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Variability of Temperature Structure Around the Tropical Tropopause

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1. Introduction

Variability in the tropical tropopause temperature is primarily important to assess dryness in the lower stratosphere. Some numerical studies [e.g., *Highwood and Hoskins*, 1998; *Norton*, 2005] showed the Matsuno-Gill response in the tropical tropopause temperature. However, its spacial and temporal variability and the quantitative evaluation of its relationship with convective activities are not clear yet.

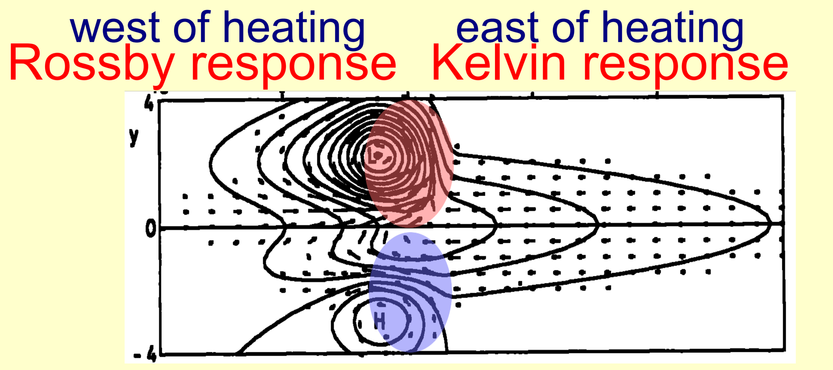


Fig. 1: Matsuno-Gill pattern with asymmetric heatings (adapted from *Gill* [1980]

2. Data

- ERA-40 Temperature @ 100hPa
- Outgoing Longwave Radiation (OLR) as a proxy of deep convection
- Southern Oscillation Index (SOI) to assess the ENSO effect

3. General Features

Low temperatures generally occur over the equator in the Eastern Hemisphere and extend north-west and south-west in the subtropics to form a horseshoe-shaped structure, especially during the northern and southern summers (Fig. 2).

Convective activities are present adjacent to monsoon regions during the northern and southern summers. During the northern summer, convective activities occur two monsoon areas with different variability [*Murakami and Matsumoto*, 1994].

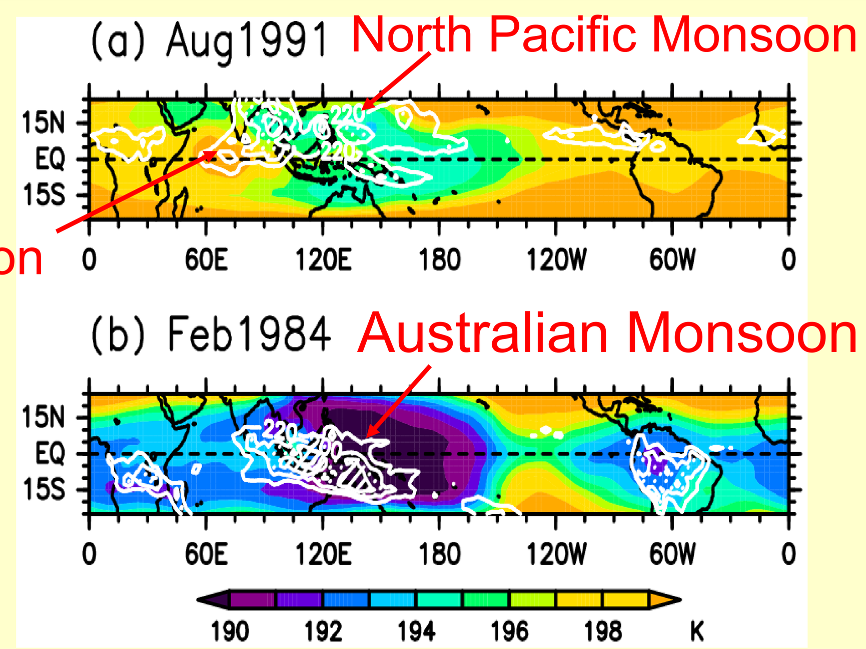


Fig. 2: Maps of temperatures at 100 hPa and OLR at (top) August 1991 and (bottom) February 1984.

4. Definition of Indices

Because the horseshoe-shaped structure resembles the Matsuno-Gill pattern, we define two preliminary indices as follows:

- HSI-R (Representative of the Rossby response)

$$\mathrm{HSI\text{-}R}(x,t)=\frac{T(10°N\sim15°N)+T(10°S\sim15°S)}{2}-\mathrm{Teq}$$

- HSI-K (Representative of the Kelvin response)

$$\mathrm{HSI\text{-}K}(x,t)=\mathrm{Teq}(x+10°,t)-\mathrm{Teq}(x-10°,t)$$

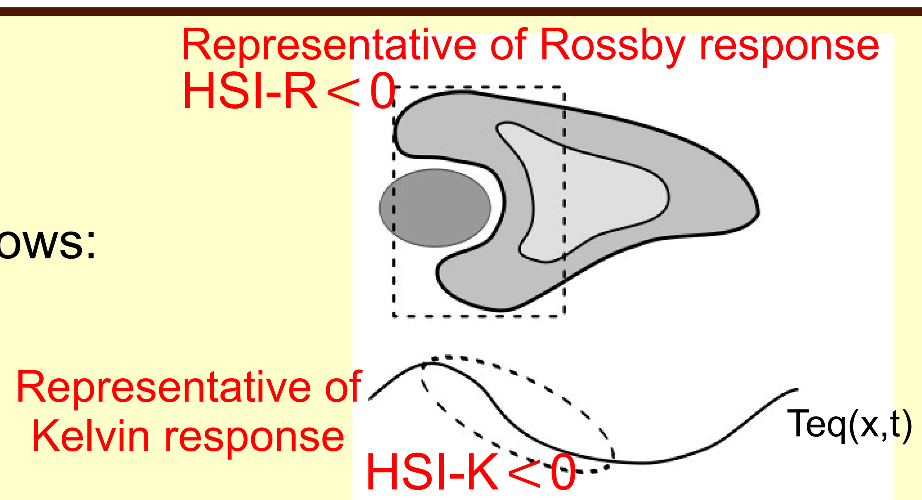


Fig. 3: A schematic diagram of the horseshoe-shaped structure

Fig. 4 reveals that negative values of HSI-R and HSI-K are present in the Eastern Hemisphere, especially during the northern and southern summer. As expected from the definition of the two indices, negative HSI-K peaks are located east of negative HSI-R peaks. This longitudinal phase lag is about 15° degrees.

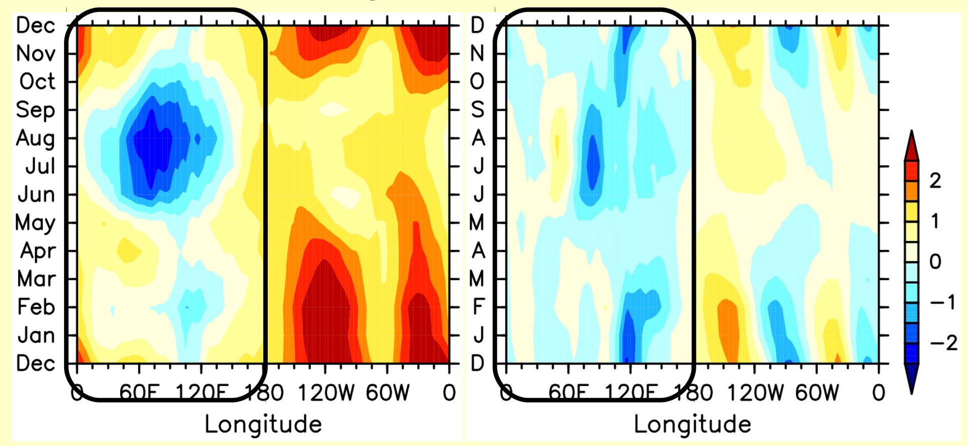


Fig. 4: Longitude-time sections of (left) HSI-R and (right) HSI-K averaged over 23 years.

5. Integrated Index

HSI-1 is integrated from a positive linear relation between HSI-R and HSI-K. This was derived by the first basis function of an empirical orthogonal function (EOF) analysis with HSI-R and HSI-K in the Eastern Hemisphere (Fig. 5).

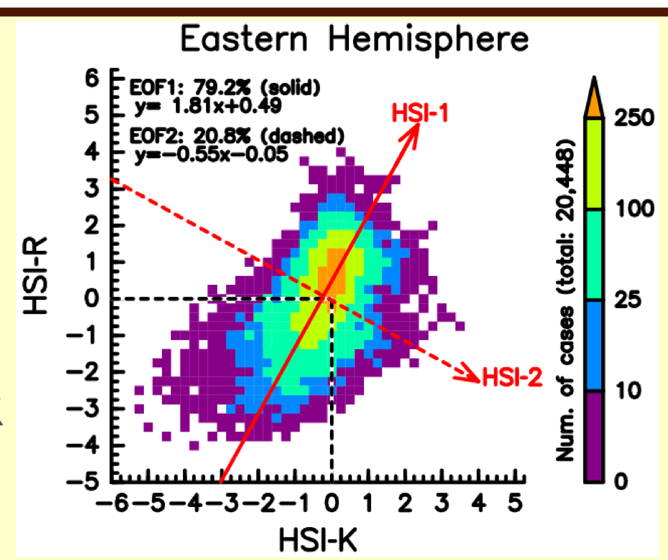


Fig. 5: Frequency of occurrence for HSI-K and HSI-R in the Eastern Hemisphere. Red solid line indicates the linear regression line of the first EOF mode.

6. Seasonal Variability adjacent to Monsoon Regions

From Fig.6, low OLR values occur adjacent to three monsoon regions: South Asian Monsoon (SAM) and North Pacific Monsoon (NPM) during the northern summer and Australian Monsoon (AUM) during the southern summer. Seasonal cycle in HSI-1 is significantly related to that in OLR values adjacent to these monsoon regions (Fig. 7).

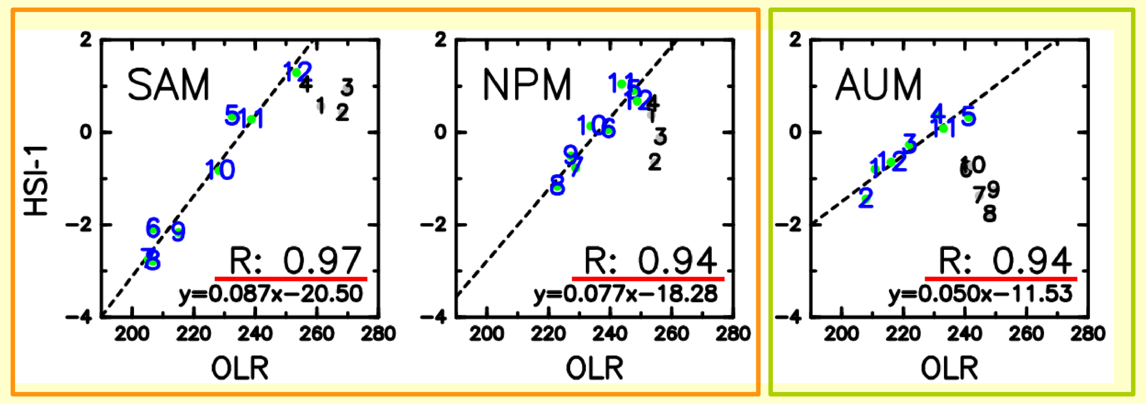


Fig. 7: Scatterplots of climatological OLR and HSI-1 values in the (left) SAM, (middle) NPM and (right) AUM domains.

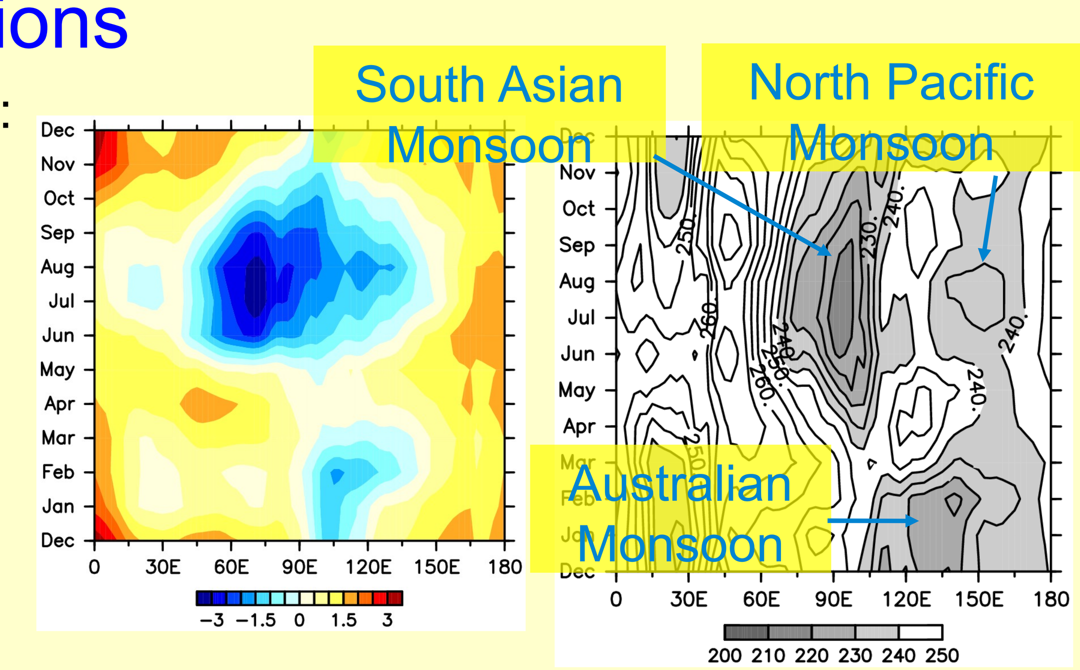


Fig. 6: Longitude-time sections of climatological (left) HSI-1 and (right) OLR.

7. Interannual Variability

7-1. Northern Summer

In the NPM domain, interannual variation in the HSI-1 values is related to that in the OLR values (Fig. 8), associated with the ENSO cycle with about a half-year time lag (not shown), consistent with *Kawamura et al.,* [1998].

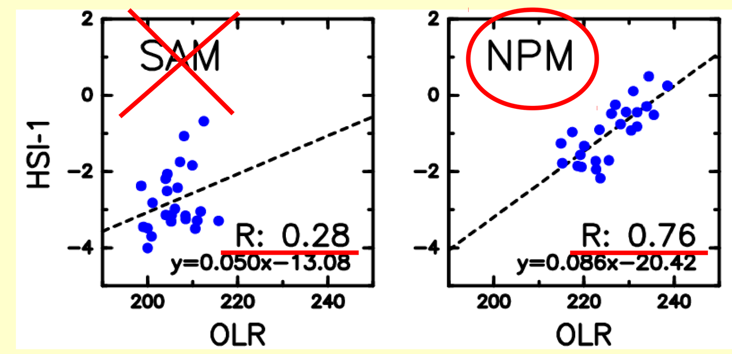


Fig. 8: Scatterplots of OLR and HSI-1 values averaged over July-August in the (left) SAM and (right) NPM areas.

In the SAM domain, interannual variation in the HSI-1 values is not related to that in the OLR values (Fig. 8). It is mainly controlled by isolated high temperatures, which are surrounded by the horseshoe-shaped temperature structure (Fig. 9). The HSI-1 values vary associated with the ENSO cycle, consistent with *Nishi et al.*'s [2010] previous study on the warm anomaly,

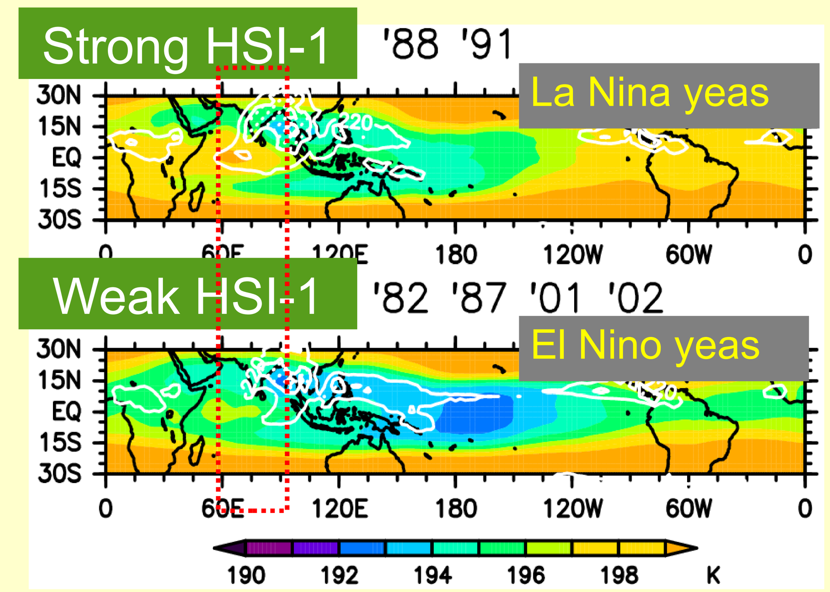
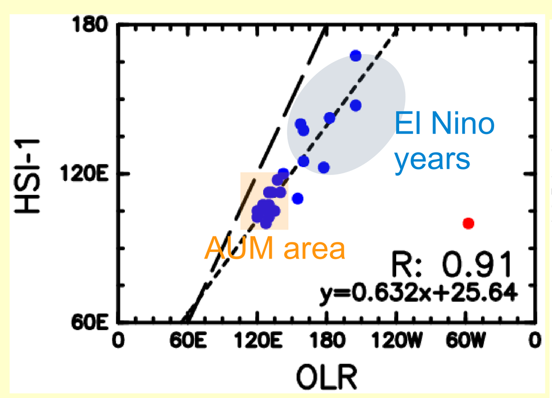
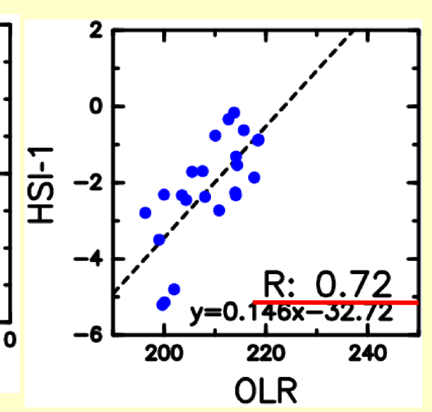


Fig. 9: Composite maps of temperature at 100 hPa and OLR for (top) the cases reflecting the strongly negative HSI-1 in the SAM area and (bottom) the cases relfecting nealy zero HSI-1.

7-2. Southern Summer

During the southern summer, the ENSO effect is expected to be maximum and involves migration of convective activities over the Pacific [e.g., *Gettelman et al.,* 2001]. Fig. 10 reveals that the longitudinal phase difference between HSI-1 and OLR is large as the minima shifts eastward. There is a positive relation between the OLR and HSI-1 minima (Fig. 11). From Fig. 12, the years when the HSI-1 minimum is nearly zero are in El Nino phase, and the horseshoe-shaped structure is present around the dateline.





(Left) Fig. 10: A scatterplot of longitude of OLR and HSI-1 minima in each year during January-February. **(Right) Fig. 11**: Same as Fig. 10, but for values of OLR and HSI-1 minima.

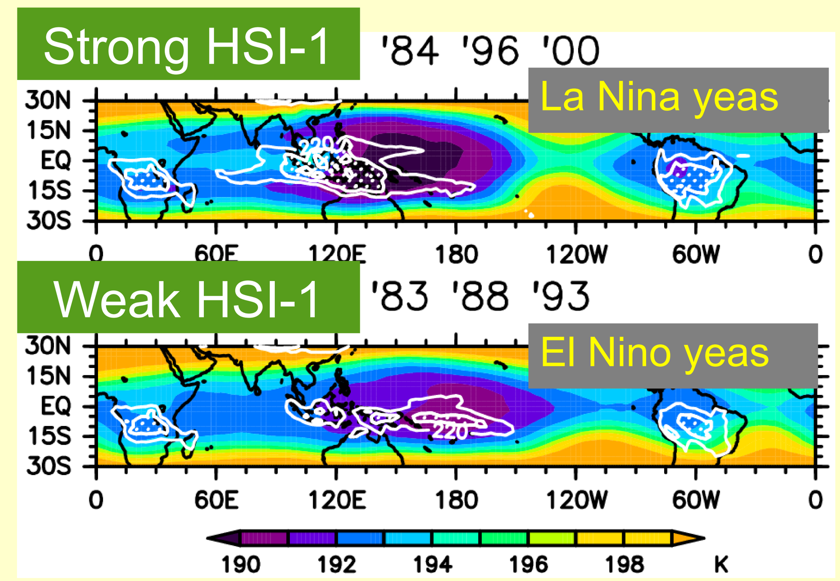


Fig.12: Same as Fig. 9, but for (top) the strong case and (bottom) the weak case in the moving frame during Jan-Feb.

8. Summary

We have established the index representing a horseshoe-shaped temperature structure in the tropical tropopause, which resembles the Matsuno-Gill pattern. Its seasonal variability is significantly related to that observed in convective activities adjacent to three monsoon regions: the SAM and NPM areas during the northern summer and the AUM area during the southern summer. ENSO-related variabilities are found in each region, especially it is dominant during the southern summer with shifting eastward in El Nino years.

Refs.; Gill, A. E. [1980], *Q. J. R. Meteorol. Soc.*; Gettelman, et al, [2001], *J. Climate.*; Highwood and Hoskins [1998], *Q. J. R. Meteorol. Soc.*; Kawamura,R.et al. [2001], *J. Meteor. Soc. Jpn.*; Murakami and Matsumoto [1994], *J. Meteor. Soc. Jpn.*; Nishi,N. et al. [2010]. *J. Geophys. Res.*; Norton,W. A. [2006], *J. Atmos. Sci.*