Annual cycle and spatial structure of zonal momentum fluxes in the deep tropics

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Abstract

The longitudinal structure and annual cycle of mean meridional and eddy momentum fluxes in the upper troposphere of the deep tropics are studied using ERA-Interim reanalysis over a 40 year period. In a zonal mean sense, these two terms oppose each other and peak during the Indian summer monsoon. This zonal mean character arises from a rich longitudinal structure revealed by splitting the globe into three zones, namely, the Asia-West Pacific, central Pacific-West Atlantic, and African sectors. The mean meridional convergence term is cohesive across these three regions; it has a single peak in the boreal summer and always acts to decelerate the zonal flow. On the other hand, eddy fluxes are much more varied and go from being small and seasonally invariant in the African sector to having large seasonal peaks of acceleration (deceleration) in the Asia-West Pacific (central Pacific-West Atlantic) sector. This longitudinal variation in eddy momentum fluxes presents interesting insights into the overturning circulation in these zonally limited sectors, which previously remained hidden in the zonal mean.

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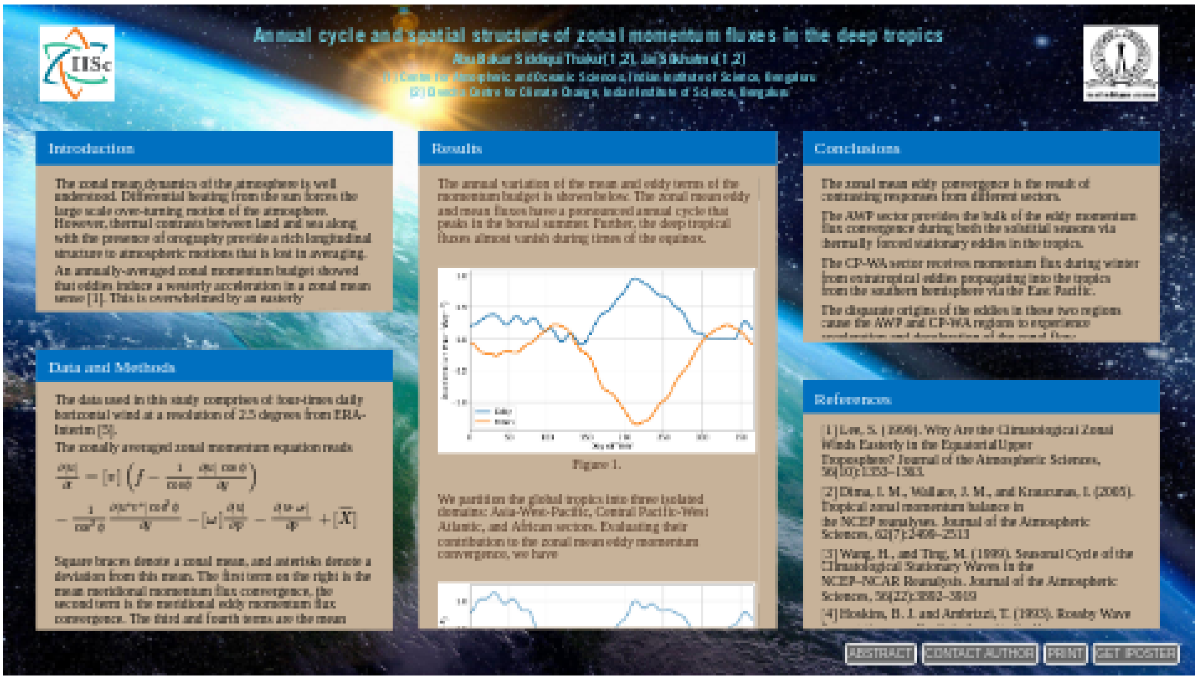

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INTRODUCTION

The zonal mean dynamics of the atmosphere is well understood. Differential heating from the sun forces the large scale over-turning motion of the atmosphere. However, thermal contrasts between land and sea along with the presence of orography provide a rich longitudinal structure to atmospheric motions that is lost in averaging.

An annually-averaged zonal momentum budget showed that eddies induce a westerly acceleration in a zonal mean sense [1]. This is overwhelmed by an easterly acceleration by the seasonally reversing Hadley Cell and causes the equatorial upper tropospheric flow to be easterly in nature. Further, the westerly acceleration in the equatorial upper troposphere was shown to be due to the convergence of eddy momentum flux by the thermally forced climatological Rossby gyres present throughout the year [2,3].

Given that the extratropical waves can reach the tropics [4], the most pertinent question to ask here is, what are the various motions that sum to give the zonal mean picture? We try to answer this question using a climatological zonal momentum budget of the upper troposphere.

DATA AND METHODS

The data used in this study comprises of four-times daily horizontal wind at a resolution of 2.5 degrees from ERA-Interim [5].

The zonally averaged zonal momentum equation reads

$$\frac{\partial[u]}{\partial t} = [v]\left(f - \frac{1}{\cos\phi}\frac{\partial[u]\cos\phi}{\partial y}\right) - \frac{1}{\cos^2\phi}\frac{\partial[u^*v^*]\cos^2\phi}{\partial y} - [\omega]\frac{\partial[u]}{\partial p} - \frac{\partial[u^*\omega^*]}{\partial p}$$
$$+ [\overline{X}]$$

Square braces denote a zonal mean, and asterisks denote a deviation from this mean. The first term on the right is the mean meridional momentum flux convergence, the second term is the meridional eddy momentum flux convergence. The third and fourth terms are the mean vertical advection and vertical eddy flux convergence. Consistent with previous studies, we find these to be small in comparison to the first two terms on the RHS. The last term is a residual and accounts for all sub-grid-scale processes.

Here, we focus on the climatological Day of Year variation of the first two terms with special attention to the eddy term evaluated for the tropical upper troposphere. Daily estimates are calculated for each term and then these are averaged over the respective days over all years on record.

RESULTS

The annual variation of the mean and eddy terms of the momentum budget is shown below. The zonal mean eddy and mean fluxes have a pronounced annual cycle that peaks in the boreal summer. Further, the deep tropical fluxes almost vanish during times of the equinox.

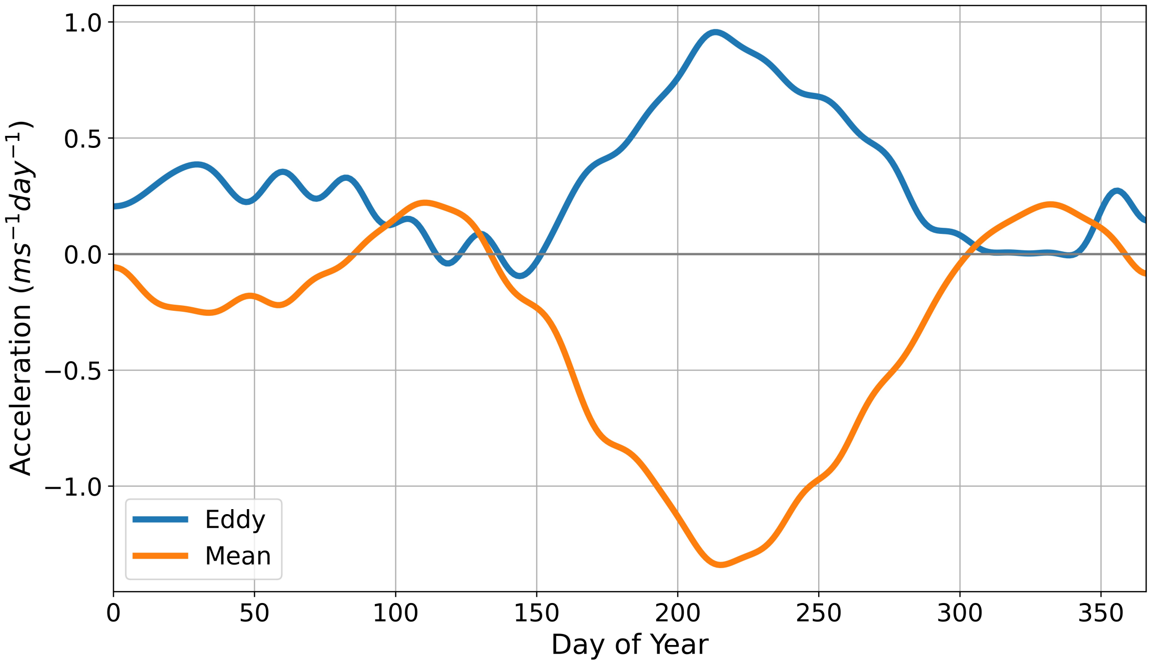

Figure 1.

We partition the global tropics into three isolated domains: Asia-West-Pacific, Central Pacific-West Atlantic, and African sectors. Evaluating their contribution to the zonal mean eddy momentum convergence, we have

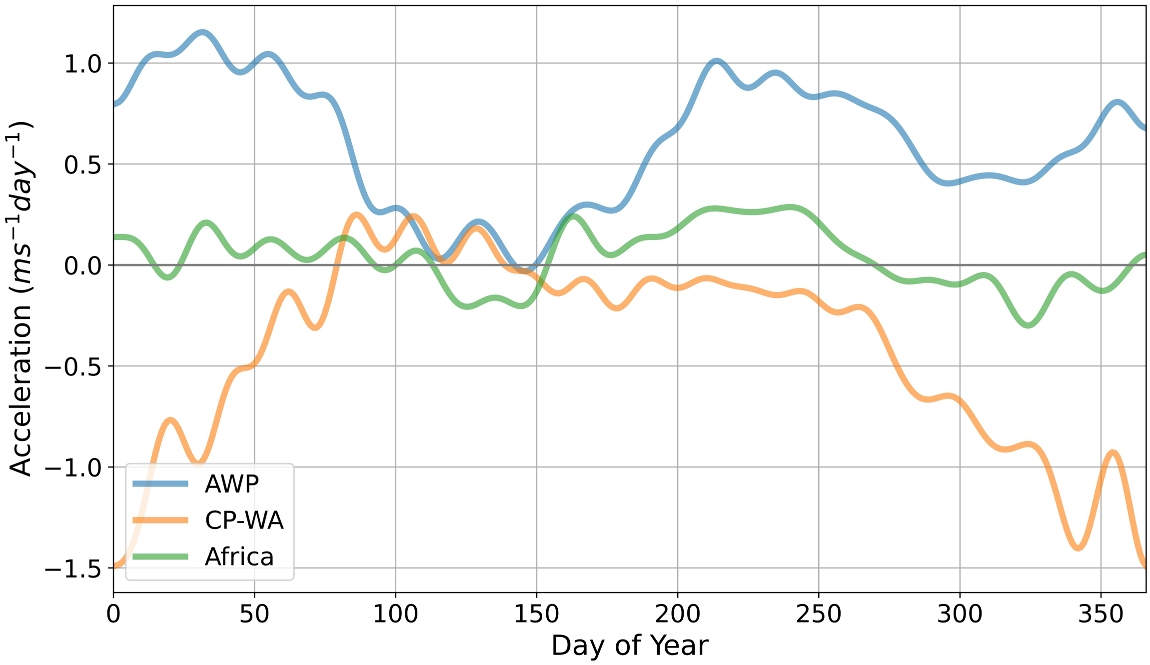

Figure 2

From the above figure, it is evident that the NH winter is the season of the stark contrast between sectors. Considering the winter-time spatial structure of eddy momentum flux convergence and the extra-tropical wave activity flux vectors [6],

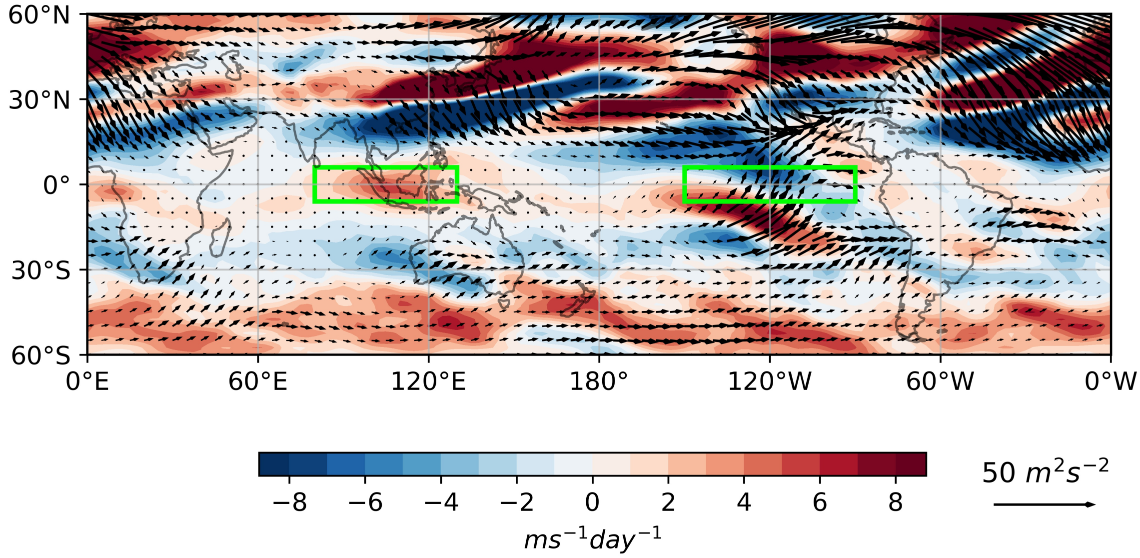

Figure 3

the compensation between the eddies of different origins (highlighted with green boxes), is clear.

When the eddy convergence is calculated globally, there is a cancellation between the positive contribution around 120E and the negative contribution from approximately 120W. In fact, the eddy momentum flux divergence due to the 120W box can be seen in the orange curve (CP-WA) of Figure 2. The positive eddy convergence in the 120E box is linked to the two off-equatorial anti-cyclonic Rossby gyres straddling the equator around the Maritime Continent, of which the Southern Hemispheric (SH) gyre is tied to the Australian Monsoon. The eddy momentum convergence features associated with the 120W box are related to the Pacific Ocean upper tropospheric troughs. These eddies can also be seen in the stationary wave patterns during the winter season [7].

CONCLUSIONS

The zonal mean eddy convergence is the result of contrasting responses from different sectors.

The AWP sector provides the bulk of the eddy momentum flux convergence during both the solstitial seasons via thermally forced stationary eddies in the tropics.

The CP-WA sector receives momentum flux during winter from extratropical eddies propagating into the tropics from the southern hemisphere via the East Pacific.

The disparate origins of the eddies in these two regions cause the AWP and CP-WA regions to experience acceleration and deceleration of the zonal flow, respectively.

The African sector shows relatively low levels of eddy flux throughout the year.

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ABSTRACT

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