1. Methods

Two approaches to adjusting CPT trends:

- **Nearby Level** approach: Add together the temperature trend at a fixed level (100 hPa or 70 hPa) from an adjusted data set and the trend in the difference between temperatures at the CPT and the fixed level in the unadjusted data set.

- **Diurnal Difference** approach: Subtract trend in difference between midday and midnight observation (temperature, height or pressure) from midday trend to remove solar heating bias.

1. **Background**

- The cold temperatures at the tropical tropopause, a transition layer between the troposphere and stratosphere, restrict transport of radiatively and chemically active water vapor to the stratosphere.

- Cold-point tropopause (CPT) is defined as the point of minimum temperature in a vertical profile up to stratosphere.

2. **Conceptual Model of Tropopause**

- Tropospheric warming and stratospheric cooling have competing effects on tropopause temperature.

- In contrast, tropospheric warming and stratospheric cooling both drive an increase in tropopause height.

3. **Tropical Average Monthly Anomaly Time Series**

- Long-term cooling around tropopause, increasing with altitude (from 100 hPa to CPT to 70 hPa).

- CPT height and pressure anti-correlated, height exhibits positive trend, pressure exhibits negative trend.

- Adjusted data sets exhibit less cooling than the unadjusted IGRA data set at 100 hPa and 70 hPa.

- Temperature drops, height increases, and pressure drops at end of 2000; these were described in previous studies and attributed to strengthening stratospheric upwelling. However, these do not seem unusual in the context of the overall period, at least not when averaged over the entire tropics.

4. **Constraining CPT Trends: Nearby Level Approach**

- Wide range of estimates for adjusted CPT temperature trend.

- All are less negative than unadjusted trend. Some confidence intervals even encompass zero.

5. **Sensitivity Tests**

- Multi-decadal trends generally not sensitive to the years considered between 1970 and 2010.

- RAOB CORE-based CPT trends exhibit warming up to 2001 (but not significant); other data sets do not produce positive trends (not shown).

- Estimated CPT temperature trends still seem inconsistent with apparent positive trend in stratospheric water vapor up to 2000, as in previous studies [Fraedrich and Haynes, 2005; Zhou et al., 2001].

- Trends sensitive to inclusion of outlier station Thiruvananthapuram (Trivandrum) in India.

- Inclusion of this and other problematic stations in previous studies (e.g. Zhou et al., 2001) could have contributed to large cooling trends.

6. **Constraining CPT Trends: Diurnal Difference Approach**

- Regions surrounding the 90° and 180° meridians exhibit largest trends in 12Z-00Z temperature in the unadjusted data set. Largest solar heating effect where 00Z or 12Z corresponds to local midday.

- Similar longitudinal pattern for height. Geopotential height is calculated from temperature. Pressure unaffected by diurnal effects.

- Adjusted CPT temperature trend averaged across longitudes is \(-0.75 \pm 0.11\) K/decade; cf. unadjusted trend of \(-0.59 \pm 0.12\) K/decade.

- Adjusted height trend is \(109 \pm 18\) m/decade, 10% more than unadjusted trend of \(99 \pm 17\) m/decade.

7. **Conclusions**

- Recent tropical CPT trends are less certain than implied previously, with temperature possibly not decreasing significantly and height increasing more than previously thought.

- Wide range of CPT temperature trends encompassing zero is consistent with prediction of conceptual model of tropopause. Tropospheric warming and stratospheric cooling have competing effects.

- Increase in CPT height consistent with conceptual model. Tropospheric warming and stratospheric cooling act in same direction.

- Smaller or non-significant temperature trend is consistent with CCM predictions.

- Possible causes of inconsistency between temperature and water vapor trends before 2000 include changes in the location of water vapor transport changes, in small-scale processes, and remaining biases in adjusted temperature data.

**Acknowledgments**

James Wang is supported by NOAA ARL through a National Research Council Research Associateship. We thank Yehui (Ally) Zhang for sharing computer code, Elizabeth Jung for helping carry out the initial phase of the project, and Leopold Haimberger for providing RICH data.