Global Ocean Vertical Velocities from ECCO v4

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Background

- Ocean vertical velocities are important in various ways
- Ocean dynamics
- Vertical exchange of ocean properties and tracers
- ECCO estimates of the ocean vertical heat flux show that the spatial pattern of the vertical heat exchange is determined by vertical velocities.

Liang et al, 2015
Background

• Ocean vertical velocity associated with large-scale circulation cannot be measured directly.

• Estimates of ocean vertical velocities are limited. Previous estimates based on simplified dynamical models: $10^{-5}$ m/s (1 m/d) near the surface and $10^{-7}$ m/s (1 cm/d) in the deep ocean.

• However, in many of these previous estimates, temporal and spatial variations as well as various important processes, such as mesoscale eddies, were ignored.

• Although $w$ has been considered implicitly when conducting budget analysis of heat, salt, and biogeochemical tracers as well as investigating ocean circulations, they are seldom focuses of studies.
Methods

- **Eulerian W**: the term used in momentum equations; diagnosed from volume continuity in ECCO v4

- **Bolus W**: represents the integral effects of mesoscale eddies on the vertical transport of ocean properties and tracers; parameterized following Danabasoglu et al. (1994)

- **Residual W**: sum of the Eulerian and Bolus vertical velocities; term used in the tracer equations
Three-Dimensional Vertical Velocities: Eulerian W

- In the upper ocean, the Eulerian W shows the conventional wind-driven patterns.

- In the ocean interior, the spatial structure of Eulerian W is complex, with a reduction of the direct wind-driven patterns and generally smaller magnitudes except in the high-latitude regions.

- On approaching the sea floor, the spatial structure of Eulerian W in the abyssal ocean is to a large extent related to the bathymetry.
Three-Dimensional Vertical Velocities: Bolus W

- At all the sample depths, the most significant eddy-induced features appear in the Southern Ocean and near Greenland.

- These structures are associated with steep isopycnal slopes and the expected strong baroclinic instability in those regions.

- Comparison of Eulerian and bolus W at all the sample depths shows a clear compensation between them.
Compensation of Eulerian and Bolus Vertical Velocities

- The most significant compensation occurs in the ocean interior and away from the surface and the bottom
- Compensation between them is common almost everywhere, and not confined to the Southern Ocean.
Three-Dimensional Vertical Velocities: Residual $W$

- The residual $W$ directly controls the vertical transport of properties and tracers.
- Visually, residual $W$ in the upper ocean is similar to the Eulerian $W$.
- Strongest residual upwelling and downwelling in the deep and abyssal oceans occur in the Southern Ocean and near Greenland. They also appear vertically coherent.
- These “pipe-like” structures at high latitudes might be important for transporting abnormal climate signals to the deep and abyssal oceans.
Surface and Bottom Related Patterns

Spatial patterns of the Eulerian W indicate different physics operating at different depths. The upper ocean is controlled by Ekman pumping and suction, but in the deep ocean, topographic impacts are dominant.
Surface and Bottom Related Patterns

- Globally the wind-driven patterns can extend from the surface to about 750m, and the bathymetry-related patterns can extend from the seafloor to about 2000m.

- The competition between surface and bottom controls in the ocean interior varies for different ocean regions, particularly in and out of the Southern Ocean.
“Deacon cell” appears in the zonal averaged Eulerian vertical velocity

Comparing the zonal averages with the three-dimensional pictures indicates that the conventional two-dimensional or zonally averaged views of ocean circulation hide many dynamics that are important for the vertical transport.

In particular, the zonal distribution of upwelling and downwelling in the Southern Ocean as well as its relationship with the zonal change of topography disappear in the zonally averaged view.

As a consequence, some possible responses of the vertical transport of heat, salt, or biogeochemical tracers to the changing climate will be missed in those zonally averaged conceptual/numerical models.
Summary

• Conventional patterns of vertical velocity, Ekman pumping, appear in the upper ocean, with topographic dominance at depth.

• Eulerian and parameterized eddy-induced $W$ are of opposite signs in numerous regions around the global ocean, particularly in the ocean interior away from surface and bottom. Nevertheless, residual $W$ is primarily determined by the Eulerian component, and related to winds and large-scale topographic features.

• Intense and vertically coherent upwelling and downwelling occur in the Southern Ocean. These “elevators” at high latitudes connect the upper to the deep and abyssal oceans and working together with isopycnal mixing are likely a mechanism, in addition to the formation of deep and abyssal waters, for fast responses of the deep and abyssal oceans to the changing climate.

• The Intense and vertically coherent upwelling and downwelling in the Southern Ocean are likely due to the interaction of the Antarctic Circumpolar Current and large-scale topographic features and are generally canceled out in the conventional zonally averaged results.
Thanks!

More can be found in

Liang, Spall and Wunsch, Global Ocean Vertical Velocity From a Dynamically Consistent Ocean State Estimate, JGR-Ocean, 2017