Understanding Recent Tropical Expansion and its Impacts

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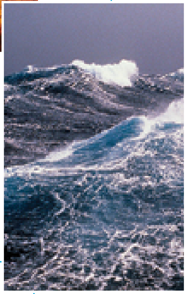

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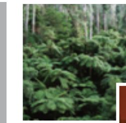
Papers



- Lucas C, Nguyen H, Timbal B. An observational analysis of Southern Hemisphere tropical expansion. *J. Geophys. Res*. 2012, 117:D17112, doi:10.1029/2011JD017033

- Nguyen H,, Evans A, Lucas C, Smith I, Timbal B. The Hadley circulation in reanalyses: climatology, variability and expansion., *J. Climate*. 2013, 26: 3357-3376. doi:10.1175/JCLI-D-12-00224

- Lucas C, Timbal B, Nguyen H. The expanding tropics: A critical assessment of the observational and modelling studies. *WIREs Climate Change*, 2013, doi: 10.1002/wcc.251

- Lucas C, Nguyen H, Timbal B. Radiosonde analysis of Northern Hemisphere tropical expansion. In Prep.

- Nguyen H, C Lucas, B Timbal + others. Unprecedented expansion of the Hadley Cell. In prep.

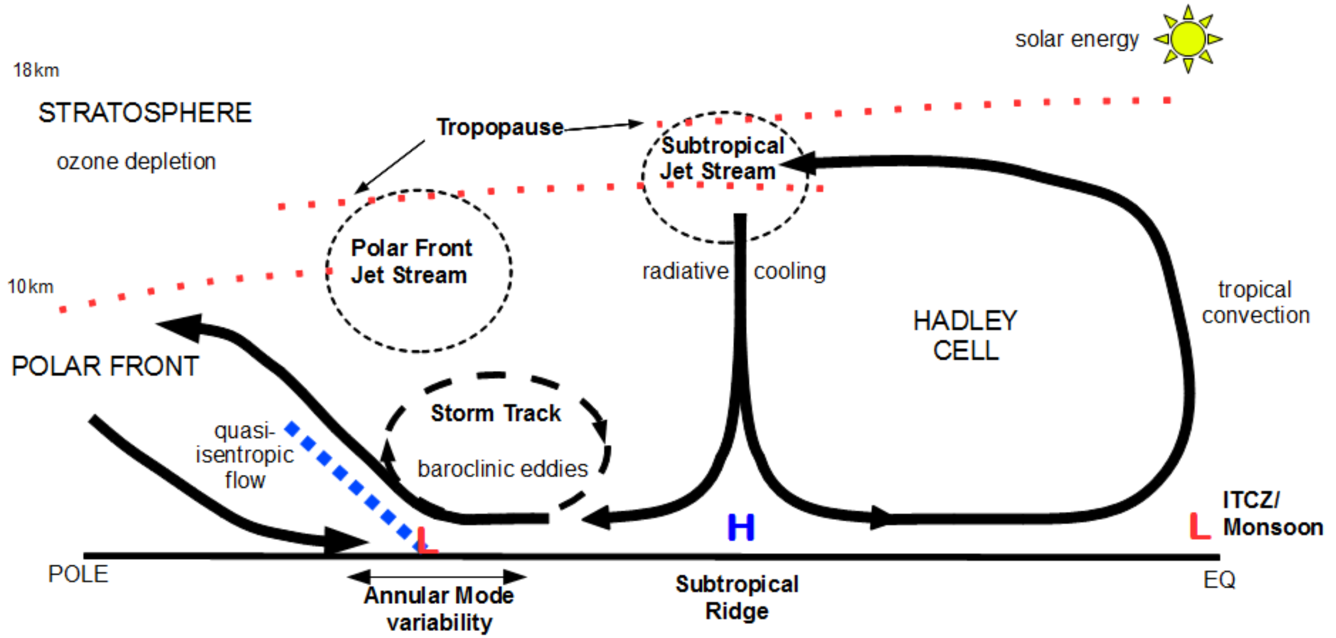
- Lucas C, B Timbal: What drives SH tropical expansion?, In Prep.

Introduction

- What is tropical expansion?
- Why do we care?
  - Subtropical drought

- The mean meridional circulation (MMC)
- How fast are tropics expanding?
  - Consistency of metrics and observations
  - How much to trust reanalysis?
  - Pre-satellite era measures of TE
  - Regional and hemispheric characteristics
- Forcing factors of SH expansion
  - What is behind it all.

Idealized Model of MMC



Inspired by isentropic view of MMC; Interpreted through 'classical' meteorological concepts

Shares some characteristics with classic three-cell model, but visualizes circulation as a whole-hemisphere enterprise

Extratropics not an 'afterthought' of MMC

Tropical-extratropical interactions vital. Subtropics are the nexus of this interaction

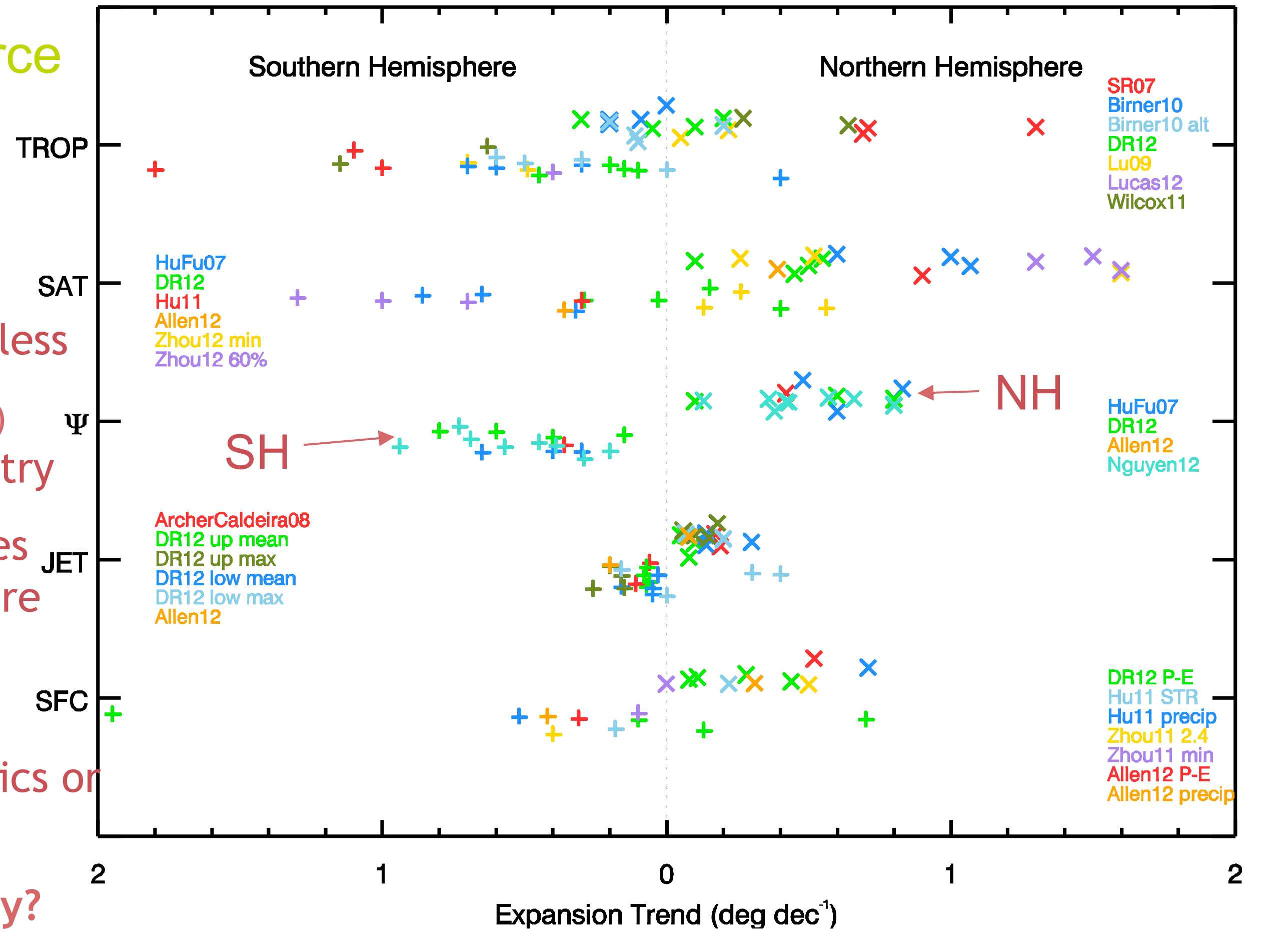
Observational studies of tropical expansion

Summary

- General consensus on tropical expansion since 1979
- Wide range of estimates
  - More scatter in satellite, less in jet
- Different hemispheric asymmetry
  - Is expansion equal, or does one hemisphere expand more than the other? Which one expands more?
- Consequence of different physics or other data issues?
- Can we reduce the uncertainty?

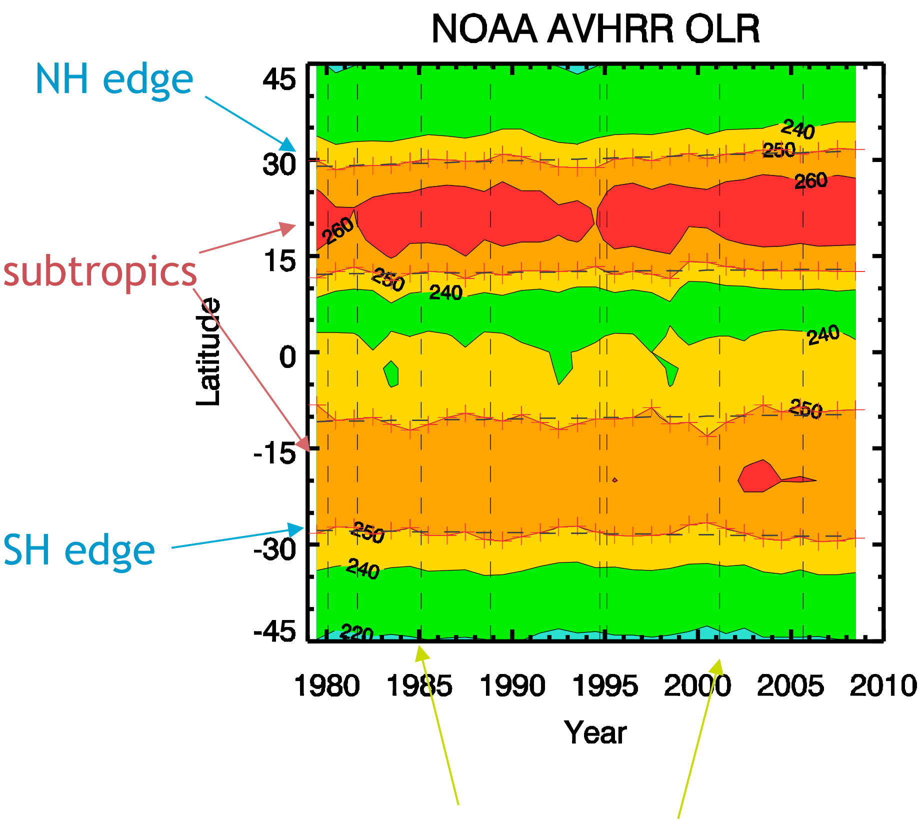
Methodology or Data Source

- tropopause height (Z_T)
- satellite-based data
- mass streamfunction (Ψ)
- jet stream
- surface-based (rainfall, sfc pressure, P-E, etc)



Trends units are **degrees latitude per decade**

OLR estimates



Time-latitude plot of annual zonal-mean OLR

- 250 W m^{-2} used to define edge
- Get trend from temporal variation of edge
- Expansion trends: 0.82 in NH, -0.32 in SH

Data are composite of many satellites

- Satellites ‘drift’, changing time the scene is viewed
- Equatorial crossing time (ECT) bias, especially over land areas

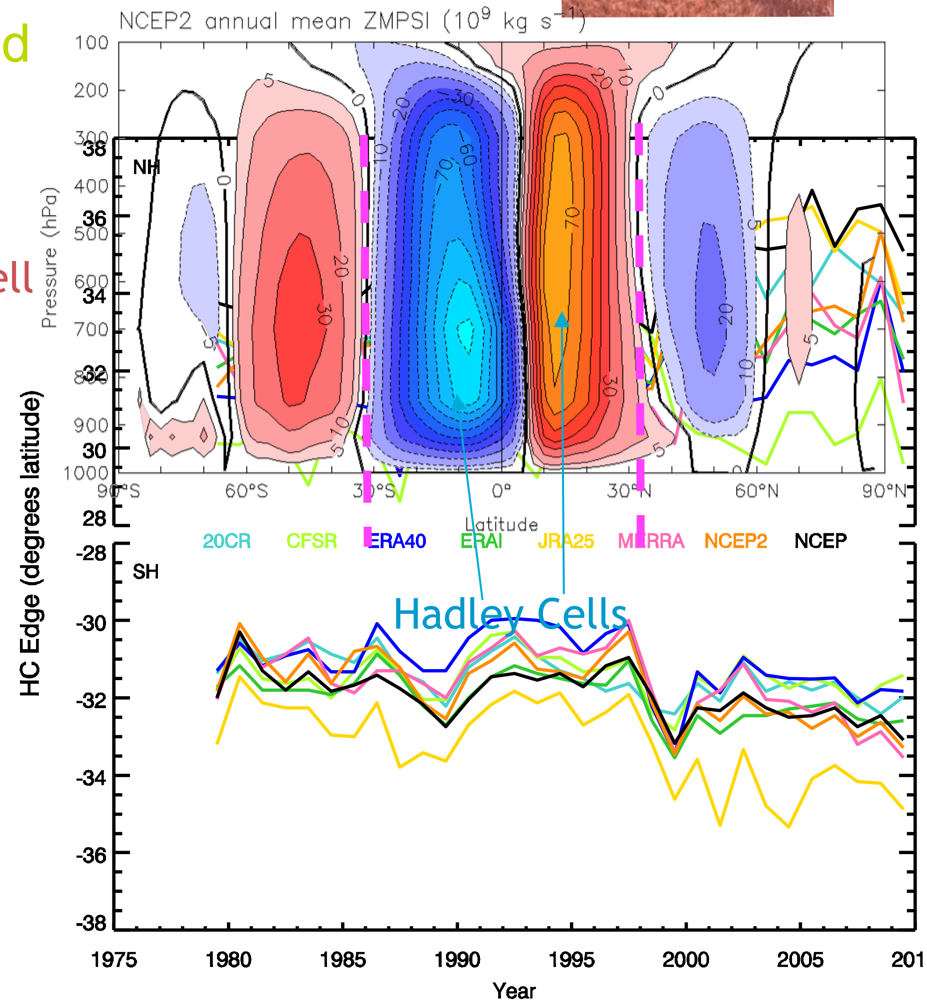
ECT-bias needs to be removed

- Sapiano et al [2010] dataset

Zero trend in uncorrected version!! More consistent with expectations

Isobaric Mass Streamfunction (Ψ)

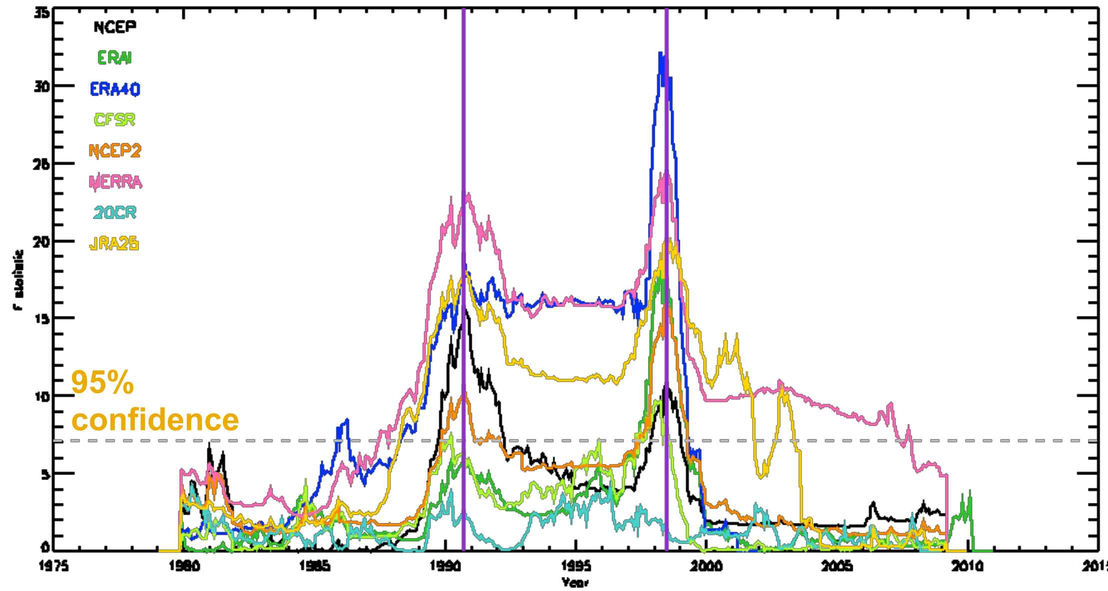
- Vertical integral of mean meridional wind
  - Computed in eight reanalyses
  - Three cell model of MMC
  - Edge is poleward boundary of the Hadley cell
  - See Nguyen et al [2012] in J Climate
- Temporal variation of edge gives trend
  - More consistent in SH
  - SH expansion: 0.1 to 0.8 deg/decade
  - NH expansion: 0.2 to 0.9 deg/decade
  - Greater expansion during warm seasons
- What is going on in SH during late-1990s? Is it real?



Possible breakpoints in Hadley Cell

Apply homogeneity tests to time series

- Two-phase regression
- Use test statistic of Lund and Reeves [2002]
- Broad region of significant scores
- Possible breakpoint where score is a maximum



Two times of concern

- 7 of 8 RAs suggest breakpoint in early 1998 (March or June)
- 6 of 8 RAs in Sept 1990 (CFSR slightly different)

The 20CR shows no possible breakpoints during this period

Newer RAs like CFSR, ERA-I minimize or don’t contain the 1990 breakpoint

What is role of changes to global observing system?

GPCP Minimum Precipitation

GPCP global satellite-gauge precipitation dataset

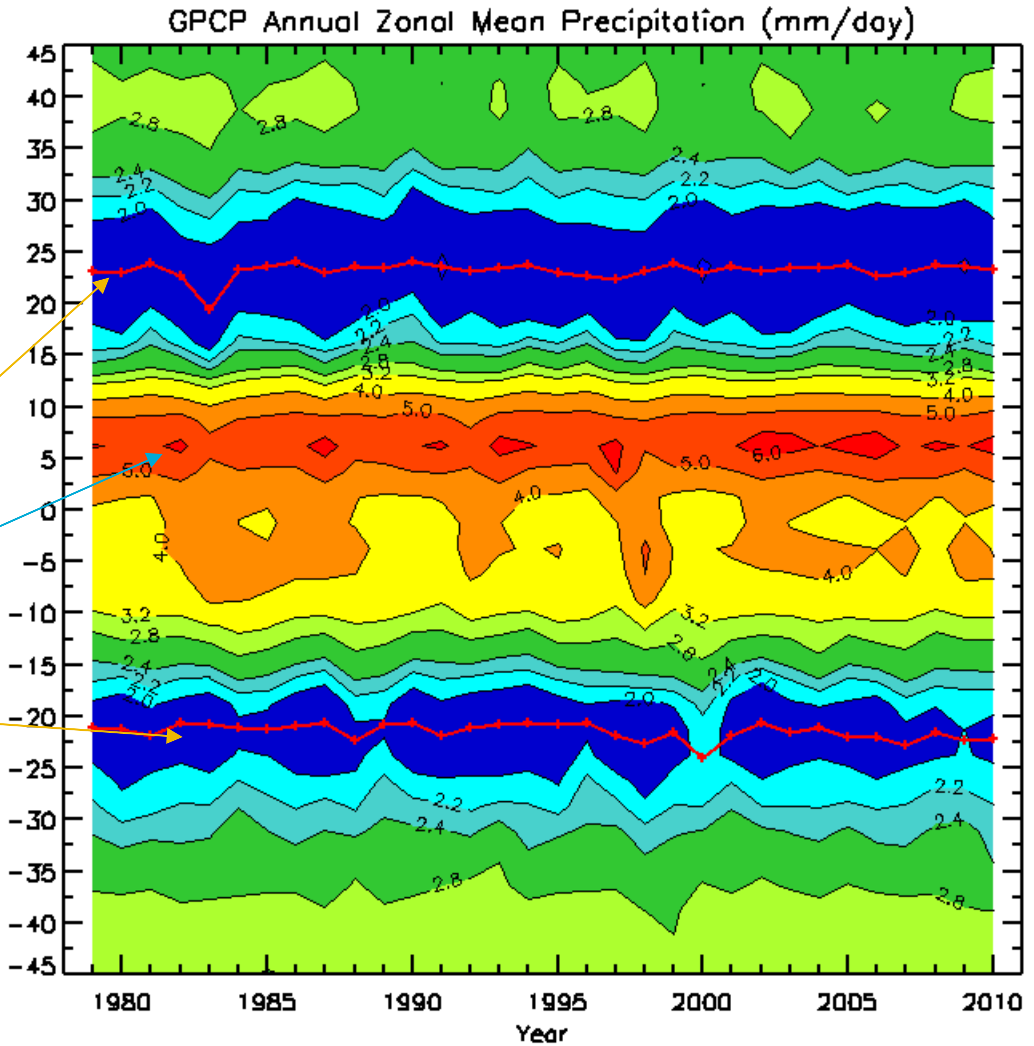
- Identify subtropical minimum precipitation
- Two studies show different results with different versions of dataset (v 2.1 and 2.2)

Results here generally consistent with previous results with v2.2

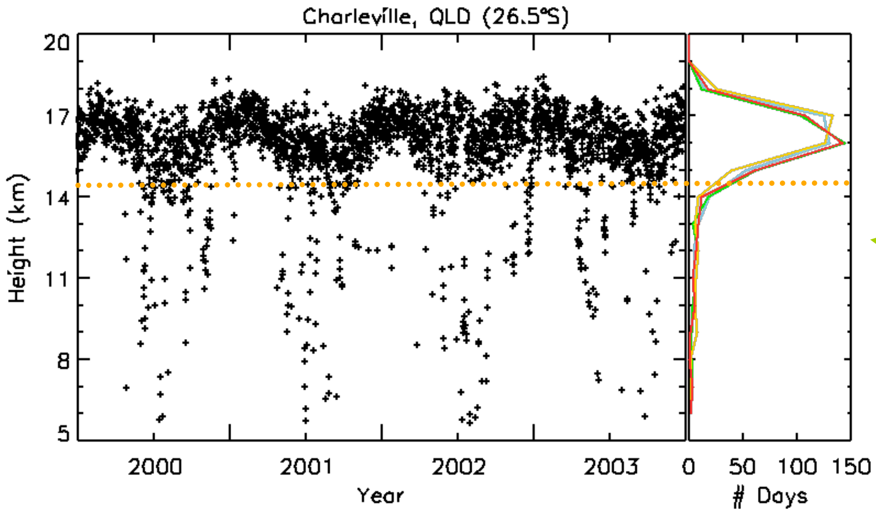
- SH expansion: 0.38 deg/decade
- NH expansion: 0.15 deg/decade

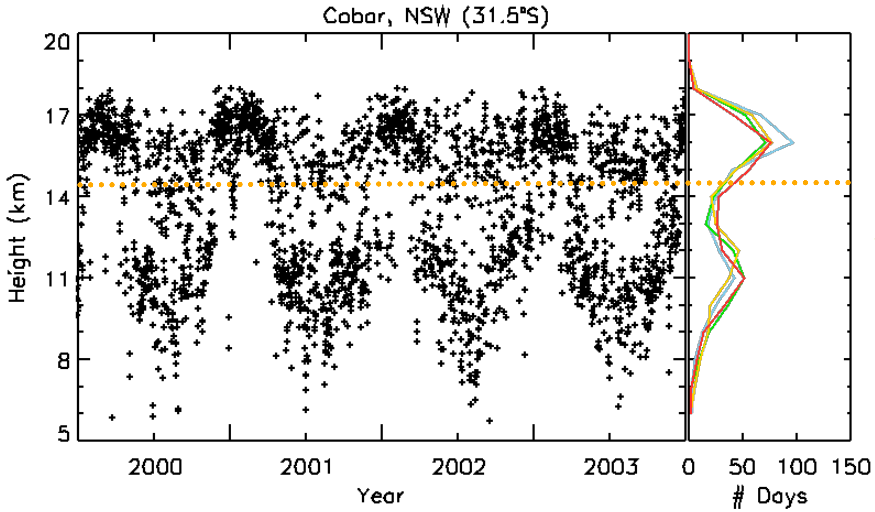
ITCZ

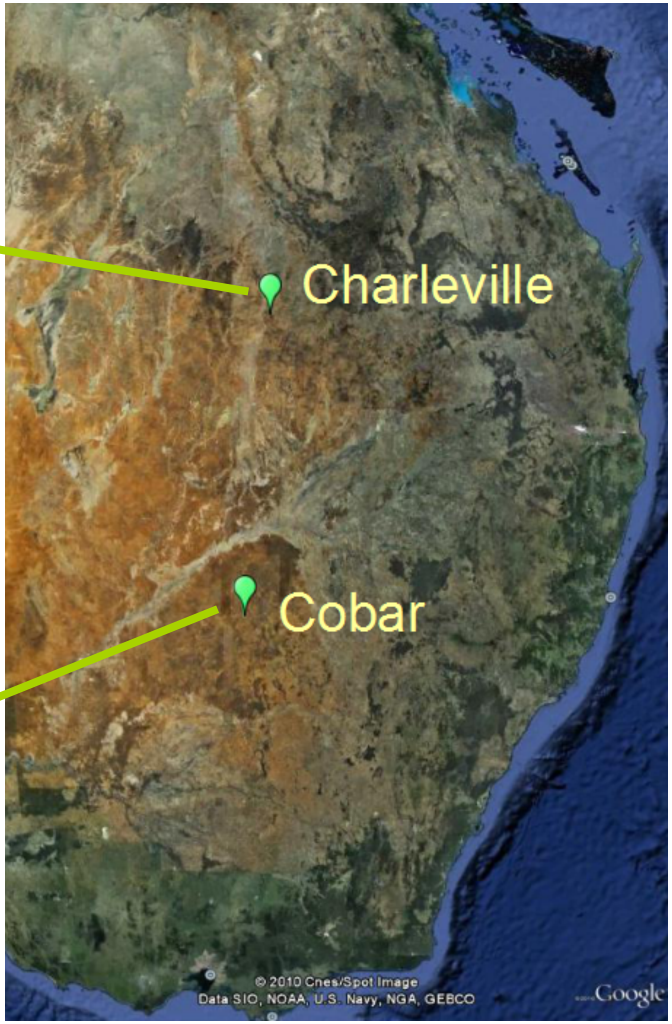
Subtropical Dry Zone



The Edge of the Tropics







each dot is one observation of the tropopause, bin size = 1 km, centred

Tropopause Height Frequency

Annual frequency of subtropical tropopause height is bimodal

- Tropical – peak at 15-16 km
- Extratropical – peak at 12-13 km

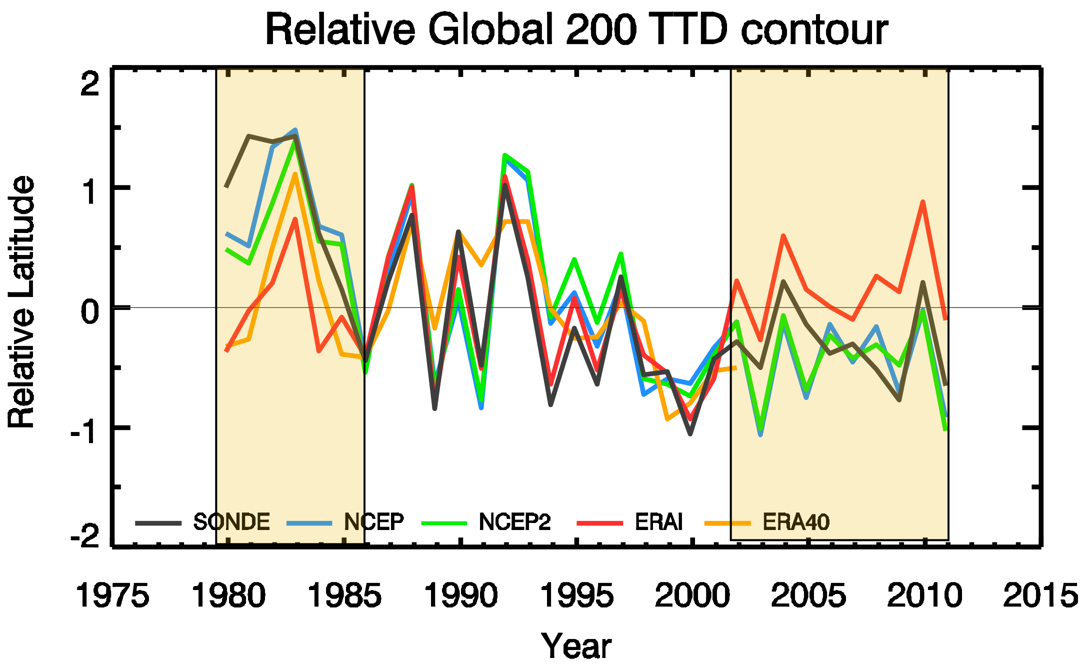
Estimate edge from number of tropical tropopause days (TTD)

- focus on TTD=200 contour
- computed from 1979-2011 using IGRA radiosondes and 4 reanalyses

Trends (SH only)

- sondes: 0.4 deg dec^{-1} (expansion)
- NCEP, NCEP2: 0.3 – 0.5 deg dec^{-1}
- ERA-I: no trend

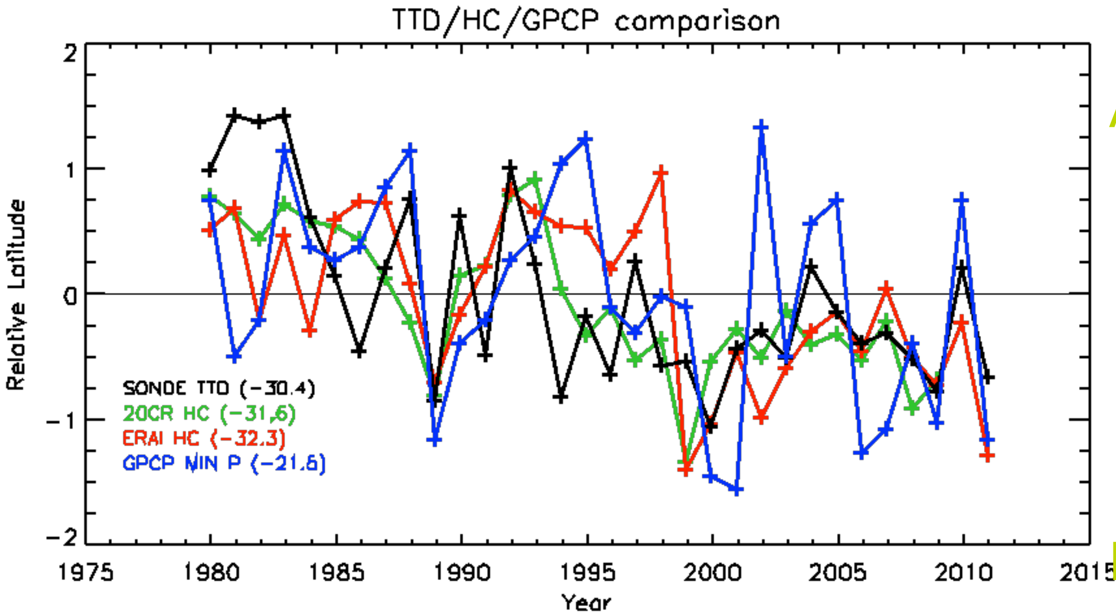
See Lucas et al [2012] in JGR



Two periods of notable difference

- post-2002 -- better satellite observations improving ERA-I, creates inhomogeneity
- pre-1985 – ??

Comparison of Edge Metrics



Compare relative position and variability of edges as defined from sonde TTD, HC metrics for 20 CR and ERA-I and GPCP min precip

Source	Trend/2-σ CI
Sonde TTD	-0.48/0.23
20CR HC	-0.47/0.27
ERA I HC	-0.39/0.28
GPCP	-0.32/0.31

A reasonably good comparison!

- Captures interannual variability (e.g. 1989, late-1990s, 2010)
- Trends roughly same magnitude across all metrics…**tropical expansion of 0.3 to 0.5 degrees/ decade in SH**

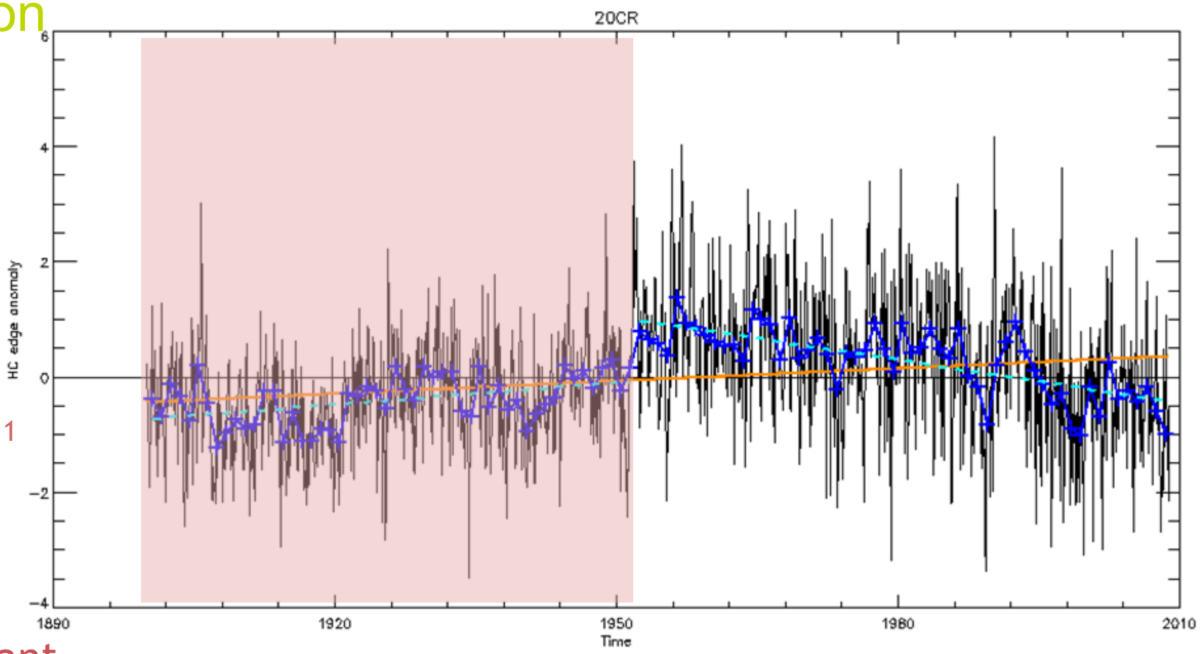
Not as good at some times

- No other metric sees the pre-1985 sonde TTD position
- Differences in HC measures in 1990s
- Noisier GPCP precipitation edge after 2000

20c SH HC edge

What happened with expansion prior to 1979?

- Use 20CR to extend record of expansion
- Use the Ψ methodology
- Period of record: 1900-2008
- Trend: 0.07 ± 0.03 deg decade^{-1} contraction!!



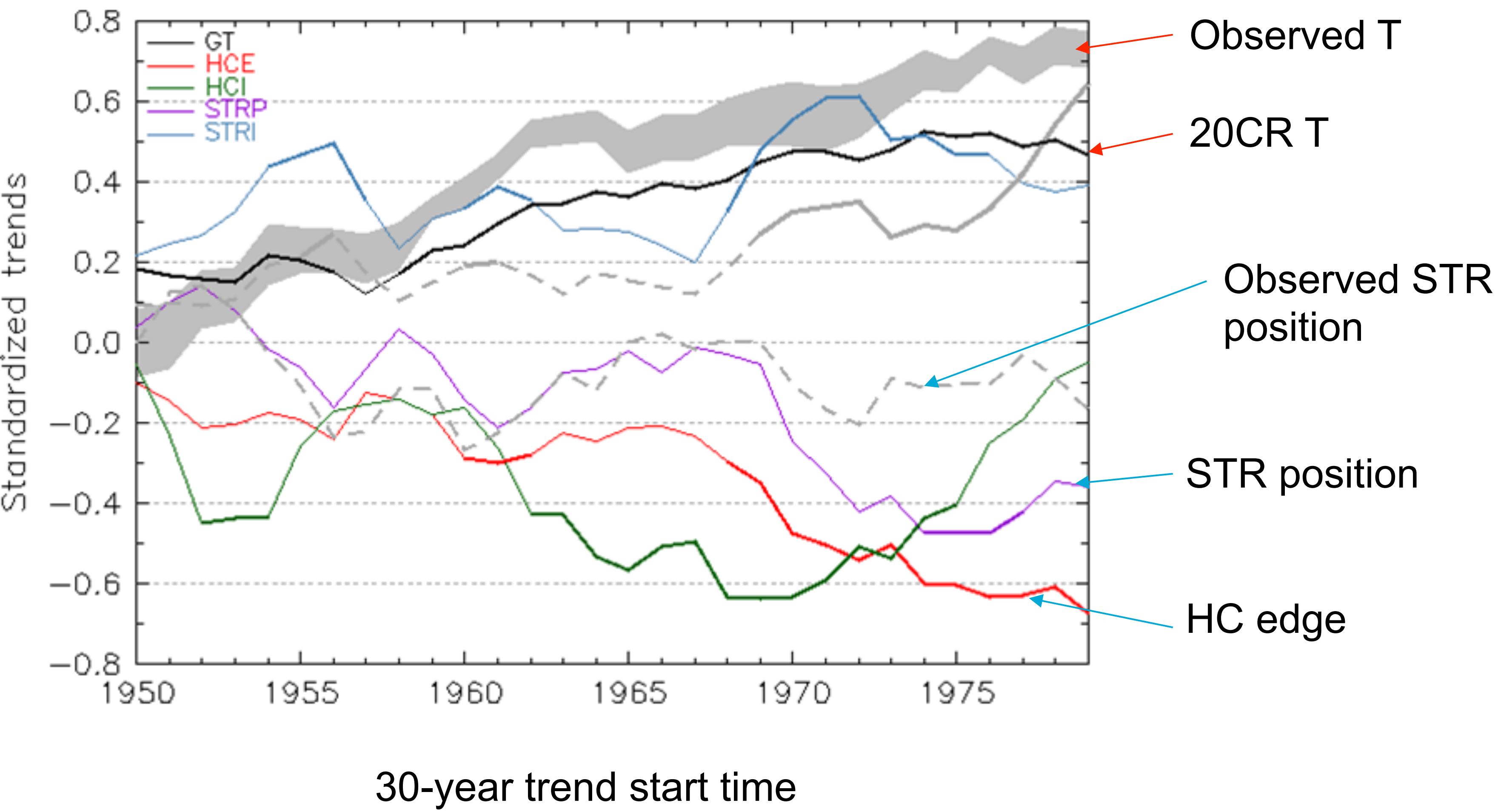
Can we believe these data?

- Analysis suggests highly significant breakpoint in July 1951
- Lower variance, different behaviour before BP
- BP doesn't **prove** anything by itself

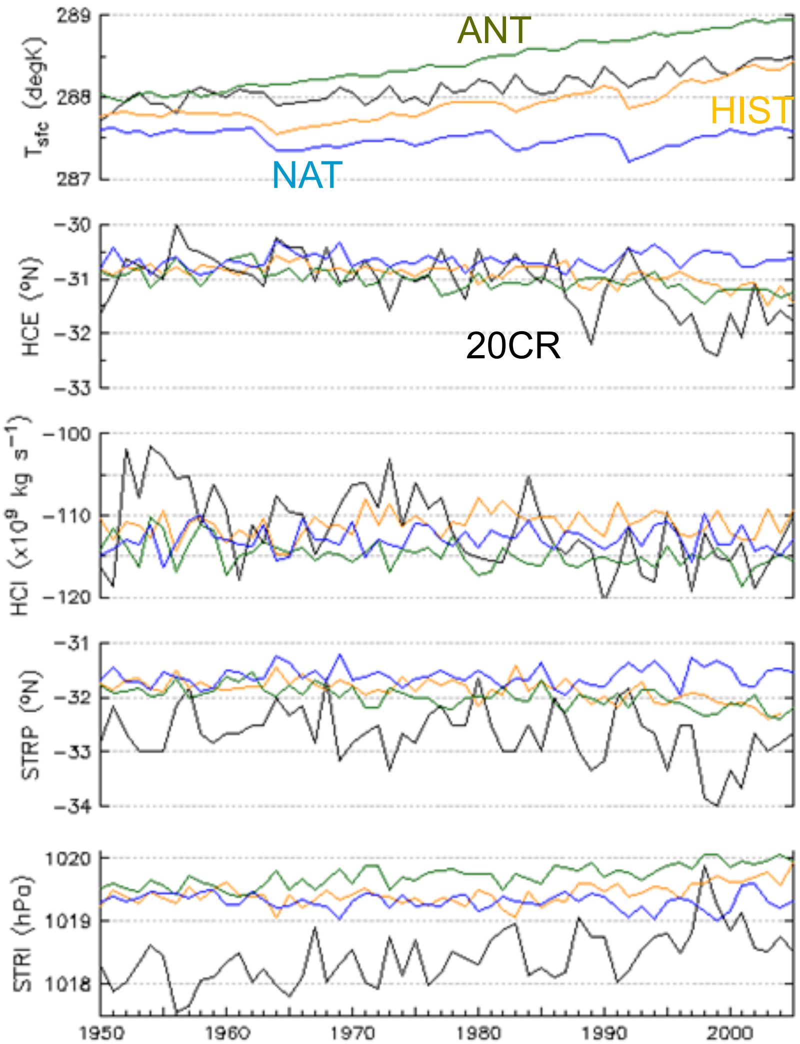
Expansion trend from 1952-2008: -0.26 ± 0.07 deg decade^{-1}

Variation of 20CR trends with time

Plot shows variation of 30-year trends with time



CMIP 5 modelling

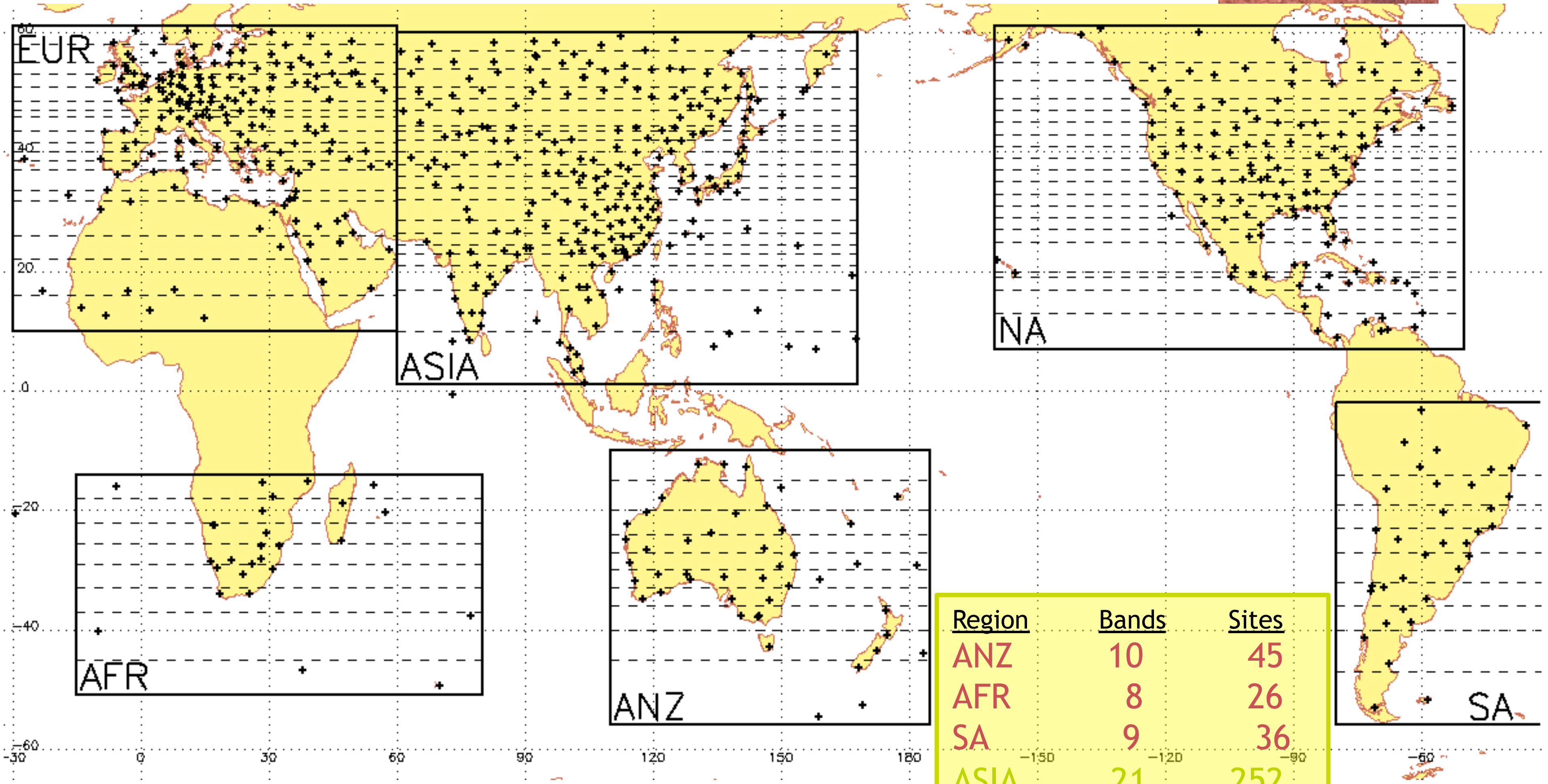


Comparison of 20CR and CMIP5 multi-model ensemble

Simulations do not capture acceleration of trend in HC position

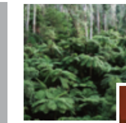
Simulations also do not capture acceleration of trend in STR position

NH Expansion from Radiosondes



Region	Bands	Sites
ANZ	10	45
AFR	8	26
SA	9	36
ASIA	21	252
EUR	19	178
NA	20	136

NH TTD contours by region



Structure of ‘subtropics’ different in the regions of the NH

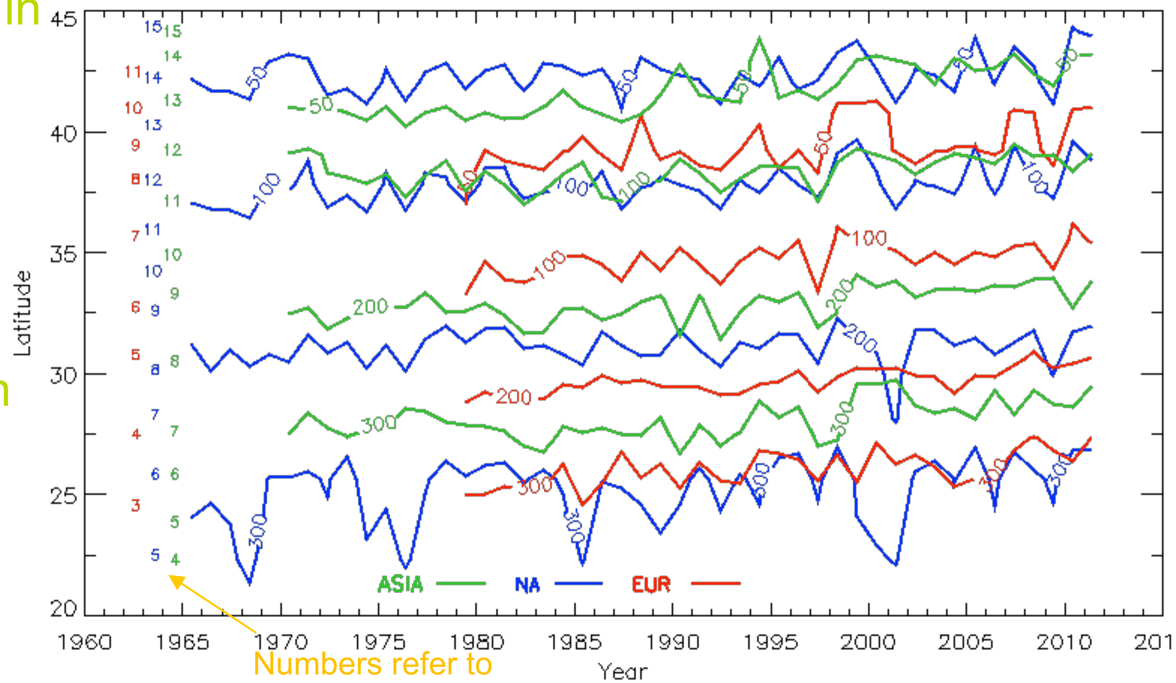
- Less poleward extent in EUR
- 300,200 contours shifted poleward in ASIA
- Thickest in NA

Significantly different variability in NA

- ‘Dips’ on 300 contour
- Responses around 2000
- Volcanic response?

Trends (since 1979)

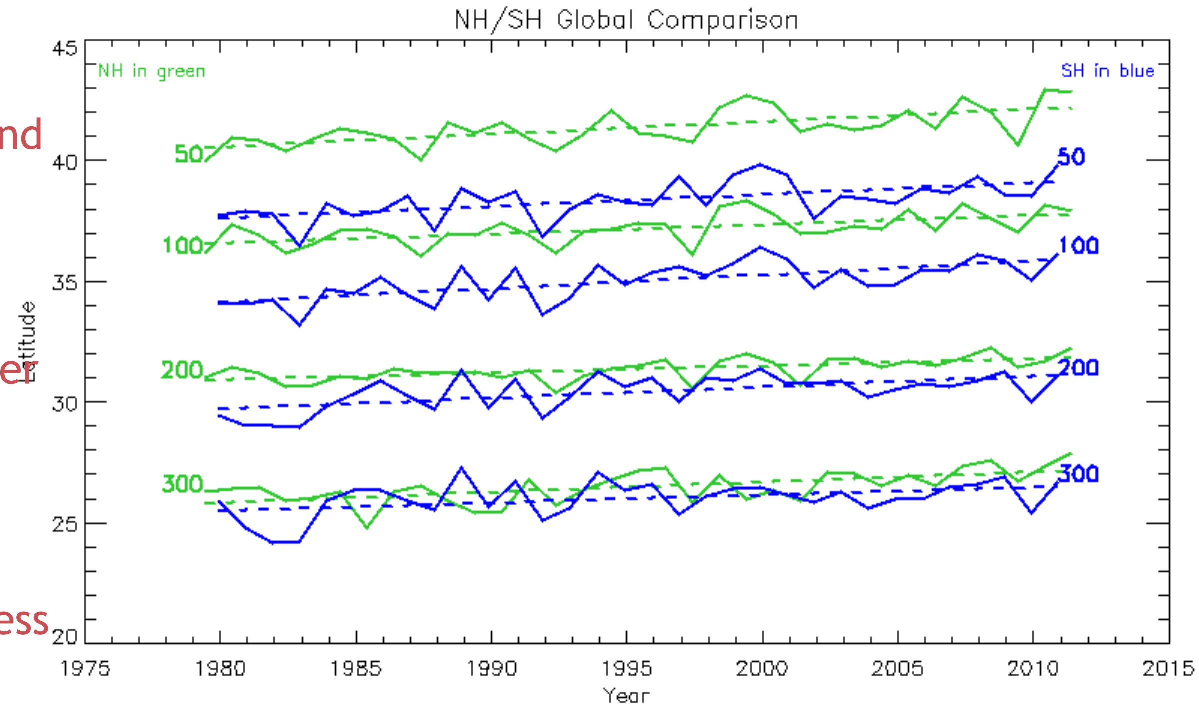
- Largest in ASIA (0.5 - 0.8)
- Insignificant in NA (0-0.3)
- Moderate in EUR (0.4-0.5)



Numbers refer to band locations

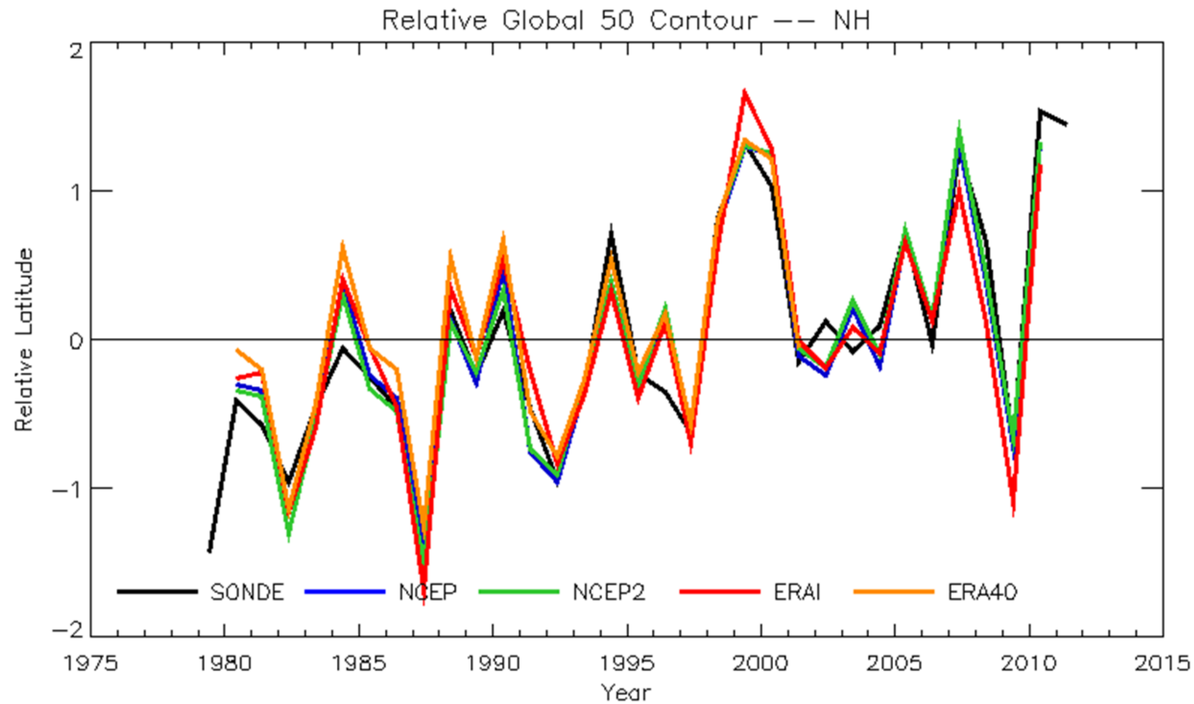
NH/SH ‘global’ comparison

- Subtropics in NH are larger compared to SH
  - Start in same place, but extend further poleward
  - Likely related to greater land are in NH
  - Analogous to finding with other variables (e.g. Ψ)
- Is tropical expansion asymmetric?
  - Trends in SH on 300,100, 50 less reliable (data issues)
  - SH trends are larger on 200,100 contours, but not statistically significantly so (about 1-σ difference)



NH ‘global’ summary

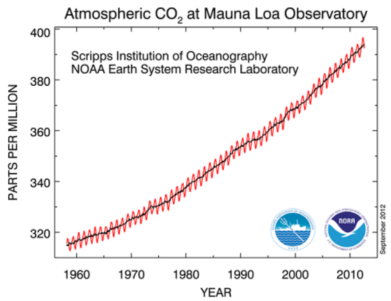
- Weighted average TTD=200 contour across all regions
  - Removing mean position accounts for shift
  - Volcanic response more visi in this view
- Generally good agreement pı to 2002
  - 1987-88?
- Significant differences occur after 2002, just as for SH
  - Suggests inhomogeneity in reanalysis fields
  - Hypothesis: related to significant improvement in satellite instrumentation (AIRS)

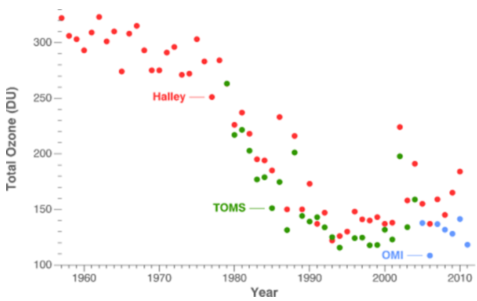


BUT…
There appears to be little sign of this poleward of 35 N…data match up very well there

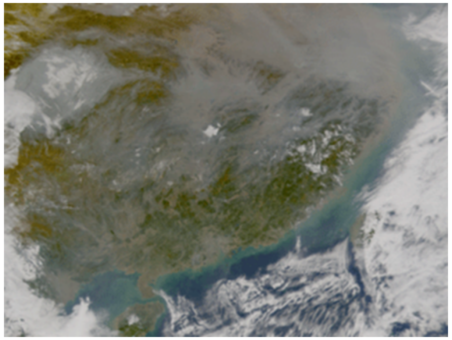
Forcings of tropical expansion

1. Carbon Dioxide + other GHG





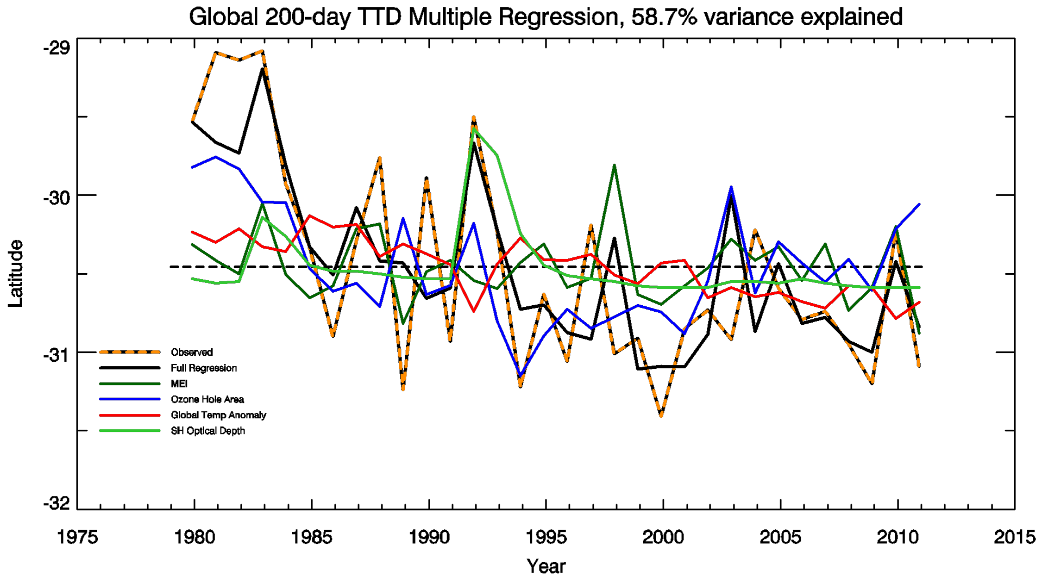
2. Stratospheric Ozone Depletion



3. Aerosol – Direct and Indirect Effects

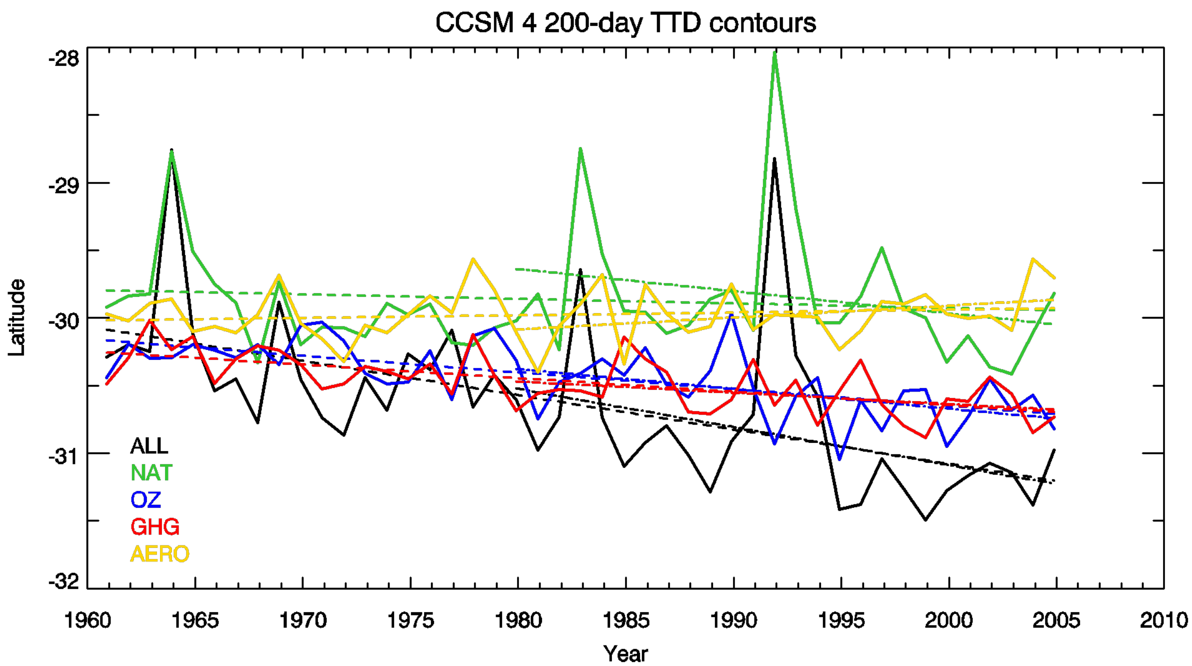
4. Natural Variability – e.g. volcanic eruptions, ENSO

Observations -- Multiple Linear Regression



- 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 correlation between these two variables is problematic in the analysis, yielding different results. Assign a range based on the two regressions:10-40% of total trend is due to global temperature (i.e. GHG increase), the remainder (60%-30%) is due to ozone depletion. The first number of the range is the value with SH temperature

Modelling – CCSM4 Single Forcing Runs



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 of individual forcings add up to that in the ALL experiments
- From 1960, O3 and GHG are the dominant forcings. NAT and AER result in small trends
- No relationship is observed with a model-derived Southern Oscillation Index (SOI)

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

Summary

- The rate of tropical expansion is towards the low end of the range of measurements…on the order of 0.5 degres/decade since 1979
  - This rate may be overestimated due to natural variability at start of period
  - Amplification of expansion rate in late 1960s
  - Regional and hemispheric differences in expansion observed
- Reanalyses have homogeneity issues
  - Trends may not be trustworthy

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