Tropical broadening in ERA-Interim

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1. Abstract

A climatology of a new flow-dependent tropopause definition has been produced using ERA-Interim. Increasing trends in tropopause height are identified over most of the globe in all seasons. These trends are particularly large in the subtropics, indicating a broadening of the tropical region. New metrics have been developed to quantify this broadening.

2. Tropopause definition

The tropopause is defined as a flow-dependent combination of the dynamic (PV=2PVU) and standard thermal tropopauses, where the height of the tropopause, h_{trop}, is given by:

$$h_{trop} = \begin{cases} h_{dynamic} & \text{where } \theta < 350 \text{ K} \\ \left(\frac{\theta_{PV2}-350}{20}\right) h_{min} + \left(1 - \frac{\theta_{PV2}-350}{20}\right) h_{dynamic} & \text{where } 350 \leq \theta \leq 370 \text{ K} \\ h_{min} & \text{where } \theta > 370 \text{ K} \end{cases}$$

where θ_{PV2} is the potential temperature on the dynamic tropopause, $h_{dynamic}$ is the height of the dynamic tropopause, and h_{min} is the lower of the height of the dynamic and thermal tropopauses.

3. Tropopause trends

Trends in the tropopause were evaluated for ERA-Interim (1989-2007) using the least squares method, and assuming linear trends.
Trends are calculated for the annual-mean tropopause, and for the December to February (DJF) and June to August (JJA) mean.

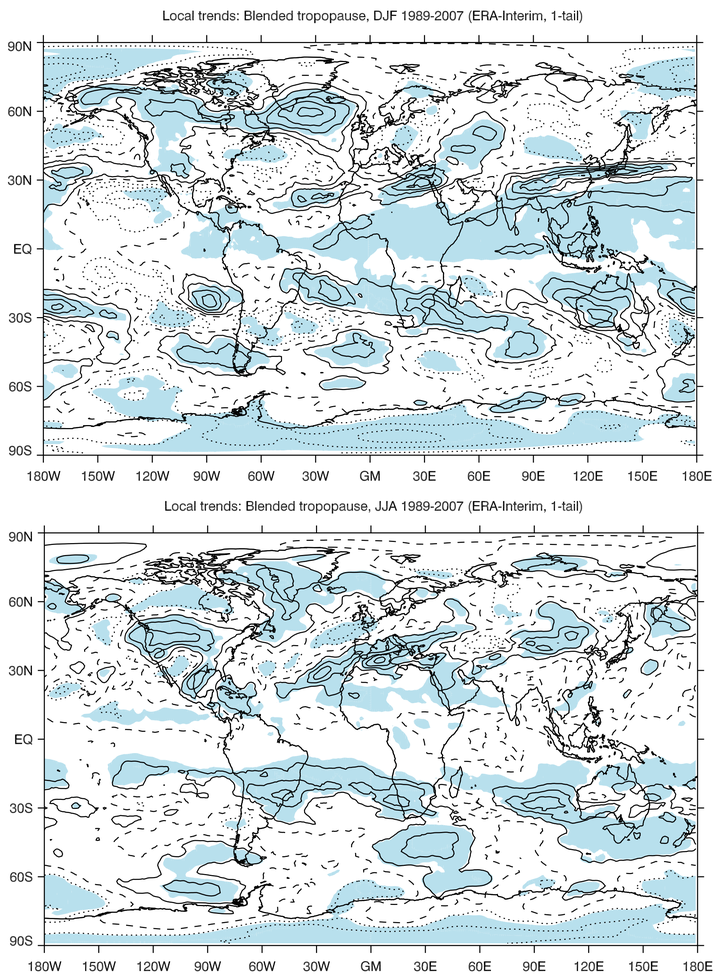

Figure 1: *Trends in tropopause height for DJF (top) and JJA (bottom) 1989-2007. Solid contours show positive trends, the zero line is dashed, and negative contours are dotted. The contour interval is 100 m decade^{-1}. Shading indicates where trends are significant at or above the 5% level.*

- Tropopause height is mostly increasing outside the Antarctic
- Large positive trends in the subtropics indicate a broadening of the tropical region
- Subtropical trends are larger in the eastern hemisphere, particularly in DJF

4. Tropical broadening

- Zonal average expansion is larger in the Southern Hemisphere (SH) than the Northern Hemisphere (NH)
- Expansion into the SH is less seasonally dependent than into the NH

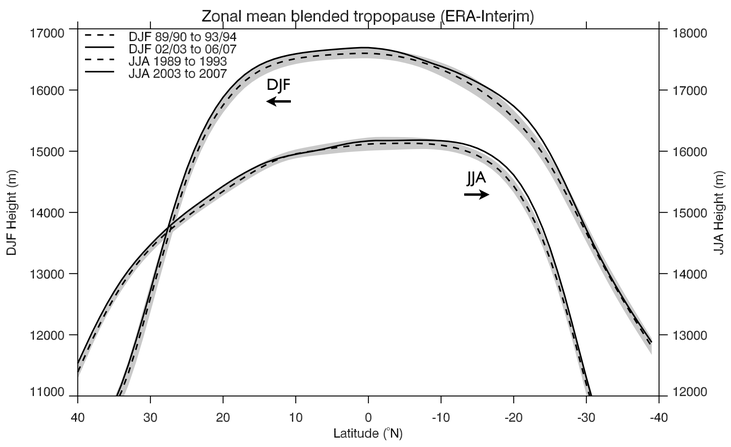

Figure 2: *Zonal mean tropopause height. The average for the first (dashed) and last 5 years (solid) of the 1989-2007 climatology are shown for JJA and DJF. Shading shows the average of the first five years ± the de-trended standard deviation for the range of five year periods in the whole climatology.*

5. Metrics

Three metrics have been used to quantify the rate of tropical broadening in ERA-Interim: a critical height, based on Seidel and Randel (2007), and two new metrics based on tropopause height and zonal wind trends.

Critical height

Tropical tropopause defined to have a seasonal-mean zonal-mean height of ≥15km

- Rate of expansion is 0.9° decade^{-1} in DJF and JJA in ERA-Interim
- Greater expansion into the SH

Height trends

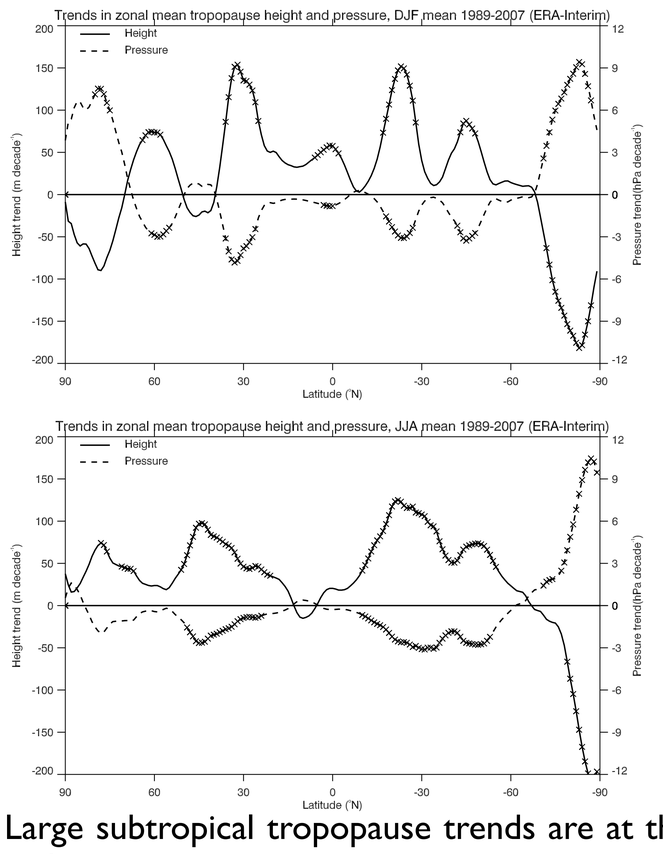

Figure 3: *Trends in seasonal-mean zonal-mean tropopause height and pressure for DJF (top) and JJA (bottom) 1989-2007. Crosses indicate significance at or above the 5% level.*

Large subtropical tropopause trends are at the same latitudes as large tropopause gradients

Trends divided by gradient gives an estimate of the rate of broadening

- Rate of expansion is 1.3° decade^{-1} in DJF, considering trends over 100 m decade^{-1}
- Rate of expansion is 1.1° decade^{-1} in JJA, considering trends over 90 m decade^{-1}
- Greater expansion into summer hemisphere

Zonal wind trends

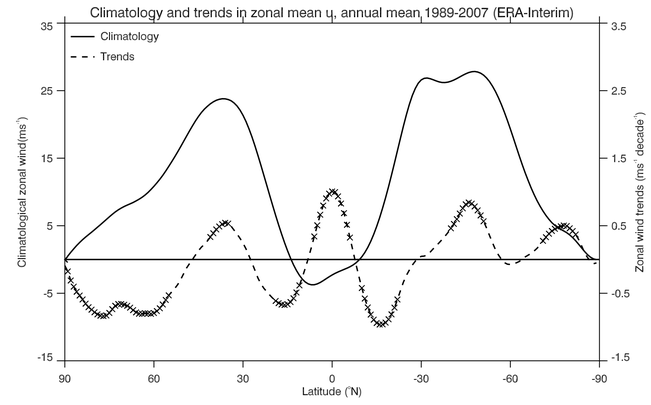

Figure 4: *Trends in annual-mean zonal-mean tropopause-level zonal wind (1989-2007). Crosses indicate significance at or above the 5% level. The climatology of the wind is shown for reference.*

For each hemisphere:
Find latitude where climatology is zero: A
Find latitude of largest negative trends: B
Find time taken for trends at B to reduce climatology at B to zero: $(u/trend)_B$

$$Rate = \frac{latB - latA}{(u/trend)_B}$$

- Rate of expansion is 1.0° decade^{-1} in DJF
- Rate of expansion is 2.2° decade^{-1} in JJA
- Greater expansion into SH

6. Summary

- A new flow-dependent tropopause defintion has been used to produce a tropopause climatology for ERA-Interim (1989-2007)
- Three metrics have been used to quantify the rate of tropical broadening in this period

	DJF	JJA
Critical height	0.9° decade^{-1}	0.9° decade^{-1}
Height trends	1.3° decade^{-1}	1.1° decade^{-1}
Zonal wind trends	1.0° decade^{-1}	2.2° decade^{-1}

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References

Seidel, D. J., and W. J. Randel (2007): Recent widening of the tropical belt: Evidence from tropopause observations, *J. Geophys. Res.*, **112**, D20113, doi:10.1029/2007JD008861.