Spatial Variability in the Antarctic Circumpolar Current in a Global Climate Model

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Motivation:

Water at the surface of the Southern Ocean has the same density as water thousands of meters deep near the equator. Since ocean mixing occurs in regions of constant density, the Southern Ocean surface layer provides a channel through which heat and carbon dioxide flows from the atmosphere into the deep ocean near the equator (Gille, 2010). Arguably the most prominent feature of the Southern Ocean is the Antarctic Circumpolar Current (ACC). Driven by the strong westerly trade winds, it flows completely around the globe from west to east, transports more water than any other ocean current, connects the Atlantic, Pacific, and Indian Oceans, and regulates general ocean circulation and the global climate (Radko, 2006). The flow of the ACC is not spatially uniform; filaments of the flow may diverge north or south into the surrounding ocean basins, or may downwell. In this project, we examined the net volume flux into the ACC from the surface layer in each basin. The volume flux, that is, the transport of water through a given cross sectional area, is the product of the velocity and area.

$$\frac{dV}{dt} = \frac{ds}{dt} * Area$$

If we assume that the water is an incompressible fluid, then volume in the surface layer of the ACC is conserved, and the net volume flux into a given basin is the difference between the volume flux going in and the volume flux going out. By comparing this value for each basin, we infer general characteristics of the current; i.e. a negative transport of water indicates that the surrounding basins act as sources, or inputs, to the ACC. A positive transport indicates that the ACC is diverging in that basin, and that the surrounding basins receive that outflow. This project was motivated dually by the physical problem, and also by student interest in developing skills to process and manipulate large global climate data sets with some of Pythons powerful mathematics, scientific, and mapping libraries. Incorporating Dun-yu's comments, we improved the methods to make them more meaningful but also more straightforward. We kept the goal of understanding variability in the eastward surface flow of the ACC, but calculated the volume flux rather than the basin-wide average velocity, as we had previously proposed.

Summary of Results:

We compared the net volume flux of the surface layer of the ACC between the Atlantic, Pacific, and Indian Oceans using the Community Climate System Model (CCSM4). This is a state of the art global climate model used widely for research by the climate science community. Our hypothesis was that the Atlantic basin will have the strongest negative transport, because:

a) there is a strong northward overturning circulation in the surface of the Atlantic Ocean and

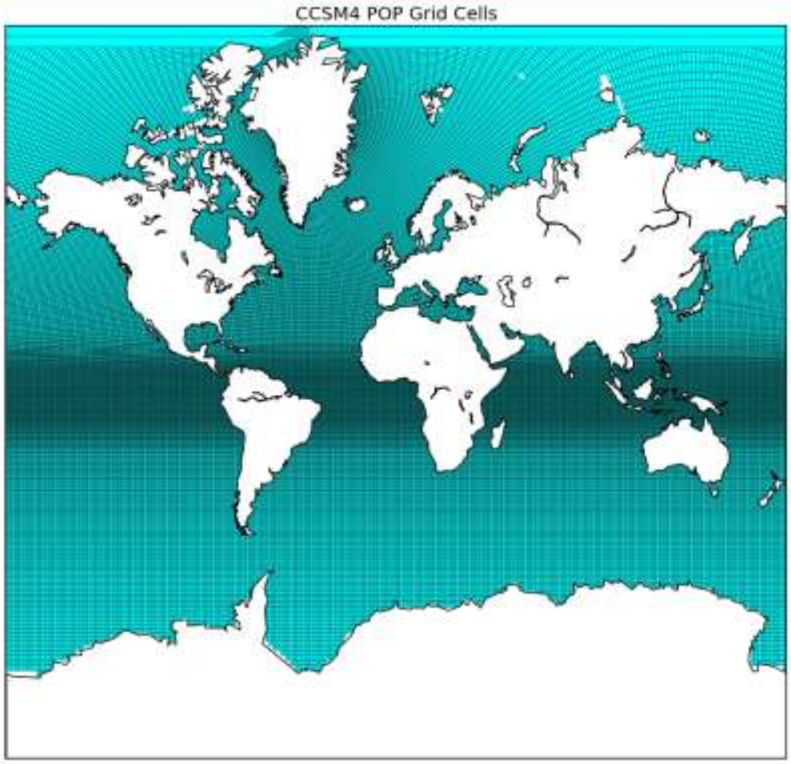
b) the Drake Passage between the Antarctic Peninsula and Argentina, is a narrow choke point for the ACC, and it causes the stream to diverge on the Atlantic side of the Drake Passage ,in the same way that a flow on the outer end of a hose sprays out in all directions if you restrict the area of the opening.

The results of our calculation as summarized as follows:

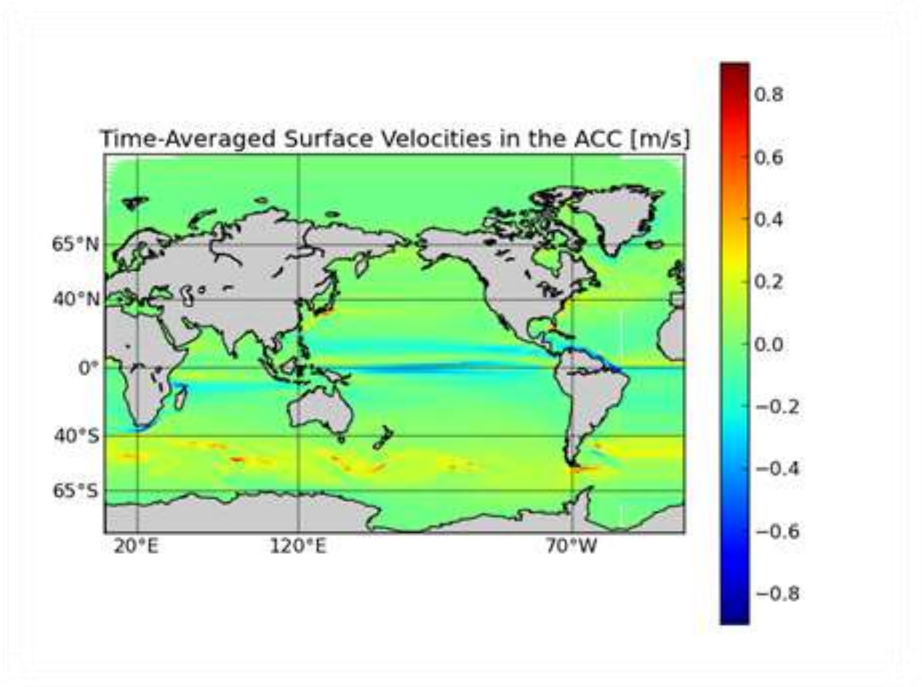
Basin	**Net Volume Flux (km^3/s)**
Pacific	5.5451×10^{-4}
Atlantic	-6.1057×10^{-4}
Indian	5.5606×10^{-5}

The Atlantic Ocean has a strong, negative volume flux, indicating that the flow diverges outward into the surrounding ocean basins. The Pacific has a positive volume flux, indicating that flow converged toward the ACC form surrounding basins. The Indian Ocean, not surprisingly, has the smallest net convergence, likely due to the small relative size of the Indian Ocean.

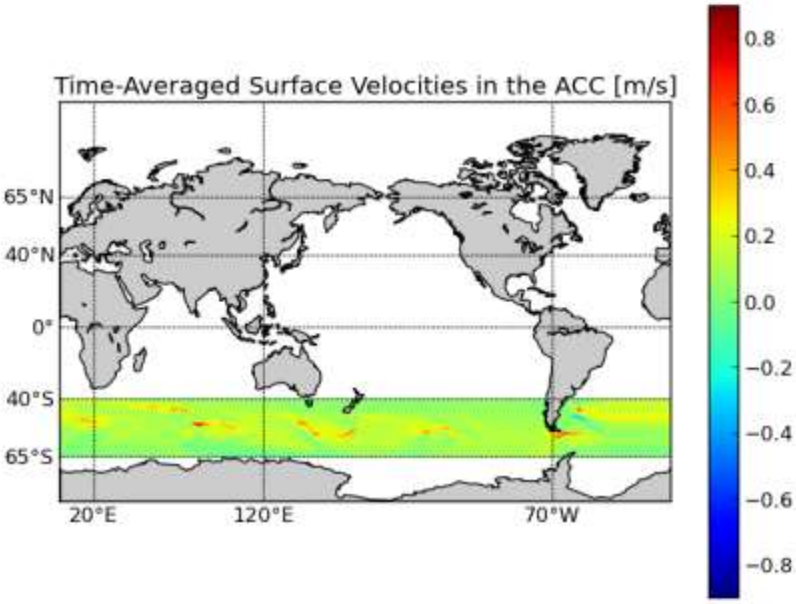
In the process of obtaining these results, we generated plots of the grid points and the velocity field to have a visual aid of the model grid. The CCSM4 ocean model grid has set the pole of the grid to be in Greenland. This avoids the troublesome numerical instabilities that arise when trying to integration equations of fluid motion in Arctic Ocean at the North Pole where the meridians converge. We've included this plot of the grid to explain why there is some distortion of the data near the boundaries on the plots below that we were not able to resolve.



The plots below show the time averaged Eastward surface velocities for the entire spatial data set, and for the region only within the ACC. The sign of the value indicates the direction, with east as positive, west as negative. The ACC is seen in the band between 40 and 65 degrees South, with velocities up to 0.8 m/s.



The plot below was created by masking out all of the values outside of the ACC range. We calculated the volume flux through transects 20°E, 120°E, and 70°W.



Dataset:
The International Panel on Climate Change established the Coupled Model Intercomparison Project (CMIP5) for the purpose of serving the global community's need for accurate model predictions of climate. The CMIP5 archive contains publicly accessible model output from

simulations of the earth system under different scenarios of atmospheric conditions. We use the Community Climate System Model ocean velocity datasets from the CMIP5 archive in this analysis. The data files are netCDF format and have been downloaded from http://esg-pcmdi.llnl.gov/esgf.

Data used for this project is available on the ftp server:

ftp://gateway01.nssix.com
username: cse140
password: cse140

We analyze the dataset:
uo_Omon_CCSM4_rcp85_r1i1p1_200601-200912.nc

The naming convention is:
(u,v)o = (east/west, north/south) ocean velocity
Omon = **o**cean **mon**thly time series
CCSM4 = Community Climate System Model (developed by the National Center for Atmospheric Research)
rcp85 = representative concentration pathway 8.5. This was one of several **inputs** for climate and atmospheric chemistry for the models participating in the International Panel on Climate Change. Developed by international economists, this pathway represents increased greenhouse gas emissions over time; the 'business as usual' scenario.
200601-200912: year & month

Methods:

Note: Due to the use of non-standard libraries in this analysis, we have included more information about the code structure than requested in the homework.

1.) Processing

To first understand the data stored in the NC file, we created the script **get_nc_meta.py** which opens and reads the metadata from the NC file and write this to a text file for reference (***meta**_uo_Omon_CCSM4_...)*. This contains information about the dimensions of the variables, grid size, and units. Let x,y,z, and t, denote the longitude, latitude, depth, and time variables, respectively.

The script **get_surface_data.py**, reads in the velocity field from the NC file as a 4-D masked array **u**(**x,y,z,t**) and extracts only the surface values. This flattened the depth dimension, resulting in a 3D masked array **u**(**x,y,t**). The script pickles that data, along with the latitude long longitude grid arrays, and saved as the file 'uo_surface_data' to make the data file smaller and more manageable.

2.) Computations

All of the calculations are completed in the script **ACC_VolumeFluxAnalysis.py**. The ACC boundaries were set between 40 and 65 degrees south. The Ocean basin boundaries were set as:

Atlantic = 60°W to 28°E
Indian = 28°E to 120° E
Pacific = 120° E to 60° W

The surface velocity field is flatted from a 3D array (time, lat, lon) to a 2D array (lat, lon) by averaging over all of the time elements. Next, all of the values outside of the ACC region are masked. The volume flux is then calculated for each of the specified transects, and the difference of the volume flux on the west and east boundaries of each basin is calculated to determine the net flux in each basin.

Conclusions:

We determined that there are clear differences in the volume flux at the surface level of the Antarctic Circumpolar Current. There is a net flux out of the ACC in the Atlantic basin, and flux into the ACC from the Indian and Pacific Ocean Basins. Given more time, we'd like to tease apart the relative contributions of topography, atmospheric processes, and ocean circulation on these flux differences. This analysis used data from a computer simulation; observational data also suggests that there is more variability and outward flow of the ACC in the Atlantic Basin, as this is perhaps the most dynamic of the worlds ocean basins (Radko, 2006).

Collaboration:

A friend kindly granted us access to an FTP server for this project, so that we could store the large data sets at an accessible location.

Reflection:

This was a great opportunity to learn some specialized python skills that pertain to my field of interest. I found several helpful web references for working with netCDF data, and explored the awesome features of pythons map library! (JT)

I found this assignment challenging but maybe next time I'll choose to partner up with someone who's not absolutely crazy about atmospheric data, ha-ha (MB).

References:

Gille, Sarah. "Climate Science: Asymmetric Response", *Nature Geoscience*, 27 (2010).

Radko, T and John Marshall. "The Antarctic Circumpolar Current in Three Dimensions", *Journal of Physical Oceanography*, Vol. 36, 653 (2006).