Medicanes: the UIB toolbox. Physical processes, predictability and climatological studies

Universitat de les Illes Balears

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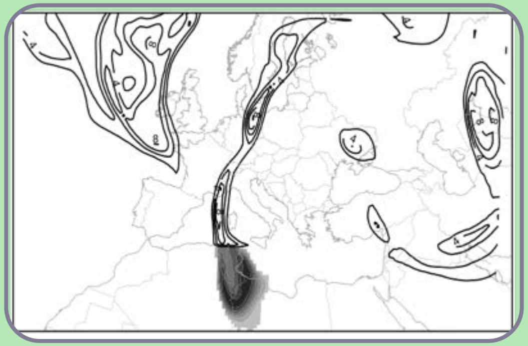
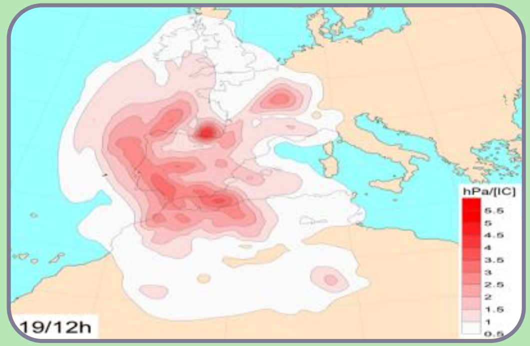
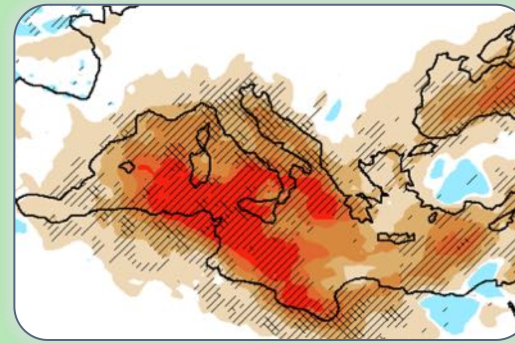
Techniques in the UIB toolbox







Physical processes

Factors Separation

PV inversion

Accumulated & Instantaneous attributions

Predictability aspects

Assimilation challenges

Covariances exploration

Climatological analysis

Statistical downscaling

Synthetic environments

UIB first paper (Homar et al. 2003)

Q. J. R. Meteorol. Soc. (2003), **129**, pp. 1469–1490 doi: 10.1256/qj.01.91

Numerical diagnosis of a small, quasi-tropical cyclone over the western Mediterranean: Dynamical vs. boundary factors

By V. HOMAR[1]*, R. ROMERO[1], D. J. STENSRUD[2], C. RAMIS[1] and S. ALONSO[1,3]

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(Received 29 May 2001; revised 19 April 2002)

SUMMARY

A small, quasi-tropical cyclone occurred on 12 September 1996 over the western Mediterranean. Intense convective activity over the region during this period also produced a tornado outbreak in the Balearic Islands and torrential precipitation over eastern mainland Spain.

UIB first paper (Homar et al. 2003)

- *Extreme windstorms physically analogous to tropical cyclones (warm-core, surface flux-driven)*

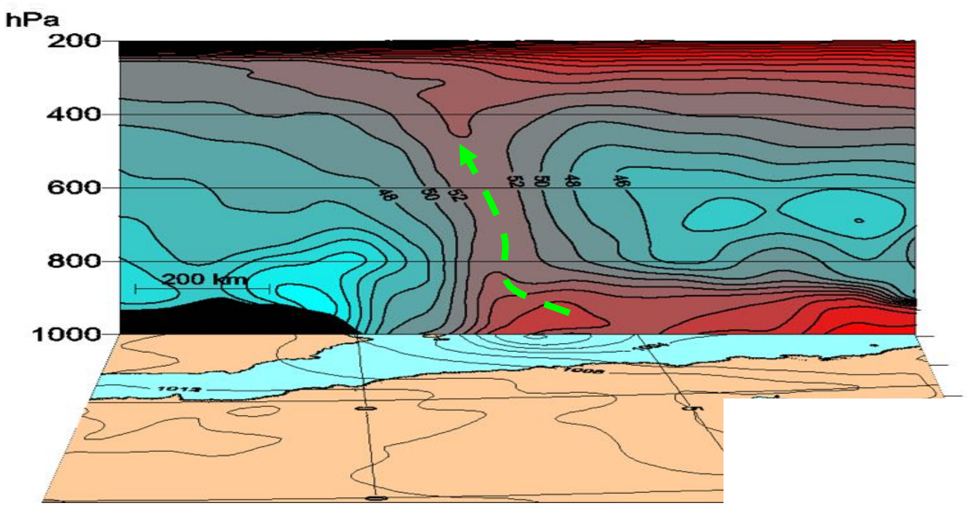


Figure 8. Vertical section across the surface cyclone centre (thick line in the ins
potential temperature (°C) at 1200 UTC 12 September 19

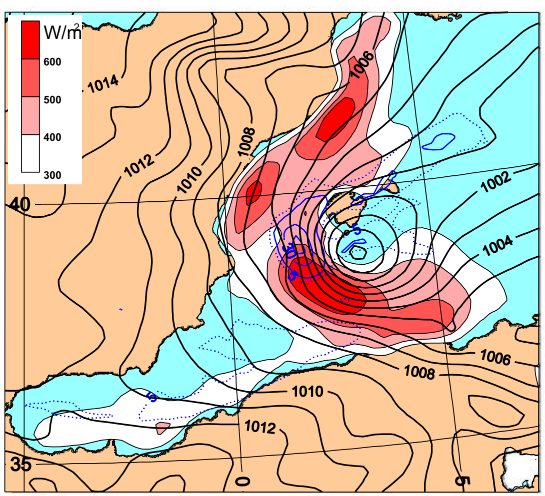
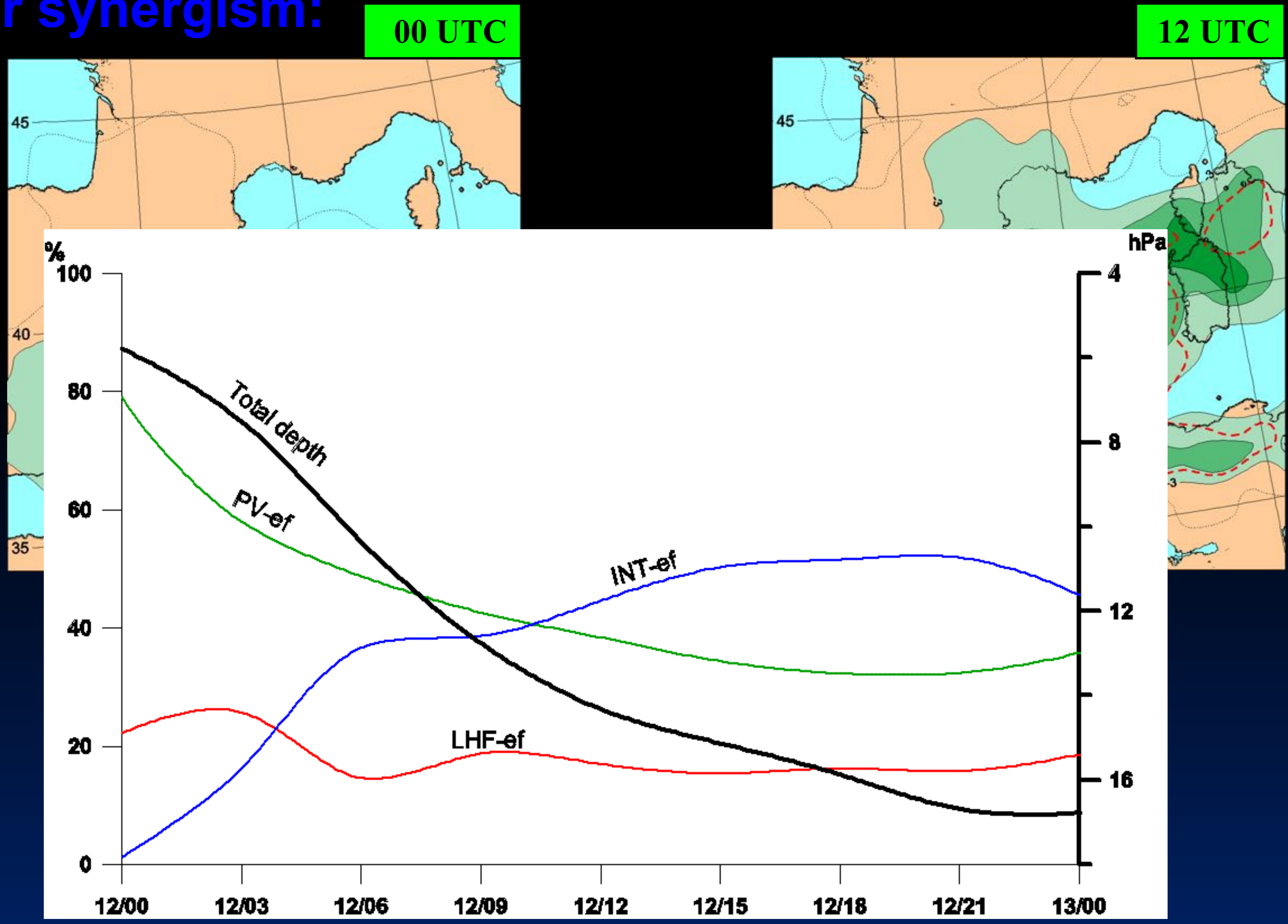


Figure 6. Sea-level pressure (hPa, full line), 3 h accumulated precipitation (mm, interval of 20 mm, dashed line) and latent-heat flux (W m^{-2}, shaded) as simulated by the model at: (a) 0300 UTC, (b) 0600 UTC and (c) 1200 UTC 12 September 1996. The dotted line depicts the 5 mm isohyet.

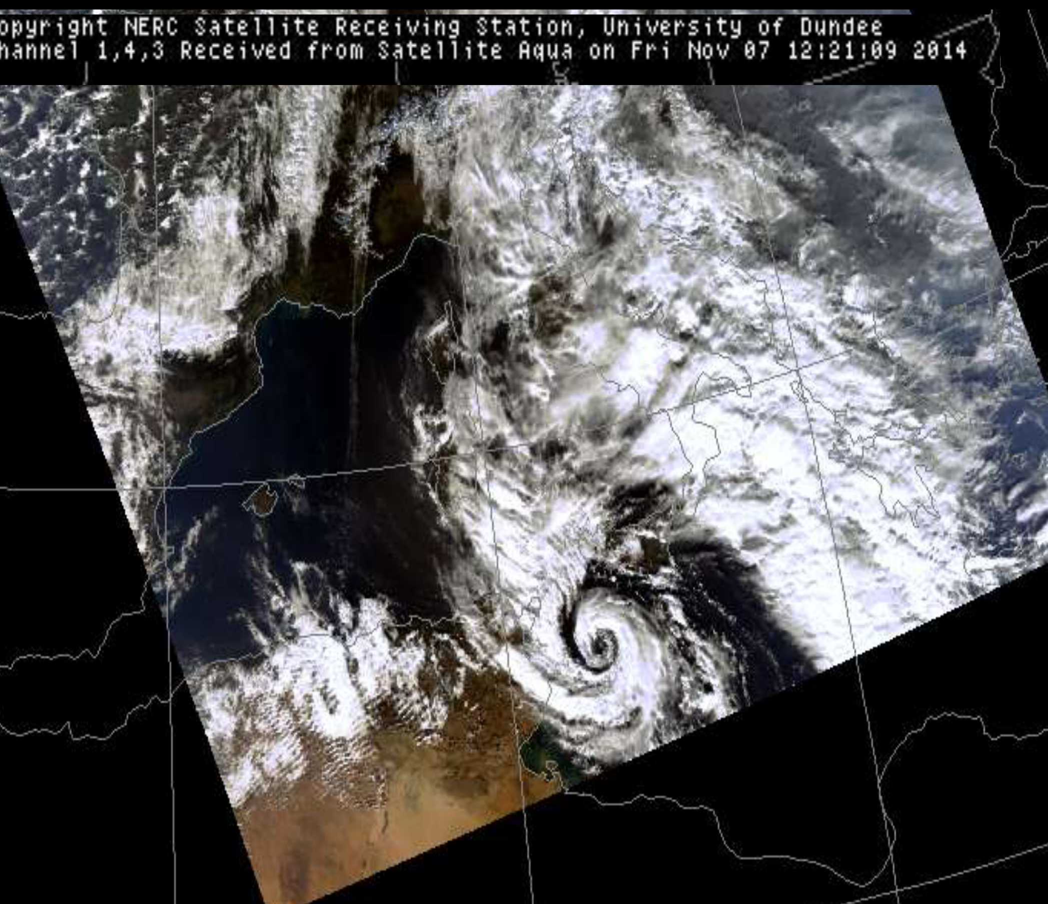
UIB first paper (Homar et al. 2003)

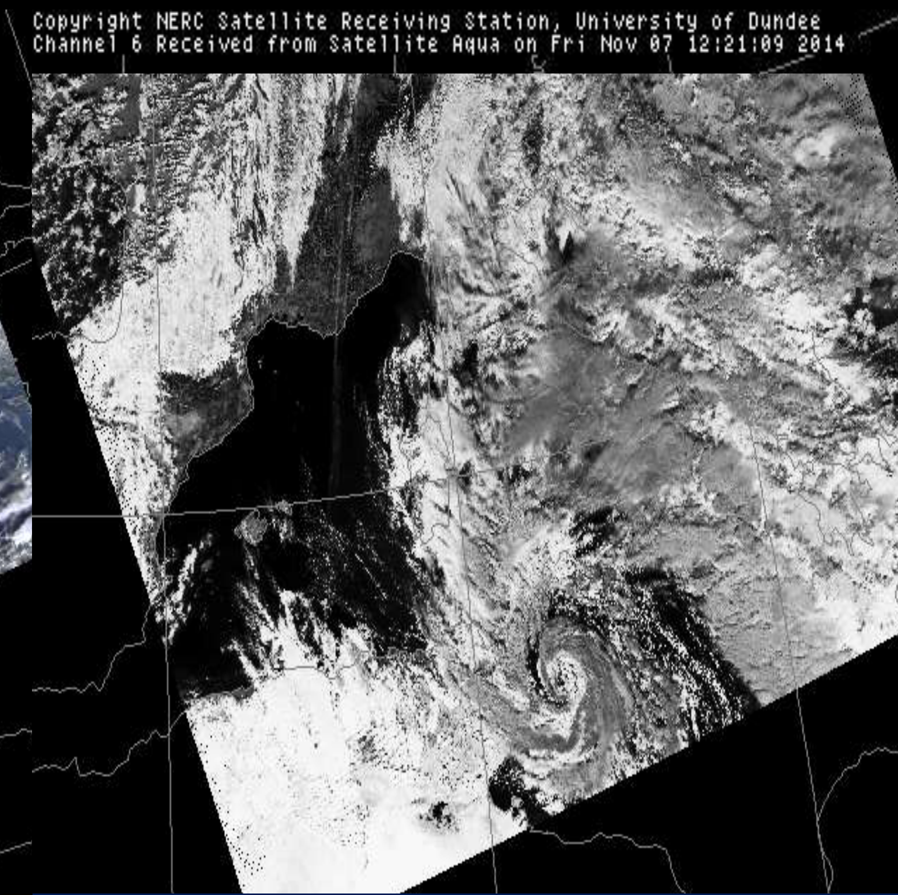
- MM5 experiments, factors separation: LHF, PV perturbation and their synergism:



Last UIB paper (Carrió et al. 2017, cond. acc.)

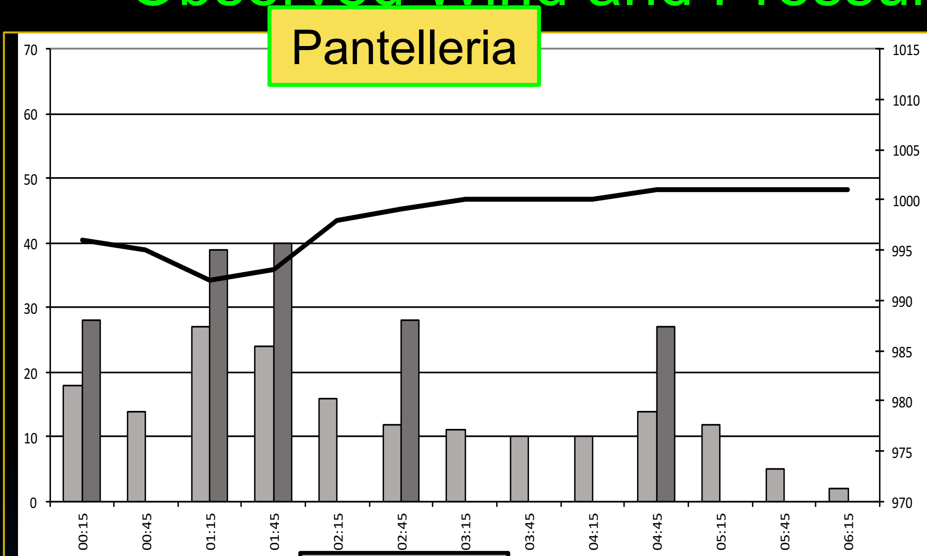
- Satellite Aqua @ 7 Nov 2014 12:21 UTC:

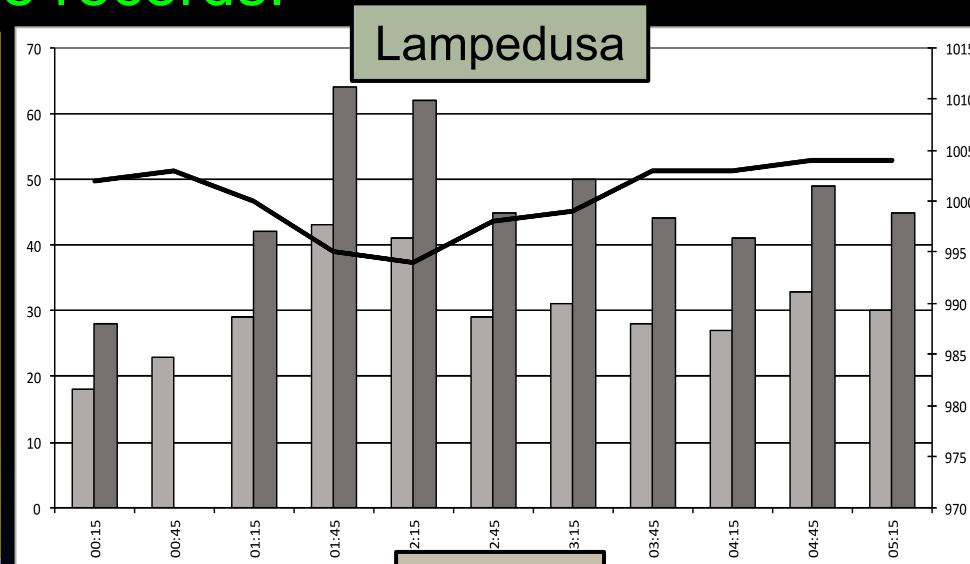


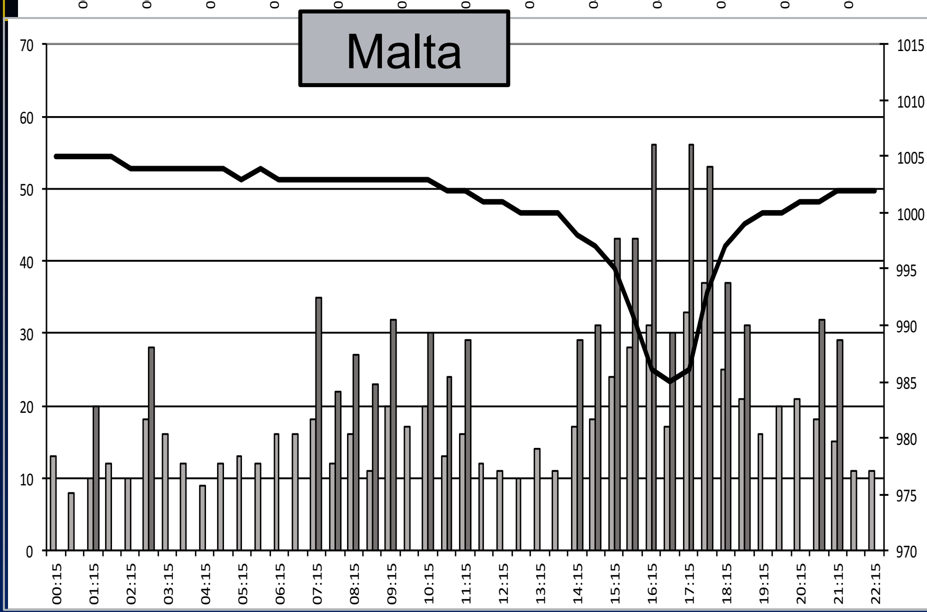


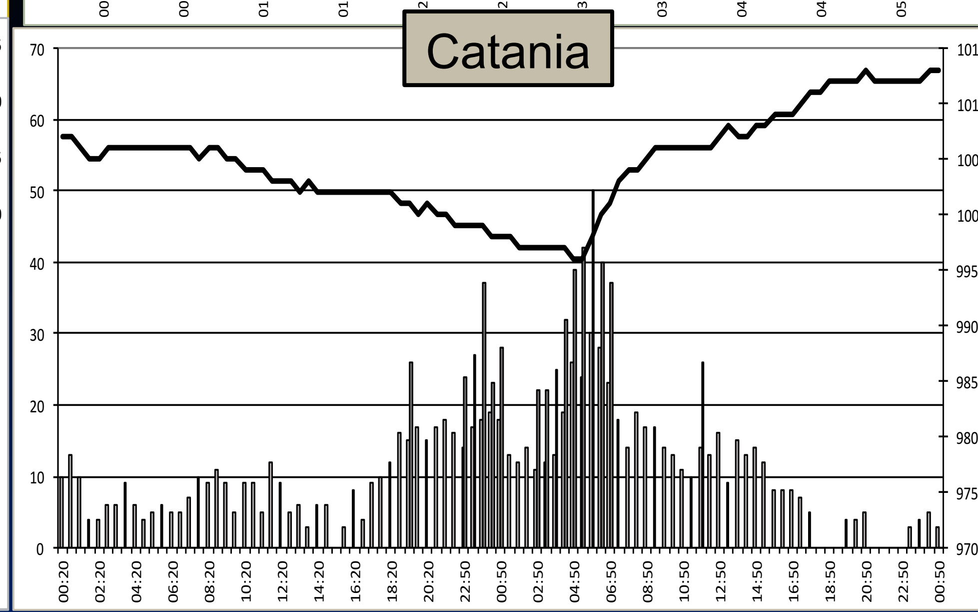
Last UIB paper (Carrió et al. 2017, cond. acc.)

- Observed Wind and Pressure records:



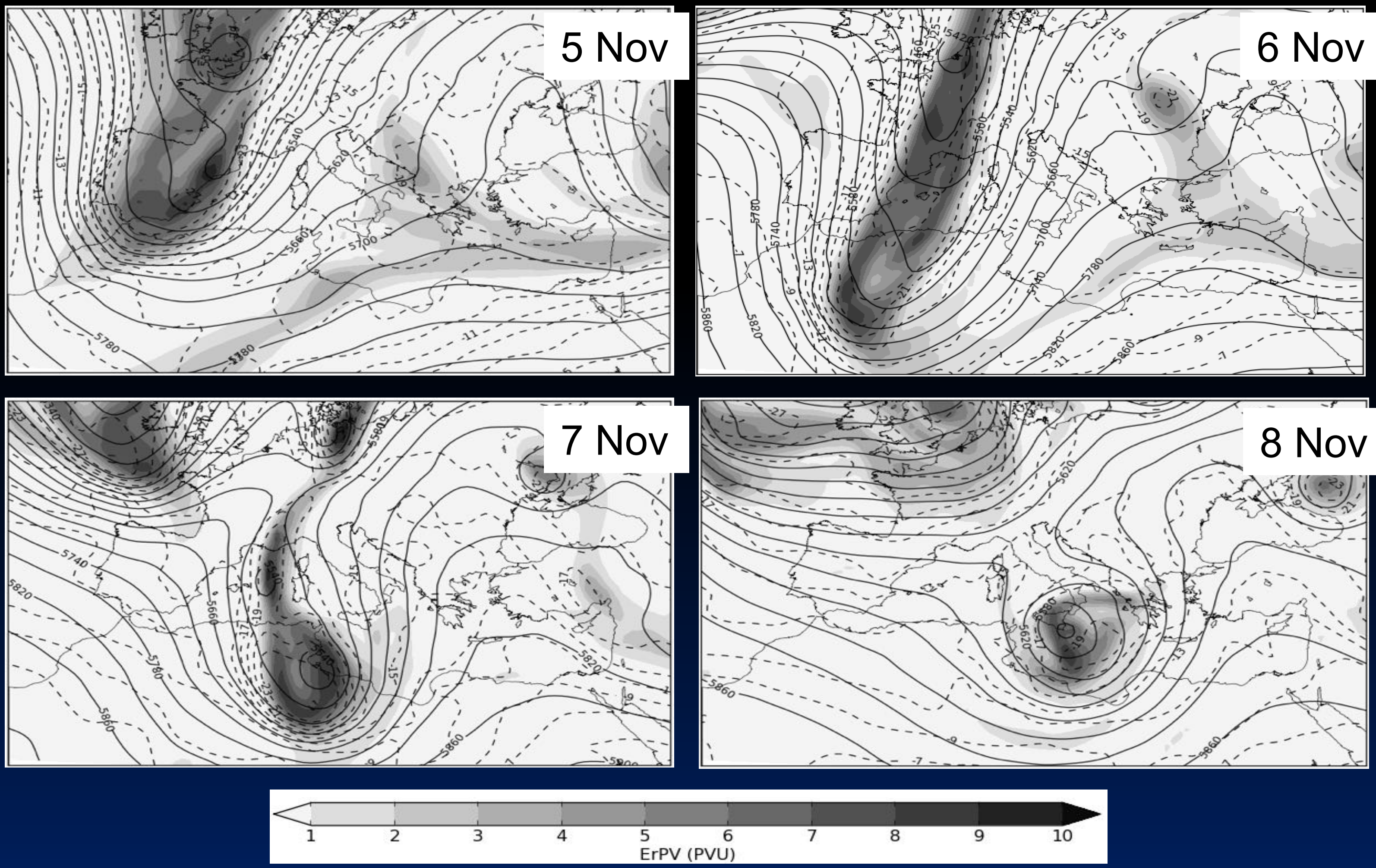






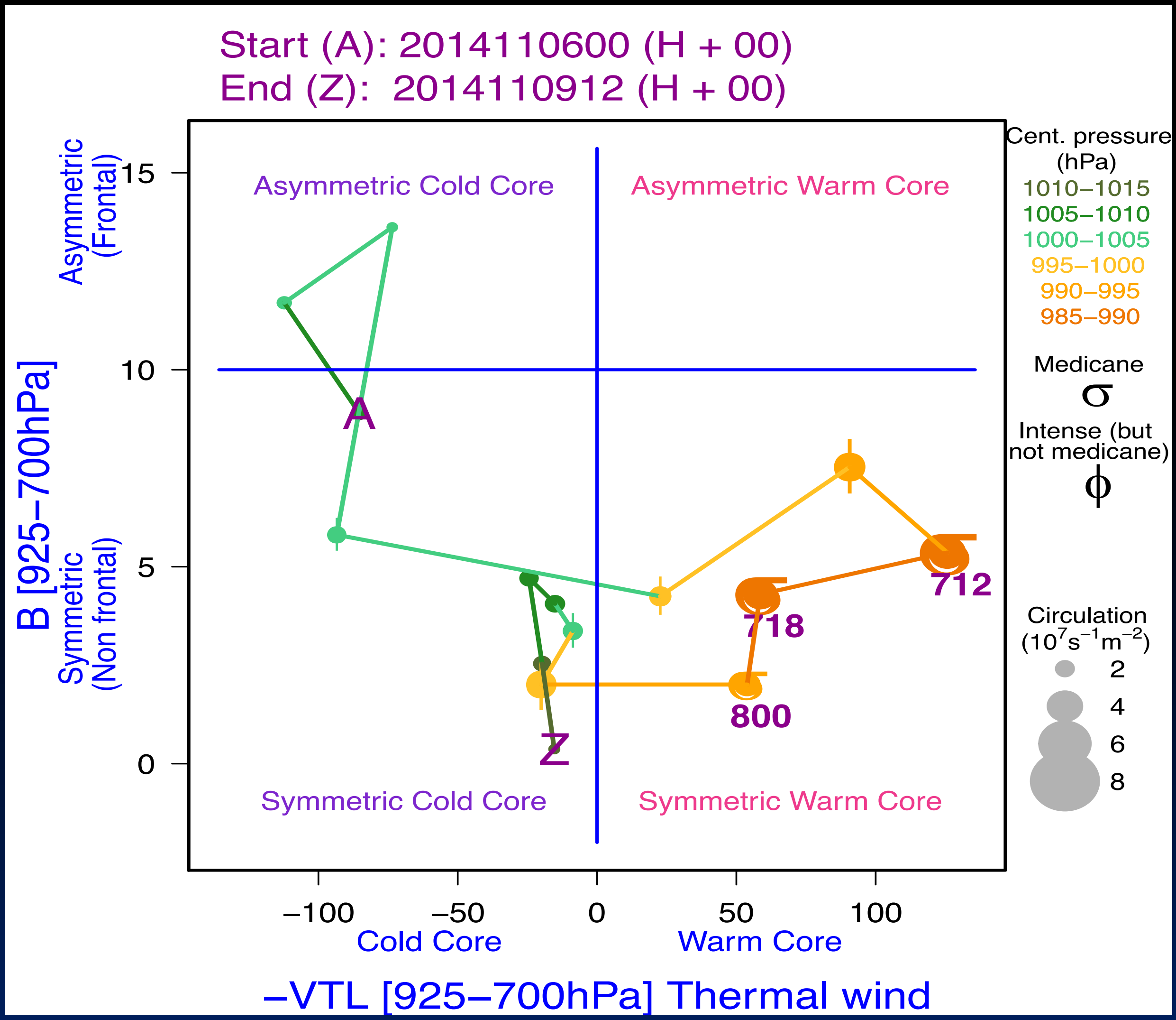
Last UIB paper (Carrió et al. 2017, cond. acc.)

Potential Vorticity (300 hPa; shaded), **geopotential** (solid lines) and **temperature** (dashed lines) at **500 hPa**



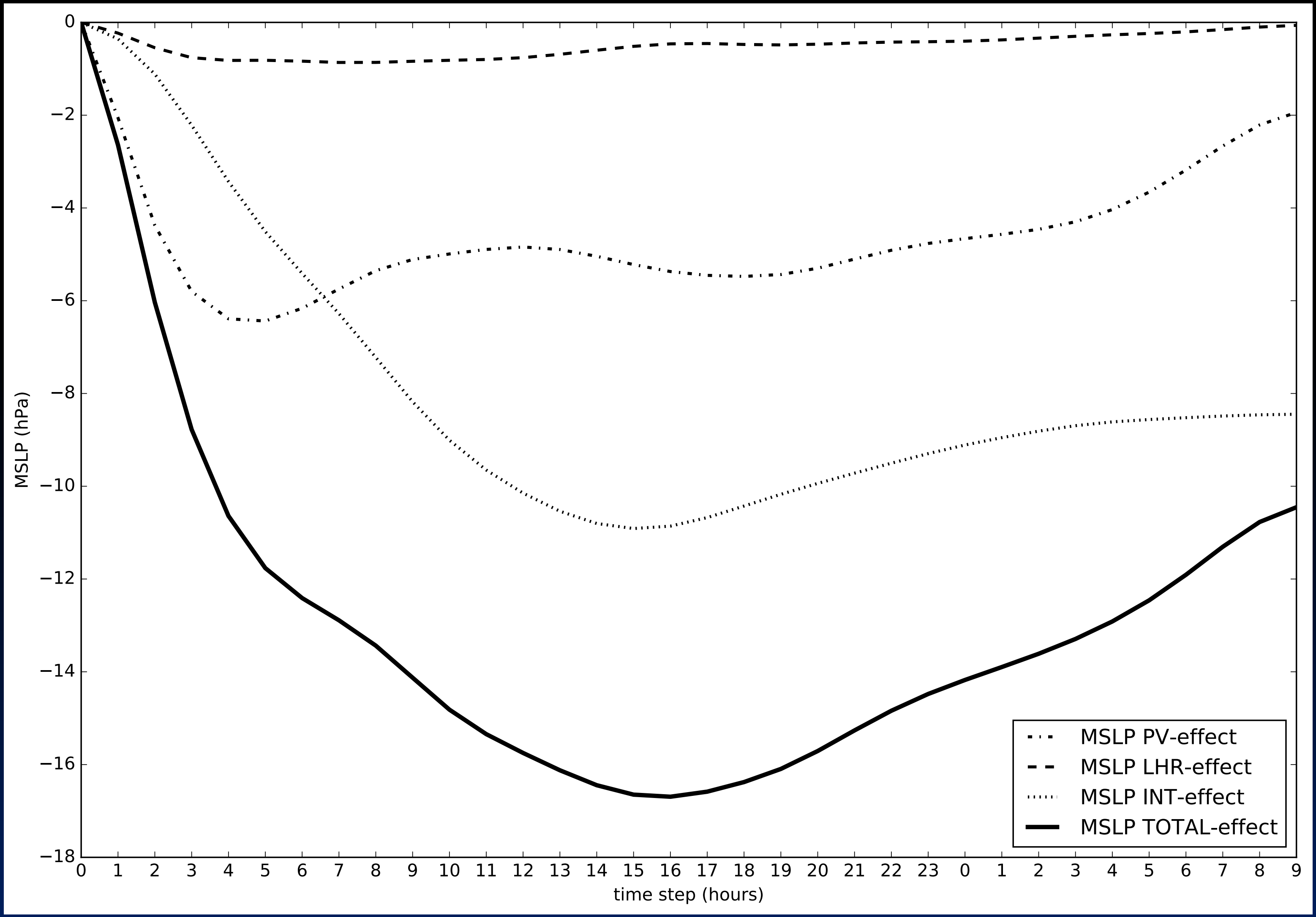
Last UIB paper (Carrió et al. 2017, cond. acc.)

- Hart diagram over ECMWF operational analysis:



Last UIB paper (Carrió et al. 2017, cond. acc.)

- WRF 2.5 km sensitivity experiments:



PV INV + FACT. SEP. diagnosis

PV-BASED PROGNOSTIC SYSTEM
(Davis and Emanuel; *MWR* 1991)

0) A balanced flow has been first found using the PV inversion technique: $q \longrightarrow (\phi, \psi)$

1) Tendency of the Charney (1955) nonlinear balance equation:

$$\nabla^2 \phi^t = \boldsymbol{\nabla} \cdot f \boldsymbol{\nabla} \psi^t + 2m^2 \left[\frac{\partial^2 \psi^t}{\partial x^2} \frac{\partial^2 \psi}{\partial y^2} + \frac{\partial^2 \psi}{\partial x^2} \frac{\partial^2 \psi^t}{\partial y^2} - 2 \frac{\partial^2 \psi}{\partial x \partial y} \frac{\partial^2 \psi^t}{\partial x \partial y} \right]$$

2) Tendency of the approximate form of Ertel's PV:

$$\begin{aligned} q^t \quad = \quad & \frac{g\kappa\pi}{p} \left[(f + m^2 \nabla^2 \psi) \frac{\partial^2 \phi^t}{\partial \pi^2} + m^2 \frac{\partial^2 \phi}{\partial \pi^2} \nabla^2 \psi^t \right. \\ & \left. - m^2 \left(\frac{\partial^2 \psi^t}{\partial x \partial \pi} \frac{\partial^2 \phi}{\partial x \partial \pi} + \frac{\partial^2 \psi}{\partial x \partial \pi} \frac{\partial^2 \phi^t}{\partial x \partial \pi} + \frac{\partial^2 \psi^t}{\partial y \partial \pi} \frac{\partial^2 \phi}{\partial y \partial \pi} + \frac{\partial^2 \psi}{\partial y \partial \pi} \frac{\partial^2 \phi^t}{\partial y \partial \pi} \right) \right] \end{aligned}$$

$\longrightarrow (\phi^t, \psi^t)$

3) Ertel's PV tendency equation (frictionless but with diabatic term included):

$$q^t = -m(\boldsymbol{V}_\psi + \boldsymbol{V}_\chi) \cdot \boldsymbol{\nabla} q - \omega^* \frac{\partial q}{\partial \pi} + \frac{m}{\rho} \boldsymbol{\eta} \cdot \boldsymbol{\nabla} LH$$

Horizontal wind — Vertical velocity $\longrightarrow q^t$

$$\boldsymbol{V}_\psi = m\boldsymbol{k} \times \boldsymbol{\nabla} \psi$$
$$\boldsymbol{V}_\chi = m \boldsymbol{\nabla} \chi$$

$$\omega^* = \frac{d\pi}{dt} = \frac{\kappa\pi}{p} \omega$$

PV INV + FACT. SEP. diagnosis

PV-BASED PROGNOSTIC SYSTEM

4) Omega equation:

$$
\begin{aligned}
& f\eta\frac{\partial}{\partial\pi}\left[\pi^{1-1/\kappa}\frac{\partial}{\partial\pi}(\pi^{1/\kappa-1}\omega^*)\right] + m^2\nabla^2\left(\frac{\partial^2\phi}{\partial\pi^2}\omega^*\right) \\
& -m^2 f\frac{\partial}{\partial\pi}\left(\frac{\partial\omega^*}{\partial x}\frac{\partial\psi}{\partial x\partial\pi} + \frac{\partial\omega^*}{\partial y}\frac{\partial\psi}{\partial y\partial\pi}\right) \\
& +\left(f\frac{\partial\eta}{\partial\pi}\frac{1/\kappa-1}{\pi} - f\frac{\partial^2\eta}{\partial\pi^2}\right)\omega^* = m^3\nabla^2\left[(\boldsymbol{V}_\psi + \boldsymbol{V}_\chi)\cdot\boldsymbol{\nabla}\theta\right] \\
& +mf\frac{\partial}{\partial\pi}\left[(\boldsymbol{V}_\psi + \boldsymbol{V}_\chi)\cdot\boldsymbol{\nabla}\eta\right] - m^2\boldsymbol{\nabla}f\cdot\boldsymbol{\nabla}\left(\frac{\partial\psi^t}{\partial\pi}\right) \\
& -2m^4\frac{\partial}{\partial\pi}\left[\frac{\partial^2\psi^t}{\partial x^2}\frac{\partial^2\psi}{\partial y^2} + \frac{\partial^2\psi}{\partial x^2}\frac{\partial^2\psi^t}{\partial y^2} - 2\frac{\partial^2\psi}{\partial x\partial y}\frac{\partial^2\psi^t}{\partial x\partial y}\right] \\
& -m^2\nabla^2 LH
\end{aligned}
$$

$\longrightarrow \omega^*$

5) Continuity equation:

$$m^2\nabla^2\chi + \pi^{1-1/\kappa}\frac{\partial}{\partial\pi}(\pi^{1/\kappa-1}\omega^*) = 0$$

$\longrightarrow \chi$

$$\theta^t = -m(\boldsymbol{V}_\psi + \boldsymbol{V}_\chi)\cdot\boldsymbol{\nabla}\theta - \omega^*\frac{\partial\theta}{\partial\pi} + LH$$

Lateral B.C (Homogeneous)

$$\phi^t = \psi^t = q^t = \omega^* = \chi = 0$$

Top-Bottom B.C (Neumann)

$$\partial\phi^t/\partial\pi = f\partial\psi^t/\partial\pi = -\theta^t$$

$\omega_T^* = 0$ $\qquad$ $\omega_B^* = \text{Topographic}$

PV INV + FACT. SEP. diagnosis

PV-BASED PROGNOSTIC SYSTEM

4) Omega equation:

$$\begin{aligned}
&f\eta\frac{\partial}{\partial\pi}\left[\pi^{1-1/\kappa}\frac{\partial}{\partial\pi}(\pi^{1/\kappa-1}\omega^*)\right]+m^2\nabla^2\left(\frac{\partial^2\phi}{\partial\pi^2}\omega^*\right)\\
&-m^2 f\frac{\partial}{\partial\pi}\left(\frac{\partial\omega^*}{\partial x}\frac{\partial\psi}{\partial x\partial\pi}+\frac{\partial\omega^*}{\partial y}\frac{\partial\psi}{\partial y\partial\pi}\right)\\
&+\left(f\frac{\partial\eta}{\partial\pi}\frac{1/\kappa-1}{\pi}-f\frac{\partial^2\eta}{\partial\pi^2}\right)\omega^*=m^3\nabla^2\left[(\boldsymbol{V}_\psi+\boldsymbol{V}_\chi)\cdot\boldsymbol{\nabla}\theta\right]\\
&+mf\frac{\partial}{\partial\pi}\left[(\boldsymbol{V}_\psi+\boldsymbol{V}_\chi)\cdot\boldsymbol{\nabla}\eta\right]-m^2\boldsymbol{\nabla}f\cdot\boldsymbol{\nabla}\left(\frac{\partial\psi^t}{\partial\pi}\right)\\
&-2m^4\frac{\partial}{\partial\pi}\left[\frac{\partial^2\psi^t}{\partial x^2}\frac{\partial^2\psi}{\partial y^2}+\frac{\partial^2\psi}{\partial x^2}\frac{\partial^2\psi^t}{\partial y^2}-2\frac{\partial^2\psi}{\partial x\partial y}\frac{\partial^2\psi^t}{\partial x\partial y}\right]\\
&-m^2\nabla^2 LH
\end{aligned}$$

$\longrightarrow \omega^*$

5) Continuity equation:

$$m^2\nabla^2\chi+\pi^{1-1/\kappa}\frac{\partial}{\partial\pi}(\pi^{1/\kappa-1}\omega^*)=0$$

$\longrightarrow \chi$

$$\theta^t=-m(\boldsymbol{V}_\psi+\boldsymbol{V}_\chi)\cdot\boldsymbol{\nabla}\theta-\omega^*\frac{\partial\theta}{\partial\pi}+LH$$

Lateral B.C (Homogeneous)

$$\phi^t=\psi^t=q^t=\omega^*=\chi=0$$

Top-Bottom B.C (Neumann)

$$\partial\phi^t/\partial\pi=f\partial\psi^t/\partial\pi=-\theta^t$$

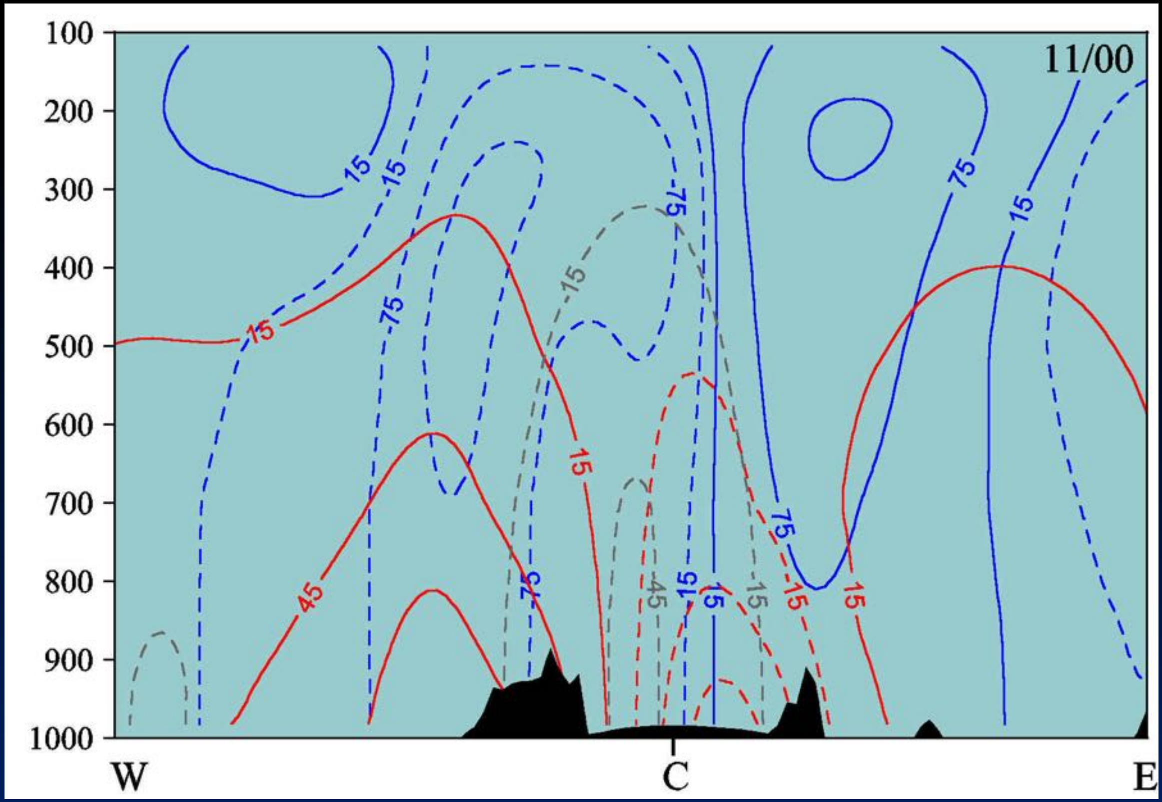
$\omega^*_T=0$ $\omega^*_B=$ Topographic

PV INV + FACT. SEP. diagnosis

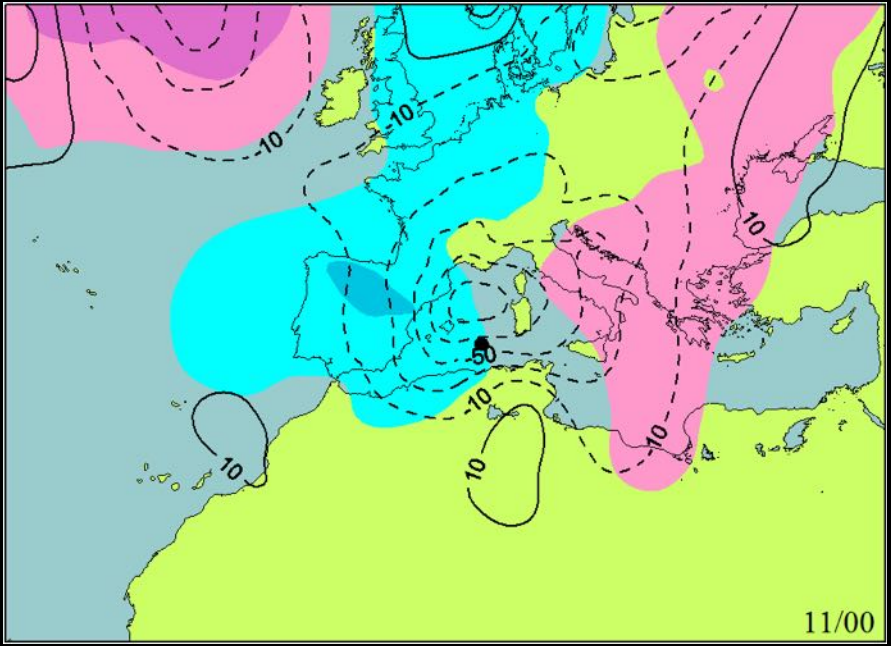
PV-based DIAGNOSIS

ULev	PV perturbation above 700 hPa
LLev	Surface thermal anomaly and PV perturbation below 700 hPa
DIAB	Positive PV perturbation below 500 hPa in areas with RH > 70%

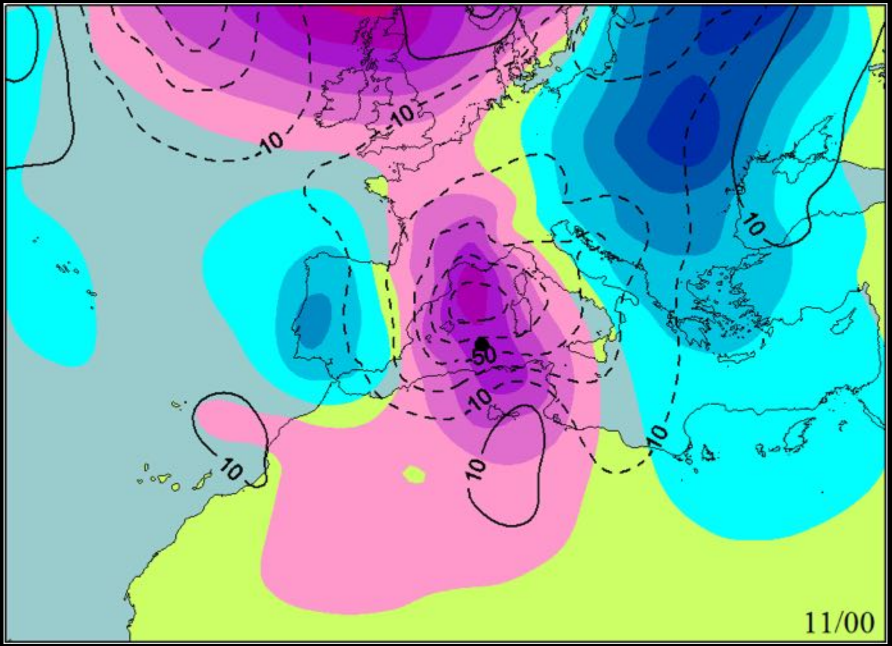
Geopotential height perturbation

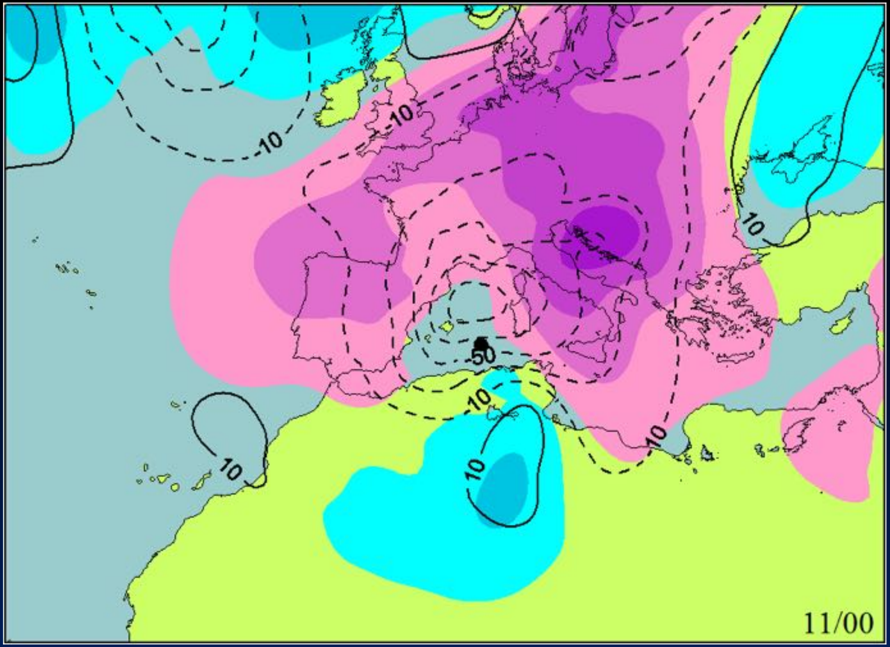


MEAN

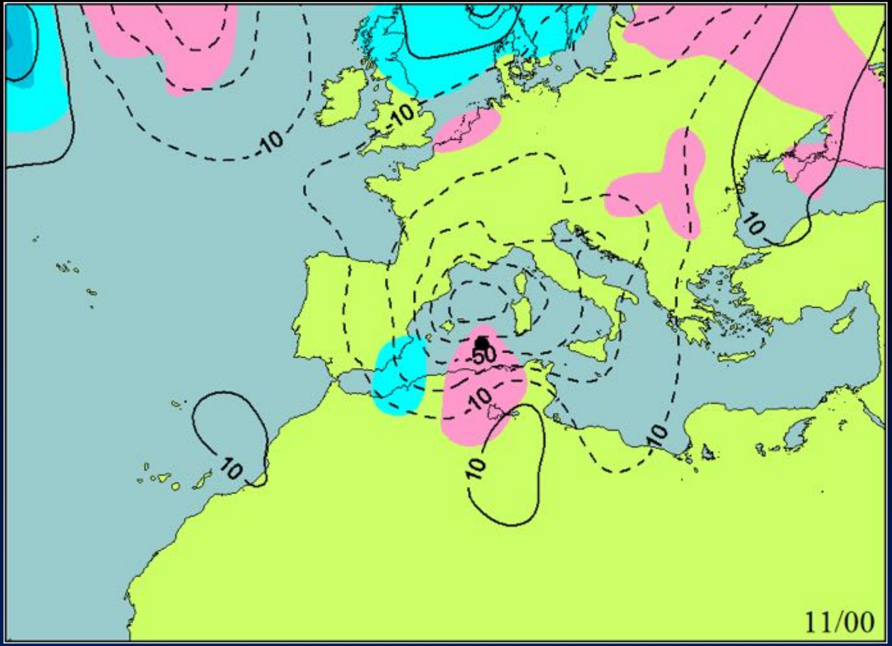


ULev





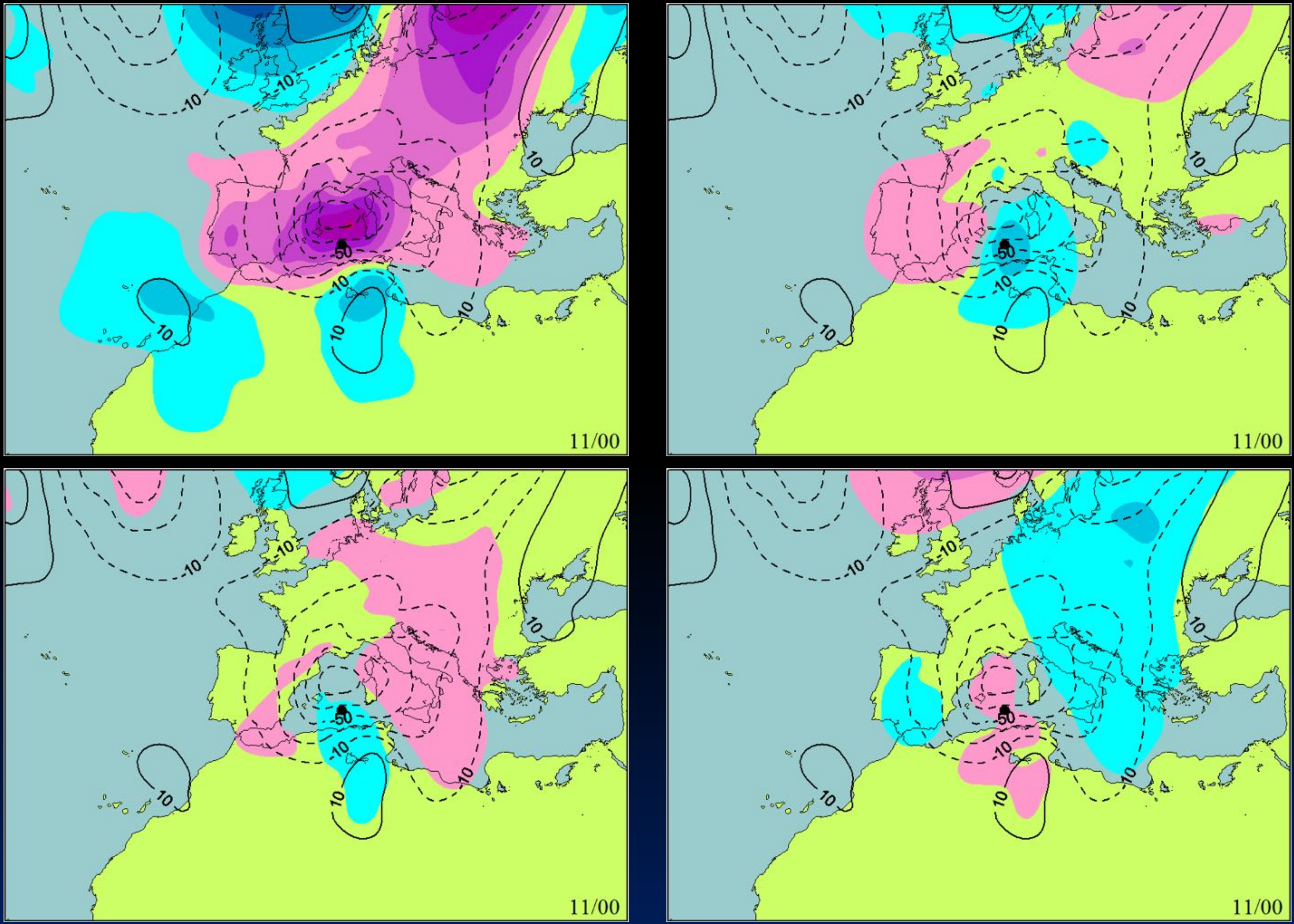
LLev



DIAB

ULev + LLev

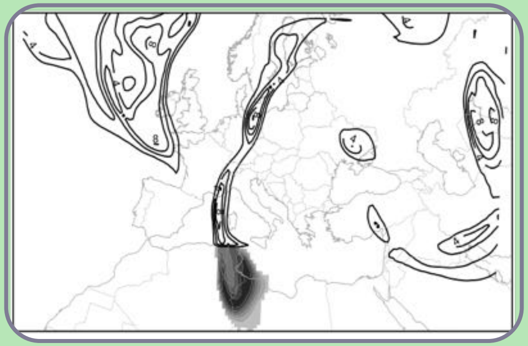
ULev + DIAB

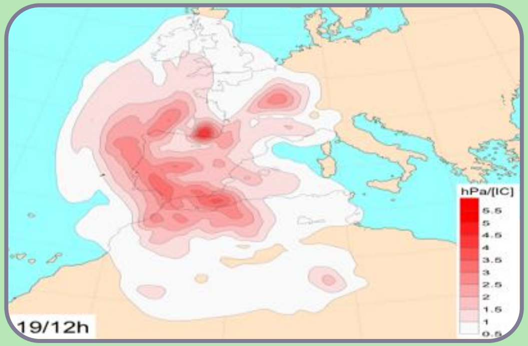


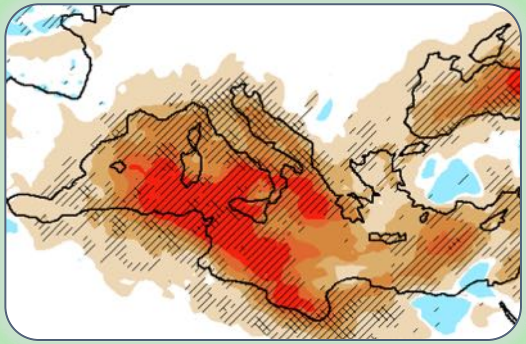
LLev + DIAB

ULev + LLev + DIAB

Techniques in the UIB toolbox







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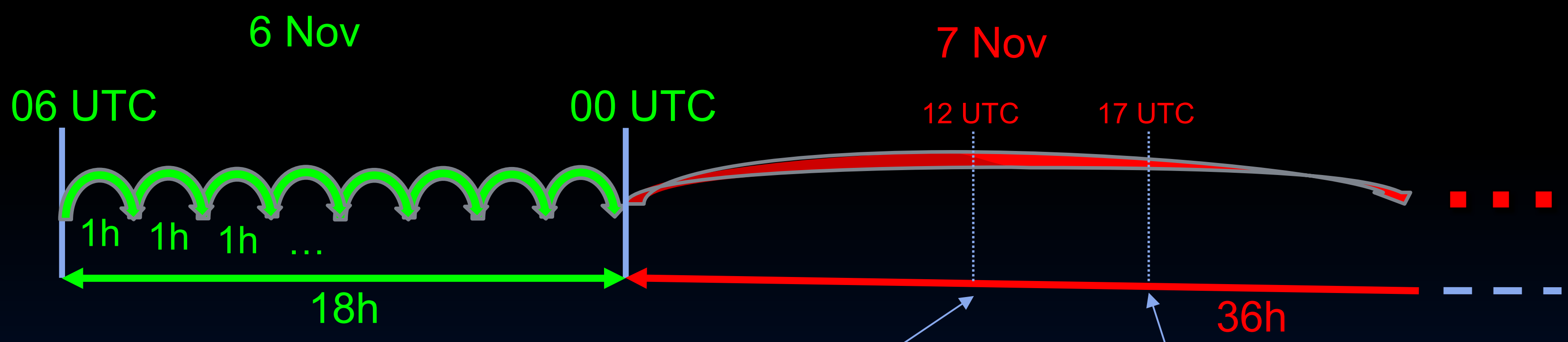
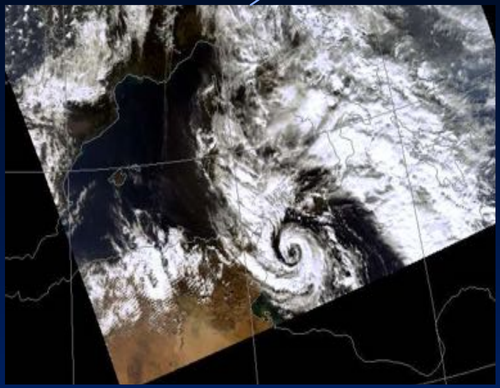
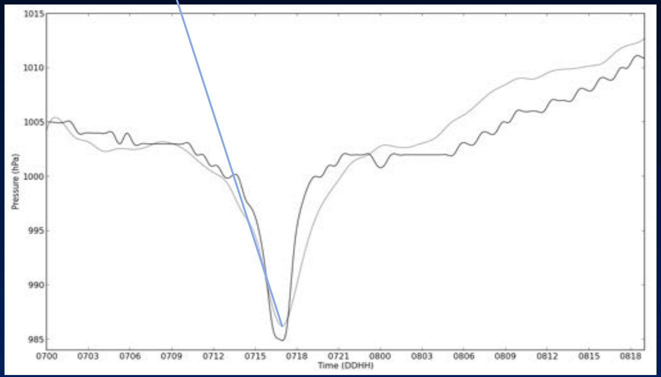
Generation of a MEPS: ENKF SETUP

MEDICANE 7th November 2014

- Set up a 1-h assimilation cycle over a 18-h window followed by a 36h forecast, 2.5km (15km larger domain)







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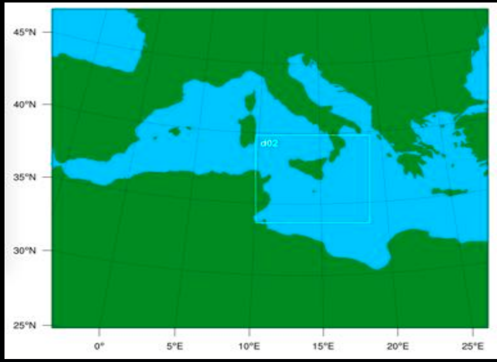
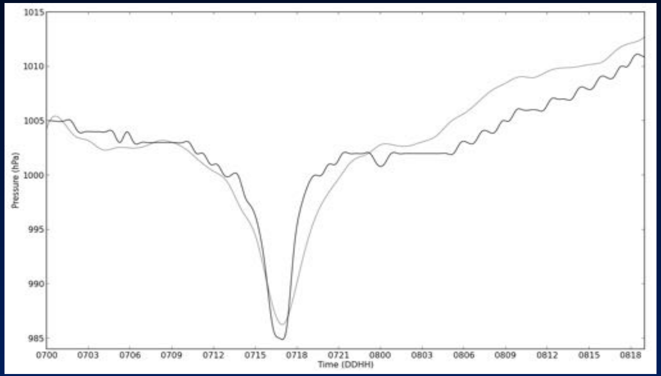
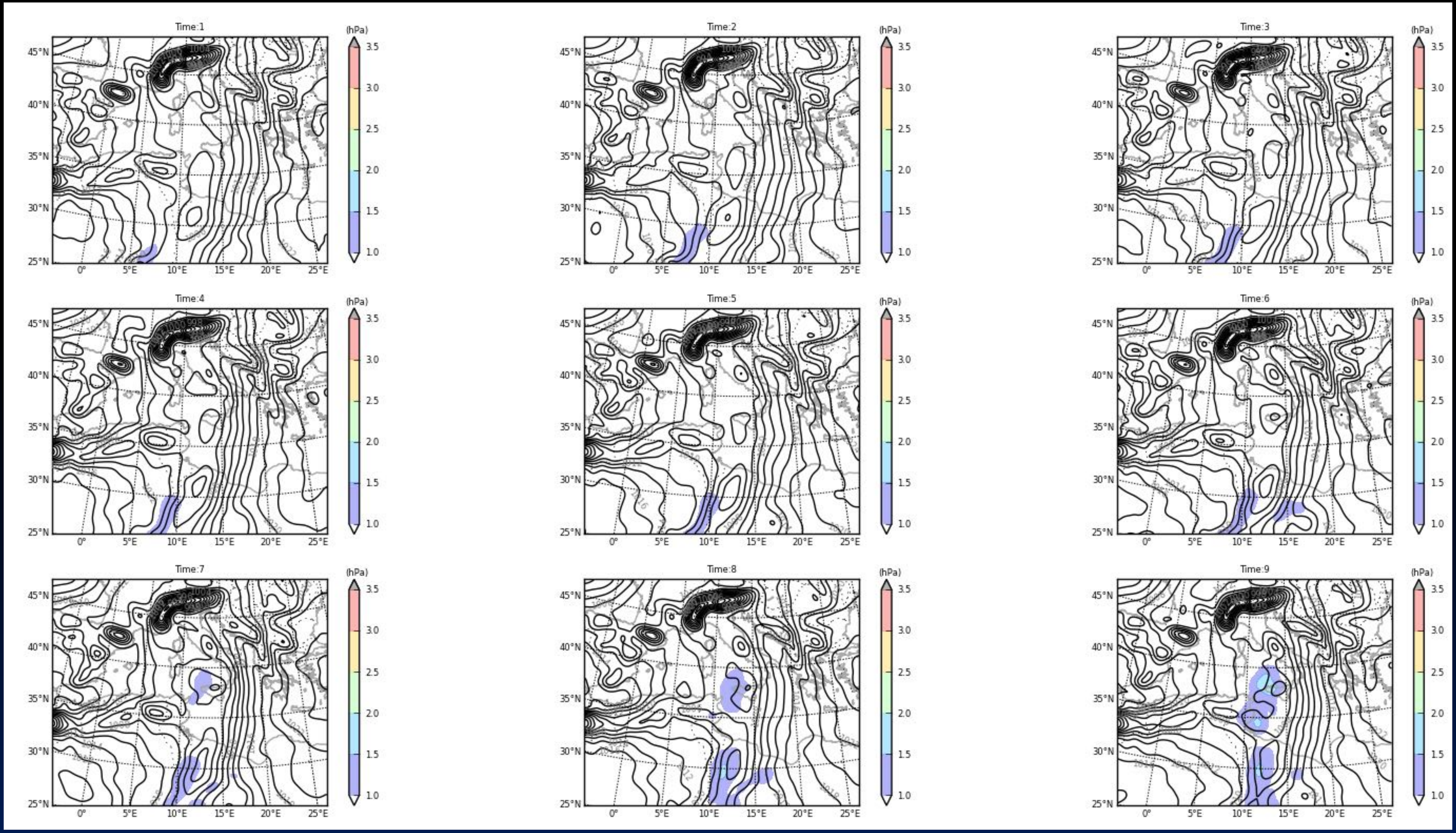


- Gaussian localization (300km H, 4km V)
- 24 members, multiphysics [2x(2xMPHY, 3xPBL, 2xRAD)]:
  - Microphysics: Thompson (8); NSSL (17)
  - PBL & SFC: Yonsei Univ. (1); Mellor-Yamada-Janjic (2); Mellor-Yamada Nakanishi Ninno (5)
  - Radiation: Dudhia (1) and RRTMG (2)
- Prior: ECMWF EPS members with largest differences over domain
- Data: “Traditional” metar, radiosonde, acars and marine



Generation of a MEPS: ENKF Safety check

- Spread growth and consolidation after 12 h of EDA:



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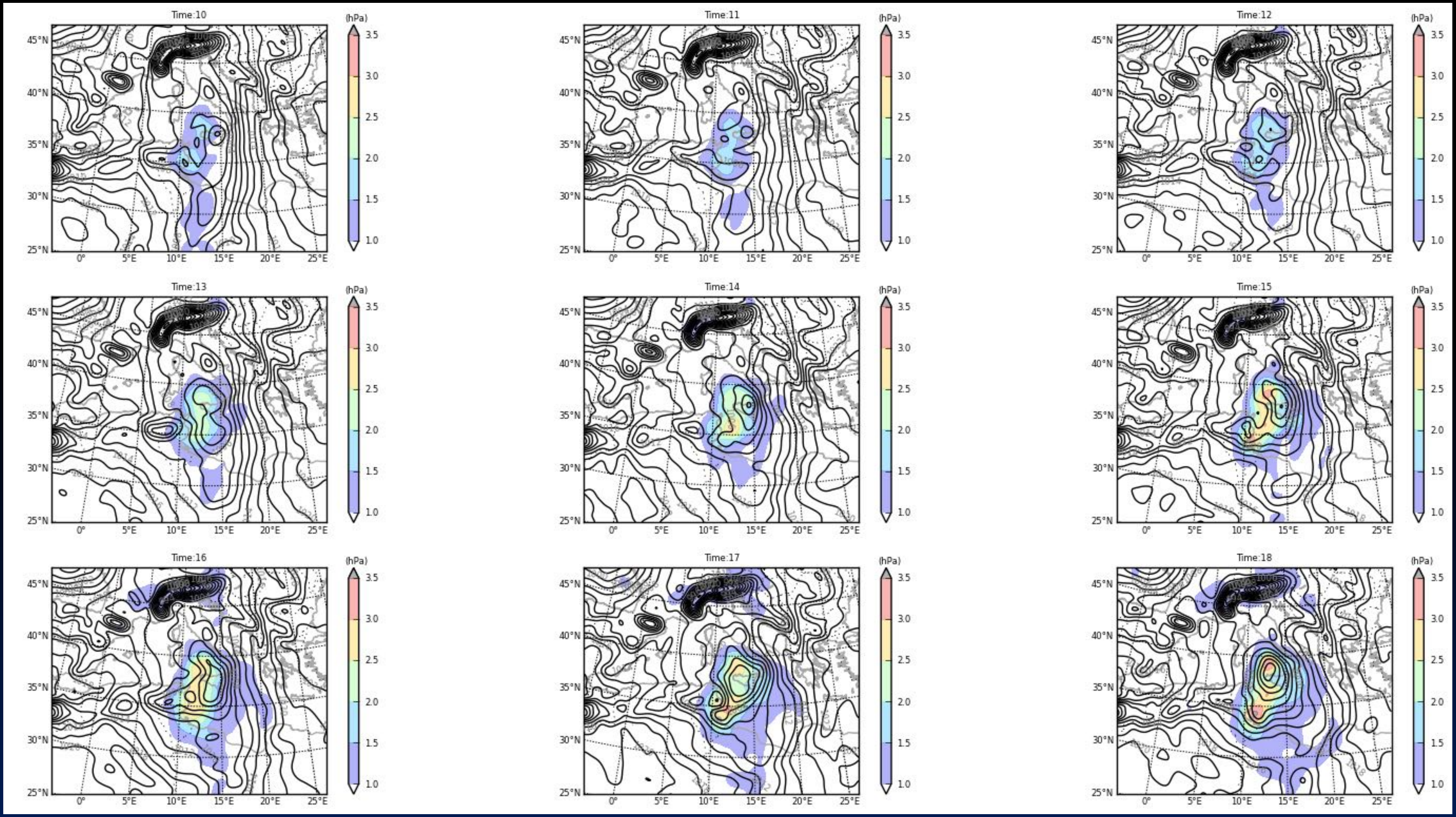
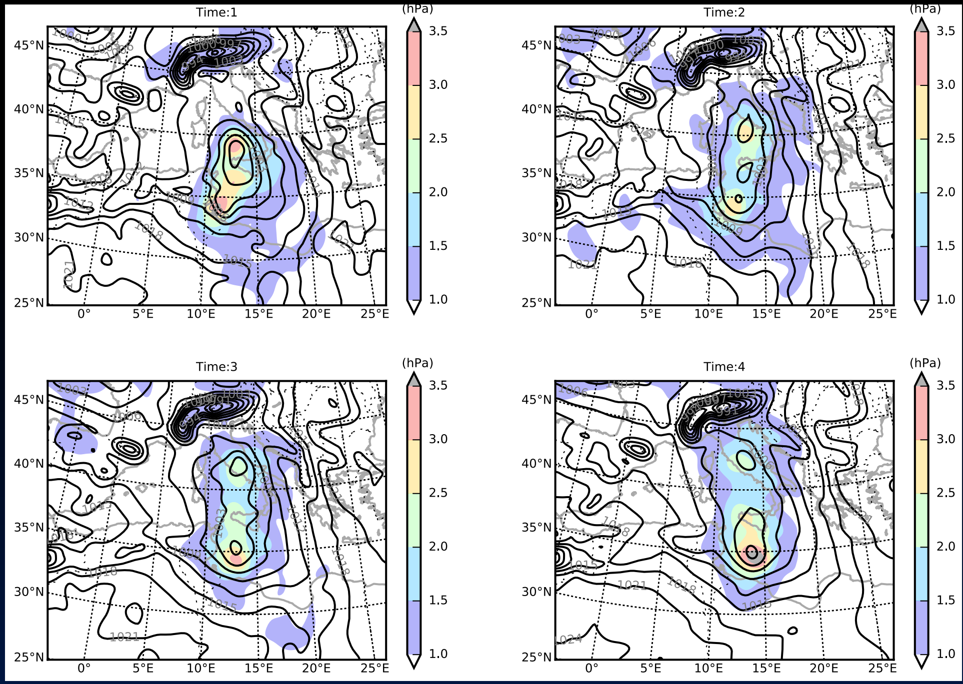
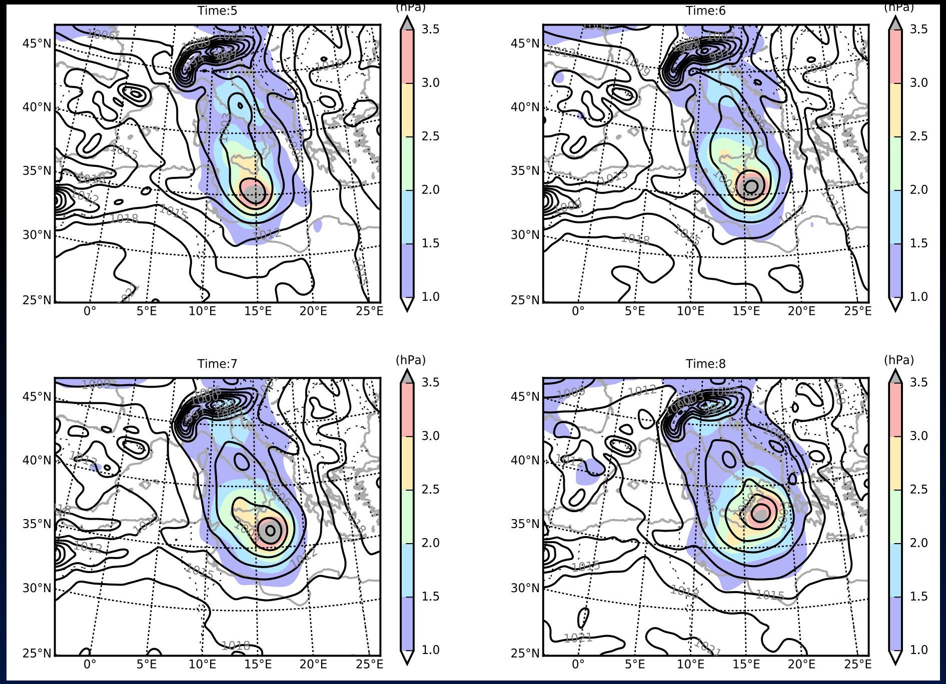


EnKF forecasts: mean fields and spread

- Mean and std MSLP
- Domain 1 (15km)

7 Nov 2014



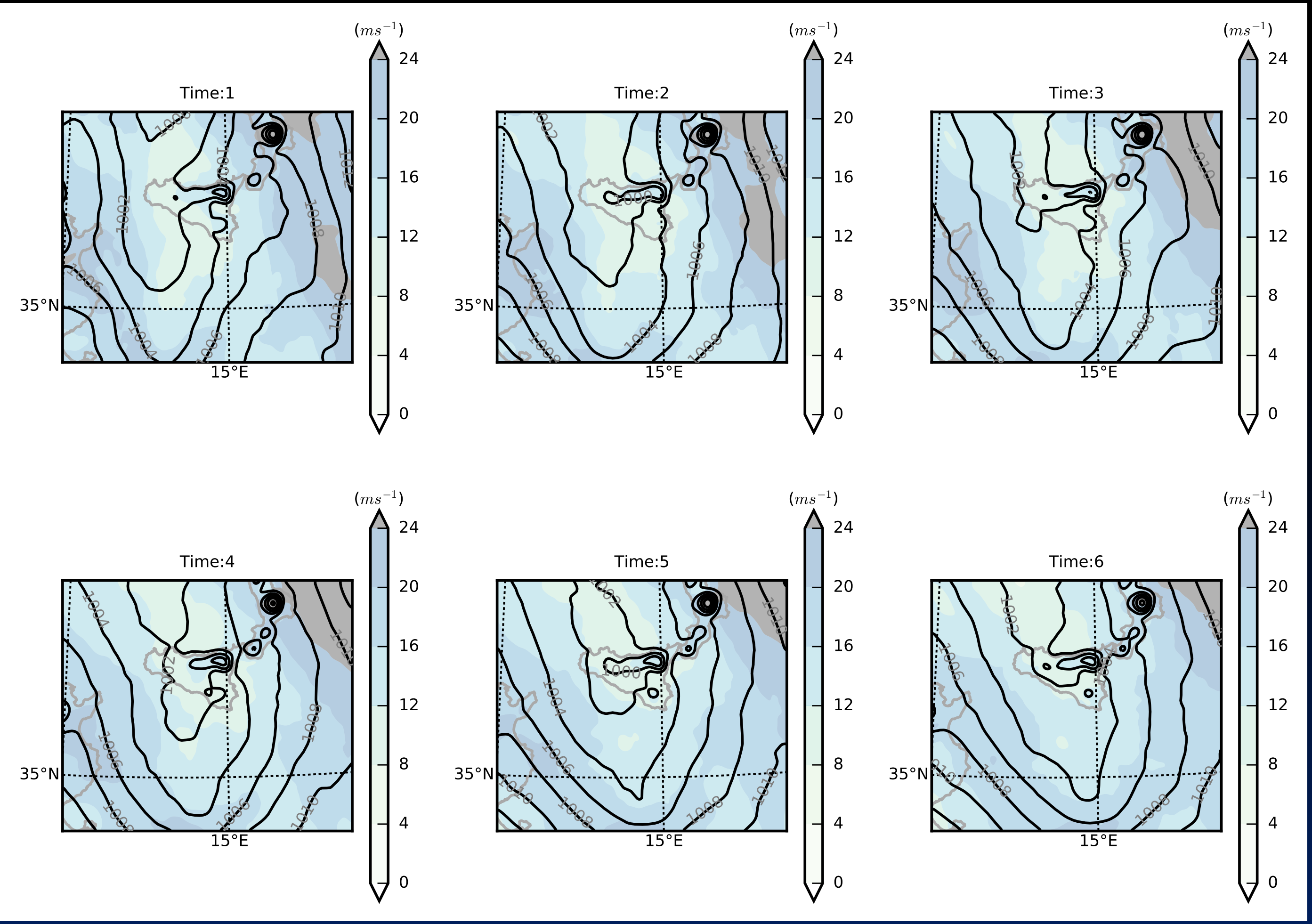


00, 03, 06 09 UTC

12, 15, 18 21 UTC

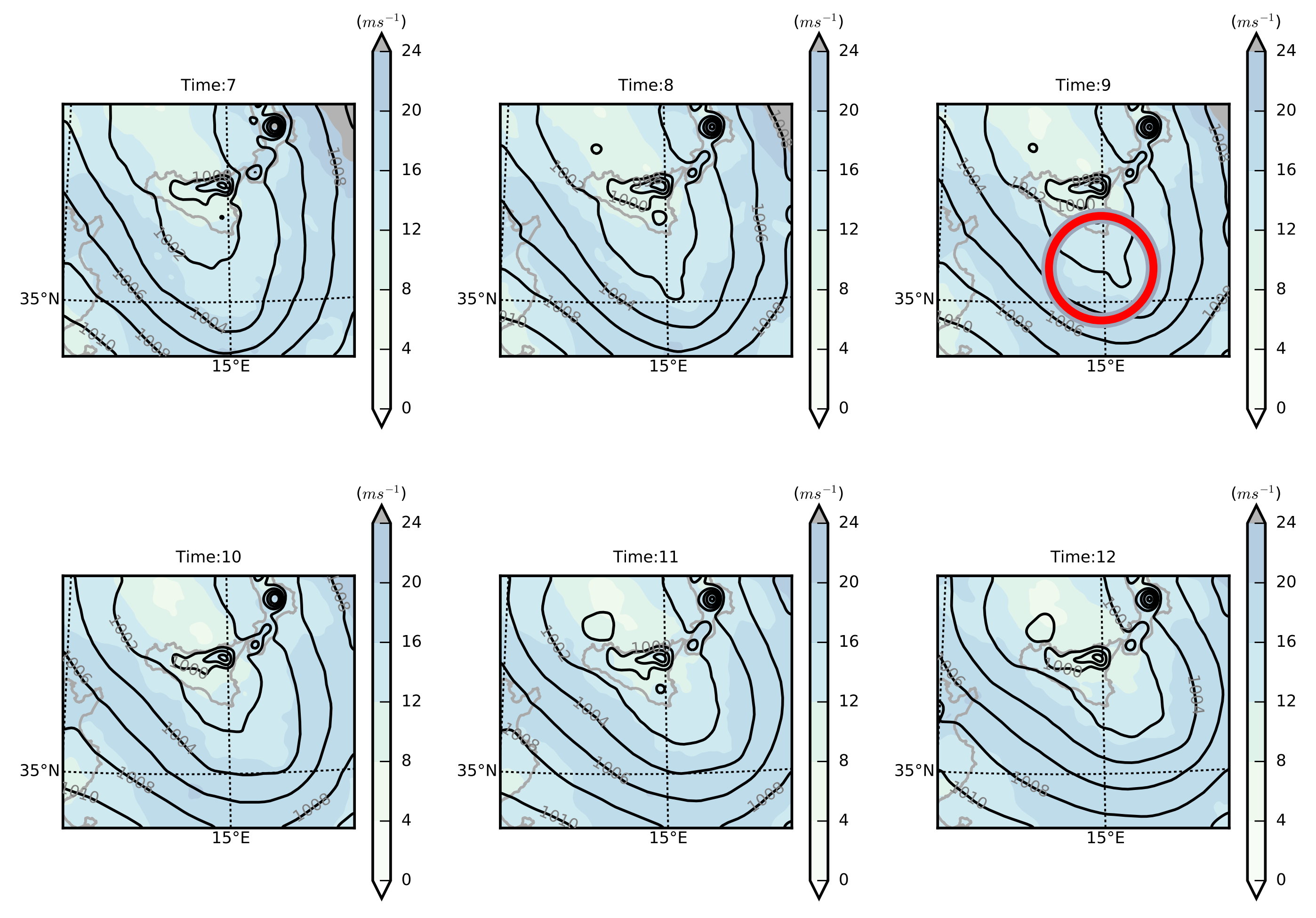
EnKF forecasts: mean fields

- MSLP and SPD 925hPa
- Domain 2 (2.5km)
- T: 4-9UTC 7Nov



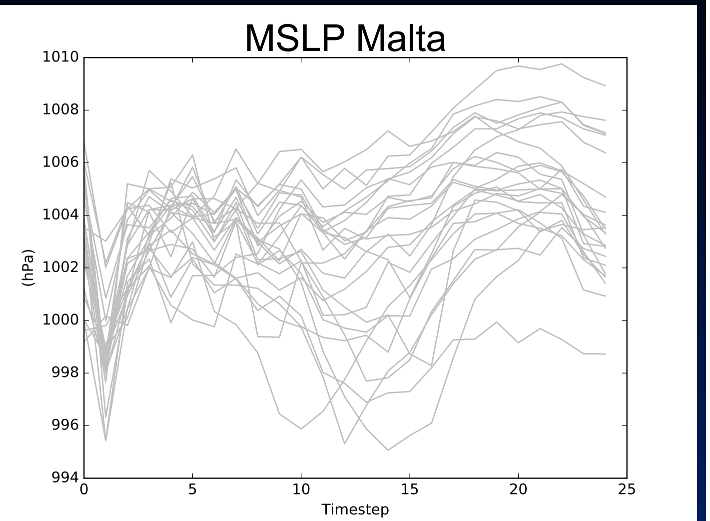
EnKF forecasts: mean fields

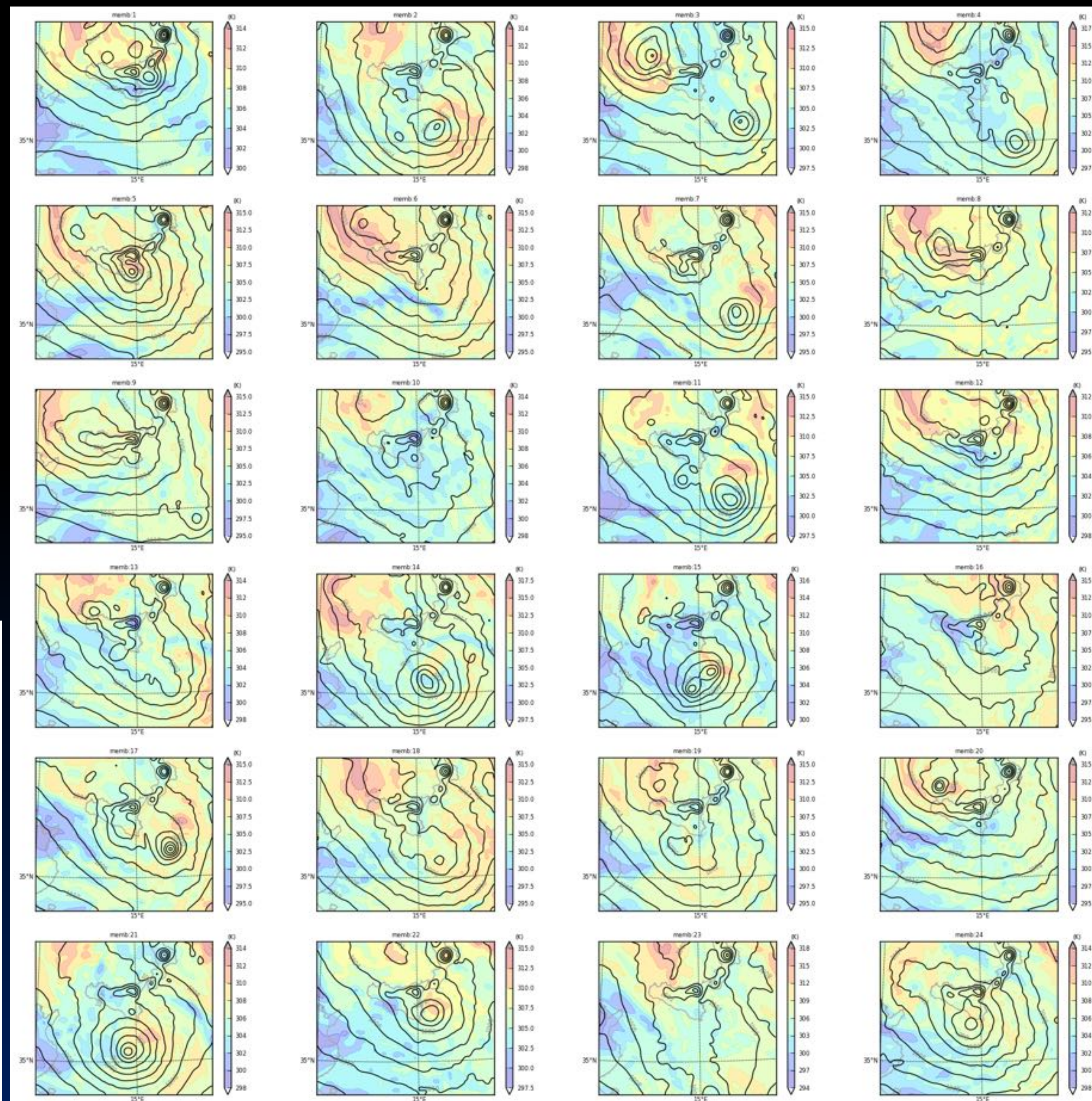
- MSLP and SPD 925hPa
- Domain 2 (2.5km)
- T: 10-15UTC 7Nov



EnKF forecasts: individual members

- MSLP and thetae-850hPa
- Domain 2 (2.5km)
- T: 14UTC 7Nov (+14h)

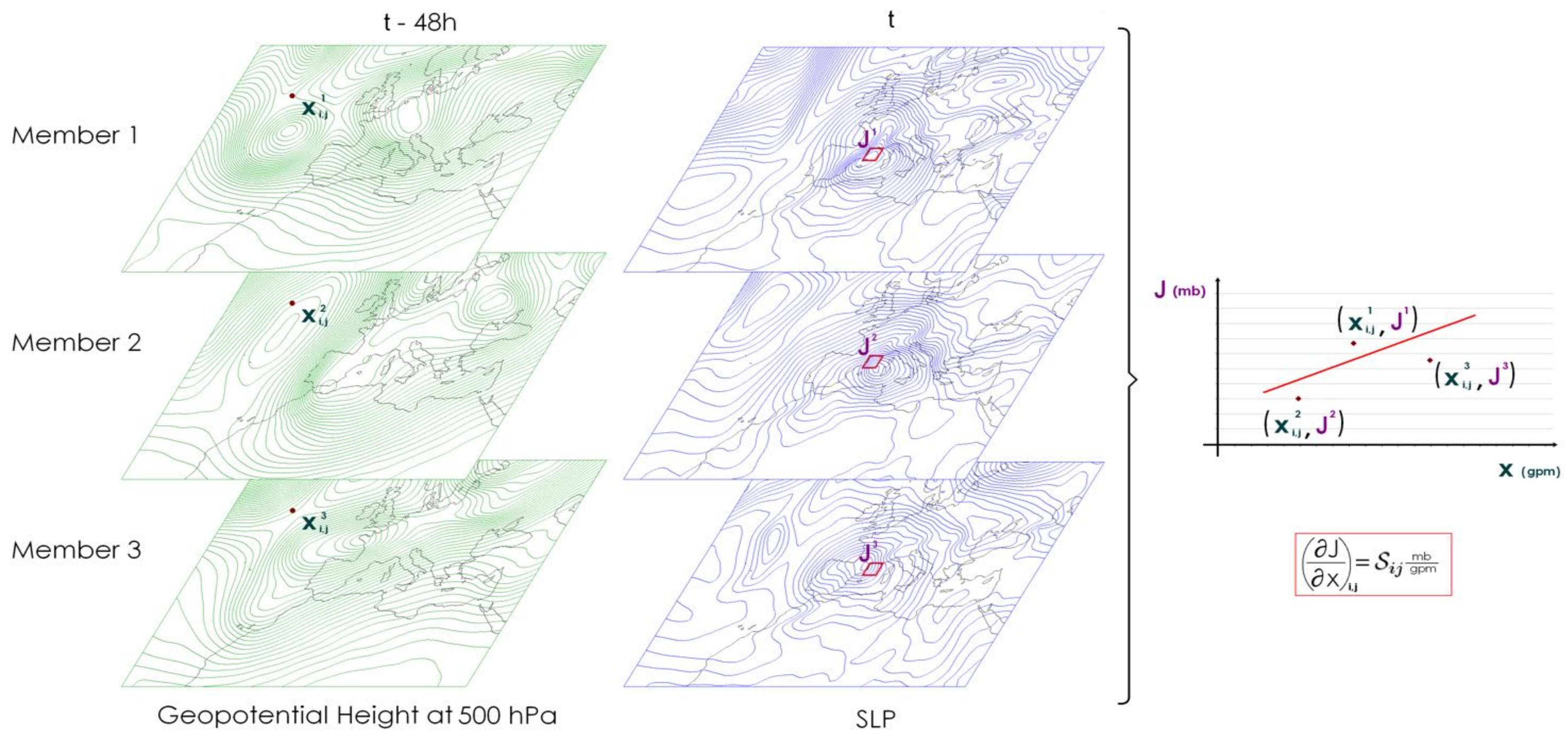




Covariances analysis

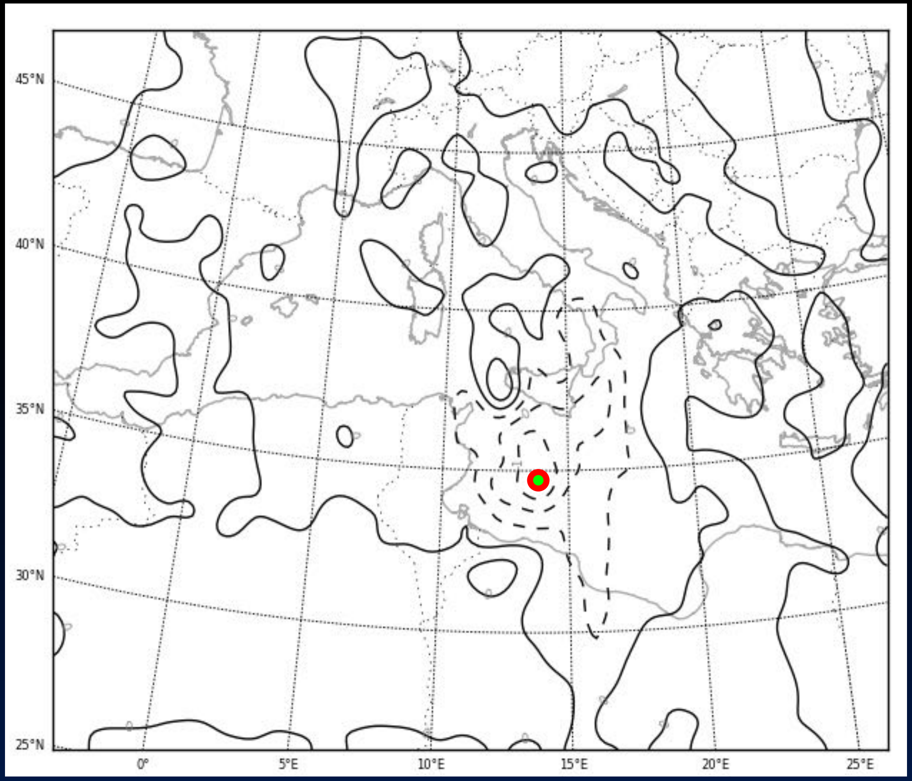
- The covariance of an scalar J to any other scalar x_{ij} is determined by:

$$COV(J, x_{ij}) = \frac{1}{n-1}\sum_{m=1}^{n}(\bar{J} - J^m)(\overline{x_{ij}} - x_{ij}^m)$$

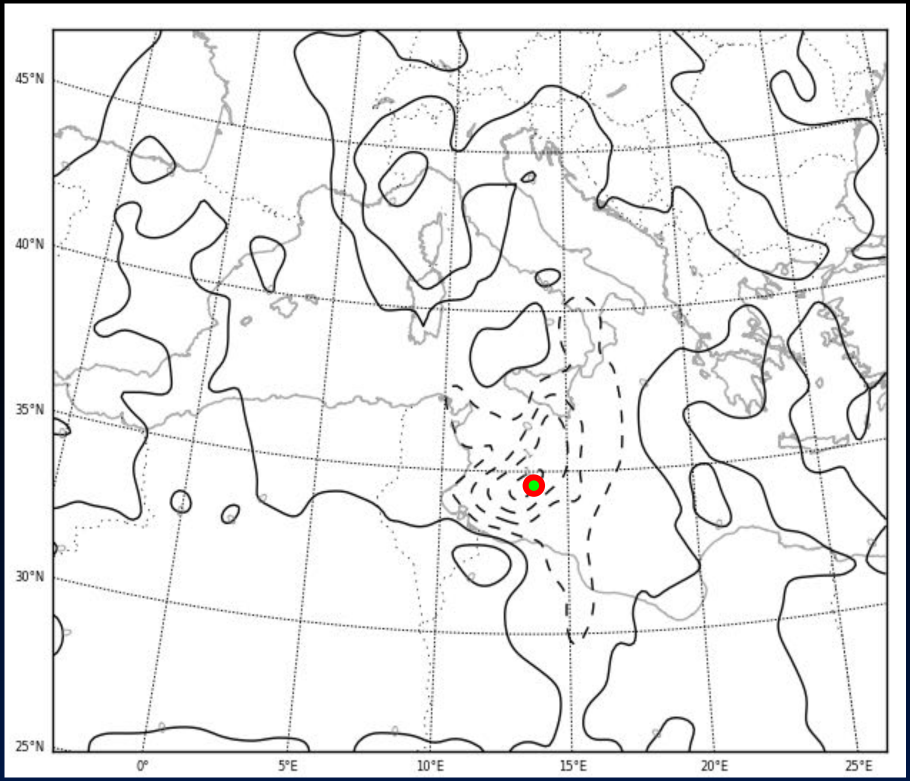


Covariances analysis: EnKF DA

- J: MSLP @
- X_{ij}: T @ low levels



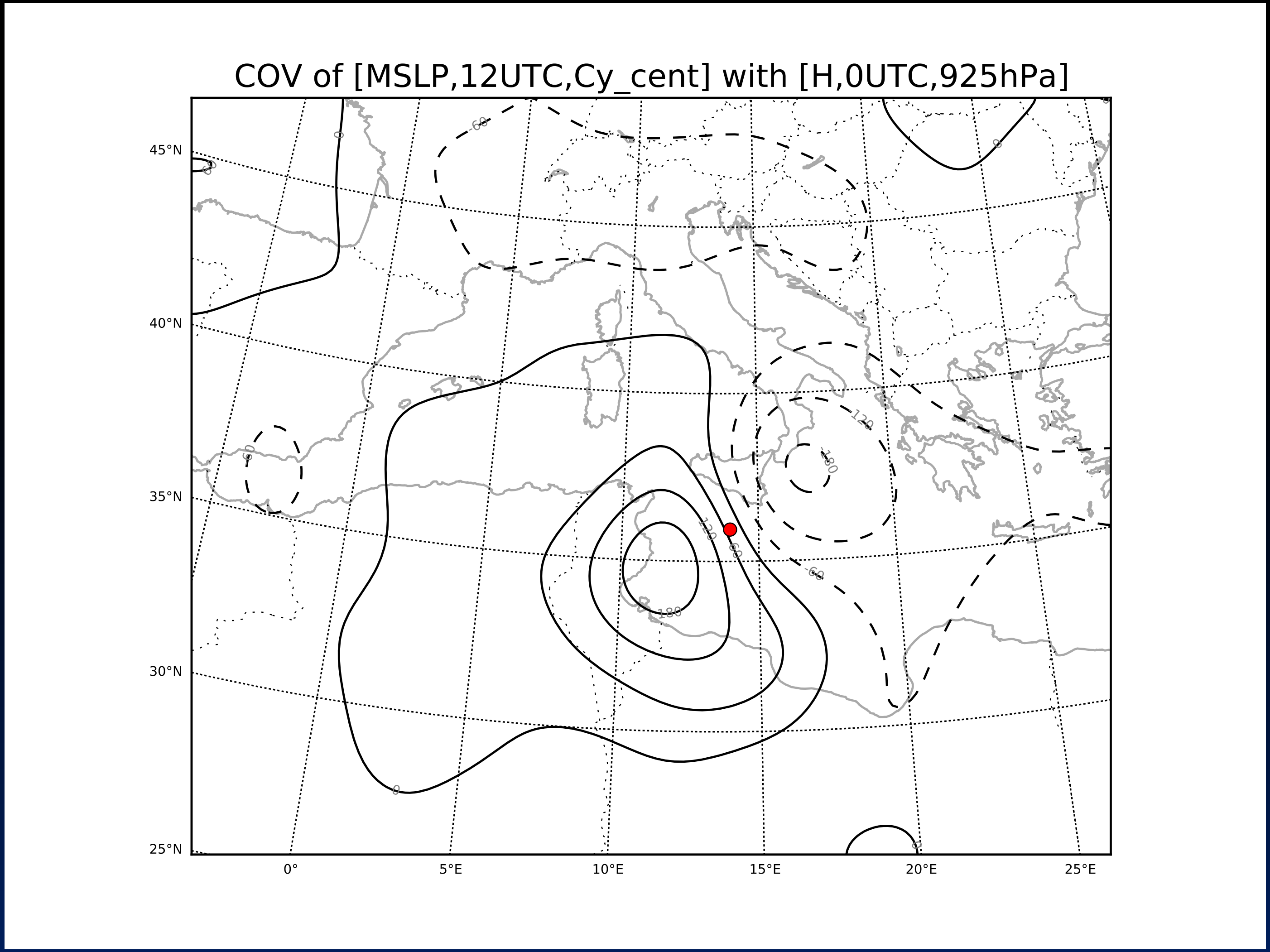
23UTC 6Nov (17 EDA cycles)



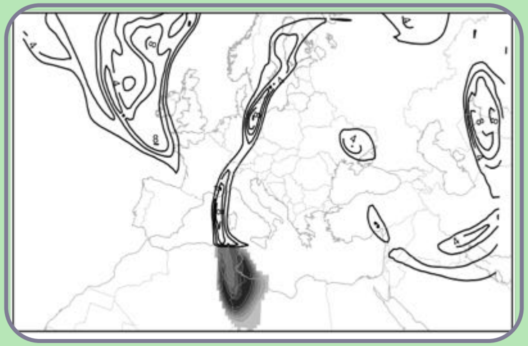
00UTC 7Nov (18 EDA cycles)

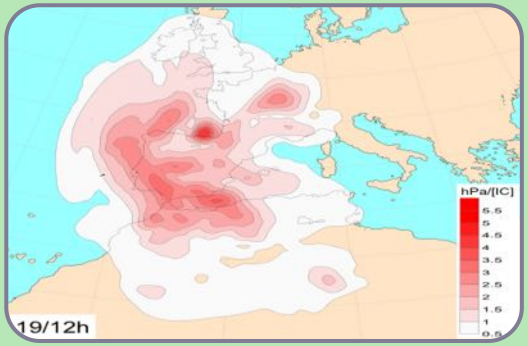
Covariances analysis: Physical analysis

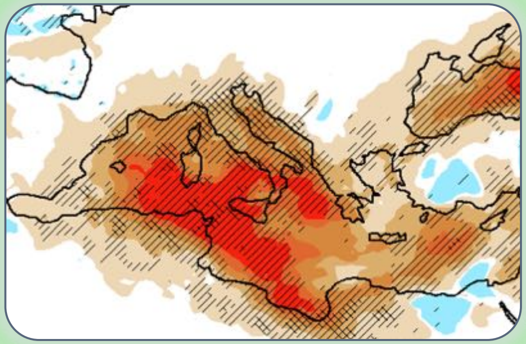
- J: MSLP @ ● 12 UTC
- X_{ij}: H @ low levels



Techniques in the UIB toolbox







Physical processes

Factors Separation

PV inversion

Accumulated & Instantaneous attributions

Predictability aspects

Assimilation challenges

Covariances exploration

Climatological analysis

Statistical downscaling

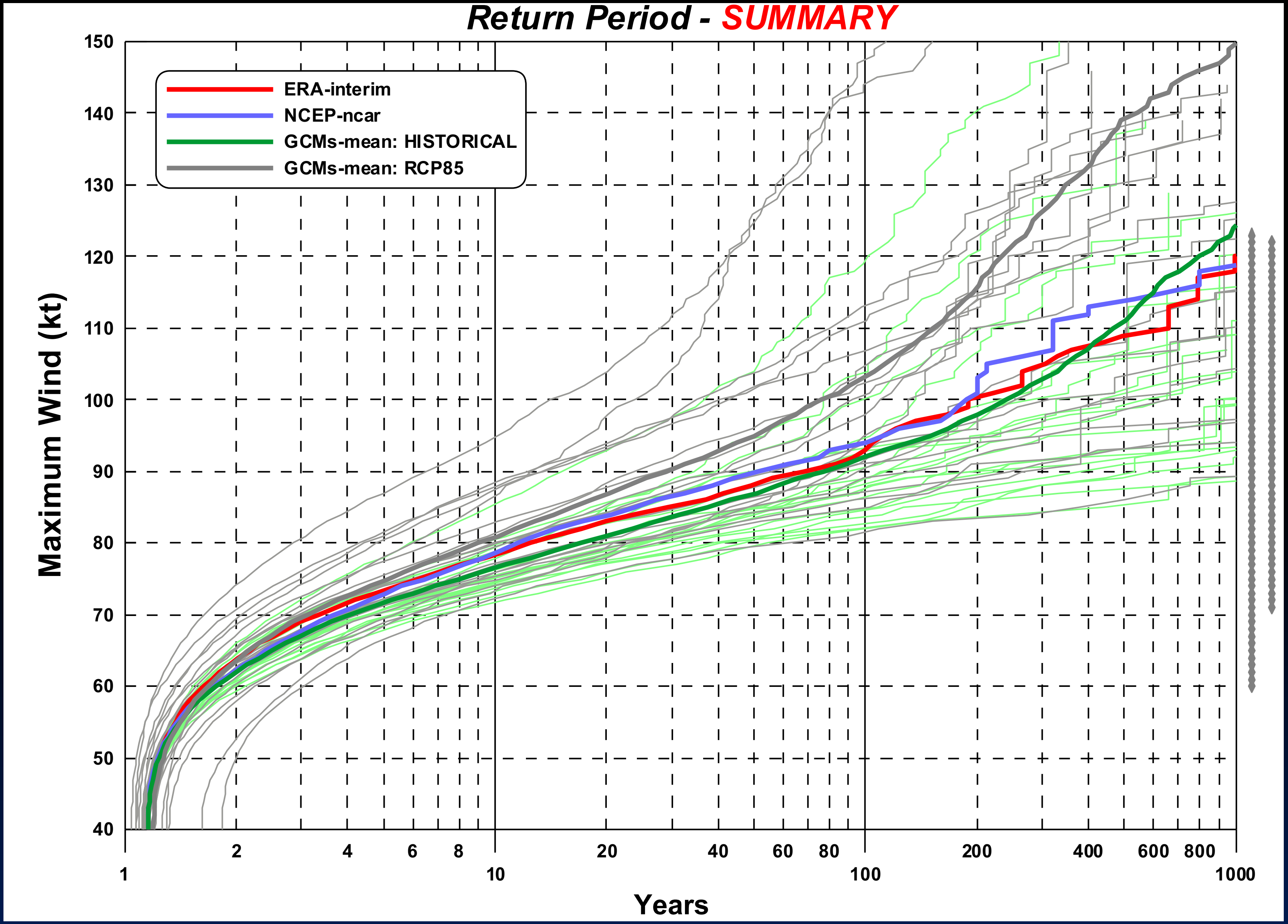
Synthetic environments

Statistical-deterministic approach

Developed by Emanuel and his team in the context of the long-term wind risk associated with tropical cyclones:

- ***Low-cost generation of thousands of synthetic storms***
- ***Statistically robust assessment of risk (e.g. return periods for winds)***

- ***Genesis: Random draws from observed PDF or Random seeding***
- ***Track: Randomly varying synthetic winds (respecting climatology)***
- ***Environment: Previous winds + monthly-mean thermodynamic fields***
- ***Intensity and radial distribution of winds: CHIPS model***



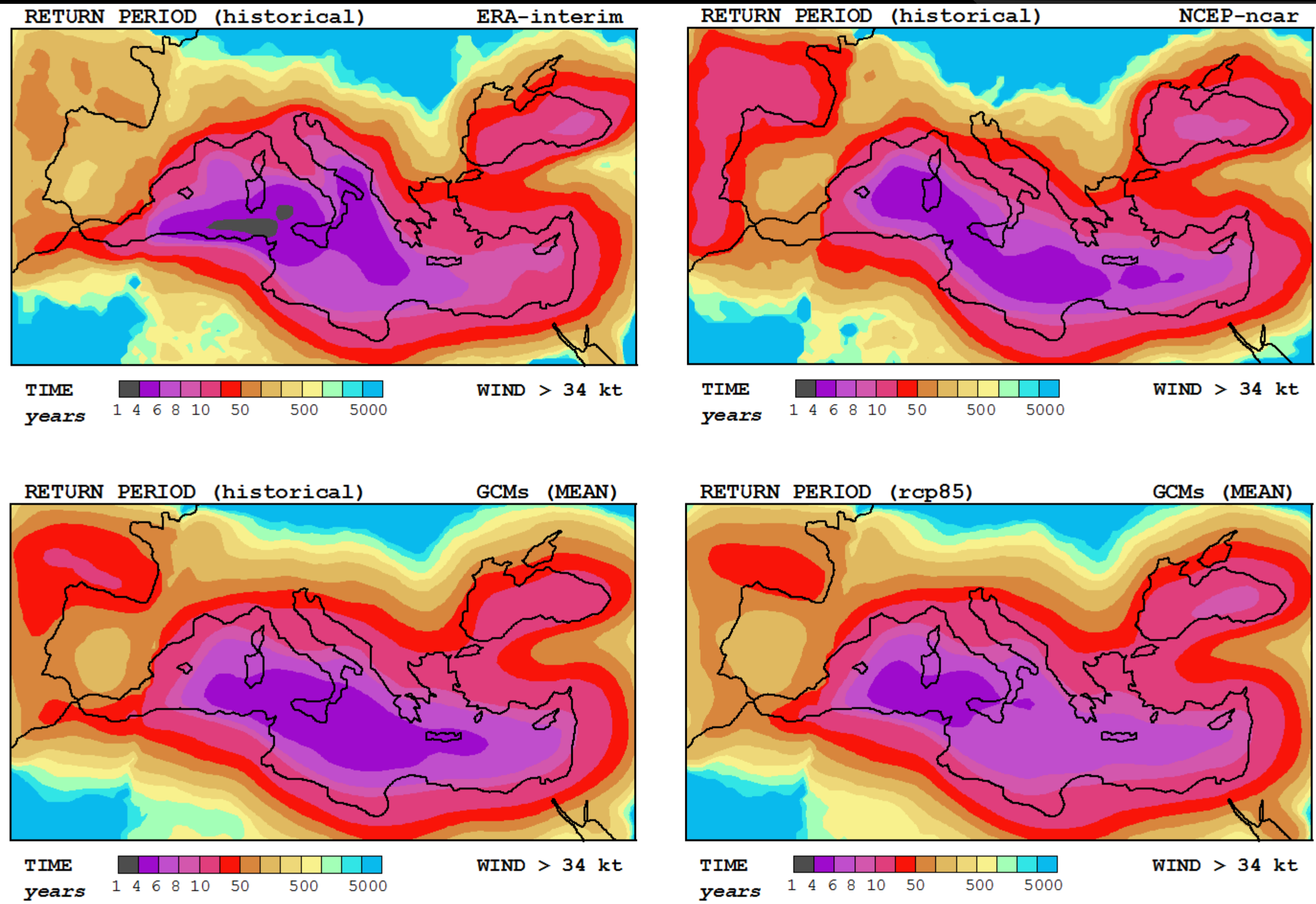
Return Period - SUMMARY
ERA-interim
NCEP-ncar
GCMs-mean: HISTORICAL
GCMs-mean: RCP85
Maximum Wind (kt)
150
140
130
120
110
100
90
80
70
60
50
40
1
2
4
6
8
10
20
40
60
80
100
200
400
600
800
1000
Years

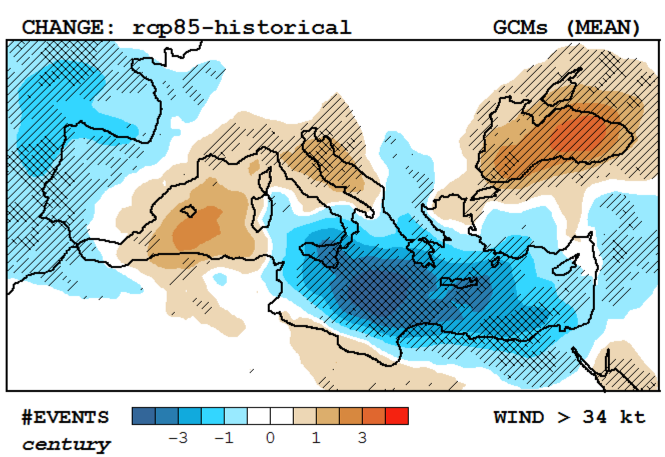
CORR

REAn01 = 0.768
REAn02 = 0.742
MEAN = **0.755**

RMSE

REAn01 = 2.157
REAn02 = 4.131
MEAN = **3.144**

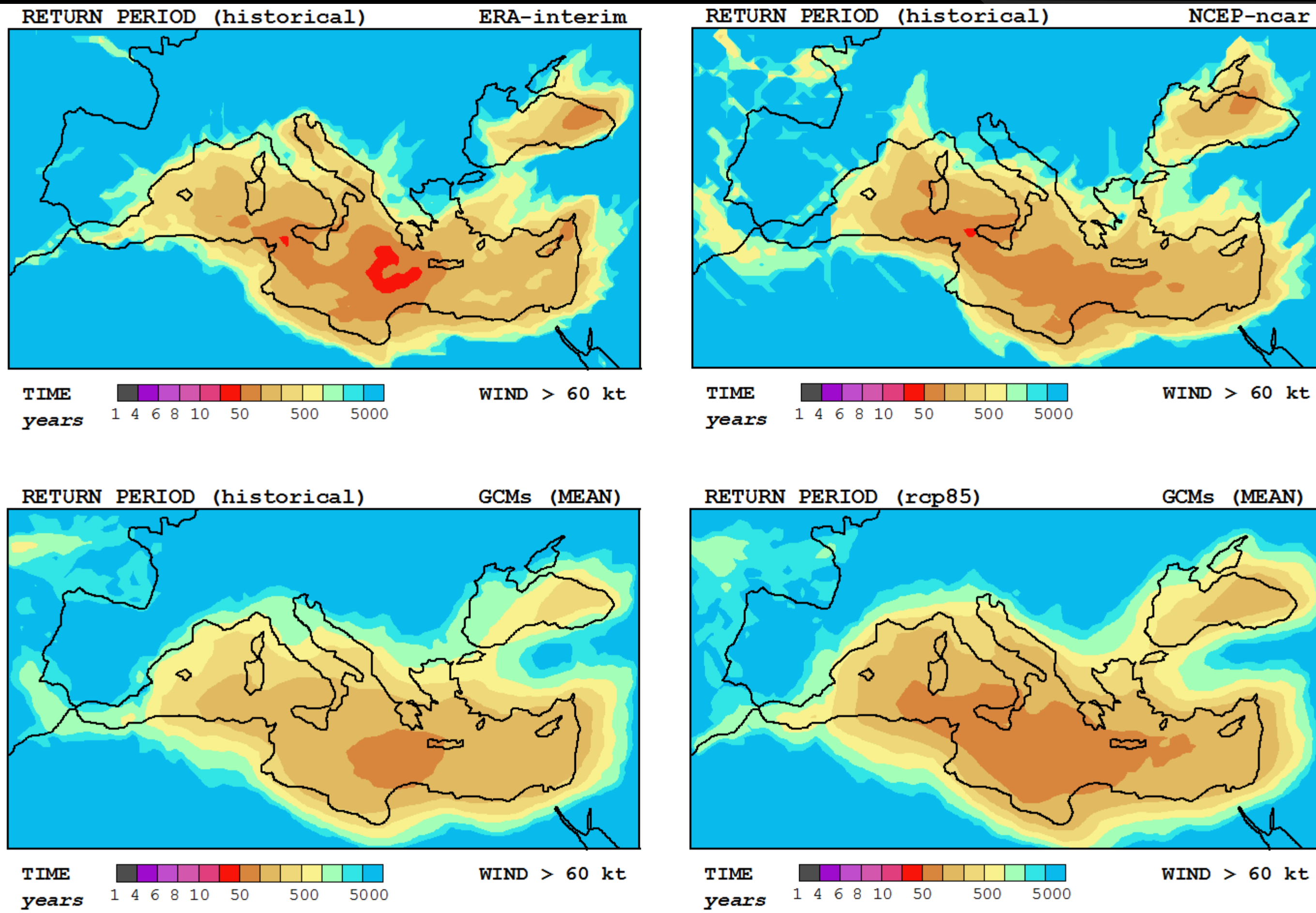


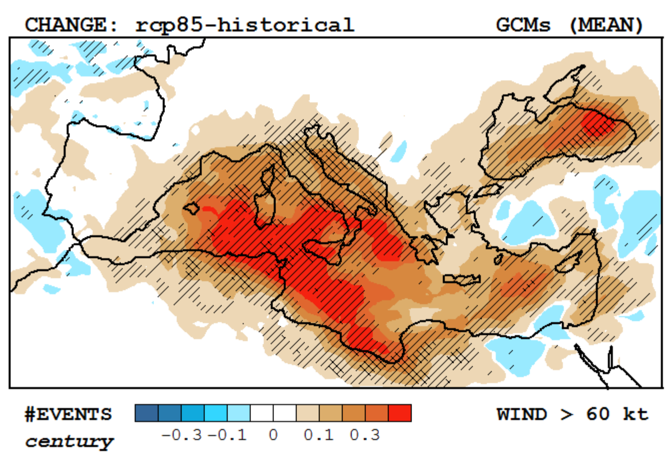


Return Period 34 kt Summary

CORR
REAn01 = 0.604
REAn02 = 0.649
MEAN = **0.626**

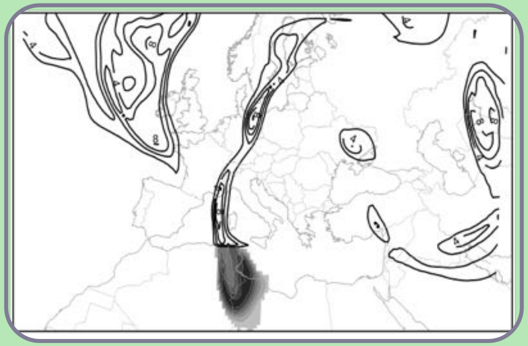
RMSE
REAn01 = 4.972
REAn02 = 8.418
MEAN = **6.695**

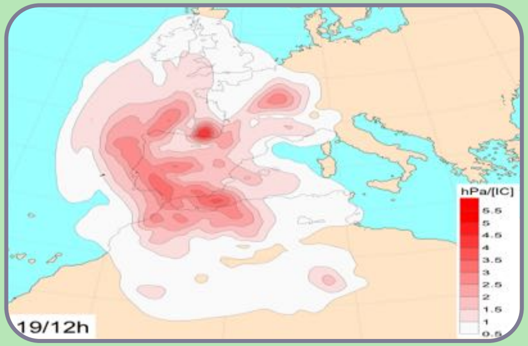


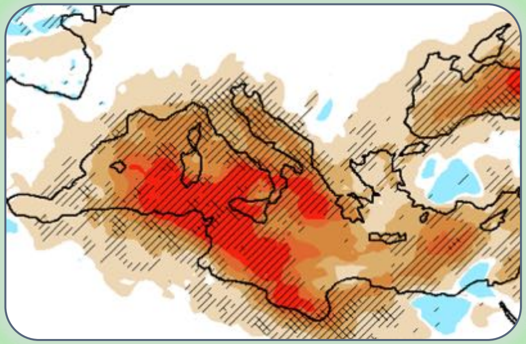


Return Period 60 kt Summary

Techniques in the UIB toolbox







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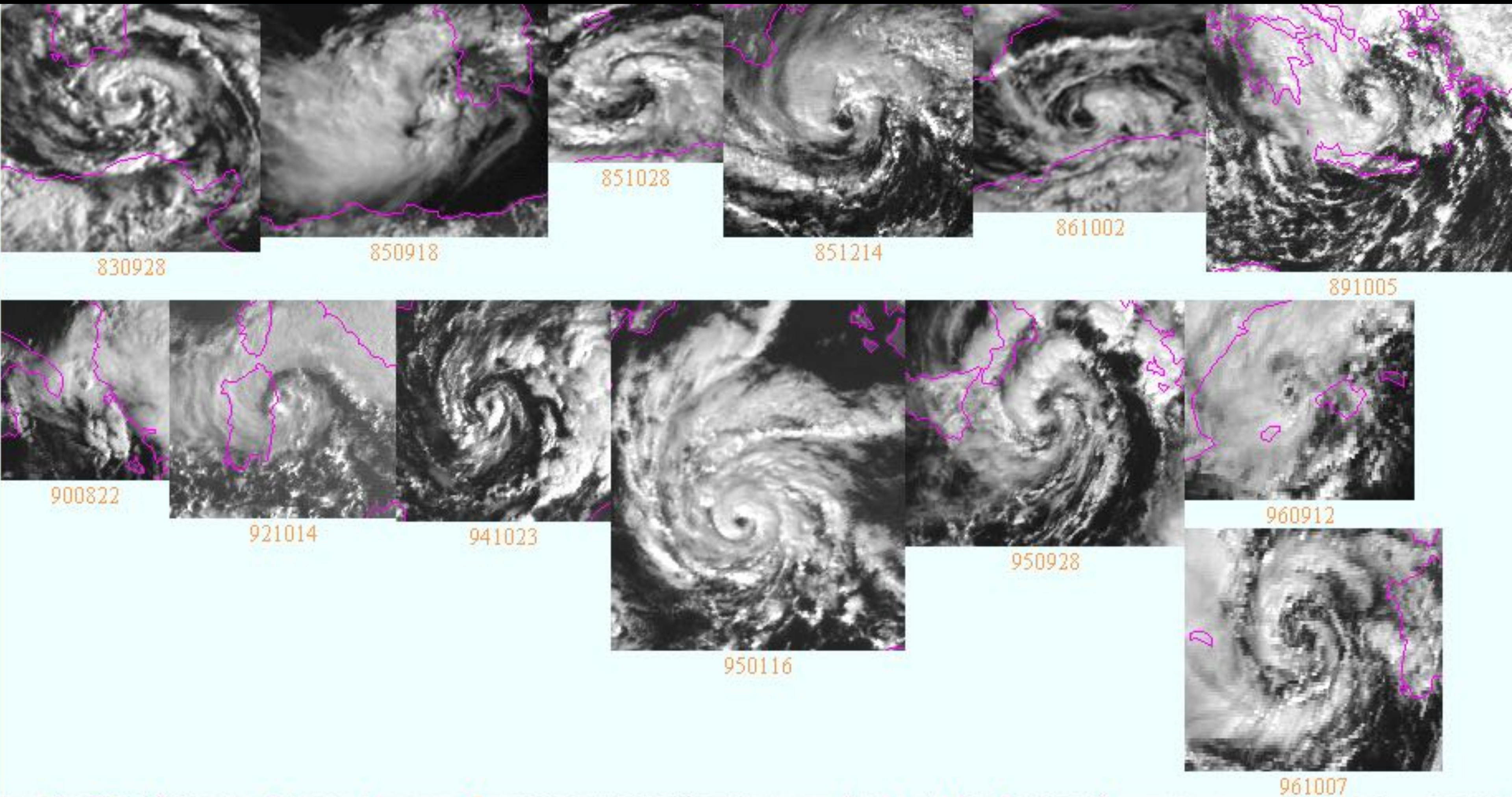
(Somewhat Outdated) Catalog of cases:



http://www.uib.es/depart/dfs/meteorologia/METEOROLOGIA/MEDICANES

Thank you!

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de les Illes Balears