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What Drives Southern Hemisphere Tropical Expansion?

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Introduction

• Since 1979, an expansion of tropics has been observed using multiple methods and observational platforms. A synthesis across the observations suggests that the expansion rate is on the order of 0.5 degrees/decade in each hemisphere.

•Anthropogenic climate forcings have been proposed as drivers of the expansion. These include: 1.) greenhouse gases; 2.) stratospheric ozone depletion; and 3.) direct and indirect aerosol effects. Natural factors, like volcanic eruptions and ENSO, also affect the position of the tropical edge on shorter time scales.[1]

•Here we will investigate the relative contribution of these forcing factors to the tropical expansion in the SH. Two approaches are used: 1) the statistical analysis of observations of tropical expansion, and 2.) 'single forcing' experiments with a state-of-the-art coupled general circulation model.

•We are particularly interested (at this stage) in the partition between ozone and greenhouse gas forcings.

Single Forcing Simulations

•Simulations with the Community Climate System Model 4 (CCSM4)[2] using the historical scenarios are analysed between 1960 and 2005.

• Five forcing 'single forcing' scenarios are examined: ALL (all forcings), NAT (volcanoes and solar), O3 (ozone only), GHG (greenhouse gas only) and AER (anthropogenic aerosol only). Three-member ensembles are used for each scenario.

•The tropospheric height frequency methodology is adapted for use with the monthly model output. The 200-day TTD contour is used as with the observations. Figure 1 shows the tropical edge positions for each single forcing ensemble.

•Trends on the 200-day TTD contour are examined over the whole period and from 1979.

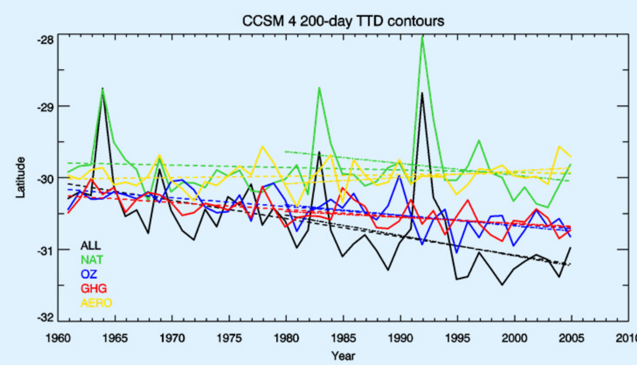

Figure 1. Single-forcing ensemble averages of the SH tropical edge position, as defined by the TTD=200 day contour. Individual ensembles distinguished by line colour following the plot legend. Linear regression fits from 1960 and 1979 are shown as dashed and solid lines, respectively

Table 1. Linear trends and 2-σ confidence intervals for the ensemble-mean tropical edge time series from 1960 (left) and 1979.

Run	Trend (1960-2005)	Trend (1979-2005)
ALL	**-0.25 ± 0.14**	-0.28 ± 0.40
NAT	-0.03 ± 0.12	-0.16 ± 0.31
O3	**-0.12 ± 0.05**	**-0.15 ± 0.12**
GHG	**-0.10 ± 0.04**	-0.08 ± 0.11
AER	+0.02 ± 0.05	+0.09 ± 0.11

•Trends from individual forcings add up to that in the ALL experiments, indicating an quasi-linear response to the forcings (Table 1).

•From 1960, O3 and GHG are the dominant forcings. NAT and AER result in small trends over this time frame

•No relationship is observed with a model-derived Southern Oscillation Index (SOI)

• From 1979, NAT plays accounts for ~40% of the simulated expansion, followed by O3 at nearly the same magnitude. The magnitude of the GHG trend is about half of that from O3 and NAT, while AER shows a distinct contraction of the tropical edge.

References

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Statistical Analysis of Observations

•Observations of tropical edge in the SH are derived from radiosonde observations over three broad regions using the tropopause height frequency methodology.[3] Here, the tropical edge is taken as the annual position of the 200 tropical tropopause days (TTD) per year contour. Results from the three individual regions are averaged to produce a global composite. The observed trend in the global composite is ~0.45 degrees latitude per decade.

•These results are related to observable proxy variables representative of the forcing factors. These variables are:

- Multivariate ENSO Index[4]
- NASA Ozone Hole Area (proxy for ozone forcing)[5]
- Global or SH Temperature Anomaly (GISS, proxy for GHG and aerosol)[6]
- Stratospheric Aerosol Optical Depth (proxy for volcanoes)[7]

•Annual values of the predictors are shown in Figure 2.

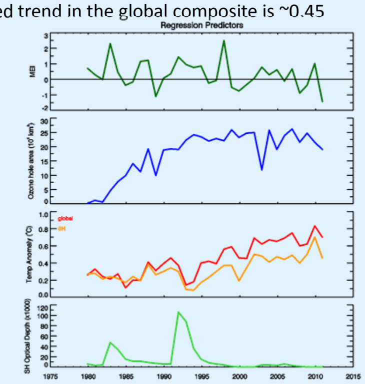

Figure 2. Proxy variables used in regression analysis. Shown from top to bottom are: MEI, ozone hole area, global and Southern Hemisphere temperature and aerosol optical depth.

•These proxy variables are used as multiple linear regression predictors of TTD-based tropical edge.

•As the proxies are cross-correlated, linear effects are removed from in the following order: 1.) Stratospheric Aerosol; 2.) MEI; 3.) Temperature. Ozone hole area and global temperature are most correlated. After this removal process, the correlation between all variables is zero.

•Two versions of regression are performed using either the global or SH temperature series.

•The regression (Figure 3) captures 58.7 (globe)–59.4 % of the variance; the RMS error of the regressions is 0.4 degrees. The trends for both regressions is ~0.37 deg decade^{-1}, close to the observed value.

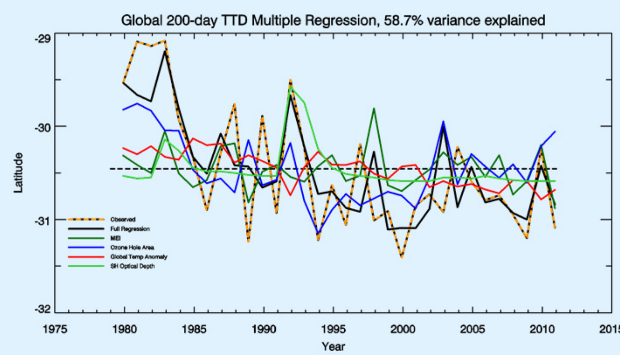

Figure 3. Observed SH tropical edge time series and results of full regression and individual components. Refer to plot legend to distinguish lines.

•Approximately 30% of trend is due to natural factors (10% MEI, 20% volcanoes). This is simply a matter of the timing over which the trend is computed.

• The remaining 70% of the trend is due to anthropogenic forcing. The two temperature series produce different results. Here, we attribute the trend as a range based on the two regressions: 10-40% of total trend is due to global temperature, the remainder (60%-30%) is due to ozone depletion. The first number of the range is the value with SH temperature

Conclusions

• Observational and modelling results broadly agree on the partition of forcing factors of SH tropical expansion.

• Combining results, the **best estimate is that since 1979, the partition of forcing factors is 30% resulting from natural factors (volcanoes and ENSO), 40% resulting from stratospheric ozone depletion and 30% resulting from increasing greenhouse gases**, with an error range *roughly* estimated at ± 5%.

•The large role of natural factors is largely the result of the choice of staring point of the analysis.

•The role of aerosol remains unclear, but the CCSM4 simulations suggest that it is unimportant for SH tropical expansion

•While O3 has been dominant in the recent past, its role is expected to diminish as the ozone hole recovers. GHG is expected to be more dominant in the future