T-UGOm : the Toulouse Unstructured Grid Ocean model

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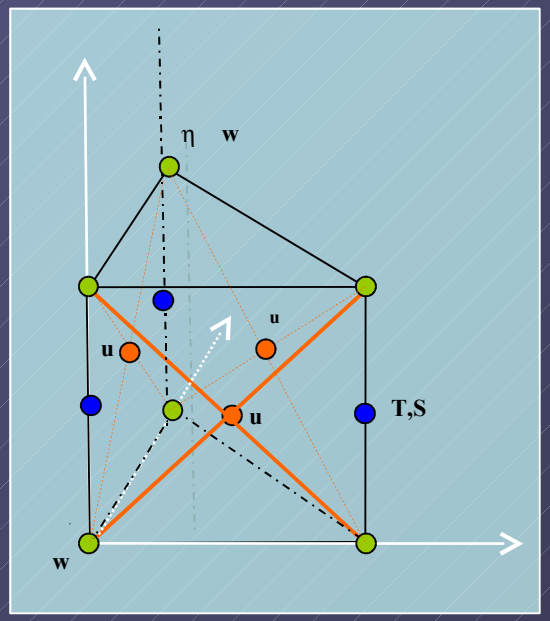
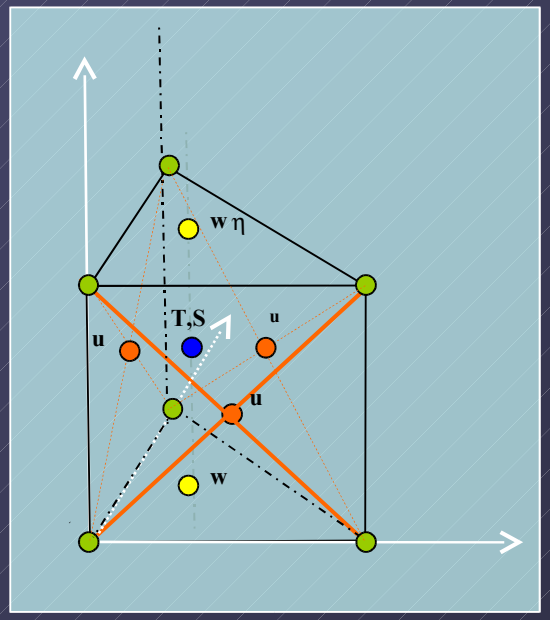
T-UGOm 2D/3D

- Modèle éléments/volumes finis
- Time-splitting
- Éléments 2D triangles
- Éléments 3D prismatiques
- Coordonnées sphériques (horizontale), sigma généralisées (verticale)
- Boussinesq, hydrostatique



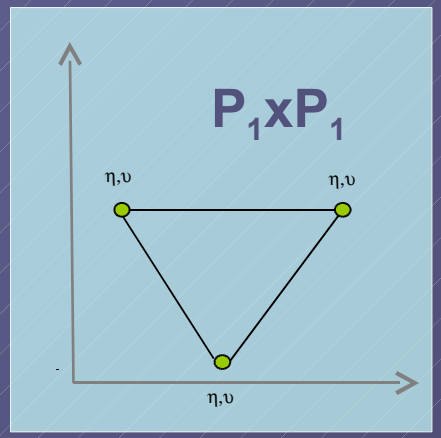
Eléments finis



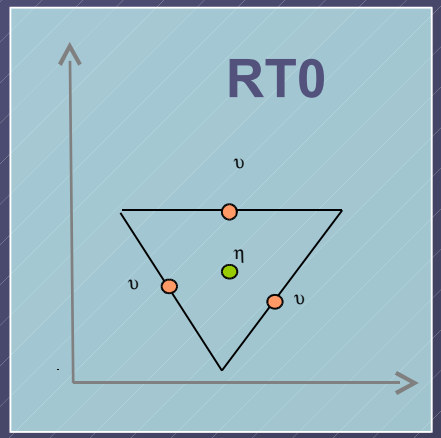
Volumes finis

Discretisation

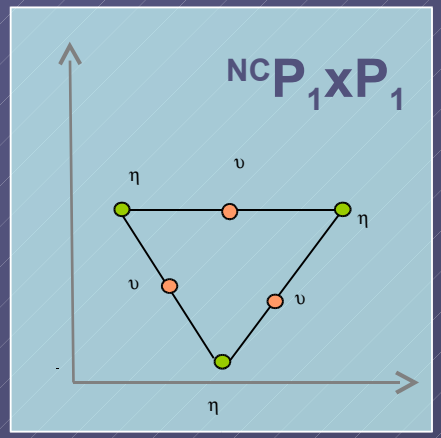
P_0 : volumes finis, discontinu, uniforme
P_1 : élements finis, continu, linéaire
$^{NC}P1$: élements finis, faiblement discontinu, linéaire



- Simplicité
- Adapté aux CL d'élévation
- Coût numérique réduit
- Dimensions
  - M éléments
  - M/2 nœuds élévations
  - M/2 noeuds vitesse



- Formulation volumes finis
- Bonne stabilité théorique
- Adapté aux CL de courants
- Coût numérique supérieur
- Dimensions
  - M éléments
  - M nœuds élévations
  - 3xM/2 noeuds vitesse

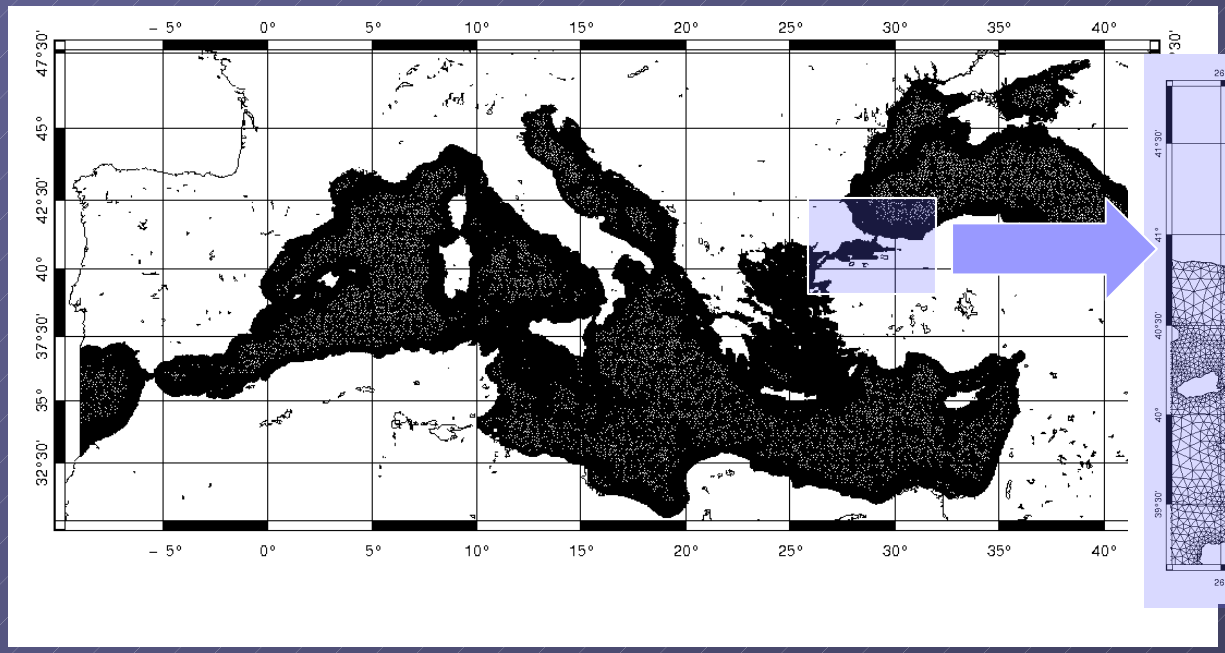


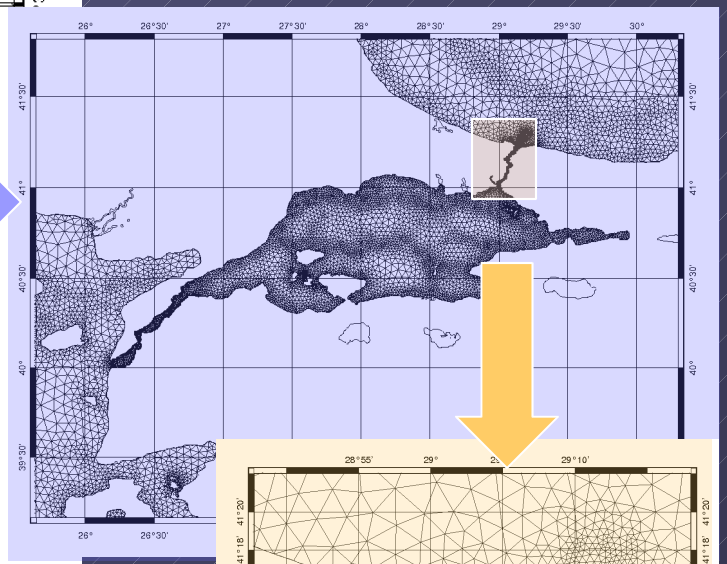
- Bonne stabilité théorique
- Adapté aux CL d'élévation
- Adapté aux CL de courants
- Coût numérique supérieur
- Dimensions
  - M éléments
  - M/2 nœuds élévations
  - 3xM/2 noeuds vitesse

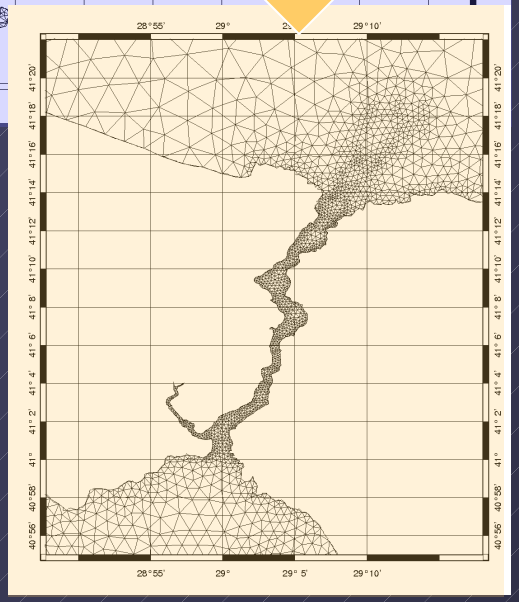
Principes du sub-cycling

- Raffinement local, multi-niveaux, de l'incrément de temps barotrope
- Architecture ré-entrante du solveur dynamique, conditions limites internes spécifiques
- Contrôle dynamique et/ou statique
  - Gestion des instabilités 2D (modes instables de pression)
  - Mélange solveur explicite (zones découvrantes, incrément temporel réduit) et implicite (mode standard, incrément temporel optimal)

Application aux échanges Mer Noire/Mer Méditerranée





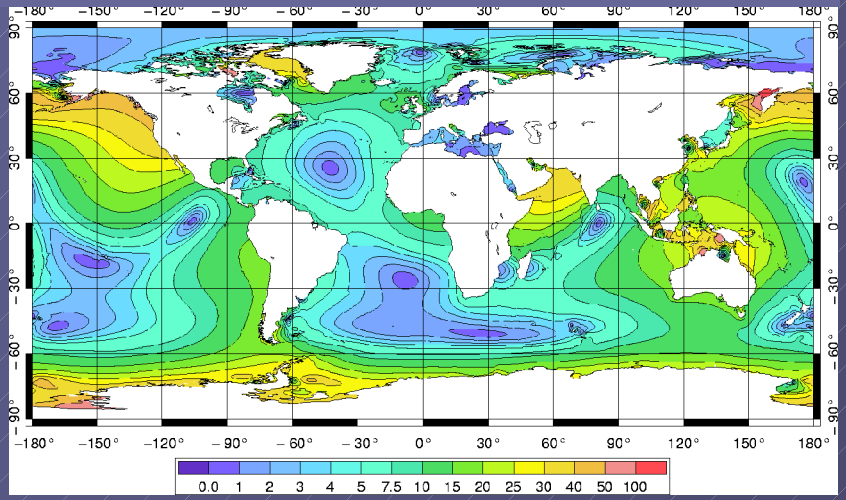


Echanges contrôlés par la différence de niveau de la mer entre la Mer Noire et la Mer Méditerranée

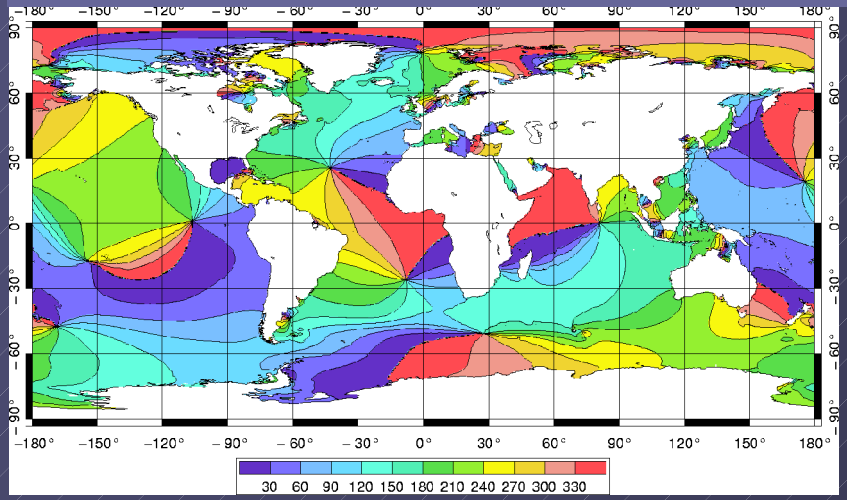
- Résolution spatiale de 4 à 20 km en régions marines
  - Incrément de temps ~120 s
- Résolution spatiale de 100 m à 1 km sur le Bosphore
  - Incrément de temps ~ 1s

Diurnal and semi-diurnal tides

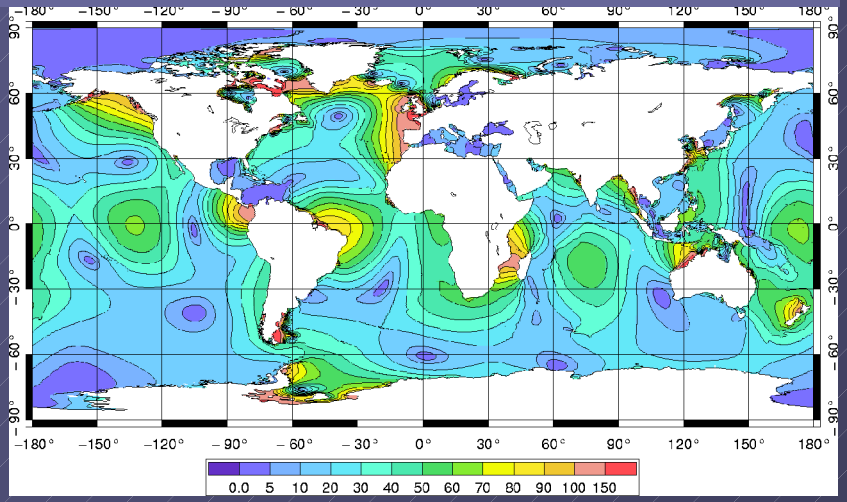
K_1 amplitude (cm)



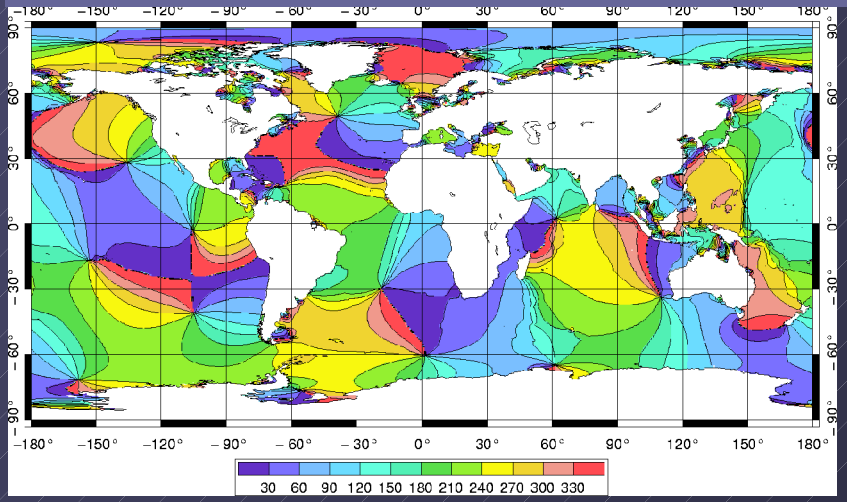
K_1 phase lag (°)



M_2 amplitude (cm)



M_2 phase lag (°)

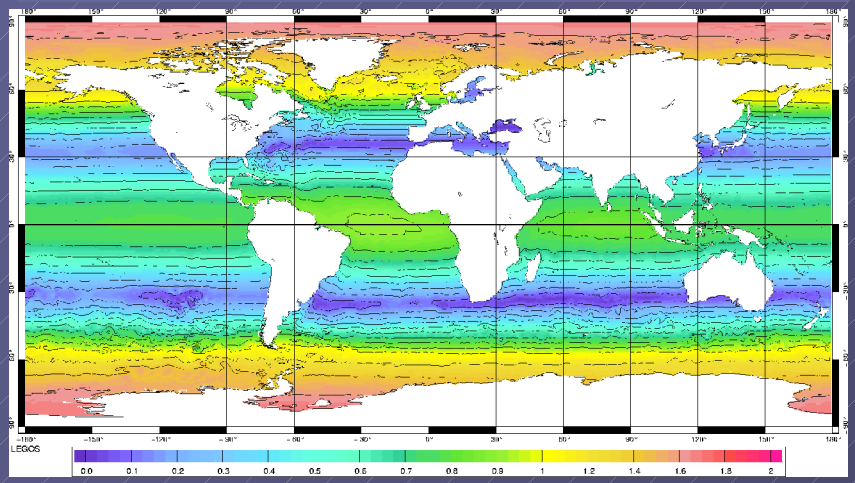


M_m long period tide

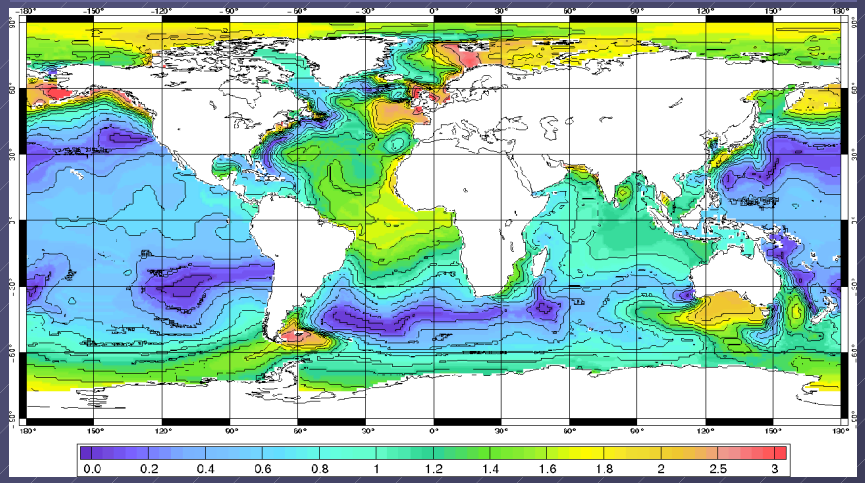
proche de la marée déquilibre

peu observable

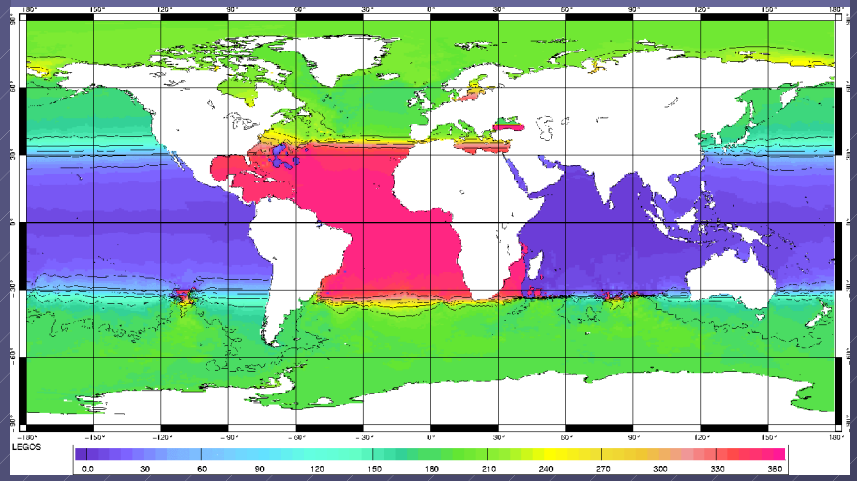
M_m amplitude (cm)

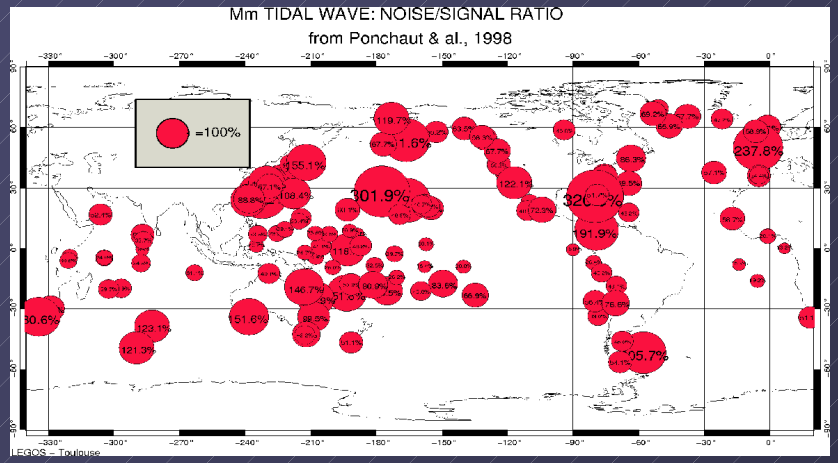


Assimilation (Schwiderski 1982)



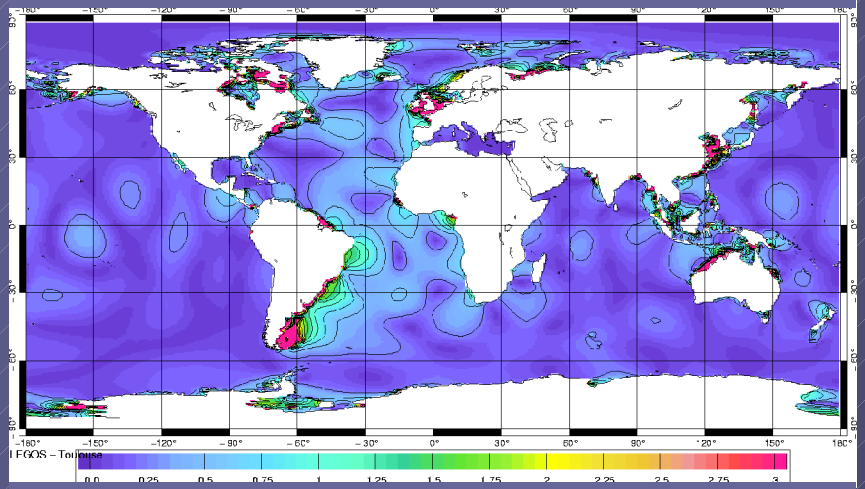
M_m phase lag (°)



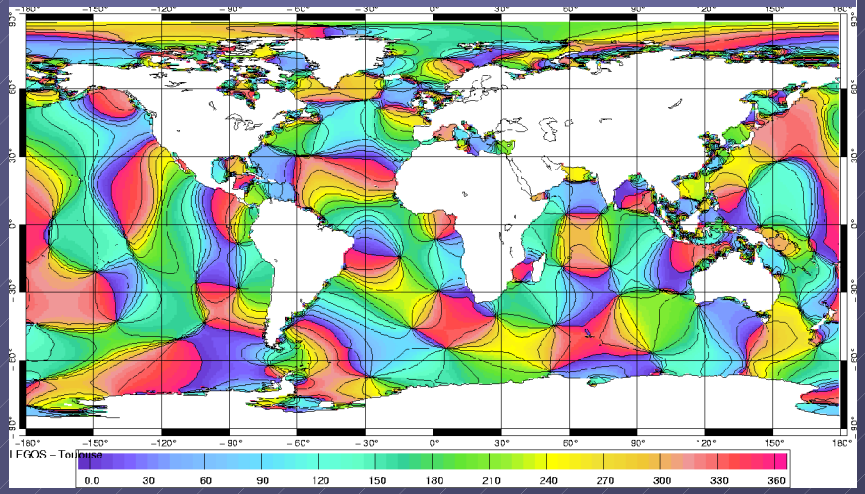


M4 non-linear tide

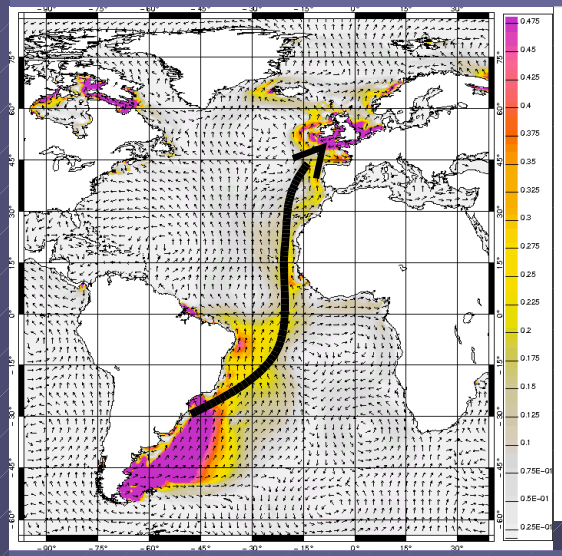
M_4 amplitude (cm)

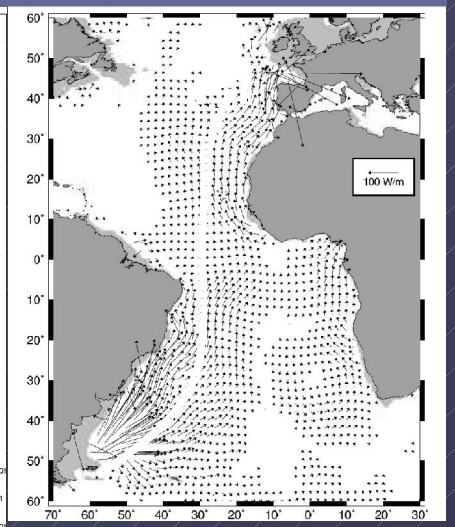


M_4 phase lag (°)



Flux d'énergie de marée M4





Lyard, 2006: modélisation

Ray, 2008: observation

1ère harmonique de l'onde M_2

periode ~ 6h15 (onde quart-diurne)

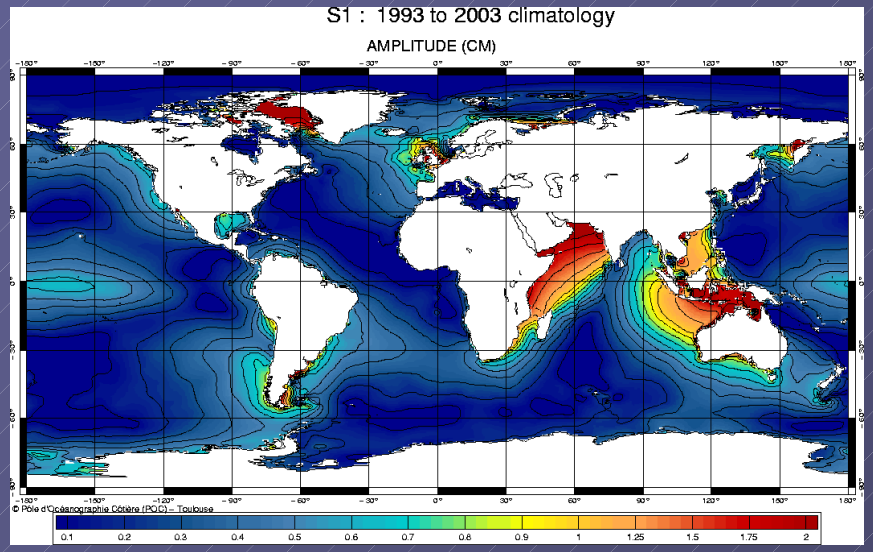
amplitude significative dans l'océan Atlantique

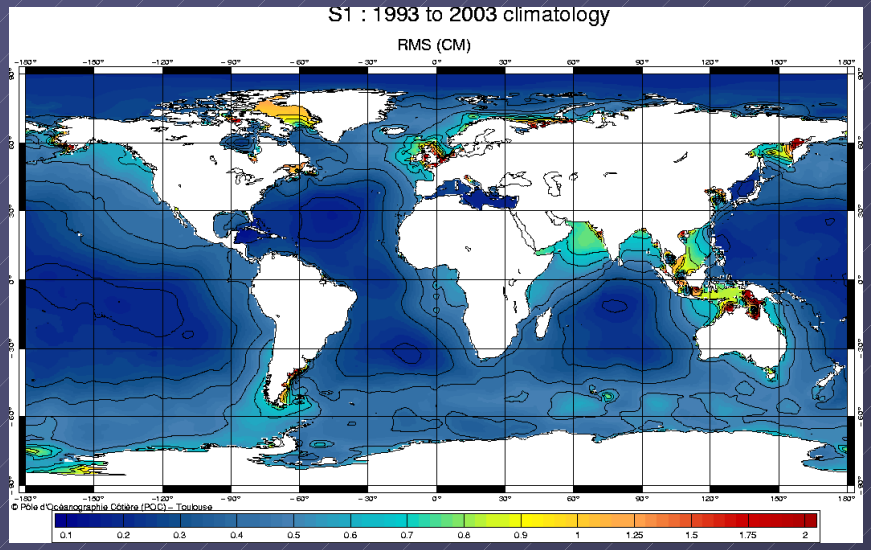
flux d'énergie entre le plateau de Patagonie et le Nord-Est Atlantique

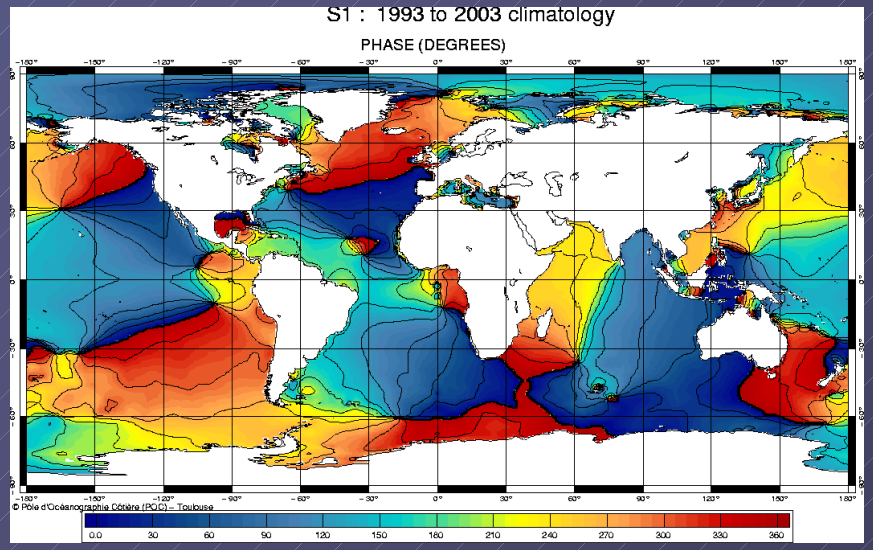
analyser les raisons de ses particularités

Pairaud et al., CSR 2008

S1 ocean tide, 1993-2003 annual variablility

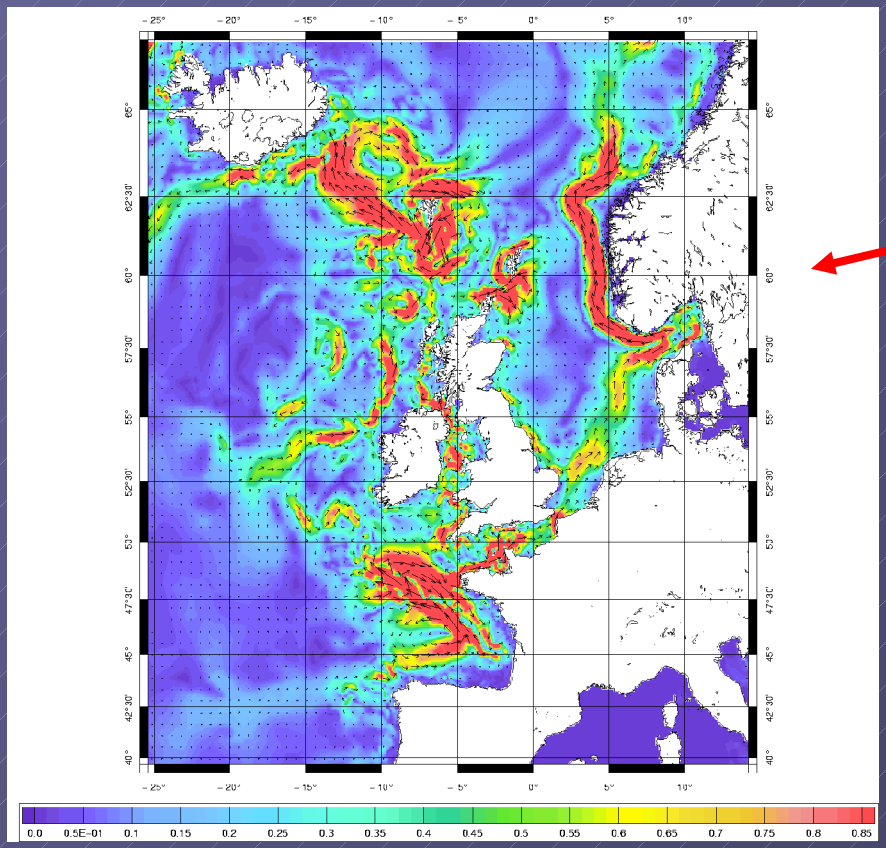




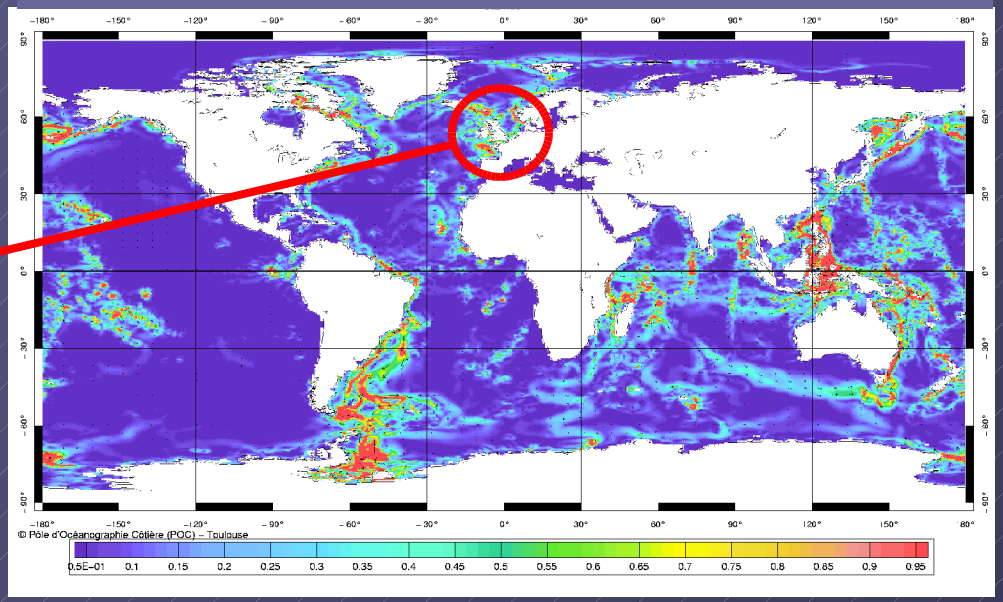


- generated by surface pressure oscillation
- linked with the atmosphere dynamic (internal waves)
- strong monthly to inter-annual variability

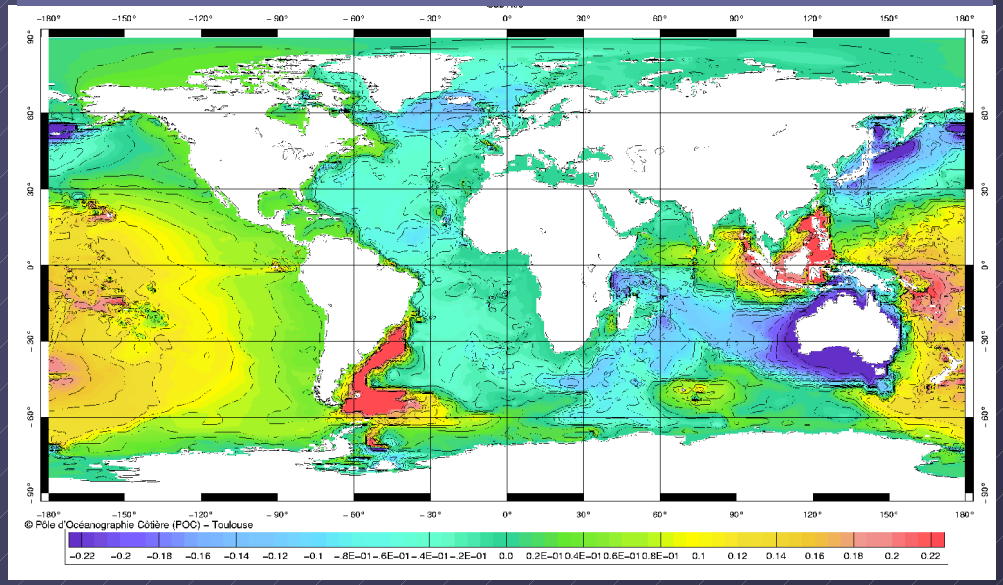
Residual tidal transport and stream function



Transport résiduel global



Fonction de courant du transport résiduel



Echelles régionales:

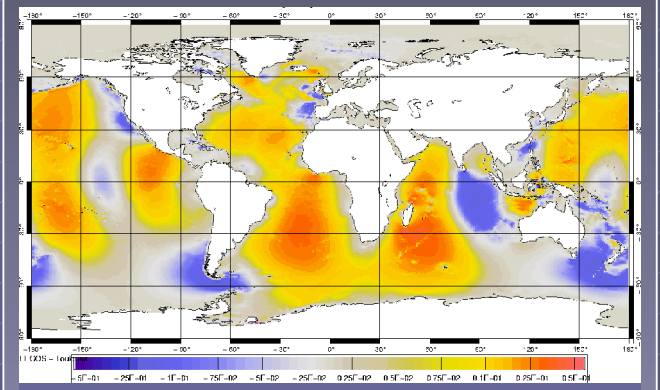
- **Flather non-adapté pour le courant moyen**
- **Conditions aux limites nécessaires**

Sinon : re-circulation dans le modèle régional

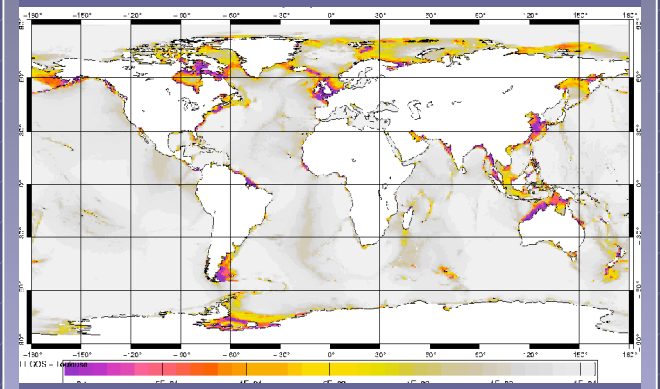
Fonctionnalités intégrées pour la marée

- Spectre harmonique complet (potentiel et non-linéaire)
- Forçage de marée:
  - Potentiel astronomique (analytique)
  - Potentiel d'auto-attraction (atlas harmonique FES2004)
  - Elevations(/courants) aux frontières ouvertes
- Déformation radiale:
  - Marée solide (analytique)
  - Effets de charge (atlas harmonique FES2004)
- Prédiction (forçages) et analyse (solutions harmoniques)
- Extension par la méthode des admittances
- Paramétrisation dissipation par générations d'ondes internes
- Bilans d'énergie spectraux: flux d'énergie, dissipation, etc…
- Carte d'élévations minimum pour le seuillage bathymétrique
- Wetting/drying

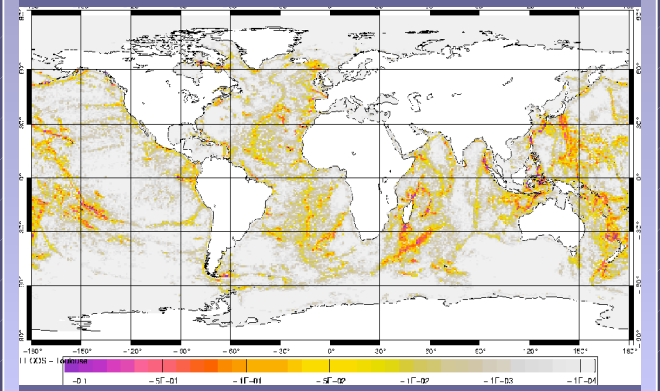
Transfert d'énergie marée barotrope/ondes internes



Astronomic forcing RoW ~2.43 TW



Bottom friction RoW ~ 1.8 TW

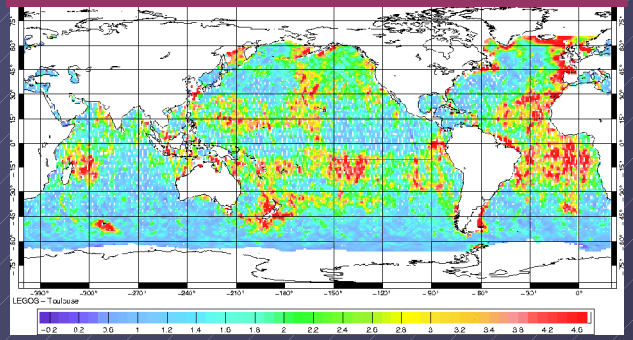


Internal wave drag RoW ~0.7 TW

Rationales

- Unbalanced energy budgets
- Quasi-ubiquity of the internal tides (observation T/P)

M2 internal tide signal to noise ratio



Hypothesis

- Significant energy transfert from barotropic to baroclinic tides
- Transfer must be parameterized in models

Conclusion

- Un nouveau terme dissipatif (traînée barocline)

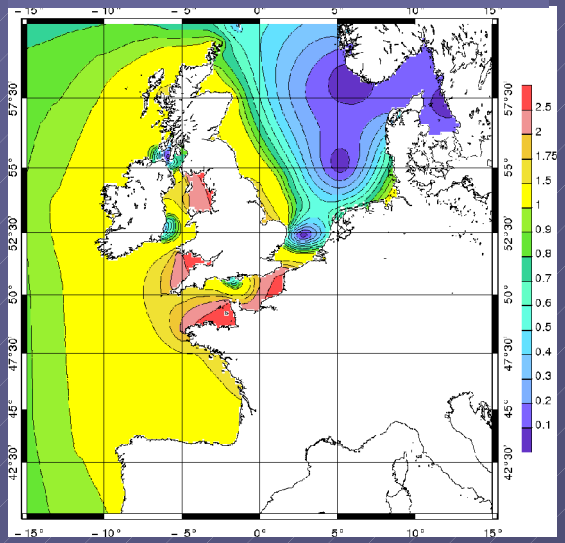
$$\vec{F}_{iwd} = -C_d \rho_o \kappa^{-1} \overline{N} \left(\vec{\nabla} H \cdot \vec{U}\right) \vec{\nabla} H$$

- Reduced error budget in barotropc computation (by a factor of 2)
- Balanced energy budgets
- Quantitative assessment of internal tide energy

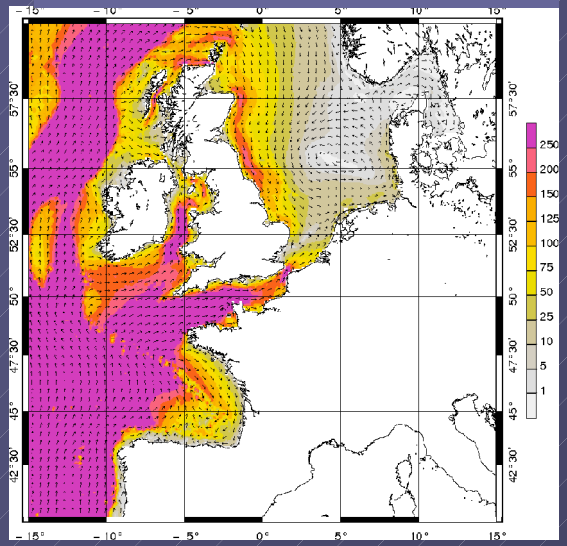
Lyard et Le Provost, 1997; Lyard et al., OD 2006; Auclair et al., JAOT 2008

Marée M_2 (modèle NEA)

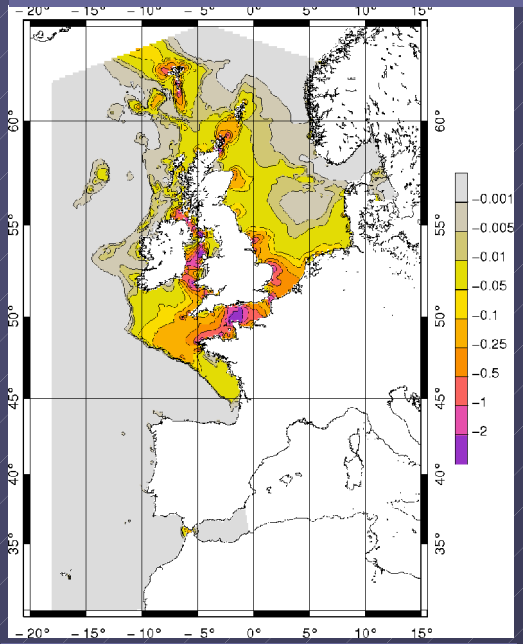
M_2 amplitude (cm)



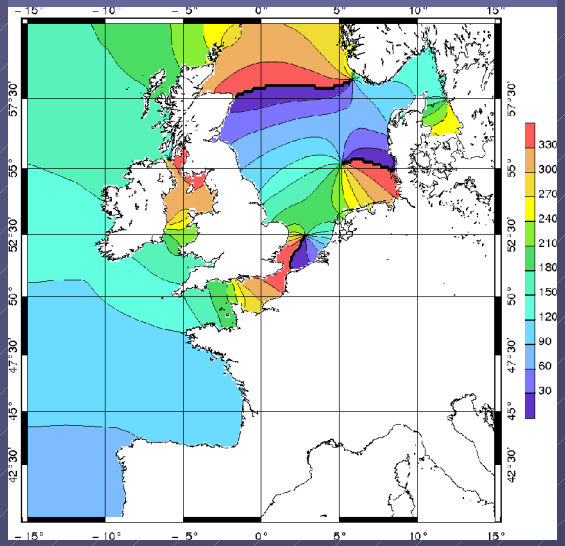
M_2 energy flux (w/m)



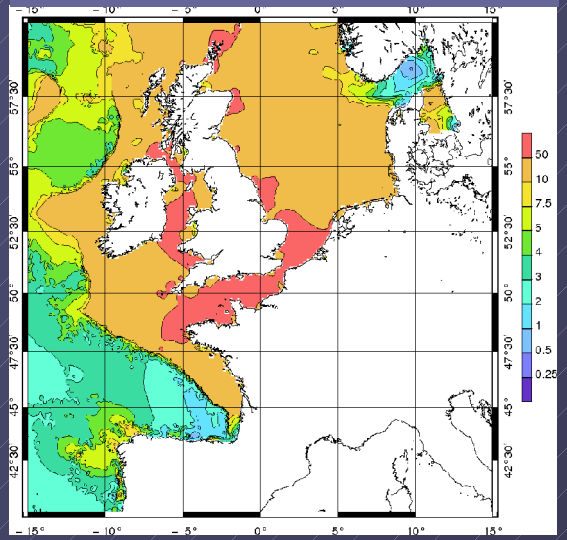
M_2 bottom friction (w/m²)



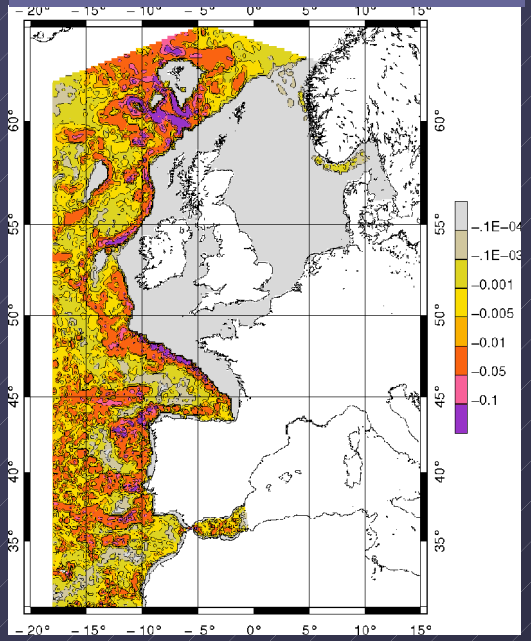
M_2 phase lag (°)



M_2 max current (cm/s)

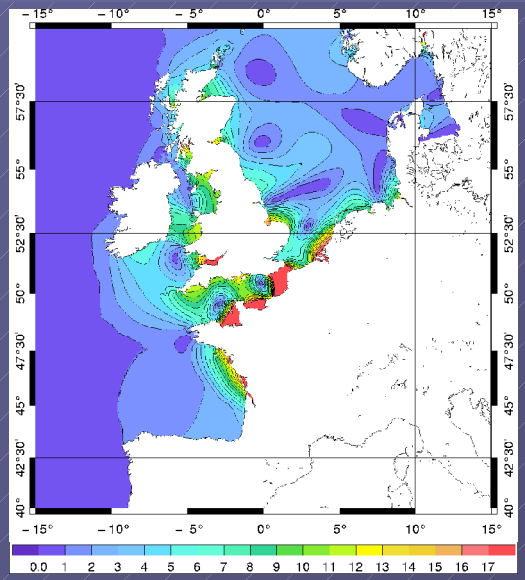


M_2 wave drag (w/m²)

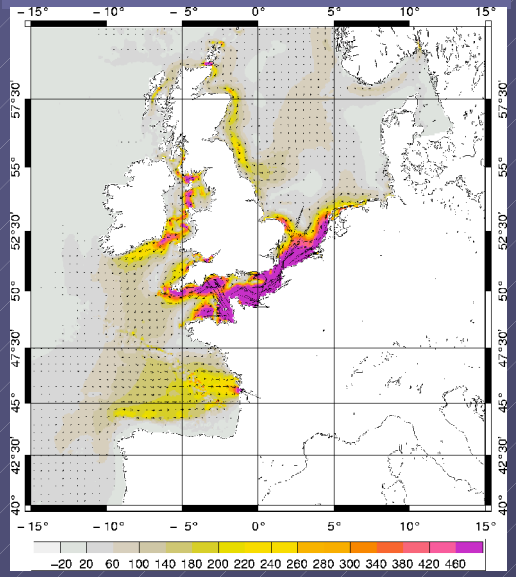


Marée M_4 (modèle NEA)

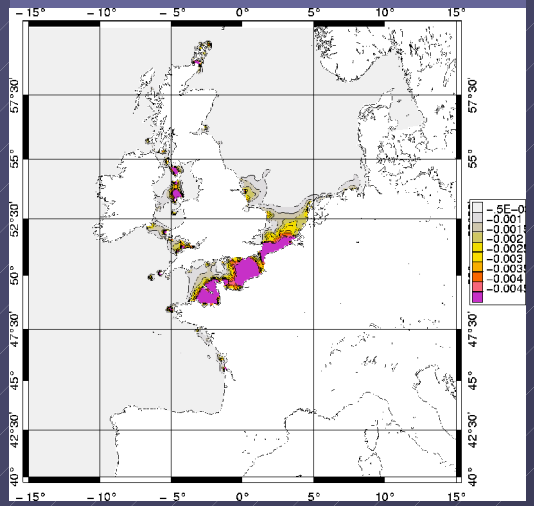
M_4 amplitude (cm)



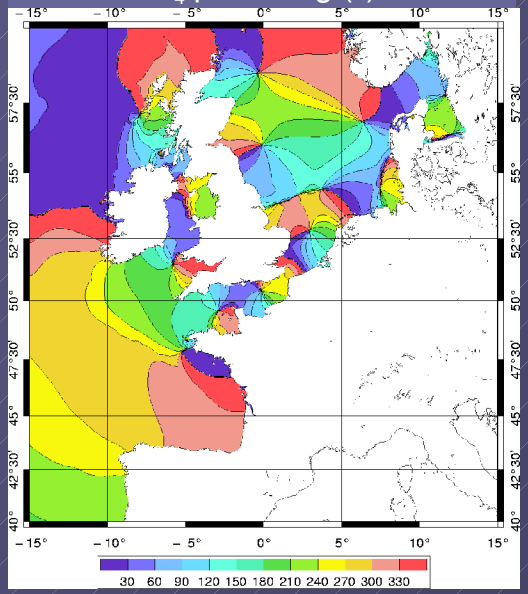
M_4 energy flux (w/m)



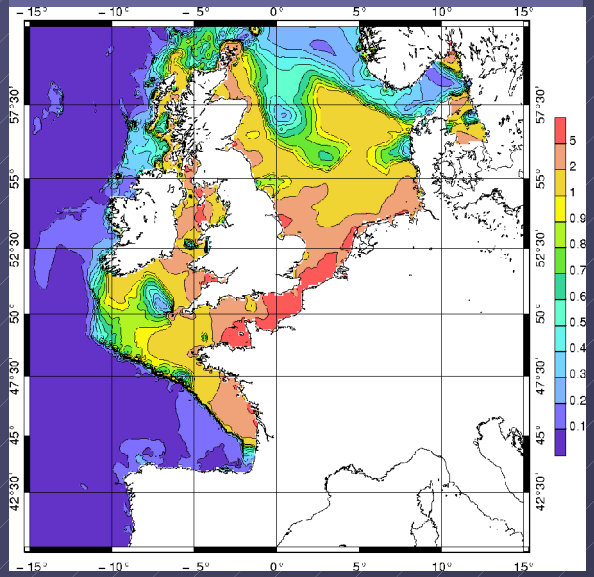
M_4 bottom friction (w/m²)



M_4 phase lag (°)



M_4 max current (cm/s)



Méthodes d'assimilation pour la marée

- Données:
  - marégraphes
  - altimètres
  - radars côtier
- Assimilation EnOI:
  - simulations d'ensemble
    - bathymétrie
    - longueur de rugosité
    - coefficient de traînée barocline
    - conditions aux limites
  - Analyse harmonique des solutions
  - Calcul des représenteurs et inversion dans l'espace spectral
    - Mono-chromatique
    - Mode couplé (M_2/M_4/..)
- Assimilation EnKF
  - simulations d'ensemble
    - …
  - assimilation séquentielle par filtre de Karman

Quick assimilation experiment

- Bathymetry ensemble
  - ✓ Primary statistics based on *GEBCO (gridone)*, *Smith and Sandwell* versions 6/8, *ETOPO2*, *TerrainBase*
  - ✓ Reconstruction of bathymetry

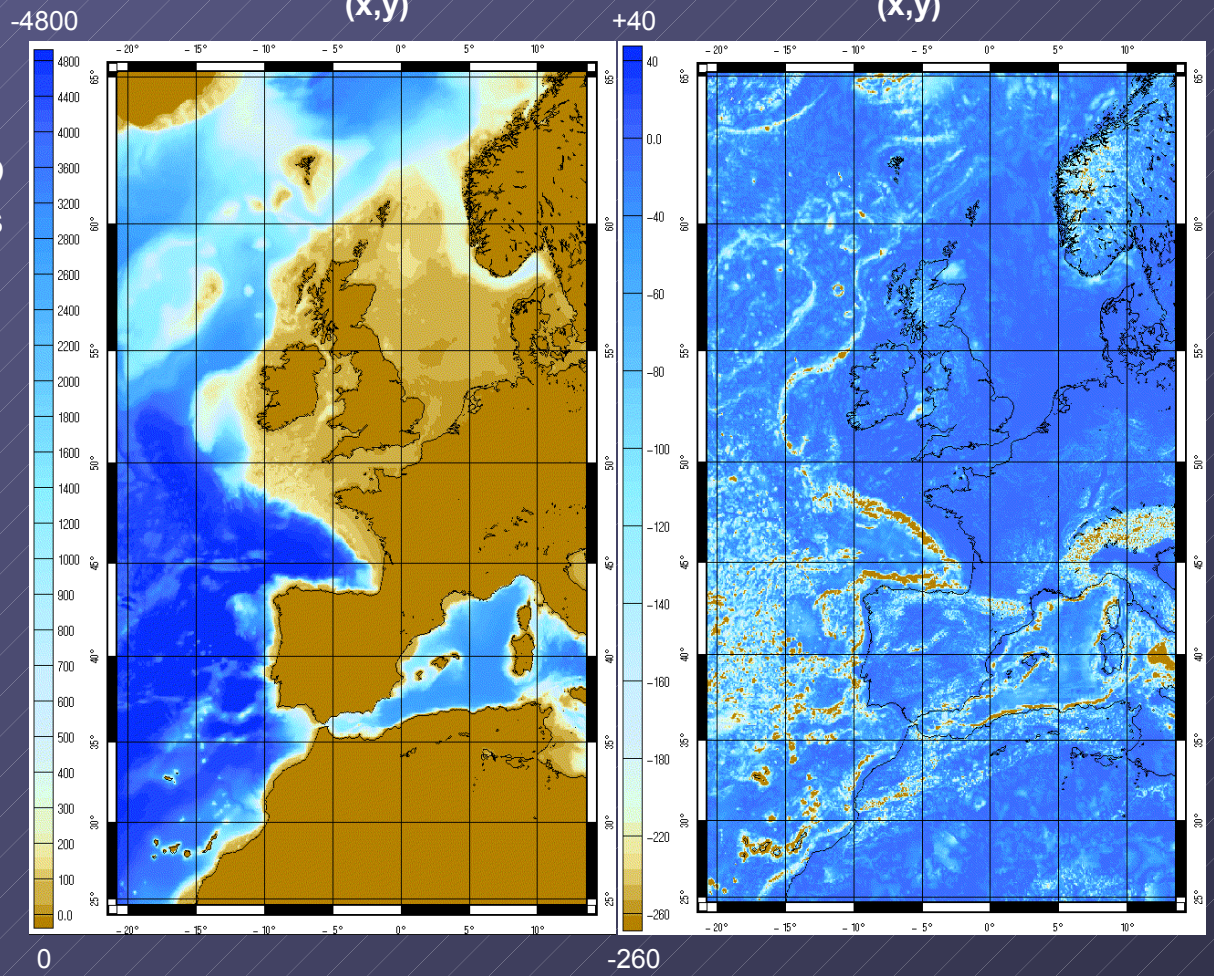
$$p_\alpha(x,y) = m(x,y) + \alpha * \sigma(x,y)$$

α : moyenne nulle, écart-type=1, max/min = +/-1.67

1st hydrodynamic sub-ensemble

mean bathymetry m (x,y)

Standard deviation σ (x,y)



Quick assimilation experiment

- Bottom friction ensemble

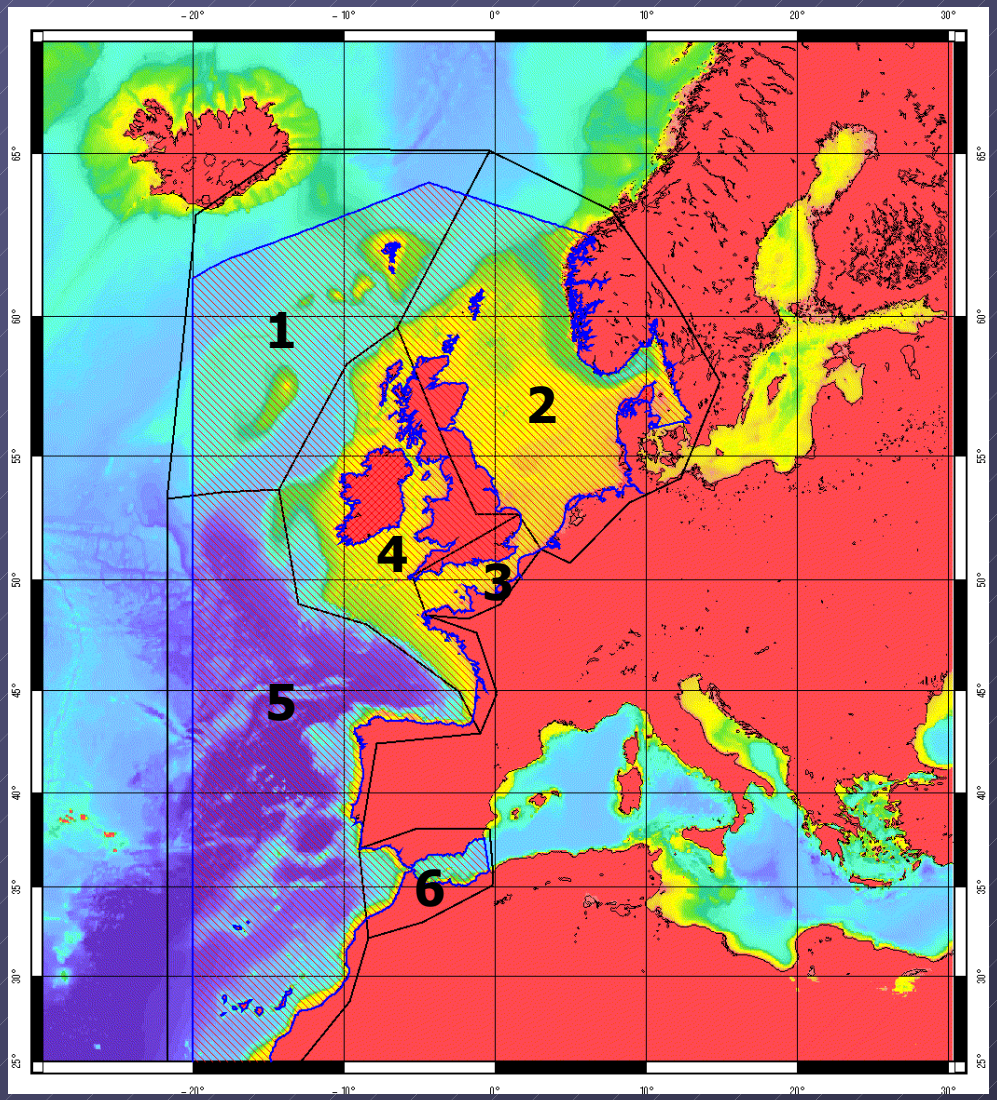
  Geographically-dependent bottom friction coefficient

  - abyssal plain (region 1 and 5),
  - open shelf (region 4),
  - semi-enclosed shelf (region 2),
  - straits (region 3 et 6)

- Internal waved drag ensemble

  Geographically-dependent IWD coefficient

2nd and 3rd hydrodynamic sub-ensembles



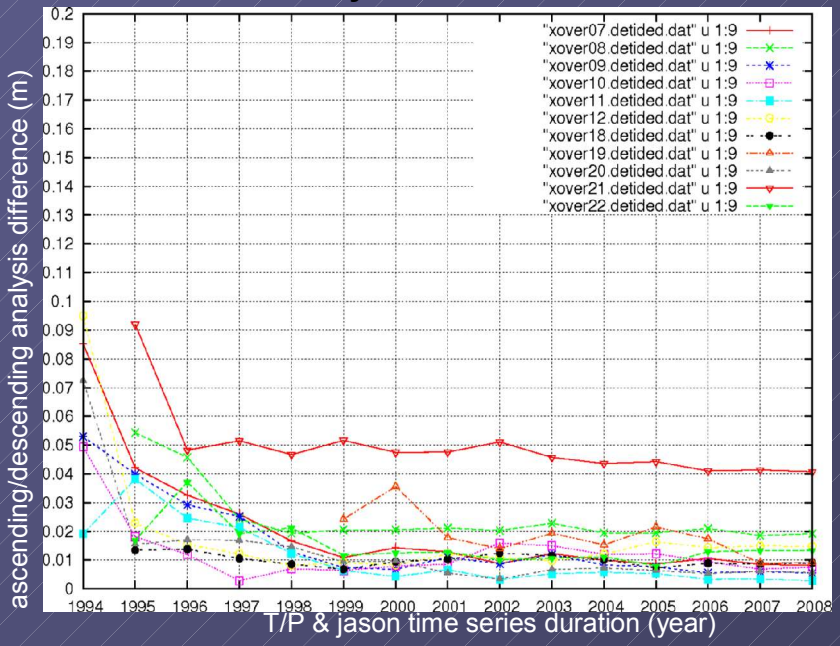
ALTIMETRY TIDAL ANALYSIS AND ERROR ESTIMATES

Fully re-process altimetry data for tidal analysis

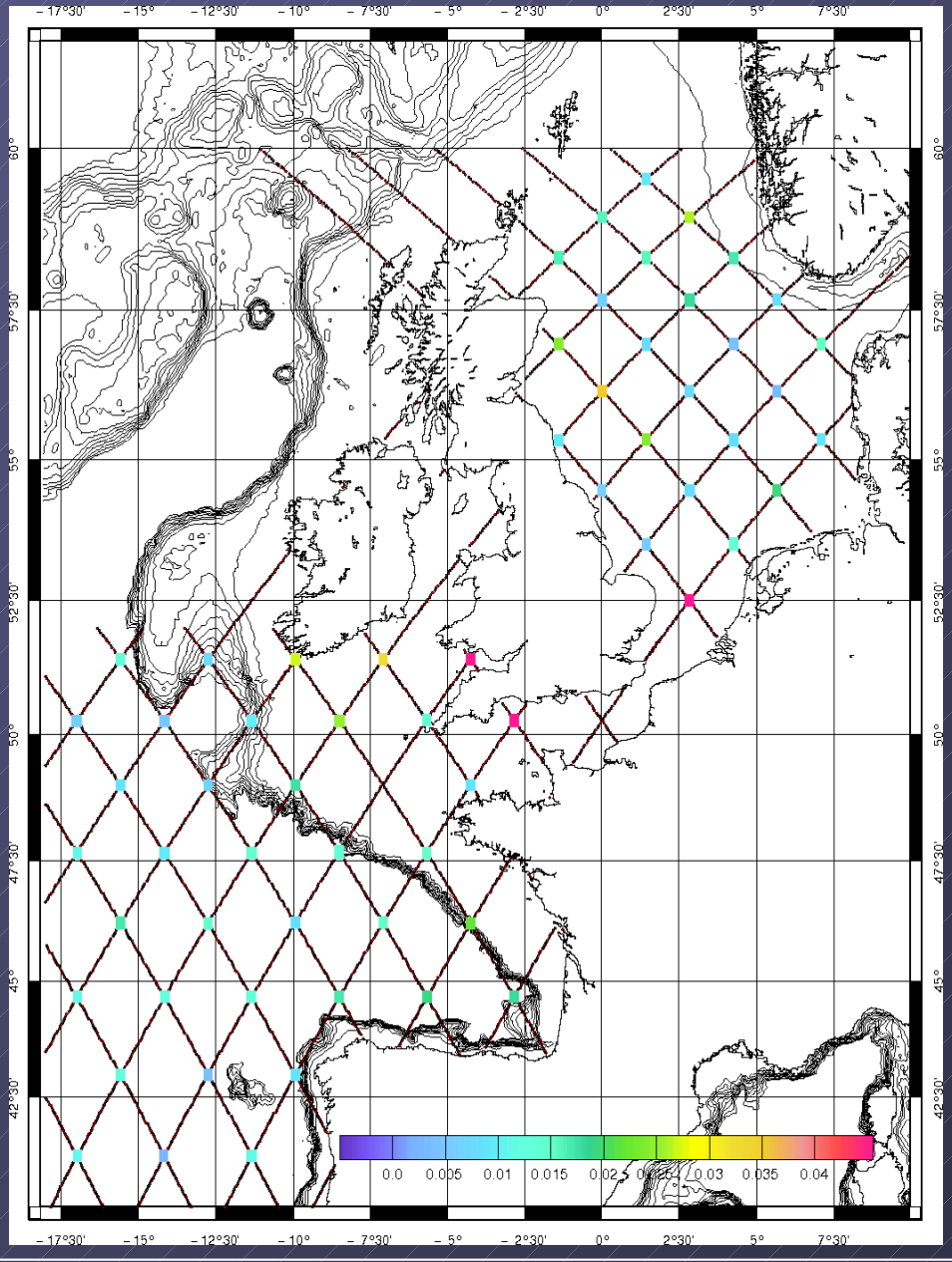
in connection with Marina efforts

Crossover difference estimates:

- **for time series ranging from 1 to 15 years for convergence examination**
- **for time series of 15 years to estimate tidal atlases accuracy**



M2 tide: harmonic constants discrepancies at xovers location, evolution with analysed time series' length



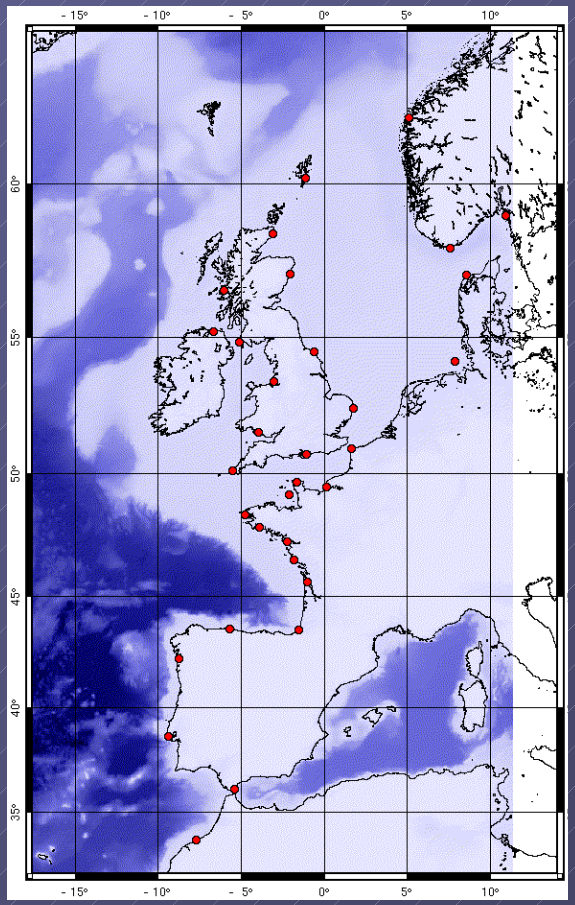
M2 tide: harmonic constants discrepancies at xovers location, 15 years of T/P &Jason harmonic analysis

Quick assimilation experiment

Validation against observation

Coastal tidal gauges

	FES04		GOT00		GOT4.7		T-UGO2D-NEA		T-UGOm* NEA	
	bias	rms	bias	rms	bias	rms	bias	rms	bias	rms
K1	0.3	**1.2**	0.5	**1.5**	0.2	**0.9**	0.4	**1.5**	0.3	0.8
K2	0.4	**4.0**	0.2	**3.6**	0.2	**2.5**	0.2	**2.9**	0.4	1.8
M2	4.8	**26.2**	3.1	**24.1**	2.1	**18.3**	2.2	**18.1**	1.7	13.7
N2	1.2	**6.4**	0.8	**4.7**	0.8	**3.6**	0.4	**3.0**	0.5	2.7
O1	0.4	**1.0**	0.3	**1.2**	0.5	**0.9**	0.3	**1.6**	0.1	0.6
P1	0.2	**0.6**	0.2	**0.7**	0.1	0.5	0.2	**0.6**	0.1	**0.6**
Q1	0.3	**0.7**	0.2	**0.6**	0.1	**0.5**	0.2	**0.5**	0.1	0.4
S2	1.4	**11.7**	1.0	**10.8**	1.1	**7.0**	0.7	**7.0**	0.2	4.3
		29.7 cm		**27.1 cm**		**20.1 cm**		**20.0 cm**		**14.8 cm**



(again…)

- **Regional, purely hydrodynamic, models compare favorably with global (semi-) empirical models for astronomical tides**

- **Regional data assimilation allows for reaching the best overall accuracy on open ocean and CSSs**

Génération de maillage - I

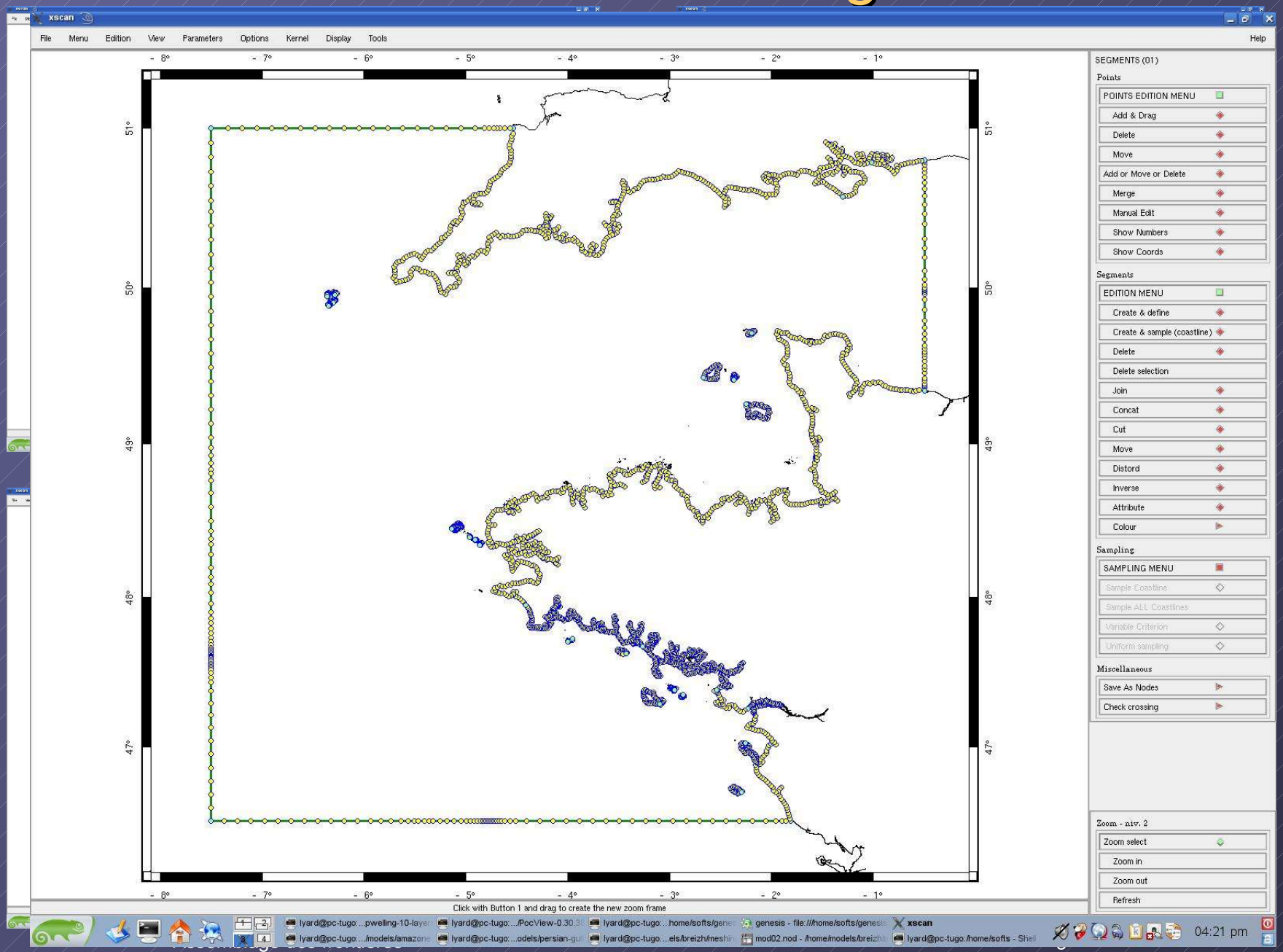
- Les grilles non-structurées permettent une grande liberté:
  - emprise géographique
    - extension
    - estuaires, fleuves
    - frontières océaniques (isobathes)
  - niveau de détail local souhaité

- Investissement très stratégique:
  - prise en compte des processus dynamiques

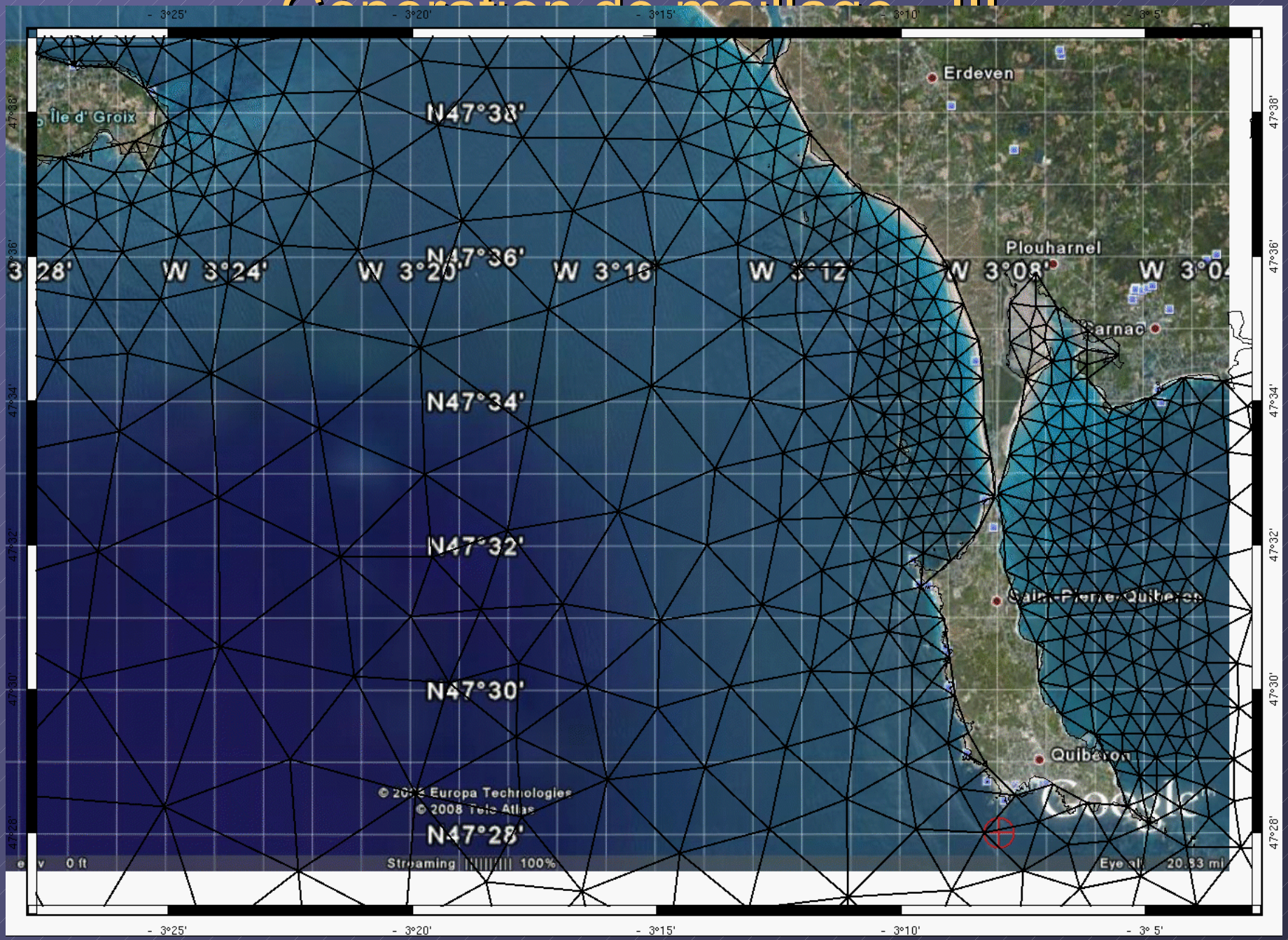
    résolution indéxée sur sqrt(gH), $\Delta H/H$, longueur d'onde de la houle
  - stabilité du modèle et coût numérique

- Les outils:
  - DES générateurs "automatiques"
  - interface graphique d'édition (xscan, pocview)
  - outils annexes (nettoyage, convertisseurs, etc…)

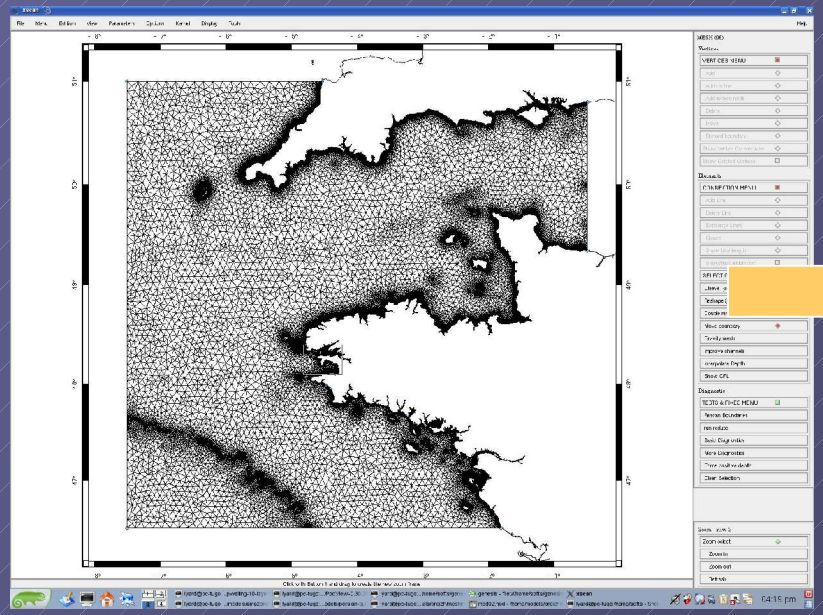
Génération de maillage - II



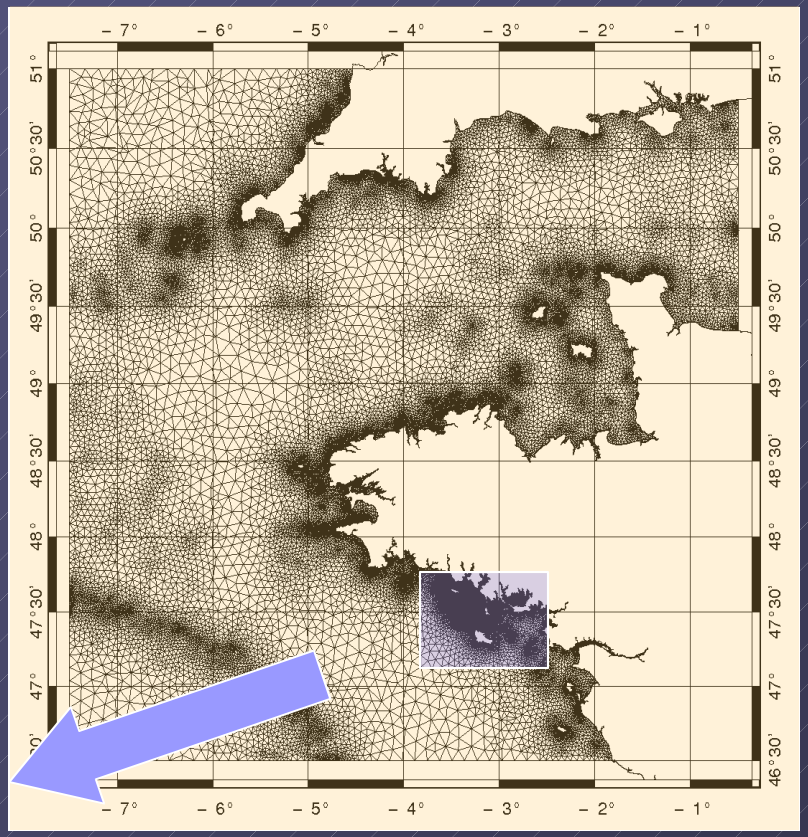
Génération de maillage - III



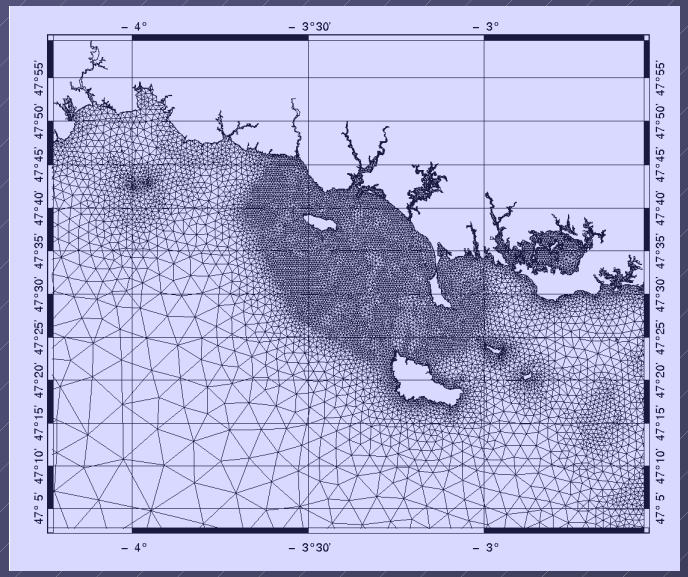
Génération de maillage - IV



Ebauche

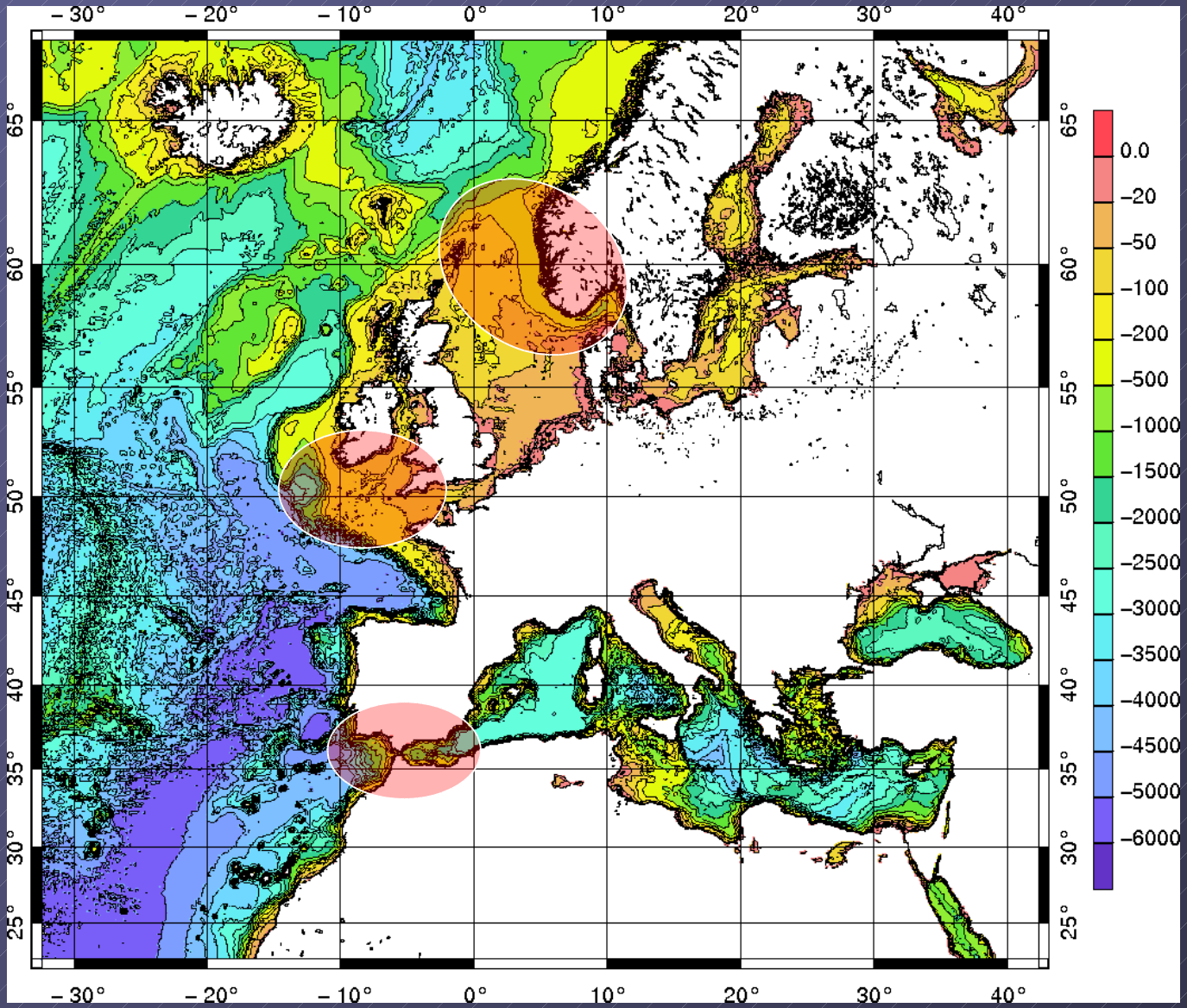


Maillage final

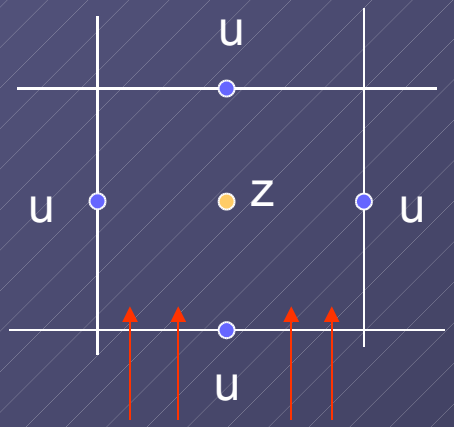
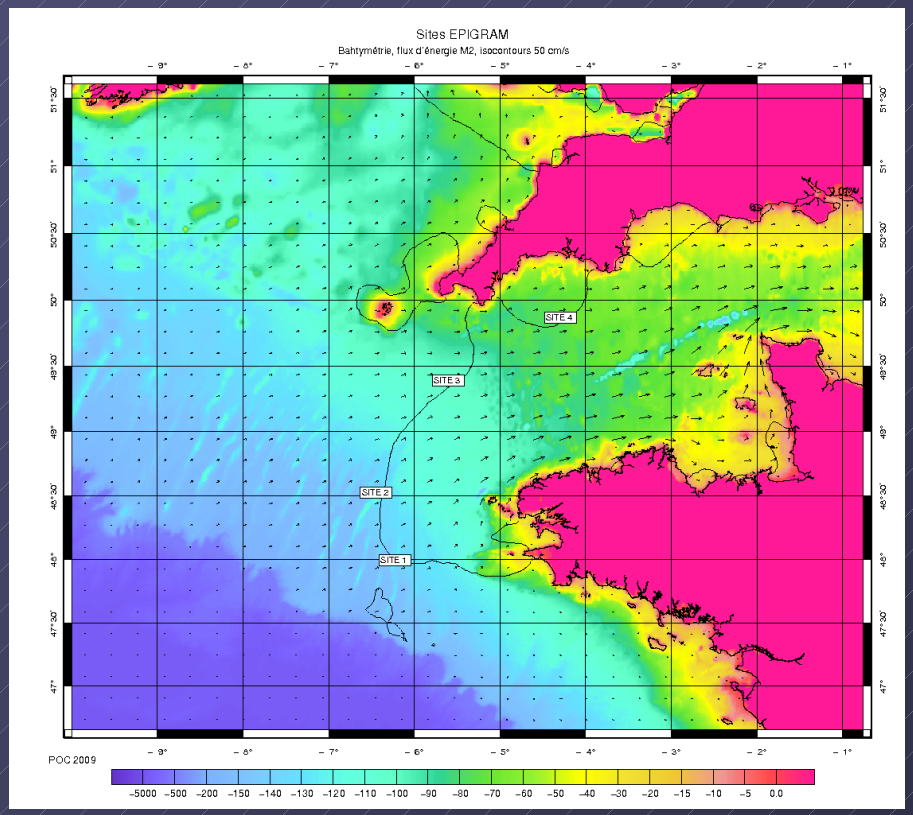


- Critères finaux:
  - optimisation de la densité général des nœuds de calcul
  - régionalisation sur zone d'intérêt

Bathymétrie composite 30"x30"
base SW08 (Gebco+Smith&Sandwell v8)



POC/Mercator/SHOM

EPIGRAM

- Modélisation 2D et 3D barotrope
- Assimilation
- Campagne 2009:
  - Bilan énergétique
  - Friction
  - Effets de sillages