Ocean Turbulence from Space

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Abstract

Understanding the turbulent nature of the world's oceans is challenging. The most energetic part of this turbulence consists of eddies and jets interacting over a few orders of spatio-temporal scales: from hours to months and from hundreds of meters to thousands of kilometers.

Satellite altimeters, including the recent SWOT altimeter, have unveiled oceans populated with mesoscale eddies. These eddies (>10 km-size) are also detected by SAR, ocean color, and infrared satellite images that also emphasize the surface signature of eddy-eddy interactions.

The main purpose of the class is to show how ocean dynamics can be inferred from heterogeneous satellite observations through the dynamical framework of geostrophic turbulence. We will review the basic properties of non-linear geostrophic turbulence (e.g. potential vorticity dynamics, particles and tracer dispersion, frontal dynamics, inverse and direct energy cascades). We will illustrate how these theoretical concepts can be used to exploit the synergy of combining different satellite observations. We will aim to understand the turbulent nature of the oceans and, in particular, to diagnose parts of 3D ocean dynamics in the first 500 m of the water column.

1 Key dates

Classes take place M/W 10:30-11:50am, NH 101.
Quarter starts Thursday, Jan 2 - ends Saturday March 22
Instruction ends Friday March 14

Holidays:

- Martin Luther King, Jr. Holiday Monday, January 20
- Fifteenth day of instruction Monday, January 27
- Presidents' Day Holiday Monday, February 17

2 Synopsis

Week 1: Mon Jan 6 & Wed Jan 9. Introduction.

Week 2: Mon Jan 13 & Wed Jan 15 Eddies from satellite observations

Week 3: Wed Jan 23. Eddy dynamics from 30 years of satellite altimetry

Week 4: Wed Jan 29. Beyond the geostrophic balance (impact of nonlinear terms)

Week 5: Mon Feb 3 & Wed Feb 5. 2D Turbulence I & II

Week 6: Mon Feb 10 & Wed Feb 12. 2D Turbulence III (Inverse KE cascade and direct enstrophy cascade)

Week 7: Wed Feb 19. 2D Turbulence IV (Spectral characteristics of kinetic energy, enstrophy and tracer)

Week 8: Mon Feb 24 & Wed Feb 26. 3D rotating and stratified eddy turbulence I & II

Week 9: Mon Mar 3 & Wed Mar 5. 3D rotating and stratified eddy turbulence III & Guest speaker Matthew Archer (JPL)

Week 10: Mon Mar 10 & Wed Mar 12. 3D rotating and stratified eddy turbulence IV & Guest speaker Yao Yu (SIO)

Week 11: Mon Mar 17 & Wed Mar 19. Student presentations

3 Content

1. Week 1 Introduction. Motivation of the class, definition of eddy turbulence, brief history (from Stommel to SWOT), numerical results on heat and primary production
2. Week 2. Eddies from satellite observations. Examples on synergy between different satellite observations
3. Week 3. Recap of what 30 years of satellite altimery taught us about mesoscale turbulence
4. Week 4. Impact of non-linear terms on eddy dynamics (Okubo-Weiss quantity, Finite Size Lyapunov Exponent, tracer dispersion, direct cascade of tracers governed by non linear terms)
5. Week 5. 2D Turbulence I. Euler equations, Vortex evolution and interactions, OW (again), vortex merger, numerical results and observations.
6. Week 6. Inverse KE cascade and direct enstrophy cascade. Some theoretical, numerical and satellite results.
7. Week 7. Spectral characteristics of kinetic energy, enstrophy and tracers. Theoretical and numerical results.
8. Week 8. 3D rotating and stratified eddy turbulence. SQG and IQG. KE and APE budgets in 3D eddy turbulence.
9. Week 9. 3D rotating and stratified eddy turbulence III. SQG and IQG cascades. Guest speaker: First results from SWOT (Archer et al. 2025 Nature)
10. Week 10. 3D rotating and stratified eddy turbulence IV. Regimes of 3-D eddy turbulence observed by satellite altimeters (SQG, IQG, or both?). Guest speaker: High-resolution bathymetry from SWOT (Yu et al. 2025 Science)

4 Evaluation

Student presentation of a relevant paper of your choice during week 11.