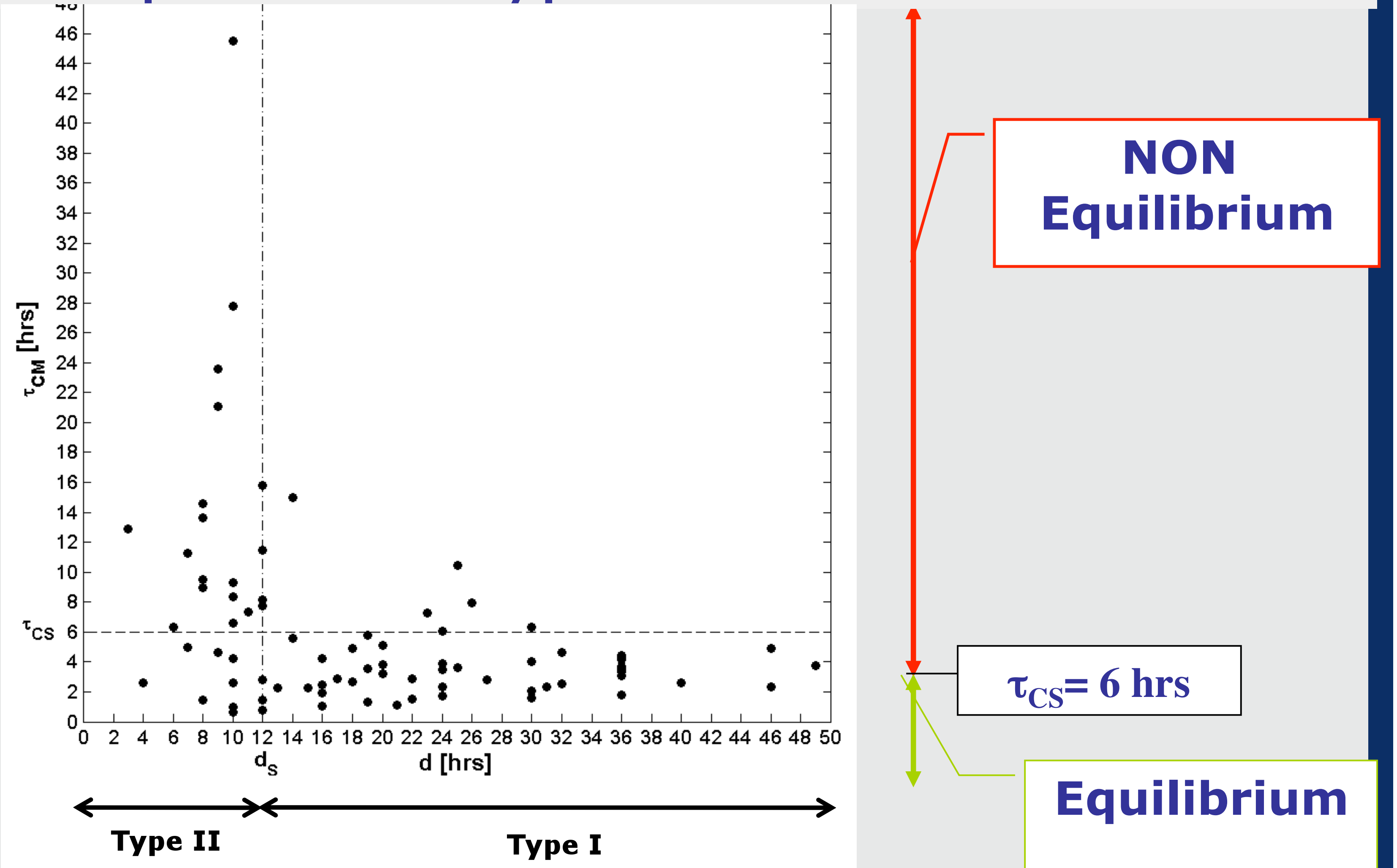
t_{CS}= 6 hrs



L. Molini, A. Parodi, N. Rebora, G. C. Craig, Classifying severe rainfall events over Italy by hydrometeorological and dynamical criteria, QJRMS, 137, 654, 148–154, 2011.

Type I events (**90%**) are largely associated to equilibrium conditions and hence more predictable

Type II events (**66%**) are characterized by non-equilibrium conditions and consequently are expected to be hardly predictable



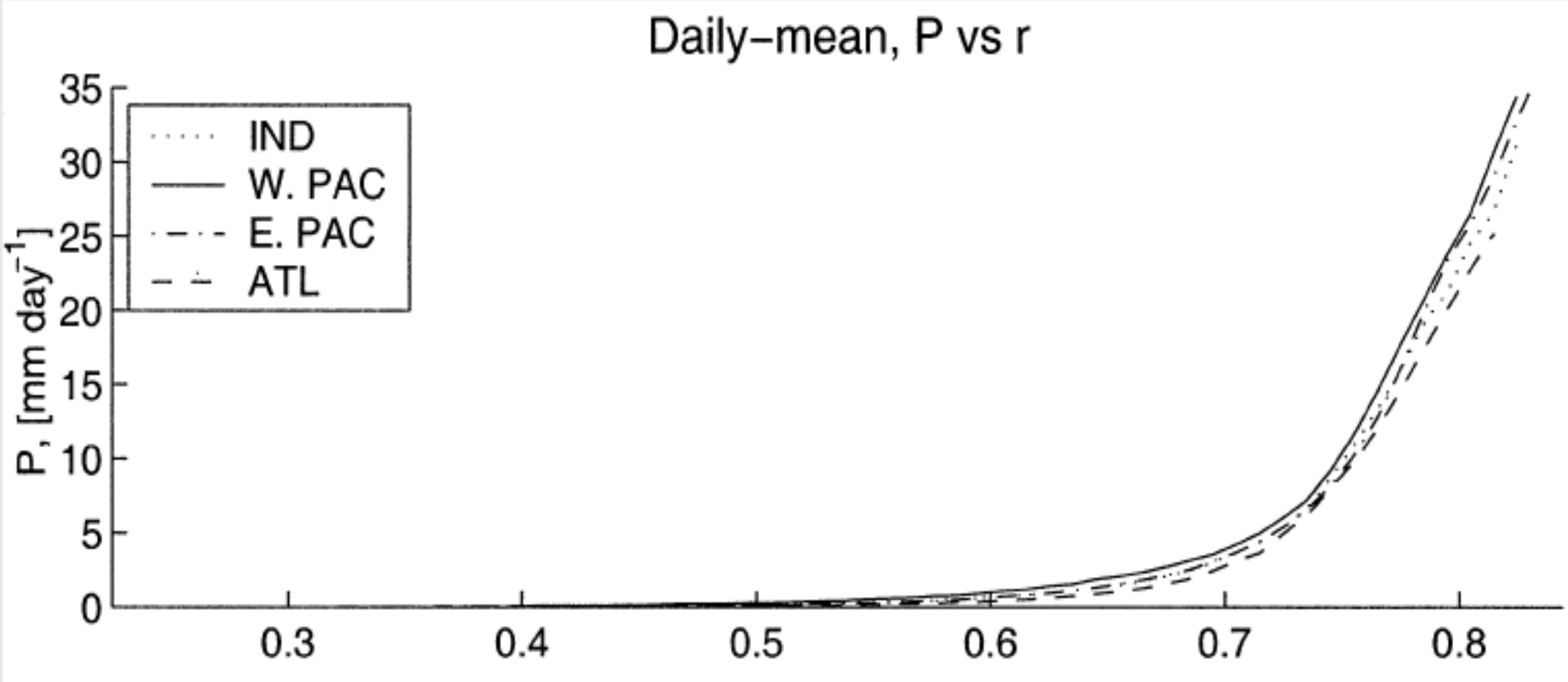
Other predictability tools - SF

- Saturation Fraction indicates how much saturated a column of tropospheric air is in respect to water vapor

$$SF = \frac{Precipitable\ water}{Saturated\ precipitable\ water}$$

- So far basically employed for tropical convection studies
- High SF associated to stratiform systems; lower SF to convective environments (Raymond et al., 2009)

- Over tropical oceans, rain rate is a strong nonlinear function of saturation fraction (Bretherton et al., 2004):



Other predictability tools - NGMS

- GMS: some kind of estimation of the 'convective behavior' in convectively-coupled systems (in other words: the relationship between convective forcing and convection response)

$$NGMS = \frac{\int_s^t \nabla_H \, Moist\ entropy}{\int_s^t Moisture\ convergence}$$

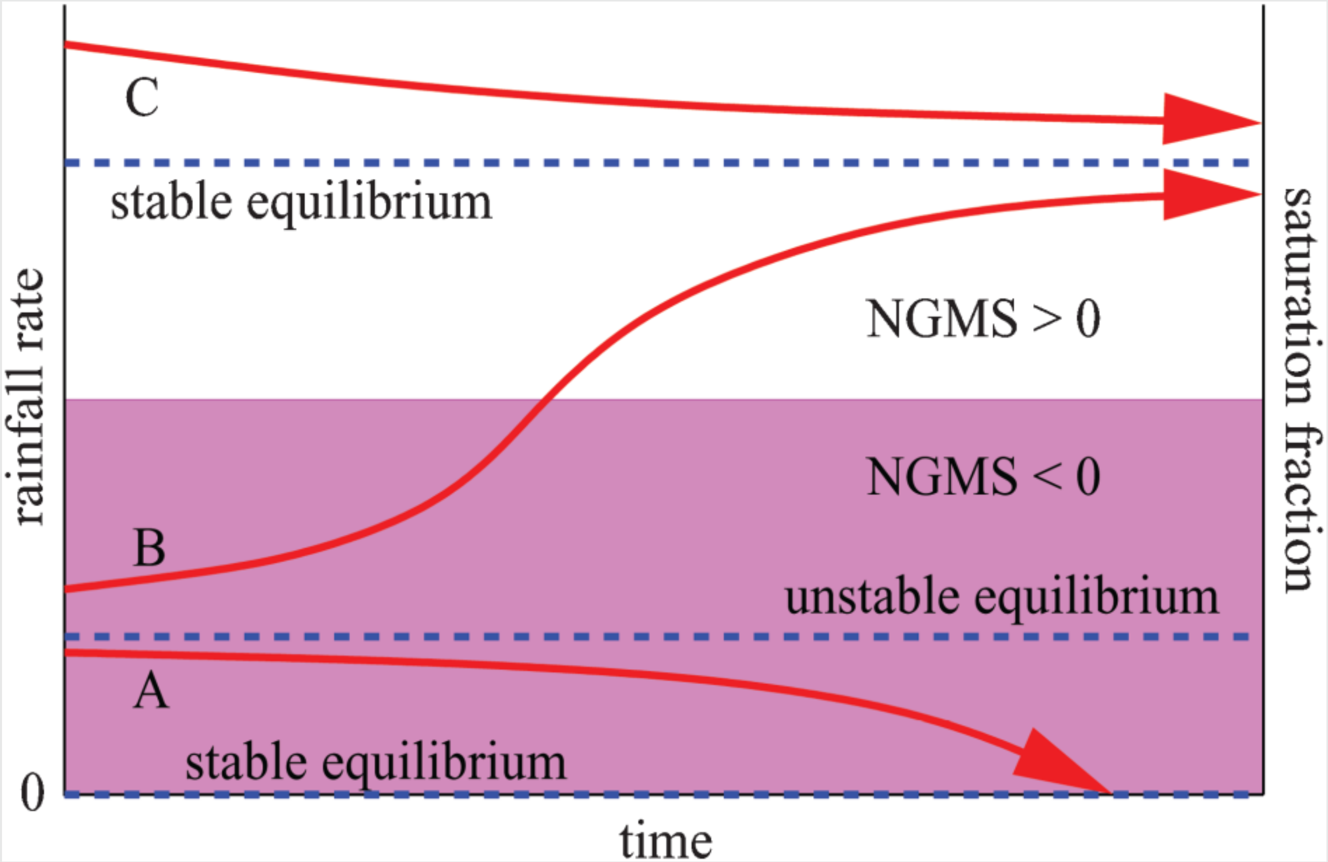
- Numerator: also moist static energy, or equivalent Θ (variables conserved in slow moist adiabatic processes)
- Denominator: also convective mass flux or divergence of Θ flux (a variable representative of the moist convection per unit area)

SF & NGMS - Relationship

- Precipitation over warm tropical oceans → Function of column RH or SF (Raymond, 2000)

- SF and rain rate related by NGMS values!
- NGMS in multiple equilibria conditions:

(From Raymond et al., 2009)



Hypothesis

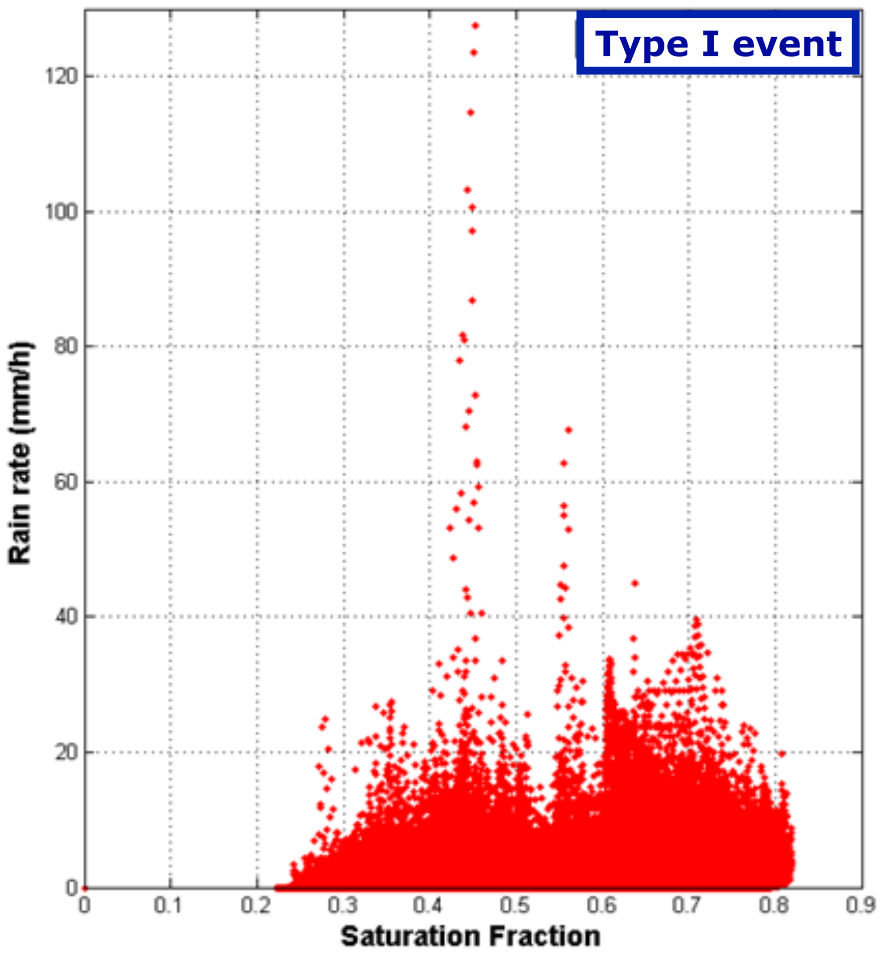
- Can tropical indices such as SF and NGMS be used successfully to characterize predictability also in the Mediterranean, mid-latitude environment?
- If so, how well do they distinguish between type I and II severe rainfall events (as τ_c does)?
- According to Raymond and Fuchs (2009), it would be expected to find high SF values and NGMS>0 for type I (~stratiform) events, and lower SF values and NGMS<0 for type II (~convective) events.

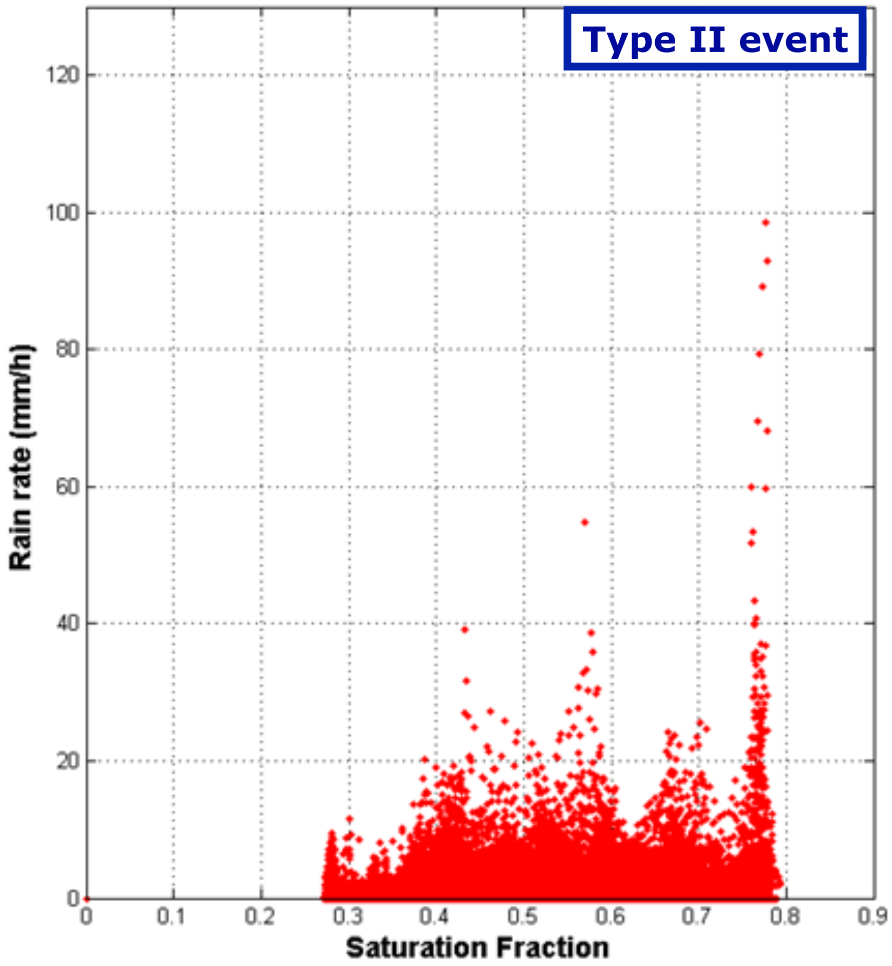
- Work out the spatial mean NGMS and every gridpoint SF for each severe rainfall event (59) from January 2007 to February 2009.

- Atmospheric variables from ECMWF ERA-INTERIM reanalyses (spatial res. 0.60º, temporal res. 3h)

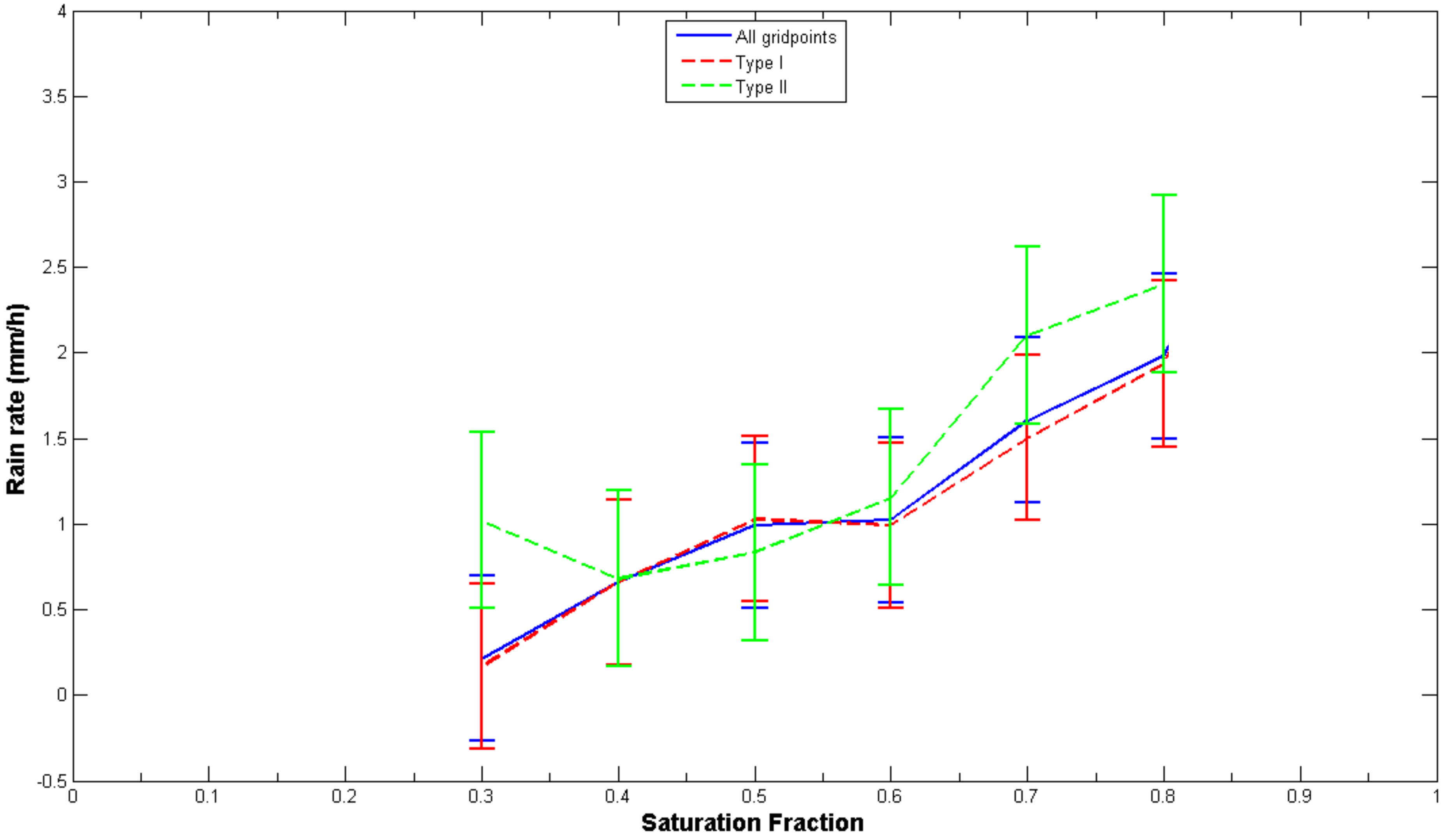
- And spatially interpolated to the same grid as precipitation (spatial res. 7x7 km^2, temporal res. 1h)

Results - SF

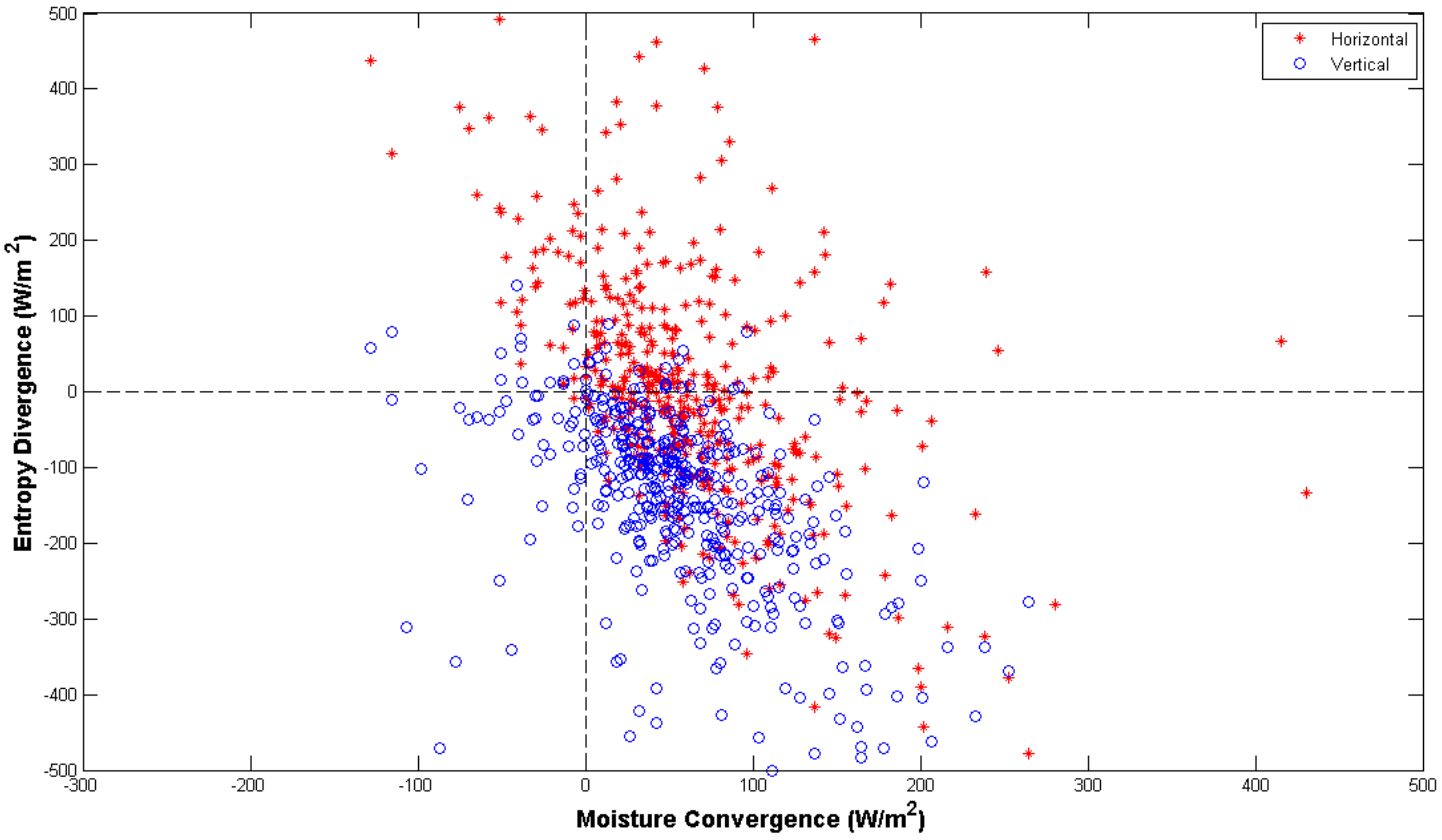

Type I event
Rain rate (mm/h)
Saturation Fraction
0
20
40
60
80
100
120
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9


Type II event
Rain rate (mm/h)
Saturation Fraction
0
20
40
60
80
100
120
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

Results - SF

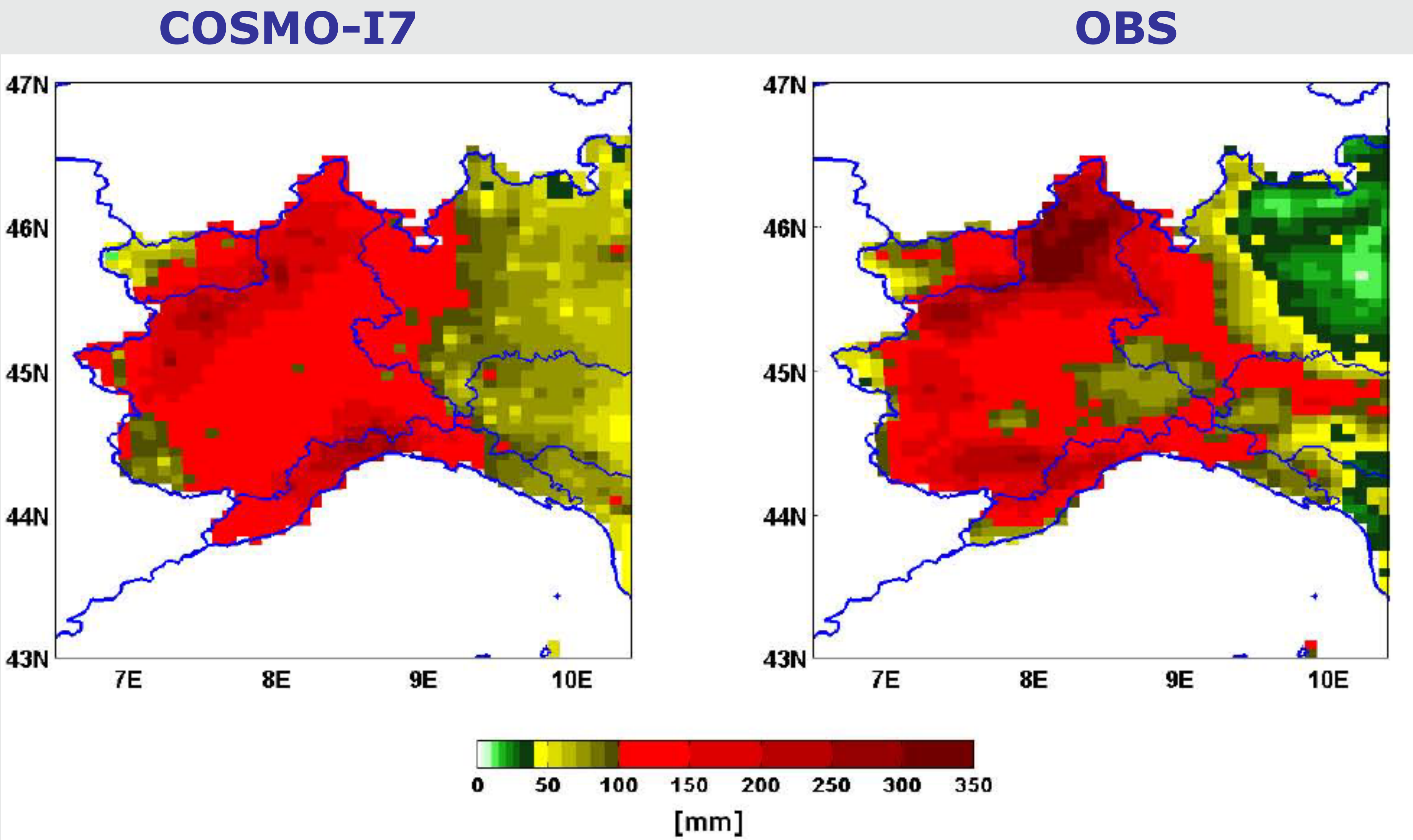

All gridpoints
Type I
Type II
Rain rate (mm/h)
Saturation Fraction
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Results - NGMS

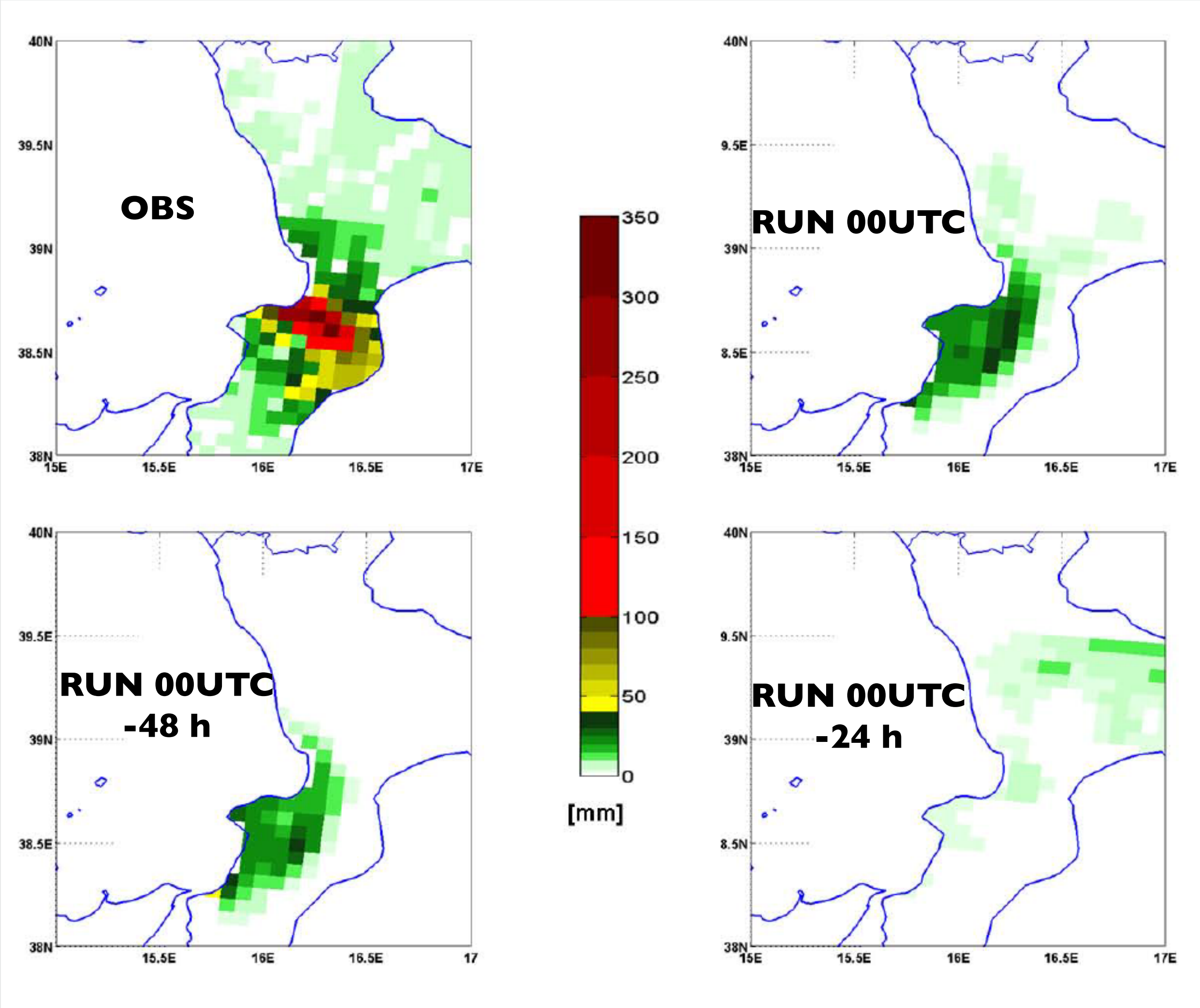


What's about predictive ability?

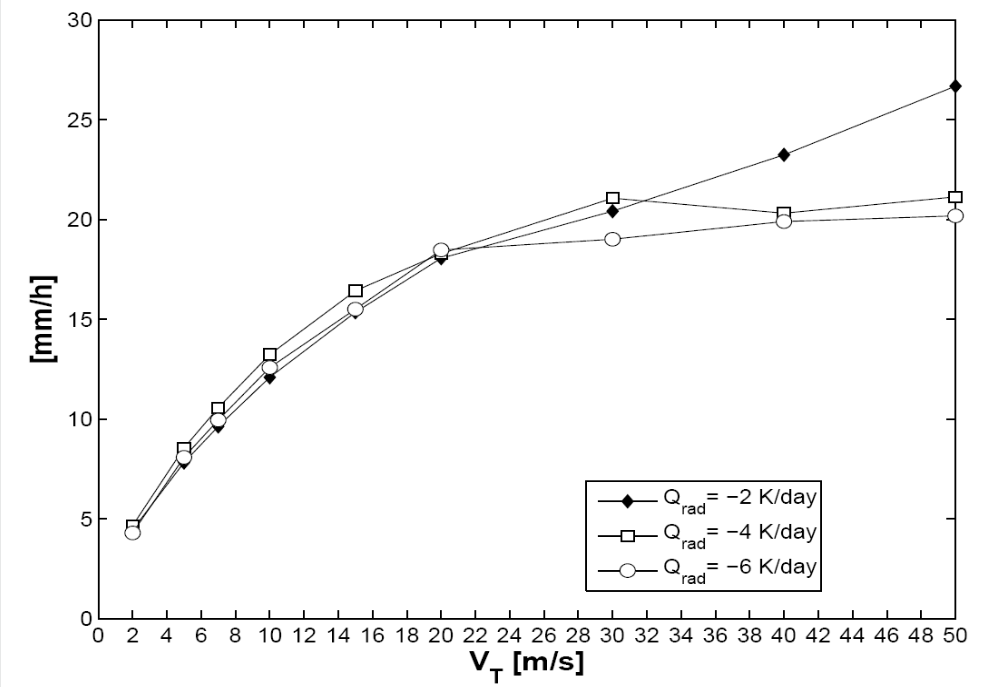
Type I. 14-16 September 2006: d=60 h



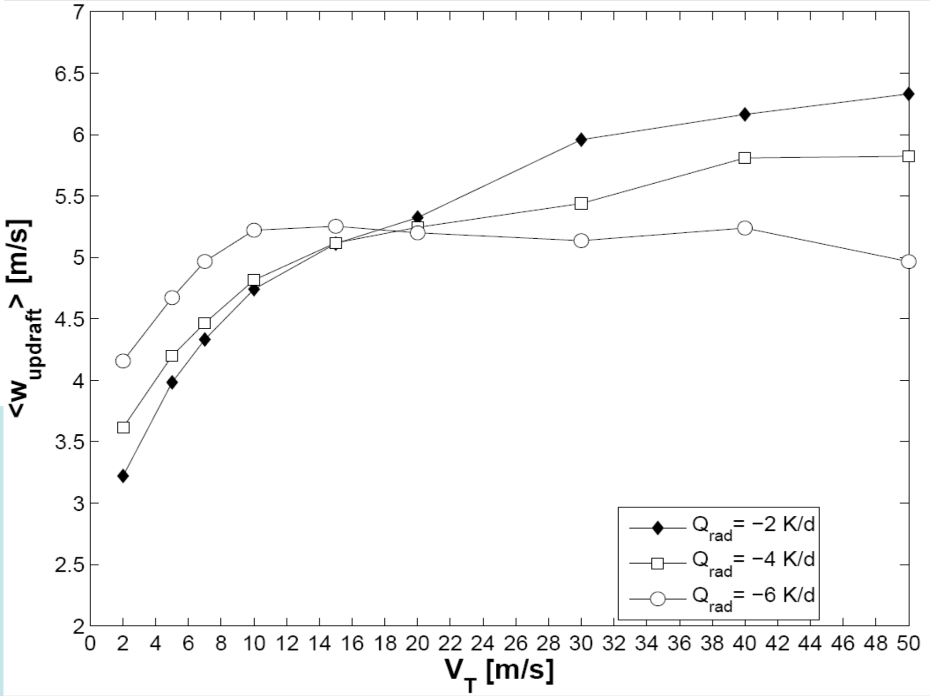
Type II. 3 July 2006: d=9 h



Microphysics and severe rainfall predictability



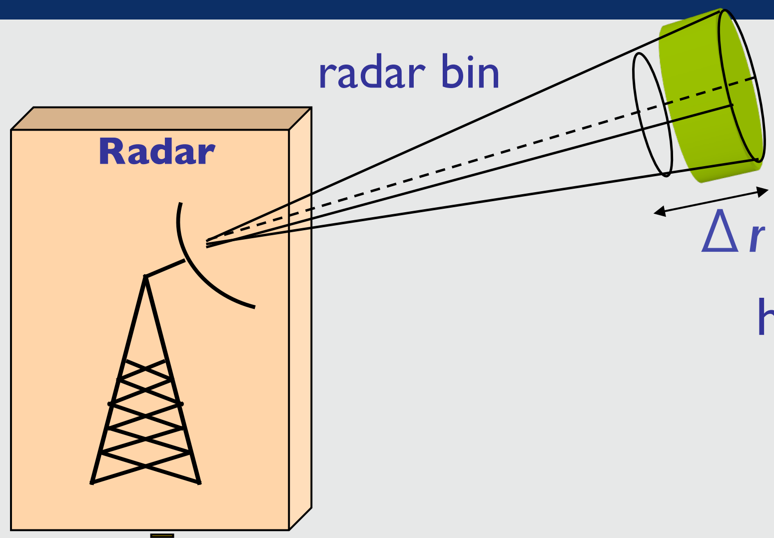
Convective updraft velocities and rainfall intensity scale with the terminal velocity of raindrops

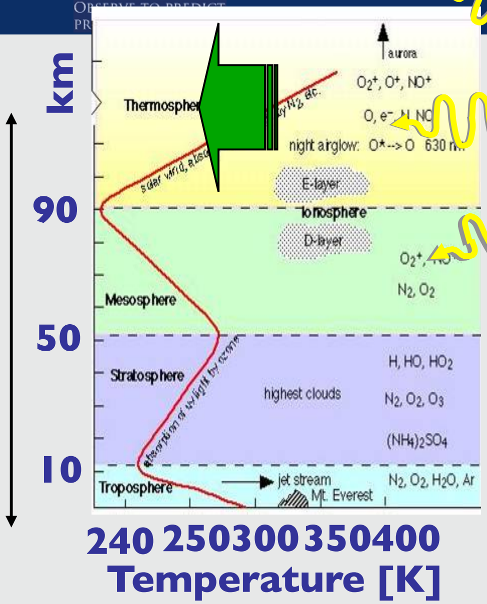


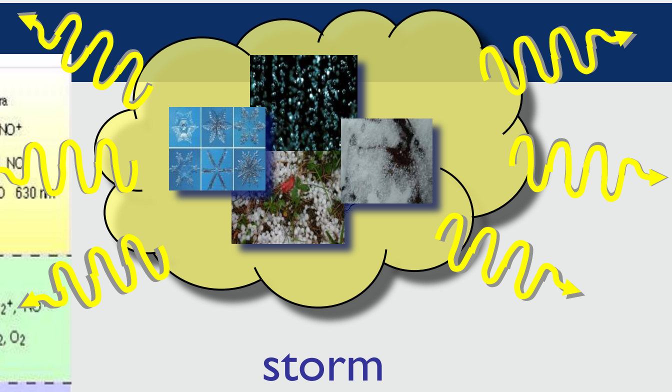
Parodi, A. and Emanuel, K., A theory for buoyancy and velocity scales in deep moist convection, Journal of Atmospheric Sciences 66, 10, 3449-3463, 2009

Parodi, A., Foufoula-Georgiou, E., and Kerry, A., Journal of Geophysical Research, 116, D14119, 12 pp, 2011 doi:10.1029/2010JD015124.

supervised classification algorithm***







Measured radar observables

$$\mathbf{x} = \left\lfloor Z_{hh}, Z_{dr}, K_{dp}, T \right\rfloor$$

radar observables plus temperature

Supervised Bayesian Classification Approach

Assigning correct hydrometeor classes to radar bins

- Classified maps
- Water content

Unknown hydrometeor classes (c_i)

c_i:

i=0, **LD**: *Large Drops*		*i=5,* **H**: *Hail*	
i=1, **LR**: *Light Rain*		*i=6,* **G/SH**: *Graupel/Small Hail*	
i=2, **MR**: *Medium Rain*		*i=7,* **DS**: *Dry Snow,*	
i=3, **HR**: *Heavy Rain*		*i=8,* **WS**: *Wet Snow,*	
i=4, **H/R**: *Hail/Rain mixture*		*i=9,* **IC**: *Ice Crystals*	

***F.S. Marzano, D. Scaranari, M. Montopoli, and G. Vulpiani:
Supervised Classification and Estimation of Hydrometeors From C-Band Dual-Polarized Radars: A Bayesian Approach, IEEE transactions on geoscience and remote sensing, vol. 46, no. 1, January 2008

M.te Settepani weather radar

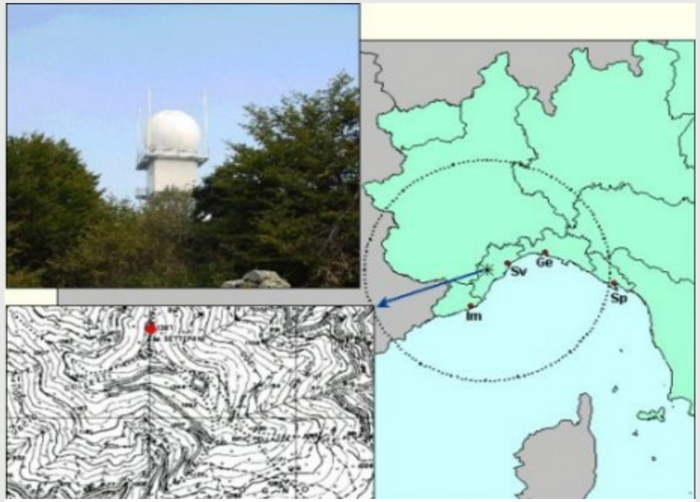


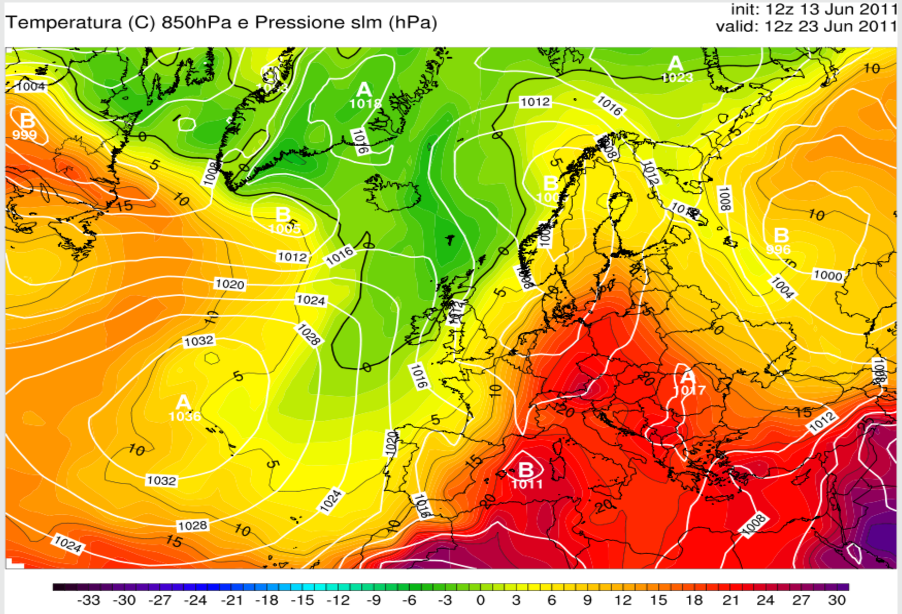
TABLE 1. Characteristics of Settepani C-band radar system (S/N = signal to noise ratio).

Radar characteristics	
Radar model	GPM250C (Selex-Gematronik)
Radar height	1400 m
Beam width	1°
Operational frequency	5600–5650 MHz
Sensitivity	−10 dBZ, with S/N = 0 dB at 50 km
Pulse lengths	0.5/ 1.5/ 3.0 μs
Peak power	≥250 kW
Transmitter	coherent, klystron

TABLE 2. Operational polarimetric scan characteristics.

Radar characteristics	
PRF	1100 Hz
Max distance	136 km
Beam width	1°
Pulse length	0.5 μs
Bin radial resolution	0.3 km
Number of elevations	11
Scan time	10 min
Measured moments	Z_H, Z_{DR}, V_r, ϕ_{DP}, ϱ_{HV}(Lag 1)

Temperature from Era-Interim



ERA-Interim analysis daily products from 1 Jan 1979 can be accessed by MARS users (expver=1, class=ei). Also available are twice daily ten-day forecasts and monthly means. The ERA-Interim archive is more extensive than that for ERA-40, e.g. the number of pressure levels is increased from ERA-40's 23 to 37 levels and additional cloud parameters are included. ERA-Interim products are also publicly available on the ECMWF Data Server, at a 1.5° resolution, including several products that were not available for ERA-40.

Temperature native resolution is 79km and then interpolated over a 1-km polar grid centred on radar's site.

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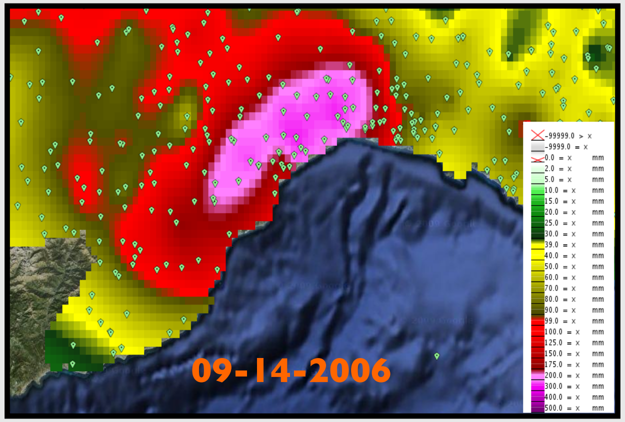
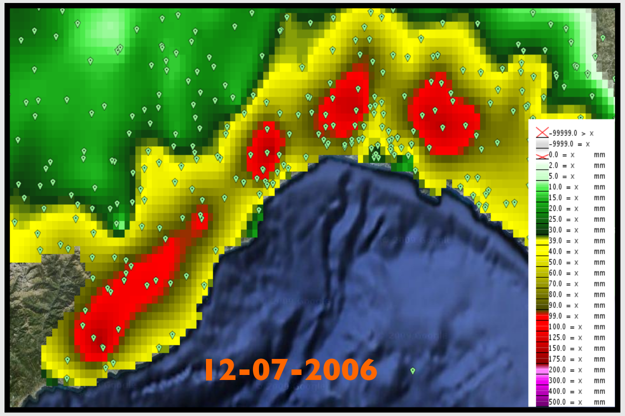
Case Studies

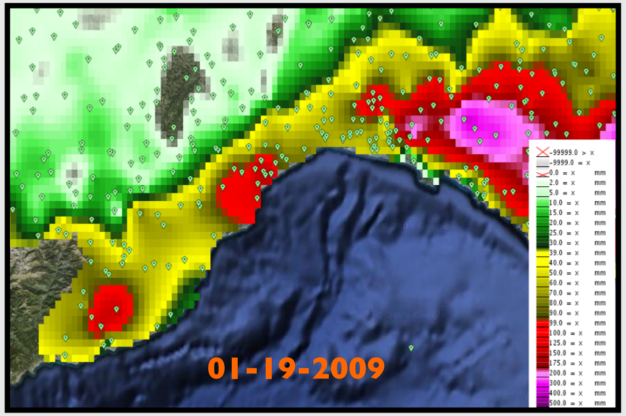
Type I



s:02UTC d:
46hrs

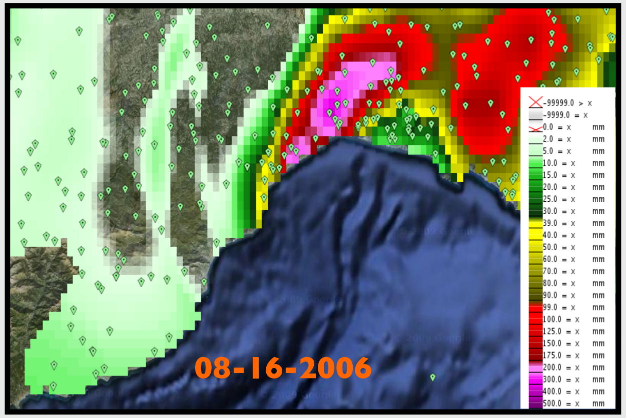


s:13UTC d:
36hrs

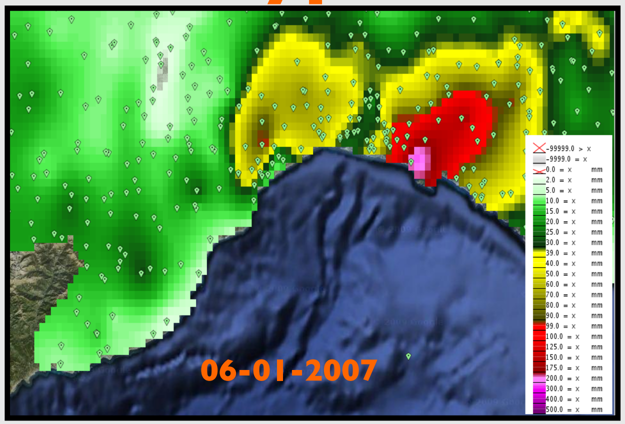


s:12UTC d:
20hrs

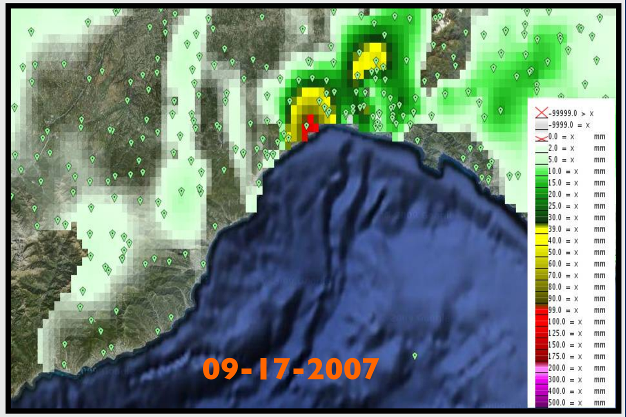
Type II



s:00UTC d:
8hrs



s:04UTC d:
6hrs

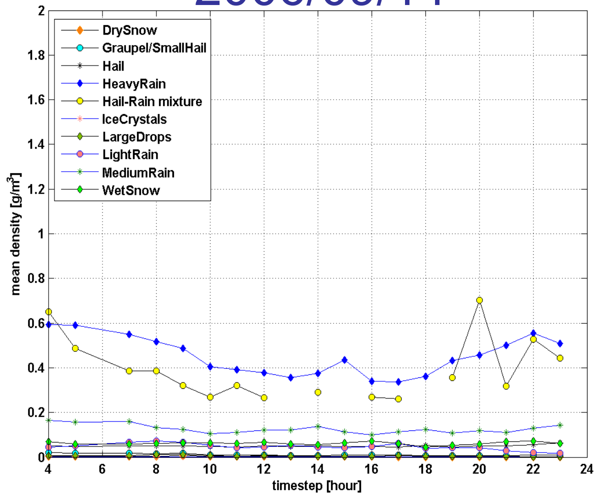


s:00UTC d:
3hrs

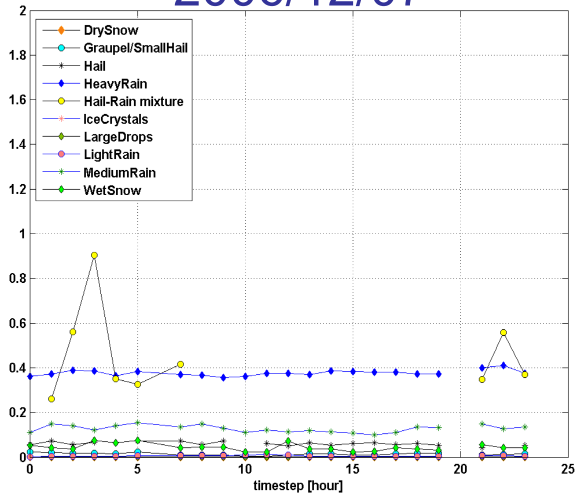
Densities (time series)

Type I

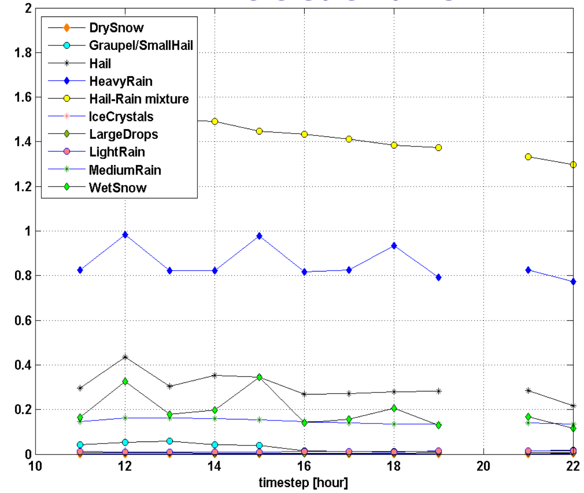
2006/09/14



2006/12/07

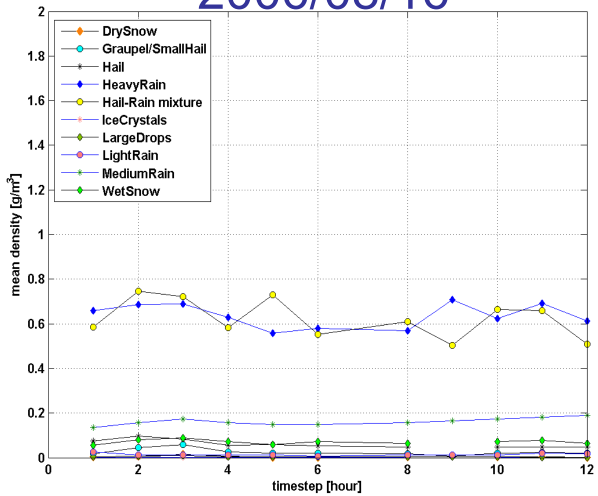


2009/01/19

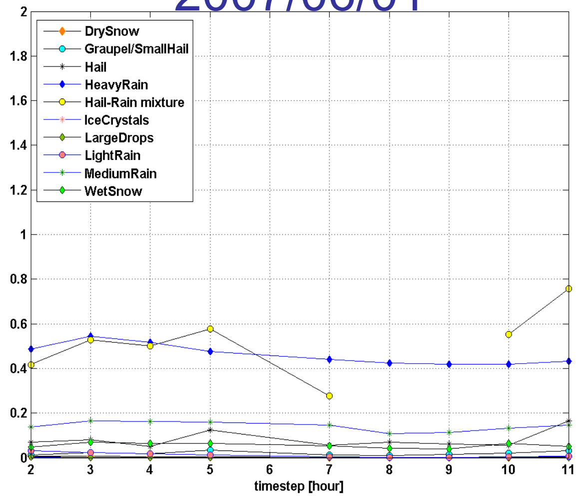


Type II

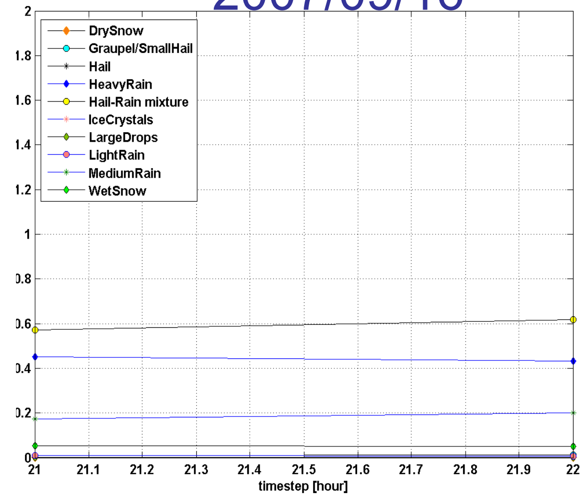
2006/08/16



2007/06/01



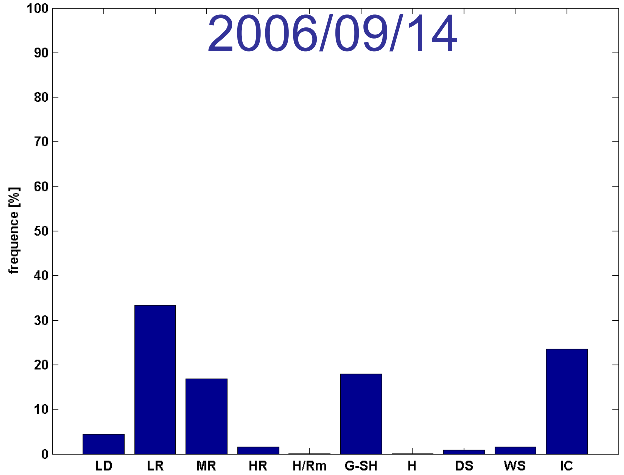
2007/09/16

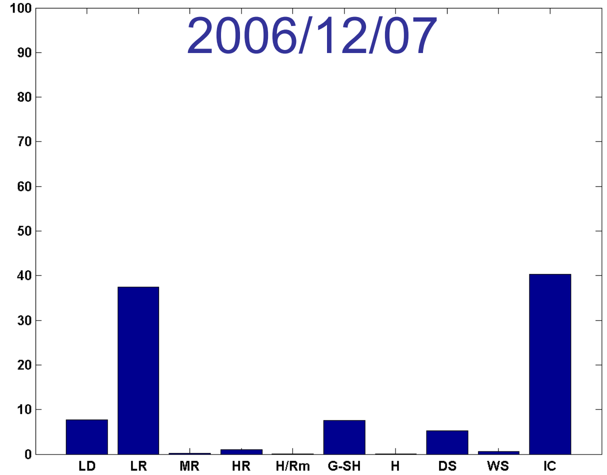


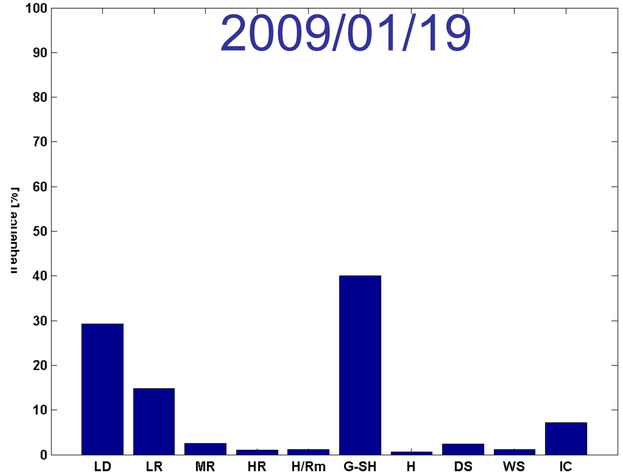
no significant transition during lifetime (mean density timeseries)

Occurrences

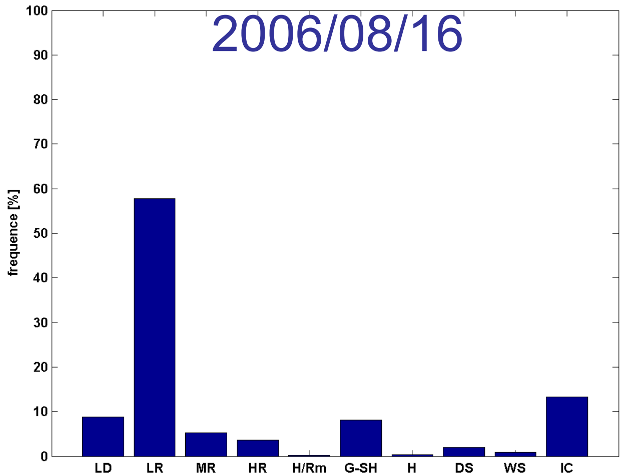
Type I

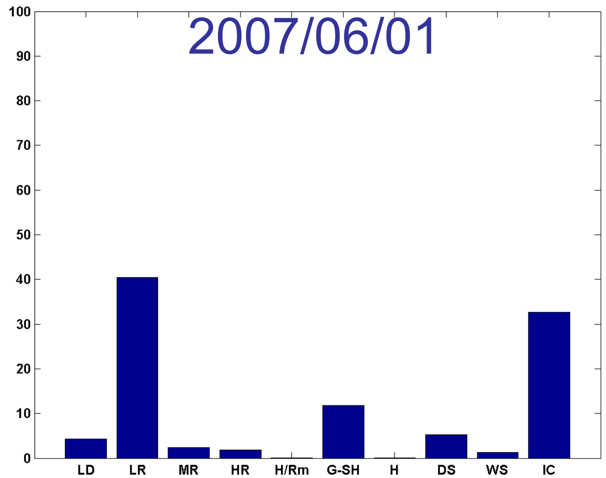


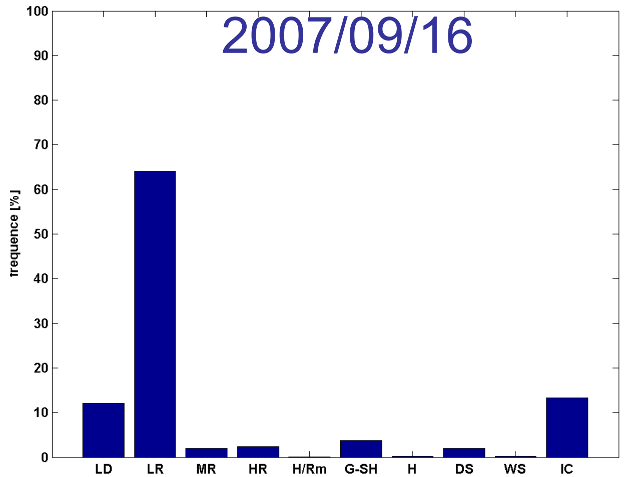




Type II

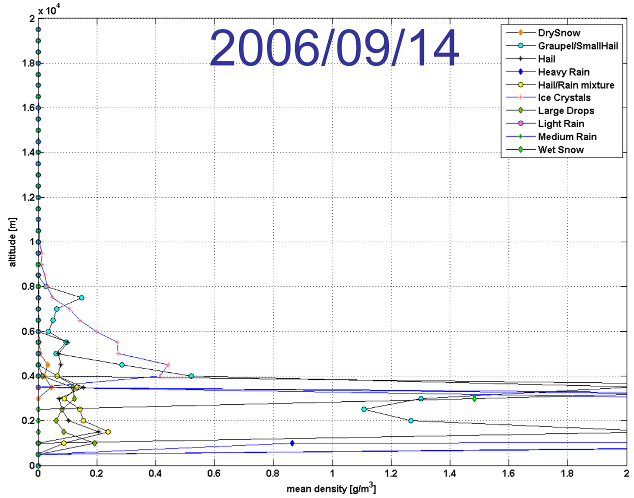


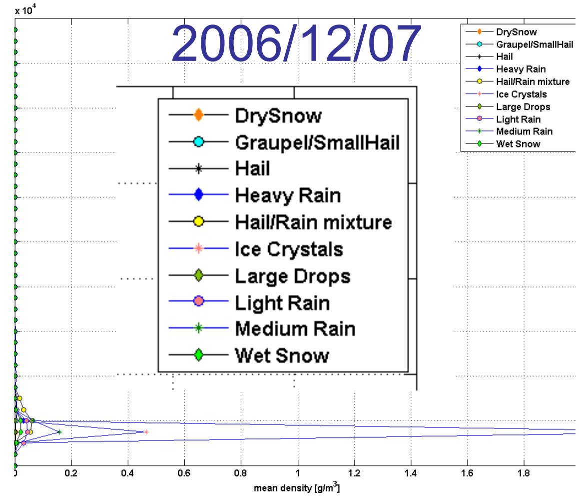


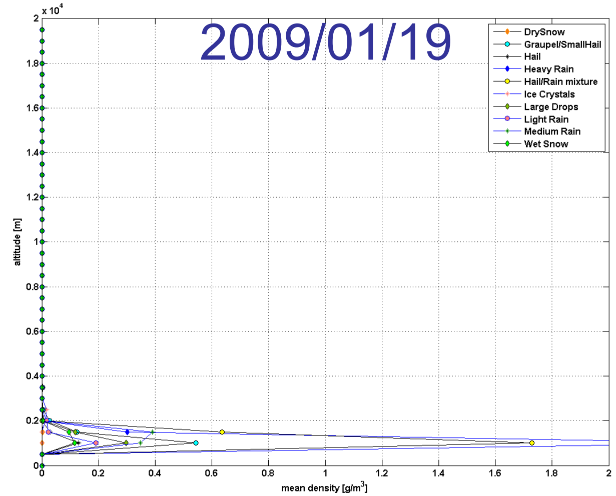


Vertical Profiles

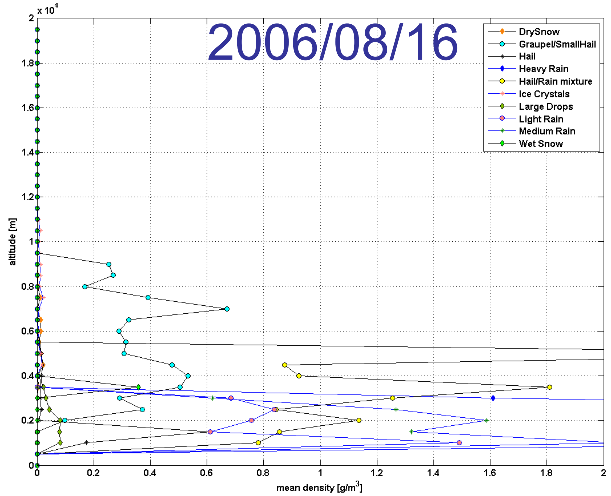
Type I: hardly climb over 4-5km of altitude

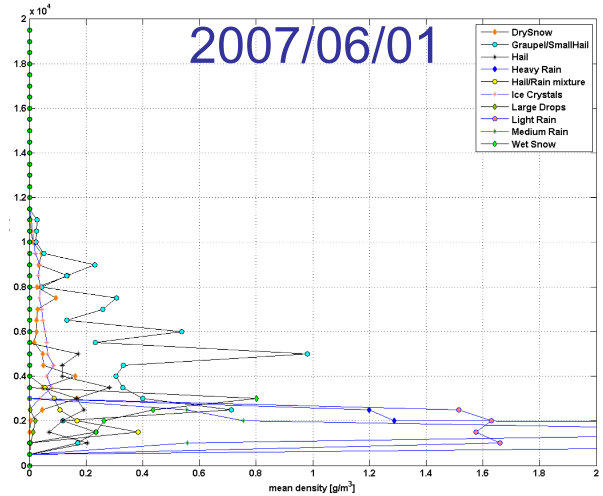


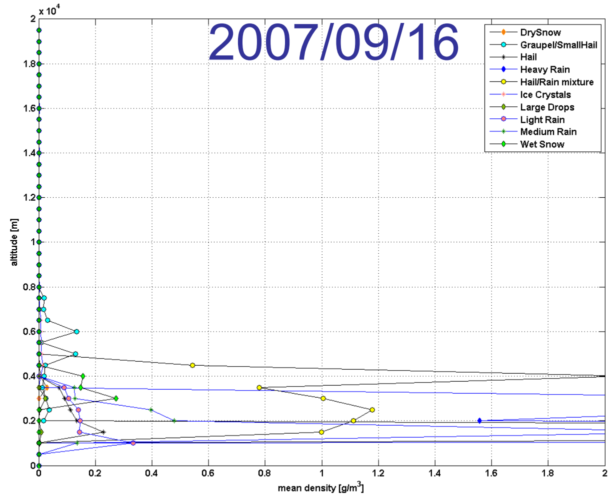




Type II: a more developed vertical profile







Conclusions

- Type I events are largely associated with equilibrium conditions and thus more predictable
- Type II events are characterized by non-equilibrium condition and consequently are expected to be hardly predictable
- SF against rain rates in the Mediterranean environment fit to some extent the observed behavior in the tropics. Further studies could confirm its potential use in predictability
- Not clear what NGMS<0 means in the Mediterranean... But it most probably it is not a good predictability index in our environment...
- Some useful preliminary insight from microphysics analysis