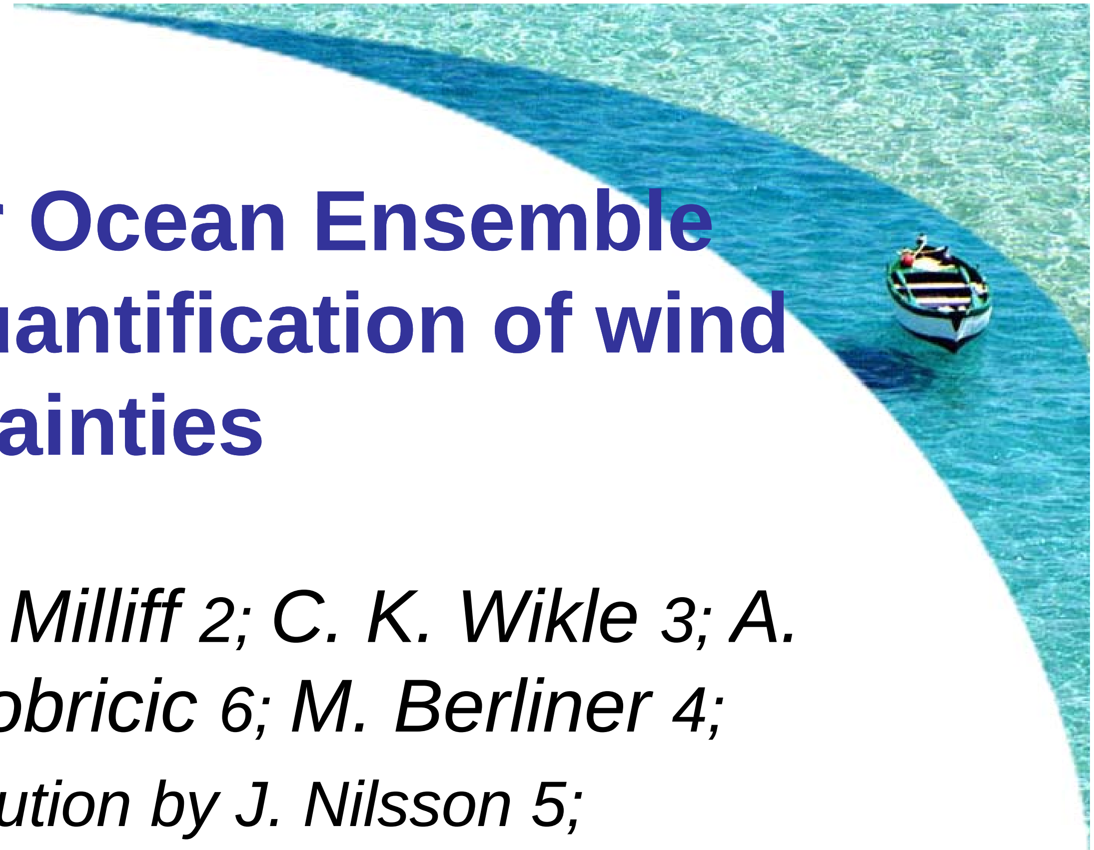


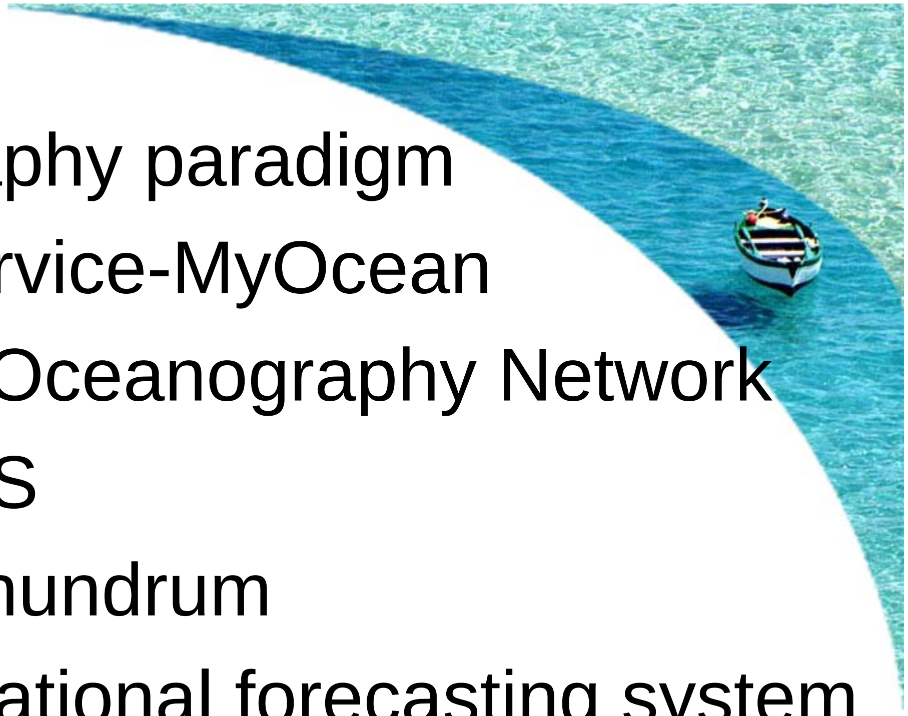
A new method for Ocean Ensemble Forecasting with quantification of wind uncertainties

N. Pinardi [1]; R. F. Milliff [2]; C. K. Wikle [3]; A. Bonazzi [5]; S. Dobricic [6]; M. Berliner [4];

and a contribution by J. Nilsson [5];

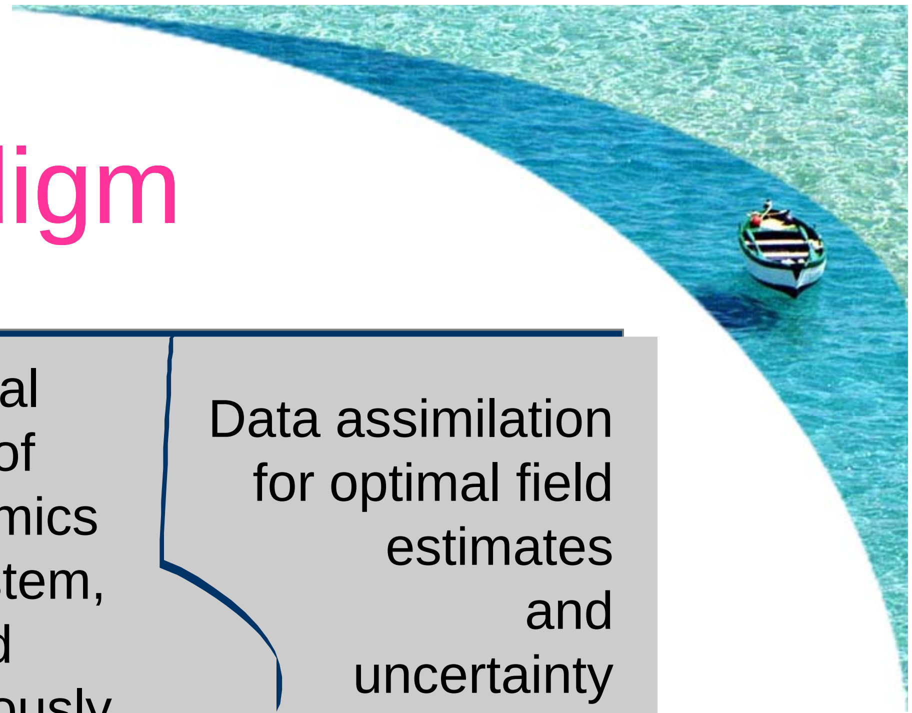
1.National Group of Operational oceanography (GNOO), U. Bologna, Italy
2.NWRA, Colorado Research Associates Div., Boulder, CO, USA.
3. Statistics Department, University of Missouri, Columbia, MO, USA.
4.Statistics Department, Ohio State University, Columbus, OH, USA.
5.National Group of Operational oceanography, INGV, Bologna, Italy. 6.
6. Centro Euro Mediterraneo per i Cambiamenti Climatici, Bologna, Italy.

Outline



- The Operational Oceanography paradigm
- The GMES Marine Core Service-MyOcean
- Mediterranean Operational Oceanography Network
- Uncertainty reduction in MFS
- The forecast uncertainty conundrum
- The MFS deterministic operational forecasting system
- A Bayesian Hierarchical Model (BHM) to quantify the Surface Vector Wind (SVW) uncertainty and distributions
- A new method of Ocean Ensemble Forecasting using the BHM-SVW
- Comparison with other ensemble methods
- Final considerations

The Operational Oceanography paradigm



Multidisciplinary Multi-platform Observing system (permanent and relocatable)

Numerical models of hydrodynamics and ecosystem, coupled a/synchronously to atmospheric forecast

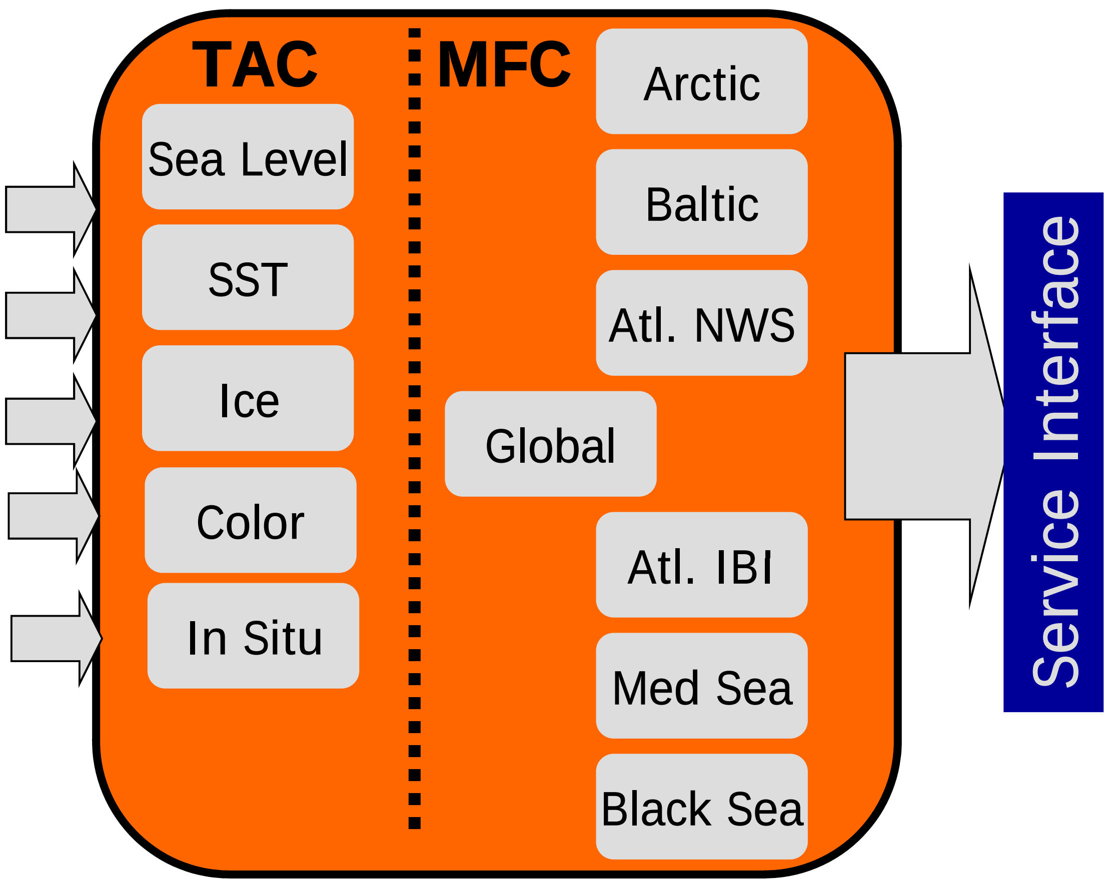
Data assimilation for optimal field estimates and uncertainty estimates

Continuos production of nowcasts/forecasts of relevant environmental state variables

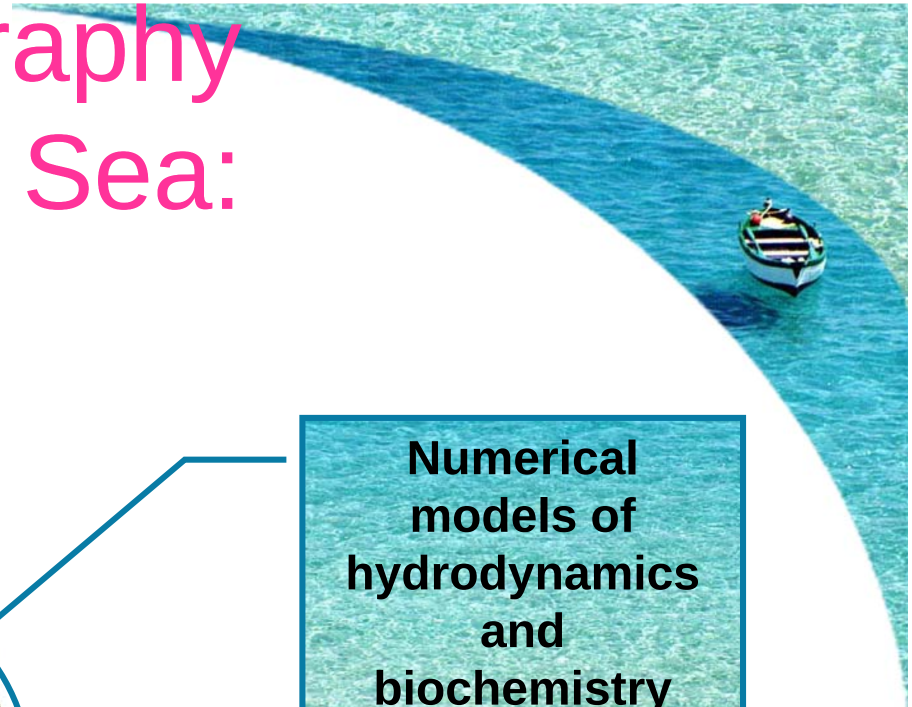
Real time products with internationally agreed standards

The GMES Marine Core Service implementation: the MyOcean project (2009-2012)

12 PRODUCTION UNITS



Operational oceanography in the Mediterranean Sea: 1995-today



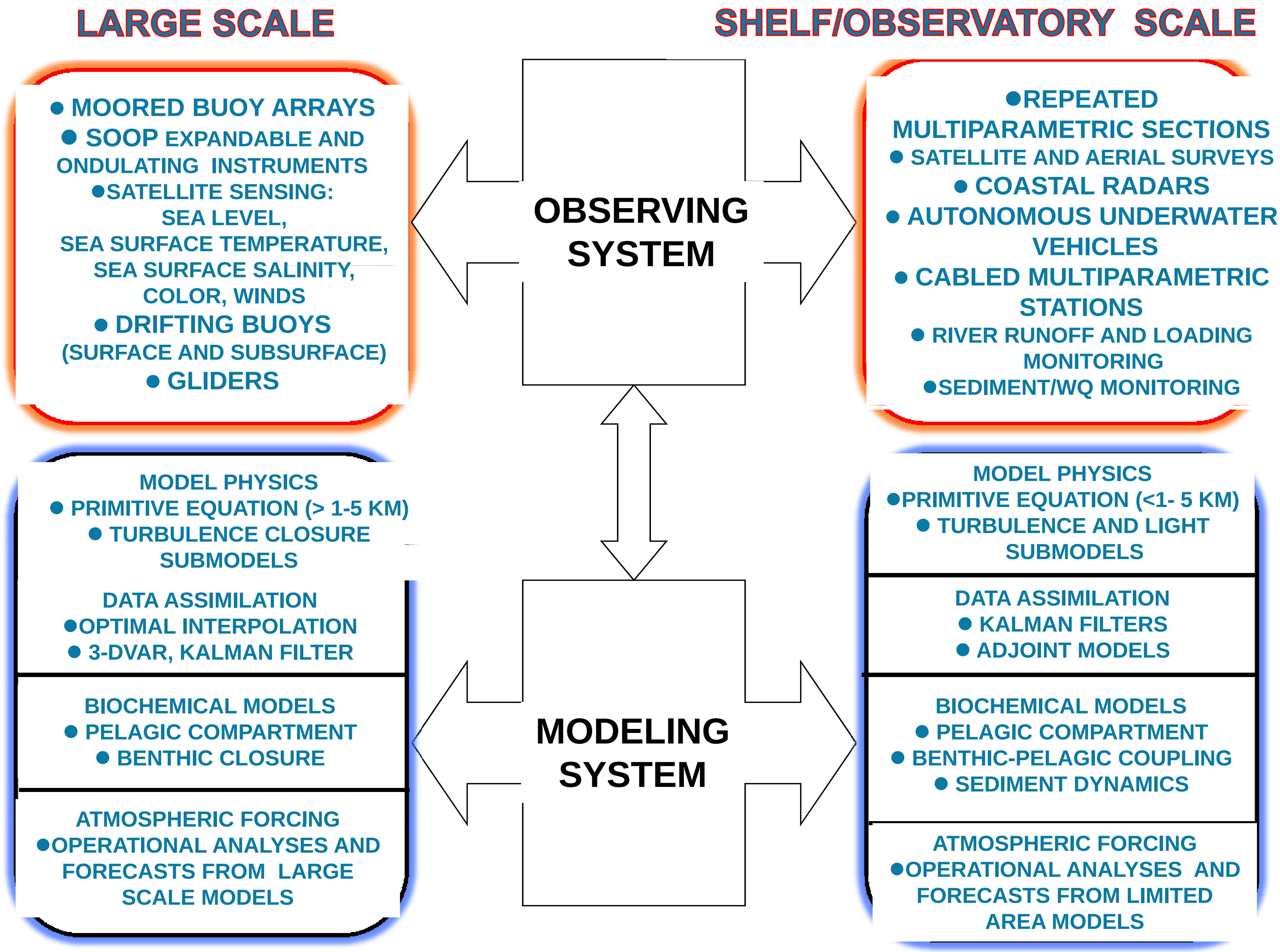
Real Time Observing System from satellites and in situ platforms

Numerical models of hydrodynamics and biochemistry at basin scale

Numerical models for shelf and coastal areas

End-User applications - Downstream services

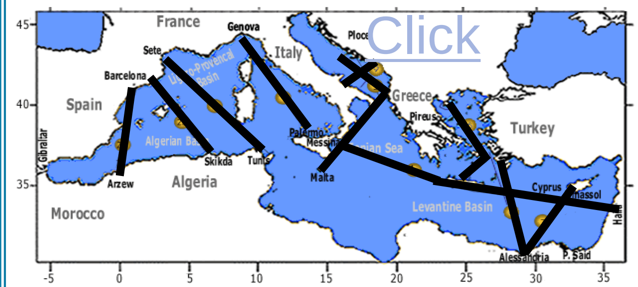
MOON: Mediterranean Operational Oceanography Network
16 nations involved, 36 institutions
http://www.moon-oceanforecasting.eu


LARGE SCALE
SHELF/OBSERVATORY SCALE
● MOORED BUOY ARRAYS
● SOOP EXPANDABLE AND ONDULATING INSTRUMENTS
●SATELLITE SENSING: SEA LEVEL, SEA SURFACE TEMPERATURE, SEA SURFACE SALINITY, COLOR, WINDS
● DRIFTING BUOYS (SURFACE AND SUBSURFACE)
● GLIDERS
OBSERVING SYSTEM
●REPEATED MULTIPARAMETRIC SECTIONS
● SATELLITE AND AERIAL SURVEYS
● COASTAL RADARS
● AUTONOMOUS UNDERWATER VEHICLES
● CABLED MULTIPARAMETRIC STATIONS
● RIVER RUNOFF AND LOADING MONITORING
●SEDIMENT/WQ MONITORING
MODEL PHYSICS
● PRIMITIVE EQUATION (> 1-5 KM)
● TURBULENCE CLOSURE SUBMODELS
DATA ASSIMILATION
●OPTIMAL INTERPOLATION
● 3-DVAR, KALMAN FILTER
BIOCHEMICAL MODELS
● PELAGIC COMPARTMENT
● BENTHIC CLOSURE
ATMOSPHERIC FORCING
●OPERATIONAL ANALYSES AND FORECASTS FROM LARGE SCALE MODELS
MODELING SYSTEM
MODEL PHYSICS
●PRIMITIVE EQUATION (<1- 5 KM)
● TURBULENCE AND LIGHT SUBMODELS
DATA ASSIMILATION
● KALMAN FILTERS
● ADJOINT MODELS
BIOCHEMICAL MODELS
● PELAGIC COMPARTMENT
● BENTHIC-PELAGIC COUPLING
● SEDIMENT DYNAMICS
ATMOSPHERIC FORCING
●OPERATIONAL ANALYSES AND FORECASTS FROM LIMITED AREA MODELS

MOON large scale data collection

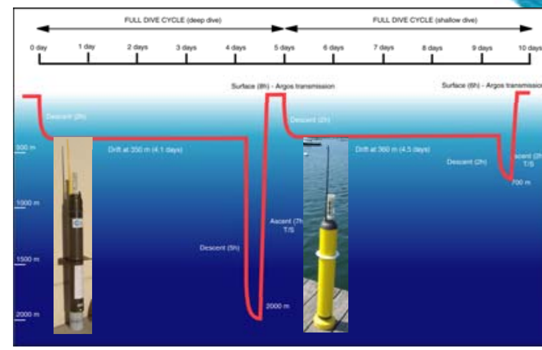
click

Multiparametric buoys in: Ligurian Sea, Adriatic Sea and Cretan Sea
(few hours delay)

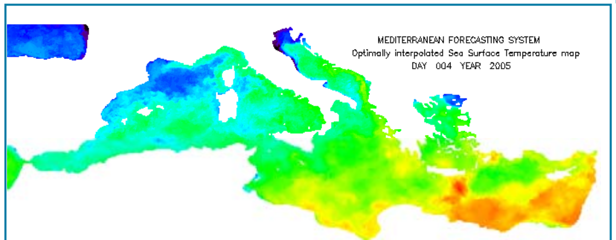


Click

XBT VOS/SOOP high resolution (12 nm along track and full profile transmission, few hours delay)

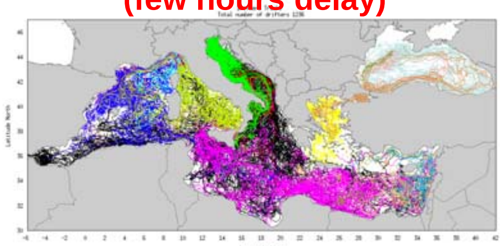


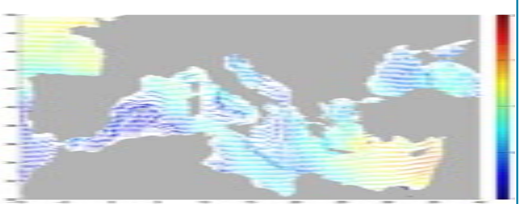
20 ARGO floats deployed from VOS
(few hours delay)



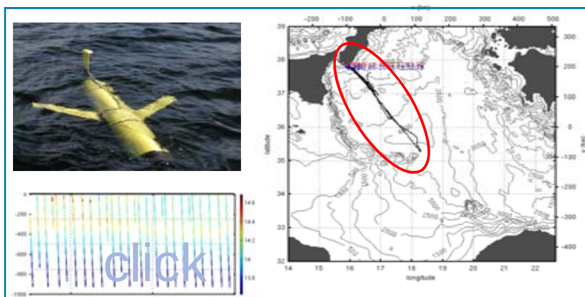
Daily satellite SST interpolated in RT on model grid (one day delay)

Surface drifters
(few hours delay)



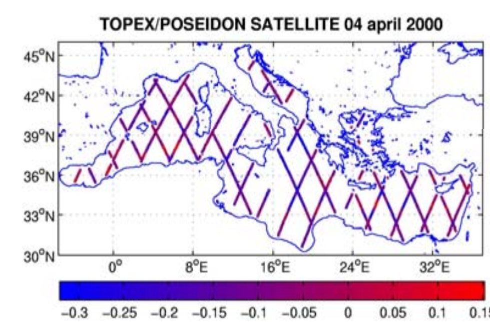


Scatterometer DAILY winds analysis, 1/2x1/2
(one week delay)

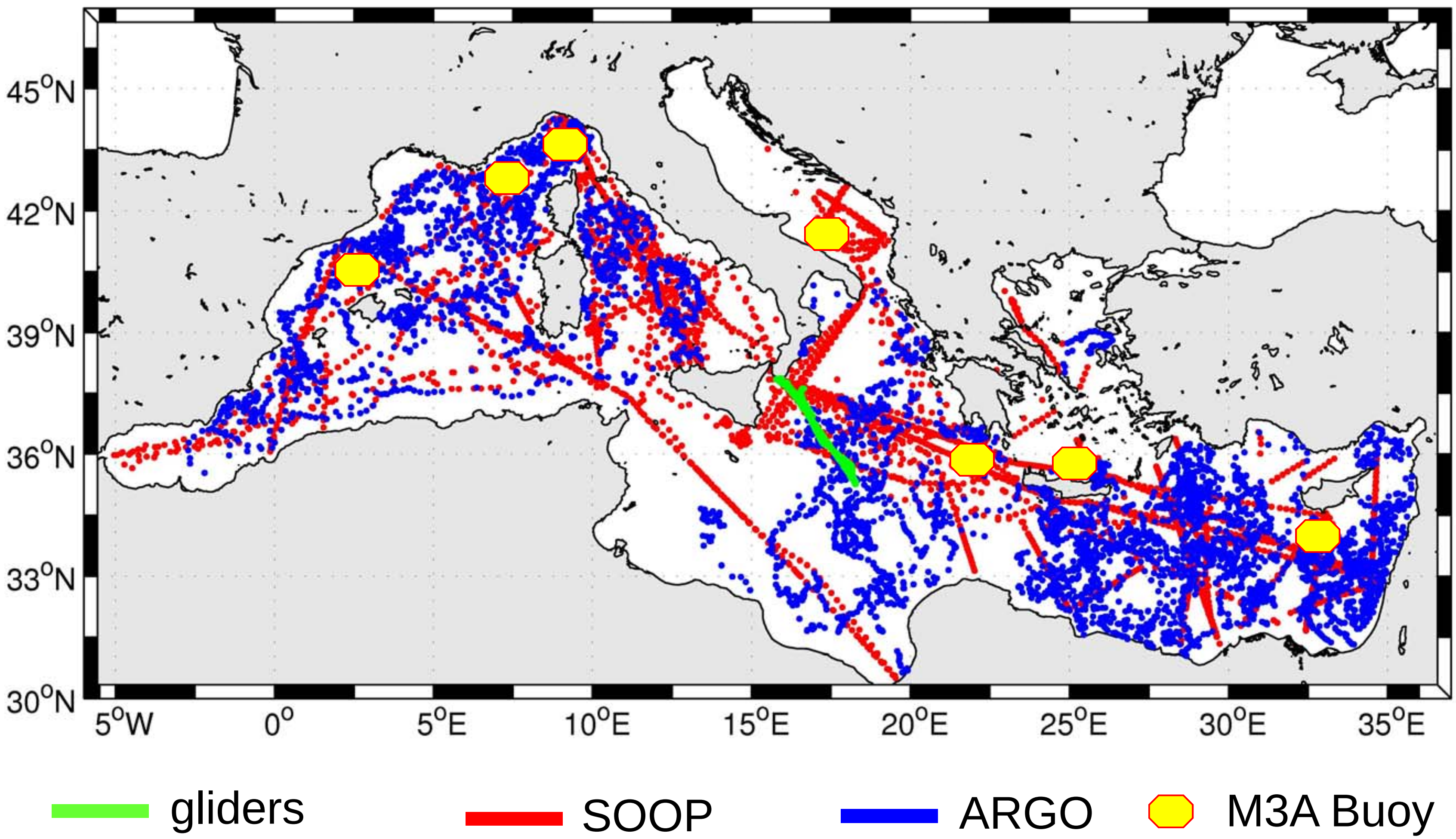


click

Open ocean monitoring by gliders
(few hours delay)

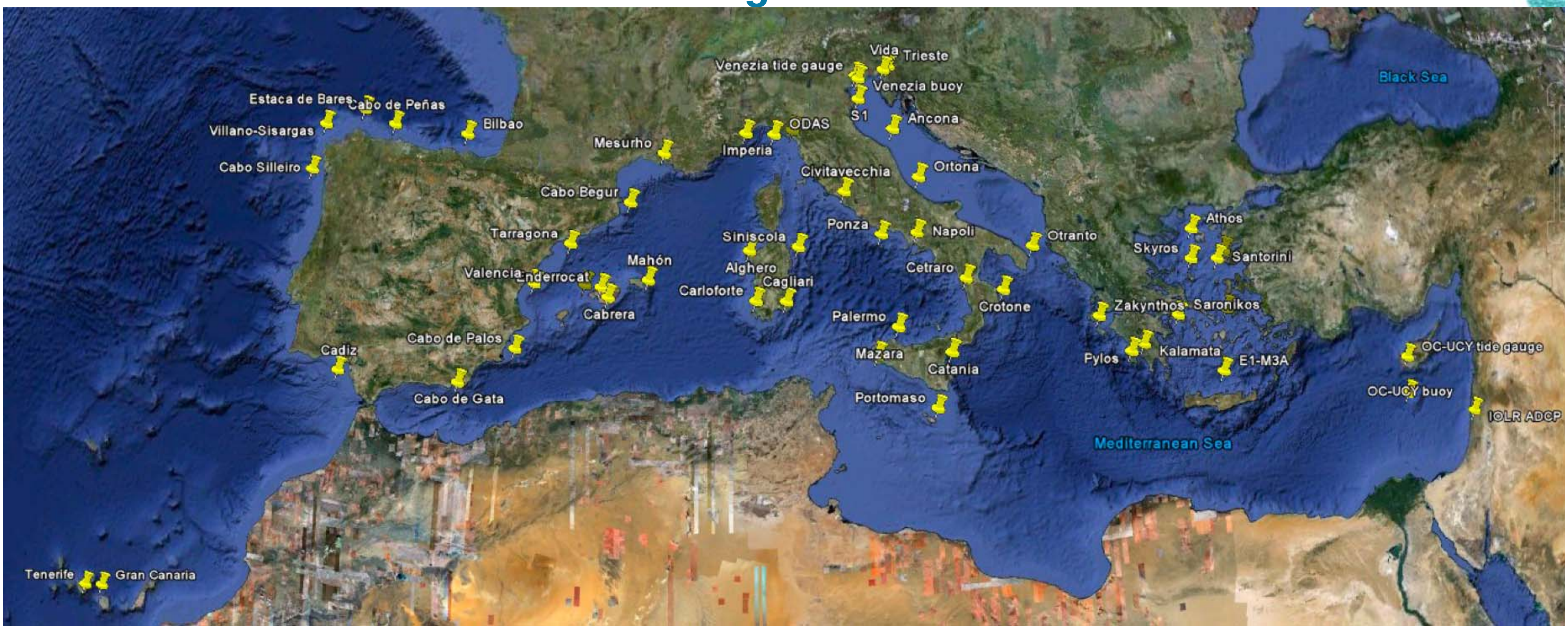


MOON LARGE SCALE data collection: real time data coverage (2004-2008 period)



MOON recent developments: data exchange from national networks observatories

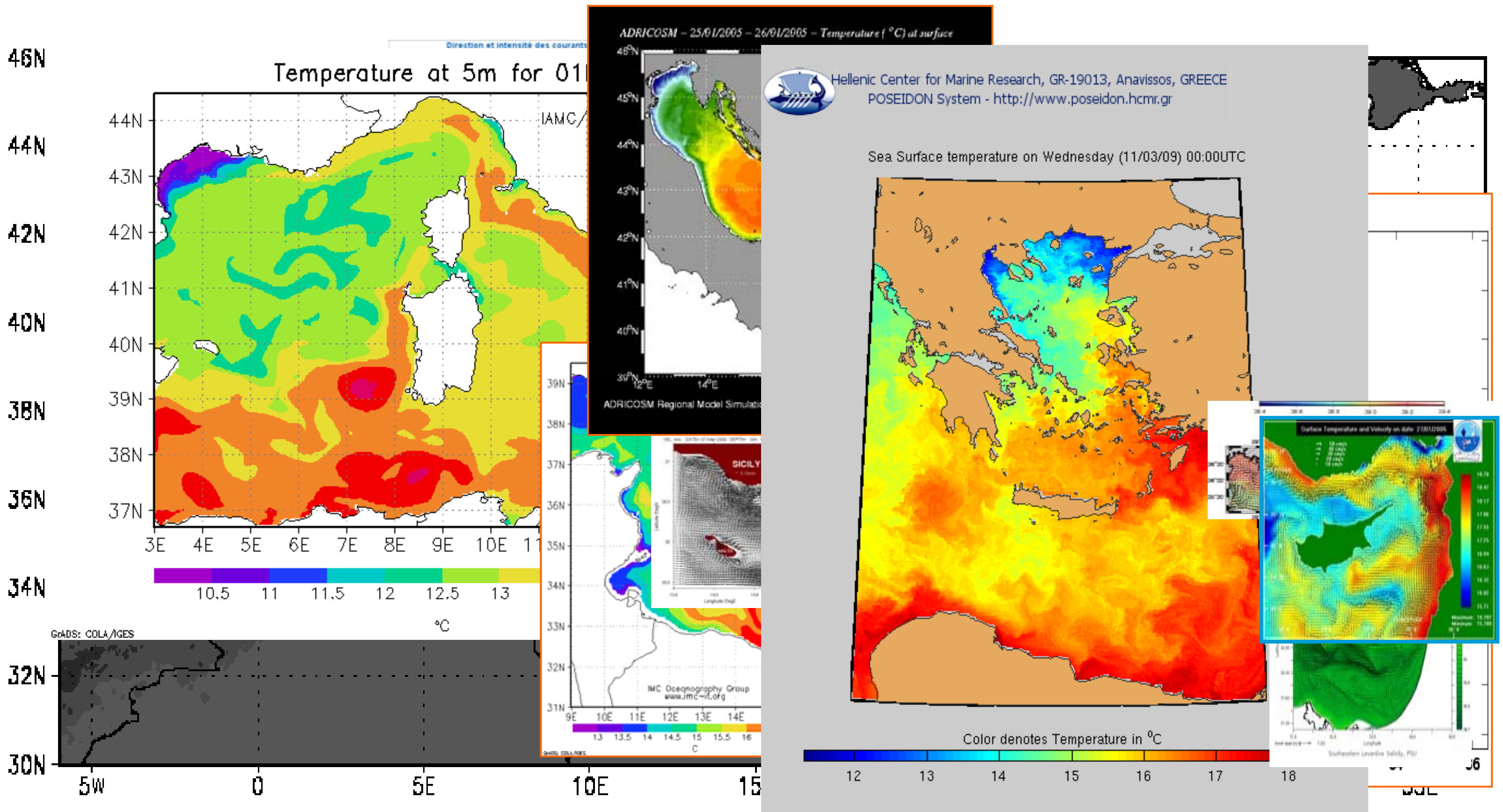
The MyOcean Validation network composed of national real-time transmitting stations



wave, surface meteorological parameters and sea level

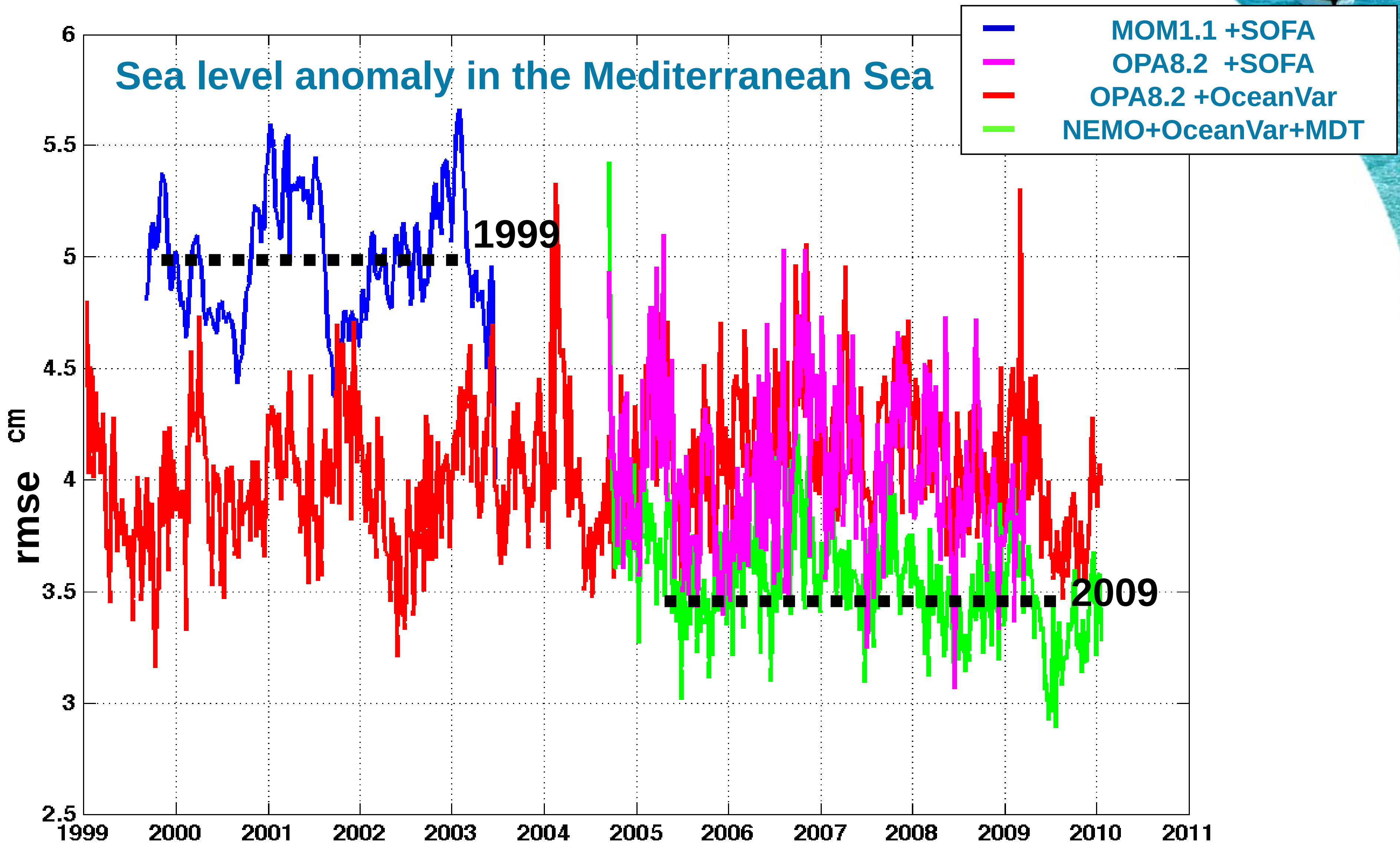
Marine and coastal environment: limited area modelling for the shelf and coasts

MyOcean disseminates daily forecasts to 13 nested national models every day

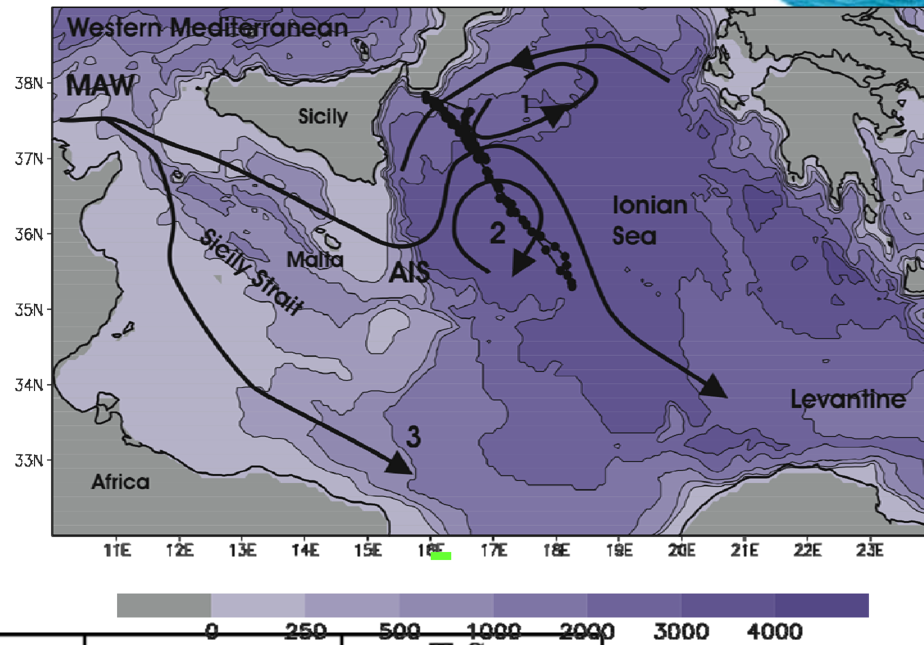


ıelf and sub-regional models now reach 1 - 3 km resolution

Operational oceanography: 10 years of quality increase



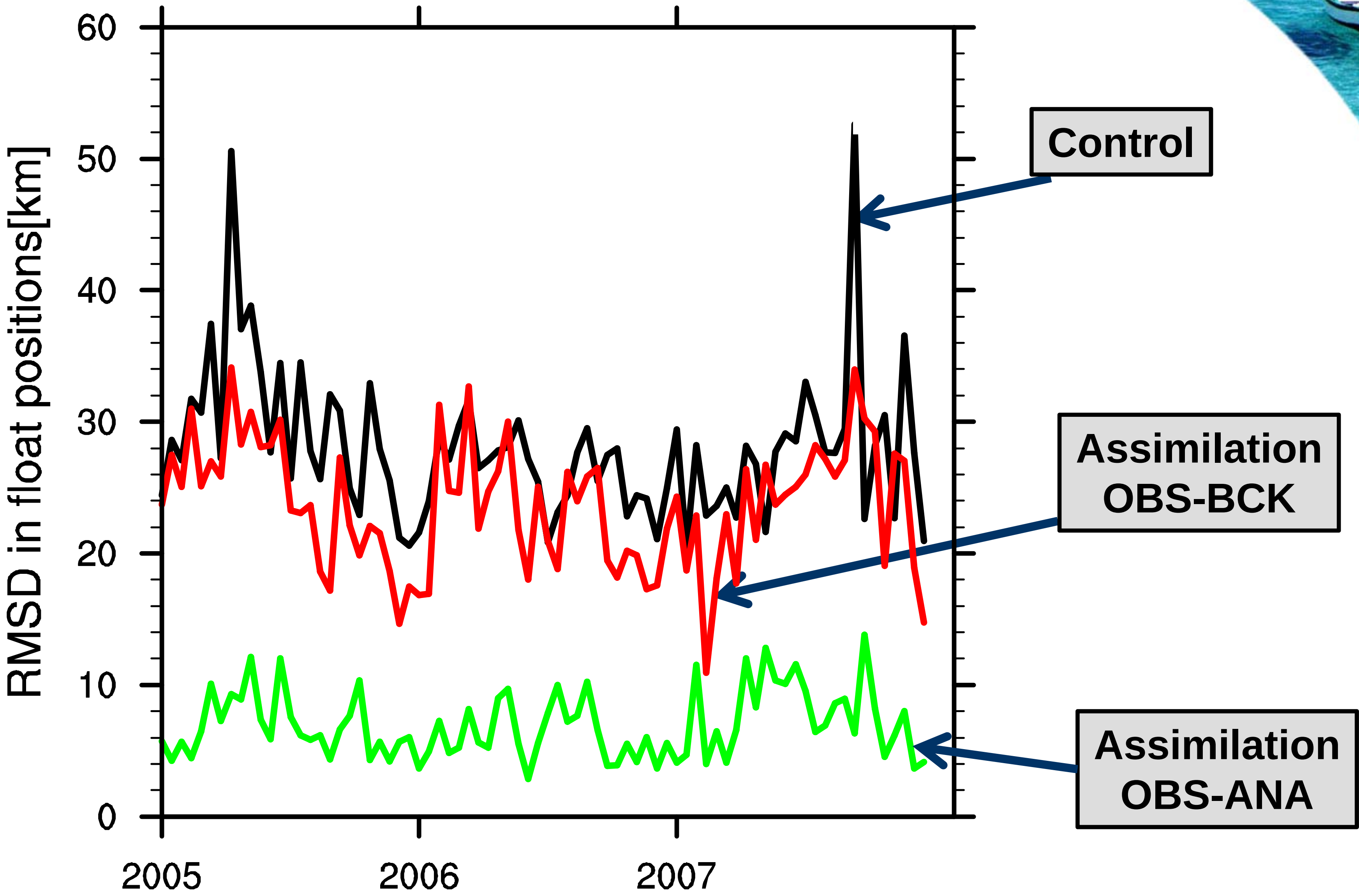
Assimilation of glider observations of T, S and drift



	Control	T,S	v	T,S,v
$\overline{rms(T)}^{0-50m}$	1.47	0.90	2.14	0.86 *
$\overline{rms(T)}^{50-200m}$	0.46	0.31	0.51	0.31 *
$\overline{rms(S)}^{0-50m}$	0.39	0.22	0.48	0.21 *
$\overline{rms(S)}^{50-200m}$	0.28	0.13	0.30	0.11 *
$rms(\lvert\overline{\mathbf{v}}^{0-200m}\rvert)$	0.096	0.118	0.090	0,083 *
$rms(SLA)$	4.06	4.10	3.79 *	3.79 *

THE MOST ACCURATE ESTIMATES FOR ALL PARAMETERS WHEN ALL OBSERVATIONS ARE ASSIMILATED SIMULTANEOUSLY
(Dobricic et al. 2010 JDAO)

Assimilation of Argo float position observations

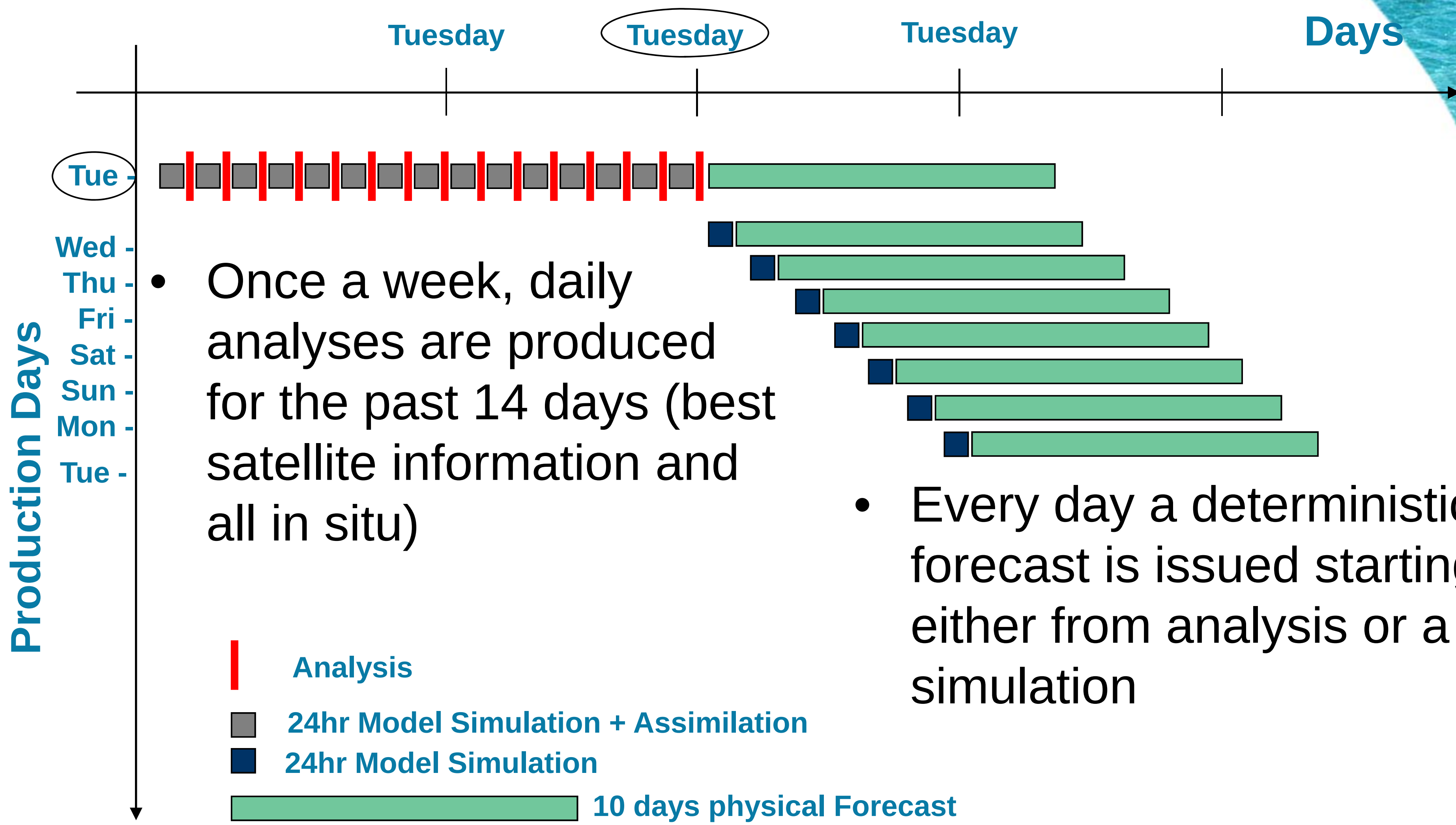


The forecast uncertainty conundrum

- Uncertainty principle of W.Heisenberg (1927):
  - There is a theoretical limit on the combined accuracy of simultaneous measurements of position and momentum that is related to Planck's constant.
- In the ocean the question is:
  - What is the accuracy limit of ocean forecasts?
  - How can we establish a framework for Ocean Ensemble Forecasts based on objective means?
- Uncertainty of ocean forecasts depends on:
  - Ocean Initial condition errors
  - Atmospheric forcing errors
  - Model errors (Physics, numerics)
- We concentrate on atmospheric forcing errors due the surface winds

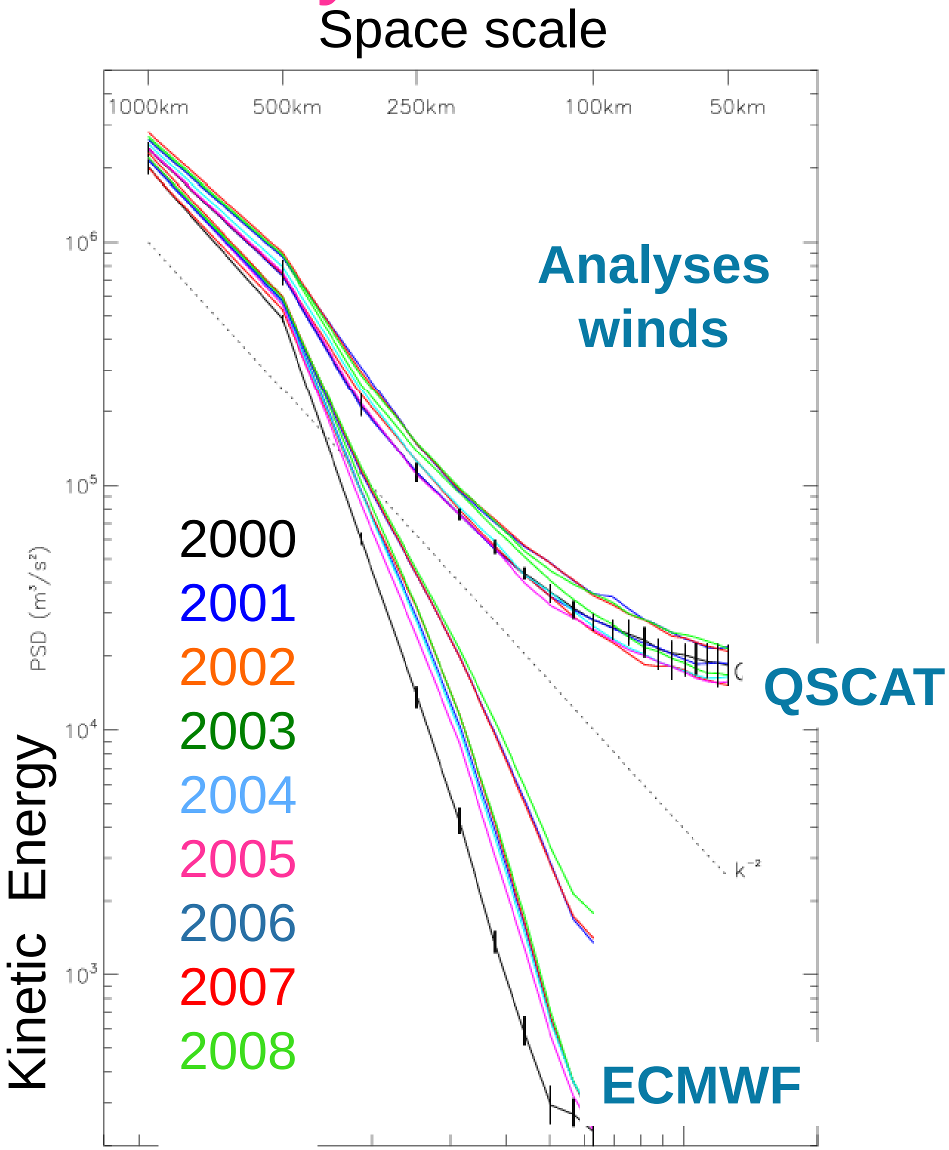
The MFS deterministic forecast system

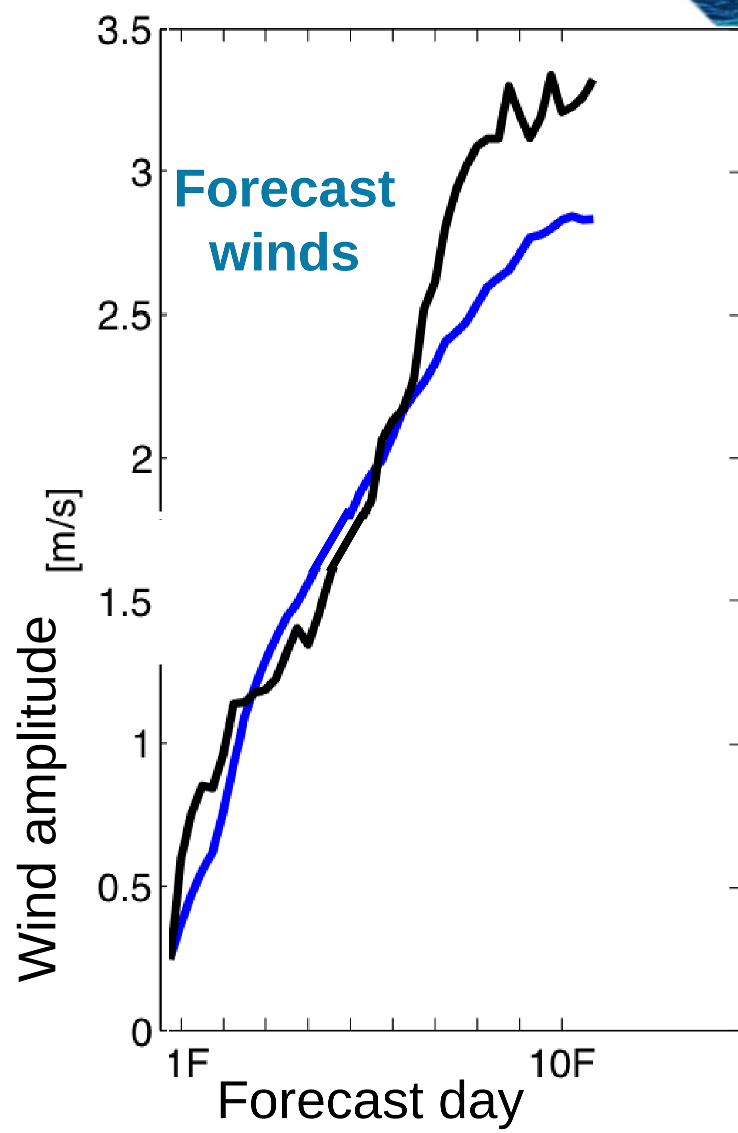
Forecast and analyses production cycle



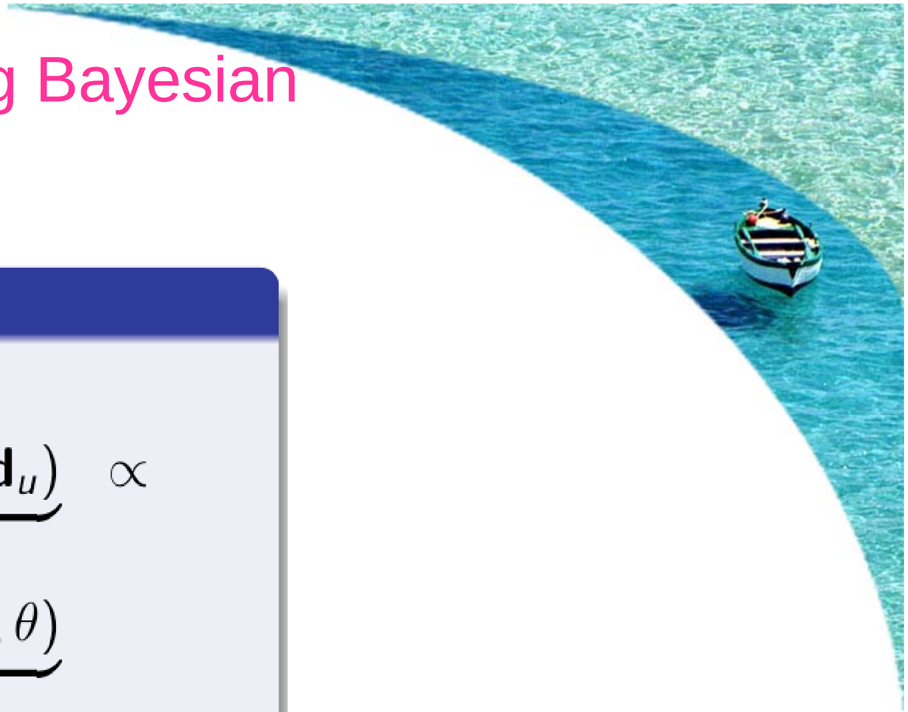
- Once a week, daily analyses are produced for the past 14 days (best satellite information and all in situ)
- Every day a deterministic forecast is issued starting either from analysis or a simulation

ECMWF NWP surface winds uncertainty over the Med Sea





Building the wind distributions using Bayesian Hierarchical Modelling (BHM-SVW)



Posterior Distribution

$$\underbrace{p(\mathbf{u}, \mathbf{p}, \theta | \mathbf{d}_u)}_{\text{Posterior}} \propto \underbrace{p(\mathbf{d}_u, \mathbf{d}_p | \mathbf{u}, \mathbf{p}, \theta)}_{\text{Data Stages}} \underbrace{p(\mathbf{u}, \mathbf{p}, \theta)}_{\text{Priors}}$$

Conceptual and implementation blocks:

Process model stage:

Raylegh friction surface model translated into a stochastic finite difference equation

$$u = -\frac{f}{\rho_0\left(f^2+\gamma^2\right)}\frac{\partial p}{\partial y} - \frac{\gamma}{\rho_0\left(f^2+\gamma^2\right)}\frac{\partial p}{\partial x}$$

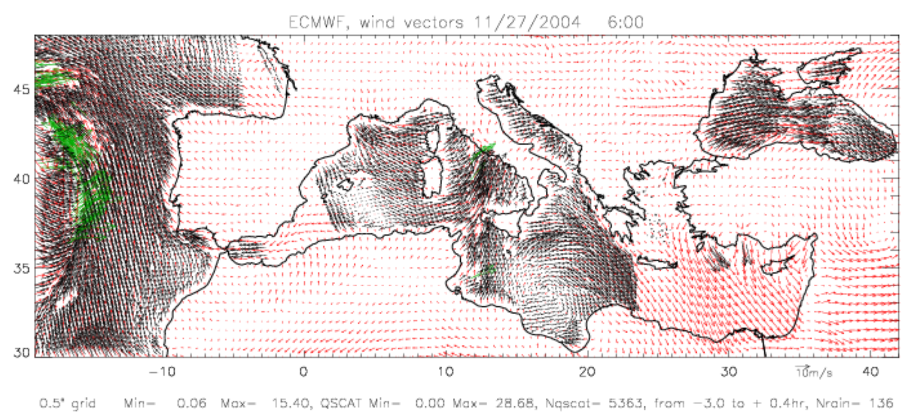
$$v = \frac{f}{\rho_0\left(f^2+\gamma^2\right)}\frac{\partial p}{\partial x} - \frac{\gamma}{\rho_0\left(f^2+\gamma^2\right)}\frac{\partial p}{\partial y}$$

$$\begin{aligned} U_t &= \theta_{uy} D_y P_t + \theta_{ux} D_x P_t + \epsilon_u \\ V_t &= \theta_{vx} D_x P_t + \theta_{vy} D_y P_t + \epsilon_v \end{aligned}$$

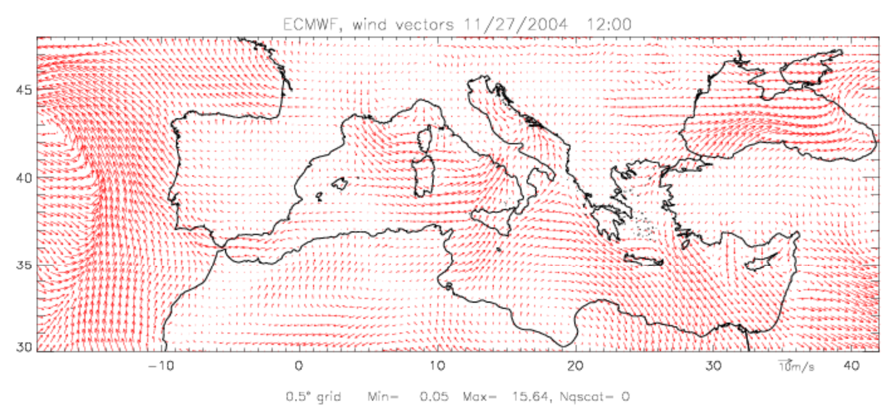
Building the wind distributions using Bayesian Hierarchical Modelling (BHM-SVW)

Conceptual and implementation blocks:

Data Stage: QSCAT winds and Numerical Weather Prediction (NWP) analyses/forecasts

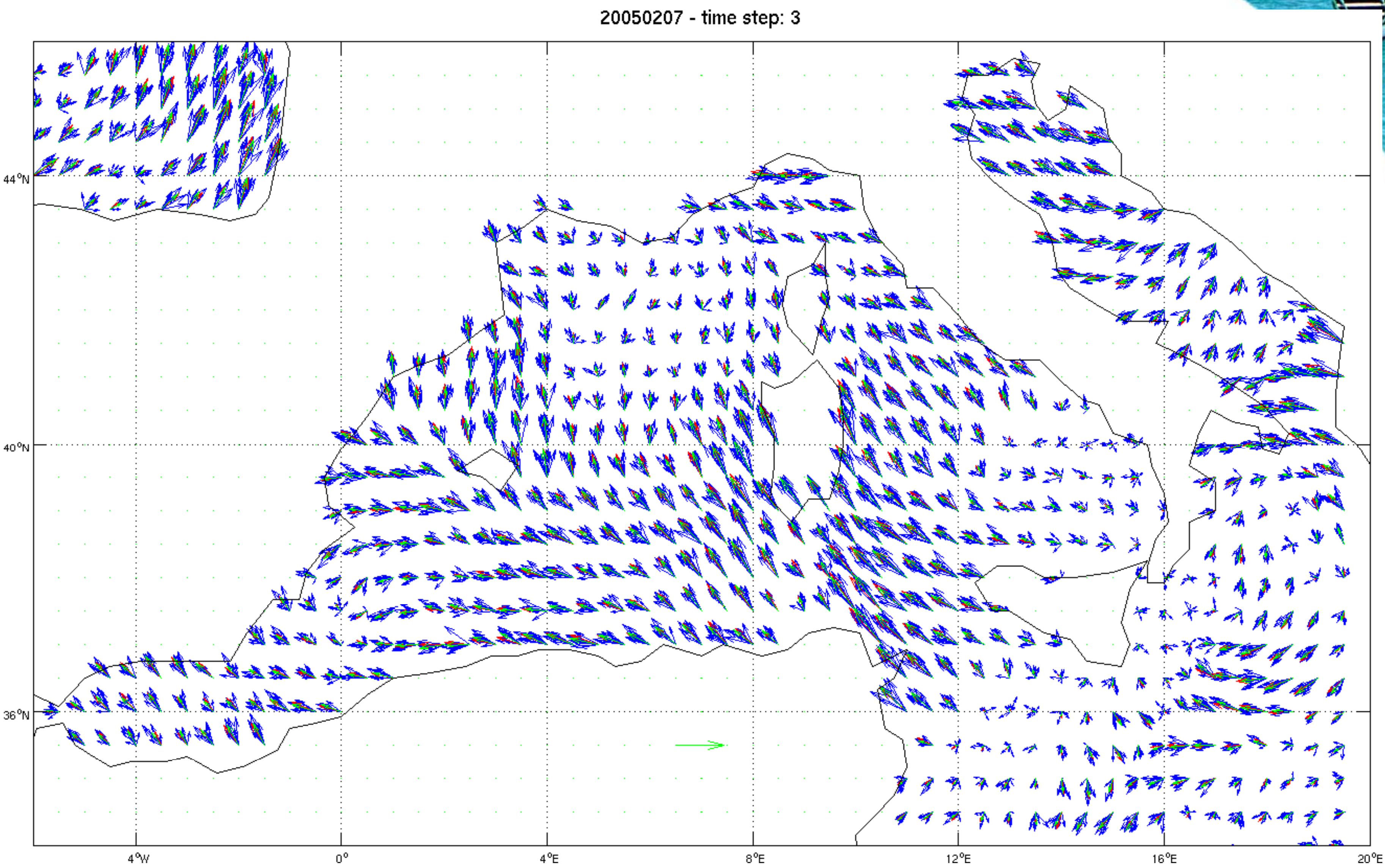


QSCAT

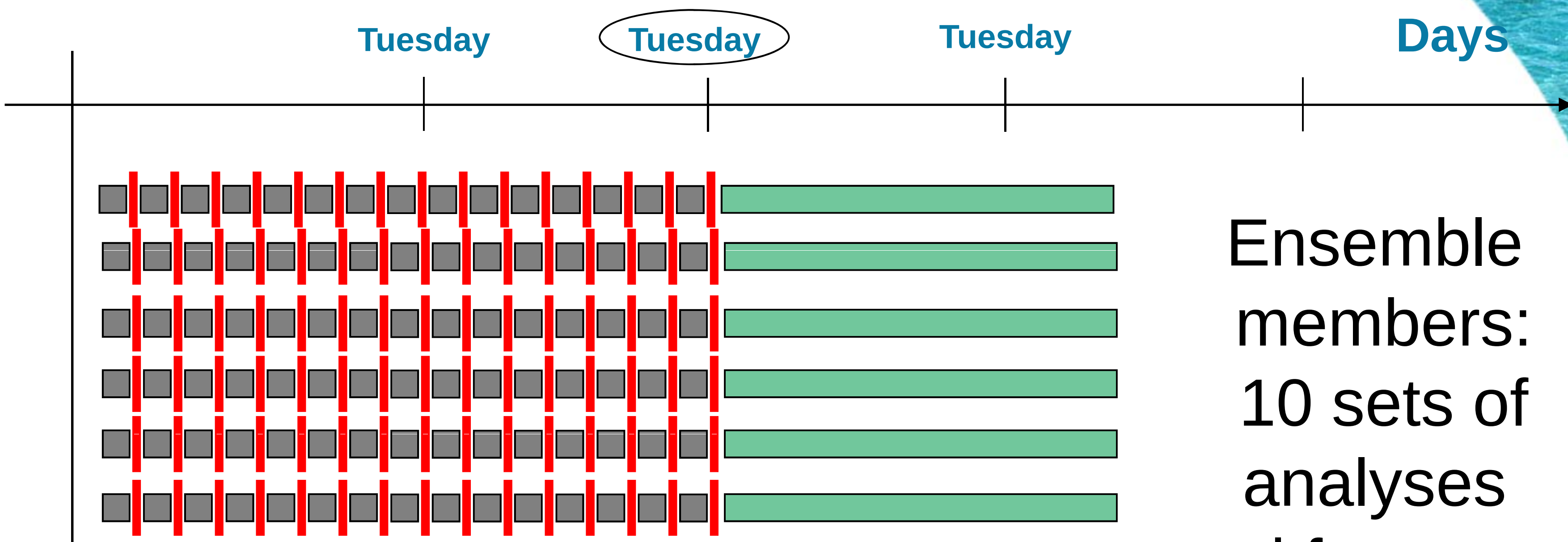


ECMWF

BHM-SVW realizations: example for February 7, 2005 at 18:00 GMT



The BHM-SVW Ocean Ensemble Forecast method



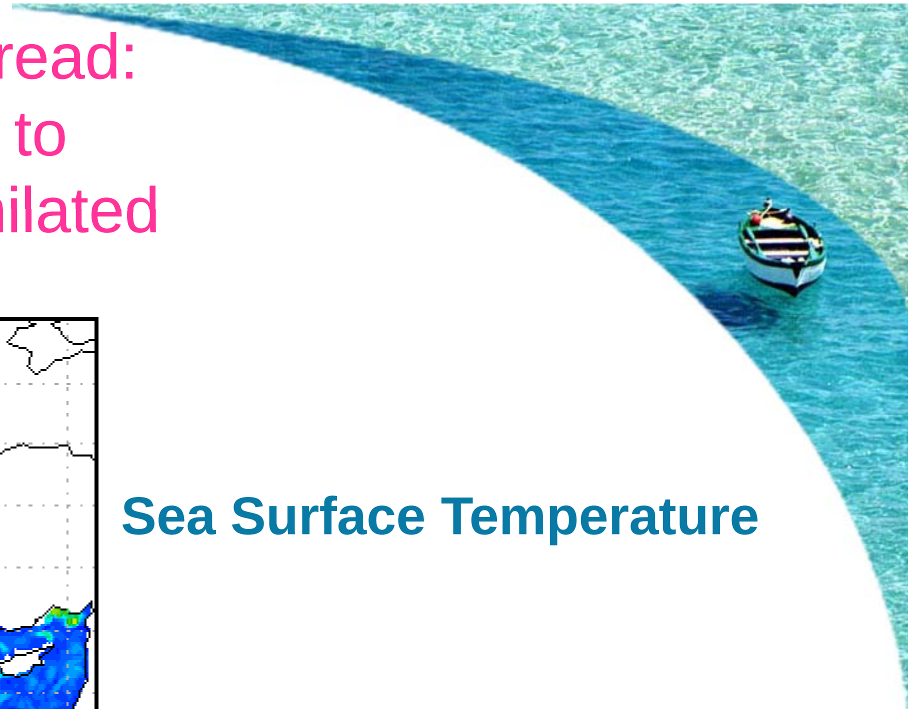
Ensemble members: 10 sets of analyses and forecasts forced by BHM-SVW realizations

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

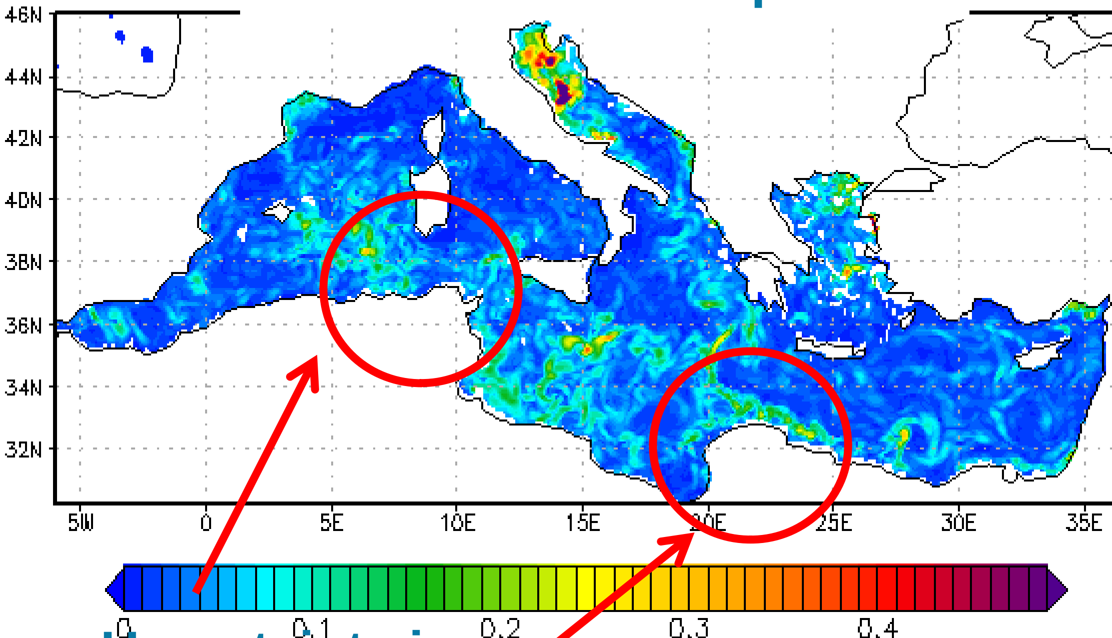
10 days Forecast

Analysis

BHM-SVW-OEF initial condition spread: amplification of the uncertainty due to winds where there is no data assimilated



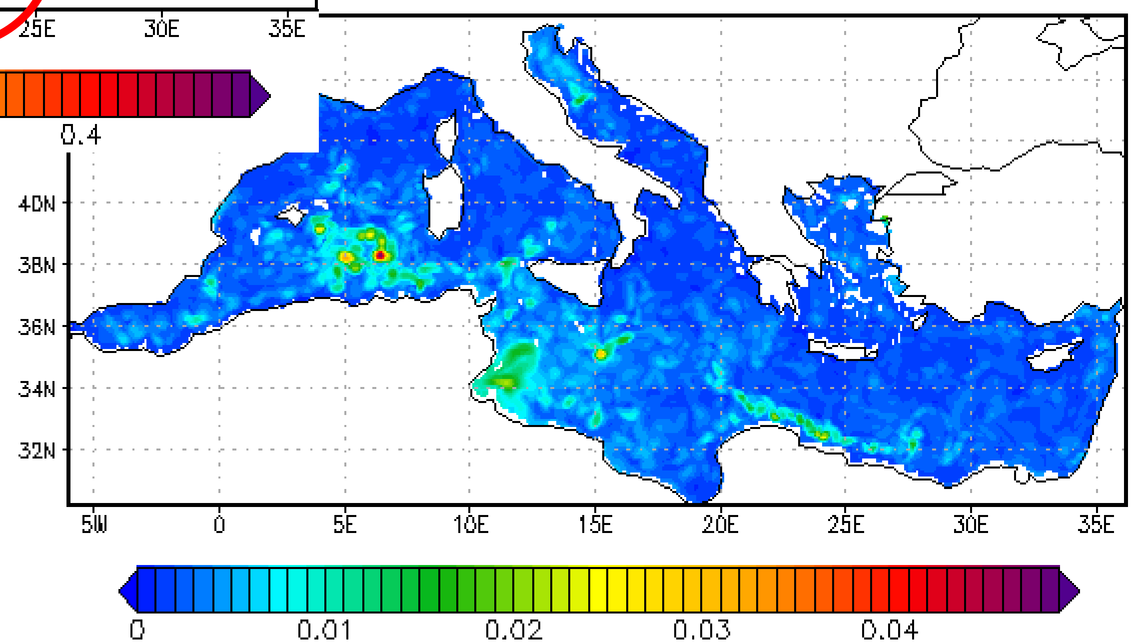
Initial condition spread



Sea Surface Temperature

Uncertainty is concentrated at the mesoscales

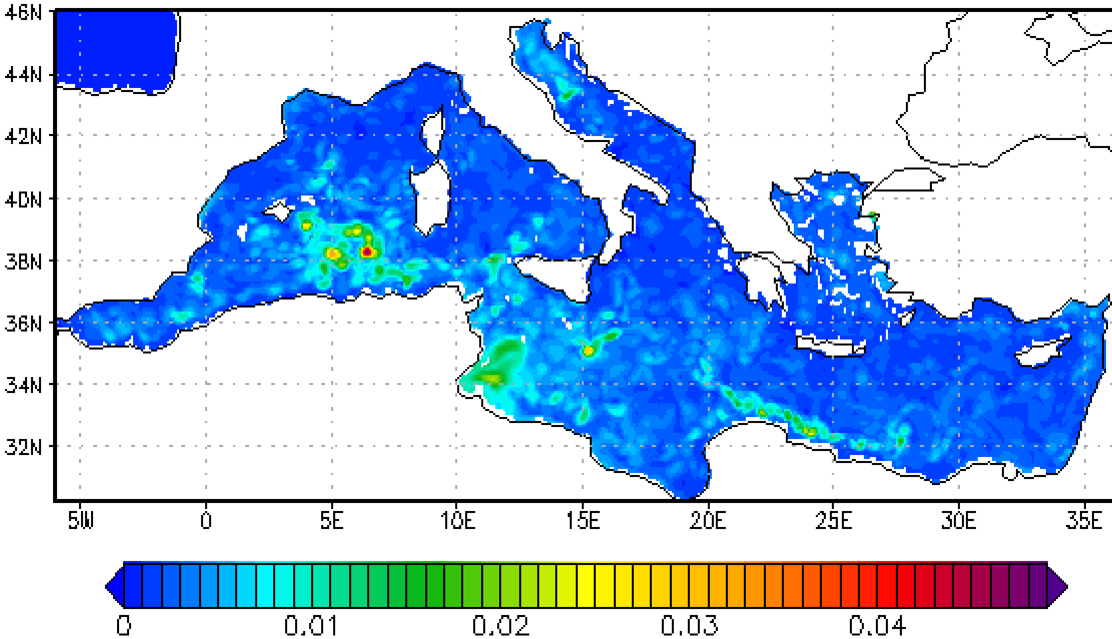
Initial condition spread



Sea Surface Height

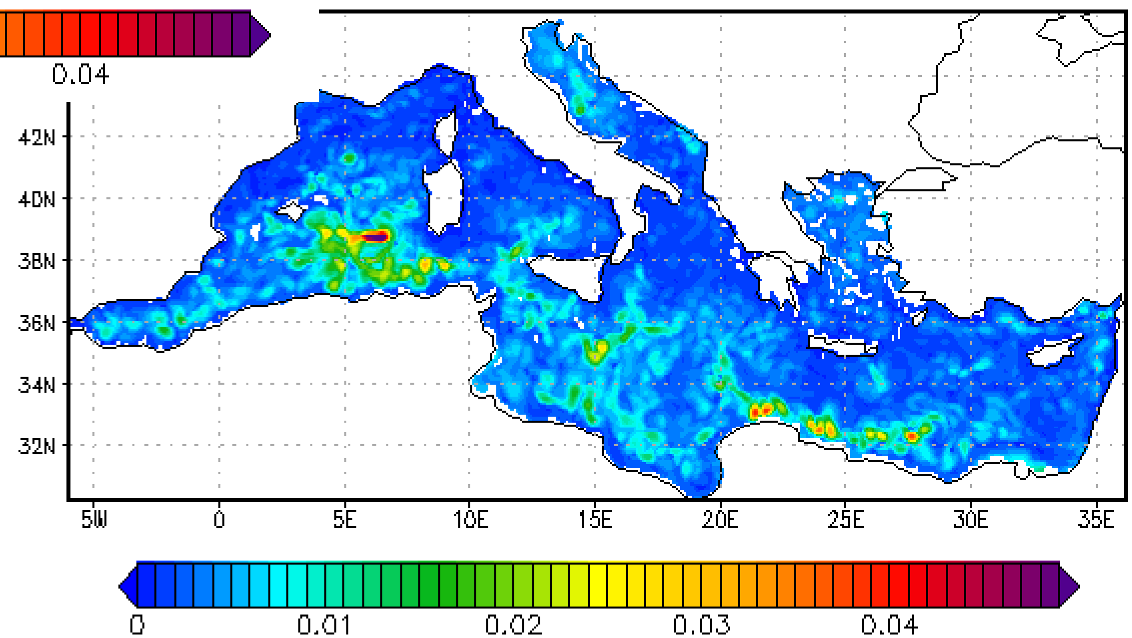
BHM-SVW-OEF last forecast day spread

Initial condition spread



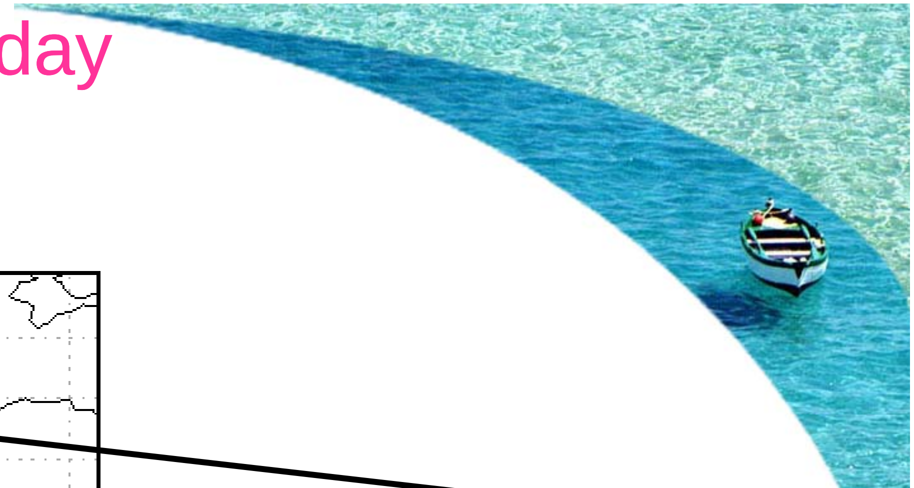
Sea Surface Height

10-th fcst day spread

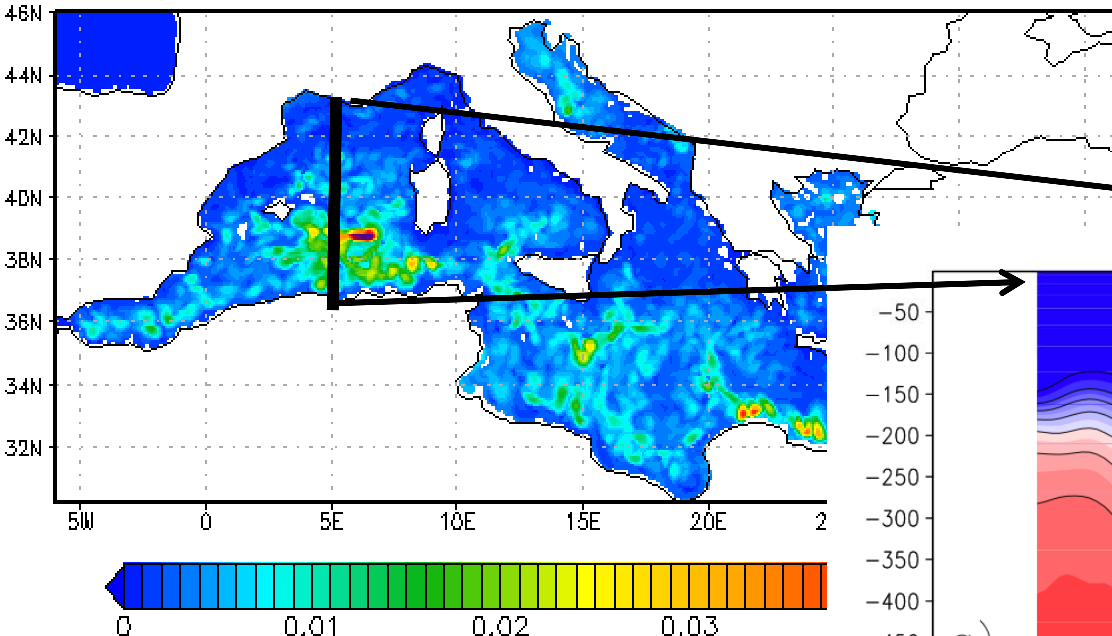


Initial condition ensemble spread has amplified at the 10 fcst day in mesoscale regions

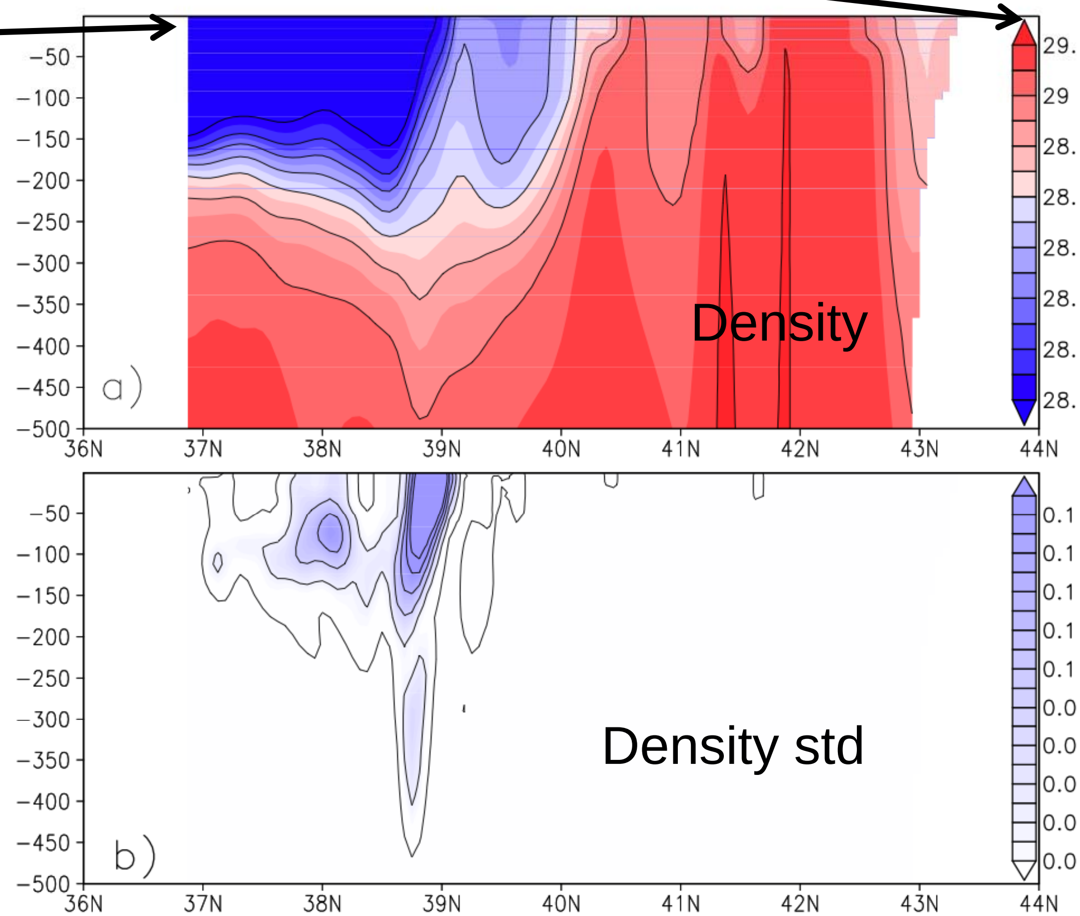
BHM-SVW-OEF last forecast day spread



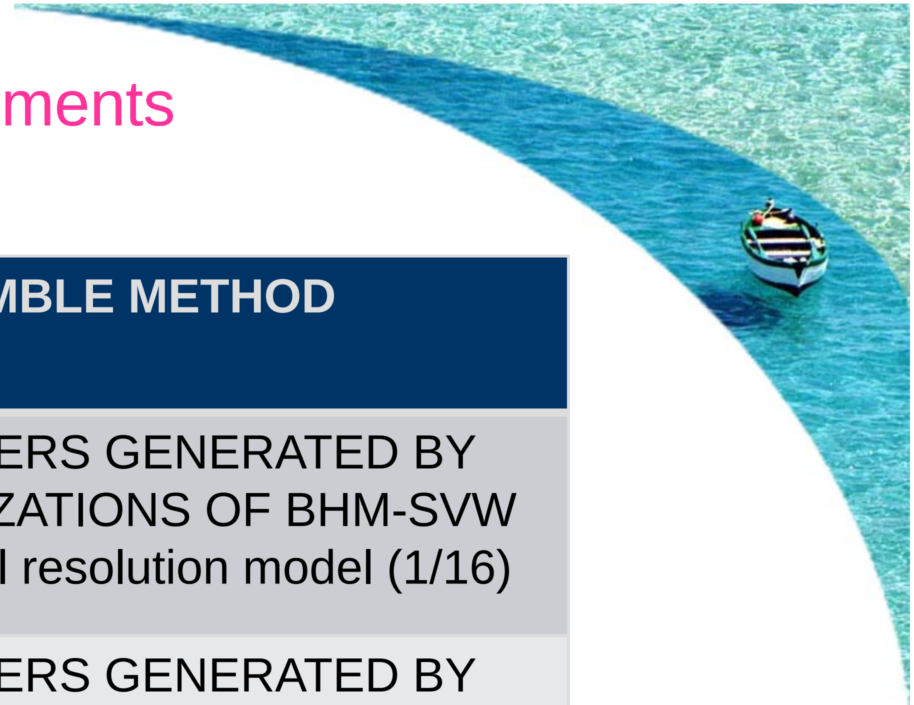
10-th fcst day spread



Ensemble Forecast spread is upper thermocline intensified



Ocean Ensemble Forecast Experiments



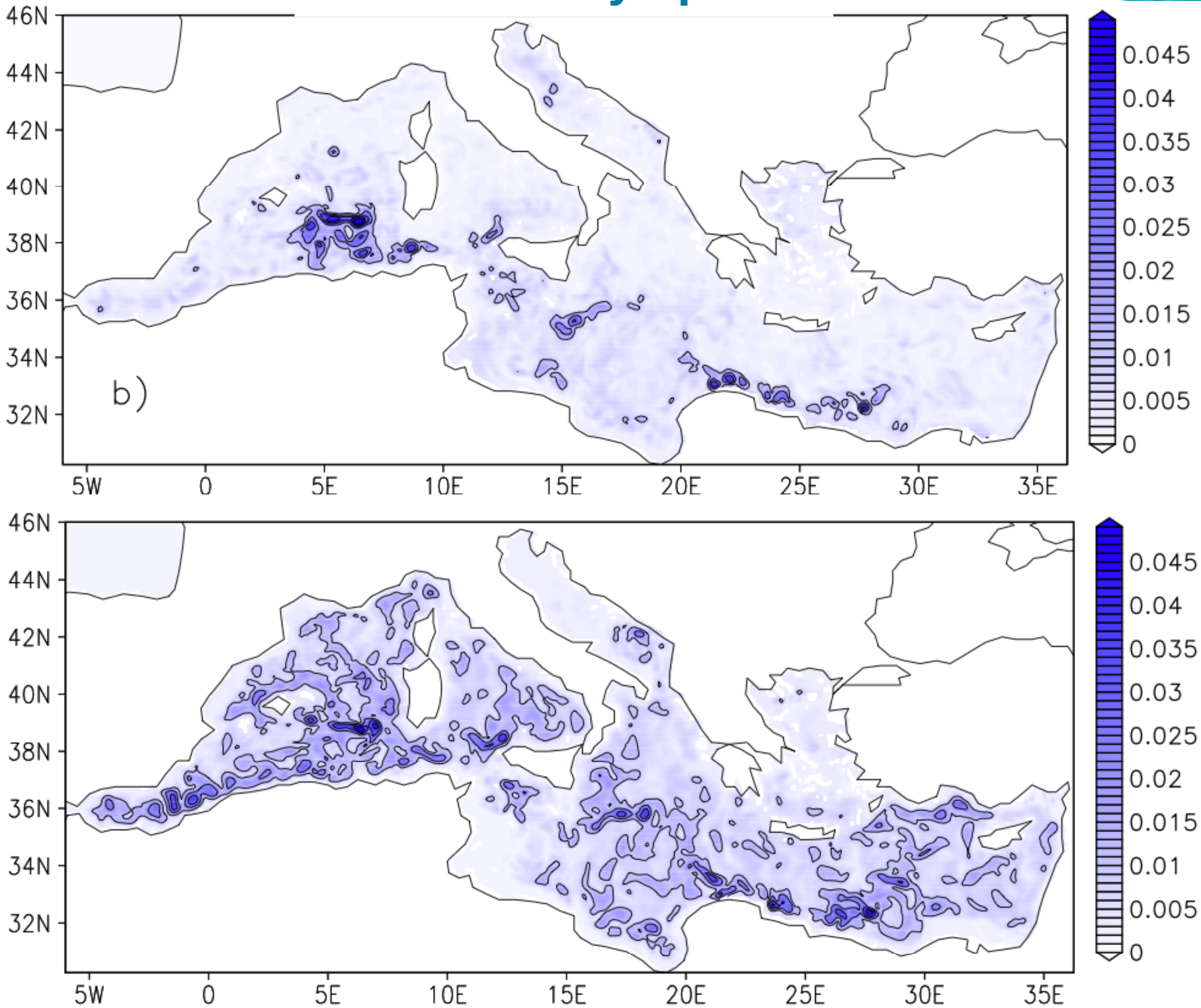
NAME OF THE EXPERIMENT	ENSEMBLE METHOD
BHM-SVW-OEF-16	MEMBERS GENERATED BY REALIZATIONS OF BHM-SVW with full resolution model (1/16)
EEPS-OEF	MEMBERS GENERATED BY ECMWF EPS WINDS, SAME INITIAL CONDITION
TIRP-EOF	MEMBERS GENERATED BY PERTURBED INITIAL CONDITIONS
BHM-SVW-OEF-4	MEMBERS GENERATED BY REALIZATIONS OF BHM-SVW with low resolution model (1/4)

Comparison TIRP-OEF and BHM-SVW-OEF spread

10-th fcst day spread

BHM-SVW-OEF

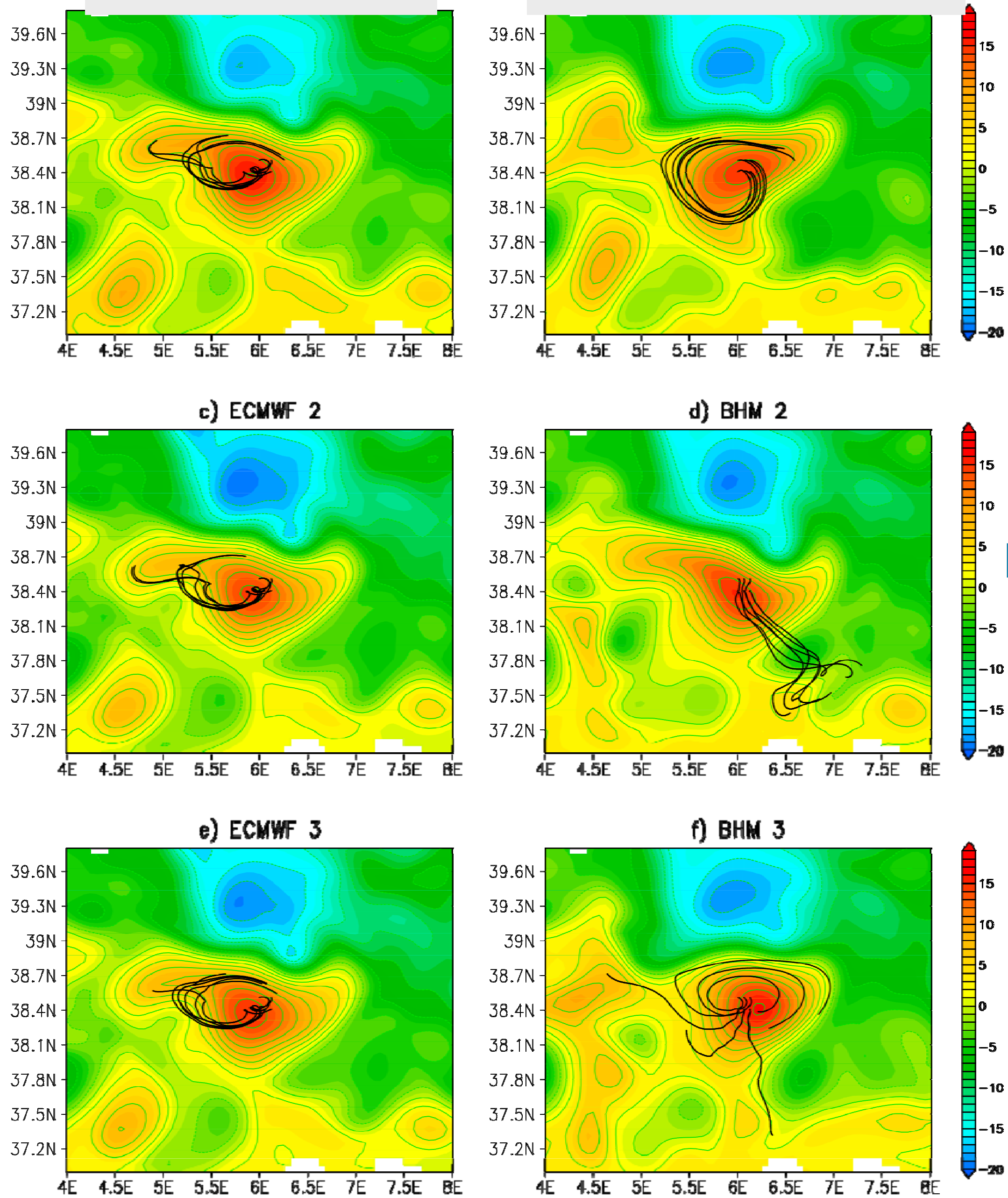
TIRP-OEF

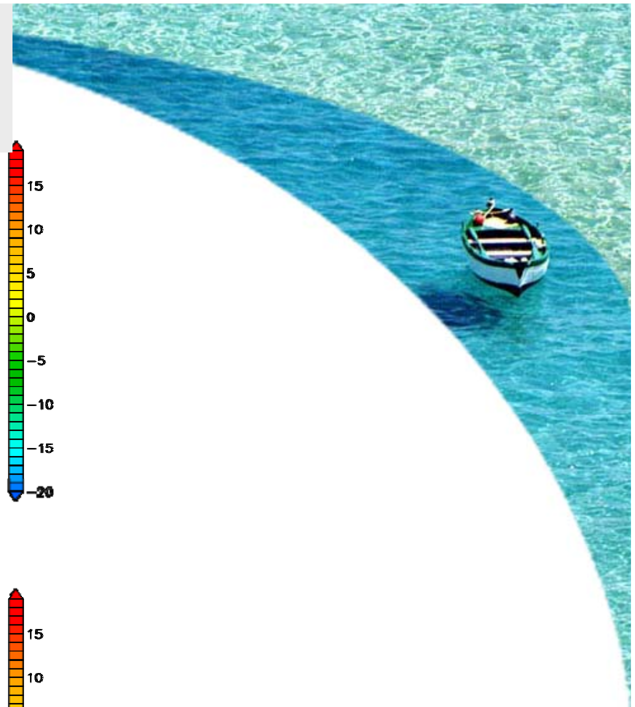


TIRP Perturbations vertical structure has been chosen ad-hoc

EEPS forced ensemble

BHM-SVW ensemble

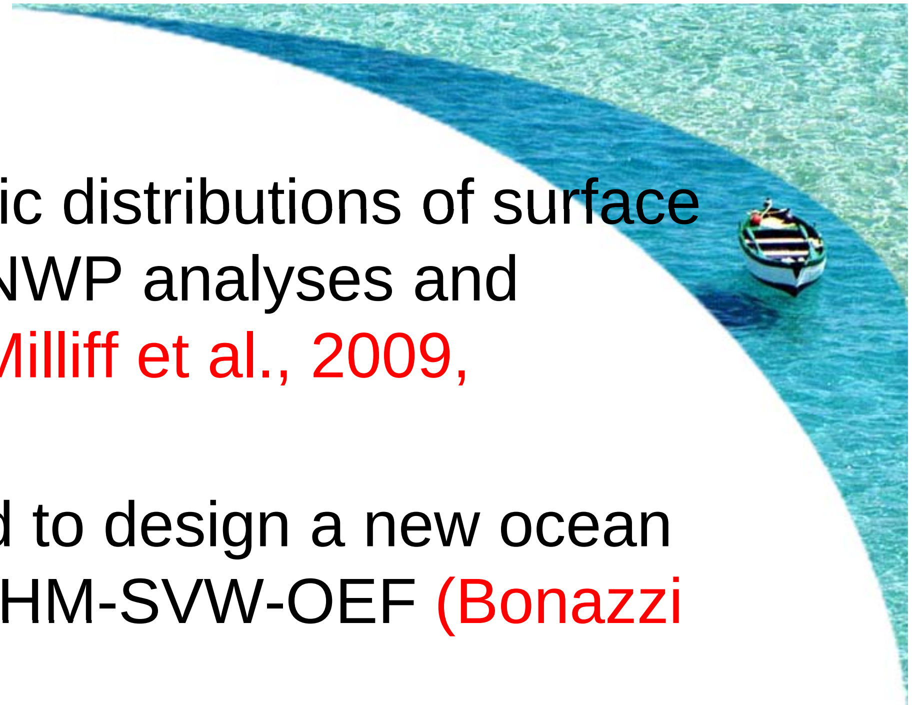




The forecast spread at 10F

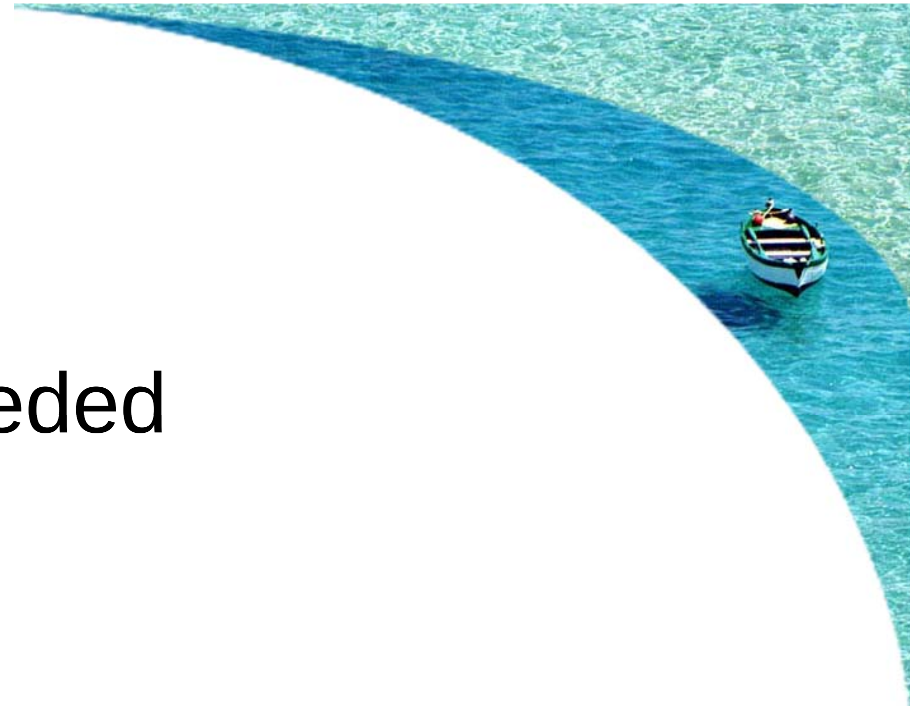
ECMWF EPS forcing is not effective to produce flow field changes at the mesoscales

Final considerations



- A new method to produce realistic distributions of surface winds (SVW) from QSCAT and NWP analyses and forecasts has been developed (Milliff et al., 2009, submitted)
- BHM-SVW distributions are used to design a new ocean ensemble forecasting method: BHM-SVW-OEF (Bonazzi et al., 2009, submitted)
- The BHM-SVW-OEF produces 10 days forecast spread at the mesoscales and in the upper thermocline
- Ad-hoc I.C. perturbations can produce similar results while large scale NWP ensemble prediction winds are not effective
- BHM-SVW-OEF coupled to IC condition perturbation methods promises in the future to contribute to the understanding of the ‘uncertainty conundrum’

- Additional slides if needed



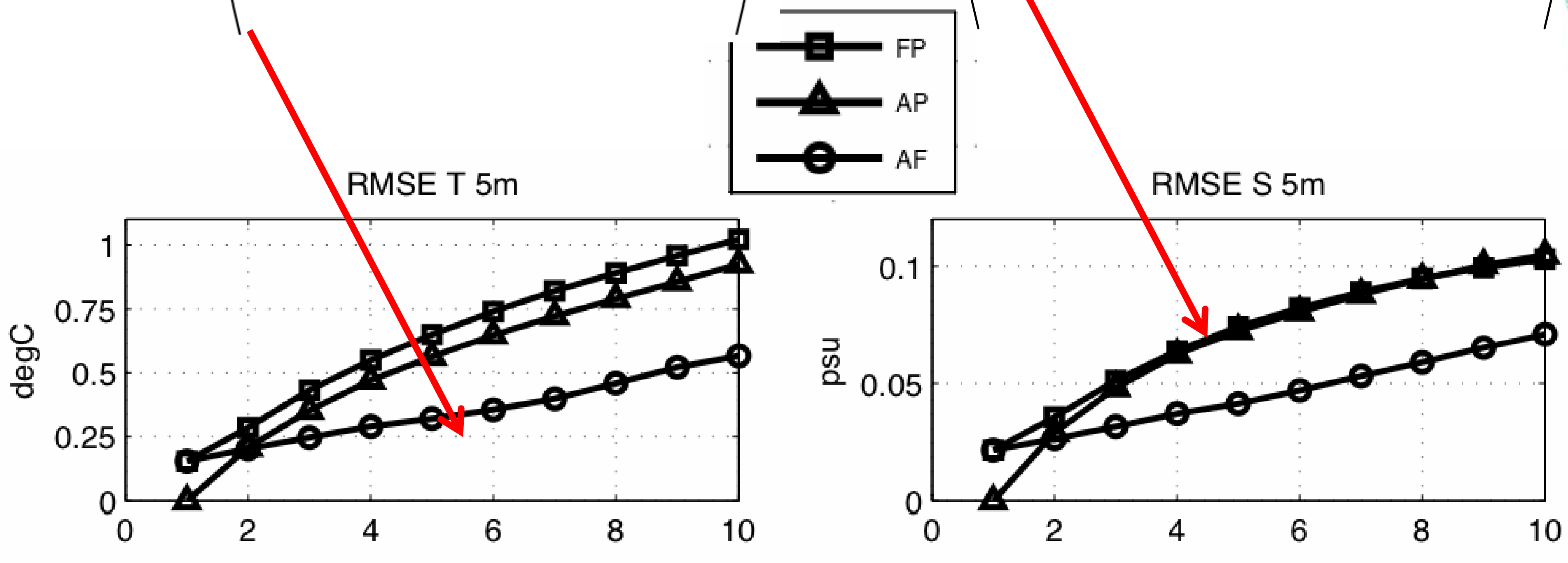
MFS forecast accuracy assessment
(year 2005, Tonani et al., 2010)

Analysis-Forecast

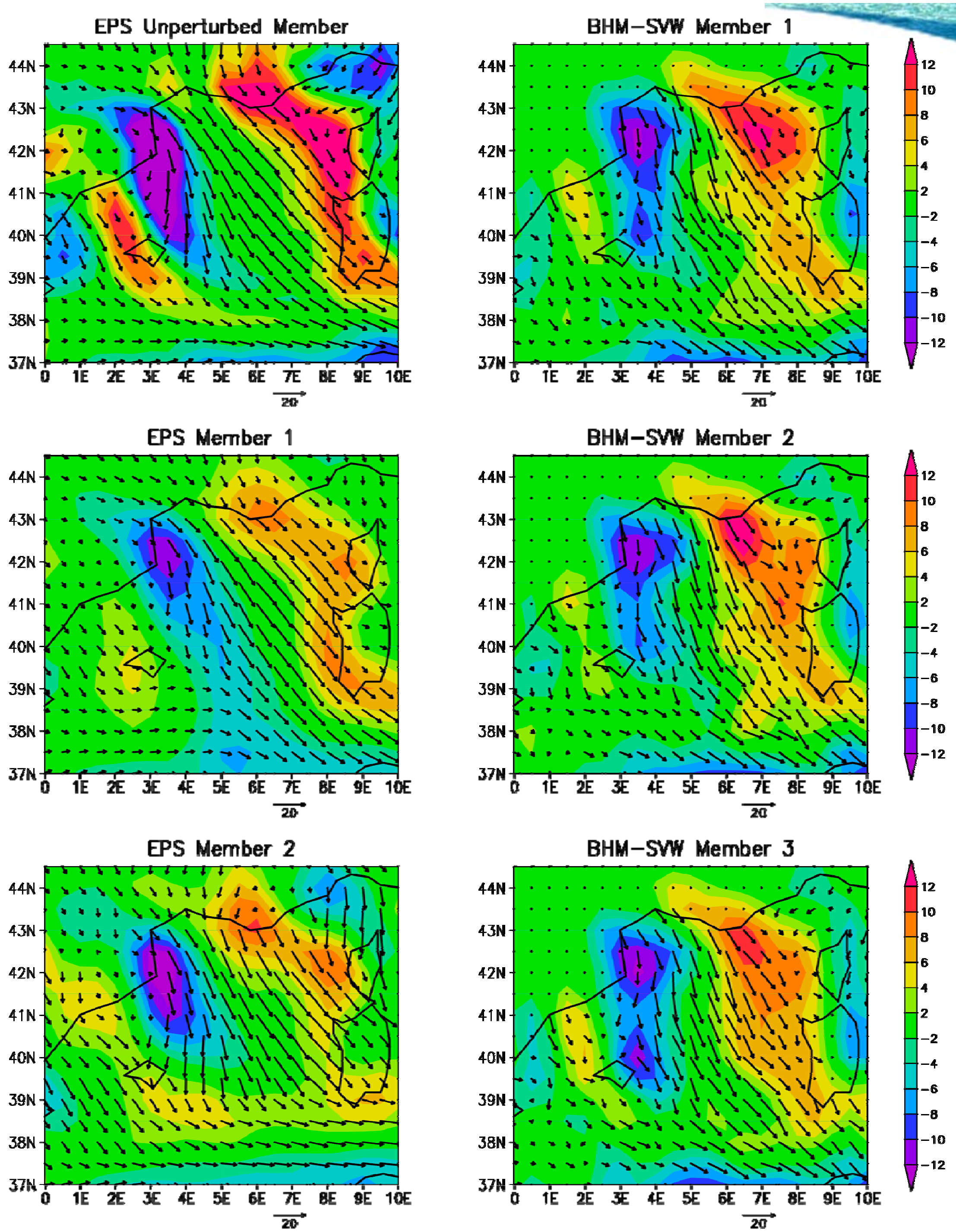
$$AF_c(t) = \left\langle \sqrt{\frac{\sum_{1}^{N}\left(X_{FC}(t) - X_{AN}(t)\right)^2}{N}} \right\rangle$$

Analysis-Persistence

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



Forecast days


EPS Unperturbed Member
BHM−SVW Member 1
EPS Member 1
BHM−SVW Member 2
EPS Member 2
BHM−SVW Member 3
44N
43N
42N
41N
40N
39N
38N
37N
0
1E
2E
3E
4E
5E
6E
7E
8E
9E
10E
20
12
10
8
6
4
2
−2
−4
−6
−8
−10
−12