Recent Widening of the Tropical Belt

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Recent Widening of the Tropical Belt

- How do we define tropical belt width?
- What is the observational evidence for expansion?
- Can models reproduce observations?
- What is expected in the future?
- What are unresolved questions?
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Popular Concepts of Tropics

Sources: NOAA, National Geographic

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Cartographic / Astronomic Tropical Belt
Meteorological Tropical Belt(s)

JJA zonal winds

DJF streamfunction

Hadley cell
Meteorological Tropical Belt(s)

Seidel et al. (2008)
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Zonal Mean Meridional Mass Streamfunction in Reanalyses

Fig. 1. Time evolution of zonal mean meridional mass streamfunction (MMS) at 500 hPa in NH for September-November (SON) from three reanalyses. The unit of MMS is $1.0 \times 10^{10}$ kg s$^{-1}$ and the color interval is $2.0 \times 10^{10}$ kg s$^{-1}$.

Hu and Fu (2007)
Zonal-Mean Meridional Mass Streamfunction in Reanalyses

Total widening 1979-2005

ERA40  2.6
NCEP/NCAR  2.7
NCEP/DOE  3.1
Summer and fall dominate

Hu and Fu (2007)
Jet Stream in ERA40

Archer and Caldeira (2008)
Tropopause Heights in NCEP/NCAR Reanalysis

Days/Yr with Height > 15 km

Seidel and Randel (2007)
Tropopause Heights in Reanalyses

Seidel and Randel (2007)
Dependence of trends (lat/10 yr) on tropopause thresholds and reanalysis dataset
Outgoing Longwave Radiation

Most poleward latitude with zonal mean OLR=250Wm$^{-2}$

Hu and Fu (2007)
Seasonal and Zonal Mean Time Series
Outgoing Longwave Radiation

HIRS Pathfinder

Hu and Fu (2007)
Seasonal and Zonal Mean OLR Time Series

Total widening 1980-2003

← HIRS Pathfinder 4.5
GEWEX RFA 2.3
ISCCP 4.0
Little seasonal variation

Hu and Fu (2007)
N. Hemisphere Total Ozone

TOMS total ozone March 11th, 1990

Tropical Area Anomalies

1979-2003 NH tropical expansion ~ 2.7

Hudson et al. (2006)
Stratospheric Residual Circulation

Transformed Eulerian Mean Residual Circulation invoked to explain stratospheric H$_2$O and CH$_4$ trends

Rosenlof (2002)
Summary of Observed Trends

<table>
<thead>
<tr>
<th>Study</th>
<th>Indicator</th>
<th>Data</th>
<th>Widening</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rosenlof [13]</td>
<td>Tropical upwelling (60 hPa)</td>
<td>Analyses</td>
<td>3.0</td>
</tr>
<tr>
<td>Reichler and Held [14]</td>
<td>Tropopause height</td>
<td>Radiosonde</td>
<td>0.4</td>
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<tr>
<td></td>
<td>Tropopause height</td>
<td>Reanalyses</td>
<td>0.7</td>
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<tr>
<td>Fu et al. [15]</td>
<td>Tropospheric temperatures</td>
<td>MSU</td>
<td>0.7</td>
</tr>
<tr>
<td>Hudson et al. [16]</td>
<td>Total ozone</td>
<td>TOMS</td>
<td>1.0 (NH only)</td>
</tr>
<tr>
<td>Seidel and Randel [17]</td>
<td>Tropopause height</td>
<td>Radiosonde, reanalyses</td>
<td>1.8–3.1</td>
</tr>
<tr>
<td>Hu and Fu [59]</td>
<td>Outgoing longwave radiation</td>
<td>Various satellite sensors</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>Mean meridional circulation</td>
<td>Reanalyses</td>
<td>1.0</td>
</tr>
<tr>
<td>Archer and Caldeira [92]</td>
<td>Jet stream separation</td>
<td>Reanalyses</td>
<td>0.3</td>
</tr>
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<td>Seidel et al. [23]</td>
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Natural forcings (SST and sea ice) alone do not explain widening.

Lu, Deser, Reichler (2009)
GCM Simulated Trends

OLR-based width       streamfunction-based width

PIC = pre-industrial control ~ natural variability
AMIP2 and 20C-A1B = forced 20th century forcings
B1, A1B, A2 = future
ALL smaller than observed 20th century trends

Johanson and Fu (2009)
Role of Antarctic Ozone Hole

Ozone recovery reverses some trends in IPCC AR4 GCM runs

Son et al. (2009)
Multiple Forcings, Multiple Models, Multiple Measures of Tropical Width

• Lamarque and Solomon (2010)
  – Coupled chemistry climate model forced by sst, ghg, halocarbons shows
  – Different forcings cause changes in different tropical width metrics (ozone, tropopause, winds)

• Lorenz and DeWeaver (2007)
  – GCM IPCC runs w/CO$_2$ increase and simple runs with raised tropopause
  – Poleward shift of jets associated with increase in tropopause height
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21st Century Predicted Widening

Ensemble mean ~2 latitude

Lu et al. (2007)

[Diagram showing modeled latitude changes and model names: bccr_bcm2_0, cccma_cgcm3_1, cnrm_cm3, csiro_mk3_0, gfdl_cm2_0, gfdl_cm2_1, giss_model_e_r, inmcm3_0, ipsl_cm4, miroc3_2_medres, mpi_echam5, mri_cgcm2_3_2a, ncar_ccsm3_0, ukmo_hadcm3, ukmo_hadgem1]

Dry Zone

Southern Edge

Northern Edge
Predicted Hydrological Response

Lu et al. (2007)

P minus E (mm/day) change from 2001-2020 to 2081-2100 in ensemble of IPCC AR4 runs; A2 emissions scenario
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Outstanding Questions

• Observed widening
  – How robust are estimated widening rates?
  – What is seasonal, regional structure of changes?
  – Have trends continued since published studies?

• Causes of widening
  – Can forcings (and natural variability) be sorted out (with formal detection and attribution)?
  – Are changes related to changes in climate modes of variability?

• Implications of widening
  – How are UTLS changes connected with surface and stratospheric climate?
  – What are likely future changes?
Take-home messages

- Many ways to measure tropical width
- Observational evidence exists for expansion since 1979, but not consistent
- Variety of models, with variety of forcings, do not fully reproduce observed changes
- Future evolution uncertain, but ozone recovery may reverse some changes
- Many unresolved questions remain
EXTRAS
Tropopause in Subtropics More Frequently Tropical

Seidel and Randel (2007)
NH Total Ozone

TOMS total ozone March 11th, 1990

Monthly mean relative areas
- Tropical
- Mid-latitude
- Sub-arctic
- Polar

1979-2003 NH tropical expansion ~ 2.7

Hudson et al. (2006)
Comparison of Observations

Seidel et al. (2008)

Width of the Tropical Belt

Degrees of Latitude

Outgoing Longwave Radiation (Hu and Fu)
Hadley Circulation (Hu and Fu)
Jet stream separation (Reichler)
Tropopause (Seidel and Randel)
Ozone (NH only, Hudson et al.)

Seager et al 2003

Fig. 14. (a) The anomaly in meridional wavenumber (El Niño minus the climatology, units of yr$^{-1}$, colors), and the anomalous EP fluxes (arrows). (b) The anomalous mean vertical pressure velocity (Pa s$^{-1}$, black contours, negative values dashed, zero line thick) and the corresponding temperature anomalies (°C, colors; see text for details).
FIG. 5. Widening of the Hadley cell from 1979 to 1999 [°(lat) (21 yr)$^{-1}$] from $\psi_{500}$ and OLR in observations and (a) GCM simulations of 20C and (b) AMIP2. The range of observed widening from individual datasets is given by the crossbars, which are centered at the multiset dataset mean widening. Also shown is the multimodel ensemble mean widening (large circles), ensemble mean widening from each individual model (medium circles), and widening from each model ensemble member (small circles). Only models providing output for both $\psi_{500}$ and OLR are included here.
Figure 2. Trend relationship between the location of westerly jet and the poleward boundary of the Hadley cell in the SH summer. Color code is identical to one in Figure 1, and negative values denote the poleward shift of westerly jet and poleward expansion of the Hadley cell.