Ocean Scale Interations from Space

Patrice Klein[1,2,3], Guillaume Lapeyre[4], Lia Siegelman[1,2,5], Hector Torres[1], Zhan Su[2], Shafer K. Smith[6]

[1]Jet Propulsion Laboratory (NASA) , Pasadena, USA
[2]California Institute of Technology, Pasadena, USA
[3]Lops-Ifremer/CNRS FRANCE
[4]LMD, ENS, Paris, FRANCE
[5]LEMAR/IUEM/CNRS, FRANCE
[6]Courant Institute, New-York University, USA

Key Points:

- 25 years of satellite altimetry and recent numerical simulations highlight that all the oceans are fully turbulent.
- This turbulence involves energetic Ocean Scale Interactions over a broad range of scales, from 1km to 10,000km.
- These interactions drive the kinetic energy budget, heat storage and therefore the climate system.

Corresponding author: Patrice Klein, `patrice.klein@ifremer.fr`

Abstract

Satellite observations of the last two decades, combined with *in situ* measurements, have led to a major breakthrough emphasizing the existence of a strongly energetic mesoscale turbulent eddy field in all the oceans. This ocean mesoscale turbulence (OMT) is characterized by cyclonic and anticyclonic eddies (with a 100–300 km size and depth scales of ~500–1000 m) that capture approximatively 80% of the total kinetic energy and is now known to significantly impact the large-scale ocean circulation, the ocean's carbon storage, the air-sea interactions and therefore the Earth climate as a whole. However, OMT revealed by satellite observations has properties that differ from those related to classical geostrophic turbulence theories. In the last decade, an explosion of theoretical and numerical studies has pointed to the impact of sub-mesoscale surface fronts (1–100 km, not resolved by altimetry and not taken into account by geostrophic turbulence theories) on larger scales as the key suspect explaining these discrepancies. Sub-mesoscale surface fronts have been shown to impact larger scales in counter-intuitive ways. The ocean engine is now known to involve energetic scale interactions, over a much broader range of scales than expected one decade ago, from 1 km to 10 000 km, that significantly impact the climate system. However, new space observations with higher spatial resolution are highly needed to question and eventually improve these recent theoretical and numerical results.

1 Introduction

In 1992, a very precise altimeter Topex/Poseidon system (T/P) (CNES/NASA) was designed to observe Sea Surface Height (or SSH, a proxy of surface pressure) over a range of scales from 10,000 to 100 km. These SSH observations allowed to retrieve oceanic surface motions using the geostrophic approximation (these motions are hereafter referred to as balanced motions, BMs). Walter Munk, testifying before the U.S. Commission on Ocean Policy in April 2002, emphasized that T/P was "the most successful ocean experiment of all time". First analyses of T/P products indeed profoundly revolutionized the field of oceanography. In particular, they showed that General Ocean Circulation Models with low resolution existing at that time were strongly deficient in estimating the kinetic energy content [*Fu and Smith*, 1996; *Stammer et al.*, 1996].

More than 25 years later, in September 2018, over three hundred ocean scientists attended a five-day symposium in Ponta Delgada (Azores Archipelago) to celebrate 25 Years of Progress in Satellite Radar Altimetry. Ocean monitoring over more than two decades, using T/P and other satellite altimeters (Figure 1), has led to a major scientific breakthrough: altimeter data have revealed that all the oceans are populated by numerous coherent eddies at mesoscale (100–300 km) that capture almost 80% of the total oceanic kinetic energy (KE) [*Wunsch*, 2002, 2009; *Chelton et al.*, 2011; *Morrow and Le Traon*, 2012; *Xu and Fu*, 2012] (see Figure 2a). In that respect, the Earth oceans are even more turbulent that the Earth atmosphere [*Jansen and Ferrari*, 2012] and seem to share the same turbulent properties as the atmospheres of other planets such as Jupiter [*Adriani et al.*, 2018].

Since the ocean fluid is a geophysical fluid (i.e. stratified in a rotating frame), its highly turbulent character was previously suggested by the geostrophic turbulence theory described in the seminal paper of *Charney* [1971] and detailed in the numerical simulations of *Hua and Haidvogel* [1986] and *McWilliams* [1989]. This turbulent nature was also emphasized in the early 2000' by ocean regional models with moderate resolution (between 1/6th and 1/10th of a degree, see *Smith et al.* [2000]) but not fully trusted until later confirmed by altimeter observations. Further analyses identified disconcerting discrepancies between SSH observations and the geostrophic turbulence properties as well as with these regional models, in particular in terms of spectral characteristics. As detailed in section 2, the key suspect, identified later on by numerical simulations with much higher spatial resolution, are the impacts of smaller-scale frontal dynamics at the ocean's surface on mesoscale eddies. In the last fifteen years, an explosion of numerical and theoretical studies has led to better understand these discrepancies in terms of the interactions between mesoscale eddies and frontal dynamics at