Heat transport in the atmosphere and oceans: Implications for paleo-, modern and future climates

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Introduction:

The tropics receive more energy from the sun than they radiate to space. The poles radiate more energy away than they receive from the sun. Thus, energy needs to be transported from the tropics to the poles to keep the Earth’s climate in thermal equilibrium. This transport is accomplished by both the eddy transfer across the atmospheric jet stream and the ocean currents. Observations indicate that the atmosphere transports most of the heat in the extratropics and that ocean transport dominates in the tropics. Although much is known about how the atmosphere and the oceans accomplish this task individually, much less is known about how they work together. For example, the existence of continents results in the formation of the western boundary currents, like the Gulf Stream and Kuroshio, that dominate the poleward heat transport in the oceans. This project investigates various aspects of how the ocean circulation affects the atmosphere and, in turn, how the atmosphere circulation affects the ocean.

In previous studies by our group (Wilson et al. 2009, 2010), we examined the role of mountains and ocean dynamics affected the jet stream (Figure 1). We found that incorporating ocean heat transport led to a slight poleward shift of the jet stream. Due to the overall requirement to transport heat poleward, if there is not enough meridional ocean heat transport, then the atmosphere has to carry the heat transport, leading to a more active eddy transfer across the jet stream at lower latitudes. Conversely, including ocean heat transport led to the atmosphere carrying slightly less heat (the atmosphere still carries the bulk of the heat transport), so that the atmospheric jet occurs slightly further poleward.

Project Summary

The breadth of this project will allow students selecting this topic to develop their own research project. Some of the topics that might be investigated include the following, although applicants are free to suggest their own topics, as well.

1. How does the ocean heat transport alter the climate system in various configurations of continents and oceans? Following up from the Wilson et al. (2009, 2010), idealised configurations of continents and oceans could explore the factors controlling the balance of heat
transport in the oceans versus the atmosphere. This project would have obvious implications for our understanding of the Earth’s paleoclimate, as well as exoplanets.

2. How much have changes in the atmospheric circulation over the past 60 years been driven by changes in ocean heat content? For example, mid-latitude weather systems grow in preferred regions, referred to as storm tracks, formed on the western side of the ocean basins. The growth of these storms might be energized by the warming and moisture release by the underlying warm waters of the western boundary currents (Hoskins and Valdes, 1990). In addition, as the ocean temperatures increase, the amount of summer precipitation over Europe increases (Sutton et al., 2012). The rate of precipitation increase is greater than that due to the increase due to the Clausius–Clapeyron equation, implying a change in atmospheric dynamics and the source of the moisture. For another example, the warming of the Arctic Ocean has been suggested to change the frequency of blocking patterns of the jet stream. Idealised coupled atmosphere–ocean model experiments could be used to explore these questions.

The student will use the Fast Ocean Atmosphere Model (FOAM), NCAR Community Earth System Model, or another suitable model to explore the coupled effect of the atmosphere and ocean on the circulation of each. For some projects, analysis of large-scale atmospheric and ocean datasets, such as those from reanalyses from weather centres (ECMWF or the Hadley Centre) or satellite-derived precipitation, may also be useful. Thus, the student will gain experience with numerical modeling, as well as learning how to turn fundamental questions on how the Earth system works into testable hypotheses using accessible tools.

Training

The student will participate in the Doctoral Training Programme of the DTP. The student will be encouraged to apply for any international training schools. The grant includes funds for students to attend one national and one international conference/workshop during the course of their studentship.

Background of applicant

Students need to have a good degree (first class or upper second) in a numerate science, such as physics, mathematics, meteorology, ocean sciences or engineering. A willingness to engage with testing theoretical hypotheses, applying numerical experiments and analysing atmospheric and ocean data is crucial. Funding for the studentship is only available via NERC algorithm awards, so restricted to UK and EU nationals who fulfill NERC’s eligibility requirements.
Figure 1. Storm tracks in four very different realisations of the FORTE coupled atmosphere–ocean model: (a) control state with mountains and ocean dynamics; (b) ground state without mountains or ocean dynamics; (c) with mountains and without ocean dynamics; (d) without mountains and with ocean dynamics. The storm tracks are shown by the square root of the high-pass filtered eddy kinetic energy density (shaded, m s\(^{-1}\)) at 250mbar, over ten winters. The time-mean flow is shown by the 250mbar velocity streamfunction (contours, interval 1.5 x 10\(^7\)m\(^2\)s\(^{-1}\)) (Wilson et al. 2010).

References


