

Ocean Predictions and uncertainty estimates

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SUMMARY

1. The prediction/forecasting problem concepts and historical notes
2. Ocean forecasting at work: the Mediterranean Sea
3. The uncertainty in winds projects on the ocean mesoscales

*What is it that I really seek? Whither am I steering?
 I could not free myself from the thought
 that “There is after all but one problem worth attacking,
 viz, the precalculation of future conditions.”*

V. Bjerknes, ‘Meteorology as an exact science’, Monthly Weather Review, 1914

Napier, 1614, *Mirifici logarithmorum canonis descriptio*



Deg. o	+/-	Logarithm	Sines
0		0.000000000000000	1.000000000000000
1	-	0.434294481903550	0.841470953769237
2	-	0.868588784145168	0.656234148965587
3	-	1.302882097449432	0.470567945908458
4	-	1.737175420745747	0.284856931615914
5	-	2.171468744033130	0.099098987691914
6	-	2.605762067320503	-0.198498434674424
7	-	2.139855398159779	-0.392708825152125
8	-	2.574148696965126	-0.587018212530125
9	-	2.008441995454148	-0.781327599916712
10	-	2.442735383985610	-0.975636776713712
11	-	2.877028675744671	-1.1699314649
12	-	3.311321955757988	-1.3642294478
13	-	3.745615665557988	-1.5585273847
14	-	4.179908451777415	-1.7528252217
15	-	4.614201338451771	-1.9471230587
16	-	4.04849414141513	-0.6414210546
17	-	4.482787345697373	-0.8357198844
18	-	4.917080340599493	-1.0300188444
19	-	5.351373420535188	-1.2243163444
20	-	5.7856663198120	-1.4186134444
21	-	6.21995931895135	-1.6129103440
22	-	6.654252451017114	-1.8072073439
23	-	7.08854500706	-2.0014957767
24	-	6.681149645469493	-2.1957754646
25	-	7.115437034231676	-2.3899731515
26	-	7.5497384384494	-2.5839971454
27	-	7.984076741246113	-2.7780996913
28	-	8.41738031610143	-2.9722099612
29	-	7.775186757517515	-3.1663199611
30	-	8.2091381474347	-3.3603199610

Deg. 89

Deg. o	+/-	Logarithm	Sines
30	-	8.736147845914510	38.1 0.999619.10
31	-	9.170438454914510	40.1 0.999519.618
32	-	9.604789454914510	42.1 0.999419.618
33	-	10.039138454914510	44.1 0.999319.618
34	-	10.47338454914510	46.1 0.999219.618
35	-	10.907638454914510	48.0 0.999119.618
36	-	11.34198454914510	50.0 0.999019.618
37	-	11.776338454914510	51.8 0.998919.618
38	-	12.21068454914510	54.8 0.998819.618
39	-	12.645038454914510	57.0 0.998719.618
40	-	13.07938454914510	59.1 0.998619.618
41	-	13.513738454914510	61.1 0.998519.618
42	-	13.94808454914510	63.1 0.998419.618
43	-	14.382438454914510	65.1 0.998319.618
44	-	14.81678454914510	67.1 0.998219.618
45	-	15.251138454914510	69.1 0.998119.618
46	-	15.68548454914510	71.1 0.998019.618
47	-	16.119838454914510	73.0 0.997919.618
48	-	16.55418454914510	74.9 0.997819.618
49	-	16.988538454914510	76.8 0.997719.618
50	-	17.42288454914510	78.7 0.997619.618
51	-	17.857238454914510	80.6 0.997519.618
52	-	18.29158454914510	82.5 0.997419.618
53	-	18.725938454914510	84.4 0.997319.618
54	-	19.16028454914510	86.3 0.997219.618
55	-	19.594638454914510	88.2 0.997119.618
56	-	20.02898454914510	90.1 0.997019.618
57	-	20.463338454914510	92.0 0.996919.618
58	-	20.89768454914510	93.9 0.996819.618
59	-	21.332038454914510	95.8 0.996719.618
60	-	21.76638454914510	97.7 0.996619.618

Deg. 89

The forecasting/prediction problem definition 1/2

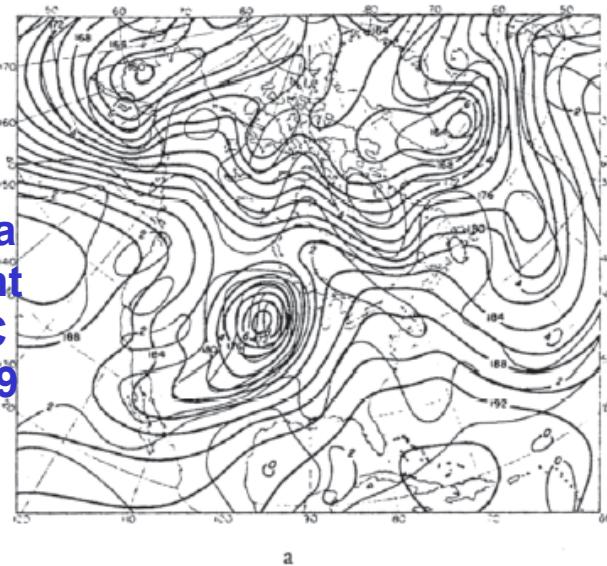
- Bjerknes (1904, 1914) defined for the first time the ‘rational method for weather predictions’
- In opposition to purely empirical and statistical methods, Bjerknes presented his rational version of forecasting based on the laws of mechanics and physics of the atmosphere
- Bjerknes developed a method to “*construct the pictures of the future states of the atmosphere from the current state of the atmosphere at a starting point*” following the deterministic approach set by Pierre de Laplace in 1820: “*We ought to regard the present state of the universe as the effect of its antecedent state and as the cause of the state that is to follow*”

The prediction problem definition 2/2

- Two conditions should be fulfilled in order to solve the prediction problem in atmosphere and oceans
 - I- Know the present state of the system as accurately as possible
 - II- Know the laws of physics that regulate the time evolution of the basic field state variables, i.e. have predictive models for atmosphere and oceans
- In order to solve the prediction problem the scientific approach should consider 3 partial problems
 - Comp.1: The observational network
 - Comp.2: The diagnostic and analysis tools/algorithms
 - Comp.3: The prognostic component

The first successful forecast: Princeton 1950

Analysis of 850 hPa Geo. Height 03:00 UTC Jan 5, 1949

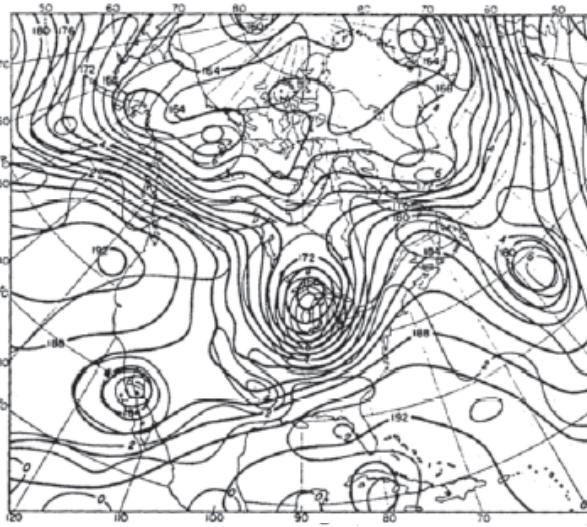


The key choice: barotropic quasigeostrophic numerical model

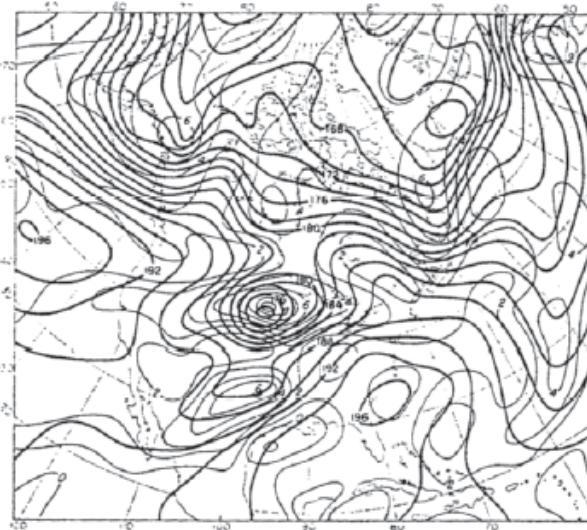
$$\frac{Dq}{Dt} = -\vec{v} \cdot \nabla q - \beta \frac{\partial \psi}{\partial x} + diss$$

$$q = \nabla^2 \psi$$

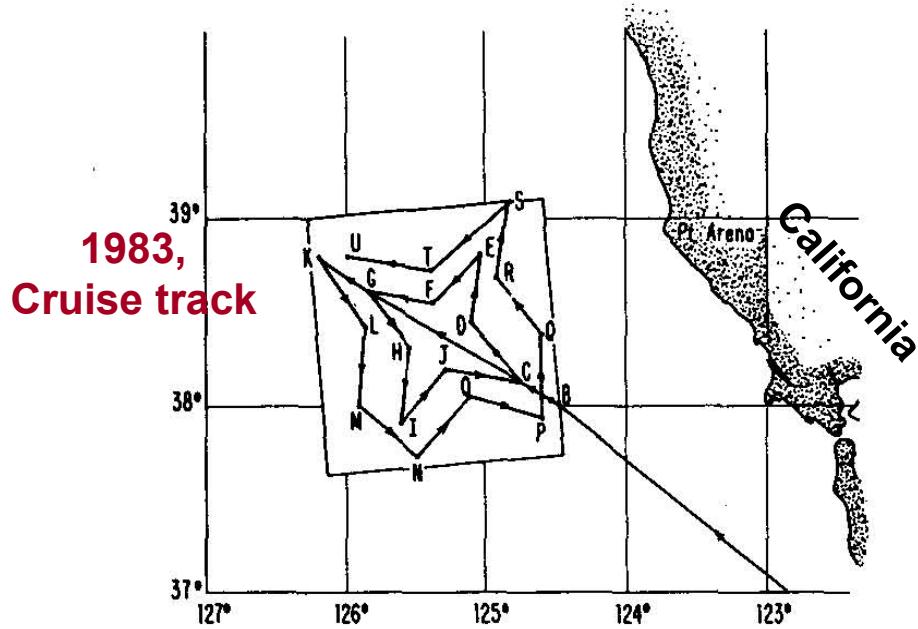
Analysis of 850 hPa Geo. Height 03:00 UTC Jan 6, 1949



Forecast of 850 hPa Geo. Height 03:00 UTC Jan 6, 1949



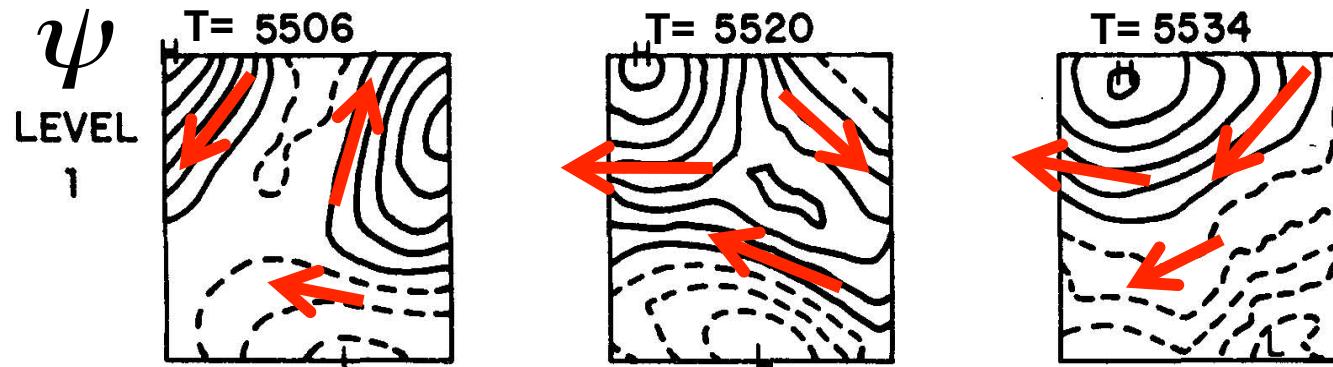
The first ocean forecast: Harvard and Monterey 1983



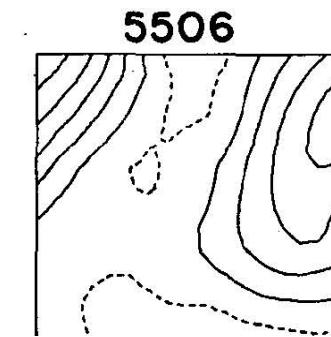
The key choice:
1) synoptic data
for initial conditions
2) baroclinic
multilevel
Quasigeostrophic
model

SEPTEMBER 1986

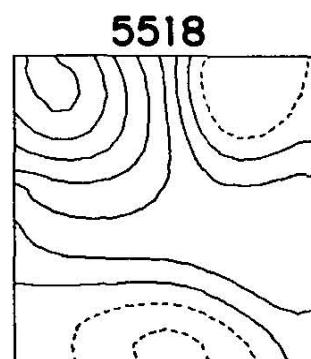
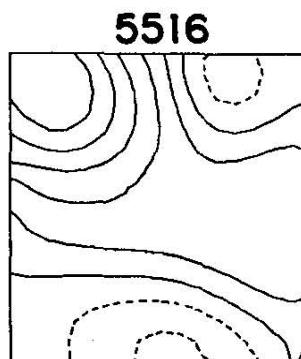
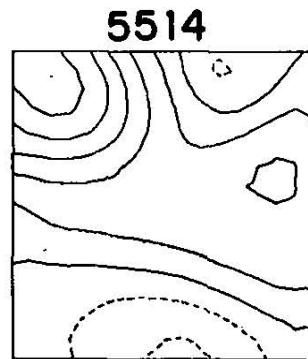
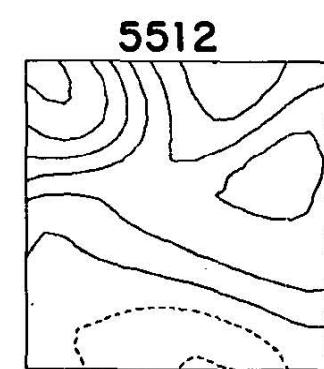
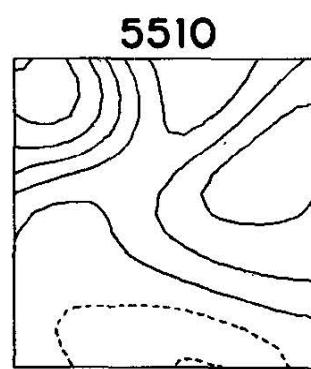
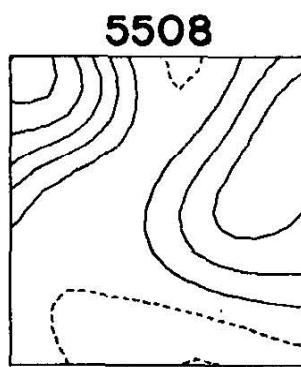
ROBINSON, CARTON, PINARDI AND MOOERS



The first ocean forecast: Harvard and Monterey 1983



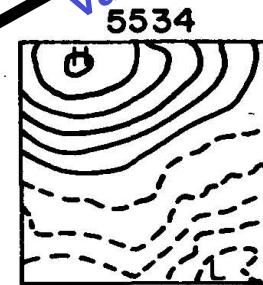
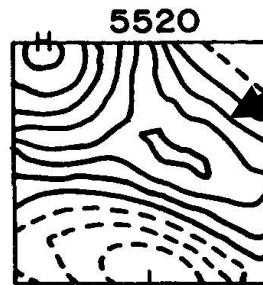
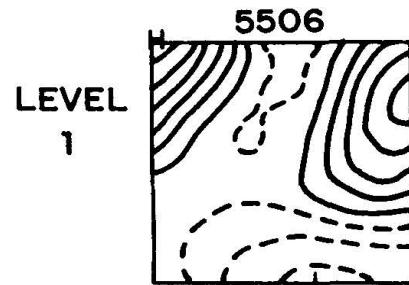
Initial condition



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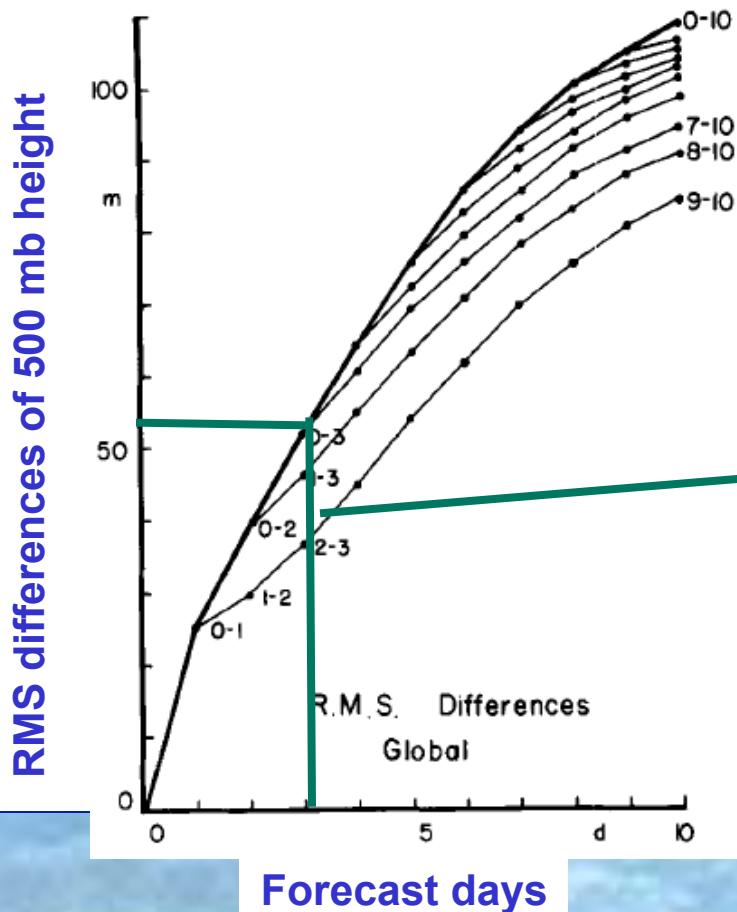
1565



validation

In the 60-80's Lorenz set the theoretical basis for the definition of the **predictability** problem

- Lorenz (1969) defined the atmospheric predictability problem as:
the time for which two analogue atmospheric states will double the initial difference among themselves.



Lorenz, 1982: used ECMWF forecasts to evaluate predictability time in a robust way

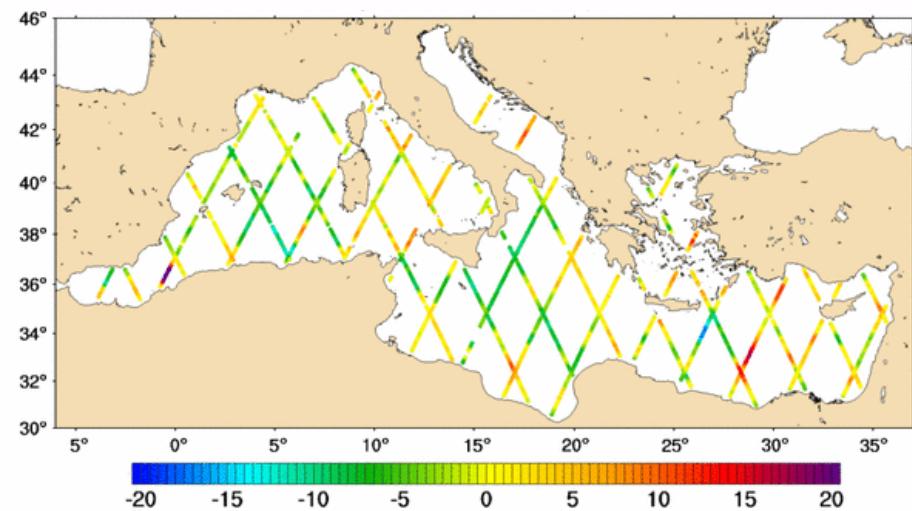
Doubling time of forecast error
~ 3 days

Ocean predictions : the operational start

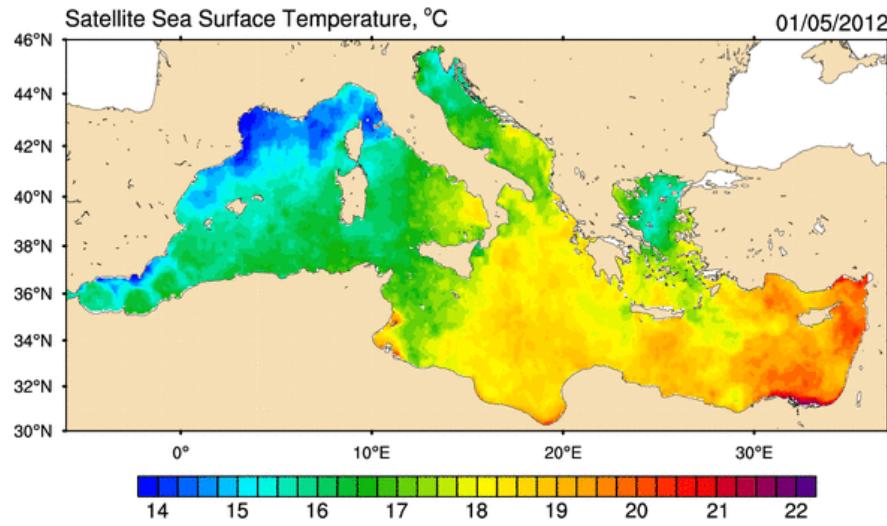
- 1992-2000:
 - Satellite altimetry started to give 10 days repeated mapping of the sea level with errors < 5 cm
 - The ship of opportunity profiles became available in near real time,
 - SST from satellite with accuracy > 0.5 deg C
 - Numerical large scale models started to resolve mesoscales and became more skillful to reproduce ocean processes
 - Atmospheric forcing became available at 50 km resolution
 - Data assimilation schemes started to be developed to assimilate both in situ and satellite sea level
- At the same time, in the Mediterranean a program of ocean predictions started to organize Bjerknes three components at the basin scales
- 2003: ARGO program started also in the Med

The near real time observing system components

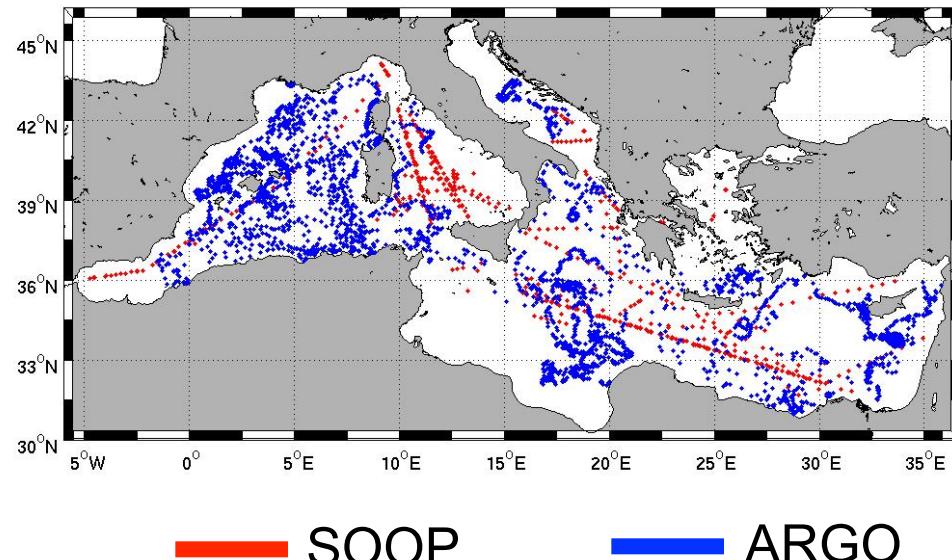
Multisatellite along track sea level



Multi-sensor daily OI SST



coverage for the
2008-2011 period



The diagnostic component today

Method is variational, so-called 3DVAR
(Dobricic and Pinardi, 2008)

A cost function, linearized around the background state,
is minimized:

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

$$\delta \mathbf{x} = \mathbf{x} - \mathbf{x}_b \quad \mathbf{d} = [H(\mathbf{x}_b) - \mathbf{y}]$$

Preconditioning is done using a control vector \mathbf{v} defined by:

$$\mathbf{v} = \mathbf{V}^+ \delta \mathbf{x}$$

$$\mathbf{B} = \mathbf{V} \mathbf{V}^T$$

\mathbf{V} is modelled as a sequence of linear operators: $\mathbf{V} = \mathbf{V}_D \mathbf{V}_{uv} \mathbf{V}_\eta \mathbf{V}_H \mathbf{V}_V$.

\mathbf{V}_V - Vertical EOFs.

\mathbf{V}_{uv} - Diagnose u and v .

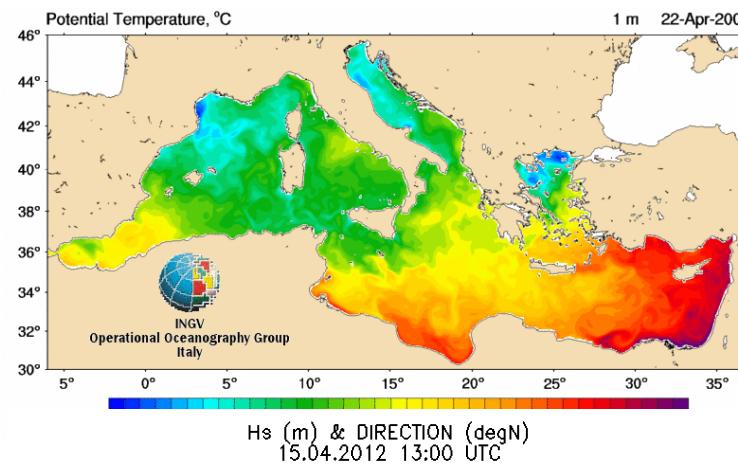
\mathbf{V}_H - Horizontal covariances.

\mathbf{V}_D - Divergence damping filter.

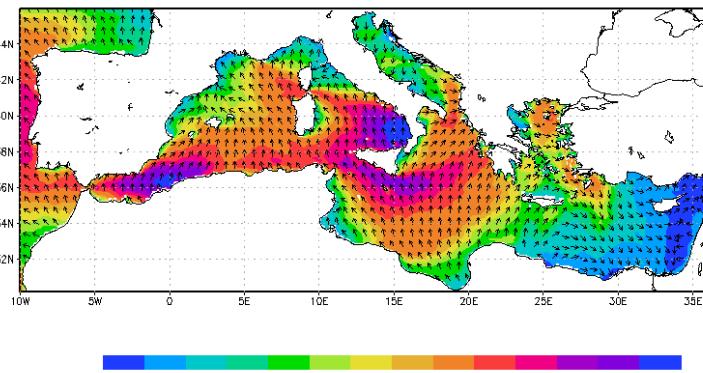
\mathbf{V}_η - Barotropic model for eta

The ocean numerical prediction models

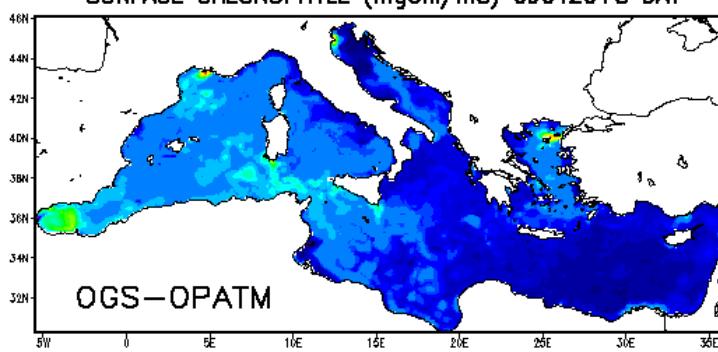
**A) Hydrodynamics
(MFS)**
1/16 deg resolution,
72 levels



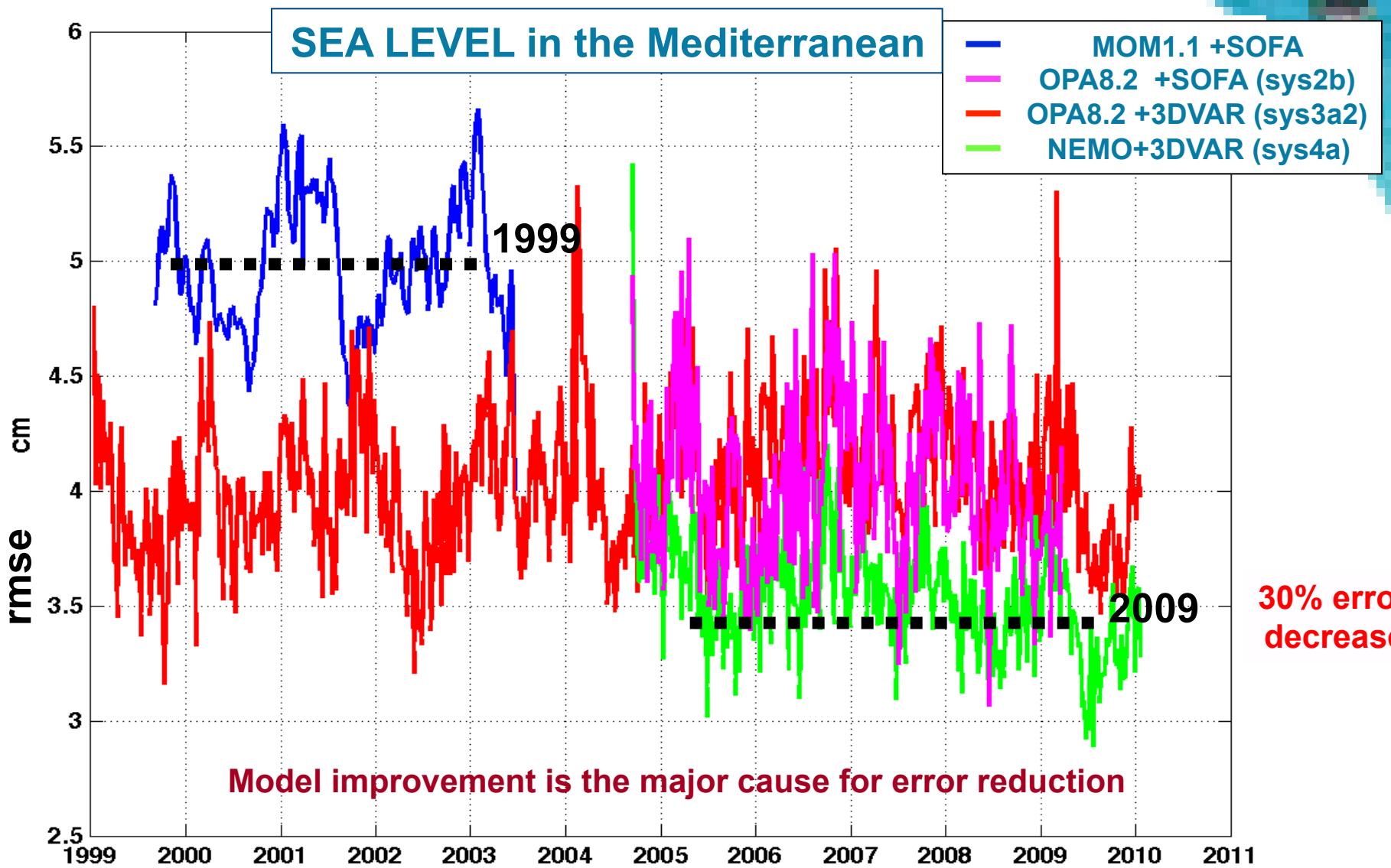
B) Waves
1/16 degree resolution
Wind drag coefficient for
hydrodynamics



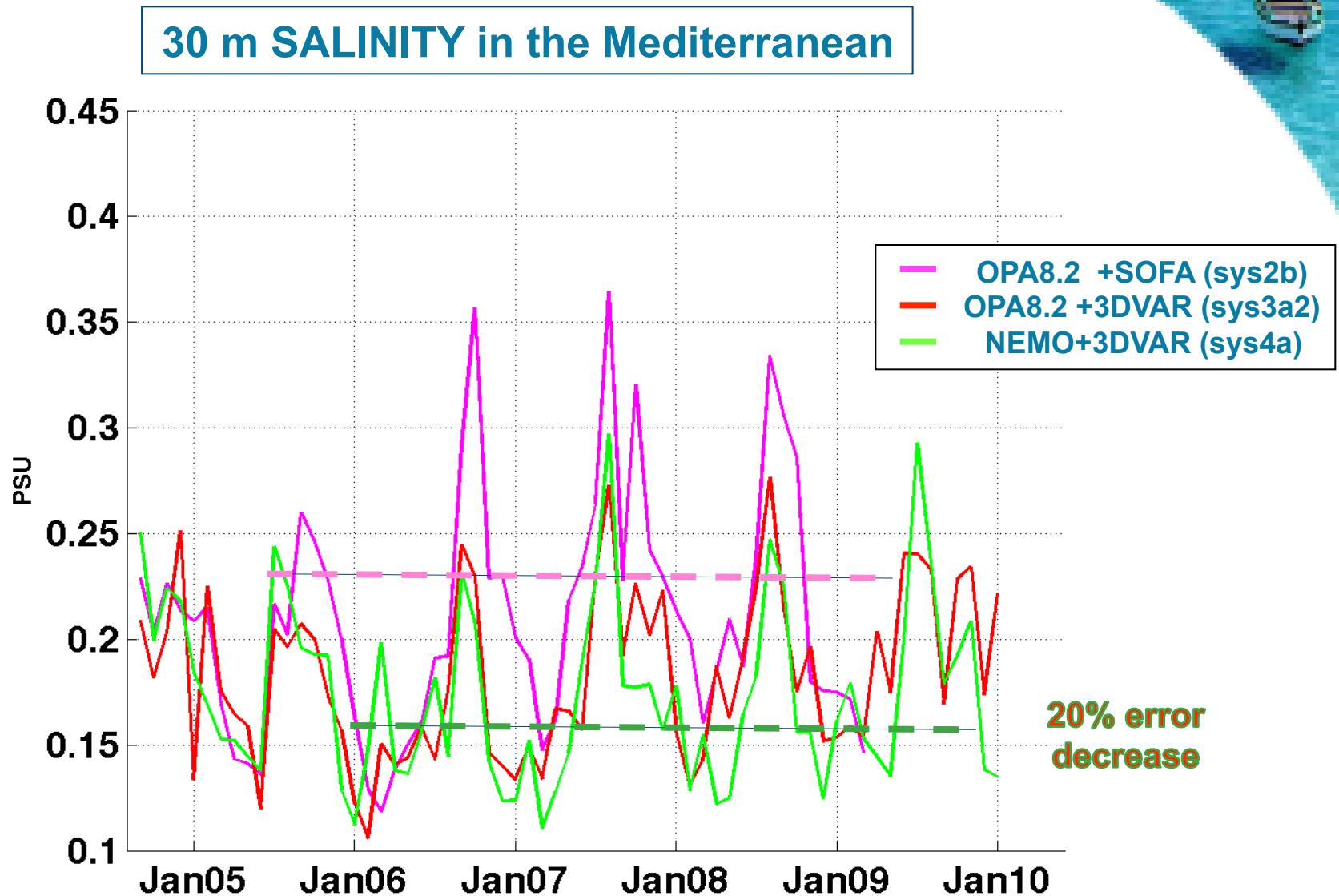
C) Pelagic Biochemistry
1/16 deg resolution



How did the error decrease in the last 10 years?



How did the error decrease in the last 10 years?



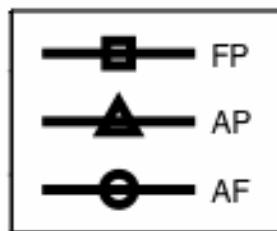
Predictability time for T and S

Analysis-forecast

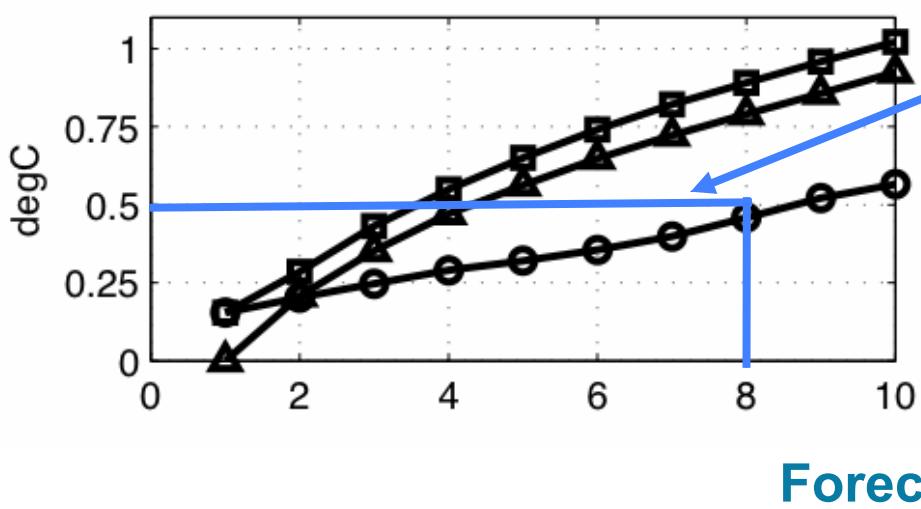
$$AF_c(t) = \sqrt{\frac{1}{N} \left\langle \sum_{i=1}^N (X_{FC}(t) - X_{AN}(t))^2 \right\rangle}$$

Analysis-Persistence

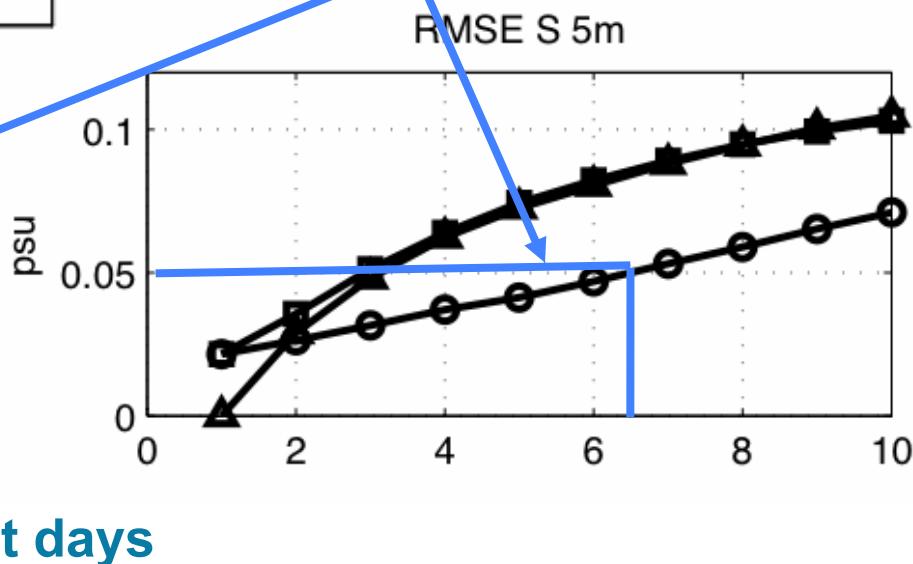
$$AP(t) = \sqrt{\frac{1}{N} \left\langle \sum_{i=1}^N (X_{AN}(t) - X_{AN}(t = d1))^2 \right\rangle}$$



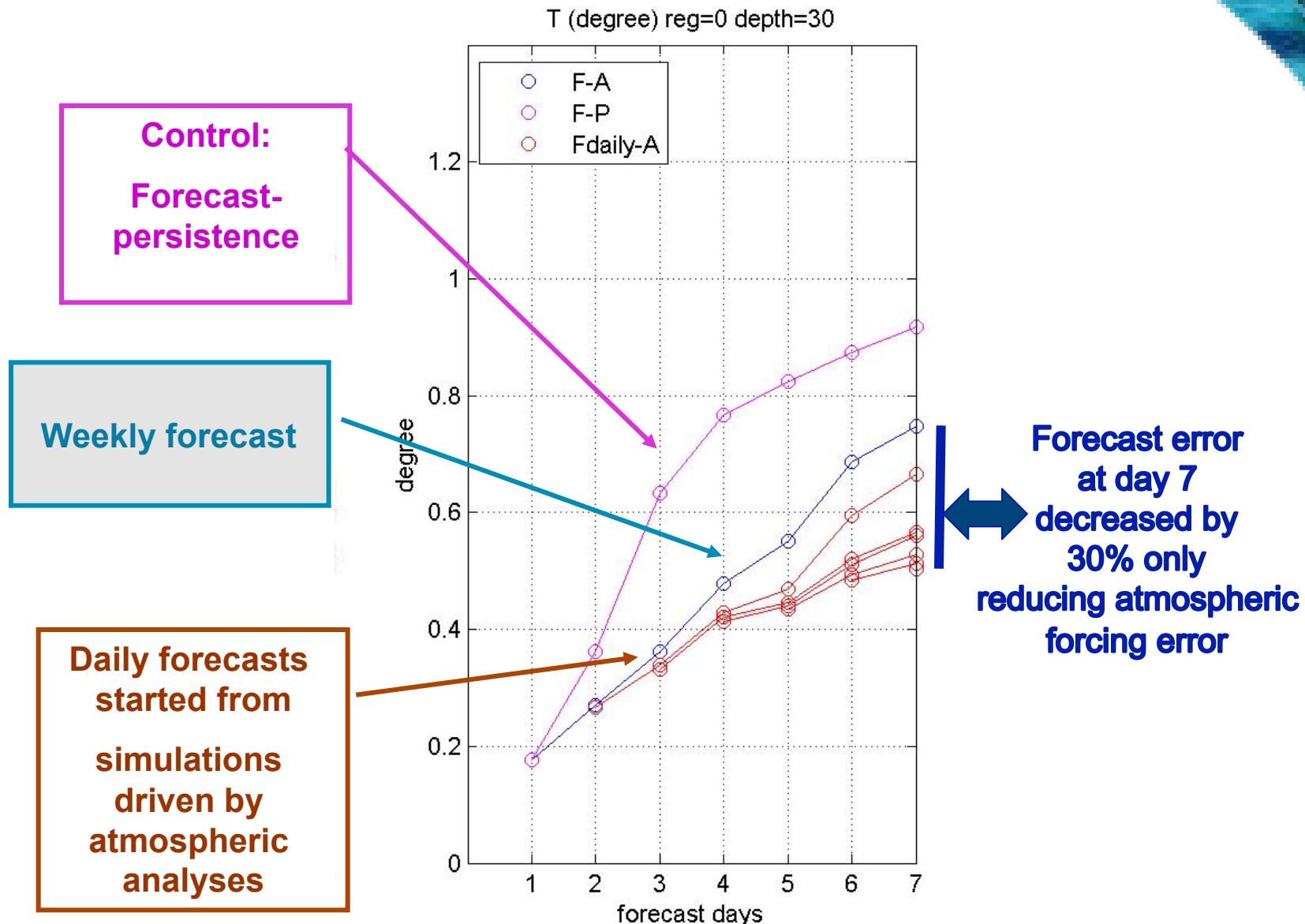
RMSE T 5m



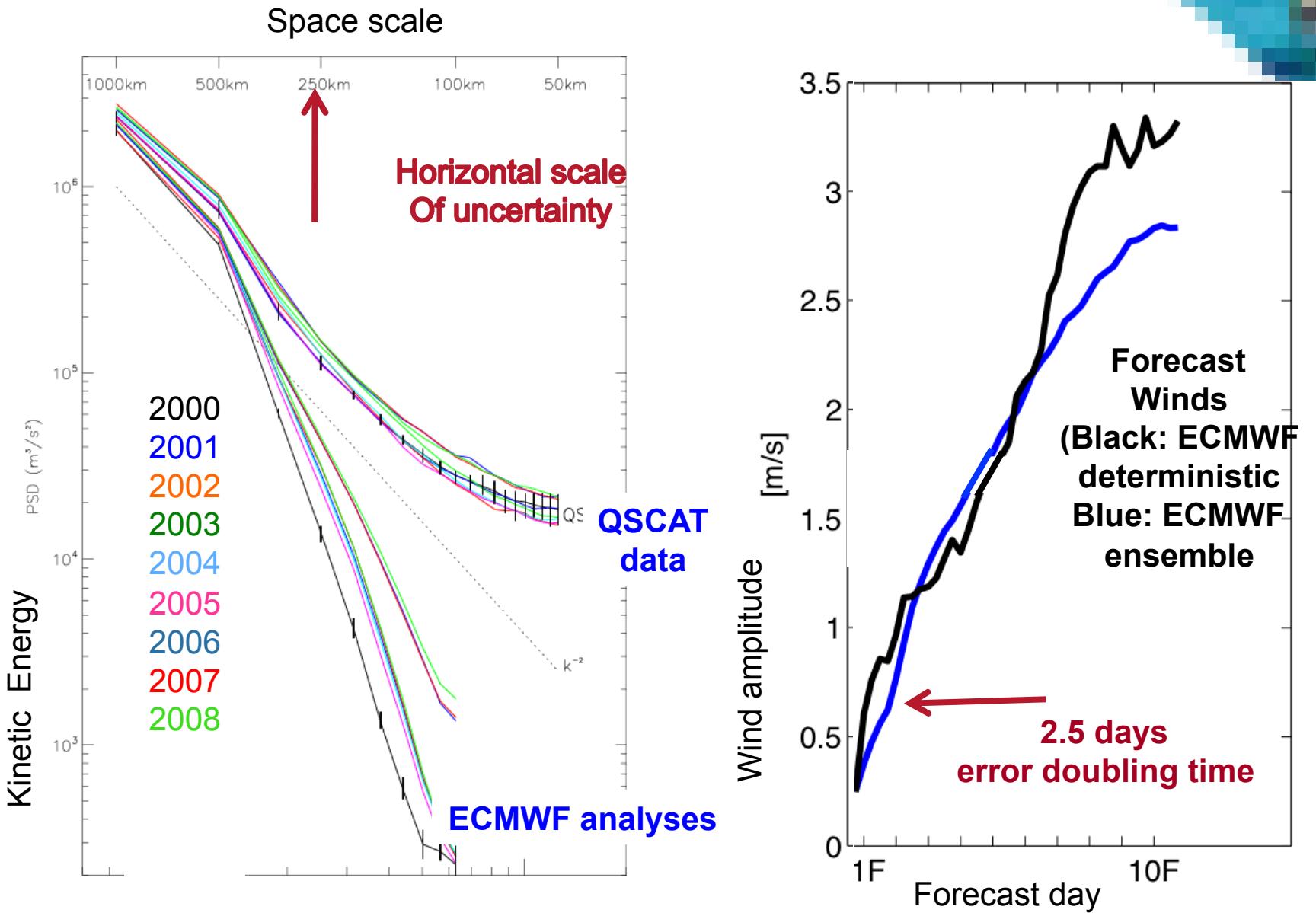
Doubling of initial error is 6-8 days



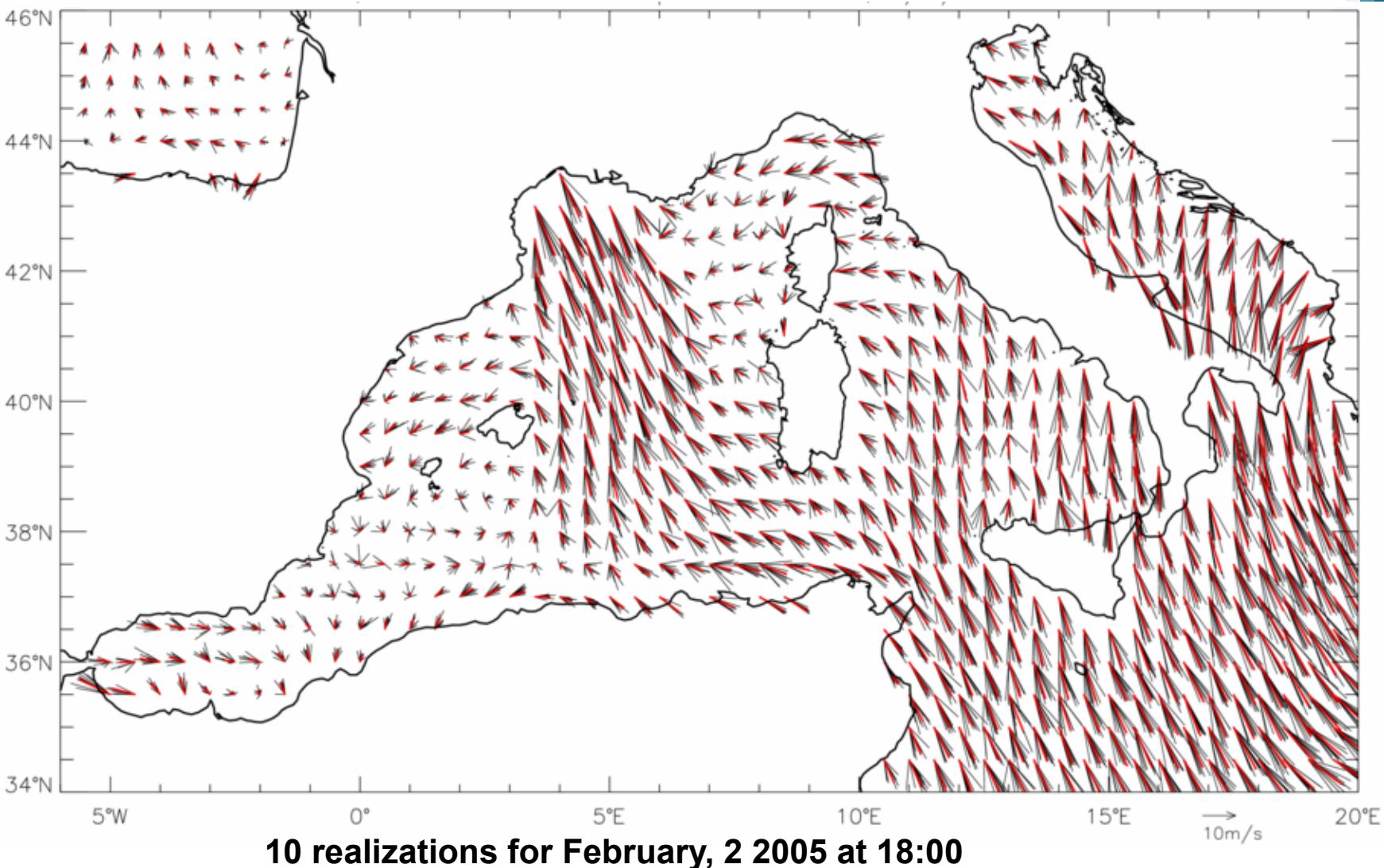
Forecast skill: the effect of atmospheric forcing errors



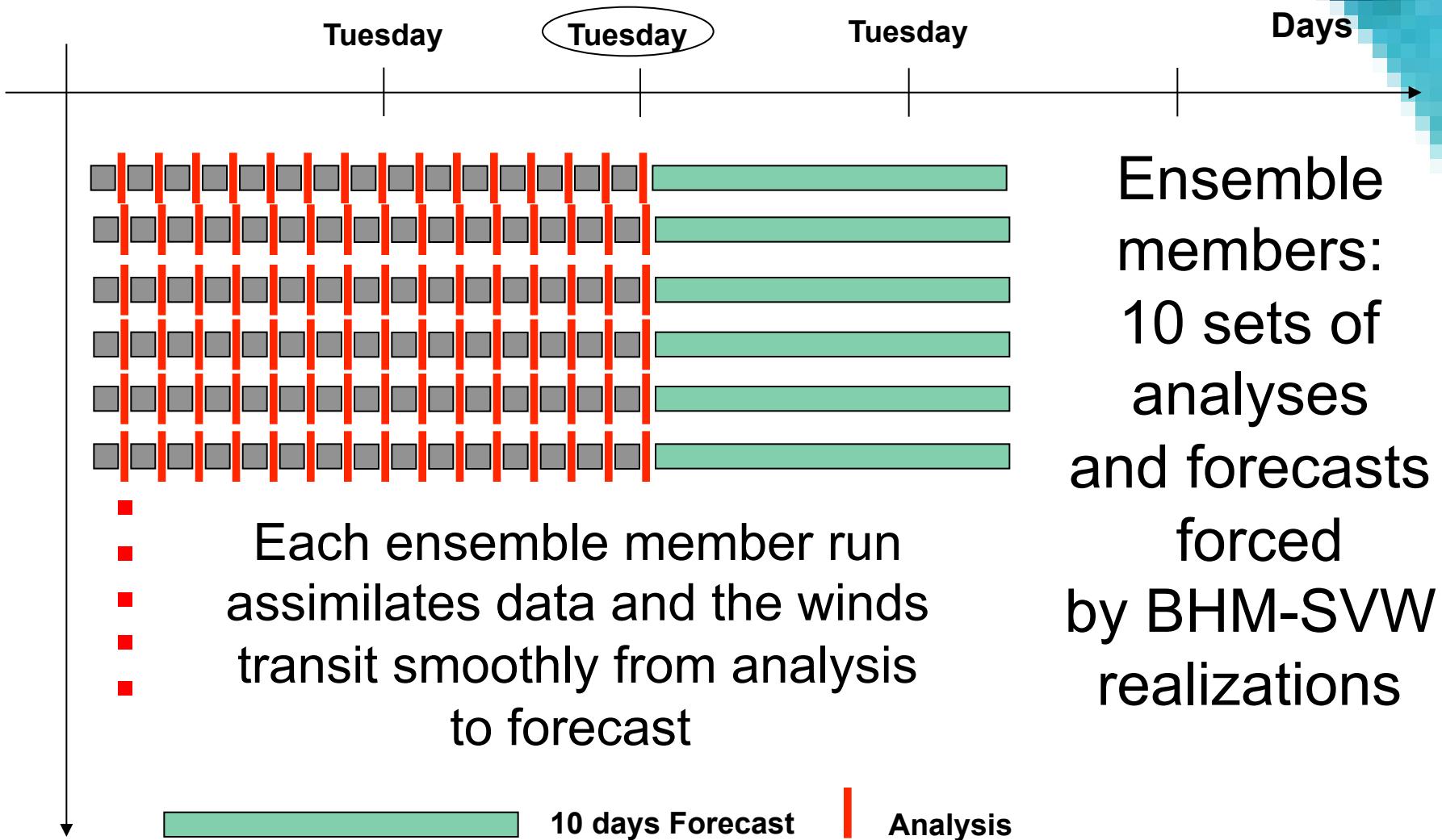
What is the uncertainty in the winds ? (Milliff et al., 2011)



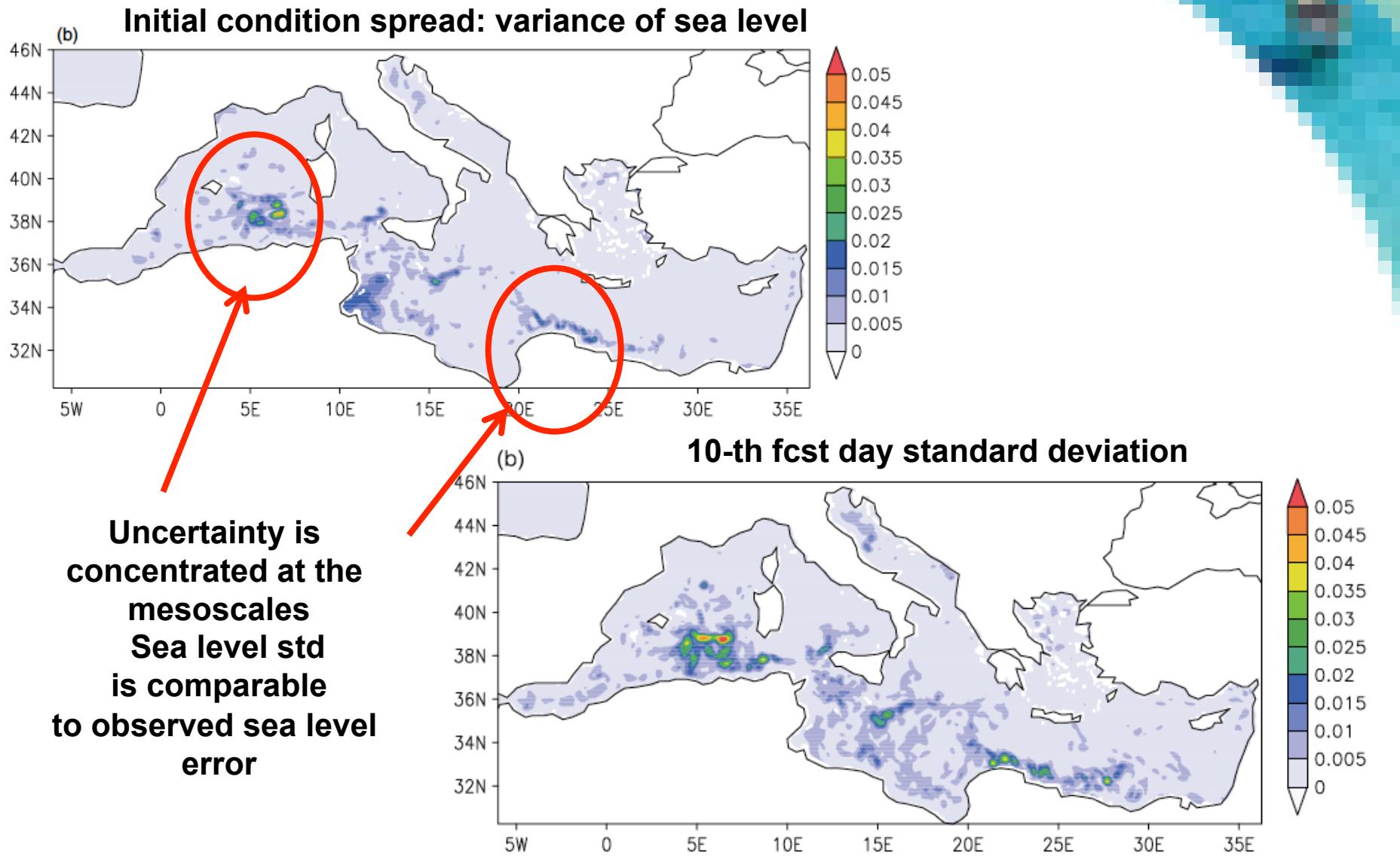
Posterior distributions of winds from a Bayesian Hierarchical Model: BHM-SVW realizations (Milliff et al., 2011)



The BHM-SVW Ocean Ensemble Forecast method (Pinardi et al., 2011)



Uncertainty in the ocean predictions due to uncertainty in the winds



In conclusions

- The Bjerknes method for atmospheric forecasting has been implemented operationally in the ocean in the past 15 years
- For the Mediterranean Sea uncertainty (rms) is connected to, in order of priority:
 1. Numerical ocean model improvements
 2. Atmospheric forcing uncertainties, in particular winds
- Predictability time scale for the ocean is 6-8 days
- Atmospheric uncertainty drives ocean forecast uncertainty with values comparable to observational errors