Internal tide surface signature observation and modelling

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The challenge for the next XX years ?

- Except of surface signature, direct internal tide observation is uneasy
- Its dynamics is strongly coupled with ocean stratification and circulations
- It is partly non-hydrostatic
- Wavelength and periods involved goes from very small to medium scales (solitons…)
- Dissipation mechanism not well known/described
- Numerical simulations extremely demanding (model tuning, resolution, time step, digital bathymetry…)

so, where are we?

Along-track tidal constants short wavelength

- **Short wavelength,**
- **uncoherent signal**

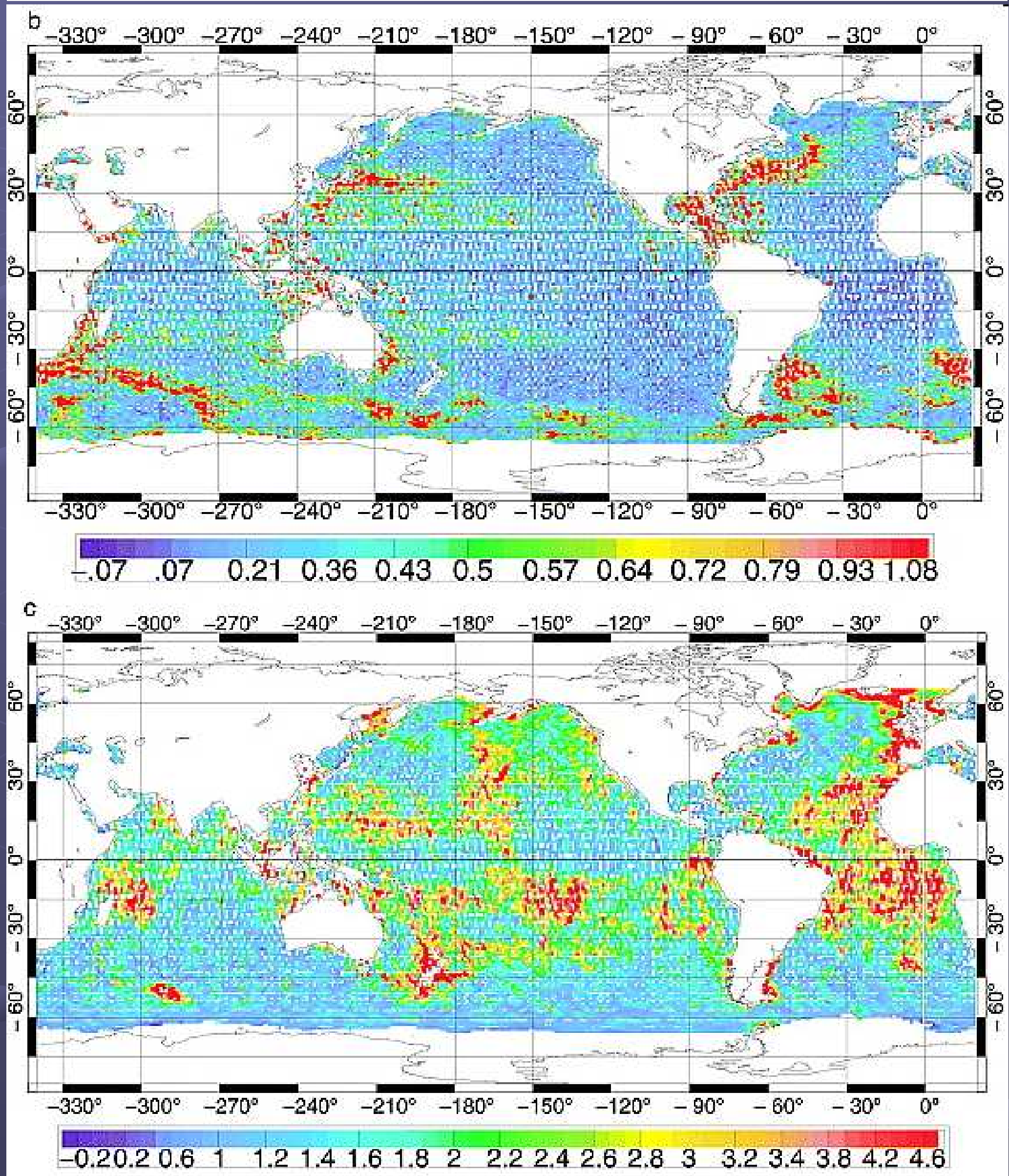
ocean meso-scale contamination

- **Short wavelength**
- **phase-locked signal**

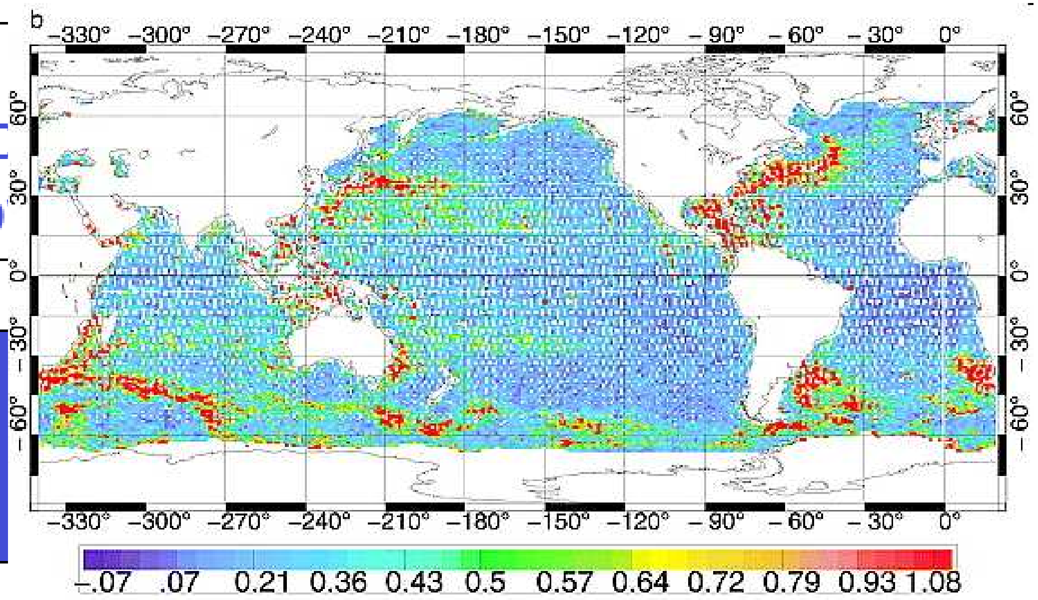
Internal tides surface signature

(Carrère et al., JGR, 2004)

Signal to noise ratio (M2 tide)



Error Assessment c
Tide Estimates b



METHODOLOGY

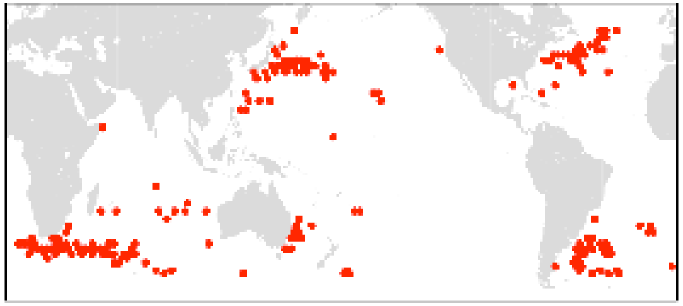
Tidal estimation for 342 T/P cycles

Tidal analysis by response method

Examine discrepancy at cross-overs

M2 discrepancy exactly equals √2 x standard error of tidal analysis.
Note large K1 cross-over discrepancies, presumably from Ssa aliasing.

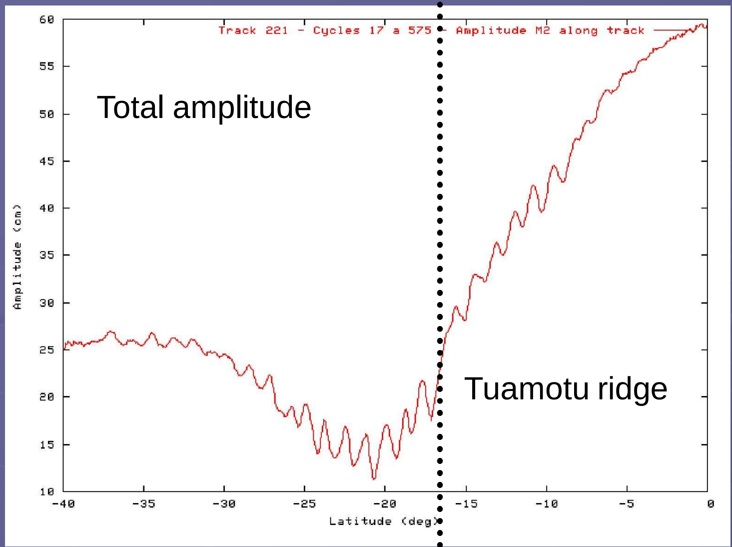
Locations of large M2 discrepancies

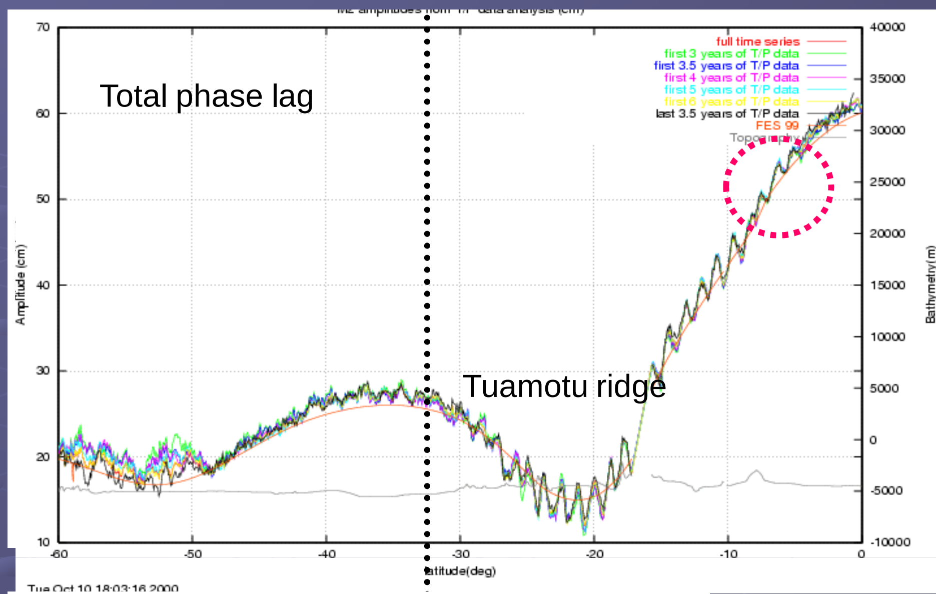


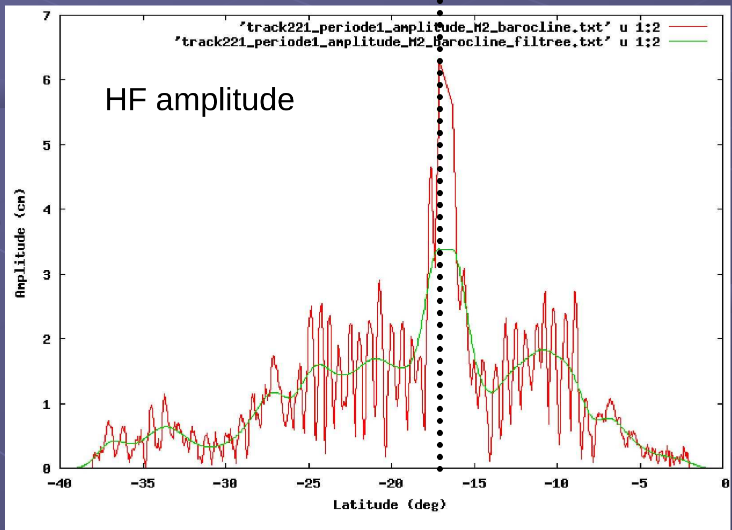
Locations of large K1 discrepancies

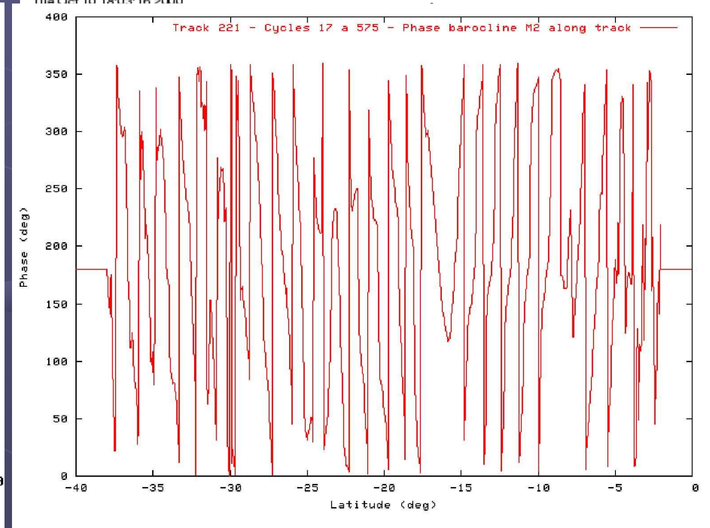
R. Ray, Biarritz T/P SWT, 2002

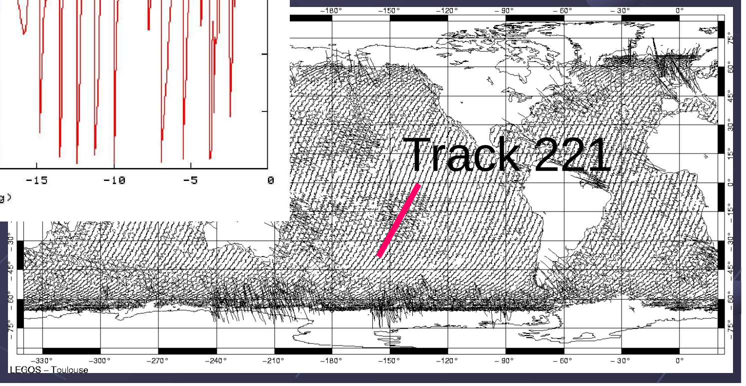
Observability of internal tide signature







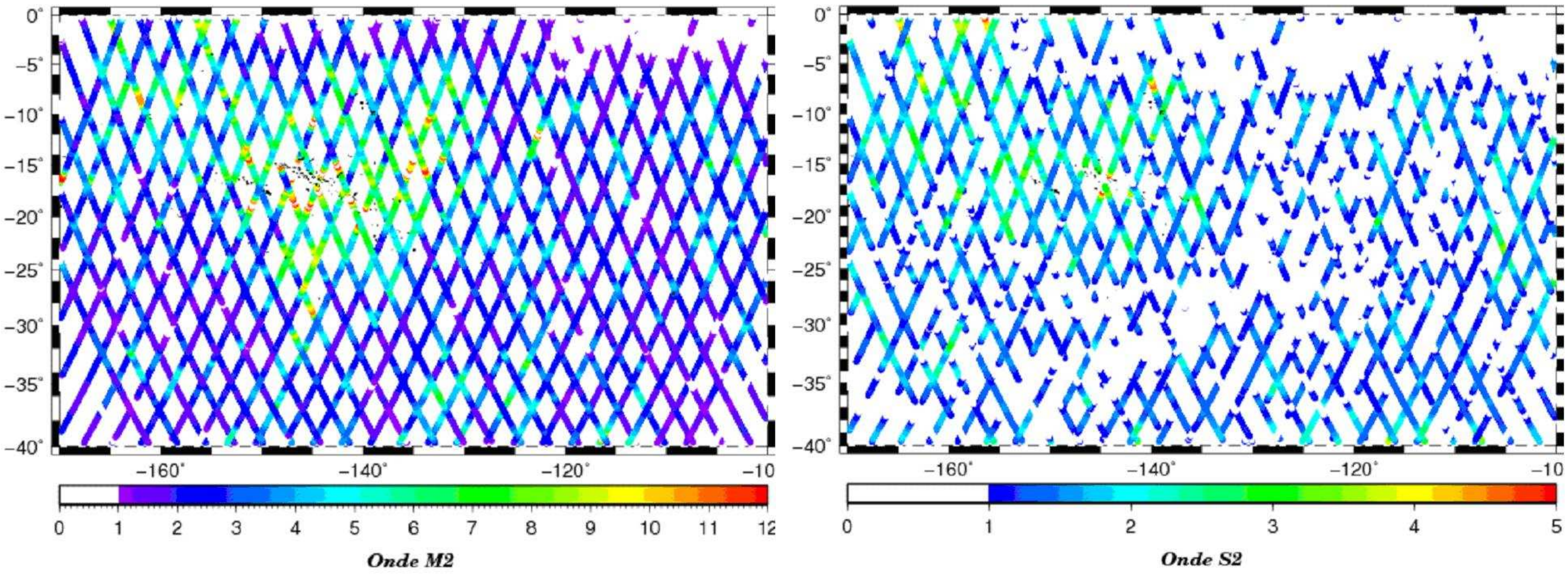




1st and higher modes visible…

Stability of internal tide signature

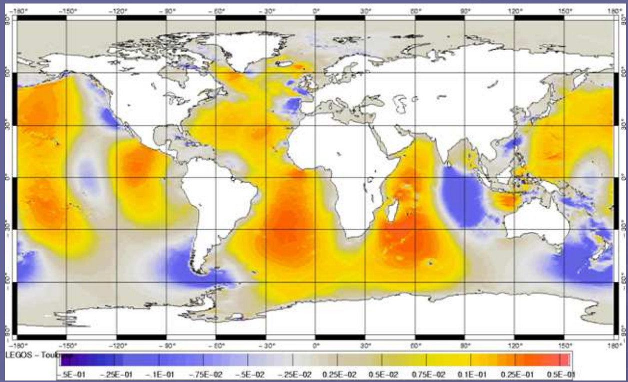
French Polynesia tropical ocean



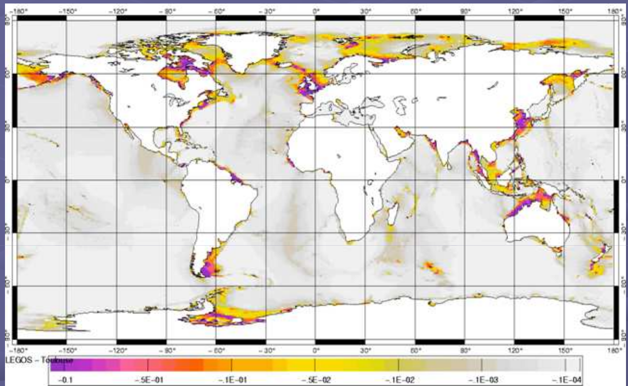
Ratio : (1993-2008) harmonic constant/STD(5 year-derived harmonic constants)

SLOOP project, CNES/Noveltis/CLS/Legos)

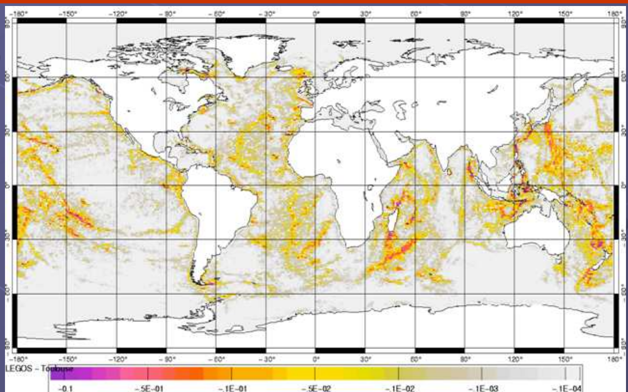
Energy conversion
Barotropic tides ➡ internal tides



Gravitational forcing ~2.43 TW



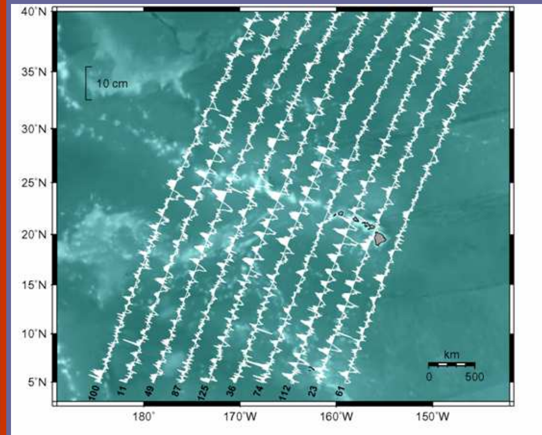
Bottom friction ~ 1.8 TW



Baroclinic drag ~0.7 TW (30%)

- Unbalanced energy budget (after assimilation)
- Internal tides ubiquity

Internal tides
=
Barotropic energy sink



M2 internal tide evidence at Hawaii ridge.
Ray et al., 1995

<u>New dissipation term</u> (baroclinic wave drag)*

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

- 50% model error reduction
- Balance energy budget
- Direct quantification of internal tide energy (~1 TW)

*Lyard et al., Ocean Dynamics, 2006

Lyard et Le Provost, 1997; Carrère et Lyard, 2003; Carrère et al., 2004; Lyard et al., 2006; Auclair & al, 2008

Impact of internal tide on Ocean mixing

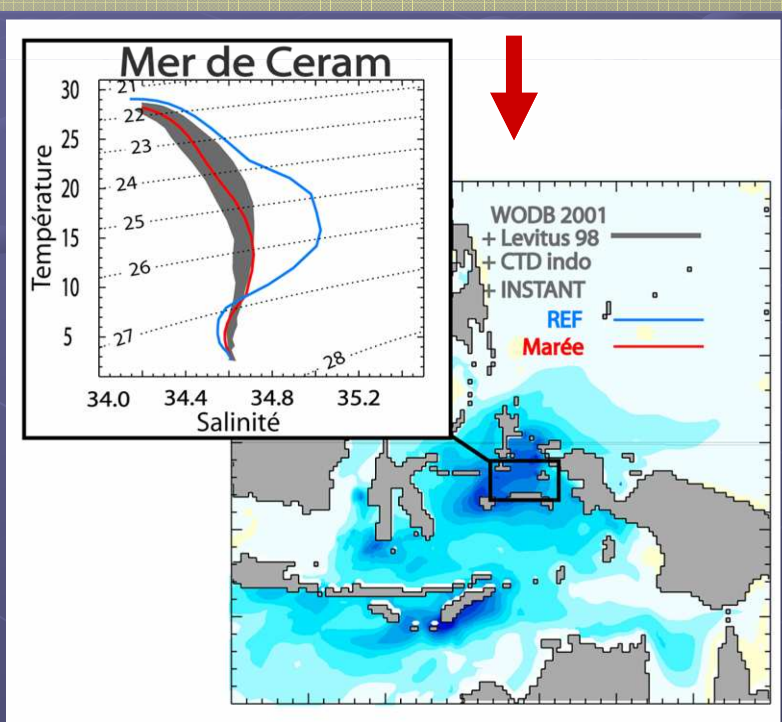
Overturning meridian circulation

Thèse L. Bessière (Madec/Lyard)

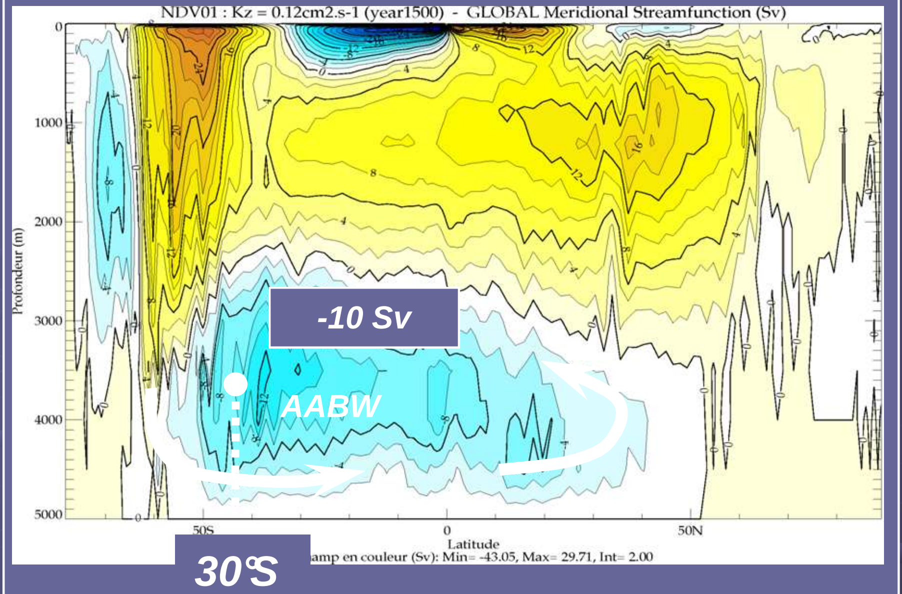
- transport abyssal associated to AABW doubled (30°S) *AABW : Antarctic Bottom Water*
- In agreement with observations 23±3 Sv (Ganachaud & Wunsch, 2000)

Regional impact

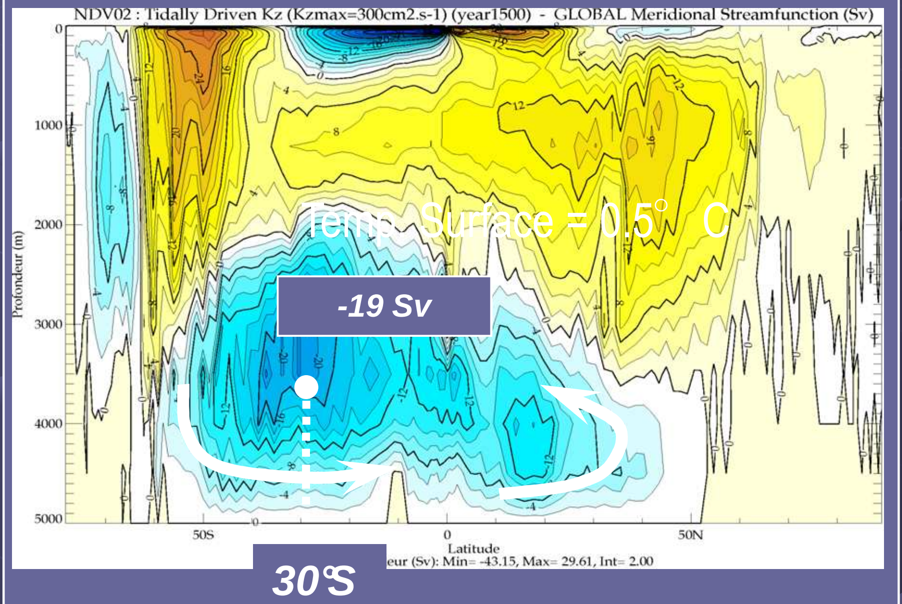
Indonesian seas, Solomon Sea



Sans tidal mixing (k_z = 0.1 $cm^2.s^{-1}$)

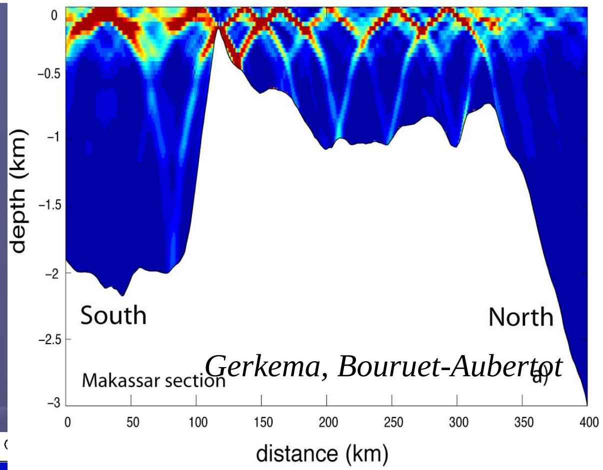


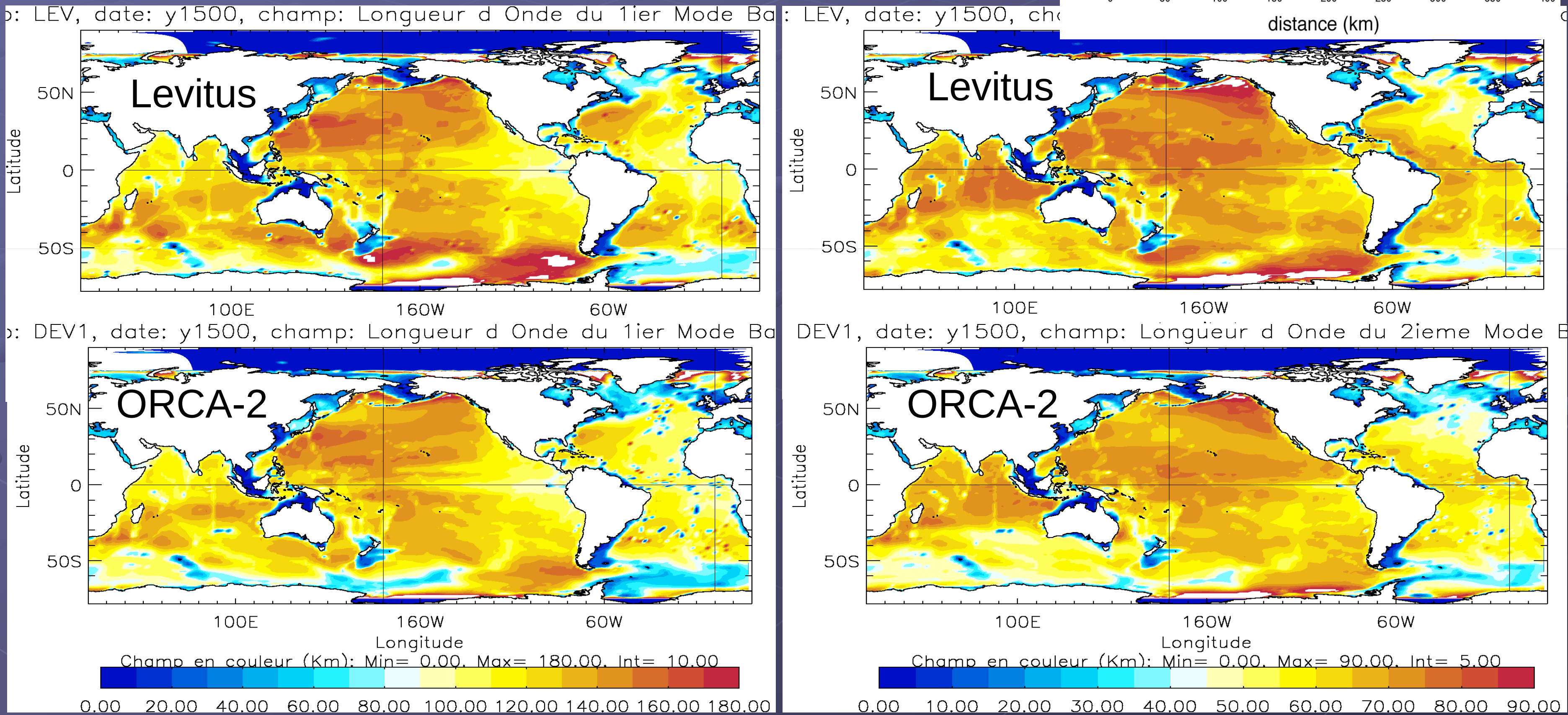
Avec tidal mixing



Koch-Larrouy et al.2008a 2008b; Koch-Larrouy et al. 2009

Sensitivity to stratification



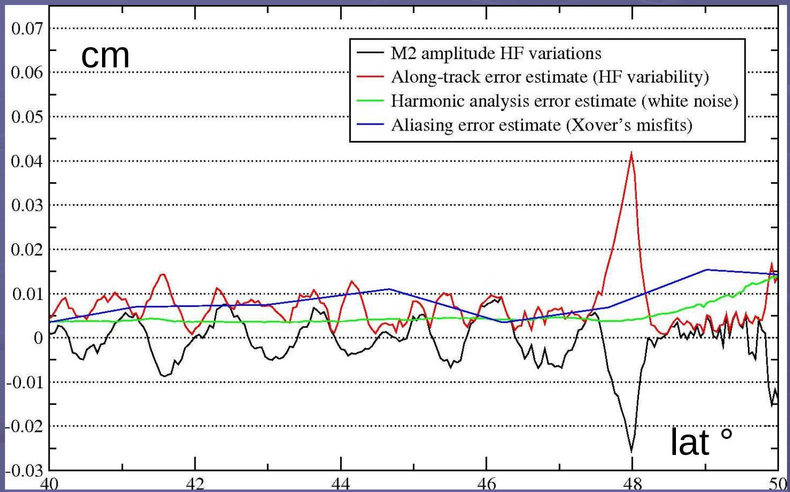


Internal wave wavelength: 1st mode

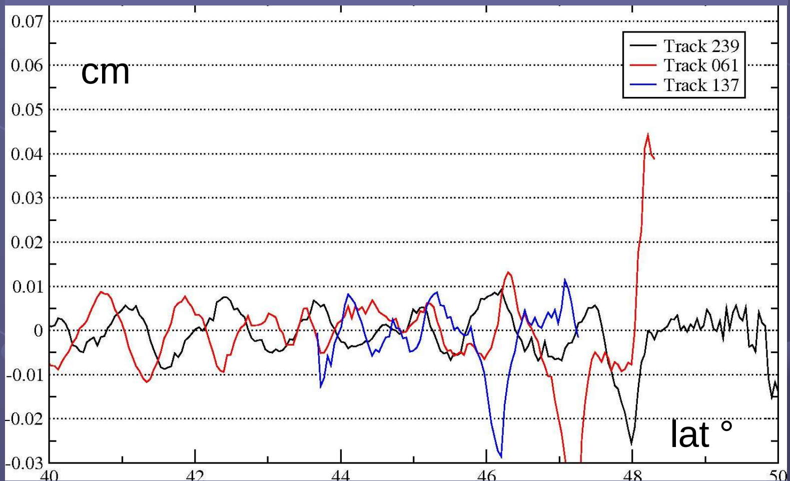
Internal wave wavelength: 2nd mode

Bessieres, 2008, PhD

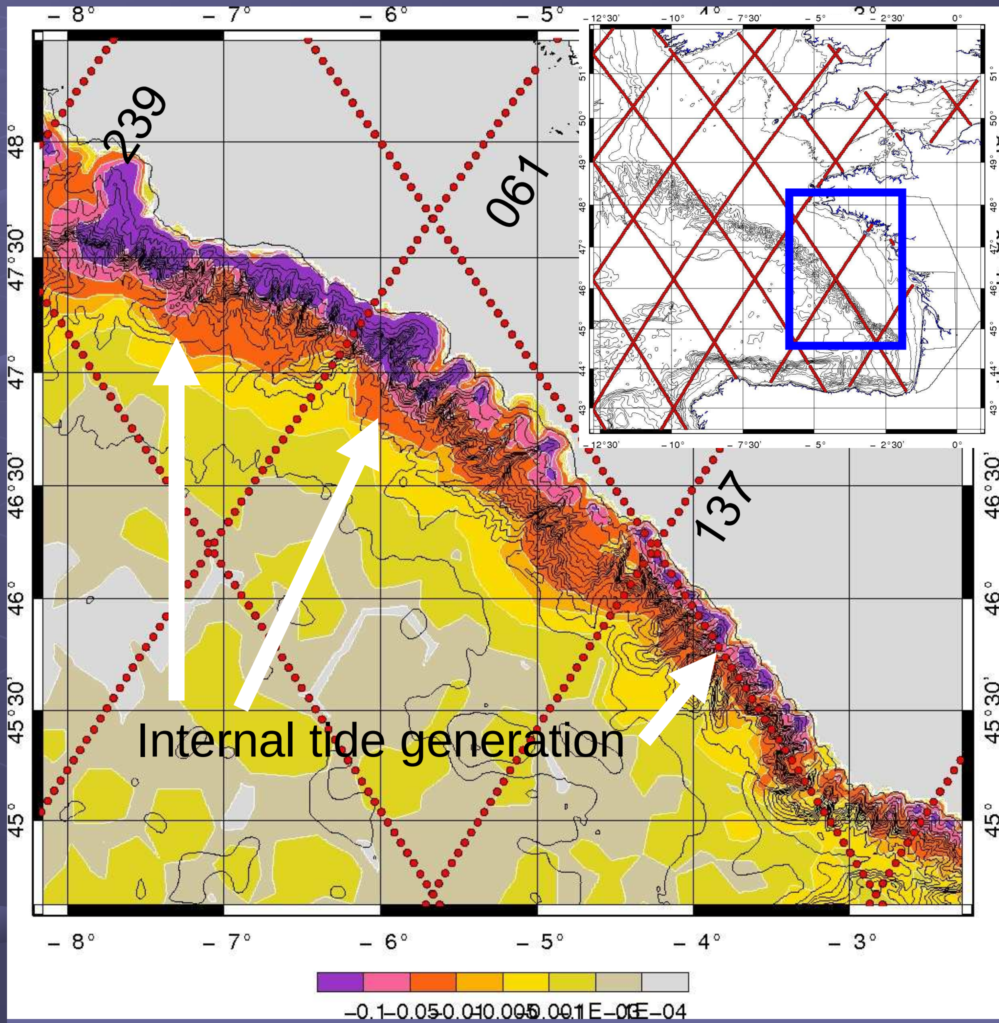
Internal tide in the Bay of Biscay



Tracks 239: internal tide surface signature and error bars



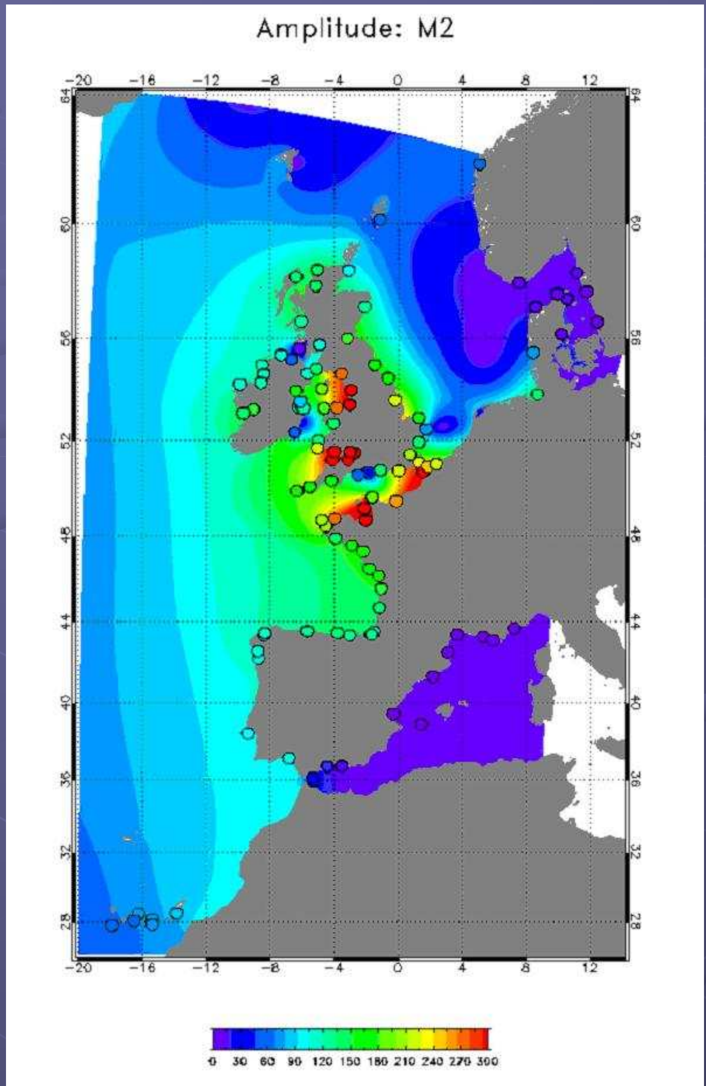
Tracks 061,137,239: internal tide surface signature

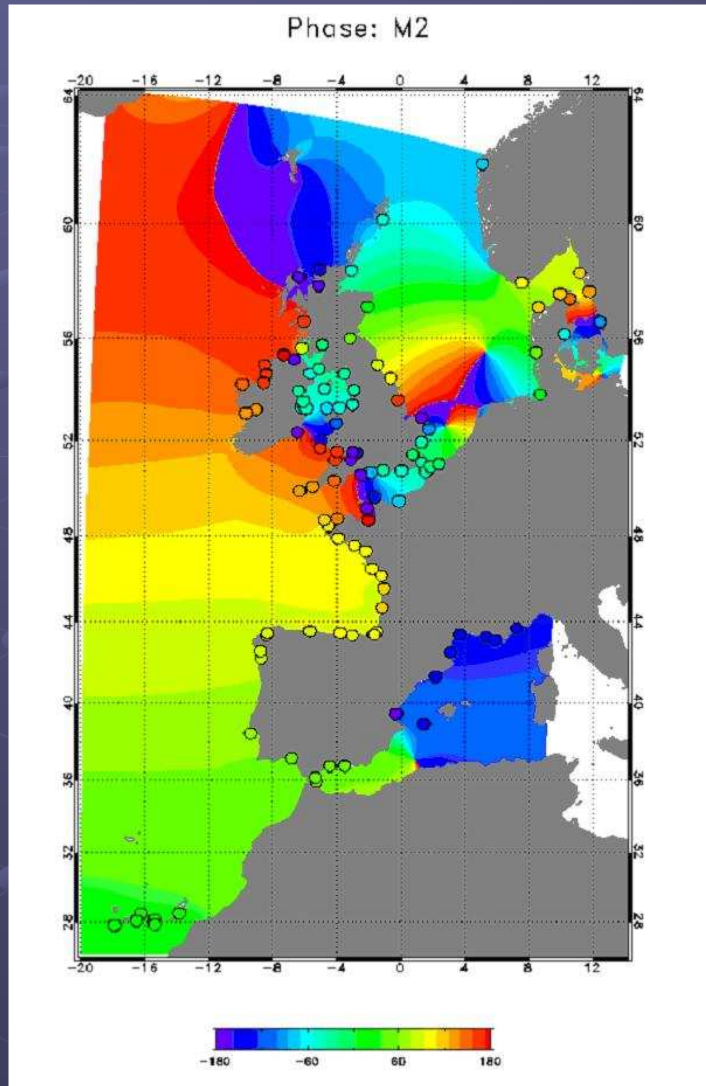


NEA-COMAPI (hydrodynamic)
Internal tide wave drag, rate of work (W/m²)

Mercator IBI-ROOS configuration

NEMO/OPA model, 1/12° and 1/36°



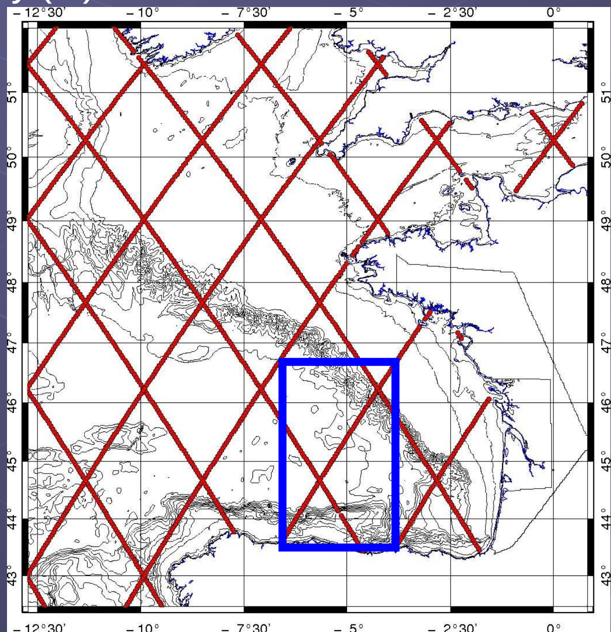


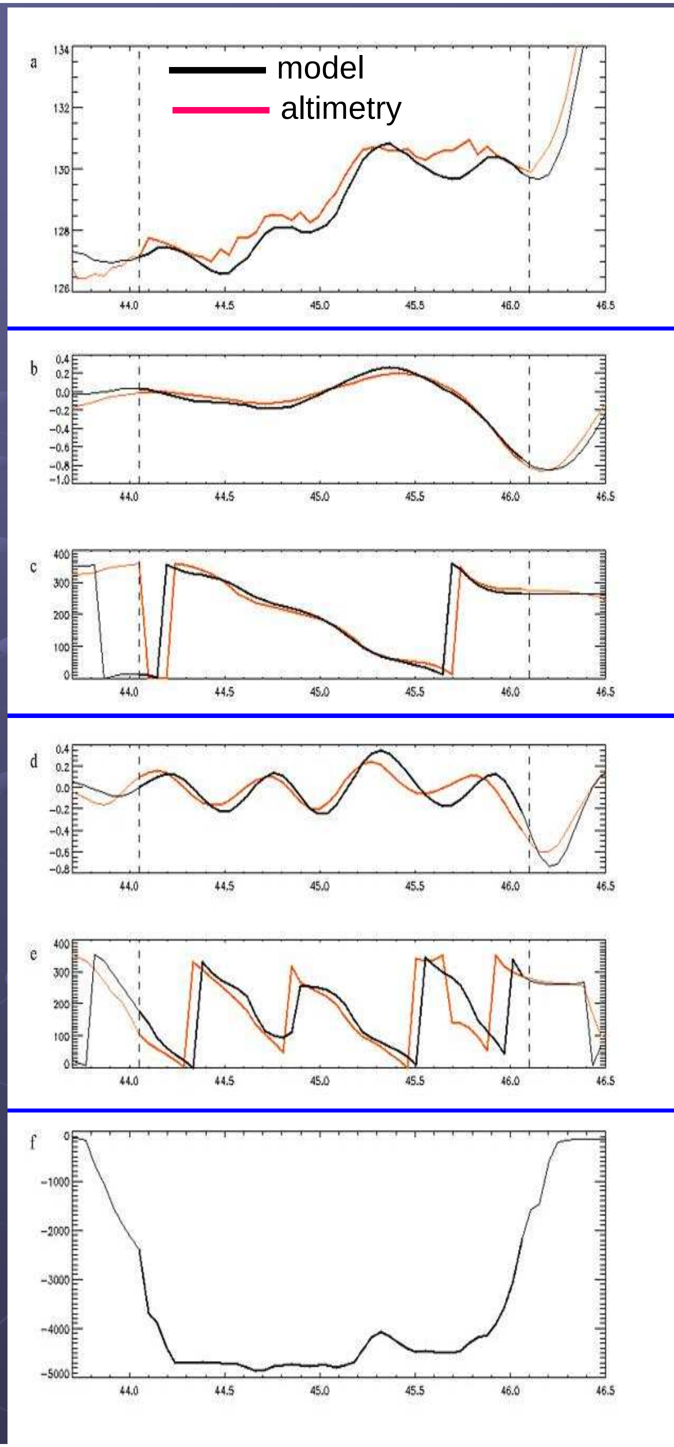
M2 barotropic tide

Internal tide from baroclinic simulation

Comparison with surface signature on Track 061

- a- Along track amplitudes (cm) deduced from the M2 harmonic analysis of altimetric data (red) and model (black).
- First vertical mode:
  - b- amplitudes (cm)
  - c- phase lag (°)
- Second vertical mode
  - d- amplitudes in cm and
  - e- Phase lag(°)
- f- Along track bathymetry (m)





Conclusions

- We know fairly well the rate and geographical distribution of internal tide generation (~1TW)

- Observability:
  - With 18 years of observations, 1st mode is well measured, higher modes can now also be detected
  - Phase-locked internal tides quite stable in time (at least in tropical ocean), but this needs further investigation because…
  - Present M2-S2 separation (3 years) does not allow for seasonal change detection

- Modeling:
  - Impact of internal tide in ocean mixing, in deep and surface layers, play a key role that is partially reproduced in circulation models (parameterization)
  - Internal tide modeling is not accurate enough for operational needs, but preliminary results are encouraging
  - Internal tide wavelength could be used as a proxy of ocean stratification (model validation)

In the perspective of SWOT…

- The M2 and S2 separation period, as well as their aliased frequency will be a key factor to compute SWOT-derived corrections
- Progresses in baroclinic tide modeling, plus some assimilation, might help for the first years of the mission (beside other mapping techniques)
- Meanwhile… we need to validate our models
  - Internal tide wavelength (from altimetry) could be used as an proxy of ocean stratification
  - We might look at the neap and spring tide modulation of internal tides (15 days in real world, 3 years in Topex and Jason) and its impact on the 15 days ocean variability
  - Tsunamis internal waves would help too if in situ, high sampling rate, observation available…