



South Eastern Australian Climate Initiative

Observation of the Hadley Cells

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Outline



- Annual cycle of the Hadley circulation in the reanalyses
- Interannual variability
 - Impact of the El-Niño Southern Oscillation (ENSO)
 - Relationship with variability of global surface temperature and sub-tropical ridge (STR)
- Changes over the last 30 years?
 - Relationship with global warming and trends in STR

Data and methods

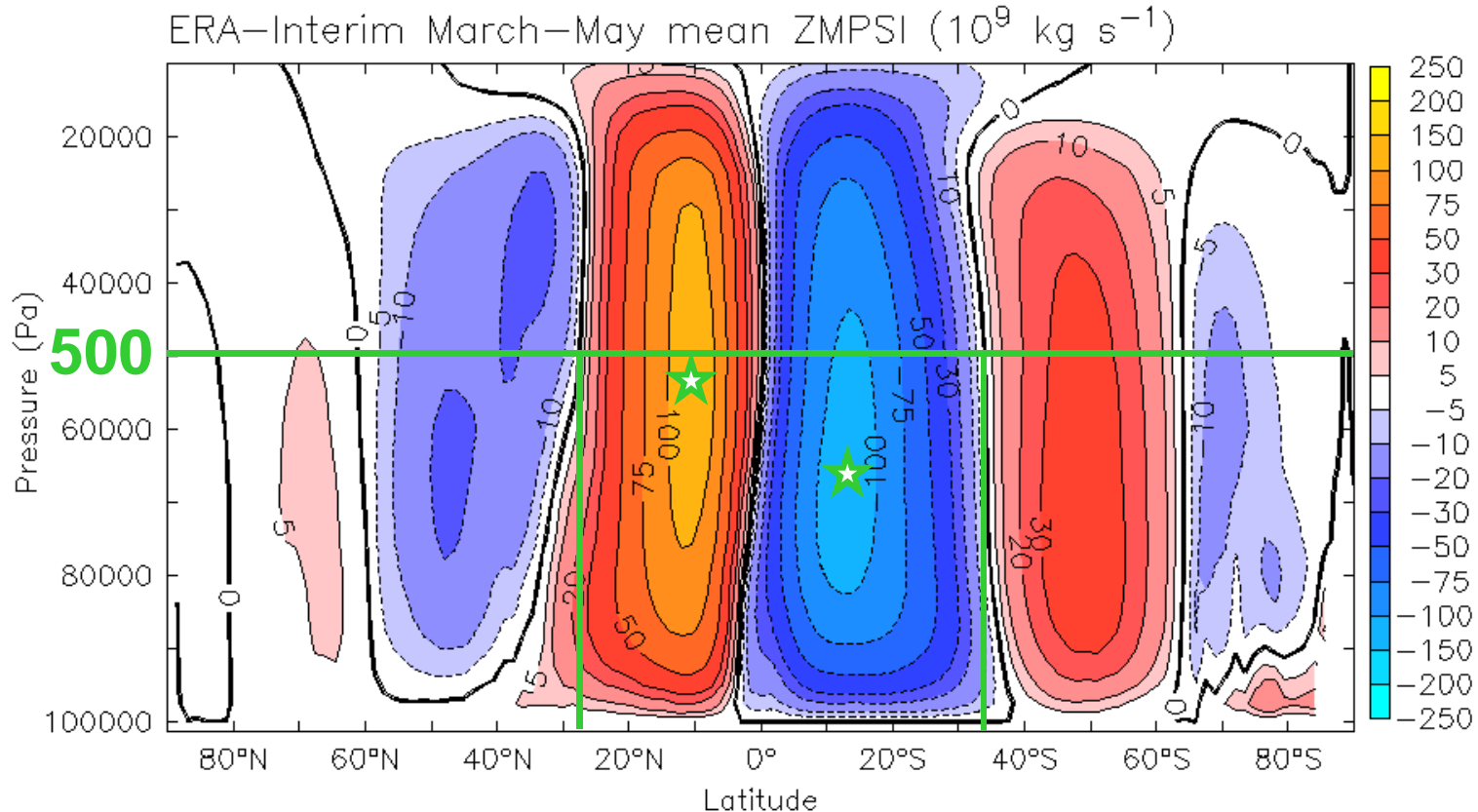


- Seven reanalysis monthly data sets are used:
 - Three from the NCEP (NCEP-NCAR, NCEP-DOE II, CFSR)
 - Two from the ECMWF (ERA40 and ERA-Interim)
 - One from the NASA (MERRA)
 - One from the Japan Meteorological Agency (JRA25)
- Common period used is 1979-2009 with exception for the ECMWF → multi-linear scaling.
- The Hadley cells are defined using the zonal mean meridional streamfunction.

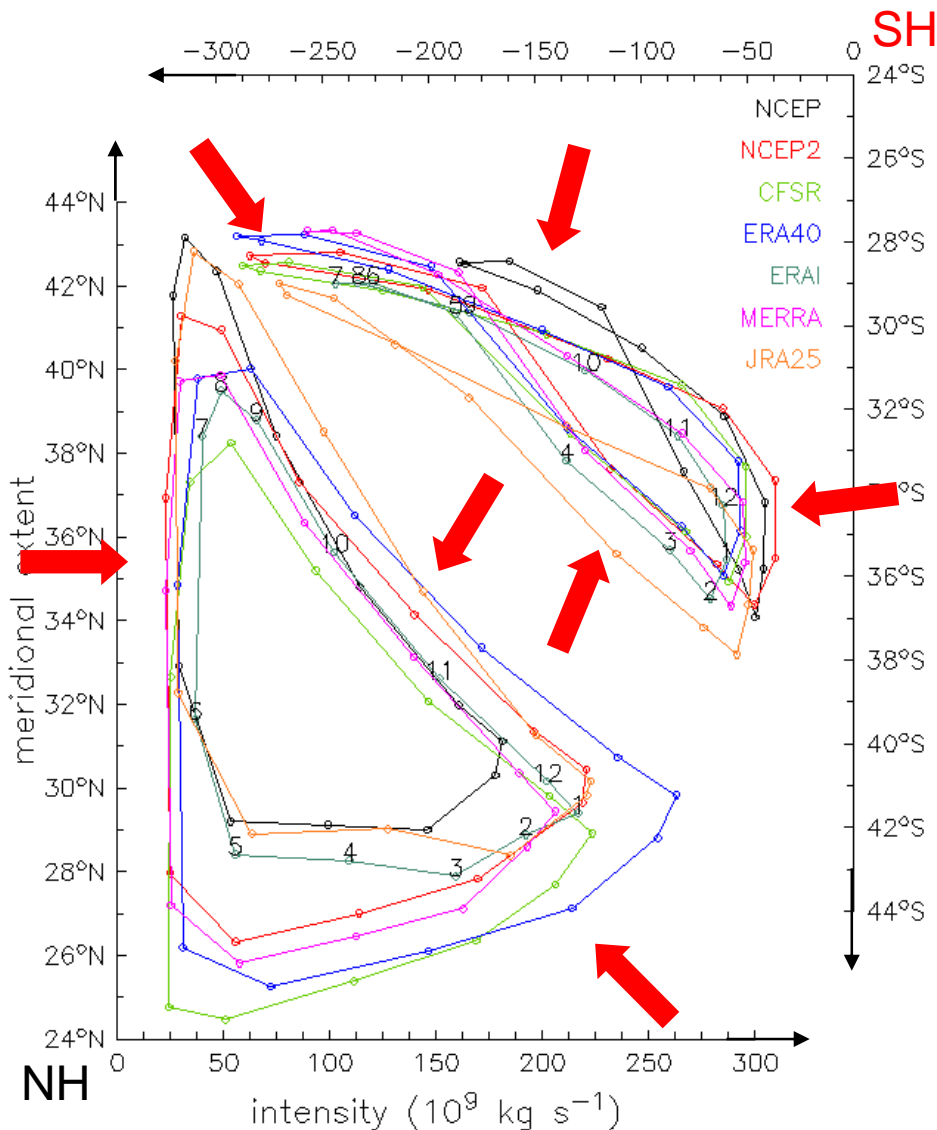
Characterisation of the Hadley cells



$$\psi_x(p, y) = \frac{2\pi a \cos(y)}{g} \int_p^{P_s} V(p, y) dp \quad (\text{Buja, 1994})$$



Annual cycle of the Hadley cells



Mean features of the annual cycle

Northern cell has triangular shape:

- Rapid weakening, slow narrowing from Jan to Jun.
- Rapid widening → Aug.
- Gradual strengthening and narrowing → Jan.

Southern cell cycle is more complex:

- Rapid widening from Dec to Feb.
- Rapid strengthening and narrowing → May.
- Further strengthening → Jul.
- Gradual weakening and widening → Dec.

Notable discrepancies amongst data sets

NCEP: Northern cell shifted polewards.
Southern cell weaker, tends to shift equatorward

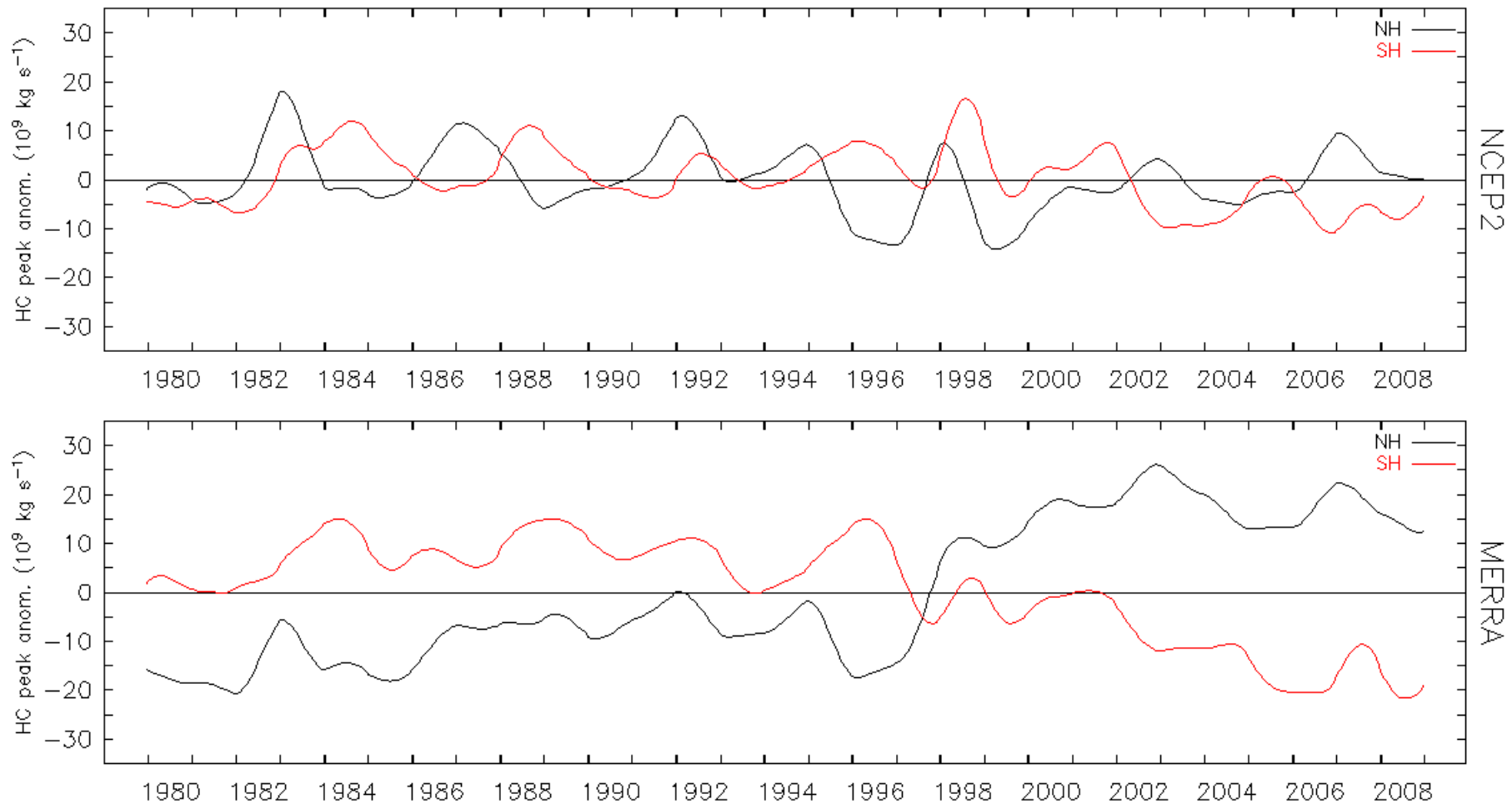
JRA25: Northern cell similar to NCEP
Southern cell shifted polewards by about

2°

Interannual variability



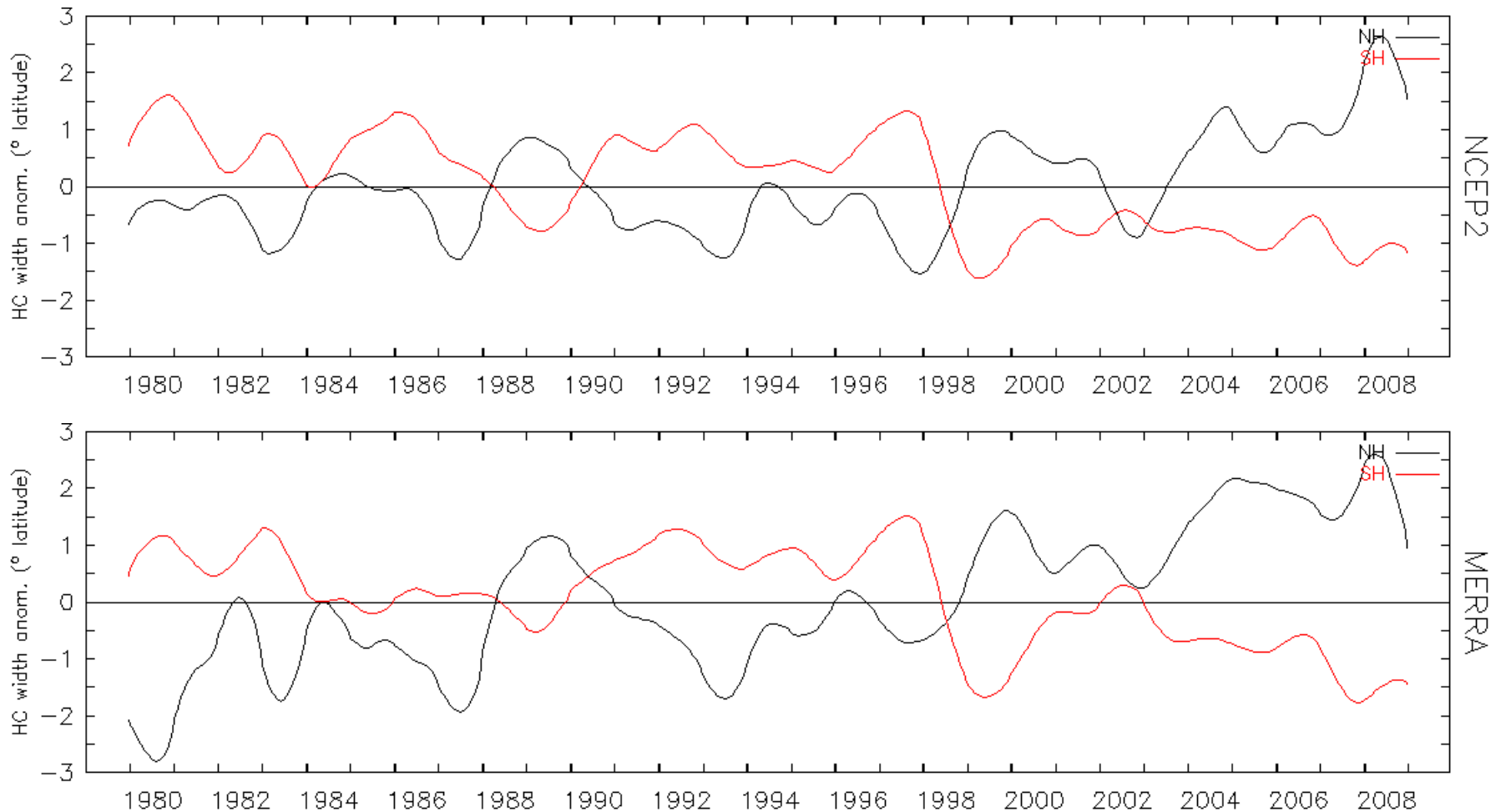
Low-pass filtered anomalies of the Hadley cells intensity



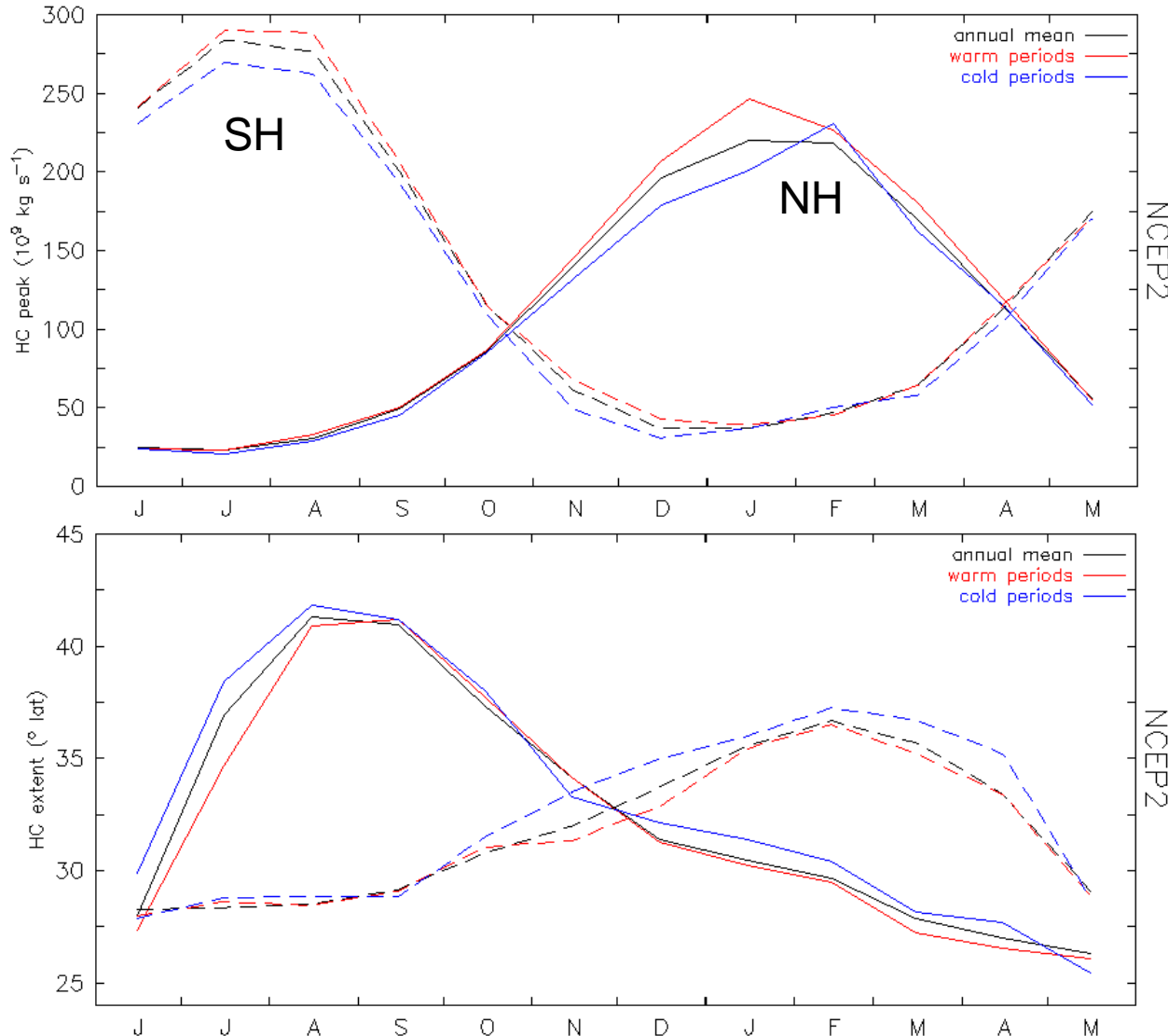
Interannual variability



Low-pass filtered anomalies of the Hadley cells extent



Impact of the ENSO: NCEP2



The ENSO index is obtained from the CPC NOAA Oceanic Nino Index (ONI).

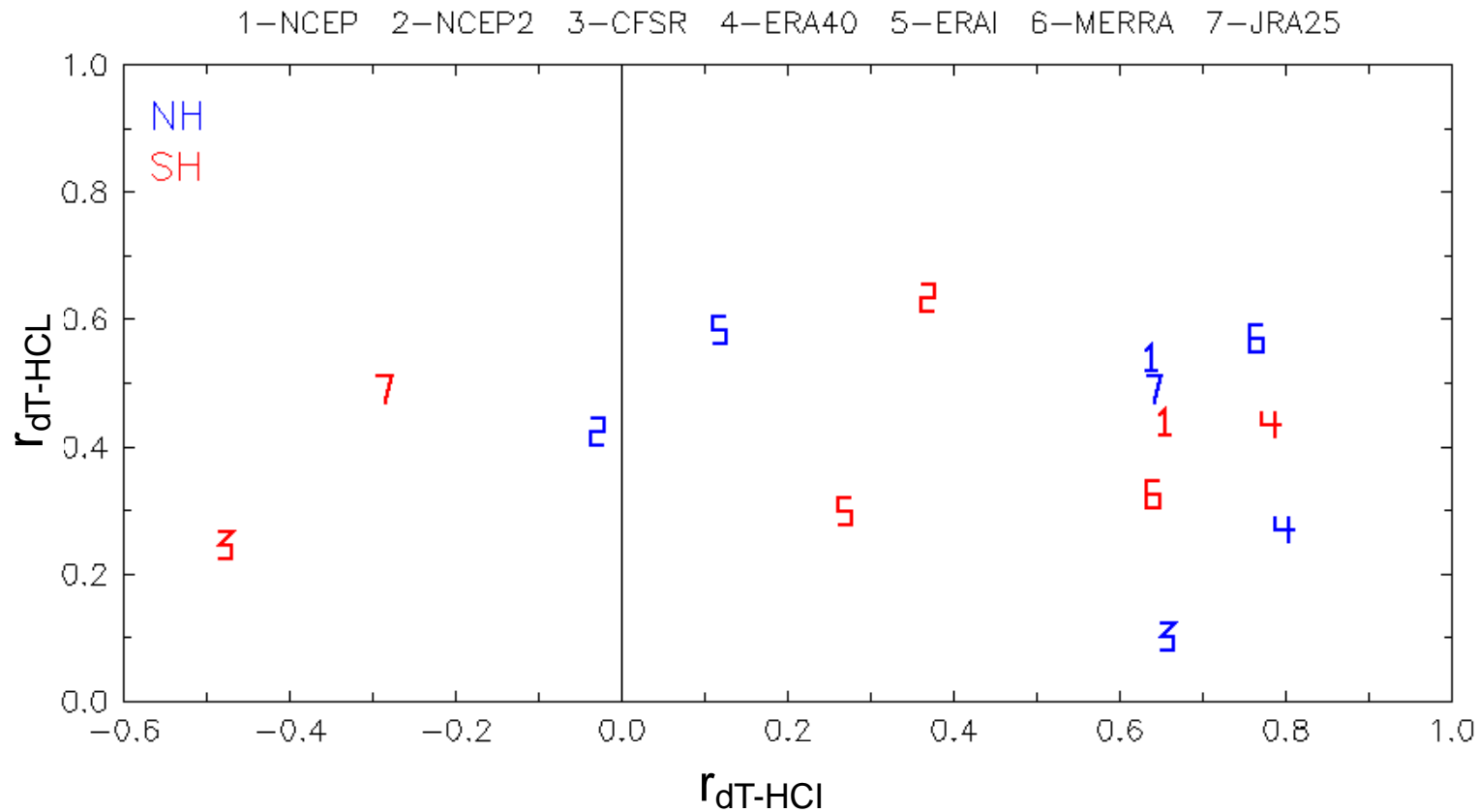
During 1979-2009: 10 warm and 7 cold episodes

Intensification and narrowing of the HC during warm periods.

Weakening and widening of the HC during cold periods.

Anomalies associated with sampling?

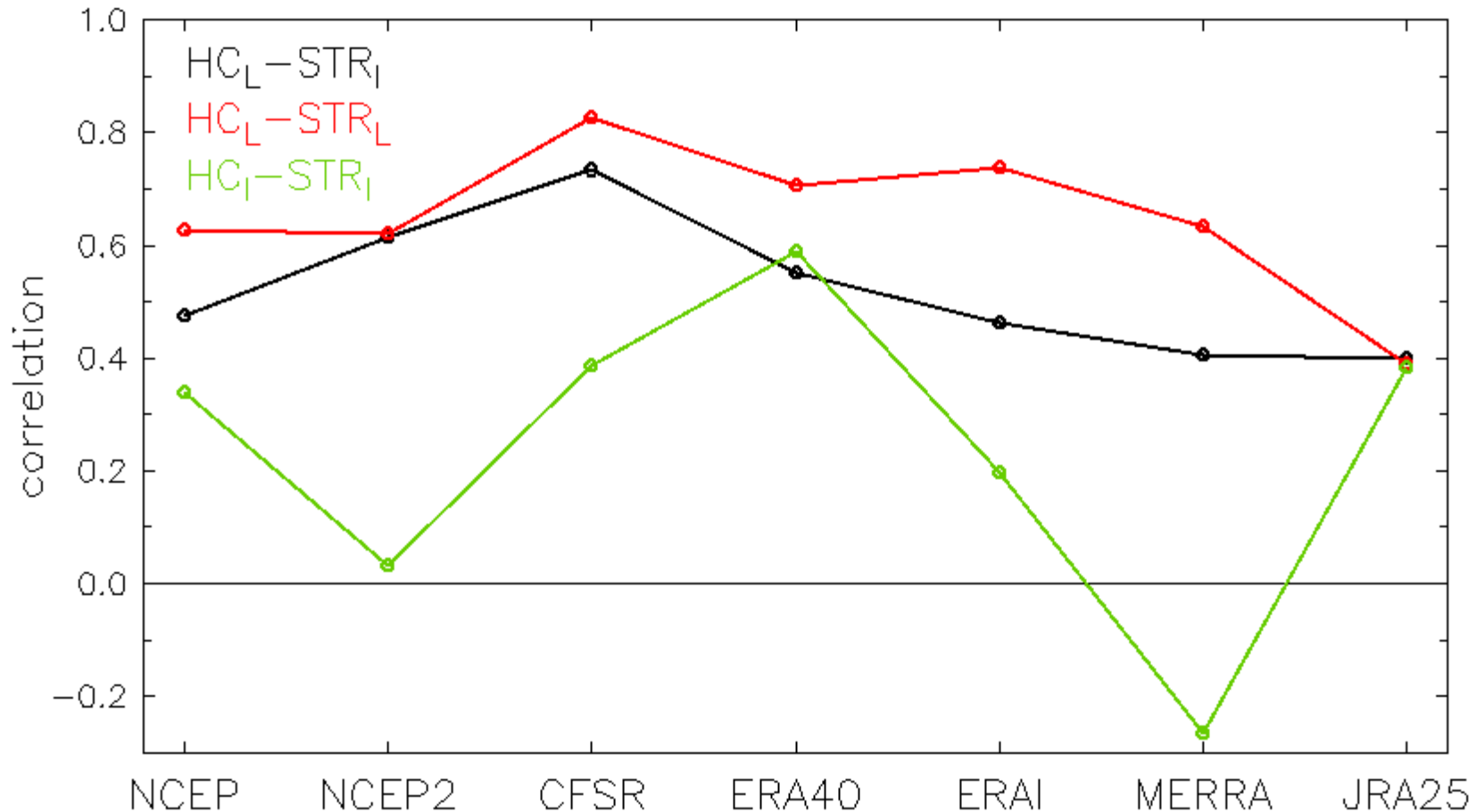
Correlation between HC and global surface temperature anomalies



Variability in HC extent and global dT **always** positively correlated (mean: $r \sim 0.4$)

Variability in HC intensity and dT positively correlated (can be high but inconsistent)

Correlation between HCSH and STR

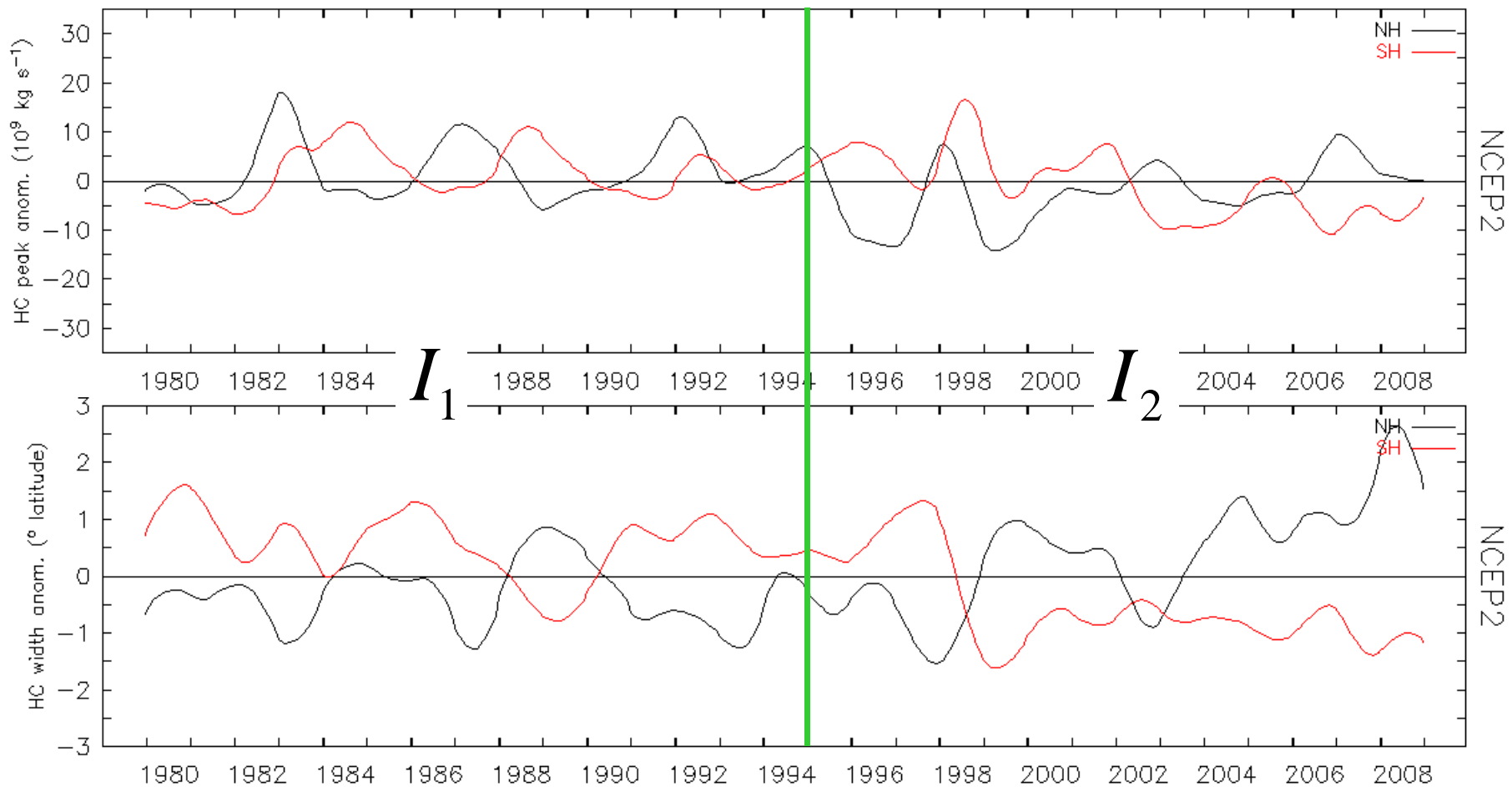


Variability in HC extent is related to **both variability in STR location** and **intensity**
No significant correlation between variability in HC intensity and variability in STR

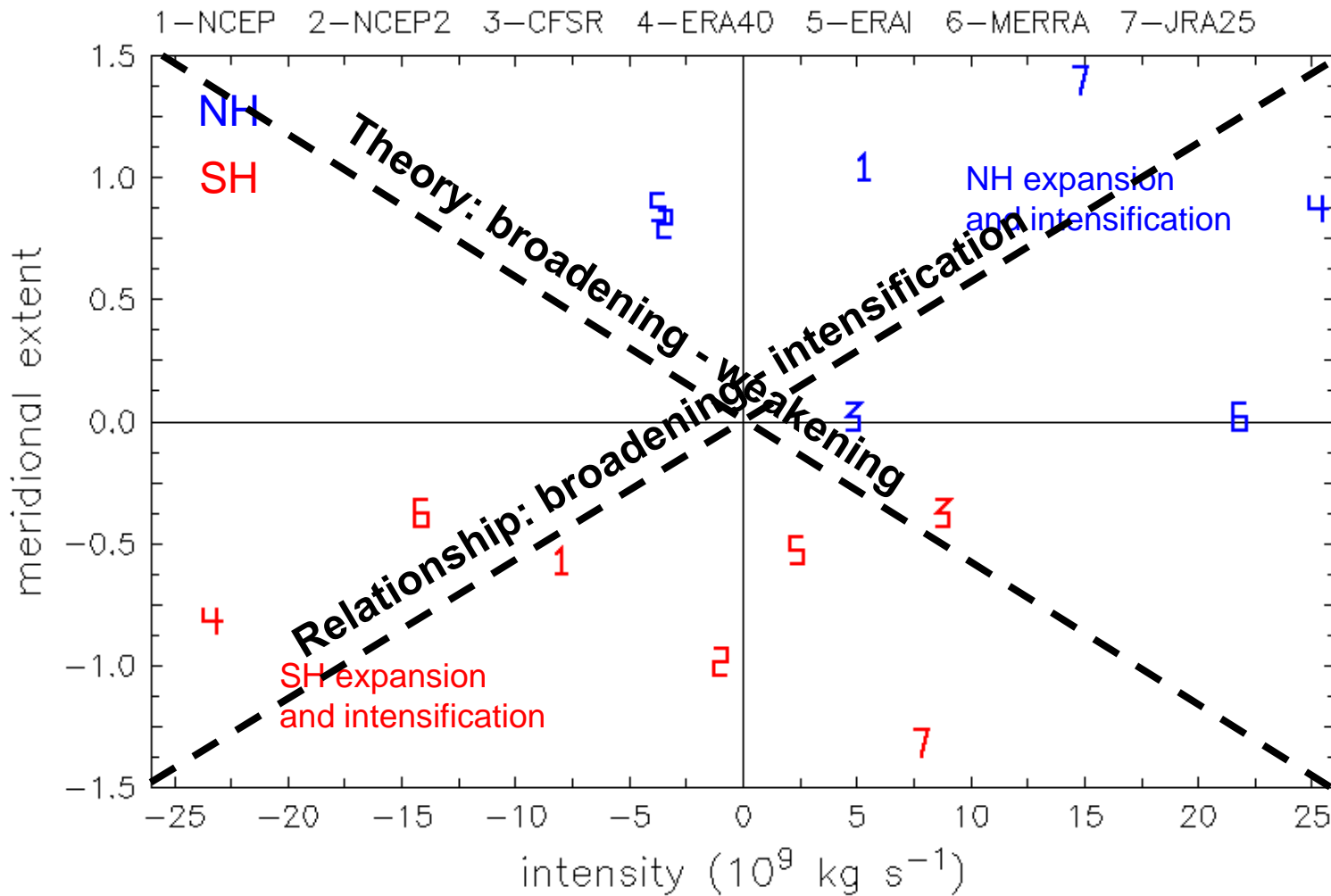
Trends: definition



$$\Delta_I = I_2 - I_1$$



Trends in HC (intensity & expansion)



Expansion in both Hemispheres.

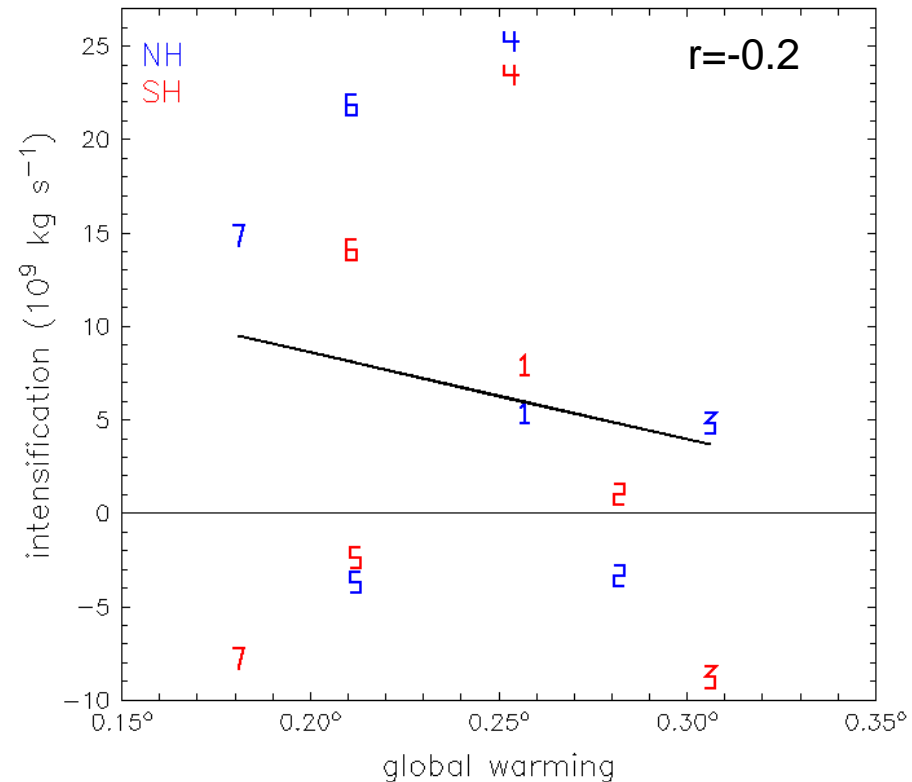
Disagreement between datasets in intensification :

- ERA-Interim is weakening in both hemispheres;
- NCEP2 in the NH;
- CFSR and JRA25 in the SH.

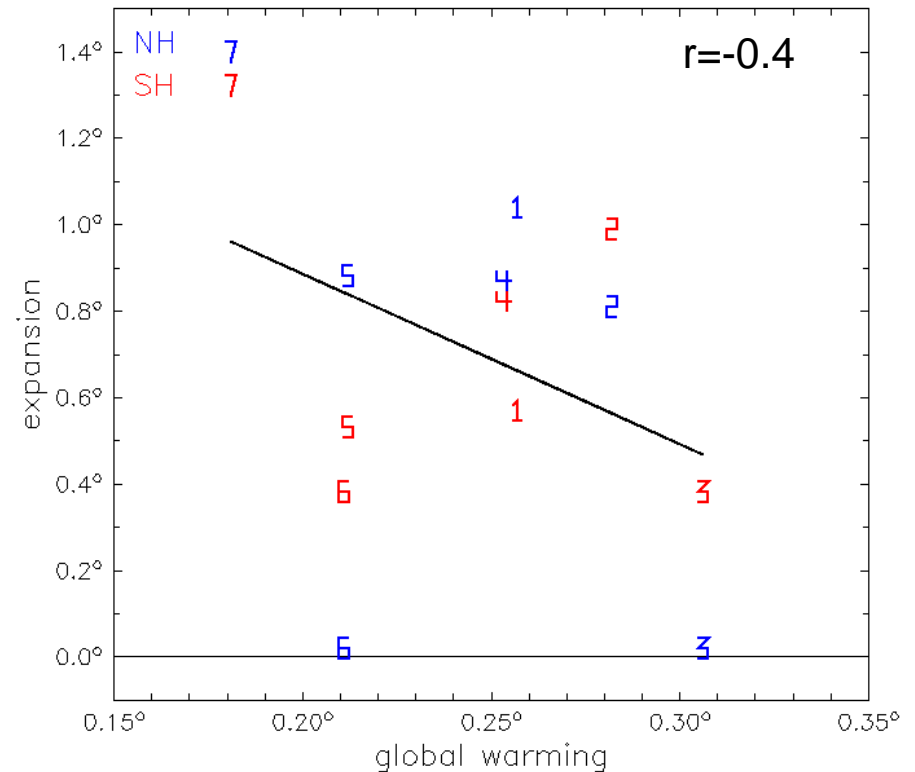
Relationship with global warming



1-NCEP 2-NCEP2 3-CFSR 4-ERA40 5-ERA1 6-MERRA 7-JRA25

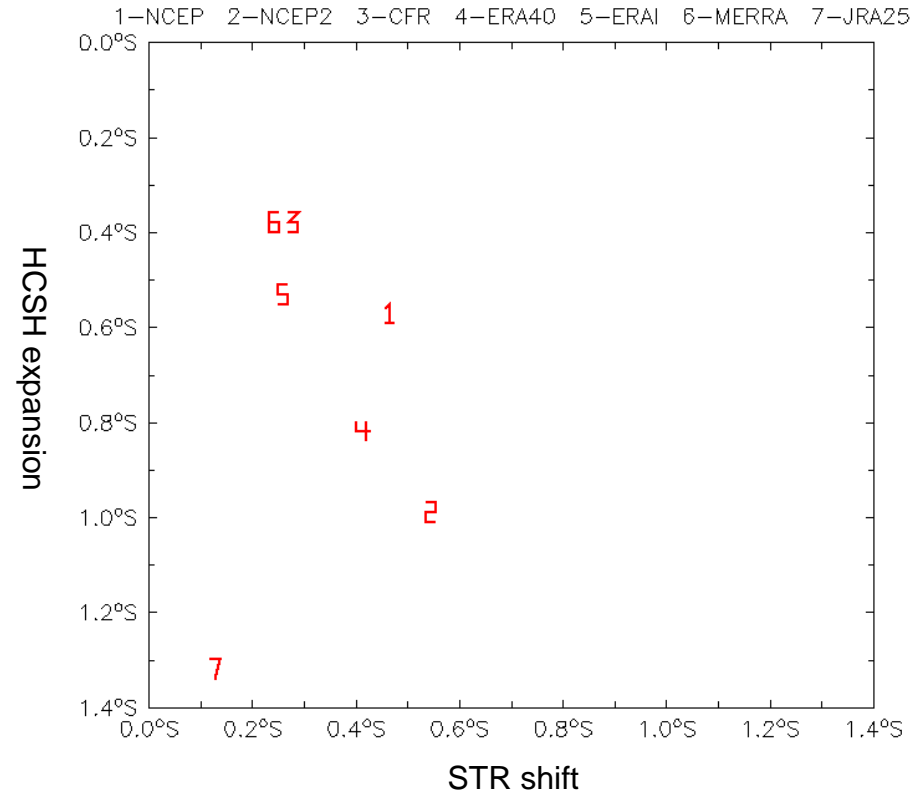
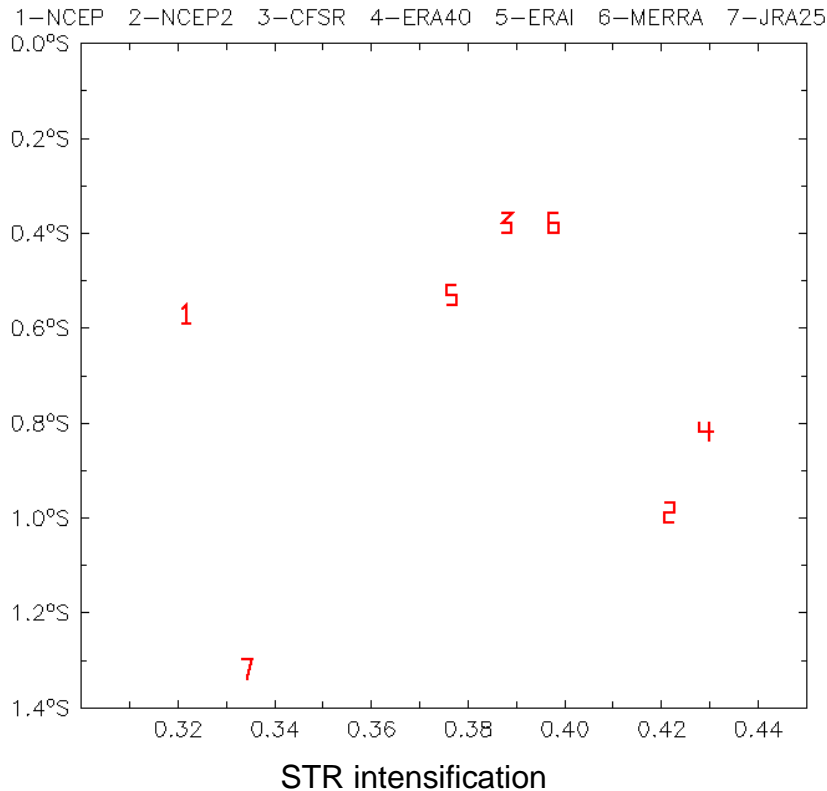


1-NCEP 2-NCEP2 3-CFSR 4-ERA40 5-ERA1 6-MERRA 7-JRA25



Relationship between HC intensification and global warming is unclear
Hint to a negative relationship between HC expansion and global warming

Relationship with surface sub-tropical climate



The STR tends to intensify and be shifted polewards with respect to the HCSH expansion, with a ratio of 1 to 2 (consistent with Kang & Polvani, J. Clim, 2011).

Note: JRA25 often an outlier (overall poor performance)

no significant relationship was found with the HCSH intensity.

Summary: Annual cycle



- Climatology generally in agreement amongst the datasets except for NCEP and JRA25.
- Clearly defined seasonality
- Marked hemispheric differences
 - Different seasonality
 - NH extent range larger than SH
 - NH intensity range weaker than SH

Summary: Interannual variability



- Strong interannual variability in both intensity and extent.
- Notable discrepancies between the data sets, especially for the intensity.
- Influence from the ENSO is weak.
- Post-1996 change observed in all data sets needs further investigation (i.e. relationship to the rainfall decline in South-East Australia)
- Positive correlation between HC extent anomalies and dT ($r \sim 0.4$) (possibility to attribute).
- Correlation between HC intensity anomalies and dT is inconsistent amongst the data sets.
- Both STR intensity and position anomalies are positively correlated with HC extent ($r = 0.52$ and 0.64 respectively).

Summary: Trends



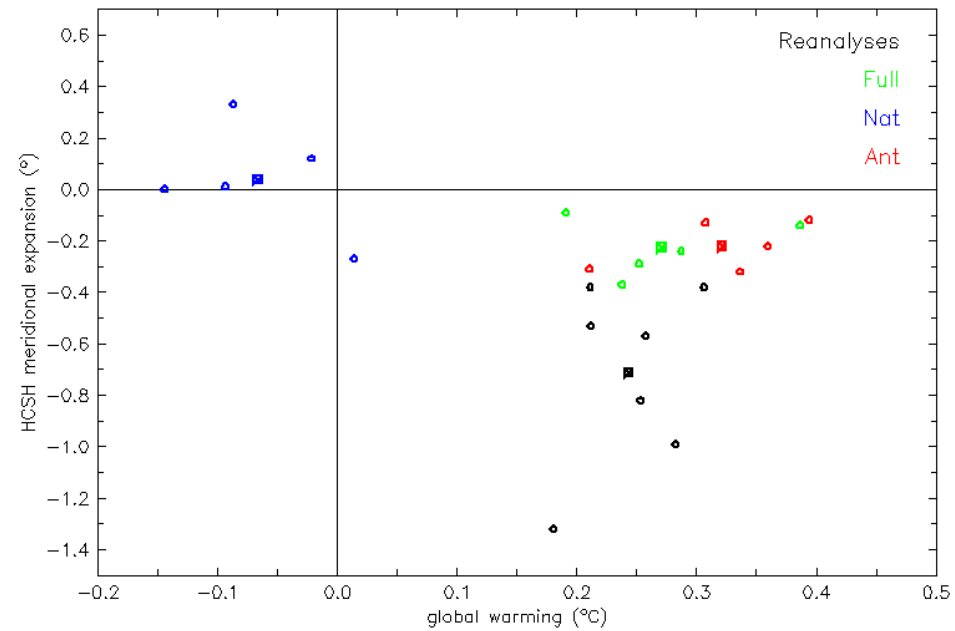
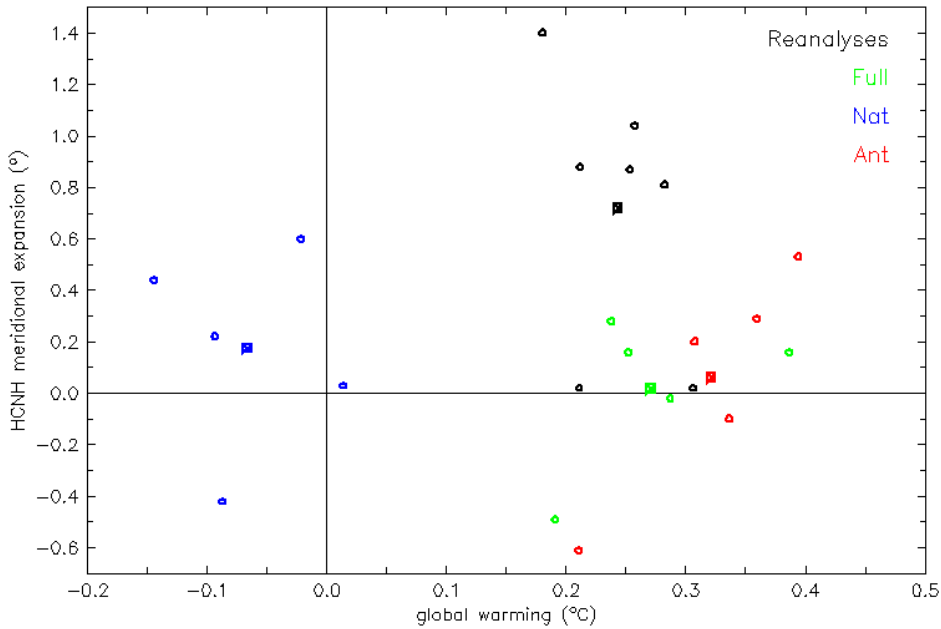
- Agreement on expansion in both hemispheres.
- Most (but not all) data sets show intensification.
- A potential decline of HC expansion under global warming
- HCSH expansion is associated with STR intensification and poleward shift with a 1 to 2 ratio



Anthropogenic forcing on HC expansion



Runs from CCSM3 model



Anthropogenic forcing on STR



Runs from CCSM3 model

