The Mediterranean ocean Forecasting System

Real Time observing system and marine forecasting from the overall basin to the coastal scales

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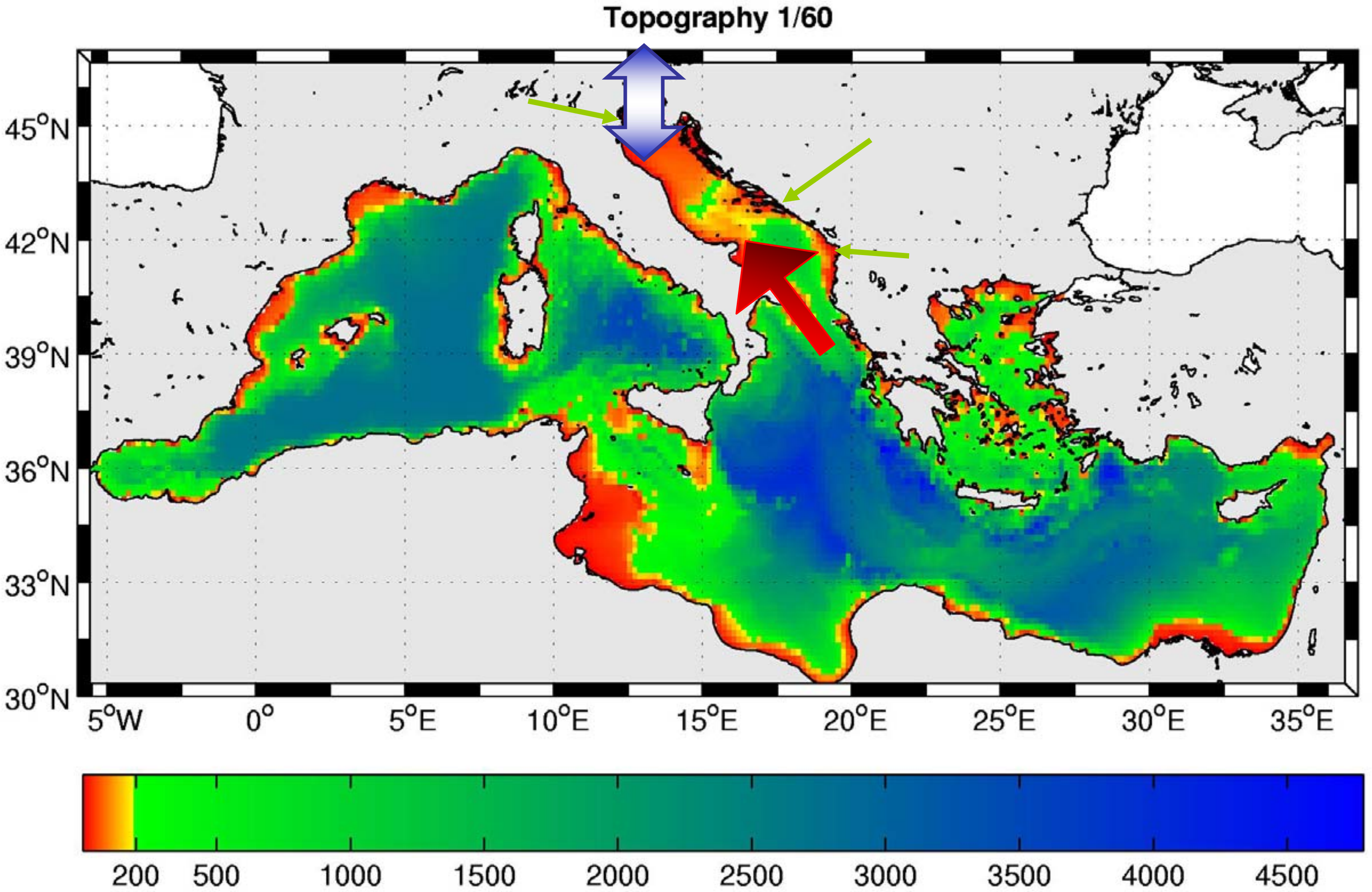
Outline

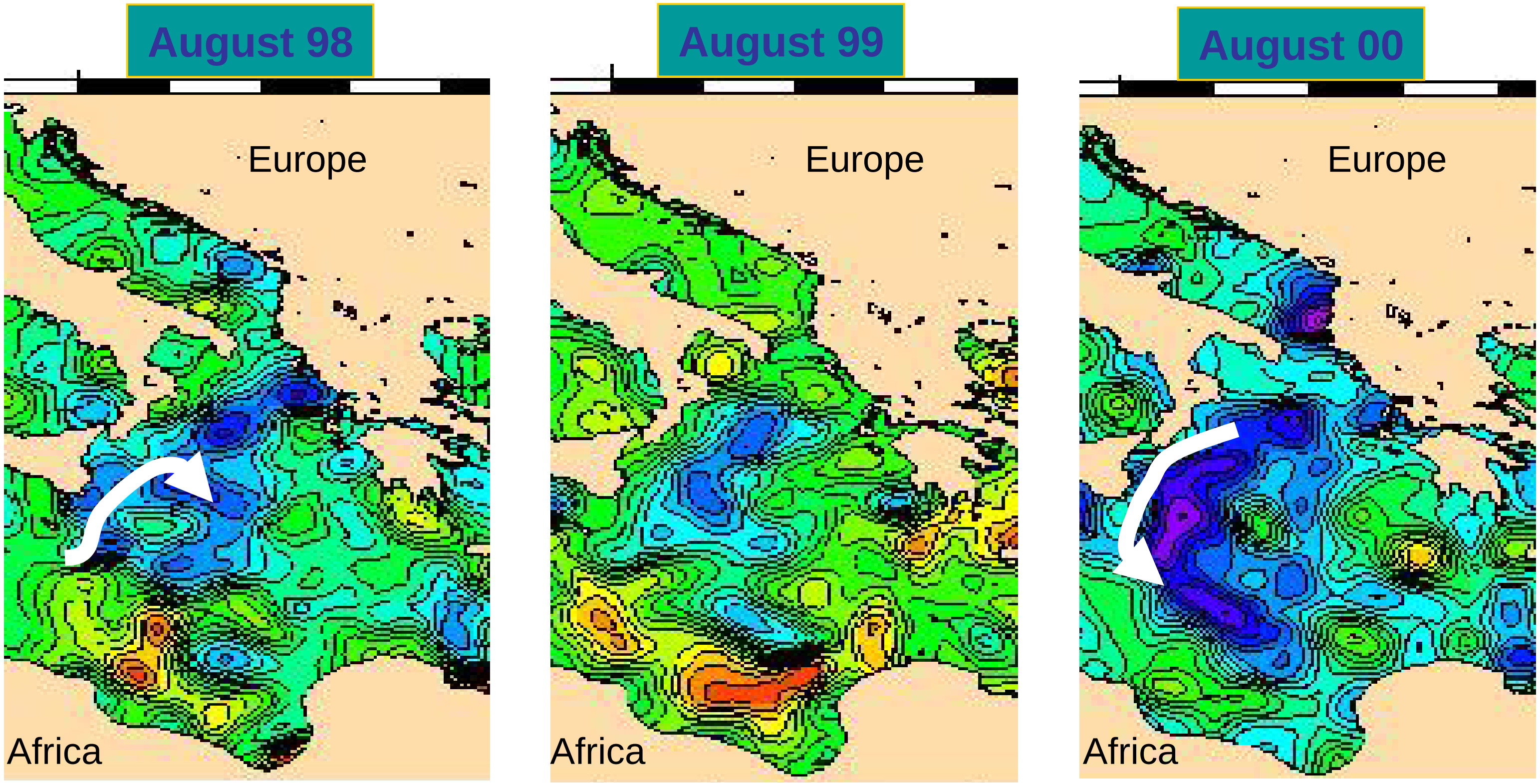
- The known variability and the scientific approach to environmental monitoring and predictions
- The Mediterranean ocean Forecasting System: the implementation and the operational products
- Operational oceanography in support of sustainable development of the Mediterranean open ocean and coastal areas
- Conclusions and future outlook

The Mediterranean shelf areas:

forced by large air-sea interactions, deep ocean currents variability and river runoff changes

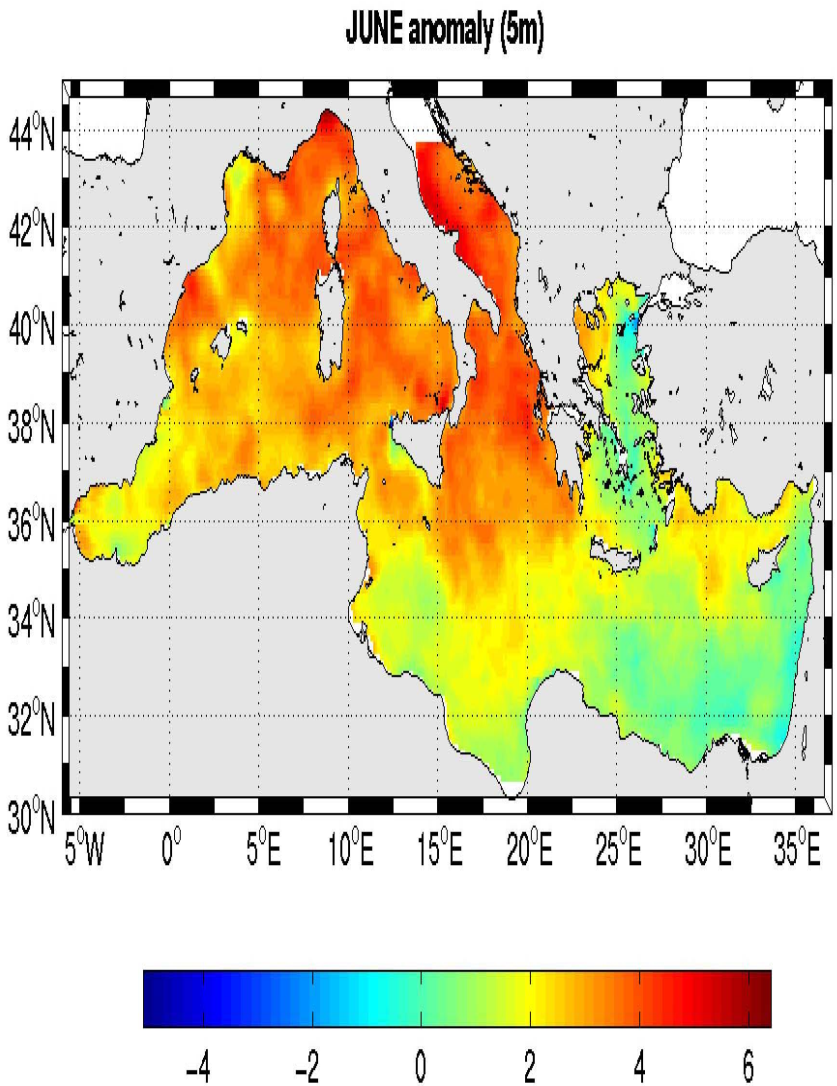


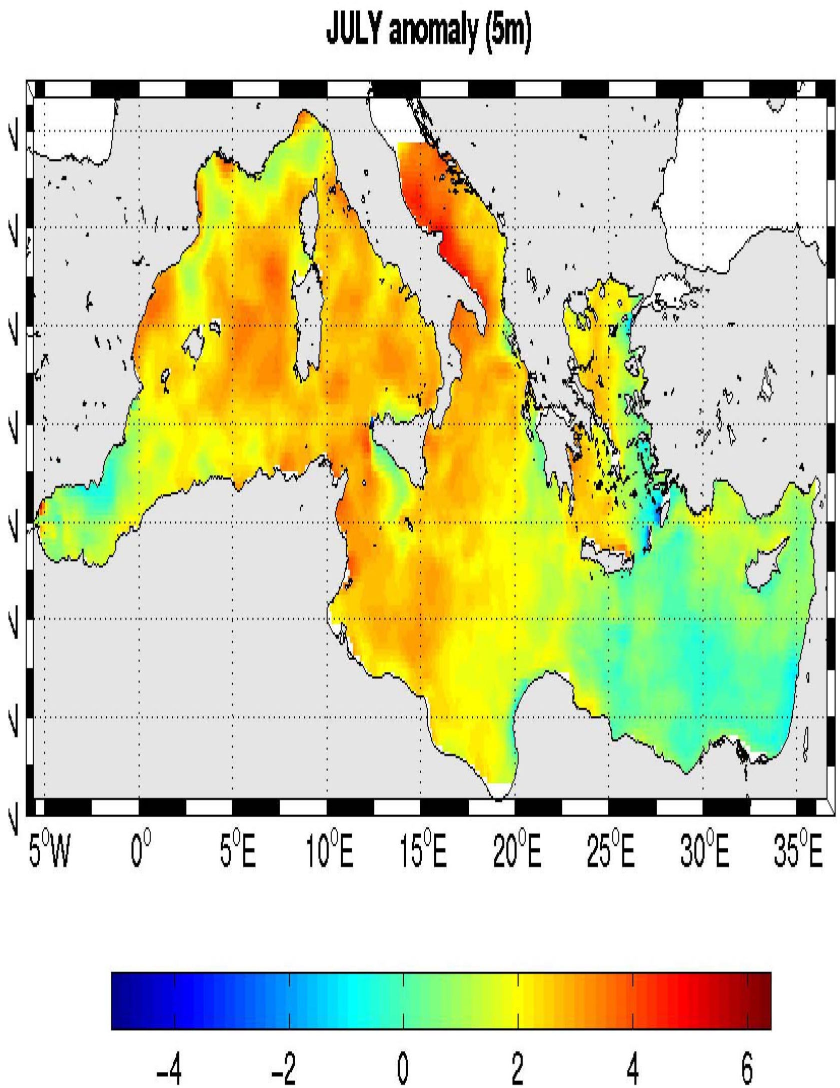
The known large scale variability



Combined analysis of T/P and ERS2 data

The exceptional summer of 2003: SST anomalies





How do we build predictive capabilities?

- In the 80's: three phases of knowledge were postulated to be necessary (Robinson, 1986):
  1. Descriptive/phenomenological with observations
  2. Dynamical and calibration/validation with observations and models
  3. Assessment of predictive skills and re-formulation of the problem
- In the 90's: operational systems started to be developed, i.e., advancements started to be connected to growth of the efficiency and quality of the predictions by incremental steps (the basis of operational science)

Marine Environmental Prediction System

Multidisciplinary Multi-platform Observing system (sustained and relocatable)	Numerical models of hydrodynamics and ecosystem, coupled asynchronously to atmospheric forecast	Data assimilation for optimal field estimates and parameter estimation

Continuos production of nowcasts/forecasts of relevant environmental state variables

The MFS approach:
from large to coastal space scales,
weekly to monthly time scales,
nesting approach for physical and
ecosystem processes

LARGE SCALE

- MOORED BUOY ARRAYS
- VOS XBT AND ONDULATING INSTRUMENTS
- SATELLITE: SEA LEVEL, SEA SURFACE TEMPERATURE, SEA SURFACE SALINITY, COLOR, SURFACE WINDS
- DRIFTING BUOYS (SURFACE AND SUBSURFACE)
- GLIDERS
- AIRPLAINE SURVEYS WITH AXBT

SHELF SCALE

- REPEATED MULTIPARAMETRIC SECTIONS ACROSS SHELF*
- REMOTE SENSING IN GENERAL
- FERRY SURVEYS OF SURFACE PARAMETERS
- BUOY STATIONS
- MESOSCALE SURVEYS
- COASTAL RADAR
- AUTONOMOUS UNDERWATER VEHICLES
- RIVER RUNOFF AND LOADING MONITORING
- SEDIMENT ANALYSIS

OBSERVING SYSTEM

MODELING SYSTEM

Large scale

MODEL PHYSICS

- PRIMITIVE EQUATION ($\supseteq$ 5 KM)
- INTERACTIVE OCEAN ATMOSPHERE COUPLING

DATA ASSIMILATION

- OPTIMAL INTERPOLATION AND/OR KALMAN FILTER

ECOSYSTEM MODELS

- PELAGIC COMPARTMENT
- BENTHIC CLOSURE

ATMOSPHERIC FORCING

- OPERATIONAL ANALYSES FROM LARGE SCALE MODELS
- ENSEMBLE FORECASTS

Shelf scale

MODEL PHYSICS

- PRIMITIVE EQUATION ($\subseteq$ 5 KM)
- INTERACTIVE OCEAN ATMOSPHERE COUPLING
- TURBULENCE AND LIGHT SUBMODELS

DATA ASSIMILATION

- OPTIMAL INTERPOLATION AND/OR KALMAN FILTER
- ADJOINT MODELS

ECOSYSTEM MODELS

- PELAGIC COMPARTMENT
- BENTHIC-PELAGIC COUPLING
- SEDIMENT DYNAMICS

ATMOSPHERIC FORCING

- OPERATIONAL ANALYSES FROM LARGE SCALE MODELS
- MESOSCALE MODEL OUTPUT

MFSTEP (mar. 2003- feb. 2006)

Mediterranean Forecasting System Toward Environmental Predictions

RT Observing System
satellite SST, SLA, VOS-XBT, moored multiparametric buoys, ARGO and gliders

Upgrade of present basin scale operational system
New model and assimilation

Ecosystem Models
Validation/calibration of Coupled physical and biochemical numerical models

Marine forecast downscaling
Regional and shelf models nesting

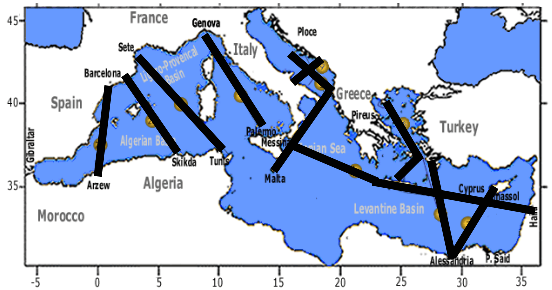
End-User applications
Development of modules for oil spill monitoring, ICZM and fishery management

Meteorological forecast downscaling
10 km LAMs and 4 km N.H. mesoscale models

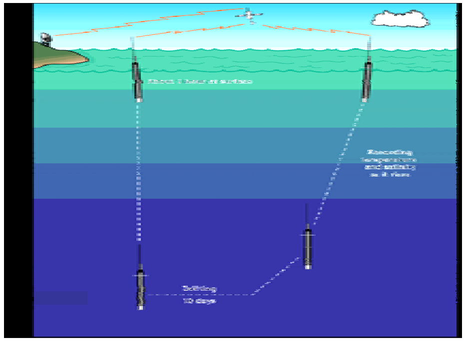
15 nations involved, 48 institutions

Overall Basin Scale Observing System

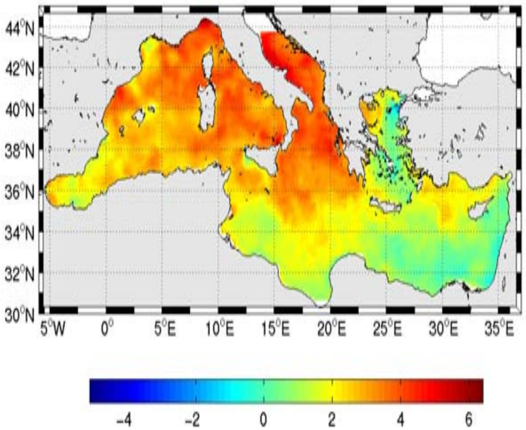
3 multiparametric buoys into: Ligurian Sea, Adriatic Sea and Creatan Sea



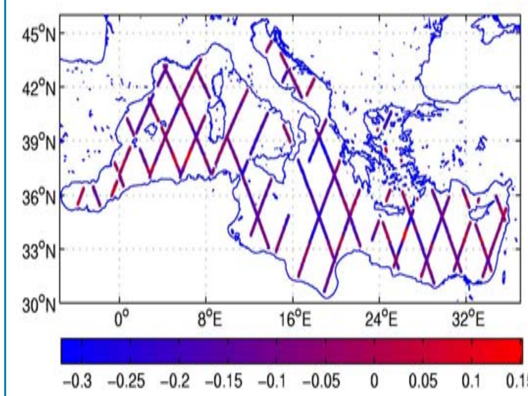
XBT VOS high resolution system (12 nm along track and full profile transmission)



25 ARGO floats deployed from VOS



Daily satellite SST interpolated in RT on model grid

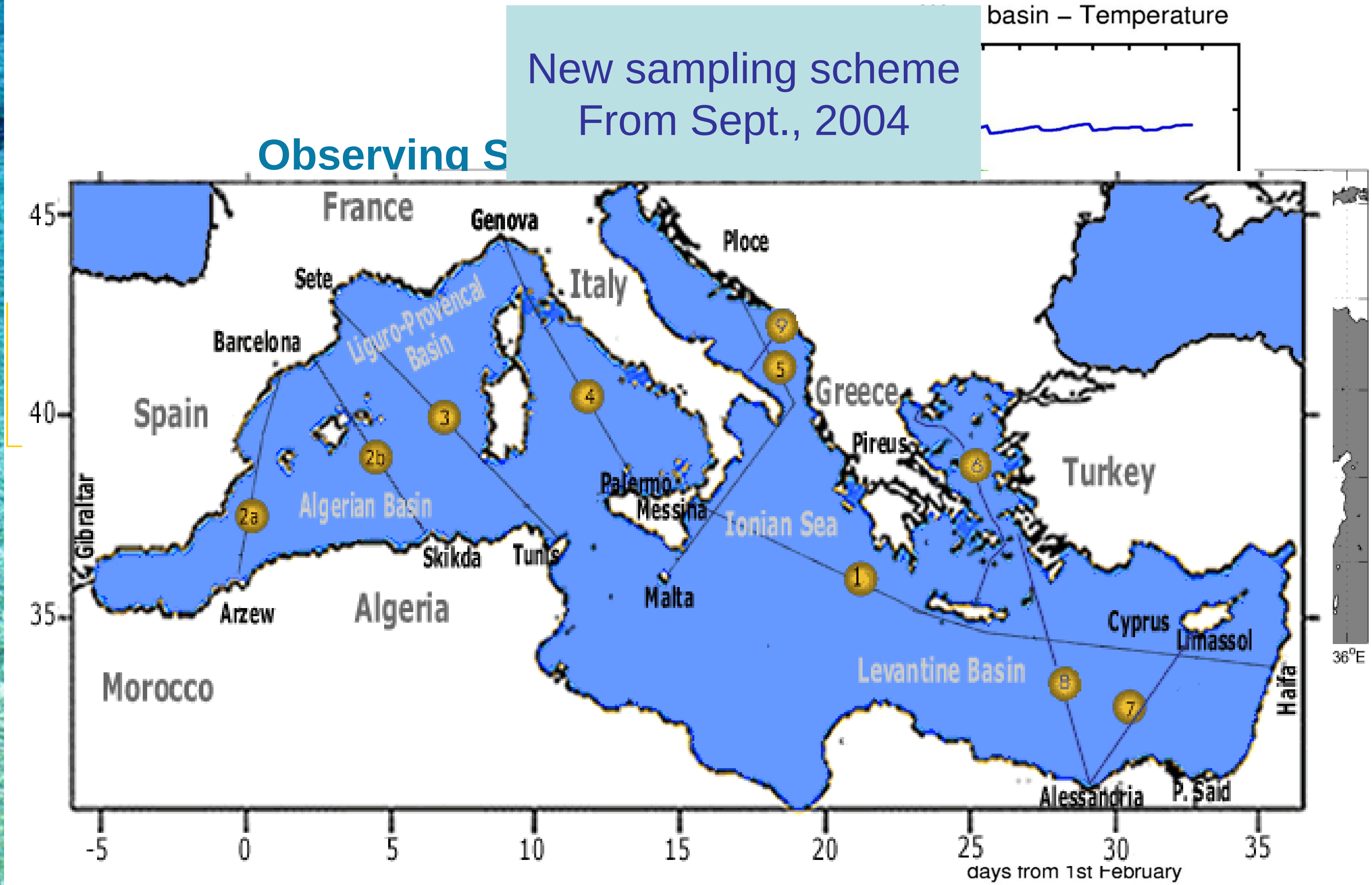


JASON-1, GFO, ENVISAT, T/P Sea Level Anomalies RT products

Open ocean monitoring by gliders

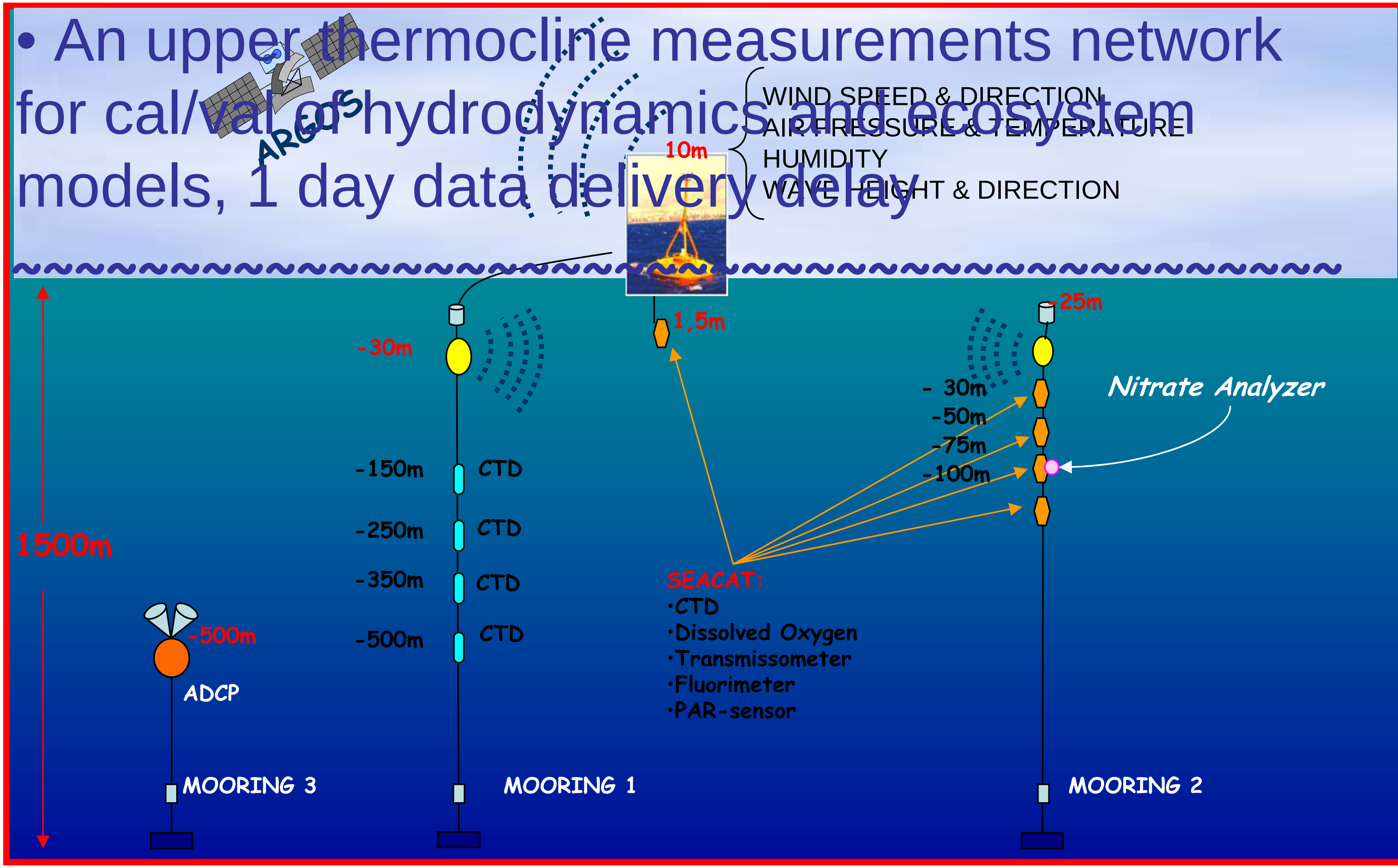
The VOS system: full temperature profiles in RT (12 hrs delay), 12 nm horizontal resolution

New sampling scheme
From Sept., 2004

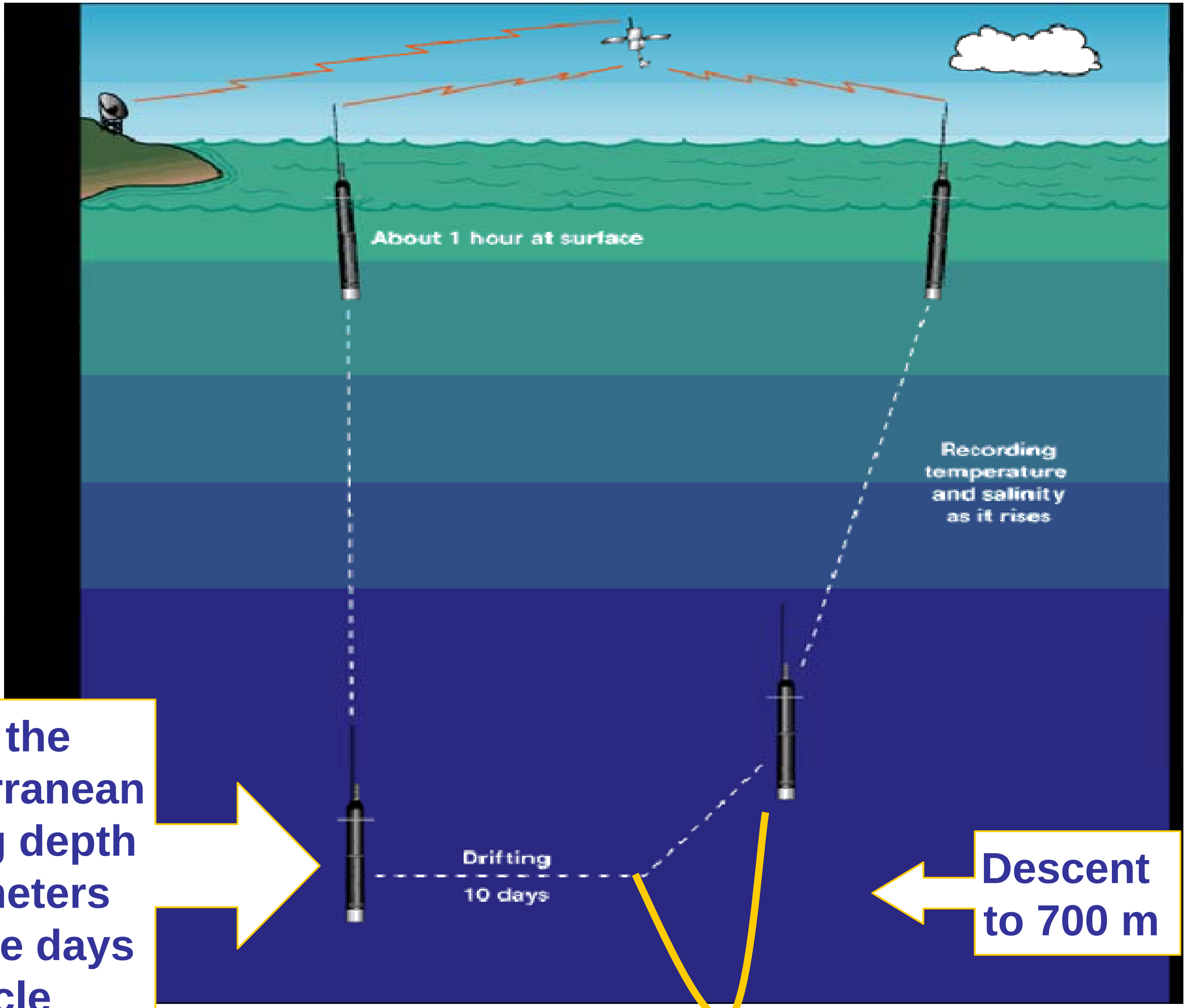


The fixed buoy array: Mediterranean Multisensor Moored Array-M3A

• An upper thermocline measurements network for cal/val of hydrodynamics and ecosystem models, 1 day data delivery delay



The MedARGO experiment: 25 floats unevenly launched from VOS, 1 day data delivery delay



For the Mediterranean drifting depth 350 meters and five days cycle

Descent to 700 m

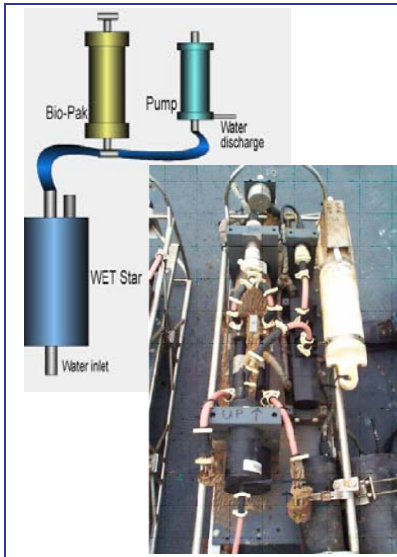
The new technology: increasing the efficiency

VOS: increasing cost/benefit of the system: *multiple launcher and T-FLAP*

Development of a multiple launcher for expendable probes

Temperature - Fluorimetric Launcheable Probe (T-FLAP)

M3A: new *antifouling techniques* and new *underwater communication modem*



Antifouling techniques: 1) Bromine solution in the closed water circuit; 2) Replacement of plastic tubing parts of the circuit by copper ones

LinkQuest Underwater Acoustic Modem for M3A-E1 buoy in the Cretan Sea

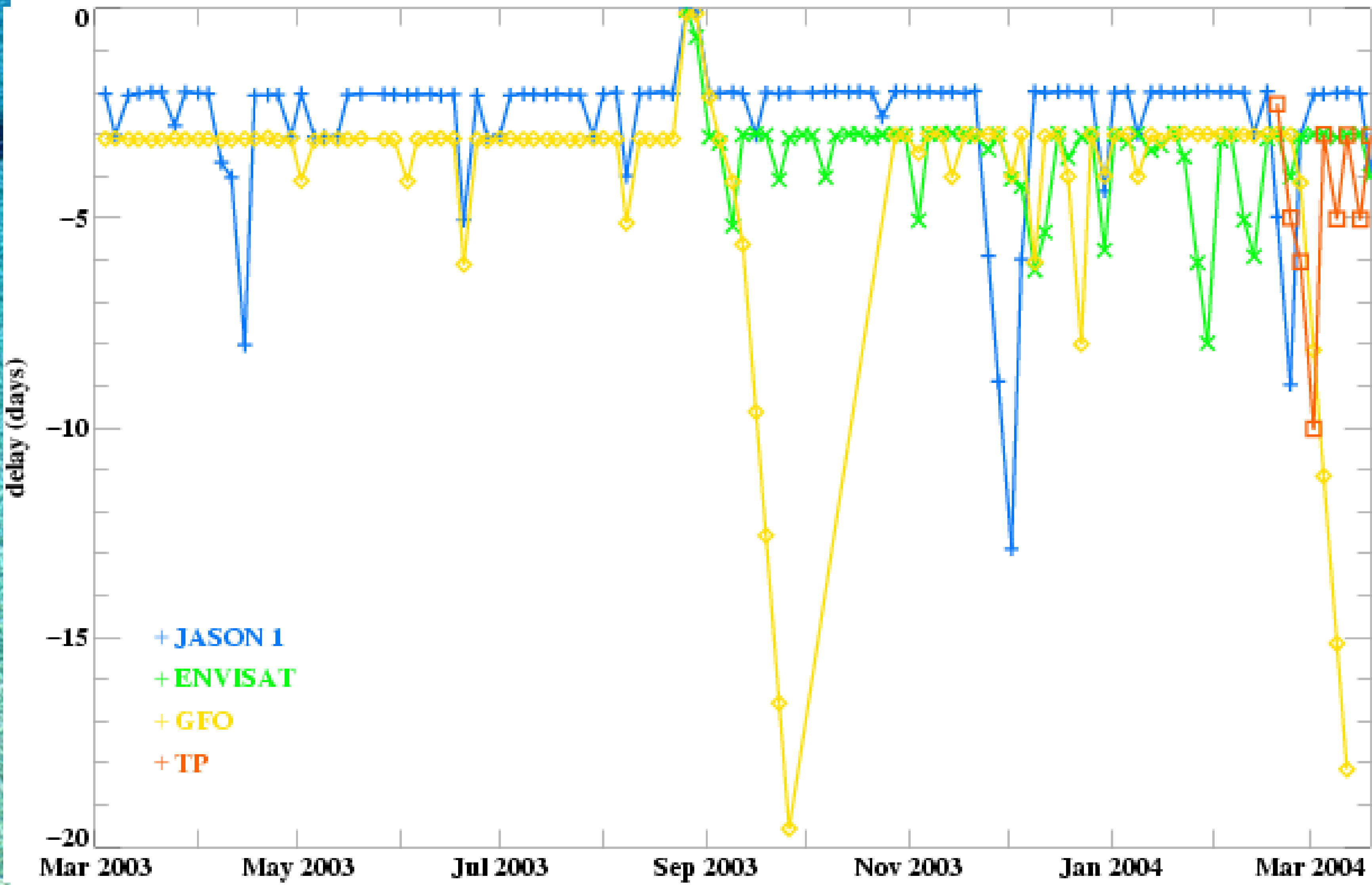
ARGO: *Deployment case*

Deployment case (cardboard case which can be tossed by two people)

Applications: Fishery Observing System *LOG-BOOK* and *Temperature and Pressure recorders* on the nets

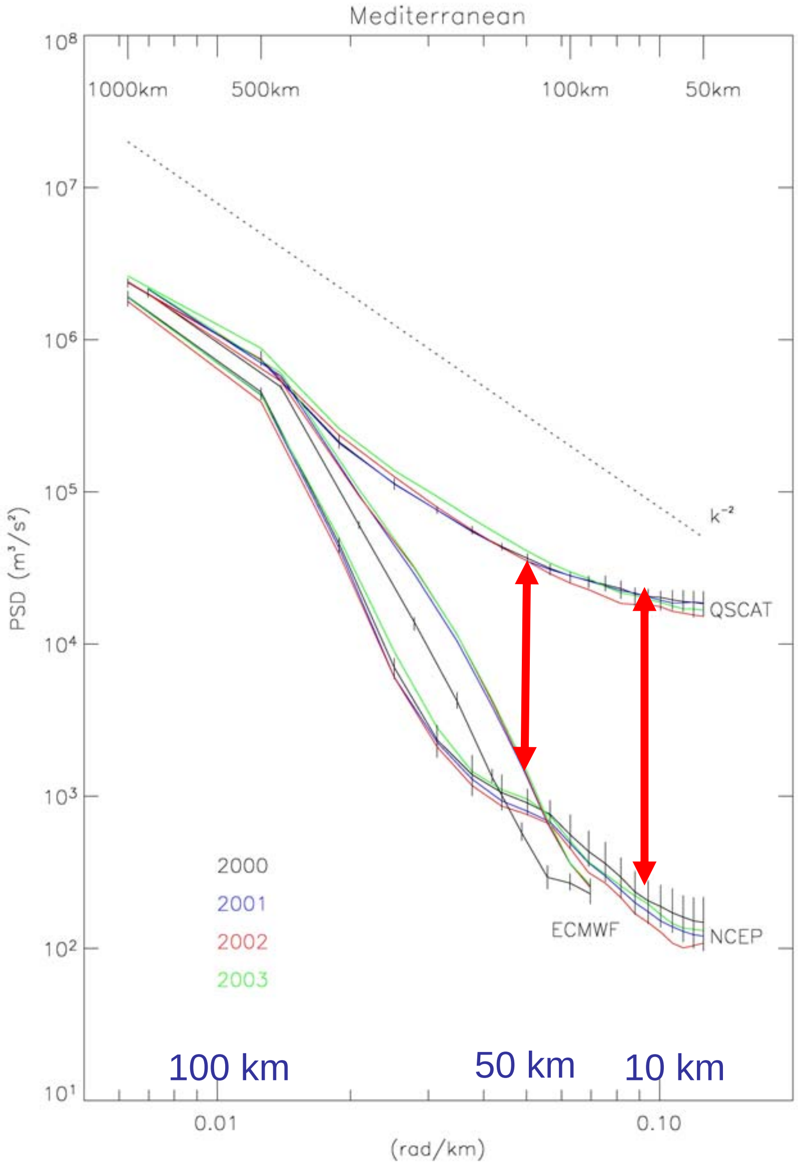
The Fishery Observing System - Real Time recording system: LOG-BOOK and temperatue and pressure recorders installed on the net

Four real time altimeters data are available in RT

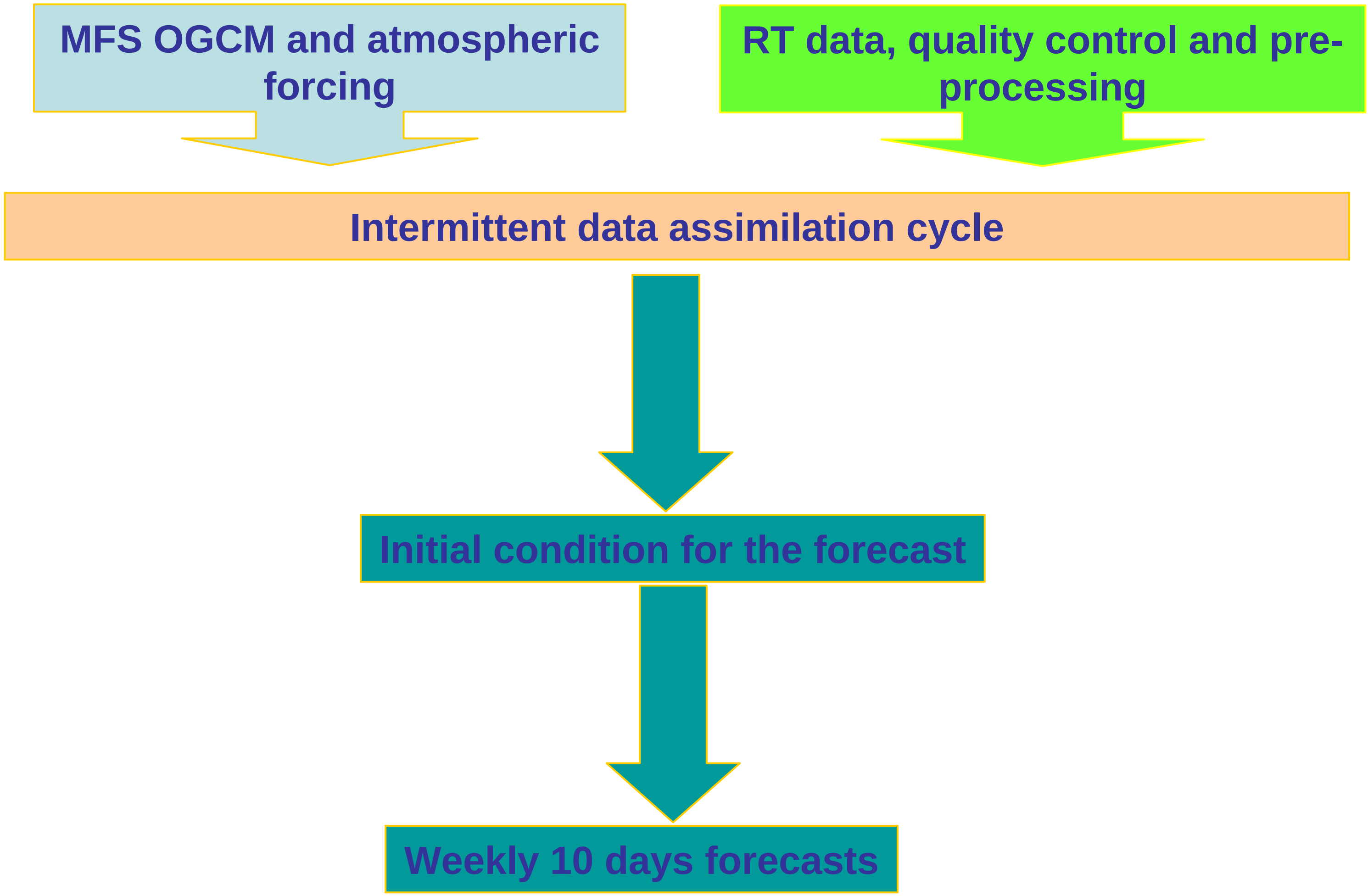


Scatterometer data analysis in RT: blended product with NCEP analyses

Even the latest
ECMWF forecast model
cannot reproduce the
power in the high
wavenumber range:
Scatterometer
winds needed
to quantify uncertainty
in wind forcing



The MFS operational system



The forecasting system: the OGCM

- **$1/8^0$ x $1/8^0$ x 31 levels unevenly spaced**
- **Atlantic box 3X3 degrees to parametrize Gibraltar inflow/outflow system**
- **Biharmonic horizontal visc. and diff.: A_h=5 10^{17} , K_h=1.5 10^{18} (cgs)**
- **Vertical mixing: A_v=1.5, K_v=0.3 (cgs), conv. adj. passes= 10**
- **full diagnostic computation of sea surface height in rigid lid approximation**

Air-Sea physics

•Heat flux is re-computed using interactive formula with ocean SST and bulk formulas adapted to the Mediterranean case:

$$\rho_0 K_v \left.\frac{\partial T}{\partial z}\right|_{z=h} = \frac{1}{C_p}\left\{Q_s(C,\alpha,t) - Q_B(T_a,T_s,C,rh) - LE(T_a,T_s,rh,|\vec{v}_w|) - H(T_a,T_s,|\vec{v}_w|)\right\}$$

•momentum flux is computed with interactive wind stress drag coeff.

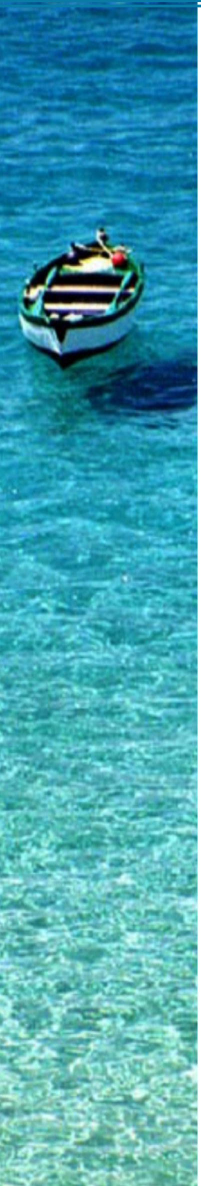
•Salt flux is climatological

Asynchronous atmospheric Forcing

•ECMWF 6 hours analyses and/or forecast parameters: air and dew point temperature, mean sea level pressure, clouds, 10 m winds

The key: the combination of the different ocean data sets

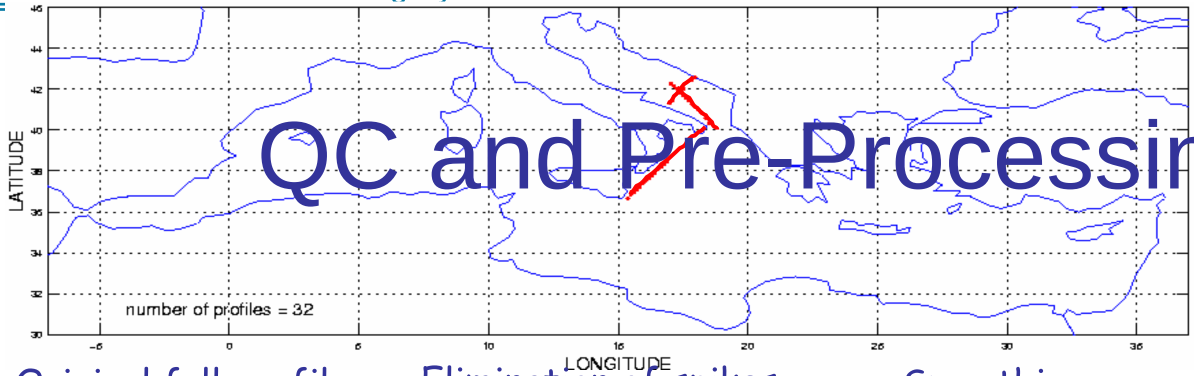
- In situ data are sparse but they give detailed information about the system (i.e. profiles of field state variables): they have a smaller Real Time data delivery delay
- Satellite data have good coverage but they are only surface and they are available only 48 hr after last collection
- Satellite and in situ data have different error models and very different observation models (satellite have more complicated ones)
- In situ data need to be optimized because expensive in terms of maintenance and they should be developed to extend the value of satellite data to increase predictive capabilities



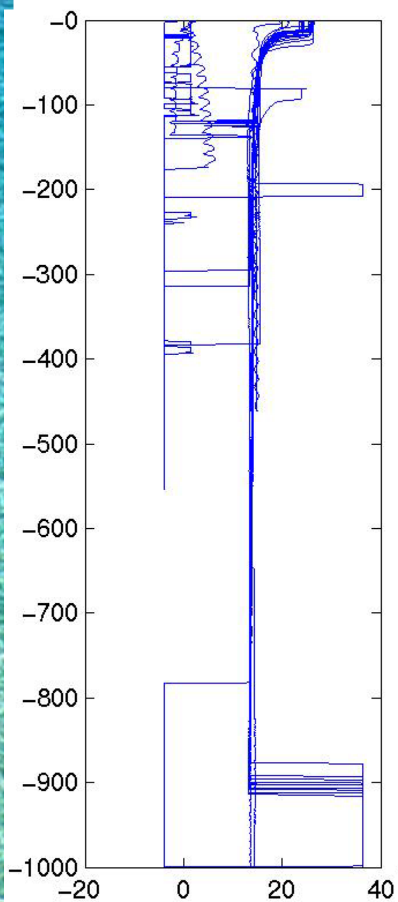
The Forecasting system: the data quality control and pre-processing

- Real Time data sets collected every week: SLA, SST and XBT, ARGO, CTD
- Quality control and pre-processing is applied to XBT, SLA and SST.
  - XBT: new method required for RT data
  - SLA: Mean Sea Level Anomaly (MSLA) subtracted from along track data
  - SST: daily declouding and gap filling with OA
- Model sea surface height pre-processed to get SLA

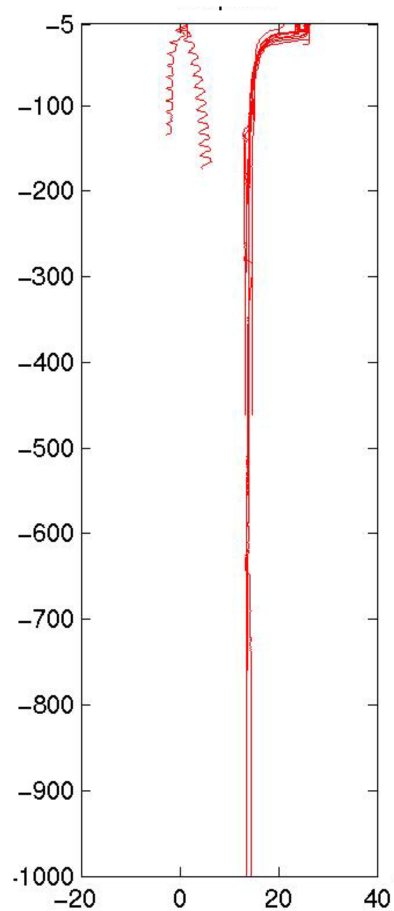
QC and Pre-Processing XBT



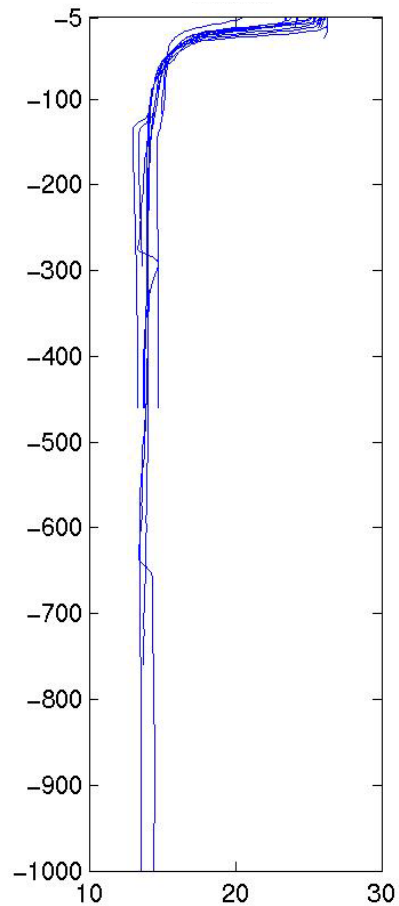
Original full profile



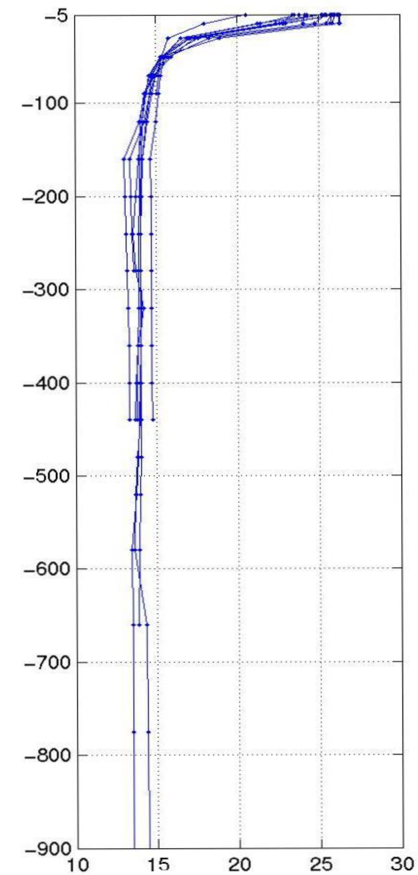
Elimination of spikes



Smoothing



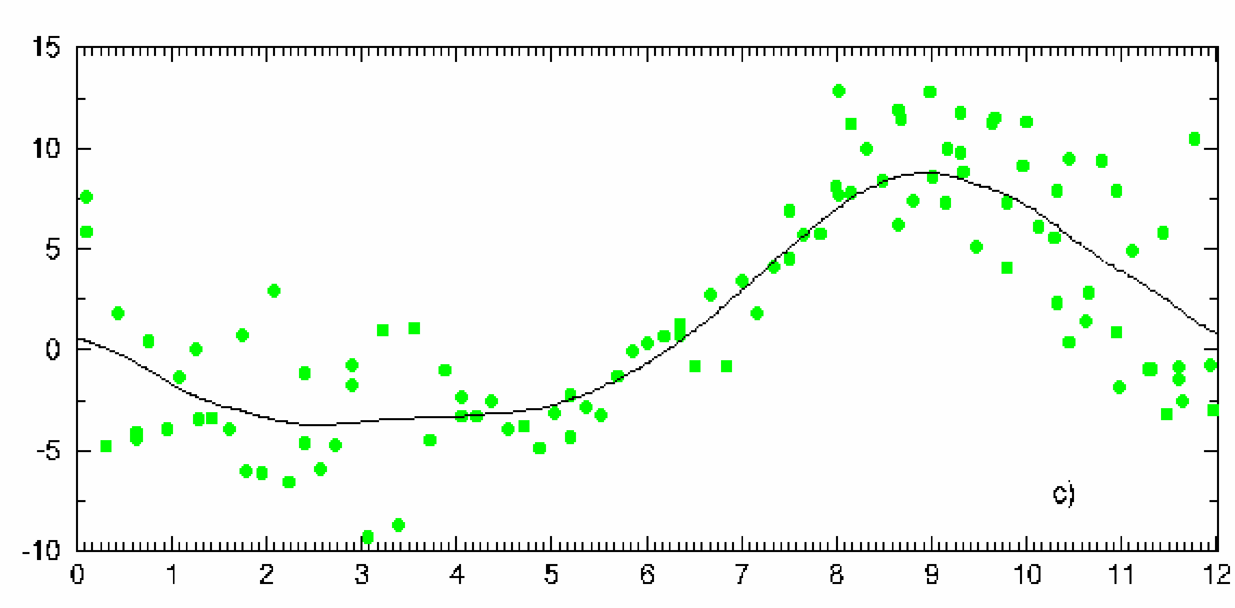
Interpolation on MOM levels



Pre-processing of SLA: de-biasing for volume changes

- A regression curve was found to fit the volume changes in the Mediterranean from T/P data (MSLA)

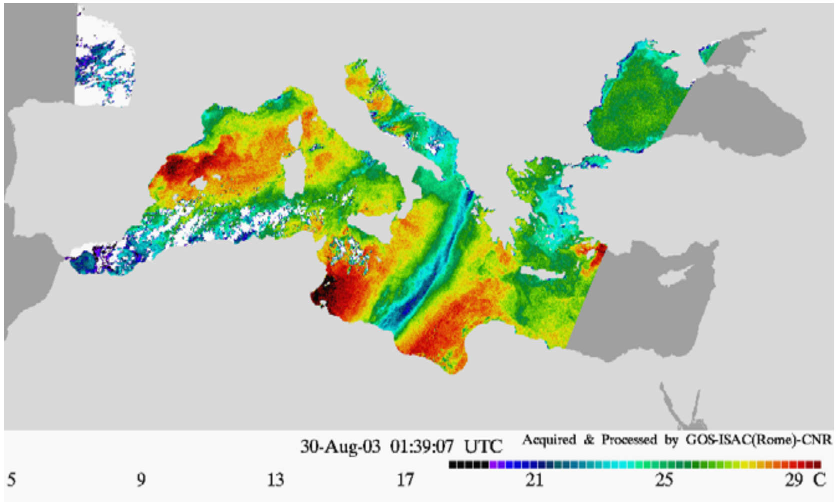
MSLA (cm)



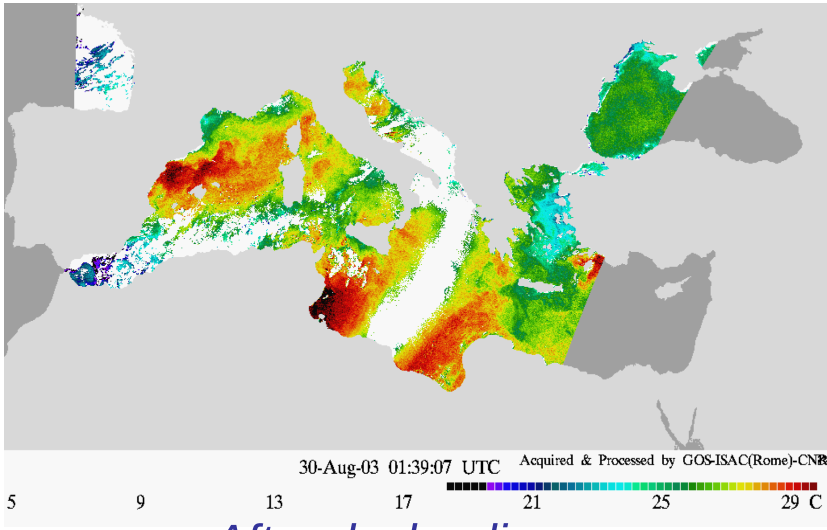
Month

The MSLA is subtracted from along track data before assimilation since model is rigid lid

Satellite daily SST is produced in RT from nightime images with cloud detection: field is interpolated on model grid with objective analysis scheme



Before declouding



After declouding

SST is inserted in the model as a heat flux correction

$$Q_{corr} = Q - \left.\frac{\partial Q}{\partial T}\right|_{T=T^*} (T - T^*)$$

The MFS operational data assimilation system

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

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

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

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

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

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

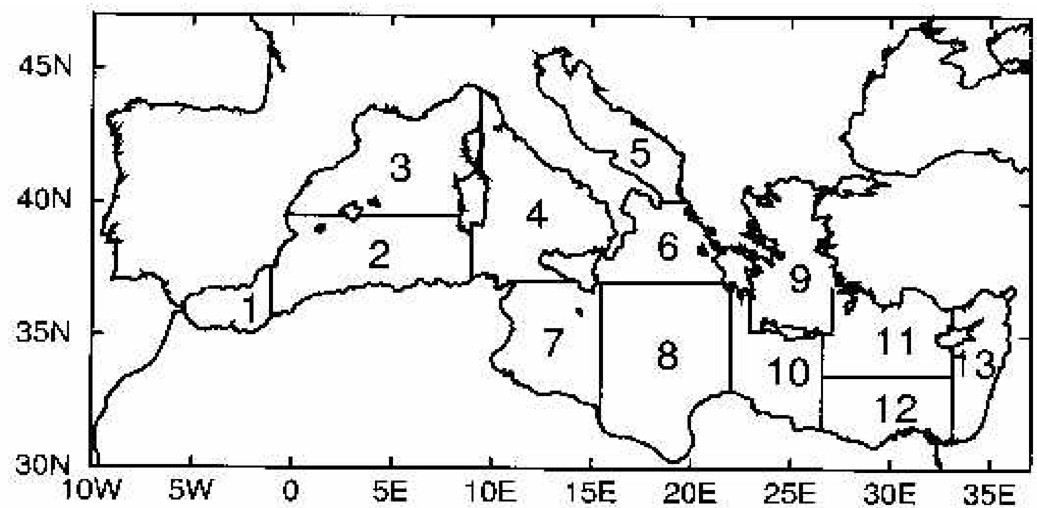
Simplification: reduce the order of B

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

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

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

where S contains different vertical EOFs for 13 different regions



The multivariate background error covariance matrix

- **How is B defined?**

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

But practically $\mathbf{B} = \left\langle (\mathbf{X}^{o,b} - \overline{\mathbf{X}}^{o,b})(\mathbf{X}^{o,b} - \overline{\mathbf{X}}^{o,b})^{\mathrm{T}} \right\rangle = \left\langle \mathbf{X}'\mathbf{X}'^{\mathrm{T}} \right\rangle$

$$\mathbf{B} = \left| \begin{array}{cccc} \mathbf{T}'\mathbf{T}' & \mathbf{T}'\mathbf{S}' & .. & \mathbf{T}'\boldsymbol{\eta}' \\ \mathbf{S}'\mathbf{T}' & \mathbf{S}'\mathbf{S}' & \mathbf{S}'\mathbf{U}' & \mathbf{S}'\boldsymbol{\eta}' \\ \mathbf{U}'\mathbf{T}' & .. & ... & .. \\ \boldsymbol{\eta}'\mathbf{T}' & \boldsymbol{\eta}'\mathbf{S}' & & \boldsymbol{\eta}'\boldsymbol{\eta}' \end{array} \right|$$

Water mass properties

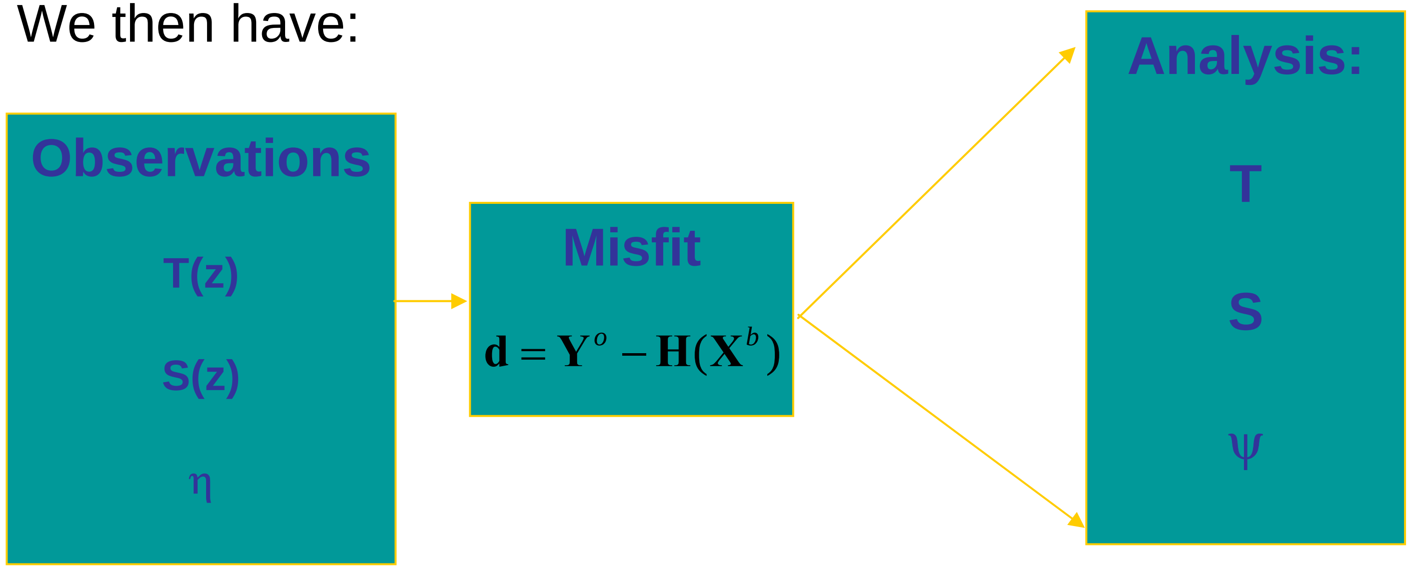
Important for T,S profiles assimilation

Correlation SLA With thermocline and halocline

Important for SLA Assimilation: extrapolation to T,S corrections

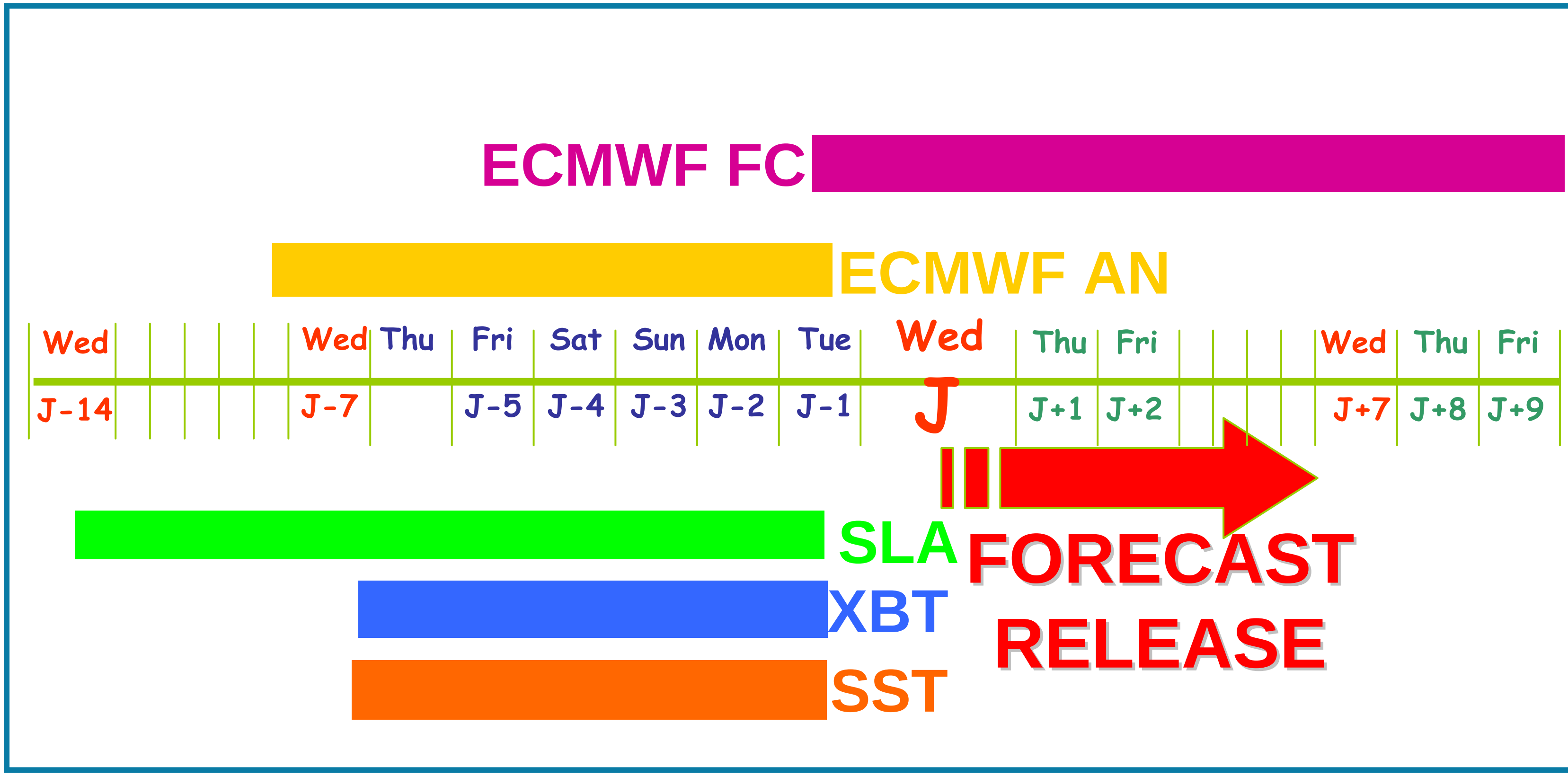
The practical implementation of the assimilation scheme in MFS op. syst. is:

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



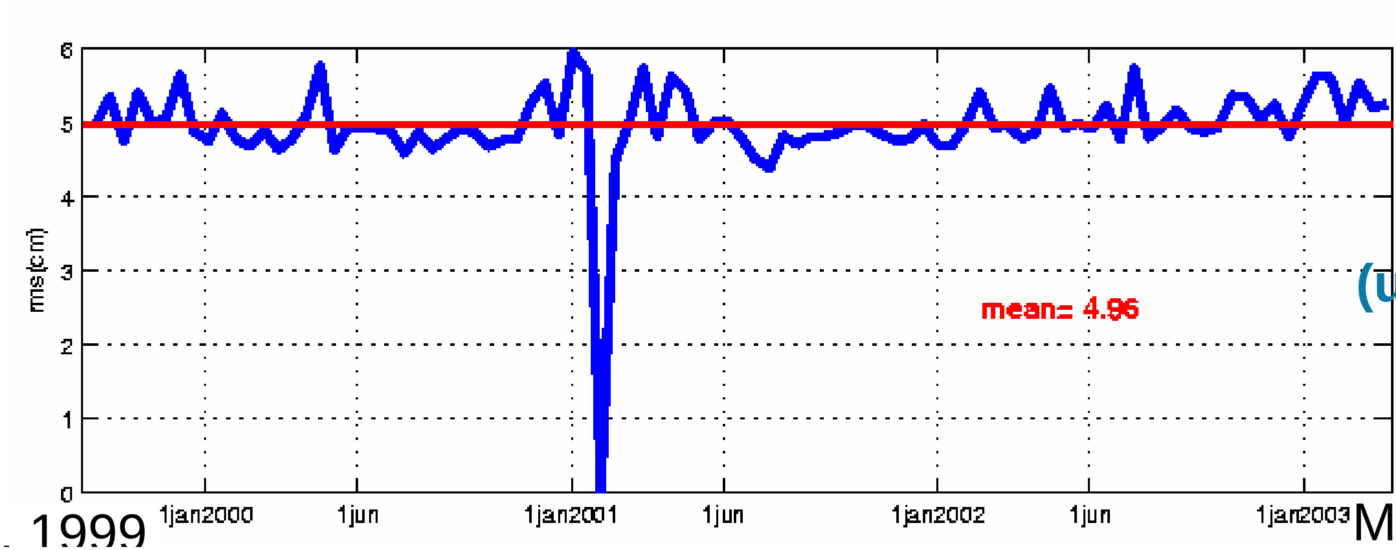
Up to May 2004, MFS had SYS2 system with only one vertical EOF for SLA assimilation

The present day MFS (SYS3) weekly forecasting system



Data are disseminated through a Web/ftp service (www.bo.ingv.it/mfstep)

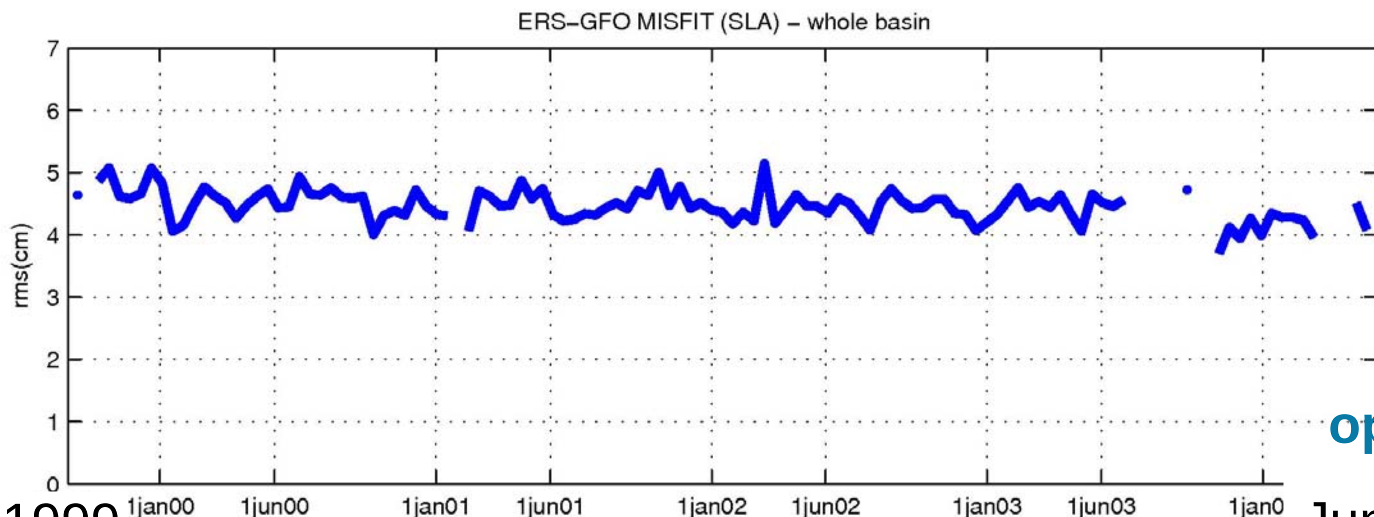
MFSPP-SYS2 versus MFSPP-SYS3 assessment: SLA rms misfit



Sept. 1999

May, 2003

SYS2 (up to May 2004)

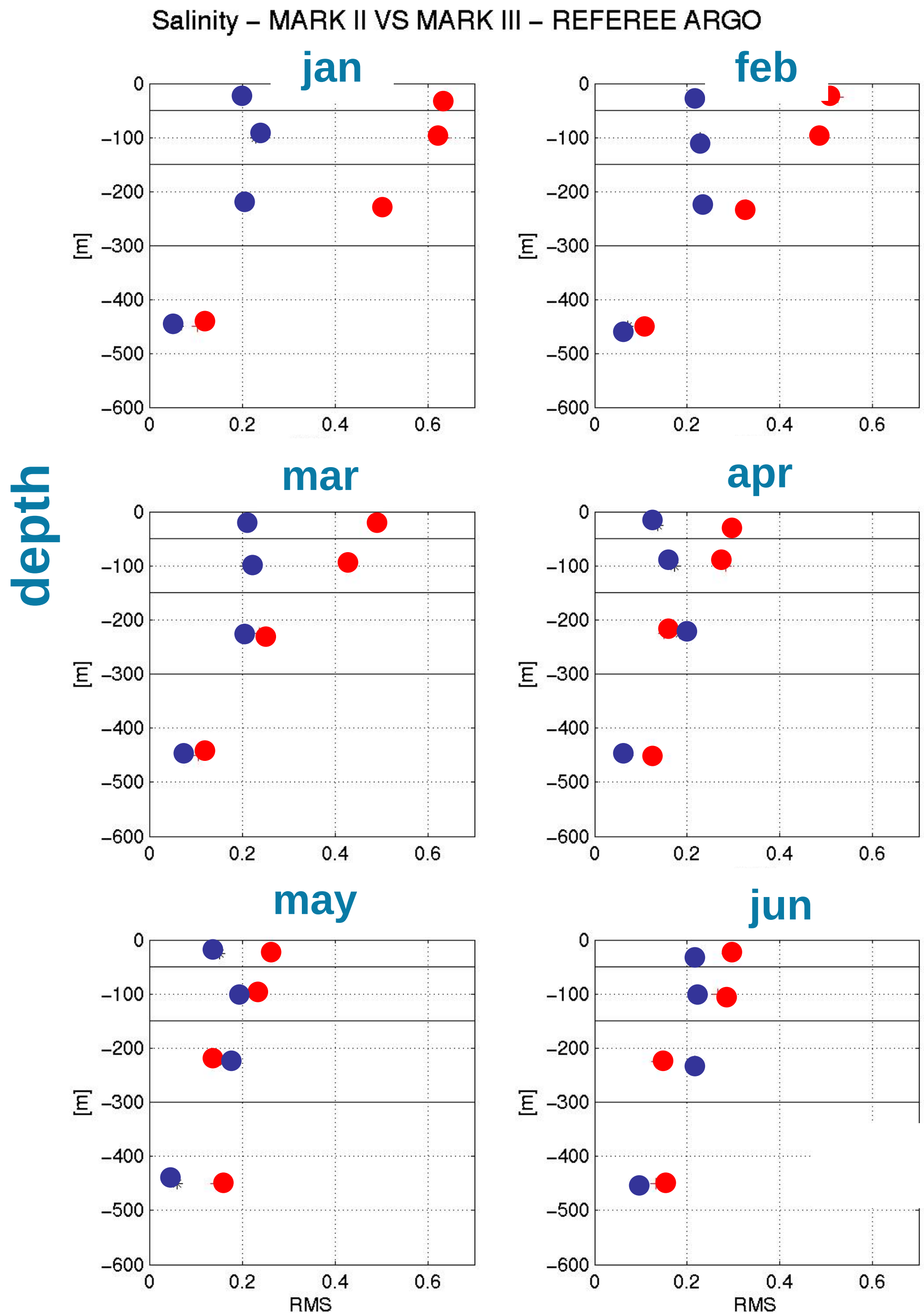


Sept, 1999

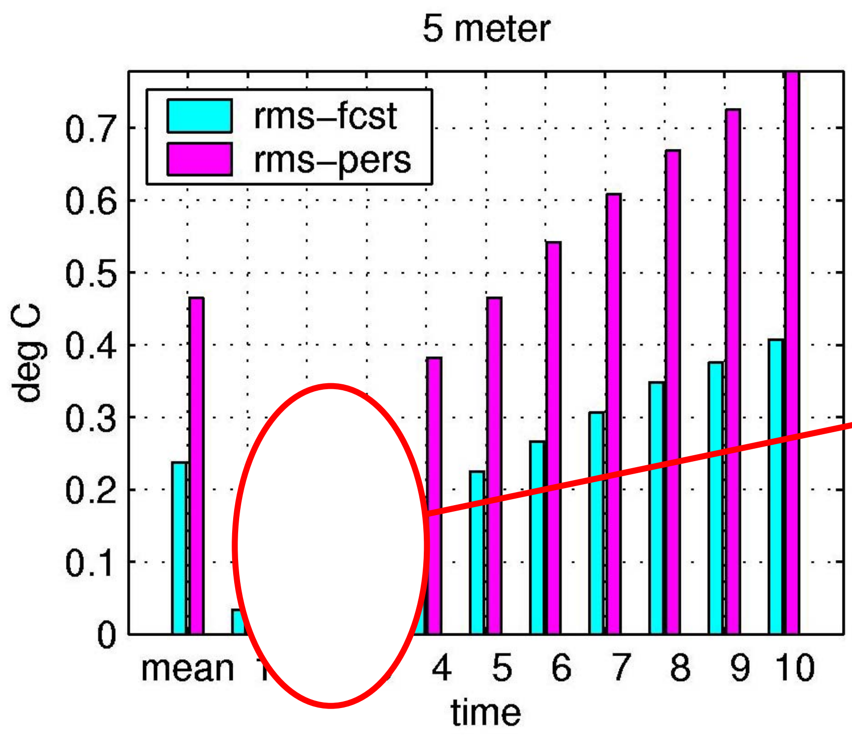
June, 2004

SYS3 (now operational)

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



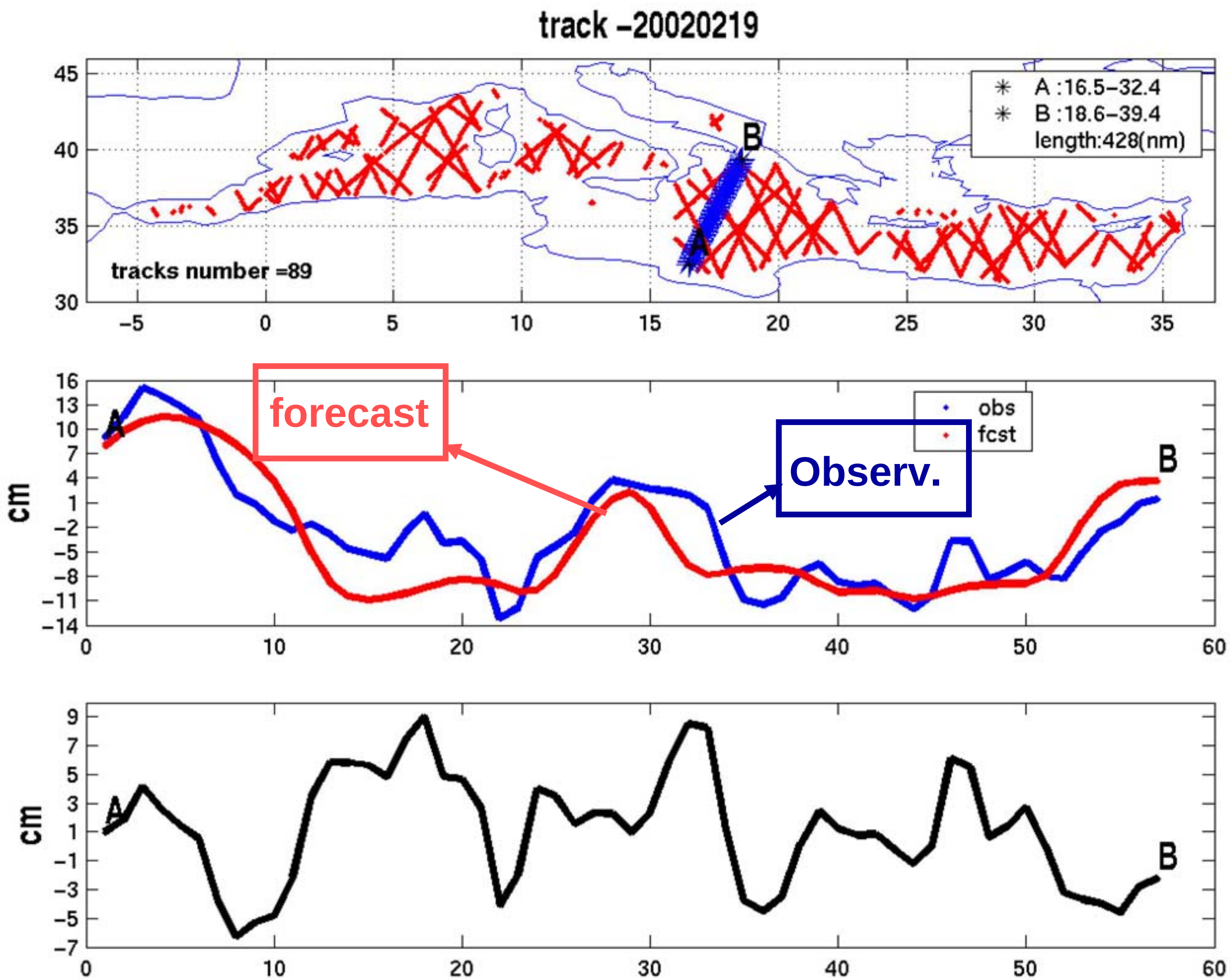
Assessment of the MFS forecast: comparison between root mean square error of forecast and persistence



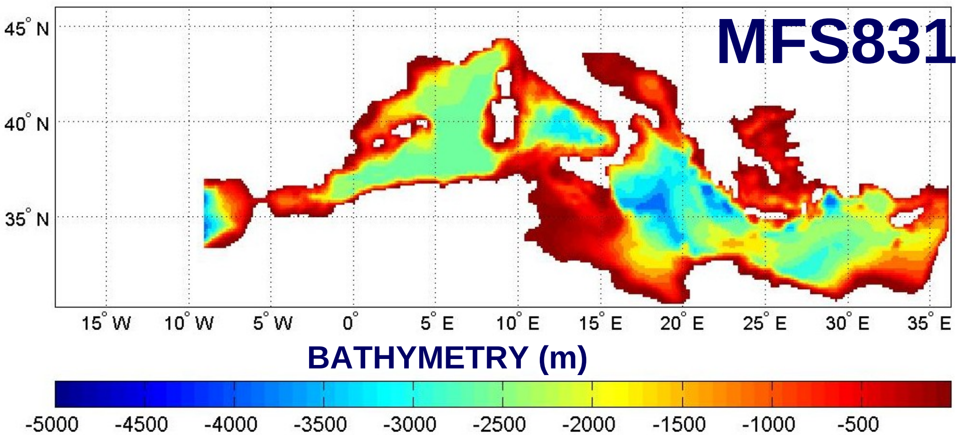
Conclusion: forecast is important from the second day

Basin 2002

Quality assessment: misfit on a single track

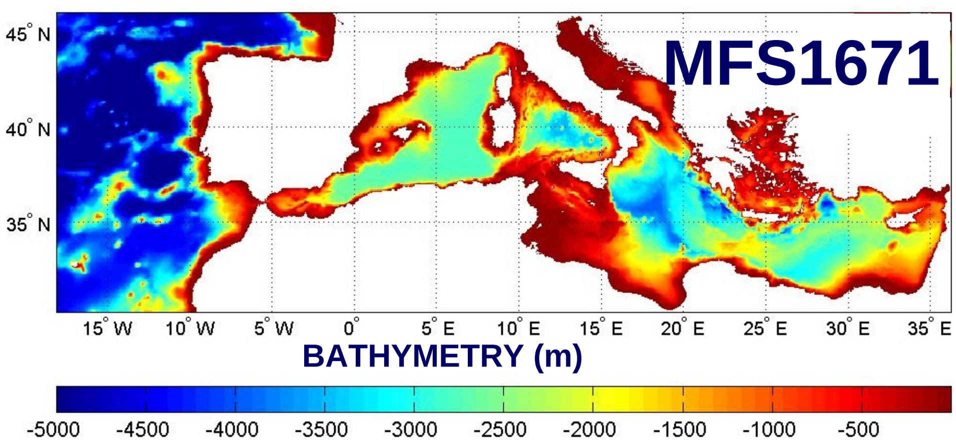


MFSTEP UPGRADE: new basin scale model



MFSPP OGCM

MOM 1.1
1/8º x 1/8º horizontal grid
31 vertical levels (5-3850m)
9 islands

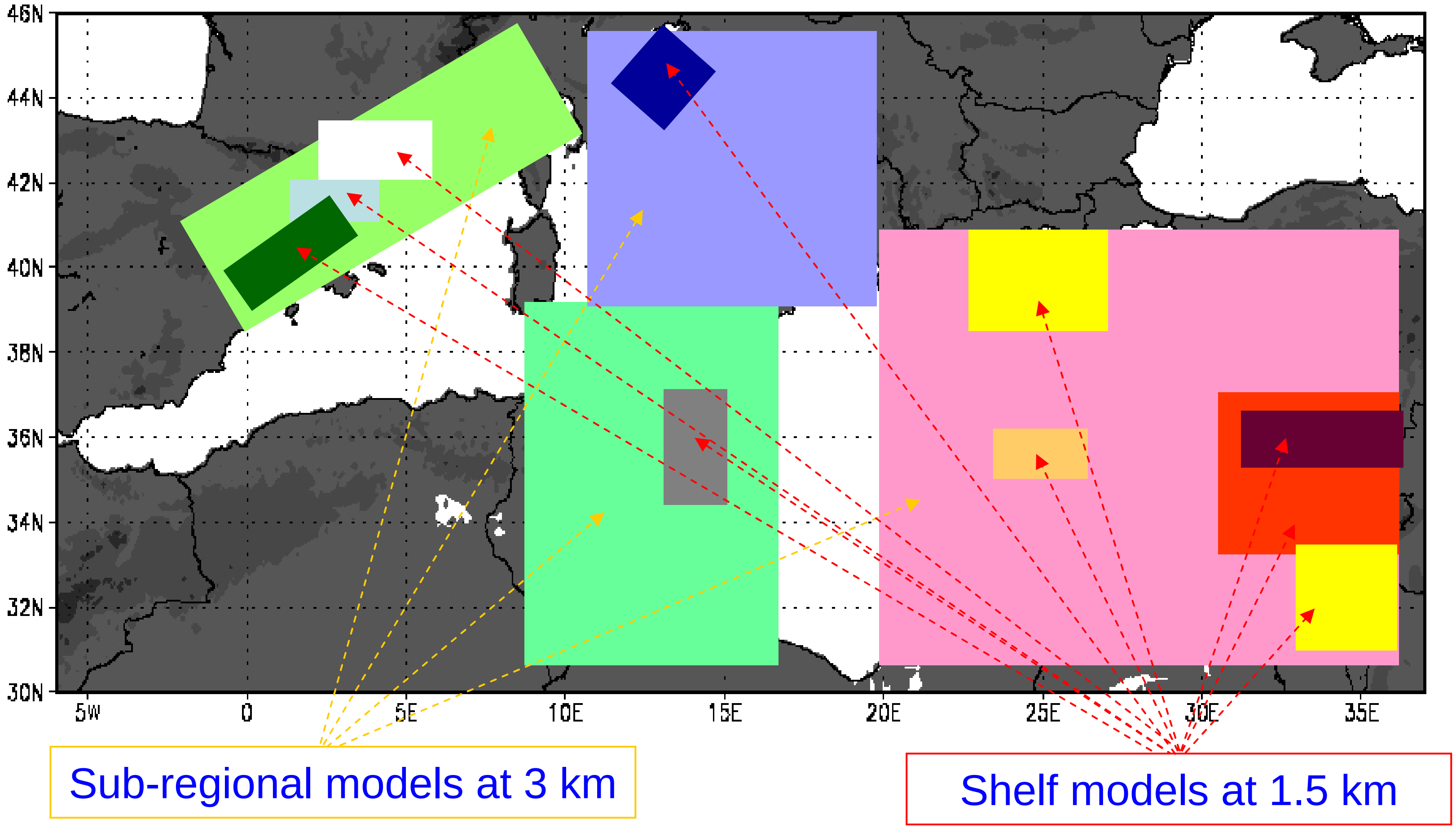


MFSTEP OGCM

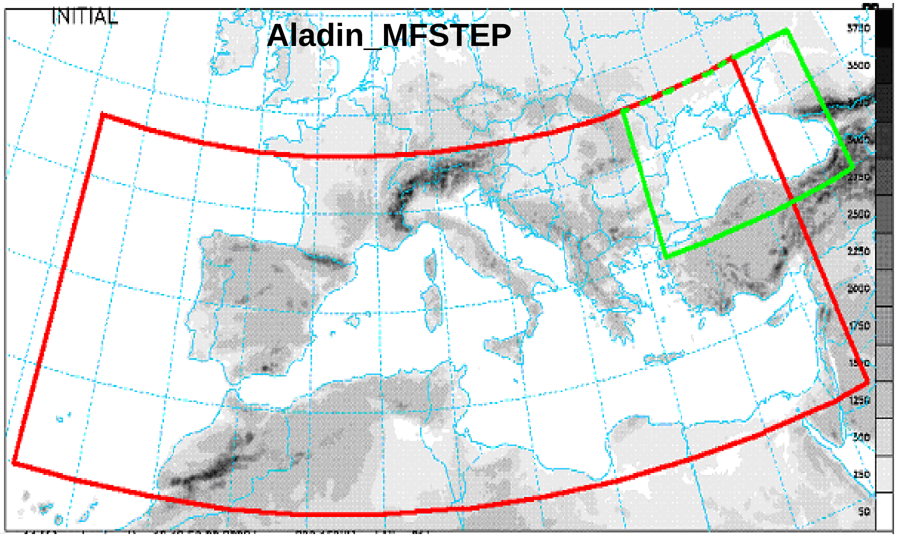
OPA 8.1
1/16º x 1/16º horizontal grid
71 vertical levels (1.5-5000m)
49 islands

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

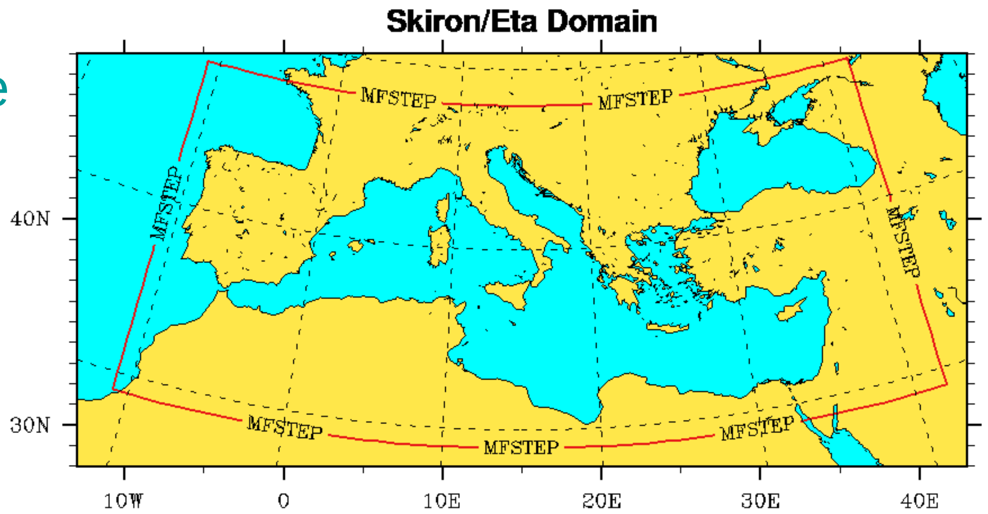


Atmospheric modelling and air sea interactions

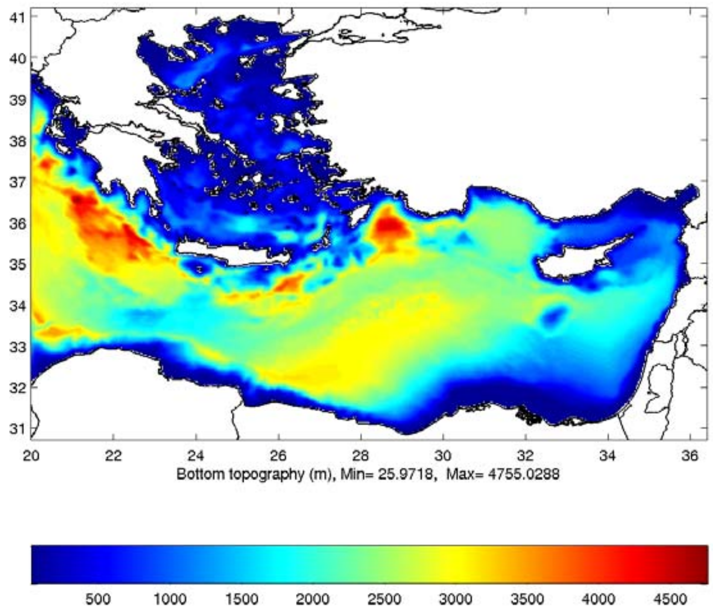


Forcing for sub-regional models will come from Limited Area Models at 10 km and 1 hr resolution
atmospheric surface fields
(5 days forecasts only)

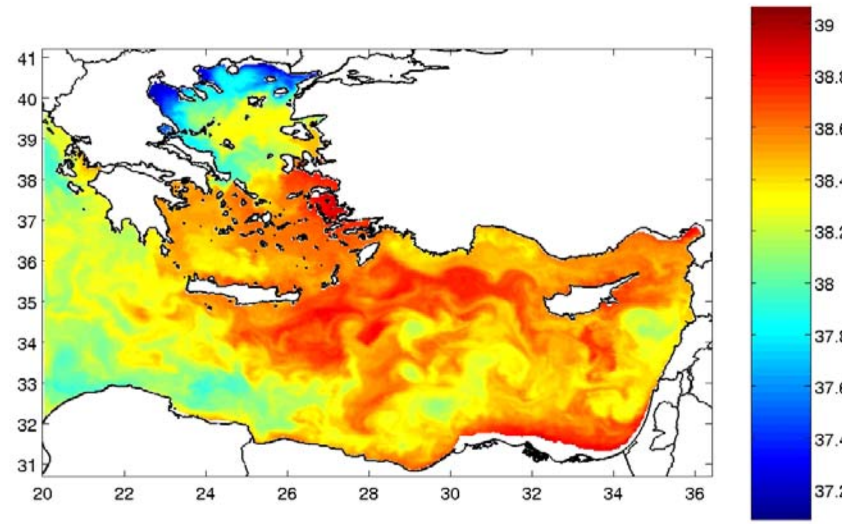
Special configurations of the Aladin model and SKIRON/Eta model were setup by MF, CHMI and IASA



MFSTEP ALERMO forecast: weekly and five days into the future



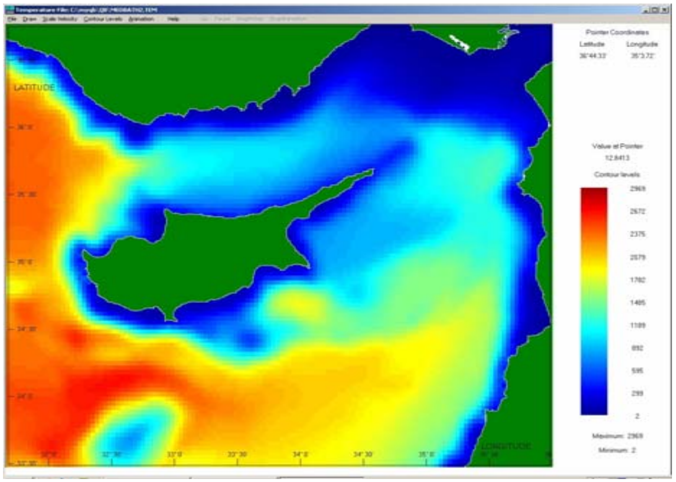
Bathimetry



15/1/2003 Salinity at 30m

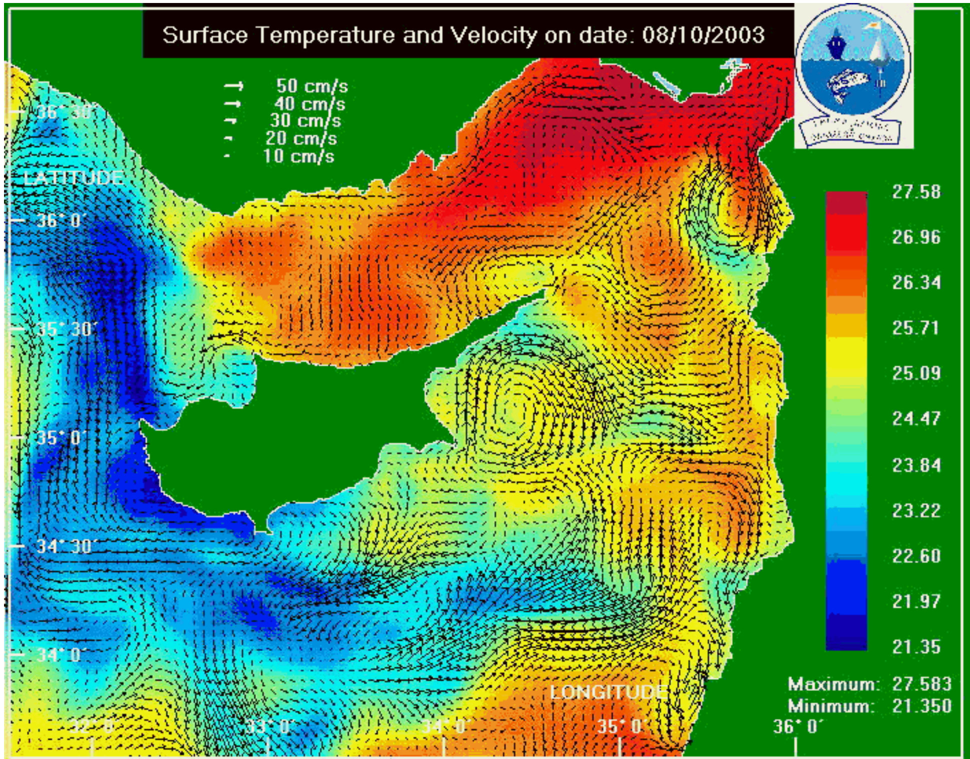
Geographical Coordinates: 20oE - 36.4oE / 30.7oN - 41.2oN
Horizontal Resolution: 1o/30
Vertical Resolution: 25 sigma levels (logarithmic)
Lateral Boundary Conditions: MFSTEP OGCM
Surface Boundary Conditions: Skiron Weather Forecast

CYCOFOS high resolution nested in MFS system in operational mode

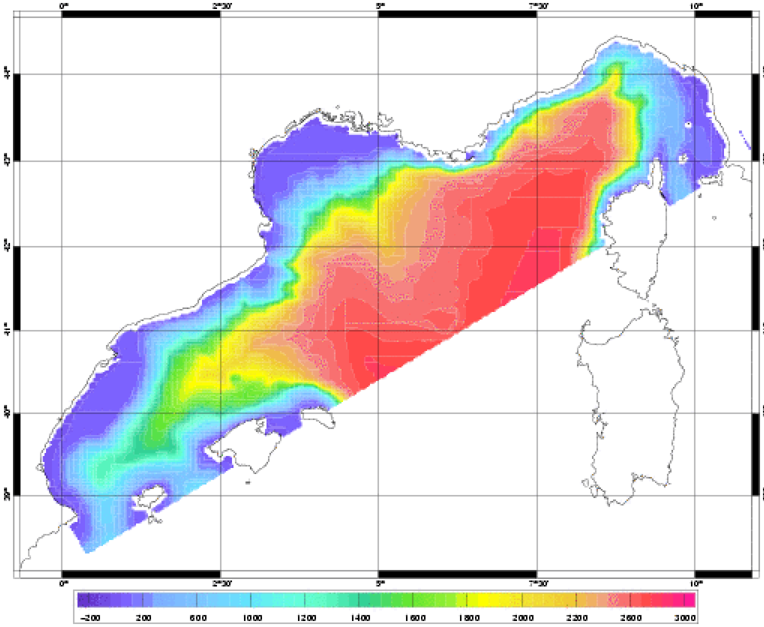


CYCOFOS 1.5 Km bathymetry

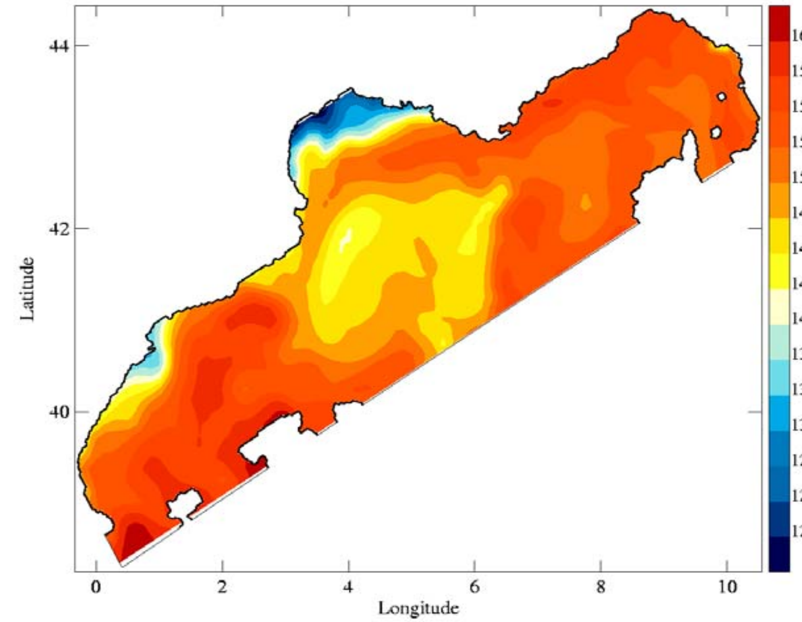
Current forecast from CYCOM for 08-17/10/2003



MFSTEP North West Mediterranean Model (NWMED): weekly and 5 days fcst



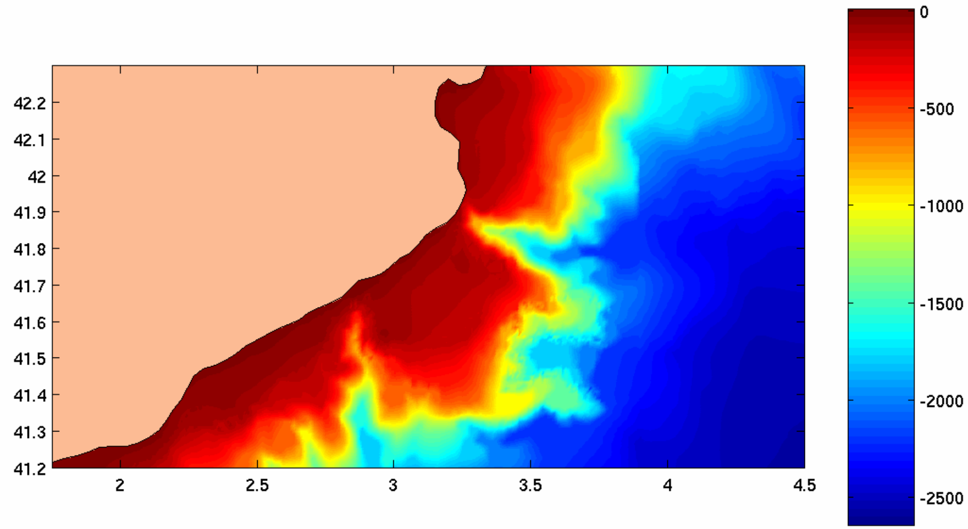
Bathimetry



Surface Temperature

Geographical coordinates : -1.74 E - 10.95 E / 38.26 N - 45.61 N
Horizontal resolution : 3 km * 3 km
Vertical resolution : 40 hybrid sigma levels
Lateral Boundary Conditions : MFSTEP OGCM
Surface Boundary Conditions : Skiron Weather Forecast

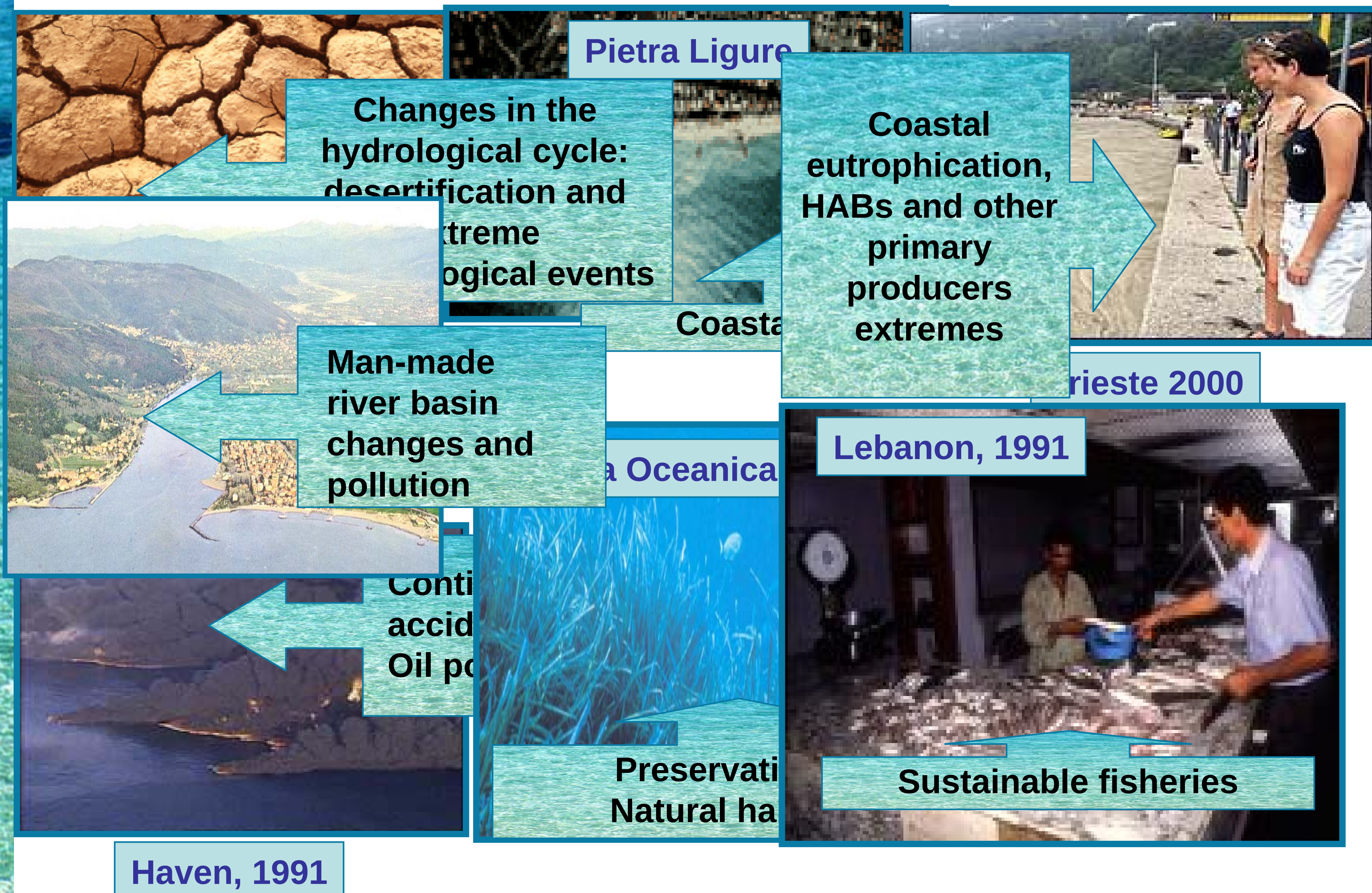
Catalan Sea shelf model



Bathimetry

Geographical Coordinates: 41.2ºN to 42.3ºN ; 1.75ºW to 4.5ºW
Model: non-hydrostatic version of the z-level, fourth-order accurate DieCAST ocean circulation model (Dietrich and Ko, 1994; Dietrich, 1997)

How can operational oceanography help?



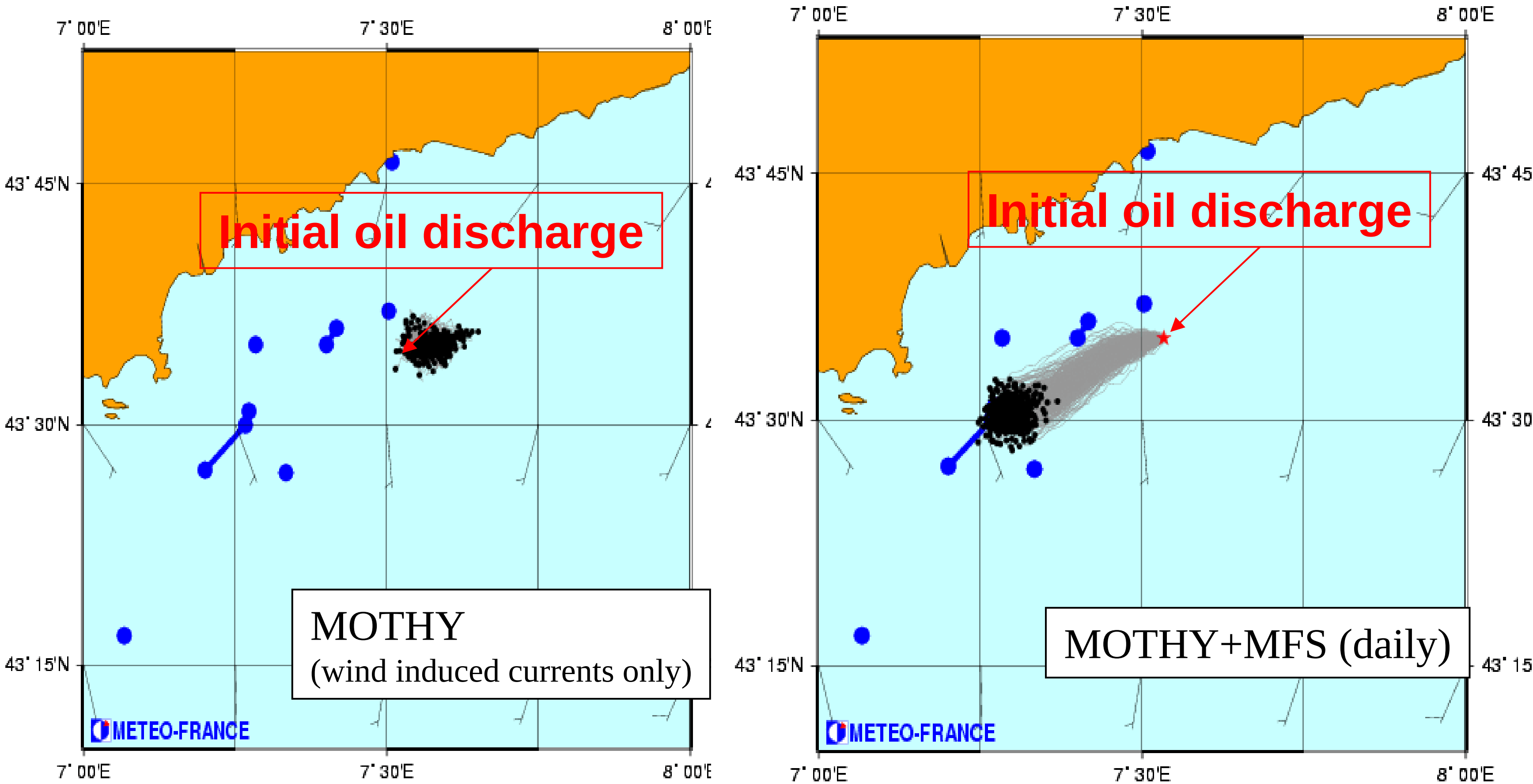
MFS has focused on pollution issues both open ocean and coastal

- MFS products are coupled operationally to numerical predictions of open ocean contaminants and oil dispersion
- Pollution in the coastal areas is related to health of the ocean isues. MFS develops ecosystem models
- MFS has started a special effort In the Adriatic with ADRICOSM. The sustainability concept is connected to ICZM and commercial fishing activities
  – ICZM should consider large river discharges from urban settlements and related water quality issues: ADRICOSM develops the appropriate downscaling, the coupling with local monitoring systems and the integrated modelling
  – For sustainable fisheries the approach is to develop a Fishery Observing System with capabilities comparable to the space/time resolution of the MFS observing system for physical state variables

MFS products: advection-diffusion modeling of oil spills

24 hours forecast

MOTHY/ARPEGE : Prévision pour le 12/05/2003 à 14 utc

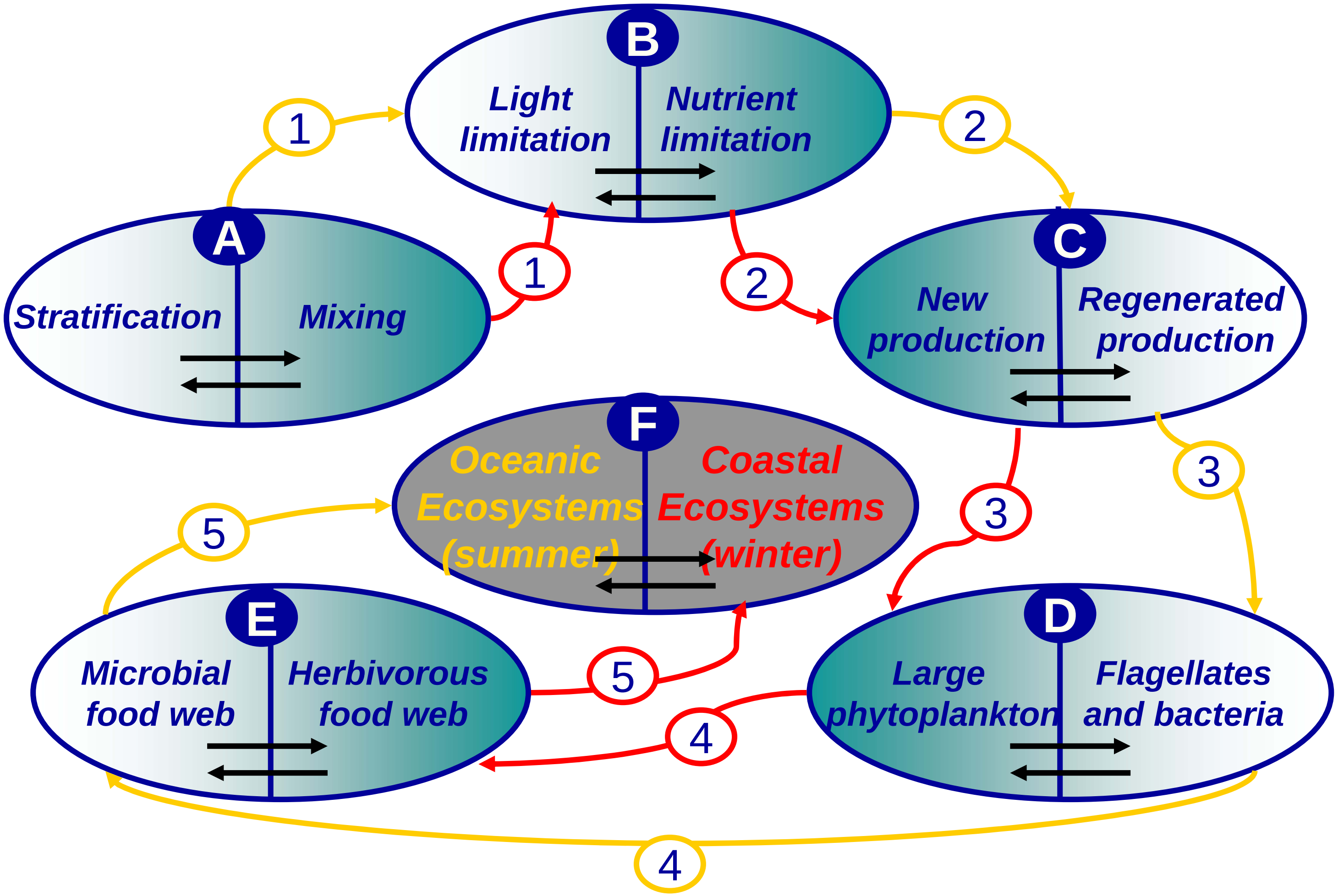


Attention : document technique de prévision de dérive d'hydrocarbure, réalisé à partir d'un seul point choisi dans un ensemble complexe de nappes (observées ou non).

Caution: Technical support for oil drift forecast from a single point out of a complex set of slicks (observed or not).

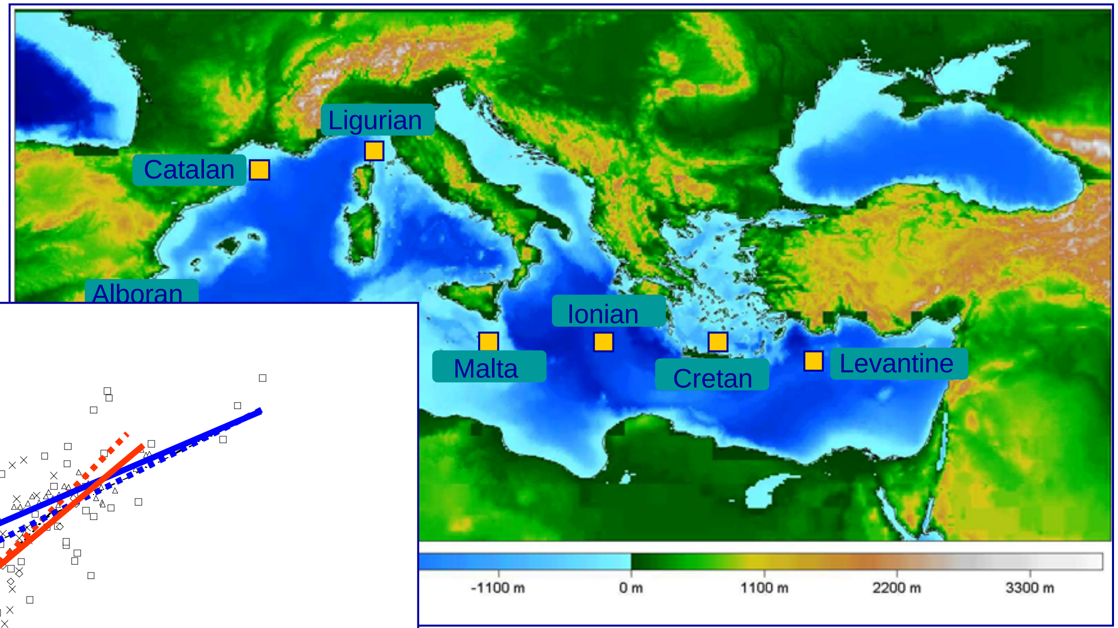
Ecosystem functioning in open ocean and coastal areas

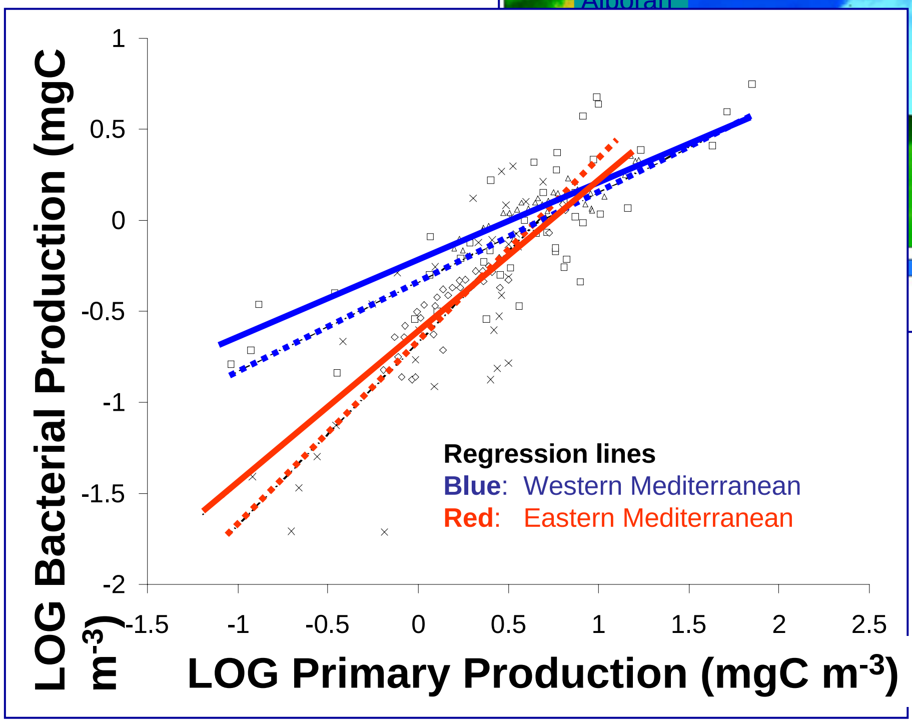
Multivorous food webs



Ecosystem model validation in different Mediterranean areas

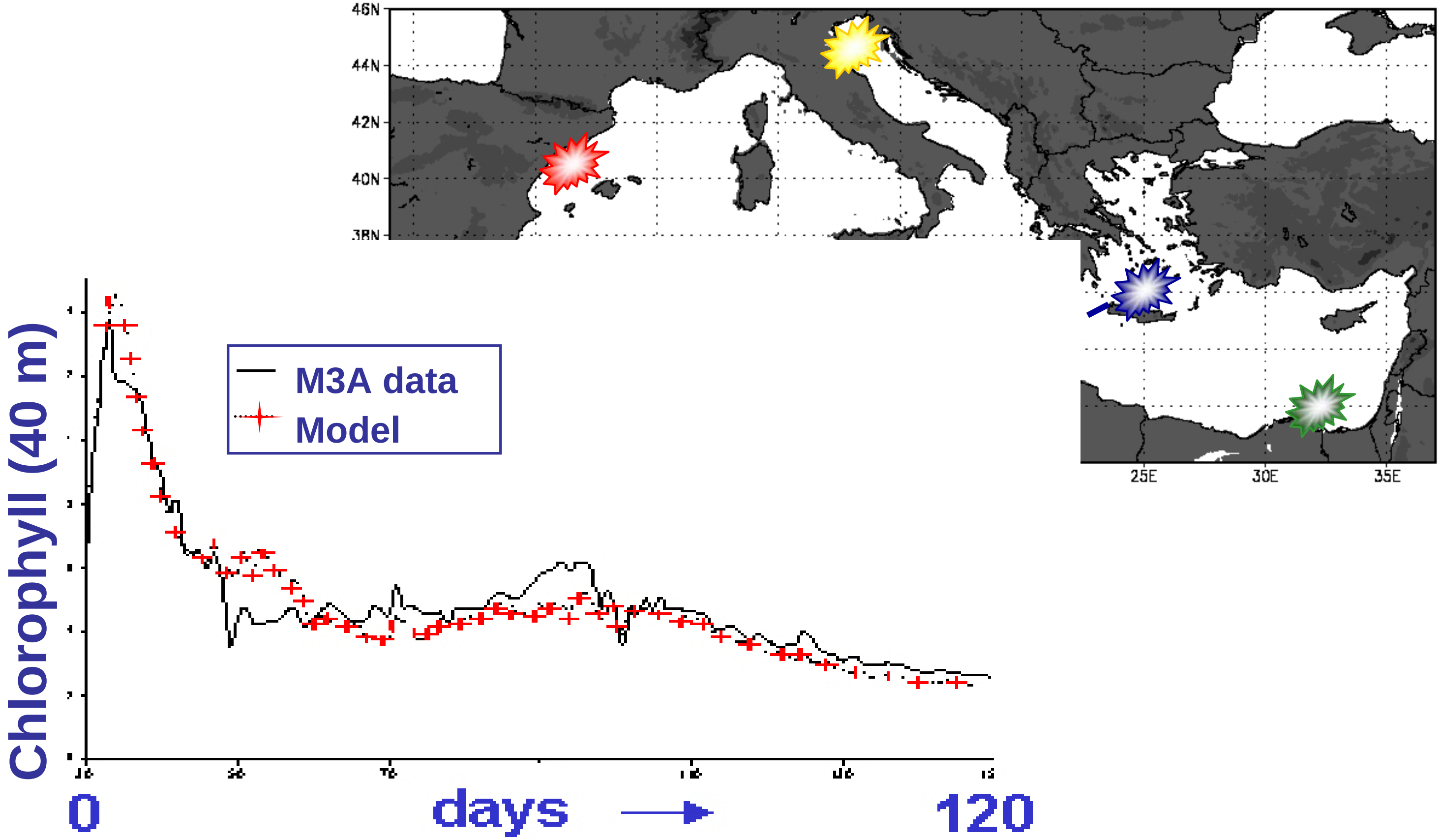
Simulation sites Position





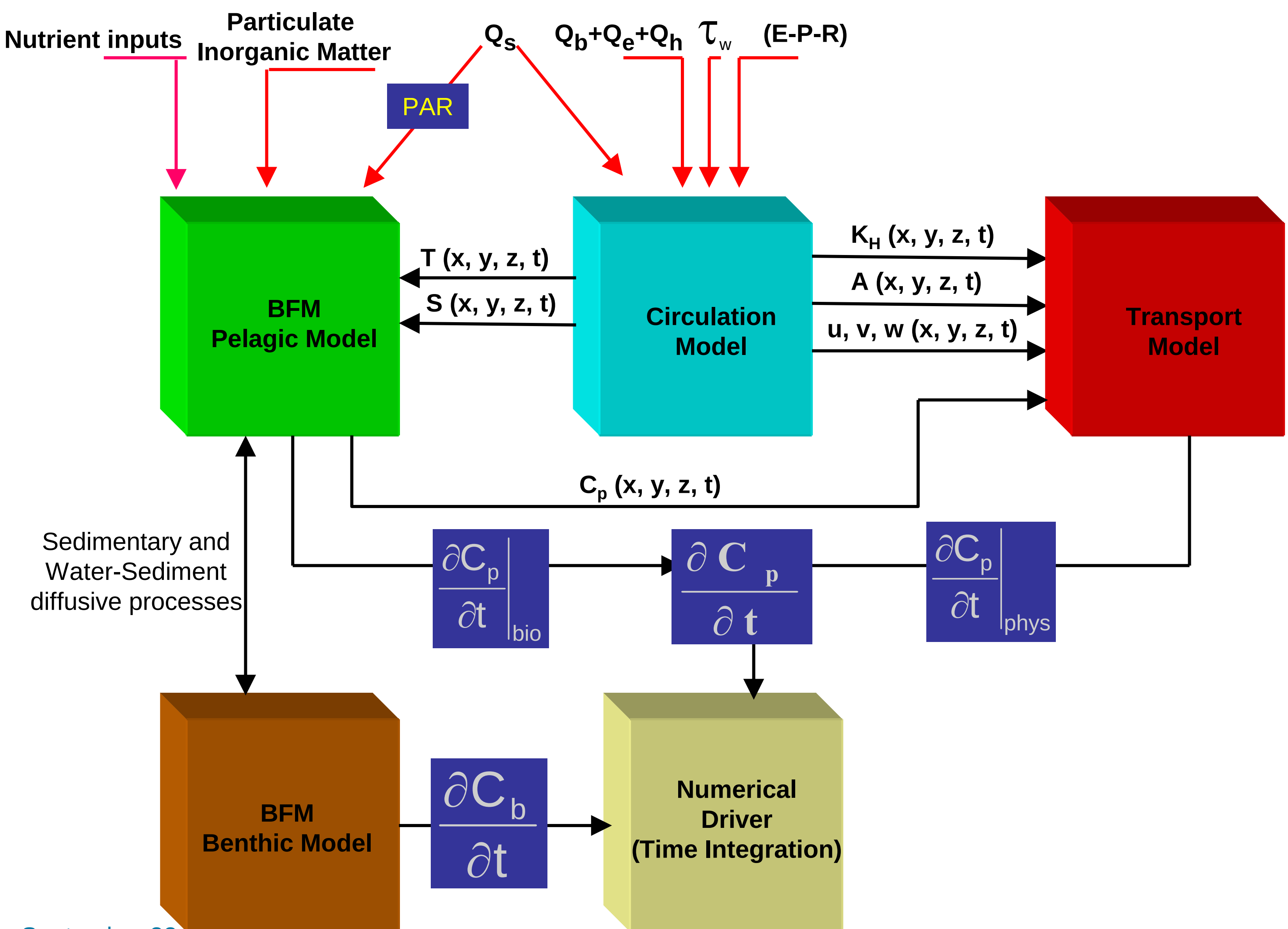
Model (dots) - Data (continuos) intercomparison

Ecosystem Model calibration areas



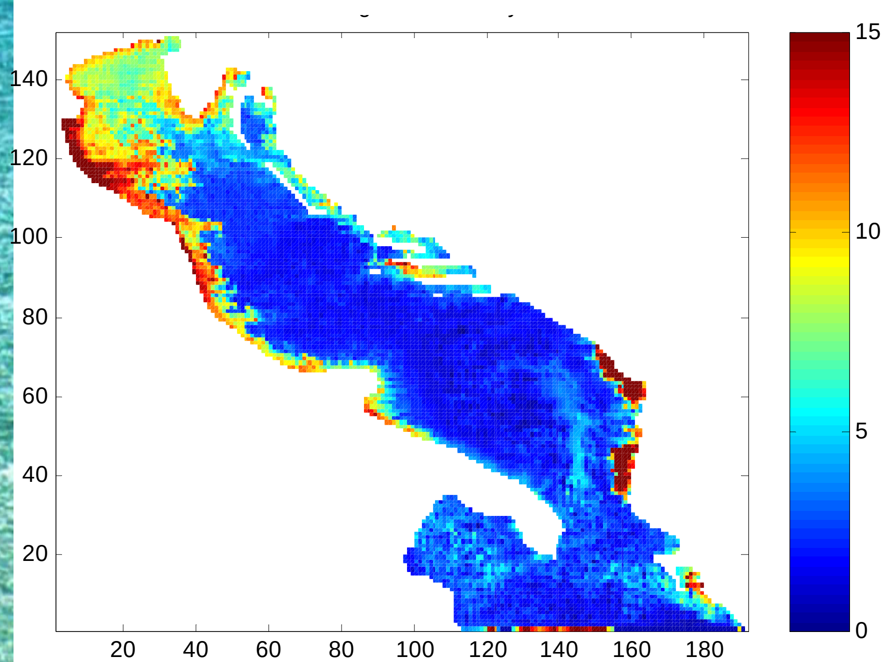
Plymouth Marine Laboratory
NATURAL ENVIRONMENT RESEARCH COUNCIL

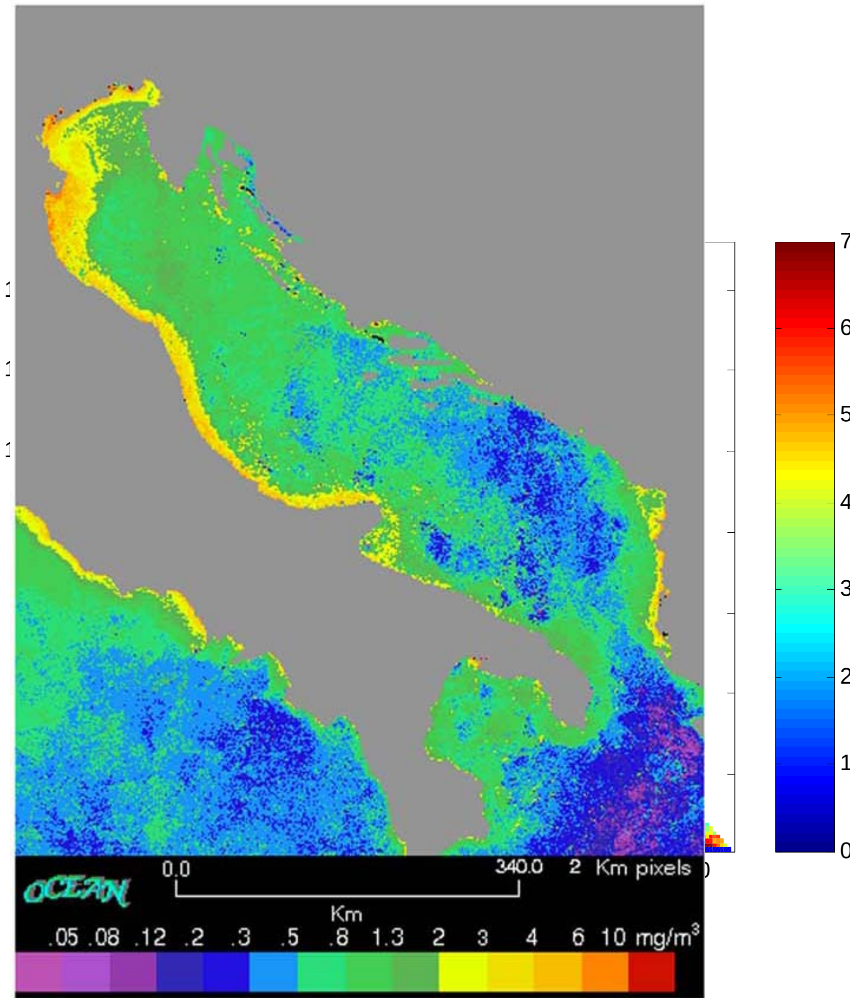
THE GENERAL STRUCTURE OF THE ecosystem MODELS FORCING AND COUPLING



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

Surface Chl-a January





The ADRICOSM Pilot Project

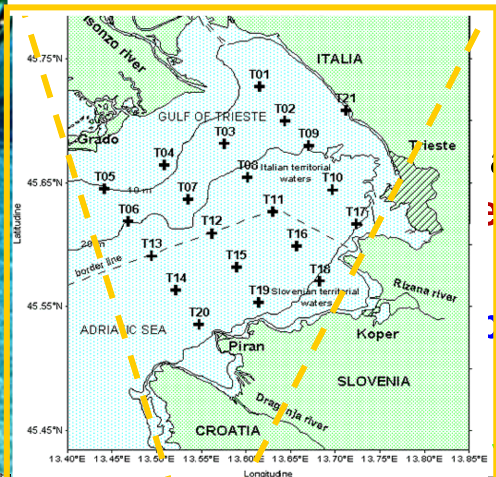
- **ADRICOSM basic goals:**
  - **Demonstrate the feasibility of marine nowcasting/forecasting at weekly time scales in this critical shelf area**
  - **develop coupling with river basin management systems for coastal pollution and marine ecosystem health management**

Coastal Observing System:
satellite SST, SLA, VOS-XBT, coastal CTD and buoy stations

Forecasting
MFS OG
regional sca
with data ass
nested shelf a
mode

Experimental coupling of river basin monitoring and modelling system with marine hydrodynamic models

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



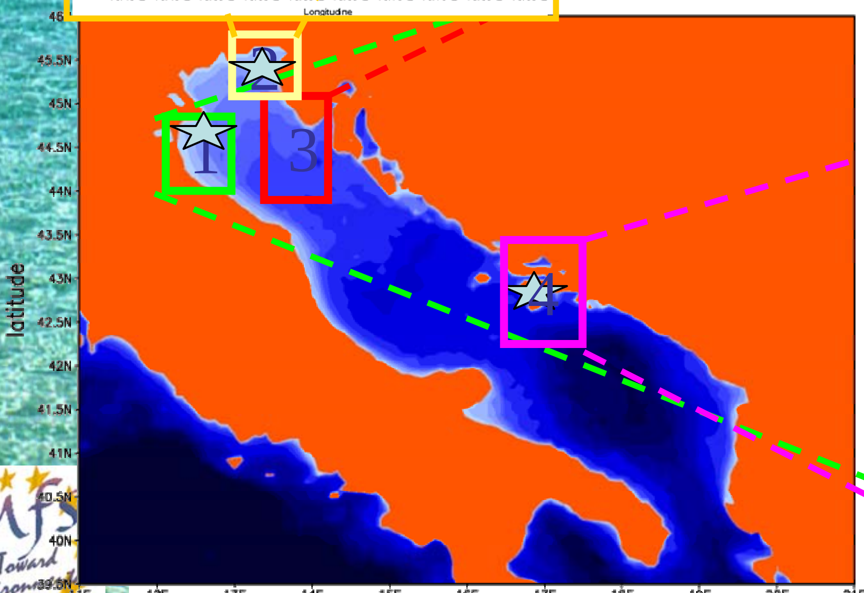
☆ Buoy stations

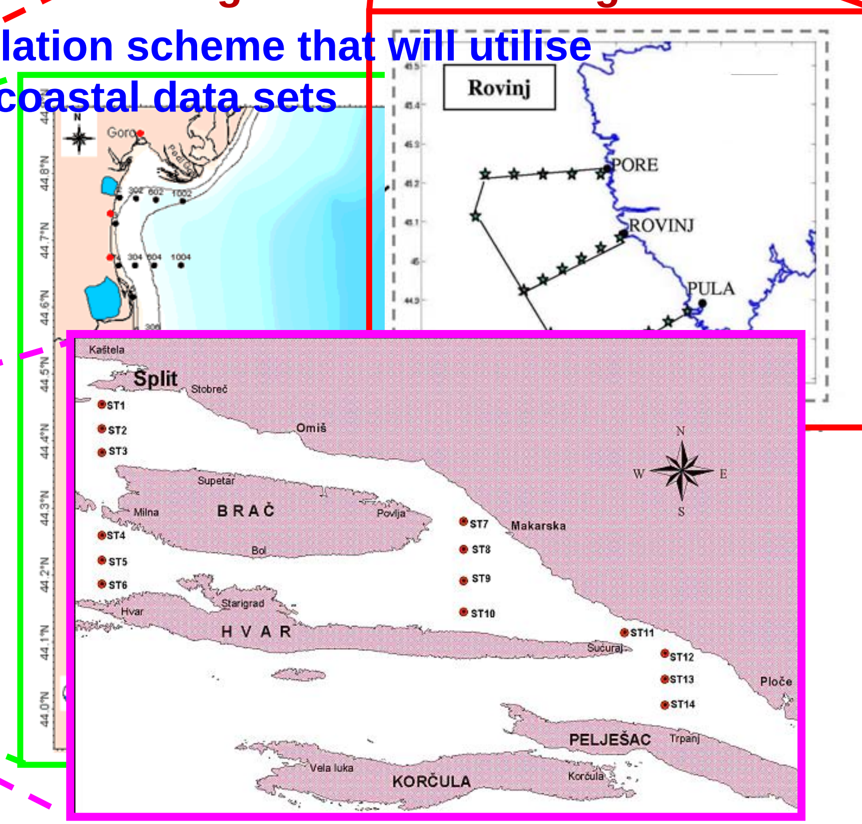
…and optimize **coastal networks of CTD stations** in **4**

…eas, complementing the Med large scale monitoring.

…efficient data assimilation scheme that will utilise

…oth large scale and coastal data sets





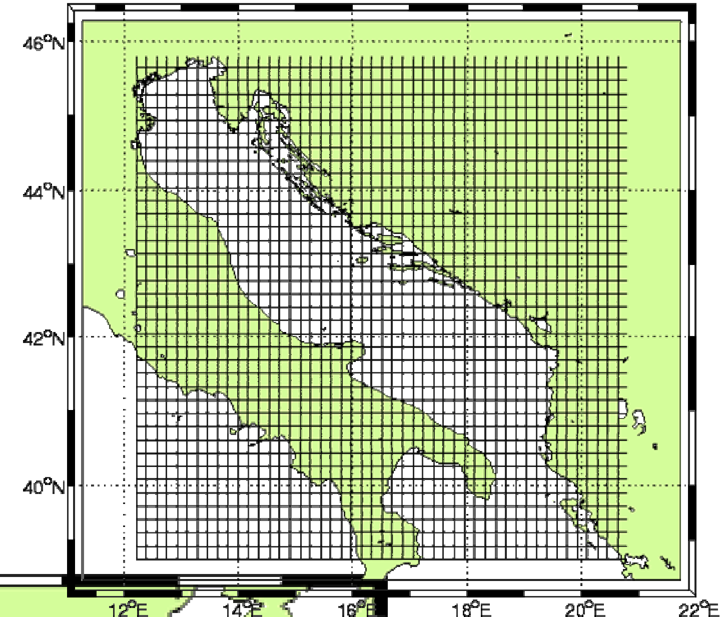
The Adriatic forecasting model

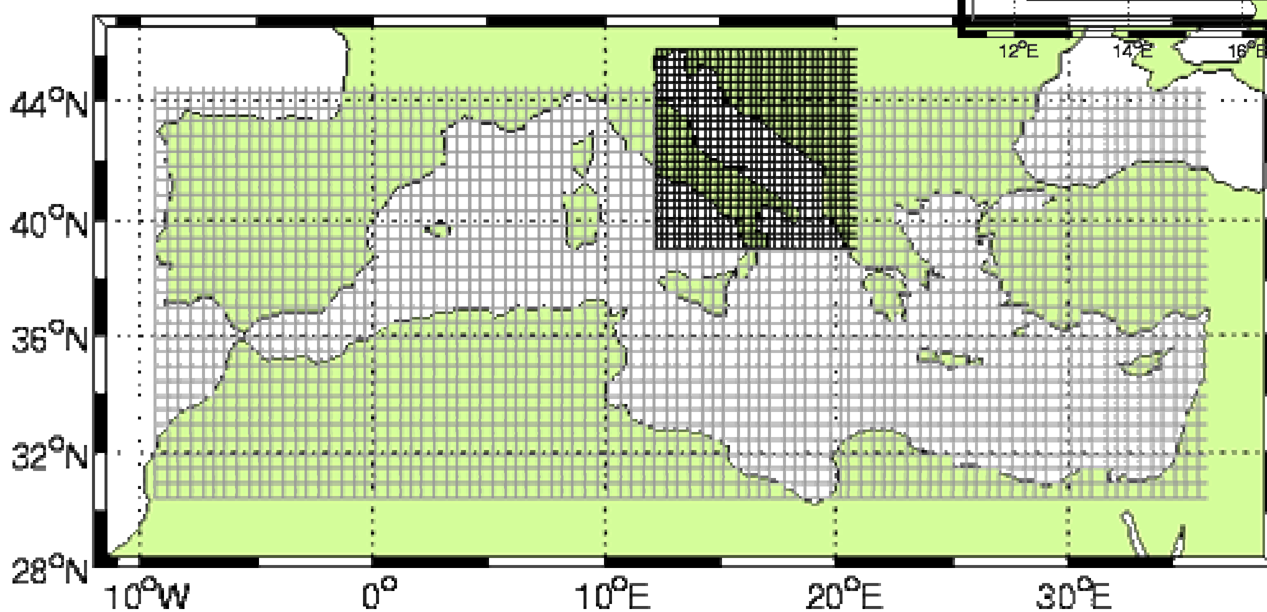
POM based code

5 Km horiz. Resol. and 21 vertical sigma layers

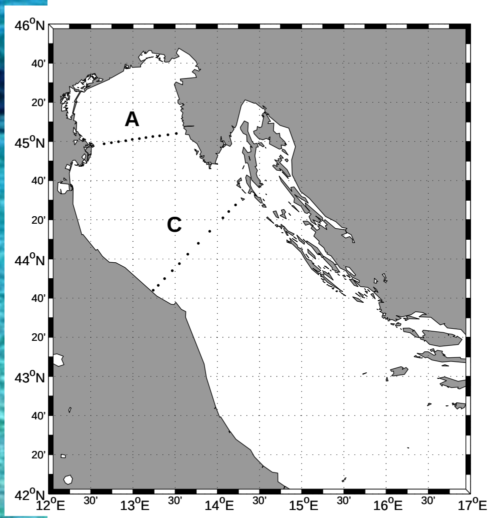
Interactive surface fluxes with ECMWF forcing

1-way nesting with MFS model





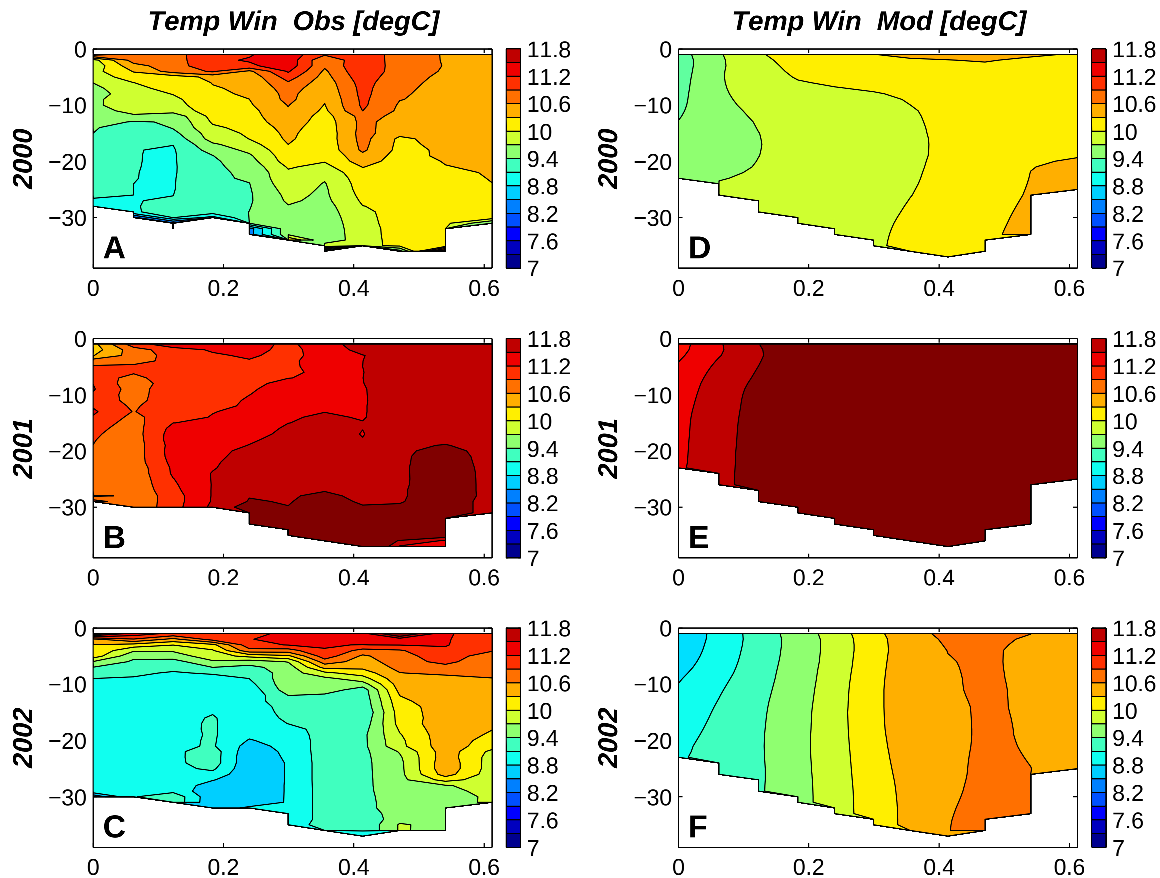
AREG model validation: Intercomparison with MAT data set



Winter Mean
Transect A

Observation

Model Results

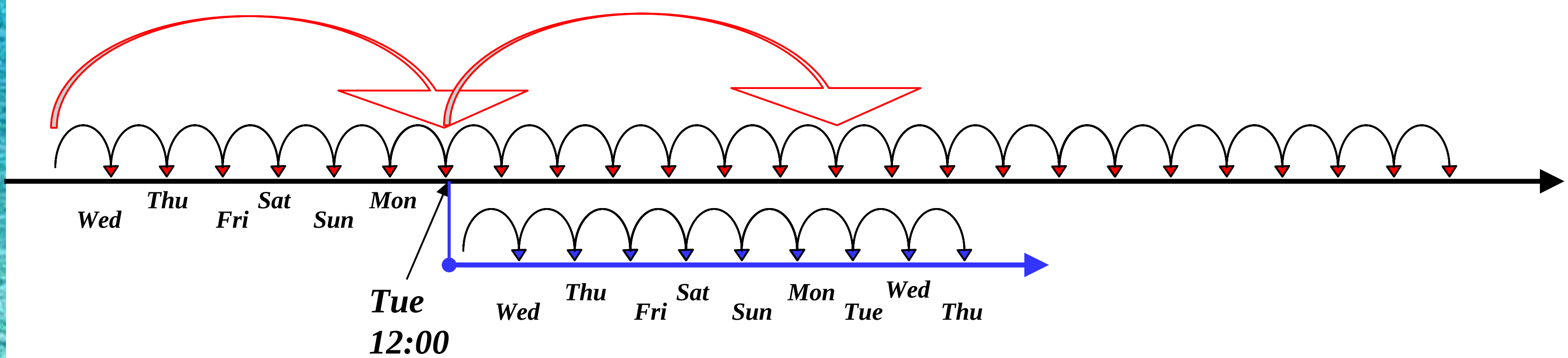


Simulation-Forecast procedure for AREG

Daily Po river runoff, 34 rivers in total

ECMWF surface field analyses

Lateral boundary conditions from MFS OGCM



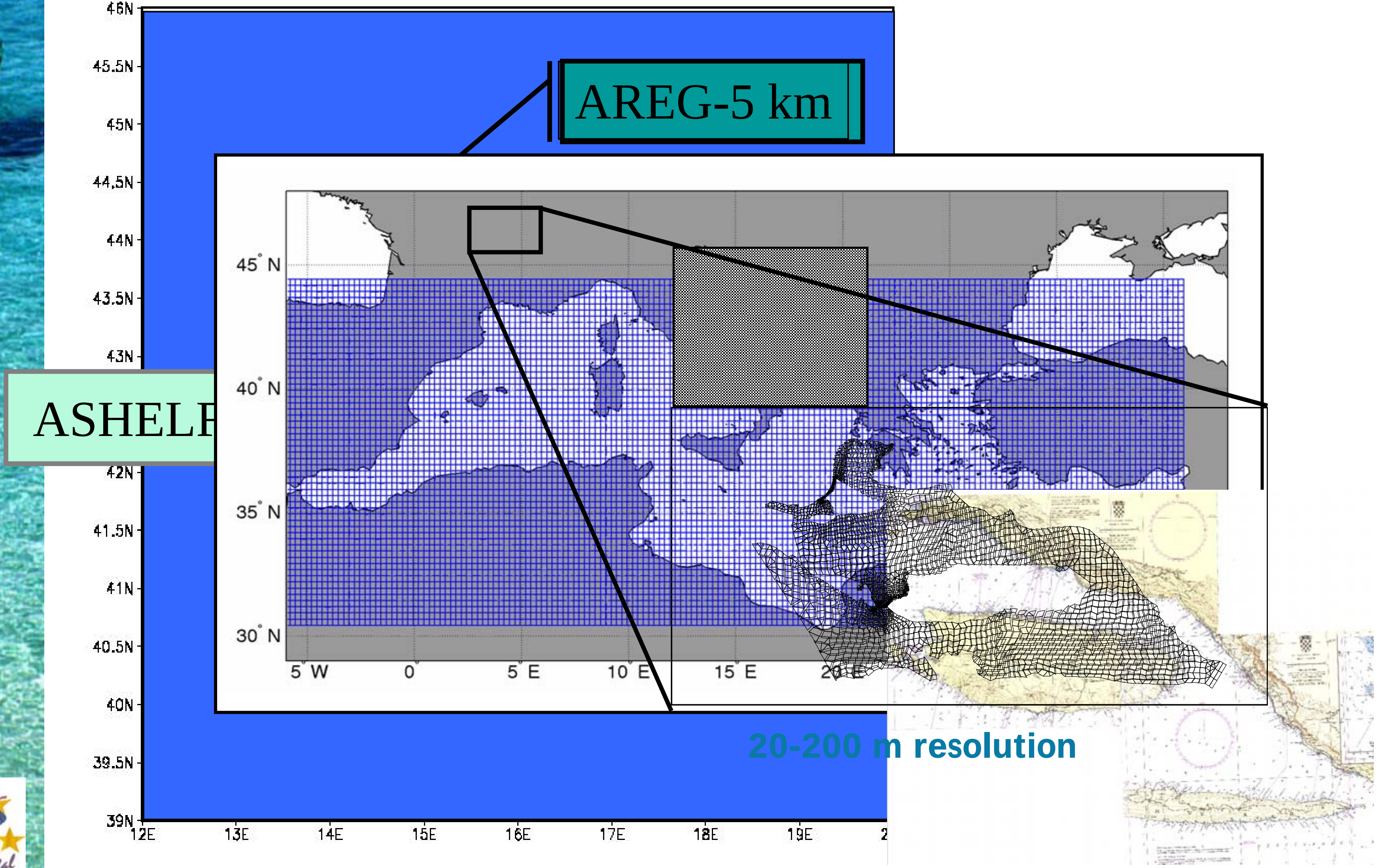
AREG forecast

LBCs Forecast

Atmospheric Forecast

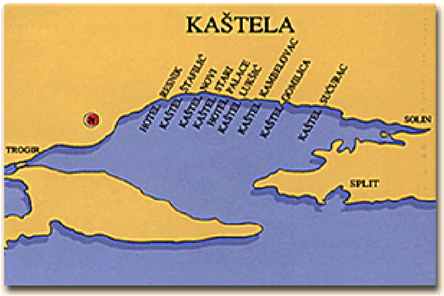
Costant Po

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

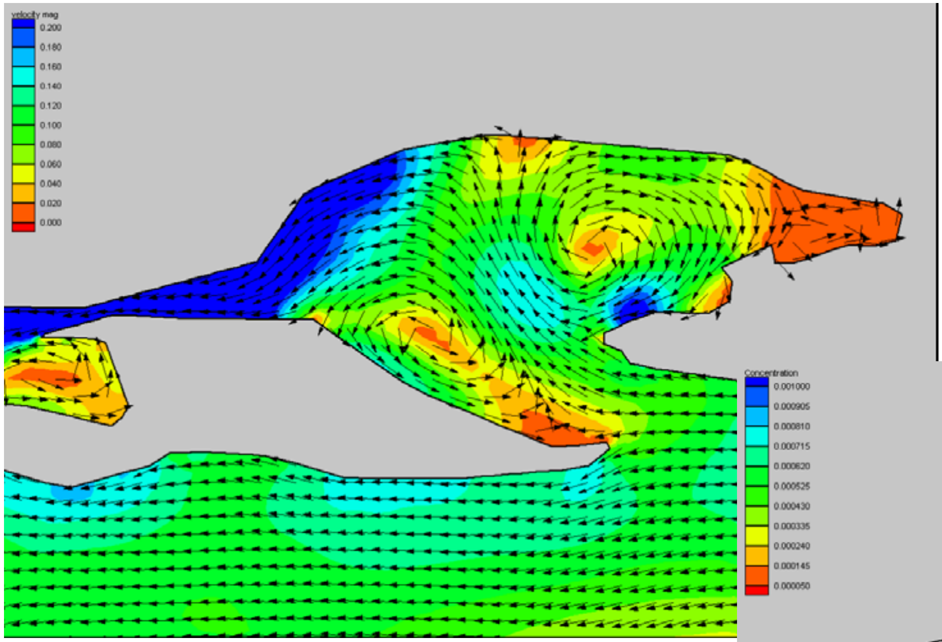


Simulation in the Kastela Bay

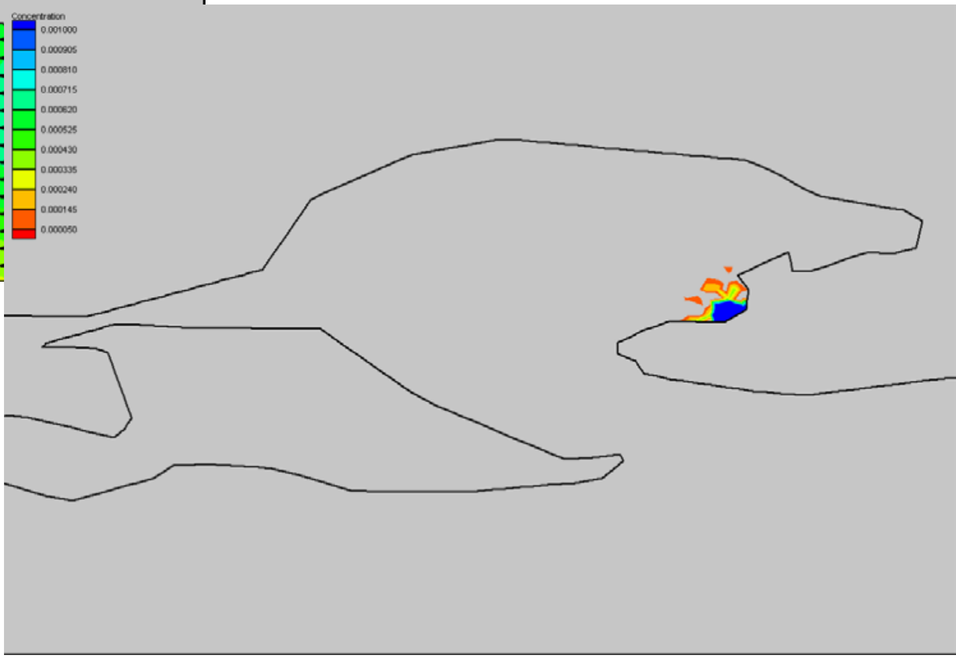
Main Hot Spot

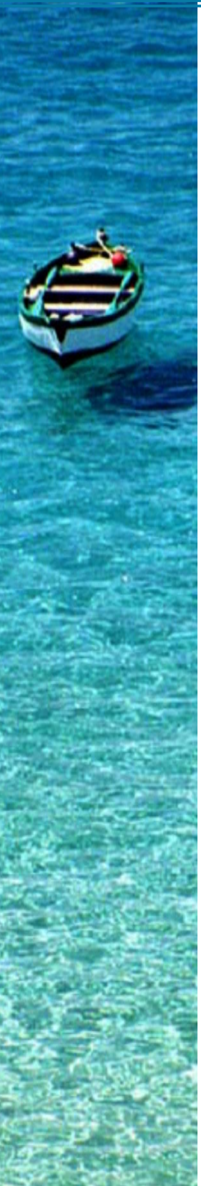


100 m hydrodynamics



Sewage outlfow

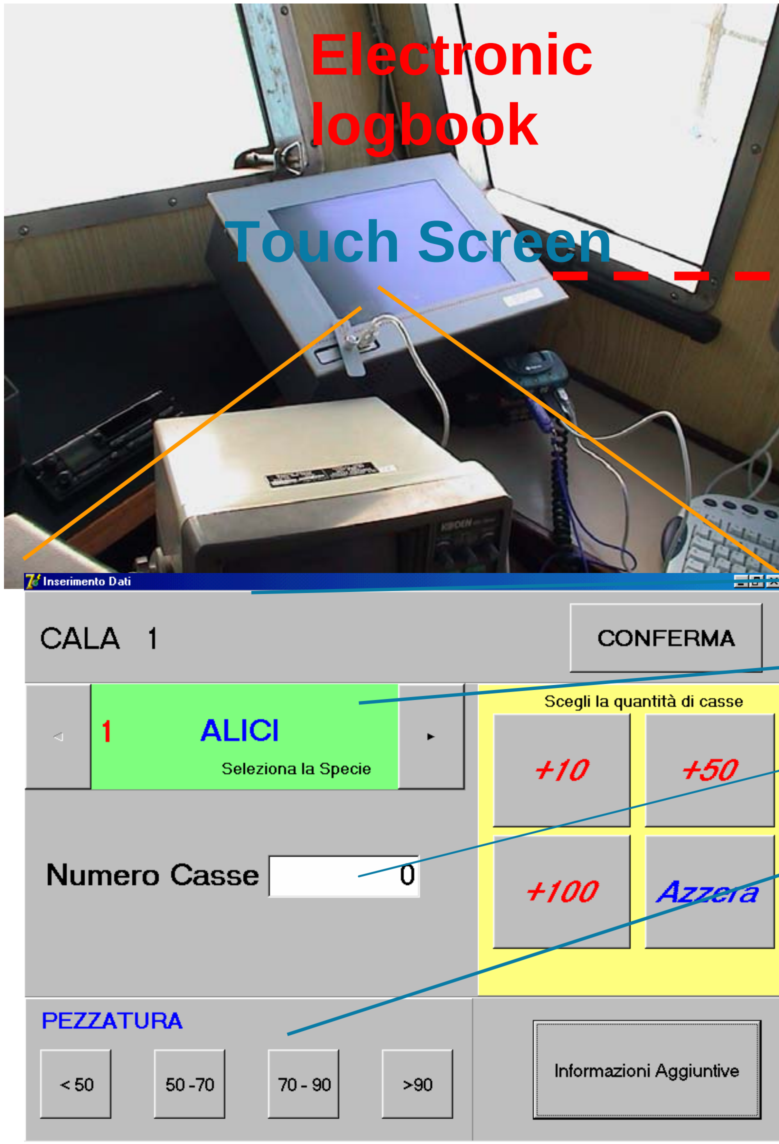




Sustainable commercial fisheries: the FOS – Fishery Observing System

- A system based upon new observations of fish abundance and size of comparable coverage and quality to the physical fields
- Should be based on GPS data loggers installed on commercial fishing vessels and on electronic log-books recording catches and related data
- These fishery data should be then correlated to environmental variables and then used for recruitment and fish stock assessment models
- The FOS will give the first Real Time spatially and temporally resolved fields of fishing effort and commercial catches to be coupled to marine nowcasts/forecasts

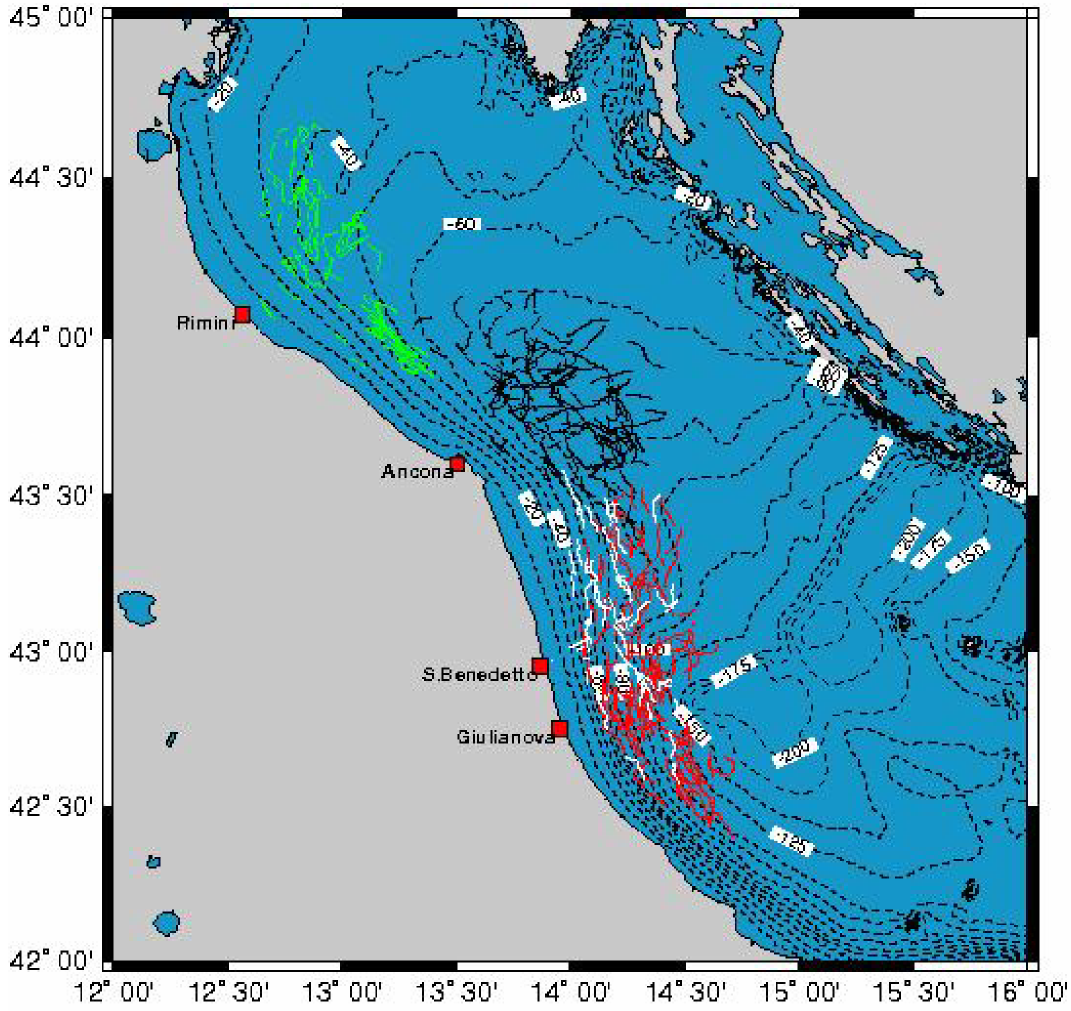
The FOS: the fishing effort Real Time recording system



- •haul number
- •species of fish caught
- •quantity expressed in boxes
- •size
- •date and time
- •longitude and latitude
- •fish depth (only for p.s.w.l)

Pelagic Trawlers Tracks

from October 2003 to February 2004



575 Hauls

Percentage of tracks with temperature data:

Rimini 75% (full period)

Ancona 28% (full period)

S.Benedetto 87% (started on last January)

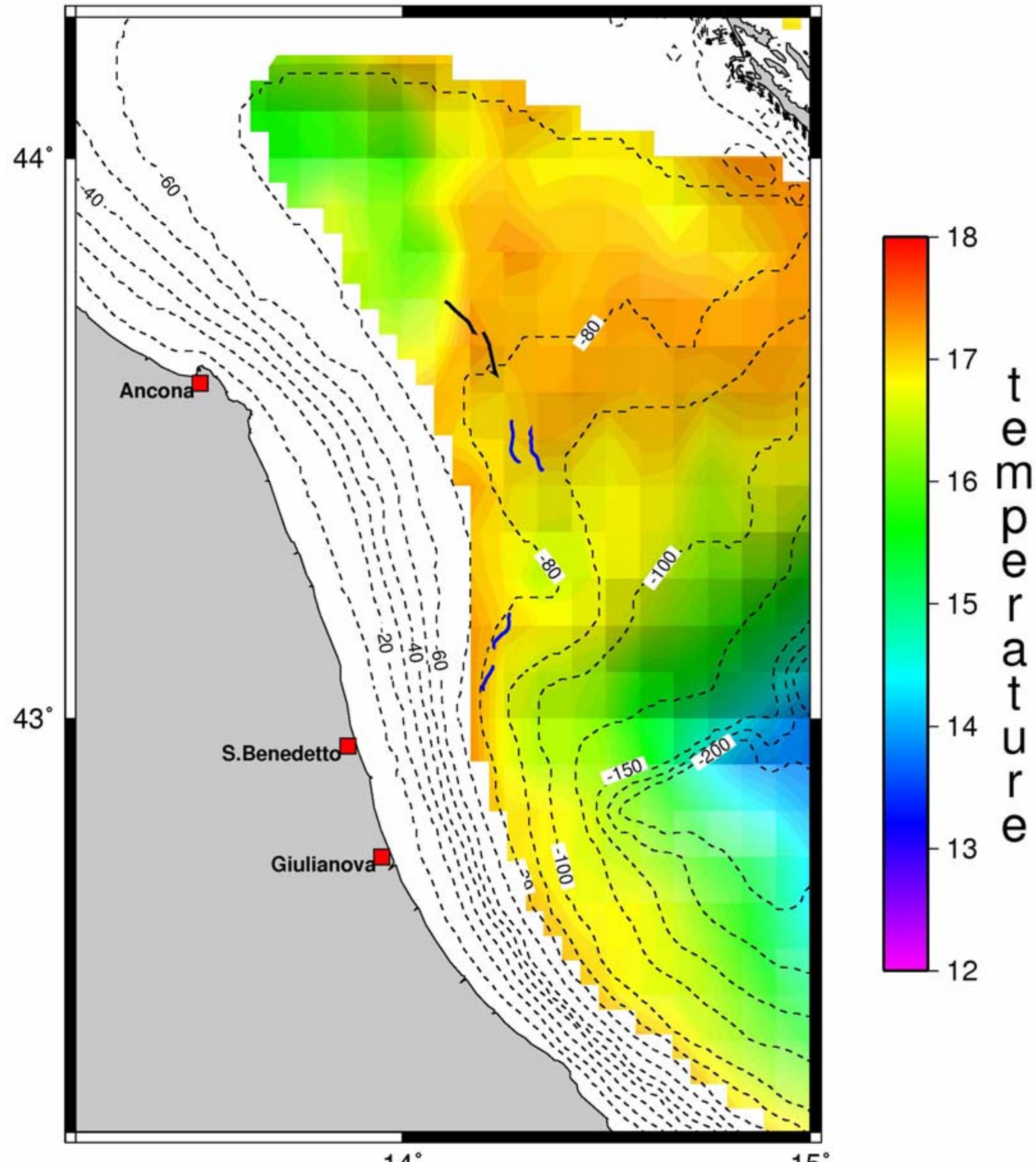
Giulianova 74% (full period)

First correlation between fish size, abundance and temperature distributions

18/11/03
Ancona 500 boxes
(black tracks)

Giulianova 60 boxes
(blue tracks)

SAME SIZE
ANCHOVIES



Conclusions

- Design and implementation of basin scale and coastal marine forecasting system is implemented for the Mediterranean basin and different coastal areas
- Large scale monitoring system need technology improvements and OSSE
- 10 days marine forecasts are getting more and more accurate by amelioration of data assimilation hypothesis
- Progress in ecosystem modeling is fast and accuracy is increasing: predictions could be done on seasonal time scales if external inputs are known
- MFS applications of oil spill monitoring, ICZM and fishery management show promising results

In conclusion

The Mediterranean coastal areas can be saved!
We are worried but optimistic