Diagnosis of the upper ocean dynamics from high-resolution SSH

(Ifremer, France and Earth Simulator Center, Japan)
A fully turbulent ocean!
Observations and modelling studies of the last 10 years have strengthened the vision of an upper ocean crowded with a large number of strongly interacting eddies.

Mesoscale eddies (with 100km scales) are in all the oceans (Courtesy Raf Ferrari)
Ocean color and SST images at resolution of 1km further reveal at the surface a large number of submesoscales (< 30km) produced by the mesoscale eddy interactions.

These satellite images do not provide any dynamical information on these submesoscales.
Mesoscale eddies and submesoscale structures
ubiquitous on satellite data

@ Mesoscale eddies (100-300km) well captured by conventional altimetry and reproduced by recent OGCM

Existing dynamical studies indicate that they have strong impacts
@ on the large-scale ocean circulation (meridional heat transports)
@ on the biogeochemical system (30% of the total nutrient supply)

@ Submesoscale structures (10-30km elongated filaments) captured only by HR SST and color images.

These structures were considered (until a few years) to be very weakly energetic ($k^3 - k^4$ velocity spectrum) with NO impact on the ocean properties.

Very recent studies suggest a quite different view: a synthesis

=> OS'10 (Submesoscales from Space to the Deep Ocean Interior)
Large scales

Kc (≈ 200km)

SQG (driven by surface density)

~20km

Small scales

- Baroclinic instability
- $k^3$
- Large $u,v$ in the upper layers

- Frontogenesis
- $k^{5/3}$
- Large $w$ in the upper layers

In the middle:

- PE direct cascade
- Direct KE cascade
- KE inverse cascade

JASON

SWOT

Eddy intensification $\iff$
Evidence that submesoscales are more energetic: velocity and density spectra have a shallower slope \((k^{-2} \text{ instead of } k^{-3} \text{ in the interior})\)

Models: Capet et al. 2008; Klein et al., 2008

Observations: Ferrari & Rudnick, 2000
Le Traon et al., 2008

Why are these submesoscales important?
Because of their energetic divergent motions
High resolution altimetry data combined with results from theoretical studies may allow to diagnose not only the surface currents but also the 3D motions (including the vertical velocity) in the first 500m below the surface.

=> Access to the horizontal and vertical fluxes of any tracers
Assessment of the potentiality of HR SSH:
Use of simulations (as testbeds) of eddy turbulence forced by realistic HF winds

PE model 1/100e degree, 200 levels
[3000km*2000km*4000m]

@ Eddy turbulent field:
* surface kinetic energy (300km) with a k^-2 spectrum slope
* thin (<10km) submesoscales with large vorticity values (-f to 3f) quickly evolving (=>large W)
(Klein et al, JPO, 2008, Capet et al.,2008)

@ Active mixed-layer forced by HF (3h) winds:
  - 80m deep
  - energetic near-inertial motions

Surface relative vorticity field
surface oceanic vorticity: day=495
Near-inertial motions have no signature on the SSH

Surface motions with scales larger than 20 km are dominated by the geostrophic (SSH) contribution

These properties suggest that a snapshot of high resolution SSH may allow to diagnose low frequency motions with scales larger than 20 km in the upper oceanic layers using the method proposed by Lapeyre and Klein (JPO 2006)

(see also Isern et al., JGR 2008; Klein et al., GRL 2009; Sasaki et al., in preparation)
One important property of the SSH is the absence of an inertial peak in its frequency spectrum (near-inertial motions have no signature on the SSH).
@Surface motions with scales larger than 20 km are dominated by the geostrophic (SSH) contribution

@Surface motions with scales smaller than 20 km are affected by the ML dynamics
Lapeyre and Klein (JPO 2006):

PV anomalies in the ocean interior (driven by baroclinic instability) are correlated to the surface PV anomalies (driven by surface frontogenesis) [see also Isern et al., JGR 2008; Klein et al., GRL 2009; Sasaki et al., in preparation].

This leads to propose a method to diagnose the 3D dynamics from either the SSH or the surface buoyancy.

This diagnosis method is based on the SQG dynamics (Held et al, 1995):

\[ \hat{\psi}(k, z) = g f_0^{-1} \hat{\eta}(k) \exp(N_0 f_0^{-1} k z) \]

No/fo takes into account the contribution of the interior dynamics.
Reconstruction of 3D dynamics in the North Pacific using outputs of realistic high-resolution ocean simulations

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SSH and Mixed Layer Depth (OFES, 01/01/15th yr)

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{sshmld.png}
\caption{(Left) Sea surface height (cm), (Right) mixed layer depth (m) of OFES daily mean on Jan. 1st, 15th model year. The esSQG reconstruction is conducted for each 5deg. x 5deg. domain. Correlation maximum of RMS of vertical motions between the esSQG reconstruction and OFES: ◦: > 0.4, △: > 0.2. Reconstruction cannot be adapted due to sea mount in regions “X”.
\end{figure}
Vertical Motion and Potential Density (OFES)

32.5°N

37.5°N

42.5°N

47.5°N

? Longitude–vertical section of vertical velocity (color, m/day) and potential density (contour, $\sigma$ $\theta$).
Relative Vorticity and Vertical Motions (eSQG Reconstruction vs OFES)

150–155°E, 30–35°N

165–170°E, 30–35°N
Conclusions

First results are promising

@ H.R. SSH should allow to diagnose the 3D motions (including the W field) in the upper ocean;

⇒ access to the horizontal and vertical fluxes

Some work has still to be done:

@ Further tests in different oceanic regions using OFES simulations and improvement of the method used

@ We need a better knowledge of the climatological stratification (No) (comparison of SST and SSH fields, use of Argo floats ?)

@ We need to better assess the mixed-layer dynamics (combination of SSH, SST and SAR data ?)
Meridional section of relative vorticity (contours) and $W$ (color: m/day)

Dynamics within the ML differs from that below the ML