Breve storia della modellistica numerica fluido-dinamica

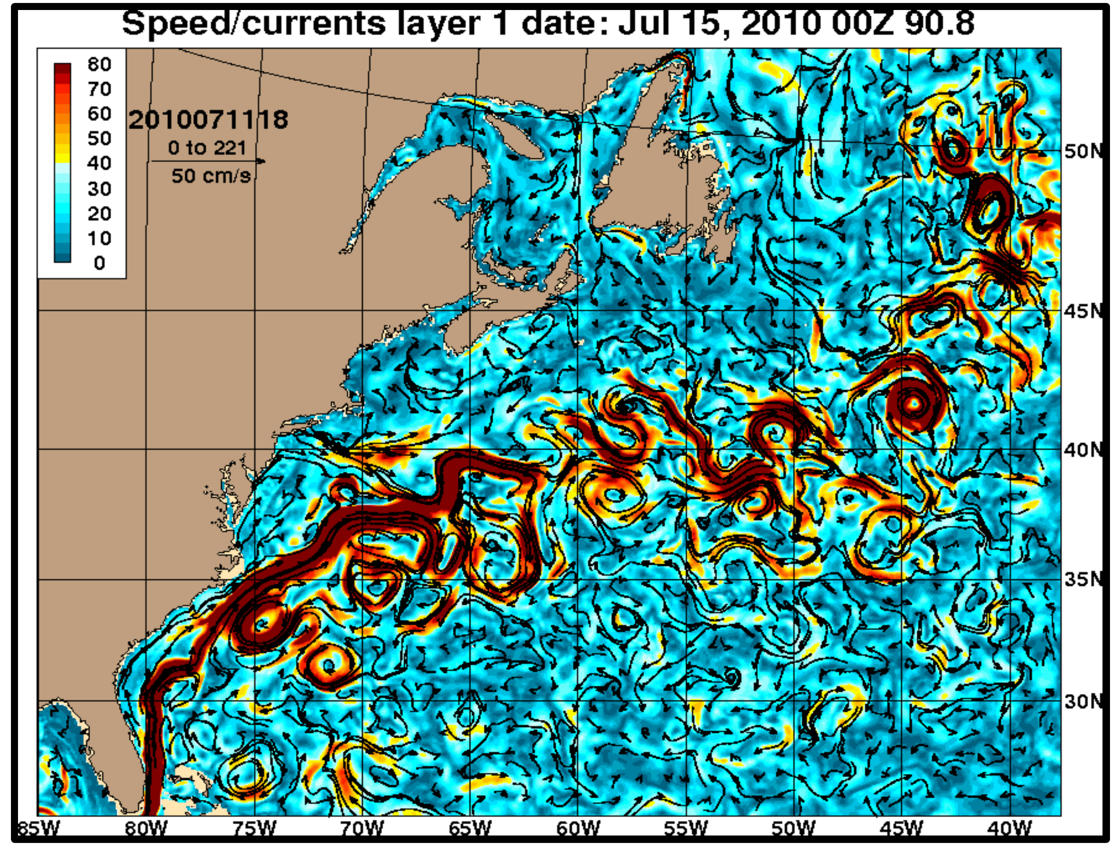
Andrea Doglioli

Mercoledì 14 Luglio 2010

Sala conferenze ISMAR-CNR, Venezia

I E R I

O G G I



Mappa della Corrente de Golfo di Franklin-Folger, stampata nel 1769-1770.

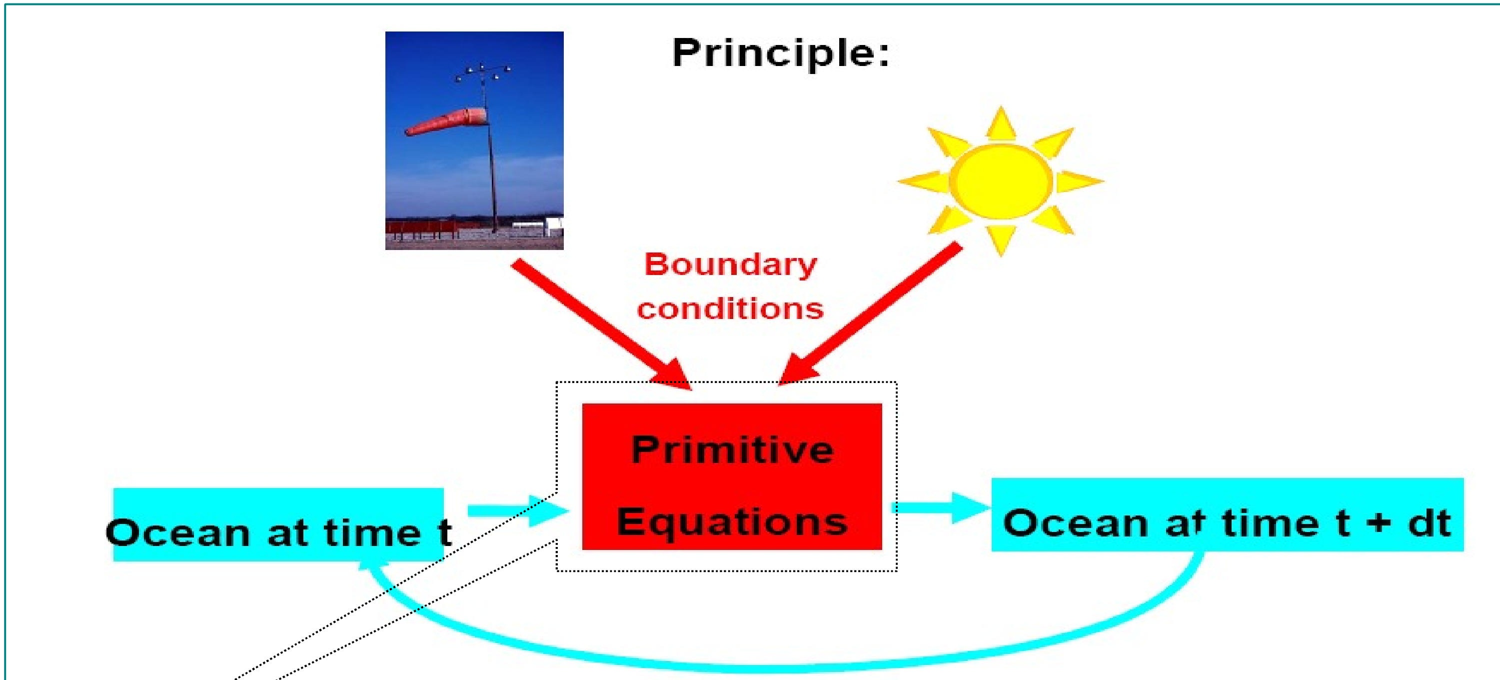
Intensità e direzione della corrente superficiale di domani calcolata dal modello globale (1/12°) HYCOM

http://hdl.loc.gov/loc.gmd/g9112g.ct000753

http://www7320.nrlssc.navy.mil/GLBhycom1-12/glfstr.html

Cos'é un modello numerico dell'oceano?

Un *software* basato su questo principio



Equazioni per

- Velocità
- Temperatura
- Salinità

Equations to solve : the primitive equations (PE)

$$\frac{\partial u}{\partial t} + u.\nabla u - fv = -\frac{1}{\rho_0}\frac{\partial P}{\partial x} + A_h \nabla_h^2 u + A_v \frac{\partial^2 u}{\partial z^2}$$

$$\frac{\partial v}{\partial t} + u.\nabla v + fu = -\frac{1}{\rho_0}\frac{\partial P}{\partial y} + A_h \nabla_h^2 v + A_v \frac{\partial^2 v}{\partial z^2}$$

$$0 = \frac{\partial P}{\partial z} + \rho g$$

$$0 = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}$$

$$\frac{\partial T}{\partial t} + u.\nabla T = K_h \nabla_h^2 T + K_v \frac{\partial^2 T}{\partial z^2}$$

$$\frac{\partial S}{\partial t} + u.\nabla S = K_h \nabla_h^2 S + K_v \frac{\partial^2 S}{\partial z^2}$$

$$\rho = \rho(T, S, z)$$

Breve storia dei modelli atmosferici ed oceanici

1904 Bjerknes

se si conoscono con sufficente precisione

- lo stato dell'atmosfera a un dato istante (i.e. le condizioni iniziali) e
- le leggi che ne governano l'evolversi, allora

possibile prevedere l'evolversi del tempo

Bjerknes V., 1904 : Das problem von der Wettervorhersage, betrachtet vom Standpunkt der Mechanik und der Physik. *Meteor. Zeitschrift*, 21, 1-7. Le problème de la prévision du temps du point de vue de la mécanique et de la physique. Traduction en français par D. Gondouin, 1995, *La Météorologie* 8[e] série, 9, 55-62.

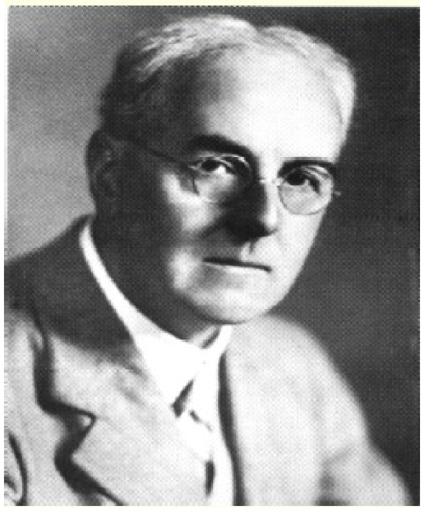
1914 Bjerknes

identificazione de problemi pratici per risolvere numericamente le complicate equazioni

Breve storia dei modelli atmosferici ed oceanici

1922 Richardson

si possono introdurre delle approssimazioni fisiche per semplificare il problema matematico e suddividere i conti da svolgere fra un gran numero di persone ben organizzate.



Idea della **fabbrica per prevedere il tempo!**

Richardson L. F., 1922 : *Weather Prediction by Numerical Process*. Cambridge University Press, reprinted Dover, 1965, 236 p.

Suddivide l'atmosfera in una griglia di maglia 230 km (in latitudine) per 200 km (in longitudine), trascura la facia equatoriale ed ottine 3 200 colonne verticali attorno alla Terra.
In verticale suddivide in tre strati a 4, 7 et 12 km d'altitudine e propone un passo temporale di 3 ore. Per essere più rapido dell'evoluzione reale del tempo, prevede gli servino 64 000 persone

Richardson L. F. (1922) Weather Prediction by Numerical Process

"After so much hard reasoning, may one play with a fantasy? Imagine a large hall like a theatre, except that the circles and galleries go right round through the space usually occupied by the stage. The walls of this chamber are painted to form a map of the globe. The ceiling represents the north polar regions, England is in the gallery, the tropics in the upper circle, Australia on the dress circle and the Antarctic in the pit.

A myriad computers are at work upon the weather of the part of the map where each sits, but each computer attends only to one equation or part of an equation. The work of each region is coordinated by an official of higher rank. Numerous little "night signs" display the instantaneous values so that neighbouring computers can read them. Each number is thus displayed in three adjacent zones so as to maintain communication to the North and South on the map.

From the floor of the pit a tall pillar rises to half the height of the hall. It carries a large pulpit on its top. In this sits the man in charge of the whole theatre; he is surrounded by several assistants and messengers. One of his duties is to maintain a uniform speed of progress in all parts of the globe. In this respect he is like the conductor of an orchestra in which the instruments are slide-rules and calculating machines. But instead of waving a baton he turns a beam of rosy light upon any region that is running ahead of the rest, and a beam of blue light upon those who are behindhand.

[…] "

Richardson L. F. (1922) Weather Prediction by Numerical Process

"[…]

Four senior clerks in the central pulpit are collecting the future weather as fast as it is being computed, and despatching it by pneumatic carrier to a quiet room. There it will be coded and telephoned to the radio transmitting station. Messengers carry piles of used computing forms down to a storehouse in the cellar.

In a neighbouring building there is a research department, where they invent improvements. But these is much experimenting on a small scale before any change is made in the complex routine of the computing theatre. In a basement an enthusiast is observing eddies in the liquid lining of a huge spinning bowl, but so far the arithmetic proves the better way. In another building are all the usual financial, correspondence and administrative offices. Outside are playing fields, houses, mountains and lakes, for it was thought that those who compute the weather should breathe of it freely."

1922 Richardson: la **fabbrica per prevedere il tempo**

Un sistema di calcolo umano (64000 persone) automatico e parallelo con una potenza di calcolo di circa 1 Flops (*Floating point operations per second*).

«Il sogno di Richardson»

Disegno di François Schuiten (2000)

Il modello di Richardson, 1922

Una prova con un numero ridotto di personale diede un *risultato molto deludente:*

- prevista una variazione di pressione circa 145 hPa in 6 ore, un valore praticamente impossibile (già 20 hPa sono un caso eccezionale)
- in realtà poi la variazione reale fu quasi nulla...

Dove fu l'errore?

Non nella concezione del modello, ma nella **poca potenza** di calcolo e nei **dati sperimentali, scarsi e poco precisi**

Oggi esiste una fitta rete di misure meteorologiche

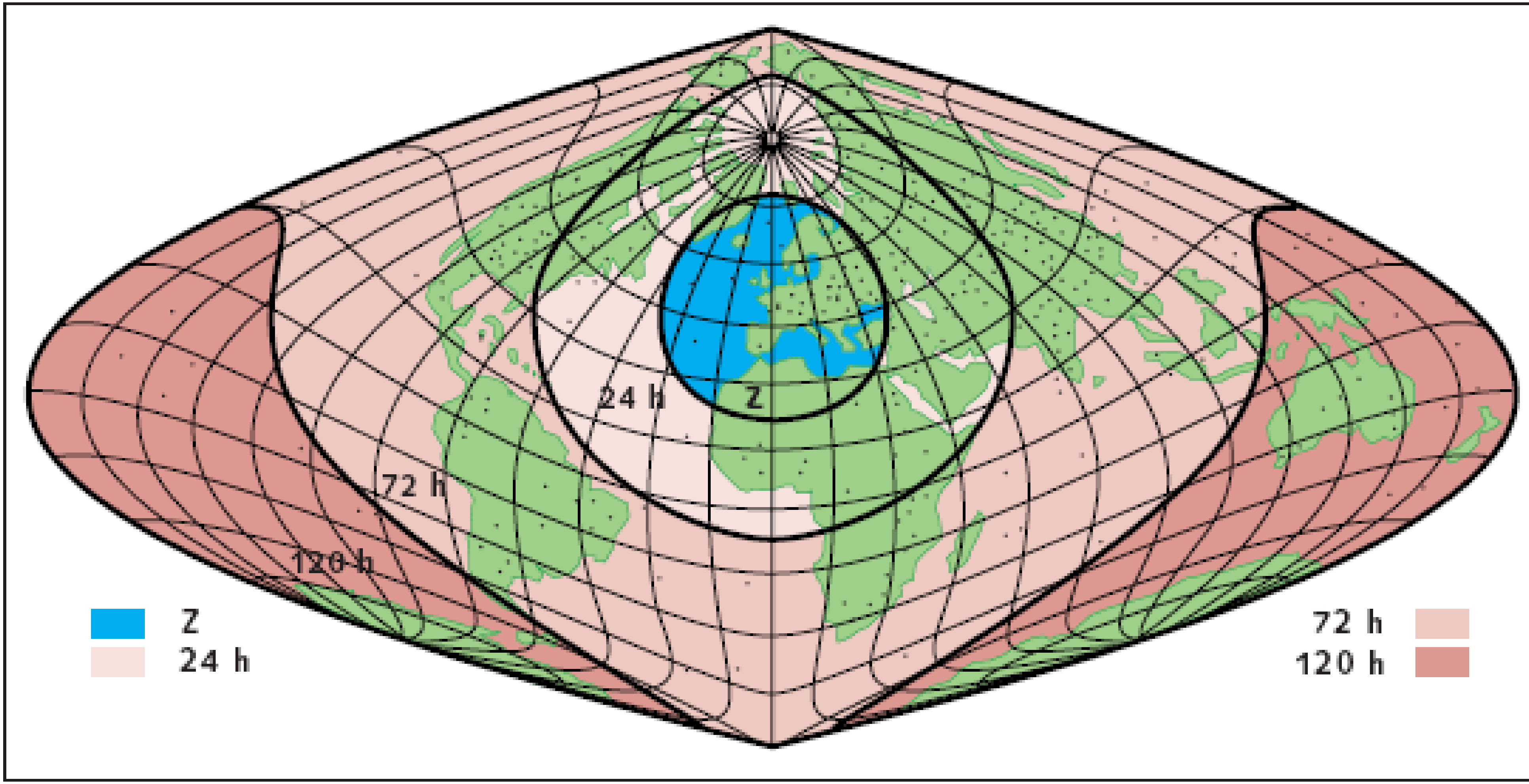


Figure 4 - Répartition mondiale des stations de radiosondage et indication des régions sur lesquelles des observations sont nécessaires pour réaliser des prévisions à échéance de 1, 3 et 5 jours sur la zone centrale Z. (Document CEPMMT)

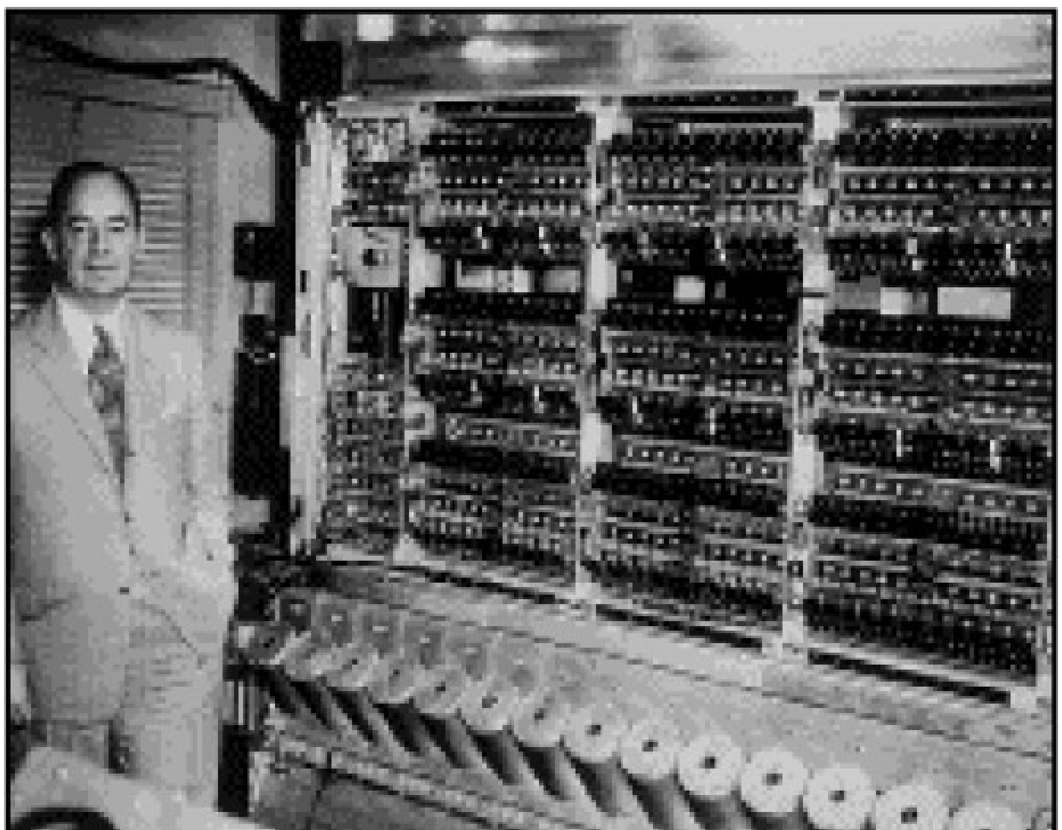
Apparizione e rapida evoluzione dei calcolatori elettronici

1946

ENIAC (*Electronic Numerator Integrator Analyser and Computer*), 500 Flops.
Von Neumann propose d'utilizzarlo per le previsioni meteorologiche

1949

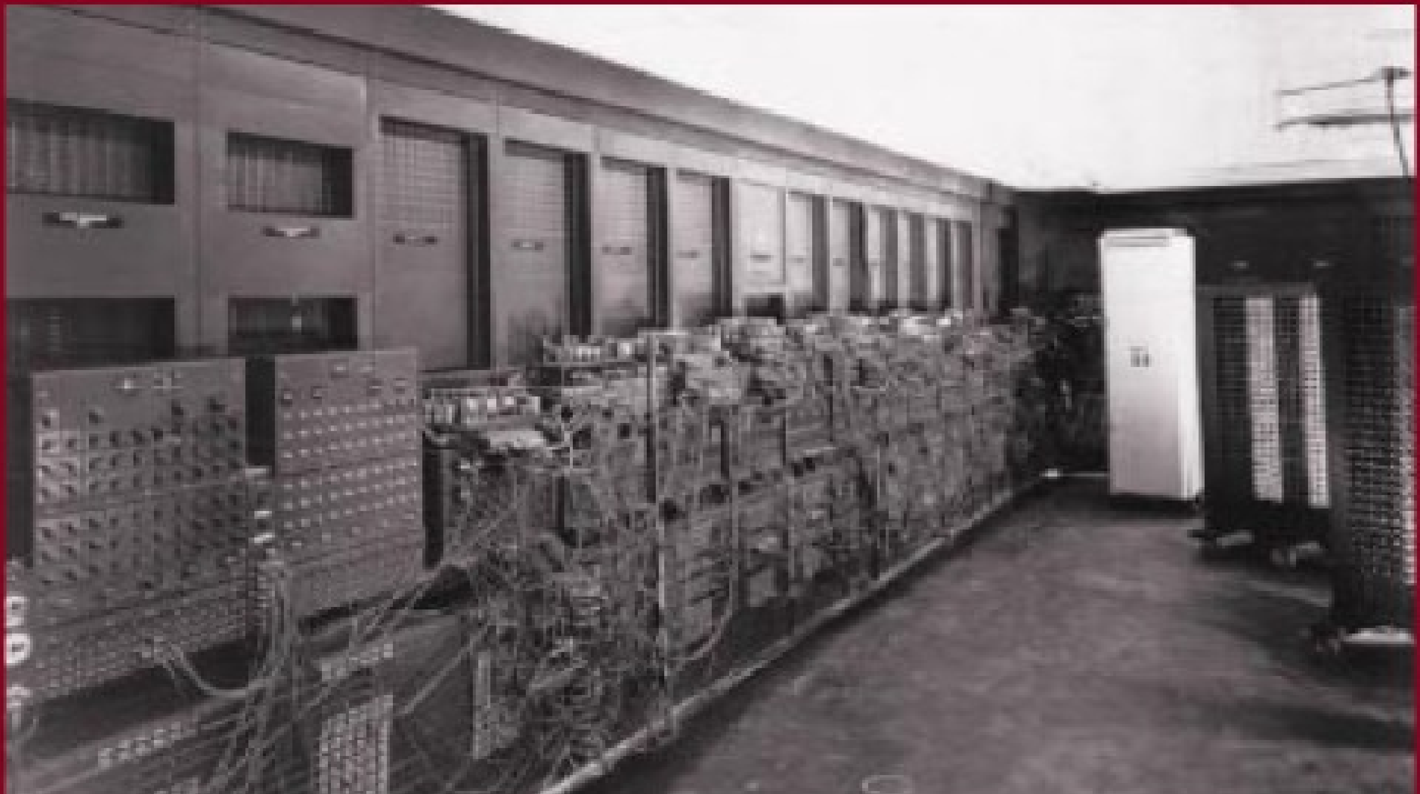
Modello barotropico 2D di Charney



Jule Charney (1917-1981). (©Nasa/ESCDC)

L'expérience historique de 1950

C'est à partir du 5 mars 1950 qu'une équipe composée de Jule Charney, Ragnar Fjörtoft, Joseph Smagorinsky, Georges Platzmann et John Freeman entreprend la mise en œuvre des calculs sur la machine Eniac installée à Aberdeen. Sur ce « monstre » comprenant 42 armoires bourrées de près de 6 000 relais, de 18 000 tubes électroniques et de bien d'autres composants, la programmation nécessite de manipuler une multitude d'interrupteurs répartis sur divers panneaux de contrôle. Dans ces conditions, pas moins de trente-trois jours et trente-trois nuits sont nécessaires aux membres de l'équipe, se relayant pratiquement sans interruption, pour effectuer trois prévisions à 24 heures d'échéance à l'aide du modèle simplifié d'atmosphère. Dans une lettre datée du 10 avril 1950 et adressée à Georges Platzmann, Jule Charney écrit : « *[...] La dernière semaine [...]* nous avons fait une prévision à 24 heures pour le 31 janvier 1949 et une autre pour le 14 février 1949 durant laquelle deux cut-off ont eu lieu. Les résultats ont montré qu'avec certaines exceptions bien marquées, les caractéristiques de grande échelle de l'écoulement sur la surface 500 hPa pouvaient être *prévues de façon barotrope* » (Platzmann, 1979). Le coupd'envoi de l'aventure de la prévision numérique vient d'être donné, donnant ainsi réalité au rêve prémonitoire de Richardson.



La partie gauche de l'ordinateur Eniac lorsqu'il était installé au Ballistic Research Laboratory de l'armée américaine. (US Army photo)

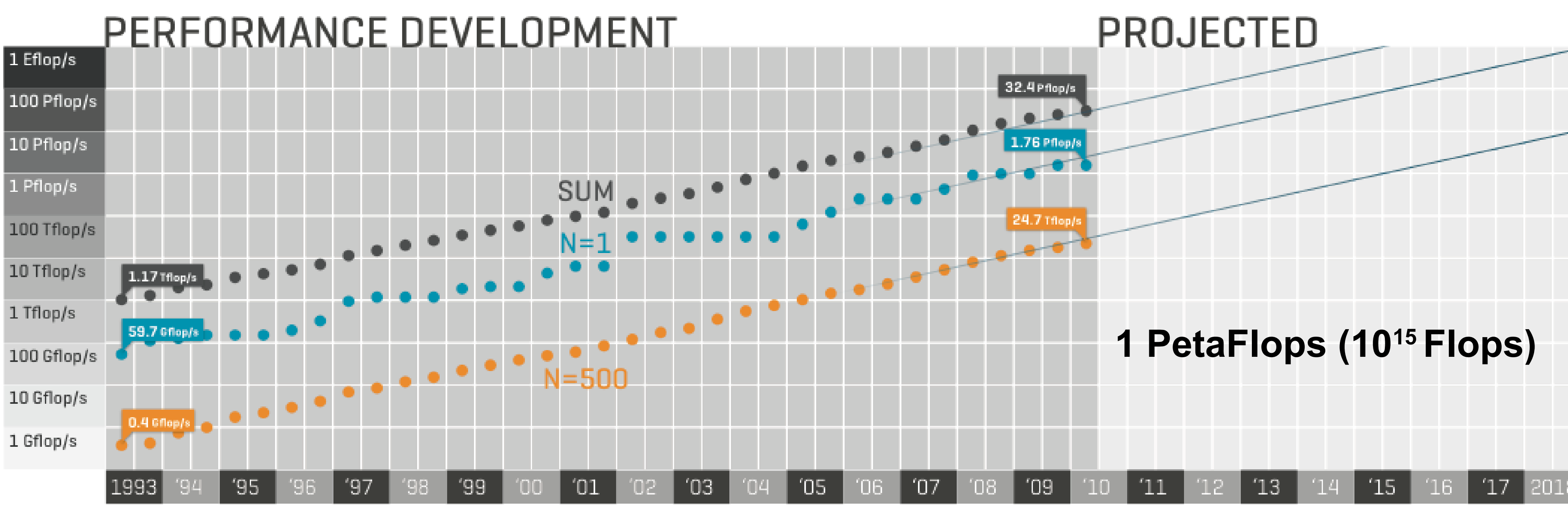
Legge di Moore (empirica) : **le prestazioni dei computer raddoppiano ogni 18 mesi**

TOP500®
JUNE 2010

PRESENTED BY
UNIVERSITY OF MANNHEIM
http://www.uni-mannheim.de/english/
ICL UT INNOVATIVE COMPUTING LABORATORY THE UNIVERSITY OF TENNESSEE
http://icl.cs.utk.edu/
BERKELEY LAB
http://www.lbl.gov/

FIND OUT MORE AT
http://www.top500.org/

	NAME/MANUFACTURER/COMPUTER	LOCATION	COUNTRY	CORES	R_{max}
1	**Jaguar**, Cray XT5 6-core 2.6 GHz	DOE / OS / ORNL	USA	224162	1.76
2	**Nebulae**, Dawning TC3600 Blade, Intel X5650, NVidia Tesla C2050 GPU	National Supercomputing Centre in Shenzhen (NSCS)	China	120640	1.27
3	**Roadrunner**, IBM BladeCenter QS22/LS21 Cluster, PowerXCell 3.2 Ghz / Opteron 1.8 GHz, Voltaire Iband	DOE / NNSA / LANL	USA	122400	1.04
4	**Kraken**, Cray XT5 6-core 2.6 GHz	NSF / U of Tennessee	USA	98928	.832
5	**Jugene**, IBM Blue Gene/P Solution	Forschungszentrum Juelich	Germany	294912	.826



Nuove architetture

SISD single instruction, single data: processore classico

SIMD single instruction, multiple data: processore vettoriale

MIMD multiple instruction, multiple data: processore parallelo

Memoria condivisa
Memoria distribuita (necessita riscrittura massiva del codice)

Seymour Cray (1925-1996). (© Gordon Bell)

Linguaggio di programmazione:
prevalentemente in FORTRAN

Ed in campo oceanografico?

Semtner, A.J. (1995) Modeling Ocean Circulation. *Science*, 269, 1397-1385;

"[…] Even though systematic observations began in the 1880s with pioneering observations by Nansen and others (3), the seagoing and theoretical efforts were mainly oriented toward describing large-scale circulation (4), which was often regarded as steady for lack of more detailed information.

It was not until the 1960s, when long-distance tracking of drifting buoys at mid-depth showed currents to be highly variable on quite small spatial scales (5), that oceanographers became aware of <u>the immensity of their task</u>.[...]"

Spirale di Ekman (1902)

$$\frac{du}{dt} - fv = -\frac{1}{\rho}\frac{\partial p}{\partial x} + F_x$$

$$\frac{dv}{dt} + fu = -\frac{1}{\rho}\frac{\partial p}{\partial y} + F_y$$

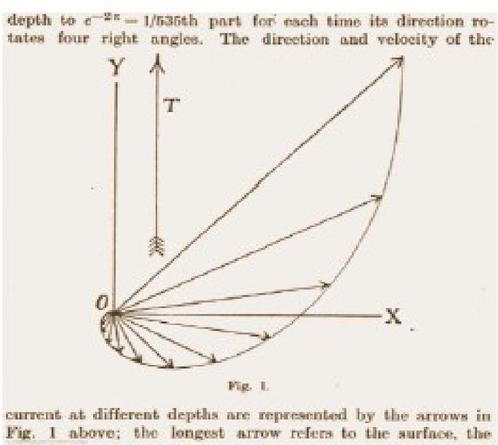
$$\frac{dw}{dt} = -\frac{1}{\rho}\frac{\partial p}{\partial z} - g + F_z$$

$$-f v_E = A_z \frac{\partial^2 u_E}{\partial z^2}$$

$$+f u_E = A_z \frac{\partial^2 v_E}{\partial z^2}$$

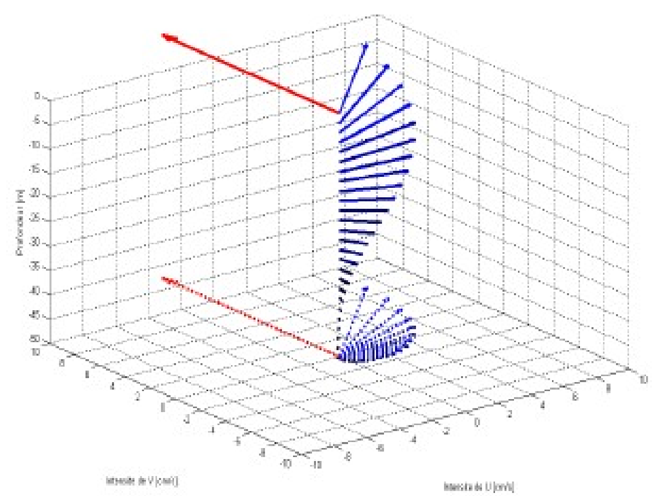
$$u = U_o e^{\frac{\pi}{D_E} z} \cos\left(\frac{\pi}{4} + \frac{\pi}{D_E} z\right)$$

$$v = U_o e^{\frac{\pi}{D_E} z} \sin\left(\frac{\pi}{4} + \frac{\pi}{D_E} z\right)$$


depth to $e^{-2\pi} = 1/535$th part for each time its direction rotates four right angles. The direction and velocity of the

current at different depths are represented by the arrows in Fig. 1 above; the longest arrow refers to the surface, the

figure du papier d'Ekman

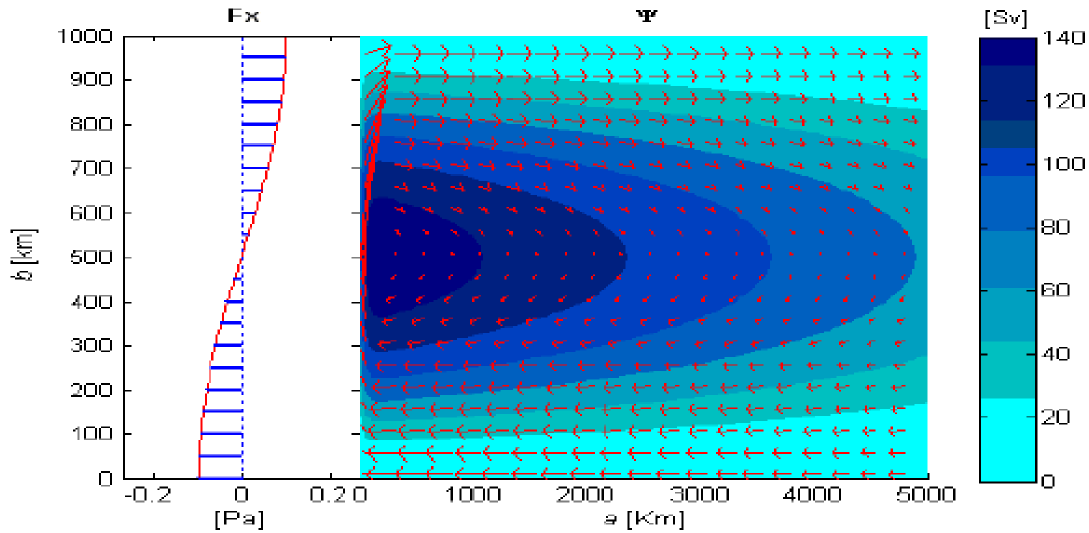


Circolazione de Sverdrup (anni 40) e di Stommel (1947)

$$\psi = \psi_I + \psi_S = \frac{F_o \pi}{\beta b} \sin\left(\frac{\pi y}{b}\right) a \left(2 - e^{-\frac{x}{\mu}} - \frac{x}{a}\right)$$

Venti Occidentali

Alisei



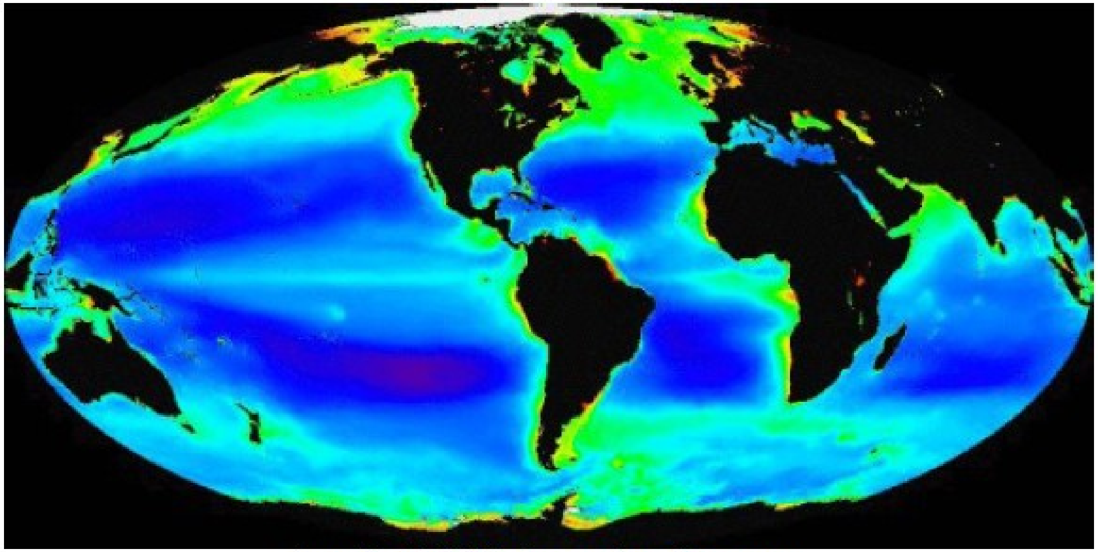
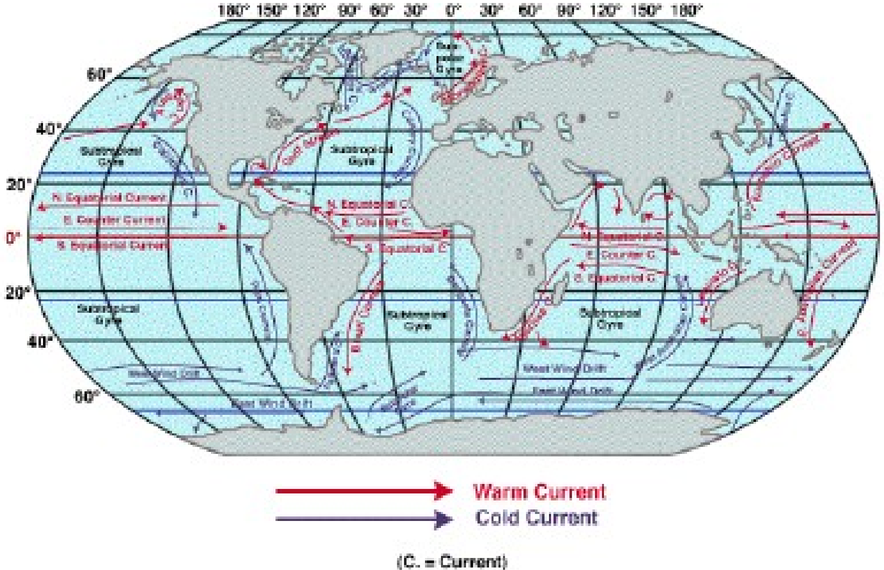


image SeaWIFS, http://oceancolor.gsfc.nasa.gov
chlorophylle-a (moyenne annuelle)



Richardson, P.L. (1979)
Gulf Stream Ring Trajectories,
***J. Physical Oceanogr.*, 10, 90-104**

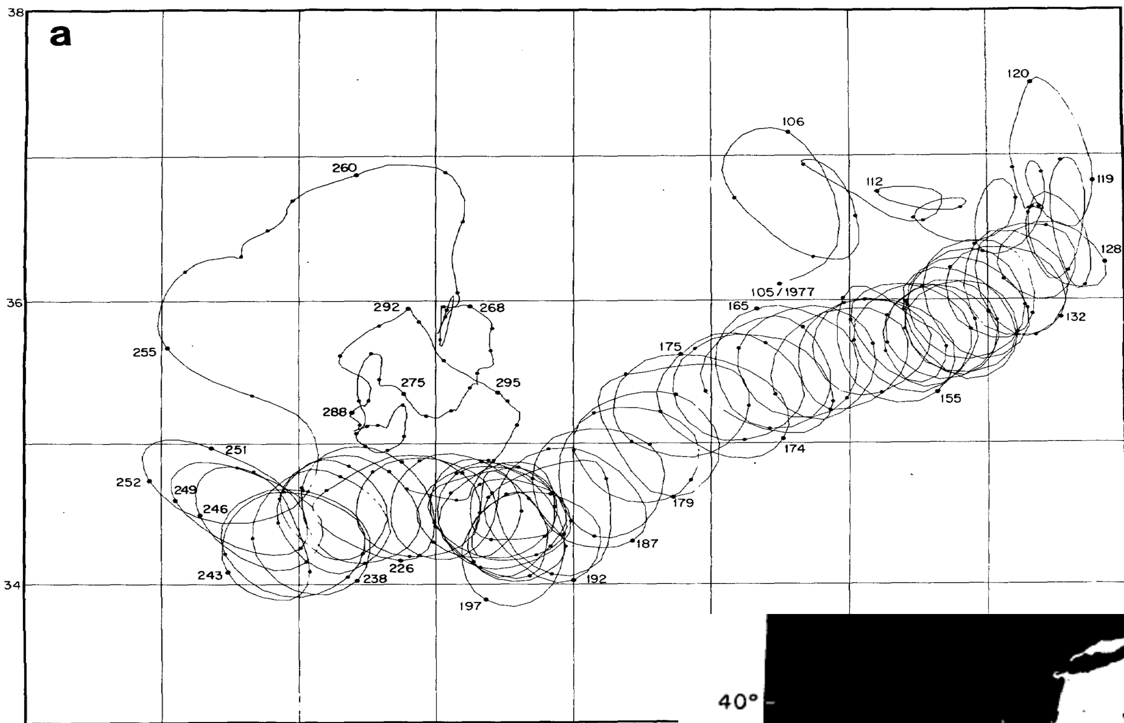


FIG. 3a. Trajectory of buoy 731 which was launched on 14 April 1977 (day 104) in ring Bob and

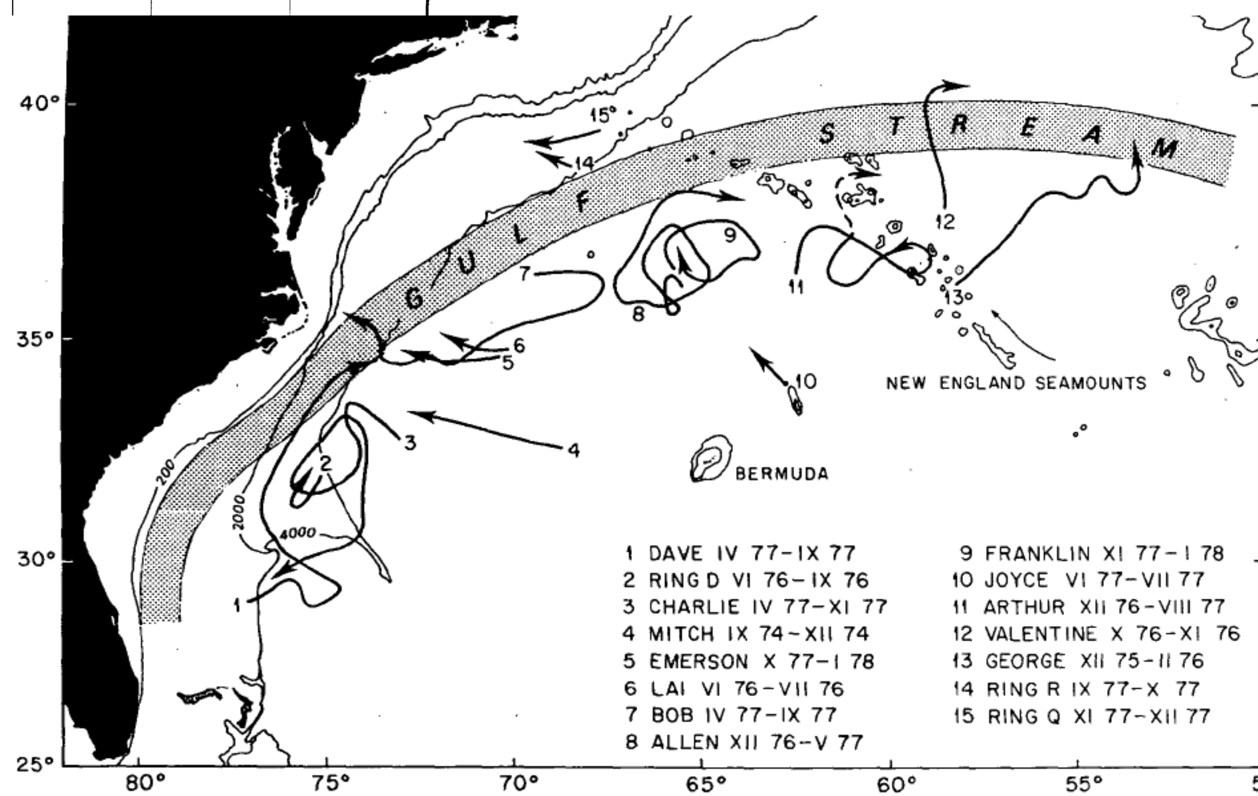
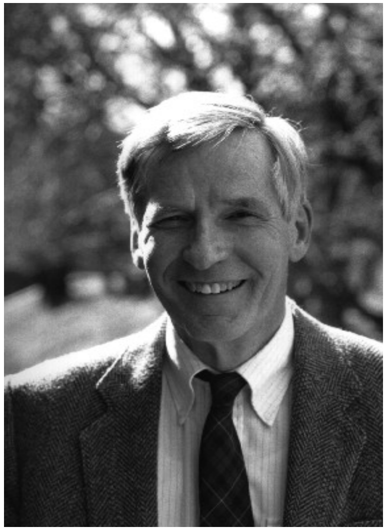


FIG. 8. The trajectories of all rings continuously tracked with free-drifting buoys plus one (ring 4) tracked by SOFAR floats (see Cheney *et al.*, 1976). The dates during which each ring was followed are given in Table 1. The mean path of the Gulf Stream is shown by shading.

Primi modelli oceanici

1963 : modello 2D
Bryan e colleghi del GFDL
Geophysical Fluid Dynamics Laboratory (GFDL)
(Princeton University &
the National Oceanic and Atmospheric Administration);



1969 : modello 3D di Bryan e colleghi.

330 JOURNAL OF PHYSICAL OCEANOGRAPHY VOLUME 2

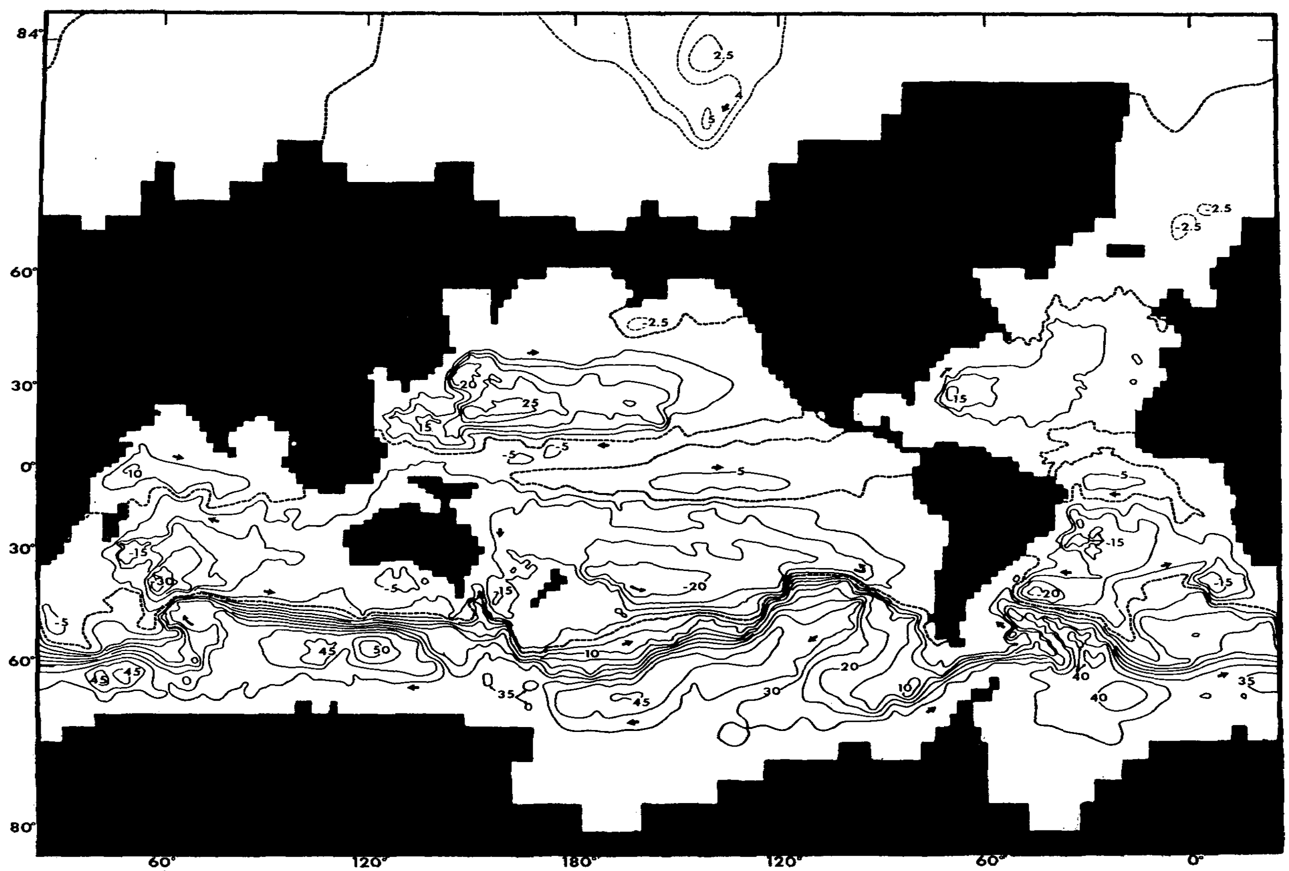
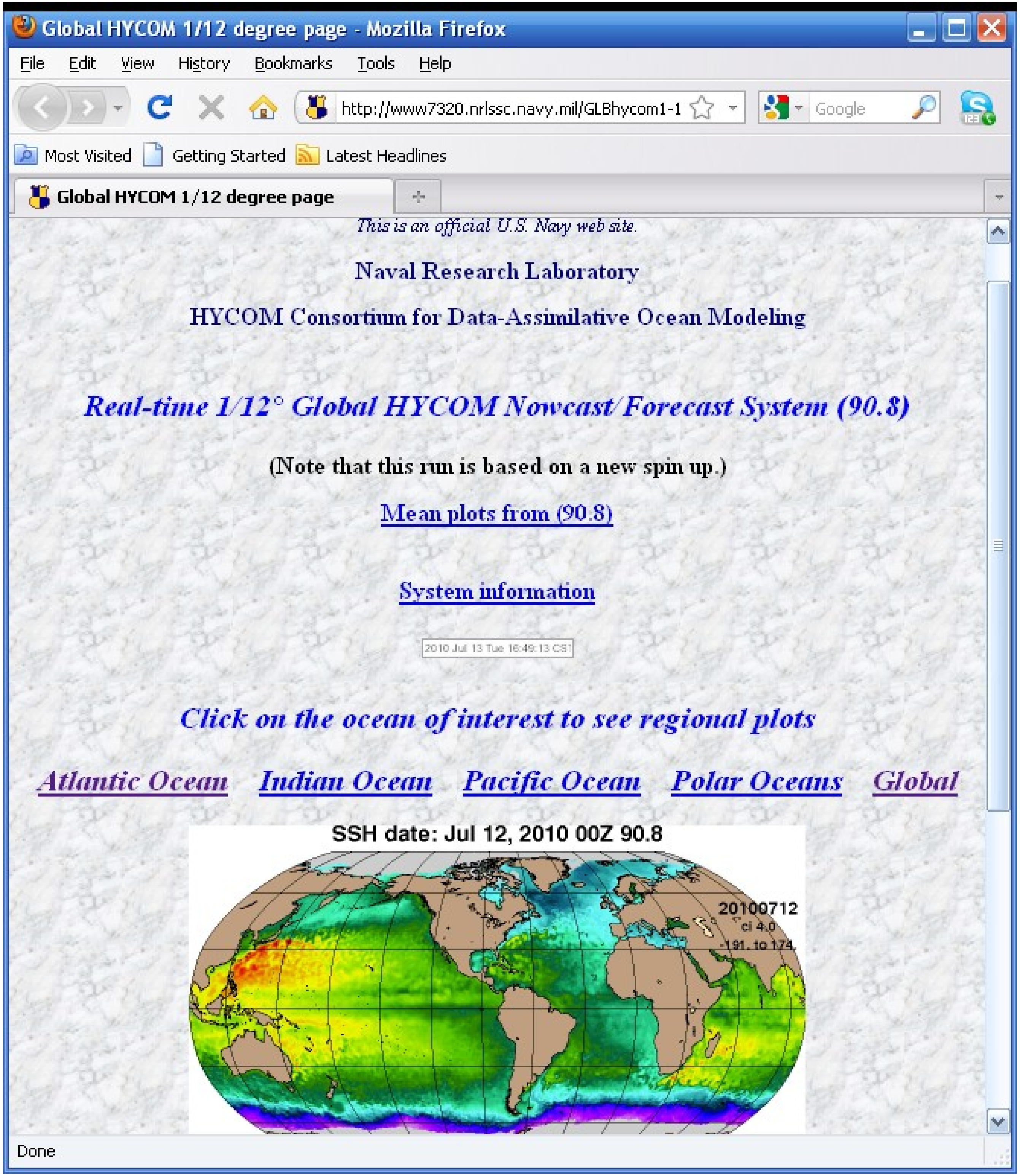


FIG. 8. Pattern of the mass transport streamfunction for the depth configuration shown in Fig. 5. A_M is equal to 4×10^8 cm^2 sec^{-1}.

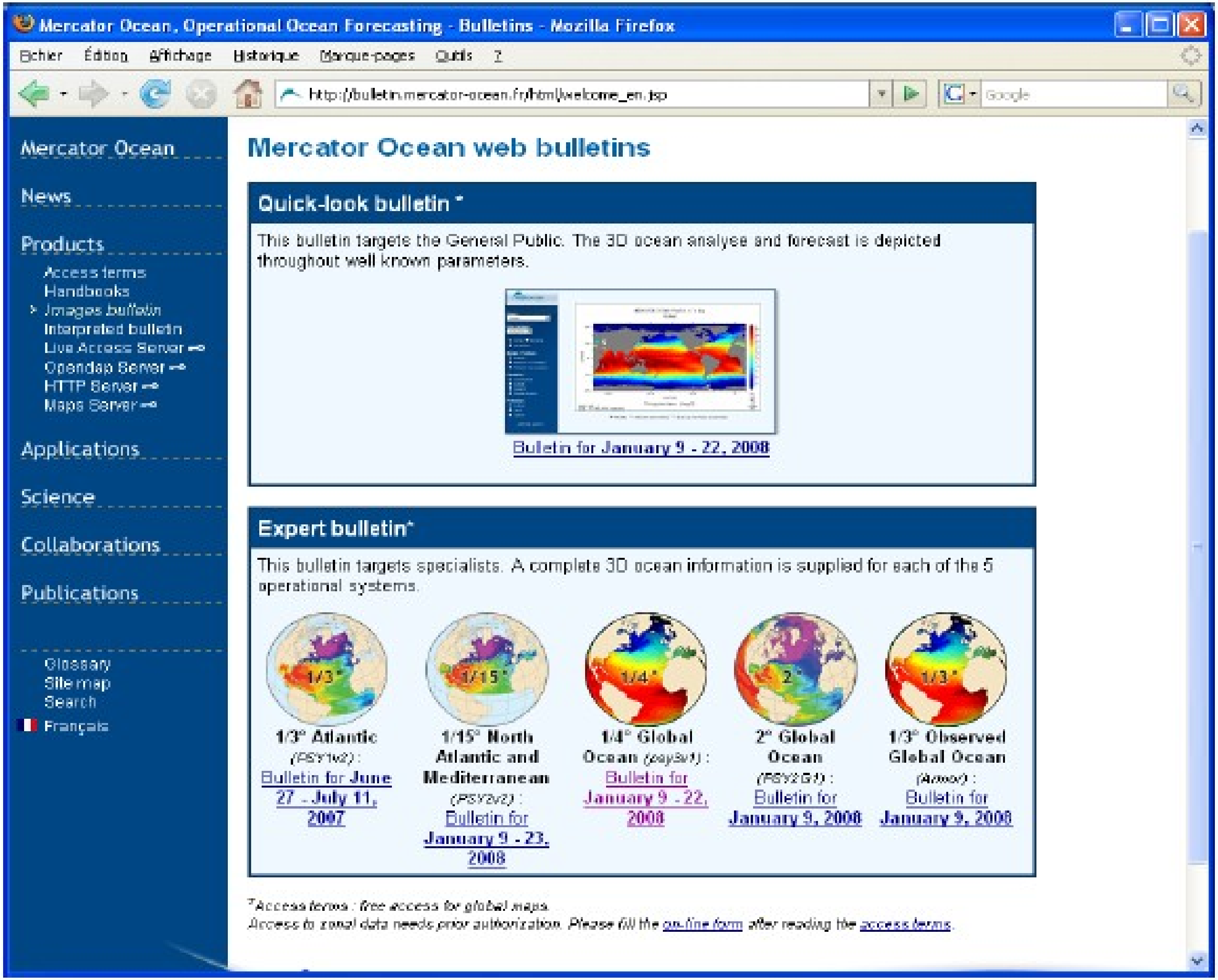
Bryan, K., and M.D. Cox,
The Circulation of the World Ocean: A
Numerical Study. Part I, A Homogene
Model,
Journal of Physical Oceanography,
2(4):319-335, 1972.

Modelli oceanici operativi



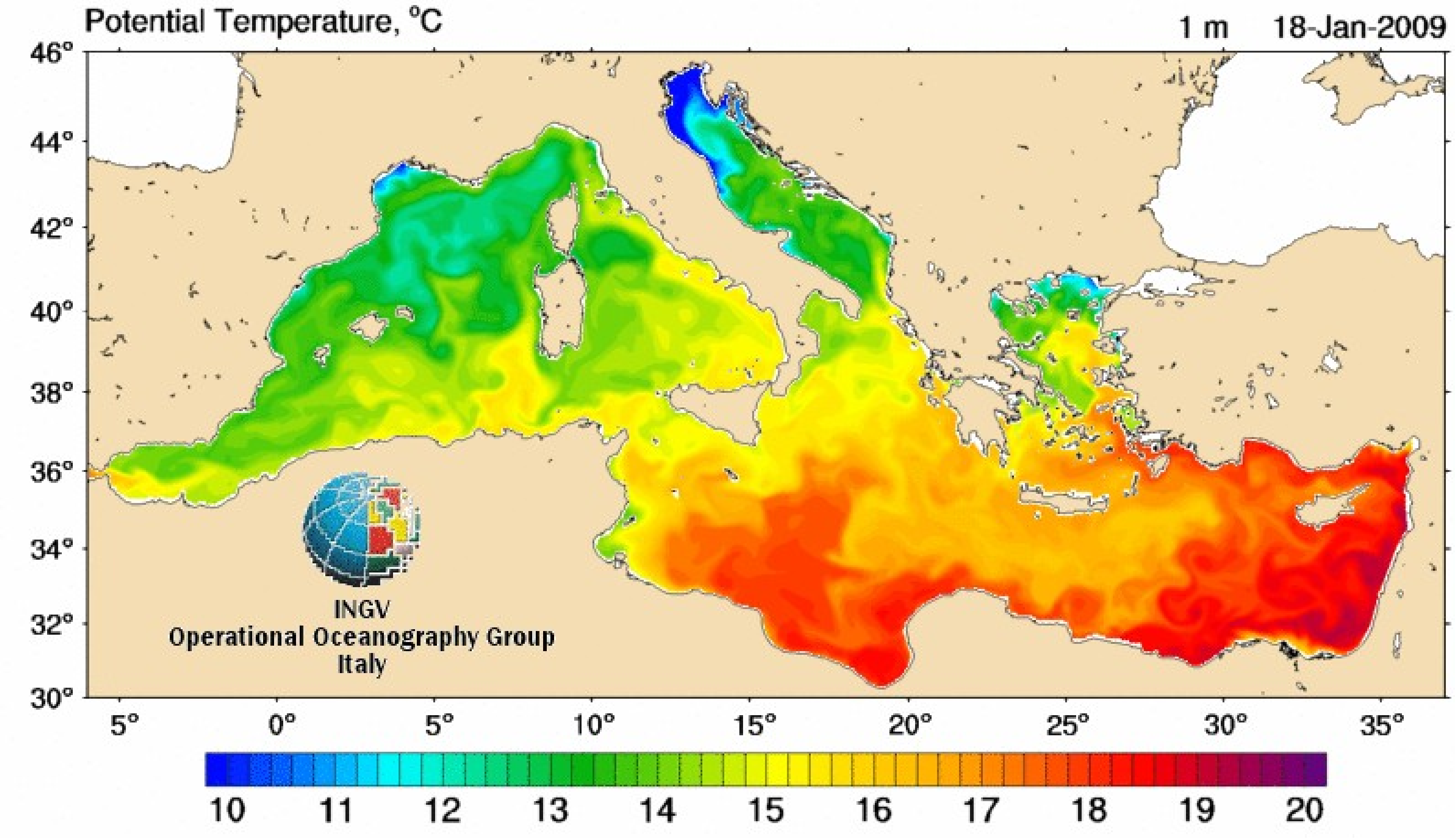
Modelli oceanici operativi

http://bulletin.mercator-ocean.fr/html/welcome_en.jsp



Modelli oceanici operativi

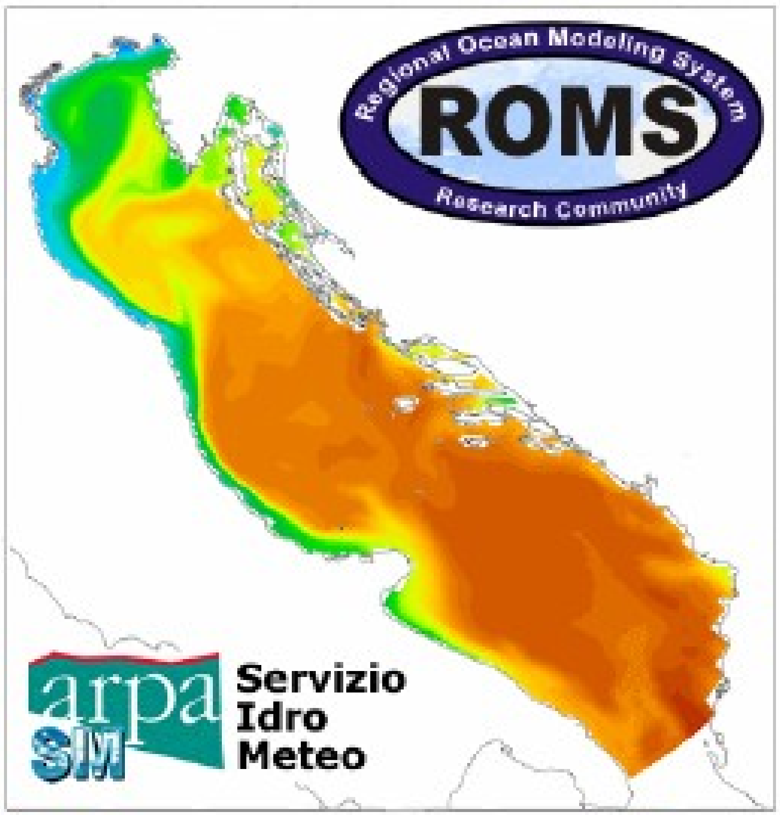
Oggi, in Italia: *Mediterranean ocean Forecasting System* http://gnoo.bo.ingv.it/mfs/



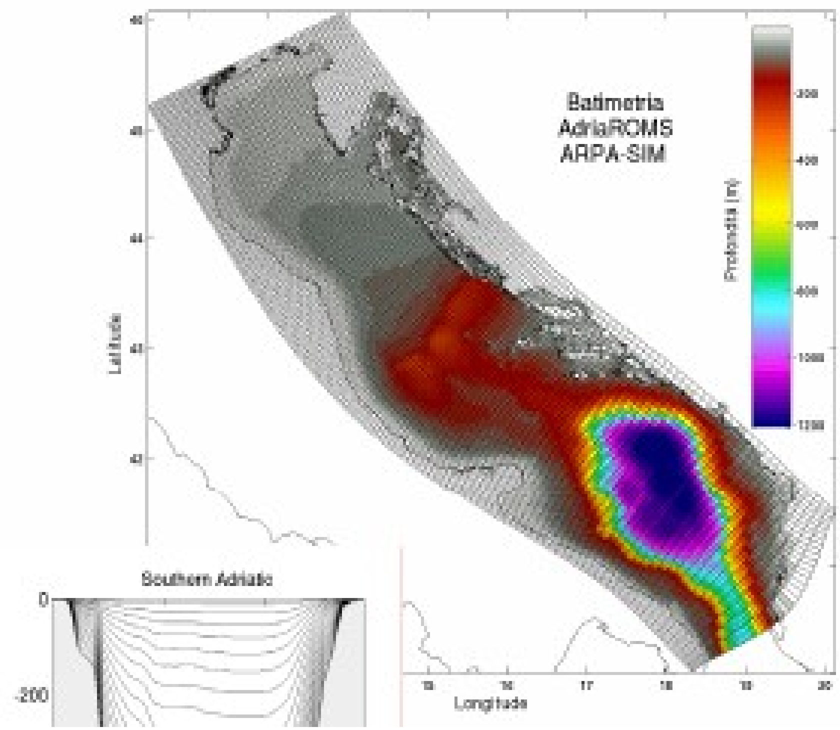
Modelli oceanici operativi

Operational Ocean Forecasting System for the Adriatic Sea: AdriaROMS-3.0

AdriaROMS 3.0

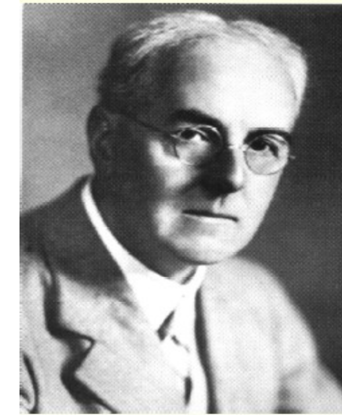


Fourthy-eight rivers (and springs) are included as well, using monthly climatological values from Raicich (1996). For the Po river, the biggest, it is used the persistence throughout the forecast.

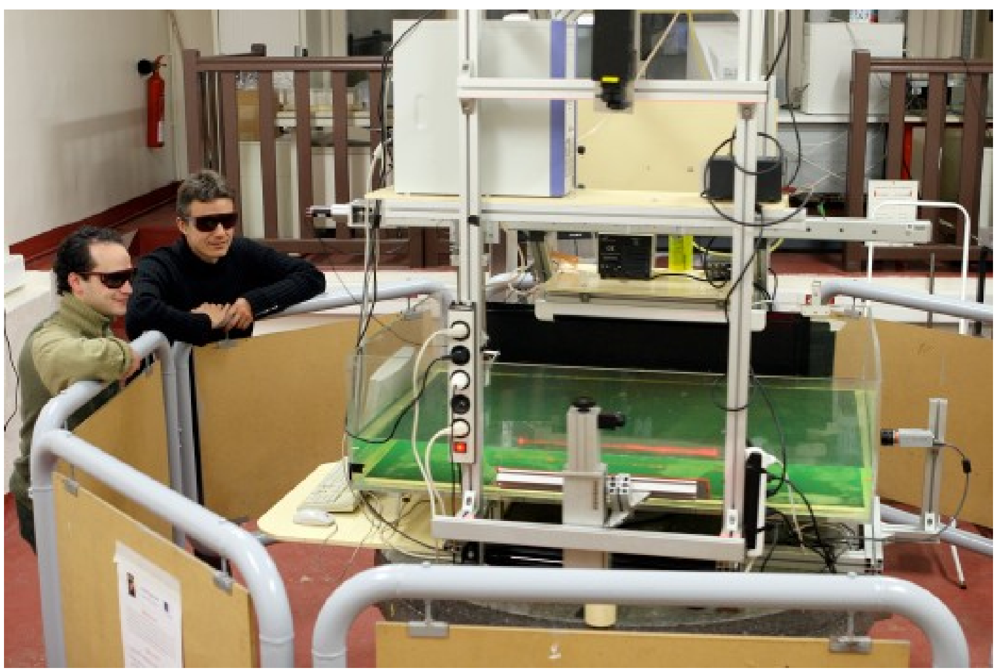


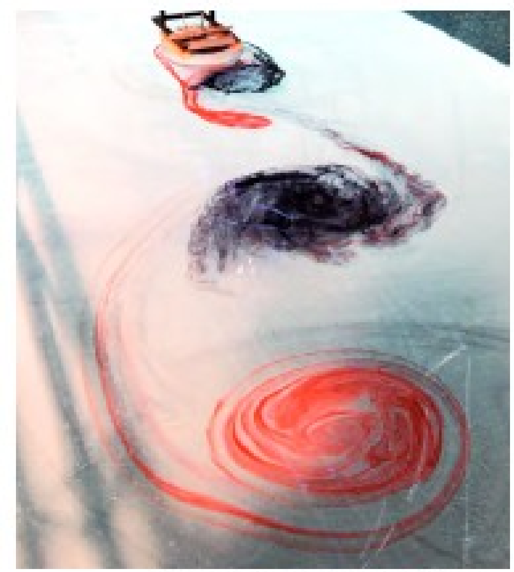
Era forse « troppo» avanzata

la ricerca di Richardson?!



E quella «dell'entusiasta che studia i vortici»?



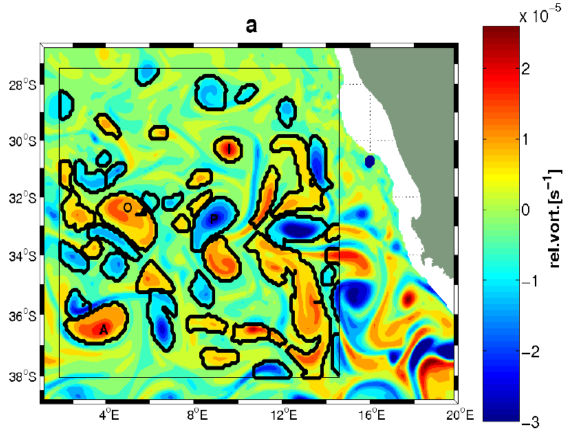


Teinturier *et al.* submitted

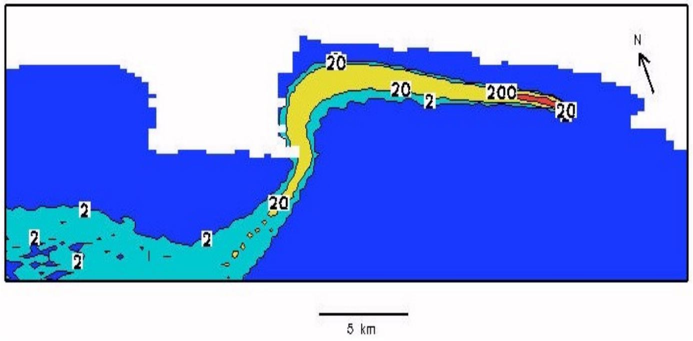
Laboratorio del Politecnico di Parigi

Esempi di applicazioni di modelli numerici :

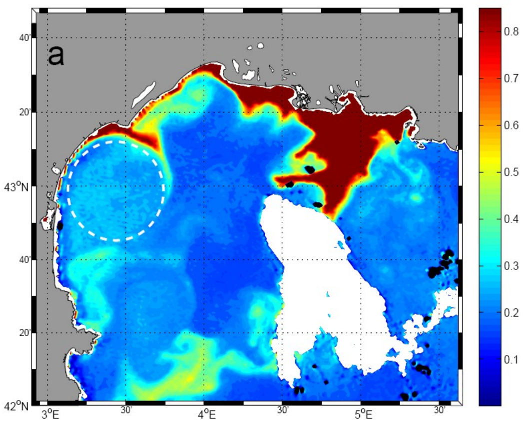
- studio dei vortici oceanici in Sud Atlantico

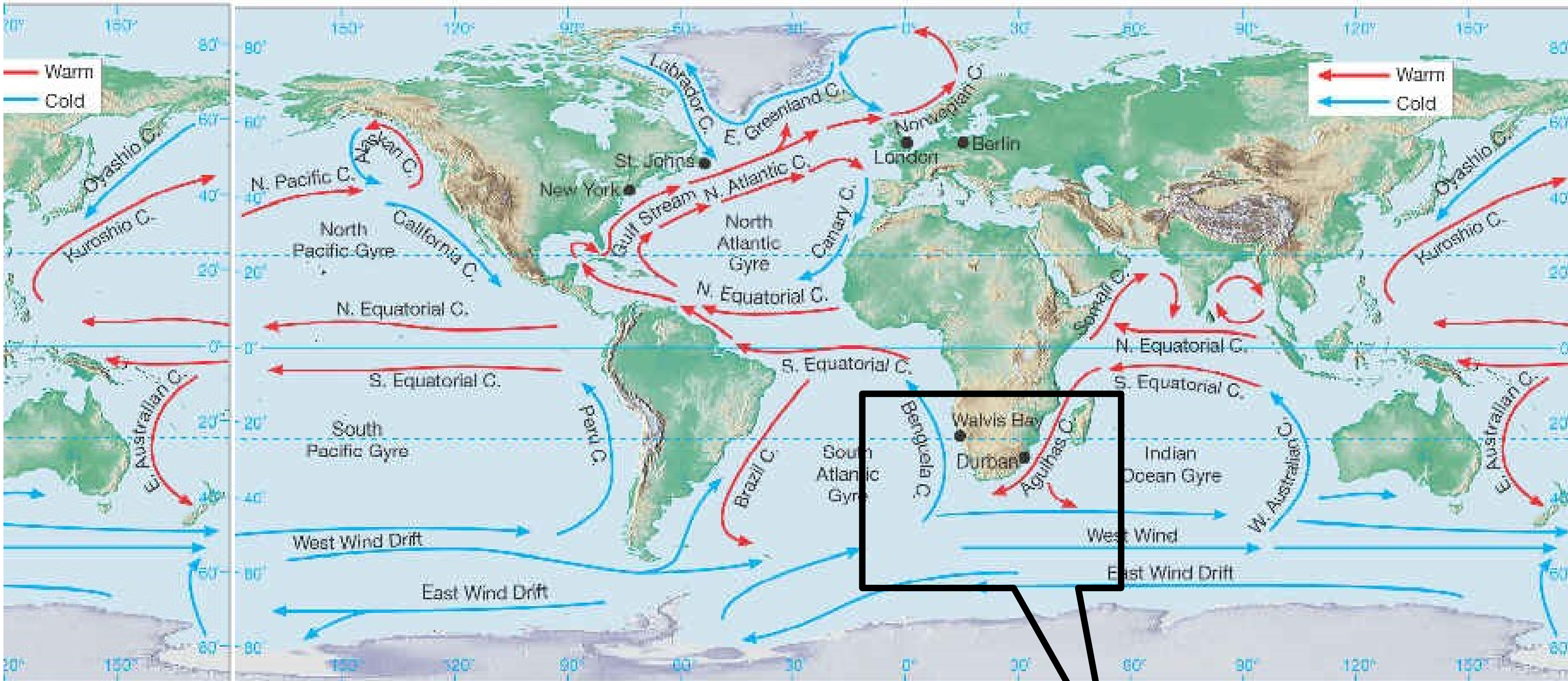


- circolazione e dispersione di inquinanti nelle acque del Promontorio di Portofino



- misura e modellizzazione dei vortici costieri del Golfo del Leone





Carta delle principali correnti oceaniche

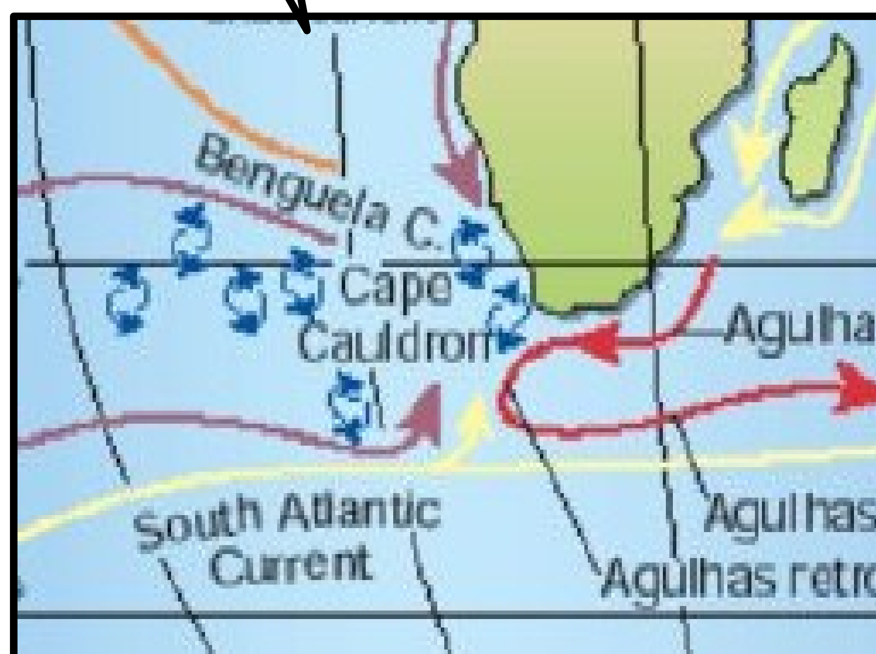
analogie fra i 5 bacini oceanici:

lato ovest correnti calde verso i poli

lato est correnti fredde verso l'equatore

Retroflessione delle Agulhas

e Agulhas Rings del *Cape Cauldron*

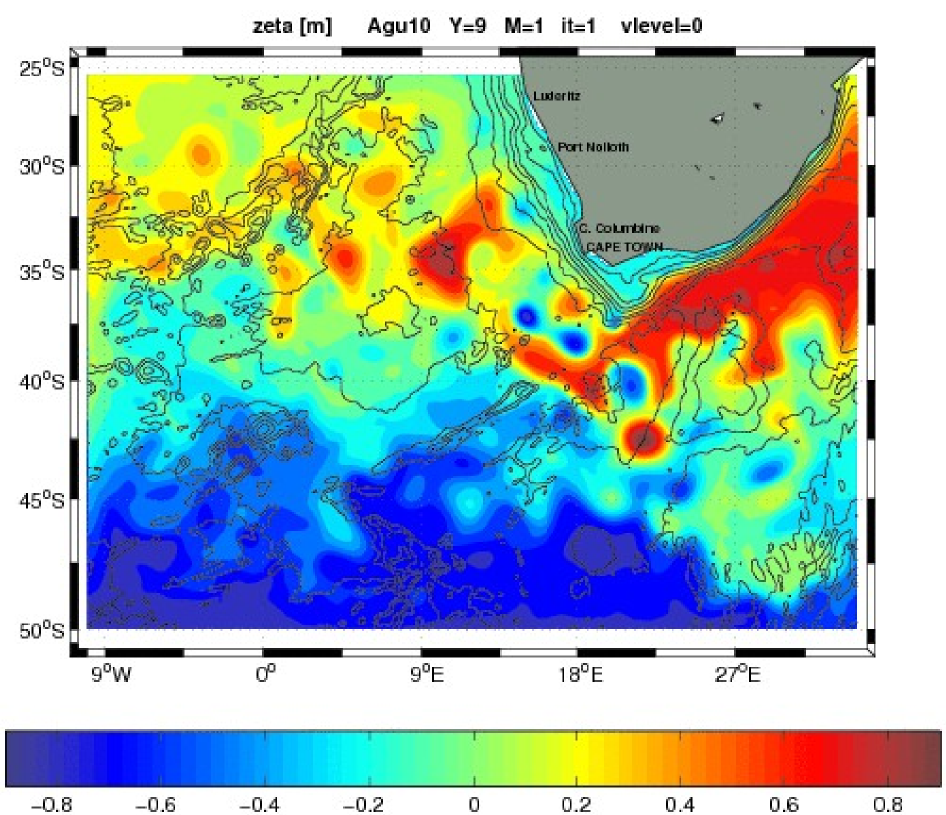


Wavelets
Analisys for
Time-tracking
Eddies in
Regional modelS

Obbiettivi del progetto

identificare nei dati forniti da un modello i vortici con metodo oggettivo

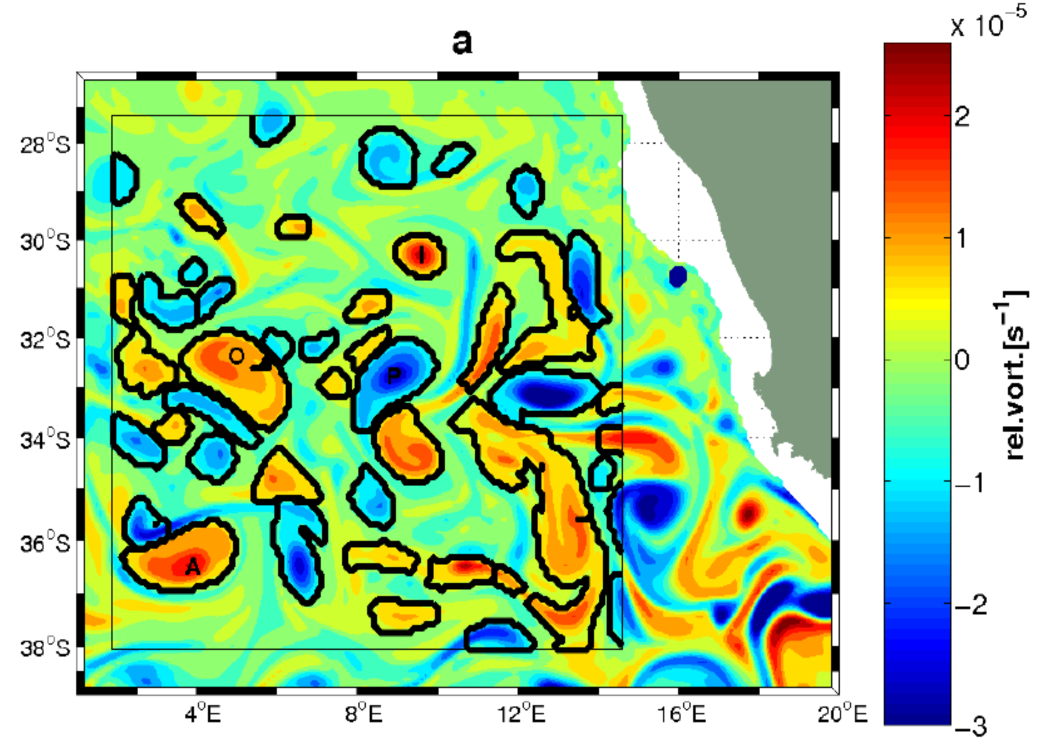
seguirli nel tempo per capire le loro caratteristiche e gli scambi tra i due oceani

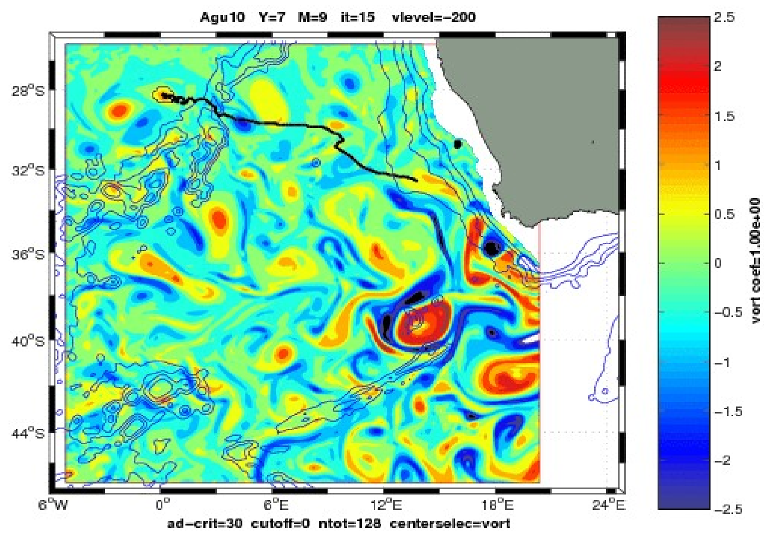


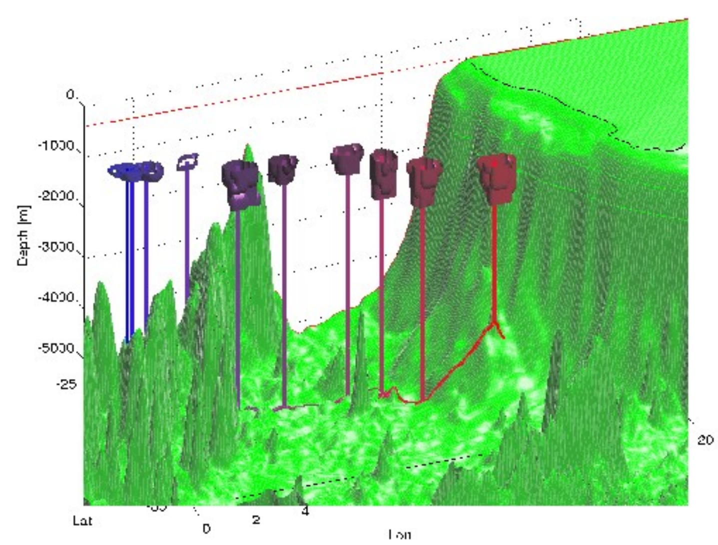
Play

ESEMPI DI VORTICI

STUDIATI





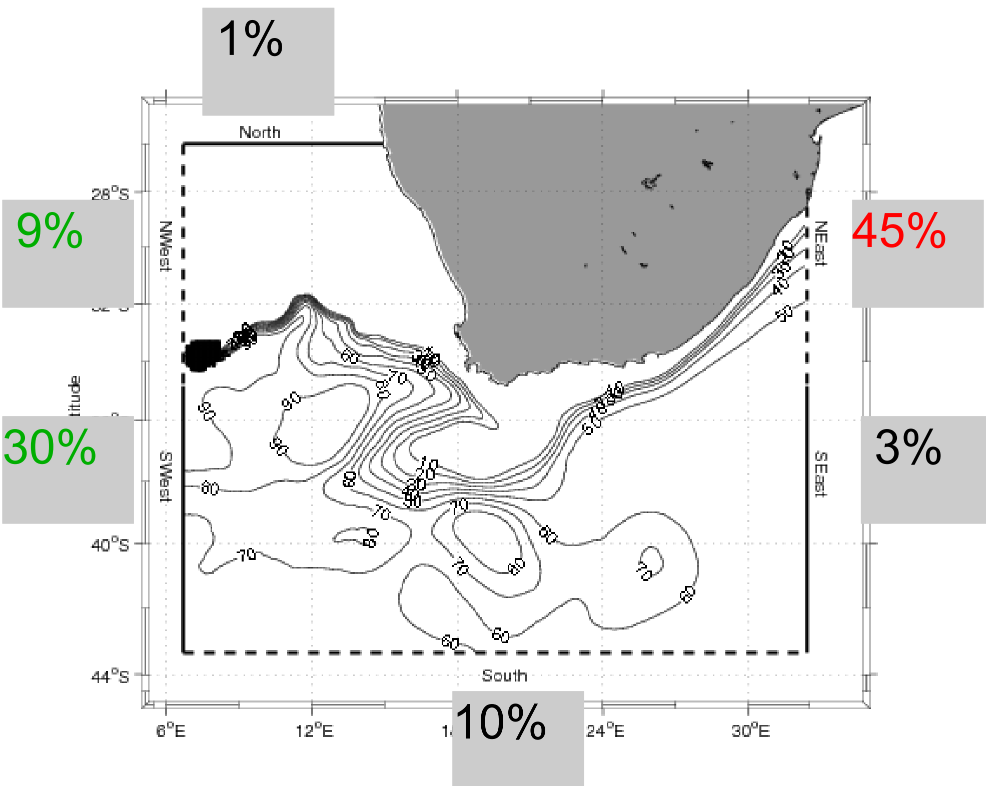


IDEFIX 2D

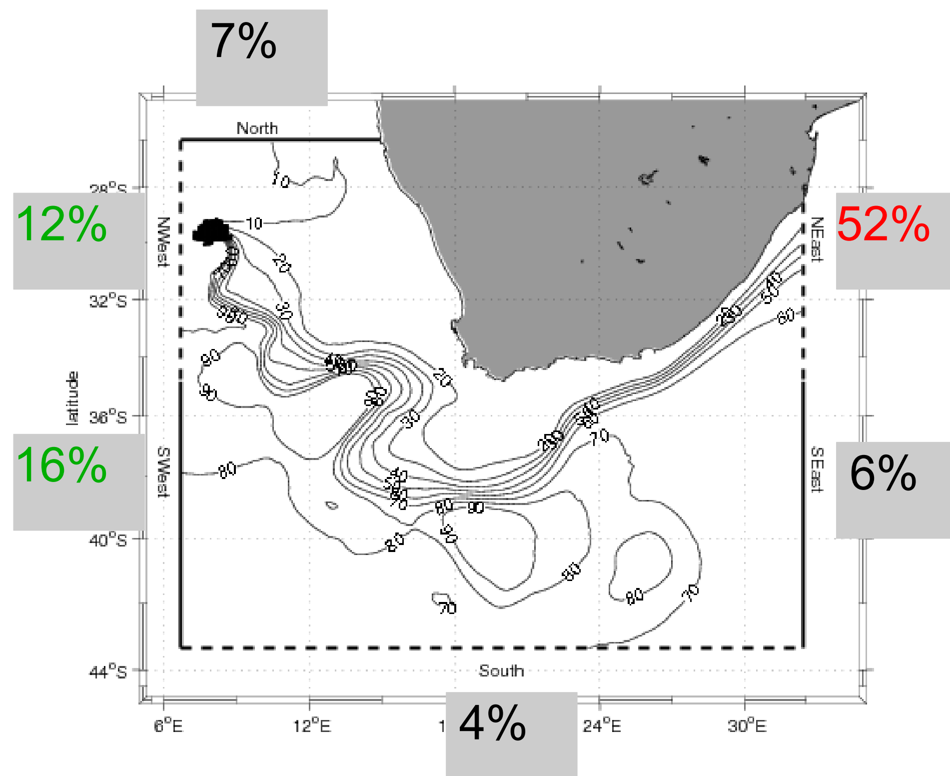
IDEFIX 3D

Stime degli scambi di masse d'acqua tra Oceano Indiano e Atlantico dovuti ai vortici

Cyclone ASTERIX



Anticyclone PANORAMIX



Enormi quantità di sale e calore!