Australian Government
Bureau of Meteorology

The Centre for Australian Weather and Climate Research

A partnership between CSIRO and the Bureau of Meteorology

CSIRO

A Critical Comparison of Tropical Expansion Metrics

Chris Lucas, Hanh Nguyen, Bertrand Timbal

The Centre for Australian Weather and Climate Research – A partnership between the Bureau of Meteorology and CSIRO, Melbourne, Australia

c.lucas@bom.gov.au

Introduction

A robust tropical expansion has been observed across multiple datasets and with various metrics. Measured rates of expansion vary from 0.1-2 degrees latitude per decade (deg decade^{-1}) depending on the methodology (Figure 1).

Estimates from each metric have particular, sometimes contradictory, characteristics; for example, satellite-based studies have largest rates of expansion, with more in Northern Hemisphere (NH),while tropopause-based metrics show more expansion in the Southern Hemisphere (SH).

Questions

Are the various metrics that have been used all measuring the same thing? What is the effect of the myriad data issues known to have an effect? How large is the effect of inconsistencies in the widely used reanalysis products? Can this be used to lower the uncertainty in estimates of tropical expansion?

Here, we address these questions through close examination of multiple time series of the tropical edge (the basis of tropical expansion estimates) from different sources, including satellite outgoing longwave radiation (OLR), reanalysis-based Hadley cell measurements, radiosonde-based tropopause observations and data from the Global Precipitation Climatology Project (GPCP).

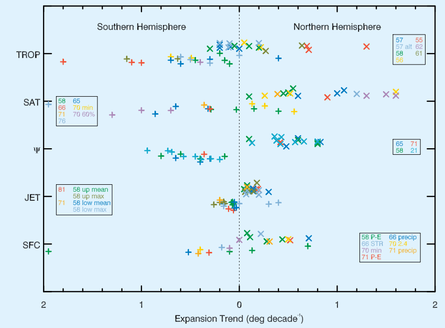

Figure 1. Summary of result of observational tropical expansion studies, broken down by categories. Pluses (+) represent SH values, crosses (x) NH values of tropical expansion trend. Symbols in the corresponding hemisphere indicates expansion, symbols in the 'opposite' hemisphere indicate contraction. Within a particular methodology, the vertical position of each symbol is randomized to improve clarity of individual symbols; no other meaning is implied.

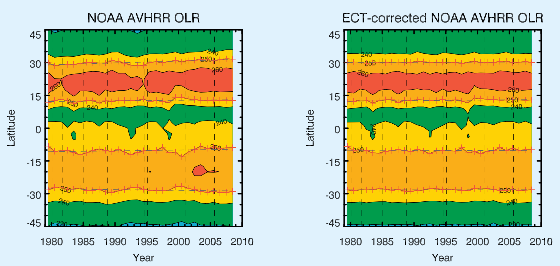

Figure 2. Time latitude profiles of annually-averaged NOAA AVHRR OLR for uncorrected (left) and the ECT-corrected data (Ref. 107) for the period 1979-2008. Vertical dashed lines indicate the changes in the satellite. Contours are every 10 W m-2, with the 250 W m-2 contour coloured in red. The trend along this contour is also indicated with a dashed line.

Satellite OLR

Estimates based on the zonal, annual average OLR indicate the highest rates of expansion, particularly in the NH (Fig 2, left). Trends for the poleward 250 K contour are 0.82 and 0.32 deg decade^{-1} in the NH and SH, respectively

The historical record of OLR is derived from multiple polar-orbiting satellites. These satellite's orbits 'drift', resulting in a gradual change in the equatorial crossing time (ECT). The varying ECT creates biases in temperature measurements, particularly over land.

These biases can be removed. Figure 2, right panel shows the same OLR data with ECT biases statistically removed. **Removing these biases effectively eliminates the expansion trend from the OLR measurements**. This agrees with expectations of little change in OLR in future climate change scenarios.

The applicability of this result for OLR to other satellite-derived metrics is unclear.

Hadley Cell

Characteristics of the Hadley Cell (HC) are determined with the isobaric meridional mass streamfunction (Ψ), a vertical integral of the zonally averaged meridional wind. The position of the tropical edge is identified as the subtropical 'zero crossing' of Ψ. Figure 3 shows the annual mean position for each hemisphere. Reanalysis-ensemble annual average expansion trends are ?? And ?? For the NH and SH, respectively.

In the SH, significant breakpoints are identified in all reanalyses *except the 20CR* in 1990 and 1998. Are these abrupt changes (i.e. 1998) the result of data artefacts or is it a real phenomenon?

Seasonality is significant in this metrics. This is particularly notable in the NH, where the expansion is largest during JJA, a season where the HC is weak and uncertainties in global wind speed may mask the circulation.

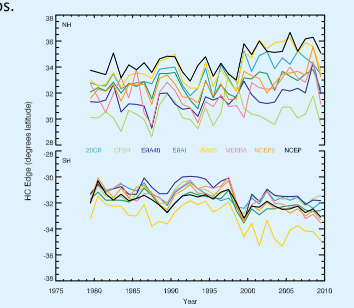

Figure 3. Time series of the position of the subtropical edge of the Hadley Cell as defined from the streamfunction in the eight modern reanalyses for the Northern (top) and Southern (bottom) Hemisphere.

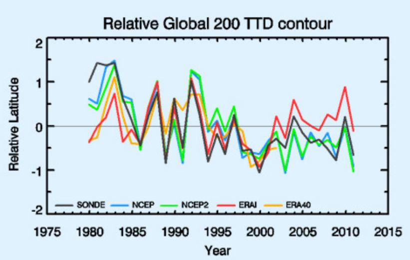

Figure 4. The relative 'global 200' TTD contour, the average position of the 200-day contour from all three regions, from radiosonde and reanalysis. The zero line represents the mean value of the contour in each analysis

Tropopause Height

Global radiosonde data are used to compute the height of the (lapse-rate) tropopause (Z_T). The tropical edge is defined based on the annual number of tropical tropopause days (TTD), defined as $Z_T > 14.5$ km. Here, the edge criterion is TTD=200 days. An expansion of 0.45 deg decade^{-1} is noted in the SH.

Figure 4 shows the radiosonde tropical edge compared to those determined from reanalyses. Radiosonde- and reanalysis-based results show varying results, with good agreement at times and poor agreement at others.

Significant differences between the ERA-I and the radiosondes are noted before 1985 and after 2001. After 2001, we speculate that this is due the introduction of advanced instrumentation into the satellite observing system.

GPCP Precipitation

The GPCP precipitation data are zonally and annually averaged. Here , we use the latitude of the observed subtropical minimum in precipitation as a measure of the tropical edge, depicted by the red lines in Fig 5.

The location of the edge as determined here is around 20° in each hemisphere, notably equatorward compared to other metrics

Previous studies that have used this metric and dataset have produced contradictory results, differing particularly on the magnitude of the expansion.

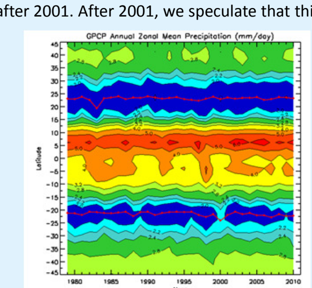

Figure 5. Time-latitude plot of zonally averaged annual precipitation from the GPCP. Red lines depict the location of the subtropical precipitation minimum

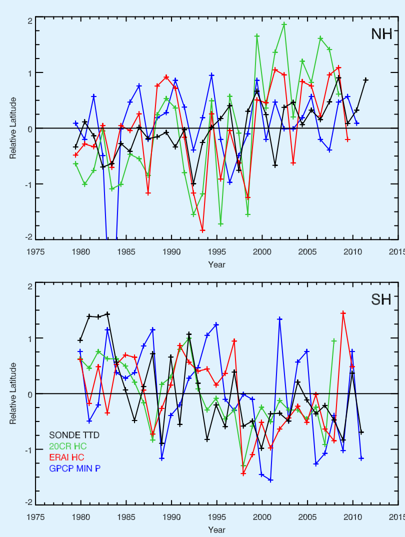

Figure 6. A comparison of time series of the relative positions of the tropical edge defined using different metrics. Shown are series from radiosonde-derived tropopause metrics (black), GPCP precipitation (blue) and HC metrics from the ERA-I (red) and 20CR (green) reanalysis products. Both the Northern (top) and Southern (bottom) Hemispheres are shown.

Discussion

Figure 6 presents the tropical edge time series described above for the NH (top) and SH (bottom), Shown are the tropopopause–based data from radiosonde. (black) , the GPCP edge (blue) and two HC –defined estimates, one from the ERA-I (red) and the other from the satellite-free 20CR (green). Relative positions are shown, with the mean removed from each series.

Interannually, the individual time series are poorly correlated with each other. However, the different metrics identify a consistent envelope that defines movement of the tropical edge over the past 30+ years. This suggests that at some fundamental level, the different metrics broadly reflect the position and variation of some 'tropical edge'. However, the specific details vary because of the 'different physics' of the metrics.

In both hemispheres, there qualitatively appears to be a shift in the position of the tropical edge in the late 1990s across all the metrics analysed here. This is analogous to what is seen in the HC times series of Fig 3, and suggests that this abrupt change to the circulation is at least partially real.

Comparison of the different metrics suggests that relative biases may remain in some metrics. For example, the NH HC from the 20CR is displaced well poleward of other estimates. A Closer examination (not shown) shows that this is due to large changes (in excess of 10° latitude at times) in the position of the HC during June and July

However, not all metrics are equal, with this analysis suggesting that the OLR-based metrics may not be suitable for the analysis of tropical expansion. Hence, we can discount these observations, which are generally higher than others. Eliminating these estimates, **the consensus of remaining observations suggests that the true rate of tropical expansion, since 1979, is on the order of 0.5 deg decade^{-1}**.