Using trajectories to explain the moisture budget asymmetry between the Atlantic and Pacific Oceans

Philip Craig[1], David Ferreira[1], and John Methven[1]

[1]University of Reading

February 21, 2018

Abstract

The net surface water flux (evaporation minus precipitation minus runoff, E-P-R) of the Atlantic Ocean is approximately 0.4 – 0.6 Sv (1 Sv = 10^9 kg s-1) larger than that of the Pacific Ocean, as shown in atmospheric and oceanic reanalyses and by oceanographic estimates. This asymmetry is linked to the asymmetry in sea surface salinity and the existence of the Atlantic Meridional Overturning Circulation. It is shown that the reason for the asymmetry in E-P-R is greater precipitation per unit area over the Pacific south of 30N, while evaporation rates are similar over both basins. It is further argued that the Pacific Ocean is anomalous compared to the Atlantic and Indian Oceans in terms of atmospheric moisture flux convergence and precipitation across the tropics and subtropics. To clarify the mechanism by which water vapour is exported out of the Atlantic basin and imported into the Pacific, we use an air mass trajectory model driven by ERA-Interim reanalysis. Using 12-hourly releases of 14-day back trajectories on the boundaries of ocean drainage basins over the period 2010-2014, we are able to partition the atmospheric moisture fluxes between basins according to their origins (i.e. last contact with the boundary layer). We show that at most a quarter of the E-P-R asymmetry is explained by higher moisture export to the Arctic and Southern basins from the Atlantic than from the Pacific. The main contributions come from differences in the longitudinal atmospheric transport of moisture between the Atlantic, Indian and Pacific basins. In particular, during the Asian summer monsoon the recurvature of the low level flow in the Somali Jet results in a much weaker westward moisture transport from the Indian into the Atlantic basin than across Central America (where it is similar to the zonal average) while there is stronger eastward transport from the Indian to Pacific basins. The net effect is stronger moisture convergence into the Pacific, but weaker into the Atlantic. In contrast to previous thinking, the role of the moisture flux across Central America in the asymmetry, albeit significant, is not dominant.

Department of Meteorology

Using trajectories to understand the moisture budget asymmetry between the Atlantic and Pacific Oceans

University of Reading

Scenario DOCTORAL TRAINING PARTNERSHIP

Philip Craig (p.m.craig@pgr.reading.ac.uk) | David Ferreira | John Methven

http://www.met.reading.ac.uk/userpages/student/np838619.php

1. Introduction

The time-averaged moisture budget ($-\text{div}\boldsymbol{Q} = \boldsymbol{P} - \boldsymbol{E}$) asymmetry between the Atlantic and Pacific Oceans is well known: the Atlantic is a net evaporative basin ($\boldsymbol{P} - \boldsymbol{E} < 0$) and the Pacific $\boldsymbol{P} - \boldsymbol{E}$ is closer to zero. This is a result of greater precipitation per unit area over the Pacific with only small differences in evaporation between the two oceans south of 30ºN (Fig. 1; Craig *et al.*, 2017). The $\boldsymbol{P} - \boldsymbol{E}$ asymmetry is linked to greater sea surface salinity (SSS) across the Atlantic than the Pacific, and therefore the existence of deep convection and a deep overturning circulation in the Atlantic but not the Pacific.

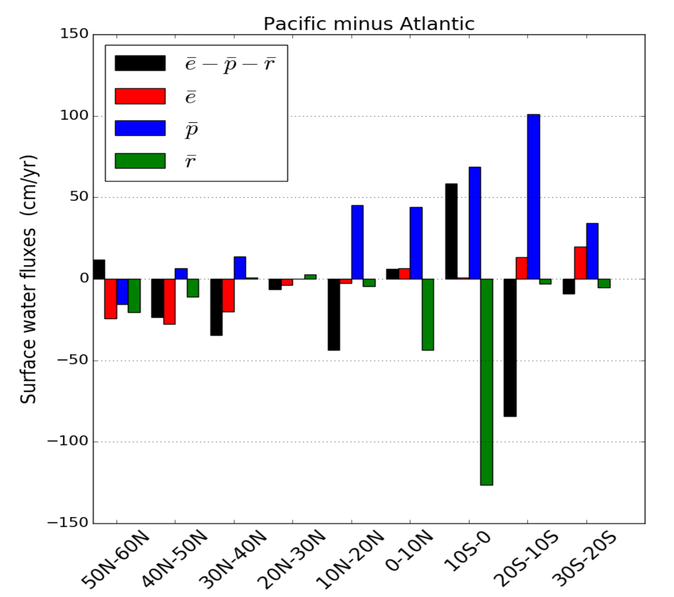

Figure 1: Differences in evaporation ($\bar{e}$), precipitation ($\bar{p}$) and runoff ($\bar{r}$) in 10º latitude bands integrated over the Atlantic and Pacific per unit area (Craig *et al.*, 2017). Runoff is taken from the Dai & Trenberth (2002) estimate, $\bar{e}$ and $\bar{p}$ are from ERA-Interim.

Net precipitation across the Pacific is often linked to the strong zonal moisture transport across Central America in the trade winds (Broecker, 1991). However, Ferreira et *al*. (2017) show that this moisture flux is similar to what would be expected from the zonal mean. Figure 2 suggests that the moisture flux across South-East Asia may play an important role in causing net precipitation across the Pacific. This research aims to provide a more complete understanding of which moisture transports between ocean drainage basins (Figure 2) contribute the most to the $P - E$ asymmetry between the Atlantic, Indian and Pacific Oceans.

2. Method

To partition the moisture fluxes in Figure 2 into their origin catchment areas, an airmass trajectory model was used (Methven, 1997). Back trajectories were released every 12 hours on 17 model levels from the catchment boundaries shown in Figure 2. The trajectories were 14 days long, a length based on the quantity of the moisture flux explained by the trajectories. Following de Leeuw *et al*. (2017) an origin based on rapid interaction with the surface was assigned to each trajectory when it either:

1. Experiences moistening by making contact with the boundary layer (well-mixed in θ_v), or
2. Experiences moistening in a cloud layer above the boundary layer (well-mixed in θ_e).

We also assign trajectories as having origin in the stratosphere if they have recently left the stratosphere before arriving at the catchment boundary.

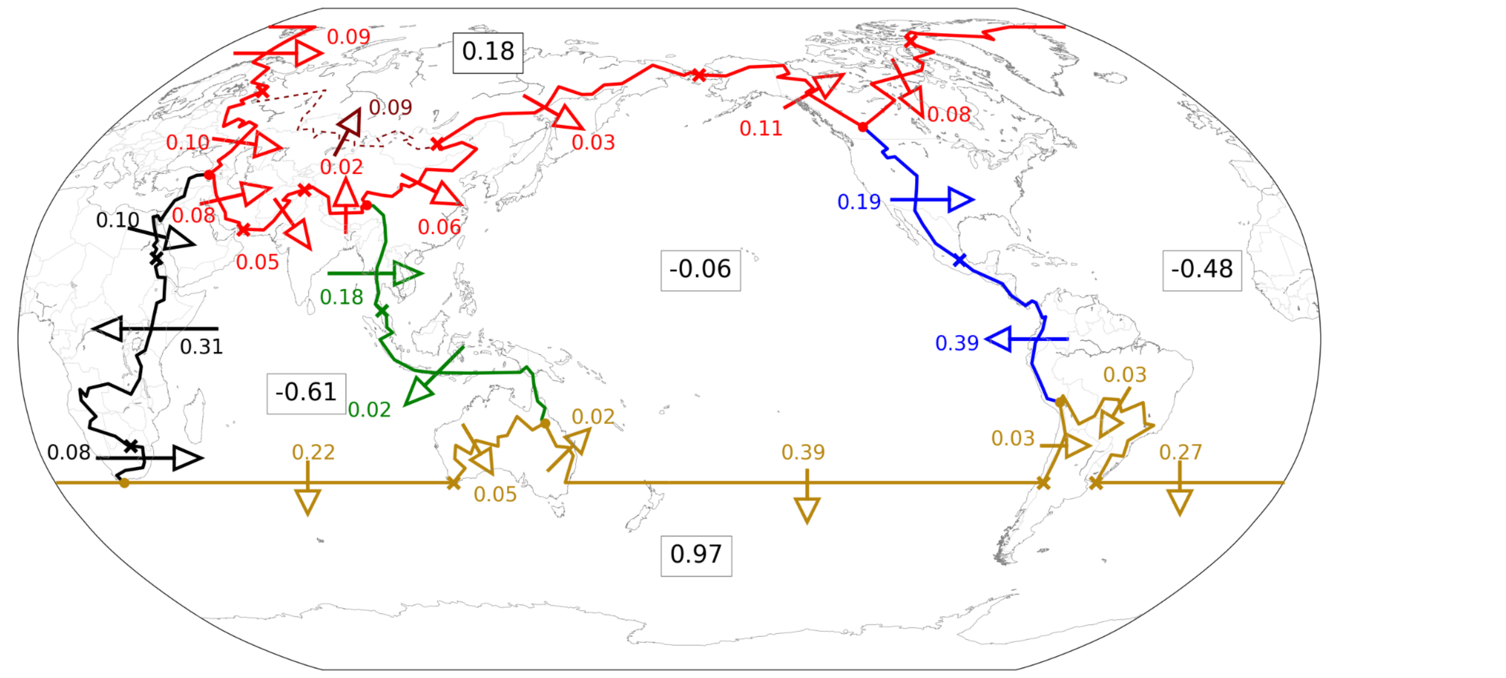

Figure 2: Annual mean (2010-2014) vertically and horizontally integrated ERA-Interim moisture fluxes (arrows) normal to the boundaries of the catchment areas of each ocean and $\boldsymbol{P} - \boldsymbol{E}$ for each catchment area (boxes). The normal fluxes are split into regions based on the net direction of the moisture flux. Units are Sverdrups (1 Sv = 10^9 kg/s).

3. Partitioning the moisture fluxes

Using the trajectory model the moisture fluxes were attributed to the origin catchment areas shown in Figure 2. The partitioned moisture fluxes across the African, South-East Asian and American catchment boundaries are shown in Figure 3. The net fluxes across the Americas and Africa are dominated by a westward flux at low latitudes, but the net flux across South-East Asia is eastward from the Indian Ocean to the Pacific.

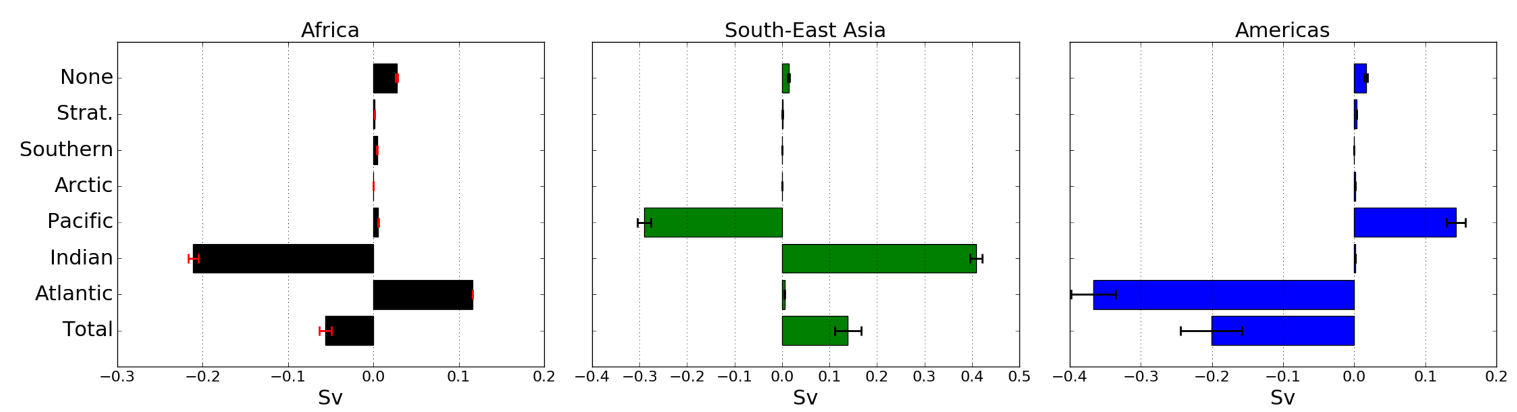

Figure 3: Annual mean (2010-2014) vertically and horizontally integrated moisture fluxes normal to the African, South-East Asian and American catchment boundaries (Fig. 2) partitioned into origin catchments. Positive (negative) fluxes indicate a northward/eastward (southward/westward) direction.

4. The Asian Monsoon

Unlike the moisture fluxes across the American and African catchment boundaries, where the net direction matches expectations from the trade winds, the flux across South-East Asia is eastward because of the flux with origin in the Indian Ocean. The seasonal cycle of the flux-weighted density of trajectory origins (Fig. 4) show that in summer the monsoon causes considerably more moisture than in any other season to cross South-East Asia from the Indian to the Pacific Ocean. The Somali low-level jet diverts moisture away from Africa towards South-East Asia and the westerly winds transport moisture into the Pacific basin (Figure 5). This flux is strongly correlated with Pacific $P - E$ on seasonal and interannual timescales. Our findings bring a quantitative support to the hypothesis of Emile-Geay *et al.* (2003) that the Pacific-Atlantic $P - E$ asymmetry is caused by the Asian Monsoon.

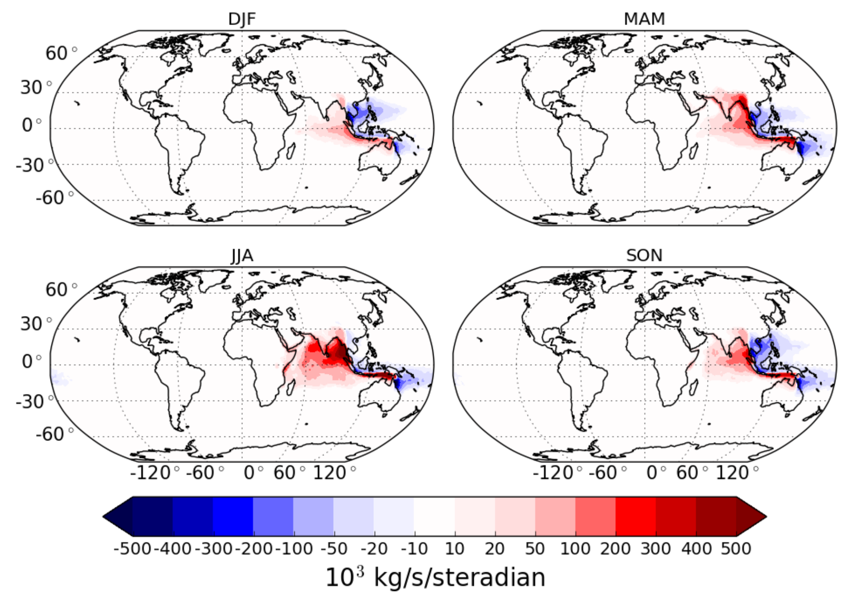

Figure 4: Seasonal cycle of flux-weighted density of trajectory origins released from the South-East Asian catchment boundary (green line, Figure 2). Red (blue) contours show regions which contribute to a northward/eastward (southward/westward) flux.

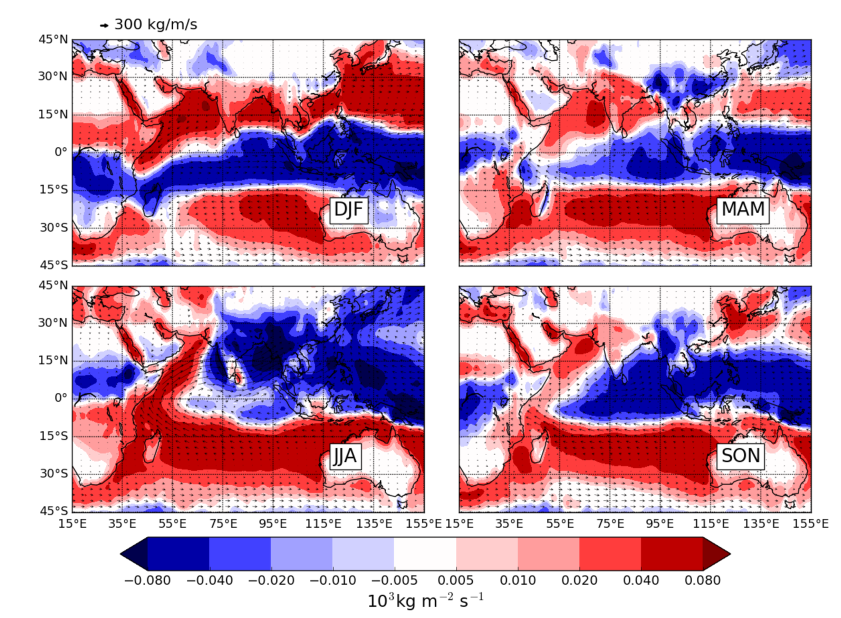

Figure 5: Seasonal cycle of the vertically integrated ERA-Interim moisture fluxes (arrows) and vertically integrated moisture flux divergence (contours) over the Indian Ocean for the period 2010-2014.

5. Conclusions and further findings

By using an airmass trajectory model to partition the moisture fluxes between ocean catchment areas we have shown that:

- The net moisture fluxes across Africa and the Americas are dominated by a westward flux in the trade winds (Figure 3)
- The net moisture flux across South-East Asia is dominated by an eastward flux from the Indian Ocean (Figure 3) which is a direct result of the monsoon in summer (Figures 4/5)
- This explains approximately 60% of the $P - E$ asymmetry between the Atlantic and Pacific Oceans.

In addition, we also found that more water vapour leaves the Atlantic into the Arctic than leaves the Pacific. This explain about 25% of the Atlantic/Pacific moisture budget asymmetry.

References

Broecker, W. (1991) The Great Ocean Conveyor. Oceanography, **4**, 79-89.

Craig, P.M., Ferreira , D and Methven, J. (2017) The Contrast between Atlantic and Pacific Surface Water Fluxes. *Tellus A*, **69**, 1330454

Dai, A. and Trenberth, K.E. (2002) Estimates of freshwater discharge from continents: latitudinal and seasonal variations. *J. Hydrometeor*. **3**, 660-687

De Leeuw, J., Methven, J. and Blackburn, M. (2017) Physical Factors Influencing Regional Precipitation Variability Attributed Using an Airmass Trajectory Method. *J. Climate*, **30**, 7359-7378

Emile-Geay, J. and co-authors (2003). Warren revisited: atmospheric freshwater fluxes and "Why does no deep water form in the North Pacific?" *J. Geophys. Res. Oceans* **108**, 3178

Ferreira, D. and co-authors (2017) Atlantic-Pacific asymmetry in deep water formation. To appear in *Annual Reviews in Earth Science*

Methven, J., 1997: Offline trajectories: Calculation and accuracy. U.K. Universities Global Atmospheric Modelling Programme Tech. Rep. 44, 18 pp.