Ocean Predictions and uncertainty estimates

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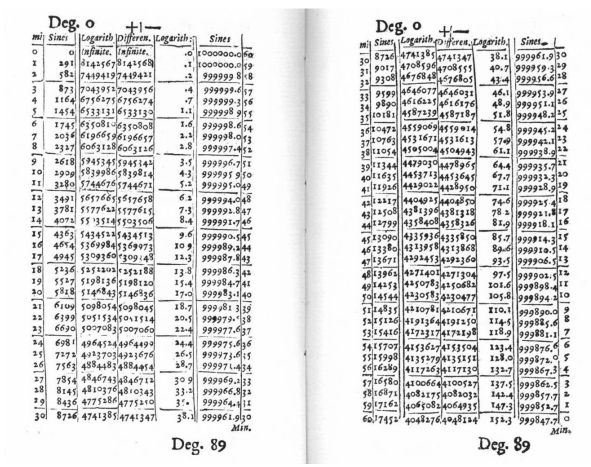
SUMMARY

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*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The forecasting/prediction problem definition 1/2

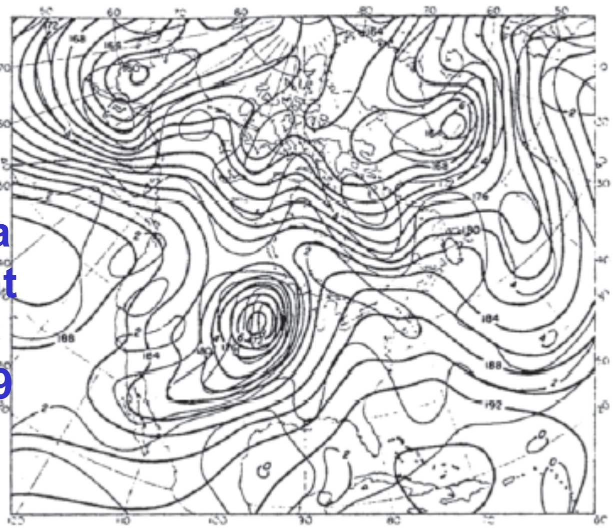
- Bjerknes (1904, 1914) defined for the first time the ‘rational method for weather predictions’
- In opposition to purely empirical and statistical methods, Bjerknes presented his rational version of forecasting based on the laws of mechanics and physics of the atmosphere
- Bjerknes developed a method 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



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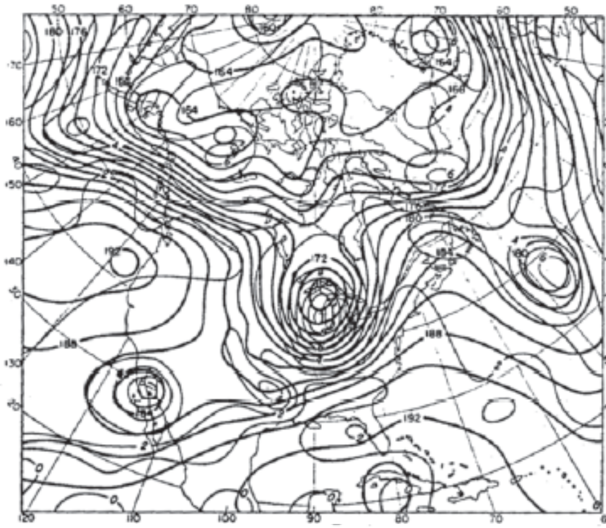
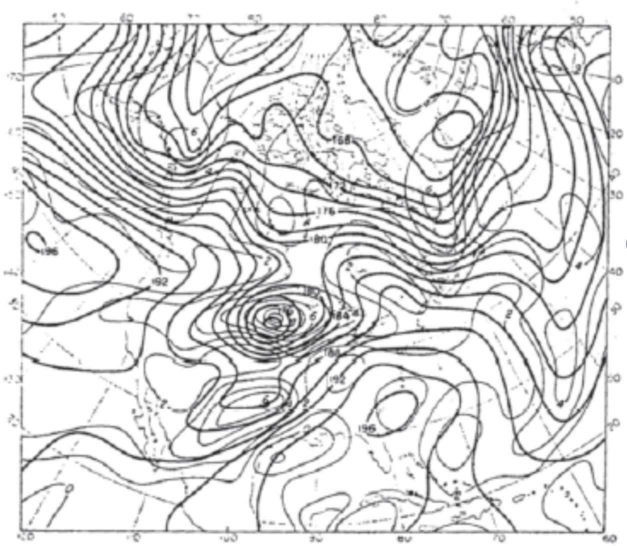


Analysis of 850 hPa Geo. Height 03:00 UTC Jan 6, 1949

The key choice: barotropic quasigestrophic numerical model

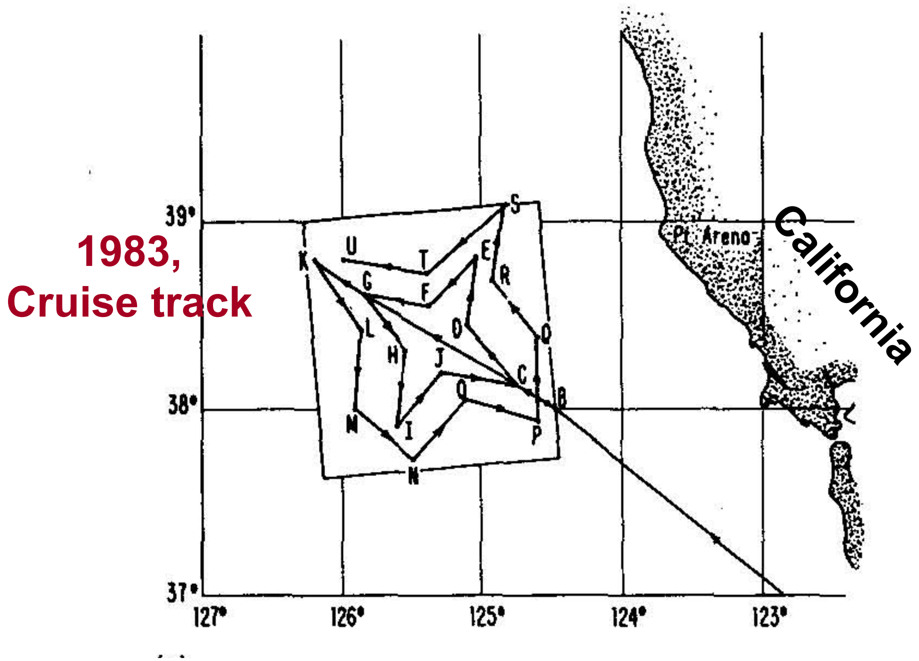
$$\frac{Dq}{Dt} = -\vec{v}.\nabla q - \beta\frac{\partial\psi}{\partial x} + diss$$

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



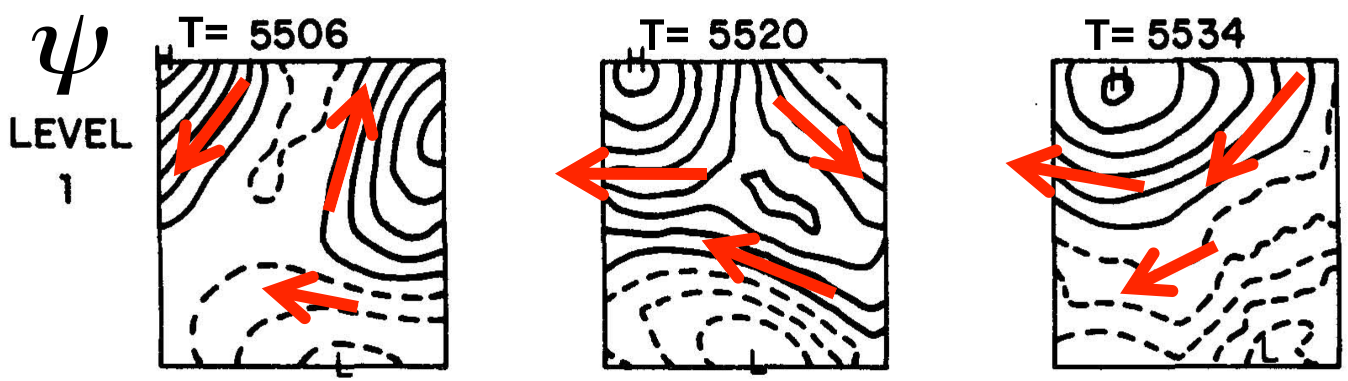
Forecast of 850 hPa Geo. Height 03:00 UTC Jan 6, 1949

The first ocean forecast: Harvard and Monterey 1983

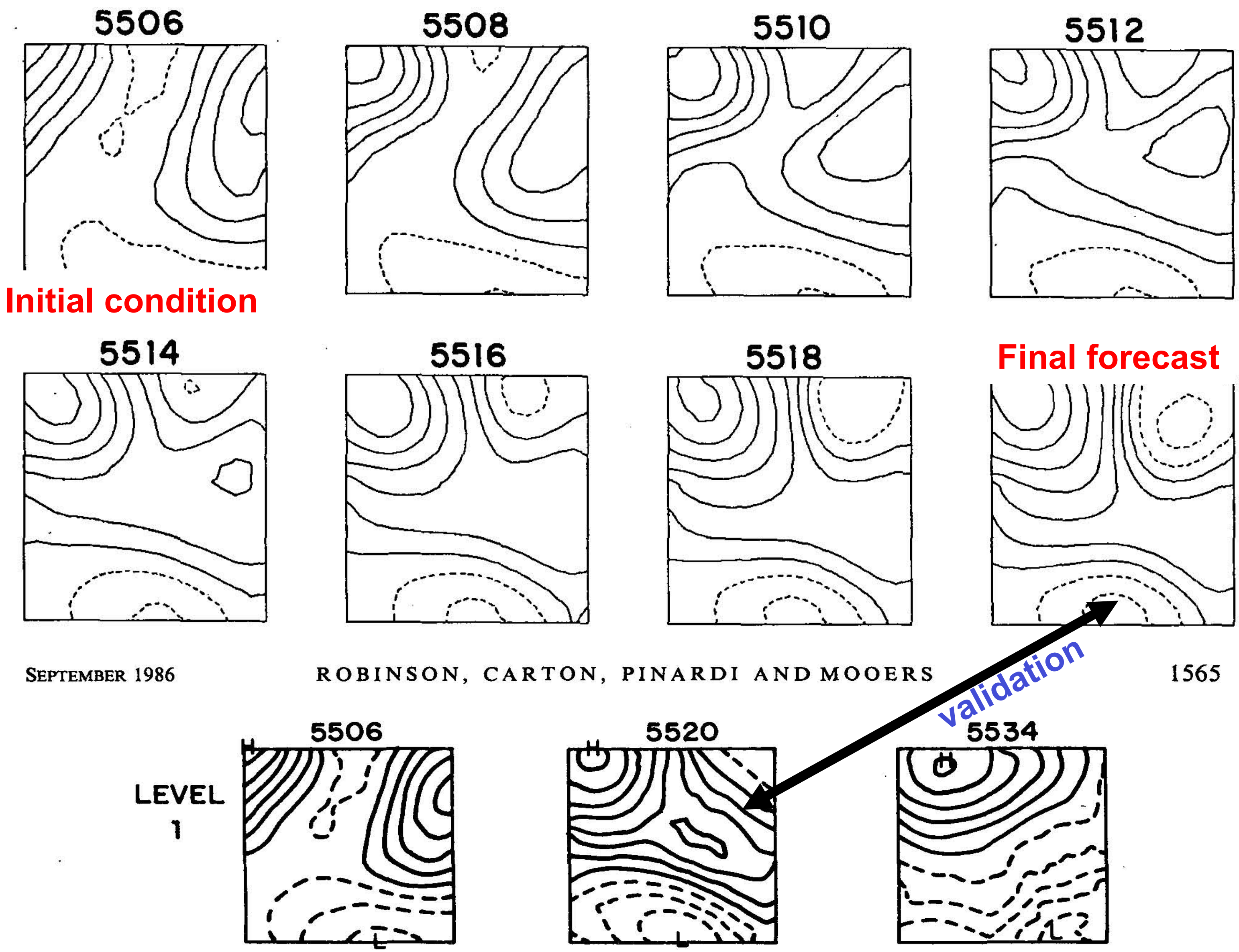


The key choice:
1) synoptic data for initial conditions
2) baroclinic multilevel Quasigeostrophic model

SEPTEMBER 1986 ROBINSON, CARTON, PINARDI AND MOOERS

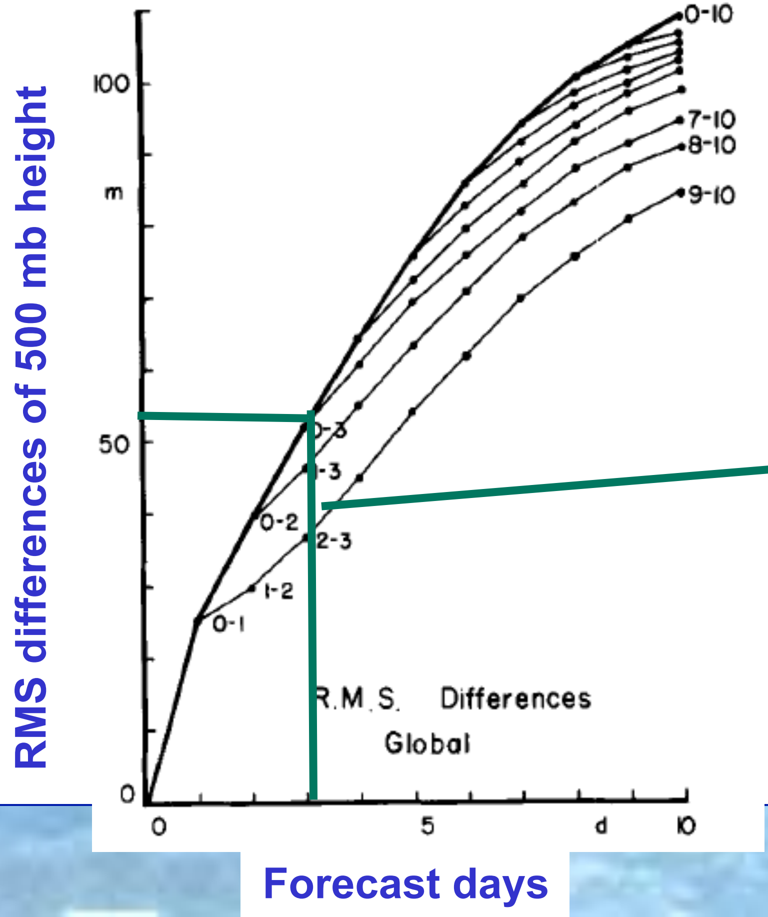


The first ocean forecast: Harvard and Monterey 1983



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

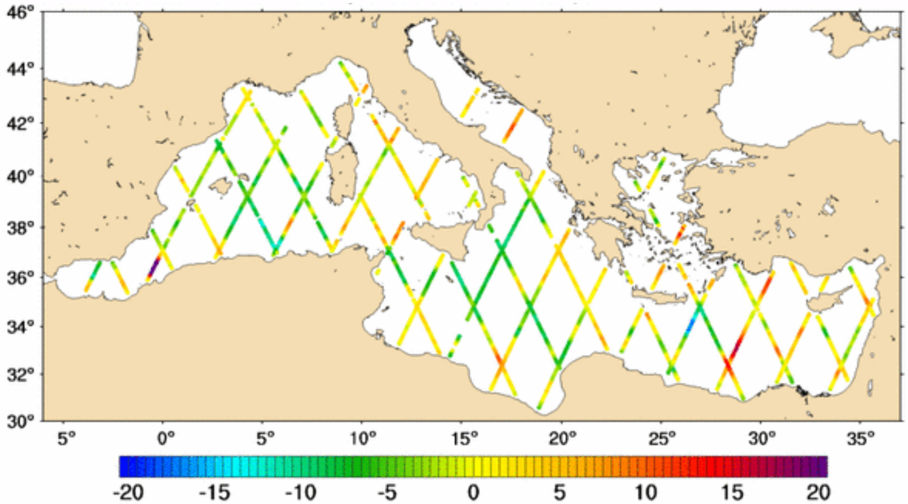
Doubling time of forecast error ~ 3 days

Ocean predictions : the operational start

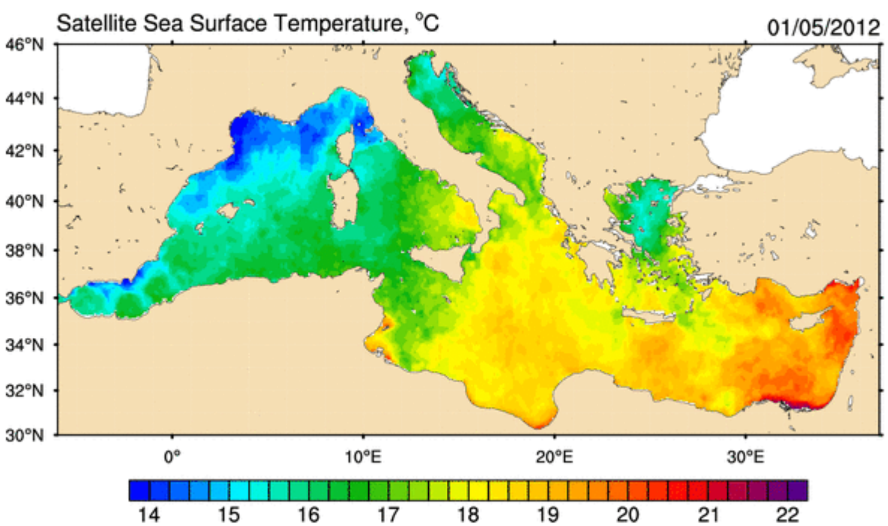
- 1992-2000:
  - Satellite altimetry started to give 10 days repeated mapping of the sea level with errors < 5 cm
  - The ship of opportunity profiles became available in near real time,
  - SST from satellite with accuracy > 0.5 deg C
  - Numerical large scale models started to resolve mesoscales and 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

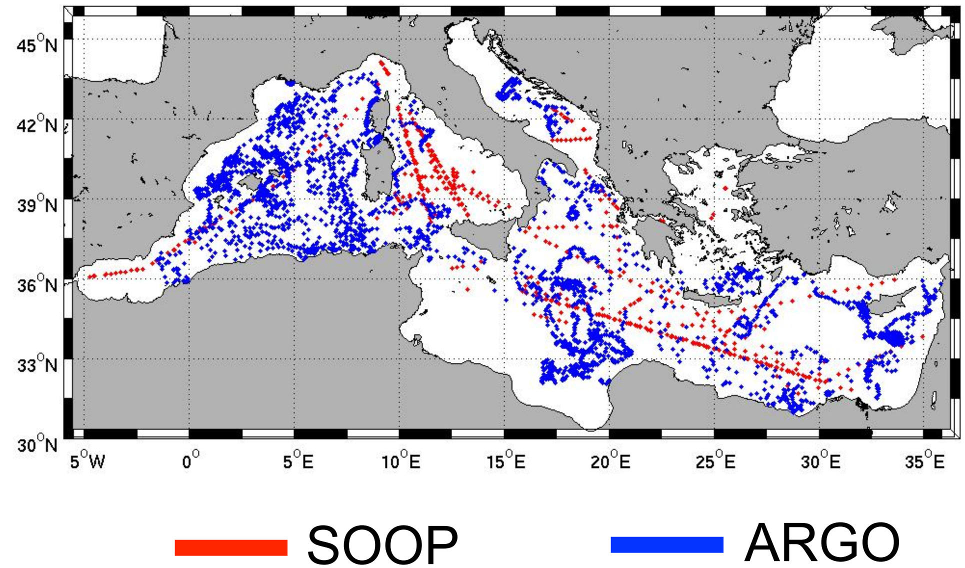
Multisatellite along track sea level



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:

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

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

Preconditioning is done using a control vector v defined by:

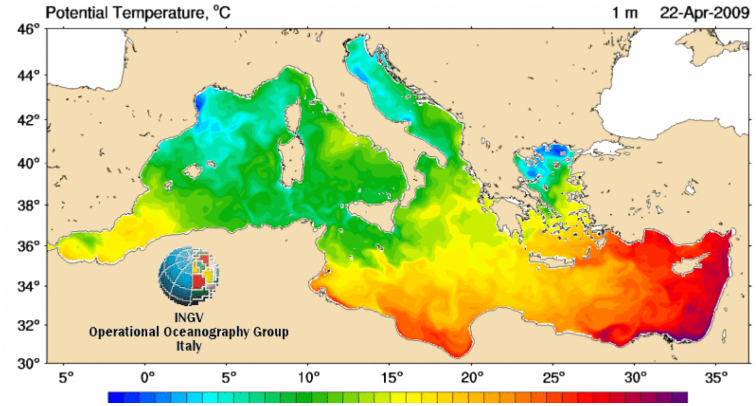
$$\mathbf{v} = \mathbf{V}^{+}\delta\mathbf{x} \qquad \mathbf{B} = \mathbf{V}\mathbf{V}^T$$

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

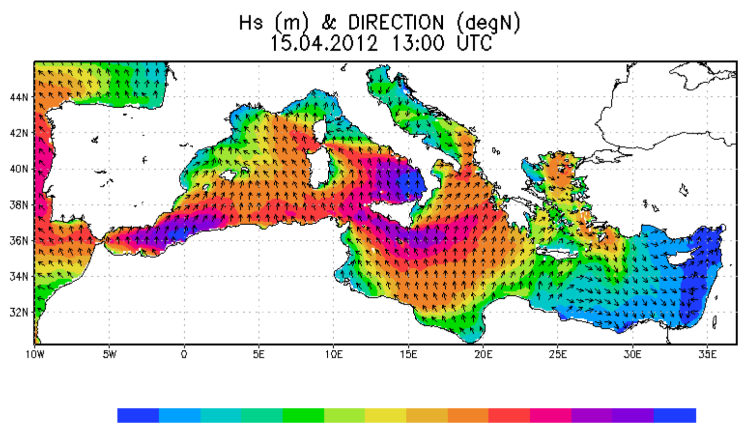
- $\mathbf{V}_V$ - Vertical EOFs.
- $\mathbf{V}_H$ - Horizontal covariances.
- $\mathbf{V}_\eta$ - Barotropic model for eta
- $\mathbf{V}_{uv}$ - Diagnose u and v.
- $\mathbf{V}_D$ -Divergence damping filter.

The ocean numerical prediction models

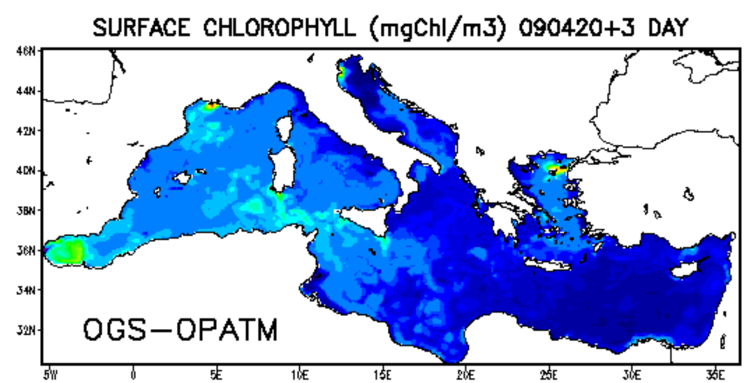
A) **Hydrodynamics**
(MFS)
1/16 deg resolution,
72 levels



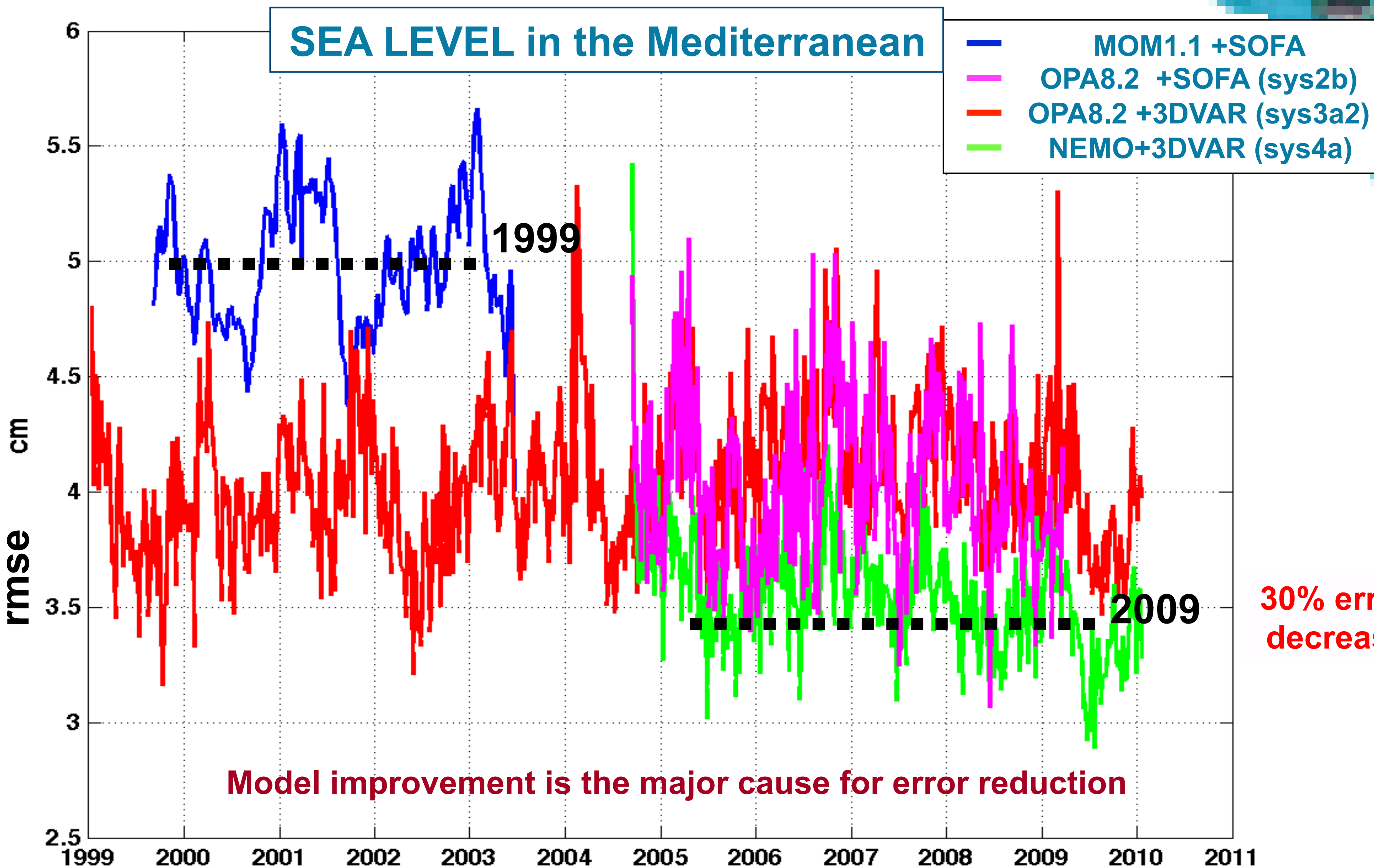
B) Waves
1/16 degree resolution
Wind drag coefficient for hydrodynamics



C) Pelagic Biochemistry
1/16 deg resolution

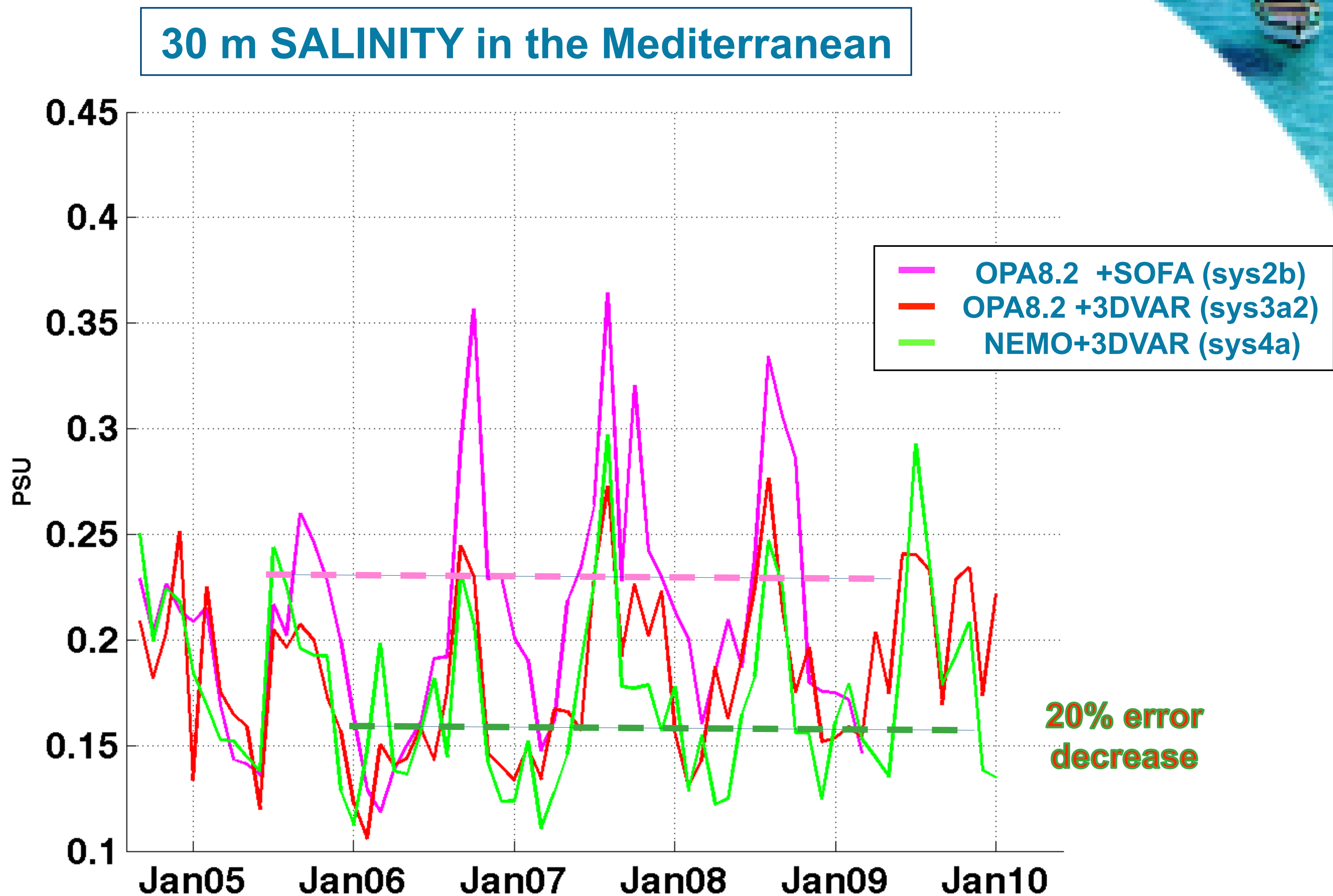


How did the error decrease in the last 10 years?



30% error decrease

How did the error decrease in the last 10 years?



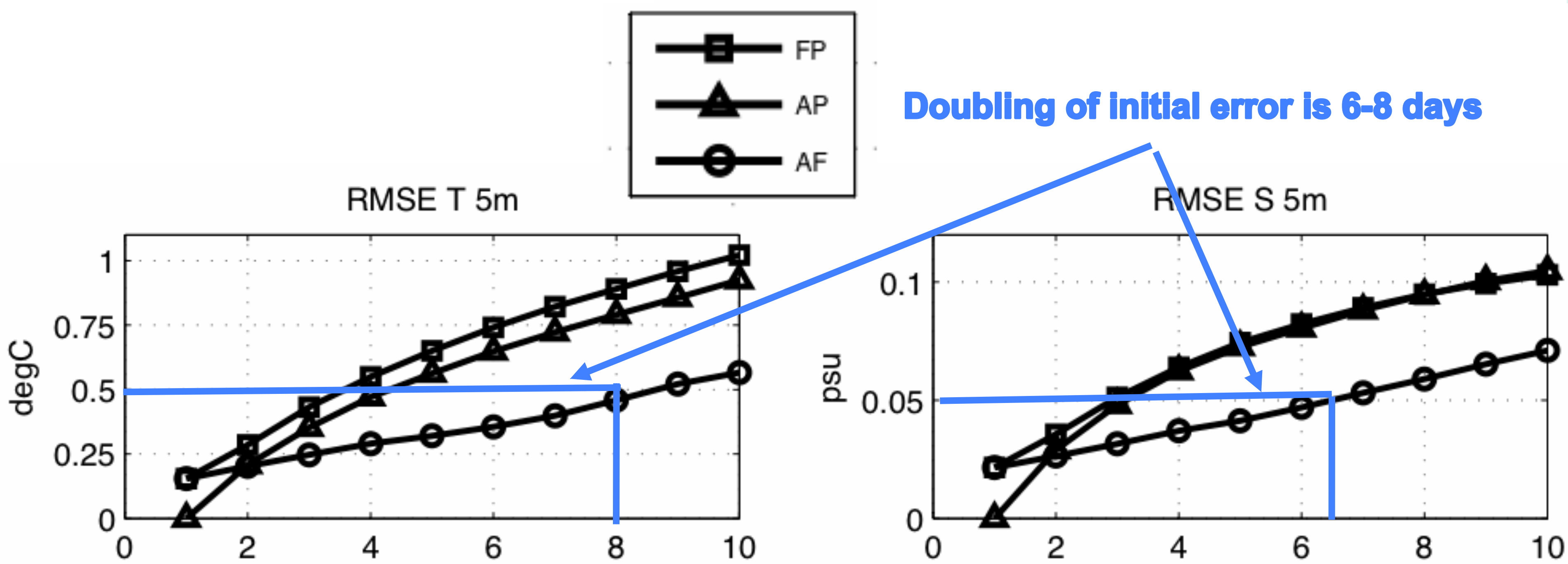
Predictability time for T and S

Analysis-forecast

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

Analysis-Persistence

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



Forecast days

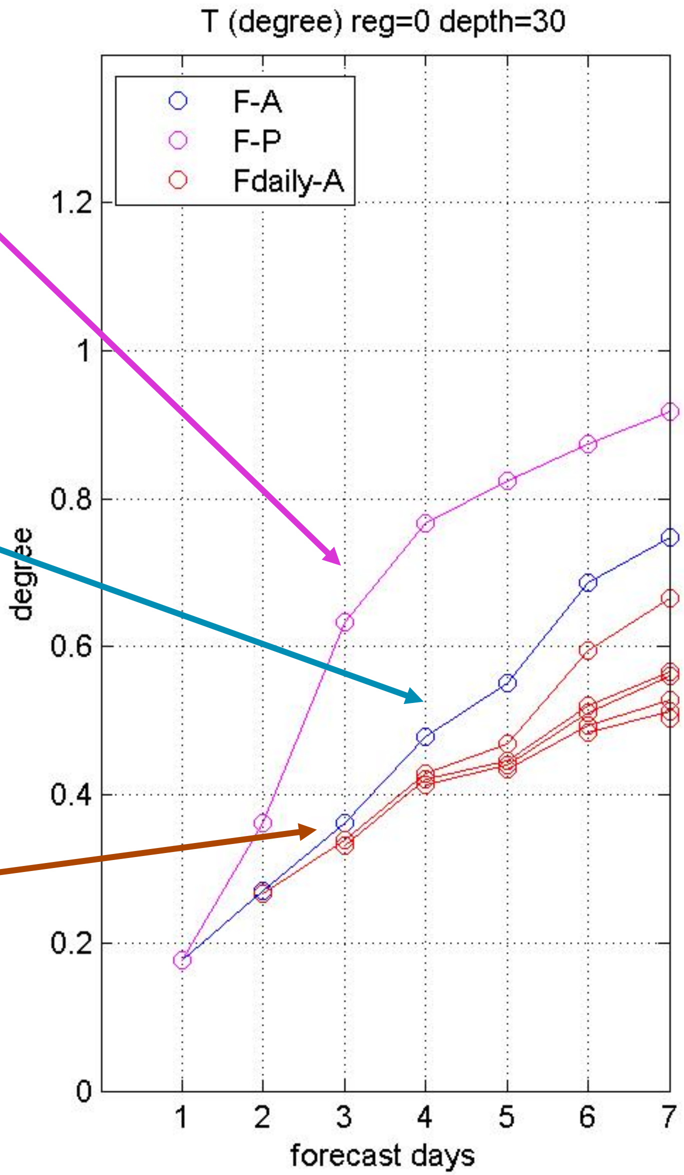
Forecast skill: the effect of atmospheric forcing errors

Control:

Forecast-persistence

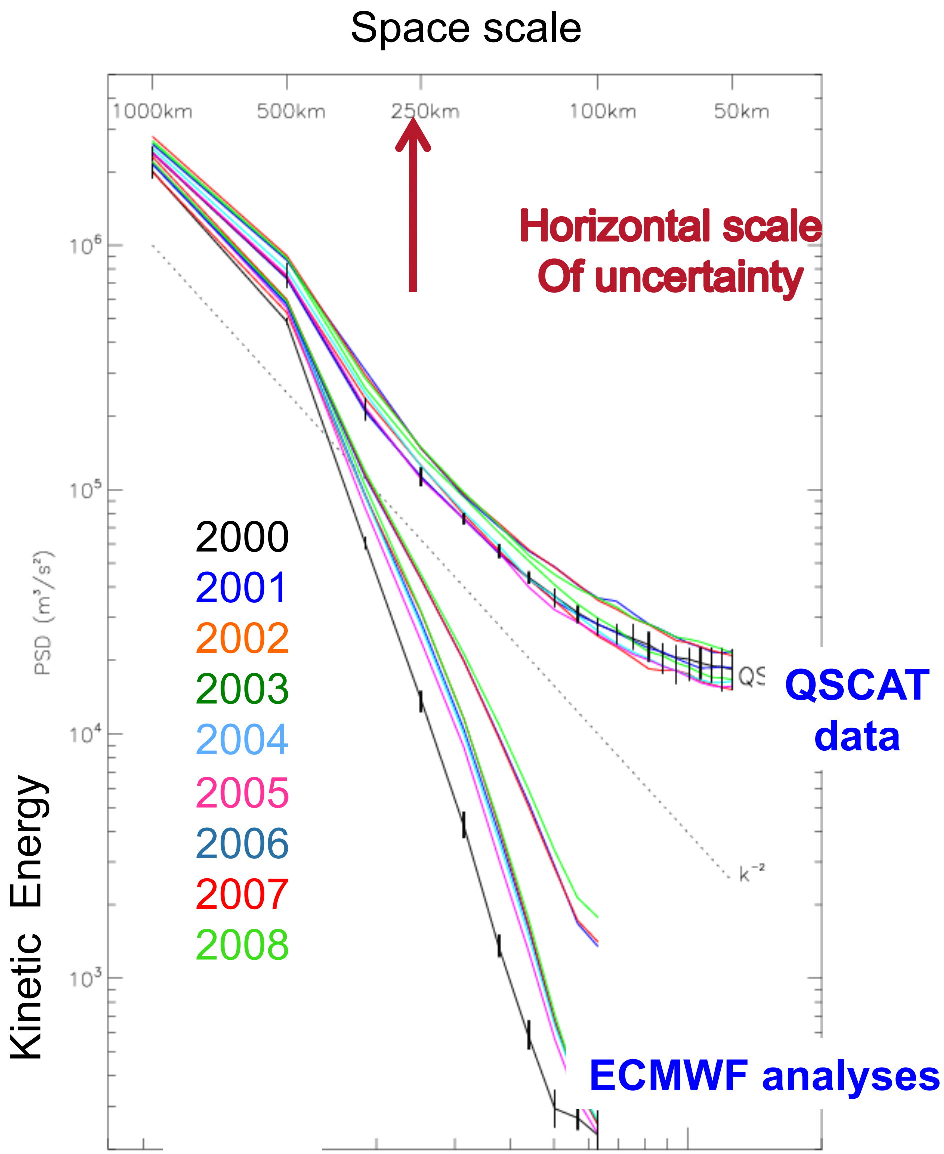
Weekly forecast

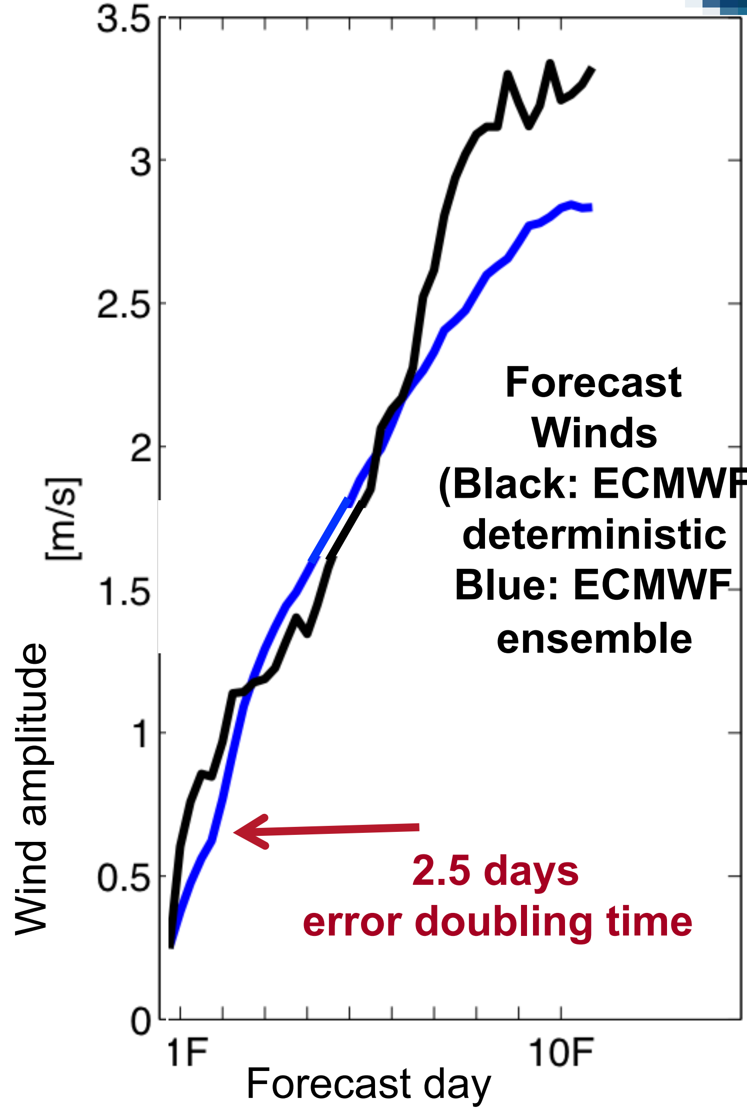
Daily forecasts started from simulations driven by atmospheric analyses



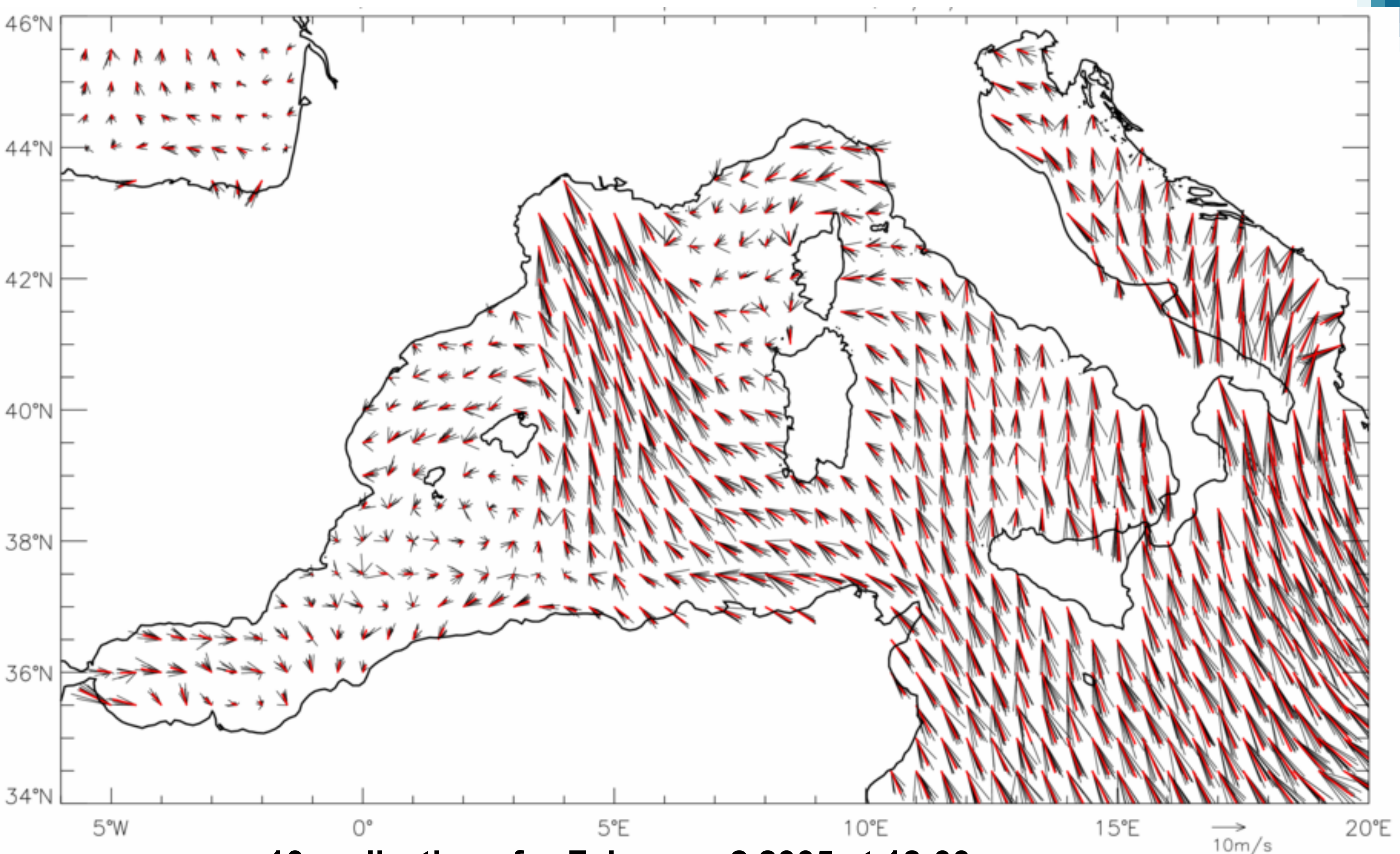
Forecast error at day 7 decreased by 30% only reducing atmospheric forcing error

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



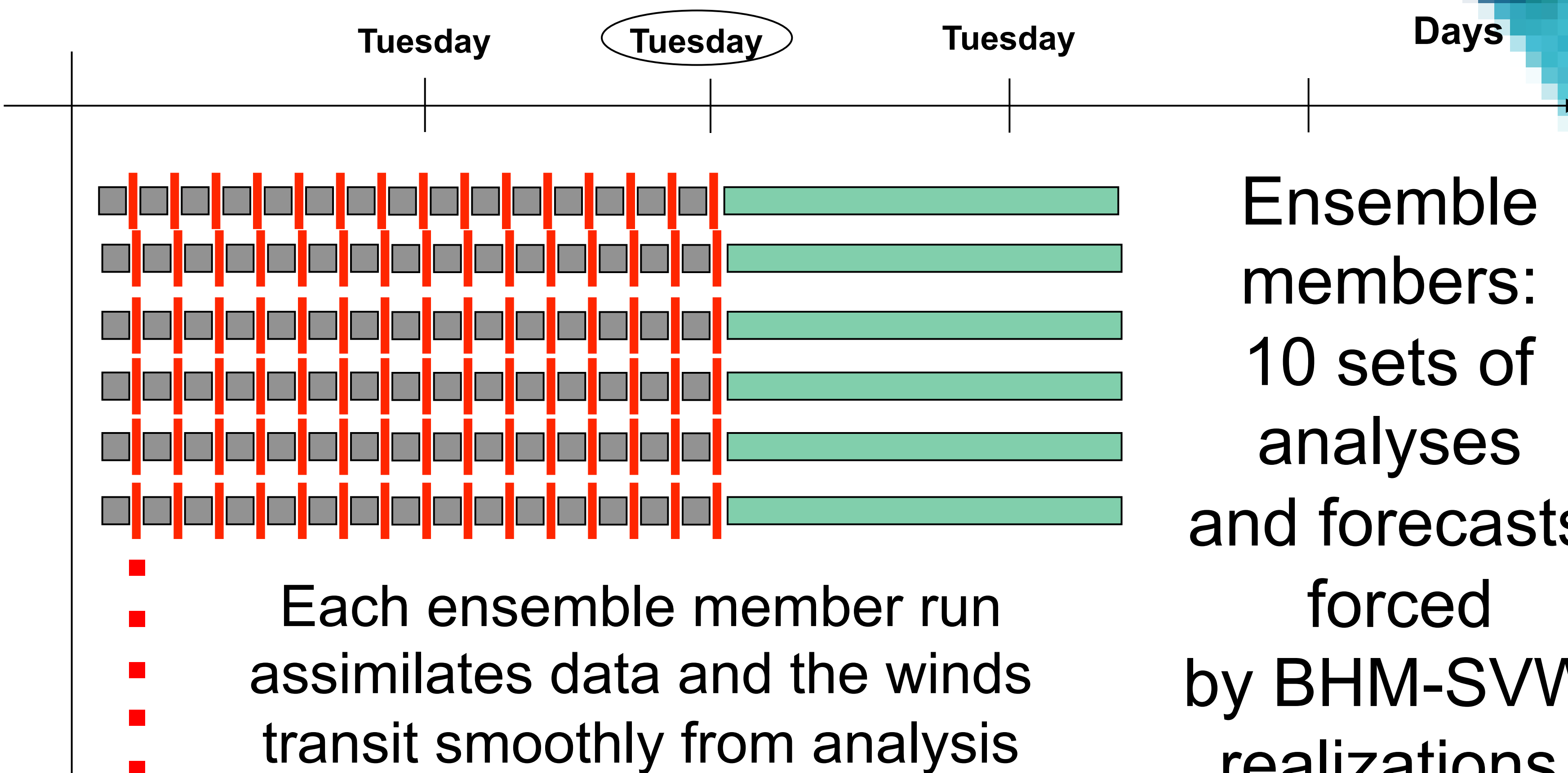


Posterior distributions of winds from a Bayesian Hierarchical Model: BHM-SVW realizations (Milliff et al., 2011)



10 realizations for February, 2 2005 at 18:00

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



Ensemble members: 10 sets of analyses and forecasts forced by BHM-SVW realizations

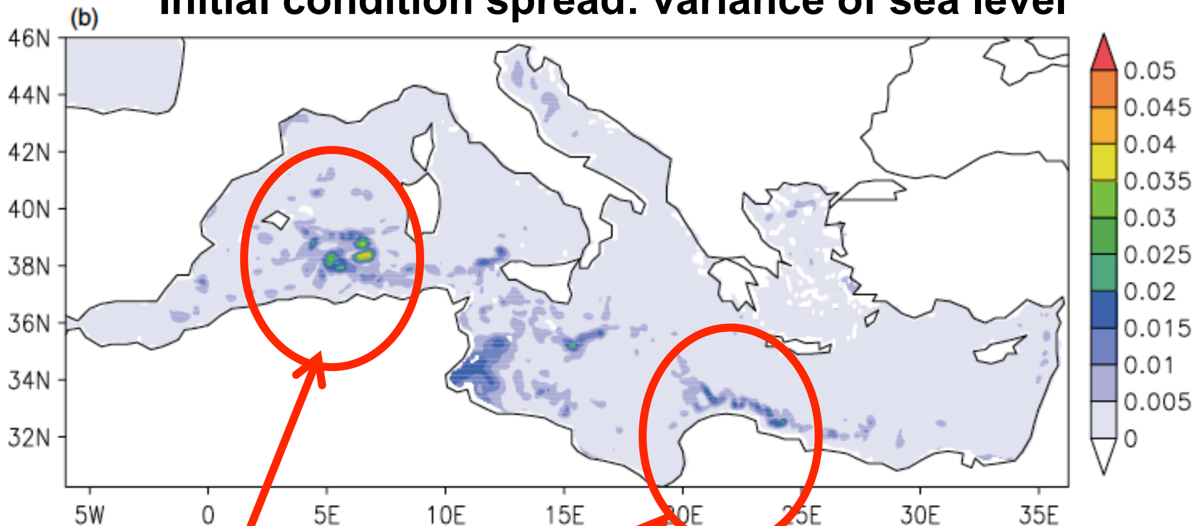
Each ensemble member run assimilates data and the winds transit smoothly from analysis to forecast

10 days Forecast

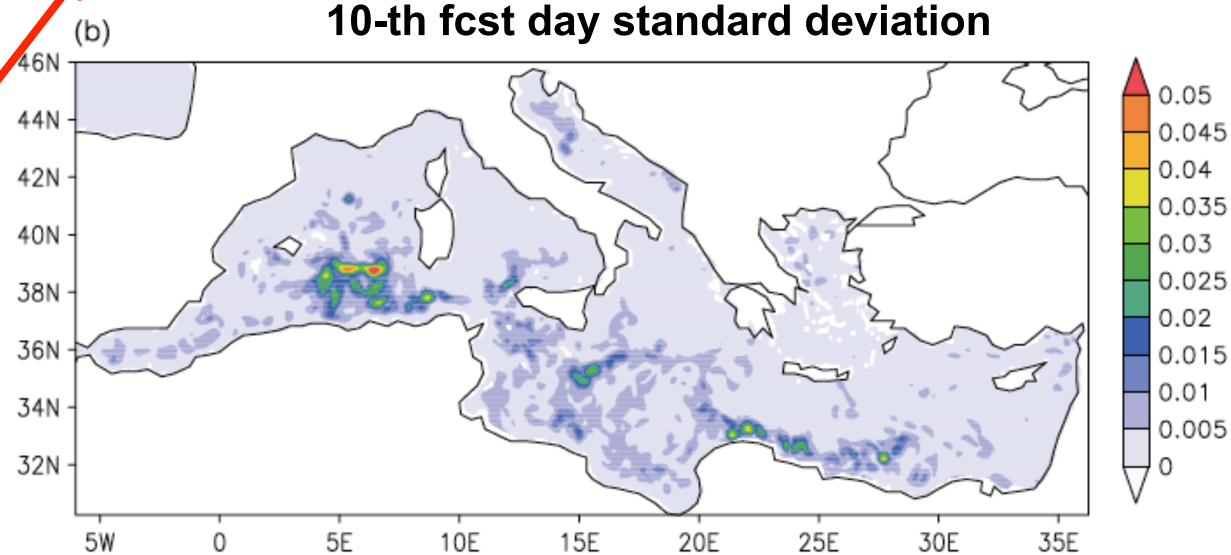
Analysis

Uncertainty in the ocean predictions due to uncertainty in the winds

Initial condition spread: variance of sea level



10-th fcst day standard deviation



Uncertainty is concentrated at the mesoscales
Sea level std is comparable to observed sea level error

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