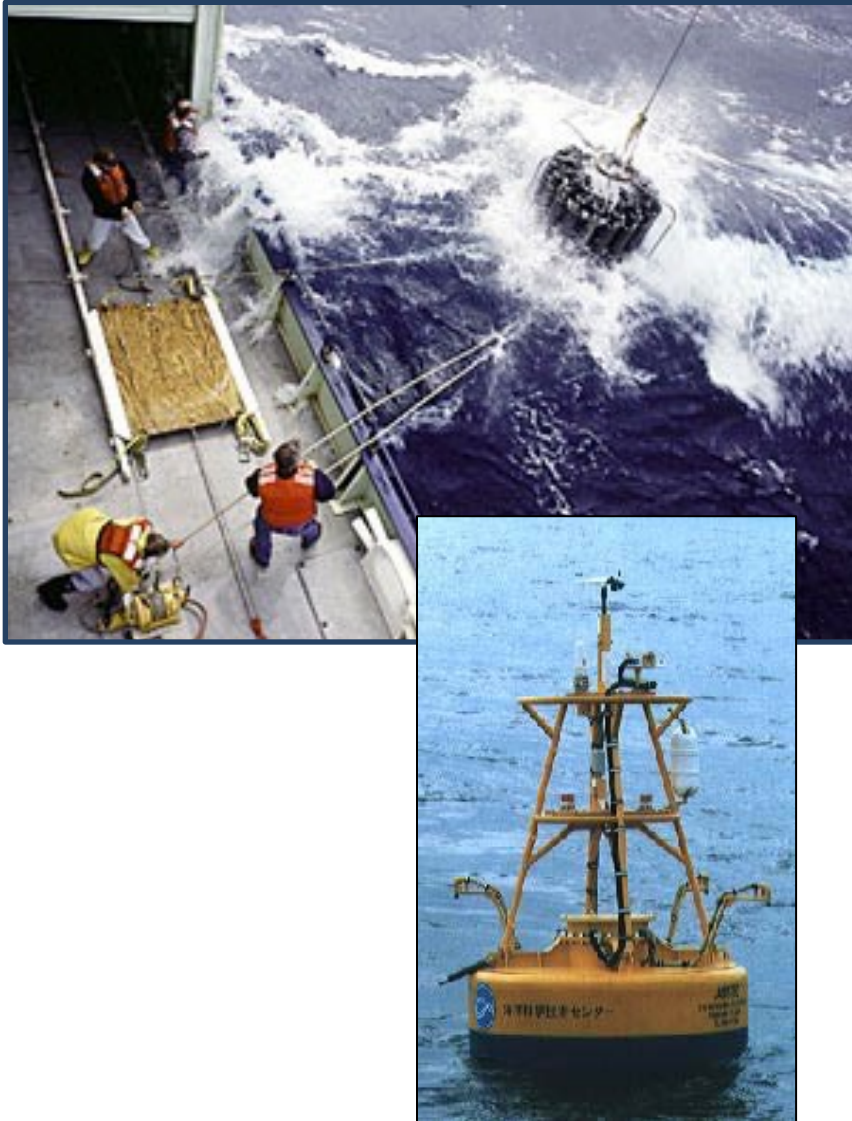


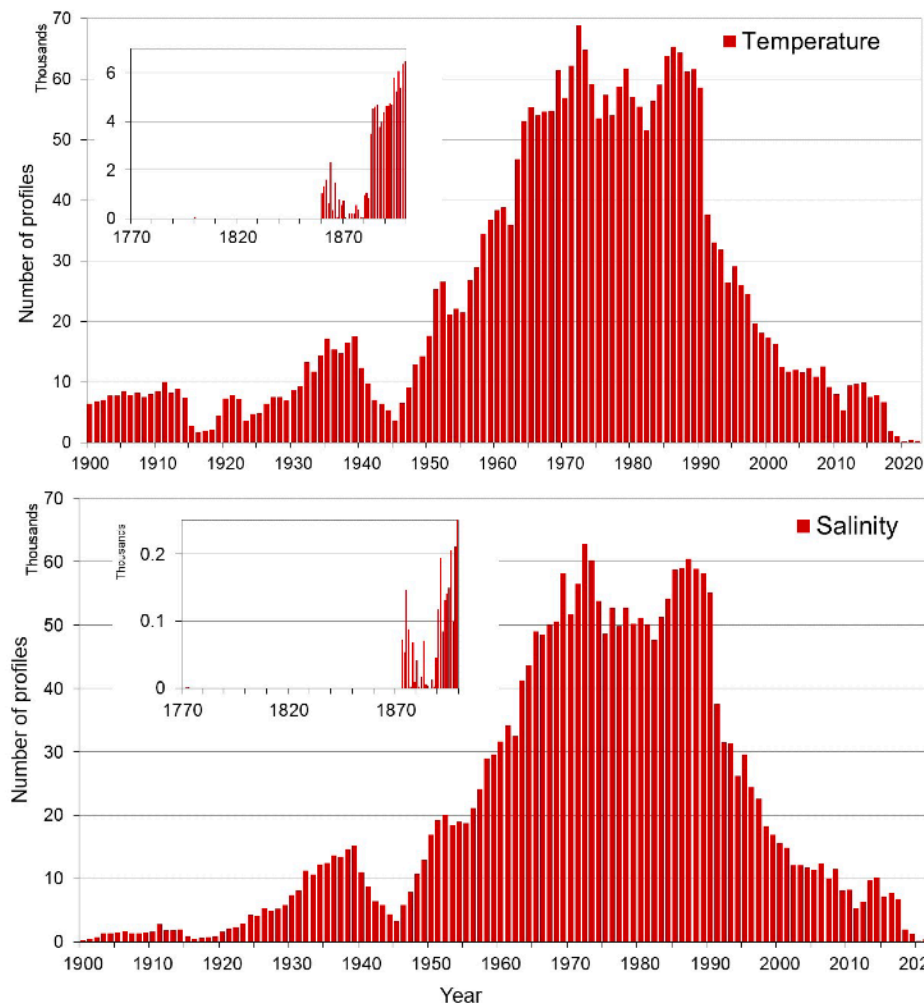


2. Μέθοδοι παρατήρησης και πρόγνωσης στη Φυσική Ωκεανογραφία

2. Observing and Forecasting methods in Physical Oceanography

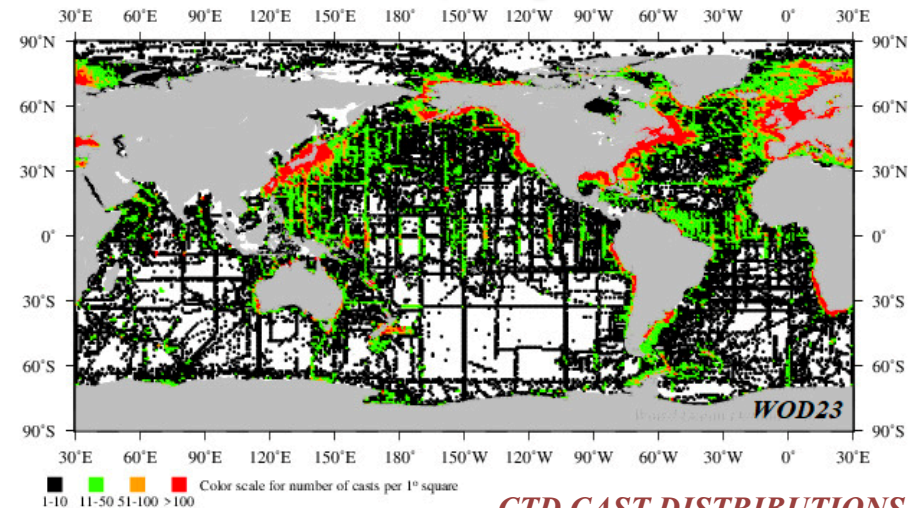
- a. Πλατφόρμες παρατήρησης - Basic observational platforms
- b. Ωκεανογραφικά Όργανα - Oceanographic instrumentation
 - Hydrography
 - Dynamic parameters
- c. Ωκεανογραφικά Μοντέλα - Ocean Modeling





DEFINING THE PROBLEM:

- Observations of the oceanic properties are costly and difficult to acquire.
- Spatio-temporal coverage is the main problem in oceanographic observations (compared to other



CTD CAST DISTRIBUTIONS

In order to overcome the problem, oceanographic observations aim at:

- “Cheaper” observing methods (get as much data as possible covering large spatial and temporal scales)
- Multi-instruments/multi-platforms
- Emphasis on the observing methodologies/strategies
- Combinations

Investigating a scientific question in the ocean:

Platforms/instruments	
Platforms	a. Research vessels (R/V) b. Ships of opportunity (SOOP) c. Moorings d. Lagrangian instruments e. Satellites
Hydrography	a. CTD b. Nansen και Niskin bottles c. Thermosalinograph d. Satellite SST (and SSS)
Dynamical observations	a. Current meters b. Pressure gauges - Wave measurements c. Lagrangian instruments d. Altimetry

Platforms (how do we observe the ocean?)

Instruments (what do we observe in the ocean?)

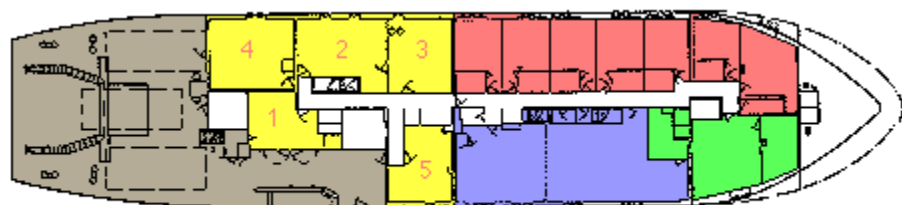


h vessels (R/V)

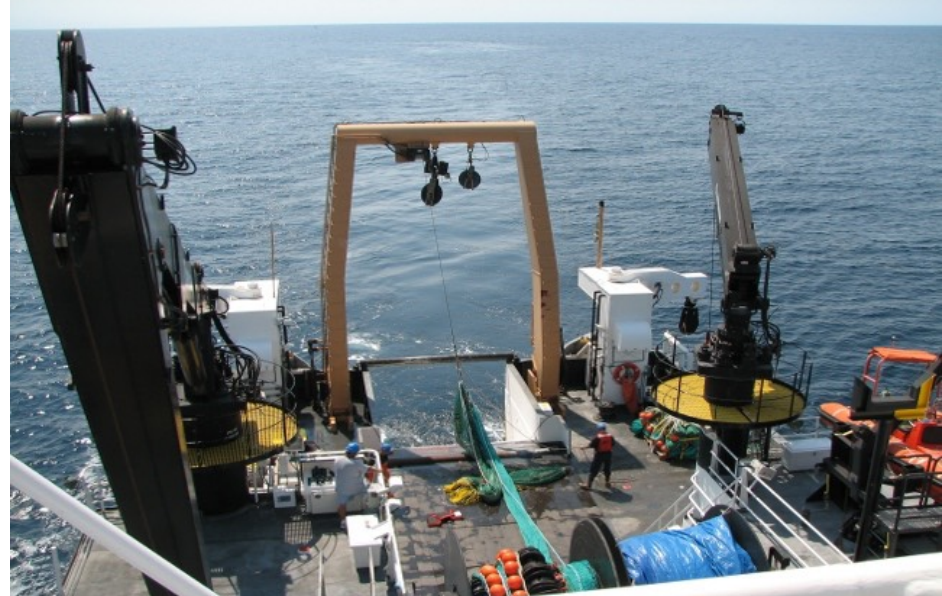




Research vessels (R/V)



working deck laboratories accommodation mess/recreation pantry/galley

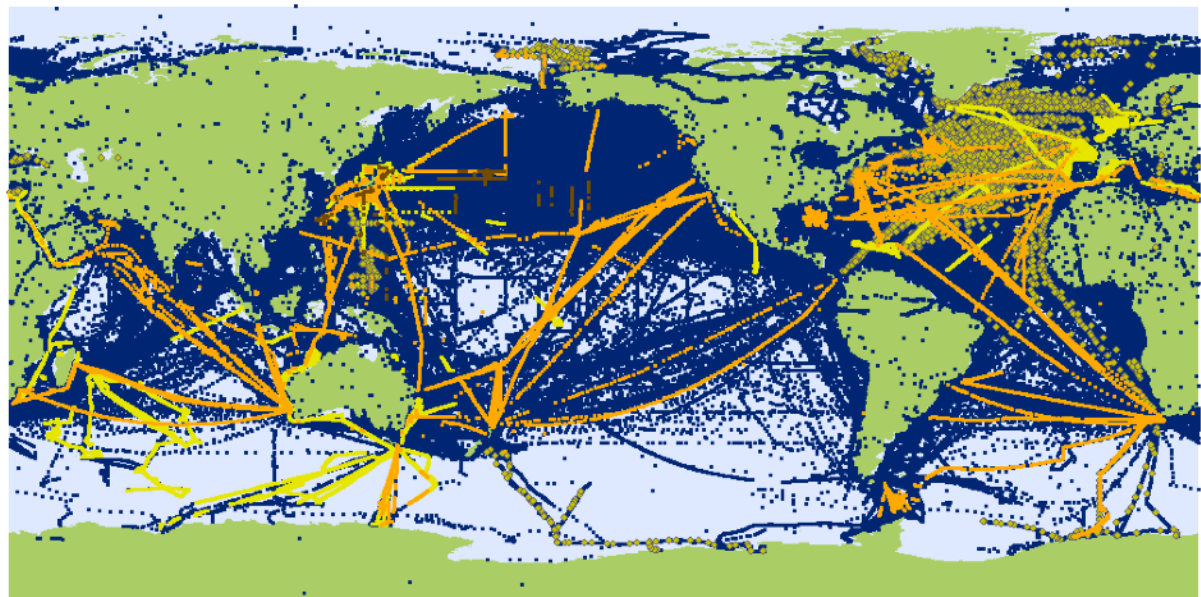
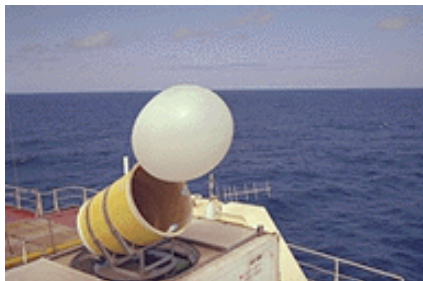








tunity (SOOPs)

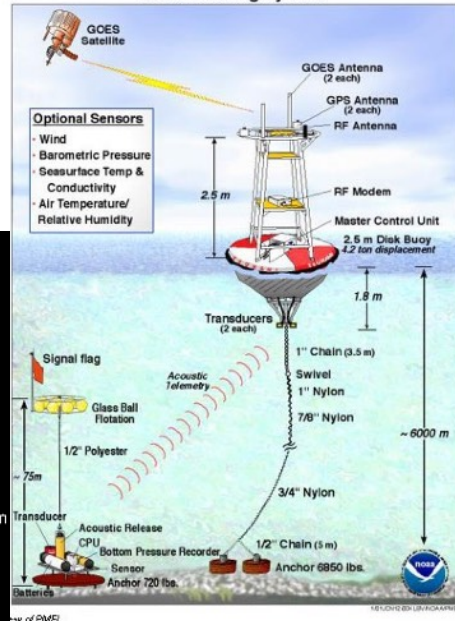
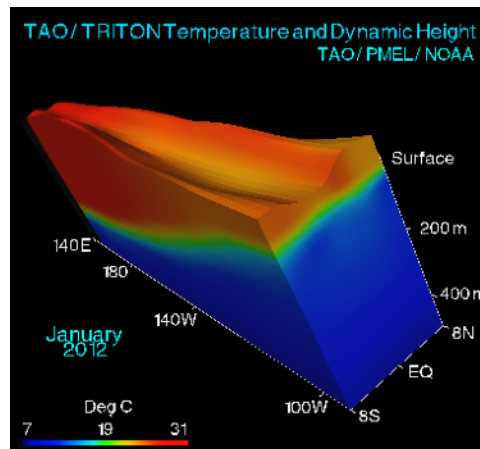
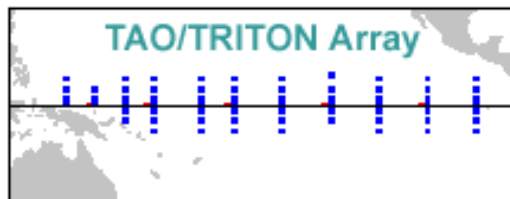


Ship Observation Team

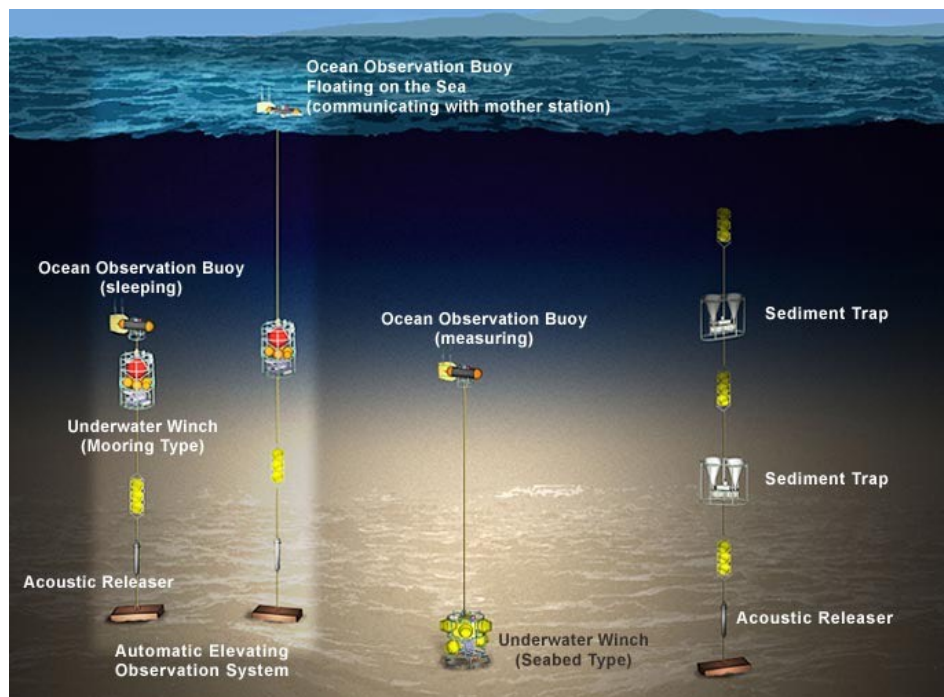
• VOS • ASAP • XBT • TSG • XCTD

2010

jcommOps
JOIM In-situ Observing Platform Support Centre



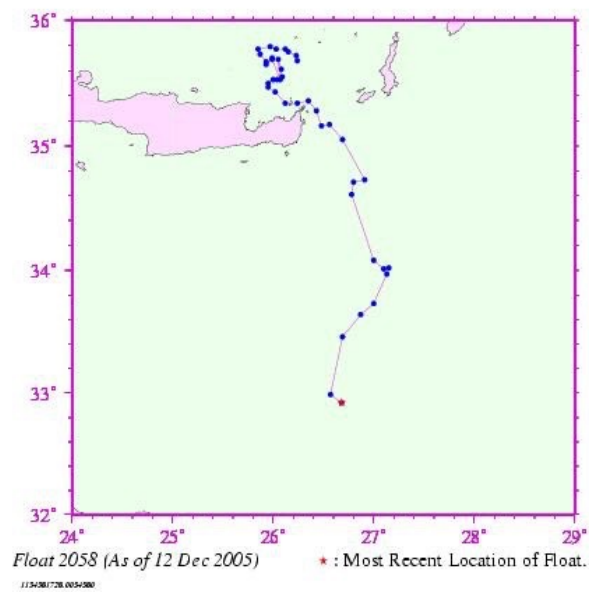
Moorings (the Eulerian approach)



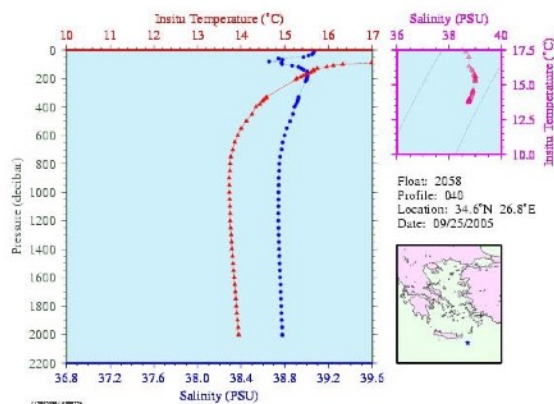
Glider



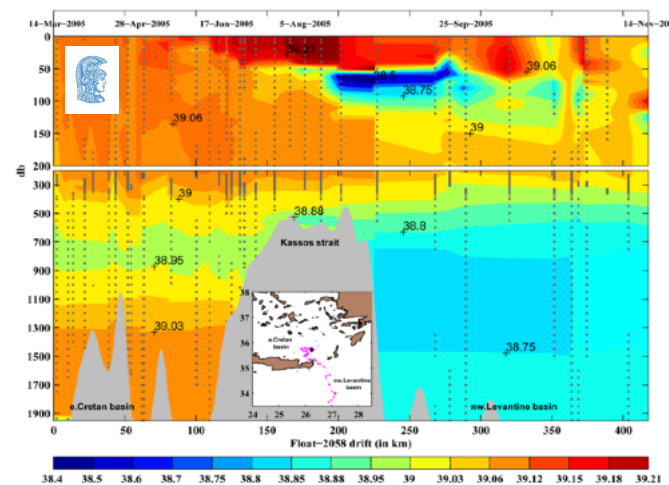
Drifting instruments (the Lagrangian approach)



(Profiling) Float

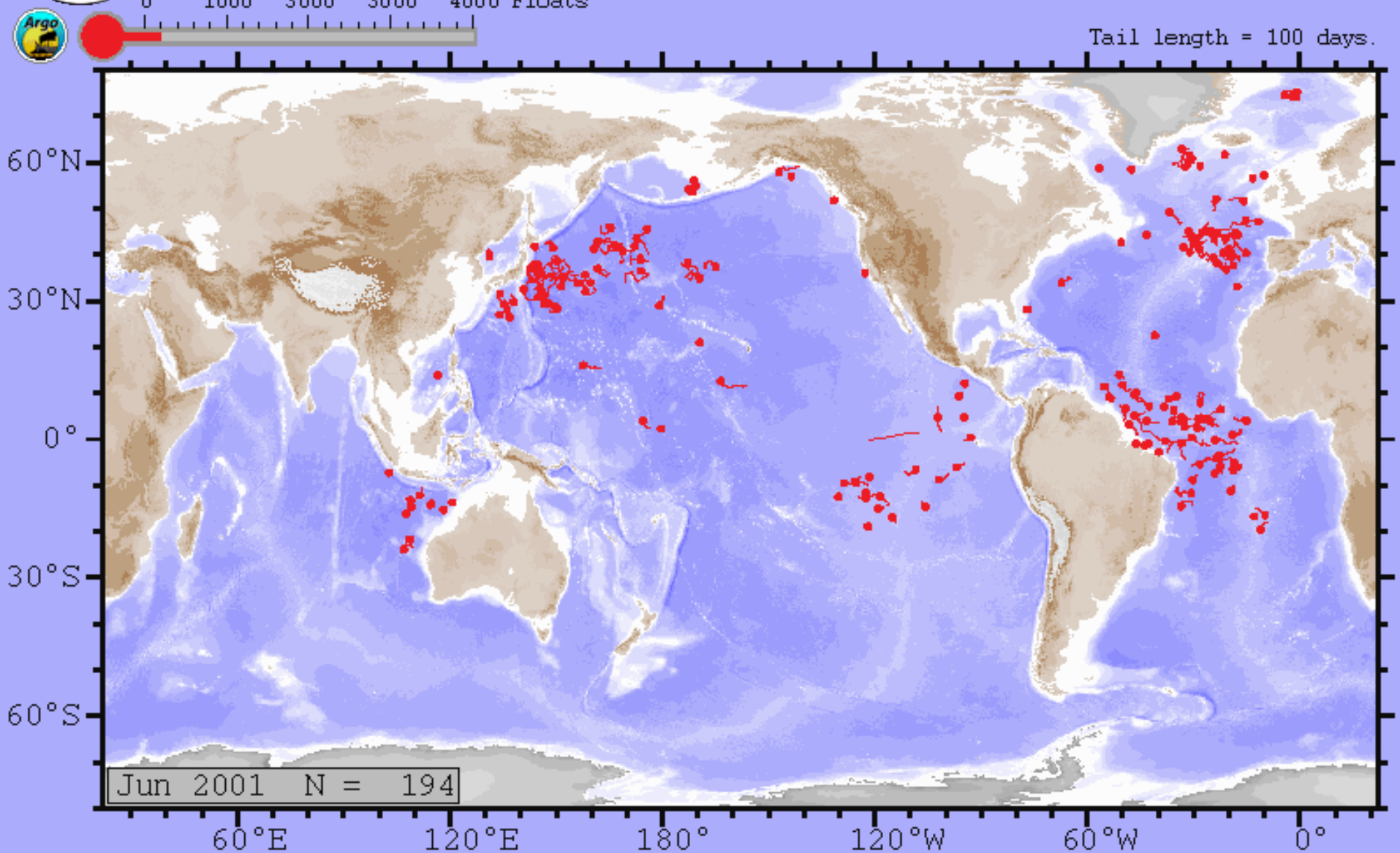


Drifter



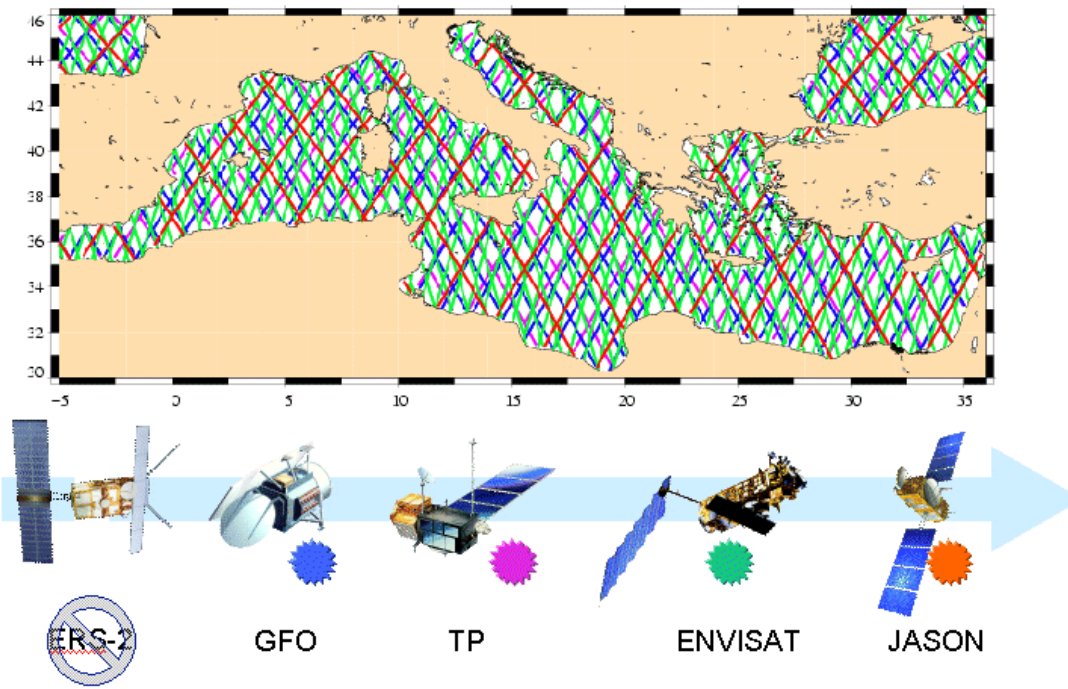
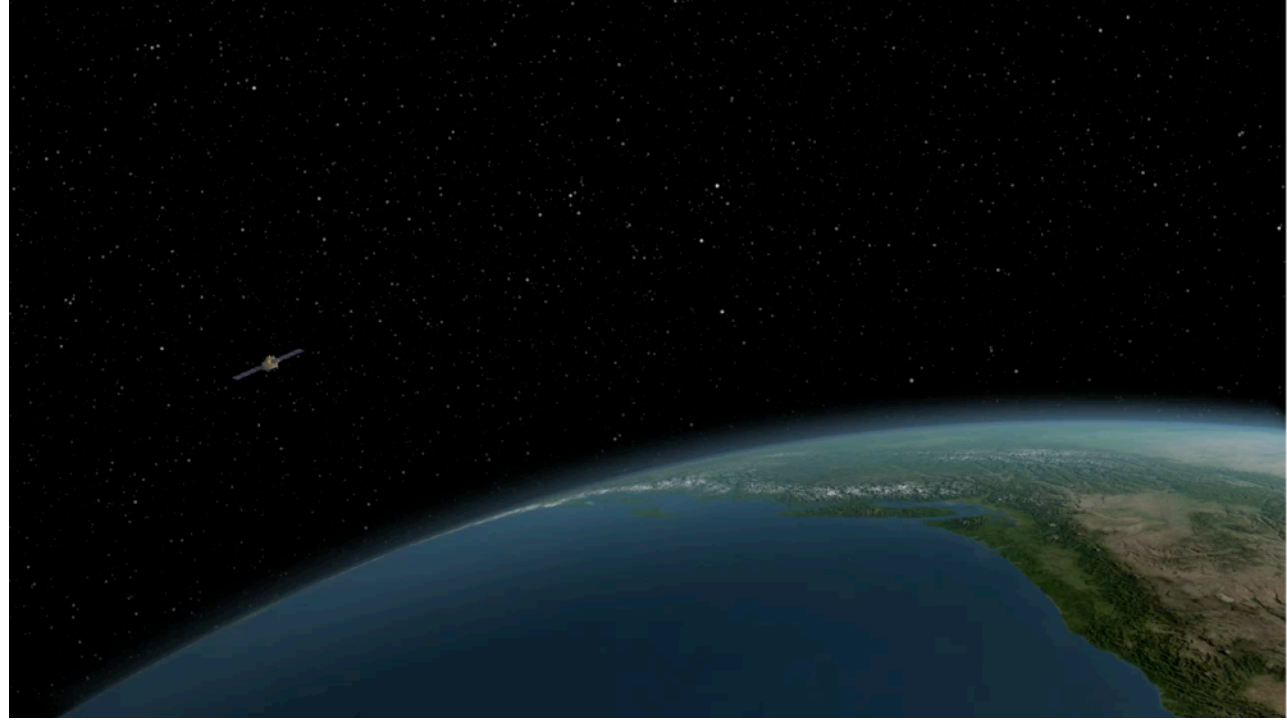


The *ARGO* initiative





Remote Sensing (Satellites)



S.S.T.
Altimetry (S.S.H.)
Ocean color
Wind
Rain
S.S.S.
Turbidity



Platforms

- a.R/Vs
- b.SOOPs
- c.Moorings
- d.Lagrangian
- e. Satellite

How can we define the proper platform(s) for our experiment

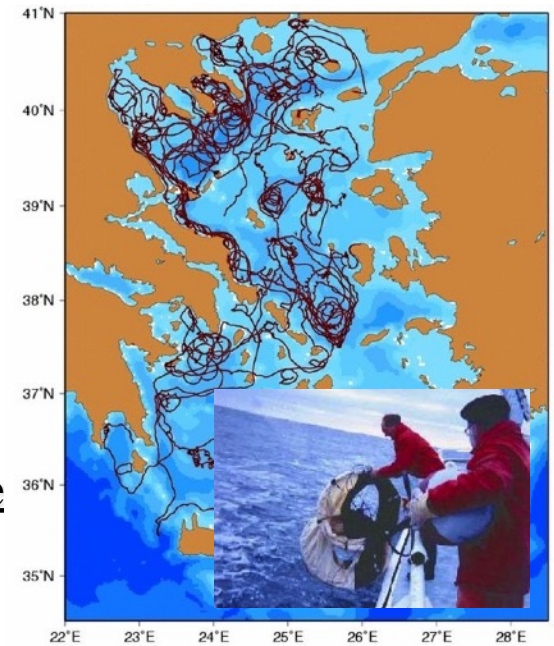
Scientific question

Area/process of interest

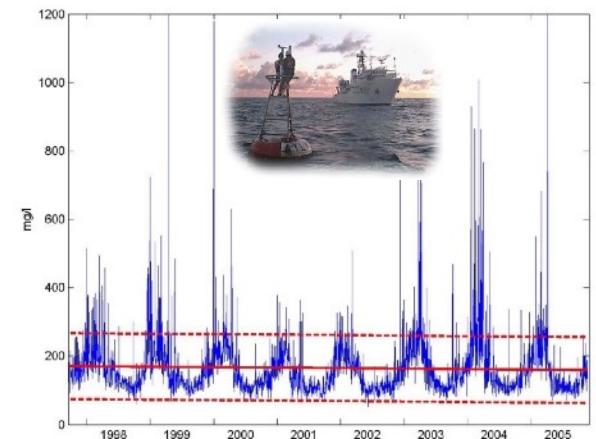
Spatial/temporal coverage requirements

Resources/Expertise

Other requirements

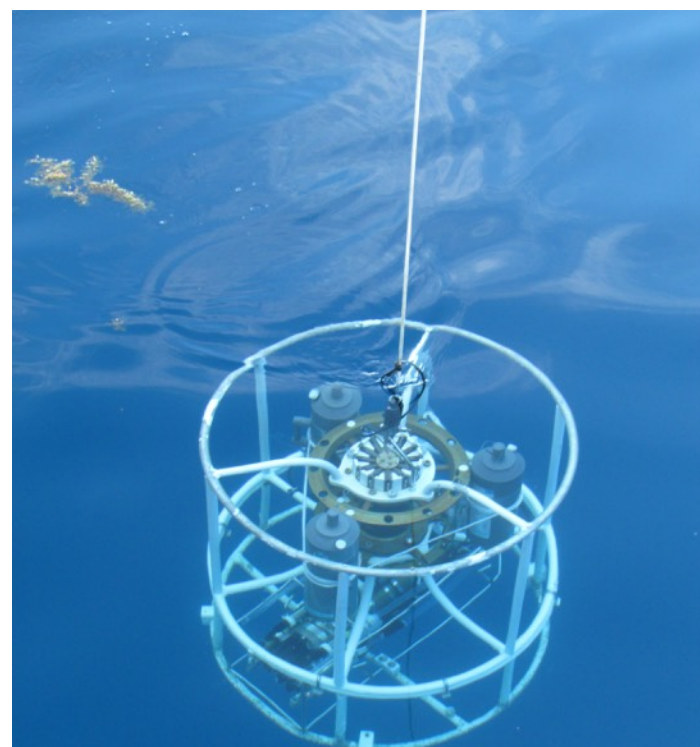
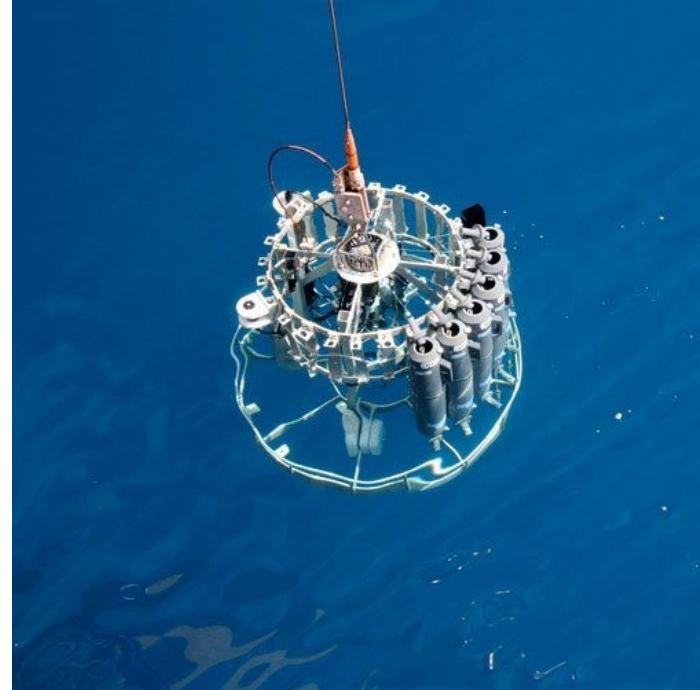
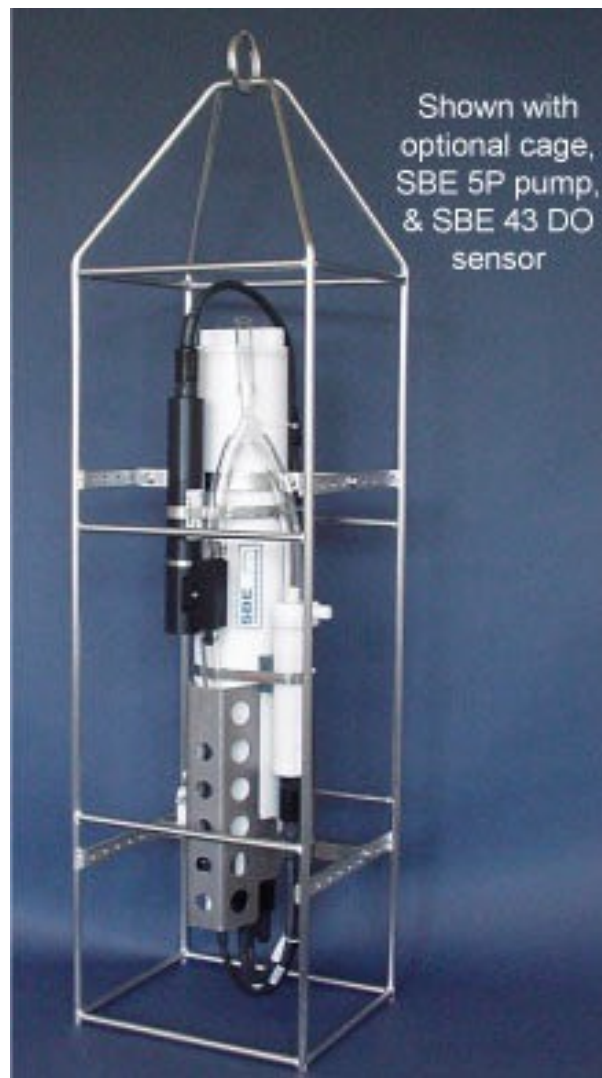
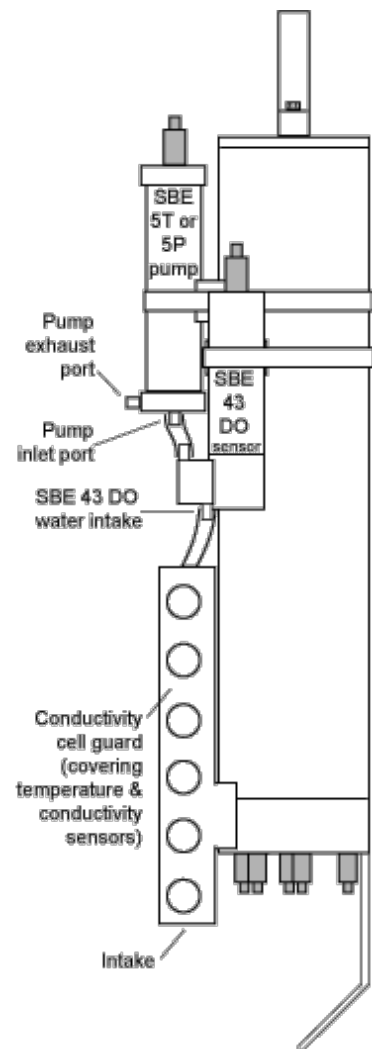


e.g. Lagrangian vs Eulerian



OGRAPHY

Temperature and *Depth*

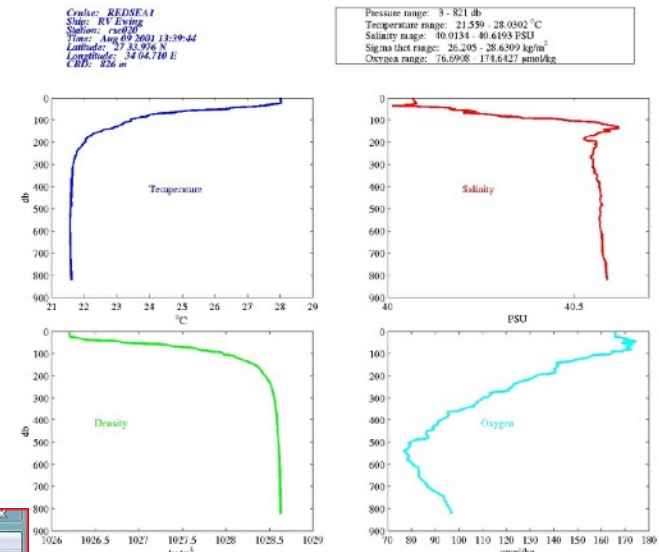
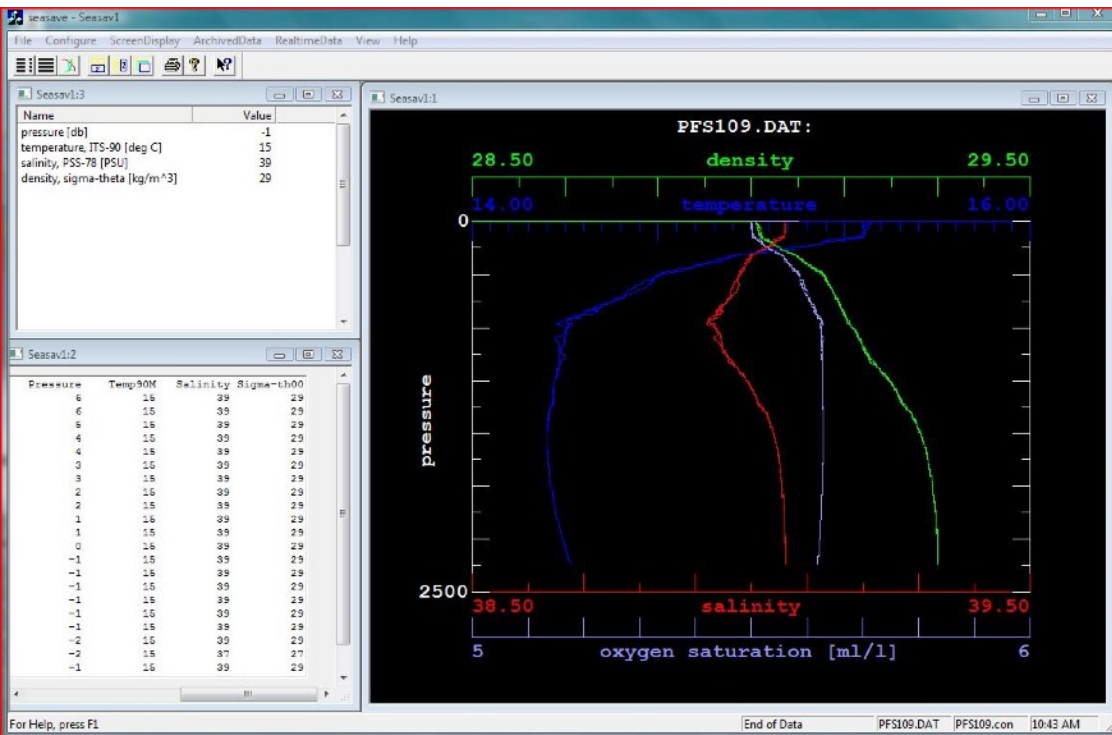


Conductivity, *Temperature* and *Depth*





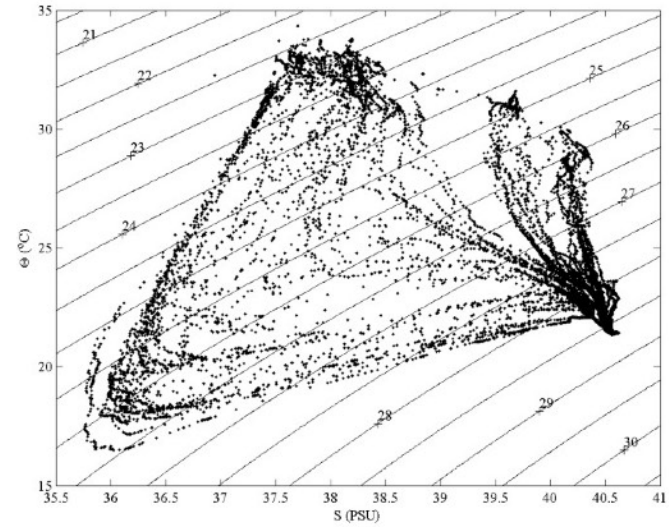
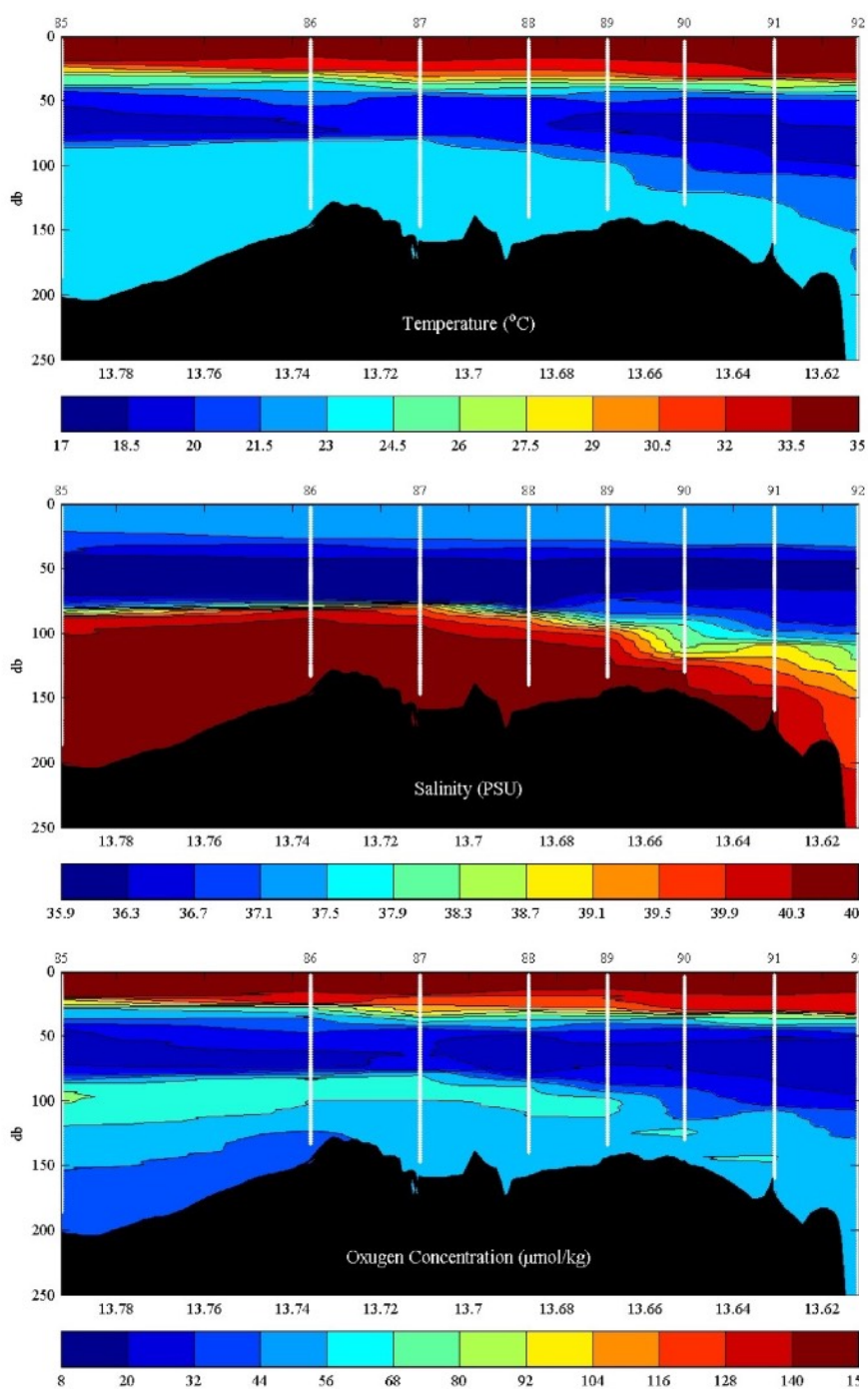
Sampling/Processing



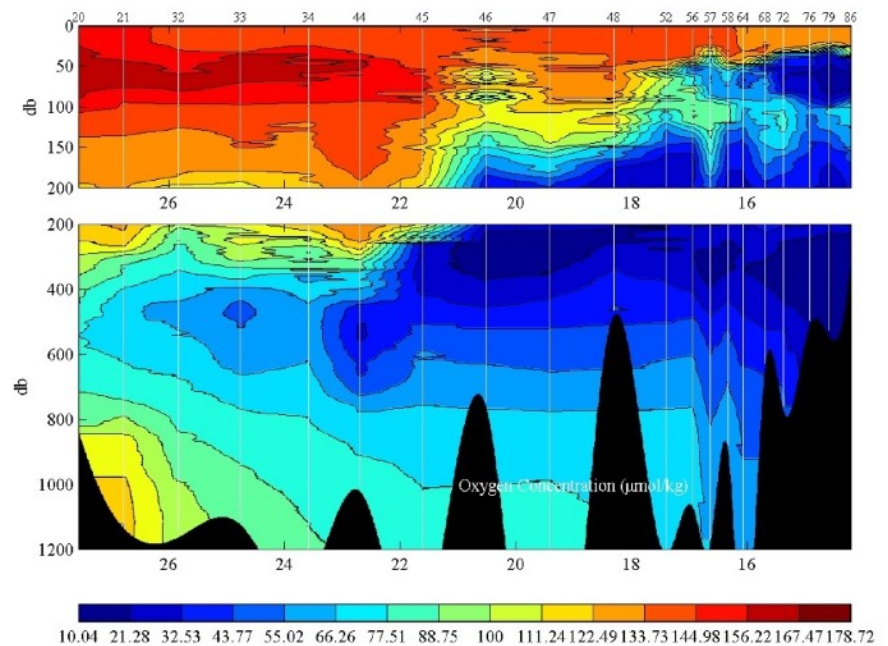
- Check/remove upcast
- Remove spikes
- Subsample
- Smooth
- Archive Data/Headers/Bottles
- Plot

Conductivity, Temperature and Depth

Conductivity, Temperature and Depth



Analyzing



**Nansen and Niskin
Bottles**

Calibration (T, S, O₂)

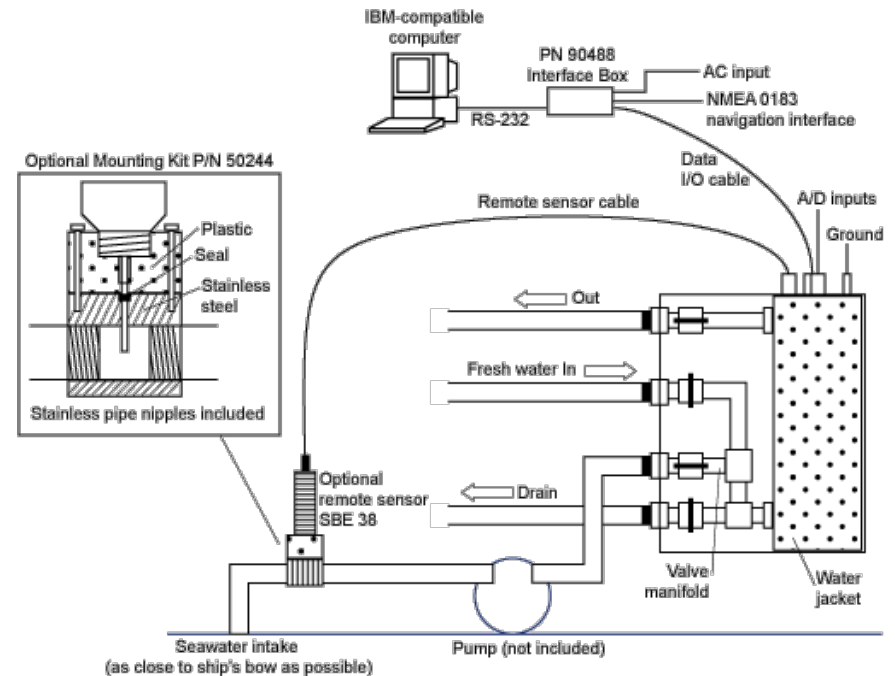
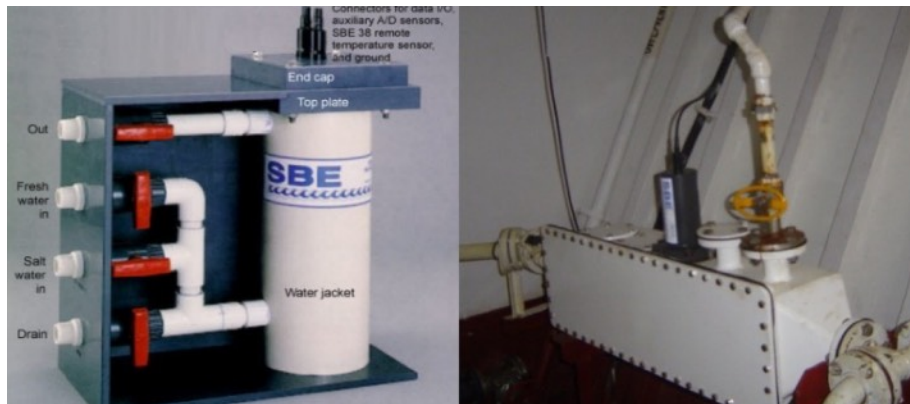
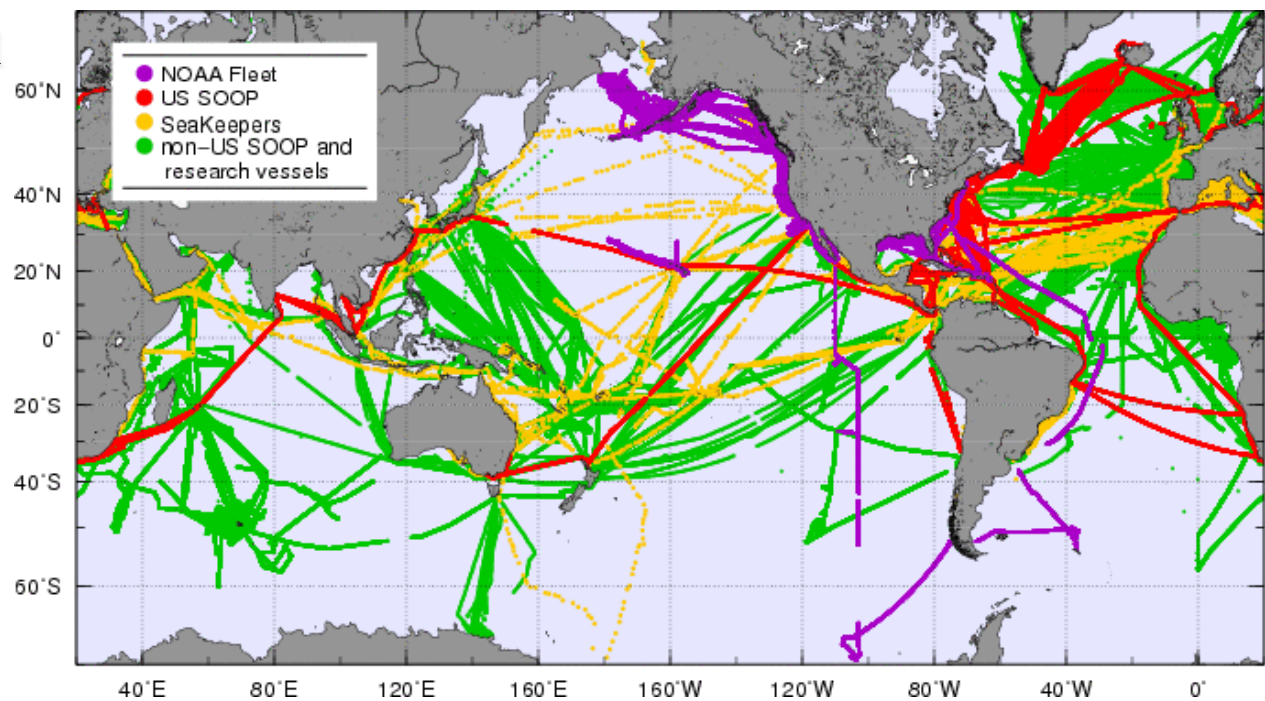


Rosette



TSG observations since 2001

Thermosalinograph (TSG)

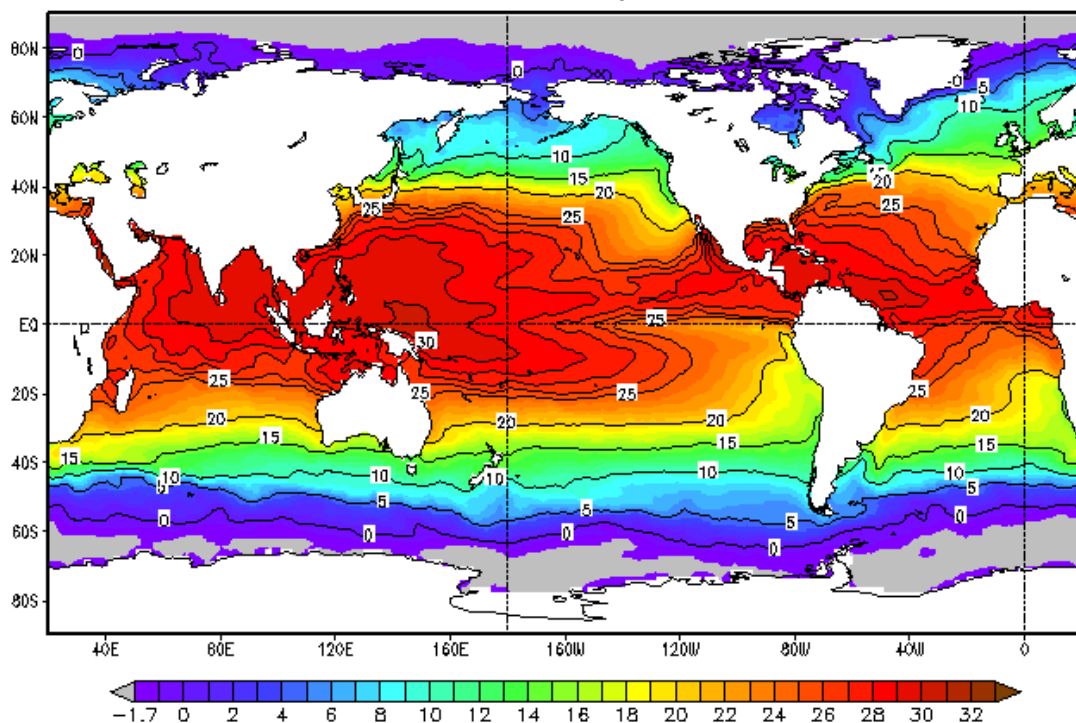




ST (and SSS)

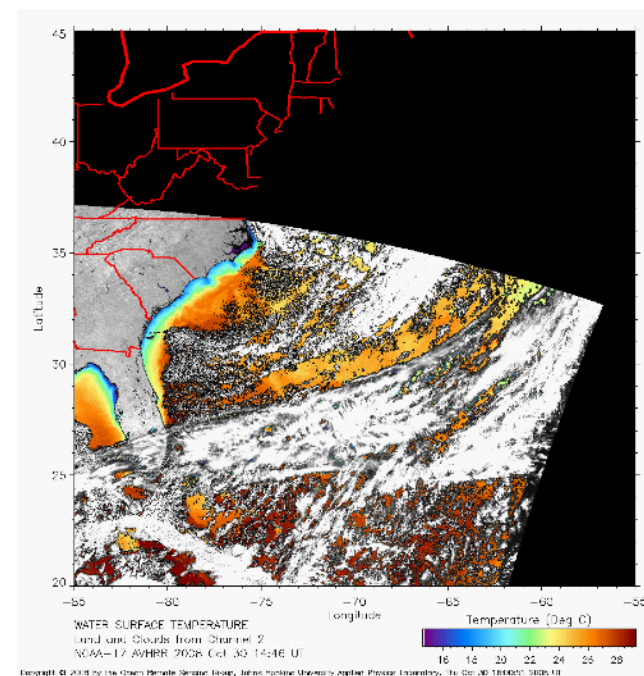
Radiometers that operate in the infrared are used to measure sea surface temperature. Their resolution has steadily increased over the years; the AVHRR (Advanced Very High Resolution Radiometer) has a resolution that comes close to 0.1°C .

Olv2 Sea Surface Temperature($^{\circ}\text{C}$)
October 1–29, 2008

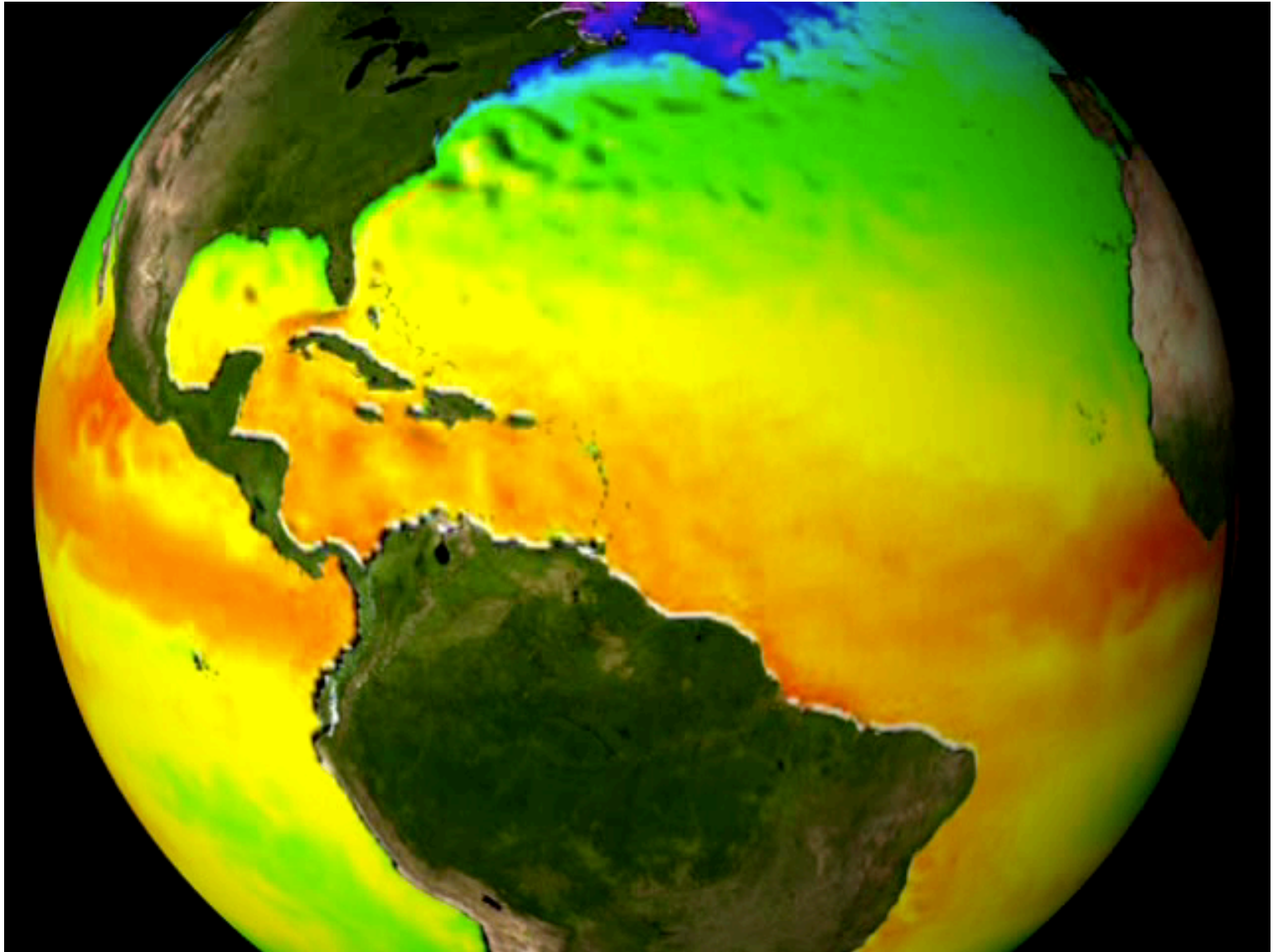


GRADS: CGLA/KGES

Climate Modeling Branch/EMC/NCEP



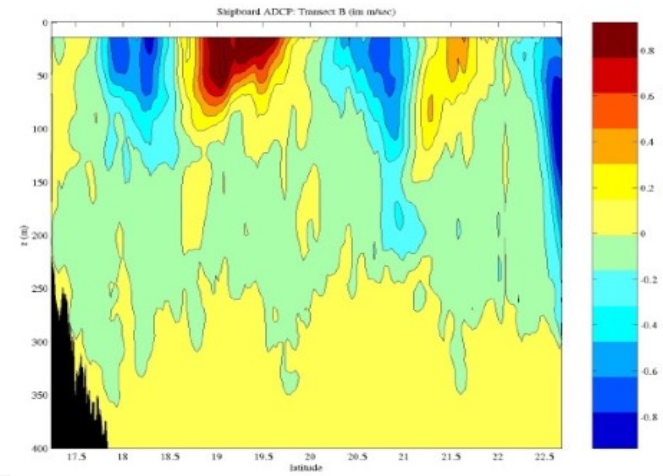
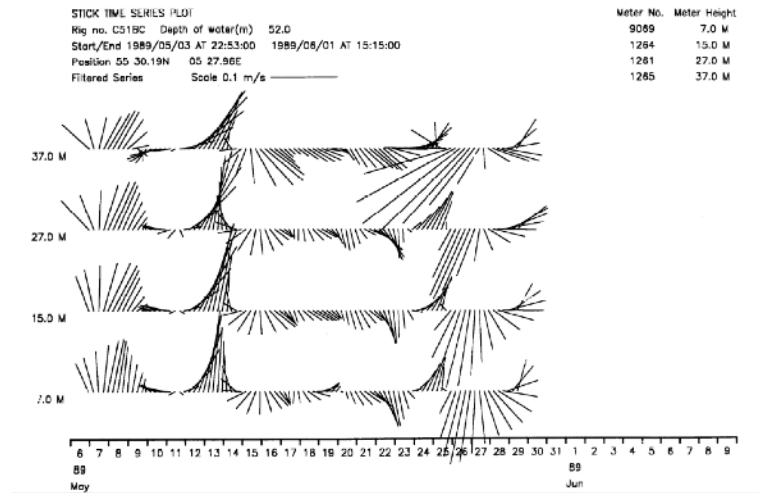
WATER SURFACE TEMPERATURE
Land and Clouds from Channel 2
NOAA-17 AVHRR 2008 Oct 30 14:46 UT
Copyright © 2008 by the Ocean Remote Sensing Group, Johns Hopkins University Applied Physics Laboratory, 1415 Co. Rd. 381, Laurel, MD 21075, USA



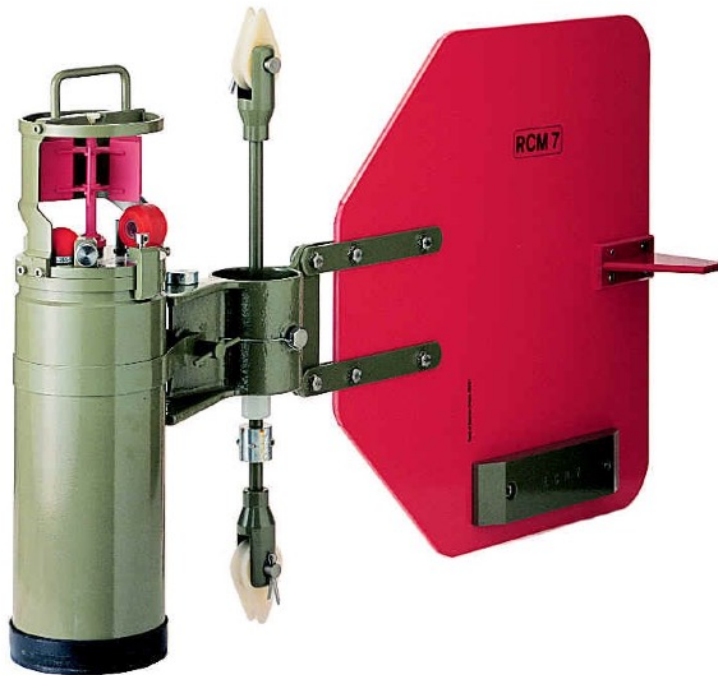
Global
SST

II. DYNAMICS

Current meters

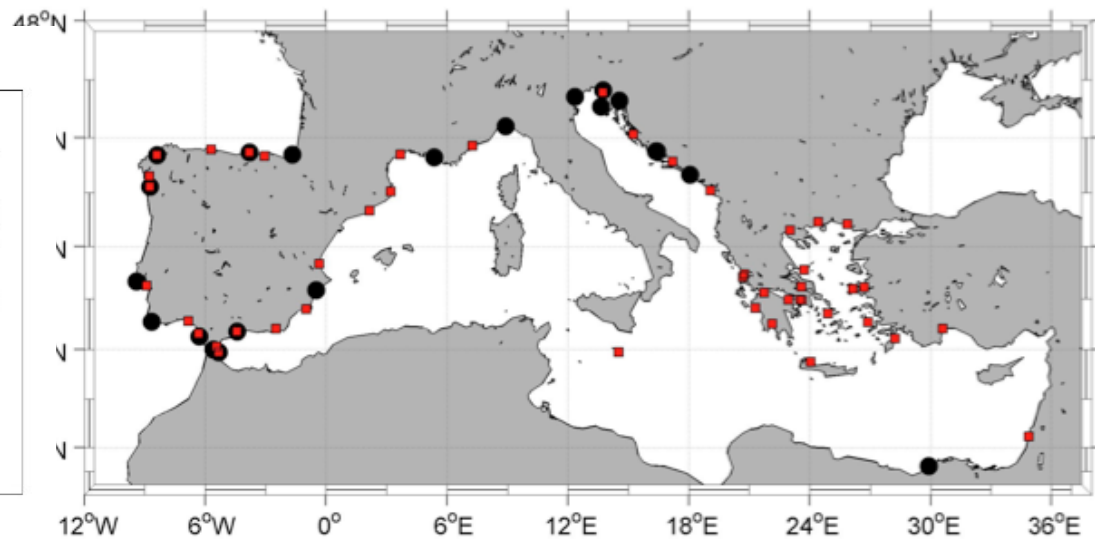
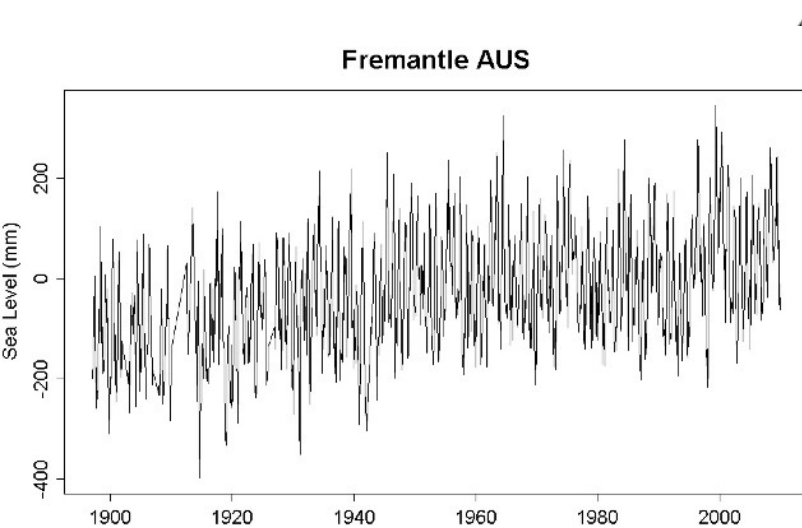


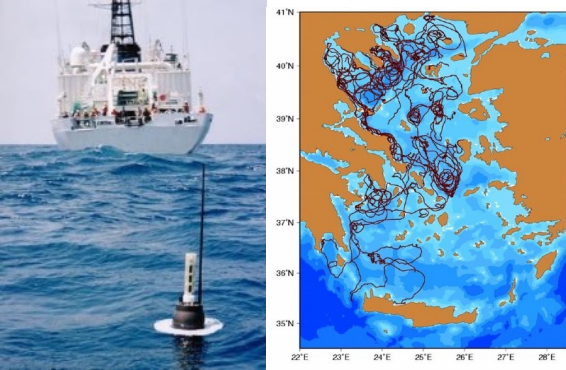
**Mechanical
A.D.C.P.**



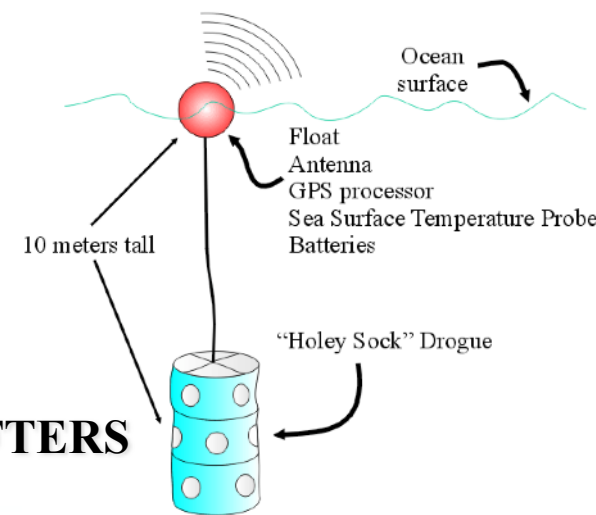
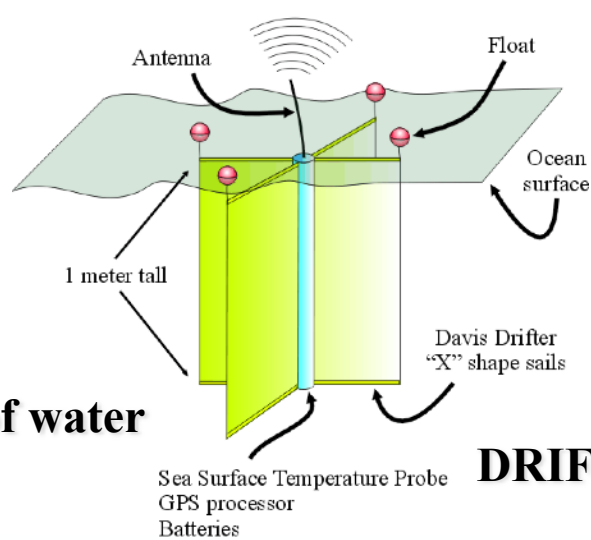


**Pressure (tide) gauges
and wave measurements**



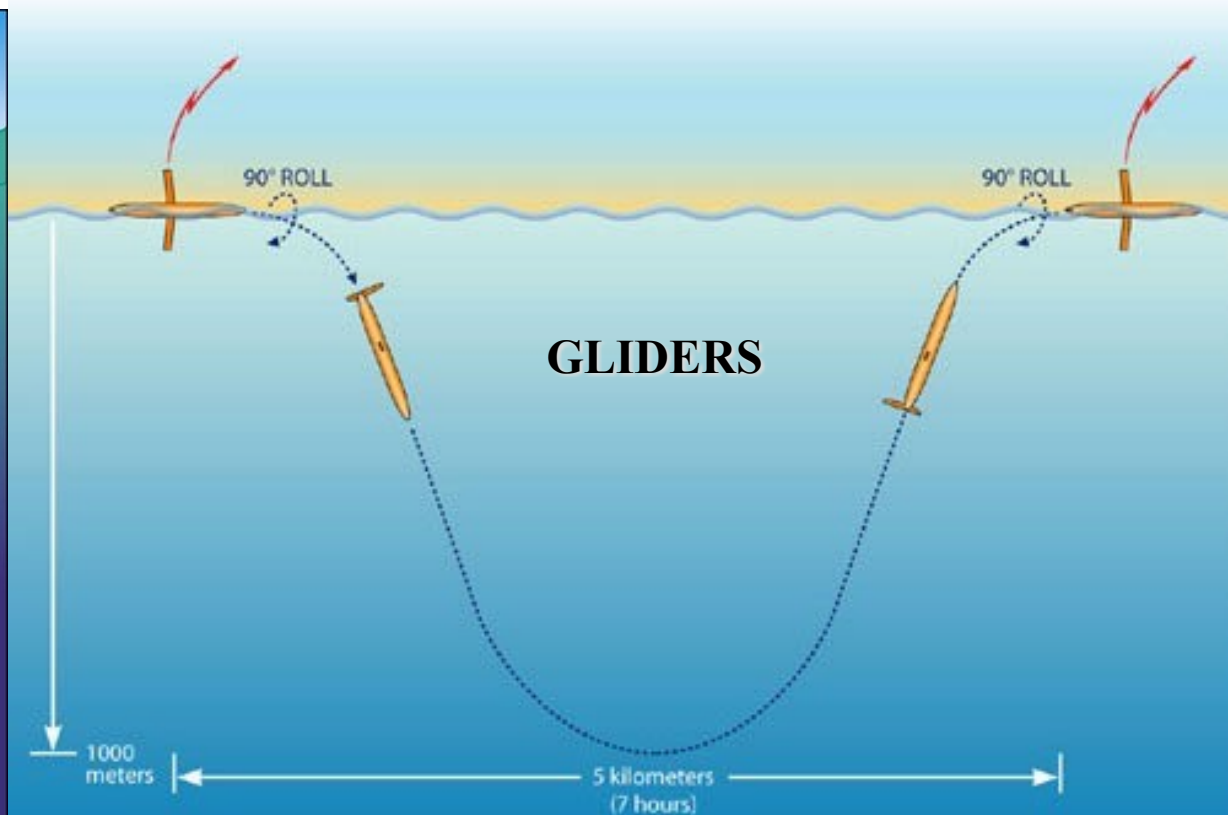
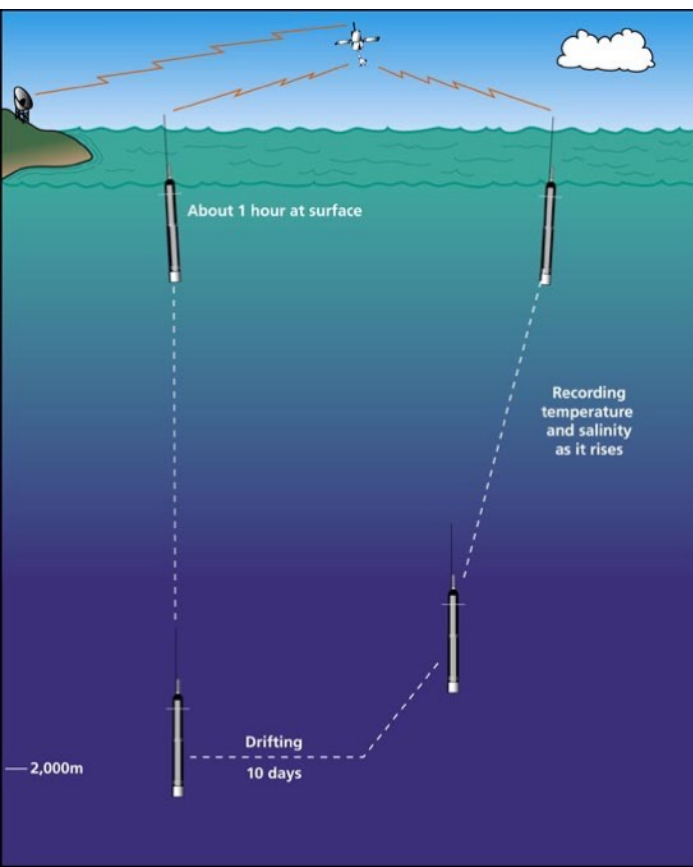


Lagrangian observations of water motion



DRIFTERS

FLOATS





The *ARGO* initiative

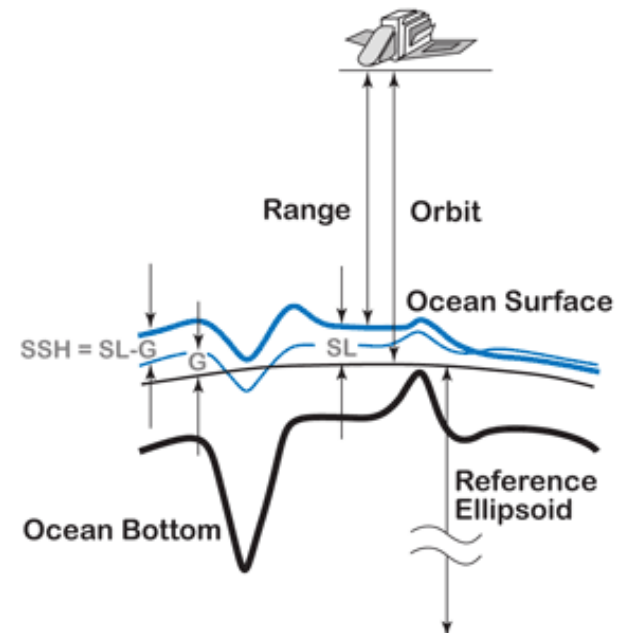
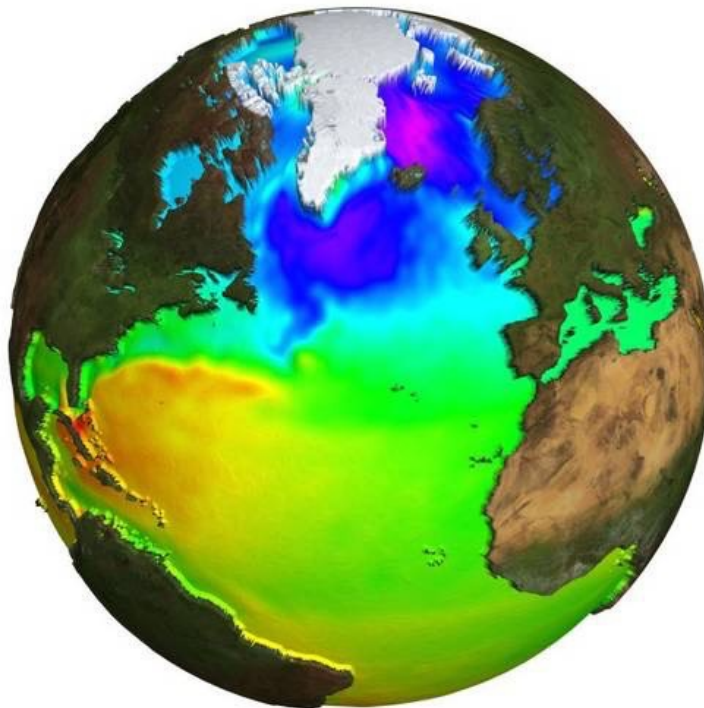


GLIDERS

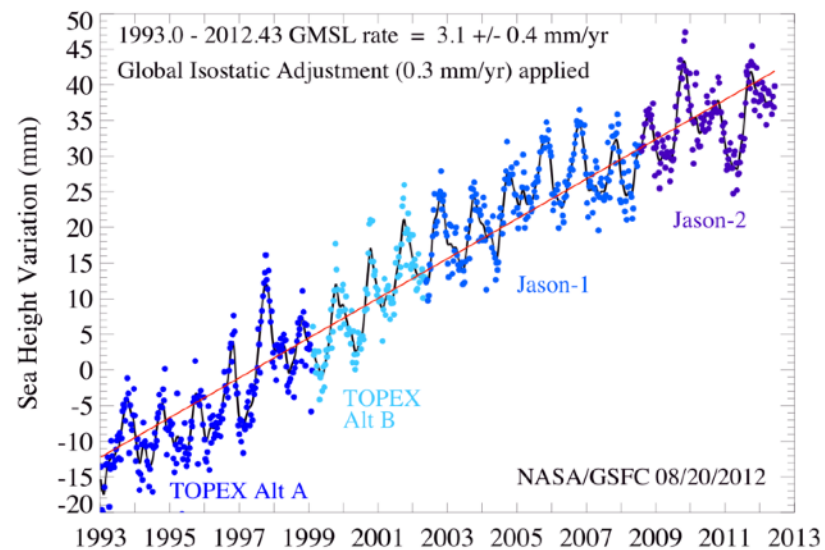
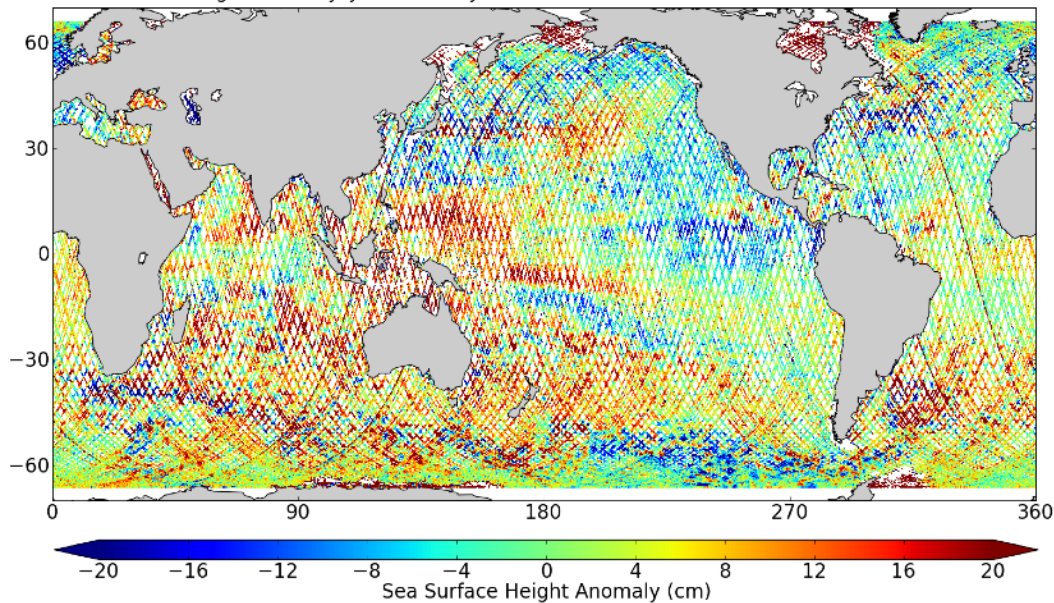




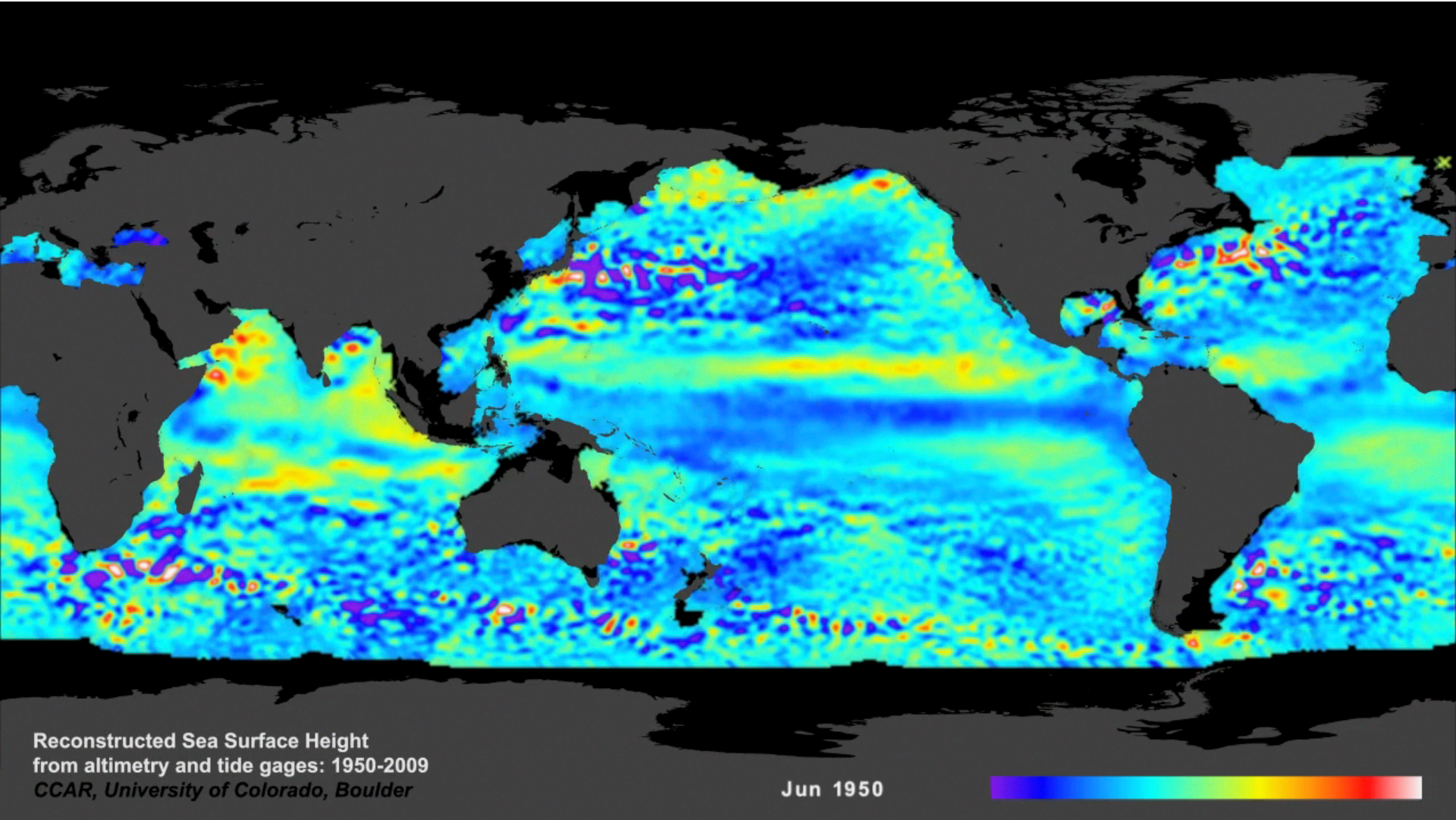
Altimetry



Sea Surface Height Anomaly: Jason-1 and Jason-2 Measurements from 07-Feb-2013 to 17-Feb-2013



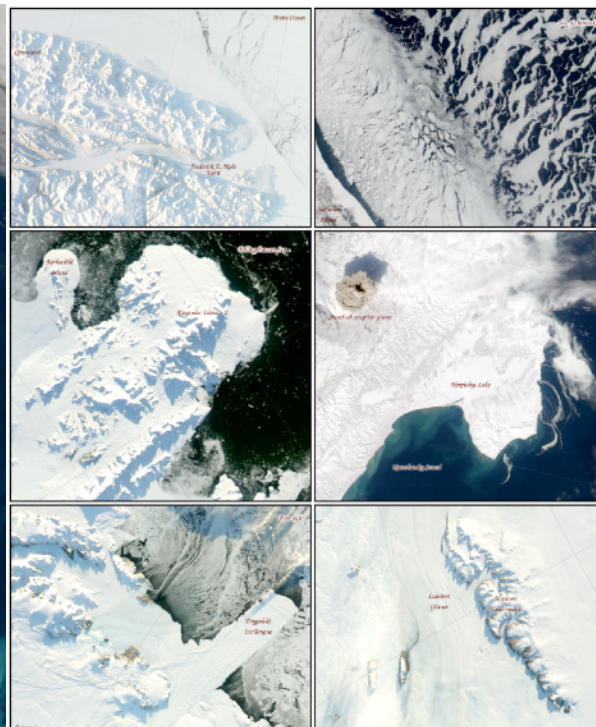
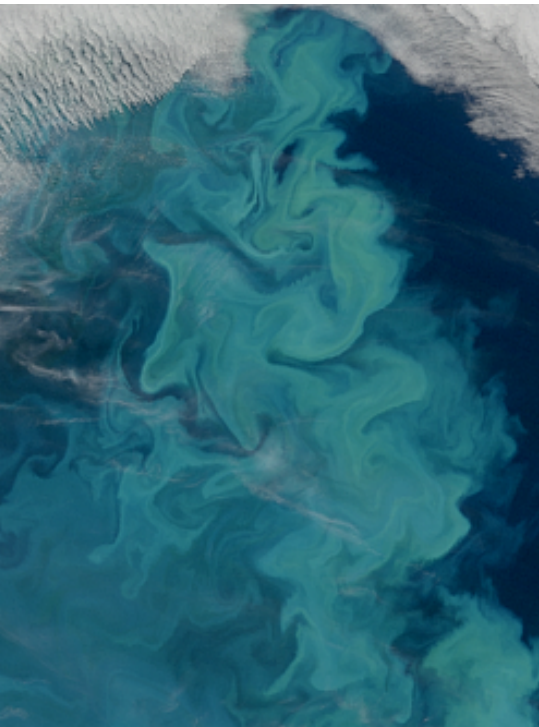
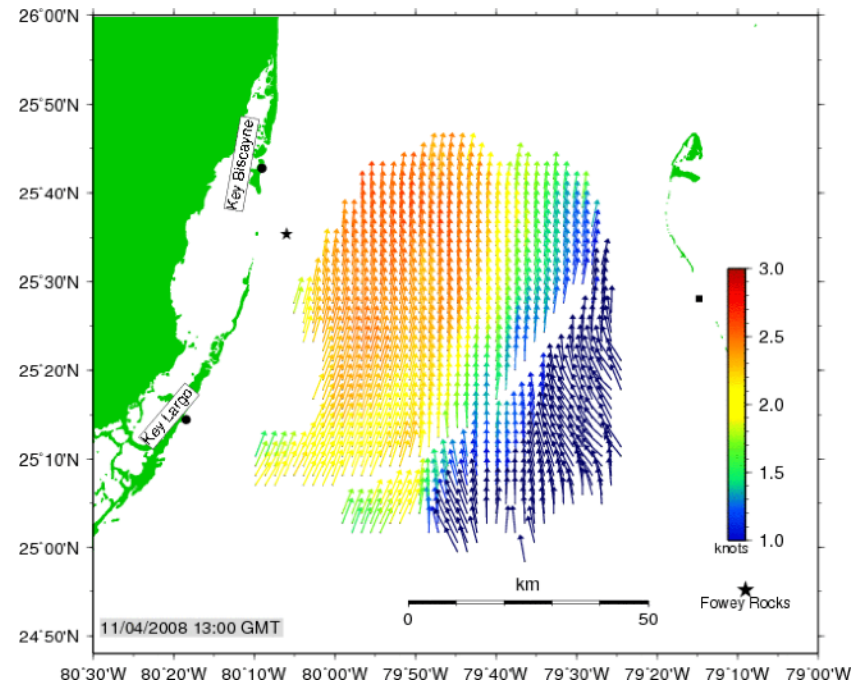
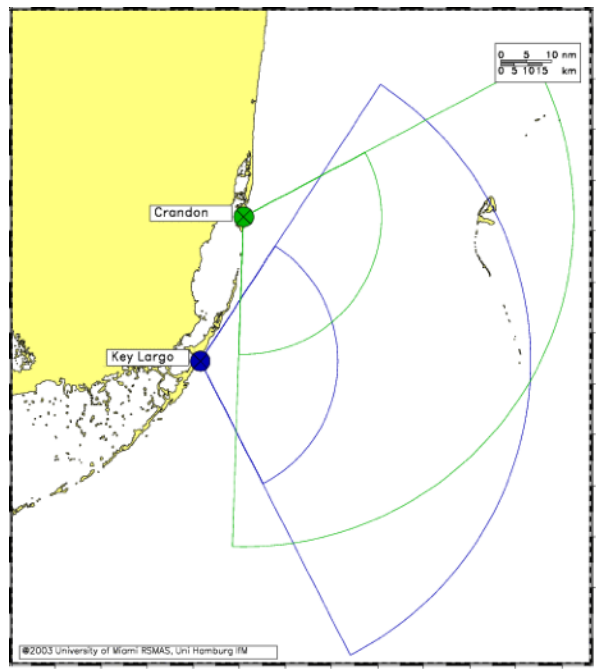
The ocean surface topography



Radars

Many more

Satellite sensors

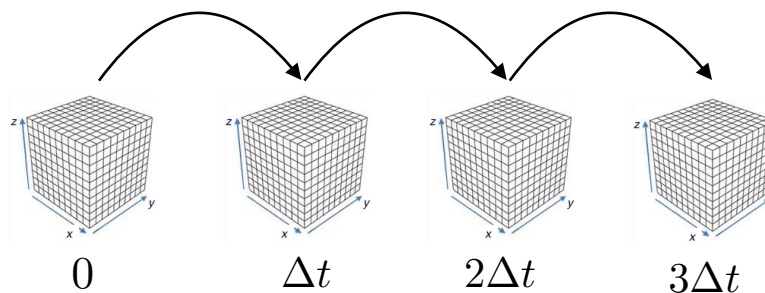
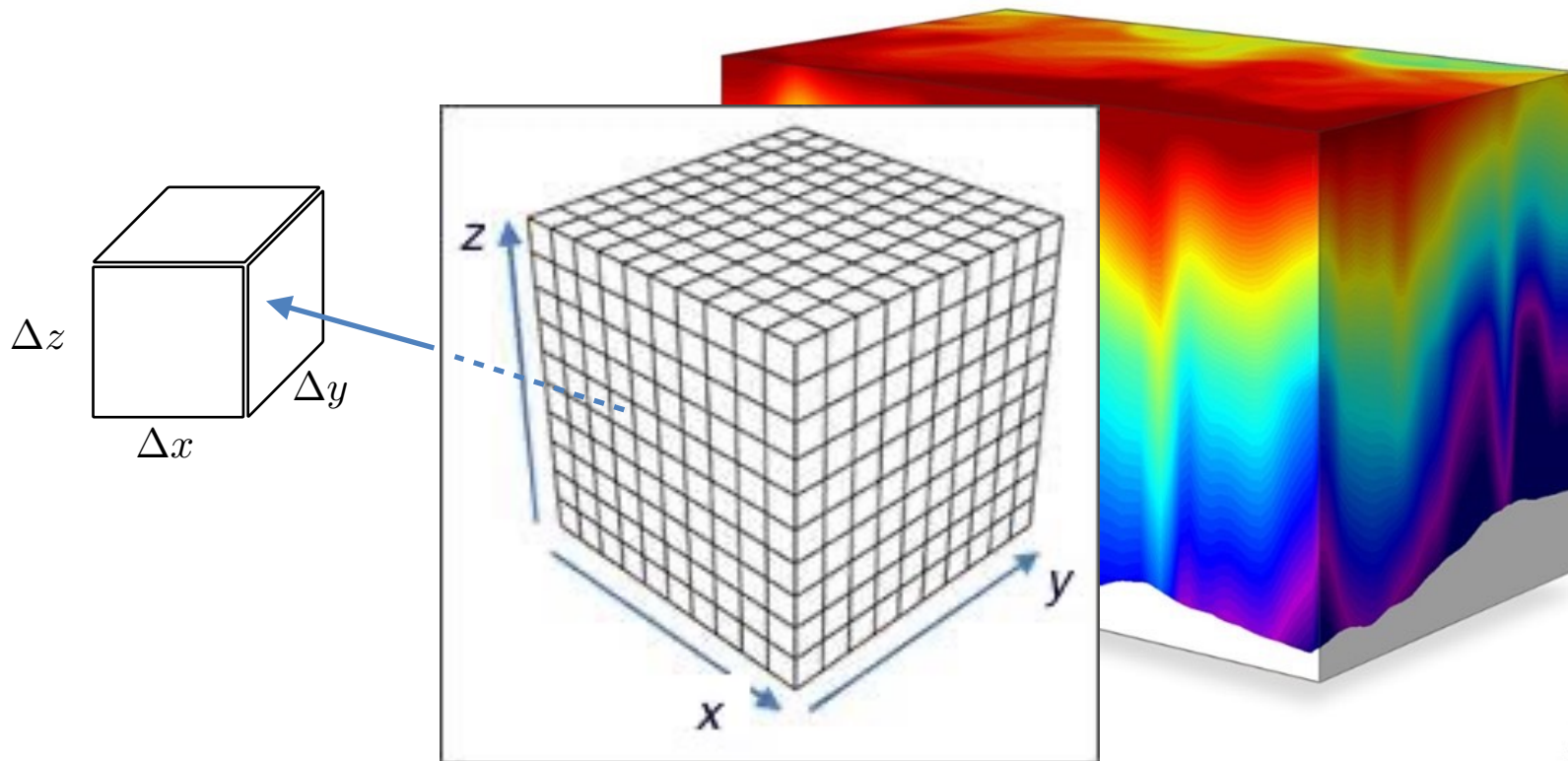


Microprofilers

Παράρτημα:

Υπολογιστική Φυσική Ωκεανογραφία

(Αριθμητικά μοντέλα και πρόγνωση)



$$\frac{du(t)}{dt} = \frac{F^V(t)}{\rho(t)}$$

$$\frac{\Delta u(t)}{\Delta t} = \frac{F^V(t)}{\rho(t)}$$

$$\frac{u(t+1) - u(t)}{\Delta t} = \frac{F^V(t)}{\rho(t)}$$

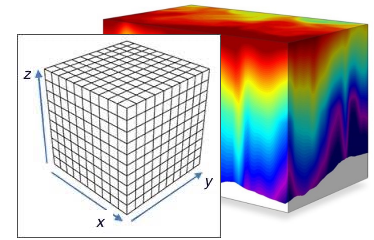
$$u(t+1) = u(t) + \Delta t \left(\frac{F^V(t)}{\rho(t)} \right)$$

$$u_{i,j,k}^{n+1} = u_{i,j,k}^n + \Delta t \left(\frac{F_{i,j,k}^n}{\rho_{i,j,k}^n} \right)$$

όπου

$t \rightarrow n$

$(x, y, z) \rightarrow (i, j, k)$

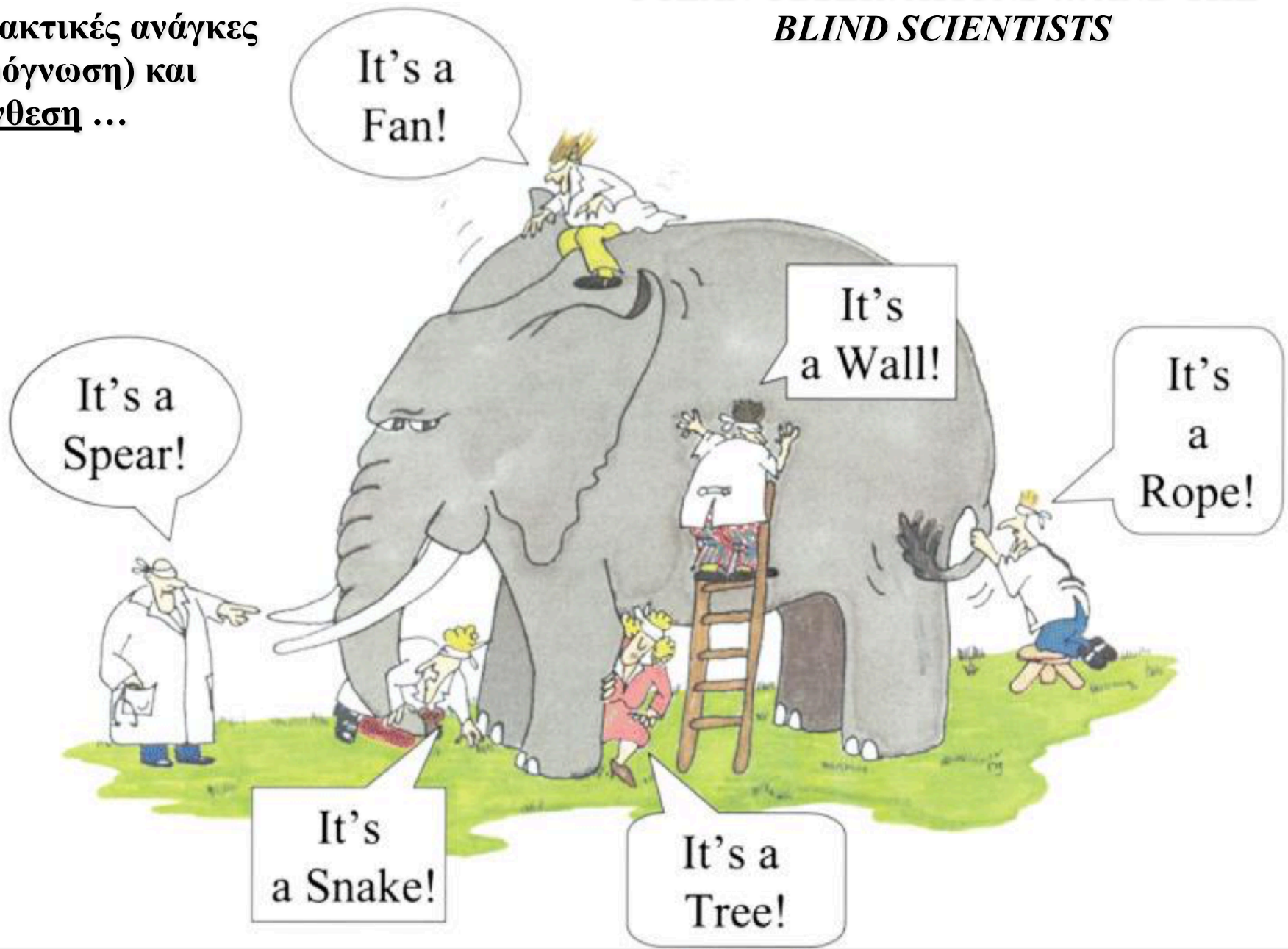


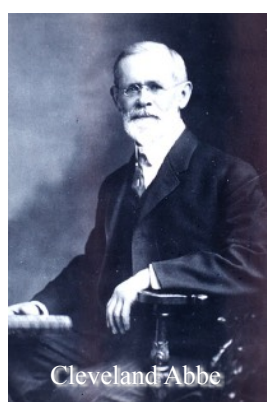
```
for n=1:N %where N*dt = length of simulation
u(n+1,i,j,k) = u(n,i,j,k)+dt*(F(n,i,j,k)/r(n,i,j,k))
end
```

Κίνητρα:

**Πρακτικές ανάγκες
(πρόγνωση) και
σύνθεση ...**

***OCEAN OBSERVATIONS ... AND THE
BLIND SCIENTISTS***

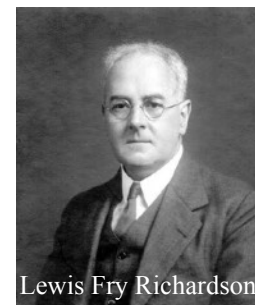
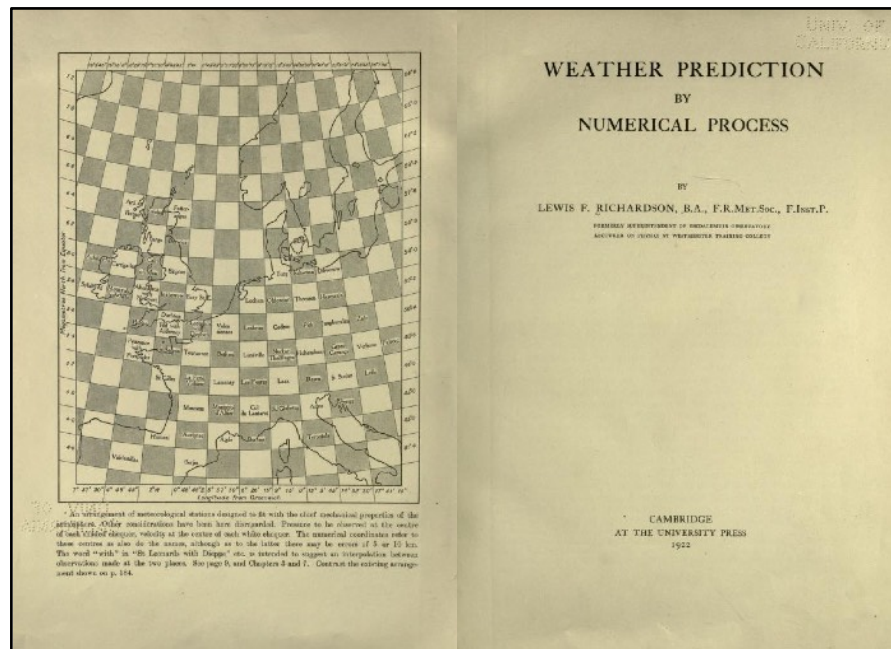




Cleveland Abbe

1838 - 1916

“Δίγη” ιστορία για την αριθμητική προσομοίωση -πρόγνωση

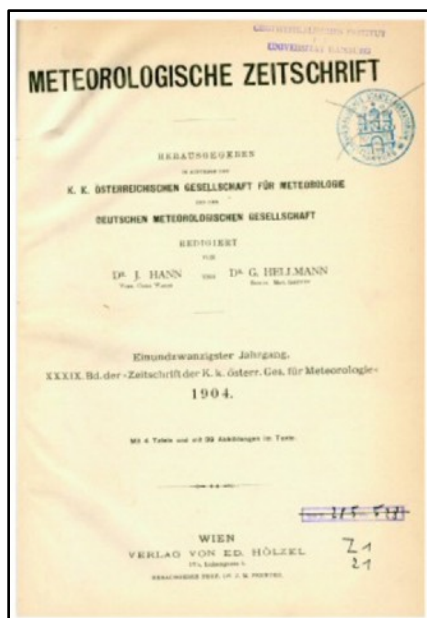


Lewis Fry Richardson

1881 - 1953

“Weather Prediction
by Numerical
Process, Cambridge
University Press,
1921

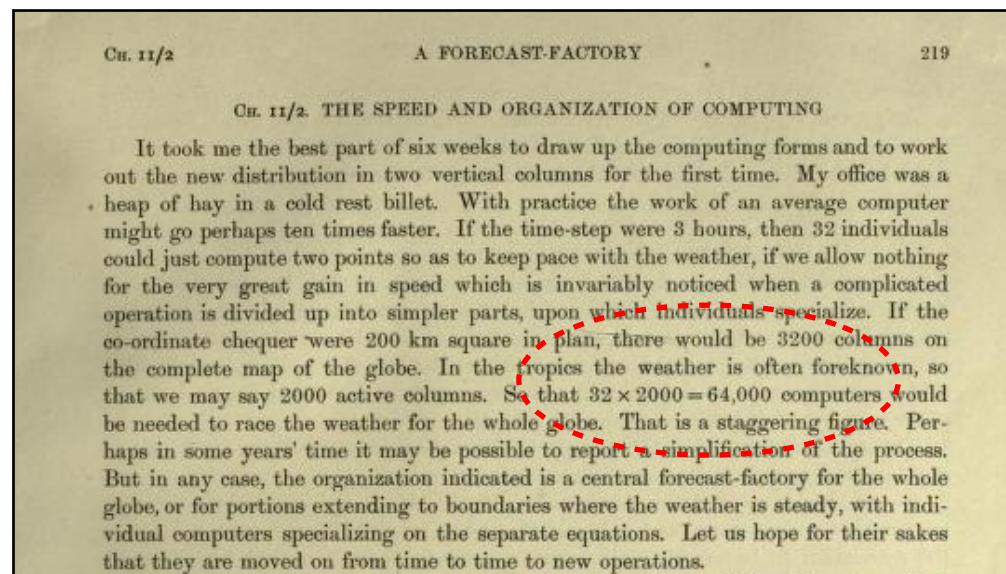
The physical basis of
long-range weather
forecasts. Mon.
Weather Rev., 29,
551-61, 1901

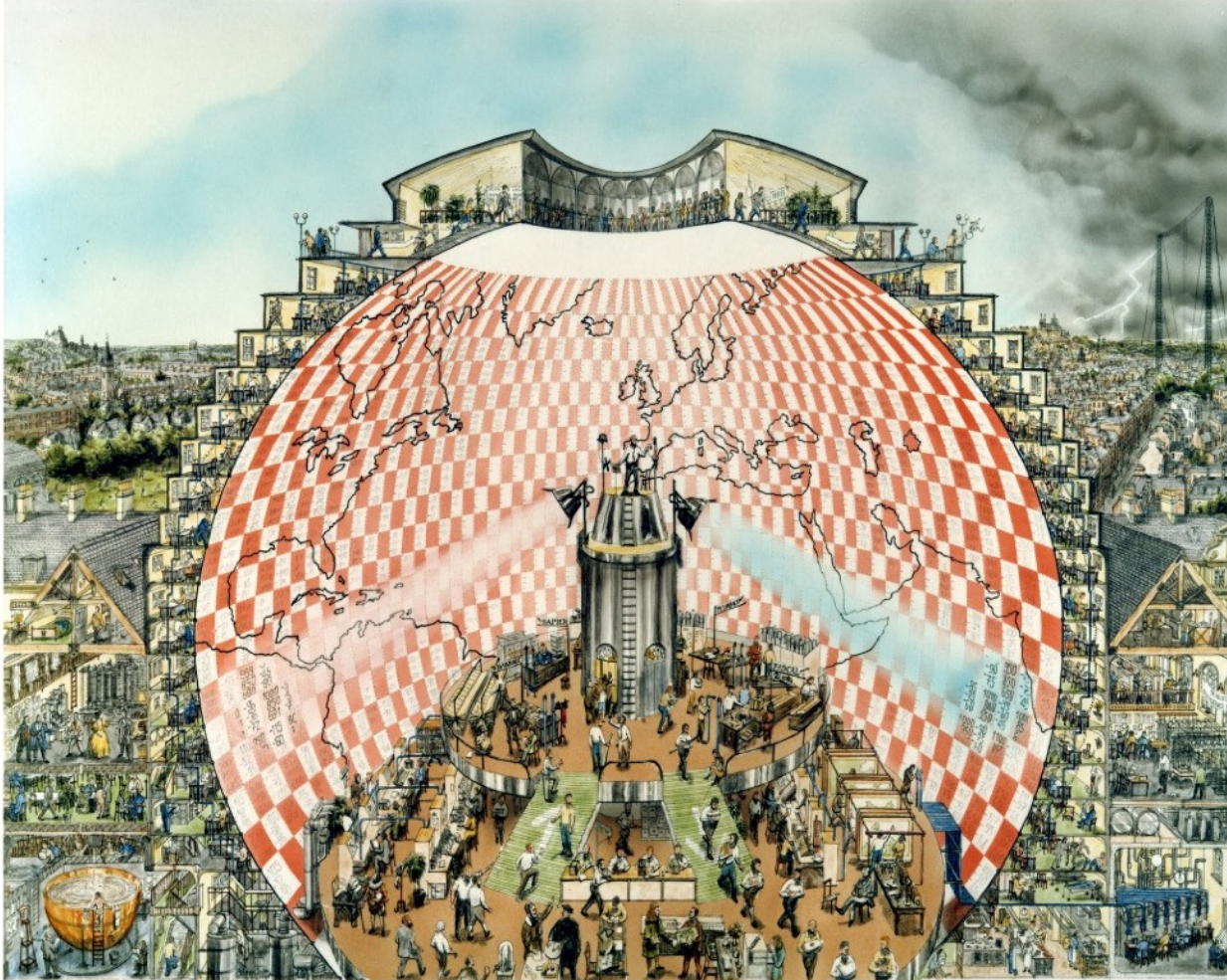


Wilhelm Bjerknes

1862 - 1951

“The problem of weather prediction, considered from the viewpoints
of mechanics and physics” Meteorologische Zeitschrift, 1904





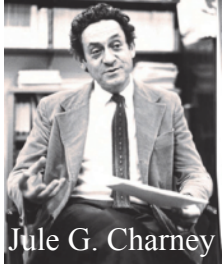
"Weather Forecasting Factory" by Stephen Conlin, 1986



"Machines Forecast the Weather", by L. Gandin, 1965



Alan Turing
1912-1954



Jule G. Charney
1917 - 1981

The first computerized weather forecast (1950) was performed by a team composed of American meteorologists **Jule Charney**, **Philip Duncan Thompson**, **Larry Gates**, and Norwegian meteorologist **Ragnar Fjørtoft**, applied mathematician **John von Neumann**, and ENIAC programmer **Klara Dan von Neumann**.

VOLUME 2, NUMBER 4 **Tellus** NOVEMBER 1950

A QUARTERLY JOURNAL OF GEOPHYSICS

Numerical Integration of the Barotropic Vorticity Equation

By J. G. CHARNEY, R. FJÖRTOFT¹, J. von NEUMANN

The Institute for Advanced Study, Princeton, New Jersey²

(Manuscript received 1 November 1950)

Abstract

A method is given for the numerical solution of the barotropic vorticity equation over a limited area of the earth's surface. The lack of a natural boundary calls for an investigation of the appropriate boundary conditions. These are determined by a heuristic argument and are shown to be sufficient in a special case. Approximate conditions necessary to insure the mathematical stability of the difference equation are derived. The results of a series of four 24-hour forecasts computed from actual data at the 500 mb level are presented, together with an interpretation and analysis. An attempt is made to determine the causes of the forecast errors. These are ascribed partly to the use of too large a space increment and partly to the effects of baroclinicity. The rôle of the latter is investigated in some detail by means of a simple baroclinic model.

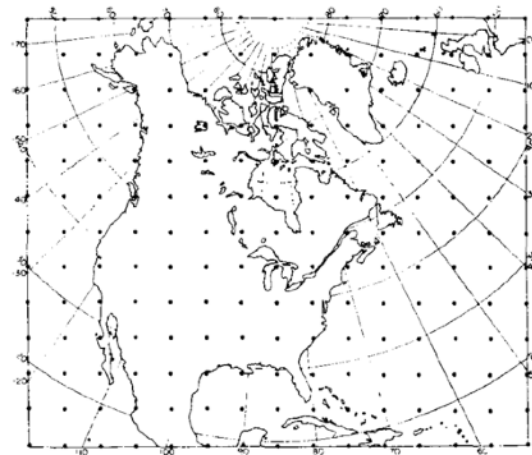
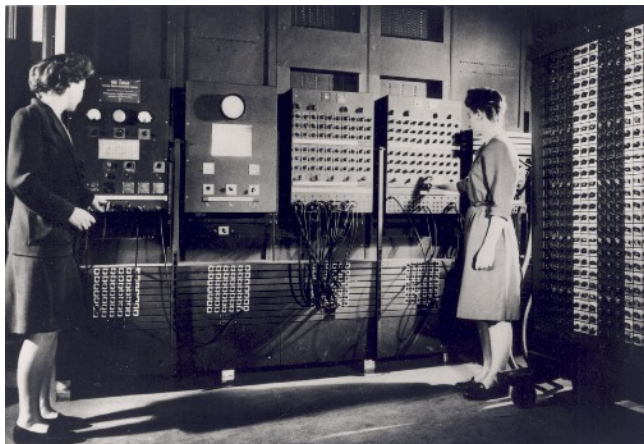


Fig. 1. A typical finite-difference grid used in the computations. A strip two grid intervals in width at the top and side borders and one grid interval in width at the lower border is not shown.

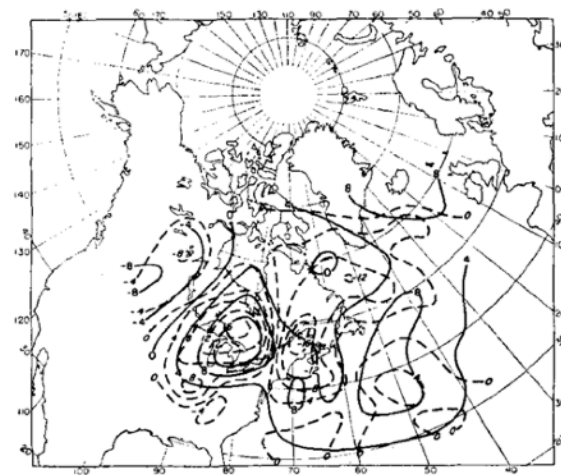


Fig. 6. Barotropically and baroclinically computed 500 mb height tendencies at 0300 GMT, January 30, 1949. The barotropic tendencies are represented by continuous lines and the baroclinic tendencies by broken lines. The unit is 100 ft/24 hours.

$$\left. \begin{aligned}
 \frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} &= -\frac{1}{\rho_0} \frac{\partial p}{\partial x} + f v + A_H \frac{\partial^2 u}{\partial x^2} + A_H \frac{\partial^2 u}{\partial y^2} + A_V \frac{\partial^2 u}{\partial z^2} \\
 \frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + w \frac{\partial v}{\partial z} &= -\frac{1}{\rho_0} \frac{\partial p}{\partial y} - f u + A_H \frac{\partial^2 v}{\partial x^2} + A_H \frac{\partial^2 v}{\partial y^2} + A_V \frac{\partial^2 v}{\partial z^2} \\
 \frac{\partial w}{\partial t} + u \frac{\partial w}{\partial x} + v \frac{\partial w}{\partial y} + w \frac{\partial w}{\partial z} &= -\frac{1}{\rho_0} \frac{\partial p}{\partial z} - g + A_H \frac{\partial^2 w}{\partial x^2} + A_H \frac{\partial^2 w}{\partial y^2} + A_V \frac{\partial^2 w}{\partial z^2} \\
 \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} &= 0 \\
 \frac{\partial T}{\partial t} + u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} + w \frac{\partial T}{\partial z} &= \kappa_T \frac{\partial^2 T}{\partial x^2} + \kappa_T \frac{\partial^2 T}{\partial y^2} + \kappa_T \frac{\partial^2 T}{\partial z^2} + \frac{Q}{c_p \rho} \\
 \frac{\partial S}{\partial t} + u \frac{\partial S}{\partial x} + v \frac{\partial S}{\partial y} + w \frac{\partial S}{\partial z} &= \kappa_S \frac{\partial^2 S}{\partial x^2} + \kappa_S \frac{\partial^2 S}{\partial y^2} + \kappa_S \frac{\partial^2 S}{\partial z^2} + S^S \\
 \rho &= \rho_0 [1 - \alpha(T - T_0) + \beta(S - S_0)]
 \end{aligned} \right\} \begin{array}{l} \rightarrow \\ \nabla \end{array}$$

$$\frac{\Delta u}{\Delta t} + u \frac{\Delta u}{\Delta x} + \dots = \frac{1}{\rho_0} \frac{\Delta p}{\Delta x} + f v + \dots$$

$$\begin{aligned}
 u_{i,j,k}^{n+1} &= u_{i,j,k}^n + \Delta t \left(u_{i,j,k}^n \frac{u_{i+1,j,k}^n - u_{i,j,k}^n}{\Delta x} + \dots \right. \\
 &\quad \left. + \frac{1}{\rho_0} \frac{p_{i+1,j,k}^n - p_{i,j,k}^n}{\Delta x} + f u_{i,j,k}^n + \dots \right)
 \end{aligned}$$

but!

but!

**Über die partiellen Differenzengleichungen der
mathematischen Physik.**

Von

R. Courant, K. Friedrichs und H. Lewy in Göttingen,

1928

Truncation error $\frac{\Delta u}{\Delta x} \neq \frac{du}{dx}$

$$u_{j+1} = u_j + \left(\frac{du}{dx} \right)_j \Delta x + \left(\frac{d^2 u}{dx^2} \right)_j \frac{(\Delta x)^2}{2} + \left(\frac{d^3 u}{dx^3} \right)_j \frac{(\Delta x)^3}{6} + \dots$$

$$\varepsilon = \left(\frac{d^2 u}{dx^2} \right)_j \frac{\Delta x}{2} + \left(\frac{d^3 u}{dx^3} \right)_j \frac{(\Delta x)^2}{6} + \dots$$

$$\dots \text{ή για απλούστευση} \quad \frac{\Delta x}{\Delta t} > C_{max} \Rightarrow \Delta t < \frac{\Delta x}{C_{max}} *$$

*Courant–Friedrichs–Lewy or CFL condition

$$\frac{\partial u}{\partial t} + C \frac{\partial u}{\partial x} = 0$$

$$\frac{u_i^{n+1} - u_i^n}{\Delta t} + C \frac{u_i^n - u_{i-1}^n}{\Delta x} = 0$$

$$u_i^{n+1} = u_i^n - C \frac{\Delta t}{\Delta x} (u_i^n - u_{i-1}^n)$$

$$u_i^{n+1} = (1 - \mu) u_i^n + \mu u_{i-1}^n \text{ where } \mu = C \frac{\Delta t}{\Delta x}$$

$$|u_i^{n+1}| = |(1 - \mu) u_i^n + \mu u_{i-1}^n|$$

$$|\alpha + \beta| \leq |\alpha| + |\beta| \text{ and for } 0 \leq \mu \leq 1$$

$$|u_i^{n+1}| = (1 - \mu) |u_i^n| + \mu |u_{i-1}^n|$$

επιλέγουμε i και n όπου

$$|u_i^{n+1}| = \max |u_i^{n+1}|$$

η ανισότητα δεν θα διαταραχθεί αν αντικαταστήσουμε τα $|u_i^n|$ και $|u_{i-1}^n|$ με $\max |u_i^n|$

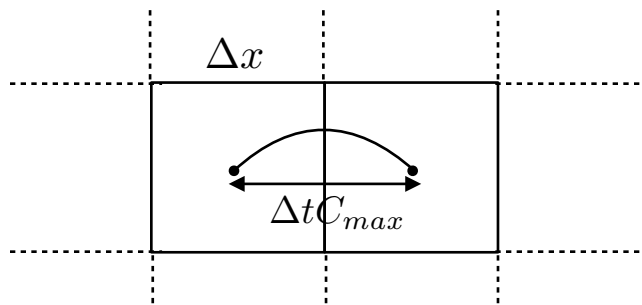
$$\max |u_i^{n+1}| \leq \max |u_i^n|$$

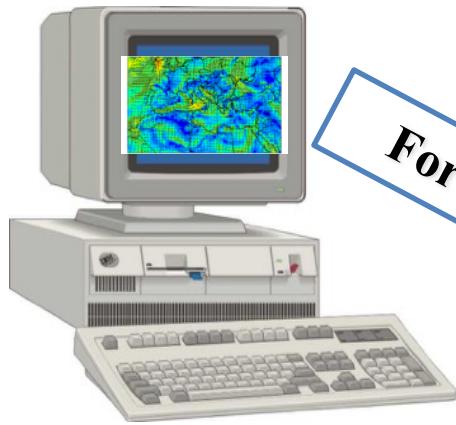
αυτό ισχύει όταν $0 \leq \mu \leq 1$ ή

$$\frac{\Delta x}{\Delta t} \geq C$$

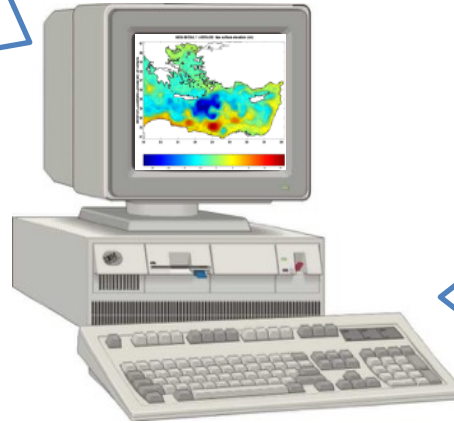
για όλα τα C δηλαδή

$$\frac{\Delta x}{\Delta t} \geq C_{max} \text{ or } \Delta t \leq \frac{\Delta x}{C_{max}}$$





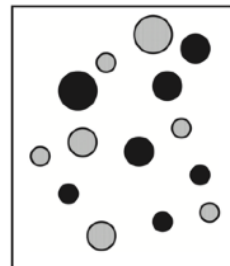
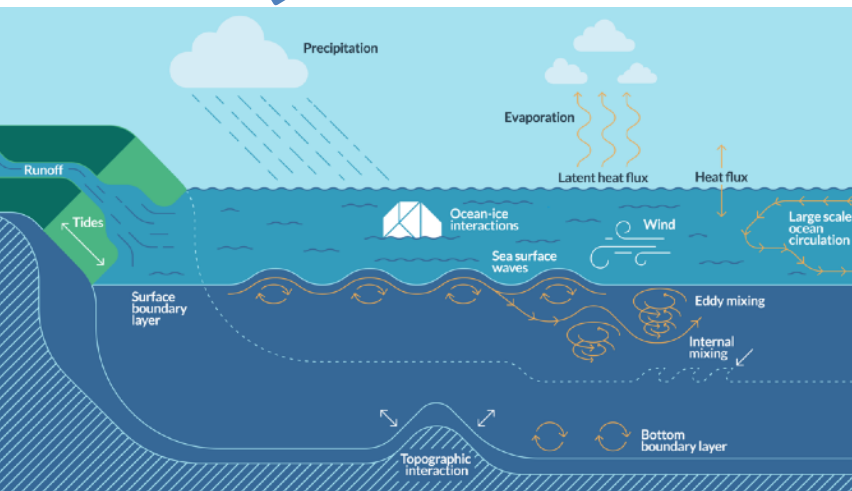
Forcing errors



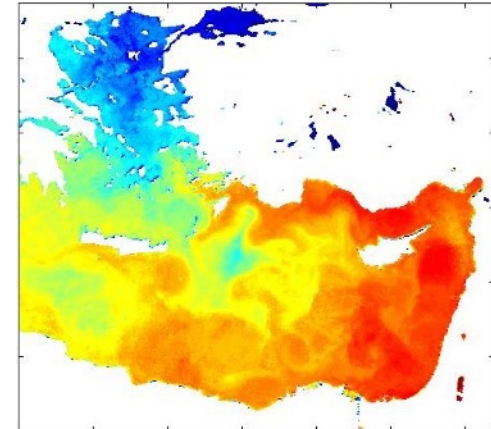
Numerical errors

Physics errors

Initial/boundary error

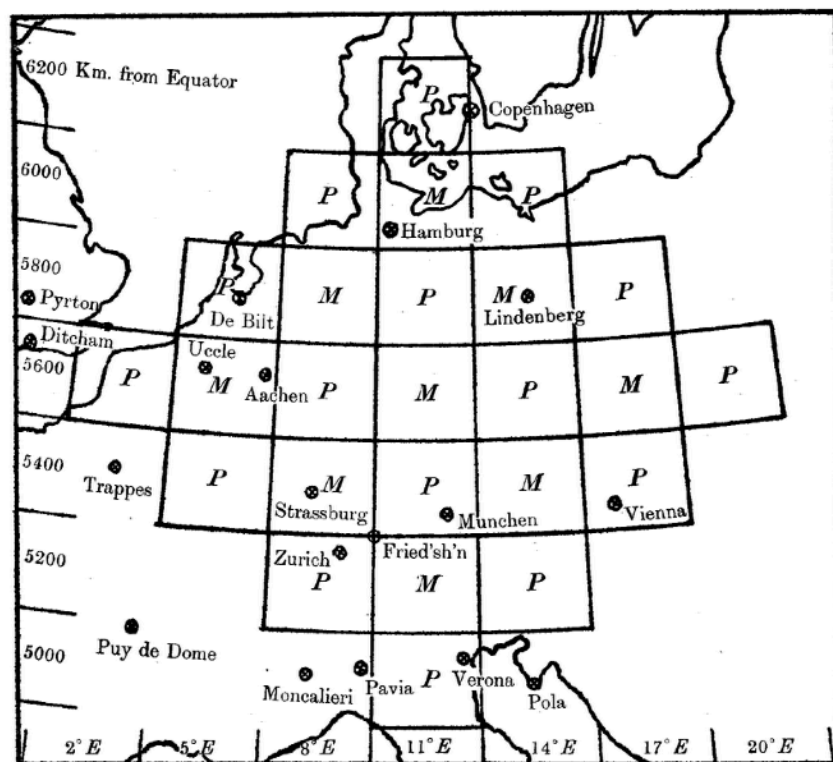


**Sub-grid scale
parameterization**



Πώς μπορούμε να μειώσουμε τα σφάλματα: Αφομοίωση δεδομένων (data assimilation)

In 1922, **Lewis Fry Richardson** published the first attempt at forecasting the weather numerically. Using a hydrostatic variation of Bjerknes's primitive equations, Richardson produced by hand a 6-hour forecast for the state of the atmosphere over two points in central Europe, taking at least six weeks to do so. His forecast calculated that the change in surface pressure would be 145 millibars, an unrealistic value incorrect by two orders of magnitude. The large error was caused by an imbalance (inconsistency) in the pressure and wind velocity fields used as the initial conditions in his analysis, indicating the need for a **data assimilation scheme**.



MAP OF POINTS FOR PRESSURE (P) AND MOMENTUM (M) USED IN THE EXAMPLE of Ch. 9.

NOTE: These points are placed at the centres of the chequers, and to the centres also the latitude and longitude refer. Each chequer measures 3° from west to east and 200 km from south to north.

* *Die physikalischen Einwirkungen des Waldes*, Berlin, Verlag von Wiegandt, Hempel und Parey, 1873.

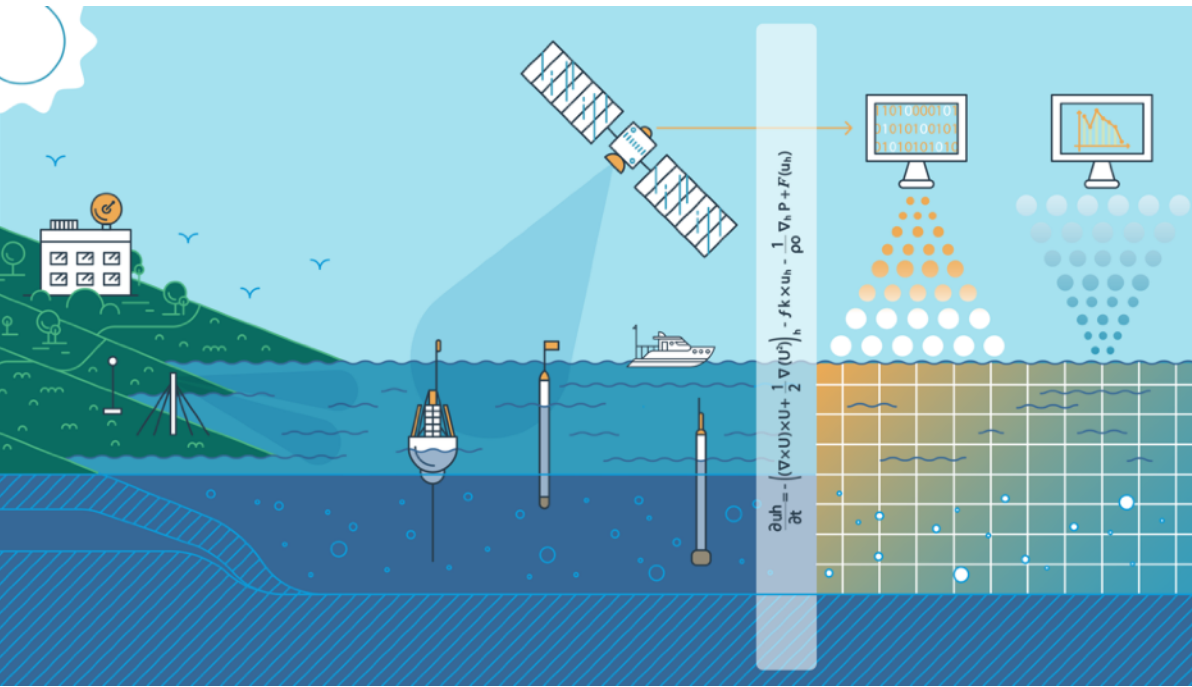
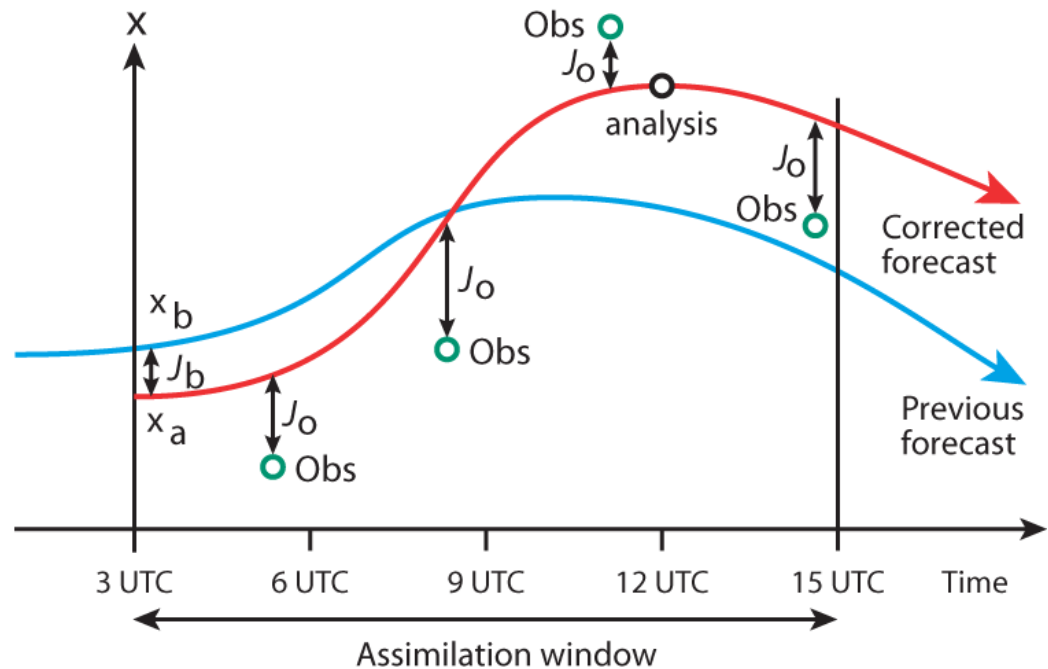
Lynch, Peter, 2008, The origins of computer weather prediction and climate modeling, *Journal of Computational Physics*. **227** (7): 3431–3444. Bibcode:2008JCoPh.227.3431L. doi:10.1016/j.jcp.2007.02.034.

Lynch, Peter, 2006, *The Emergence of Numerical Weather Prediction, Richardson's Dream*, Cambridge University Press. pp. 1–27. ISBN 978-0-521-85729-1.

Combining Observations and Models (Data Assimilation)



The quality and the structure of the observations are taken into account, as are the dynamics and the physics of the forecast model to ensure the observations are used in a dynamical consistent way.



A numerical investigation of the oceanic general circulation

By KIRK BRYAN and MICHAEL D. COX, *Geophysical Fluid Dynamics Laboratory,
Environmental Science Services Administration, Washington, D.C.*

1967

A NUMERICAL INVESTIGATION OF THE OCEANIC GENERAL CIRCULATION

57

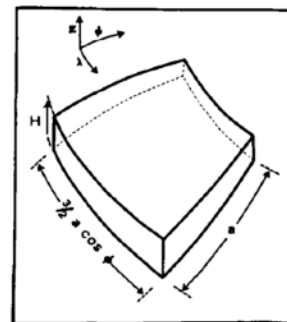


Fig. 2a

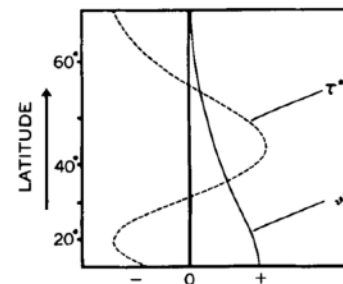


Fig. 2b

FIG. 2. (a) Sketch of the basin, (b) The temperature specified at the surface, θ^* , and the x-component of the surface wind stress.

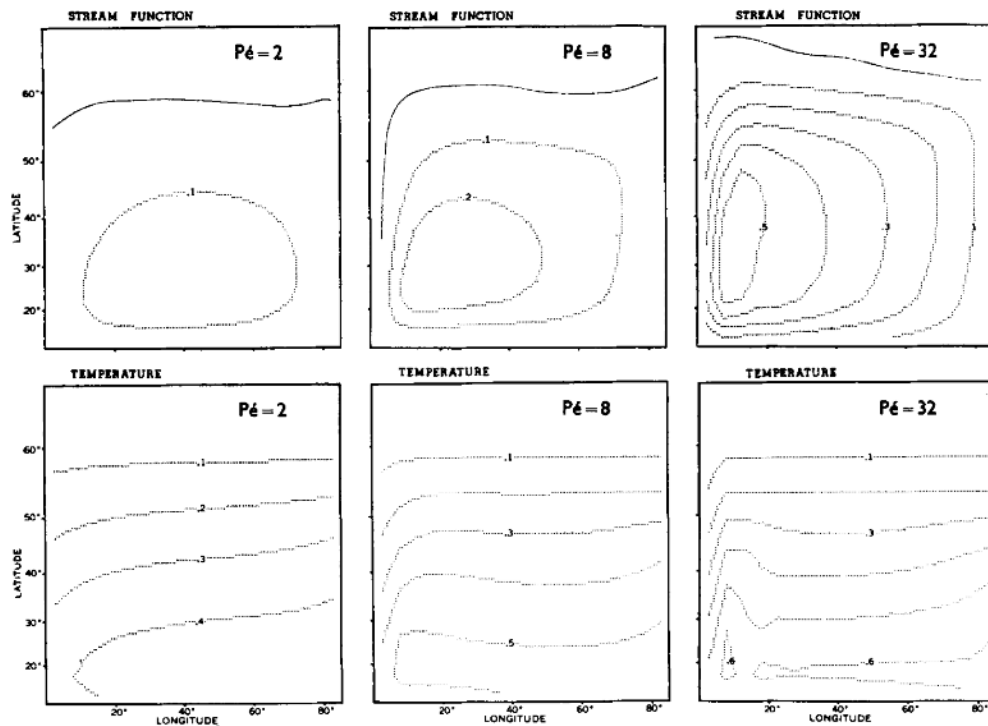


FIG. 4. Horizontal patterns of stream lines and temperature at $z = -0.6d$ corresponding (from left to right) to cases II, III and I. $Pé = 2, 8$ and 32 indicate strong, moderate and weak lateral mixing of apparent temperature. Other parameters are held constant.

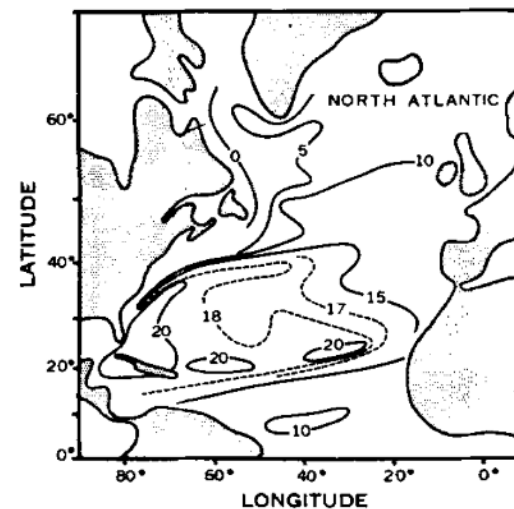


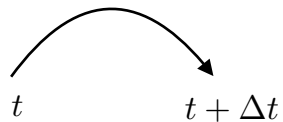
FIG. 9. The observed temperature pattern at a level 200 m below the surface in the North Atlantic based on *The Meteor Atlas* (Wüst & Defant, 1936).

a. The time coordinate problem

$$\frac{\partial \phi(t)}{\partial t} = f(t)$$

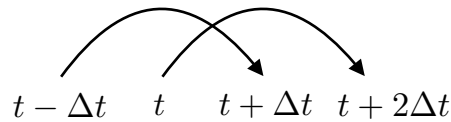
$$\frac{\phi(t + \Delta t) - \phi(t)}{\Delta t} = f(t)$$

Euler - Forward

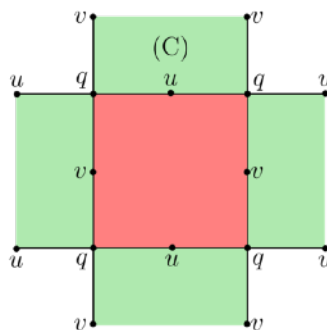
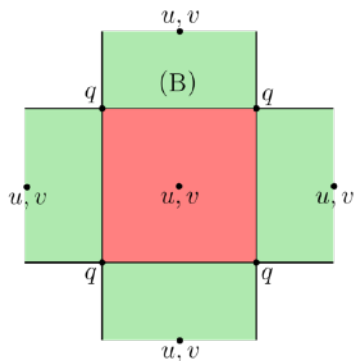
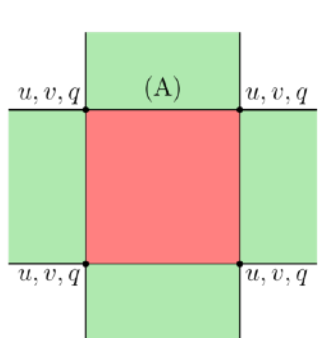


$$\frac{\phi(t + \Delta t) - \phi(t - \Delta t)}{2\Delta t} = f(t)$$

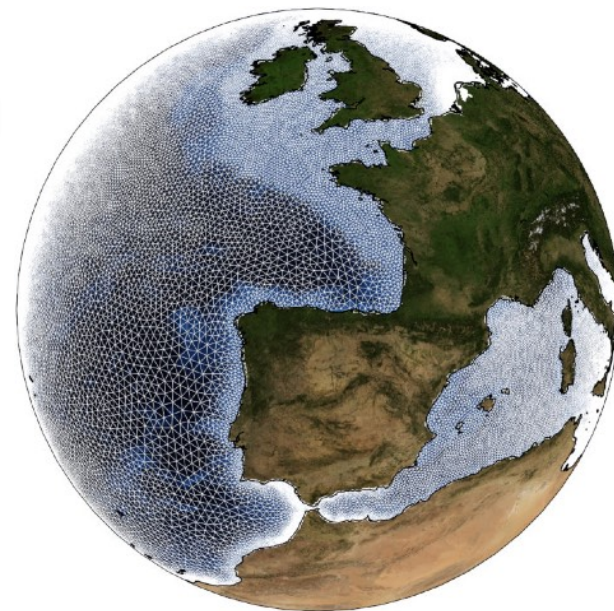
Leapfrog



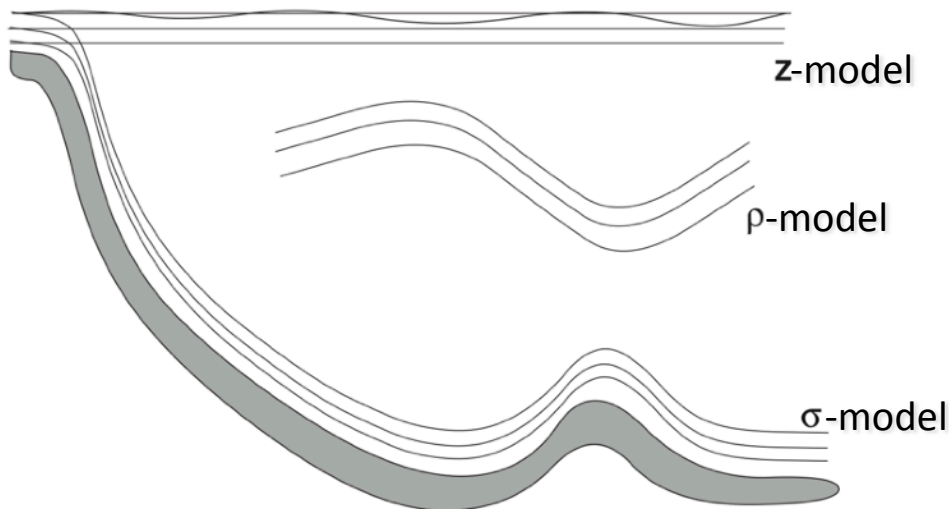
b. The horizontal coordinate problem



... and
more

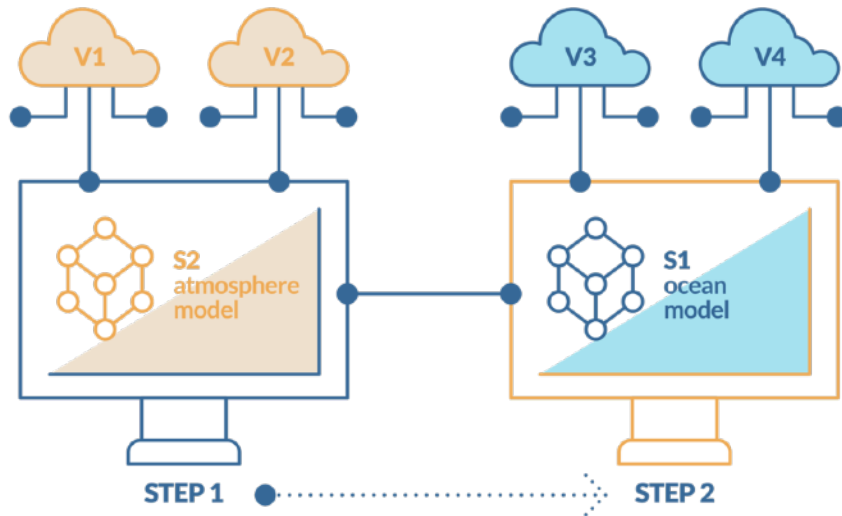
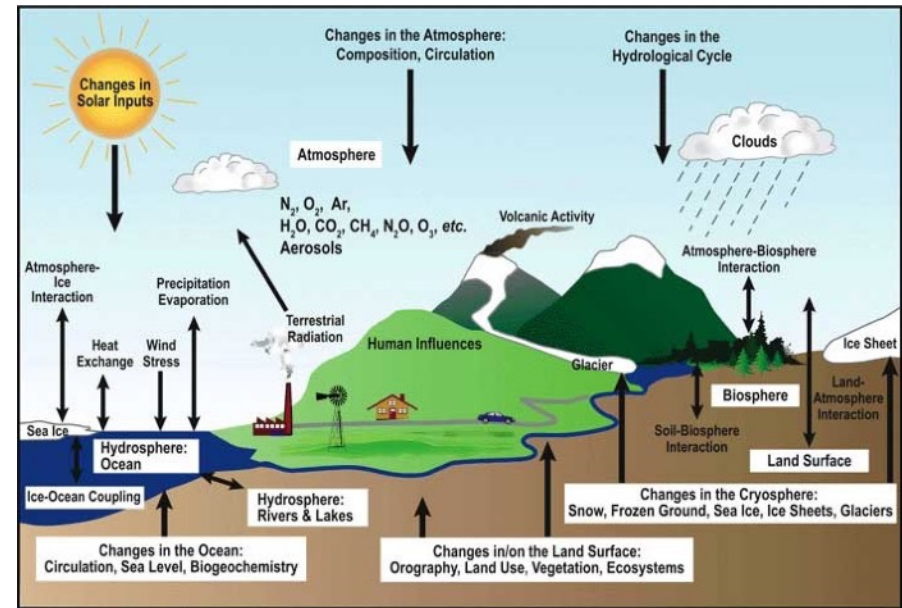
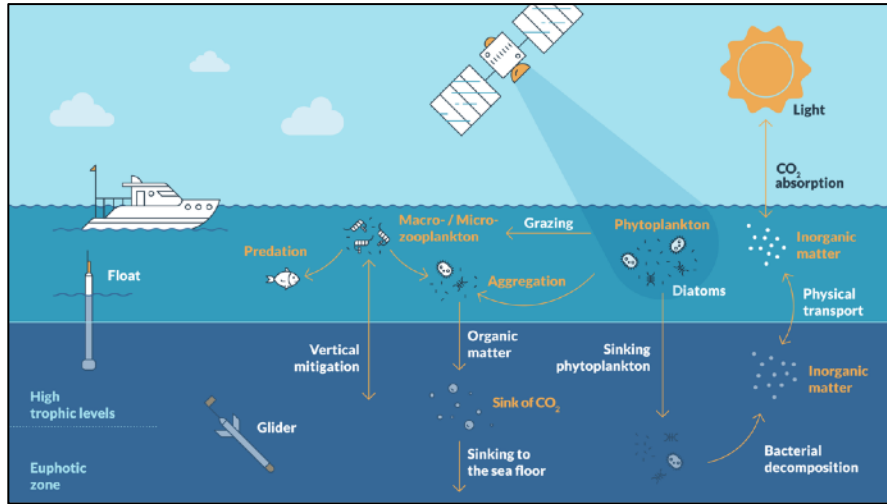


c. The vertical coordinate problem

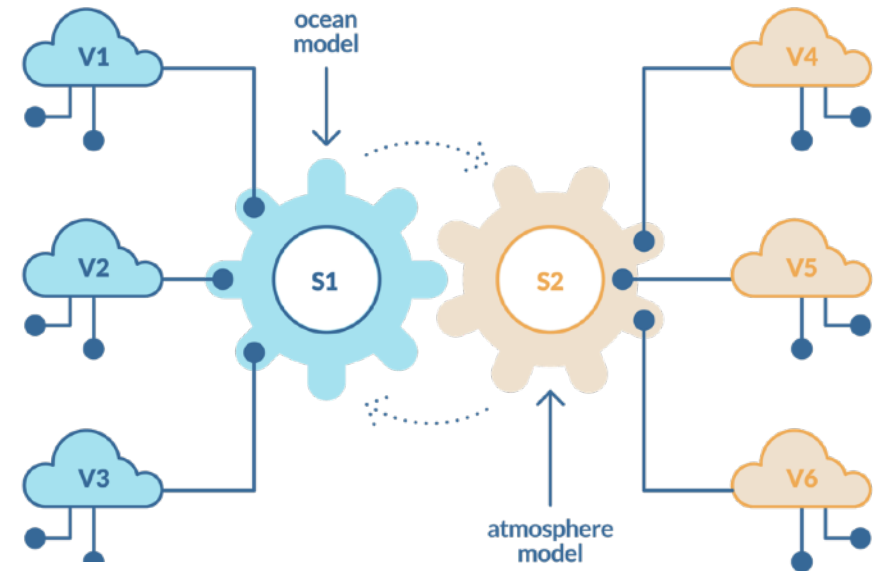


... and
combinations

Coupled models



S: systems
V: inputs

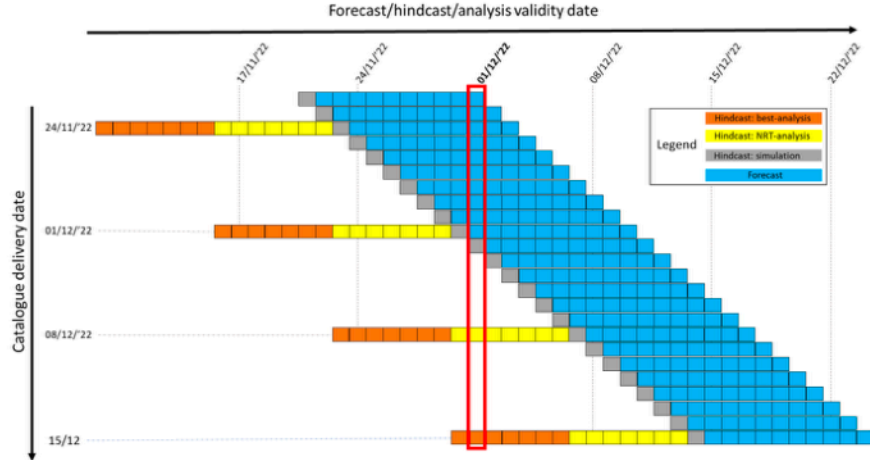


Copernicus
Europe's eyes on Earth

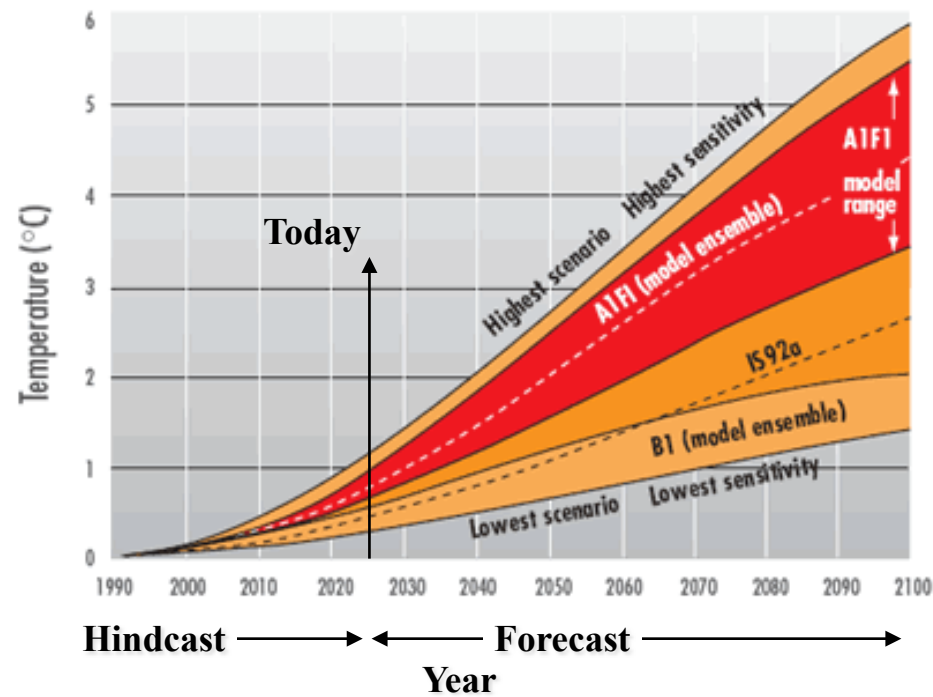


Copernicus
Marine Service

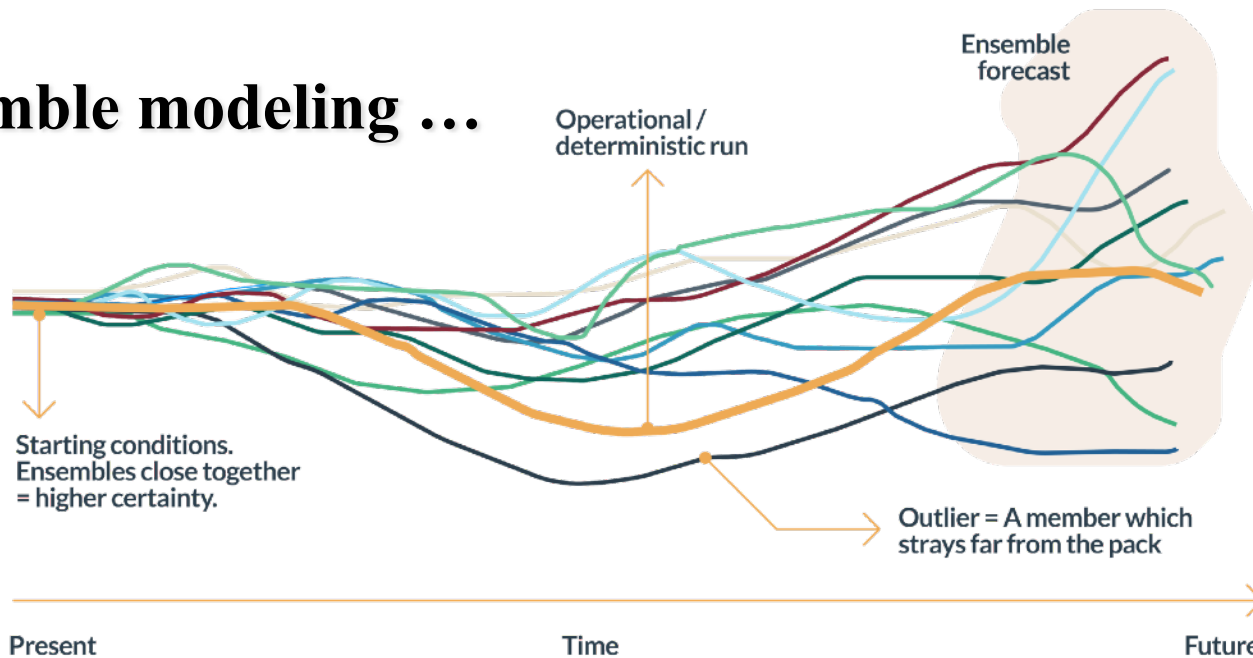
... and more components



Ocean Forecast and Climate prediction

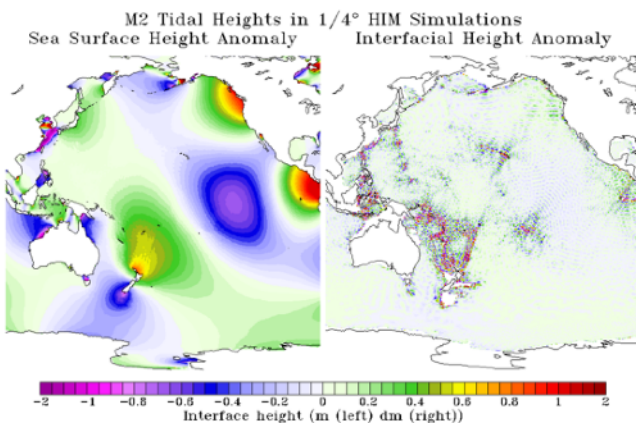
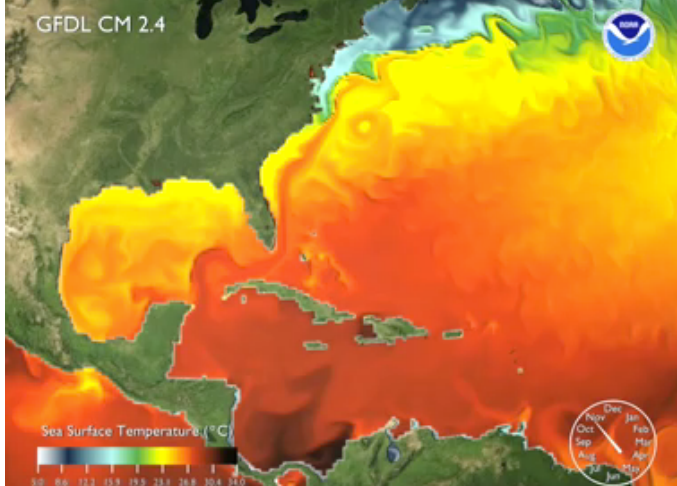


Ensemble modeling ...



... and
uncertainty
quantification

GFDL CM 2.4



Αριθμητικά Μοντέλα για τον ωκεανό

27/10/25 03:00 UTC : Significant wave height(m) and direction

