Introduzione all'uso di un modello numerico di circolazione:

ROMS-AGRIF

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AIX-MARSEILLE II

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Sala conferenze ISMAR-CNR, Venezia

Regional Ocean Modeling System (ROMS)

3 versions:

Rutgers University:

http://marine.rutgers.edu/po/index.php?page=&model=roms

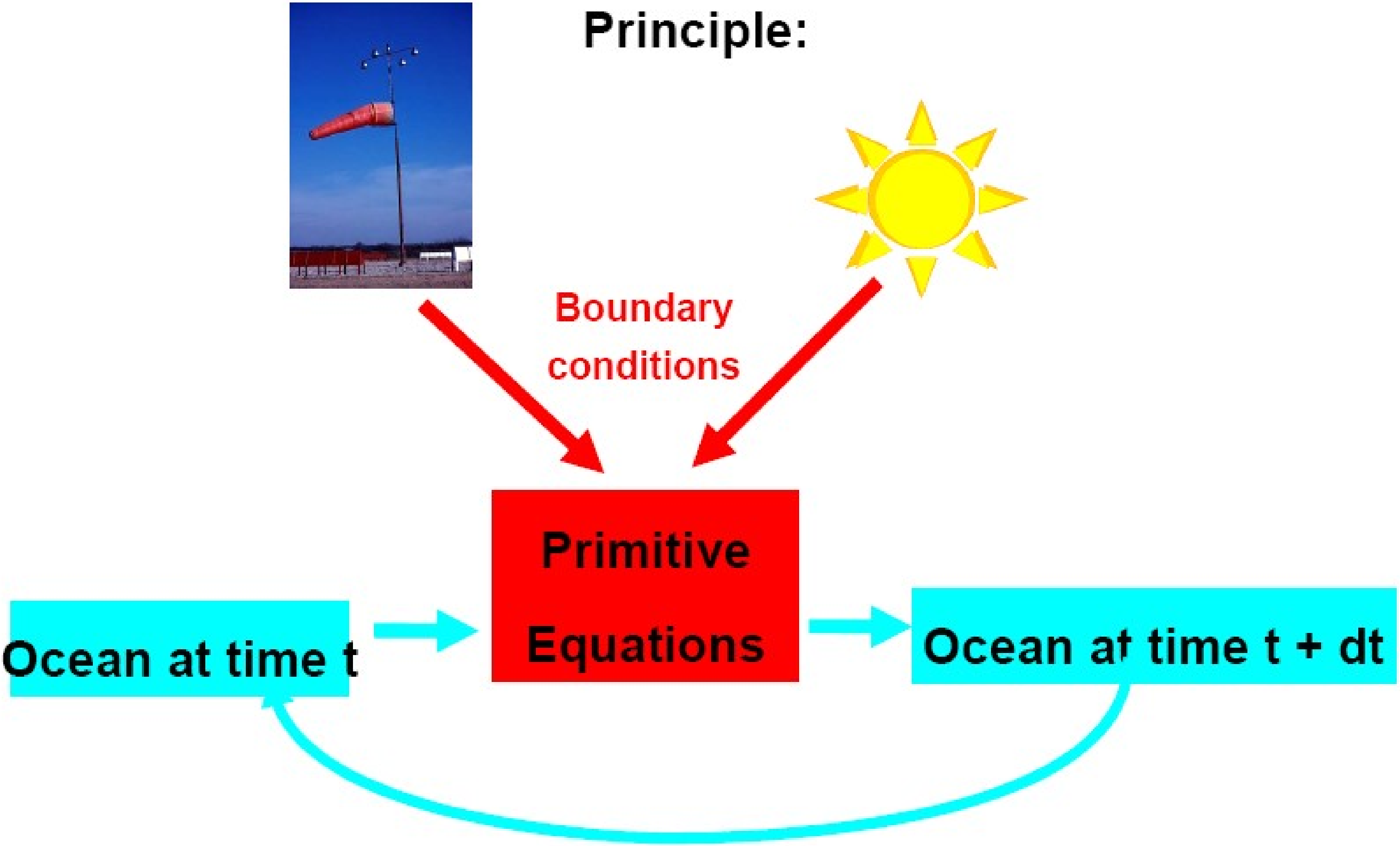
UCLA: http://www.atmos.ucla.edu/cesr/ROMS_page.html

IRD: http://www.brest.ird.fr/Roms_tools/

http://www.myroms.org/

http://lseet.univ-tln.fr/ecoleete/Documents/ROMS_TOOLS.pdf

Principle:



Boundary conditions

Primitive Equations

Ocean at time t

Ocean at time t + dt

http://lseet.univ-tln.fr/ecoleete/Documents/ROMS_TOOLS.pdf

2.1- Introduction: ROMS

Equations to solve : the primitive equations (PE)

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

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

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

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

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

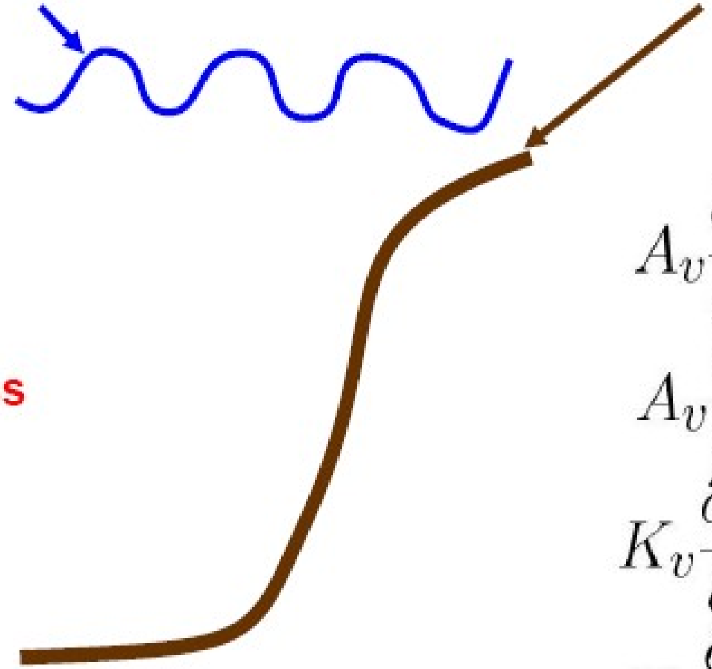
$$\frac{\partial S}{\partial t} + u.\nabla S = K_h \nabla_h^2 S + K_v \frac{\partial^2 S}{\partial z^2}$$

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

http://lseet.univ-tln.fr/ecoleete/Documents/ROMS_TOOLS.pdf

+ Boundary conditions:

Surface boundary conditions (z=η):



$$\frac{d\eta}{dt} = w$$

$$\left.\begin{aligned} A_v\frac{\partial u}{\partial z} &= \tau_x \\ A_v\frac{\partial v}{\partial z} &= \tau_y \end{aligned}\right\}$$

Wind stress

$$K_v\frac{\partial T}{\partial z} = \frac{Q}{\rho_0 C_p}$$

Heat flux

$$K_v\frac{\partial S}{\partial z} = \frac{S(E-P)}{\rho_0}$$

Evaporation – Rain : Salt flux

Bottom boundary conditions (z=-H):

$$w = -u.\nabla H$$

$$\left.\begin{aligned} A_v\frac{\partial u}{\partial z} &= -ru \\ A_v\frac{\partial v}{\partial z} &= -rv \end{aligned}\right\}$$

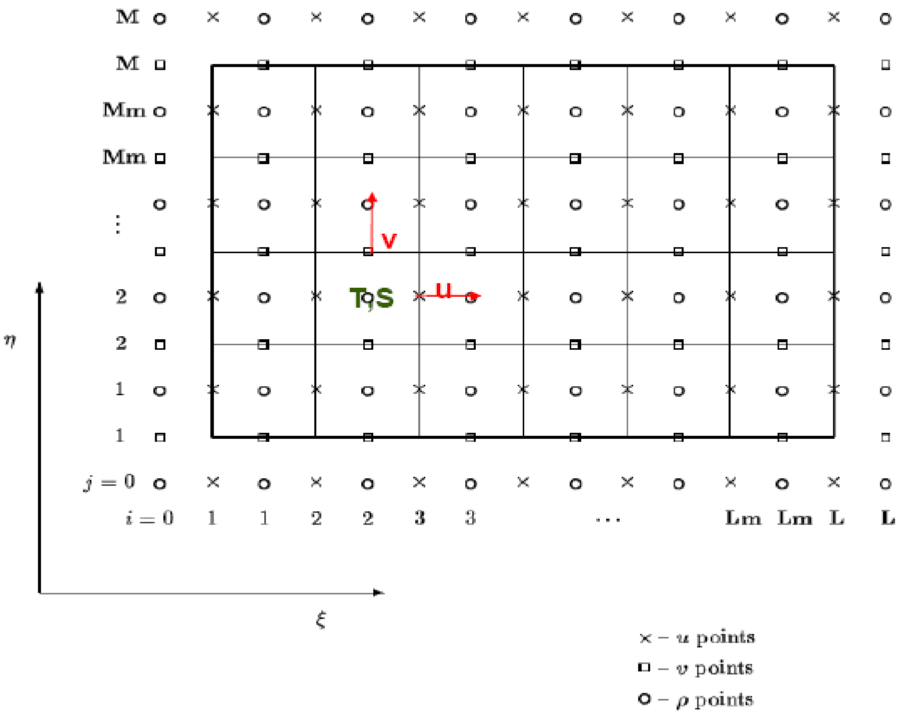
Bottom friction

$$K_v\frac{\partial T}{\partial z} = 0$$

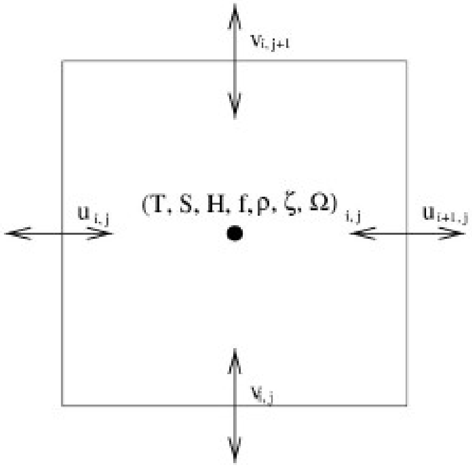
$$K_v\frac{\partial S}{\partial z} = 0$$

http://lseet.univ-tln.fr/ecoleete/Documents/ROMS_TOOLS.pdf

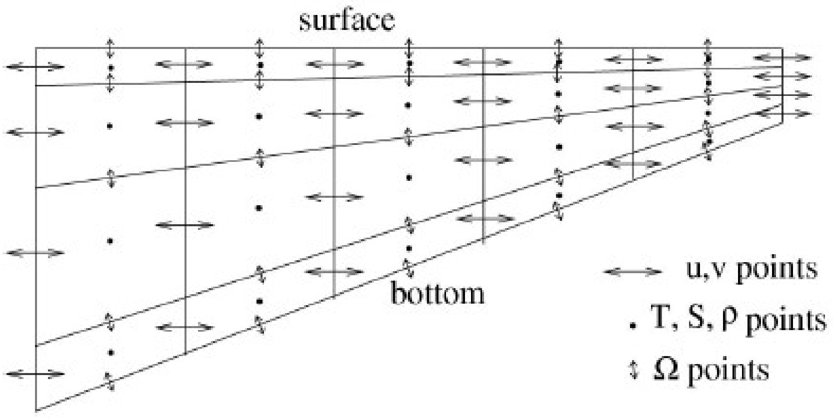
Discretization : horizontal grid

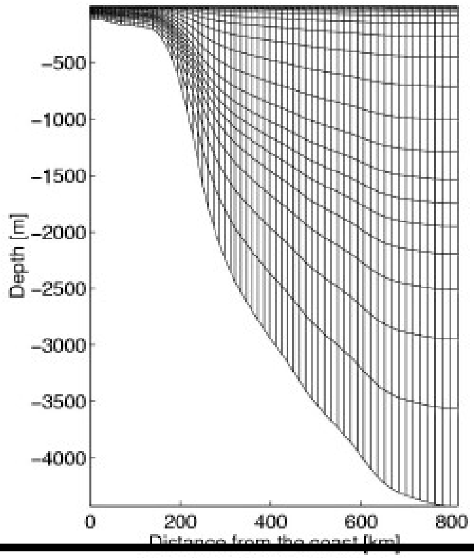


Arakawa "C" grid :



Vertical, topography following, "S" coordinate :





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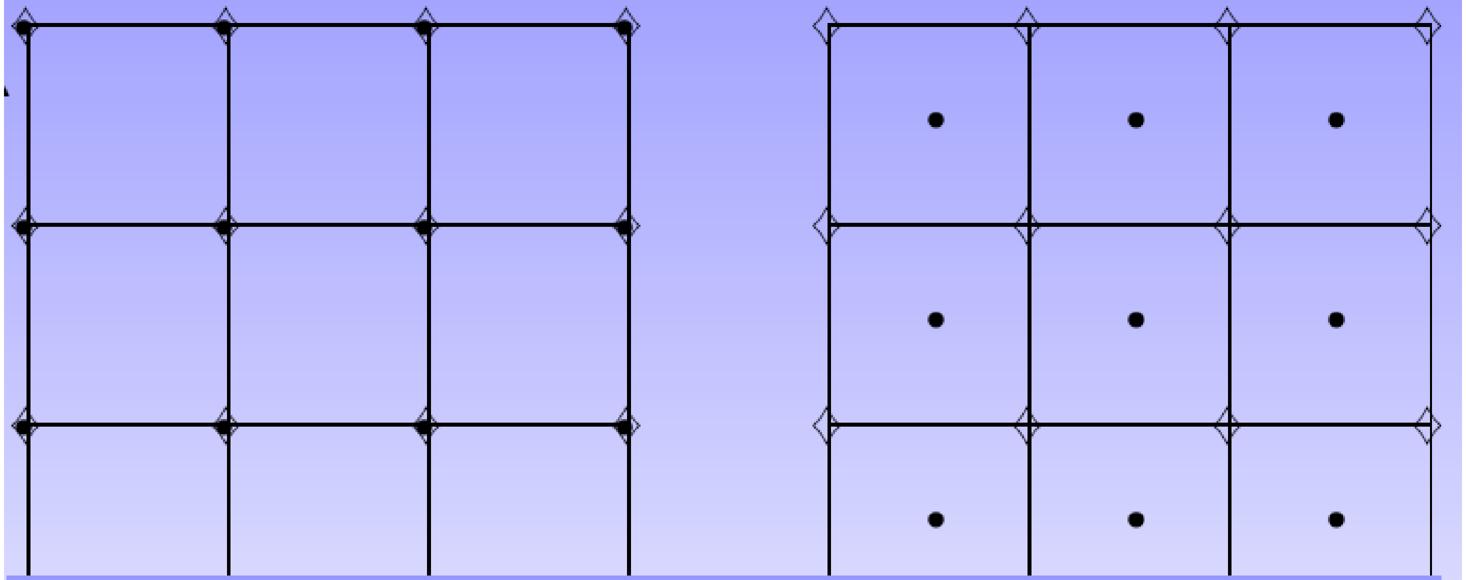
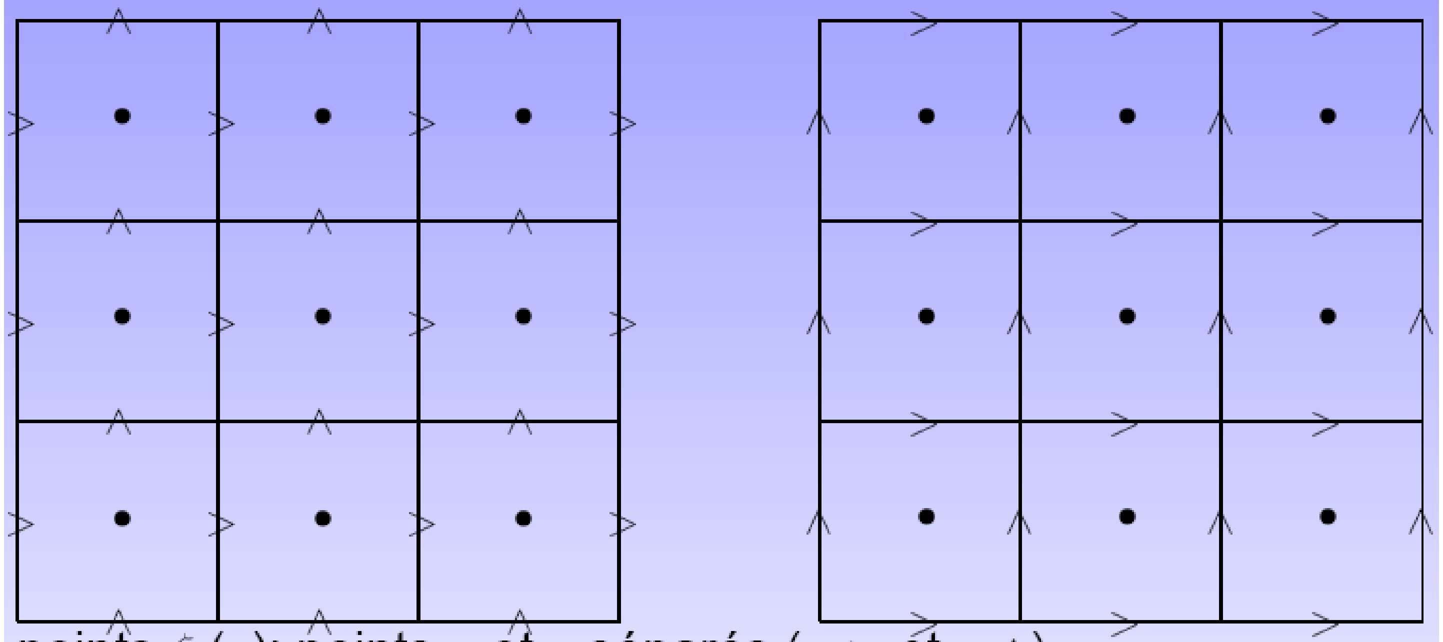
Grilles Arakawa A et B



Grilles Arakawa C et D



points ζ (•); points u et v séparés ($u >$ et $v \wedge$)

The Courant-Friedrichs-Levy (CFL) computational stability condition on the vertically integrated, external mode, transport equations limits the time step according to

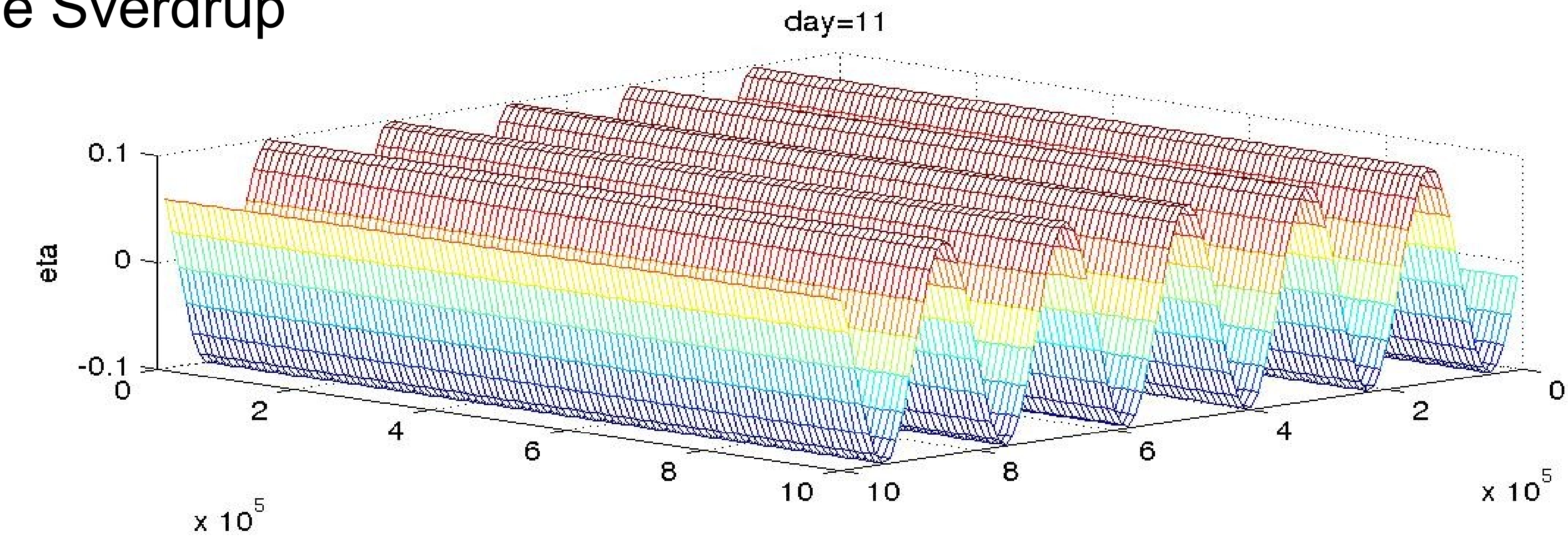
$$\Delta t_E \leq \frac{1}{C_t}\left|\frac{1}{\delta x^2} + \frac{1}{\delta y^2}\right|^{-1/2} \tag{29}$$

where $C_t = 2(gH)^{1/2} + U_{max}$; U_{max} is the expected, maximum velocity. There are other restrictions but in practice the CFL limit is the most stringent. The model time step is usually 90% of this limit. The internal mode has a much less stringent time step since the fast moving external mode effects have been removed. The time step criteria is analogous to that for the external mode given by Equation (26) and is

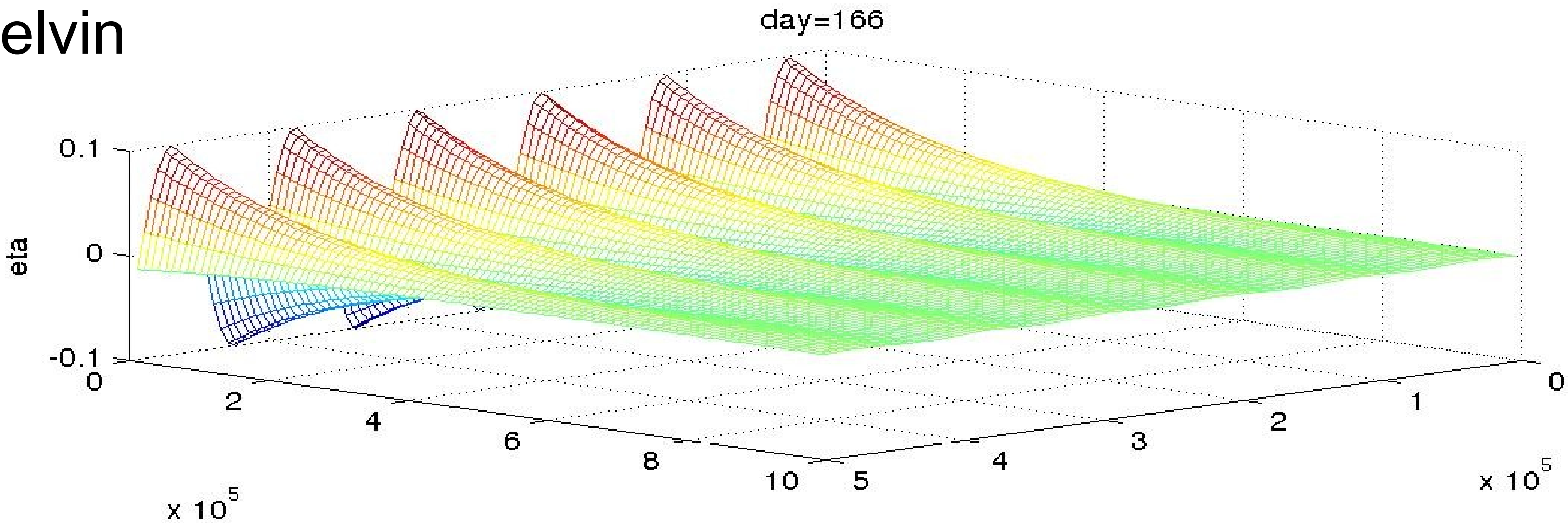
$$\Delta t_I \leq \frac{1}{C_T}\left|\frac{1}{\delta x^2} + \frac{1}{\delta y^2}\right|^{-1/2} \tag{30}$$

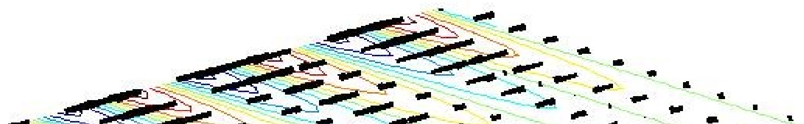
where $C_T = 2C + U_{max}$; C_T is the maximum internal gravity wave speed based on the gravest mode, commonly of order 2m/s, and U_{max} is the maximum advective speed. For typical coastal ocean conditions the ratio of the time steps, Δt_I / Δt_E = DTI/DTE, is often a factor of 50 - 80 or larger.

Onde de Sverdrup



Onde de Kelvin





THE PRINCETON OCEAN MODEL

http://www.aos.princeton.edu/WWWPUBLIC/htdocs.pom/

mode interne (lent) => 3D

mode externe (rapide) => 2D

flow diagram

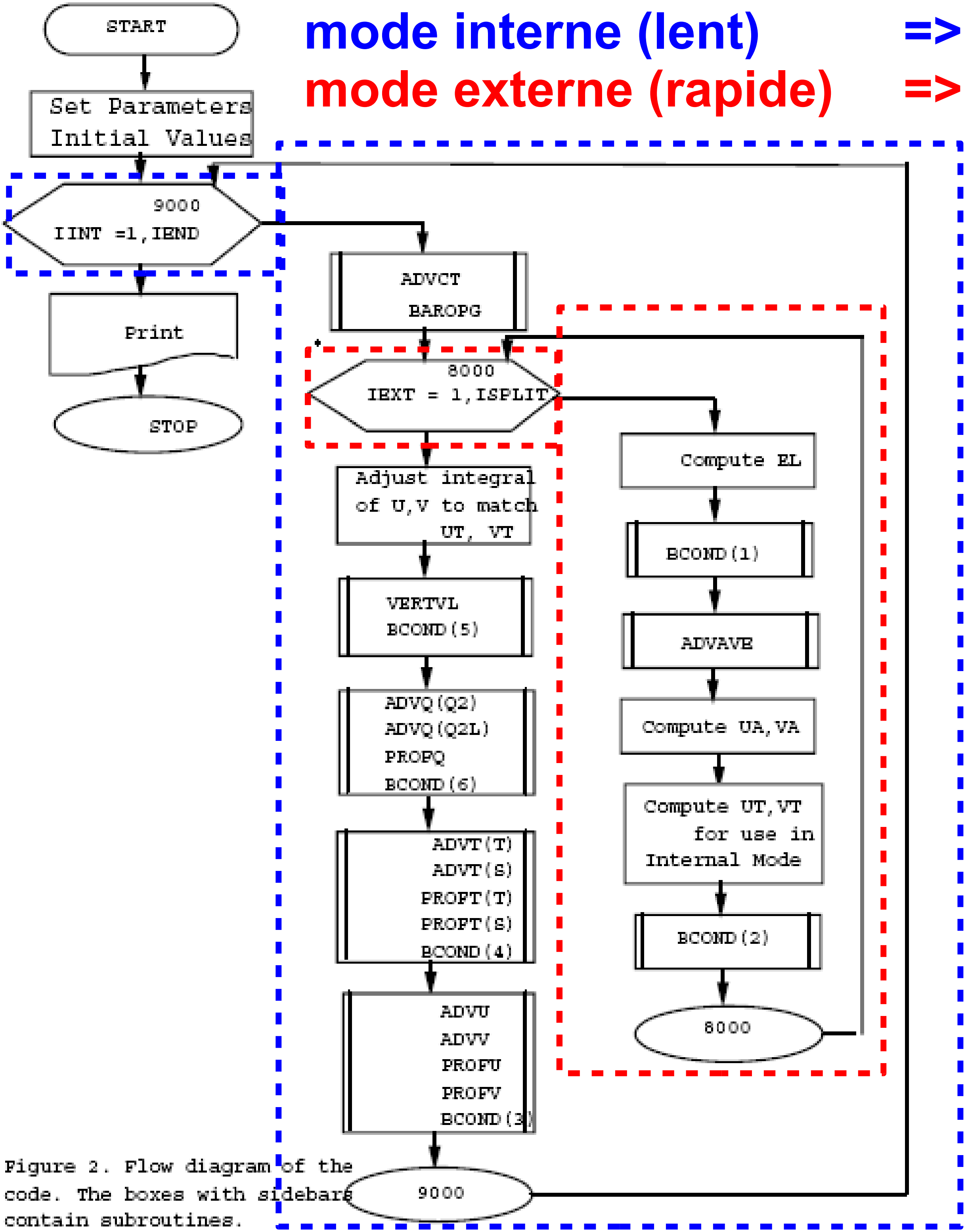


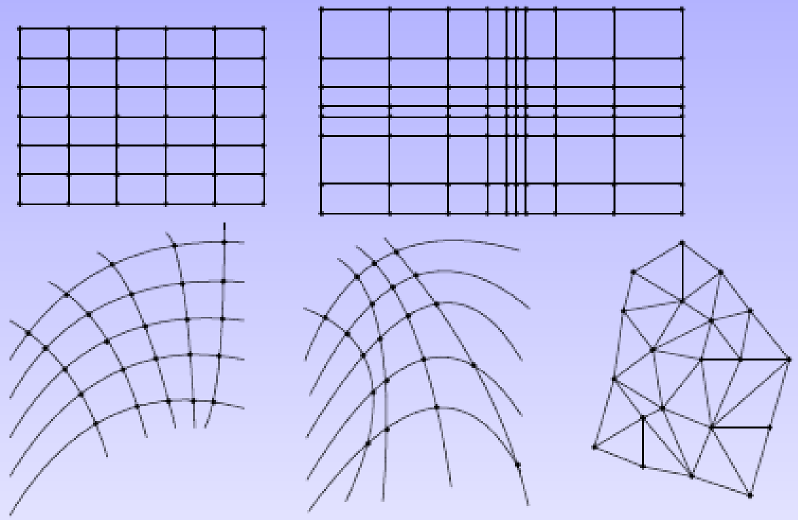
Figure 2. Flow diagram of the code. The boxes with sidebars contain subroutines.

Changements de coordonnées

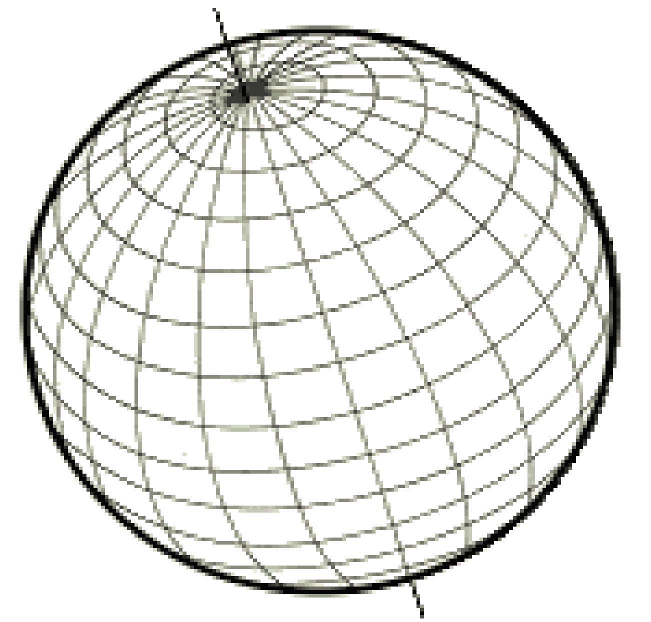
- Coordonnées géographiques (sphériques)
- Coordonnées curvilignes (côtes)
- Changements de coordonnée verticale (topographie)
- Zooming et Nesting
- Génération de grilles vs l'utilisation
- Grilles horizontales vs verticales en océanographie (rapport d'aspect)
- Formes conservatives vs formes non conservatives

Transformations de grilles

Grille cartésiennt, grille cartésienne non-uniforme, grille curviligne orthogonale, grille curviligne non-orthogonale, grille non-structurée



Ocean Modelling System
OPA
LODYC - IPSL



http://ebiquity.umbc.edu/blogger/wp-content/uploads//2006/07/latitude-longitude.gif

http://www.lodyc.jussieu.fr/opa/Docu_Free/Doc_models/Doc_OPA8.1.pdf

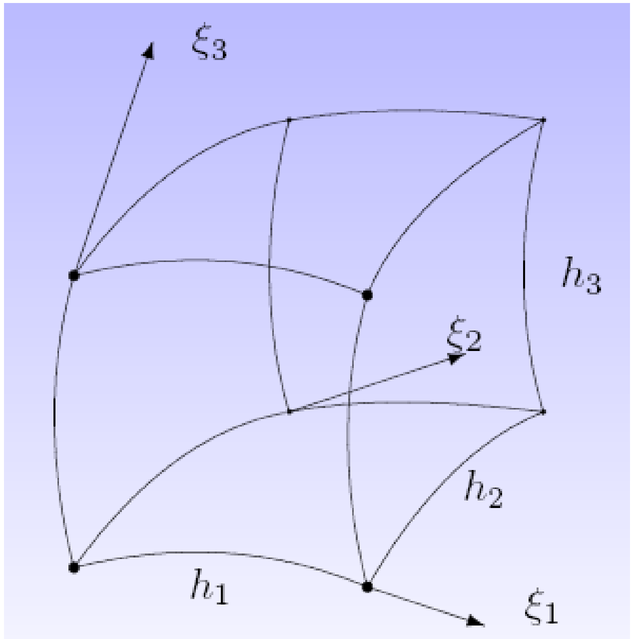
Grille curviligne horizontale

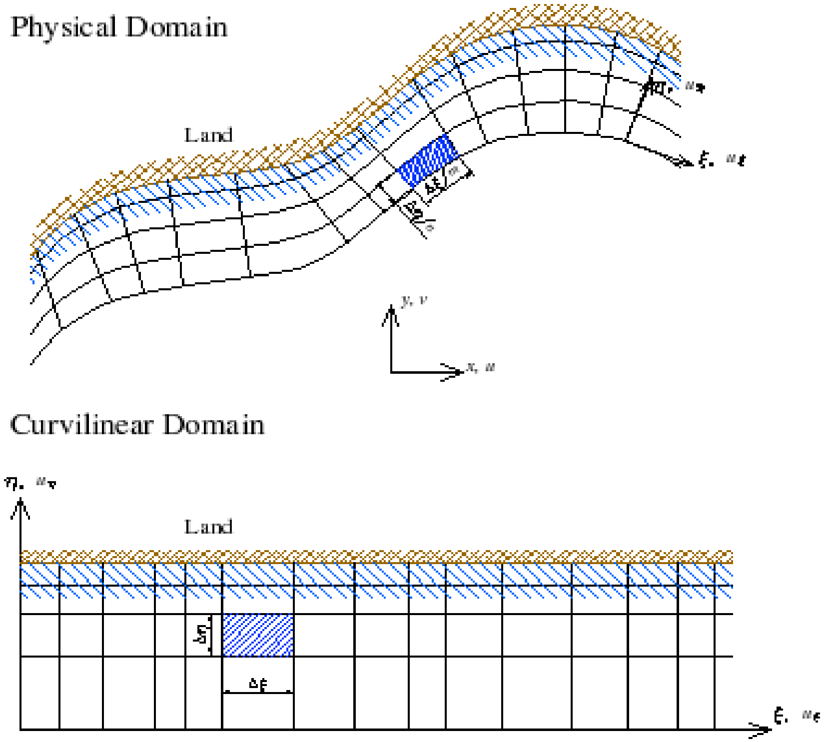
En océanographie, séparation horizontale-verticale. D'abord changement de coordonnées horizontales et éventuellement ultérieurement un changement de coordonnée verticale supplémentaire.

$$h_1^2 = \left(\frac{\partial x}{\partial \xi_1}\right)^2 + \left(\frac{\partial y}{\partial \xi_1}\right)^2$$

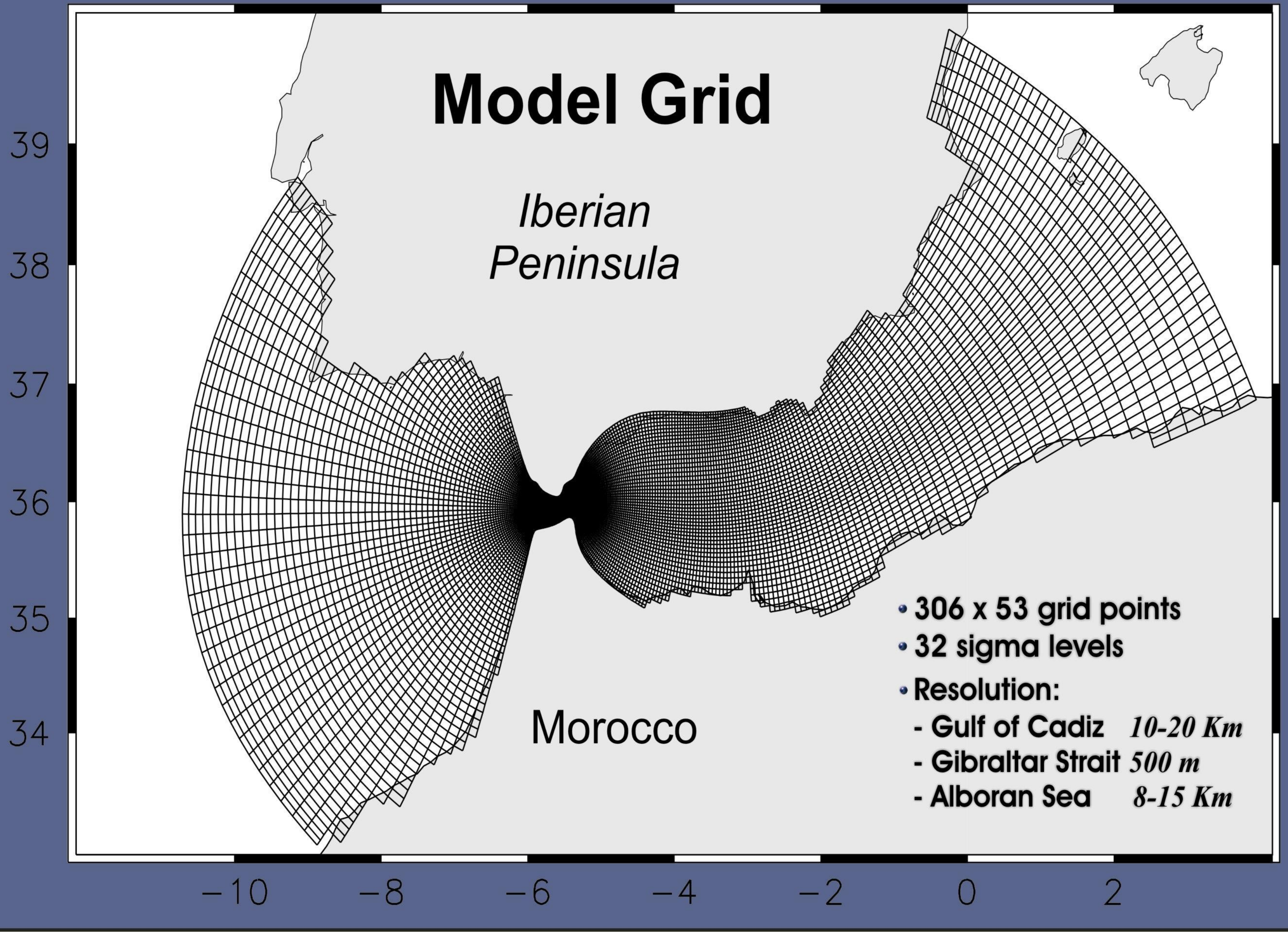
$$h_2^2 = \left(\frac{\partial x}{\partial \xi_2}\right)^2 + \left(\frac{\partial y}{\partial \xi_2}\right)^2$$

$$h_3 = 1$$





MODEL GRID

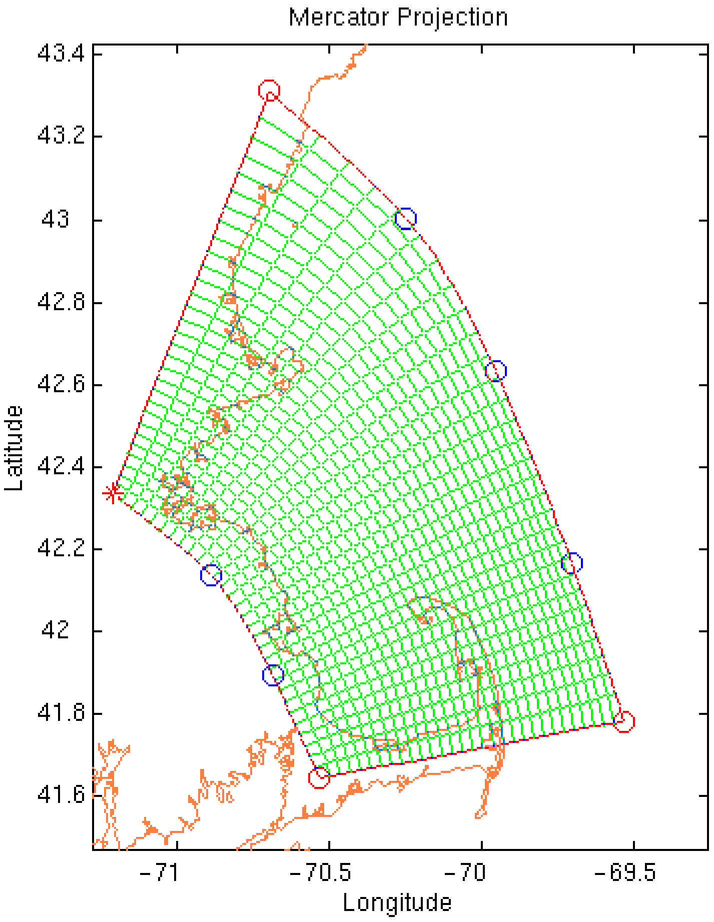


- **306 x 53 grid points**
- **32 sigma levels**
- **Resolution:**
  - **Gulf of Cadiz** *10-20 Km*
  - **Gibraltar Strait** *500 m*
  - **Alboran Sea** *8-15 Km*

SEAGRID

SeaGrid Orthogonal Grid Maker For Matlab

Dr. Charles R. Denham, U.S. Geological Survey, Woods Hole, MA 02543



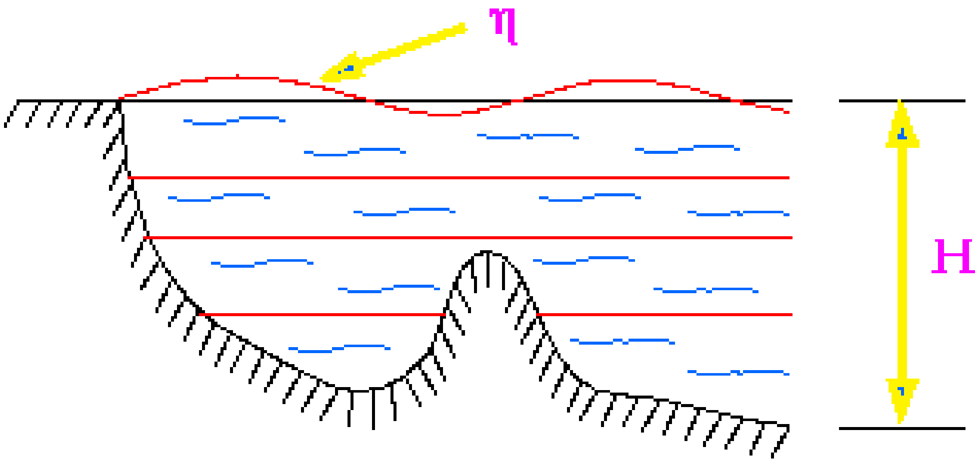
SeaGrid is a Matlab 5.2+ application for generating an orthogonal grid within a curved perimeter, suitable for oceanographic modeling.

With SeaGrid, one can:

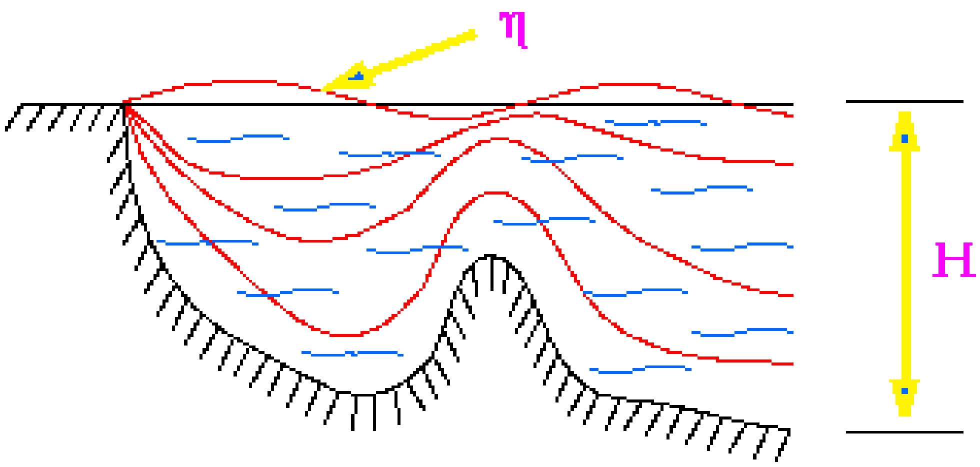
- Select a conformal map projection.
- Manually adjust grid corner points and curved boundaries.
- Modify the number of grid-cells and grid-line spacings.
- Compute depths, land-masking, and orthogonality.
- Save, then later reload a grid for further work.
- Port a grid to Matlab on another computer.
- Create SCRUM/ROMS-like and ECOM-like output files.
- Get comprehensive built-in help.

Starting from a conformal projection (such as Mercator) of the targeted area, SeaGrid uses the Ives-Zacharias scheme to conformally map the curved perimeter to a rectangle, after which, a Poisson solver fills the interior with orthogonally distributed grid points.

Griglie verticali

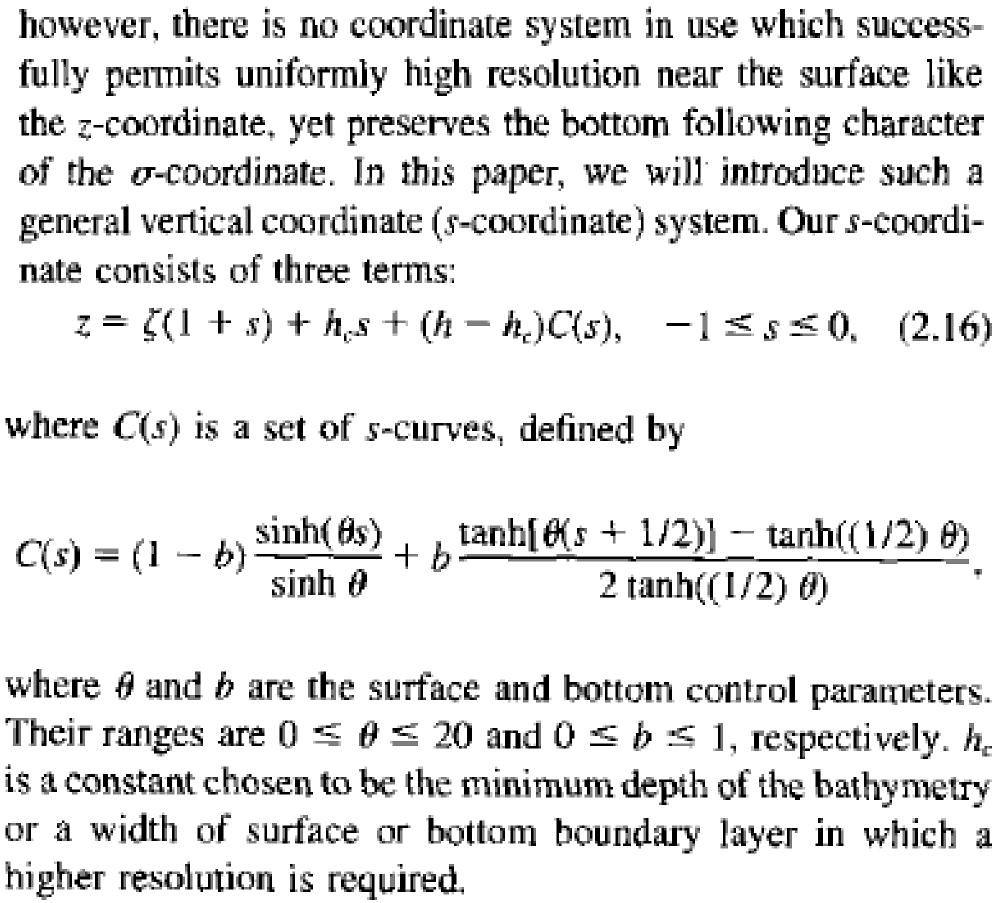


z-Coordinate Model



s-Coordinate Model

Song, Y.T., Haidvogel, D., 1994. A semi-implicit ocean circullation model using a generalized topography following coordinate system.
J. Comp. Phys. 115, 228–248.



however, there is no coordinate system in use which successfully permits uniformly high resolution near the surface like the z-coordinate, yet preserves the bottom following character of the σ-coordinate. In this paper, we will introduce such a general vertical coordinate (s-coordinate) system. Our s-coordinate consists of three terms:

$$z = \zeta(1 + s) + h_c s + (h - h_c)C(s), \quad -1 \le s \le 0, \quad (2.16)$$

where $C(s)$ is a set of s-curves, defined by

$$C(s) = (1 - b)\frac{\sinh(\theta s)}{\sinh \theta} + b\frac{\tanh[\theta(s + 1/2)] - \tanh((1/2)\,\theta)}{2\tanh((1/2)\,\theta)},$$

where θ and b are the surface and bottom control parameters. Their ranges are $0 \le \theta \le 20$ and $0 \le b \le 1$, respectively. h_c is a constant chosen to be the minimum depth of the bathymetry or a width of surface or bottom boundary layer in which a higher resolution is required.

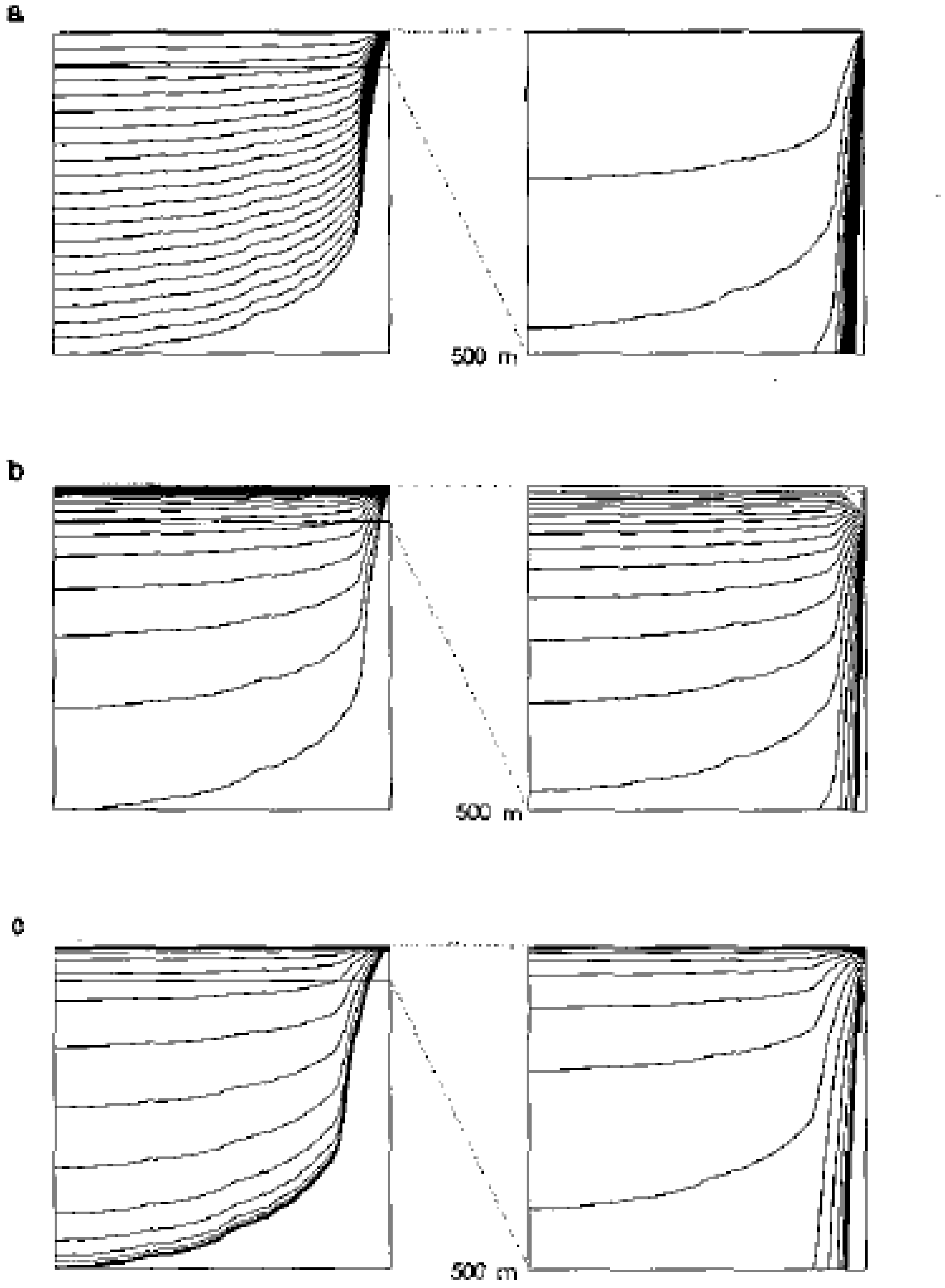
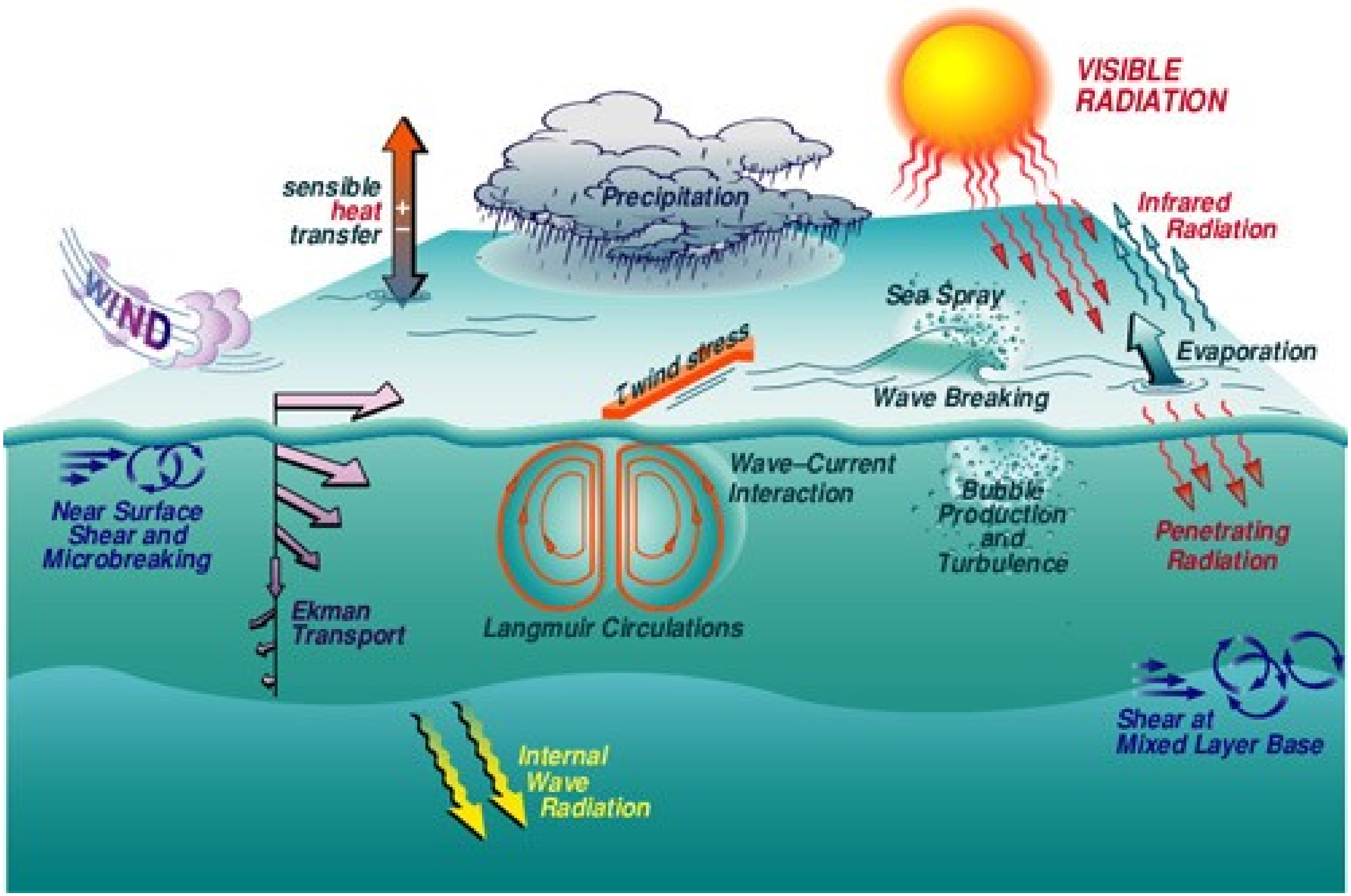


FIG. 1. Vertical computational levels for the California coastal shelf in S-coordinate, left column for the full depth and right column for the upper 500 m: (a) $\theta = 0.0001$, $b = 0$; (b) $\theta = 8$, $b = 0$; (c) $\theta = 8$, $b = 1$.

Strato Limite Oceanico



http://hpl.umces.edu/ocean/sml_main.htm

L'esperimento di Reynolds sulla turbolenza

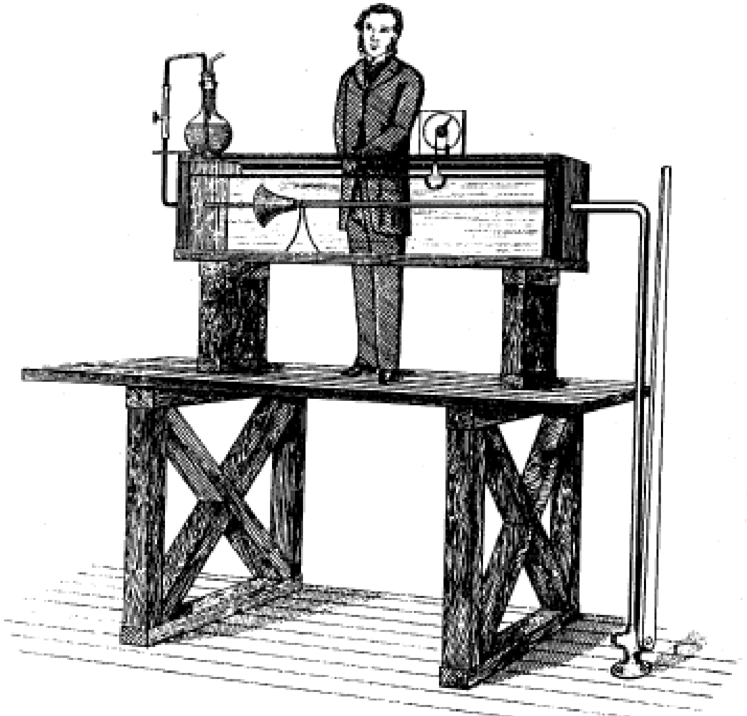


Fig. 9.1. Sketch of Reynolds's dye experiment, taken from his 1883 paper

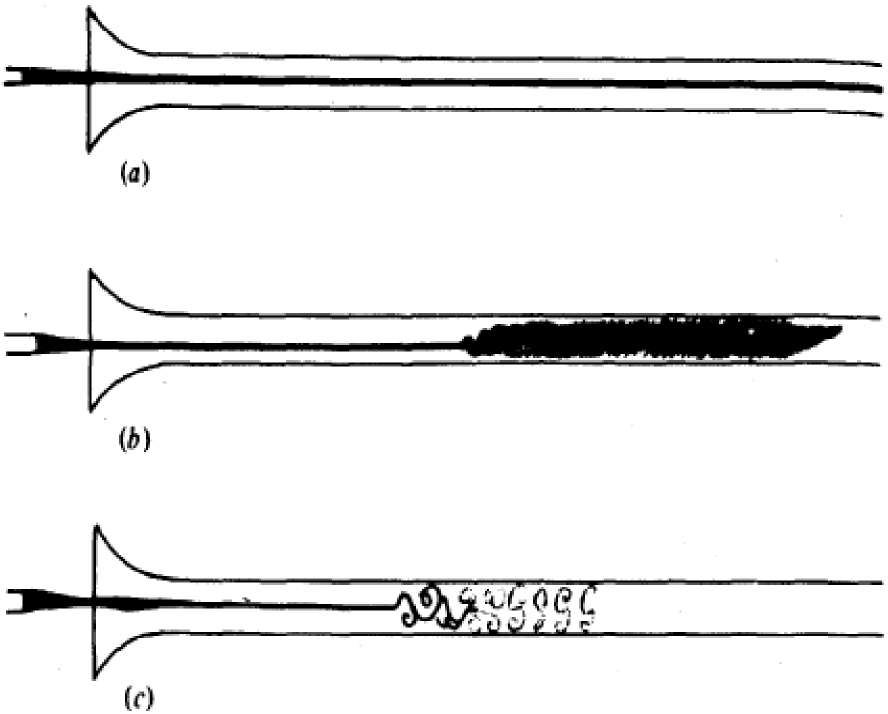


Fig. 9.2. Reynolds's drawings of the flow in his dye experiment.

His results were as follows:
1. At low velocities the streak of dye extended in a straight line along the tube.

2. If the water in the tank was not at rest, the streak would shift about the tube.

3. As the velocity increased, at some point in the tube, the color band would all at once mix up with the surrounding waters. When viewing the tube with an electric spark, this mixed fluid actually looked like a bunch of coherent eddies.

http://www.marine.maine.edu/~eboss/classes/SMS_491_2003/Week_5.htm

RANS (Reynolds Averaged Navier Stokes) equations

$$\bar{u} = \frac{1}{T}\int_0^T u\,dt \qquad \overline{u'} = \frac{1}{T}\int_0^T u'\,dt = 0$$

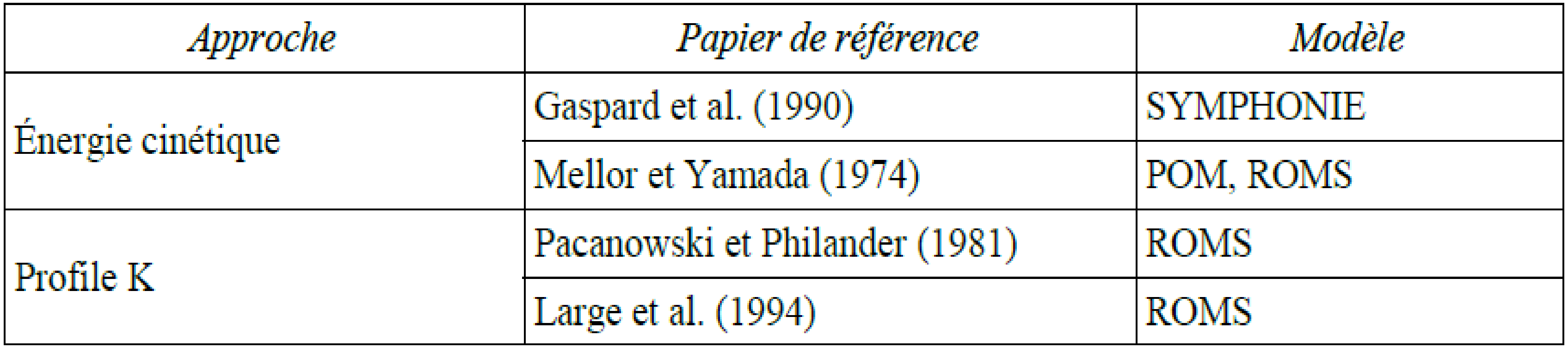
$$\frac{\partial \bar{u}}{\partial t} + u\frac{\partial \bar{u}}{\partial x} + v\frac{\partial \bar{u}}{\partial y} + w\frac{\partial \bar{u}}{\partial z} = -\frac{1}{\rho_o}\frac{\partial \bar{P}}{\partial x} + f\,v + \nu\left[\frac{\partial^2 \bar{u}}{\partial x^2} + \frac{\partial^2 \bar{u}}{\partial y^2} + \frac{\partial^2 \bar{u}}{\partial z^2}\right] - \frac{\partial \overline{u'u'}}{\partial x} - \frac{\partial \overline{u'v'}}{\partial y} - \frac{\partial \overline{u'w'}}{\partial z}$$

Tre nuove variabili!!??!!

J.V. Boussinesq (1842 – 1929) propose la sostituzione seguente

$$\overline{u'u'} = -A_x\frac{\partial u}{\partial x} \;; \qquad \overline{u'v'} = -A_y\frac{\partial u}{\partial y} \;; \qquad \overline{u'w'} = -A_z\frac{\partial u}{\partial z} \;;$$

Introducendo i coefficienti di mescolamento turbolento (*eddy viscosity*)
Ma quali valori? (In particolare per Az!!!)



Approche	*Papier de référence*	*Modèle*
Énergie cinétique	Gaspard et al. (1990)	SYMPHONIE
	Mellor et Yamada (1974)	POM, ROMS
Profile K	Pacanowski et Philander (1981)	ROMS
	Large et al. (1994)	ROMS

Coeff. verticale: approccio energia cinetica turbolenta

$$A_z = C_Q \, L \, Q^{1/2}$$

$$\frac{\partial Q}{\partial t} + \vec{v}.\vec{\nabla} Q = \underbrace{A_z\left[\left(\frac{\partial u}{\partial z}\right)^2 + \left(\frac{\partial v}{\partial z}\right)^2\right]}_{(1)} + \underbrace{\frac{g}{\rho_0} A_z \frac{\partial \rho}{\partial z}}_{(2)} + \underbrace{\frac{\partial}{\partial z}\left(A_z \frac{\partial Q}{\partial z}\right)}_{(3)} + \underbrace{\frac{\partial}{\partial x}\left(A_h \frac{\partial Q}{\partial x}\right) + \frac{\partial}{\partial y}\left(A_h \frac{\partial Q}{\partial y}\right)}_{(4)} - \varepsilon$$

Dans cette équation, la production d'énergie turbulente par cisaillement de la vitesse est représente par le terme (1), la production par la flottabilité par le terme (2), la redistribution de l'énergie par diffusion turbulente est représenté par le terme (3) dans la verticale et par le terme (4) dans l'horizontale.

La dissipation de l'énergie turbulente ε est paramétrée en fonction de la longueur de dissipation L_ε :

Coeff. verticale: approccio *K-profile*

OBL

$$\overline{w'u'}(d) = -A_z\left(\frac{\partial u}{\partial z} - \gamma\right)$$

$$A_z(\sigma) = h \; w_x(\sigma) \; G(\sigma)$$

Interior

$$\overline{w'u'}(d) = -a_z\left(\frac{\partial u}{\partial z}\right)$$

$$a_z(d) = a_z^{inst}(d) + a_z^{wave}(d) + a_z^{double}(d)$$

• Large et al.: OCEANIC VERTICAL MIXING

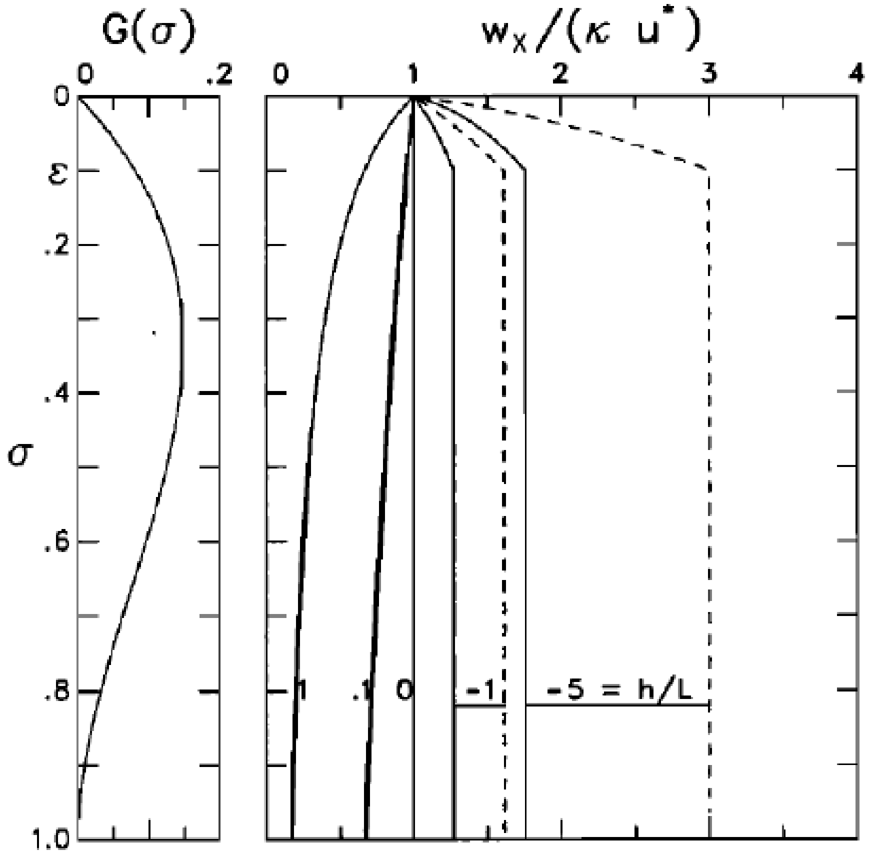


Figure 2. (left) Vertical profile of the shape function $G(\sigma)$, where $\sigma = d/h$, in the special case of $G(1) = \partial_\sigma G(1) = 0$. (right) Vertical profiles of the normalized turbulent velocity scale, $w_x(\sigma)/(\kappa u^*)$, for the cases of $h/L = 1, 0.1, 0, -1$, and -5. In unstable conditions, $w_s(\sigma)$ (dashed traces) is greater than $w_m(\sigma)$ (solid traces) at all depths, but for stable forcing $h/L \geq 0$, the two velocity scales are equal at all depths.

Le nombre de Richardson et la fréquence de Brunt-Väïsälä

$$Ri = \frac{N^2}{\left(\frac{\partial u}{\partial z}\right)^2}$$

Ri compare la stabilité statique représentée par la fréquence de Brunt-Väïsälä *N* à l'instabilité dynamique représentée par le gradient vertical de la vitesse. Si $Ri > 0.25$ le milieu est stable; si $Ri < 0.25$ un gradient vertical de vitesse augmente la turbulence.
Si le fluide est incompressible

$$N^2 = -\frac{g}{\rho}\frac{\partial \rho}{\partial z}$$

et une certaine stratification est dite « stable » si $N^2 > 0$.

On peut expliquer la nature oscillatoire des fluides stratifiés en pensant à une particule de fluide dont la densité augmente avec la profondeur. Lorsqu'elle se trouve déplacé verticalement en dehors de sa position d'équilibre, sa densité devient plus grande ou plus faible que le fluide environnant et une force de restitution excédentaire, la pesanteur ou la poussée d'Archimède respectivement, apparaît et tend à la ramener vers le point d'équilibre. En général, la particule dépasse l'équilibre sur son chemin de retour, car la force a induit une accélération.

Par exemple, entre autres paramètres, la fréquence de Brunt-Väisälä contrôle la hauteur et l'espacement entre les rues de cumulus ou les altocumulus lenticularis en aval de montagnes, ainsi que celui entre les crêtes de houle en pleine mer.

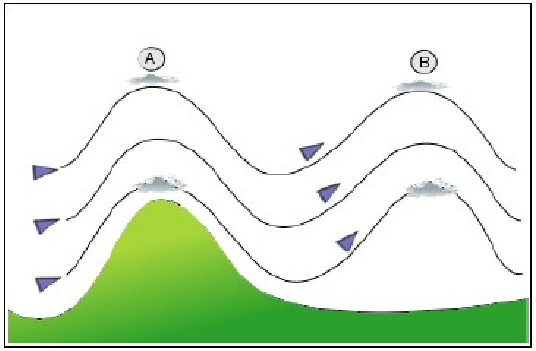
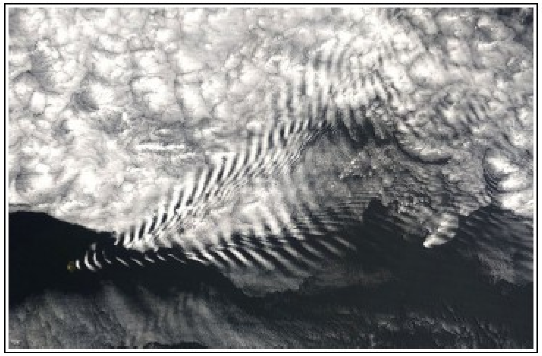


Diagramme du soulèvement orographique au-dessus d'une montagne et de l'onde qui est générée en aval. Des nuages sont créés dans les maxima de l'onde si l'air soulevé devient saturé (points A et B) [image Dake].

http://fr.wikipedia.org/wiki/Onde_orographique



Bandes parallèles de nuages formées par une onde orographique en aval de l'Île Amsterdam et dont l'espacement est gouverné par la fréquence de Brunt-Väisälä [Image NASA , satellite MODIS].

http://fr.wikipedia.org/wiki/Fréquence_de_Brunt-Väisälä

UNIVERSITÉ DE LA MÉDITERRANÉE
AIX-MARSEILLE II

Centre d'océanologie de Marseille

COMPARAISON ENTRE DEUX SCHÉMAS DE FERMETURE DE LA TURBULENCE AVEC ROMS EN ADRIATIQUE

DESBIOLLES Fabien   M1 OPCB   2010

ROMS:

- Solves the **Primitive Equations**: **Boussinesq approximation** + **hydrostatic** vertical momentum balance.
- Discretized in coastline- and **terrain-following curvilinear coordinates**.
- Split-explicit, **free-surface** oceanic model: short time steps to advance the barotropic momentum equations, and a much larger time step for temperature, salinity, and baroclinic momentum.
- Special 2-way time-averaging procedure for the barotropic mode, which satisfies the 3D continuity equation.
- Baroclinic mode discretized using a **third-order accurate** predictor (Leap-Frog) and corrector (Adams-Molton) time-stepping algorithm: substantial increase in the permissible time-step size.

- Designed to be optimized on shared-memory **parallel computer** architectures.
- Parallelization by two-dimensional subdomain partitioning.
- Multiple subdomains can be assigned to each processor to optimize the use of processor cache memory.
- Super-linear scaling: performance growth even faster than the number of CPUs.
- Ported successfully to distributed-memory platforms (clusters, earth simulator)

- **Third-order, upstream-biased advection scheme**: allows the generation of steep gradients.
- Improved calculation of the horizontal pressure gradients.
- Subgrid-scale vertical mixing processes: K-Profile Parameterization **(KPP) boundary-layer scheme**.

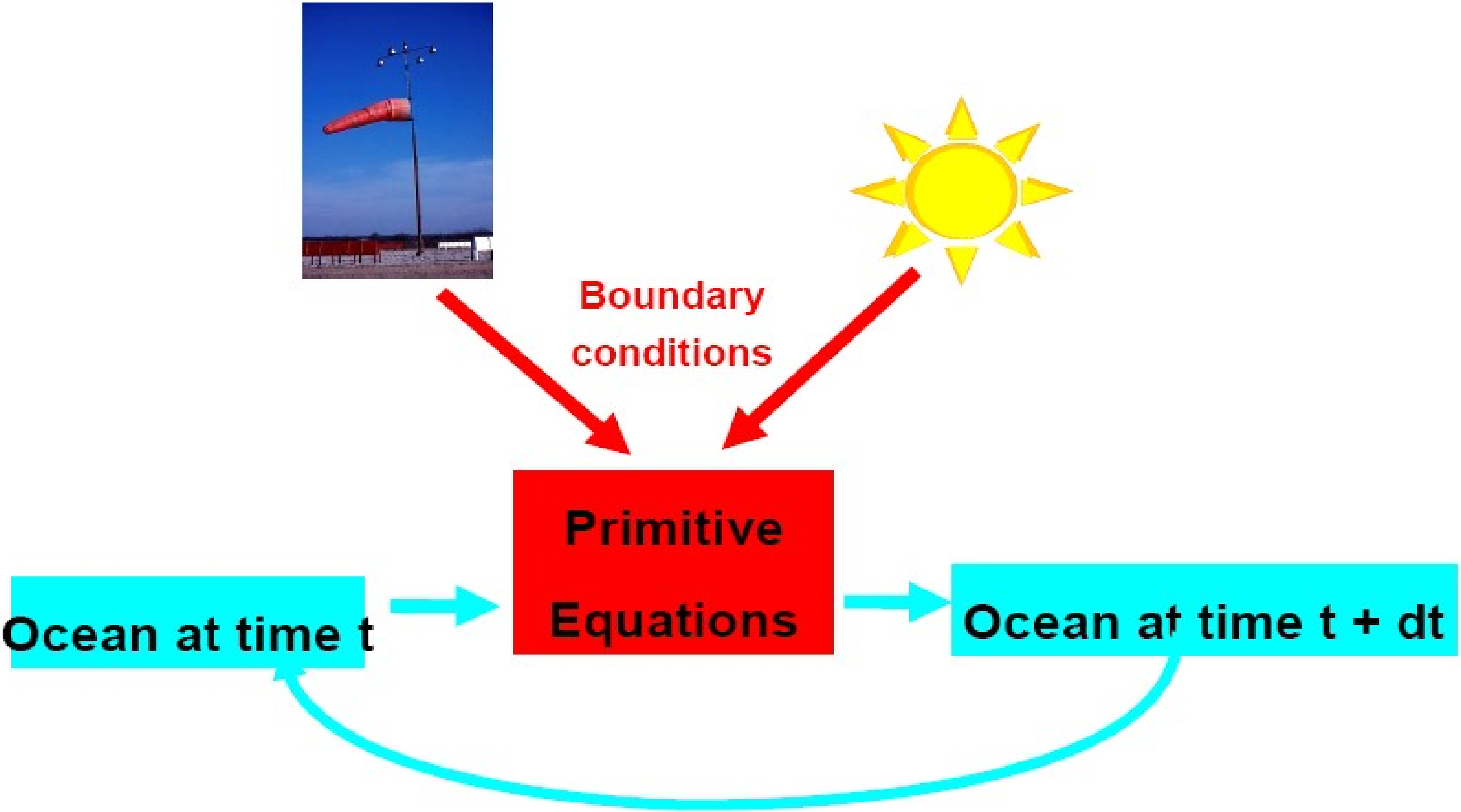
- **Open boundaries**: active, implicit, upstream-biased radiation conditions.
- **Nesting** capability: AGRIF (Adaptive Grid Refinement in Fortran) library. Arbitrary number of fixed grids.

- Sediment module.
- Biogeochemical module.
- Float tracking module.

- ROMSTOOLS: matlab scripts to help the generation and visualization of ROMS configurations.

http://lseet.univ-tln.fr/ecoleete/Documents/ROMS_TOOLS.pdf

2.2 - Why ROMSTOOLS ?



Boundary conditions

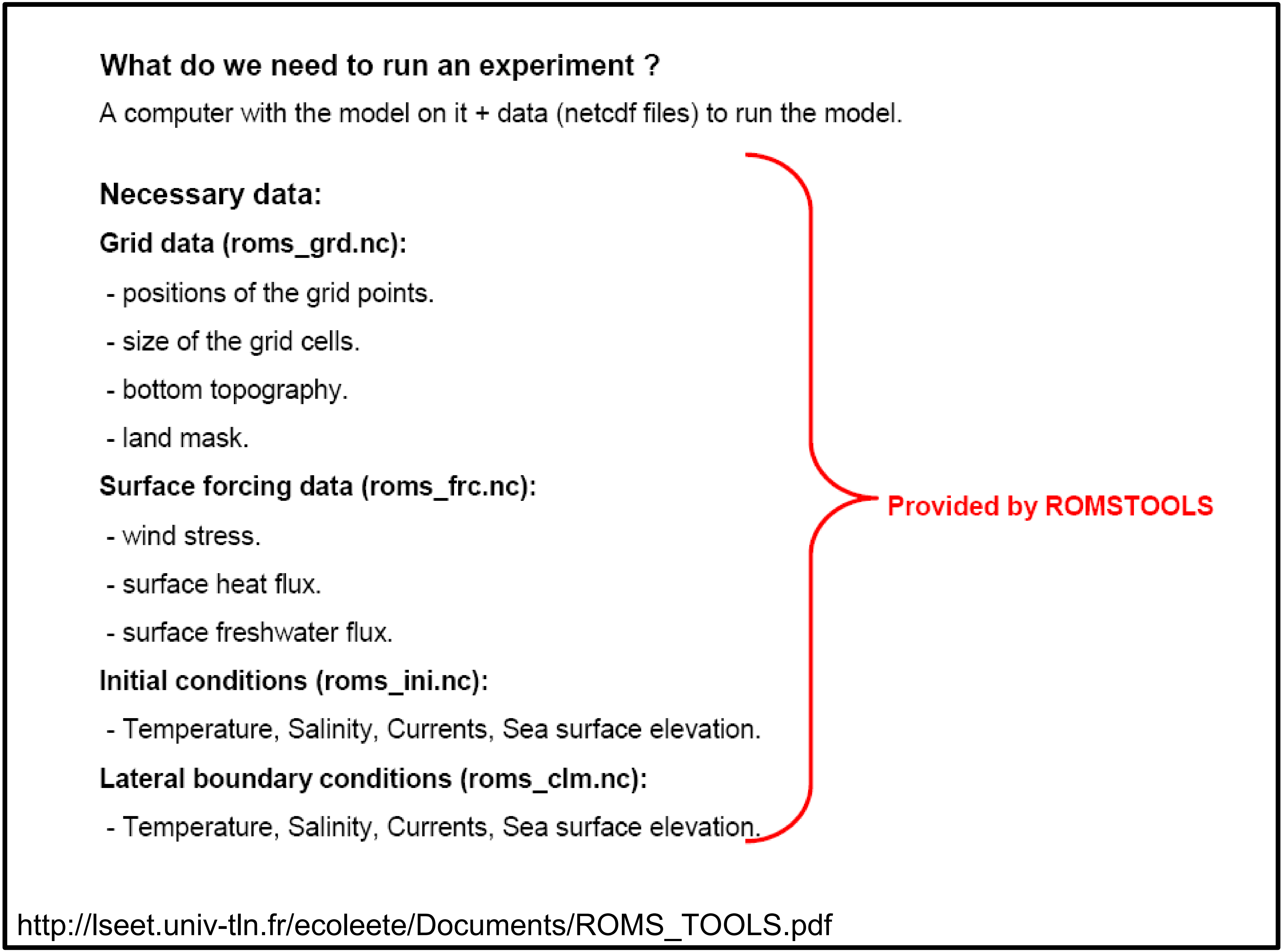
Primitive Equations

Ocean at time t

Ocean at time t + dt

What do we need to run an experiment ?

http://lseet.univ-tln.fr/ecoleete/Documents/ROMS_TOOLS.pdf



What do we need to run an experiment ?

A computer with the model on it + data (netcdf files) to run the model.

Necessary data:

Grid data (roms_grd.nc):

- positions of the grid points.
- size of the grid cells.
- bottom topography.
- land mask.

Surface forcing data (roms_frc.nc):

- wind stress.
- surface heat flux.
- surface freshwater flux.

Initial conditions (roms_ini.nc):

- Temperature, Salinity, Currents, Sea surface elevation.

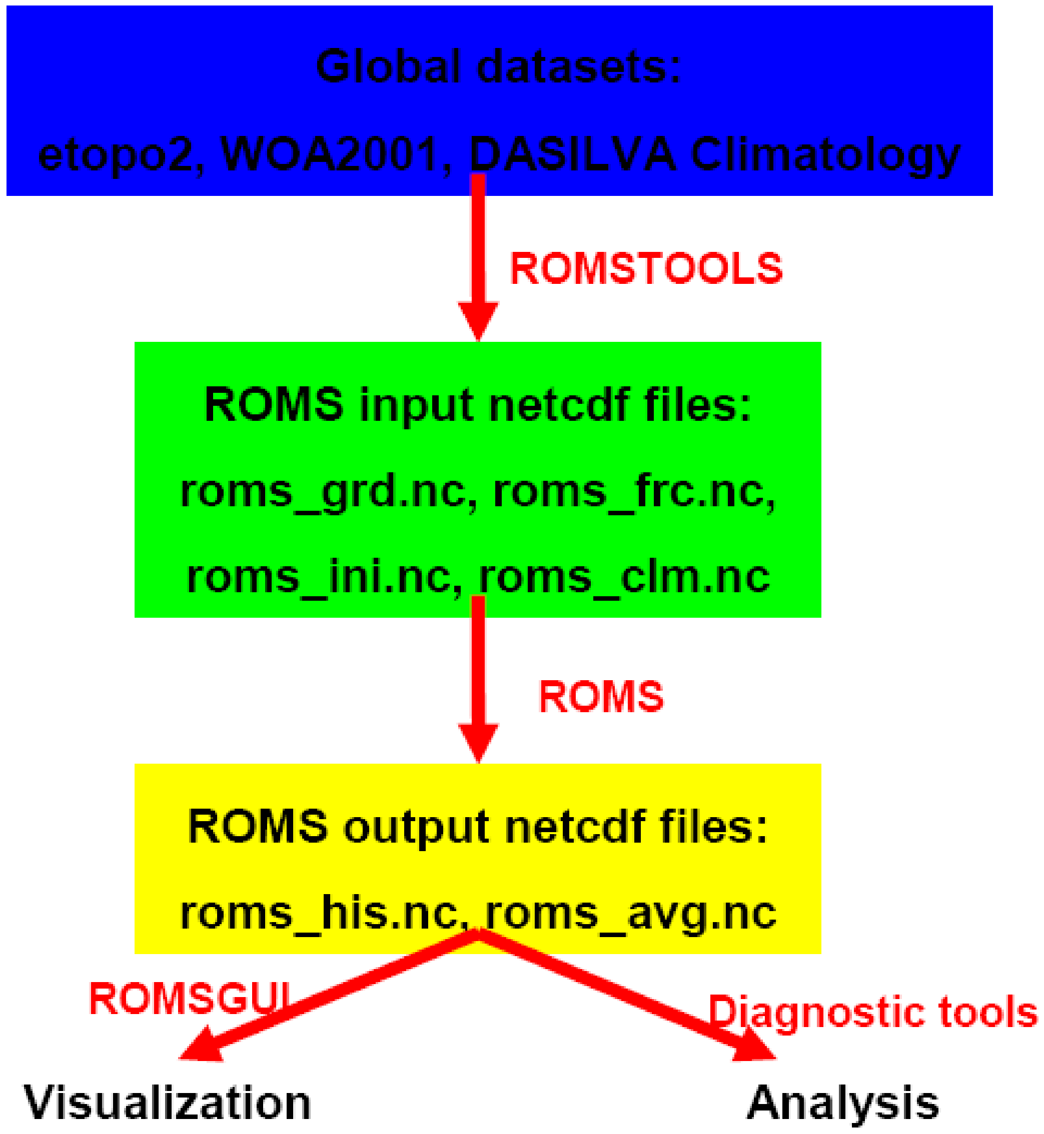
Lateral boundary conditions (roms_clm.nc):

- Temperature, Salinity, Currents, Sea surface elevation.

Provided by ROMSTOOLS

http://lseet.univ-tln.fr/ecoleete/Documents/ROMS_TOOLS.pdf

Strategy:



Global datasets:

etopo2, WOA2001, DASILVA Climatology

ROMSTOOLS

ROMS input netcdf files:

roms_grd.nc, roms_frc.nc,

roms_ini.nc, roms_clm.nc

ROMS

ROMS output netcdf files:

roms_his.nc, roms_avg.nc

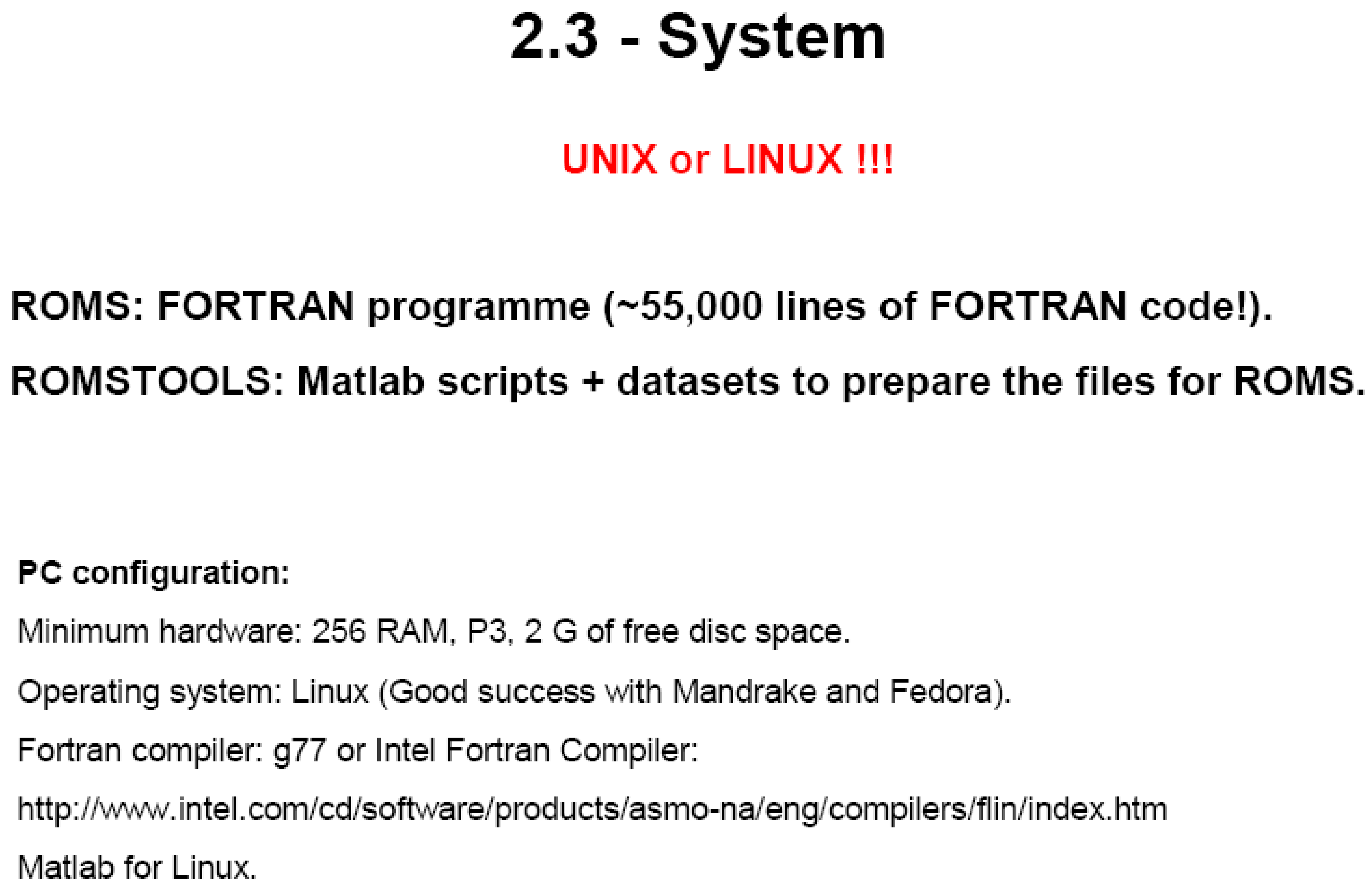
ROMSGUI

Diagnostic tools

Visualization

Analysis

http://lseet.univ-tln.fr/ecoleete/Documents/ROMS_TOOLS.pdf



2.3 - System

UNIX or LINUX !!!

ROMS: FORTRAN programme (~55,000 lines of FORTRAN code!).

ROMSTOOLS: Matlab scripts + datasets to prepare the files for ROMS.

PC configuration:

Minimum hardware: 256 RAM, P3, 2 G of free disc space.

Operating system: Linux (Good success with Mandrake and Fedora).

Fortran compiler: g77 or Intel Fortran Compiler:

http://www.intel.com/cd/software/products/asmo-na/eng/compilers/flin/index.htm

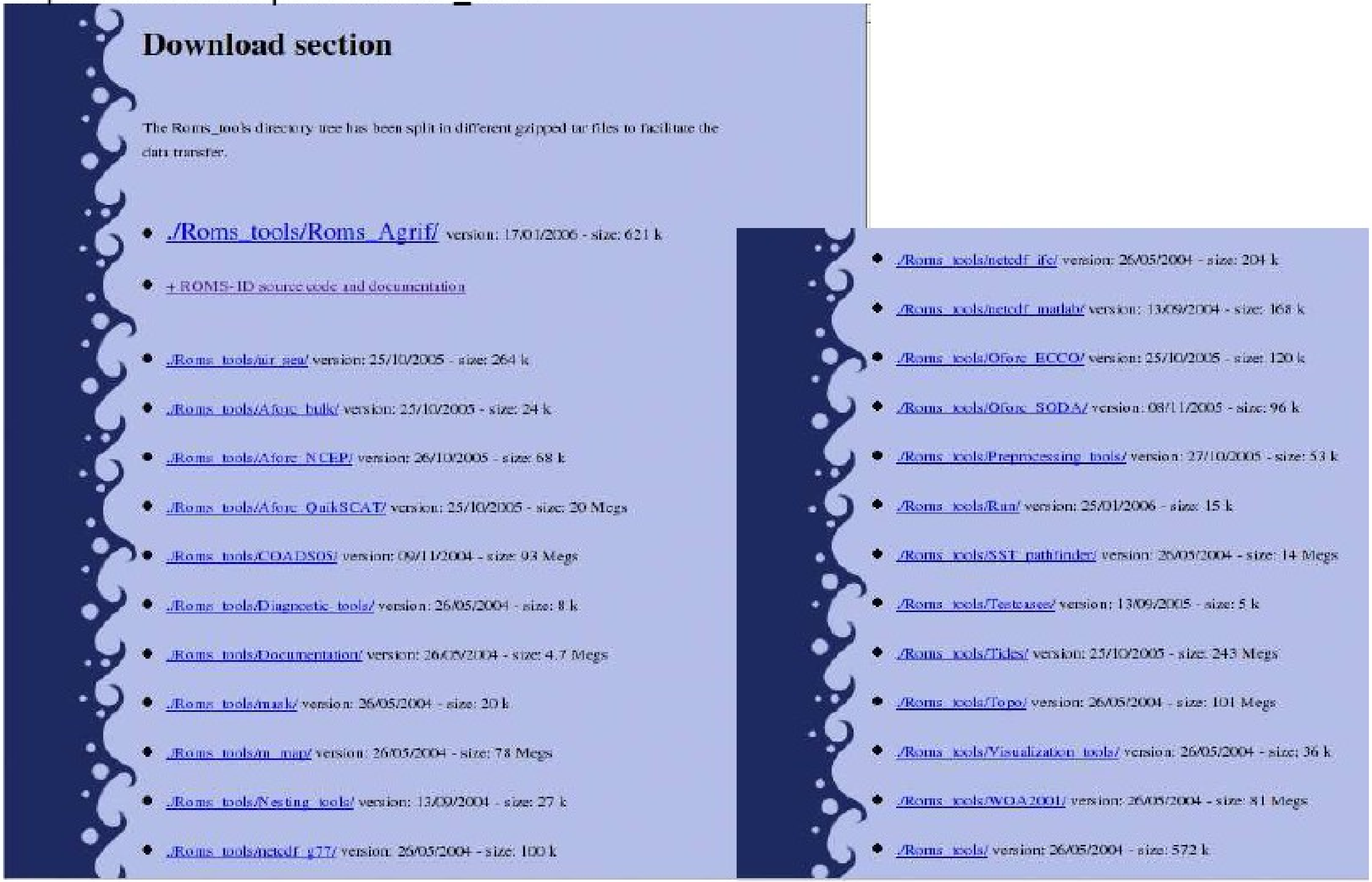
Matlab for Linux.

http://lseet.univ-tln.fr/ecoleete/Documents/ROMS_TOOLS.pdf

2.4 – How to get the tools ?

http://www.brest.ird.fr/Roms_tools/

http://sea.uct.ac.za/penven/Roms_tools/



Download section

The Roms_tools directory tree has been split in different gzipped tar files to facilitate the data transfer.

- ./Roms_tools/Roms_Agrif/ version: 17/01/2006 - size: 621 k
- + ROMS-1D source code and documentation

- ./Roms_tools/air_sea/ version: 25/10/2005 - size: 264 k
- ./Roms_tools/Aforc_bulk/ version: 25/10/2005 - size: 24 k
- ./Roms_tools/Aforc_NCEP/ version: 26/10/2005 - size: 68 k
- ./Roms_tools/Aforc_QuikSCAT/ version: 25/10/2005 - size: 20 Megs
- ./Roms_tools/COADS05/ version: 09/11/2004 - size: 93 Megs
- ./Roms_tools/Diagnostic_tools/ version: 26/05/2004 - size: 8 k
- ./Roms_tools/Documentation/ version: 26/05/2004 - size: 4.7 Megs
- ./Roms_tools/mask/ version: 26/05/2004 - size: 20 k
- ./Roms_tools/m_map/ version: 26/05/2004 - size: 78 Megs
- ./Roms_tools/Nesting_tools/ version: 13/09/2004 - size: 27 k
- ./Roms_tools/netcdf_g77/ version: 26/05/2004 - size: 100 k
- ./Roms_tools/netcdf_ifc/ version: 26/05/2004 - size: 204 k
- ./Roms_tools/netcdf_matlab/ version: 13/09/2004 - size: 168 k
- ./Roms_tools/Oforc_ECCO/ version: 25/10/2005 - size: 120 k
- ./Roms_tools/Oforc_SODA/ version: 08/11/2005 - size: 96 k
- ./Roms_tools/Preprocessing_tools/ version: 27/10/2005 - size: 53 k
- ./Roms_tools/Run/ version: 25/01/2006 - size: 15 k
- ./Roms_tools/SST_pathfinder/ version: 26/05/2004 - size: 14 Megs
- ./Roms_tools/Testcases/ version: 13/09/2005 - size: 5 k
- ./Roms_tools/Tides/ version: 25/10/2005 - size: 243 Megs
- ./Roms_tools/Topo/ version: 26/05/2004 - size: 101 Megs
- ./Roms_tools/Visualization_tools/ version: 26/05/2004 - size: 36 k
- ./Roms_tools/WOA2001/ version: 26/05/2004 - size: 81 Megs
- ./Roms_tools/ version: 26/05/2004 - size: 572 k
