Inferring Quasigeostrophic (QG) Vertical Velocities in the North Pacific

Objective:

The objective of this proposed project is to model mesoscale vertical velocities in the upper ocean and use the estimates to quantify the impact of vertical transport of water on phytoplankton productivity at the sea surface.

Introduction:

Mesoscale processes, also known as the ‘internal weather of the ocean,’ occur at temporal scales of weeks to months and spatial scales of 20 to 300 km. Phytoplankton--photosynthetic microorganisms that float in the ocean--are a keystone species for marine ecosystems because they convert nutrients and sunlight into forms consumable by other organisms. Their presence can be indirectly inferred from chlorophyll a data which can be detected via satellites.

Due to challenges in collecting adequate in-situ data, subsurface vertical velocities cannot be directly measured. Vertical movement of the ocean water has the ability to bring heat, nutrients and marine life from the deeper parts of the ocean to the sunlit surface and vice versa. We will be combining high-resolution satellite data with the quasi-geostrophic omega equation to diagnose the vertical velocities at the mesoscale. This project aims to quantify the impact of mesoscale vertical velocities on biological productivity We will test the hypothesis that upward movement of water will bring nutrients from the deeper parts of the ocean into the sunlit region and allow phytoplankton to prosper. On the other hand, downward movement can subduct the phytoplankton into the darker parts of the ocean, thereby creating a ‘marine desert’ at the surface. However, effects of subduction are beyond the scope of this project.

Vertical velocities at the mesoscale have been extensively studied via simulations and have been found to have a significant impact on the ocean biogeochemistry (Giordani et al 2006, Mahadevan et al 2016). However, there is a lack of both regional and global studies of mesoscale vertical velocities using observed data because until recently there were very few observations at the mesoscale. Recent advancements in satellite altimetry allow us to study mesoscale processes as they resolve processes that range from 1/4° to 1/8° latitude/longitude, where 1° longitude is about 110 km globally, and 1° latitude is decreases from about 110 km at the Equator to 0 km at the Poles

Theoretical Background:

Quasi-geostrophic theory simplifies geophysical fluid dynamics processes which are almost in geostrophic balance by breaking them into geostrophic and ageostrophic components. The Coriolis force is a fictitious force which helps us take the Earth's rotational effects into account and geostrophic balance occurs when the horizontal pressure gradients are balanced by the Coriolis force. In 1992, R. T. Pollard and L. A. Regier, studied vertical velocities at an ocean front and derived the oceanic Q-Vector form of the QG Omega Equation (Pollard et al 1992, Pinot et al 1996), which was previously used in atmospheric dynamics (Holton et al 1990, Hoskins et al 1978),

$$f^2\frac{\partial^2 w}{\partial z^2}+\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}\right)(N^2 w)=\vec{\nabla}\cdot\vec{Q}$$

$$\vec{Q}=\left(2f(\frac{\partial v}{\partial x}\frac{\partial u}{\partial z}+\frac{\partial v}{\partial y}\frac{\partial v}{\partial z}),-2f(\frac{\partial u}{\partial x}\frac{\partial u}{\partial z}+\frac{\partial v}{\partial y}\frac{\partial v}{\partial z})\right)$$

where w is the vertical component of the velocity, $N, f_0, u,$ *and* v are the buoyancy frequency, Coriolis frequency and the x and y components of the geostrophic velocity, respectively, and z is the vertical coordinate. The TEOS-10 toolbox in MATLAB (McDougall et al 2011)calculates the N squared given the temperature and salinity profile.

Approach:

The project uses horizontal geostrophic velocities and temperature and salinity profiles for the upper 1000 m of the ocean provided by the Copernicus Marine Environment Monitoring Service

(CMEMS). We are solving the omega equation by treating the left hand side as an elliptic operator,

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where the QG omega equation becomes

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By coding up the matrix form of the finite difference operators in MATLAB, we are able to find the divergence of the 2D Q-vector--i.e there is a Q_x and a Q_y component both of which are 3D scalar fields. Afterwards, we apply the inverted elliptic operator to the divergence of the Q-vector to get the vertical velocities:

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The vertical velocities are sensitive to the bottom and surface boundary, so we apply Dritchlet boundary conditions and set w =0 at z = 0 and z = 1000m. Previous studies have found that the vertical velocities are not sensitive to the lateral boundary conditions, so we apply the Neumann boundary condition dw/dz=0 at x_0,y_0,x_end and y_end, and since w=0 at z = 1000 m, w= 0 at all the boundaries.

We have coded the finite difference operators and the elliptic operators and have access to the data. Currently we are working on replicating results from Pascual et al (2015) which uses a CMEMS dataset for September 2005 for the Gulf Stream. After verifying the results we will study other regions in the North Pacific--most probably Kuroshio or around Hawaii. Our goal for this summer is to finish debugging the code, apply it to another region, study the impact of vertical velocities in the region and write up the results. Afterwards, we will also be documenting and polishing the code and upload it for others to use.

Student’s Responsibility:

This is a primarily student-led project with the research question and guidance from Professor Francois Primeau. My role so far has included conducting a literature review, reading textbooks, deciding between the different possible vertical velocity equations, locating data sources, processing the data, coding the numerical finite difference operators, creating data access script, replicating the Pascual et al (2005) study, and debugging the code. I also led a lecture deriving the Q-vector formulation of the QG omega equation to discuss the physics involved with my advisor.

Timeline:

- June
  - Debug QG vertical velocities code
- July
  - Replicate Pascual et al (2015) results to test code
- August
  - Submit abstract to AGU fall meeting
  - Start building simple NPP model
- September
  - Start writing results as a paper

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