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SWOT in the tropics:
A case study in the South West Pacific

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1. Motivation

The tropical Pacific ocean is characterized by:
- strong zonal currents (**Figs. 1.1**) and a high EKE level.
- intense meso/submesocale features (**Fig. 2.1**)
- a flatter SSH spectrum in the altimetry (**Fig. 1.2)** than in numerical models

The main goal of this project is to assess the observability of SWOT in the tropical Pacific Ocean, with a special focus on 2 regions of the SouthWest basin where mesoscale activity and internal tides are equally important :
- the **Solomon Sea** (major pathway between the Southern Pacific and the equatorial region, ***Tchilibou et al., 2018, 2019***)
- **New Caledonia** (to prepare an *in situ* cal/val experiment during the 1-day SWOT orbit, ***Sérazin et al., 2019***)

The specific objectives are to investigate the spatio-temporal dynamics of meso/submesoscales in the tropics, to give insight into their signature in sea level and to analyze their impact onto the large-scale ocean circulation.

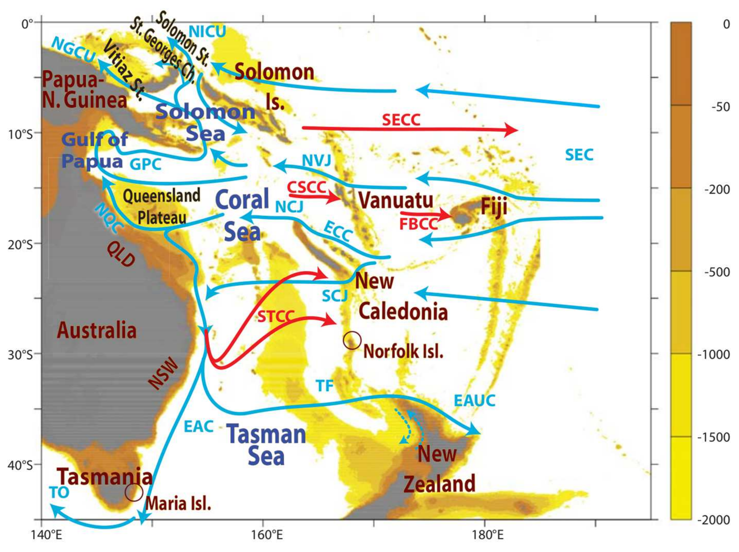


__Fig. 1.1__: Schematic ocean circulation in the SouthWest tropical Pacific (Ganachaud et al. 2014) : mean currents, integrated 0-1000m (blue arrows) and surface-trapped countercurrents (read arrow). Bathymetry in color.

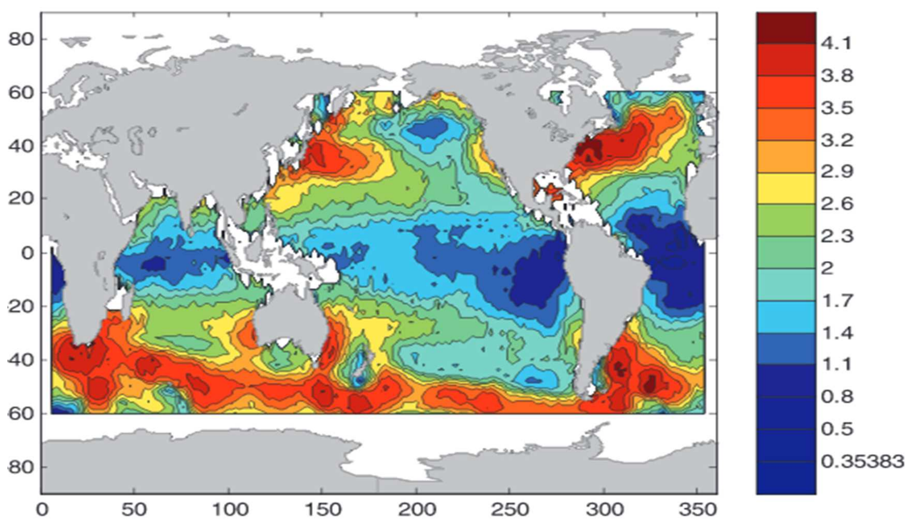


__Fig. 1.2__: SSH spectral slopes in the 70-250 km band from altimetry (Xu and Fu, 2011)

2. Spectral signature of the Tropical Pacific Dynamics

Global DRAKKAR simulation (G12) – NEMO model, 1/12° resolution, 46 vertical levels, ERA-INTERIM forcing (1989-2007), **5-day outputs** (Djath et al. 2014)

- **large range of scales and strong anisotropy for mesoscale structures near the equator**
- **smaller-scale turbulent structures in off-equatorial region**

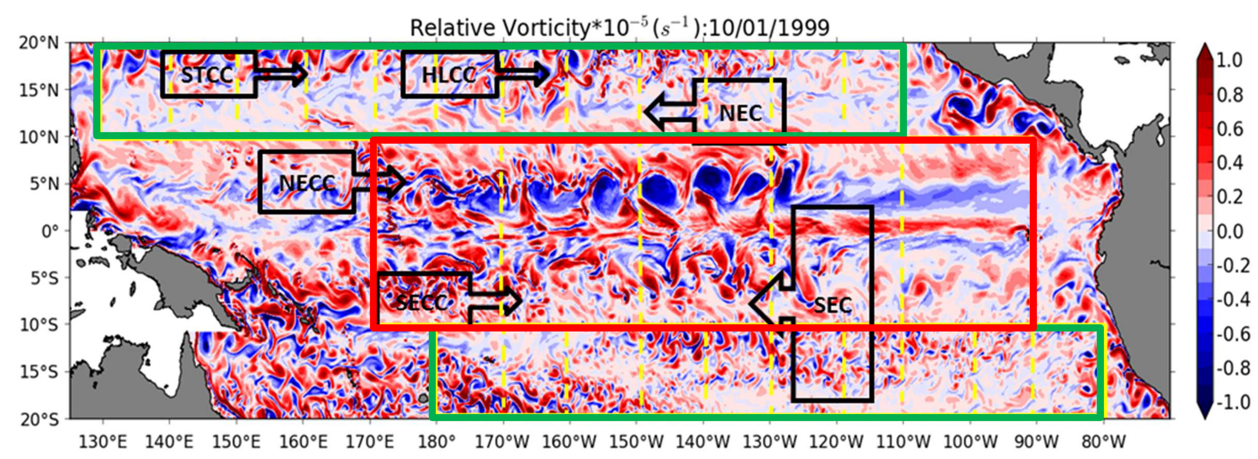


__Fig. 2.1__ : Snapshot of relative vorticity in the G12 simulation (unit : $10^{-5}\ s^{-1}$). Yellow lines delineate the equatorial and off-equatorial region. Dashed lines delineate square boxes for the different regions to compute wavenumber spectra. Black arrow illustrate the main tropical surface currents.

Equatorial versus off equatorial dynamics

Off equator (10°N-20°N et 10°S-20°S): Mesoscale range: < 250 km
From isotropic turbulence to Rossby waves

Equator (10°S-10°N): Mesoscale range: < 800 km
Two distincts dynamical regimes:
→ Long equatorial waves (zonal anisotropy)
→ Tropical instability waves and equatorial « mesoscale » (Meridional anisotropy)

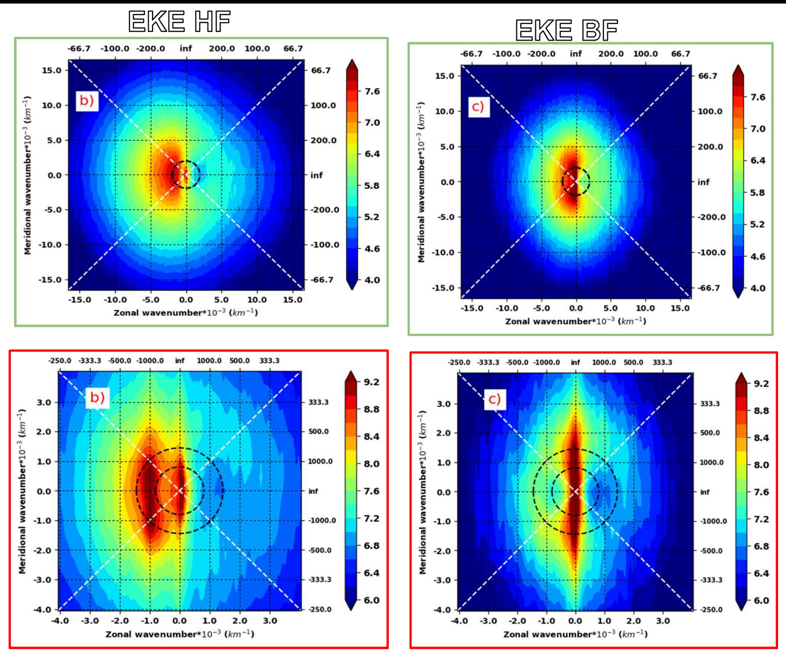


__Fig. 2.2__ : Zonal-meridional wavenumber EKE spectra over 10°NS-20°N S (Off Eq) and 10°S-10°N (Eq) for high frequency motions (< 90 days, EKE HF) and low frequency motions (> 90days, RKS LF)

Comparison of SSH/EKE spectra in equatorial and off-equatorial regions

Equator: high EKE energy, low SSH variability → Agostrophic dynamic

SSH altimetric spectra distinguish from modelled spectra for L< 300 km
→ flatter spectra ($k^{-5} \rightarrow k^{-1}$) → higher variance → inertia gravity waves???

Internal tide signature:
No more discrepancy between modelled and altimetric spectra

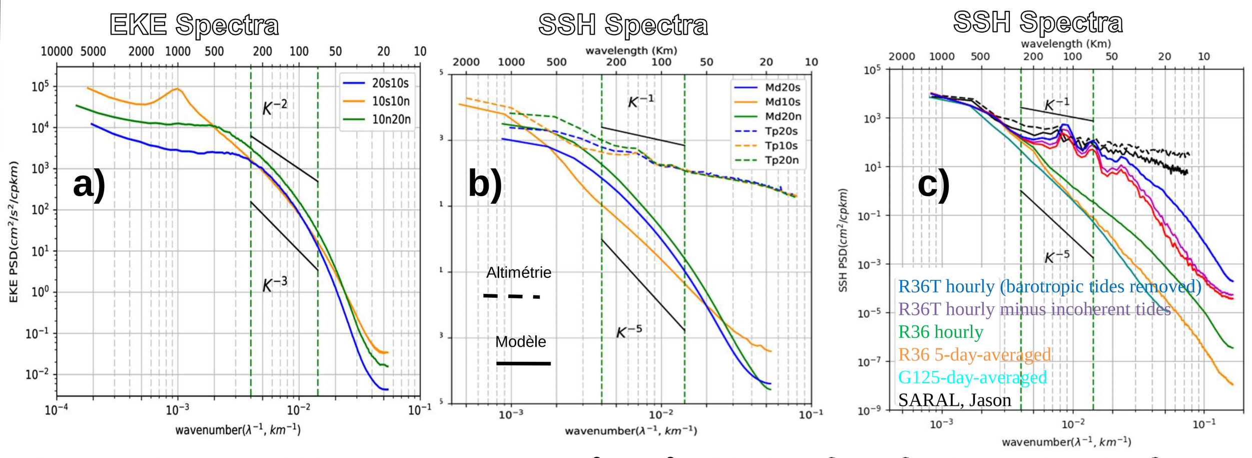


__Fig. 2.4__ : a) EKE and b) SSH spectra over 20°S-10°S (blue), 10°S-10°N (orange) and 10°N-20°N (green) from G12 model (solid lines) and Topex-Poseidon (dashed lines). c) SSH spectra at 163° E between 2°S-13°S from R36 model including explicit tides (see below). Compared to the orange spectrum, the green spectrum gives evidence of internal waves, the red spectrum of M2 coherent baroclinic tide, the purple spectrum of the full coherent baroclinic tides, and the blue spectrum of the full signal once the batropic tides has been removed.

3. M2 Internal tides in the Solomon Sea

Regional configuration of NEMO3.6 - 1/36°, 75 vertical levels, GEBCO08 bathymetry, interannual DFS5.2 forcing (1992-2000)
- **2 versions** : **without tides (R36)** and **with tides (R36T)** / 9 tide constituents from FES2014: K1,O1,P1,Q1,M2,N2,S2,K2,Ms4
- **2 outputs** : **hourly** (**El Niño**: Jan-Mar 1998; **La Niña**: April-June 1999) / **daily** (Jan 1998- Dec 1999)

→ projection on the 10 first vertical modes to separate barotropic and baroclinic tides

→ Validation

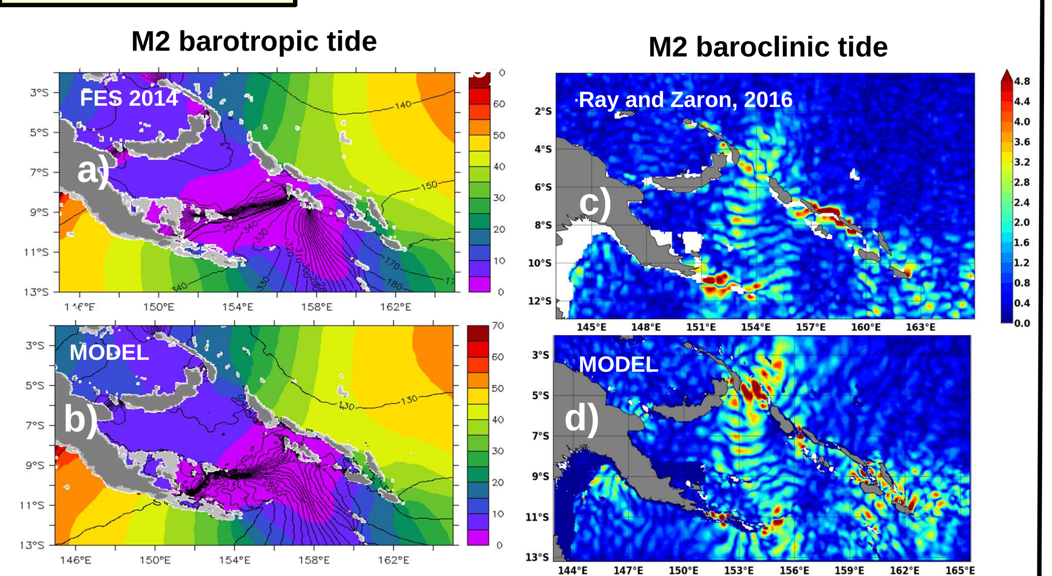


__Fig. 3.1:__ M2 barotropic amplitude (cm) and phase (contours) from __a)__ model and __b)__ FES 2014 (Lyard et al. 2018). M2 baroclinic tides amplitude from __c)__ Model and __d)__ Ray and Zaron (2016) altimetric analyses.

→ M2 internal tides generation and propagation

- **conversion of 14GW from barotropic to baroclinic tides**
- **3 main sites of generation**
- **M2 kinetic energy confined to the first 300 meters**

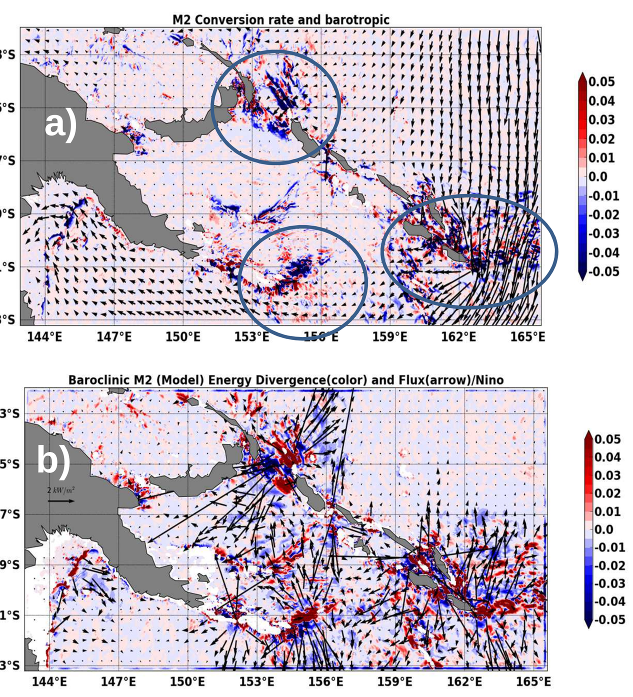
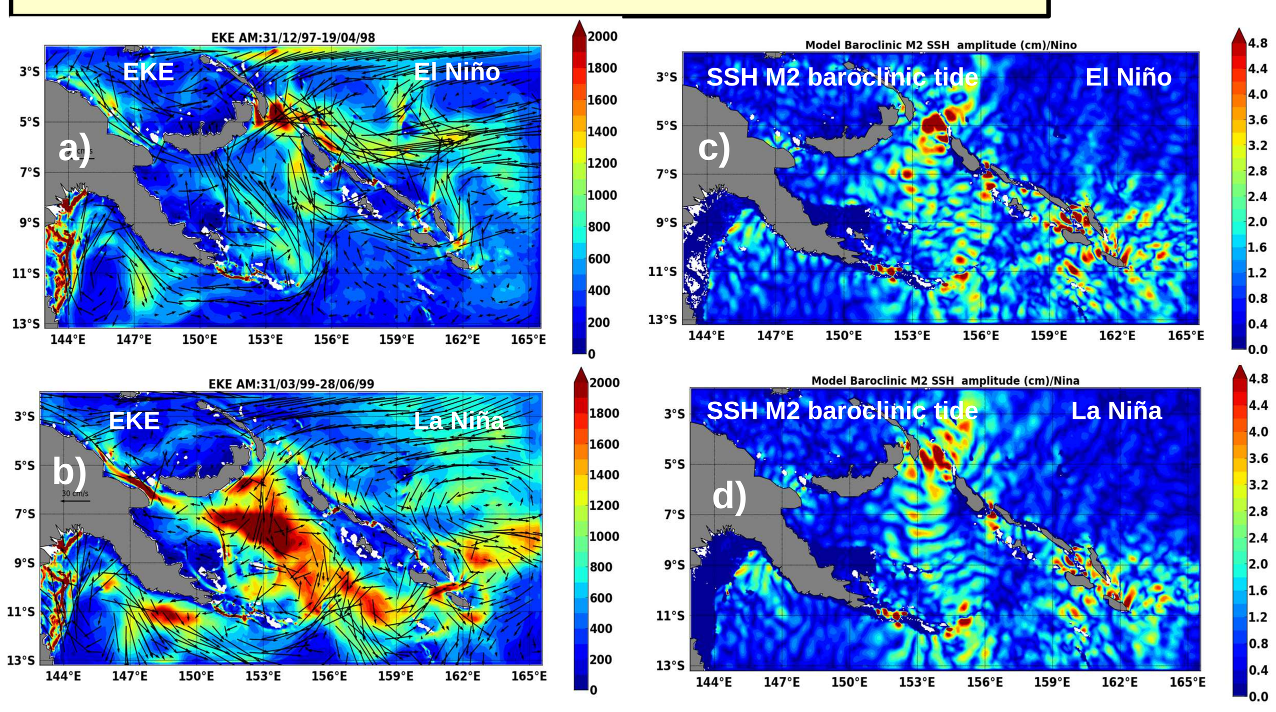


__Fig. 3.2:__
__a)__ Depth-integrated M2 conversion rate (W.m^{-2}, color) and barotropic energy flux (KW.m^{-1}, arrow);

__b)__ Depth-integrated baroclinic energy flux (KW.m^{-1} arrow) and energy divergence (W.m^{-2}, color).

→ Influence of ENSO variability

- **El Niño**: Low EKE → low incoherent tides
  Stratification in the upper layers →Unstructured internal tides
- **La Niña**: High EKE → large incoherent tides
  Deep stratification →Structured internal tides



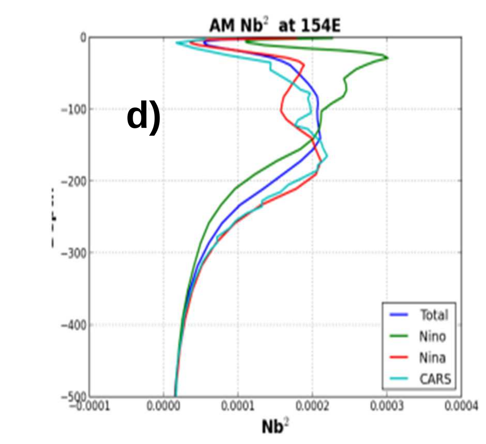


__Fig. 3.3:__ High frequency EKE during a) El Nino and b) La Nina. SSH signature of the M2 baroclinic tide during c) El Nino and d) La Nina. e) Brunt Vaissala profiles for the mean modeled conditions (blue), El Nino conditions (green), La Nina conditions (red). The CARS climatology is in cyan.

→ Evidence of diapycnal mixing due to tides
- **UTW salinity maximum erosion in the presence of tides**

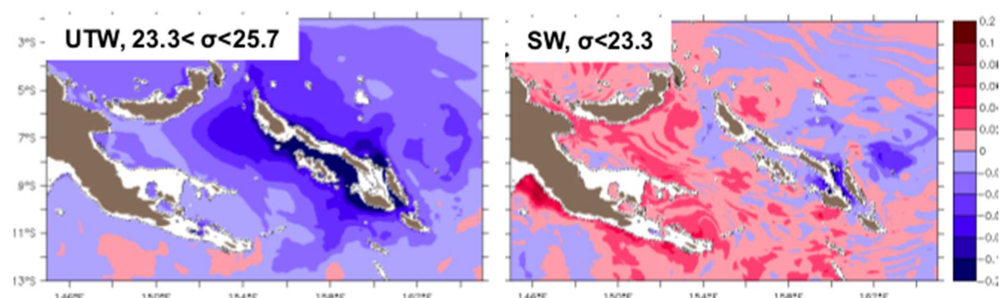


Fig. 3.4: Mean salinity difference (1998-1999) between R36 (no tides) and R36T (with tides) for __a)__ Upper thermocline waters (100-250m) and __b)__ Surface Waters (0-100m).

4. Cal/val experiment in New Caledonia

We propose New Caledonia for a cal/val in situ experiment for the SWOT fast sampling phase.

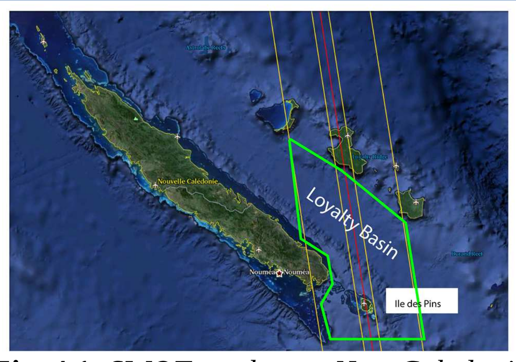


__Fig. 4.1:__ SWOT track over New Caledonia during 1-day orbit

The main motivations are :
- it is a region of strong mesoscale activity (**Fig. 4.2**)
- it is a region of strong internal tides (**Fig. 4.2**)
- it has been actively studied for the validation of Saral/Altika (Durand et al. 2017)
- the IRD center in New Caledonia is an appropriate basis for *in situ* experiments

The strategy for a cal/val experiment still needs to be defined from the ongoing analysis of historical in situ observations (SADCP, gliders, thermosalinographs,…) in the region.

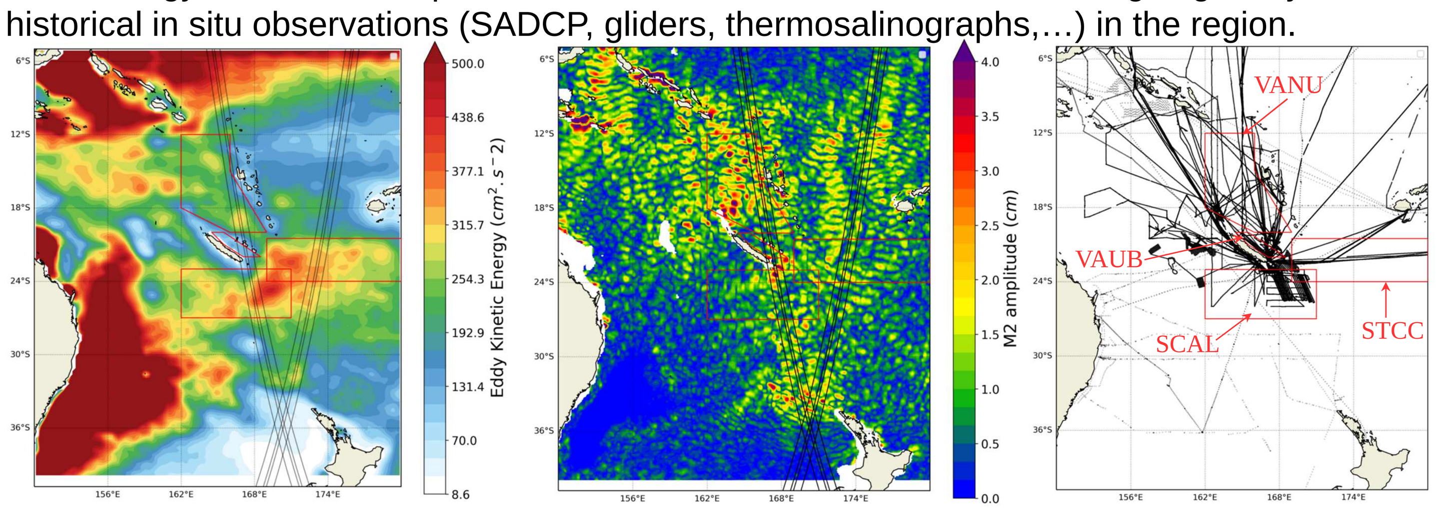


__Fig. 4.2:__ Horizontal distribution from EKE (AVISO), M2 internal tides amplitude (Ray and Zaron 2016) and S-ADCP historical observations in the SouthWest Tropical Pacific. SWOT track during 1-day orbit black line.

→ Structure functions from S-ADCP

__Method:__ Computation of 2nd-order structure function D2(r) from observed S-ADCP longitudinal ( ) and transverse (⊥) velocities separated by distance r (Balwada et al. 2016)

$$D2(\boldsymbol{r}) = \left\langle [u(\boldsymbol{x}) - u(\boldsymbol{x}+\boldsymbol{r})]^2 \right\rangle$$

- A Helmholtz decomposition is possible if rotational (ψ) and divergent (ϕ) are uncorrelated and the flow is isotropic (*Lindborg, 2015*):

$$D2_\psi(r) = D2_\parallel(r) + \int_0^r \frac{D2_\parallel(r') - D2_\perp(r')}{r'} dr'$$
$$D2_\phi(r) = D2_\perp(r) - \int_0^r \frac{D2_\parallel(r') - D2_\perp(r')}{r'} dr'$$
$$D2 = D2_\perp + D2_\parallel = D2_\psi + D2_\phi$$

- 2nd-order structure function D2 is related to classic KE spectrum E and power laws (*Lindborg, 2007*):

$$\text{Power law: } E \sim k^{\alpha}, \quad D2 \sim r^{-\alpha-1}$$
$$\text{QG: } E \sim k^{-3}, \quad D2 \sim r^2$$
$$\text{SQG: } E \sim k^{-2}, \quad D2 \sim r$$
$$\text{Kolmogorov: } E \sim k^{-5/3}, \quad D2 \sim r^{2/3}$$

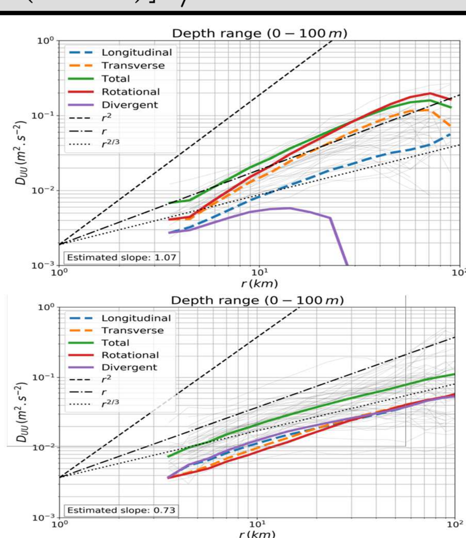


__Fig. 4.3:__ Structure fonctions in VAUB (upper) and VANU (lower)

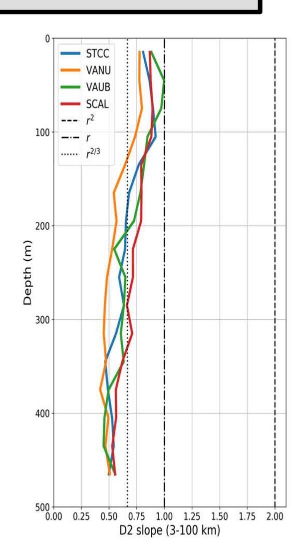


__Fig. 4.4:__ D2 slope (3-100km) vs depth

In regions of strong mesoscale activities :
- **predominance of rotational motions**
- **sharp transition from SQG (0-100m) to Kolmogorov (below 200m)**

→ Other data being analyzed :
- Amplitude of M2 internal tides from isopycnal displacements (gliders)
- surface temperature/salinity from thermosalinographs to estimate scales of the buoyancy
- Sentinel-3 data for SSH spectra

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