Servei Meteorològic de Catalunya

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NWP at METEOCAT

Firenze, 13-14 June 2018

Generalitat de Catalunya

OUTLINE

- METEOROLOGICAL MODELS
- WRF - CONFIGURATIONS
- DATA ASSIMILATION
- WRF - NOWCASTING
- PROBABILISTIC NWP
- WAVE MODELS
- VERIFICATION

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METEO MODELS

MODEL	DOMAIN	IC/BC	UPDATE	LEAD TIME	NOTES
WRF-ARW	**27 – 9 – 3 km**	**IFS - 0.5°**	**12 h**	**72 – 72 – 48 h**	**3DVAR**
WRF-ARW	9 – 3 km	GFS - 0.25°	12 h	72 – 48 h	-
BOLAM	8 km	GFS - 0.5°	12 h	72 h	-
MOLOCH	2 km	BOLAM	12 h	48 h	-
UM	4 km	UM	12 h	54 h	*UK Met Office*
AROME	1 km	ARPEGE	12 h	42 h	*Météo France*
WRF-ARW	16 – 4 km	IFS - 0.5°	12 h	72 – 72 h	-
WRF-ARW	3 km	WRF	3 h	12 h	3DVAR
WRF-ARW	3 km	WRF	3 h	12 h	LAPS/STMAS

ECMWF from **AEMet**
Limited set of variables & levels – top level 100 hPa – 0.5°

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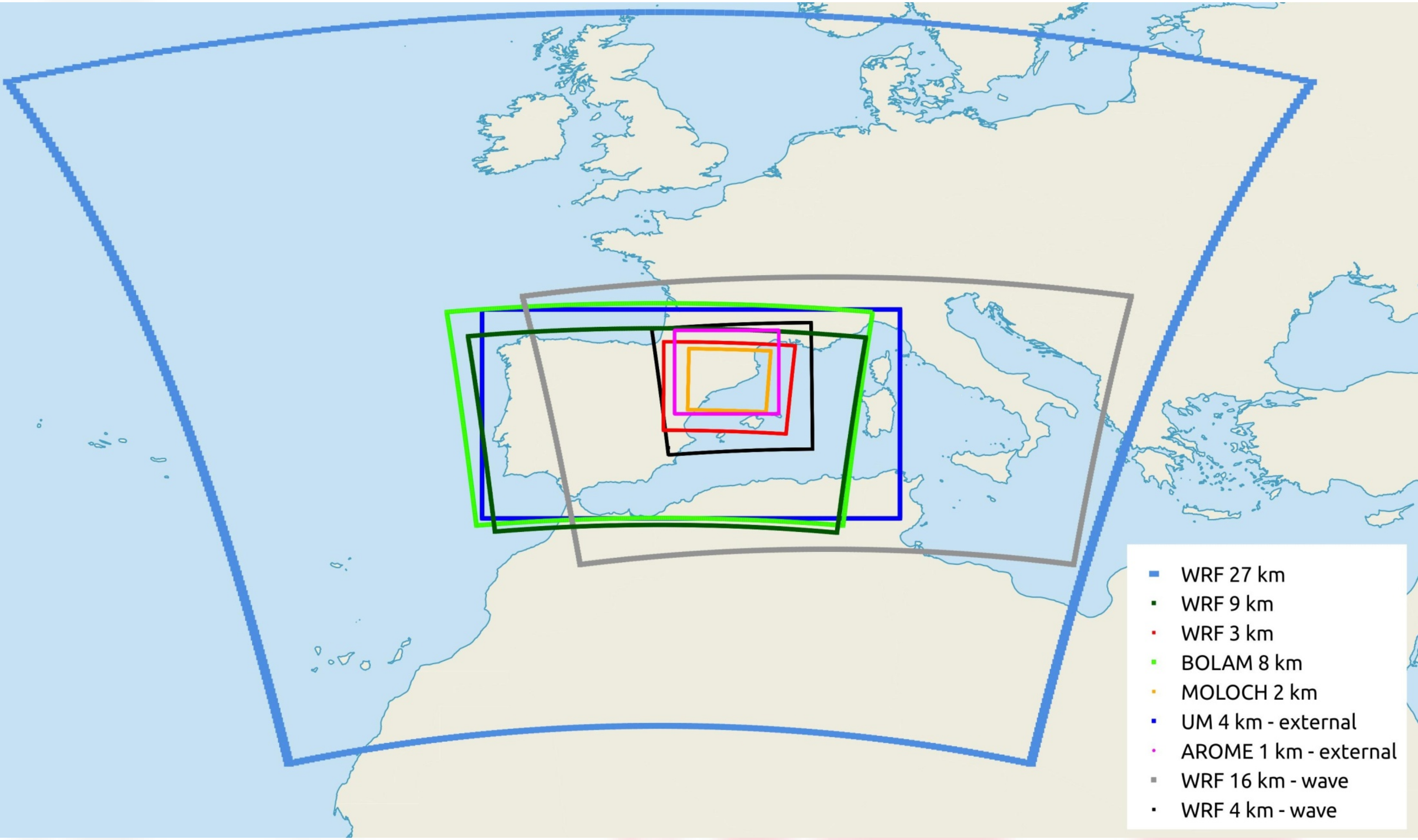
METEO MODELS



WRF - CONFIGURATIONS

Options	WRF v3.5	WRF v3.5 - WAVE
Microphysics	**WSM5**	**WSM3**
Long-wave rad	**RRTM**	**RRTMG**
Short-wave rad	**Dudhia**	**RRTMG**
PBL	YSU (from v2.2)	YSU (from v2.2)
Surface layer	MM5 Monin-Obukhov	MM5 Monin-Obukhov
Cumulus	Kain-Fritsch **(even at 3 km)**	Kain-Fritsch (16 km) **+ explicit (4 km)**
Surface model	Noah LSM	Noah LSM
Other	topo_wind = 2 (UW method)	topo_wind = 2 (UW method)

Vertical levels: 31 user specified

```
eta_levels                    =
1.000,0.998,0.993,0.986,0.975,0.960,0.940,0.910,
0.880,0.840,0.800,0.760,0.720,0.680,0.640,0.600,
0.560,0.520,0.480,0.440,0.400,0.360,0.320,0.280,
0.240,0.200,0.160,0.120,0.080,0.040,0.000
```

Analysis nudging on the coarsest domain

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WRF - CONFIGURATIONS

Options	WRF v3.5	WRF v3.9
Type of levels	**Sigma**	**Hybrid**
Microphysics	WSM5	WSM6
Long-wave rad	RRTM	RRTM
Short-wave rad	Dudhia	Dudhia
PBL	YSU (from v2.2)	QNSE-EDMF
Surface layer	MM5 Monin-Obukhov	QNSE (+ increased U*)
Cumulus	Kain-Fritsch (even at 3 km)	Multiscale KF (decoupled from YSU) even at 3 km
Surface model	Noah LSM	Noah MP (+ dveg = 5)
Other	topo_wind = 2 (UW method)	**time-varying** SST, seaice, vegetation fraction, albedo, leaf-area index and deep layer soil temperature
Dynamics	damp_opt = 0	damp_opt = 3 + zdamp = 2000

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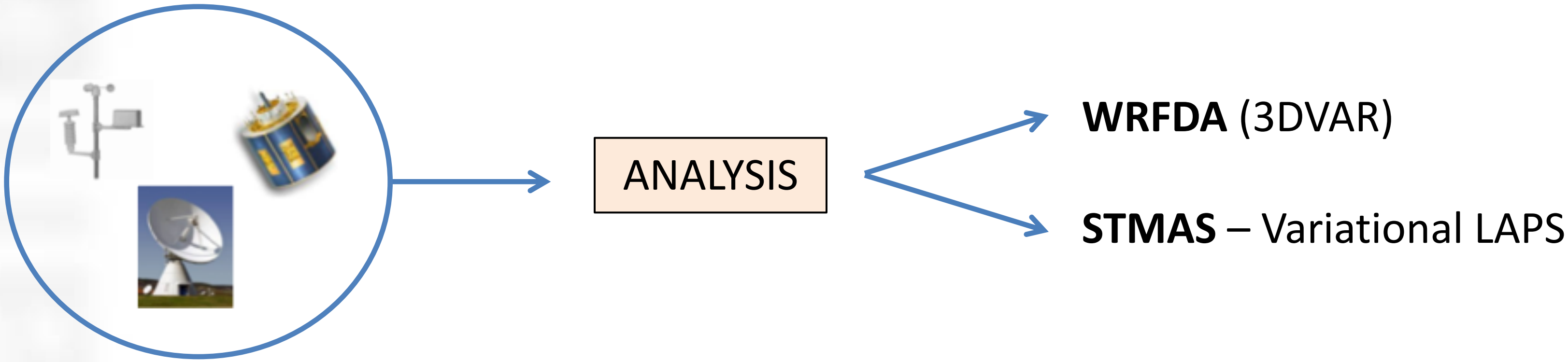
Vertical levels: 31 user specified
Analysis nudging on the coarsest domain

DATA ASSIMILATION

Data Assimilation systems



TYPE	SOURCE	NUMBER	AVAIL.	PARAMETERS
SFC	XEMA	~ 170	30’	T / RH / pmsl / PCP
	METAR	~ 10	60’	T / Td / pmsl / visibility / clouds
	SYNOP	~ 10	180’	T / Td / pmsl / visibility / clouds
RADAR	XRAD	4	6’	Reflectivity / Radial velocity
SATELLITE	MSG	1	15’	0.6 um / 3.9 um / 10.8 um

WRF - NOWCASTING

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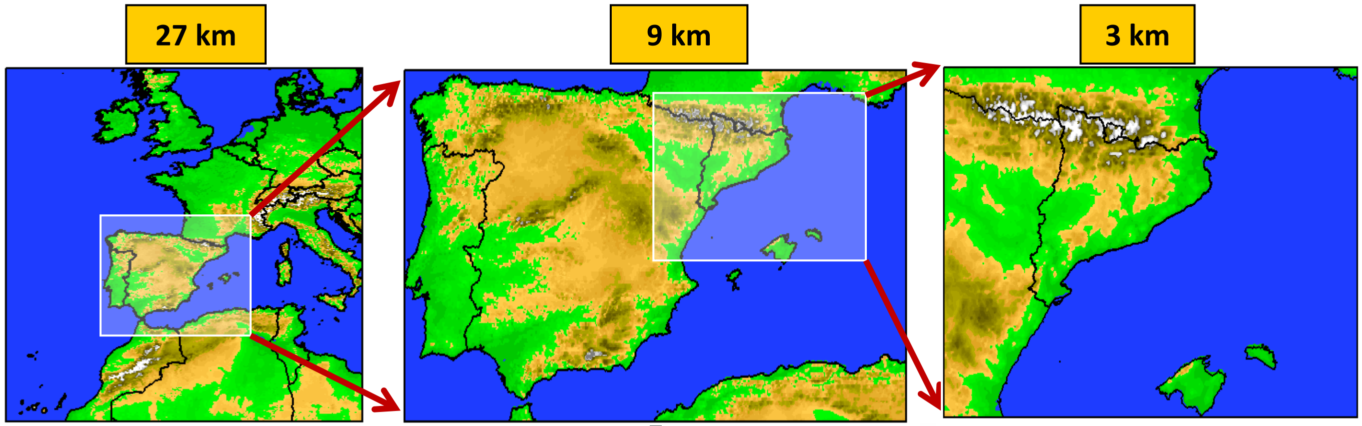
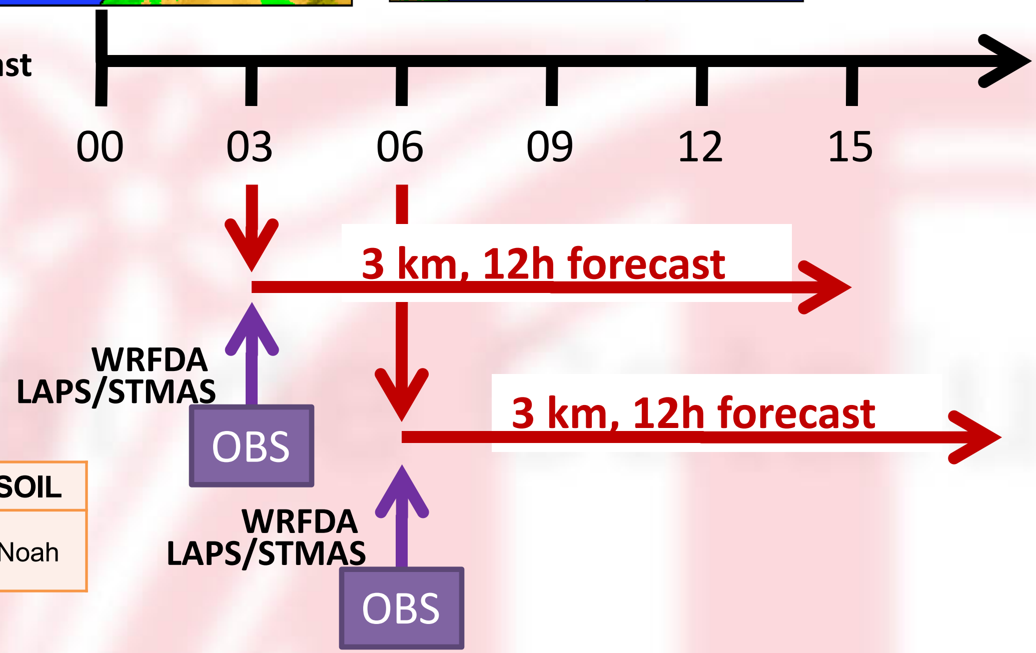
Our current model setup

00 TU
12 TU



Operational forecast
WRF 9 km



- WRF-ARW v3.5.1
- Warm start initialisation:
  - No cycle
  - Qr, Qc, Qi, Qs, Qg specified

Physics & BC	BC	PBL	MICRO	CONV	LW	SW	SOIL
	1 h (9km)	YSU	WSM5	Kain-Fritsch	RRTM	Dudhia	Noah

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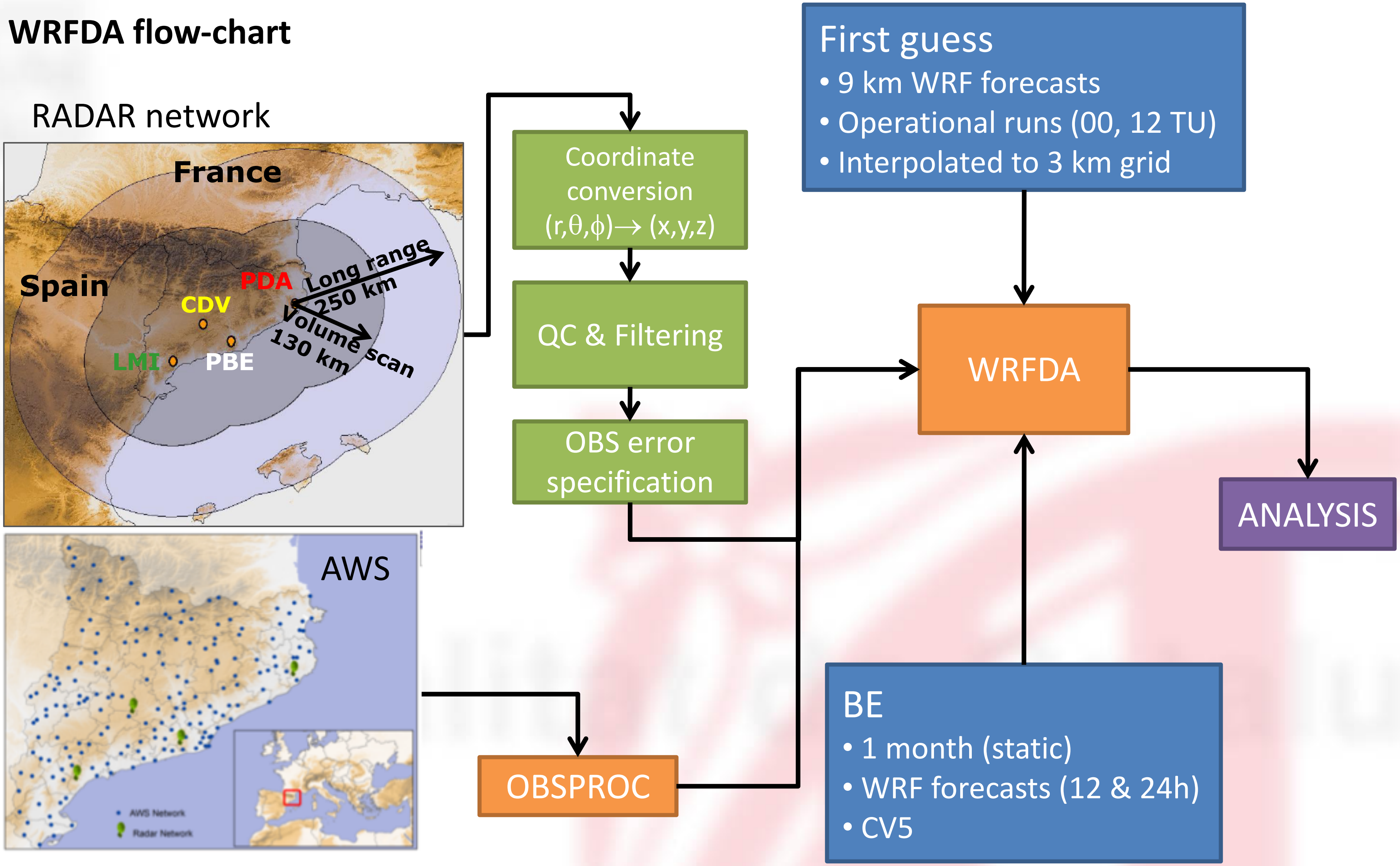
WRF - NOWCASTING

WRFDA flow-chart



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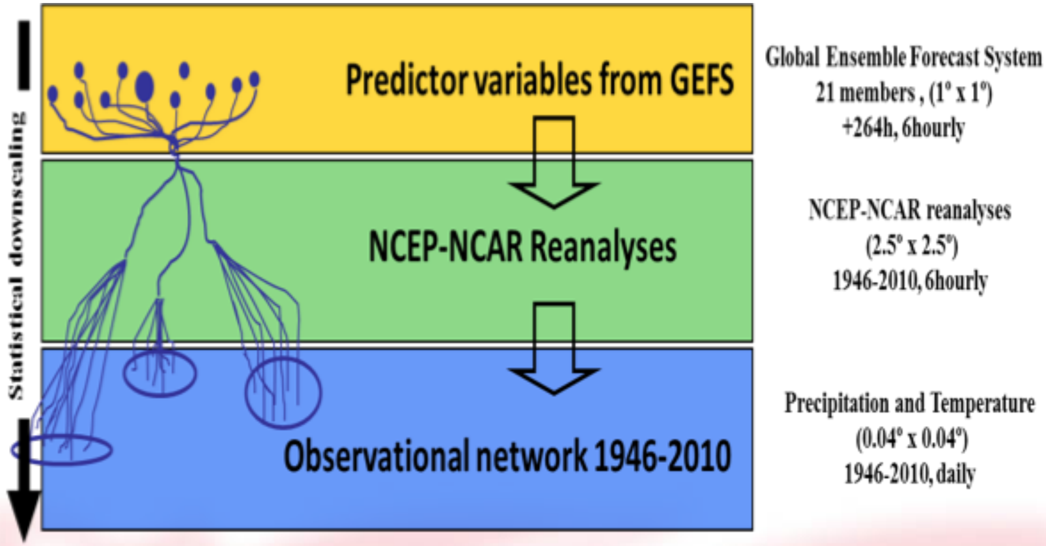
PROBABILISTIC NWP

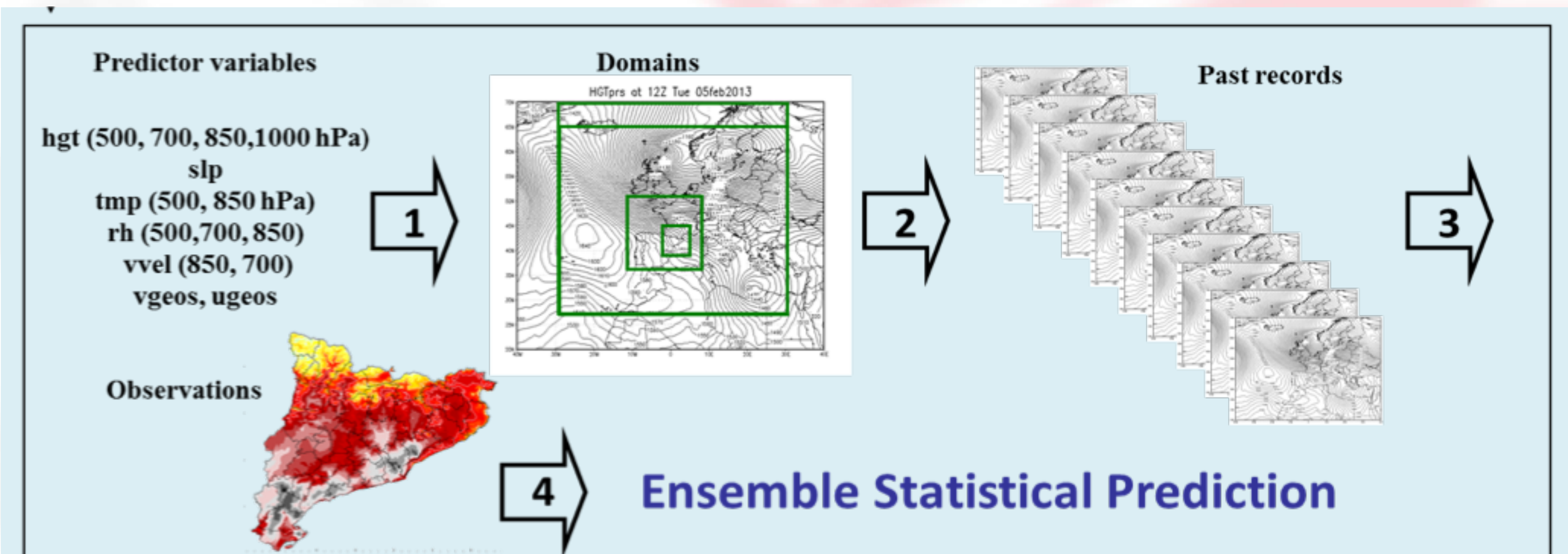
PRESCAT

Consisting of two-step process :

1- Development of statistical relationships between local variables (surface air temp, RH and precipitation) and large-scale predictors (e.g., pressure fields)

2- Application of such relationships to the output of mesoscale model.





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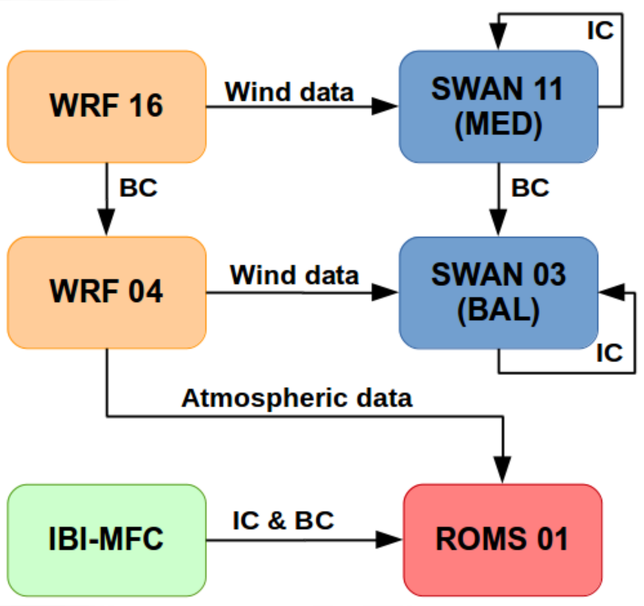
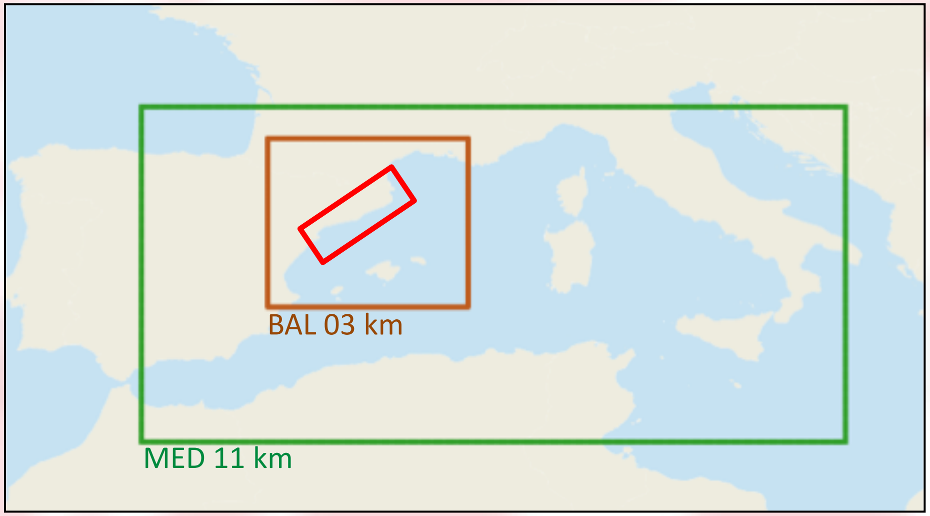
WAVE MODELS

MODEL	DOMAIN	IC/BC	UPDATE	LEAD TIME
SWAN	**11 – 3 km**	**WRF 16 – 4 km**	**12 h**	**72 – 72 h**
WW3	12 – 3 km	WRF 16 – 04 km	12 h	72 – 72 h
ROMS	1 km	IBI-MFC / WRF 04 km	24 h	72 h





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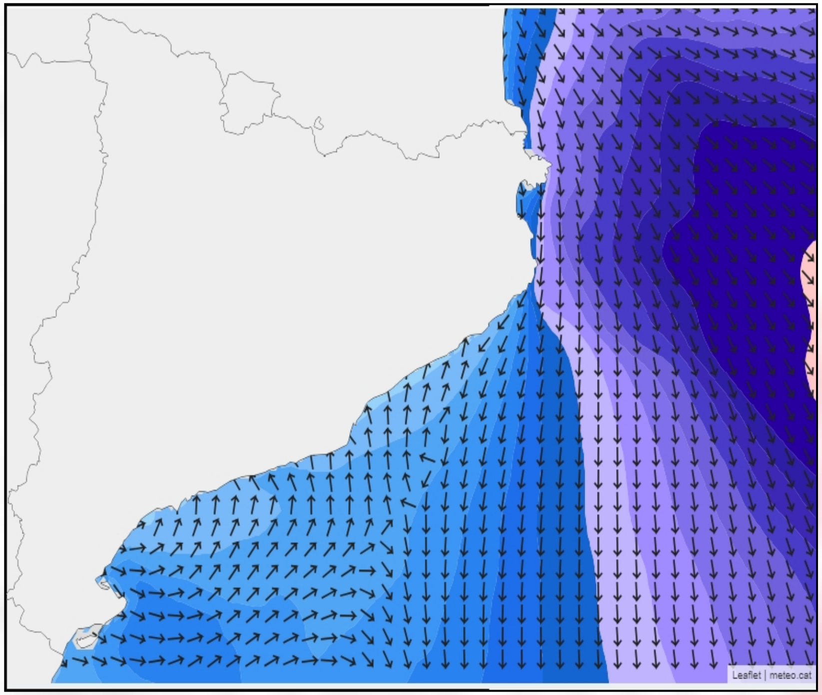
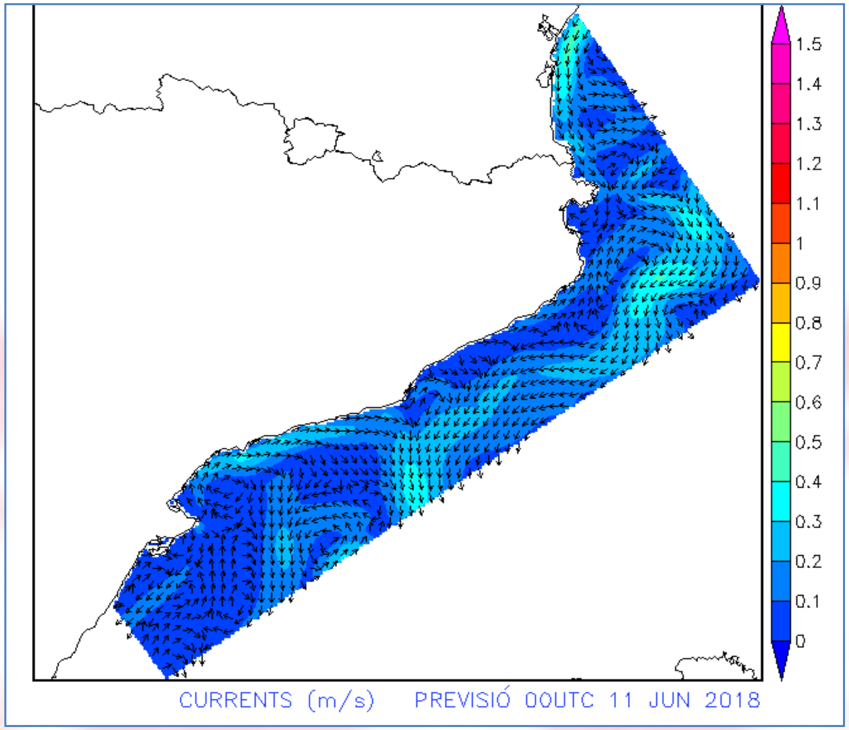
WAVE MODELS

EXEMPLES

SWAN model DX=3km



ROMS model DX=1km - **testing**



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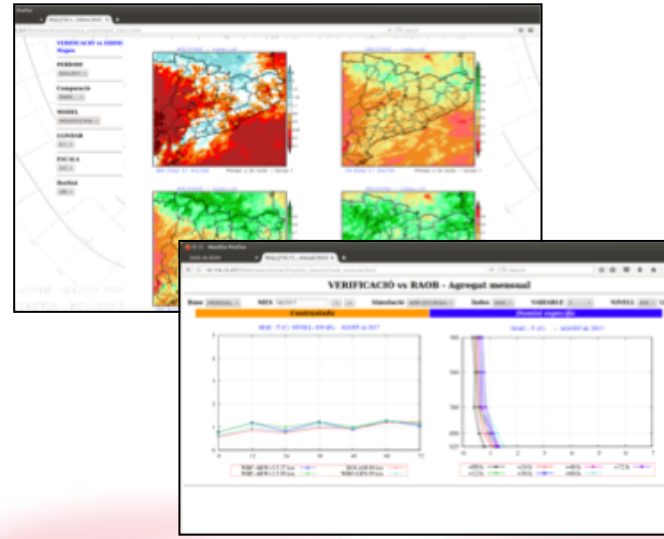
VERIFICATION

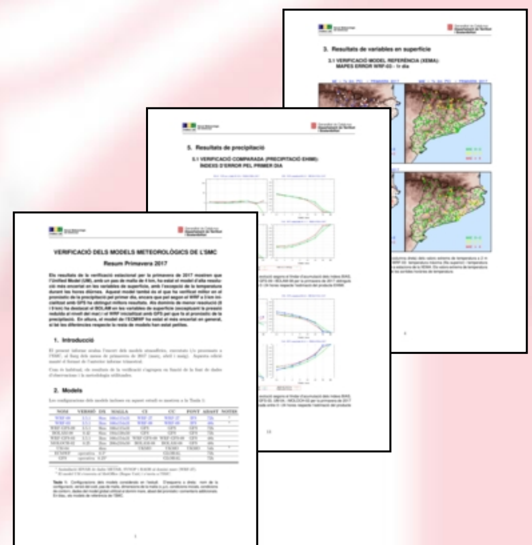


- **Operational verification:**
  - Daily & monthly (<u>intranet</u>)
  - Seasonal & yearly (<u>reports</u>)

- **MET (*Model Evalution Tools*) software**

- **STATIONS (*grid to point*)**
  - SYNOP/METAR: pmsl, t2, td2m, v10m
  - AWS: t2m, rh2m, v10m, PCP
  - RAOB: t, td, v, gh

- **ANALYSIS (*grid to grid*):**
  - EHIMI (*radar + pluviometers*): PCP

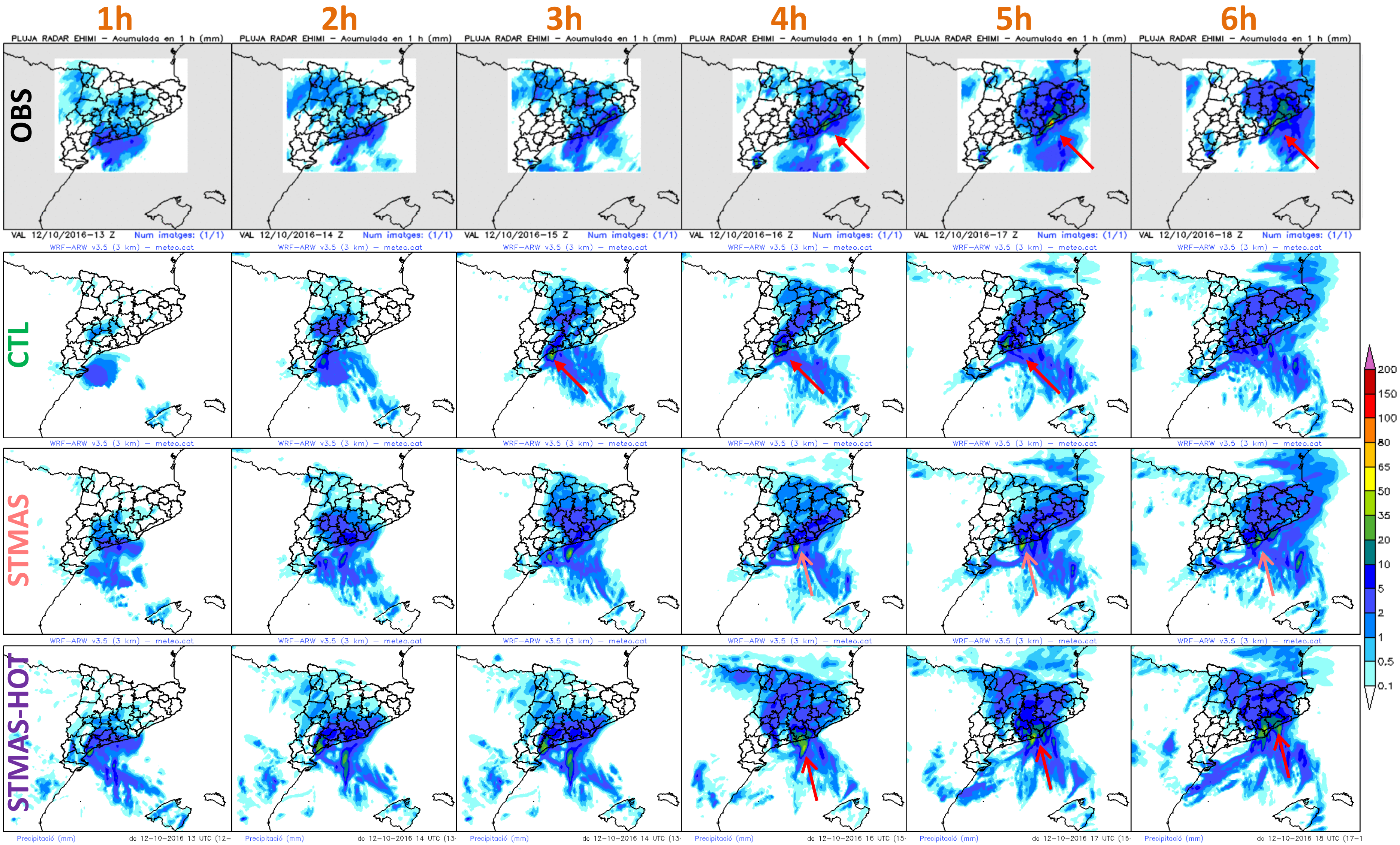


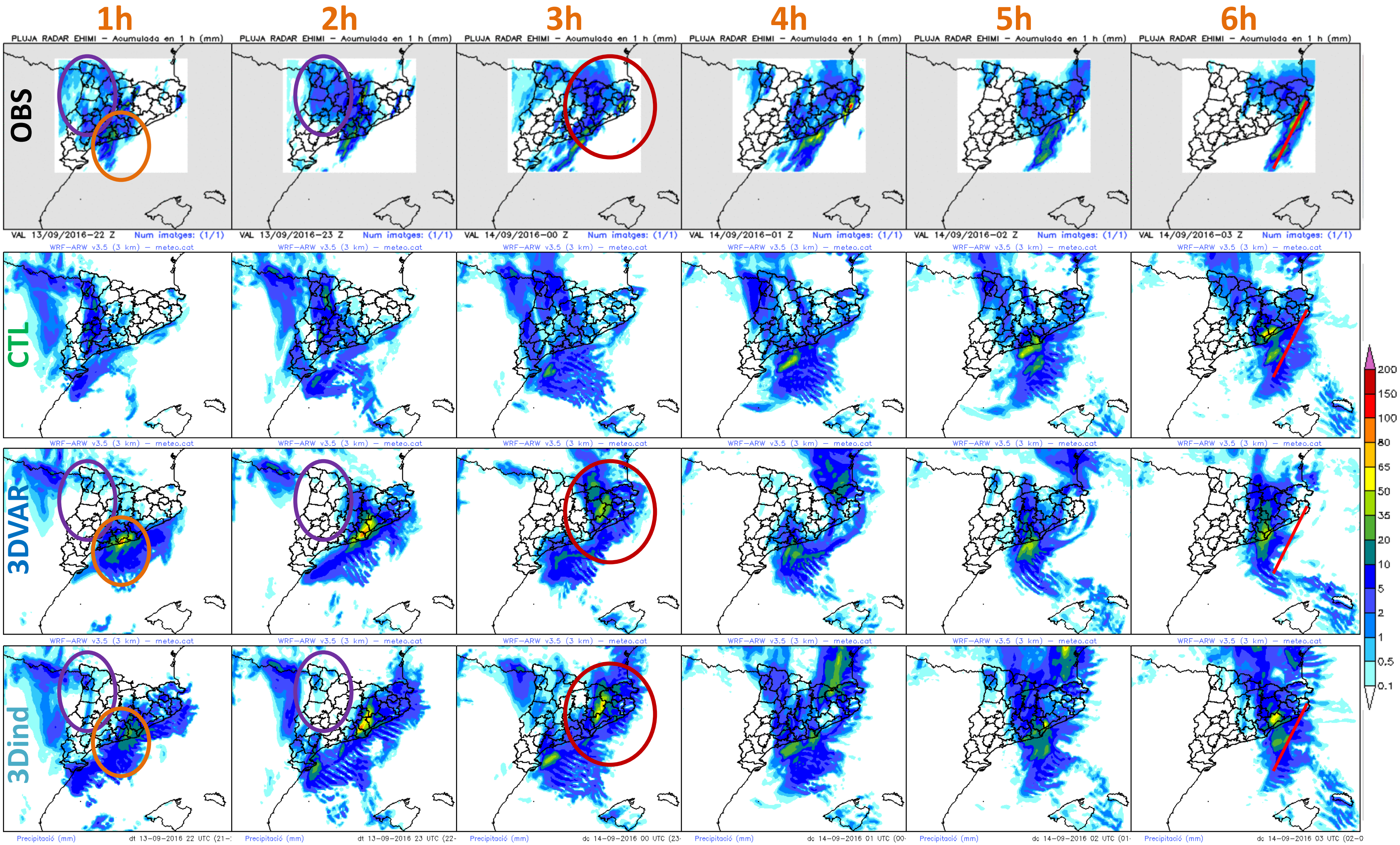
CURRENT & FUTURE WORK

- **NWP – migration to a new cluster**
- **Introduce changes in the NWP operational suite:**
  - Increase lead-time (WRF 3 km: 48 h -> 72 h)
  - Increase spatial resolution (WRF 1 km?)
  - Adjust WRF 3.9.1
  - Improve initial SFC fields (HRLDAS)
- **Probabilistic NWP:**
  - Poor man's ensemble - operational
  - PRESCAT v2: 1 km / 6 h
- **Very Short-Range NWP**
  - Hot cycle
  - Flow-dependent B-Matrix (Hybrid 3DVAR - Time Lagged Ensemble)

SUPLEMENTARY SLIDES

c) October 12th, 2016: Record-breaking intensity and stream overflowing




1h
2h
3h
4h
5h
6h
OBS
CTL
3DVAR
3Dind
PLUJA RADAR EHIMI – Acumulada en 1 h (mm)
VAL 13/09/2016–22 Z
VAL 13/09/2016–23 Z
VAL 14/09/2016–00 Z
VAL 14/09/2016–01 Z
VAL 14/09/2016–02 Z
VAL 14/09/2016–03 Z
Num imatges: (1/1)
WRF–ARW v3.5 (3 km) – meteo.cat
Precipitació (mm)
200
150
100
80
65
50
35
20
10
5
2
1
0.5
0.1

1. Our data assimilation (DA) systems

WRFDA Radar

- Minimisation of the cost function J(x)

$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{x}-\mathbf{x}_b)^T\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}_b)+\frac{1}{2}(\mathbf{y}-\mathbf{H}[\mathbf{x}])^T\mathbf{R}^{-1}(\mathbf{y}-\mathbf{H}[\mathbf{x}])$$

- The observation operator H(x) for reflectivity (Z) and radial wind (v_r) is

$$Z = 43.1 + 17.5\log_{10}(\rho q_r)$$

$$v_r = u\frac{x-x_i}{r_i} + v\frac{y-y_i}{r_i} + (w-v_T)\frac{z-z_i}{r_i}$$

Sun & Crook (1997)

$$v_T = 5.40a\cdot q_r^{0.125}, \qquad a = (p_0/\overline{p})^{0.4}$$

w and **q_r** are estimated trough diagnostic relations:

- w using the Richardson's Equation
- q_r using a warm-rain scheme to partition q_t

- Xiao & Sun (2007) approach (the only available on WRFDA v3.5).

1. Our data assimilation (DA) systems

RADAR: Data QC + thinning

15		20	20		15	10		40
		20	20	25	20	10	0	
	25	25	25	25	20	10	0	0
20	20	20	25	25	20	20	10	5
15	20	25	30	35	30	25	20	15
20	20	25	25	30	25	25	20	10
0	15	20	25	20	20	20	15	10
0	15	20	25	30	25	15	10	5
0	15	20	20	35	20	10	0	0

RAW reflectivity
(~1x1 km)

✓ **Data void check:**
- NO DATA < 1/3

✓ **Noise removal:**
- Var(Ref) $\leq$ 50 dBZ^2
- Var(v_r) $\leq$ 60 m^2/s^2

✓ **Final value:**
- average of 3x3 box

✓ **Additional constraints**
- Height $\leq$ 4000 m
- Both Ref & v_r valid at the same final grid box

	21	
21	27	17
	24	9

Filtered reflectivity
(~3x3 km)

Obs error specification:
- Reflectivity: set to 5 dBZ
- Radial velocity (m/s): $\varepsilon(v_r) = \frac{4d}{150} + 1$ *d = distance from the radar (km)*

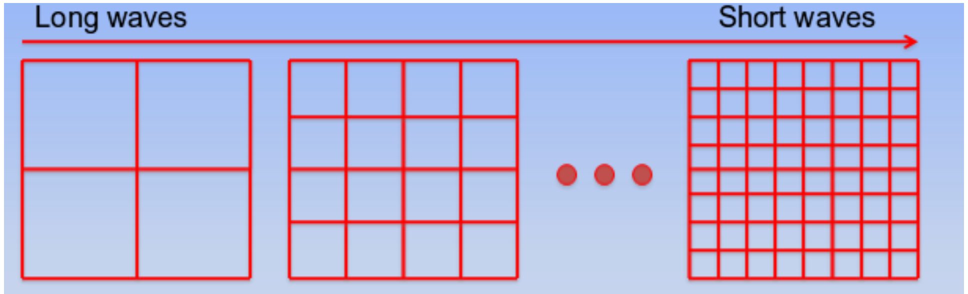
Schwitalla & Wulfmeyer (2014), Xiao et al. (2008), Montmerle & Faccani (2009)

2. Our data assimilation (DA) systems

Space-Time Multiscale Analysis System (STMAS)

- Evolution of the LAPS system.

- Sequential **variational analysis** based on a multigrid descomposition technique.



- STMAS sequentially iterates a variational analysis from larger to shorter scales – similar to a successive correction technique within a variational framework:
  - Minimisation of the cost function $J^{(n)}$ at every grid level:

$$J^{(n)}[\mathbf{X}^{(n)}] = \frac{1}{2}\mathbf{X}^{(n)^T}\mathbf{X}^{(n)} + \frac{1}{2}[H^{(n)}\mathbf{X}^{(n)} - \mathbf{Y}^{(n)}]^T\mathbf{O}^{(n)^{-1}}[H^{(n)}\mathbf{X}^{(n)} - \mathbf{Y}^{(n)}]$$

  - Final analysis is obtained by summing the analyses from all the grid levels:

$$\mathbf{X} = \mathbf{X}^b + \sum_{n=1}^{N} \mathbf{X}^{(n)}$$

where $X^{(n)}$ is the analysis increment vector at grid level n

Xie, Y., S. E. Koch, J. A. McGinley, S. Albers, P. Bieringer, M. Wolfson, and M. Chan, 2011: A space and time multiscale analysis system: A sequential variational analysis approach. *Mon. Wea. Rev.*, **139**, 1224–1240.

3. Improvements on DA systems

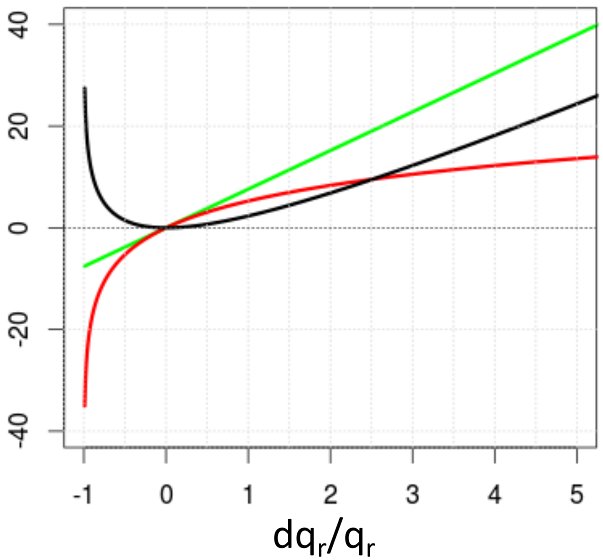
WRFDA Radar (1/2): Indirect assimilation (Wang et al., 2013)

- WRF 3D-Var minimises the cost function using a linearised observation operator

$Z = 43.1 + 17.5\log_{10}(\rho q_r)$ —Linearisation→ $dZ = \frac{17.5 dq_r}{q_r \ln(10)}$

$LE = dZ - dZ_n$

$dZ_n\ (dq_r)$ —Nonlinear perturbation→ $dZ_n = 17.5\log_{10}[(q_r + dq_r)/q_r]$



- **Several drawbacks identified:**
  - ○ $dZ > dZ_n \Rightarrow$ dry bias using dZ
  - ○ Large linear approximation errors (LE) easily reached (especially for a dry background).
  - ○ dZ invalid when $q_r = 0$ on the background ($q_r \geq 0.05$ g/kg imposed)
- **Indirect assimilation of reflectivity (WRFDA v3.7):**
  - ○ Microphysics and water vapour are retrieved and assimilated.
  - ○ Cloud control variables are added.
  - ○ Additional microphysics (rain, snow and graupel) partition described in Gao & Stensrud (2012).

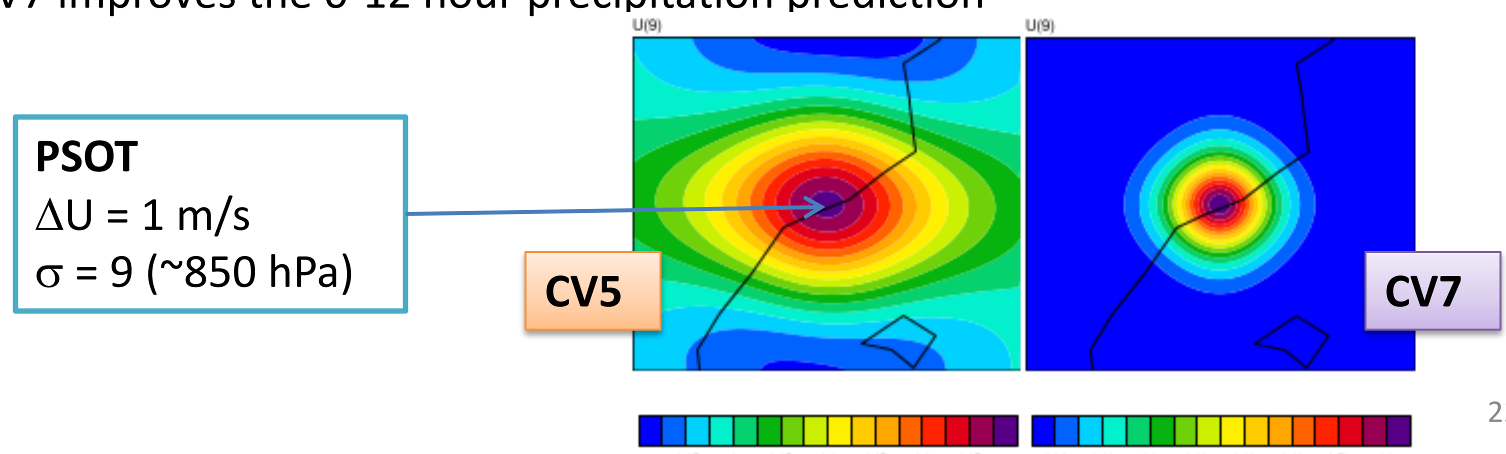
3. Improvements on DA systems

WRFDA Radar (2/2): Control variables CV7 (Sun et al., 2016)

- So far we used the **CV5** option: ψ, χ_u, T_u, RH_s, $P_{s,u}$
- Beginning in WRFDA v3.7 (corrected on v3.8) a new set of CV is available:

  u, v, T, RH_s, P_s $\rightarrow$ **CV7**

- Sun et al. (2016) show that:
  - CV5 decreases the variance & increases the length scale for u and v $\rightarrow$ **analysis increments tend to miss small-scale features**.
  - Artificial tunning (decrease) of CV5 length scales can result in unrealistic correlations at long distances.
  - **CV7 allows closer fits to radar wind observations**
  - CV7 improves the 0-12 hour precipitation prediction



4. Conclusions

- **STMAS outperforms LAPS** for the cases under study → **STMAS operational**
- The original WRFDA – Radar technique leads to unrealistic RH analyses → some forecasts perform worse than the control run.
- **Indirect reflectivity DA + CV7** in WRFDA **outperform the original approach** → **into operations at SMC this spring.**
- **Future work:** Many components of the system need to be reconsidered
  - Cycling (hot vs cold start, refreshing) for both STMAS & WRFDA
  - Background error characterisation (hybrid approach) for WRFDA
  - Cumulus: scale-aware scheme / explicit
  - Improve cloud analysis (STMAS) / Microphysics partition (WRFDA)
  - ...
- **Challenges**
  - Major bug fix in WRFDA v3.9 (17/04/2017) → repeat experiments
  - LAPS / STMAS no longer supported at NOAA/ESRL

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- Gao, J. and D.J. Stensrud, 2012: Assimilation of Reflectivity Data in a Convective-Scale, Cycled 3DVAR Framework with Hydrometeor Classification. *J. Atmos. Sci.*, **69**, 1054–1065.
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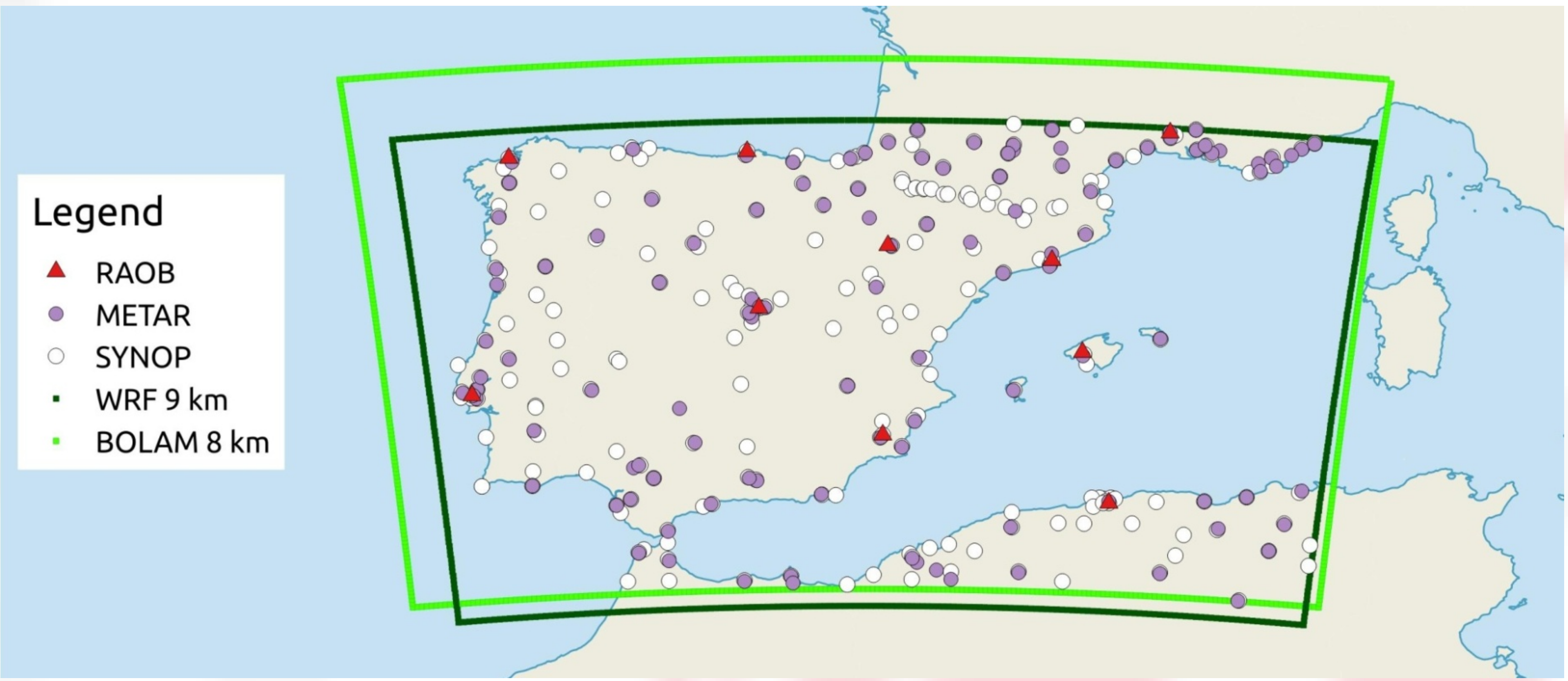
COARSER DOMAINS

- **SFC: METAR/SYNOP**
- **OBS in <u>common domain</u>**
- **Grid – Point: *nearest neighbour over land***
- **Aggregation (all stations & selected period) – MAE / ME computation**



SFC - CONCLUSIONS

BOLAM

- T2m:
  - Highest error in winter/summer
  - Cold bias – specially afternoon/evening
- Td2m:
  - Better than WRF!
  - Highest error in summer
  - Dry bias during daytime
- pmsl:
  - Slight underestimation – specially in summer
- V10m
  - Slight overestimation – specially during night

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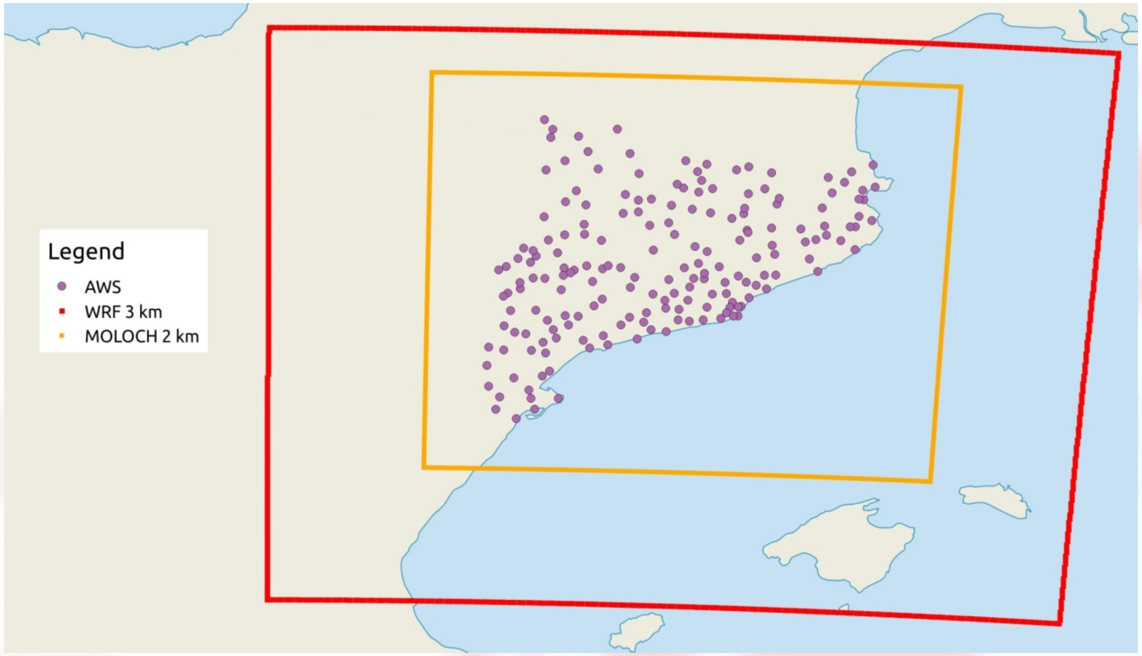
NESTED DOMAINS

- SFC: AWS
- OBS in common domain
- Grid – Point: *nearest neighbour over land*
- Aggregation (all stations & selected period) – MAE / ME computation



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SFC - CONCLUSIONS

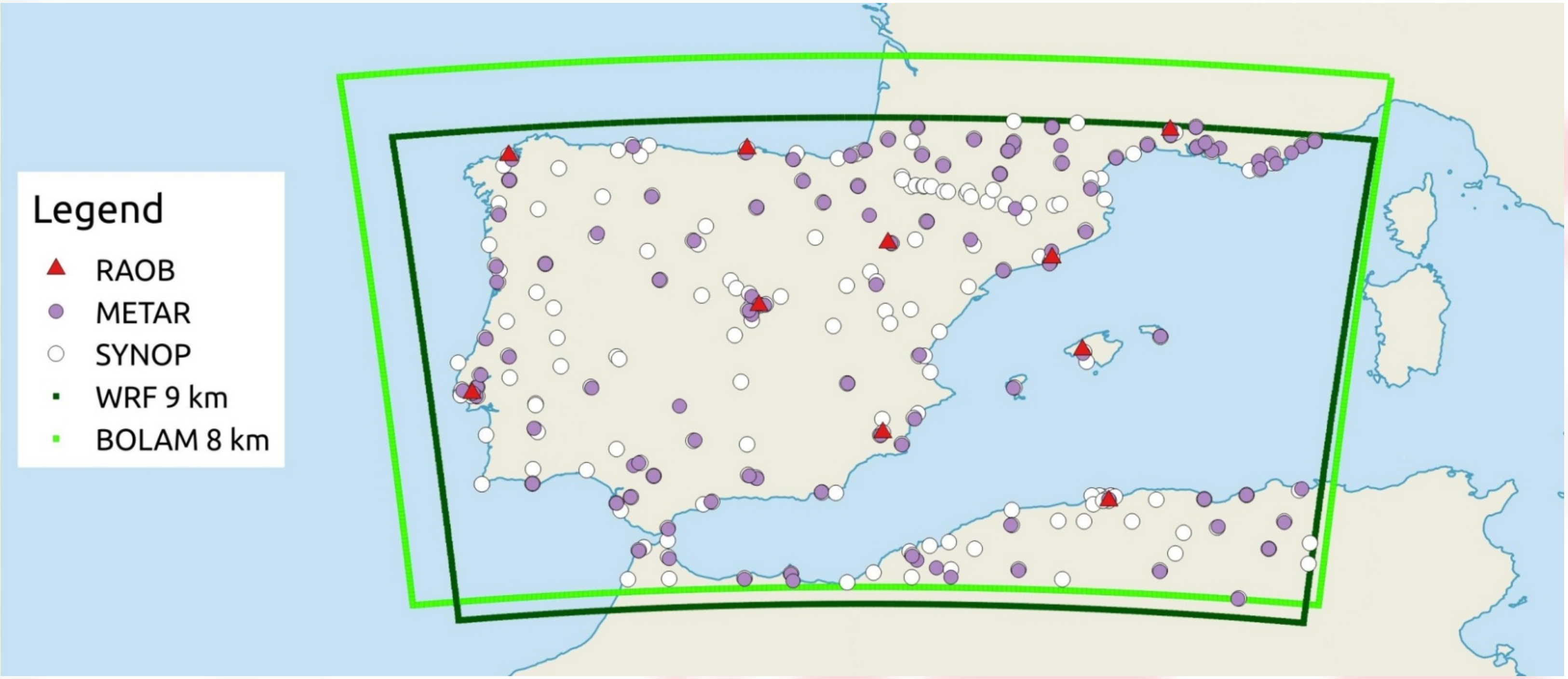
MOLOCH

- T2m:
  - Positive/negative bias during night/day
  - Highest error during night (also day in summer)
- RH2m:
  - Wet bias specially in winter (better in spring/autumn)
  - Highest error during sunrise/sunset periods
  - Dry bias at initial time (always)
- V10m:
  - Overestimation (specially during daytime)
  - A bit worse than WRF on average

WRF-ARW v2.2 YSU PBL scheme used!

COARSER DOMAINS

- **SFC: RAOB**
- **OBS in <u>common domain</u> – 10 stations**
- **Grid – Point: *nearest neighbour – 850, 700, 500, 300 hPa***
- **Aggregation (all stations & selected period) – MAE / ME computation**



UPA - CONCLUSIONS

BOLAM

- T:
  - Error increases at lowest levels in winter/summer
- Td:
  - Error increases at higher levels – specially in winter
  - Wet bias in winter – specially at highest levels
  - Dry bias in summer at lowest levels
- V:
  - Error increases at higher levels and in winter
- GH:
  - Error increases at higher levels and in winter
  - Slight underestimation

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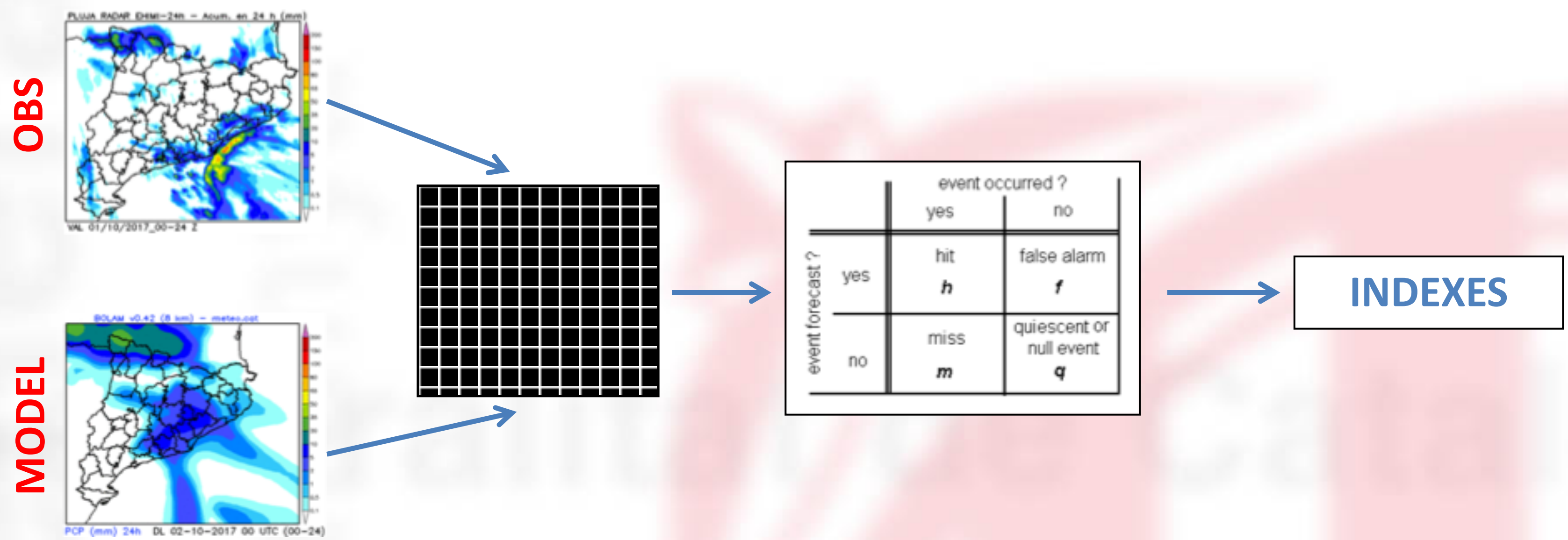
PRECIPITATION

- **Precipitation analysis: radar + pluviometers – EHIMI (1 km)**
- **Reprojection: <u>common domain</u>**
- **Grid – Grid: *dichotomous contingency tables computation (by thresholds)***
- **Aggregation (all domain & selected period) – POD / FAR / CSI / BIAS**



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RESULTS

- BOLAM
  - Small differences with WRF-ARW
  - Forecasters feedback:
    - Similar than other models (*with similar resolution*)
- MOLOCH
  - A bit worse than WRF on average

    MOLOCH explicit / WRF scheme KF – *convection over sea areas?*
  - Forecasters feedback:
    - QPF overestimation
    - Problems in localization of maxima

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SWAN

The wave forecasting system is composed of two numerical domains and is based on a downscaling technique.

The largest domain (SWAN11) covers the western Mediterranean Sea with a spatial resolution of 11 km and provides boundary conditions to a second-level domain (SWAN03), which covers the Balearic Sea with a spatial resolution of 3 km.

The SWAN11 run is forced with 10-m surface winds from WRF_ONA16 and the SWAN03 run is forced with 10-m surface winds from WRF_ONA04.

In both domains, the bathymetry used in the model is a 0.0083º grid resolution bathimetric data from GEBCO.

The spectrum is discretized with a constant relative frequency resolution of $\Delta f = 1.1$ (logarithmic distribution) and a constant directional resolution of $\Delta\theta = 10º$. The discrete frequencies are defined between 0.01 Hz and 1 Hz. Above the high-frequency cutoff, a diagnostic tail f^{-4} is added.

The model implementation considers wind growth, quadruplet wave interactions and whitecapping.

The model is run twice every day (00 h and 12 h).

The model output of the previous run is used as initial conditions.

ROMS

One domain with a horizontal resolution of 1 km and a vertical resolution of 20 sigma-levels.

The bathymetry of the domain was built using 0.0083º grid resolution bathymetric data from GEBCO. This data was interpolated to the domain mesh and smoothed by means of a Shapiro filter.

The model is forced with data from the WRF_ONA04 run: 10-m surface winds, atmospheric pressure, relative humidity, atmospheric surface temperature, precipitation and shortwave and longwave net heat fluxes.

The initial and boundary conditions are taken from the IBI-MFC (Iberian Biscay Irish – Monitoring and Forecasting Centre; (http://marine.copernicus.eu/) product, which has a horizontal resolution of 1/36º. The parameters used are: 3D daily means of temperature, salinity and baroclinic water currents and 2D (surface) hourly means of sea surface height and barotropic water currents.

The model implementation includes a Generic Length-Scale turbulent vertical mixing scheme with the $k - \omega$ parametrization, a logarithmic profile for the bottom boundary layer and horizontal mixing terms in geopotential surfaces.

The Ebro River discharge is characterized with a climatology of river runoff and temperature. The river salinity is imposed as a constant value of 18 psu.

The model is in a pre-operative phase, running once a day.