Short term ocean and seasonal forecasting: forecast quality and accuracy, development of application tools

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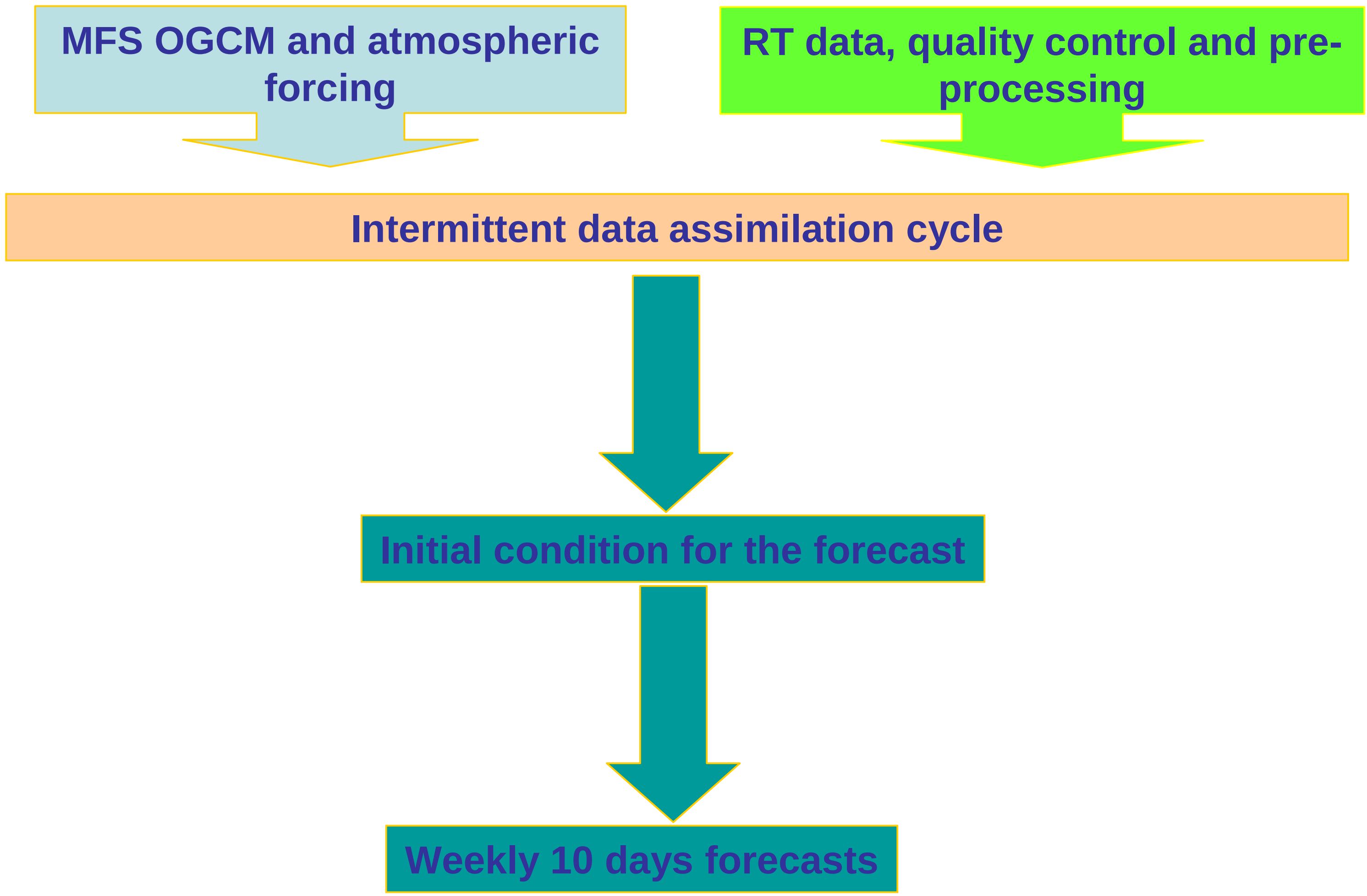
Outline

- The Mediterranean ocean Forecasting System: quality and accuracy of the forecast
- The environmental predictions development: downscaling and multidisciplinarity
- Development of application tools: oil spill, Integrated Coastal Zone Management-ICZM, fisheries
- Ensemble seasonal forecasting and the future

The MFS operational system



The MFS system: operational data assimilation system

- MFS uses a Reduced Order Optimal Interpolation scheme that is multivariate (X) and multi-data (Y) in input

$$\mathbf{X}^a = \mathbf{X}^b + \mathbf{K}(\mathbf{Y}^o - H(\mathbf{X}^b))$$

$$\mathbf{K} = \mathbf{B}\mathbf{H}^T(\mathbf{H}\mathbf{B}\mathbf{H}^T + \mathbf{R})^{-1}$$

$$\mathbf{X} = [T\ S\ U\ V\ \eta\ \psi\ \rho]^T$$

(in OGCMs, T,S,U,V, ψ, are prognostic
η and ρ are diagnostic)

- The background error covariance is separated into vertical (S) and horizontal (Br) correlation structures (valid for open ocean)

$$\mathbf{B} = \mathbf{S}\ \mathbf{Br}\ \mathbf{S}^{\mathrm{T}}$$

(De Mey and Benkiran, 2002)

Order reduction procedure for the B matrix

The order reduction is achieved because only a limited number of vertical modes are required in the ocean, thus:

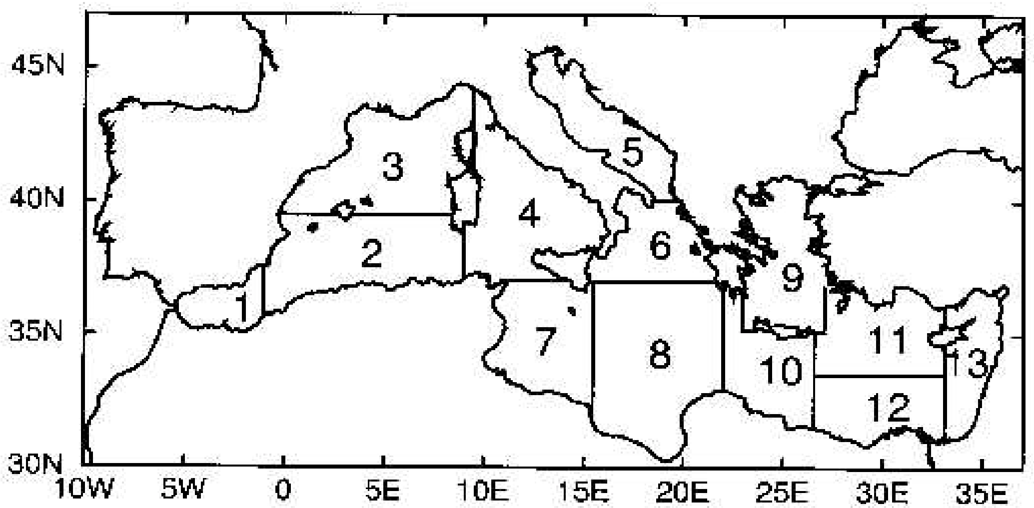
$$\mathbf{S} \approx \tilde{\mathbf{S}}$$

$$\mathbf{K}^{\mathrm{ROOI}} = \tilde{\mathbf{S}}\,\mathbf{Kr}$$

$$\mathbf{Kr} = \mathbf{Br}\,\tilde{\mathbf{S}}^{T}\mathbf{H}^{T}(\mathbf{H}\tilde{\mathbf{S}}\,\mathbf{Br}\,\tilde{\mathbf{S}}^{T}\mathbf{H}^{T} + \mathbf{R}^{*})^{-1}$$

where $\tilde{\mathbf{S}}$ contains a limited number of multivariate vertical EOFs.

For the Mediterranean, the EOFs are calculated for 13 different regions



The multivariate background error covariance matrix

- **How is B defined?**

$$\mathbf{B} = \left\langle (\mathbf{X}^b - \mathbf{X})(\mathbf{X}^b - \mathbf{X})^T \right\rangle$$

$$\mathbf{B} = \begin{vmatrix} T'T' & T'S' & .. & T'\eta' \\ S'T' & S'S' & S'U' & S'\eta' \\ U'T' & .. & ... & .. \\ \eta'T' & \eta'S' & & \eta'\eta' \end{vmatrix}$$

Water mass properties

Important for T,S profiles assimilation

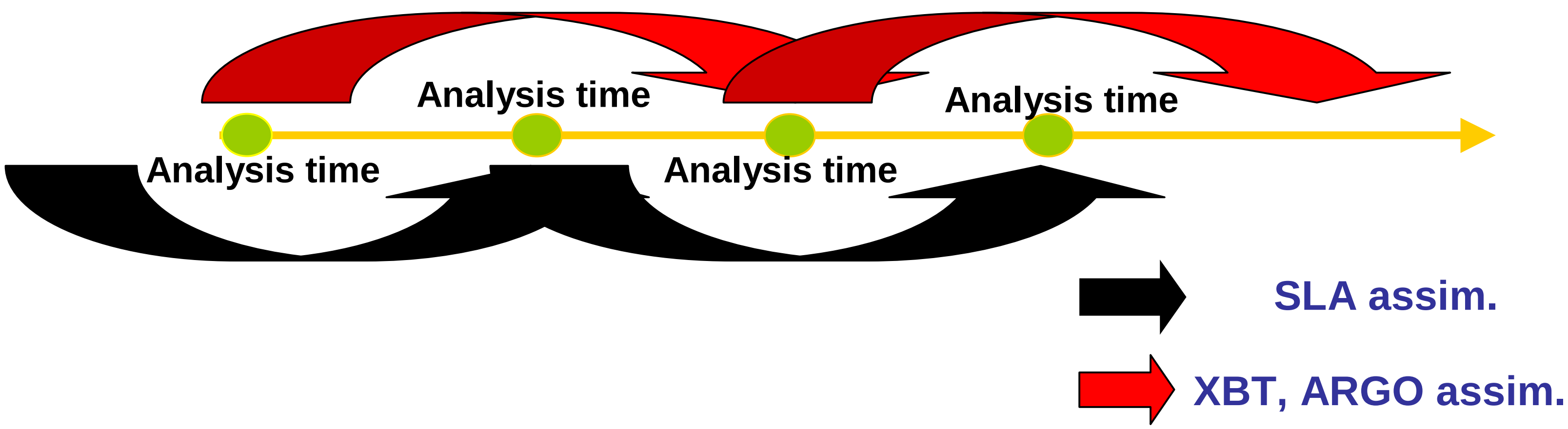
Correlates SLA with thermocline and halocline

Important for SLA Assimilation: extrapolation to T,S corrections

The MFS assimilation system: split of the analysis cycle

- Due to the specific ocean data sets (T,S profiles and SLA) the vertical modes of B, the S matrix, should be considered separately for the two data sets
- Thus the analysis cycle is split into two separate steps: one with the vertical modes for SLA and the other with the vertical modes for XBT, ARGO

Analysis cycle (WEEKLY)



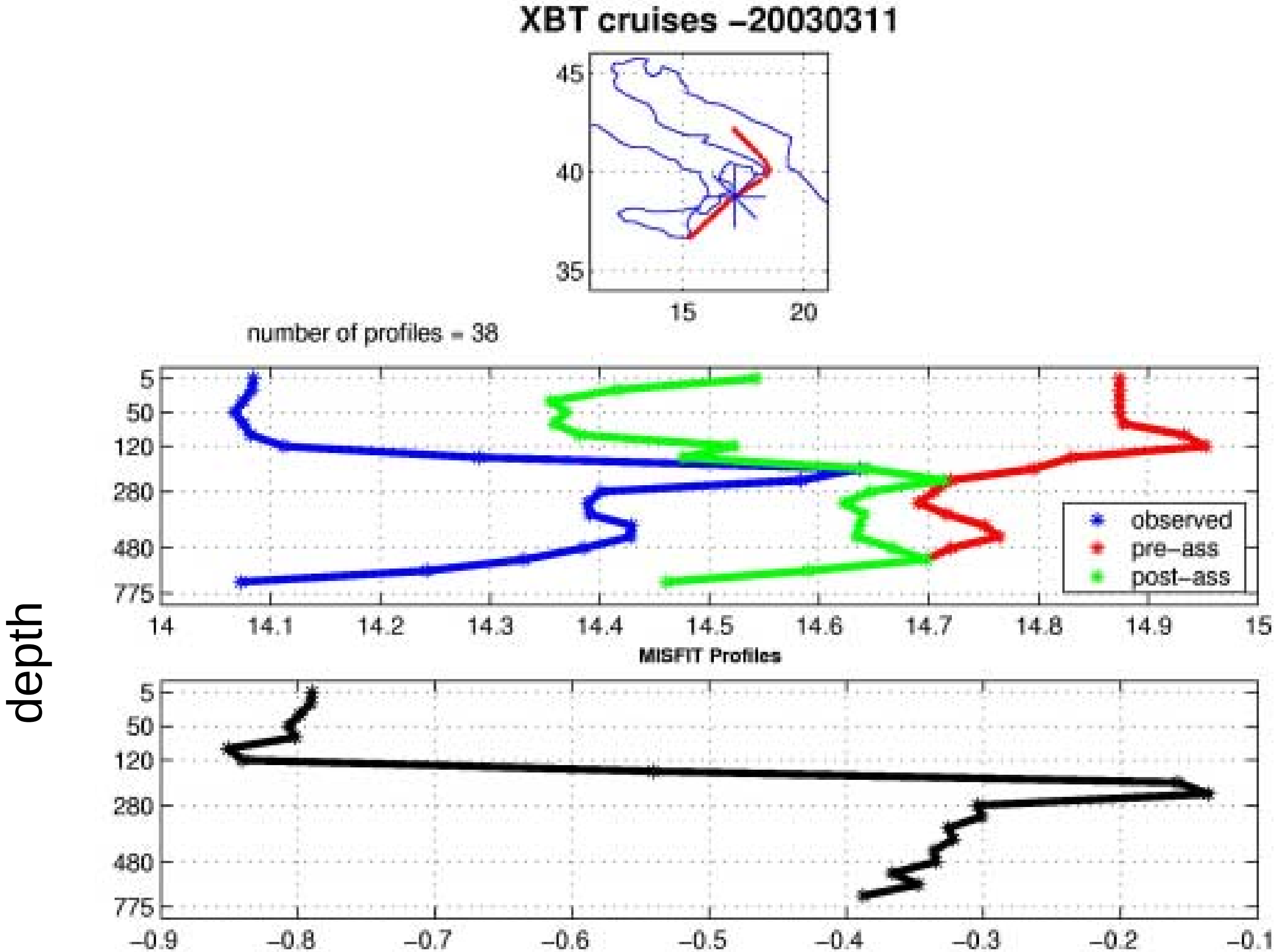
Background error covariance for XBT and ARGO profiles assimilation

- For XBT, T profiles only, we want to correct the temperature and the salinity by using extrapolation from the multivariate S covariance
- For ARGO T,S profiles we want to use the same T-S error vertical characteristics than for XBT
- The present day operational system for assimilation of XBT and ARGO uses then bi-variate vertical EOFs obtained from a B matrix written simply as:

$$\mathbf{S} = \begin{vmatrix} \mathbf{T'T'} & \mathbf{T'S'} \\ \mathbf{S'T'} & \mathbf{S'S'} \end{vmatrix}$$

- The EOFs are constructed from an historical climatological data set for T,S profiles. Thus assumption is that error behaves as variance of field

Assimilation of XBT data: balance between model error and measurement error (free parameter)



Misfit= T(model)- T(XBT)

Background error covariance for SLA assimilation

- On the basis of the a priori knowledge of the relevant physical processes we know that the geostrophic sea level is written as (Pinardi et al., 1995):

$$\eta = \frac{1}{H_0}\left\{ f\frac{\psi}{g} - \frac{1}{\rho_0}\int_{-H_0}^{0}\rho\, z dz - \frac{H_0}{\rho_0}\int_{-H_0}^{0}\rho dz \right\}$$

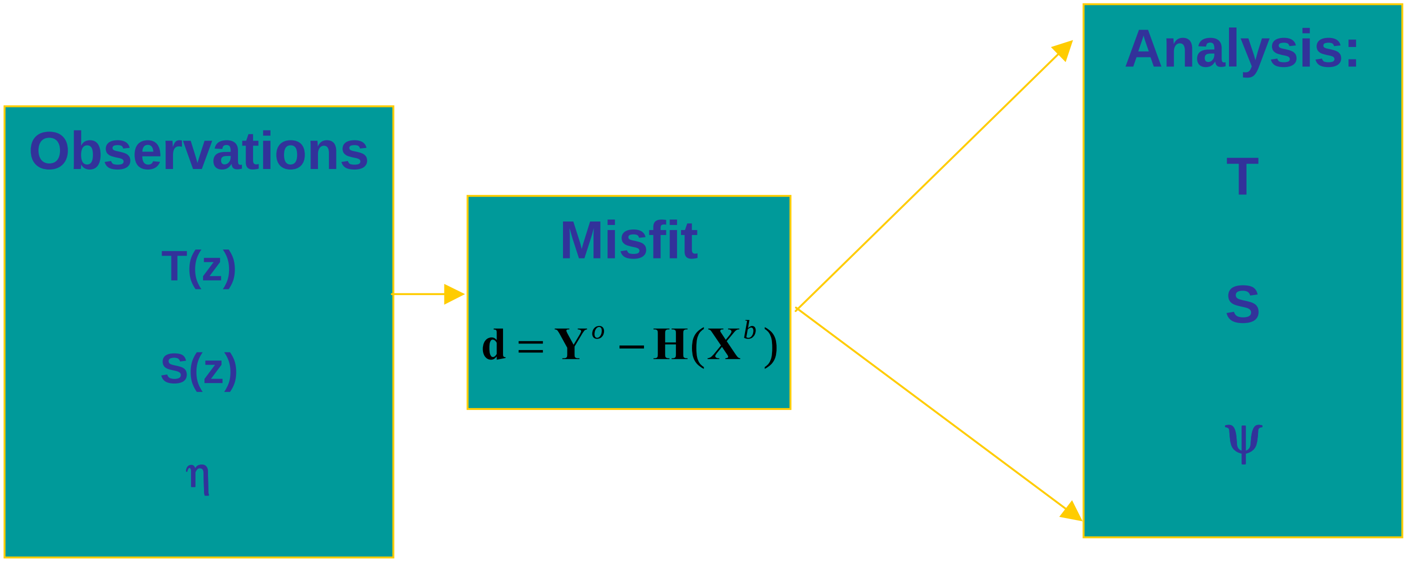
Thus **B** should be:

$$\mathbf{B} = \begin{vmatrix} \mathbf{T'T'} & \mathbf{T'S'} & \mathbf{T'\psi'} & \mathbf{T'\eta'} \\ \mathbf{S'T'} & \mathbf{S'S'} & \mathbf{S'\psi'} & \mathbf{S'\eta'} \\ \mathbf{\psi'T'} & \mathbf{\psi'S'} & \mathbf{\psi'\psi'} & \mathbf{\psi'\eta'} \\ \mathbf{\eta'T'} & \mathbf{\eta'S'} & \mathbf{\psi'\eta'} & \mathbf{\eta'\eta'} \end{vmatrix}$$

- In this case we need to use the model data to compute the multivariate vertical EOFs

The practical implementation of the ROOI

- The real time observations are: SLA, SST, XBT and ARGO.
- Assimilation of XBT and ARGO is done with 10 seasonal vertical EOFs calculated from (T,S) multivariate statistics from historical data
- Assimilation of SLA is done with 20 seasonal vertical EOFs calculated from (T,S,η,ψ) statistics from model simulations (SYS3)
- We then have:



Forecast consistency, quality and accuracy

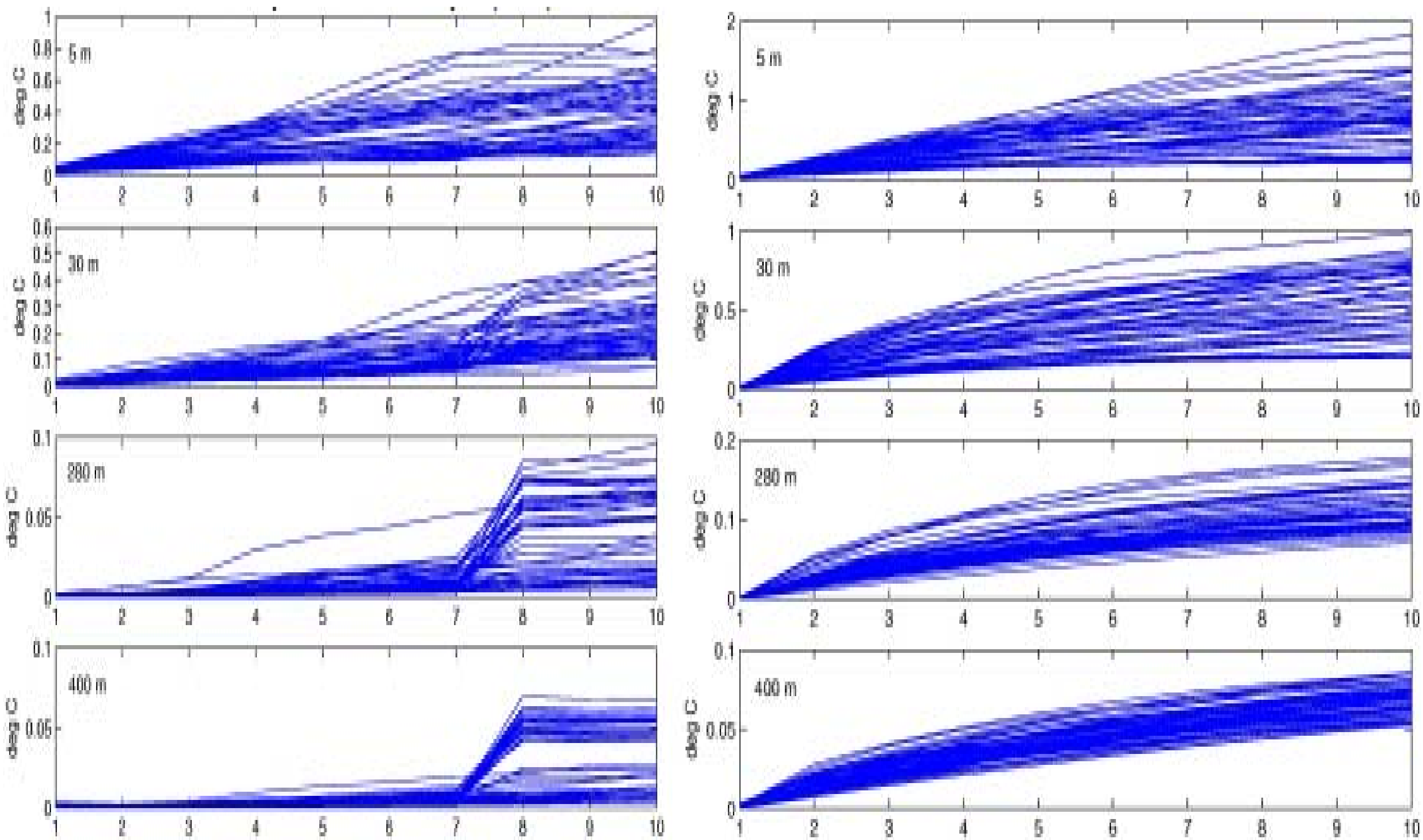
- **Consistency: " It checks the qualitative consistency between analysis and observations based upon the experience of the forecaster on the dynamics of the region and the knowledge of the relevant dynamical process "**
- **Quality : " It is the objective correspondence between *analyses* and *forecasts* using statistical indices to quantify the level of discrepancy between forecast and analyses "**
- **Accuracy: " objective corrispondence between observations and analysis using statistical indices to quantify the analysis error with respect to the data "**

Forecast quality: comparison between root mean square error of forecast and persistence

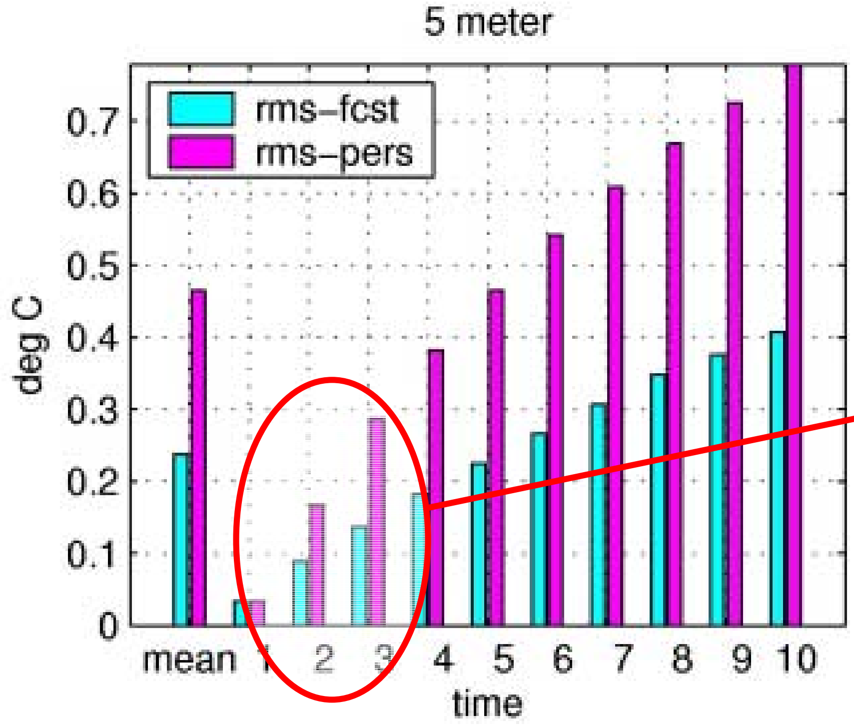
2002

Rms forecast

Rms persistency



Forecast quality: comparison between root mean square error of forecast and persistence



Conclusion: forecast is important from the second day

$$rms(fcst) = \sqrt{\frac{\sum(\phi_{FCST} - \phi_{ANAL})^2}{N}}$$

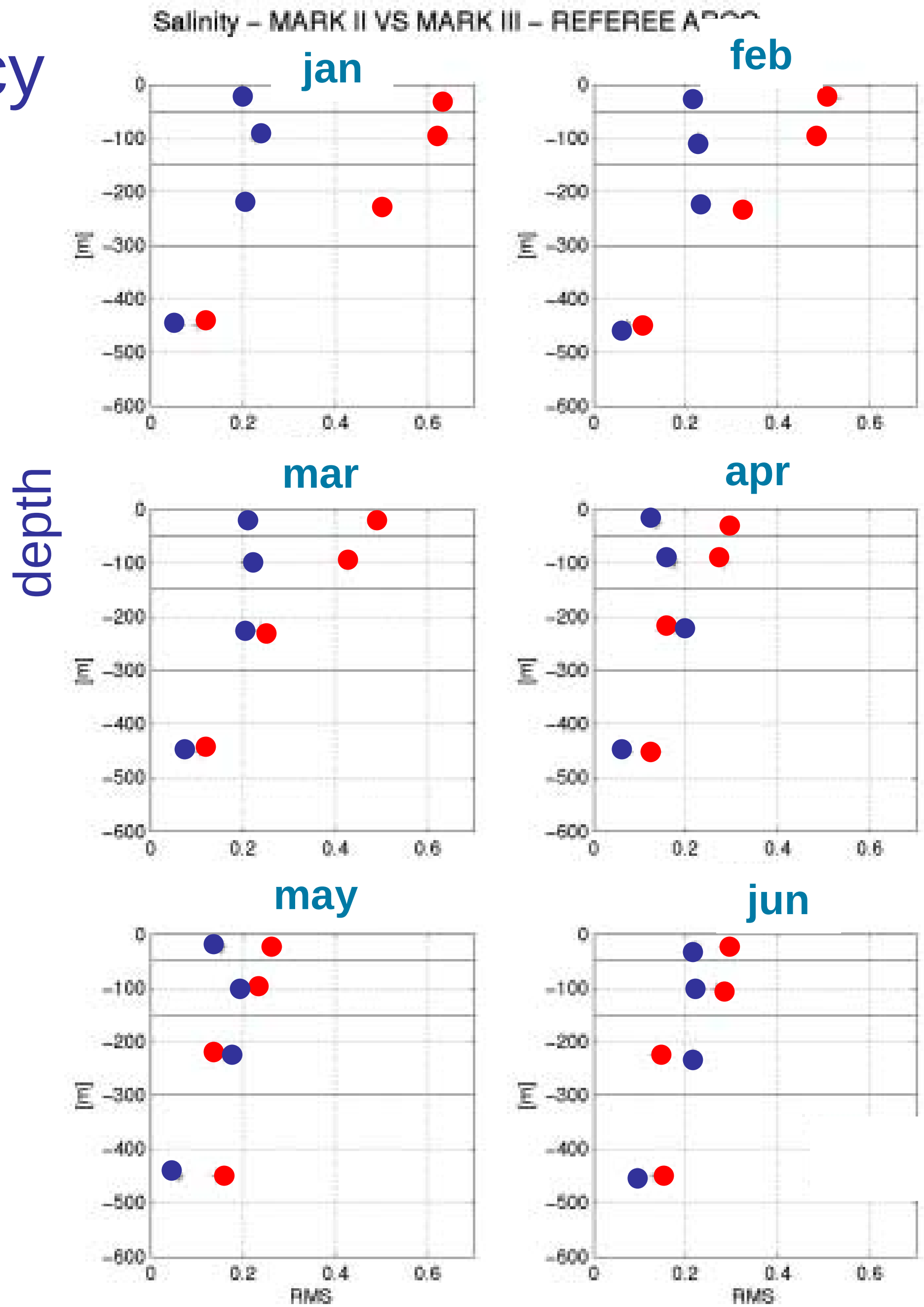
$$rms(pers) = \sqrt{\frac{\sum(\phi_{PERS} - \phi_{ANAL})^2}{N}}$$

Basin 2002

Forecast accuracy

SYS3 ● vs
SYS2 ● :
RMS error
between ARGO
and analyses

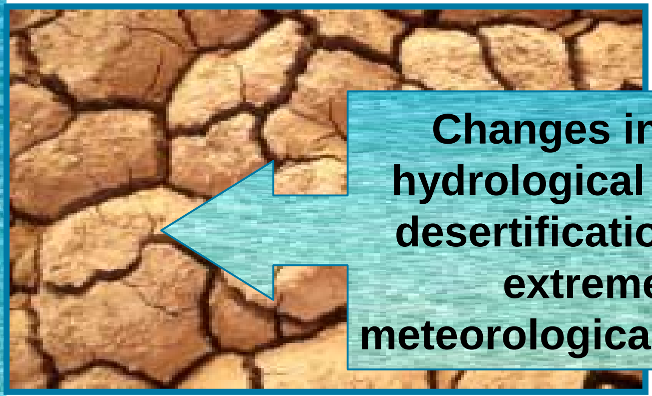
No salinity data
has ever been
assimilated at this point,
only extrapolation from
satellite altimetry



The marine environmental issues: Mediterranean examples

Haven, 1991

The marine environmental issues: Mediterranean examples



Changes in the hydrological cycle: desertification and extreme meteorological events

Pietra Ligure

Coastal erosion

Coastal eutrophication, HABs and other primary producers extremes

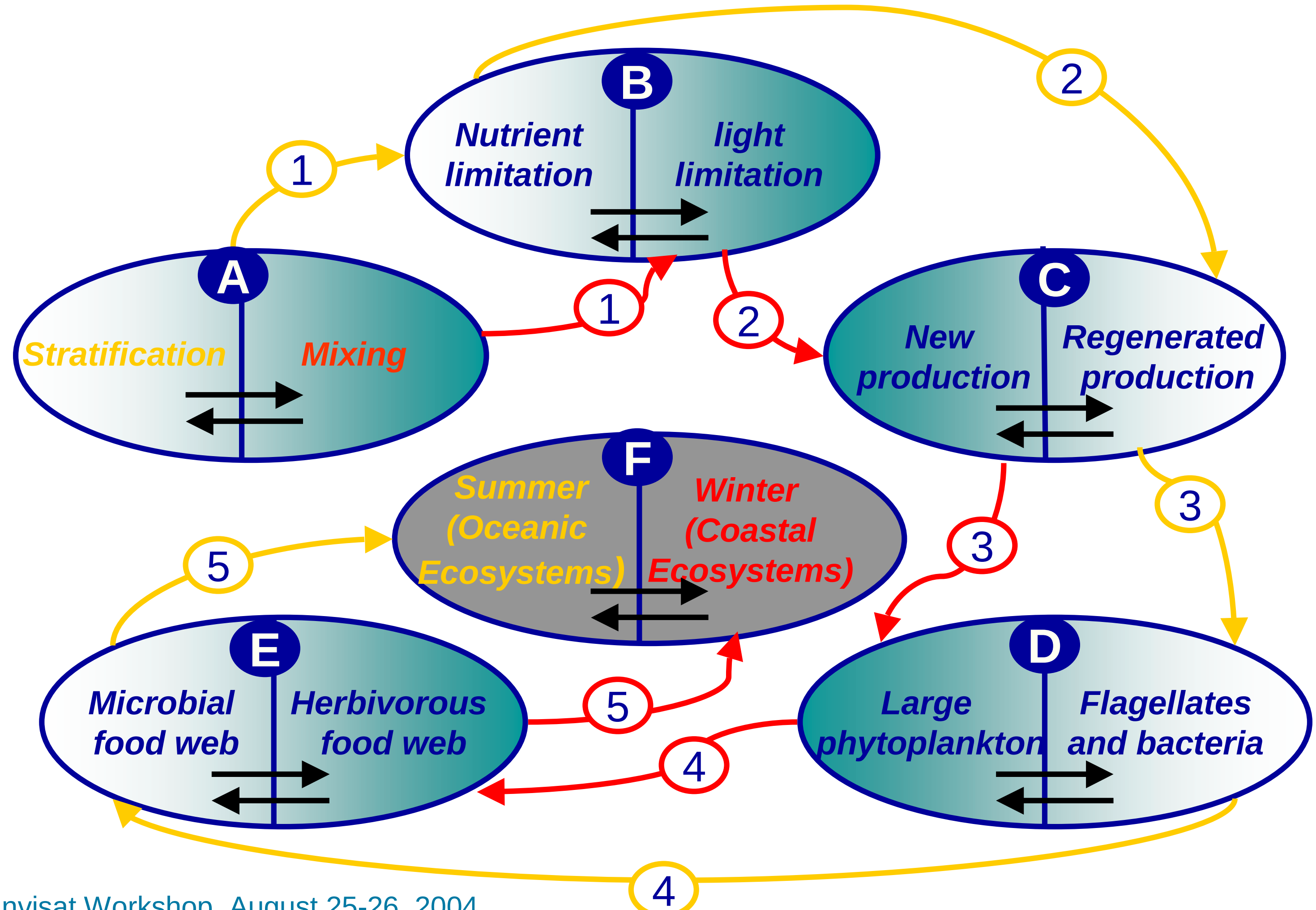
Trieste 2000

How to address these environmental issues in the framework of operational oceanography?

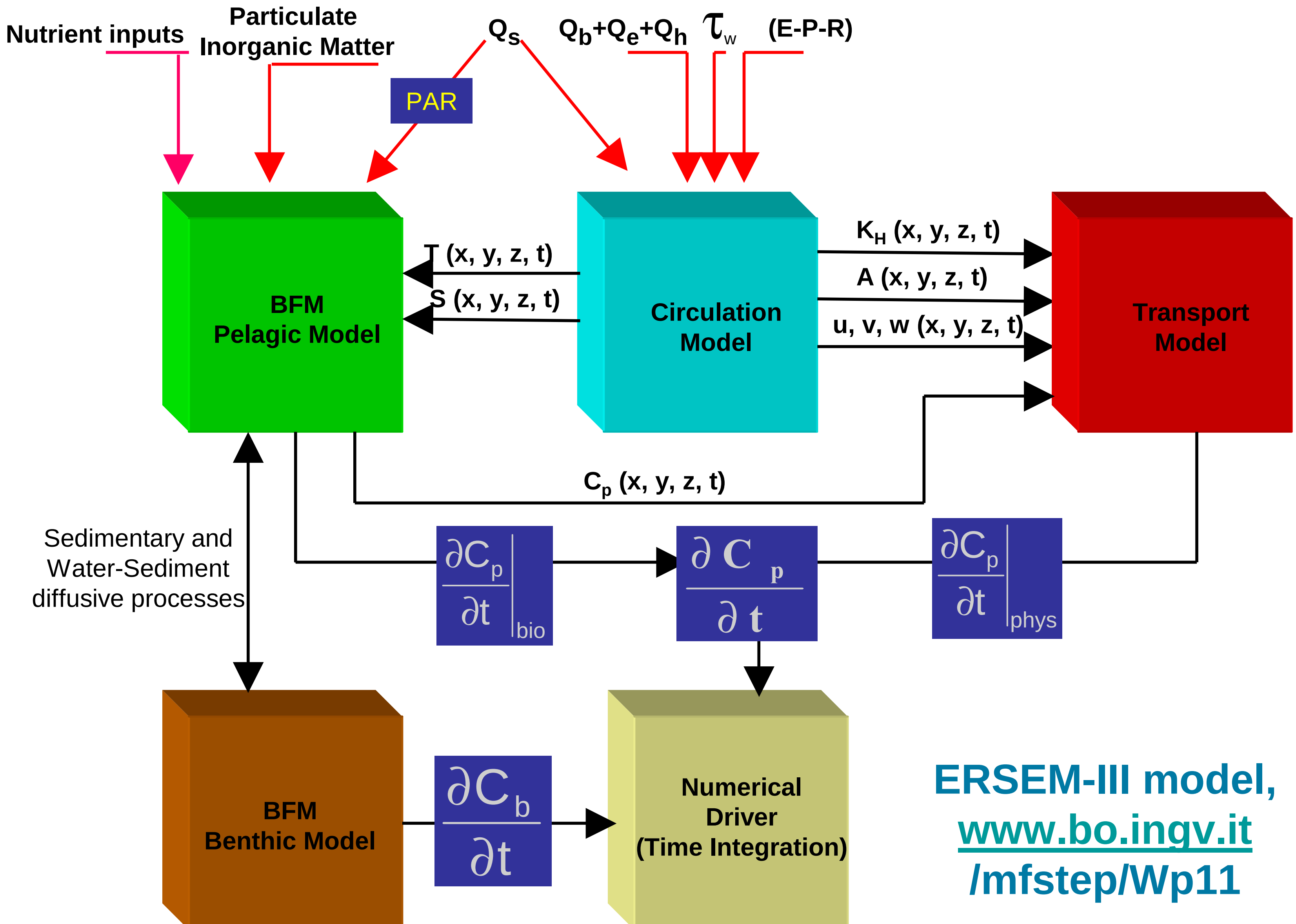
- Construct coupled physical-biogeochemical models and coupled atmosphere-ocean models
- Further develop observing system from in situ and satellite platforms to be truly multidisciplinary
- Develop data assimilation for biogeochemical modelling and contaminants
- Further develop numerical models process representation
- Downscale to the high space and time resolution required by the environmental issues: hours for open ocean oil spill emergencies, 100 m for coastal pollution, etc.

Ecosystem functioning in open ocean and coastal areas

Multivorous food webs

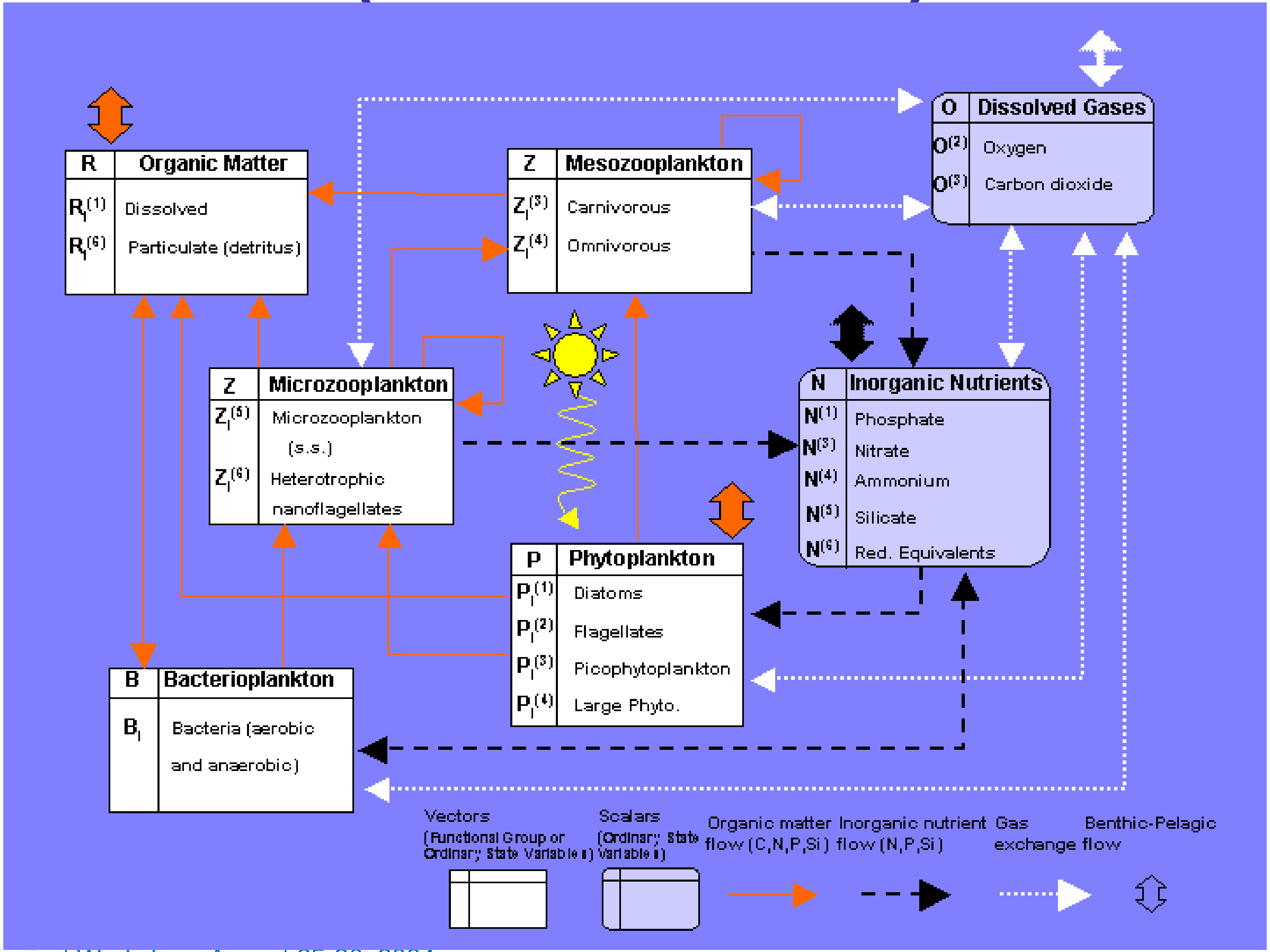


THE GENERAL STRUCTURE OF THE ecosystem MODELS FORCING AND COUPLING

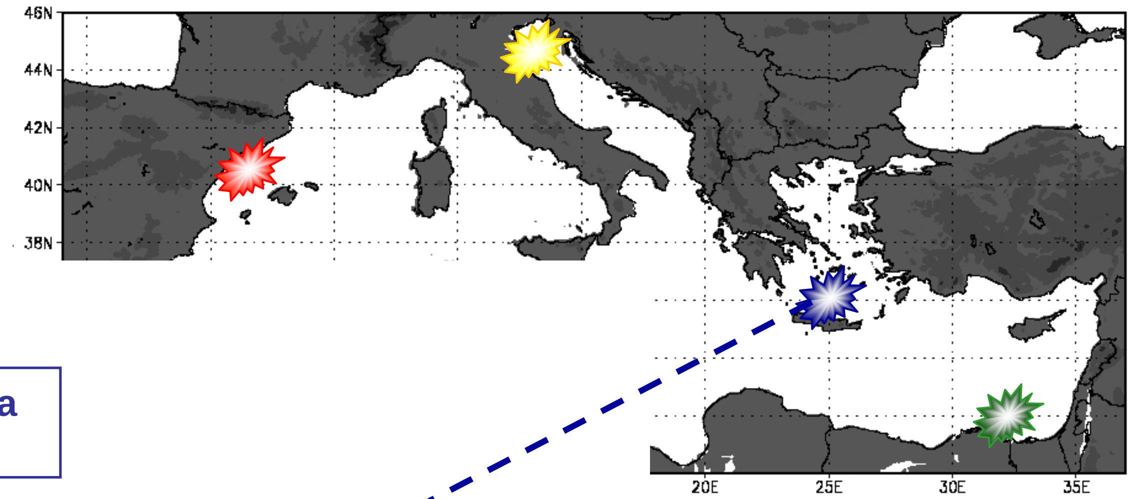


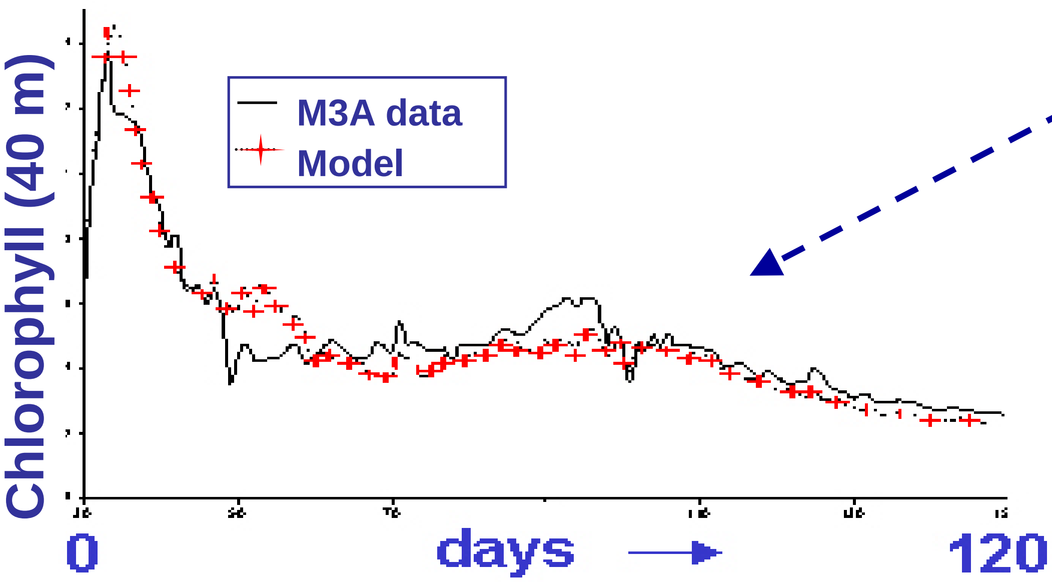
ERSEM-III model, www.bo.ingv.it /mfstep/Wp11

The pelagic model state variables (about 30 variables)



Ecosystem Model calibration areas

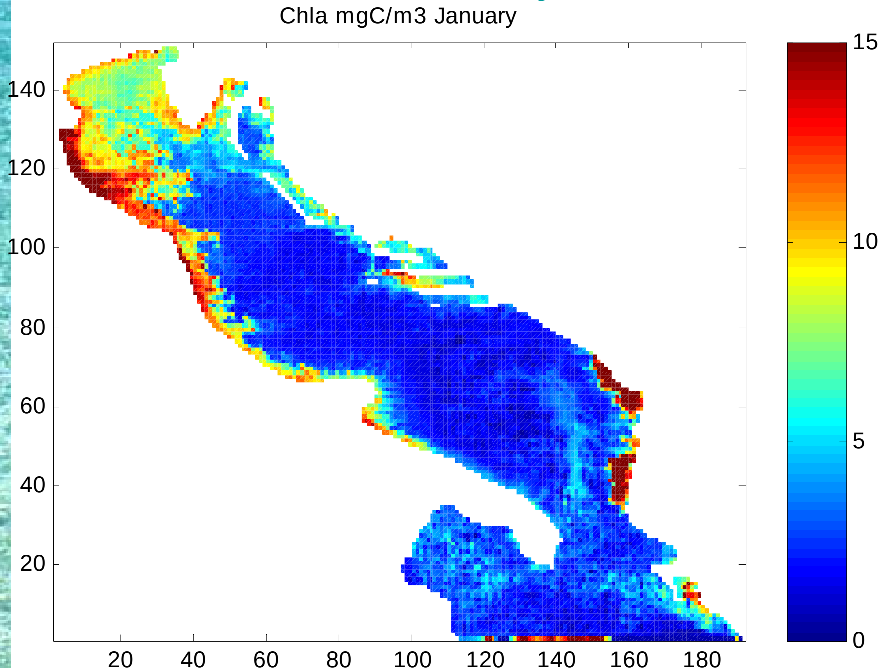


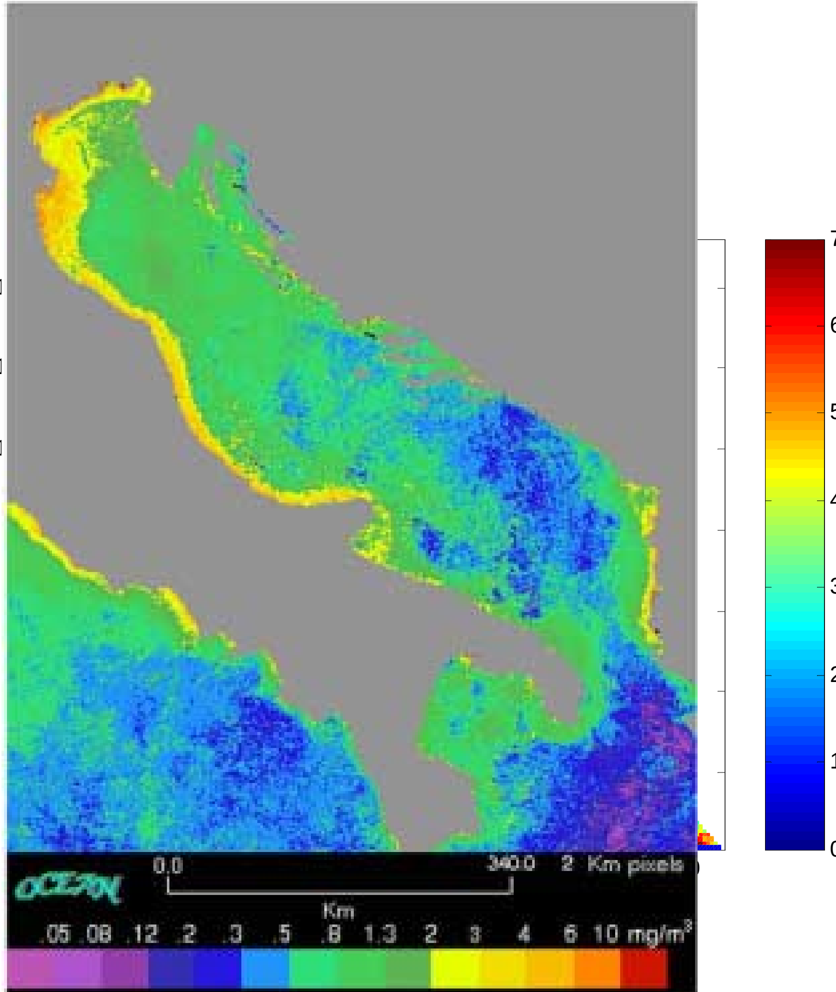


Plymouth Marine Laboratory
NATURAL ENVIRONMENT RESEARCH COUNCIL

Ecosystem Model in the Adriatic Sea:
3-D simulation with climatological forcing

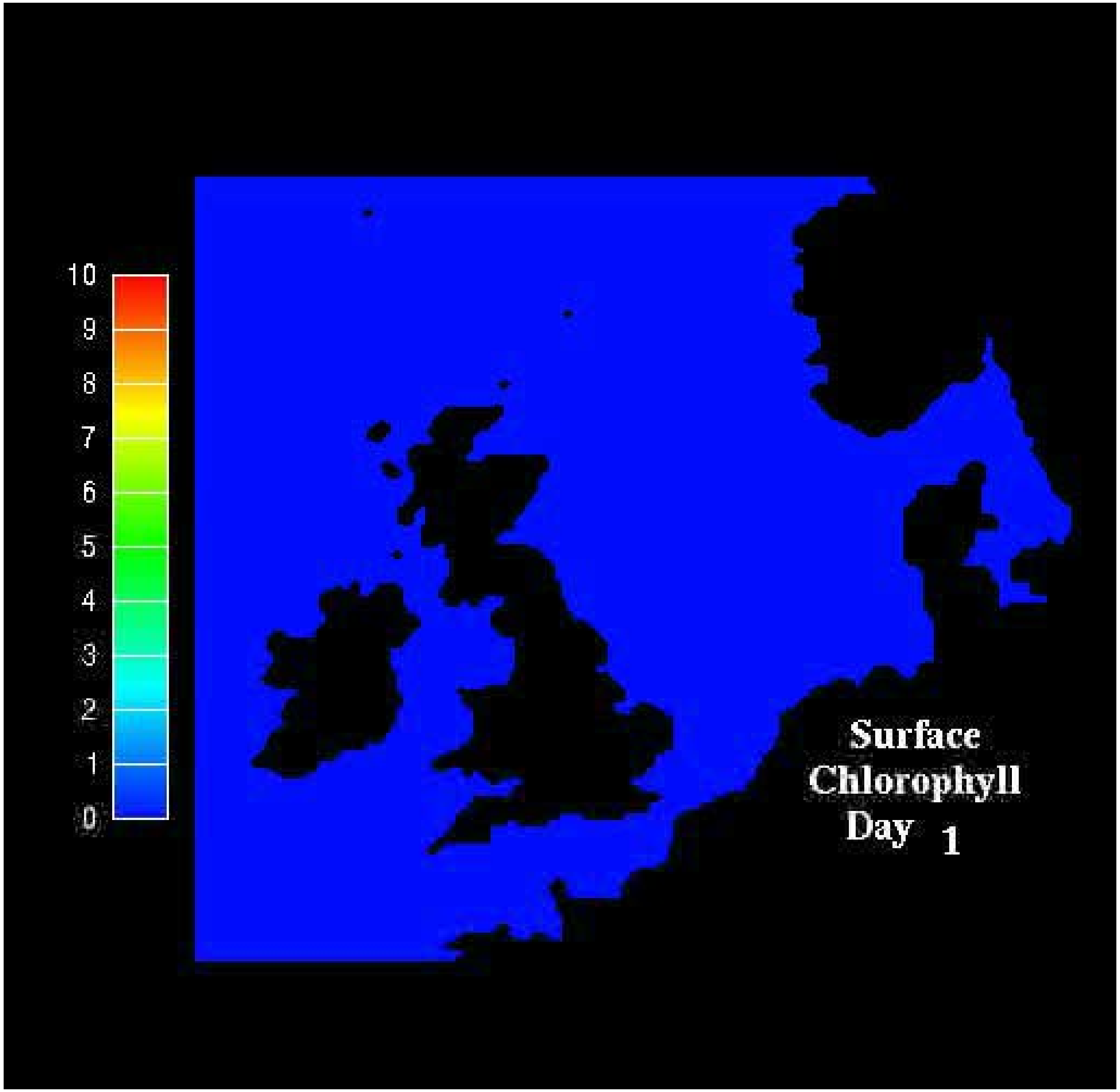
Surface Chl-a January

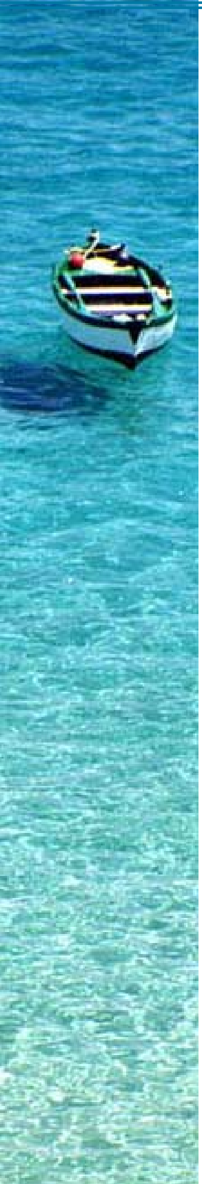




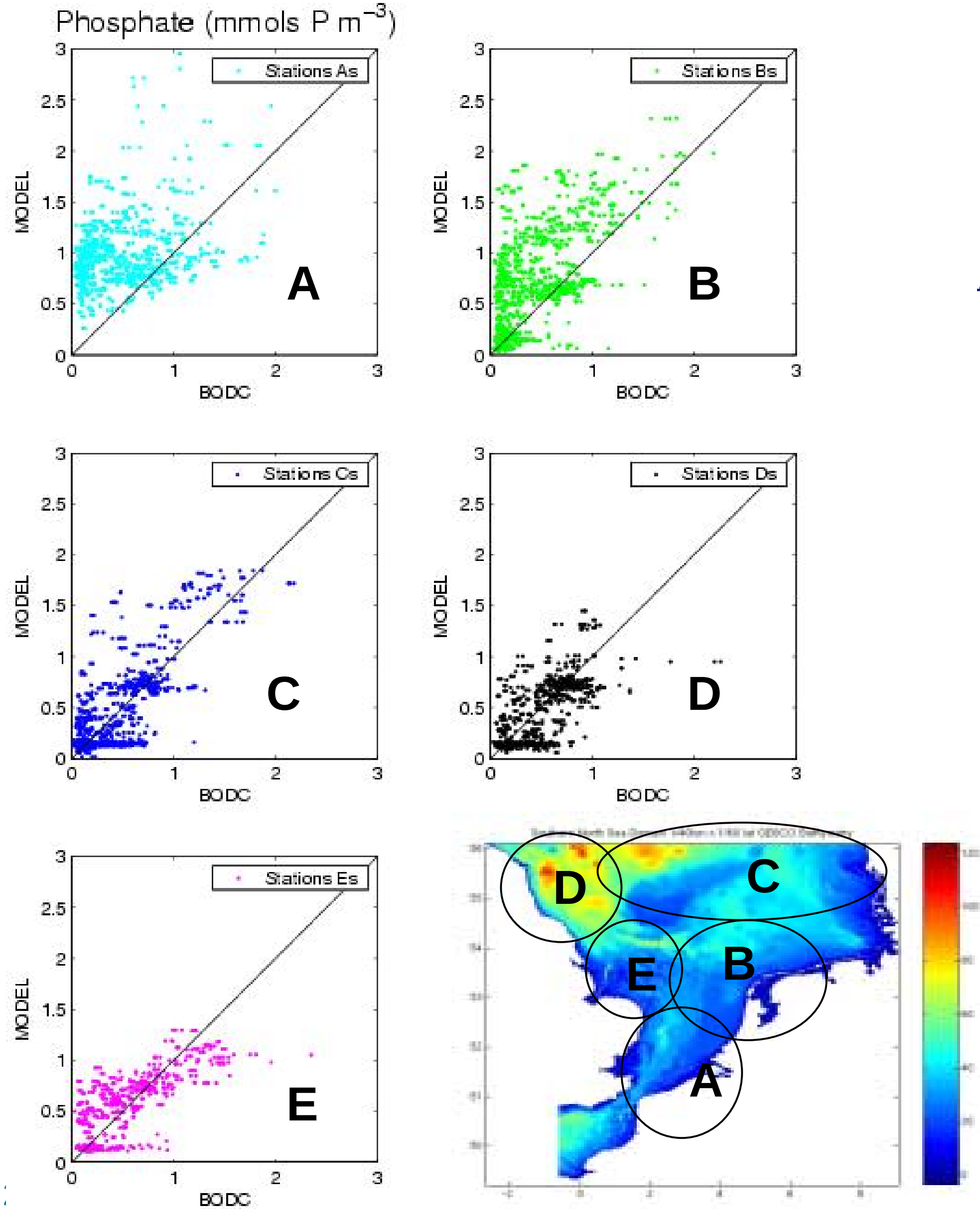
North Sea ecosystem model simulation for one year

Model simulation



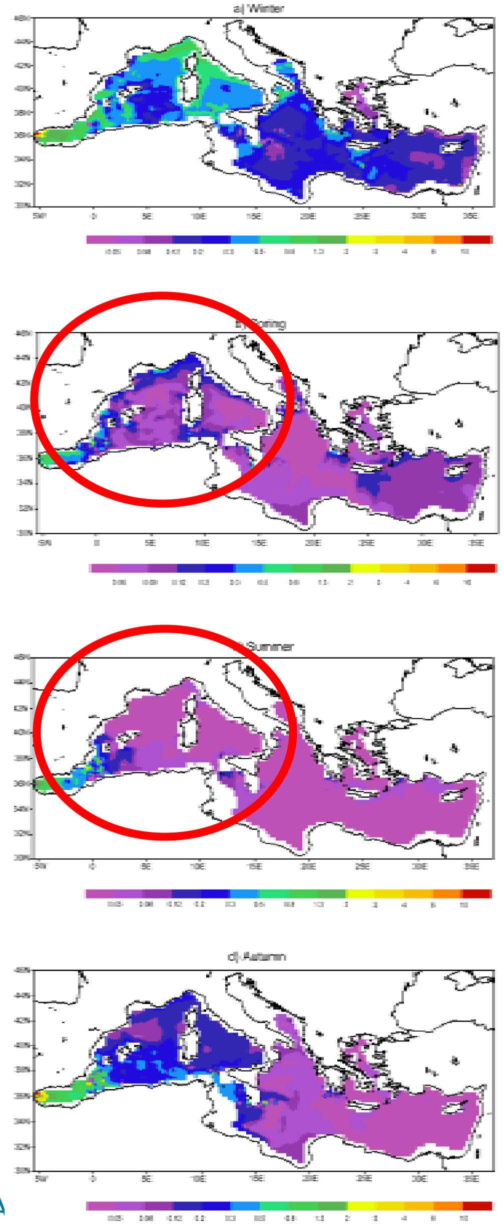


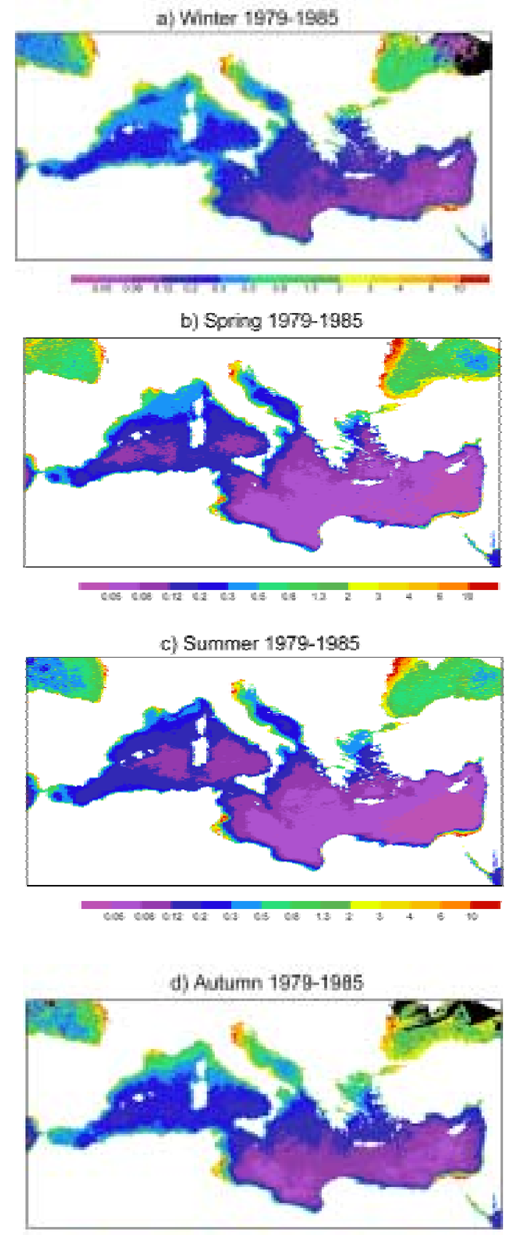
The North Sea simulations are currently being validated and evaluated for operational NOWCASTING



Seasonal simulation for the whole Mediterranean Sea

Chlorophyll concentration in the first optical length ($mgChl/m^3$) Model estimates in pelagic waters (depth> 200m)

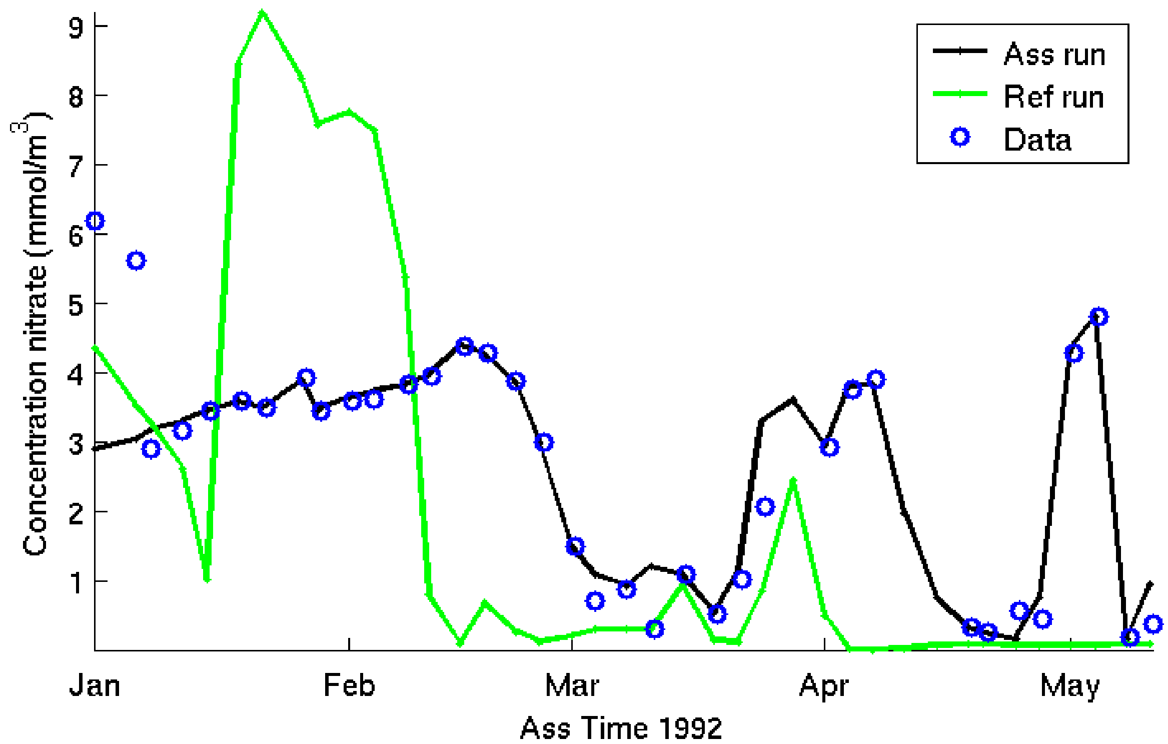




Chlorophyll concentration in the first optical length ($mgChl/m^3$) CZCS seasonal averages (JRC-Ispra, modified)

Ecosystem Data Assimilation

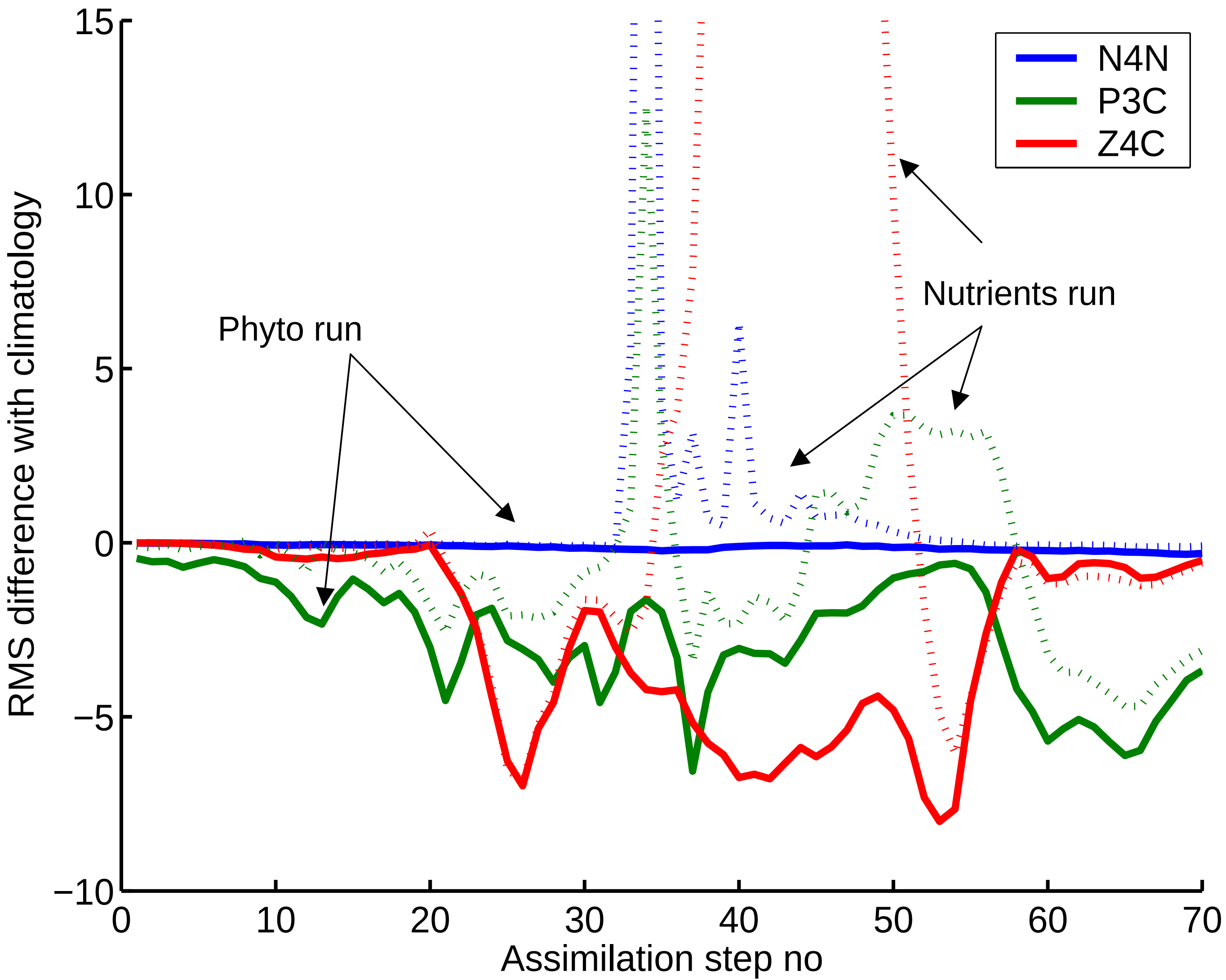
Application of Ensemble Kalman Filter data assimilation systems for ERSEM to improve out algal bloom prediction capability.



Assimilated data is chlorophyll
Model output data is nitrate.

Allen, Ekenes and Evensen Ann. Geophys 2003

The error is most successfully controlled across model variables when phytoplankton biomass is assimilated

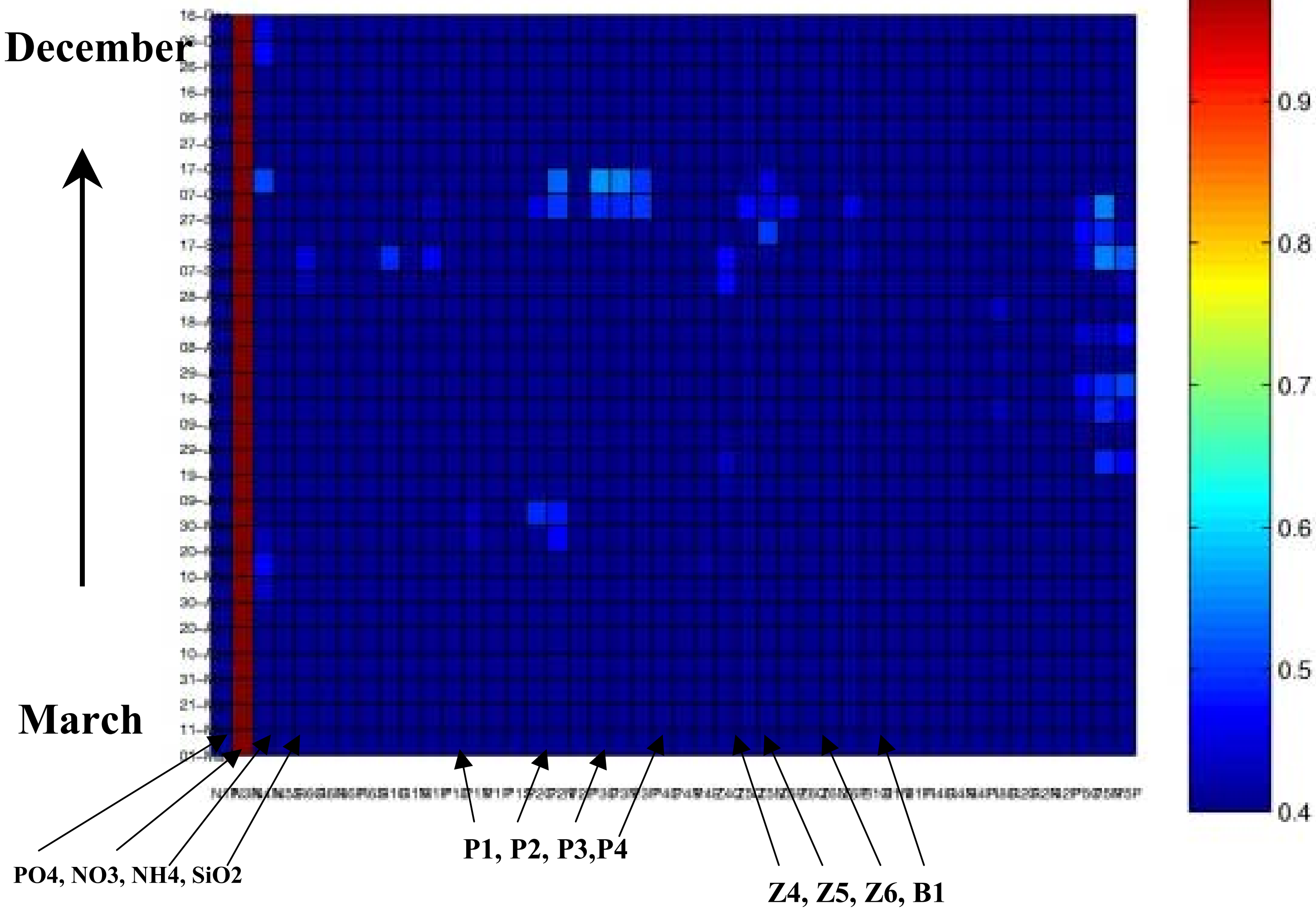


Impact of NO3 assimilation on the model

The success of the assimilation depends on the ability of the analysis scheme to spread the observations information across other model variables…

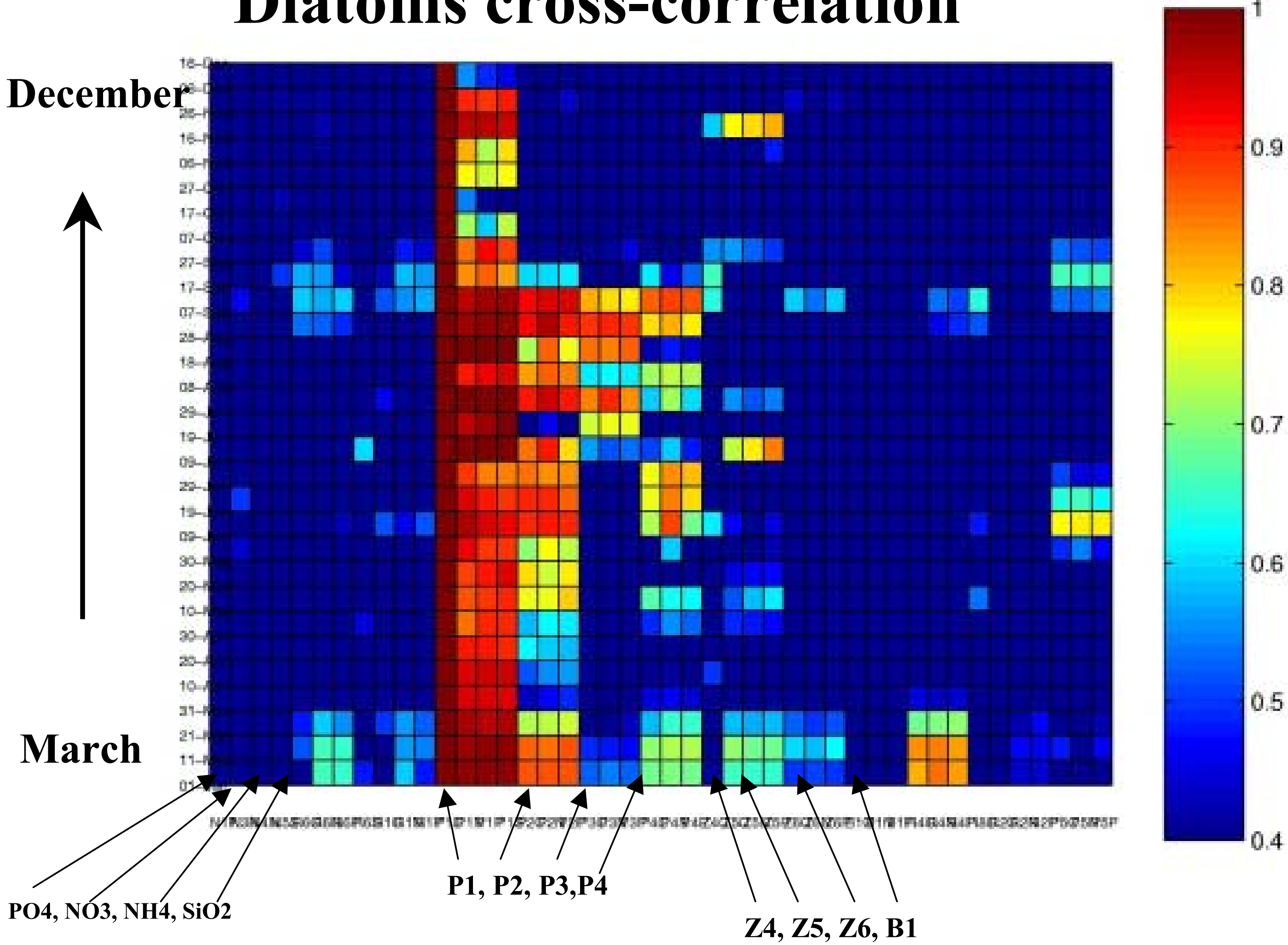
Impact of NO3 assimilation on the model

NO_3 cross-correlation



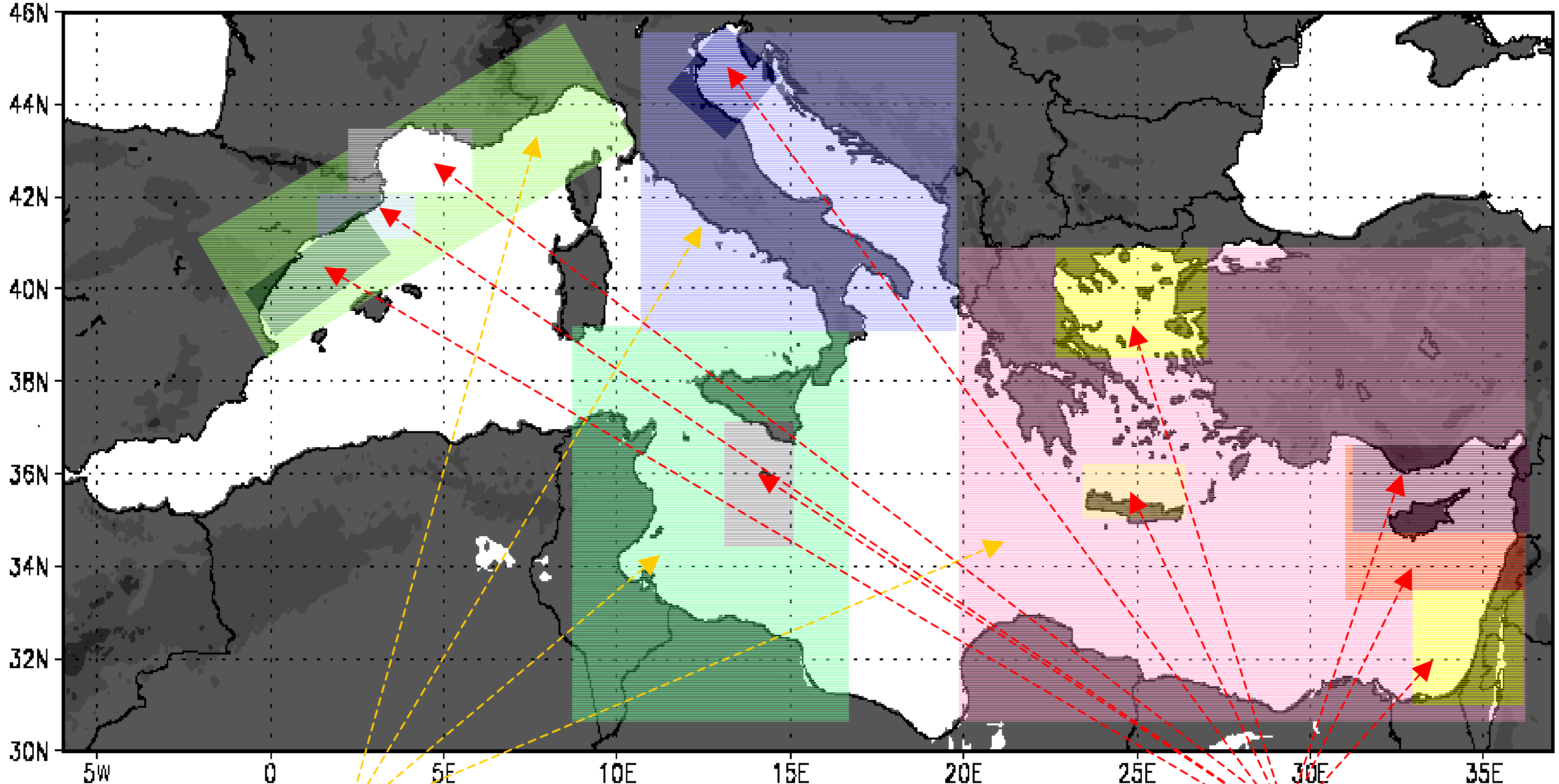
Impact of P1c assimilation on the model

Diatoms cross-correlation



MFSTEP sub-regional and shelf systems

MFS supports sub-regional (3 km) and shelf models (1 km) nesting: weekly forecasts will be produced for ALL the regional models



Sub-regional models at 3 km

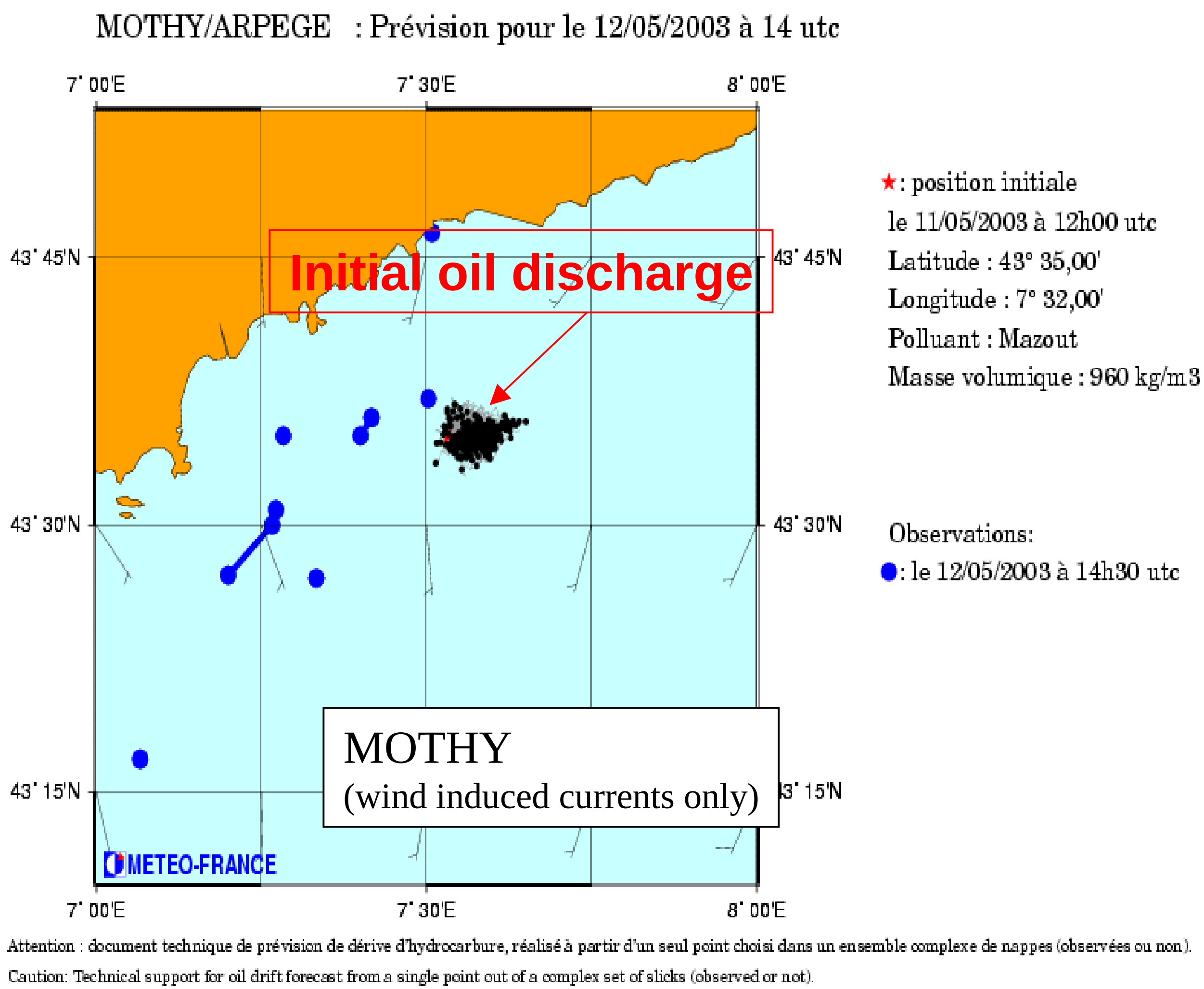
Shelf models at 1.5 km

MFS and the Sustainable Development of marine open ocean and shelf areas: oil spill modelling and Integrated Coastal Zone Modelling activities

- MFS products are coupled operationally to numerical predictions of open ocean contaminants and oil dispersion
- In the Adriatic a special effort has started with ADRICOSM, where nested coastal monitoring and modelling system is now operational
- The ADRICOSM modelling is used to set up ICZM schemes that should consider large river discharges from urban settlements and related water quality issues

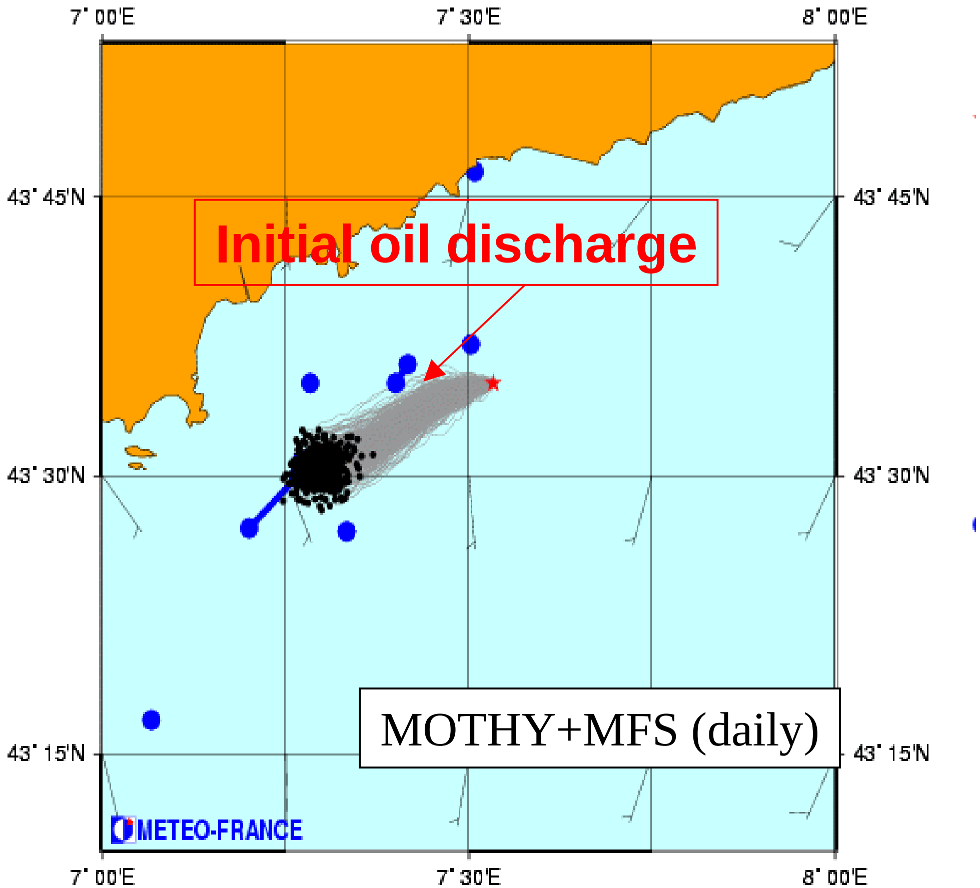
MFS products: coupling with advection-diffusion modeling of oil spills

24 hours forecast



MFS products: coupling with advection-diffusion modeling of oil spills

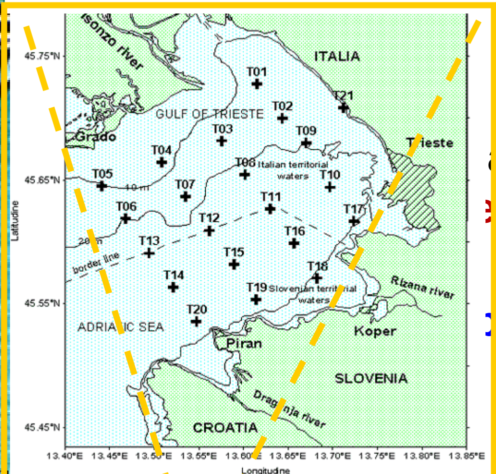
24 hours forecast

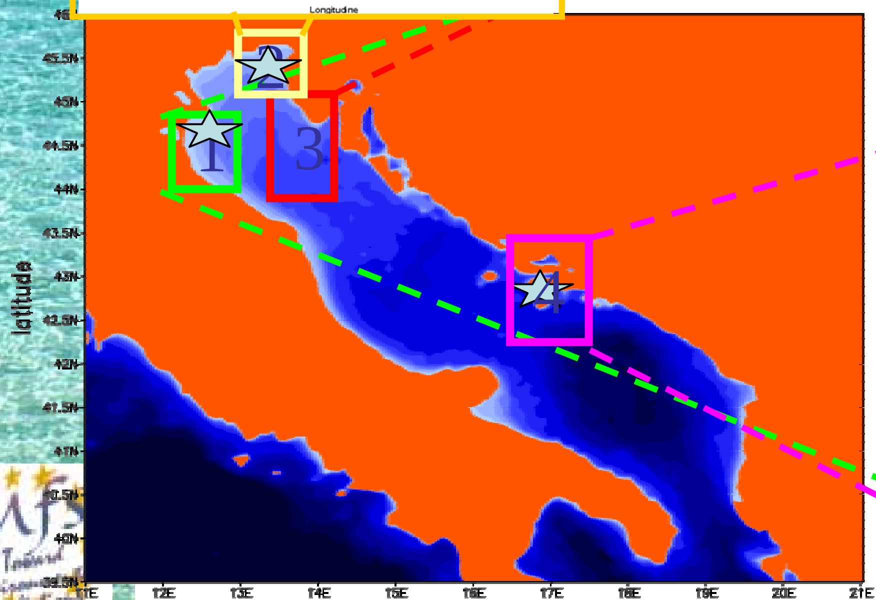


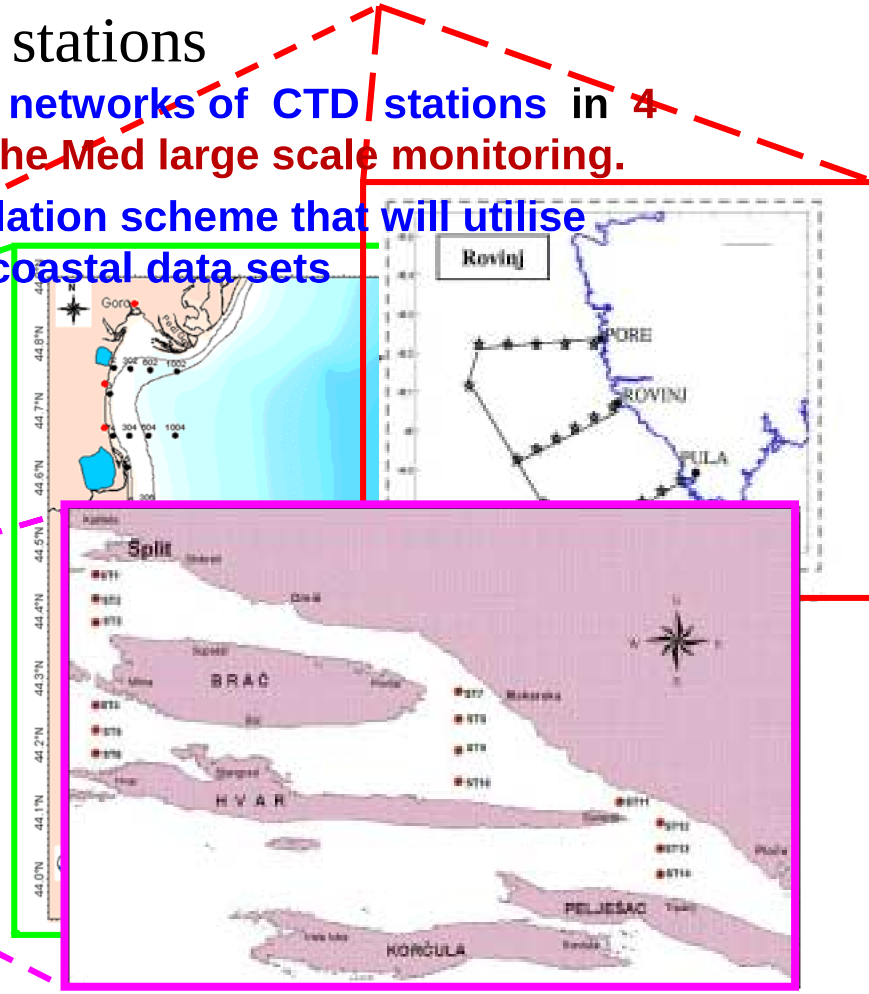
The Adriatic shelf observing system: coupled to the large scale in Real Time

☆ Buoy stations

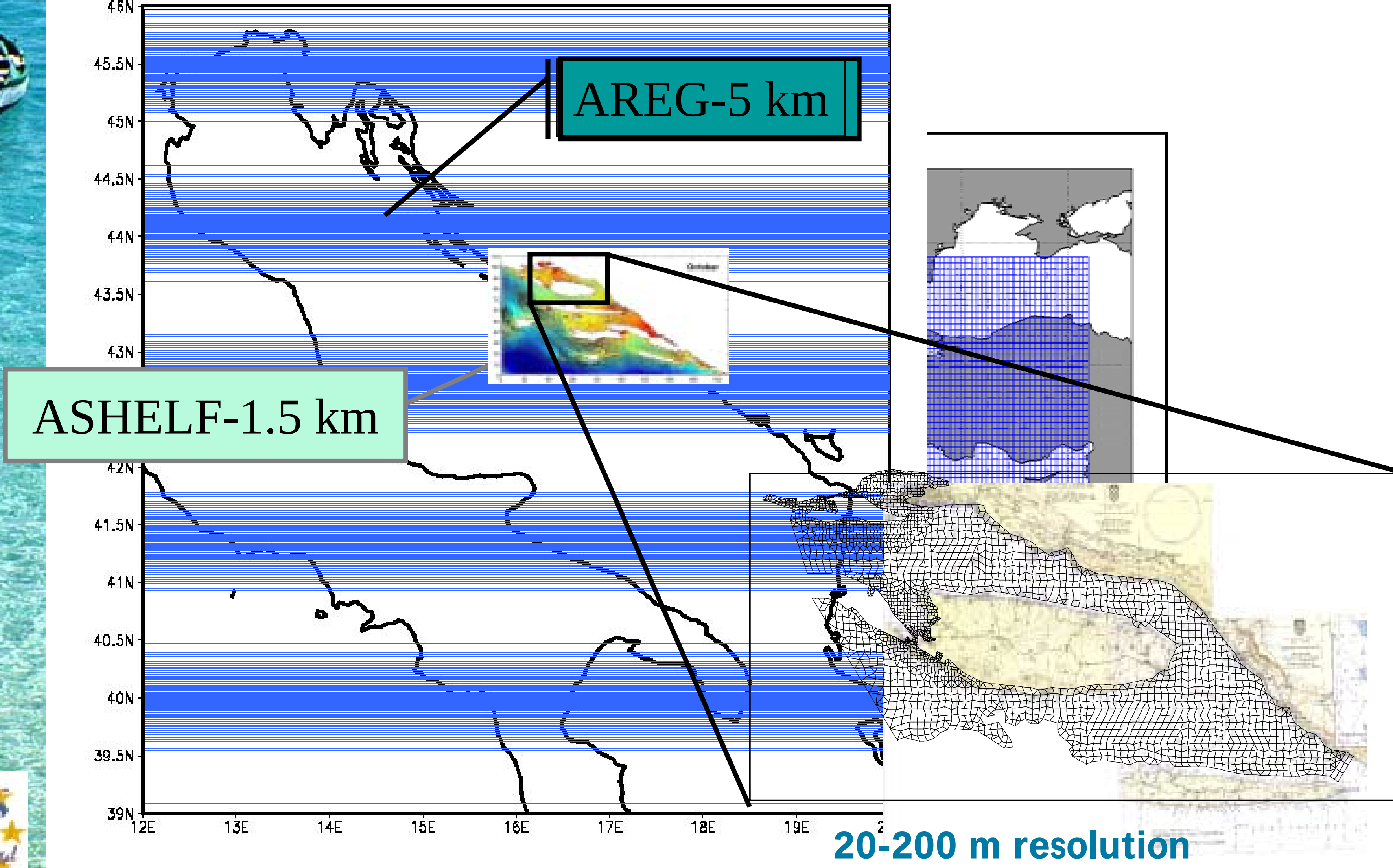
and optimize coastal networks of CTD stations in 4
…eas, complementing the Med large scale monitoring.
…efficient data assimilation scheme that will utilise
…oth large scale and coastal data sets



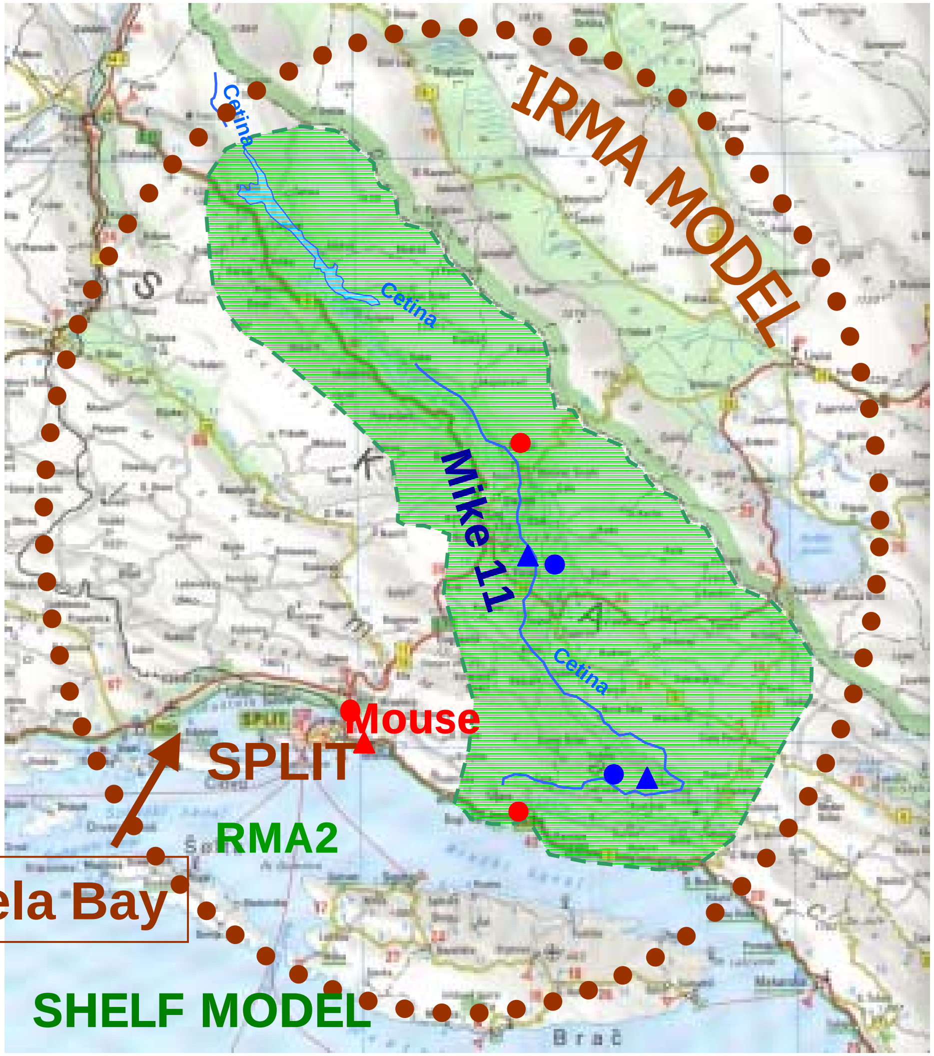




From basin scale to coasts, river and sewage overflow integrated modelling



Integrated model in the Kastela Bay-Split area and Cetina river Pilot basin



Catchment area

MONITORING

- ● FLOW MONITORS
- ● Water LEVEL METER
- ▲ ▲ WQ SAMPLER

MODELLING

IRMA = MIKE 11 + RMA2 + MOUSE

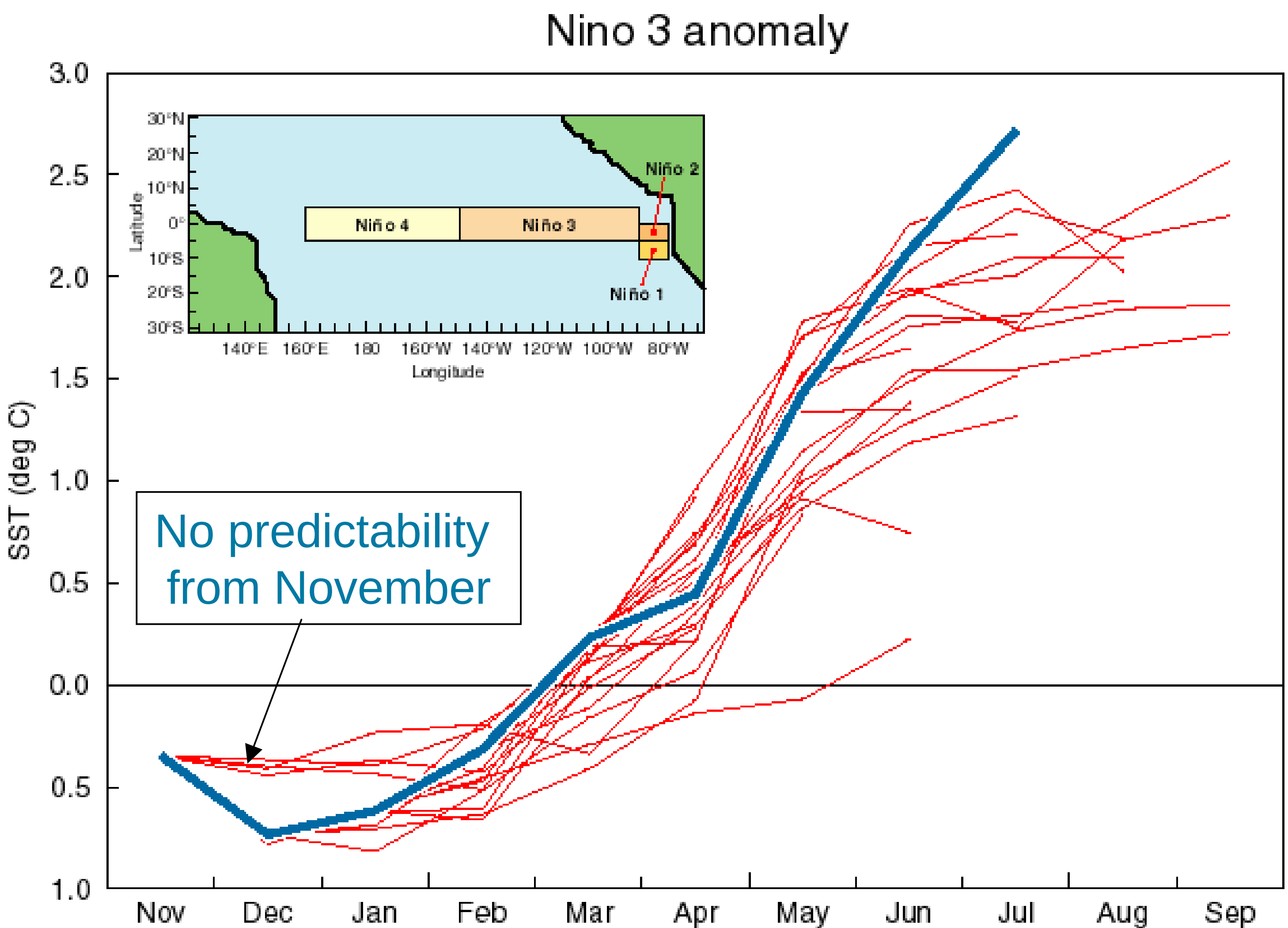
SHELF + IRMA = FULLY INTEGRATED SYSTEM

The future: ensemble forecasting

- Ensemble forecasting is required to re-cast the forecast of environmental variables in terms of probability of occurrence of forecast (most probable forecast given the uncertainities)
- For the ocean, the major uncertainties in the forecast come from
  - surface forcing that produce inadequate initial conditions (analysis step)
  - internal dynamics that produces large error growth (forecast step)
  - surface forcing that produce bad forecast (forecast step)
  - inadequate modelling of the background error covariance (analysis step)
- Ensemble forecasting tries to quantify the effects of these uncertainties on the forecast

ECMWF ensemble seasonal forecasting: perturbed initial conditions and El Nino predictions

1996-1997
El Nino event

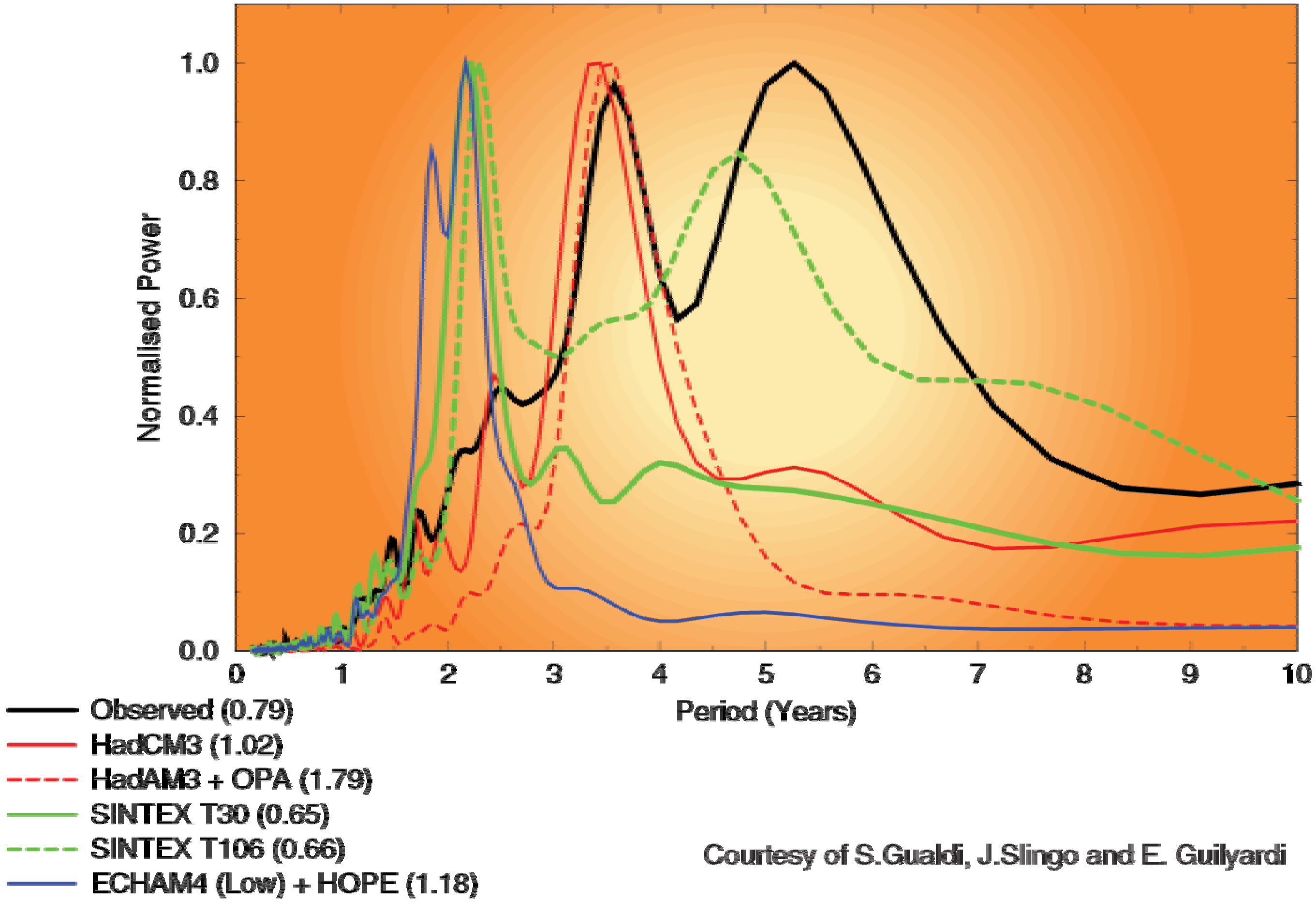


The future: multimodel estimation

- Given a specific ensemble initial perturbation strategy, model errors could change the spread of the ensemble
- Each model has strengths and weaknesses

The future: multimodel estimation

NINO3 Spectrum

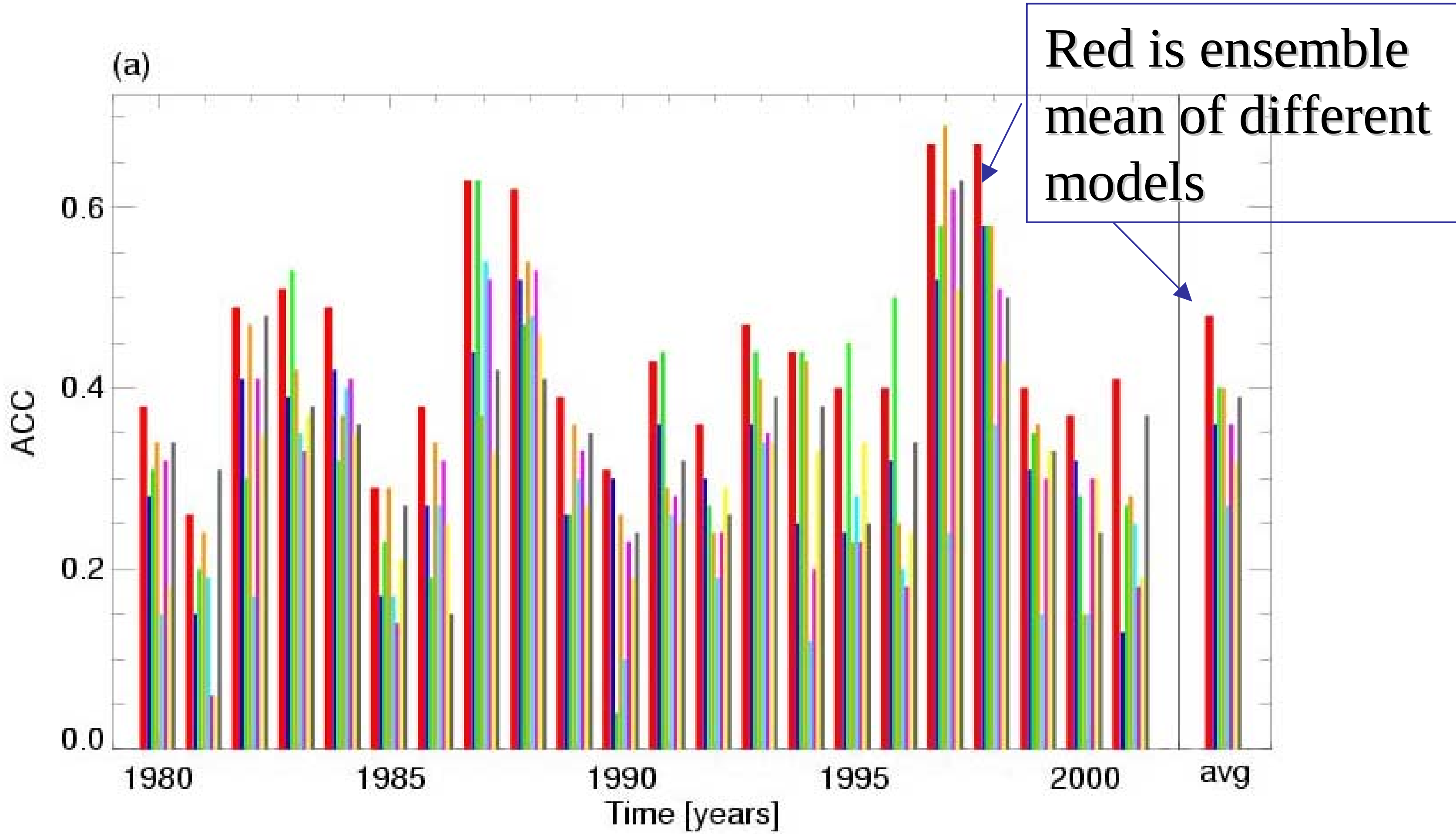


Courtesy of S.Gualdi, J.Slingo and E. Guilyardi

The future: multimodel estimation

- Thus estimation of forecast and/or system state estimation should be done combining the information from different models/predictions/assimilation systems

Ensemble mean seasonal predictions: the value of multimodel estimation from DEMETER results (see web page: www.ecmwf.int/research/demeter)



Precipitation Anomaly Correlation Coefficient in the tropics and for JJA