Final warming of the Southern Hemisphere polar vortex in CMIP5

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Project aims

How does an improved representation of the lower stratosphere change our understanding of past tropospheric climate and future climate projections?

Three specific questions:

1. Do 'high-top' models better represent past climatology and trends than those with a 'low-top'?
2. What are the anticipated future changes in final warming date?
3. What are the drivers of changes in final warming date?

Motivation

- Changes in the strength of the polar vortex are associated with persistent circulation anomalies in the troposphere and lower-stratosphere
- Changes in final warming date have been observed in recent decades, and have been shown to be strongly determined by changes in lower-stratospheric ozone concentrations
- Final warming date has been shown to propagate downwards from ~1 hPa, so it may be sensitive to the location of the model top

Final warming date

- A measure of the annual cycle
  - Identified by the minimum d^2T/dt^2 at 50 hPa [1] (Fig. 1)
- Responsive to changes in the thermal structure of the lower stratosphere
  - More stable vortices will have a later final warming date

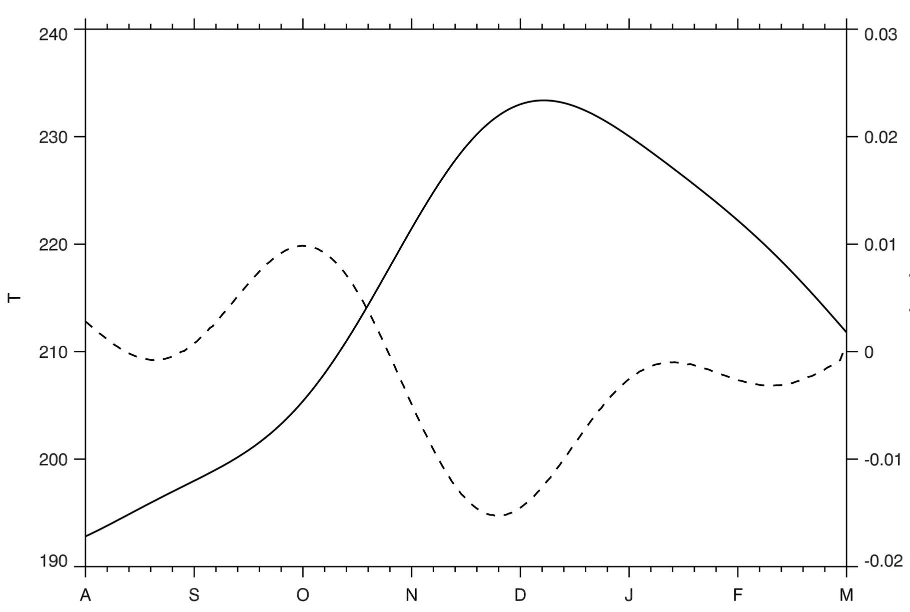
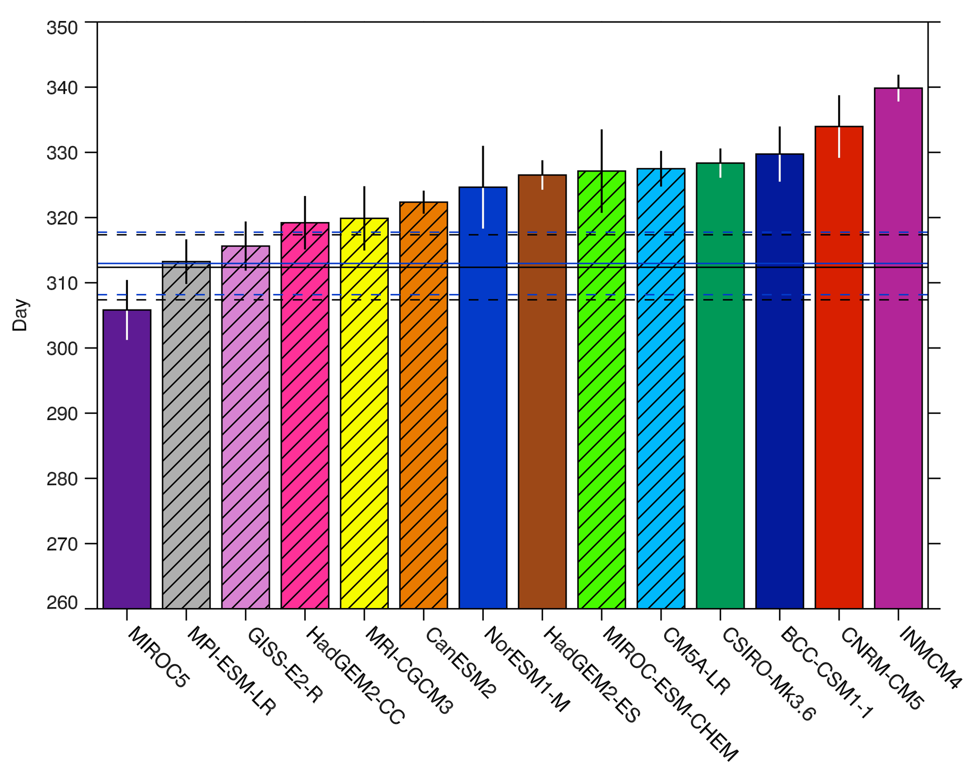


Figure 1: Polar cap average temperature (solid) and its second derivative (dashed) at 50 hPa. The final warming date is the date when the minimum in d^2T/dt^2 occurs.

Bias in final warming date



- Final warming date is one week late in high-top models, and two weeks late in low-top models
- Most models underestimate inter-annual variability

Figure 2: Mean final warming dates for each model (1979-2005). Whiskers show ±2 standard errors. High-top models are indicated by hatching. Horizontal lines show the values from ERA-Interim (black) and CFSR (blue).

GHG and ozone forcing

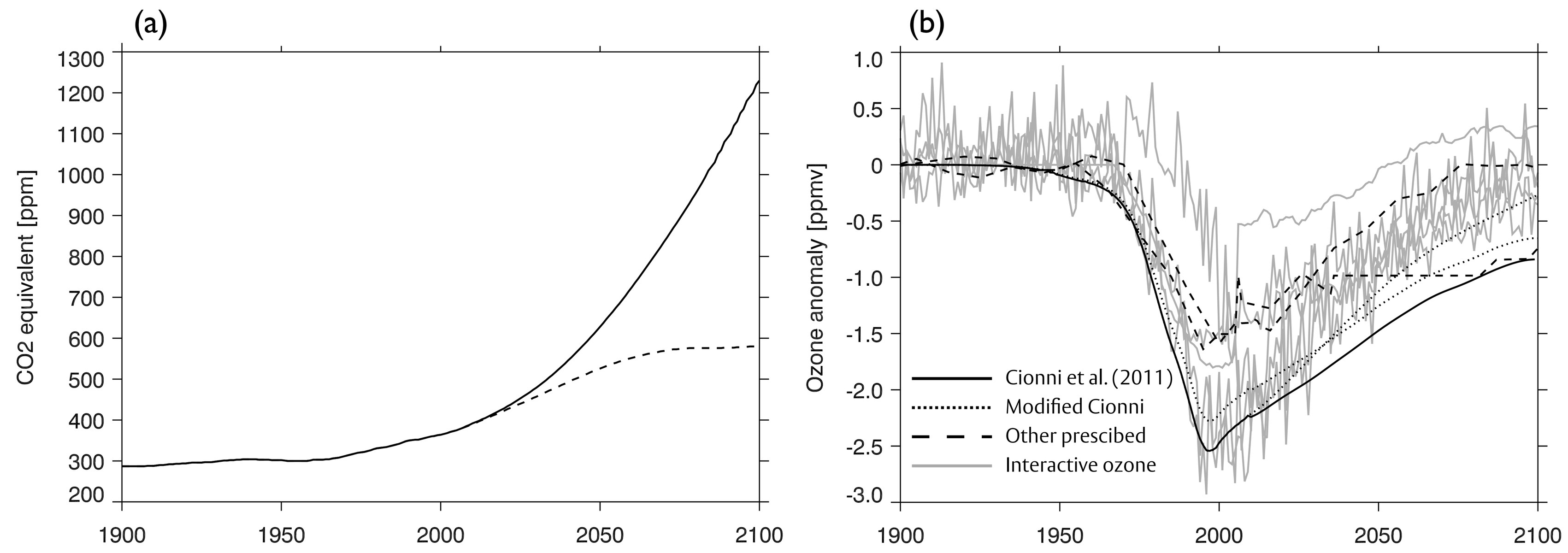


Figure 3: (a): Global-mean annual-mean greenhouse gas concentration (CO_2 equivalent) for RCP4.5 (dashed) and RCP8.5 (solid). (b): Antarctic mean (75-90°S) SON ozone concentrations at 50 hPa, relative to 1900 values.

- Variety of lower stratospheric ozone timeseries
  - Comparable turning points near 2000
  - Amplitude of ozone anomaly differs by up to a factor of 2

Past and future changes

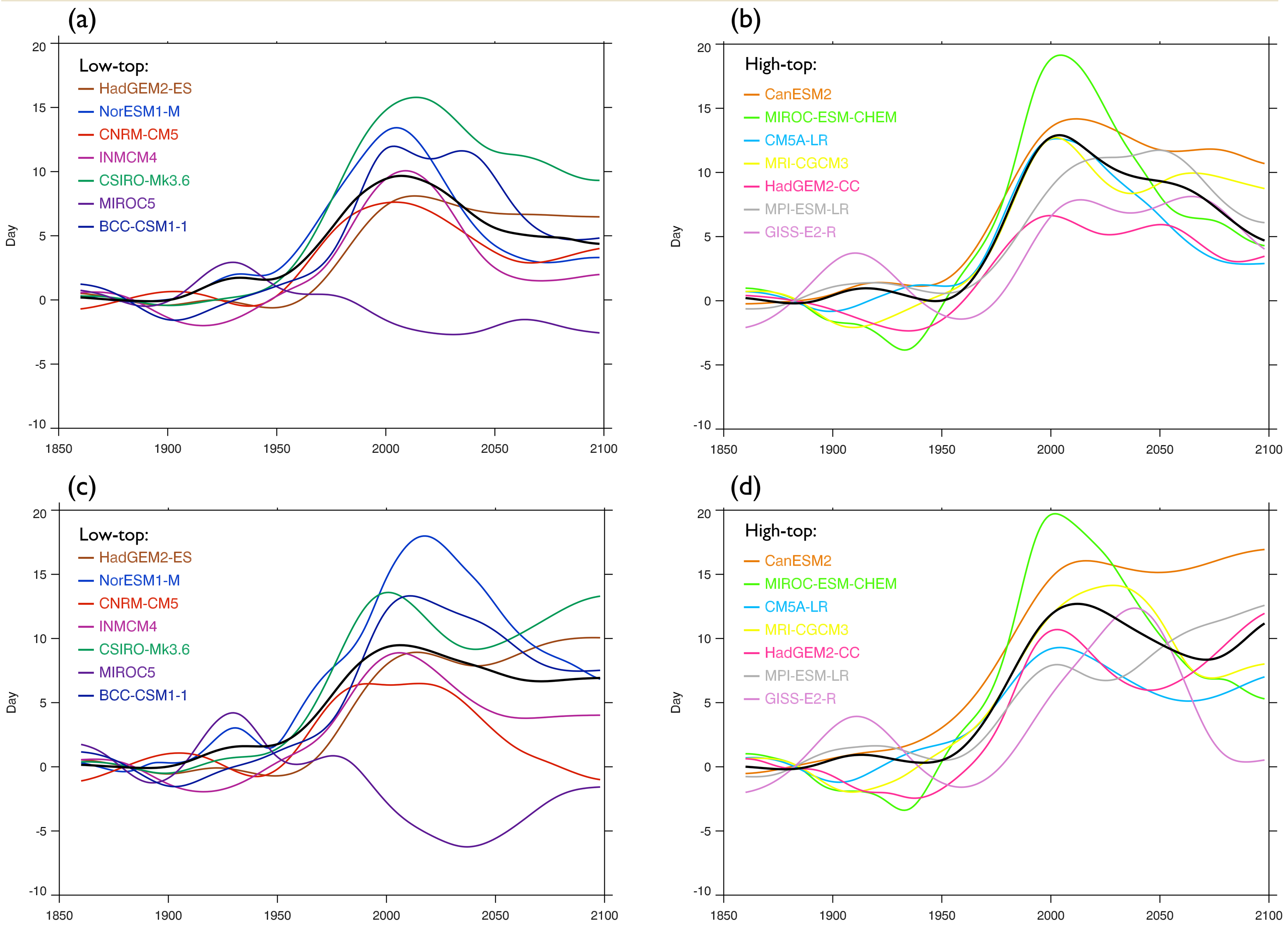


Figure 4: Final warming date for low-top (left column) and high-top (right column) models, with the ensemble mean (thick black line). (a,b): historical and RCP4.5, (c,d): historical and RCP8.5. Raw data is adjusted to the 1860-1900 mean.

- Nonlinear trends from EEMD (an algorithm that decomposes time series into characteristic frequency modes)
- Marked delay from 1970-1990s associated with stratospheric ozone depletion
  - Larger, and more consistent across models, in the high-top ensemble
- High-top mean shows a trend towards later warming by 2100 in RCP8.5

Drivers of change

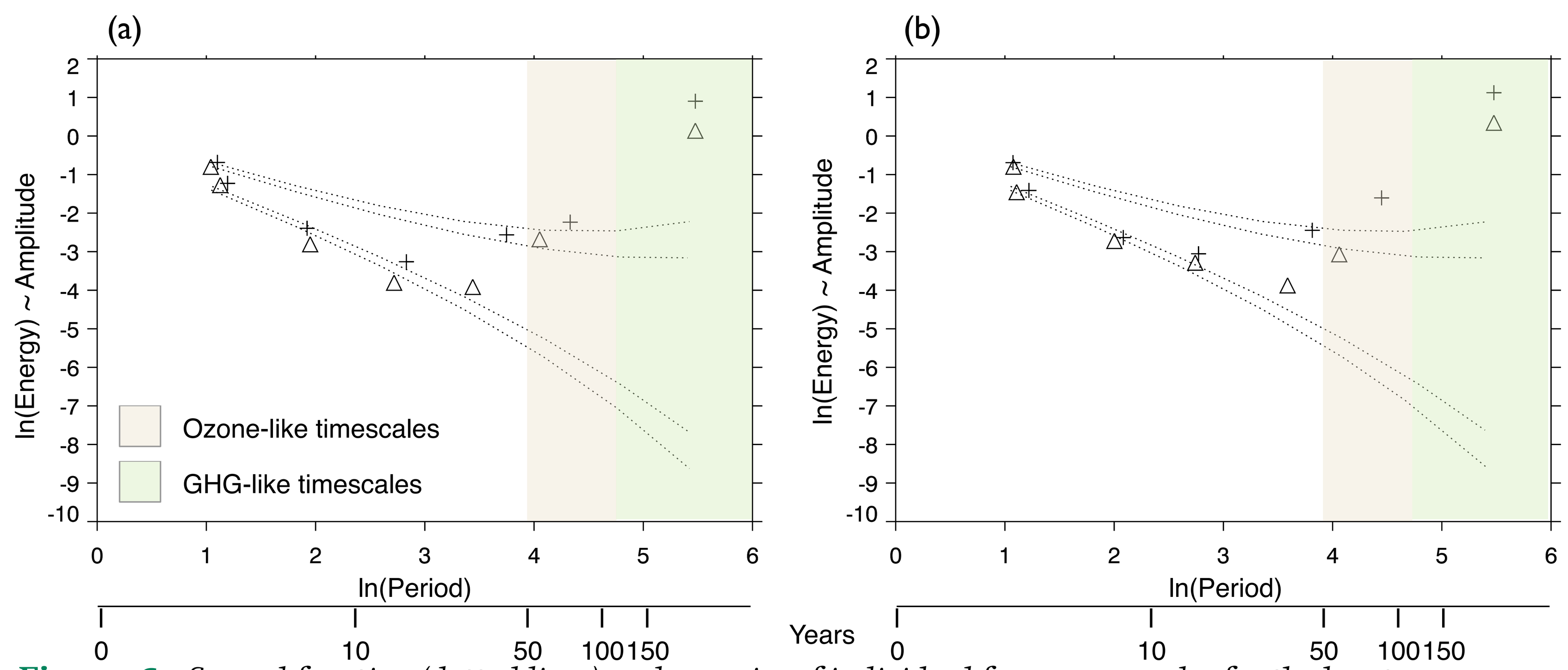


Figure 6: Spread function (dotted lines) and energies of individual frequency modes for the low-top (triangles) and high-top (crosses) ensemble means. (a): historical and RCP4.5, (b): historical and RCP8.5. The inner pair of dotted lines show the 95% confidence interval for white noise, the outer pair show the 99% confidence interval.

- Main drivers expected to be greenhouse gas and stratospheric ozone changes
  - Different timescales, so different functional forms
- Greenhouse-gas like frequency mode is always significant at 1%
- Ozone-like frequency mode is always significant at 1% in the high-top case
  - Significant at 5% in RCP4.5 in the low-top case
- Higher energies show larger response to forcing in the high-top cases
  - Multiple linear regression also shows a larger response in the high-top case

References

[1] Haigh, J. D., and Roscoe, H.K. (2009). *J. Climate.*, **22**, 5809-5819.
[2] Cionni et al. (2011). *Atmos. Chem. Phys.*, **11**, 11267-11292.

- Final warming date is 1 week late in high-top models, and 2 weeks late in low-top models, compared to ERA-Interim and CFSR
- Final warming date becomes later with ozone depletion, with a return to earlier dates as ozone recovers
- High-top models show a trend towards later dates in RCP8.5, associated with the GHG induced increase in temperature gradient

Learn more:

Wilcox, L. J., and Charlton-Perez, A. J., (2013). *J. Geophys. Res.*, **in press**.