OVERVIEW OF OCEAN AND SEA ICE MODELLING

by

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Lack of sufficient data collection and thereby general limitation regarding reliable descriptive analyses of the ocean inhibit satisfactory knowledge of the state and variable of the ocean.

In order to advance our understanding, provide forecasts and implement proper management system one need to find a compromise between observation requirements, actual data availability and mathematical model tools. This is also called optimal control problem (theory).

OCEAN AND SEA ICE MODELLING IS CAPITALIZING ON THIS

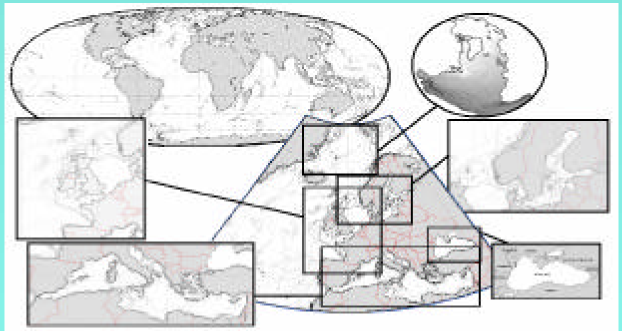
CONTENT

- *Introduction*
- *Typical temporal and spatial scales*
- *Classical models*
- *European Data Assimilation Systems*
- *Need for improvements*
- *References*

Modeling of the marine environment are characterized by:

- *dimensions in physical space (X - t);*
- *number of state variables - hydrodynamic, chemical, bio-geochemical;*
- *vertical coordinate system*
- *surface treatment (rigid lid, free surface)*
- *parameterization of vertical and horizontal diffusion (mixing in local models versus bulk models)*
- *geographical coverage, time period, specific events or processes;*
- *grid type (rectilinear, curvilinear orthogonal, curvilinear non-orthogonal);*
- *numerical method; finite difference (use squares) or finite element (use triangles)*
- *numerical scheme and choice of time descritization; explicit, implicit, semi-implicit*
- *numerical consistent scheme and stable scheme.*

In physical space one can distinguish between local, regional and global models. Within each class the marine system can have distinct length-scales and time-scales. In fact length and time scales are somewhat coupled according to particular phenomenon (i.e. El Nino, tide, storm surges, etc). This constraints the choice of model resolution.



(after MERSEA IP)

The model accuracy (or reliability) depends on the resolution, precisions of the calculations, and quality of the data used to determine parameters and boundary conditions. Models also need accurate bathymetry at the adequate resolution in order to properly account for topographic steering.

The models are commonly forced by atmospheric fields including surface wind vector (wind stress and input of turbulent energy) and fluxes of heat (radiative, sensible and latent) directly taken from atmospheric models.

Time-space characteristics

Time scale	Frequency (s^{-1})	<u>Spectral windows</u> (highlighted processes)	<u>Smaller scale fluctations</u> (filtered out processes)
1 s	1	<u>Microscale processes</u> 3 D ”eddy ” turbulence (+ surface waves)	Molecular diffusion
1 m			
	10^{-2}	<u>Mesialscale processes</u> Internal waves Vertical microstructure Inhibited “bliny”* turbulence	Eddy turbulence
1 h			
	10^{-4}	<u>Mesoscale processes</u> Inertial oscillations	“Bliny turbulence”
1 d			
	10^{-5}	Tides, storm surges Diurnal variations	

Time-space characteristics

Time scale	Frequency (s^{-1})	Spectral windows (highlighted processes)	Smaller scale fluctations (filtered out processes)
1 w			
	10^{-6}	Synoptic scale processes Frontal currents Meanders, "rossby"* turbulence	Mesoscale variability
1 month			
	10^{-7}	Seasonal scale processes	"Rossby turbulence"
1 year			
	10^{-8}	Global scale processes Climatic processes (Paleo) climatic scale processes	Seasonal variability

Model dimensions in space and time

- 1 D; simple model chosen to simulate vertical structure, mixed layer dynamics including importance of turbulent mixing

- 2 D; depth integrated barotropic models (constant density in space/time are common for tides and storm surges modelling, and shallow water modelling

- 3 D; depth resolving baroclinic models for variable vertical density

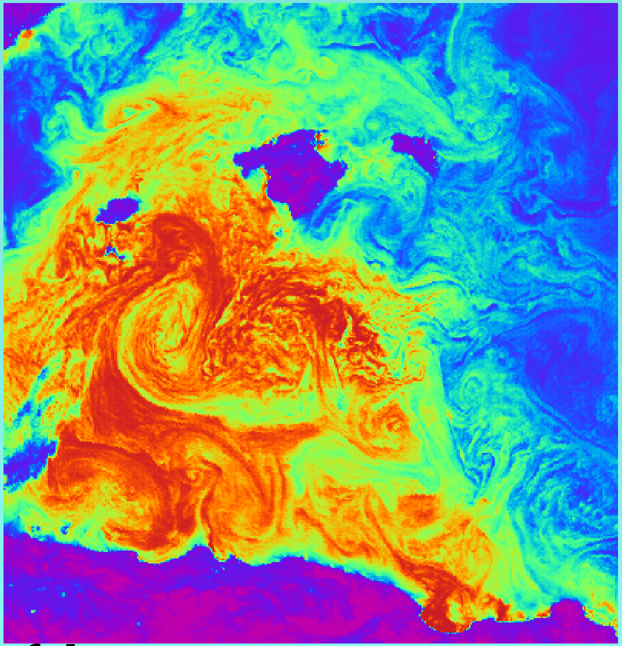
Discretization of the continuity equation and equation of motion

$?r/?t + \nabla \cdot r\,\underline{u} = 0$ ***continuity equation***

$d\underline{u}/dt = -\,1/r \cdot \nabla p - 2\underline{W} \times \underline{u} + \underline{g} + \underline{F}$ ***momentum equation***

pressure Coriolis gravity other forces (friction, tides,..)

Some fundamental hydrodynamic quantities



- Rossby radius of deformation;

$$R_d = (g\, h\, \Delta\rho/\rho)^{1/2} / f$$

typical horizontal scale of the weather in the ocean; defines the length scale at which rotation effects (scaled by Coriolis parameter f) become as important as buoyancy effects determined by $\Delta\rho/\rho$

- Brunt-Vaisala frequency N; the measure of the stratification or vertical gradient in density (buoyancy)

$$N^2 = g\,(-\,\rho\; d\rho/dz)$$

choice of vertical coordinate system

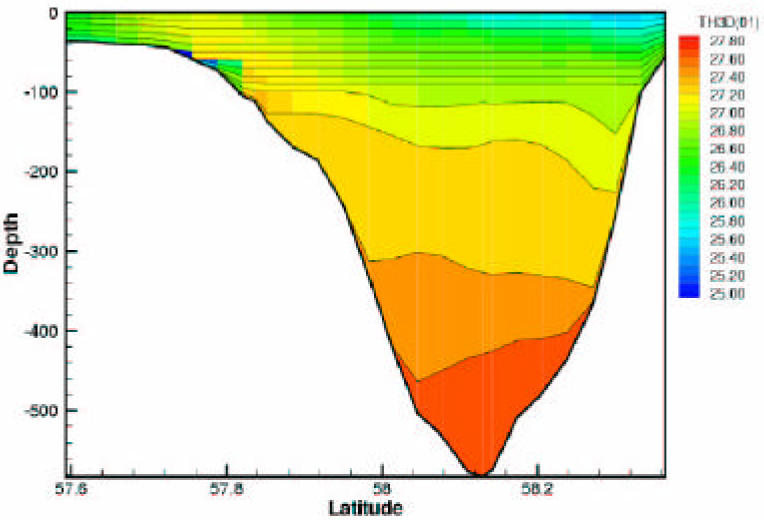
- z level; discretization in the vertical at fixed depth values - level models

- isopycnal; a fixed number of layers with constant density

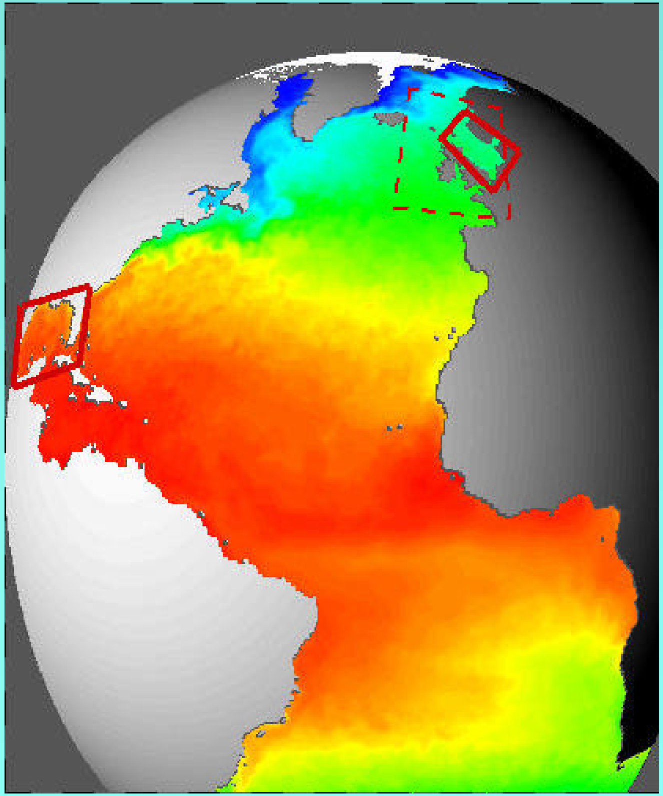
- sigma; a bathymetry following coordinate system in shallow water

LAYER MODELS

HYCOM: Hybrid coordinate ocean model (Bleck et al., 2002)-Combines all 3 coordinate systems; z-level for mixed layer representation, isopycnic for the interior ocean density, sigma for shallow water terrain following coordinates.

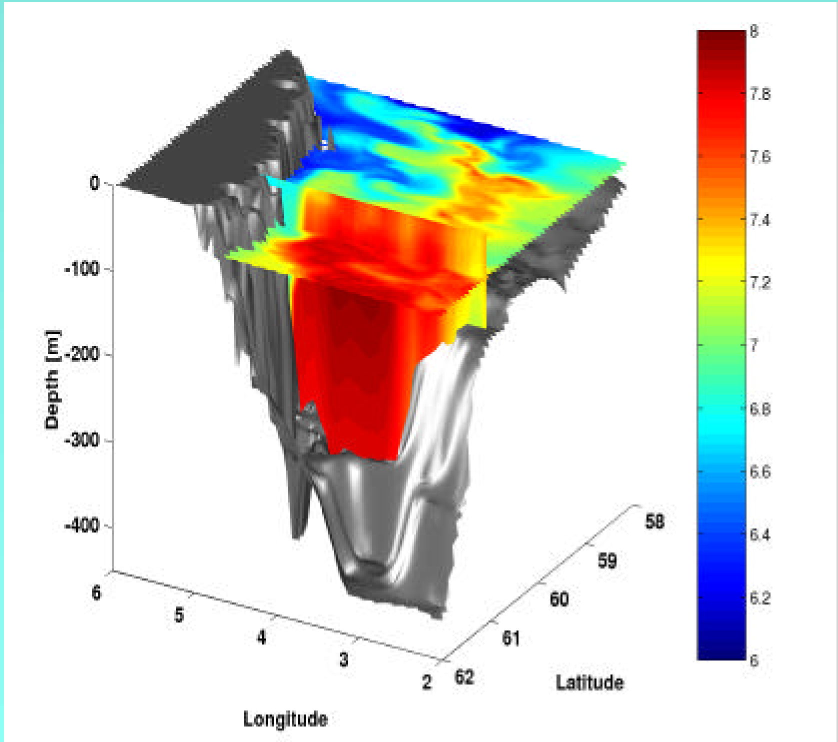


OCEAN MODELLING



Models run at a global to basin scale are used to represent circulation of large oceanic water masses, whereas at a 'nested' regional or local scale with higher spatial resolution they provide finer detail, for example where eddy resolution is required. A nested model means that a high resolution regional model receives boundary conditions from an outer model with lower resolution. In this way one can insure proper representation of the general circulation into the regional area.

OCEAN MODELLING



Ocean characteristics such as temperature, salinity and current velocity can be estimated in space and time by computer model simulation across a numerical ocean model grid. This means that one can get a fully 3-dimensional image of the ocean. Models can operate in hindcast mode to simulate historical time series of past conditions, and also in nowcast and forecast mode for operational applications.

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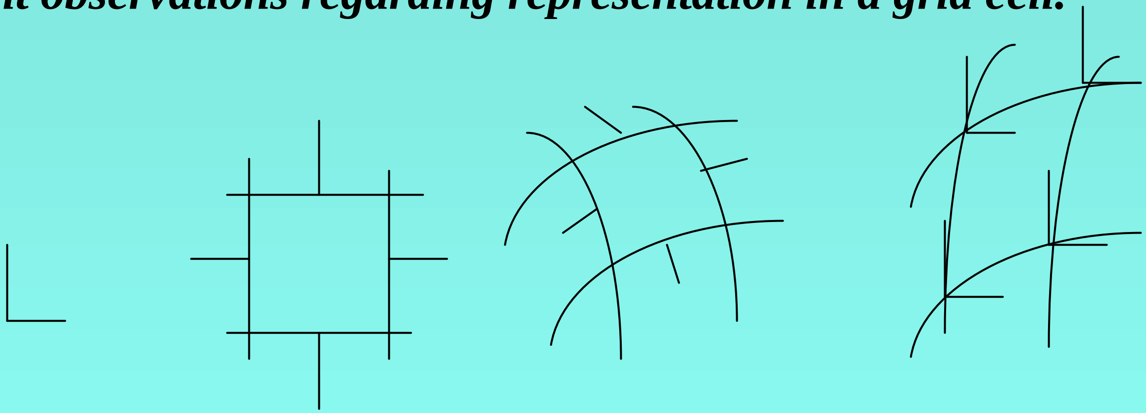
Grid Type

Satellite observations are usually slightly more favorable then in-situ point observations regarding representation in a grid cell.

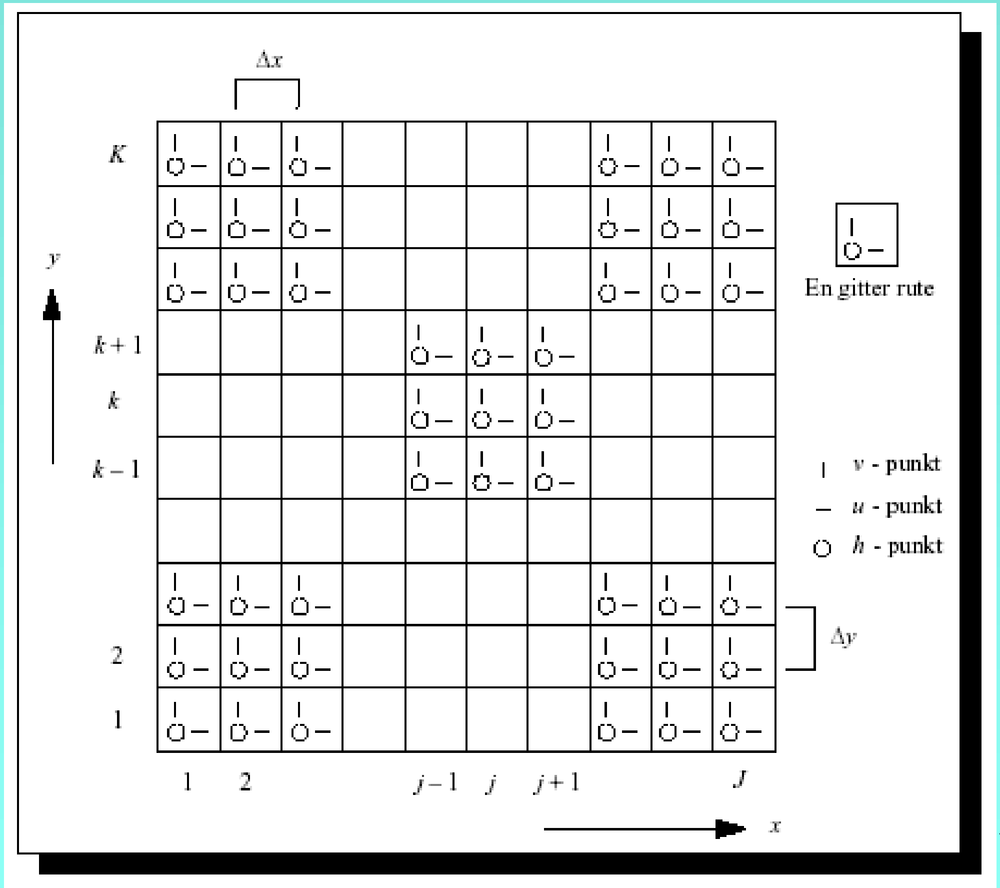


Rectilinear or Spherical (RS)

Curvilinear Orthogonal (CO)

Curvilinear Non-orthogonal (NO)

Example of Arakawa C-grid



h: pressure, temperature, salinity, sea level

u: x-velocity

v: y-velocity

This is a so-called staggered grid with one grid-interval between variables h, u, v but where the latter two are shifted half a grid interval from h.

Ease the computations of pressure gradient cont. to velocity field.

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Explicit scheme - only expressions at earlier time step n at right hand si

$$\frac{u_j^{n+1} - u_j^n}{\Delta t} = \kappa \frac{u_{j-1}^n - 2u_j^n + u_{j+1}^n}{\Delta x^2} \quad , \quad j = 2(1)J \quad , \quad n = 0(1)N$$

Implicit scheme - time step n+1 also at right hand side

$$u_j^{n+1} = u_j^{n-1} + \kappa \frac{2\Delta t}{\Delta x^2}(u_{j-1}^{n+1} - 2u_j^{n+1} + u_{j+1}^{n+1}) \; ; \quad j = 2(1)J \quad , \quad n = 0(1)\ldots$$

Semi -implicit scheme - combines explicit and implicit schemes

SOME CLASSICAL OCEAN MODELS

Authors	Identifier	Vertical Grid	Horizontal Grid	Vertical Diffusivity	Horizontal Diffusivity	Surface	System
Blumburg-Mellor	POM	σ - C	CO/C	TC or CVD	Smag or CHD	Free	
Bryan-Cox-Semtner	BCS	z - C	RS/B	RND/CA[1]	CHD	rigid	FOAM
Haidvogel	SPEM	σ - C/ Spect	CO/C	BML	BiH	rigid	
R. Bleck et al.	MICOM	Iso-pycnic	CO	Bulk mixed layer	CHD	free	
Oberhuber	OBH	ρ - C	RS/B	BML	Smag	free	MICOM
R. Bleck	HYCOM	hybrid		KPP		free	TOPAZ
G. Madec	OPA	Z - C		TKE closure		rigid	MERCATOR

Four european ocean data assimilation system

MERCATOR FR	OPA -Z coord./Rigid Lid -Simple thermo. ice model -SPIN UP 15days -TKE	-horiz. 1/15° (5-7km) 43 levels -Atl+Med from 10 to 70°N. -Relaxation to Medatlas (T,S) in Gulf of Cadiz below 500m	-Daily ECMWF forcing -Relaxation to Reynolds SST and Reynaud SSS -Monthly river runoff -Data assimilation stopped at depth 500m	-OI SOFA -SLA along track (Jason1,ERS2/Envisat,GFO) once a week -MSSH from Rio et al.(data) in the Atlantic and blend of previous runs in MED	ATL MED
TOPAZ NO	HYCOM -Hybrid coord/Free surface -dyn./thermodynanic sea ice -SPIN UP 20years -KPP mixing	-horiz. 20 to 30km 22 hybrid layers -Artic+Attlantic till 40°S. Closed boundary without relaxation. No med basin.	-6 hourly ECMWF forcing (Bulk formulae momentum&heat) -Precip Clim+ Relaxation to Levitus SSS(60days) -No river runoff -Data assimilation stopped at depth 300m	-EnKF -SLA Maps(SALTO-DUACS) once a week -SST from CLS AVHRR data once a week -Maps of ice concentration -MSSH from OCCAM run	ATL
FOAM UK	HADLEY CENTRE -Z coord./Rigid Lid -dyn./thermodynamic sea ice -SPIN UP 5months -Kraus-Turner	-horiz. 1/9° (12km) 20 levels -Atl+Med from 10 to 70°N. -No relaxation to Med Water	-6 Hourly NWP-MetOffice forcing -Weak relaxation to Levitus SST and SSS. -No river runoff -Data assimilation stopped at depth 300m	-OI Cooper&Haines -SLA along track (Jason1,GFO;Envisat) -SST 2.5° gridded (ARGO)Once a day. -T+S profiles at all depths -gridded ice concentration -MSSH from previous run	ATL MED
MFS IT	MOM -Z coord./Rigid Lid -no ice model -SPIN UP:7years -cst vertical mixing+vertical adjustment	-horiz. 1/8° 31 levels - Med only -Transport through Gibraltar parameterized	-6 Hourly ECMWF forcing (Bulk formulae momentum & heat) -relaxation to satellite night time SST and SSS climato -No river runoff -Data assimilation stopped at depth 1000m	-OI SOFA -SLA along track (SALTO-DUACS) once a week -1/8°1/8 ° SST analysis mean maps once a week -T profiles to 500m -MSSH from previous run with 1993-99 forcing.	MED

Zonal Section 26 ?N Salinity

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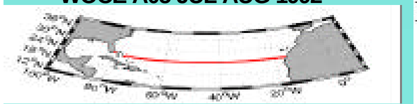

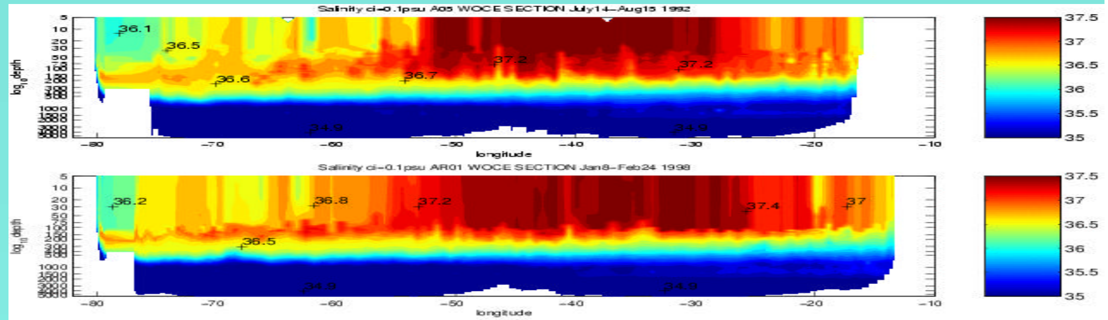

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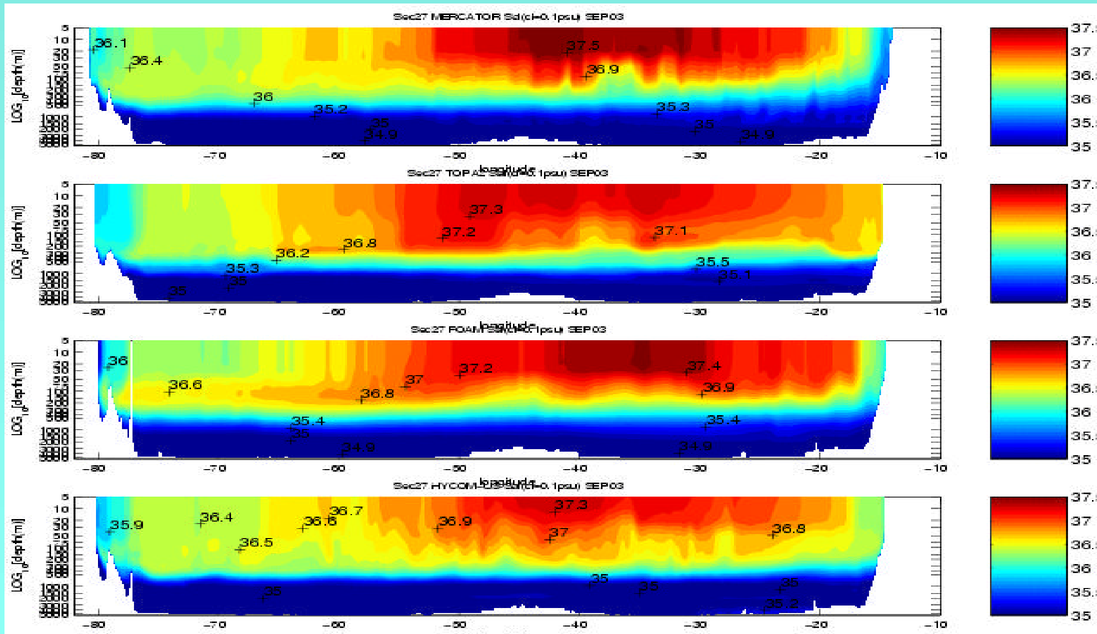

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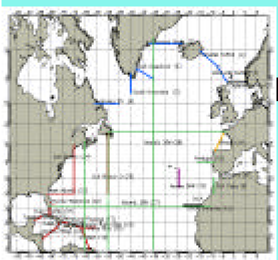

FOAM

HYCOM

IMPACT OF ASSIMILATION OF ARGO SALINITY PROFILE

Class2 Zonal Section 26°N Salinity

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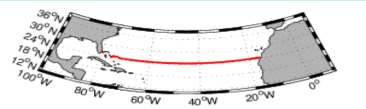
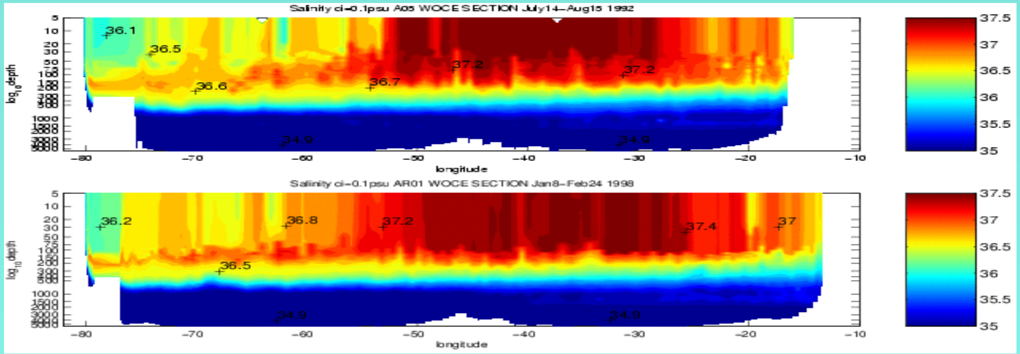
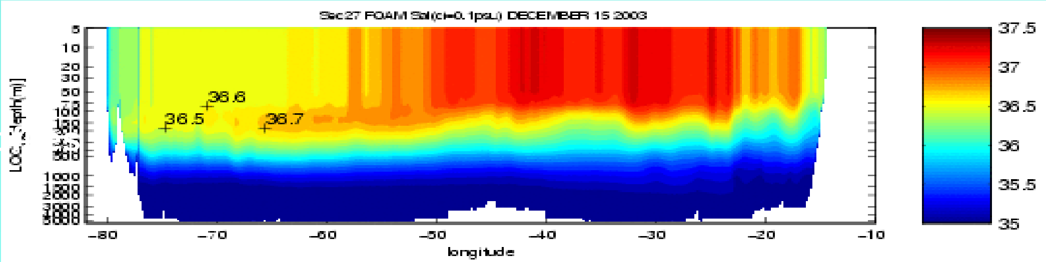


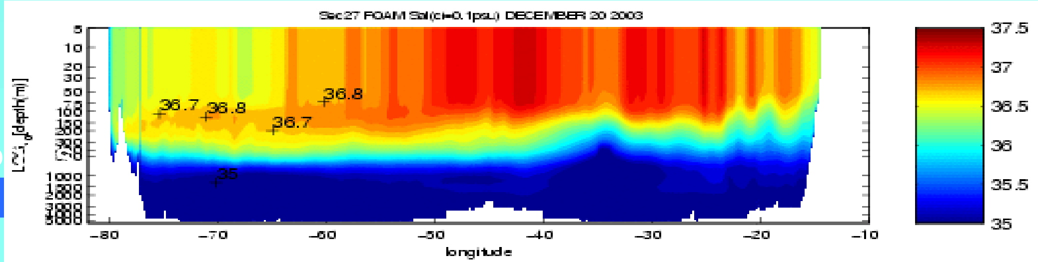


FOAM (DEC15 2003)
Before assimilation
of ARGO salinity pro



assimilation of ARGO salinity profiles from DEC17 2003 on

FOAM (DEC20 2003)
After assimilation
of ARGO salinity pro



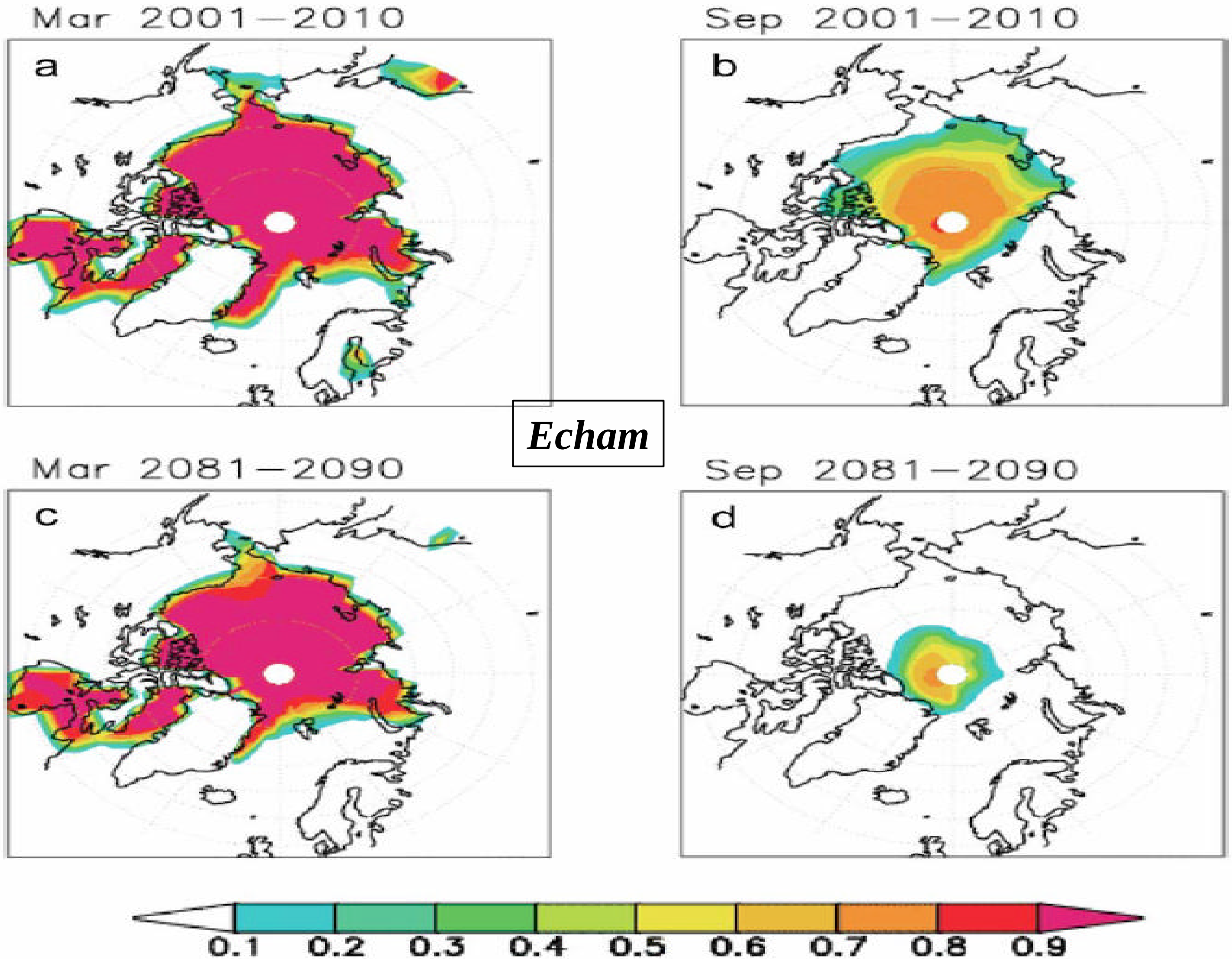
IERSC/lhp

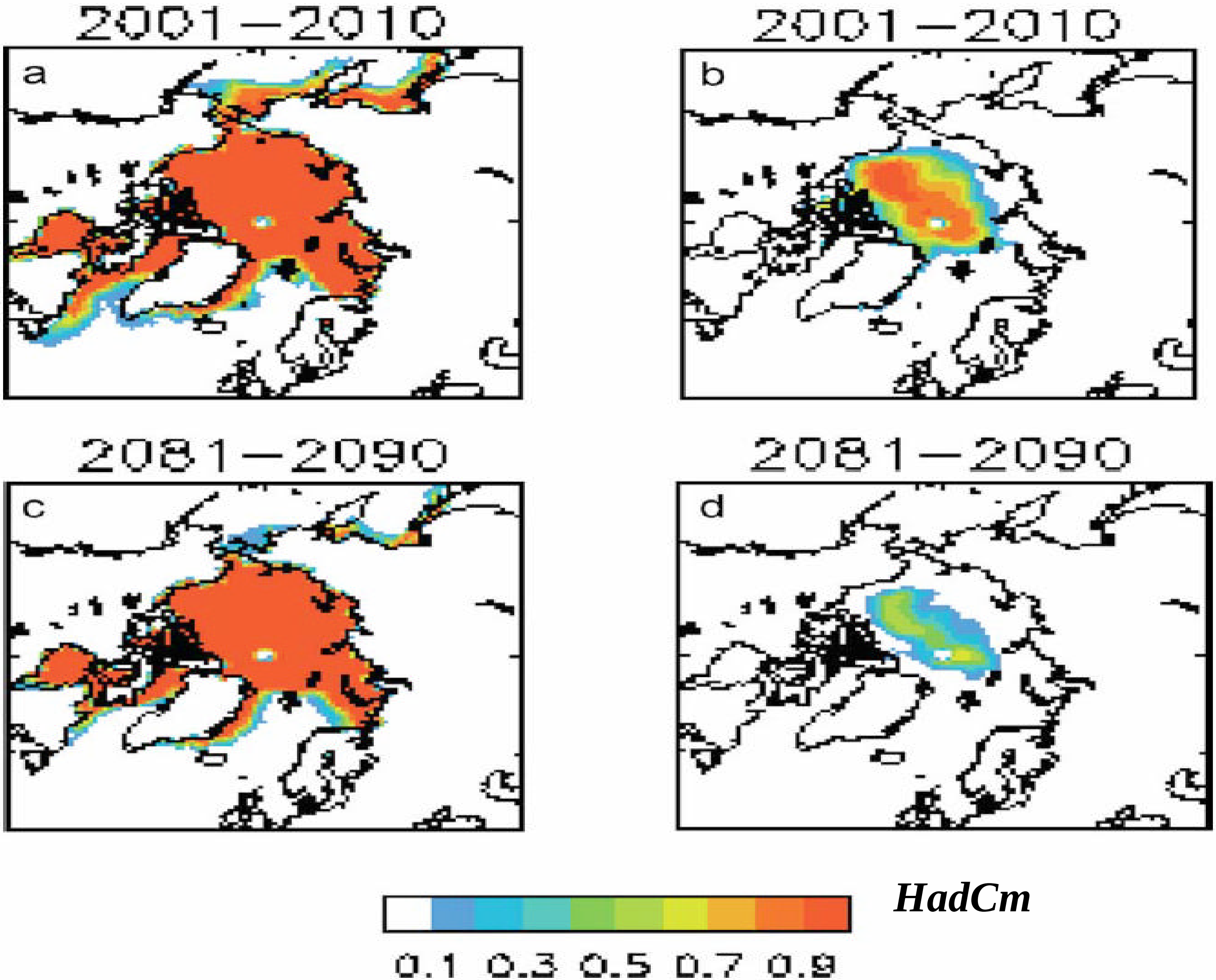
Ice models characteristics

- *define the ice concentration variable A as the fractional ice cover; i.e.* $0 < A < 1$*;*
- *h is the local ice thickness and* h_I *is the average thickness over the ice covered region;*
- *ice thickness distribution g(h);*
- *<u>slab models</u> - the vertical structure in the ice is neglected;*
- *ice rheology that parameterize internal ice stresses (plastic, elastic, viscos, pev, ev, pe);*
- *fluxes - melt rate on top, freeze rate at ice-ocean interface, freeze rate in open water, rate of frazil ice growth in water column;*
- *snow-sea ice system - strong effect on albedo*

COURTECY KWOK

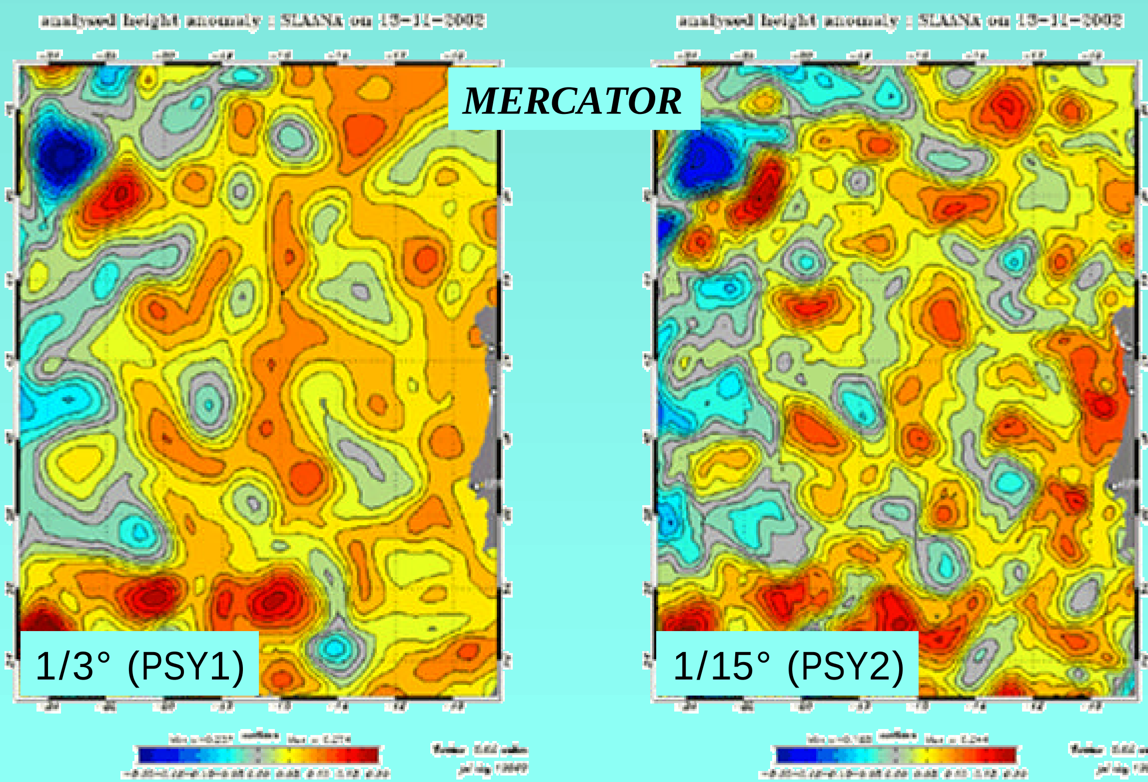
QuickTime™ og en
GIF-dekomprimerer
kreves for å se dette bildet.


Mar 2001–2010
a
Sep 2001–2010
b
Echam
Mar 2081–2090
c
Sep 2081–2090
d
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9


2001–2010
a
2001–2010
b
2081–2090
c
2081–2090
d
0.1 0.3 0.5 0.7 0.9
HadCm

Need for improvement

-Model resolution; enhanced resolution in the vertical and horizontal to obtain reliable simulations - global model at 10 km combined with nesting;

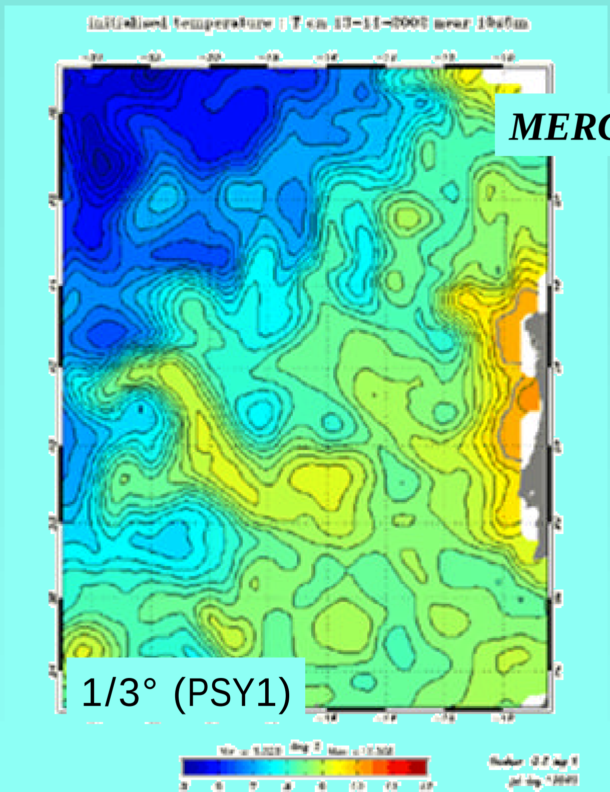


SLA

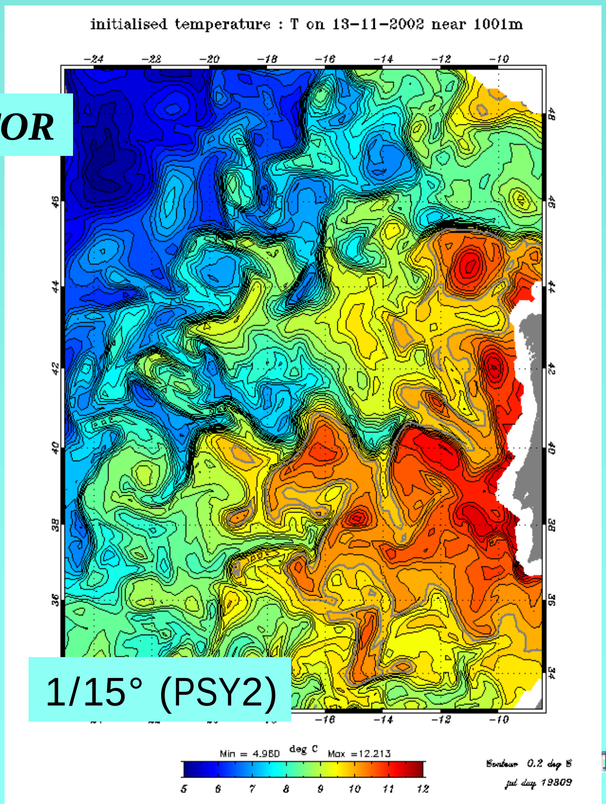
Need for improvement (cont.)

-Model resolution; ***enhanced resolution in the vertical and horizontal to obtain reliable simulations - global model at 10 km combined with nesting;***

MERCATOR



1/3° (PSY1)

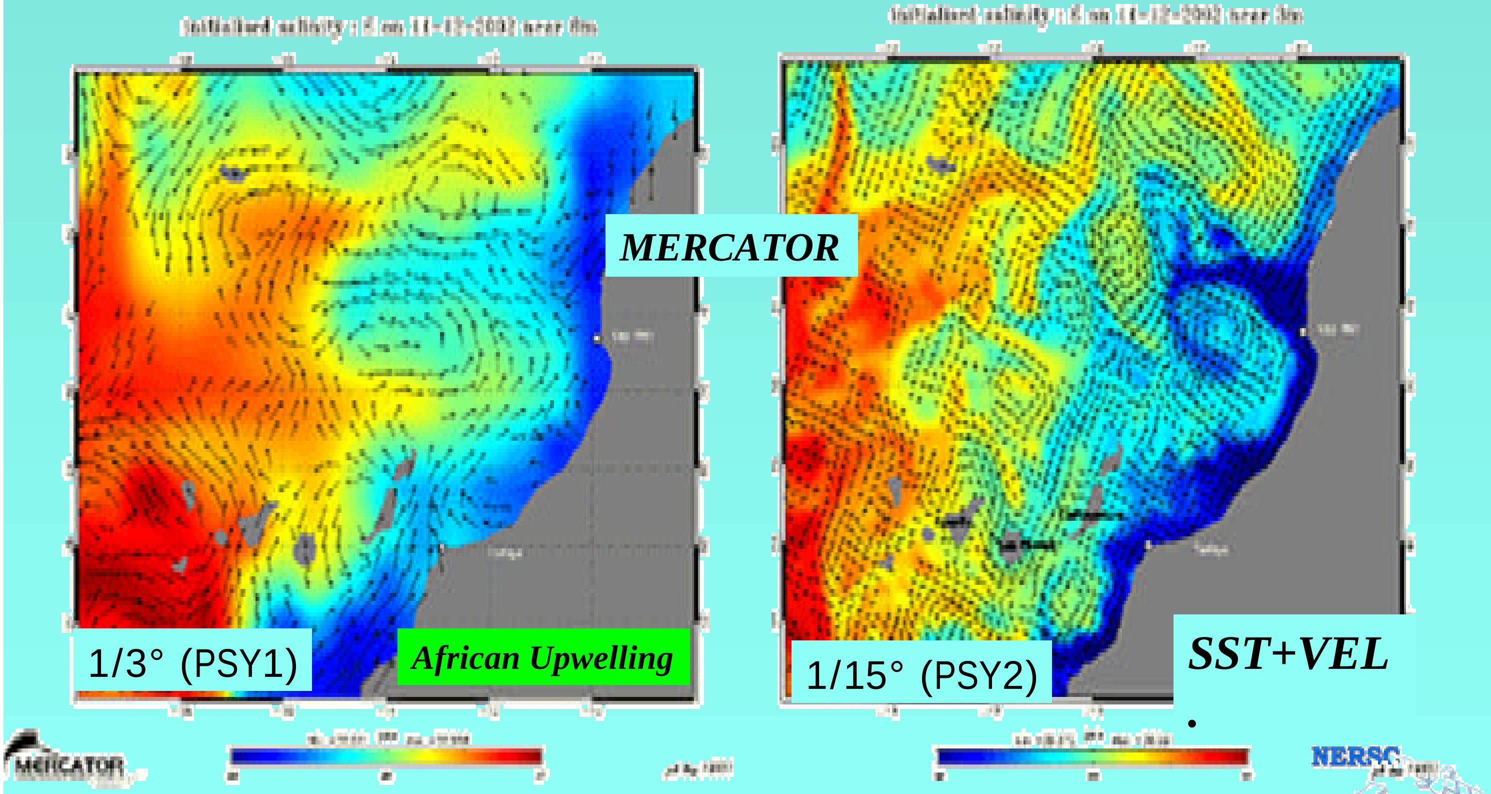


1/15° (PSY2)

SST

Need for improvement (cont.)

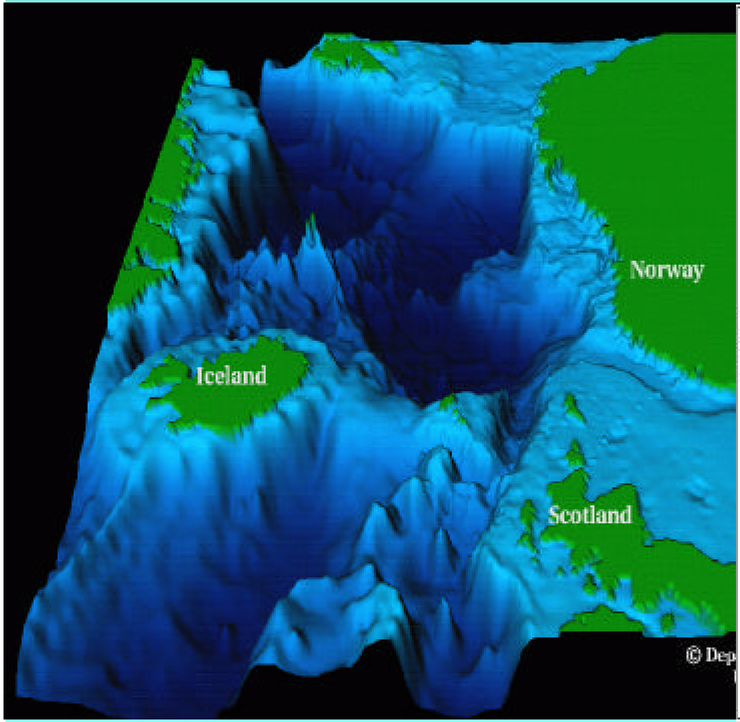
-Model resolution; ***enhanced resolution in the vertical and horizontal to obtain reliable simulations - global model at 10 km combined with nesting;***

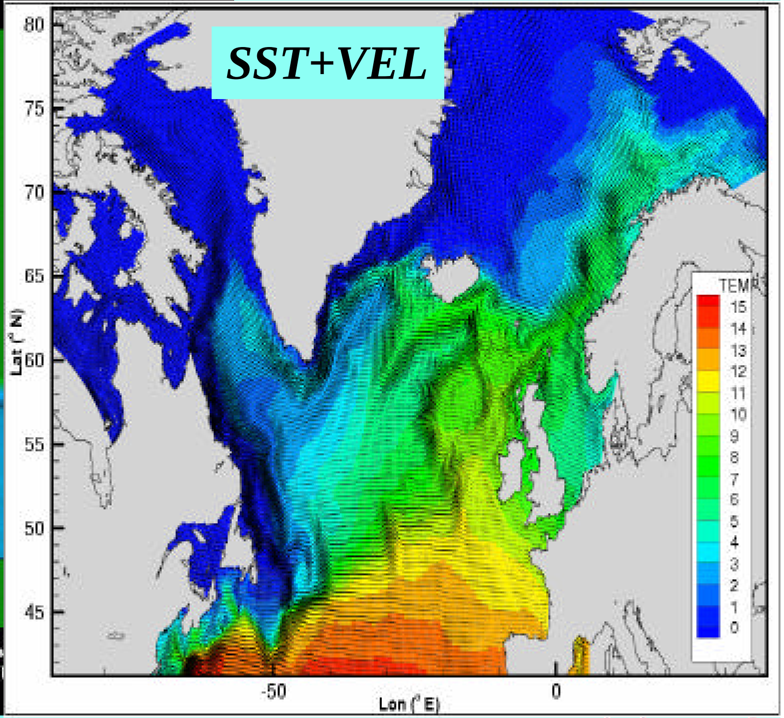


Need for improvement (cont.)

-Topography; ***Improved representation of topographic slopes is critical for simulations of mean and time-varying circulation;***

MICOM





Need for improvement *(cont.)*

- Boundary layer representation; ***both surface mixed layers and benthic layers near the bottom need to be better simulated***

- Coupling to ice models; ***ice models are essential for simulation of horizontal and vertical freshwater fluxes***

- Mixing processes; ***mixing across isopycnals need better parameterization***

- Surface fluxes; ***the ocean is driven primarily through a combination of buoyancy and momentum fluxes so reliable estimates of surface fluxes of heat, freshwater and momentum***

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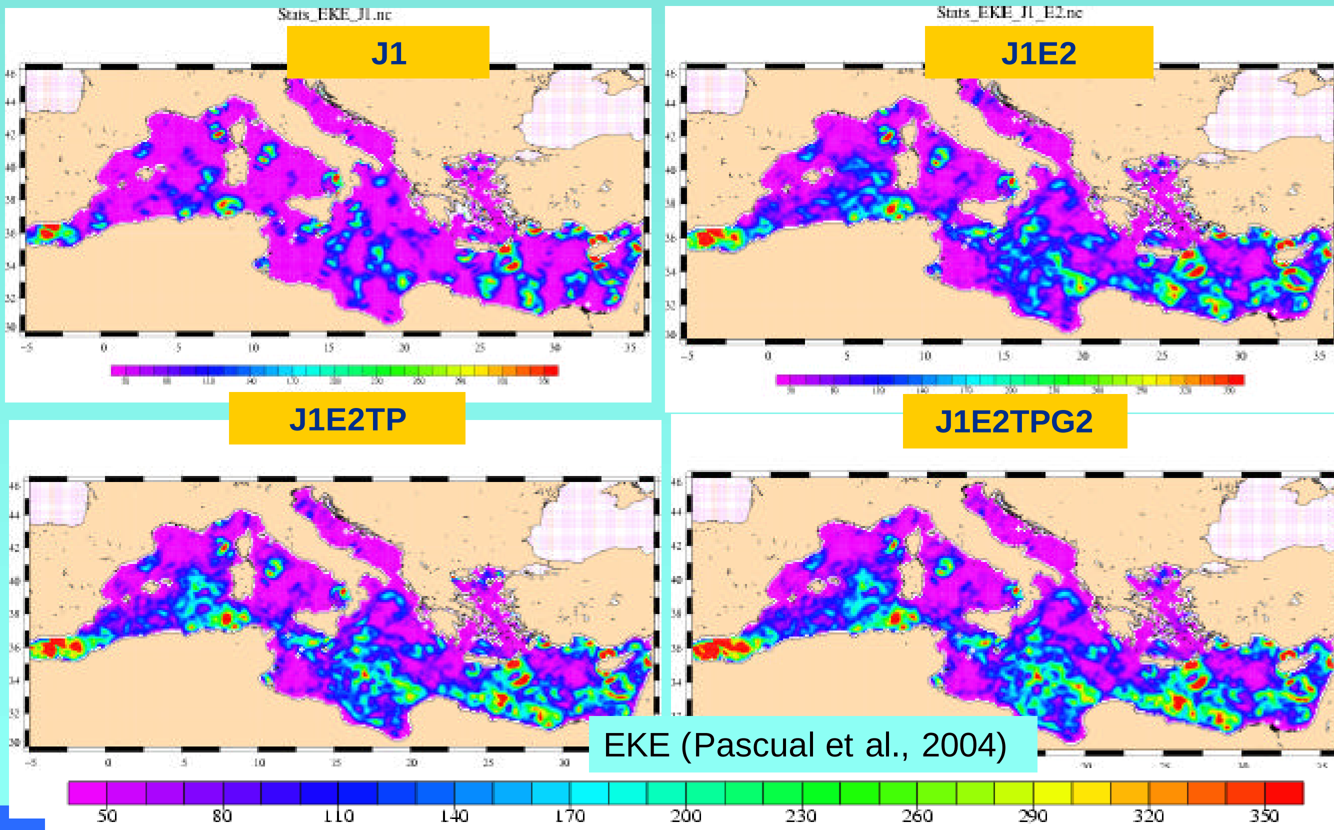
Need for improvement (cont.)

- Advance and secure the observing system; integrated observations are needed to provide reliable description of the interior ocean state and to constrain (validate) models.



RECOMMENDED LITTERATURE

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