Heavy Precipitation in Mediterranean

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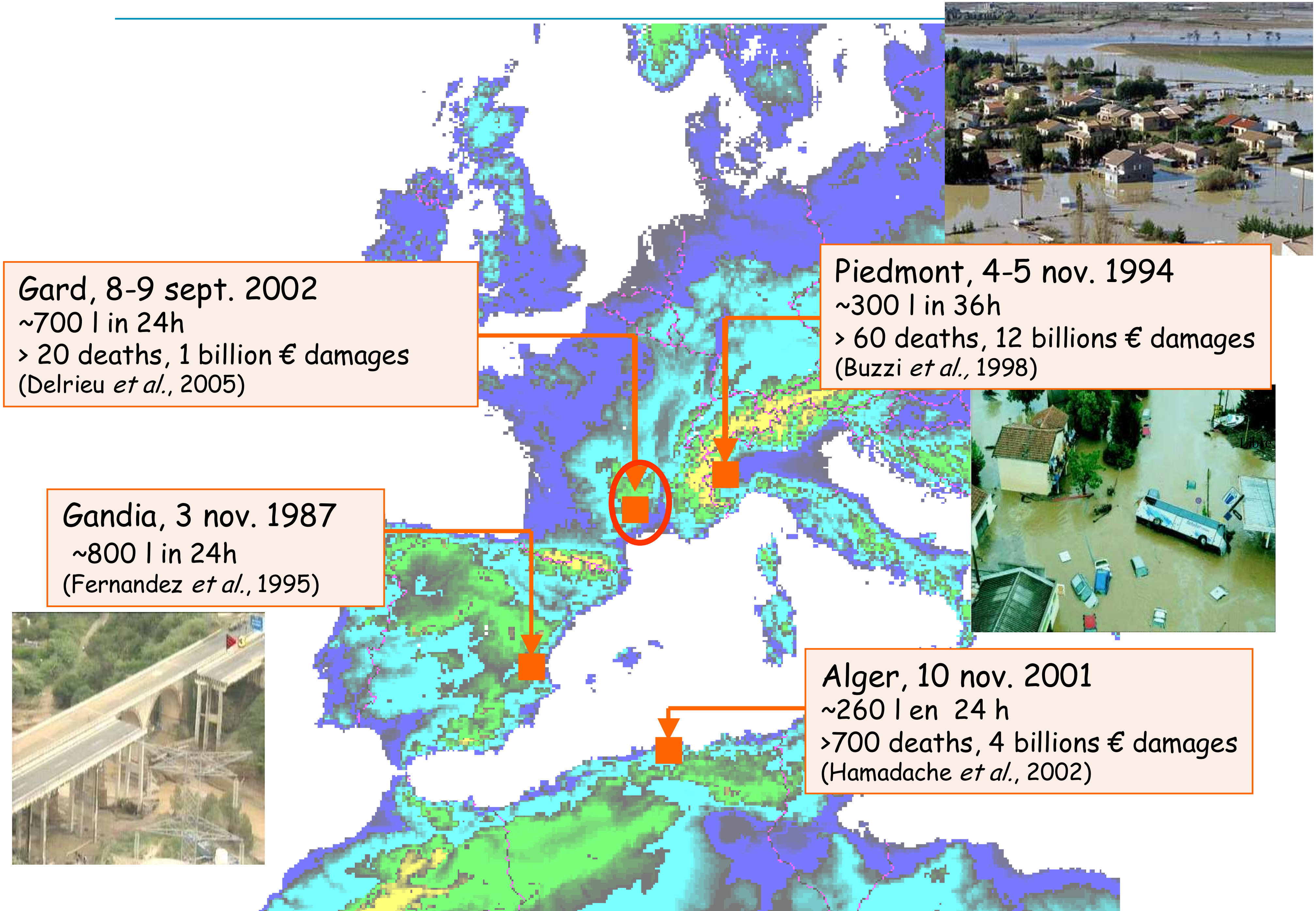
Introduction

Heavy precipitation in Mediterranean



Gard, 8-9 sept. 2002
~700 l in 24h
> 20 deaths, 1 billion € damages
(Delrieu *et al.*, 2005)

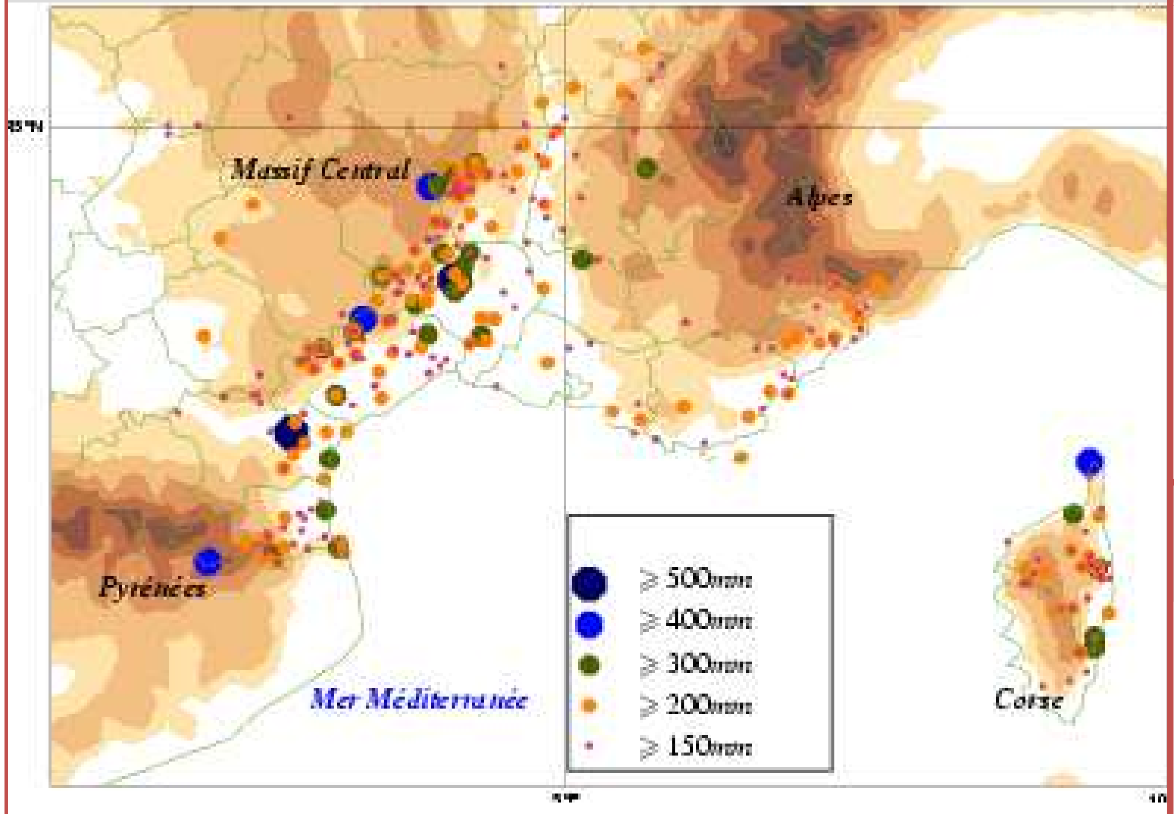
Piedmont, 4-5 nov. 1994
~300 l in 36h
> 60 deaths, 12 billions € damages
(Buzzi *et al.*, 1998)

Gandia, 3 nov. 1987
~800 l in 24h
(Fernandez *et al.*, 1995)

Alger, 10 nov. 2001
~260 l en 24 h
>700 deaths, 4 billions € damages
(Hamadache *et al.*, 2002)

Heavy precipitation in Mediterranean

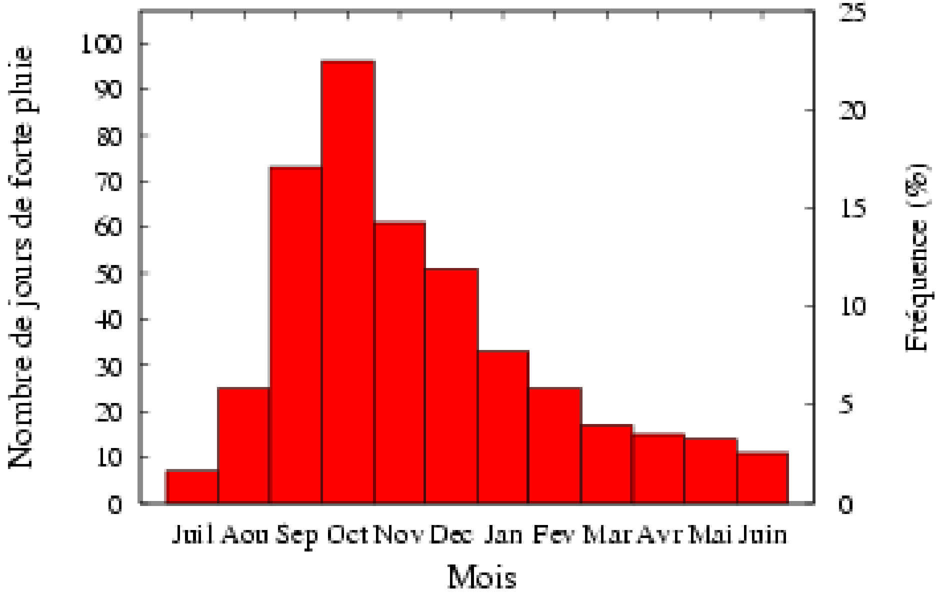
Location of the daily precipitation maximum (> 150 l/24h , 1967-2006)



A phenomenom that is not rare in Mediterranean:

Ex: 7 to 8 events per autumn in France

Rmonthly distribution of the days with heavy precipitation (> 150 l/24h, 1967-2006)

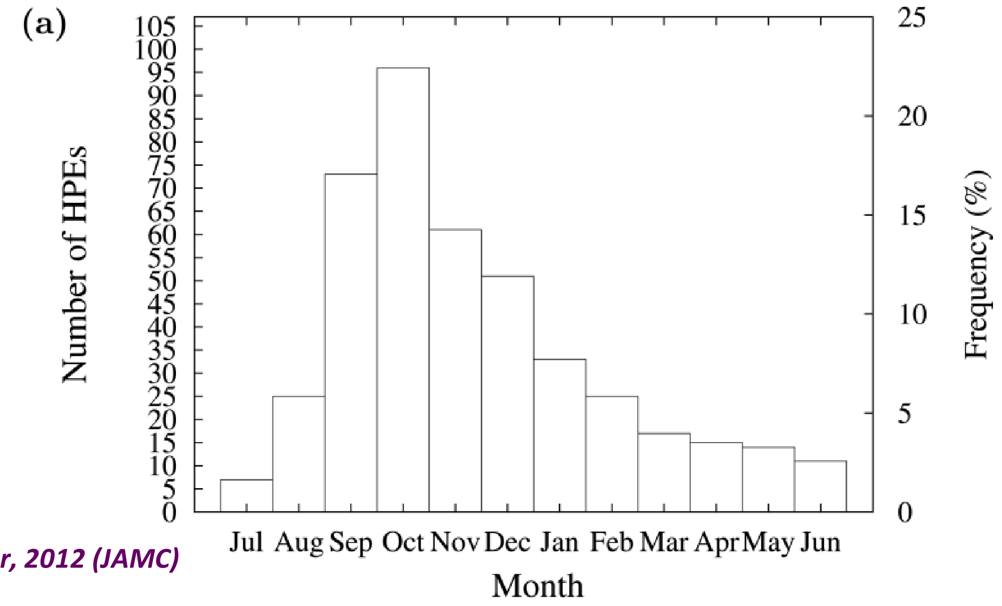


A phenomenom that takes place principally in autumn

(Ricard et al., 2012)

Autumn is the season for HPE

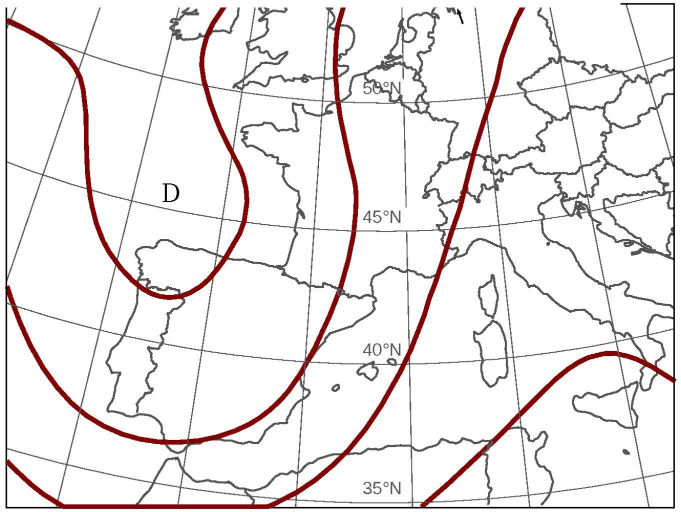
Monthly distribution of HPE
(daily rainfall > 150 mm)
over France, 1967-2006



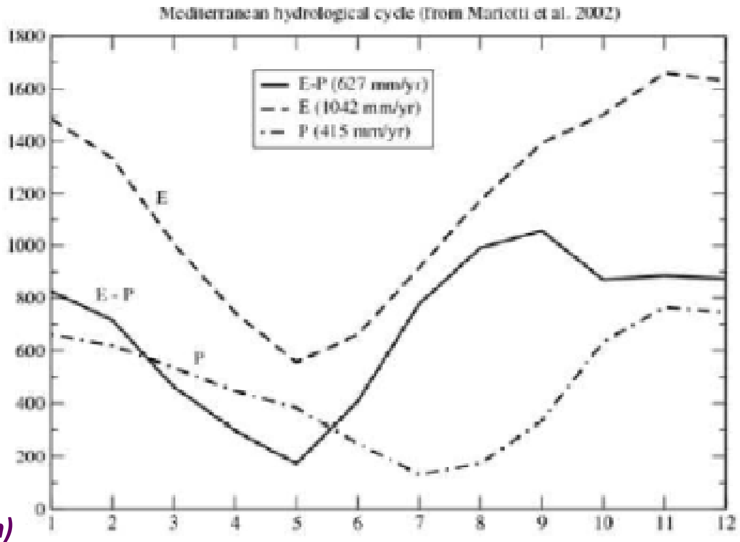
Ricard, D., V. Ducrocq and L. Auger, 2012 (JAMC)

Why autumn ?

Rossby wave breaking at the eastern end of the NA storm track



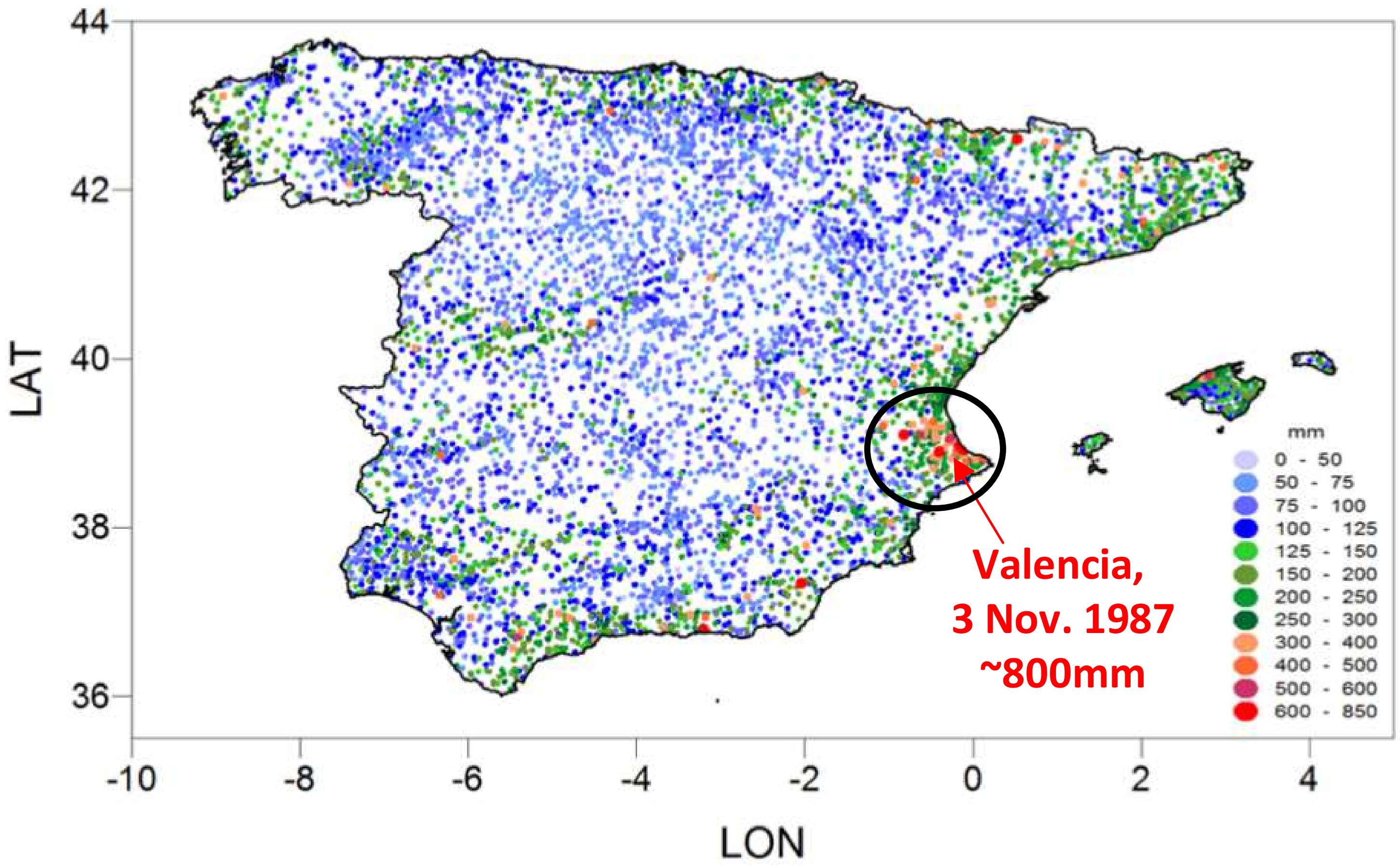
Sea evaporation is maximum



Mariotti et al, 2002 (J. Clim)

Heavy Precipitation in Spain

Location of highest value of precipitation



Valencia,
3 Nov. 1987
~800mm

Daily rainfall over ~1910-2008

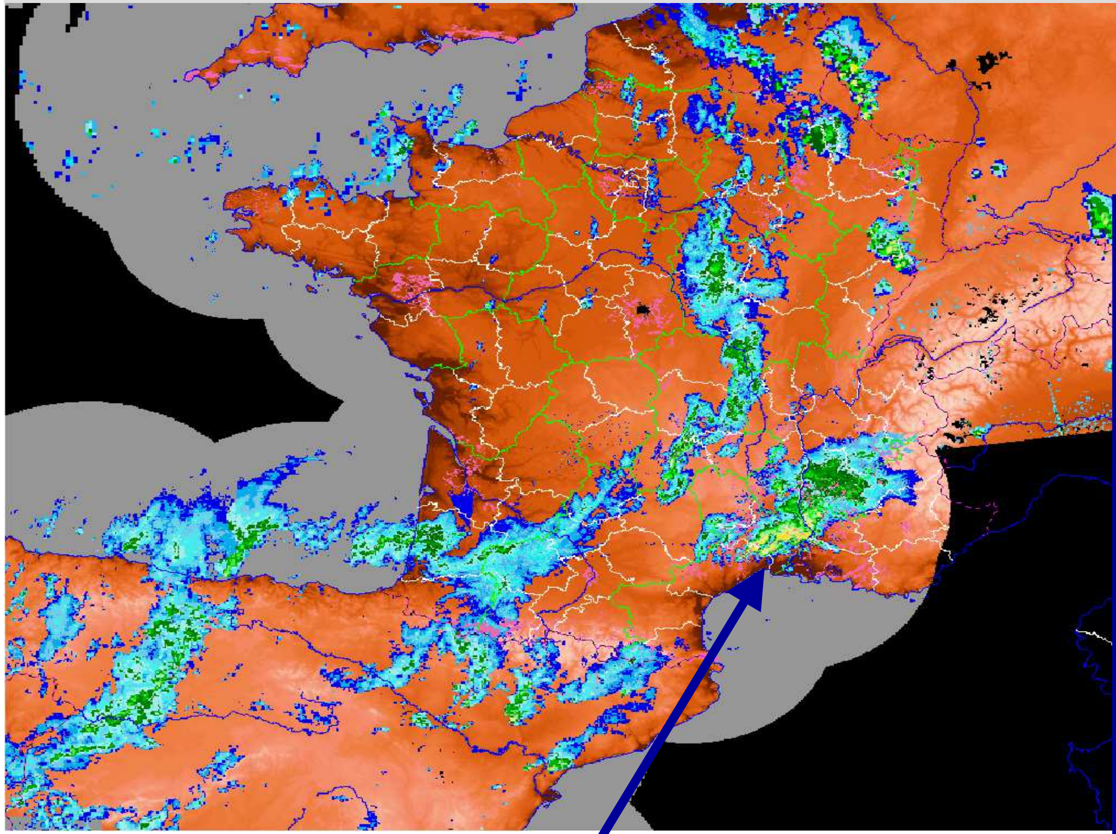
From daily raingauge AEMET network

Ramis, C., V. Homar, A. Amengual, R. Romero, S. Alonso, 2013 (NHESS)

Characteristics of precipitation systems leading to heavy precipitation events

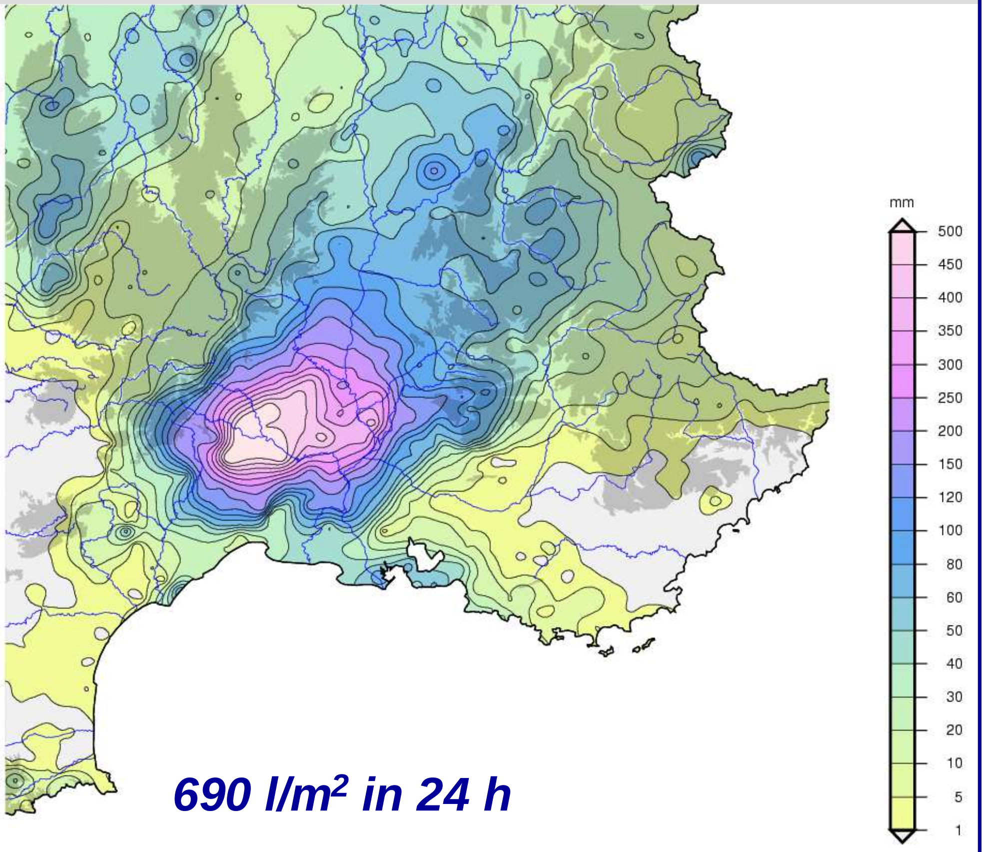
Flash-fllod in Gard, 8-9 septembre 2002

Radar at 18 UTC, 8 Sept. 2002



Quasi-stationanry convective systems
during ~ 24 h

Precipitation totals
06 UTC, 8 sept. 2002 - 06 UTC, 10 sept. 2002



690 l/m^2 in 24 h

Characteristics of precipitation systems leading to heavy precipitation events

Rhône flooding
1-3 décembre 2003

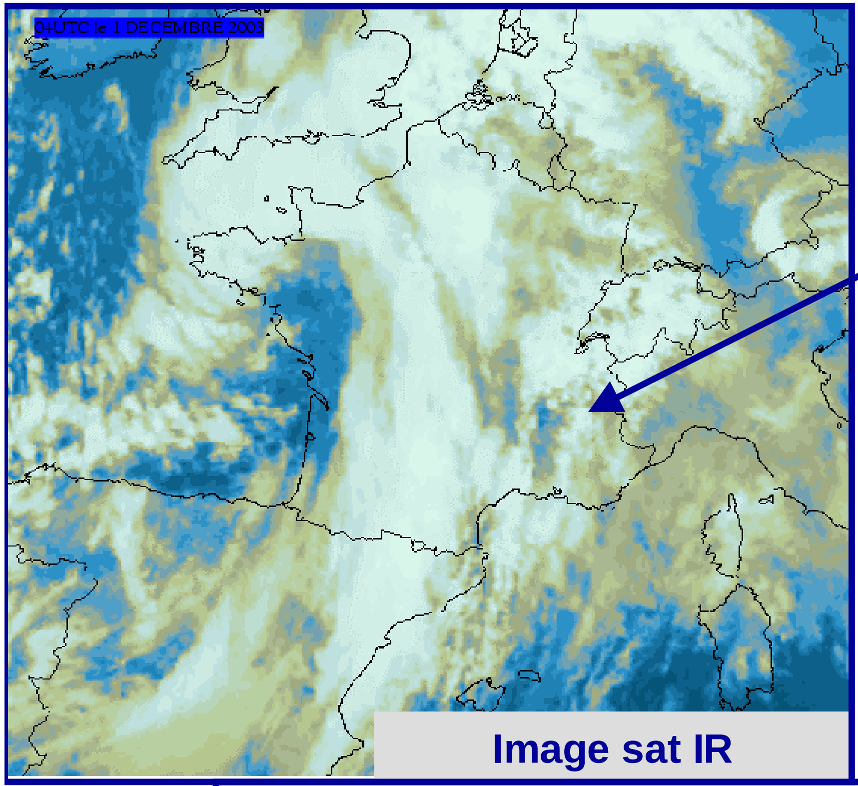
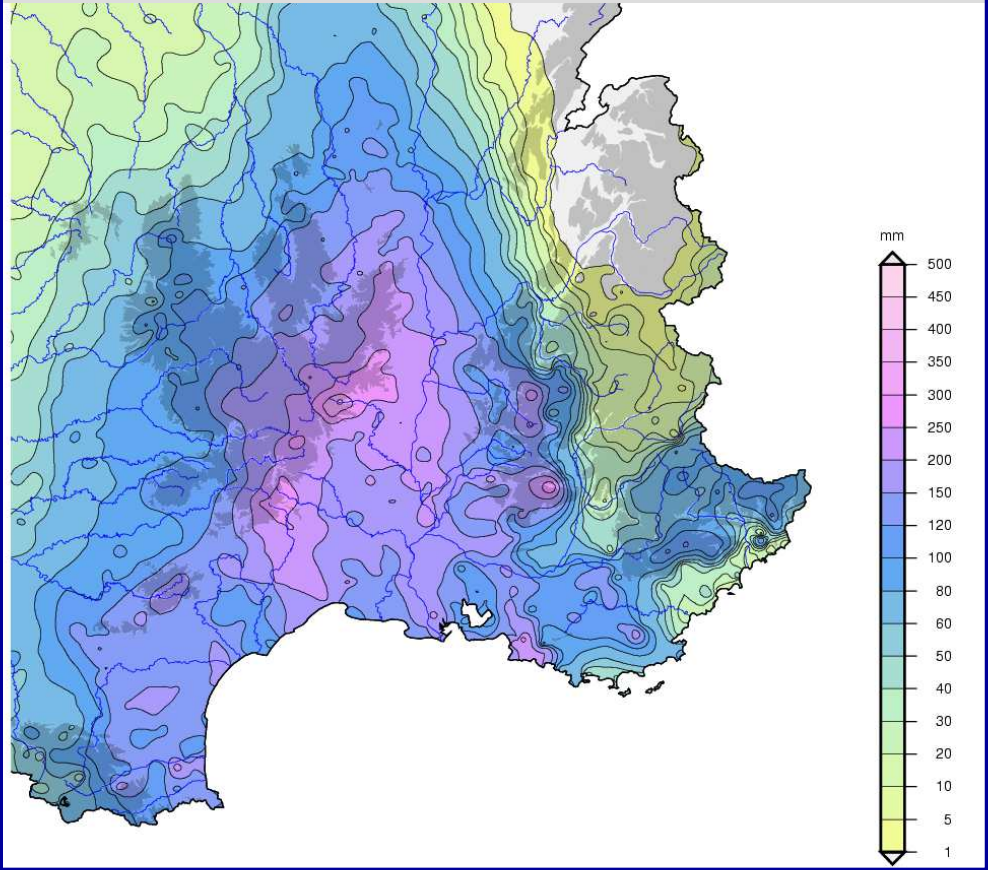


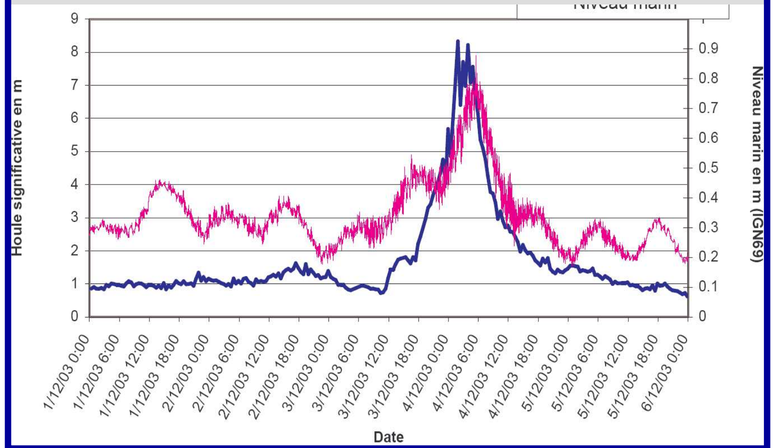
Image sat IR

Frontal disturbance
quasi-stationary during ~ 3 d

Precipitation totals
06 UTC, 1 dec. 2003 - 06 UTC, 4 dec. 2003

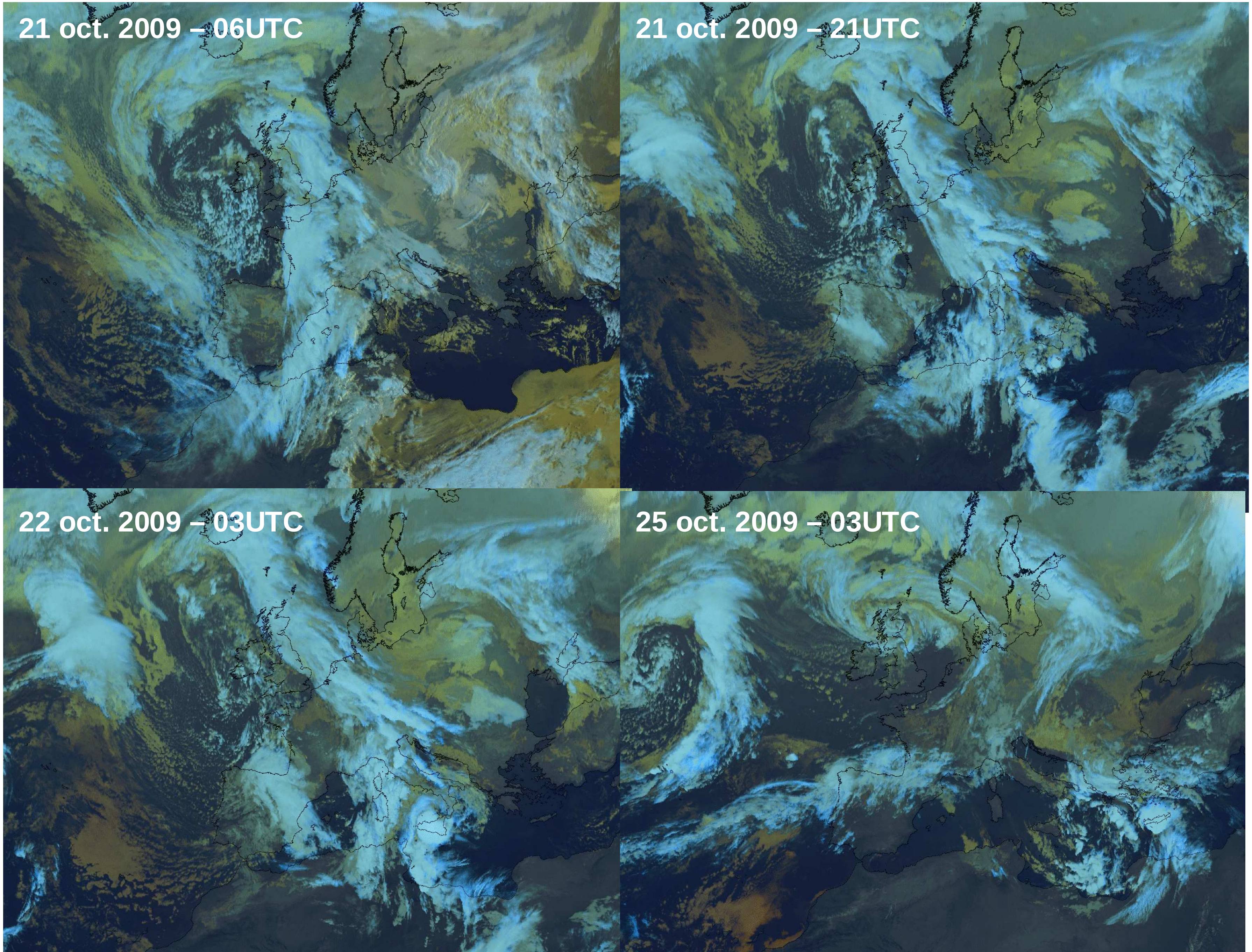


Swell (--) at Banyuls
sea level (--) à Port-Vendres



Gex-PA

Characteristics of precipitation systems leading to heavy precipitation events



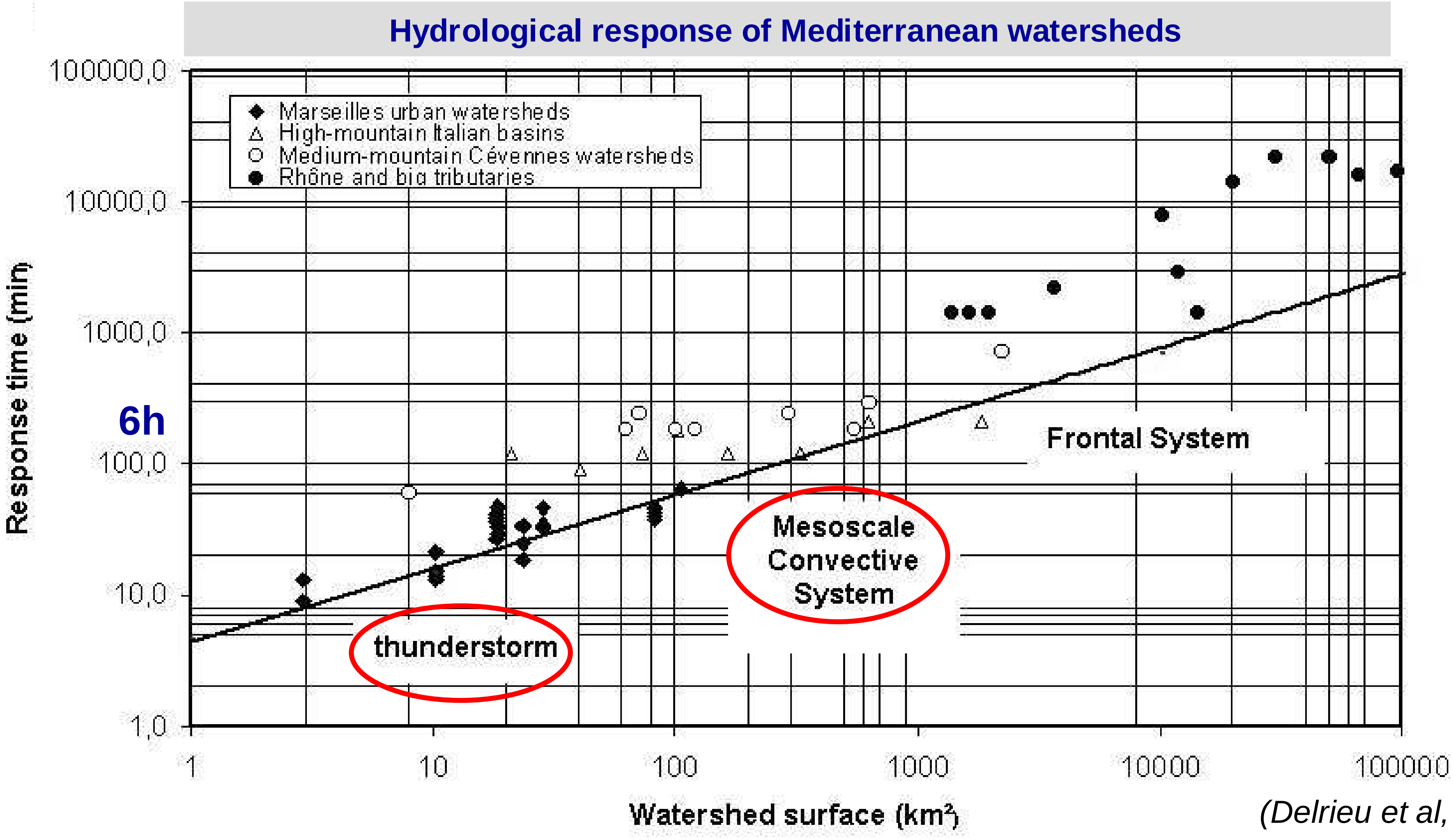
Massif Central

Southeastern France

Sicily

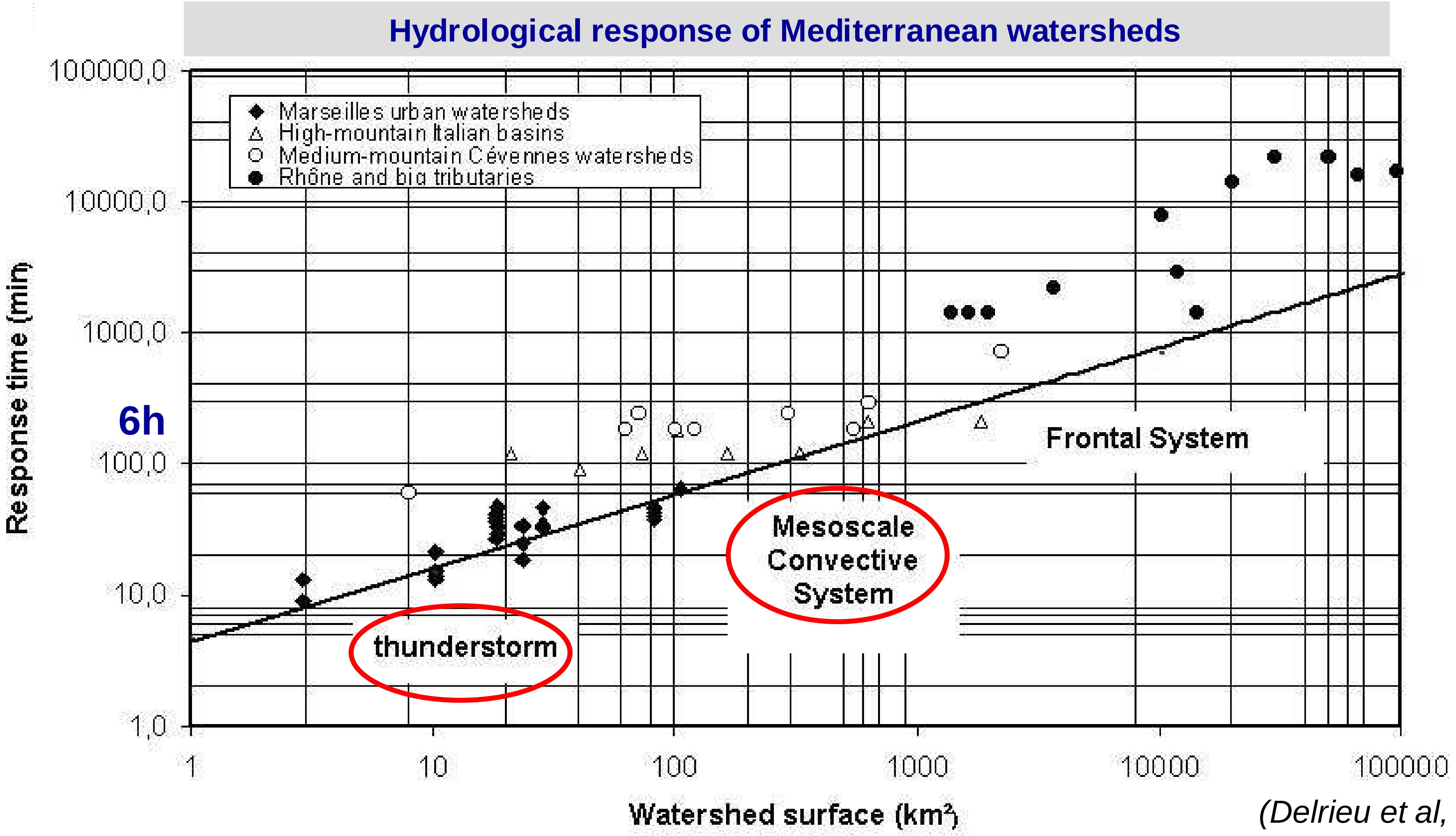
Greece

Atmospheric systems leading to flash-fllooding



(Delrieu et al, 2008)

Atmospheric systems leading to flash-fllooding



(Delrieu et al, 2008)

Moist convection

Thermodynamic invariants

Buoyancy, lagrangian parcel method, CAPE, CIN

Updraft/downdraft

Convection organization

Mesoscale convective system

Reference book:

Houze, 1993: Cloud Dynamics

Thermodynamic properties of dry air

The first law of thermodynamics:

$$dQ = C_p dT - \frac{dP}{\rho}$$

$dQ = 0$ For adiabatic displacement (without radiation, witout latent heat release,…)

<u>For dry air</u>:

$$dQ = 0 \Longrightarrow d\ln\theta = 0 \Longrightarrow$$

The potential temperature $\theta = T\left(\frac{P_0}{P}\right)^{\frac{R}{C_{pa}}}$ is conserved for adiabatic displacement

Thermodynamic properties of moist air

Moist air without water phase changes:

$$
\begin{aligned}
r &= \frac{m_a}{m_v} \\
C_{ph} &= C_{pa}\left[\frac{1+r\dfrac{C_{pv}}{C_{pa}}}{1+r}\right] \simeq C_{pa}\,(1+0.85r) \\
T_v &= T\left[\frac{1+r\dfrac{R_a}{R_v}}{1+r}\right] \\
dQ &= C_{ph}dT - \frac{dP}{\rho} = C_{pa}(1+0.85r)dT - \frac{dP}{\rho} \\
&\simeq C_{pa}(1+0.24r)dT_v - \frac{dP}{\rho}
\end{aligned}
$$

$dQ = 0 \Longrightarrow d\ln\theta_v = 0$ with $\theta_v = T_v\left(\frac{P_0}{P}\right)^{\frac{R}{C_{pa}(1+0.24q)}}$

the virtual potential temperature is the invariant for adiabatic displacement of moist air without water phase changes

Thermodynamic properties of moist air

Moist air with water phase changes:

no more adiabatic as there are sources of Q (condensation/evaporation, freezing/melting, sublimation/sedimentation)

Thus θ and θ_v are no more conserved for saturated conditions

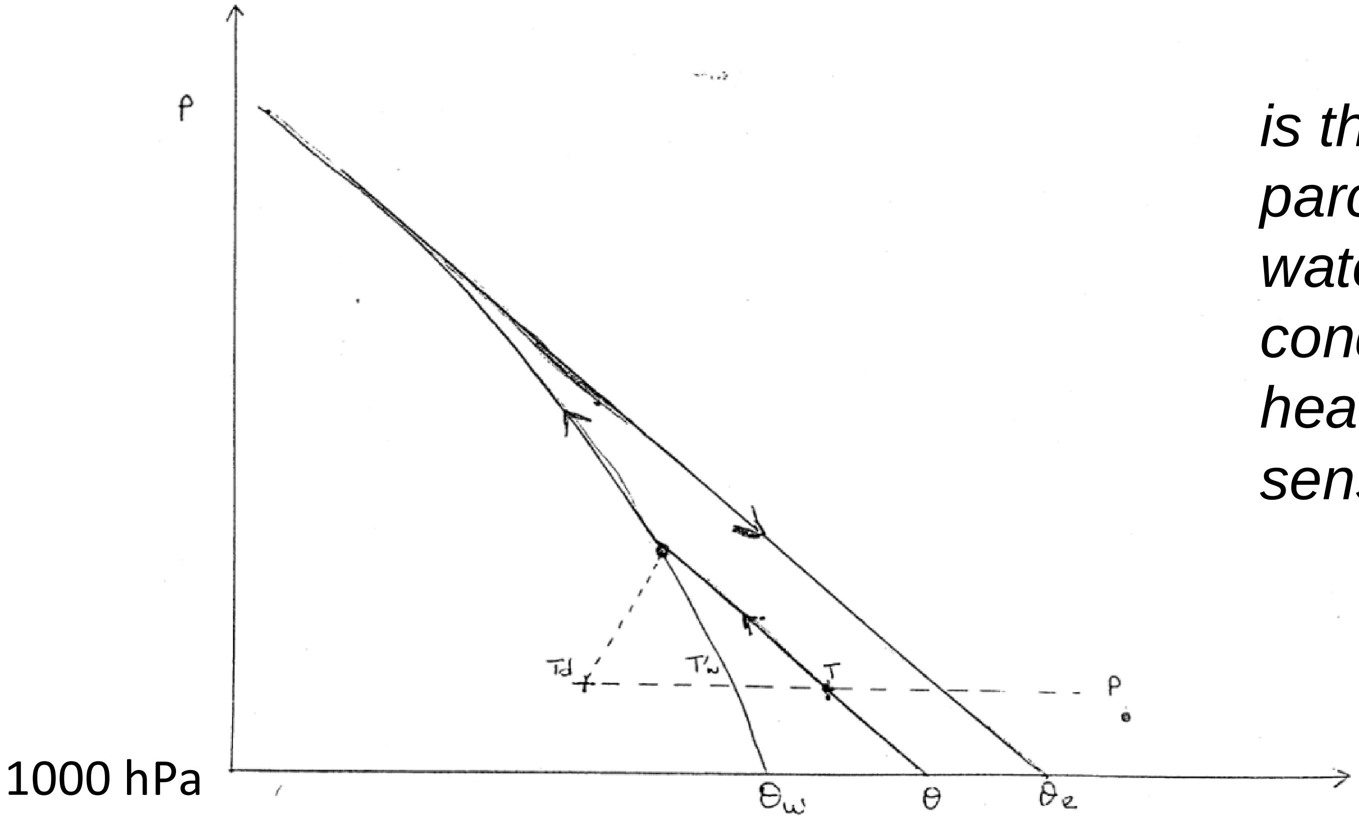
Assuming $$C_p \simeq C_{pa}: \frac{d\theta}{\theta} \simeq -\frac{L}{C_pT}dq \Longrightarrow \theta_e = \theta \exp\left(\frac{Lq}{C_pT}\right)$$

θ_e is the equivalent potential temperature

is very nearly conserved under saturated conditions

Thermodynamic properties of moist air

θ_e is the equivalent potential temperature



is the temperature that a parcel would have if all its water vapour was condensed ant the latent heat release converted into sensible heat

The Buoyancy

Eq for vertical motion:

$$\frac{dw}{dt} = -\frac{1}{\rho}\frac{\partial P}{\partial z} - g$$

Hydrostatic balance $(\frac{\partial P}{\partial z} = -\rho g)$ is not valid for deep convection

as the vertical acceleration is not negligible $\frac{dw}{dt} \neq 0$

We write the equation of motion in terms of the deviations of pressure and density from a hydrostatically balanced reference state whose properties vary only with height

$$P = \overline{P} + P' \qquad \frac{\partial \overline{P}}{\partial z} = -\overline{\rho} g$$

The Buoyancy

Eq for vertical motion (Boussinesq approximation):

$$\frac{dw}{dt} = -\frac{1}{\overline{\rho}+\rho'}\frac{\partial(\overline{P}+P')}{\partial z} - g$$

$$\frac{1}{\overline{\rho}+\rho'} = \frac{1}{\overline{\rho}}\left[1 - \frac{\rho'}{\overline{\rho}} + \left(\frac{\rho'}{\overline{\rho}}\right)^2 + \ldots\right]$$

$$\frac{dw}{dt} \simeq -\frac{1}{\overline{\rho}}\frac{\partial\overline{P}}{\partial z} - g - \frac{1}{\overline{\rho}}\frac{\partial P'}{\partial z} + \frac{1}{\overline{\rho}}\frac{\partial\overline{P}}{\partial z}\left(\frac{\rho'}{\overline{\rho}}\right)$$

$$\frac{dw}{dt} \simeq \underbrace{-\frac{1}{\overline{\rho}}\frac{\partial P'}{\partial z}}_{\text{Pressure term}} \underbrace{-g\left(\frac{\rho'}{\overline{\rho}}\right)}_{\text{Buoyancy}}$$

The Buoyancy

The Buoyancy:

$$B = -g\left(\frac{\rho'}{\overline{\rho}}\right) = g\boxed{\left(\frac{\theta'_v}{\overline{\theta}_v}\right)}$$

With air parcel with higher density (colder) than the environment:

$$\rho' > 0 \Longrightarrow B < O \Longrightarrow w \Downarrow$$

With air parcel with lower density (warmer) than the environment:

$$\rho' < 0 \Longrightarrow B > O \Longrightarrow w \Uparrow$$

The Convective available potential energy

The parcel method:
The temperature of a air parcel is assumed to change adiabatically as the parcel is displaced vertically from its original position.

$$E_p = \int B \, dz$$

Work of the buoyancy force along the displacement of the air parcel

Advantages:
-displacement of a saturated parcel within an unsaturated environment, conditional instability
-Potential energy available for convection

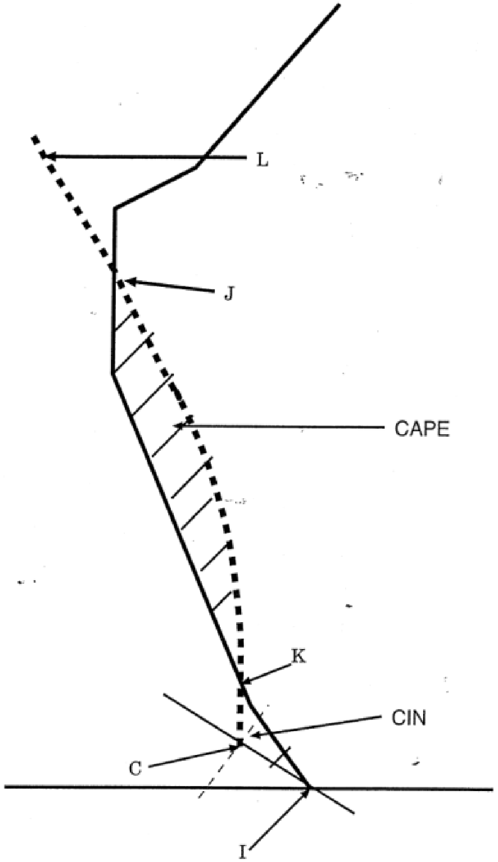
-Disadvantages:
Do not take into account effects of environment on the air parcel (pressure term of the Eq for vertical motion)

The Convective available potential energy

CAPE: Convective Available Potential Energy

$$\text{CAPE} = \int_{Z_K}^{Z_J} B\,dz = \int_{Z_K}^{Z_J} g\,\frac{\theta_{vp}-\theta_{ve}}{\theta_{ve}}\,dz$$

$$= \int_{P_J}^{P_K} R_a\left(T_{vp}-T_{ve}\right) dlnP$$



The parcel rises dry adiabatically until it becomes saturated and then rises moist adiabatically

Zk: level of free convection is the height at which the parcel becomes warmer than the environment
Zj: the cloud top is assumed to be the level where the virtual temperature of the parcel is equal to that of the environment

The Convective available potential energy

CAPE: Convective Available Potential Energy

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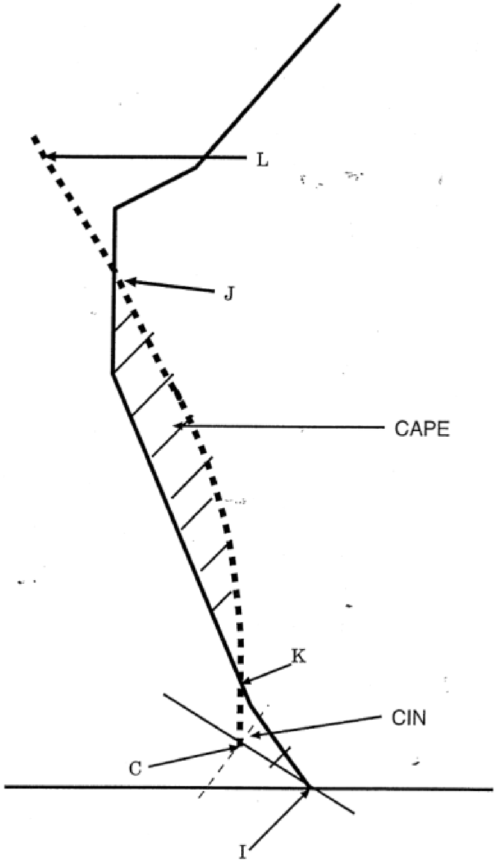
$$= \int_{P_J}^{P_K} R_a\left(T_{vp}-T_{ve}\right) dlnP$$

Kinetic Energy theorem: $\frac{1}{2}w_2^2 = \frac{1}{2}w_1^2 + E_p\ 1 \rightarrow 2$

$$w_{max} = \sqrt{2\ CAPE}$$

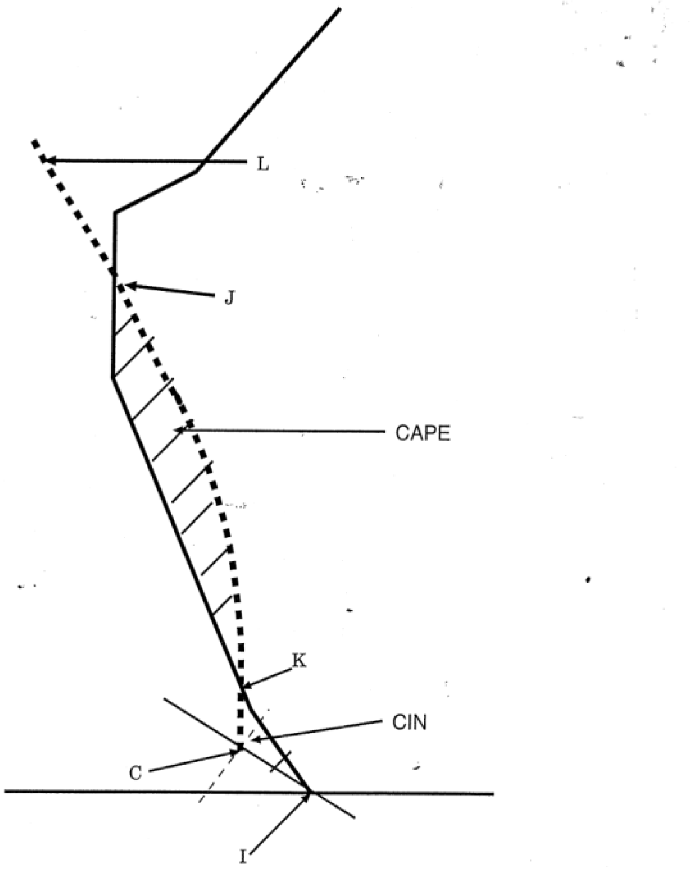


The Convective Inhibition

CAPE: Convective Available Potential Energy

$$\text{CAPE} = \int_{Z_K}^{Z_J} B\,dz = \int_{Z_K}^{Z_J} g\,\frac{\theta_{vp}-\theta_{ve}}{\theta_{ve}}\,dz$$

$$= \int_{P_J}^{P_K} R_a\left(T_{vp}-T_{ve}\right) dlnP$$



Convective Inhibition CIN

$$= \int_{Z_I}^{Z_K} g\,\frac{\theta_{vp}-\theta_{ve}}{\theta_{ve}}\,dz$$

Precipitation effect on buoyancy

1) Downward force of gravity acting on the hydrometeor particles:

Mixing ratio for water species

$$\begin{aligned} B &= g\left(\frac{\theta_v'}{\overline{\theta_v}} - q_l - q_s\right) \\ &\simeq g\left(\frac{T'}{\overline{T}} - \frac{P'}{\overline{P}} + 0.61 q_v' - q_l - q_s\right) \end{aligned}$$

Mixing ratio for ice species

Positive contributions (unstability) to buoyancy:

$$T' > 0, q_v' > 0, P' < 0$$

Negative contributions (stability) to buoyancy:

$$q_l + q_s > 0$$

Precipitation effect on buoyancy

Example:

$$T' = 1K \implies \frac{dw}{dt} \sim 10\frac{1}{300} \simeq 3cms^{-2}$$

$$\iff w = 30m/s \text{ en } 1000\ s$$

Same effect with q’v = 5g/kg (or P’=-10 hPa)

Opposite effect with ql+qs=3 g/kg

Don’t forget water vapour and hydrometeors to explain vertical acceleration and vertiacl velocity within cloud and precipitation!

Precipitation effect on buoyancy

2) Evaporation of liquid water and melting of ice water:
(latent heat due to phase changing -> decrease T)

evaporation term >> melting term

But :

Evaporation can occur only when precipitation fall within unsaturated sub-cloud air

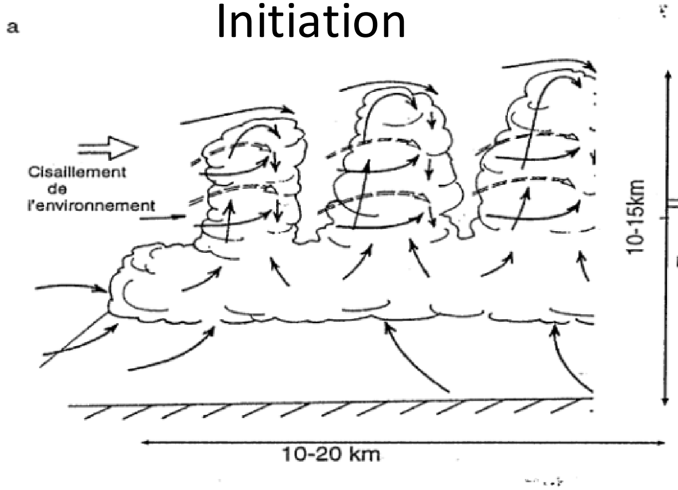
Melting can have a significant effect near iso-0 as all solid precipitation are candidate for melting when they fall below iso-0 level

Important for downdraft and density current !

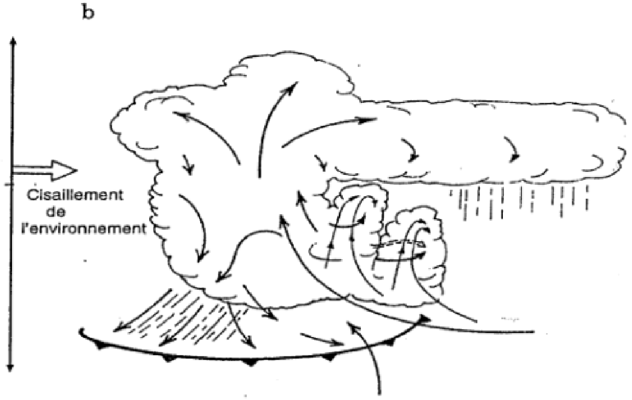
Convective systems: isolated Cb

Single-cell thunderstorm = the building block

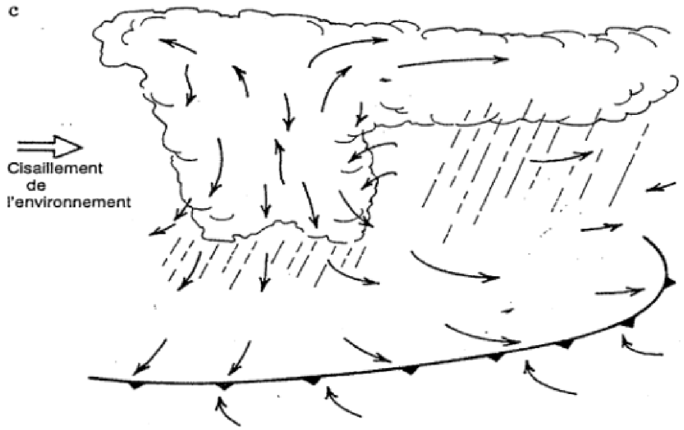
Initiation



Mature



Dissipation



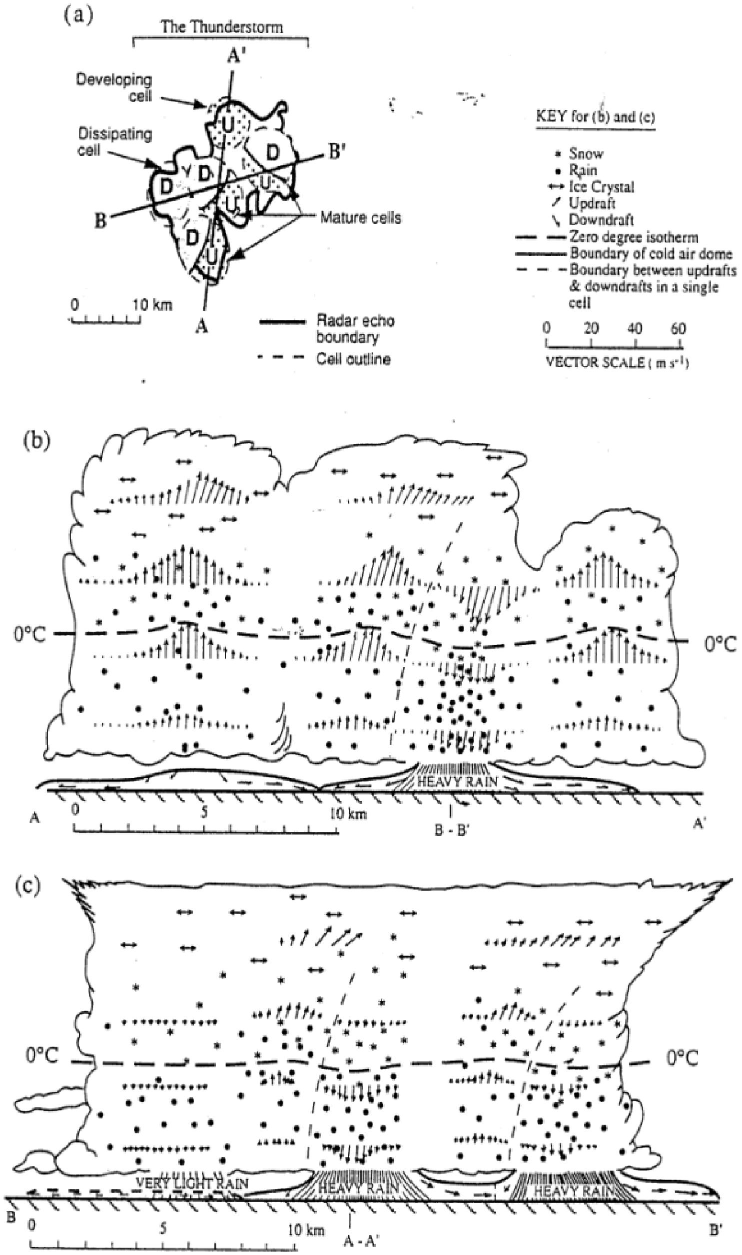
Life cycle < 1h

Convective systems: multicells

A system gathering several cells at various stages
A new cell forming each 5-10 mn

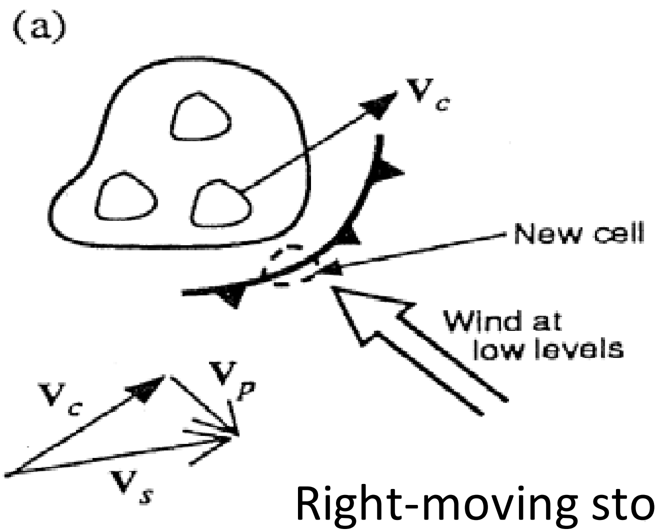
Life cycle of a cell ~20-30mn
Life cycle of the multicell thunderstorm > 1 h

The most frequent type of thunderstorms

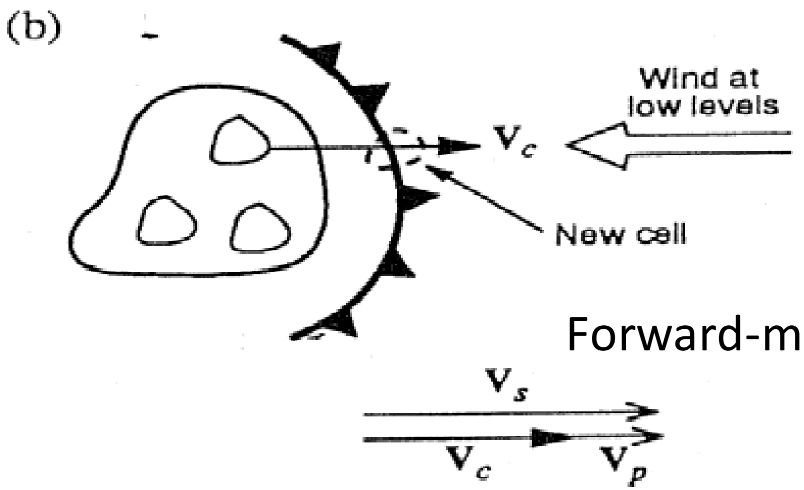


Convective systems: multicells

Thunderstorm propagation:



Right-moving storm



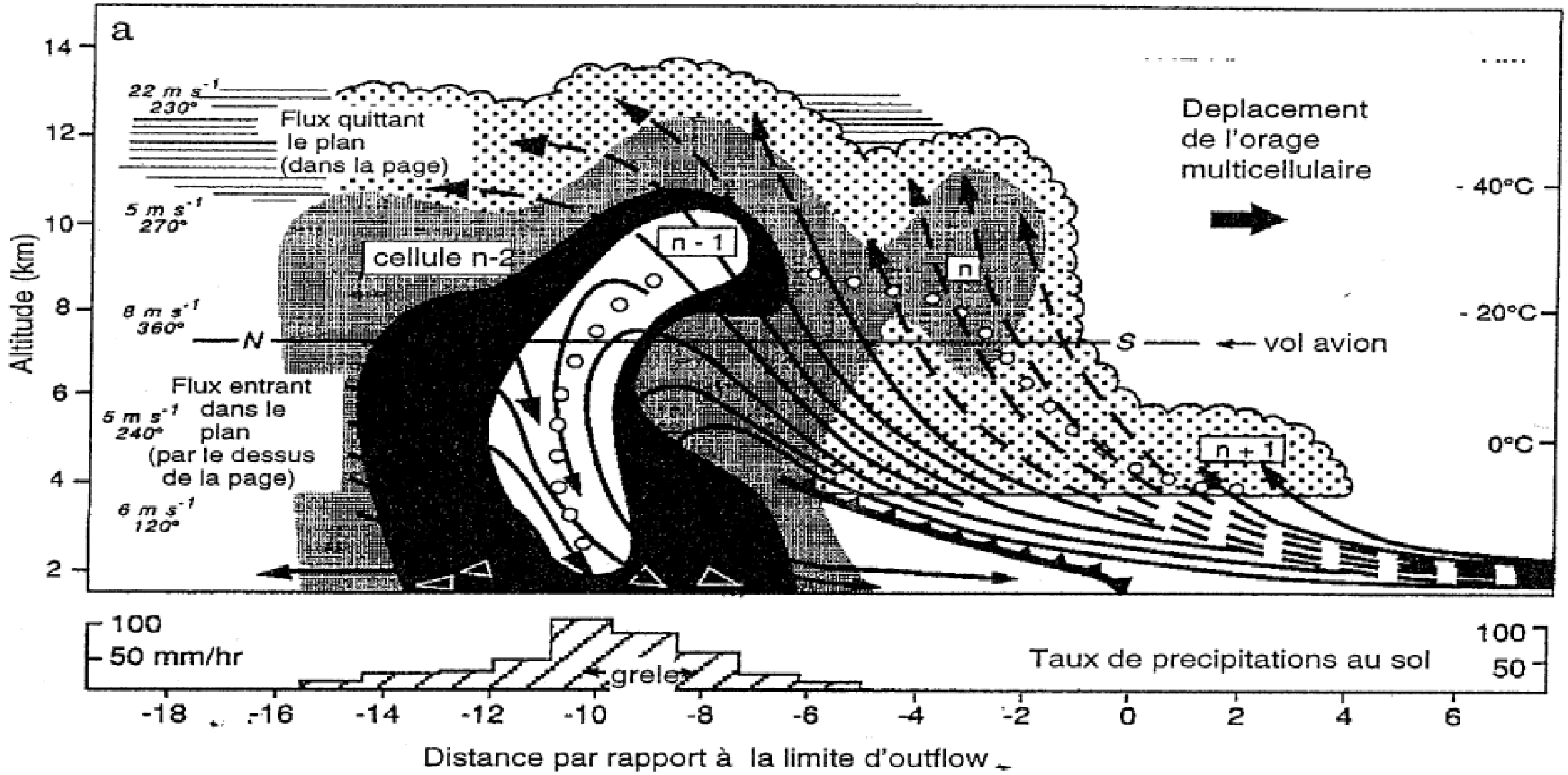
Forward-moving storm

Vc: velocity of each individual cell ;
Vp: storm propagation velocity resulting from new development
Vs: velocity of the storm as a whole (Vs)

Stationnary storm if Vc = -Vp !

Convective systems: multicells

Some times linear organization with new cells forming at the leading edge, transport of the mature and decaying cells at the back of the system



Convective systems: supercells

Supercell horizontal dimension > single cell dimension

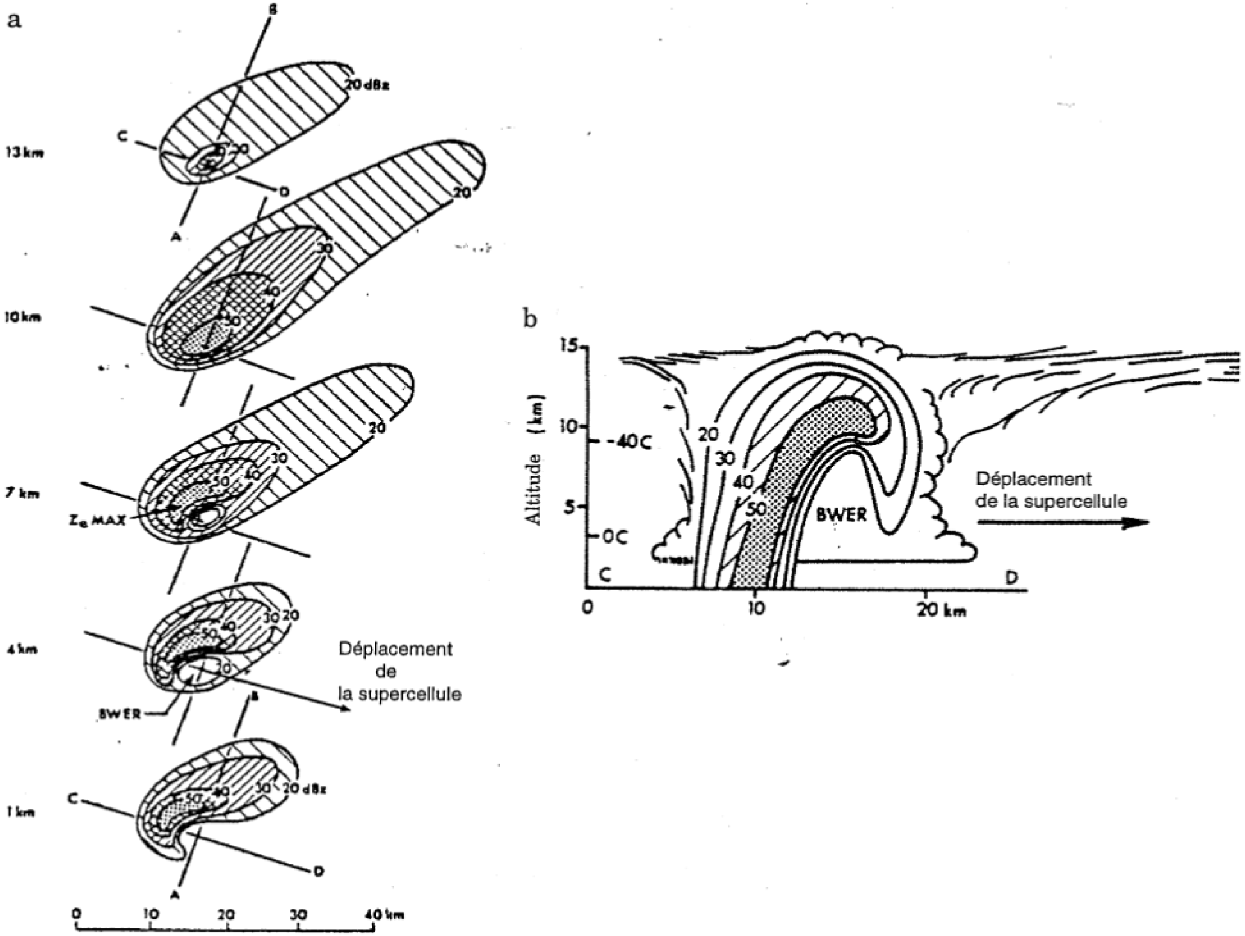
A hook signature of the precipitation

Upward/downward motions co-exist during more than 30mn
Life cycle > 1h

Stong upward motions (10-40 m/s)
Meso-cyclone (rotating upward motion)

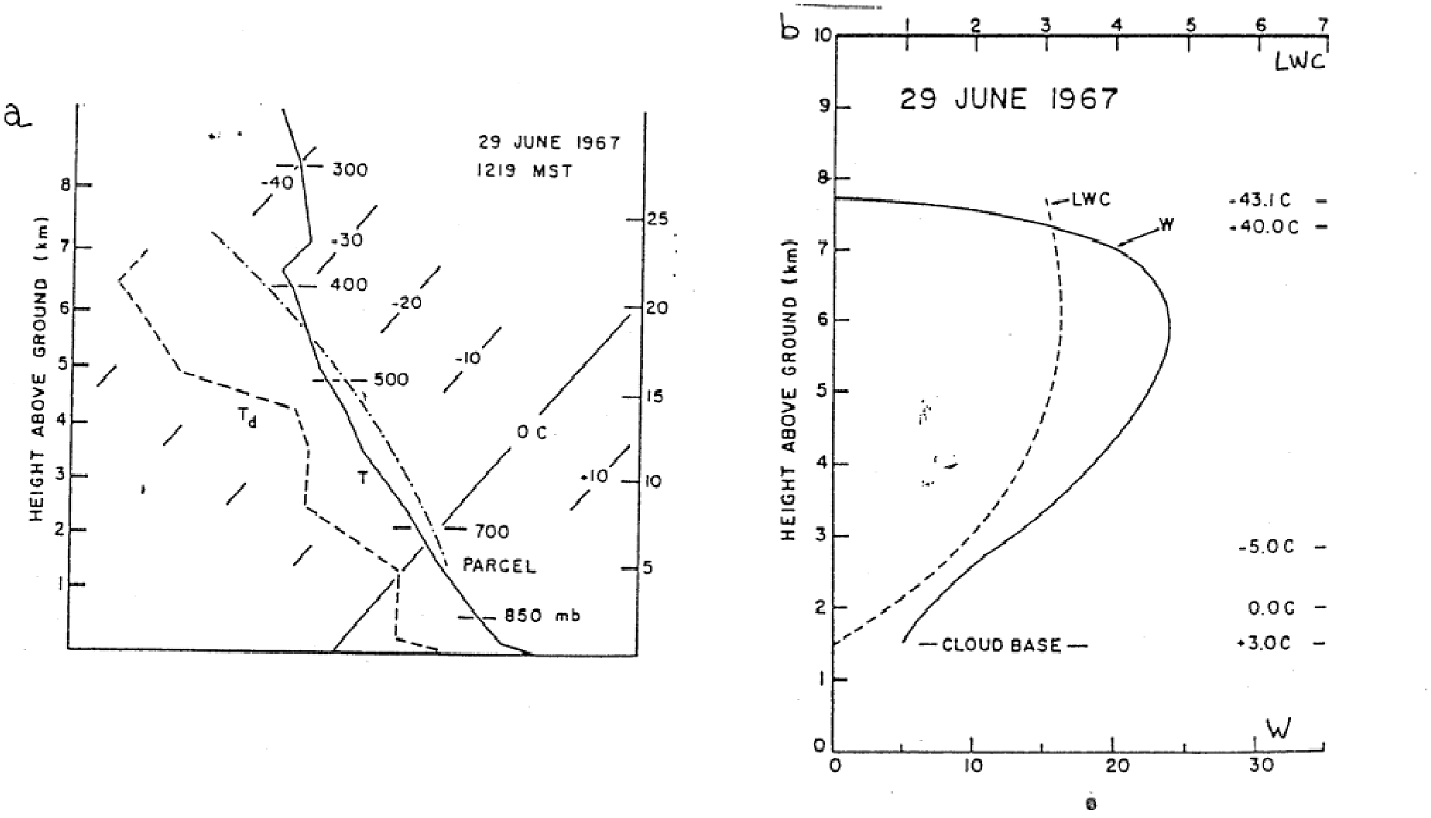
More intense/severe than the single-cell thunderstorm

Less frequent in Mediterranean than in Great US Plains



updrafts

A basic characteristics of convective systems : strong updrafts over almost all the troposphere (deep convection)



Intensity of the updrafts depends on buoyancy

$$w_{max} = \sqrt{2\ CAPE}$$

Ex: for CAPE = 2500 m2/s2 => Wmax = 70m/s

upper bound as mixing with environment and pressure term reduce Wmax by a factor ~2

downdrafts

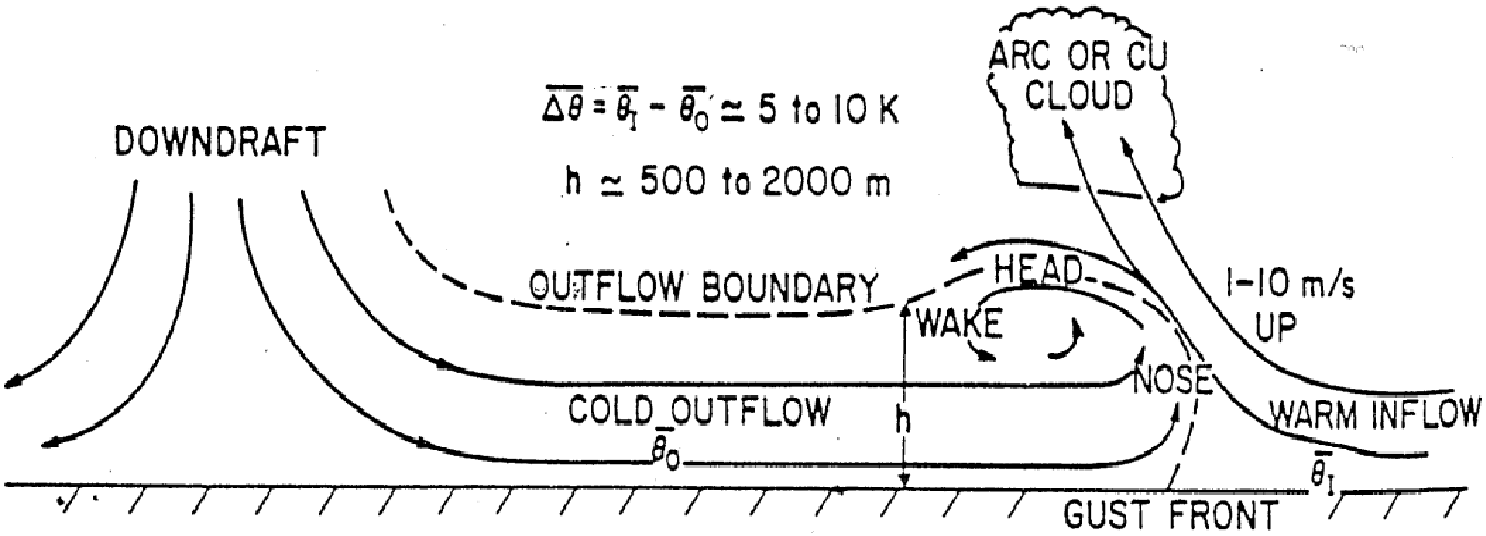
2 types:
-clear air subsidence (few m/s)
-Intense dowdrafts within precipitation (5-20m/s) => due to:
    -Precipitation weight
    -Precipitation evaporation/melting
    -Pressure gradient

Factors favouring intense downdrfats:
- a layer with low equivalent potential temperature
- precipitation falling
- a deep and dray sub-cloud layer
- droplet size distribution (DSD)

Colder dowdrafts than environment near the surface

Cold pool, density current

Colder downdrafts spread over the surface => cold pool that can take the characteristics of a density current



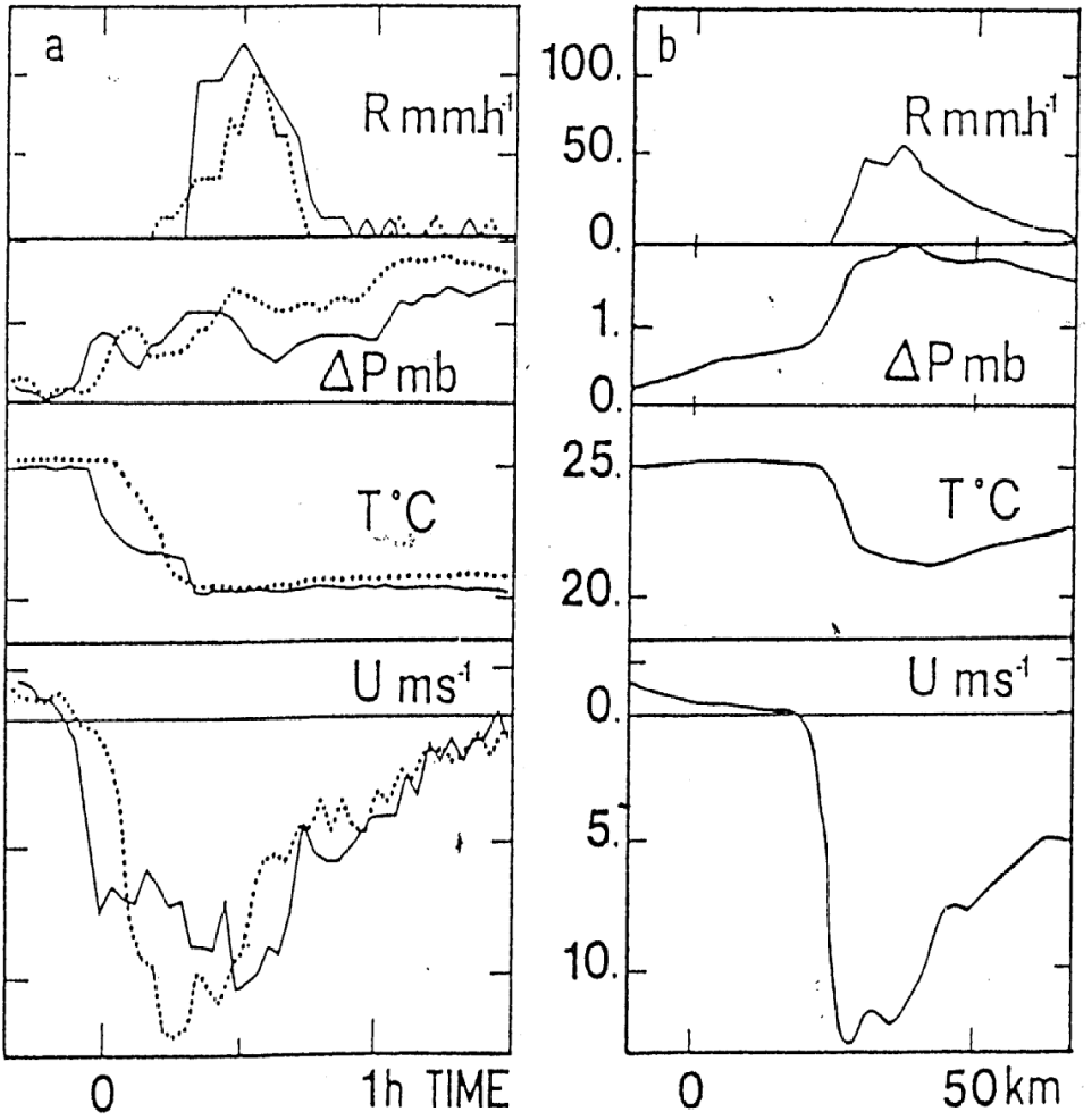
Cold pool, density current

Surface signature
of thunderstorms

Pressure increase

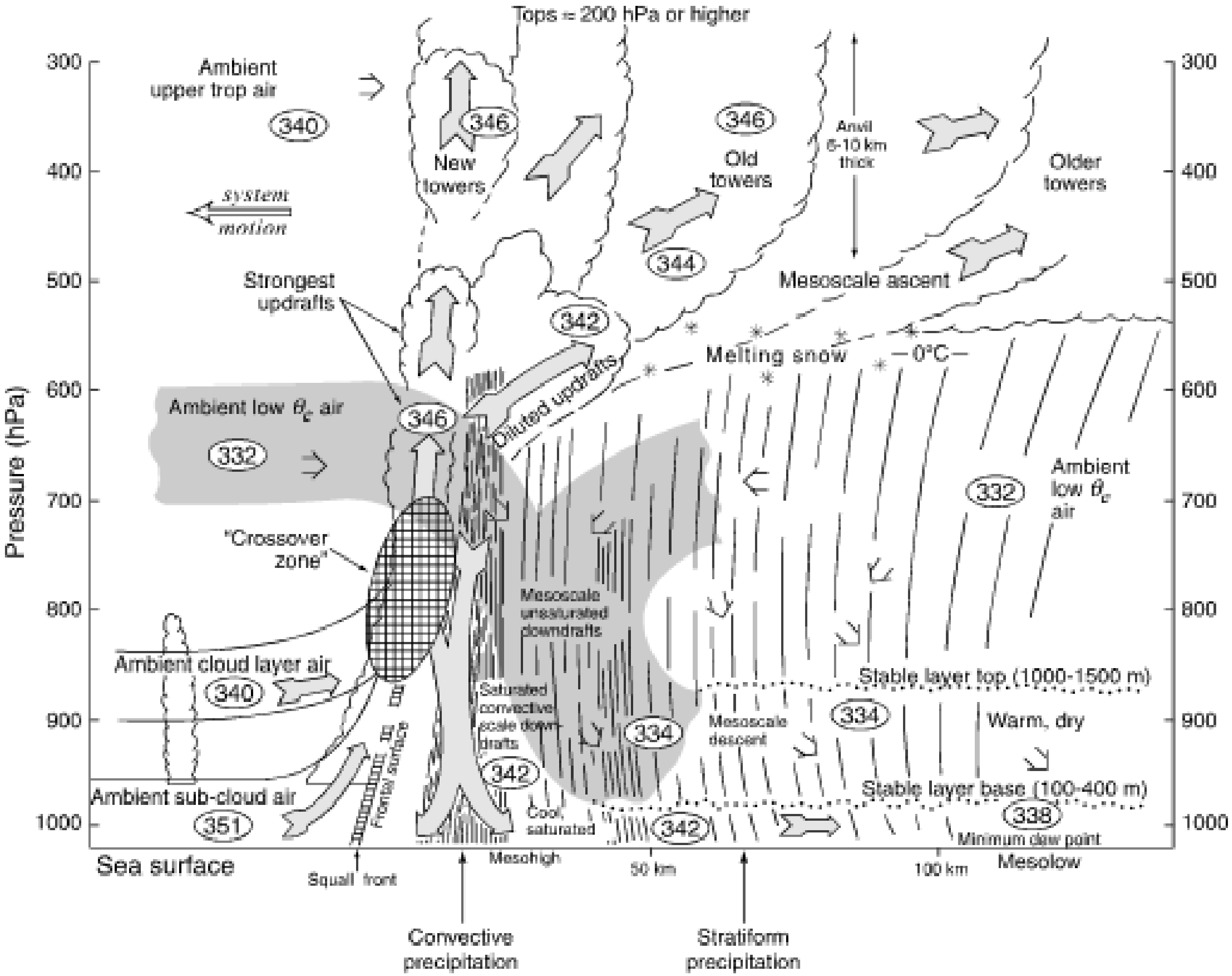
Temperature drop
(2°C –10°C)

Rotation and increase of
wind intensity

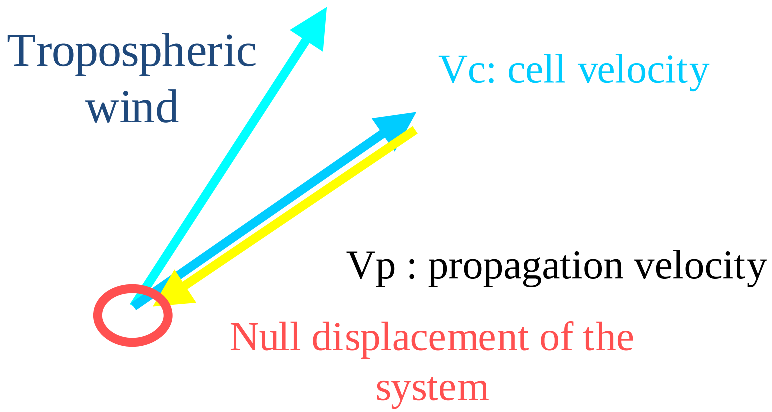


Mesoscale convective systems

MCS = a cumulonimbus cloud system that produces a contiguous precipitation area ~100 km or more in at least one direction.



Quasi-stationary MCS



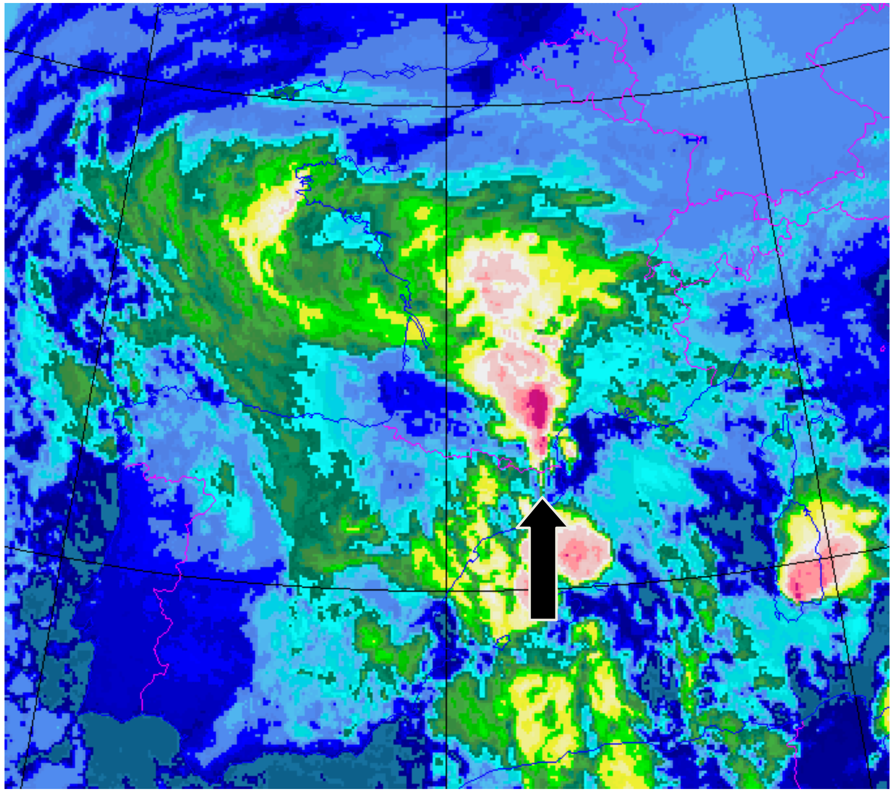
Tropospheric wind

Vc: cell velocity

Vp : propagation velocity

Null displacement of the system

- Back-building MCS, V-shape in IR sat image:
- renewal of convective cells that compensates transport of cells toward the back



Aude novembre 1999 *(Aullo et al., 2002)*

Favourable conditions for heavy precipitation

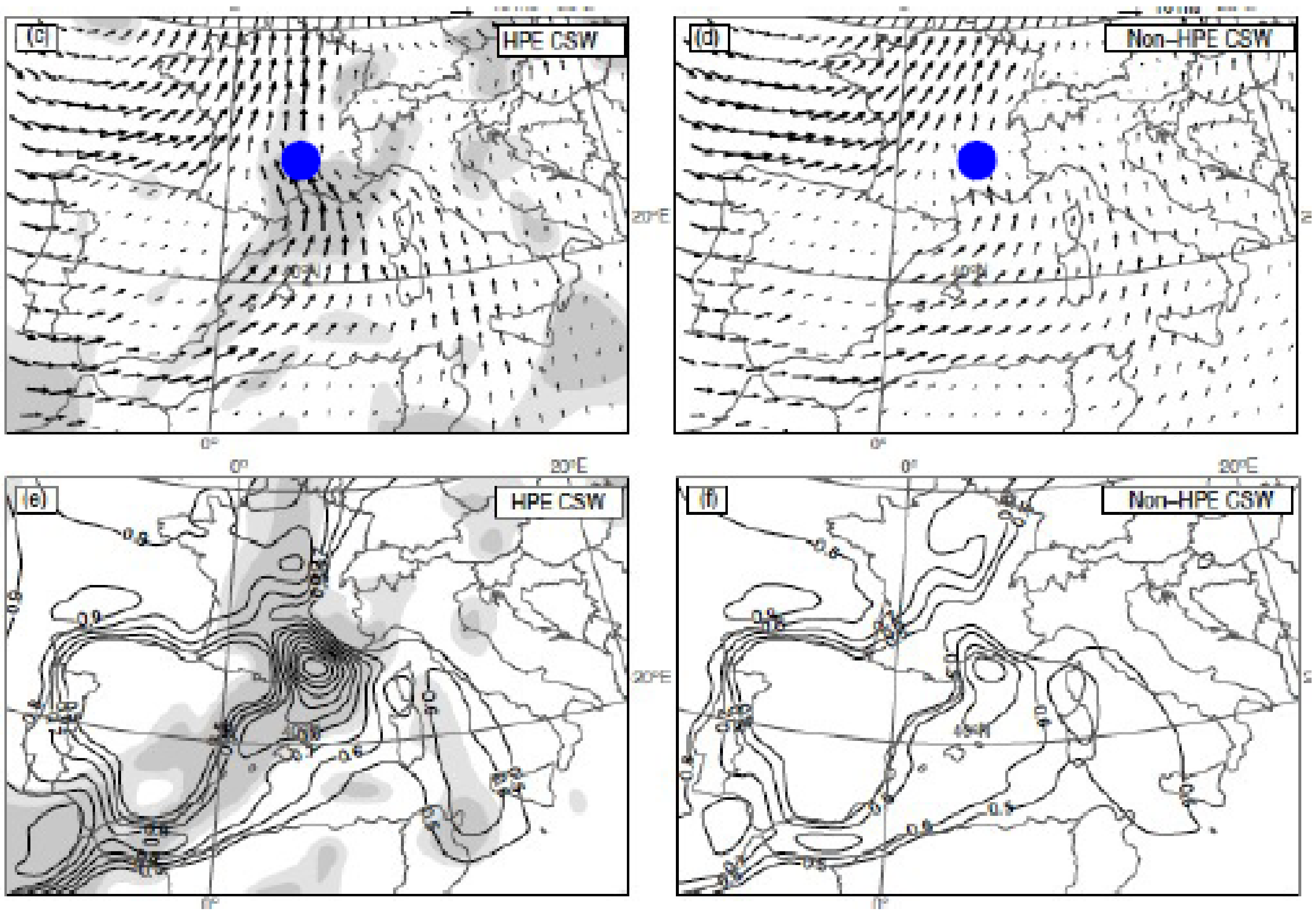
Upper level conditions

Low-level conditions

From H. Wernli Talk at the 7th HyMeX workshop
Ricard et al (2012), Nuissier et al (2011) and others

What is special about *heavy* precipitation events?

Composites for HPE and non-HPE with similar UL flow



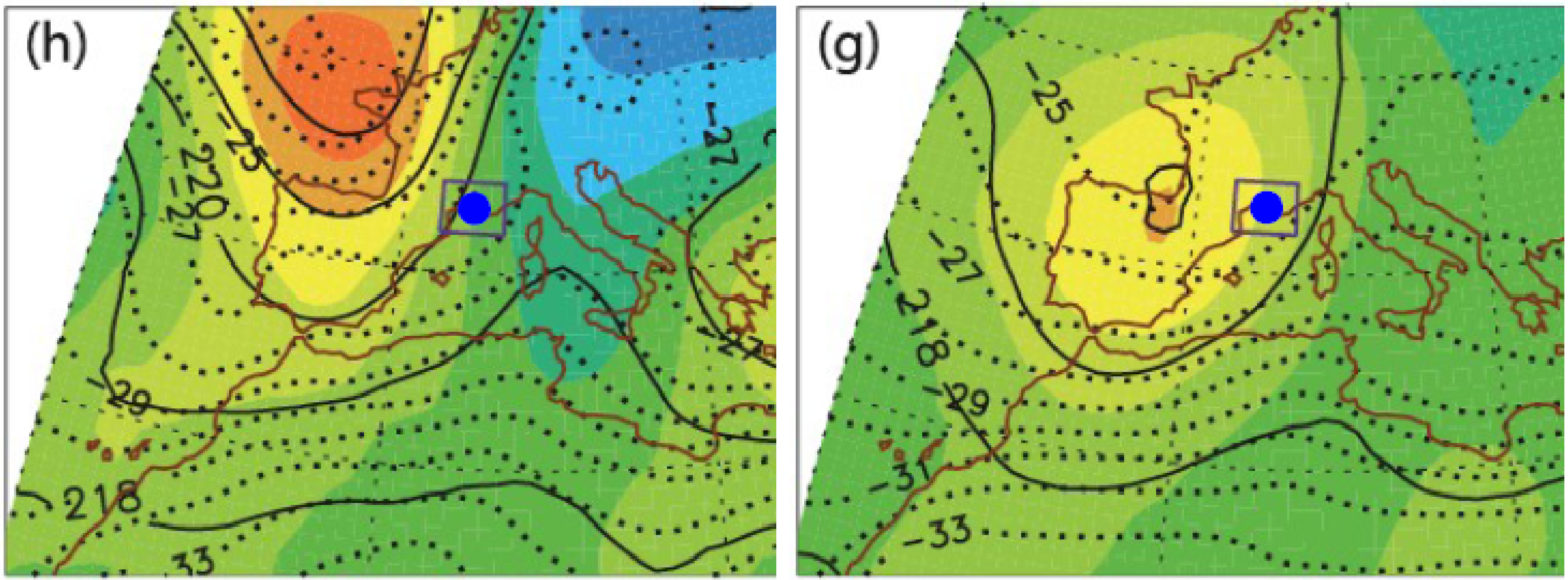
v at 925 hPa

|q**v**| at 925 hPa

Nuissier et al. 2011 (QJ)

What is special about *heavy* precipitation events?

Composites for deep convective and non-convective events

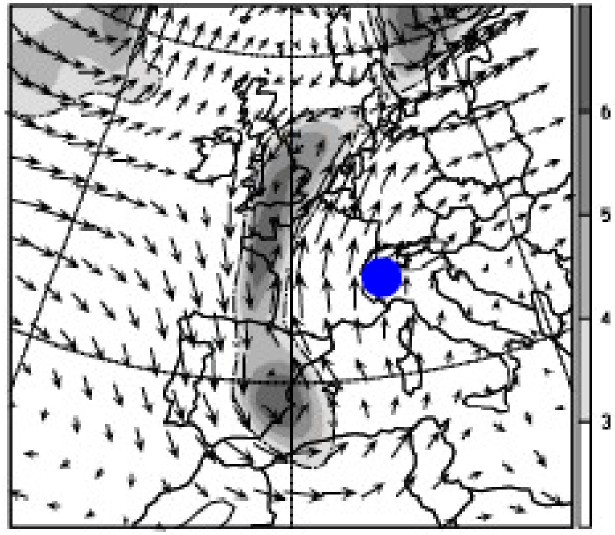


Colors: AMSU-A channel 8 anomalies as indications of UL troughs

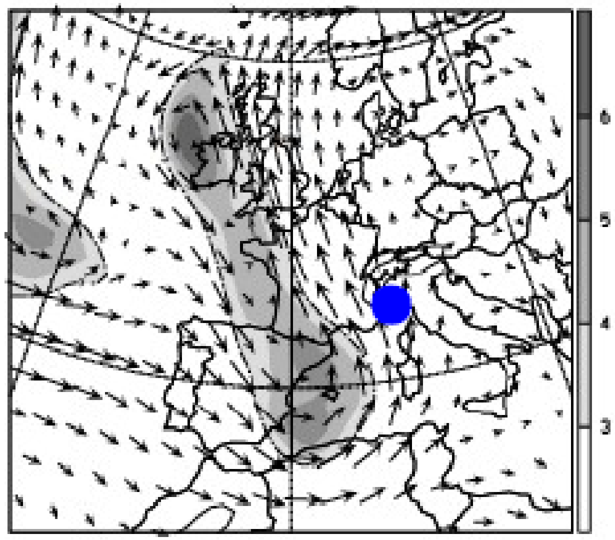
Funatsu et al. 2009 (MWR)

Upper-level forcing

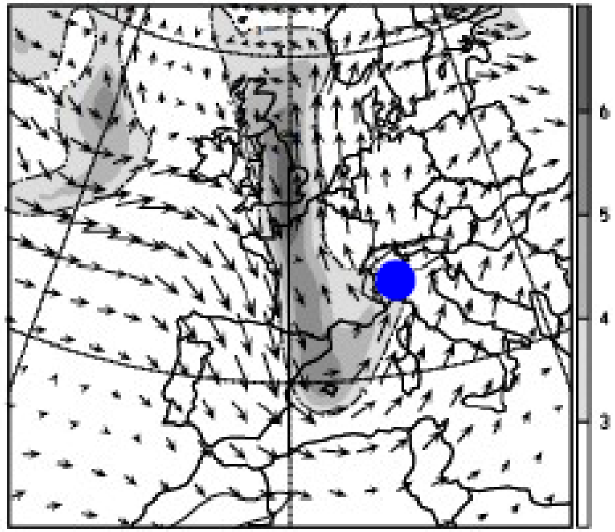
Case studies reveal characteristic pattern of upper-level PV associated with western Med HPEs



Brig (23.09.1993)



Piedmont (05.11.1994)

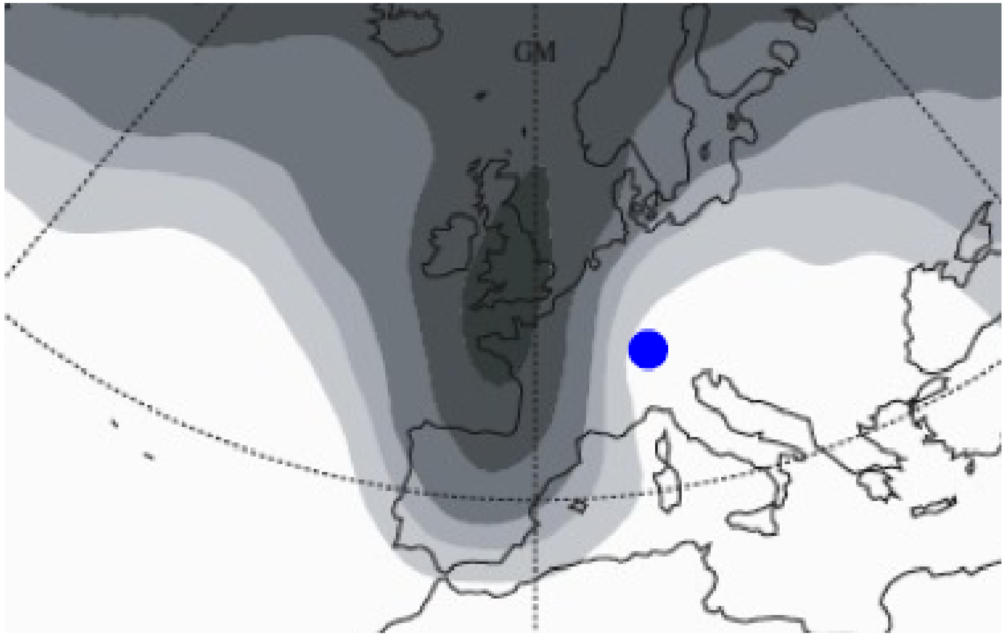


Ticino (13.09.1995)

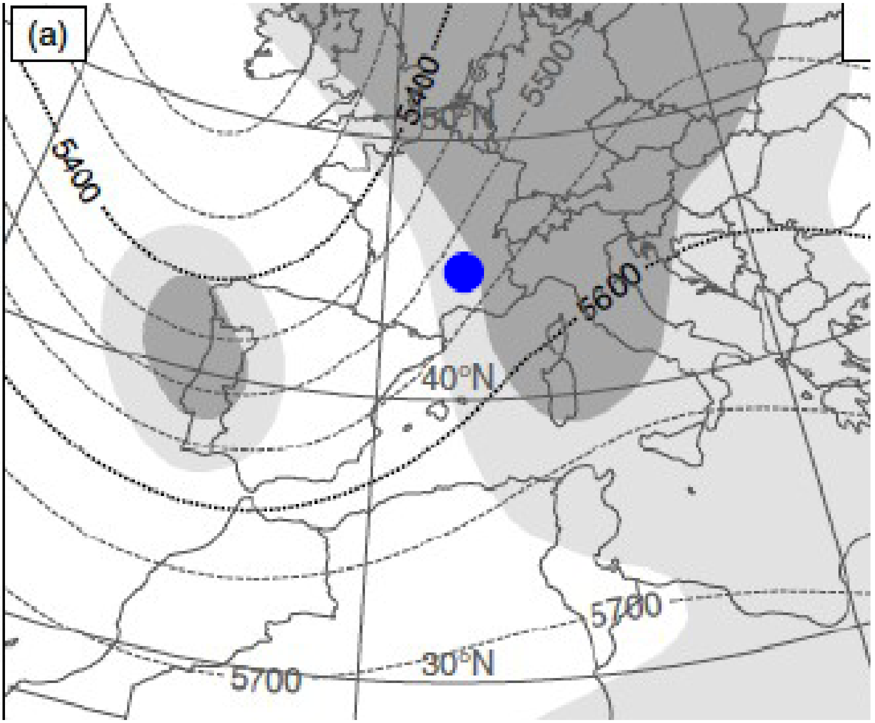
Massacand et al. 1998 (GRL)

Upper-level forcing

Characteristic pattern confirmed by composite / cluster analysis



Martius et al. 2006 (IJC)

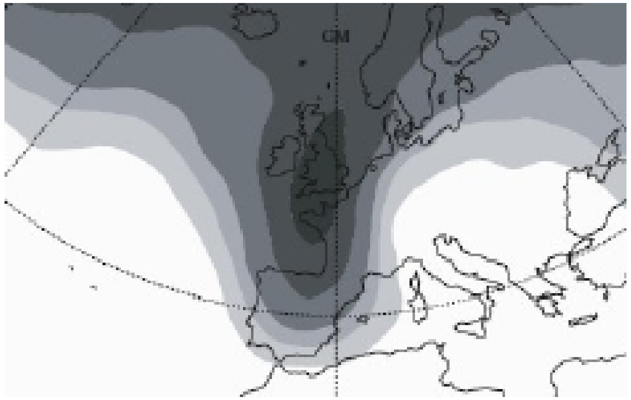


Nuissier et al. 2011 (QJ)

Upper-level forcing

This pattern („PV streamer") is result of Rossby wave breaking at the end of the North Atlantic storm track

PV streamers typically propagate slowly



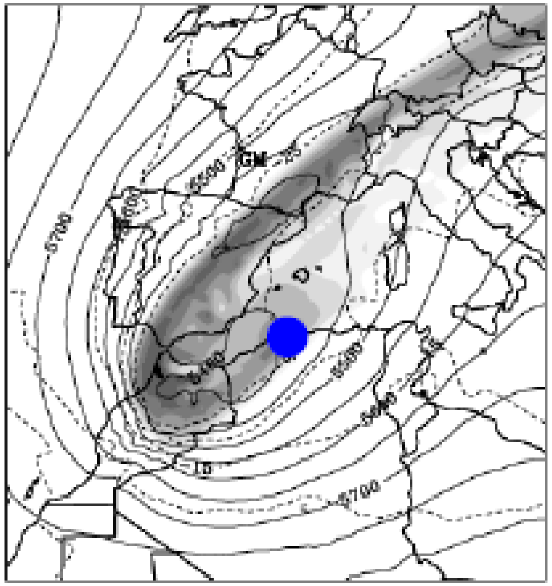
Effect on HPE is potentially 4-fold:

- reduced static stability / increased CAPE beneath PV streamer
- forcing for ascent (Q-vector convergence)
- strong low-tropospheric moisture flux
- increased evaporation due to increased surface winds

Q: What is relative importance of these effects?

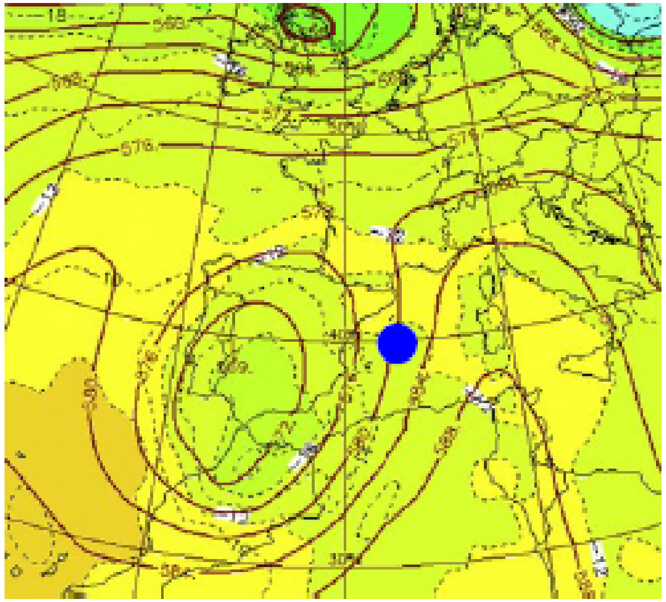
Upper-level forcing

Many other cases with pronounced UL PV feature



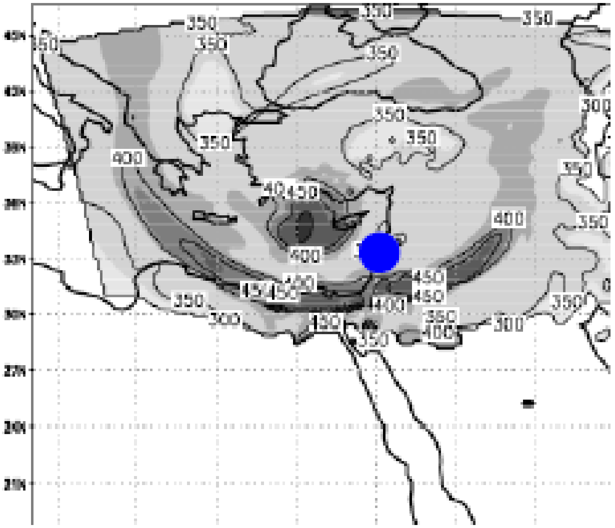
Algier (10.11.2001)

Argence et al. 2008 (QJ)



Mallorca (04.10.2007)

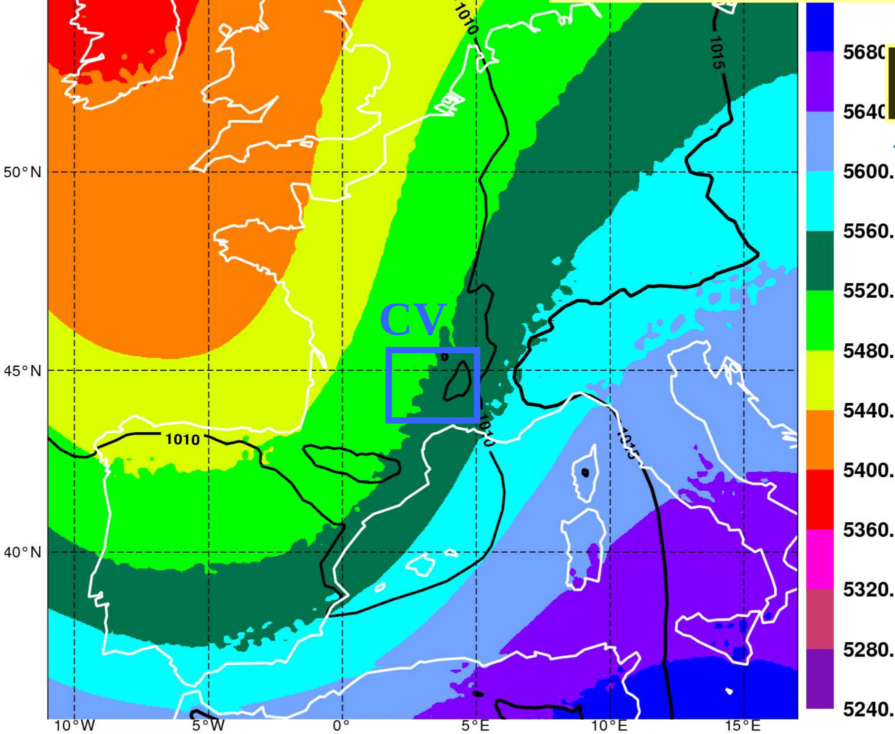
Cohuet et al. 2011 (AR)



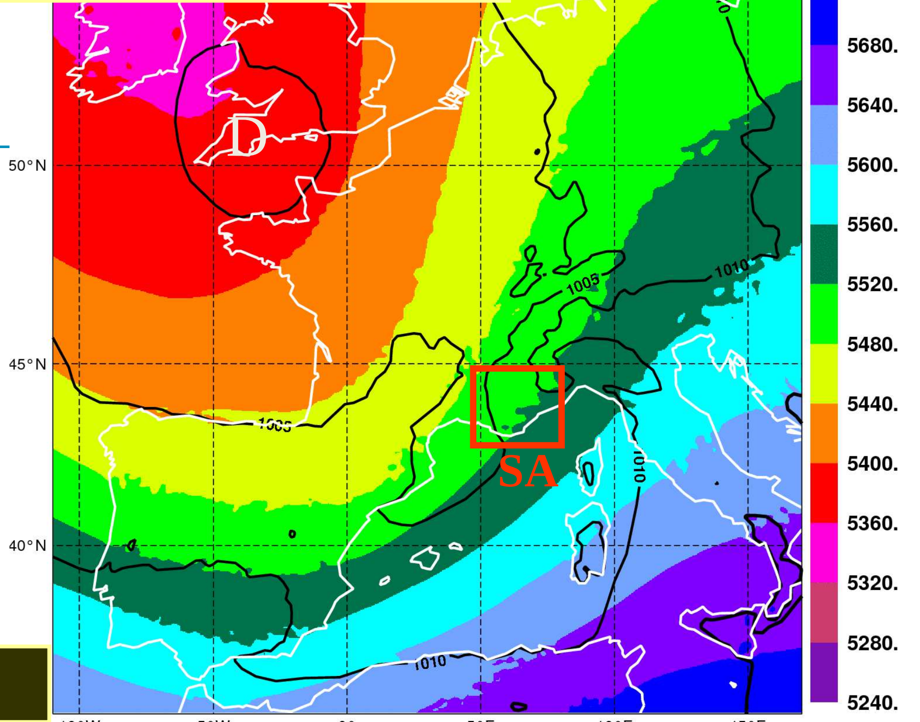
Israel (04.12.2001)

Krichak et al. 2007 (NHESS)

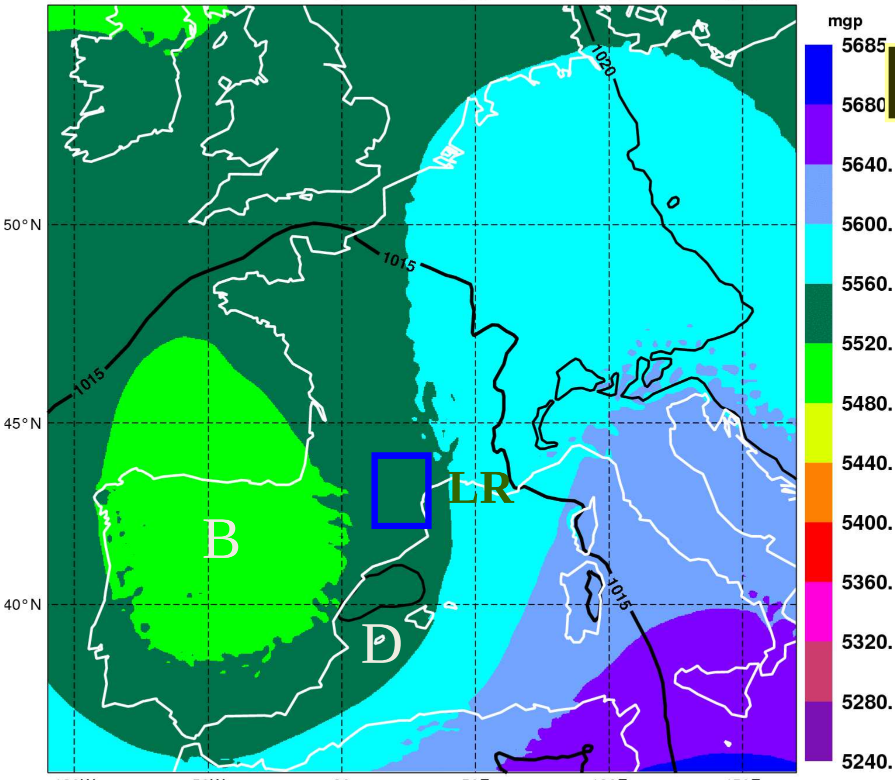
Composite analysis | > 150 mm 2002-2006: Mature phase



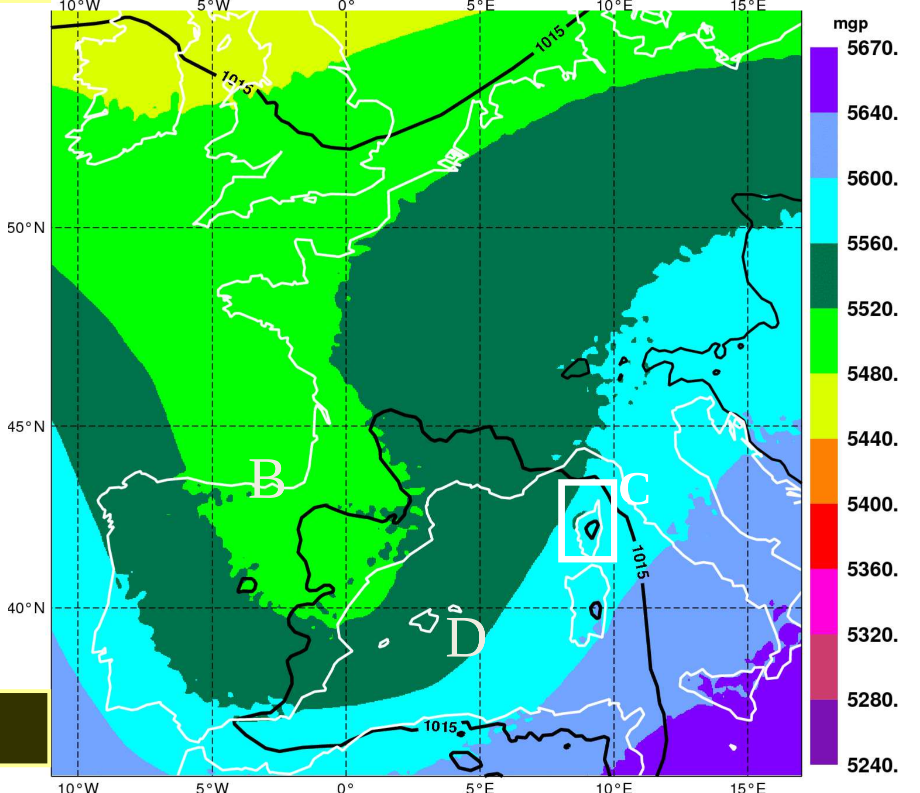
25 HPEs



15 HPEs

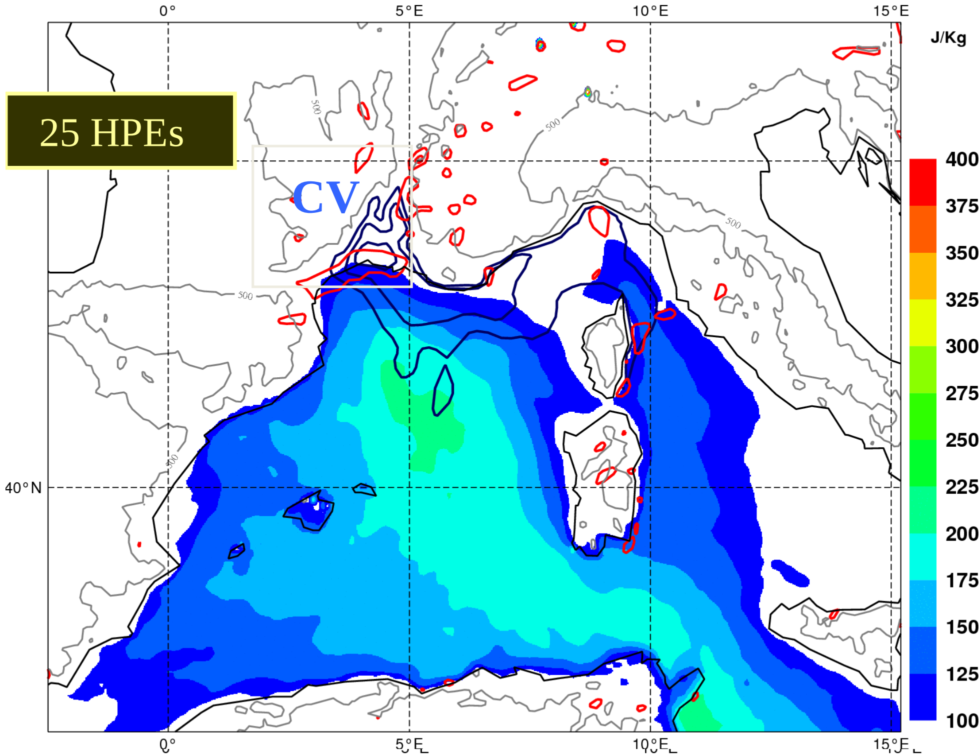


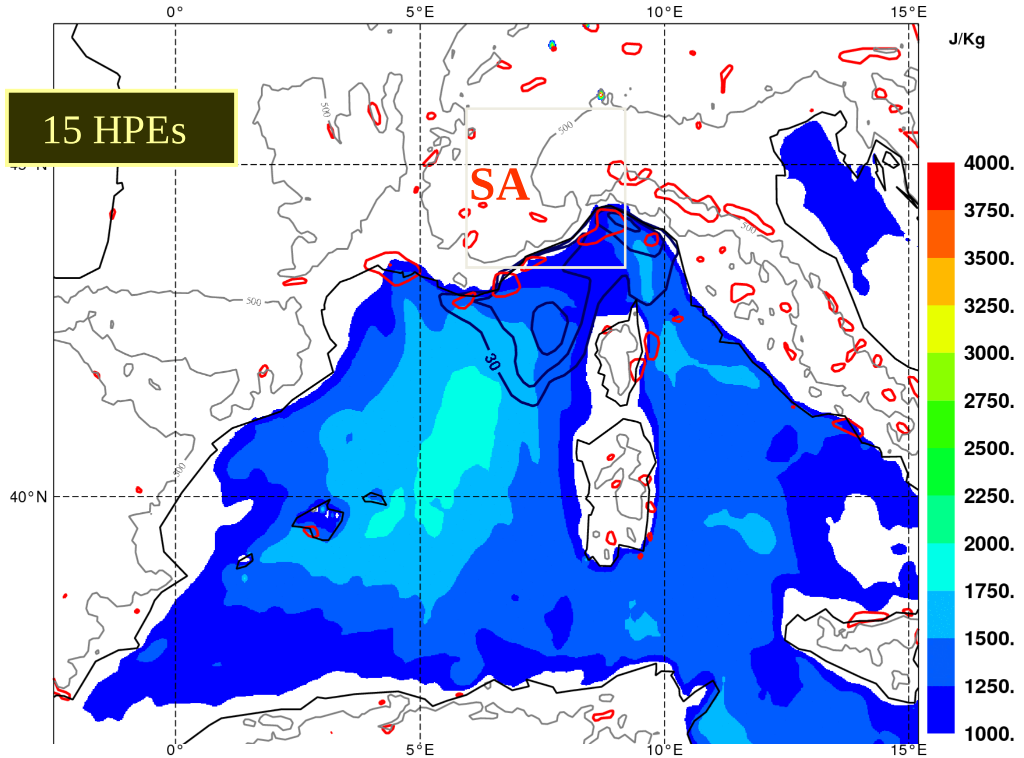
13 HPEs

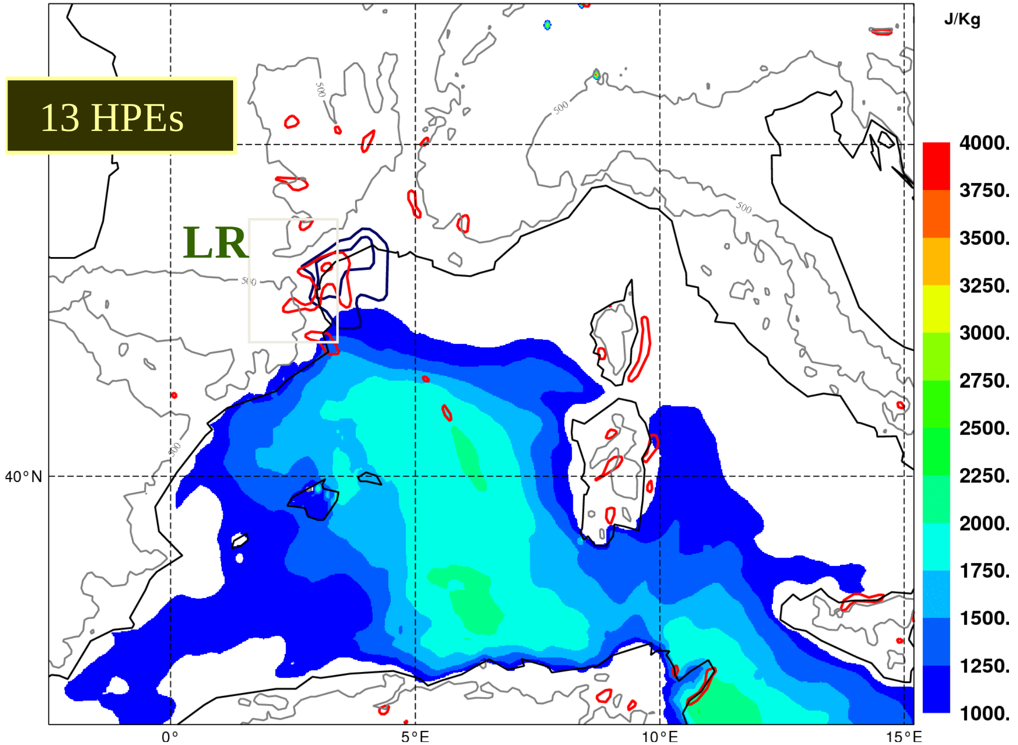


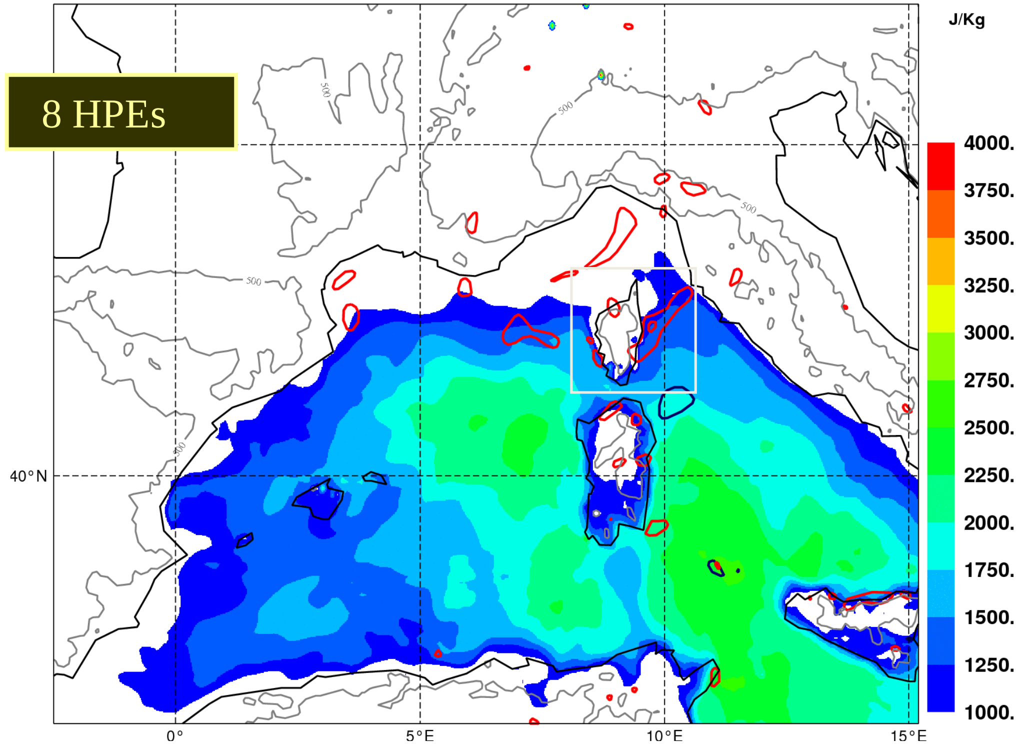
8 HPEs

Composite analysis | > 150 mm 2002-2006: Mature phase

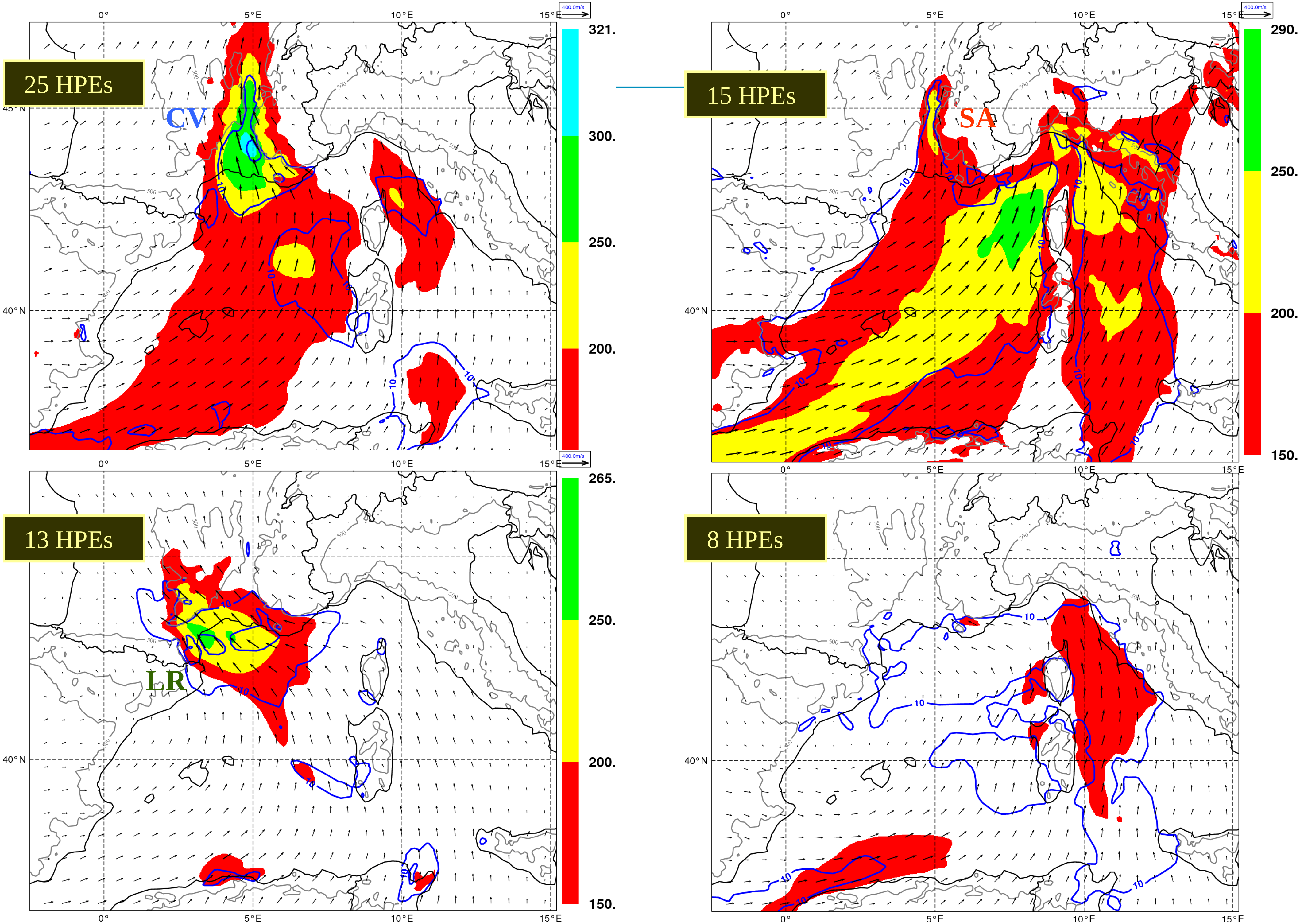




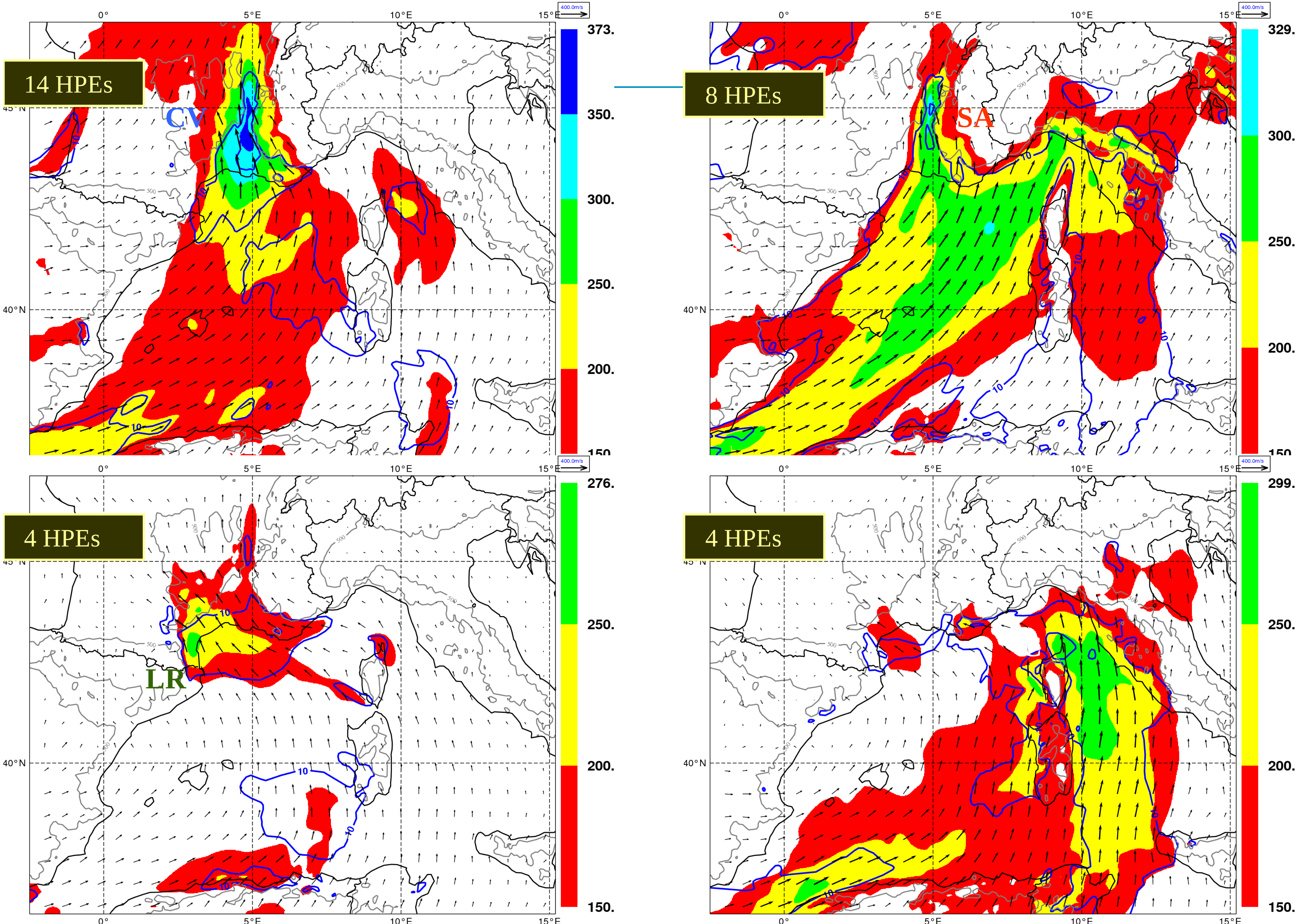




Composite analysis | > 150 mm 2002-2006: Mature phase



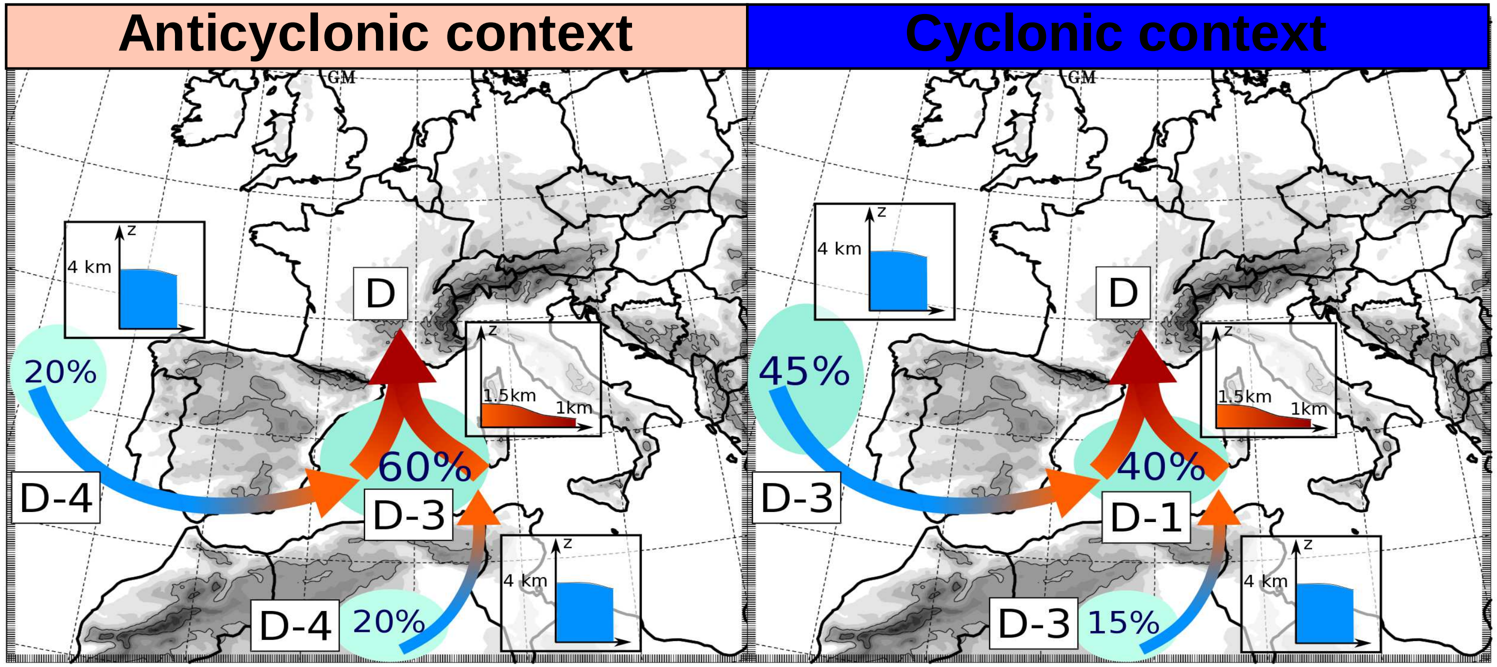
Composite analysis | > 200 mm 2002-2006: Mature phase



Sea evaporation

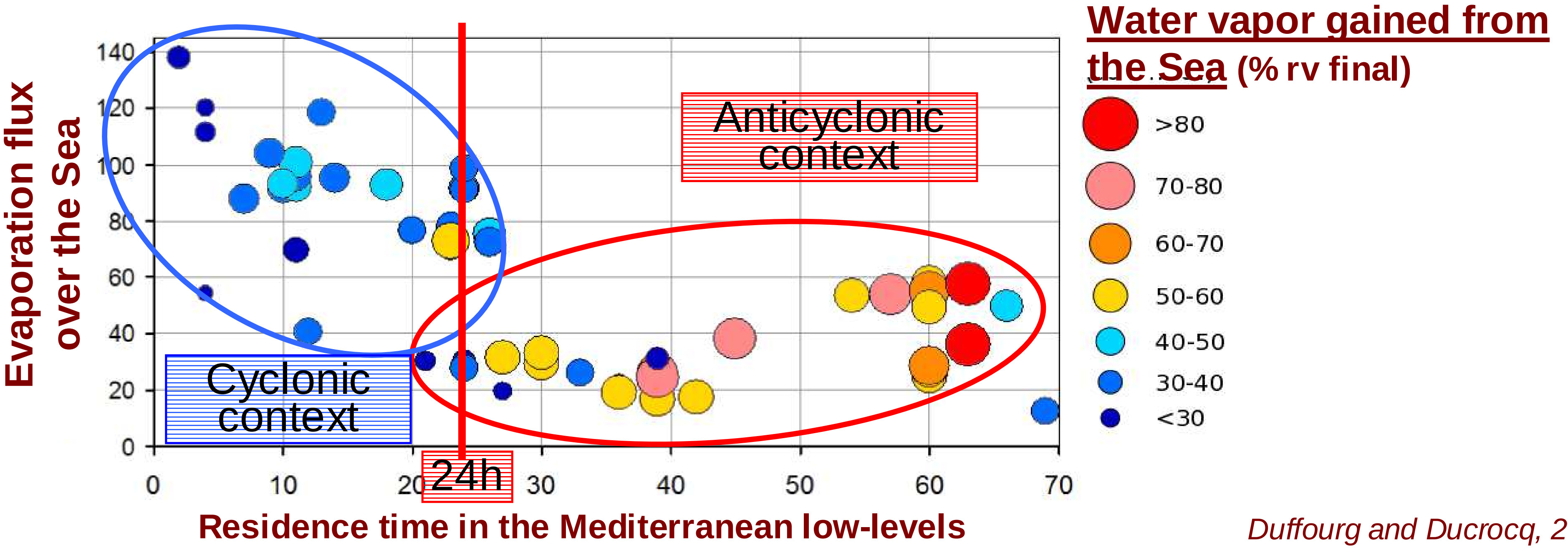
Origin and transport of humidity

Based on kilometric-scale NH simulations of 10 HPE over Southern France



Anticyclonic context

Cyclonic context



Water vapor gained from the Sea (% rv final)

Duffourg and Ducrocq, 2011, NHESS

Low-level forcing

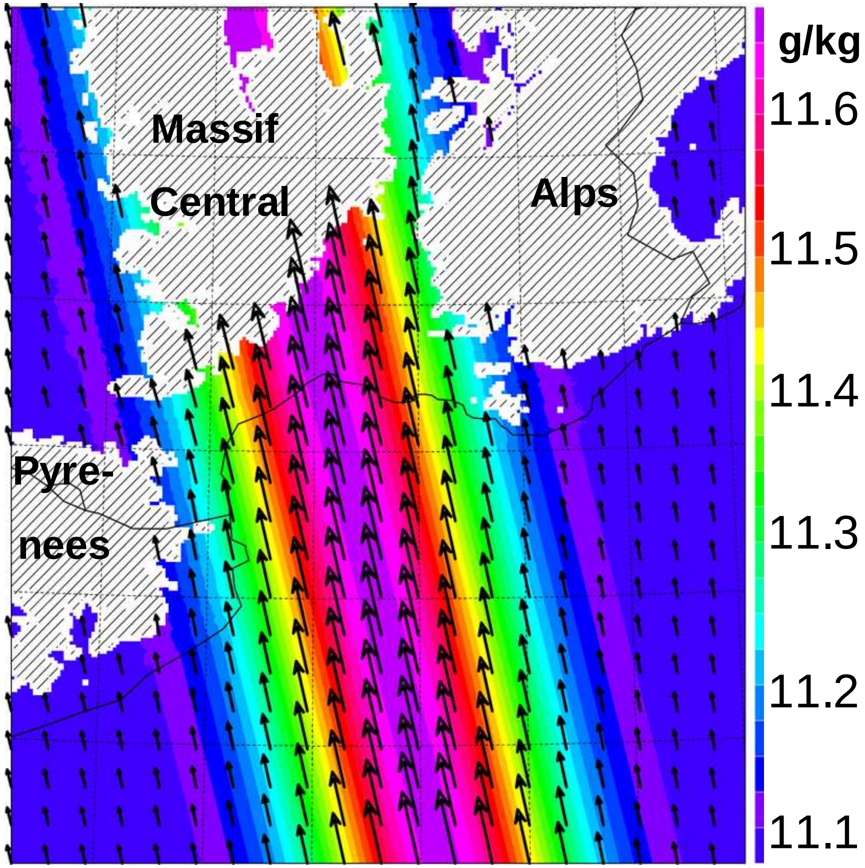
Orography
Cold pool

From Bresson et al (2012) among others

Idealized simulations: initial conditions

Meso-NH model, hor resolution=2.4km, true orography

A **moist** (weakly unstable) and **rapid** southh-southeasterly low-level flow impinging the Massif Central mountain



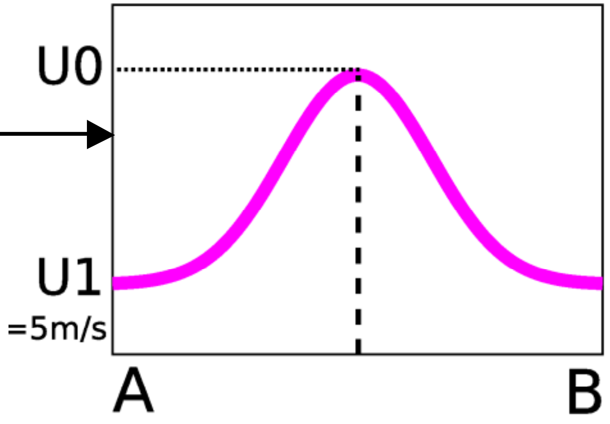
Water vapour mixing ratio (g/kg) and wind (m/s) at 500m

Idealized simulations: initial conditions

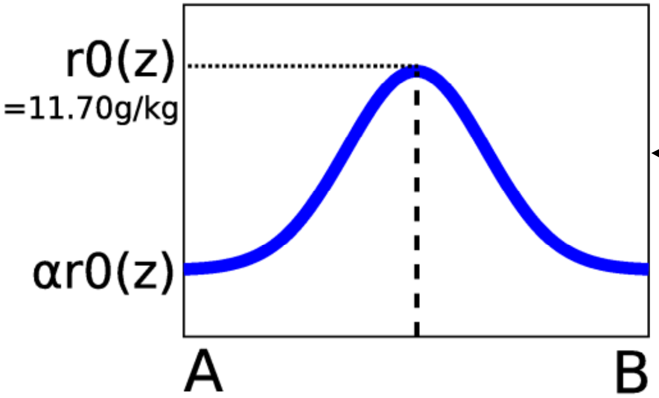
Meso-NH model, hor resolution=2.4km, true orography

A **moist** (weakly unstable) and **rapid** southh-southeasterly low-level flow impinging the Massif Central mountain

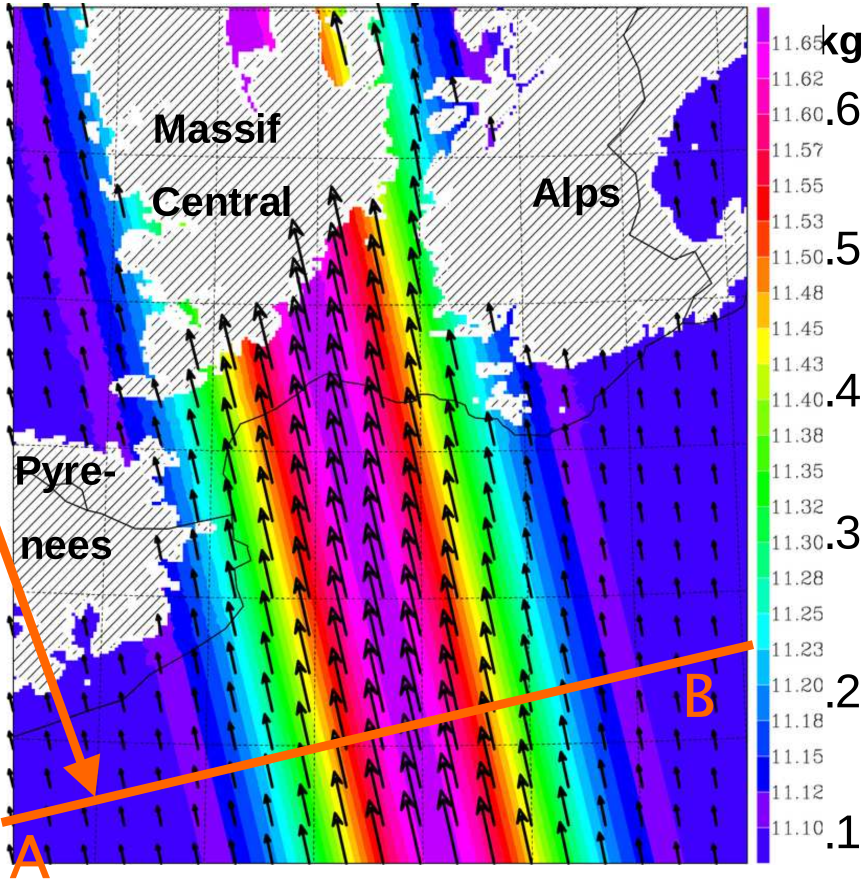
Hor variation of winds (m/s)



Hor variation water vapour (g/kg)



θ(z) hor uniform (sounding 8/9/02, Nîmes)



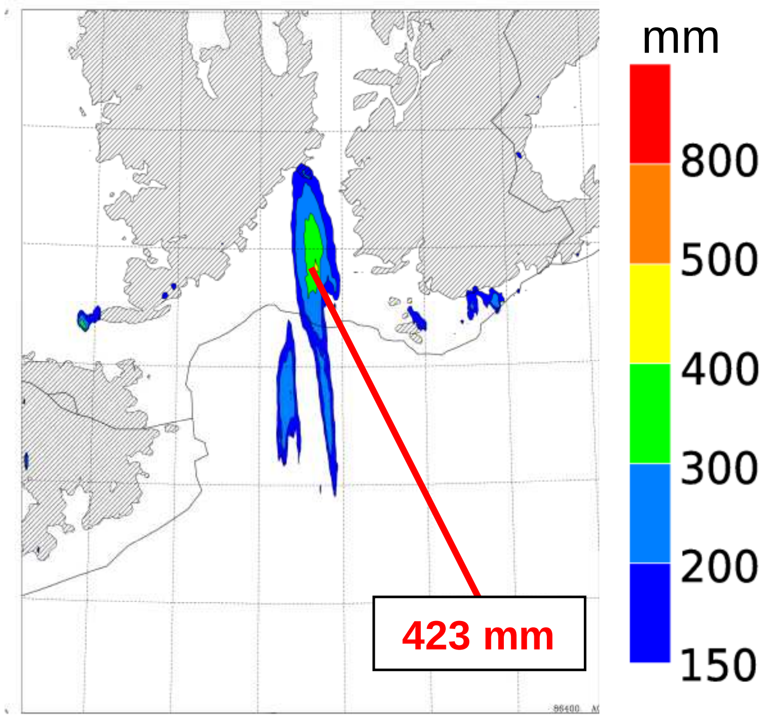
Water vapour mixing ratio (g/kg) and wind (m/s) at 500m

Numerical experiments

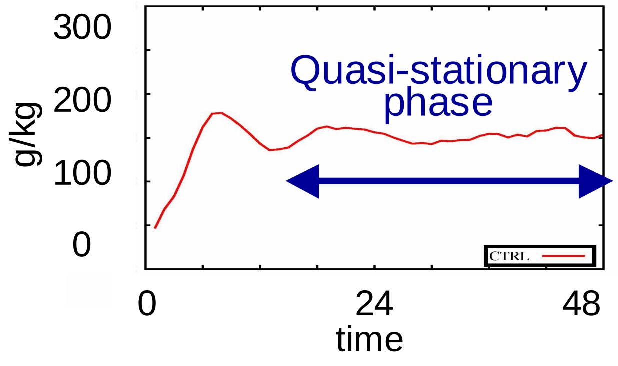
Experiments	Max winds U0 (m s^{-1})	Humidity decrease (α)	Relief
CTRL	20	0.95	true
Sensitivity to winds			
WIN10, WIN15, WIN30, WIN40	10, 15, 30, 40	0.95	true
Sensitivity to moisture			
Q85, Q90, Q100	20	0.85, 0.90, 1	true
Sensitivity to orography			
ALPS, PYREN, MASC	20	0.95	Without Alps, Pyrenees, Massif Central

initial conditions of experiments

Results: Control experiment



RR24 Cumul after 48h of simulation



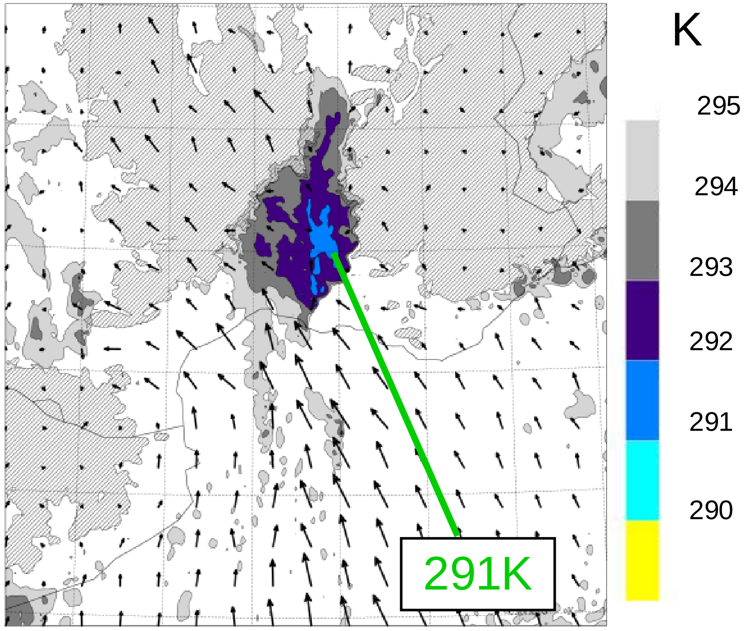
Hydrometeor time-series

CTRL succeeds in simulating:

A ***quasi-stationary MCS***

A ***heavy precipitation system upwind Massif Central***

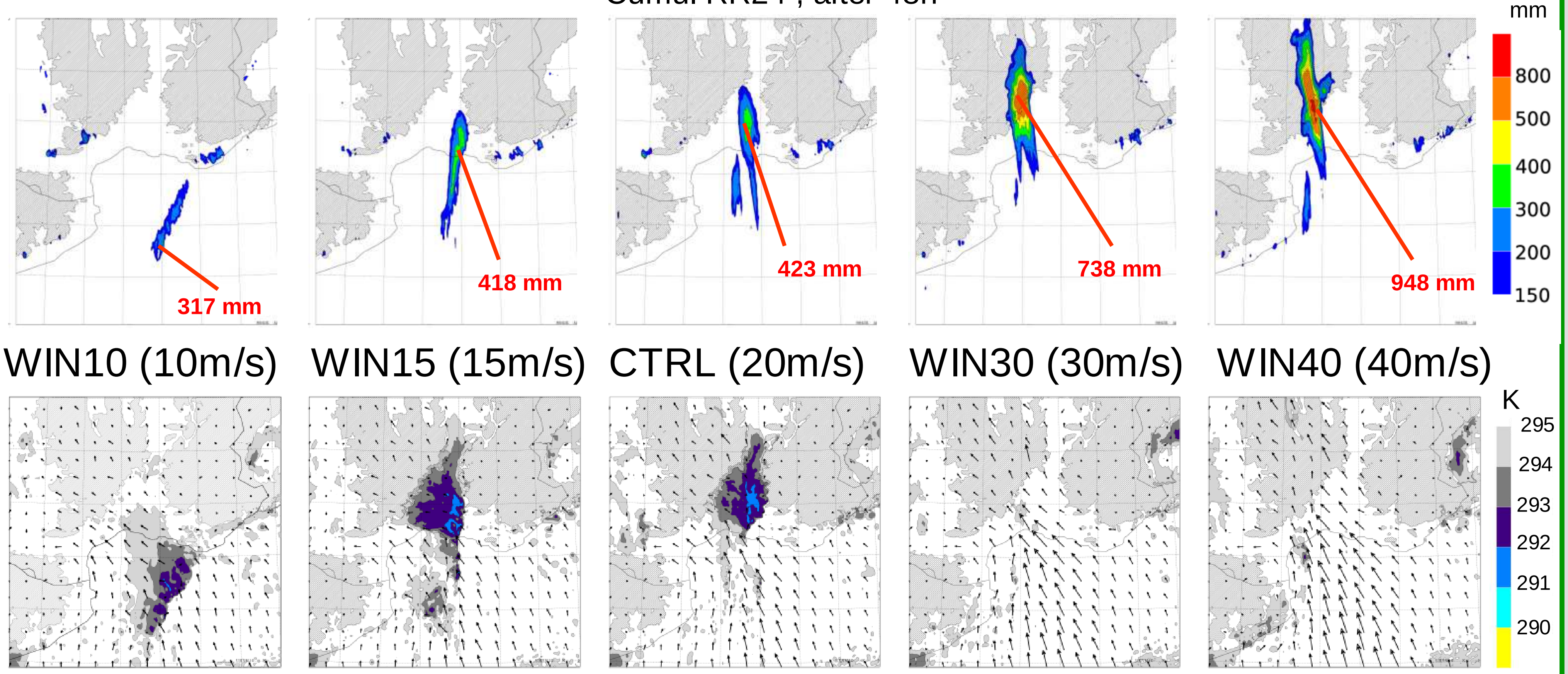
With ***a cold pool,*** facing the moist low-level flow



θv and winds at 36m, after 48h

Results: sensitivity to wind speed

Cumul RR24 , after 48h



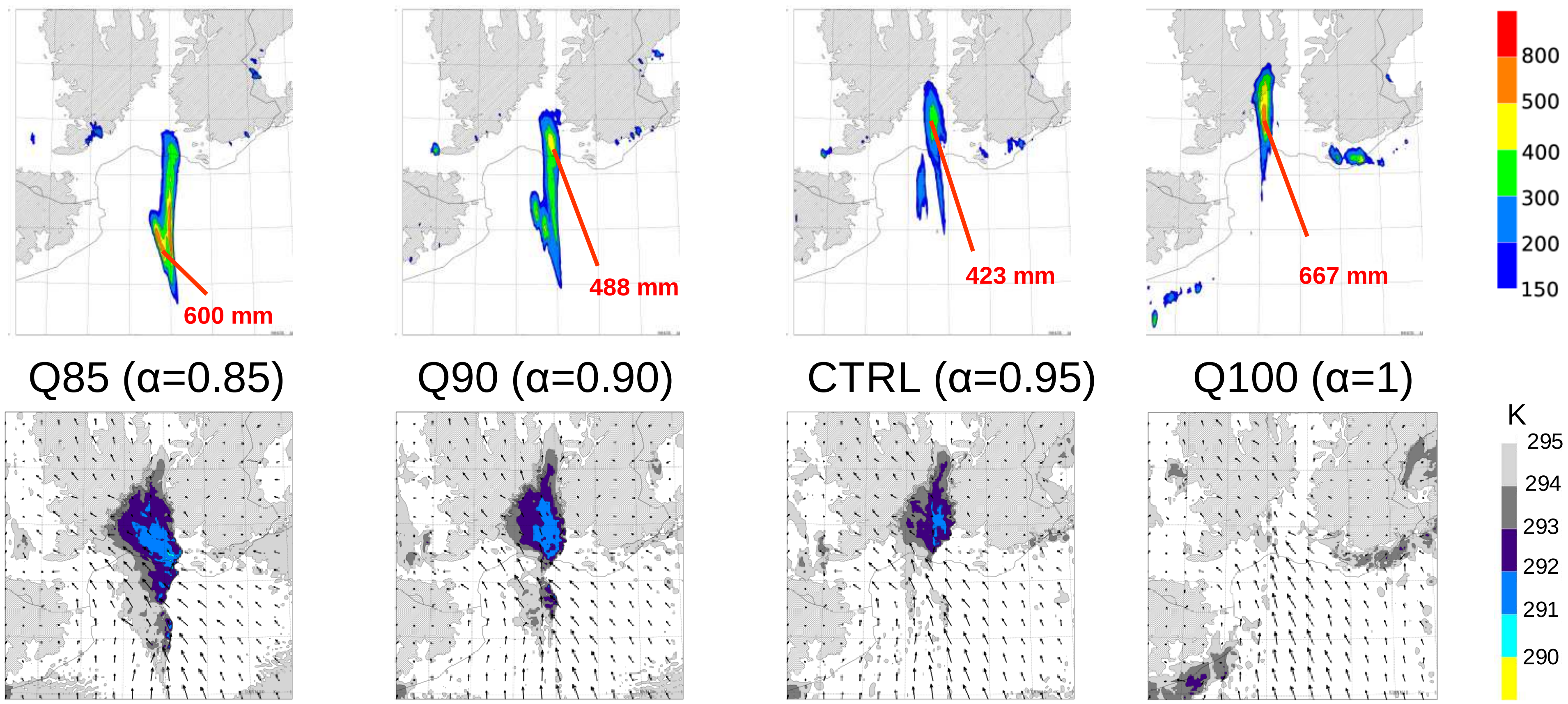
θv and winds at 36m, after 48h

when **wind speed** ↗,
- the precipitating system is located ***more northward***, reaching Massif Central mountain,
- the ***precipitation maximum*** ↗.

The ***cold pool disapears*** for the larger wind speed

Results: sensitivity to moisture

Cumul RR24, after 48h



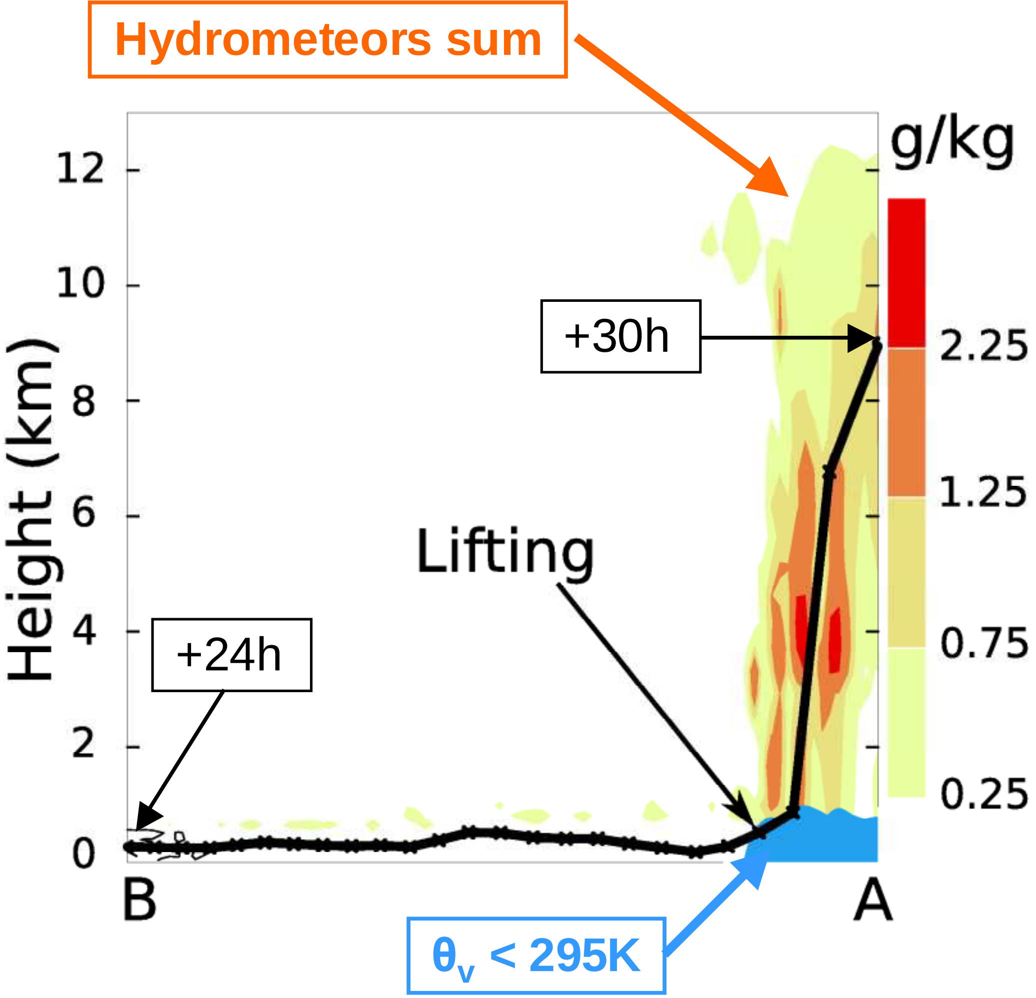
θv and winds at 36m, after 48h

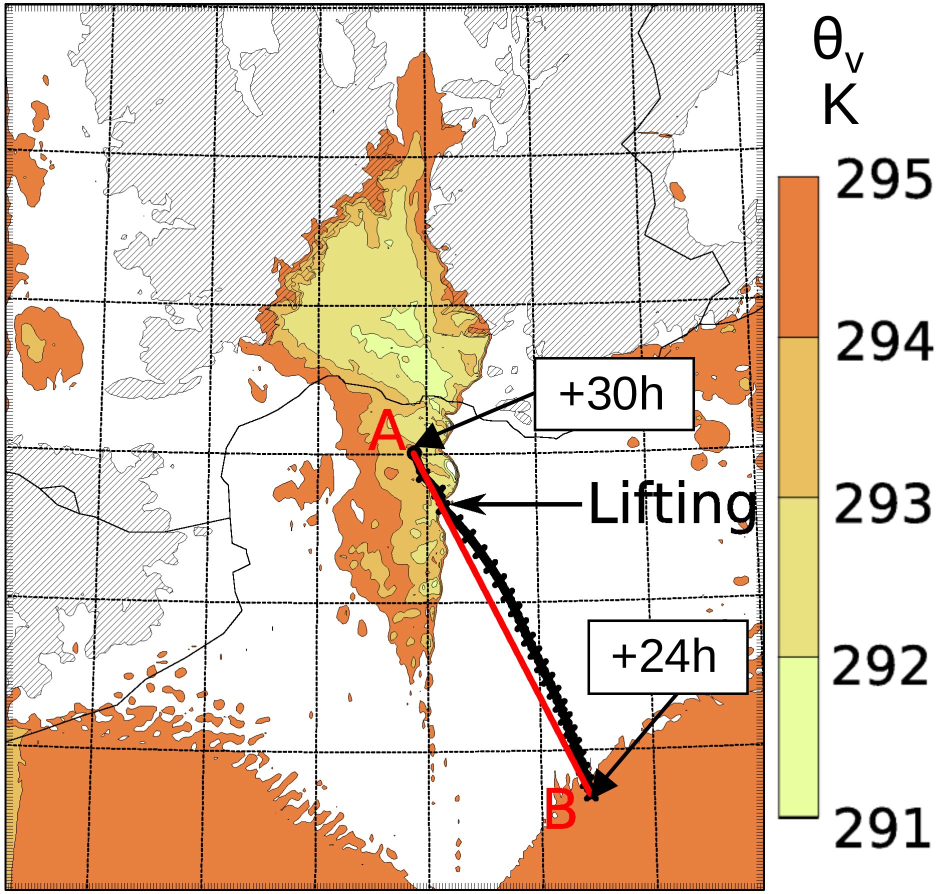
When humidity ↘,

- The precipitation system is located *more northward*, reaching the Massif Central mountain,
- ***the** cold pool* becomes *less intense*.

Cold pool

Q85

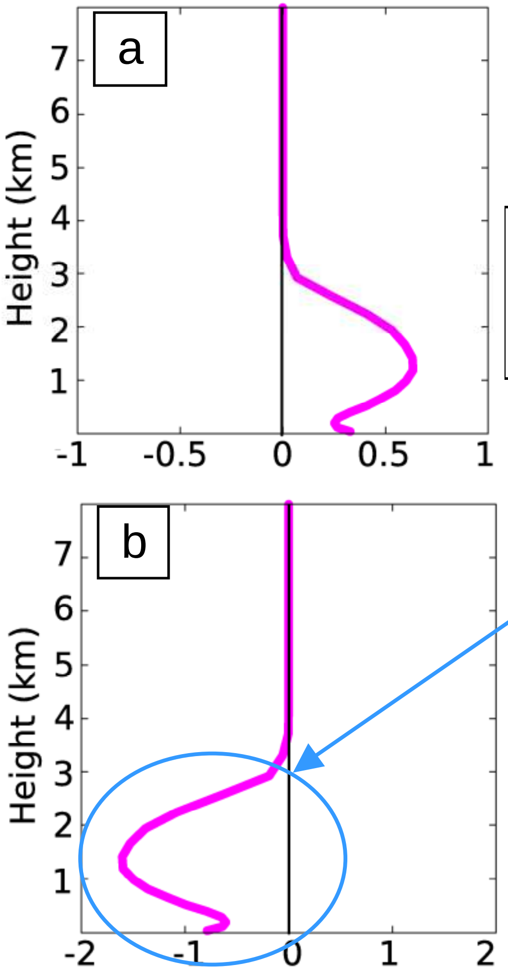




Lifting over the ***leading edge*** of the cold pool

Cold pool

CTRL

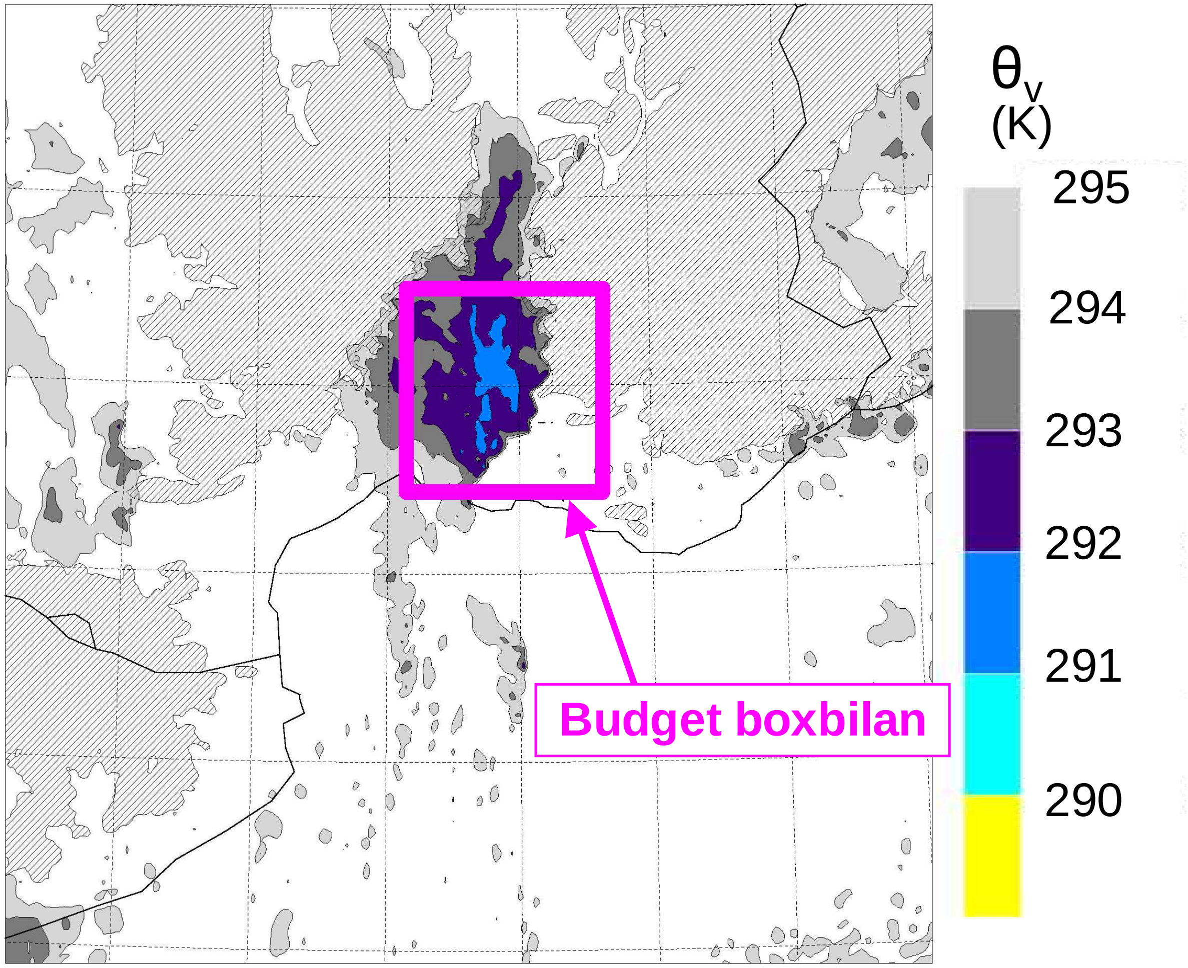


Evaporation of precip. (10^{-3}/h)

Heat rate (K/h)

cooling

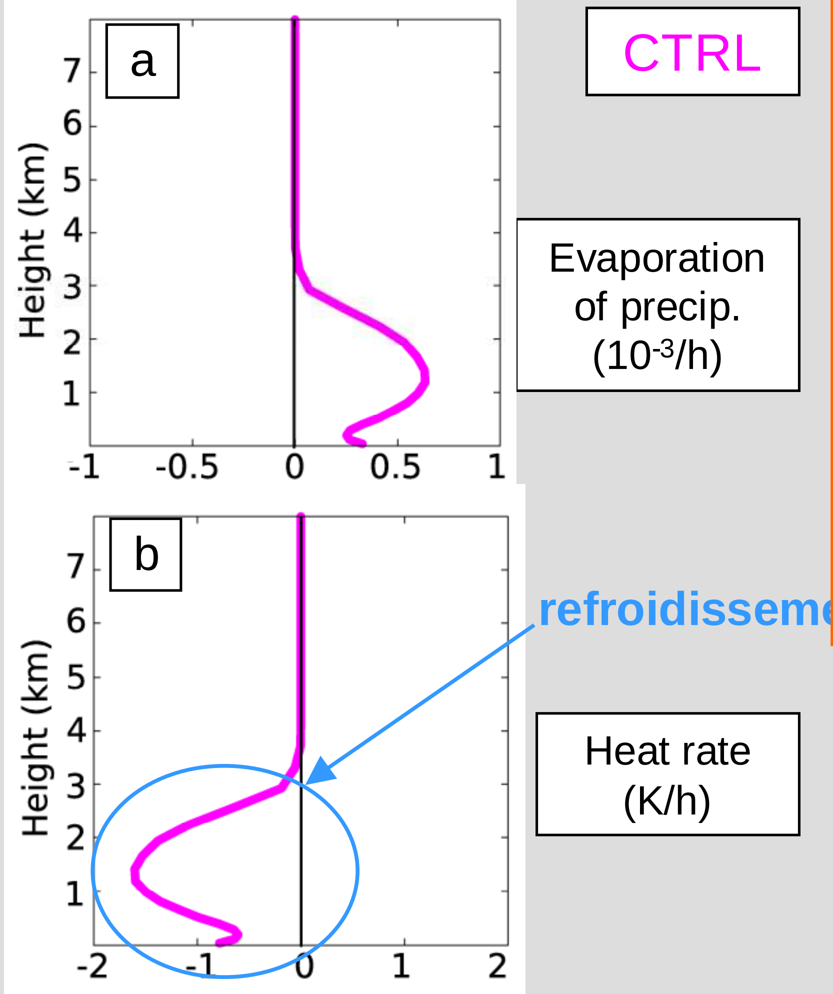
Contribution of evaporation to the water vapour and (a) and temperature (b) budget



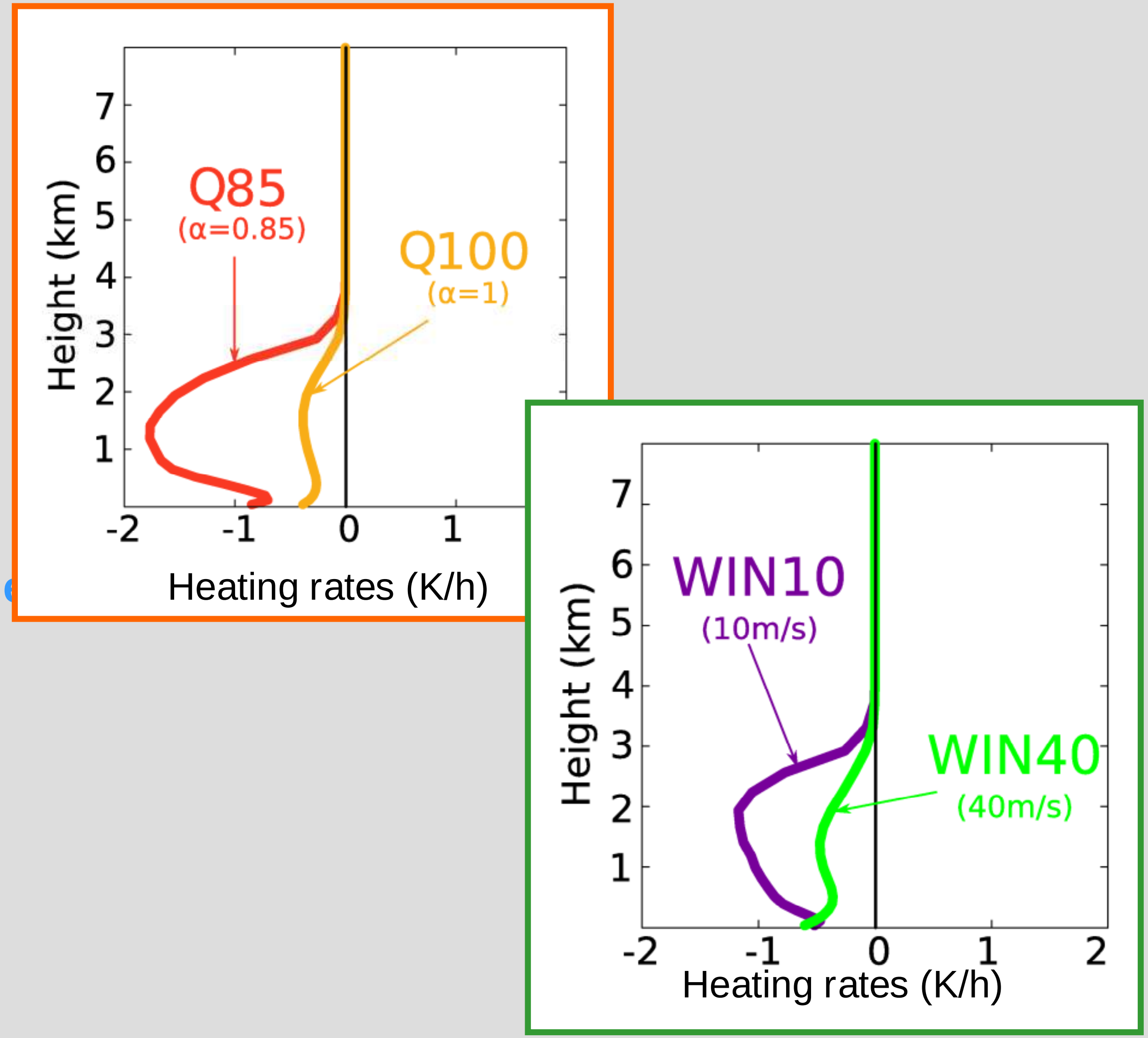
Budget boxbilan

Cooling due to ***evaporation of precipitations*** beneath the convective system

Cold pool



Contribution of evaporation to water vapour (a) and temperature (b) budget



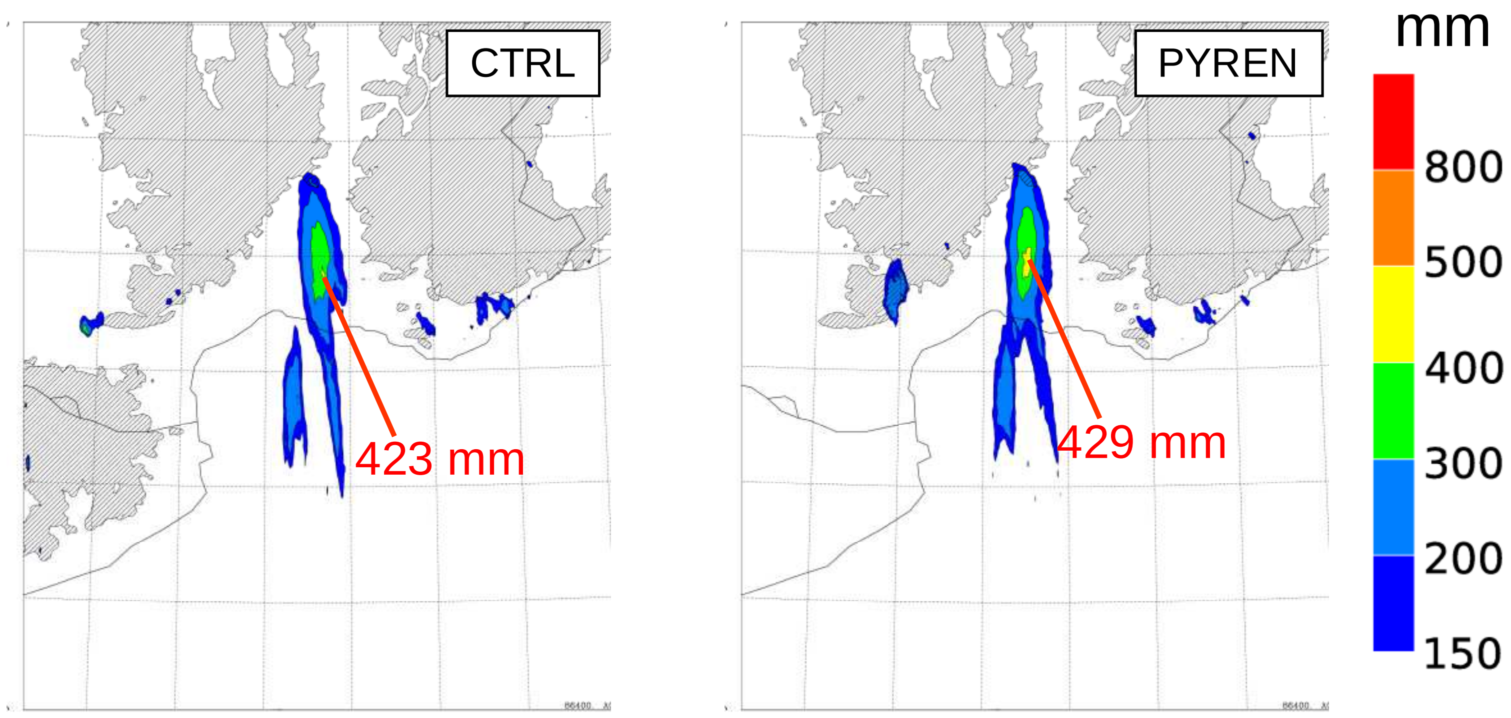
Cooling due to ***evaporation of precipitations*** beneath the convective system

- become ***more intense with a dryer flow***,
- ***Rapid flow does not favour*** its formation

Roles of mountain chains

Pyrenees effect:

Similar systems for CTRL and PYREN



Roles of mountain chains

Pyrenees effect:

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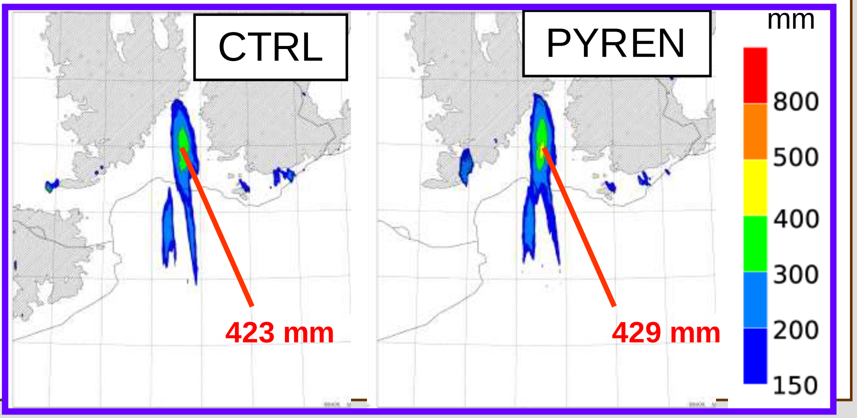
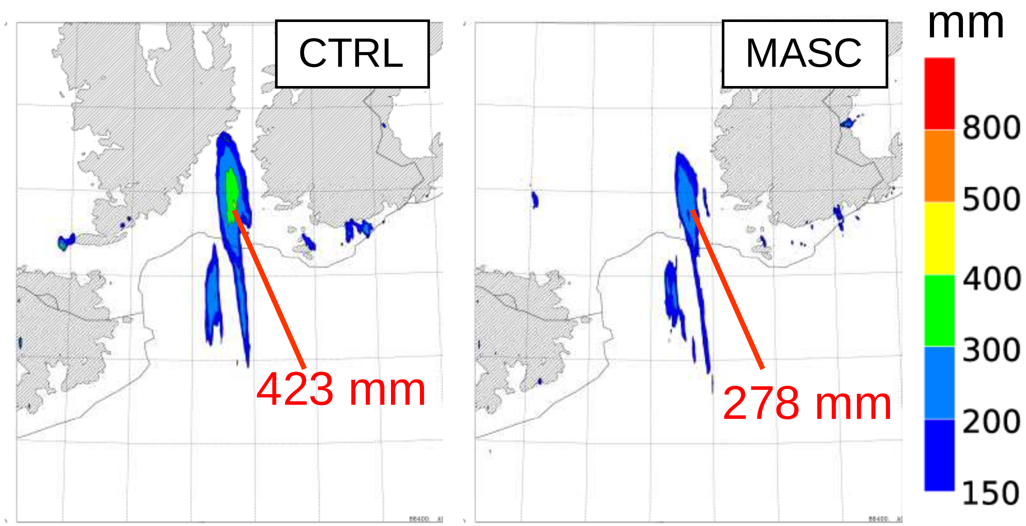
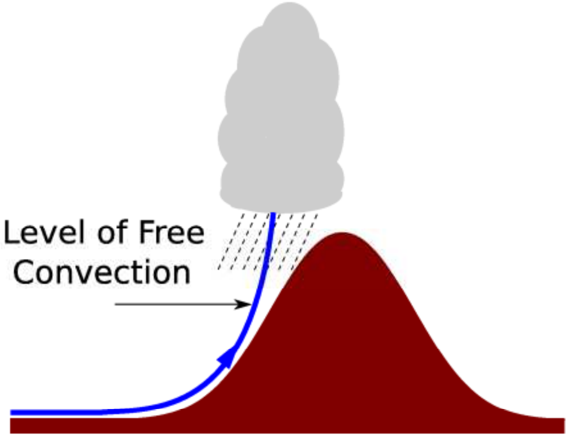


Massif Central effect:

Orographic lifting triggers deep convection



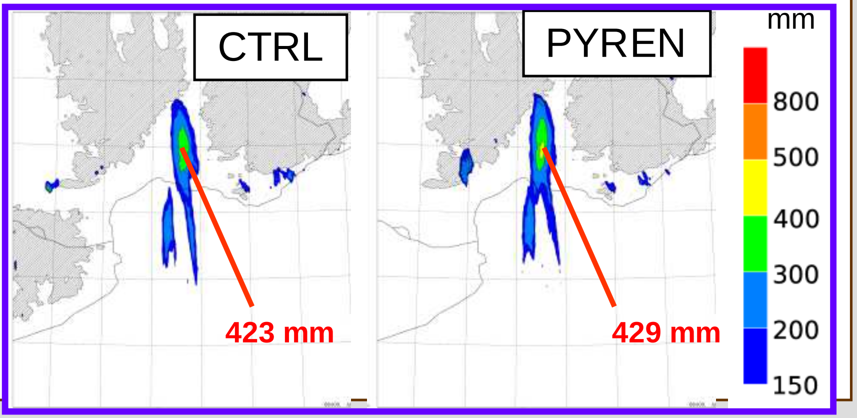


Orographic forcing

Roles of mountain chains

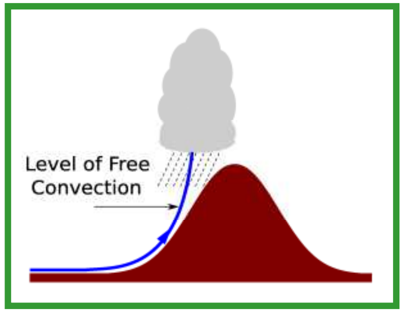
Pyrenees effects:

Similar systems for CTRL et PYREN

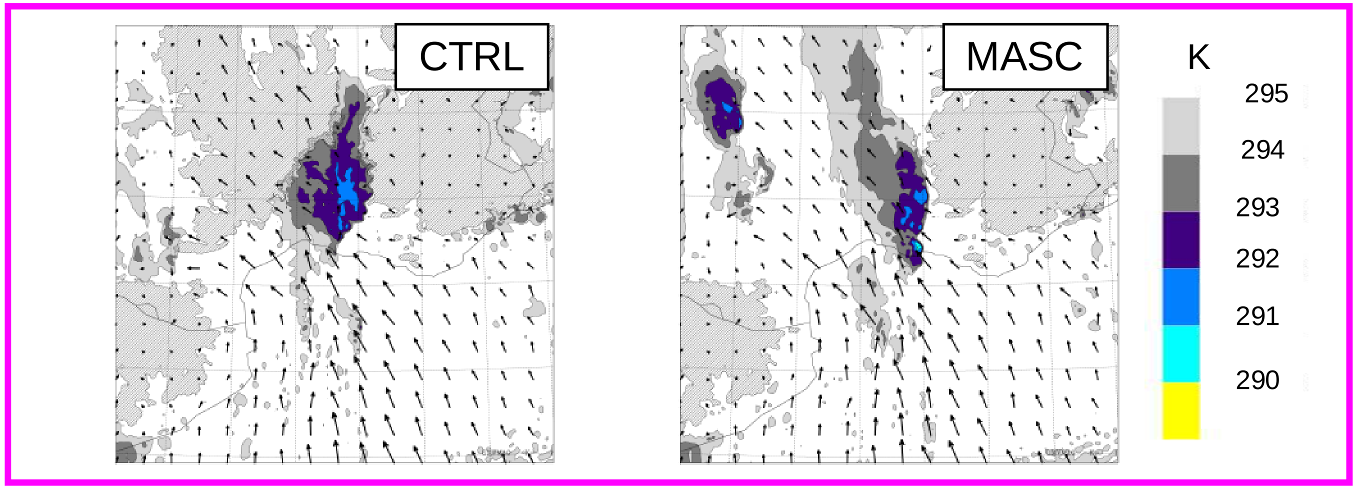


Massif Central mountain:

Orographic lifting triggers deep convection



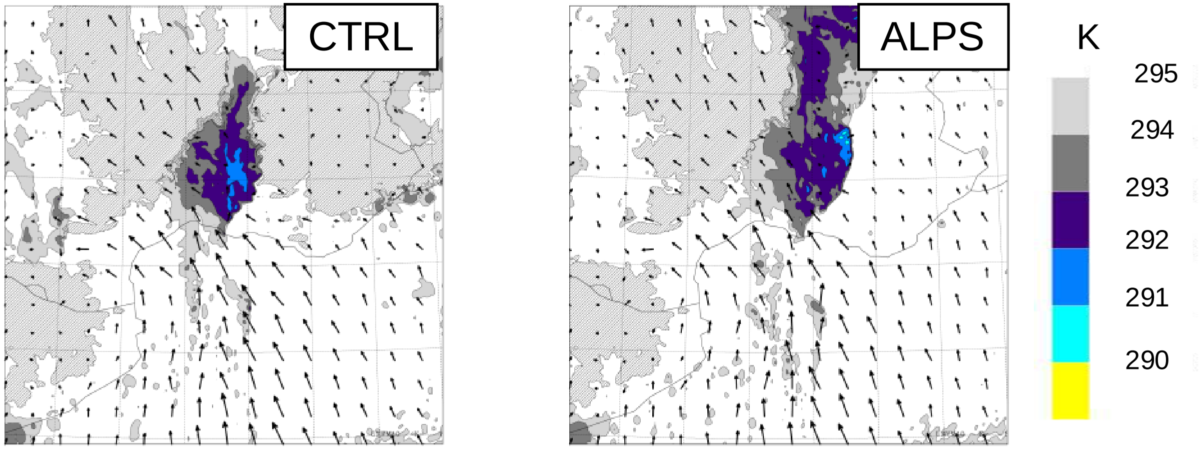
Blocking of the cold pool



Roles of the mountain chains

Alps effect:

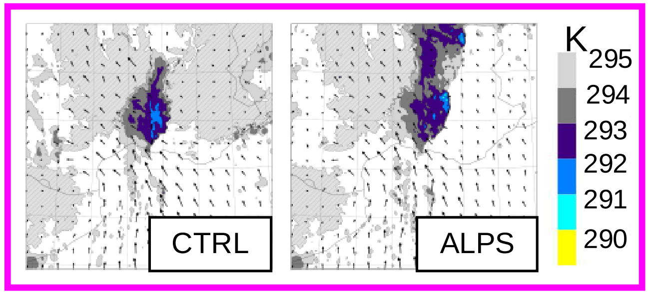
Blocking of the cold pool



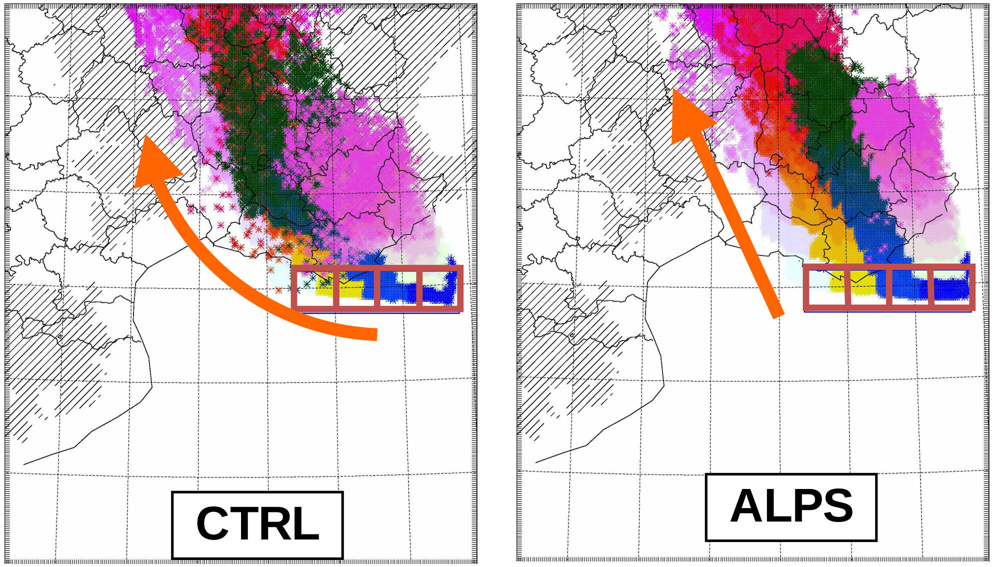
Rolesof the mountain chains

Alps effects:

Blocking of the cold pool



Deflection of the low-level flows by Alps

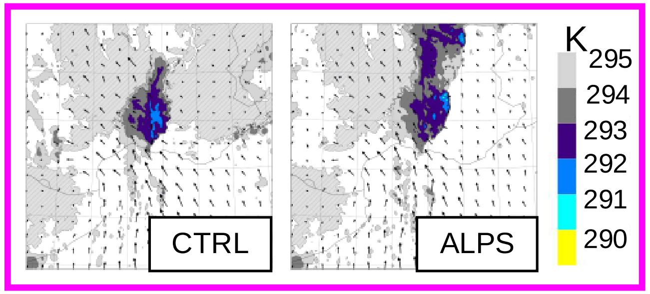


Lagrangian parcel plumes, initially within 0-500m depth boxes (from 42h to 48h)

Roles of the mountain chains

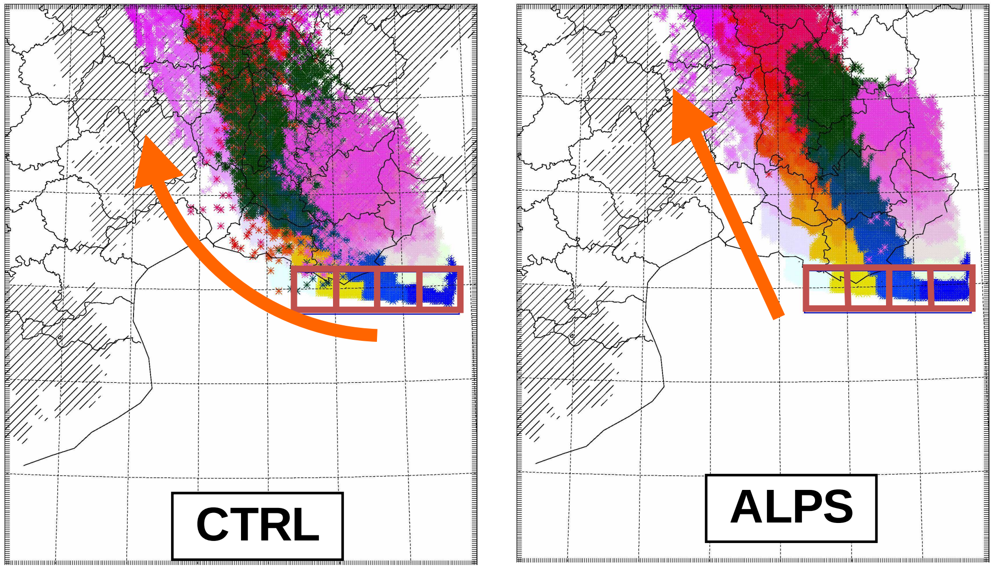
Alps effects:

Blocking of the cold pool

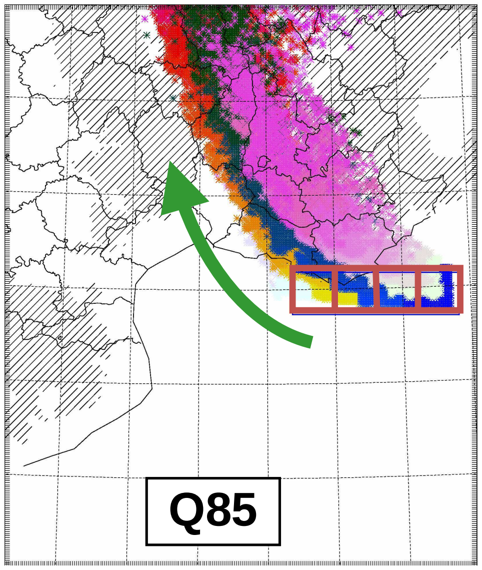


Deflection of the low-level flows by Alps

Deflection ↗ when *lateral drying* ↗



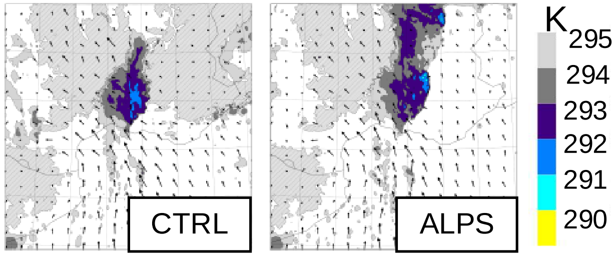
Plume of Lagrangian parcels, initially contained in 0-500m-depth boxes from 42h to 48h



Roles of mountain chains

Alps effects:

Blocking of the cold pool



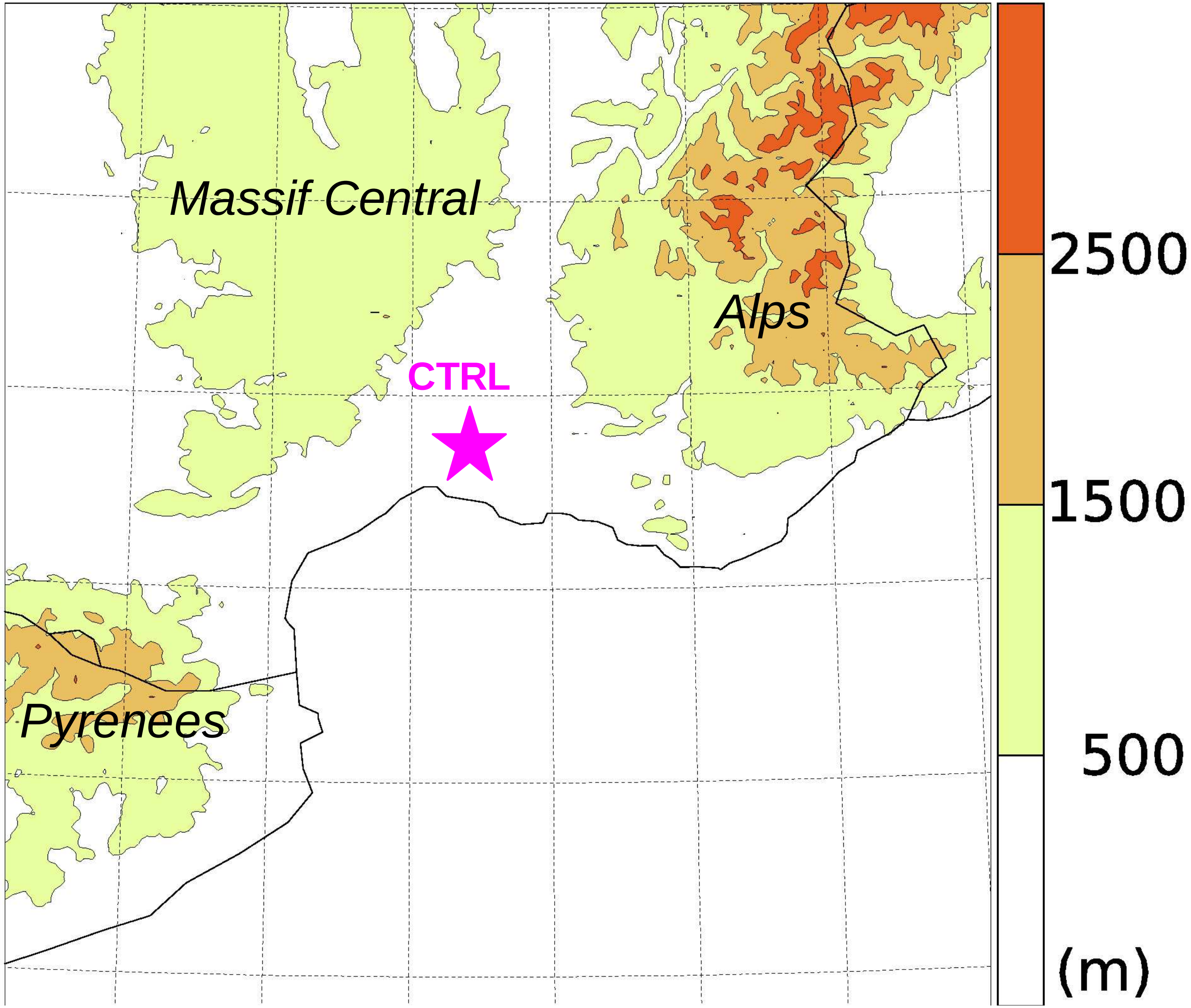
Deflection of the low-level flows by Alps

***Deflection* ↗** when ***lateral drying* ↗**

***Deflection* ↗** when **U0 ↘**

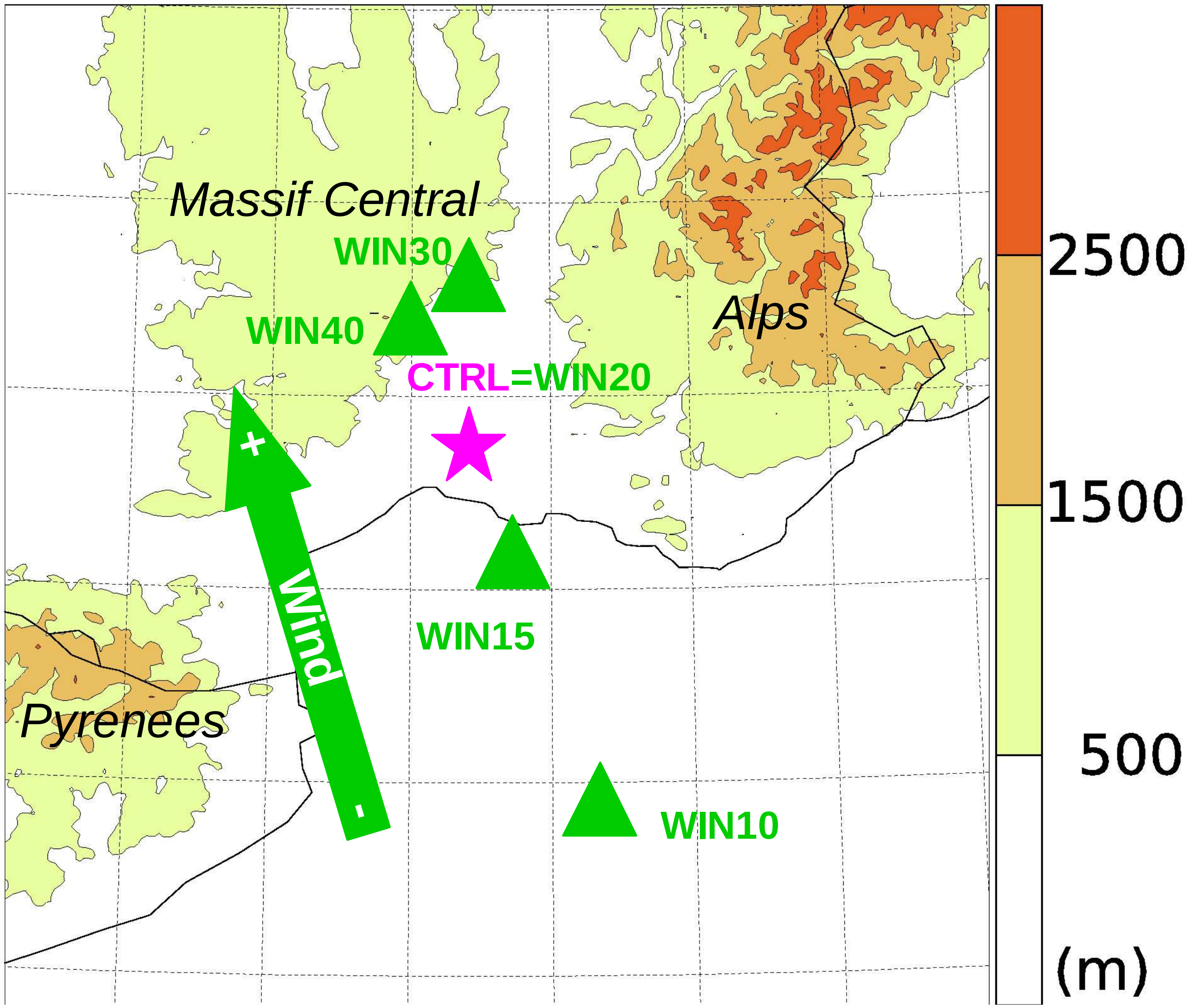
When deflectiont↗,
Low-level convergence ↗

Synthesis



Location of the maximum rainfall amounts

Synthesis



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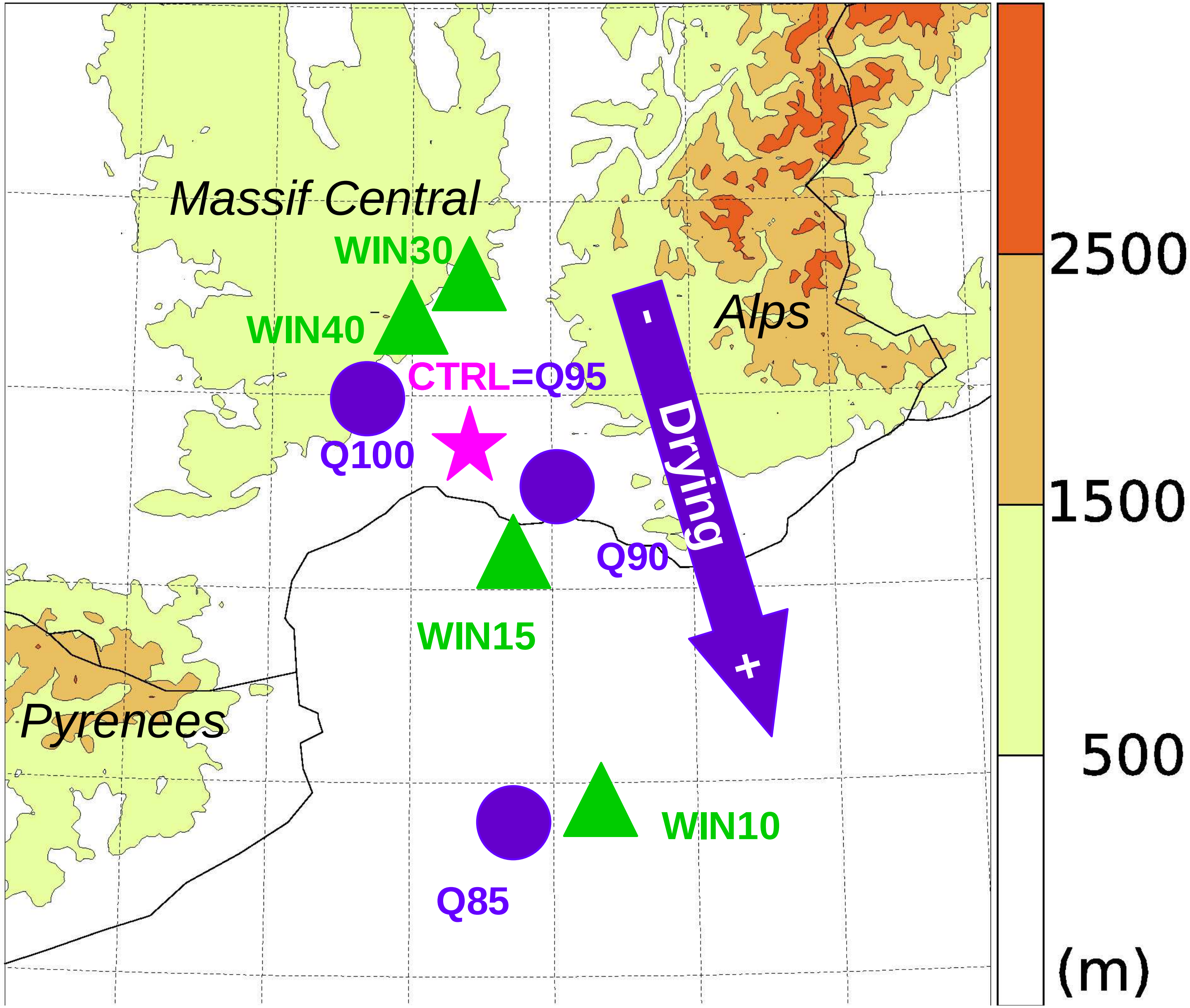

Location of the maximum rainfall amounts

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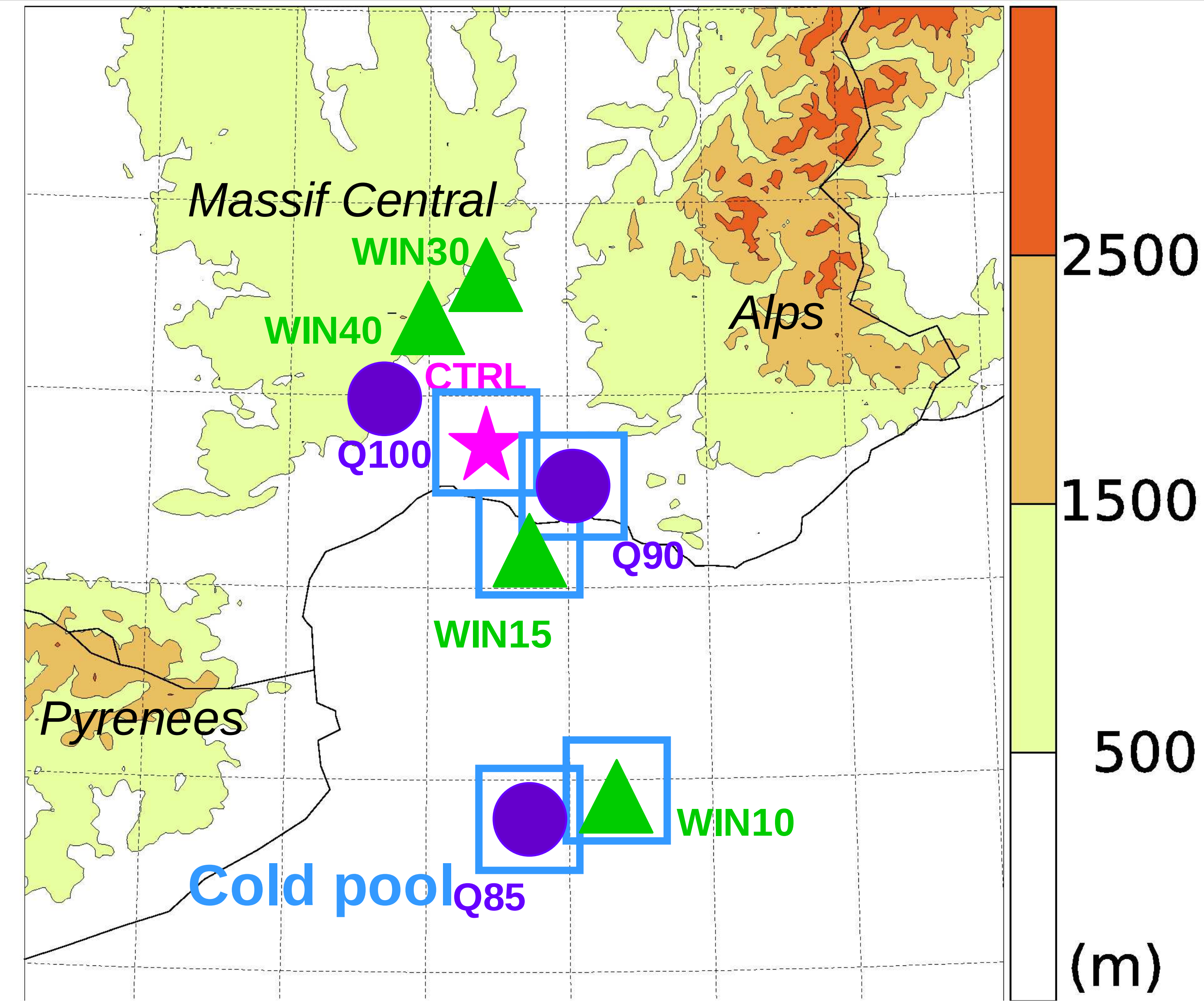

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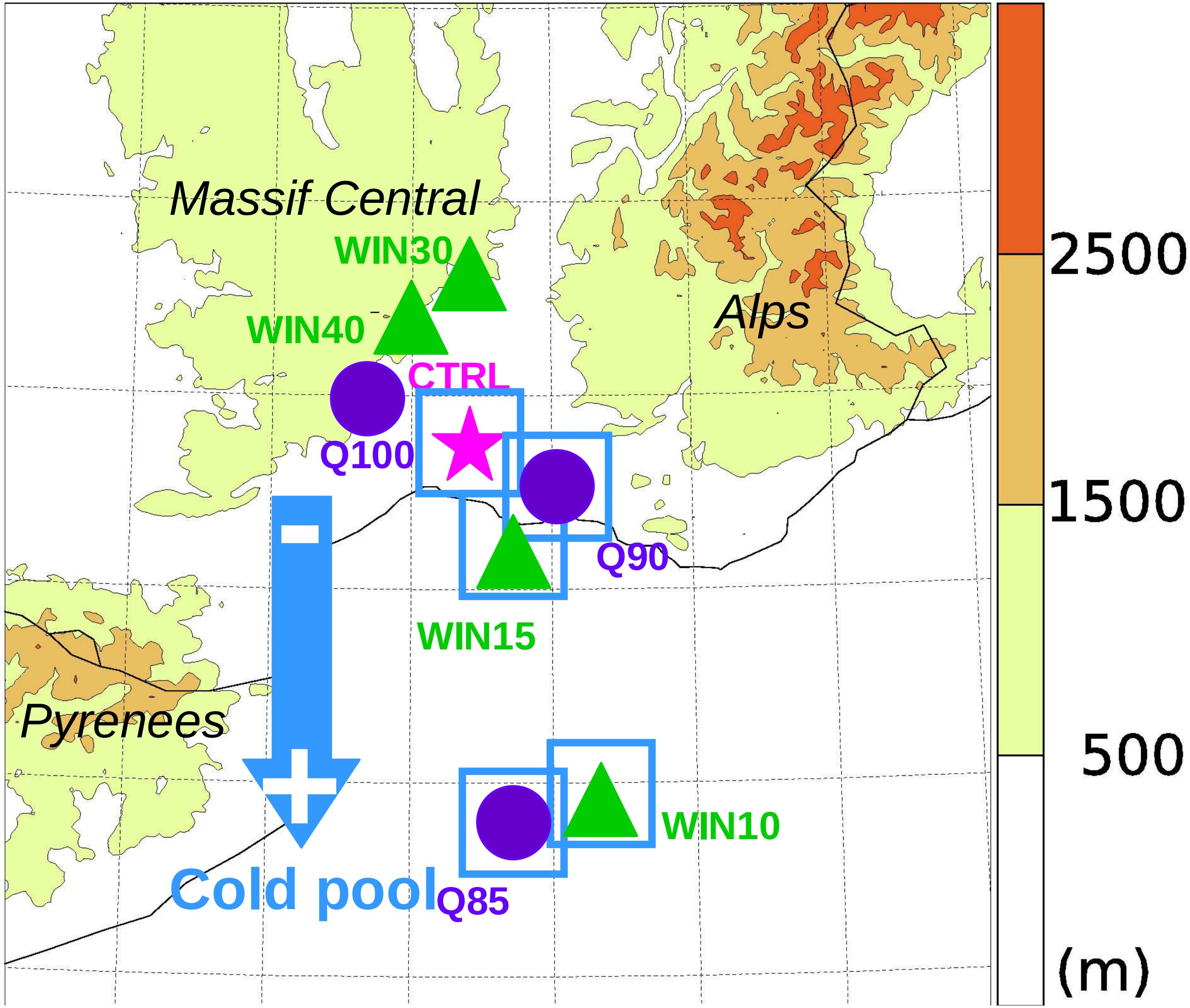

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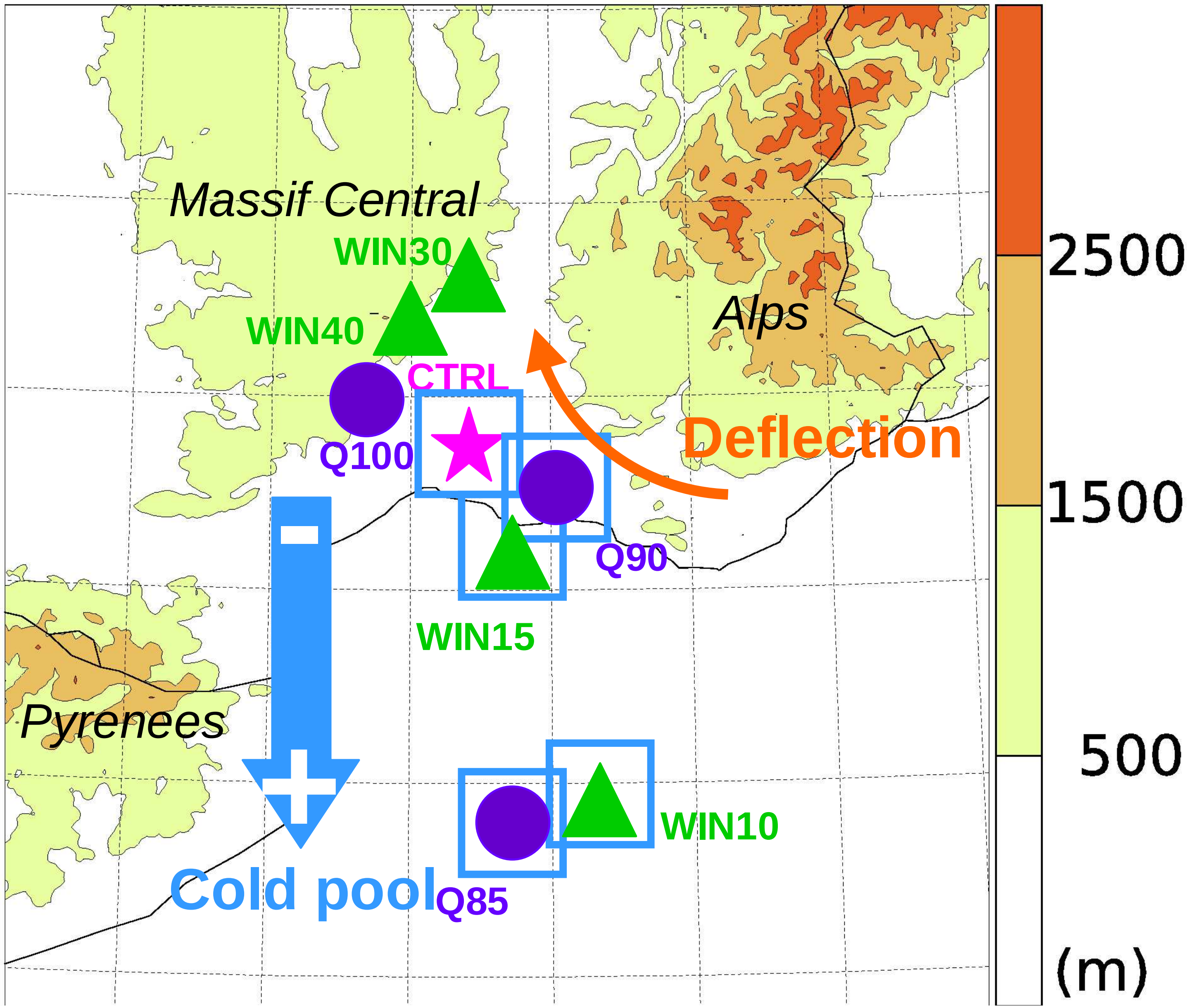

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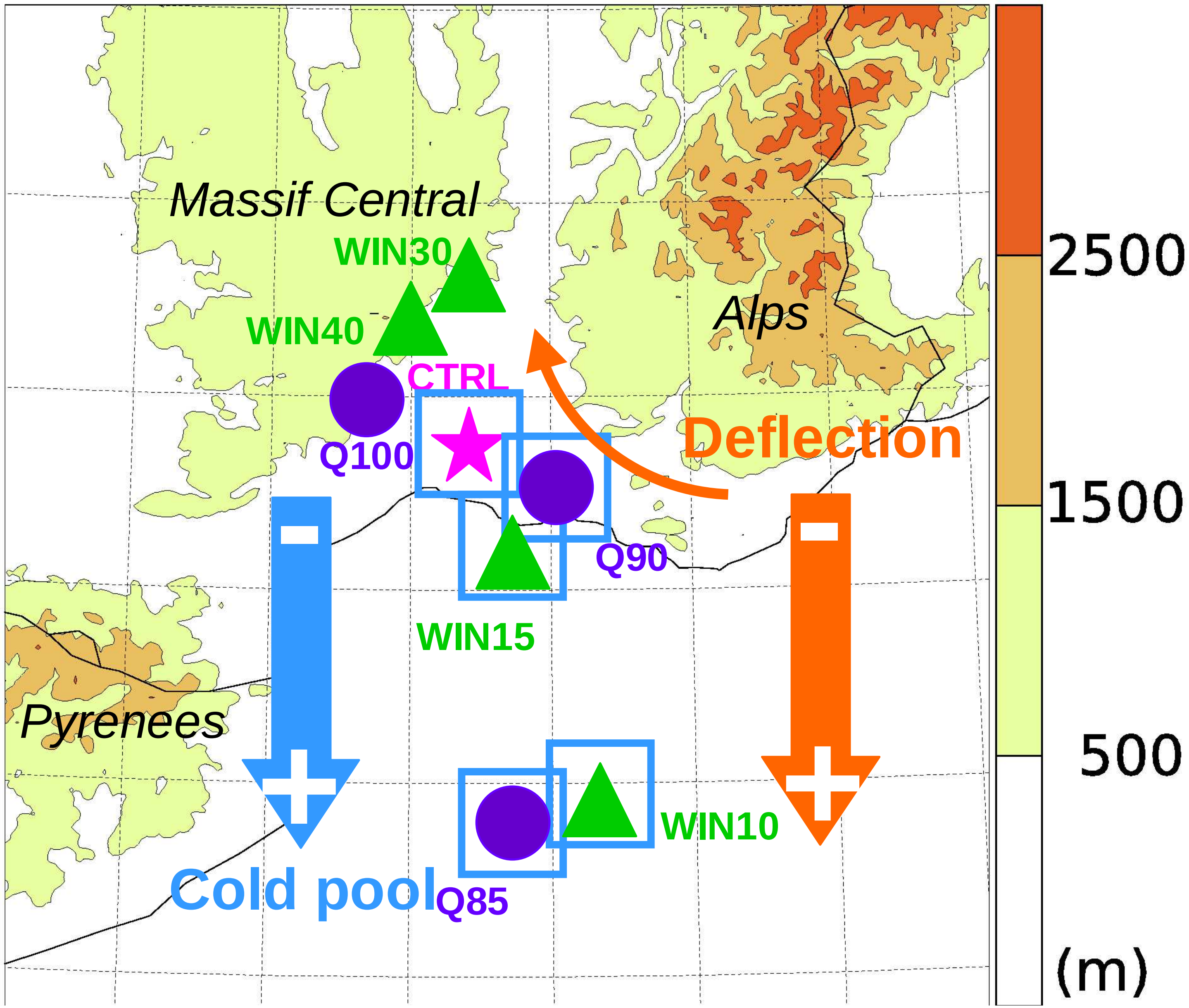
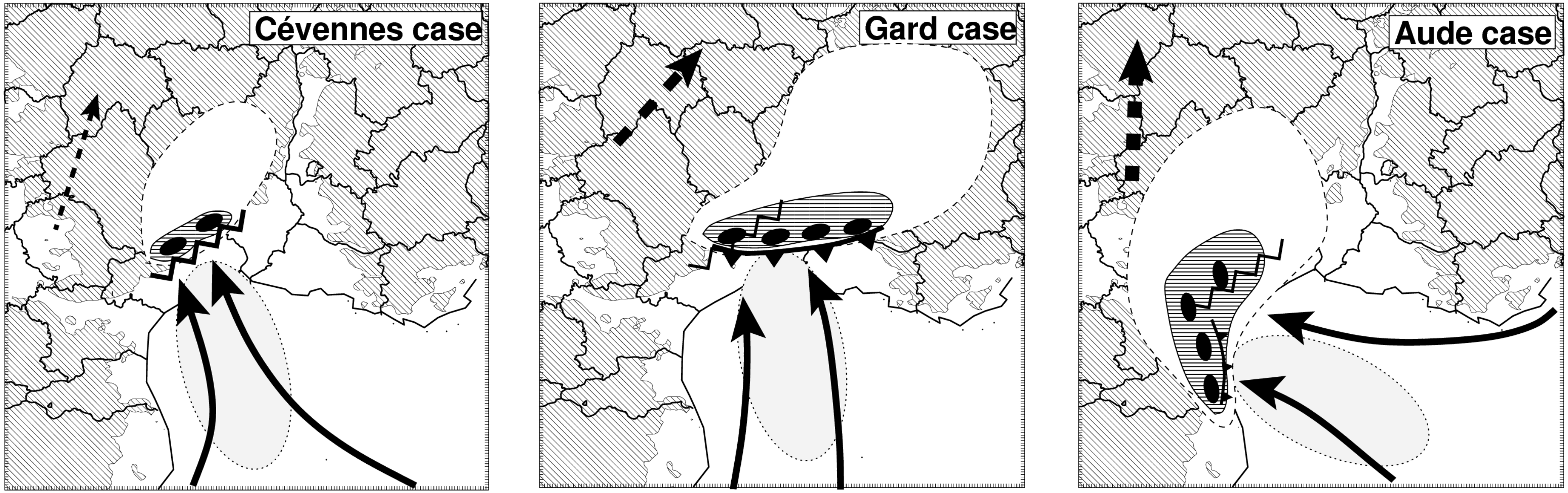
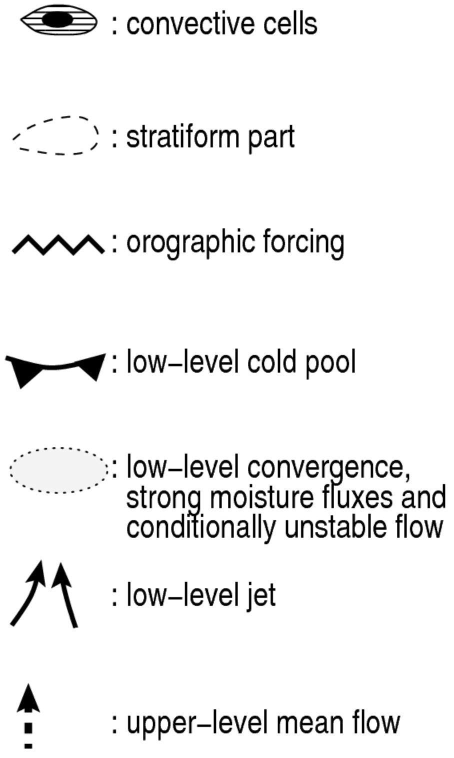


Location of the maximum rainfall amounts





A slow-evolving synoptic environment;

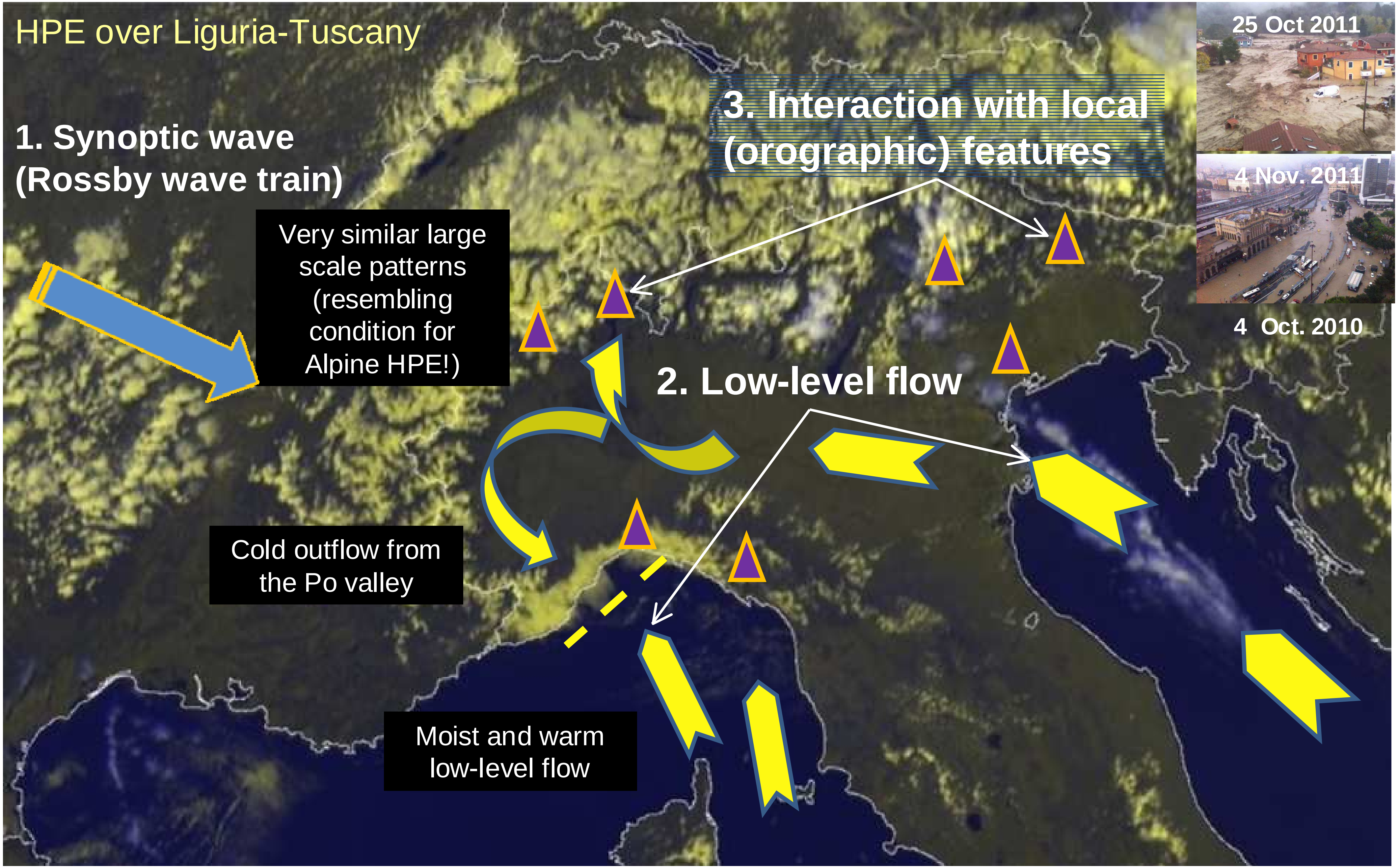
A low-level moist and conditionnaly unstable air mass;

A low-level flow flow (moderate to intense), with often convergence over the sea;

Role of mountains: lifting, blocking/chanelling of flow and density current

Conceptual models from Ducrocq et al (2008)

Similar ingredients for cases in Italy or Spain



HPE over Liguria-Tuscany

1. Synoptic wave (Rossby wave train)

Very similar large scale patterns (resembling condition for Alpine HPE!)

3. Interaction with local (orographic) features

2. Low-level flow

Cold outflow from the Po valley

Moist and warm low-level flow

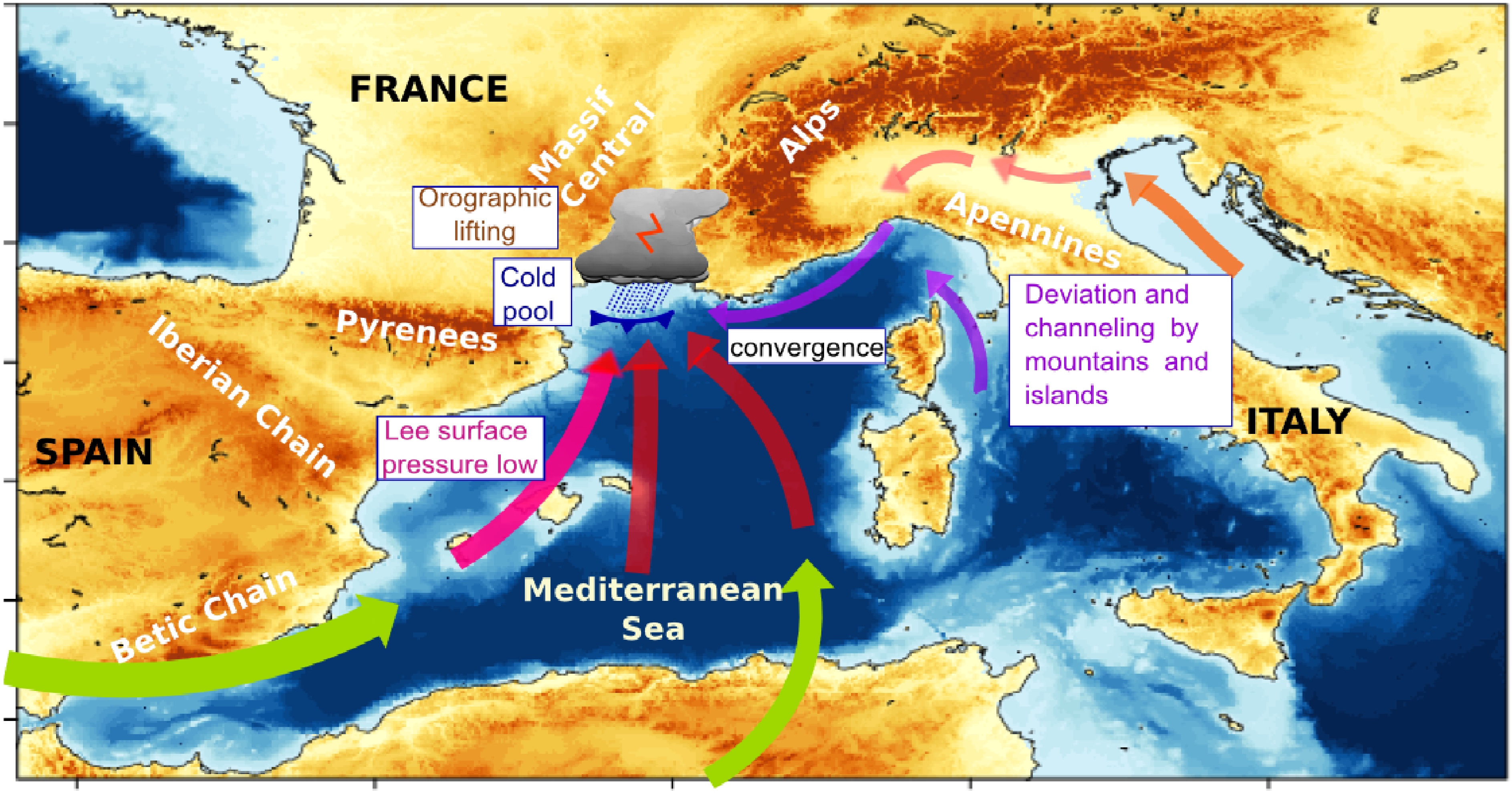
25 Oct 2011

4 Nov. 2011

4 Oct. 2010

Adapted from F. Grazzini and S. Davolio (2012)

Conceptual models from HyMeX results

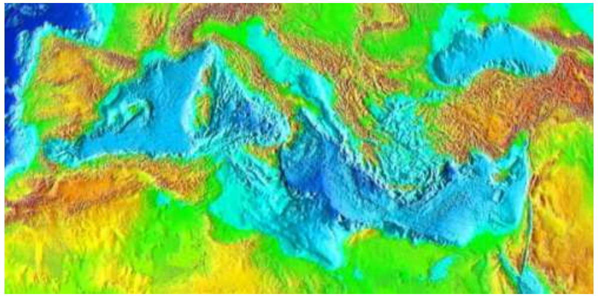


Ducrocq et al, 2016

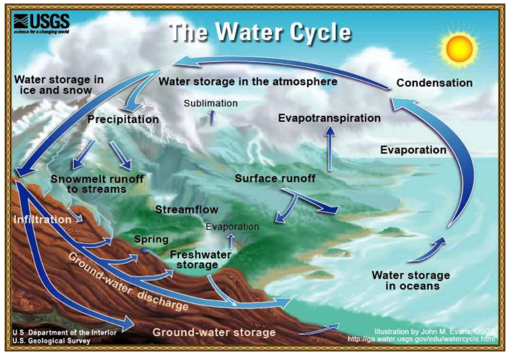
HyMeX

www.hymex.org

Motivations and Societal Stakes



A nearly enclosed ***sea*** *surrounded by* ***very urbanized littorals*** *and* ***mountains*** *from which numerous* ***rivers*** *originate*



⇨**A** ***unique highly-coupled*** (Ocean-Atmosphere-Land) ***system***

⇨**A region prone to *high-impact events* related to water cycle:**

Heavy precipitation, flash-flooding during fall
Strong winds, large swell during winters
Droughts, heat waves, forest fires during summers

⇨ ***Water resources: a critical issue***

Freshwater is rare and unevenly distributed in a situation of increasing water demands and climate change (180 millions people face water scarcity)

⇨ The Mediterranean is one of the two main ***Hot Spot regions*** of the ***climate change***

Large decrease in mean precipitation, increase in precipitation variability during dry (warm) season, large increase in temperature (+1.5 à + 6°C in 2100)

⇒ Need to advance our knowledge on *processes related to water cycle within all Earth compartments*, to progress in the *predictability of high-impact weather* events and their evolution with *global change*.

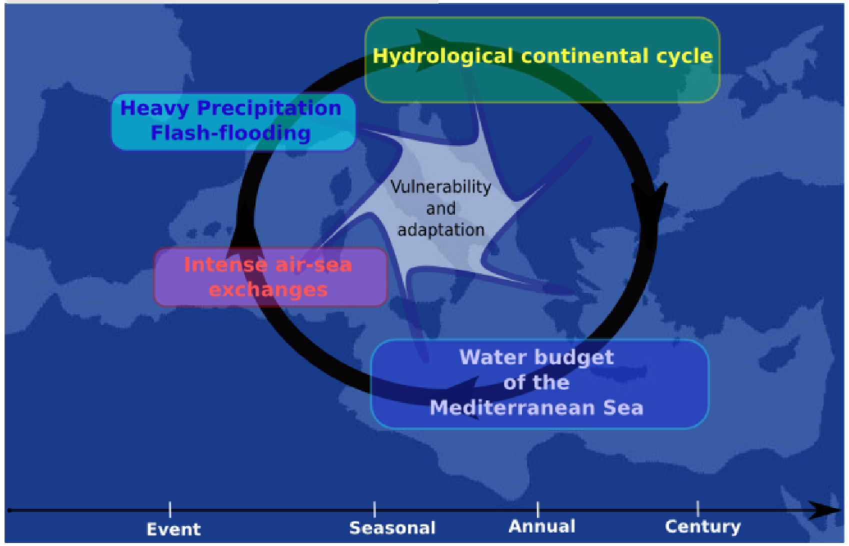
Objectives & Science Topics

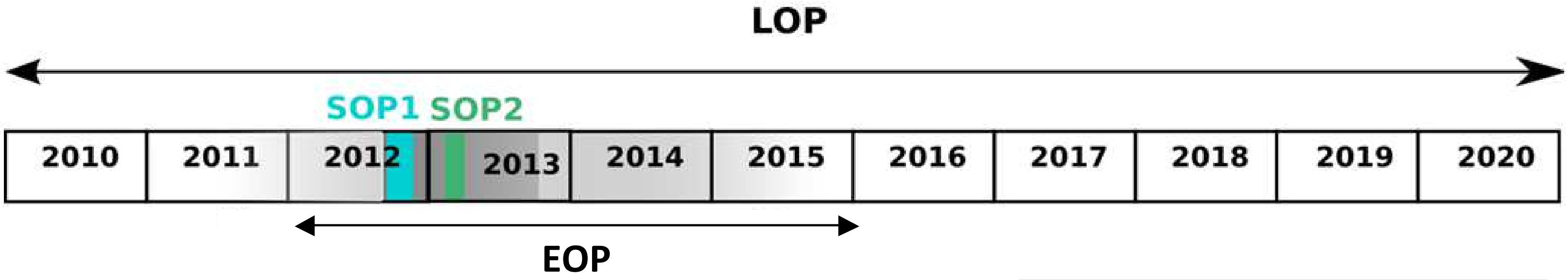
➲ to improve our understanding of the *water cycle* with emphases on the *predictability* and *evolution* of *high-impact weather events*

➲ to evaluate the *social and economical vulnerability* to extreme events and the *adaptation capacity.*

➲ A three-level nested observation approach over the 10-y program:

The five science Topics





EOP/SOP over Western Med

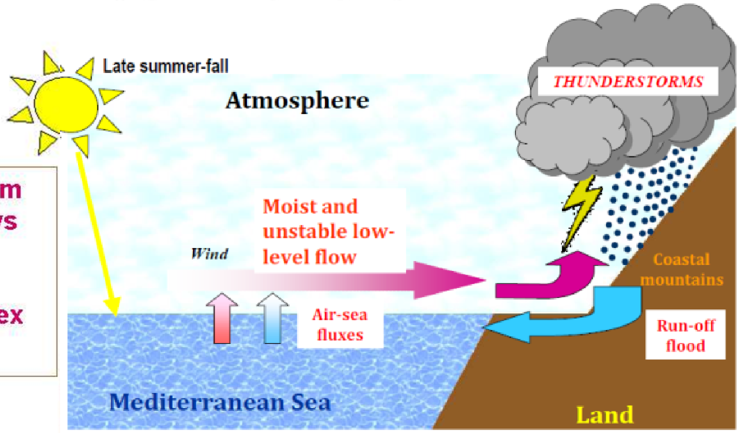
EOP/SOP over Eastern Med ?

Drobinski, P., Ducrocq, V., Alpert, P., Anagnostou, E., Béranger, K., Borga, M., Braud, I., Chanzy, A., Davolio, S., Delrieu, G., Estournel, C., Filali Boubrahmi, N., Font, J., Grubisic, V., Gualdi, S., Homar, V., Ivančan-Picek, B., Kottmeier, C., Kotroni, V., Lagouvardos, K., Lionello, P., Llasat, M. C., Ludwig, W., Lutoff, C., Mariotti, A., Richard, E., Romero, R., Rotunno, R., Roussot, O., Ruin, I., Somot, S., Taupier-Letage, I., Tintoré, J., Uijlenhoet, R. and Wernli, H., 2014: HyMeX, a 10-year multidisciplinary program on the Mediterranean water cycle, *Bulletin of the American Meteorological Society,* 95, 1063-1082.

2012-2013: two major field campaigns in NW Med (SOP1 & SOP2)

SOP1 (5 Sept. - 6 Nov. 2012)

the microphysics and dynamics of precipitating systems leading to HPE



the upstream marine flows and their interaction with complex terrain

The distributed hydrological response of the Mediterranean watersheds

the air-sea exchanges and ocean mixed layer prior and during HPE

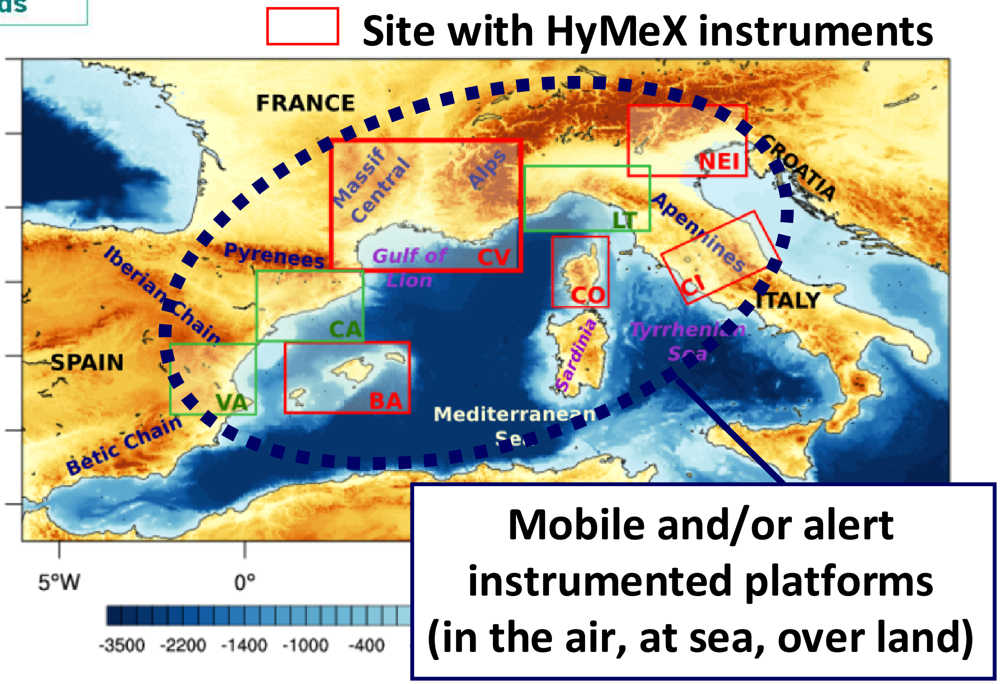
WG3 - Heavy Precipitation and flash-flooding

~200 instruments deployed

250 flight hours (SAFIRE/ATR42 & F20, KIT/DO128)

~300 scientists on the field

16 IOPs dedicated to heavy precipitation



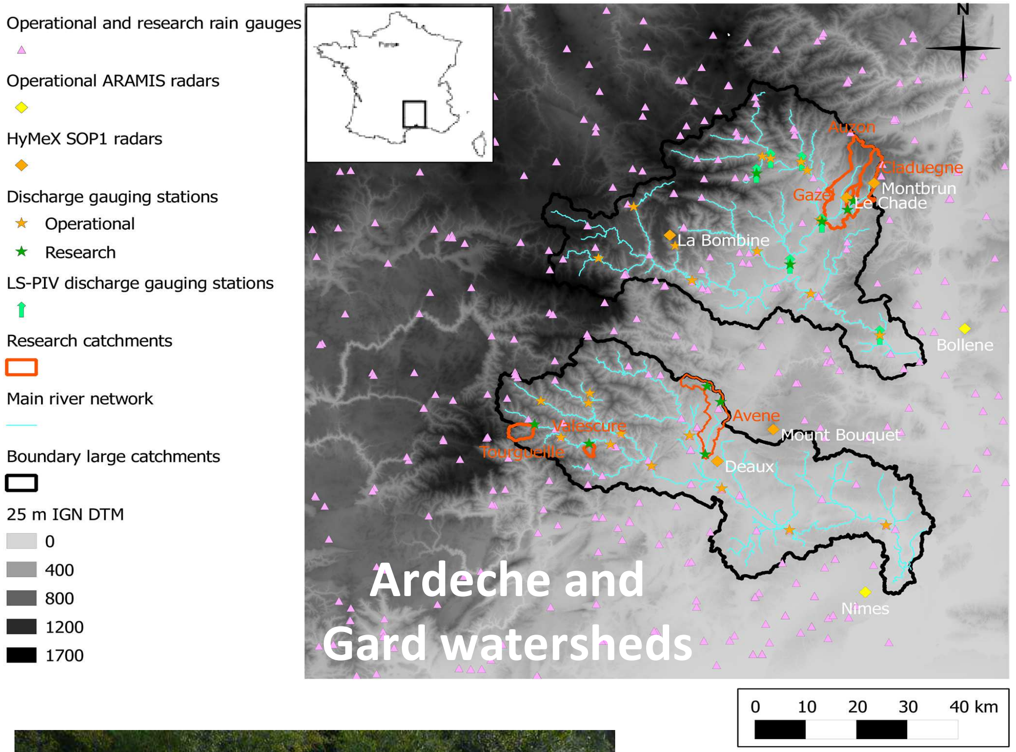
🟥 **Site with HyMeX instruments**

Mobile and/or alert instrumented platforms (in the air, at sea, over land)

SOP1 brings observations over the sea and of precipitating systems forming over the sea and affecting the coastal areas

Ducrocq, V., et al, 2014: HyMeX-SOP1, the field campaign dedicated to heavy precipitation and flash flooding in the northwestern Mediterranean, *Bulletin of the American Meteorological Society,* 95, 1083-1100.

EOP: Hydrological measurements over French Mediterranean catchments



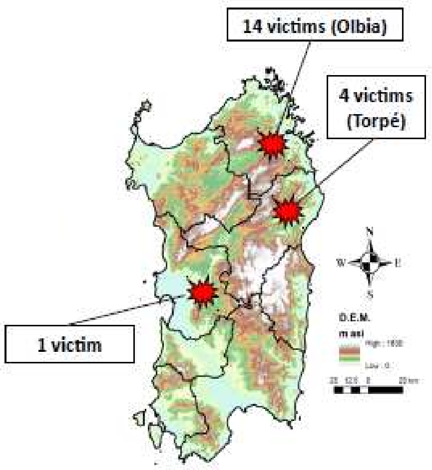
Routine and on-alert measurements each autumn 2012-2015 (sampling of flood events for geochemistry analysis, gauging of flooding rivers, soil moisture measurements, field observations of runoff) over some OHM-CV watersheds

EOP reinforcing observatory and operational observations during four years: a very successful proof of concept for flash-floods

Braud, I.et al., 2014: Multi-scale hydrometeorological observation and modelling for flash-flood understanding *Hydrology and Earth System Sciences*, 18, 3733–3761.

LOP: Intensive Post-event Campaigns (IPEC)

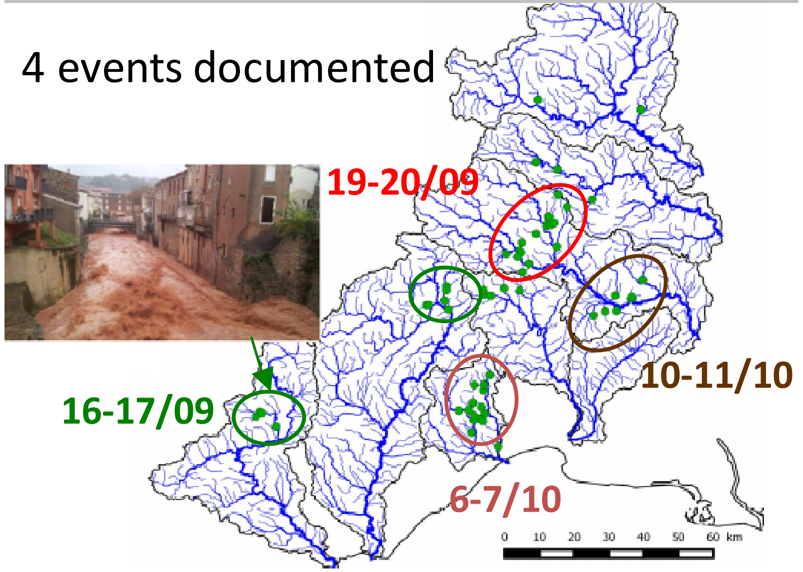
- ➲ Estimation of peak discharge over ungauged rivers, one IPEC each year



Sardinia, Nov. 2013
Precipitation: 469 mm/12 hours
Estimated 1 billion € damages

Cévennes region, autumn 2014
24 casualties
Estimated 660 millions € damages

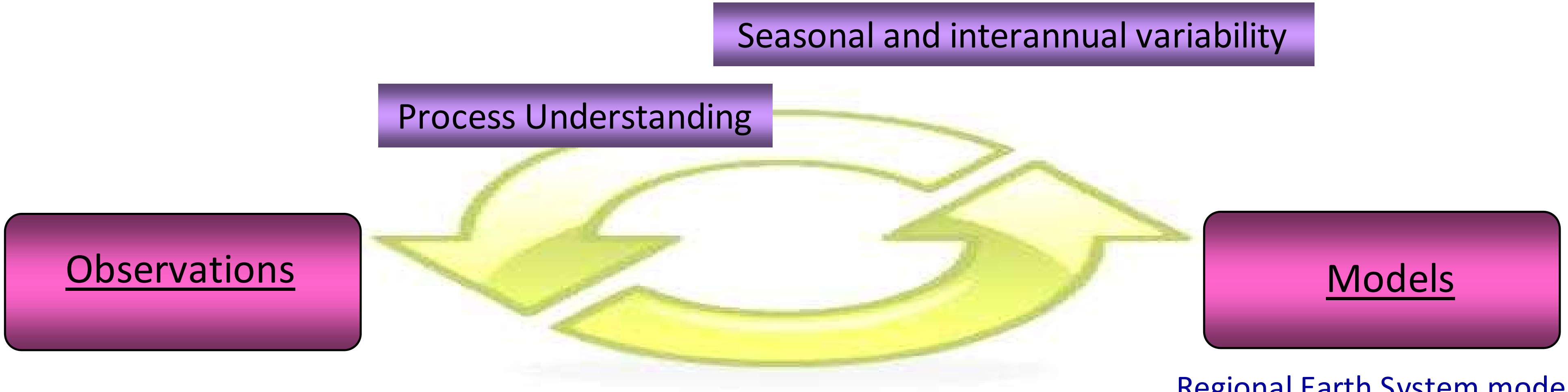
4 events documented



- ➲ Collection of rivers cross sections data with flood mark levels
- ➲ Interviews of eyewitnesses for info on dynamics of the flood and flood levels
- ➲Use of videos for estimation of flow velocities

Hydrological IPEC provides fine-scale spatial and temporal information about river flooding that are also needed for analysing social impact IPEC data about crisis behavioral responses during flood events (face-to-face interviews, on-line surveys, media network,…)

Model-Observations Strategy



Seasonal and interannual variability

Process Understanding

Observations

Models

LOP/EOP observations

SOP/EOP field campaigns

Model Validation

Data assimilation in cloud/precipitation

Improvement of model parameterizations

Regional Earth System models

Convection-permitting ensemble hydrometeorological prediction systems

Process models

Mesoscale (incl. land surface) data assimilation

Coupled O-A-wave km-scale models

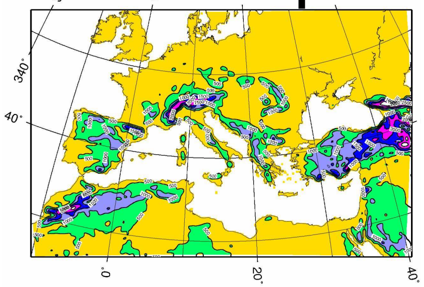
Motorist mobility and exposure model

A strong modelling component (ocean-atmosphere-hydrology, process-weather prediction-climate models) from the beginning that allows to design the field campaigns for model validation and improvement.

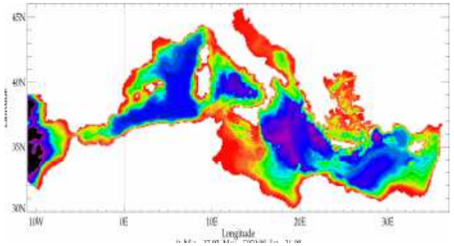
A lot of cross-validation and cross-analysis have been carried out.

Joint WCRCP/MedCORDEX & HyMeX regional climate modelling

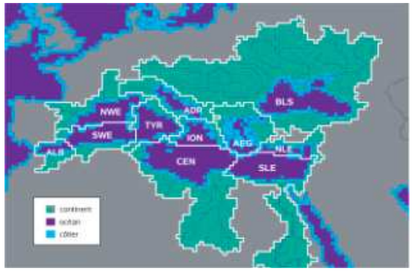
12km - atmosphere



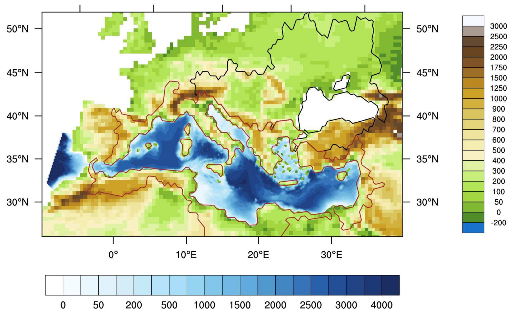
10km - ocean

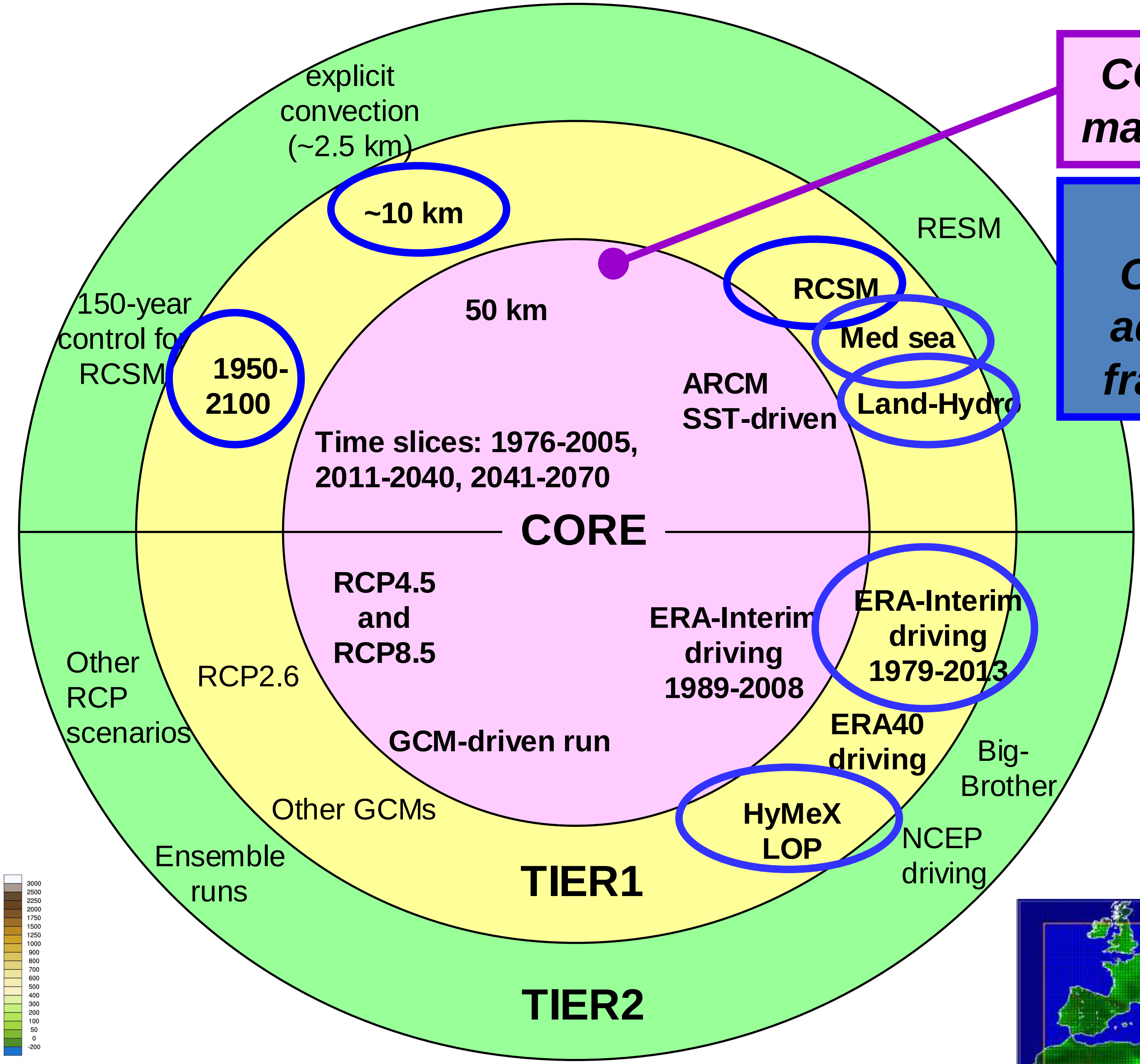


50km – river



RCSM





explicit convection (~2.5 km)

~10 km

RESM

150-year control for RCSM

1950-2100

50 km

RCSM

Med sea

ARCM SST-driven

Land-Hydro

Time slices: 1976-2005, 2011-2040, 2041-2070

CORE

RCP4.5 and RCP8.5

ERA-Interim driving 1989-2008

ERA-Interim driving 1979-2013

Other RCP scenarios

RCP2.6

GCM-driven run

ERA40 driving

Big-Brother

Other GCMs

HyMeX LOP

NCEP driving

Ensemble runs

TIER1

TIER2

CORDEX mandatory

Med-CORDEX additional framework

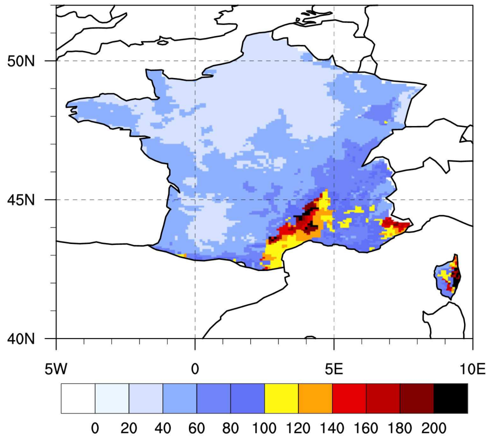
HPE: evaluation and 12-km RCM added-value

Maps of 99.9 quantiles of daily precipitation over France (30 years, SON, mm/d)

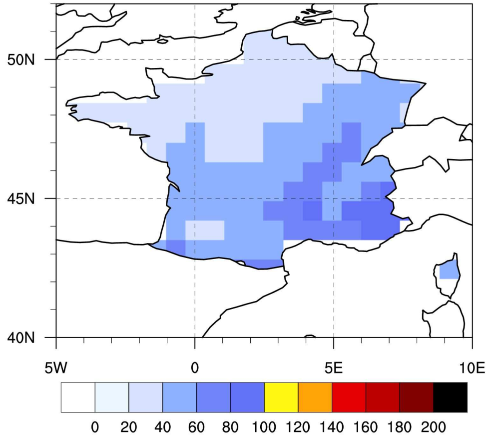
<u>Model:</u> ERA-Int (1980-2009), CNRM-CM5 (1976-2005), ALADIN-Climate

<u>Obs:</u> SAFRAN, gridded analysis, 8km

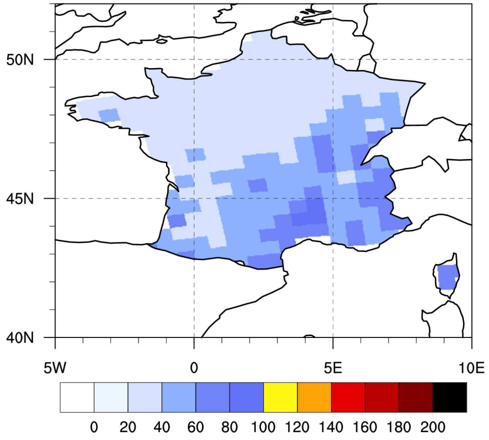
OBS - 8km



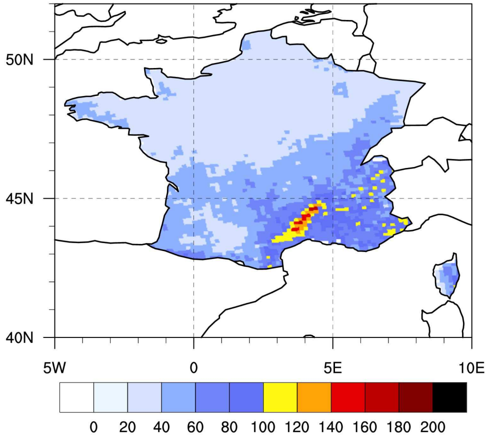
ERAInt - 80km



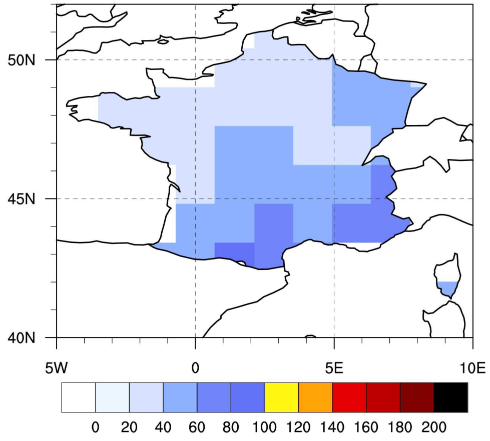
RCM50km - ERAInt



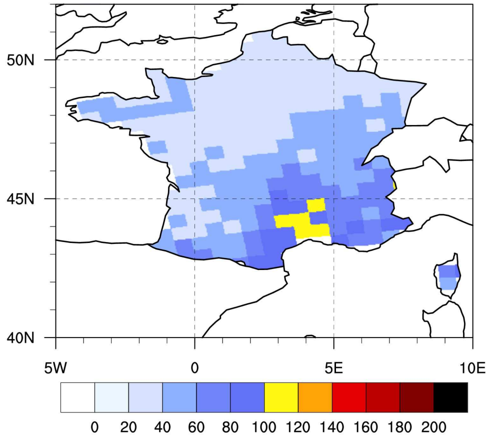
RCM12km - ERAInt



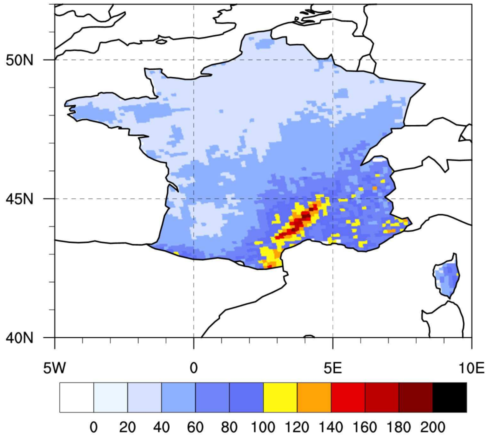
CNRM-CM5 - HIST-150km



RCM50km - HIST



RCM12km - HIST



<u>Courtesy:</u> FP7-CLIM-RUN, C. Dubois, CNRM

Thank for your attention