Response to Reviewers comments

We thank the Editor and the two Reviewers for their comments and suggestions, which greatly helped us to improve our manuscript. Our point-by-point response to their comments is given below in blue colour font.

Answers to Reviewer-2's comments

We thank once again the Reviewer-2 for his/her comments. Our response to his/her comments is given below in blue colour font.

Reviwer-2's comments

In this study, the authors investigated the influence of extratropical eastward propagating waves on the tropics using a space-time spectral analysis for the period of December 2012 to February 2013. The topic is interesting, and such a study may contribute to improve our understanding of the origin of tropical waves. However, there are several flaws in the paper. In particular, the conclusion is based on the similarity of wavenumber-frequency spectrum between the extratropical and tropical regions. There is lack of dynamical explanation. Data of one winter were analyzed. It is unclear if the results are statistically significant. The analysis methodology was not described. The discussions were not well performed. Therefore, I don't recommend publication of this paper in its current form.

Specific comments:

1) It is unclear why the authors chose the winter of 2012/13? Why not using more years? There is no assessment of statistical significance of the wavenumber-frequency spectrum.

As suggested by the Reviewer, we have made spectral analysis for the months of December-February 2000-01 to 2014-15 (15 years) and separately for the major SSW years (2001-02, 2003-04, 2005-06, 2008-09, 2013-14). The presence of 18-day wave in both high and low latitudes can be clearly seen in the averaged spectrum for the SSW years (Fig.1 attached herewith).

Similar analysis is performed for OLR for the years (2000-2013). The 18-day wave is observed in OLR also (Fig. 2 attached herewith).

2) It is unclear what waves were detected in the extratropical and tropical regions. The tropical wavenumber-frequency spectrum analysis was done at 15N for OLR (Fig. 6). Then what kind of wave is it for wavenumber 5 at 18 days that propagates eastward? Is it Kelvin wave? What is the structure (horizontal and vertical) of the wave?

It does not appear to be a Kelvin wave, as the wave amplitudes are larger in meridional winds. The latitudinal variation of the wave in different parameters (u, v and T) suggests that it is an equatorial Rossby wave (Fig 3 attached herewith) , as the amplitude of the

wave in zonal wind maximizes over equator and the amplitudes of the wave in meridional wind and temperature maximize further away from the equator. If zonal wind speed is larger, synoptic Rossby waves can move eastward, but at a phase relative to the ground that is somewhat less than the mean zonal wind speed (Holton, J., R., An introduction to dynamic meteorology, Elsevier, Academic Press, 2004 (4^{TH} edition), Pages 161-162; Mohanakumar, K., 'Stratosphere-Troposphere Interactions', Springer, 1998; Pages 166-167).

3) It is unclear through what mechanism the extratropical waves excite or influence the tropical waves.

Mid-latitude Rossby wave propagates into the eastern tropical Pacific during northern winter are associated with the intrusion of high potential vorticity air into the low latitudes and they can modulate stability, cloudiness and vertical motion. The PV normally triggers convection ahead of its intrusion. The upper level wave activity and probably the convective heating associated with it may trigger the excitation of the equatorially trapped Rossby modes (Kiladis, 1998). The tropical atmosphere selectively responds to lateral forcing generating equatorial wave disturbances with wavenumbers and frequencies similar to those of the Rossby wave (Itoh and Ghil, 1988). The waves are then enhanced by the effect of condensational heating.

4) There is no description of methodology. How was the wavenumber-frequency spectrum calculated? What filter was used to extract the 15-20 day waves? There is also no reference. How were the amplitude and phase defined? Without a clear description, it is difficult to follow the discussion. For example, on page 5 lines 10-16, it is hard to understand the meridional propagation of waves from the phase change in latitude.

The wavenumber-frequency spectrum is obtained by subjecting the two dimensional data (longitude-time) at a particular latitude and height level into two-dimensional spectral analysis.

The time and longitude variation of meridional wind (v), for example, at any latitude can be expressed as

$\mathbf{v(\lambda, t) = \sum_{k}\sum_{\pm\omega} R_{s,\pm\omega} \cos(k\lambda \pm \omega t + \varphi_{k\pm\omega})}$**, where**

$R_{k,\pm\omega}$ is the amplitude, ω is frequency, k is zonal wavenumber, φ is phase.

+ sign: eastward propagating wave, - sign: westward propagating wave.

First, the longitude variation of v at each 't' is subjected to Fourier Transform in longitude

$$\mathbf{v(\lambda, t) = \sum_{k} C_k(t)\cos(k\lambda) + S_k(t)\cos(k\lambda)}$$

to obtain time variation of Fourier coefficients $C_k(t)$ and $S_k(t)$ for each zonal wavenumber 'k'.

These time variation of Fourier coefficients for each zonal wavenumber 'k' are subjected to Fourier transform in time to get Fourier coefficients corresponding to different Fourier frequencies. From these coefficients, the amplitudes (and hence power) and phases are calculated (Hayashi et al., 1971). For filtering, Butterworth filter is adopted. To see whether the peaks observed in the spectrum are significant or not, significance test is carried out against a null hypothesis, which is a non periodic and noisy time series (Emery and Thomson, 2001). The variance of the spectral peak can be compared to the background value determined by either white noise or a red noise fit to the spectrum or theoretically computed spectrum from autoregressive parameters. However, there is also a method in which a greatly smoothed version of the raw periodogram is used as the null continuum. The smoothing is done in such a way that there is no bulge in the spectrum at the frequency of interest so that it can be different from the variance of the raw spectrum (against null hypothesis). The significance of the spectral peak can be evaluated by comparing the ratio of the spectral peak power with the Chi-squared value with the corresponding number of degrees of freedom. The variance of the spectral peak should be greater than $\frac{(\nu-1)}{\chi^2_{1-\alpha/2,\nu}}$ s(f), where s(f) is the power of the smoothed spectrum corresponding to the frequency f and ν is the number of degrees of freedom. The χ^2 values are taken from chi-square table and α is 0.05 for indicating 95% confidence level of the spectral peaks. We found that the spectral power corresponding to 18-day wave is significant in all the cases presented.

The meridional propagation of the wave is clearly evident from the figure, as the phase of the wave in zonal and meridional winds at higher latitudes leads that at lower latitudes and there is a gradual progression.

Other comments:

1) Page 2, line 9: "dominant than" –> "larger than".
   It is changed as suggested.
2) Page 3, line 5: define the "MJO".
   MJO is Madden-Julian Oscillation. It is defined in the revised manuscript as suggested.

3) Page 6 line 2: this sentence was repeated (lines 26-27 of Page 5).

The sentence, which is repeated, is removed.

4) Page 6 lines 27-29: I don't see any eastward propagation.

The time-longitude cross section of zonal wind is presented. It shows the presence of eastward winds around 200°E. However, Hoskins and Yang (2000) showed that higher latitude forcing can project directly onto equatorial waves and give a significance tropical response in both westward and eastward tropical flow.

5) Page 7, lines 11-13: Eastward propagation is not clear or very limited in longitude.

Eastward propagation is clearly visible. However, eastward propagation with larger amplitudes is limited in longitudes.

6) Page 7, line 19: "shorter zonal wavenumbers" –> "smaller zonal wavenumbers".

Changed as suggested.

7) Page 8, line 1: was SSW defined?

SSW is sudden stratospheric warming. It is defined as suggested.

8) Page 8, lines 14-16: Unclear what "poleward tilt in phase" means. Why baroclinic in NH and barotropic in SH?

In the figure, it is clear that there is a northward shift in phase of the wave in northern hemisphere. In the southern hemisphere, there is no much variation of the phase with height.

As there is no abrupt change in phase of the wave between lower and higher heights, the extratropical wave (at 45°N) behaves like barotropic in both hemispheres. It is corrected in the revised manuscript. The equatorial wave is dominant only in the northern hemisphere (15°N) and for this also, there is no abrupt change in phase between lower and higher heights. It also behaves like a barotropic wave.