The Annual Temperature Cycle of the Tropical Tropopause :A Simple Model Study

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Abstract

A simple radiative-convective model is used to simulate the annual temperature cycle near the tropical tropopause and lower stratosphere (TTL region). Seasonally varying Residual vertical velocity is imposed according to dynamical and thermodynamic constraints and ozone profiles are derived from 7 years (1998-2004) of southern hemisphere additional ozonesonde (SHADOZ) data. Convection is treated only by eliminating lapse rates greater than 6.5 K/km. An upwelling rate proportional to the extratropical wave driving is sufficient to explain the annual cycles of TTL temperature above 80 hPa and of tropopause pressure, each maximizing in northern summer and minimizing in northern winter. However, temperatures below 80 hPa lag those predicted, indicating either a delay in upwelling or the influence of tropospheric convection. The annual cycle of ozone in the TTL plays an important role in modulating that of temperature: without ozone variations, the simulated temperature amplitude at 70 hPa falls from ~8K to 5K, and the maximum temperature occurs in July, one month earlier than observed. When the seasonal cycle of ozone is included in the calculation, the amplitude and phase of the temperature cycle come into close agreement with observations.

1.Introduction

• The Transformed Eulerian Mean (TEM) thermodynamic equation

$$\frac{\partial\bar{\theta}}{\partial t}+\frac{\bar{v}^*}{a}\frac{\partial\bar{\theta}}{\partial\phi}+\bar{w}^*\frac{\partial\bar{\theta}}{\partial z}=\bar{Q}-\frac{1}{\rho_0}\frac{\partial}{\partial z}\left(\rho_0\frac{\overline{v'\theta'}\theta_\phi}{a\bar{\theta}_z}+\overline{w'\theta'}\right)$$

$$\frac{\partial\bar{\theta}}{\partial t}\approx\bar{Q}-\bar{w}^*\frac{\partial\bar{\theta}}{\partial z}$$

The seasonal cycle can be considered as the balance between the adiabatic cooling (upwelling) and diabatic radiative heating (Rosenlof, 1995, Kerr-Munslow and Norton 2006)

• The upwelling of the tropical tropopause and stratosphere is controlled by Brewer-Dobson circulation (Yuleava et al., 1994, Reid and Gage, 1996, Randel et al., 2002).

• The ozone and water vapor distributions are closely connected with the thermal structure of the TTL.

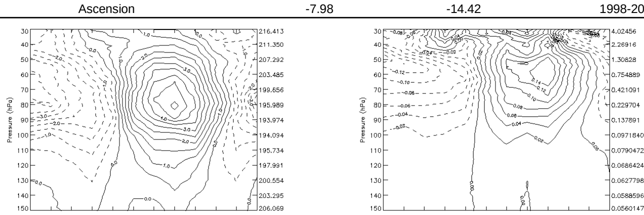
2. Data

• The Southern Hemisphere Additional Ozonesondes (SHADOZ) project, which provided over 1000 ozone and temperature profiles during the period 1998-2004 (Thompson et al. 2003).

• Only 10 stations within 20 S and 20 N that began collecting data by 1999 are included

Table 1. SHADOZ Stations and Locations

SHADOZ Stations	Latitude	Longitude	Year
Suva, fiji	-18.13	170.40	1998-2004
Watukosek, Java	-7.57	112.65	1998-2004
Kuala Lumpur, Malaysia	2.73	101.7	1998-2004
Malindi, Kenya	-2.99	40.19	1999-2004
Nairobi, Kenya	-1.27	36.80	1998-2004
Natal, Brazil	-5.42	-35.38	1998-2004
Paramaribo, Suriname	5.81	-55.21	1999-2004
San Cristobal	-0.92	-89.60	1998-2004
Samoa	-14.23	-170.56	1998-2004
Ascension	-7.98	-14.42	1998-2004



(a) (b)

Fig 1. Annual Cycle of SHADOZ (Annual average of each pressure level is removed in contours, and showed at the right side axis.) (a) Temperature. Contour interval is 0.5K (b) Ozone. Contour interval is 0.02ppmv. Solid lines of both figure indicate positive and dash is negative.

• We used NCEP/NCAR reanalysis data from 1998 to 2004 for eddy heat flux as a proxy for EP flux.

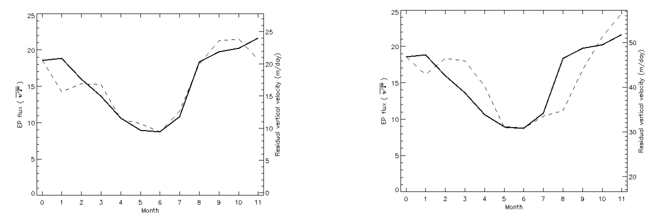
3. Model

• We used the Column Radiation Model (CRM), which is a stand-alone version used in version 3 of the National Center for Atmospheric Research (NCAR) Community Climate Model (CCM3) (http://www.cgd.ucar.edu/cms/ccm3/).

• Since the TTL and lower stratosphere are of primary interest, the layers have constant pressure spacing of 2 hPa from 130 hPa to 30 hPa, and outside this they have 5 hPa (140 – 130 hPa, 25 – 10hPa) 10 hPa (160 – 140 hPa), 20 hPa (200 – 160 hPa), and 100 hPa (surface to 200 hPa).

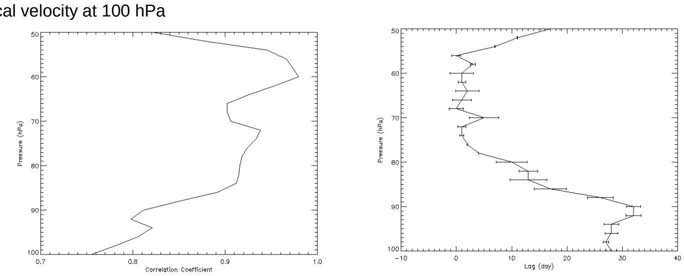
• Carbon dioxide is assumed to be well mixed and taken by single mixing ratio of 355 ppmv.

4. EP flux vs. Residual vertical velocity



(a) (b)

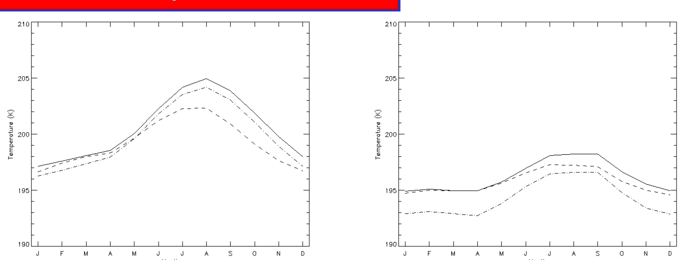
Figure 2. (a) Time series of monthly averaged eddy heat flux at 100 hPa (Km/s) (40-70 latitude) and the Residual vertical velocity (dashed line) at 70 hPa (b) The same as (a) except the residual vertical velocity at 100 hPa



(a) (b)

Figure 3. The correlation coefficient (a) and lag correlation (b) between the residual vertical velocity calculated by thermodynamic equation and eddy heat flux . The 1-sigma error bars were obtained by bootstrap resampling of the available stations and years.

5. The annual temperature simulation



(a) (b)

Figure 4. Annual temperature cycle calculated with annual ozone change (solid line) and with fixed (January) ozone (dash), and observation (dash-dot). (a) 70 hPa (b) 100 hPa.

6. Summary

The $\overline{w}*$ variation compares very favorably with dynamical calculations of midlatitude wave driving, indicating that the annual cycle of lower-stratospheric temperature (above 80 hPa) is fully explained by this forcing to within observational uncertainties. This does not appear to be the case below 80 hPa, where ascent is stronger than expected throughout the year and lags the forcing by almost one month. These probably include cooling due to deep convective overshooting and/or local ascent possibly associated with wave-mean flow interactions driven by asymmetries in tropospheric heating.

It is the annual cycle of ozone in the TTL that produces the additional one-month time lag, as well as a 3-4 K increase in the seasonal temperature range in the lower stratosphere.

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