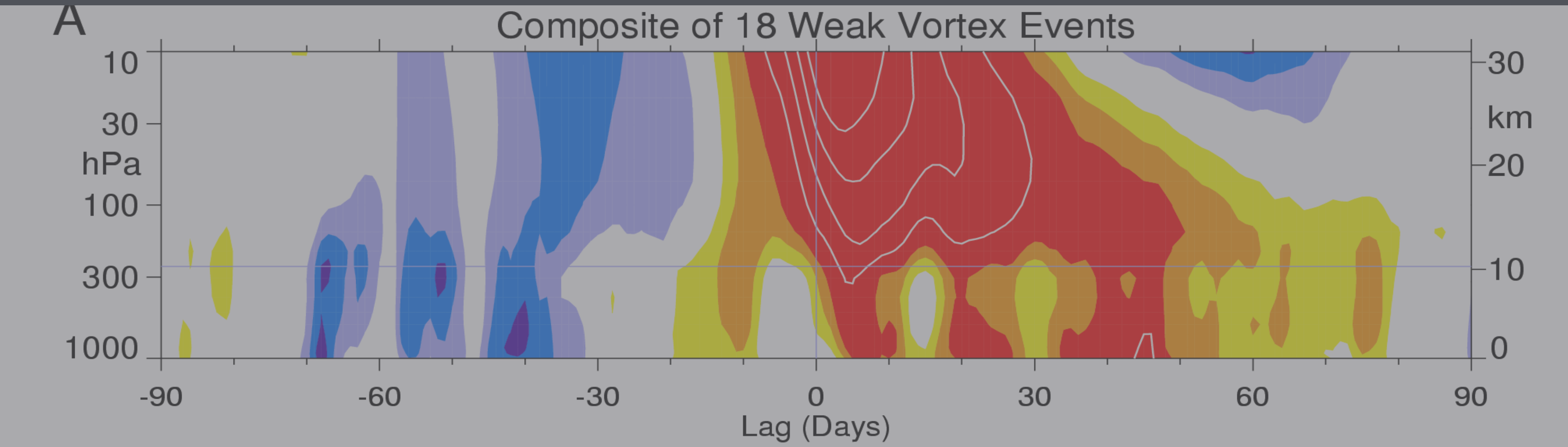
METEOROLOGY

University of Reading

ATMOSPHERIC TELECONNECTIONS: FROM CAUSAL ATTRIBUTION TO STORYLINES OF CIRCULATION CHANGE

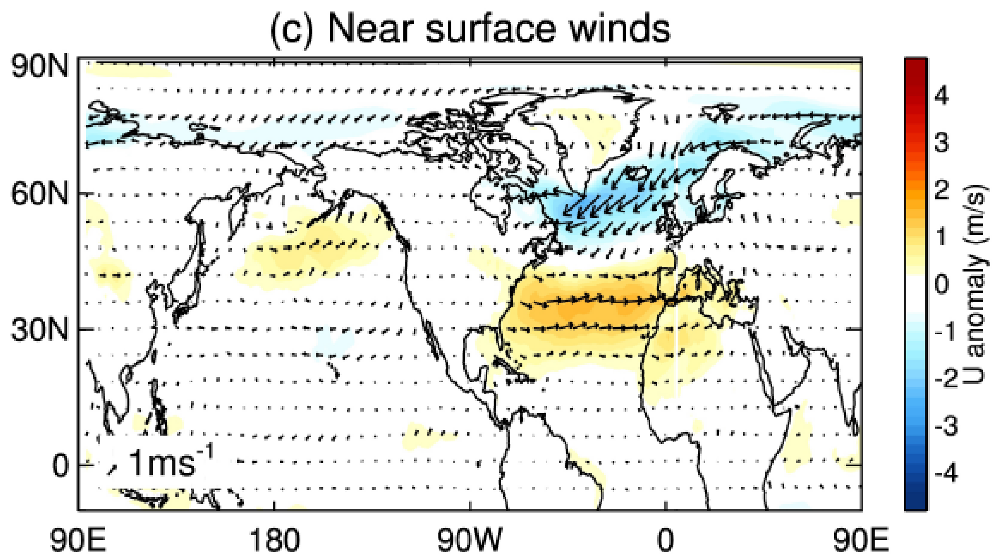


Ted Shepherd
Grantham Chair of Climate Science

European Research Council
Established by the European Commission

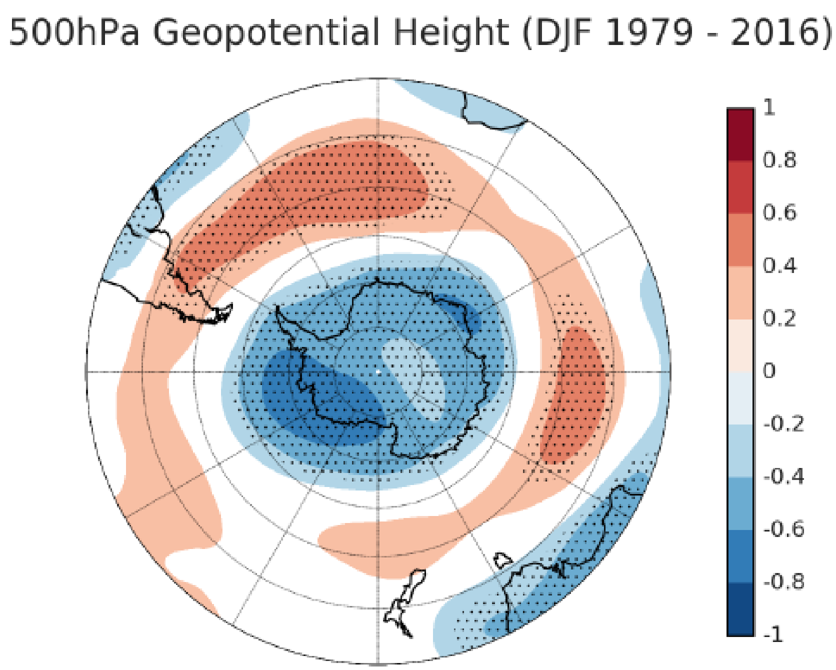
- **Stratosphere-troposphere coupling:** stratospheric polar vortex variability affects tropospheric circulation

NH: response for 30 days after SSW



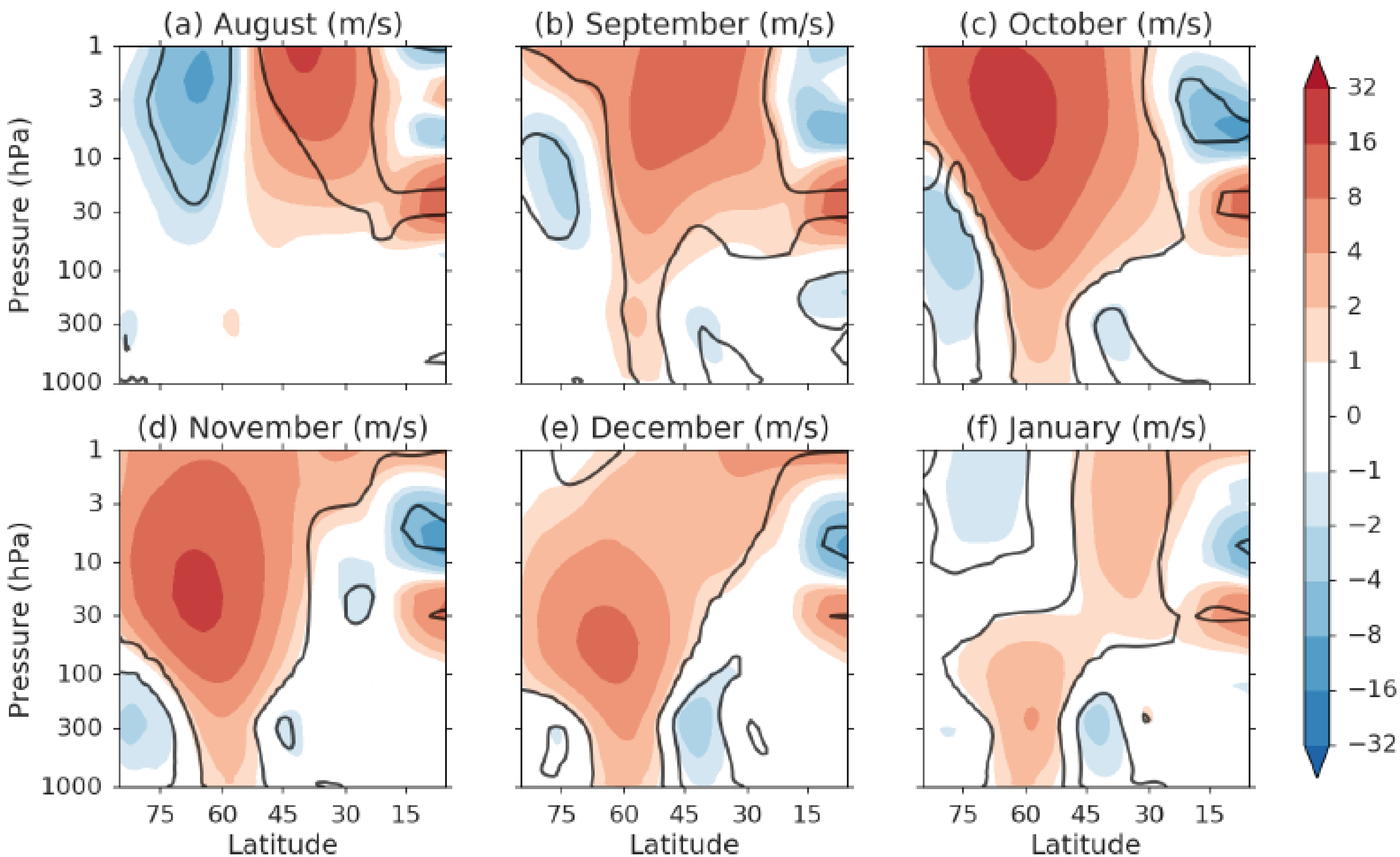
Hitchcock & Simpson (2014 JAS)

SH: correlation with vortex breakdown date



Byrne & Shepherd (J. Clim., submitted)

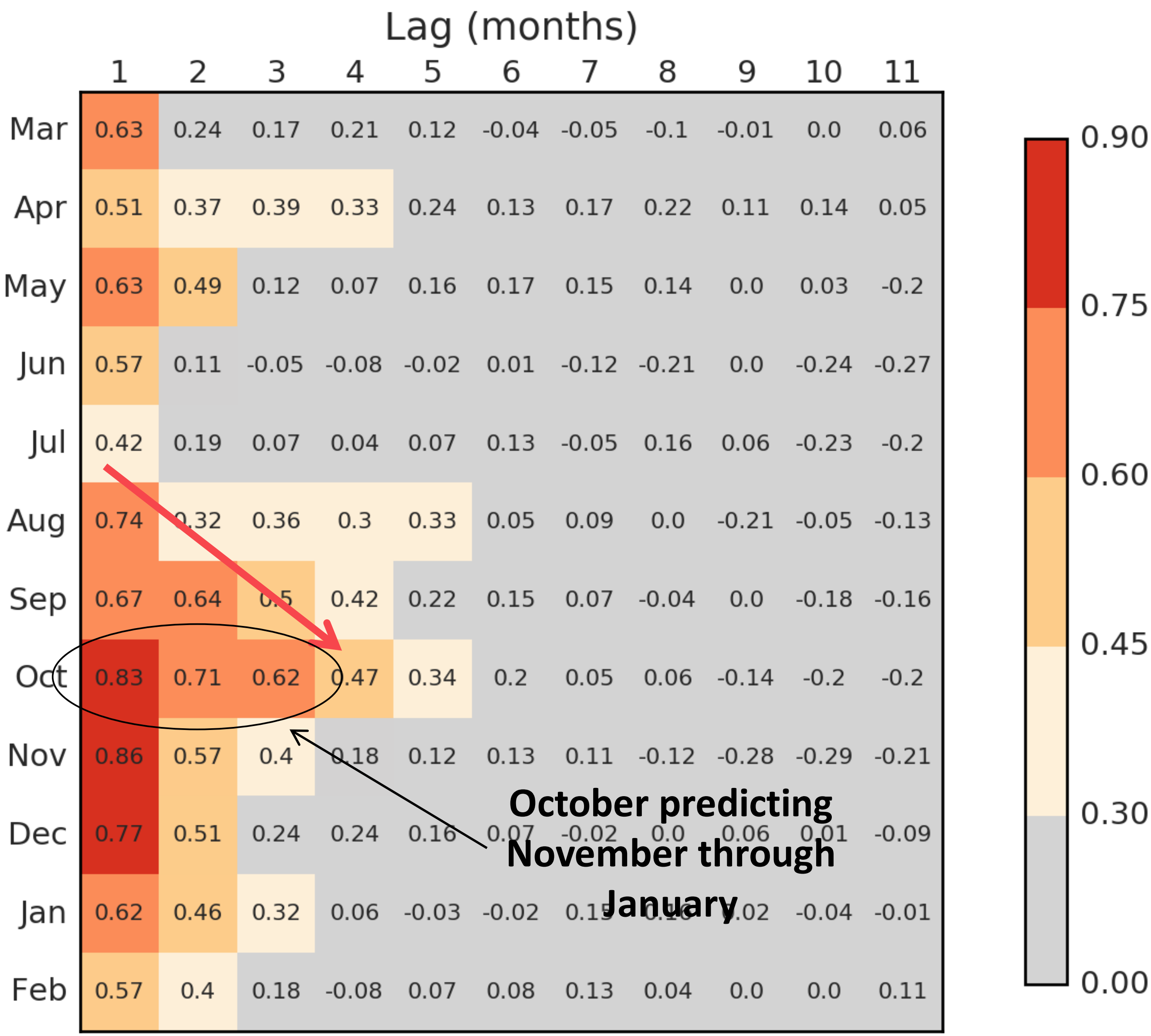
- Variability in the SH vortex breakdown has **intraseasonal coherence** (cf. PJO); 2 std of EOF explaining 73% of variance
  - Suggests potential for seasonal predictability



Zonal mean zonal wind

Byrne & Shepherd (J. Clim., submitted)

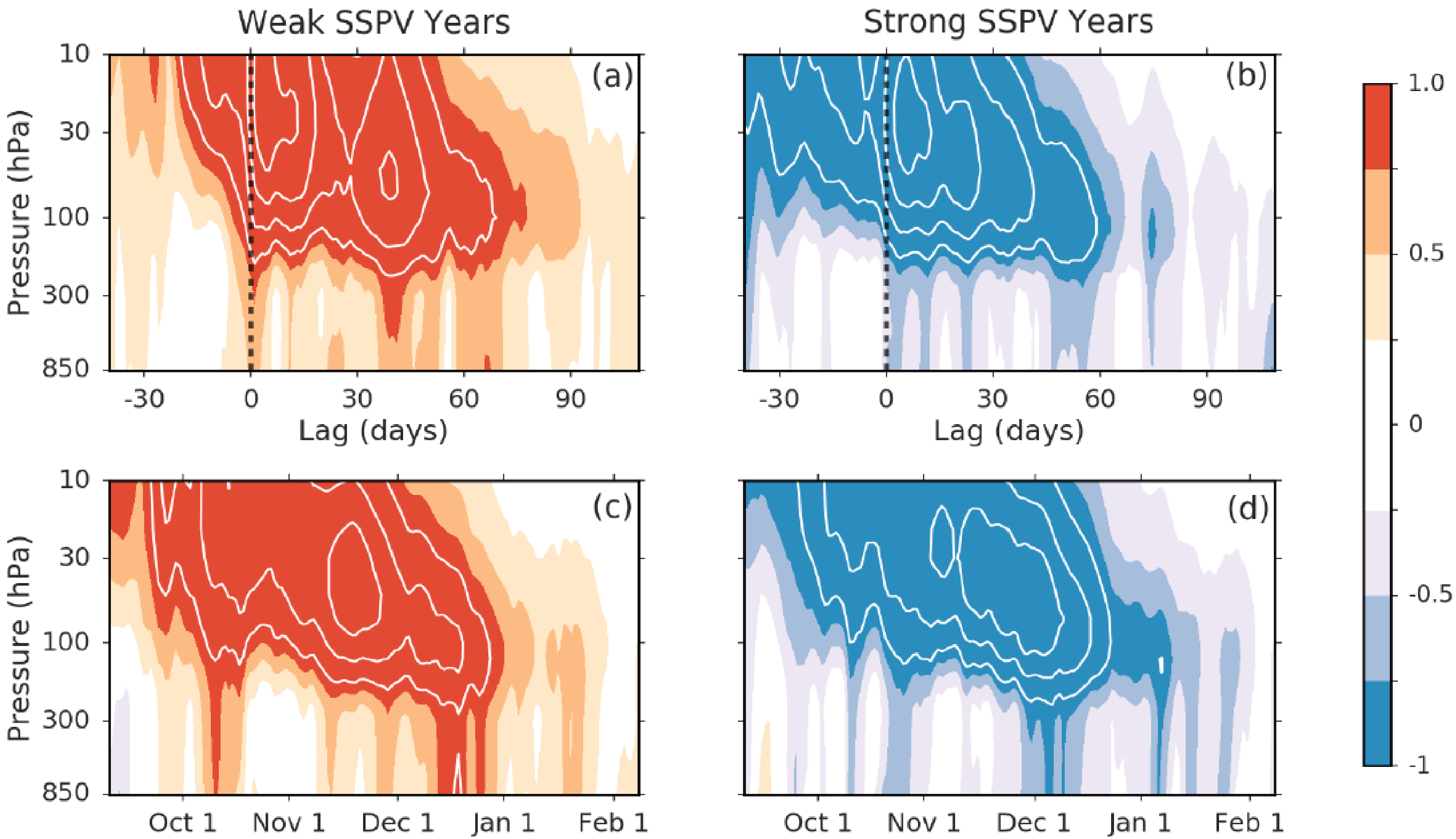
- Autocorrelations of monthly mean 30 hPa polar vortex anomalies



Anomalies build up through late winter/early spring, provide predictability through late spring/early summer

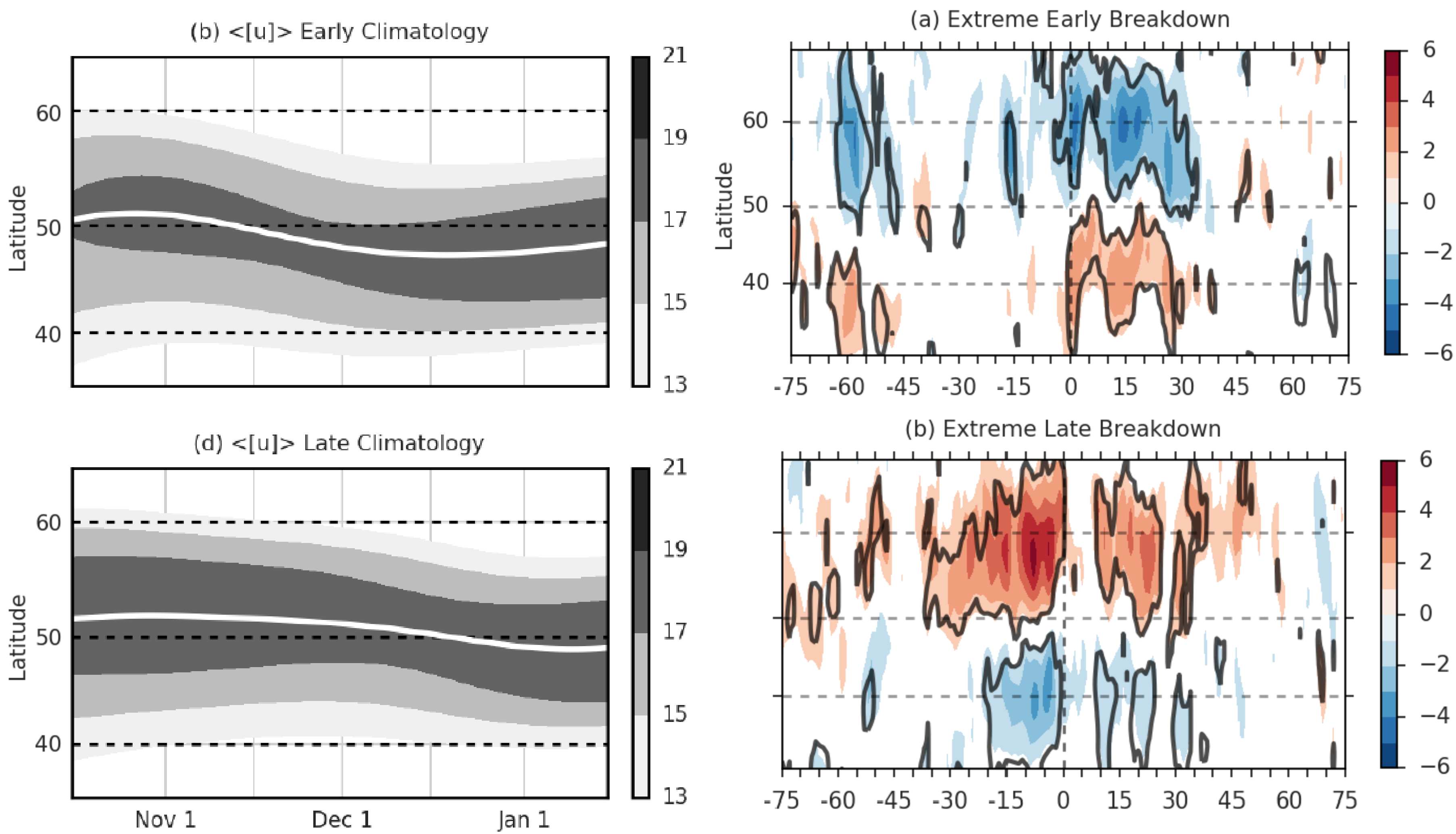
Byrne & Shepherd (J. Clim., submitted)

- Downward propagation of anomalies is just as apparent when plotted against calendar date vs relative to SSPV anomaly
  - Plots show annular mode indices ('dripping paint' plots)



Byrne & Shepherd (J. Clim., submitted)

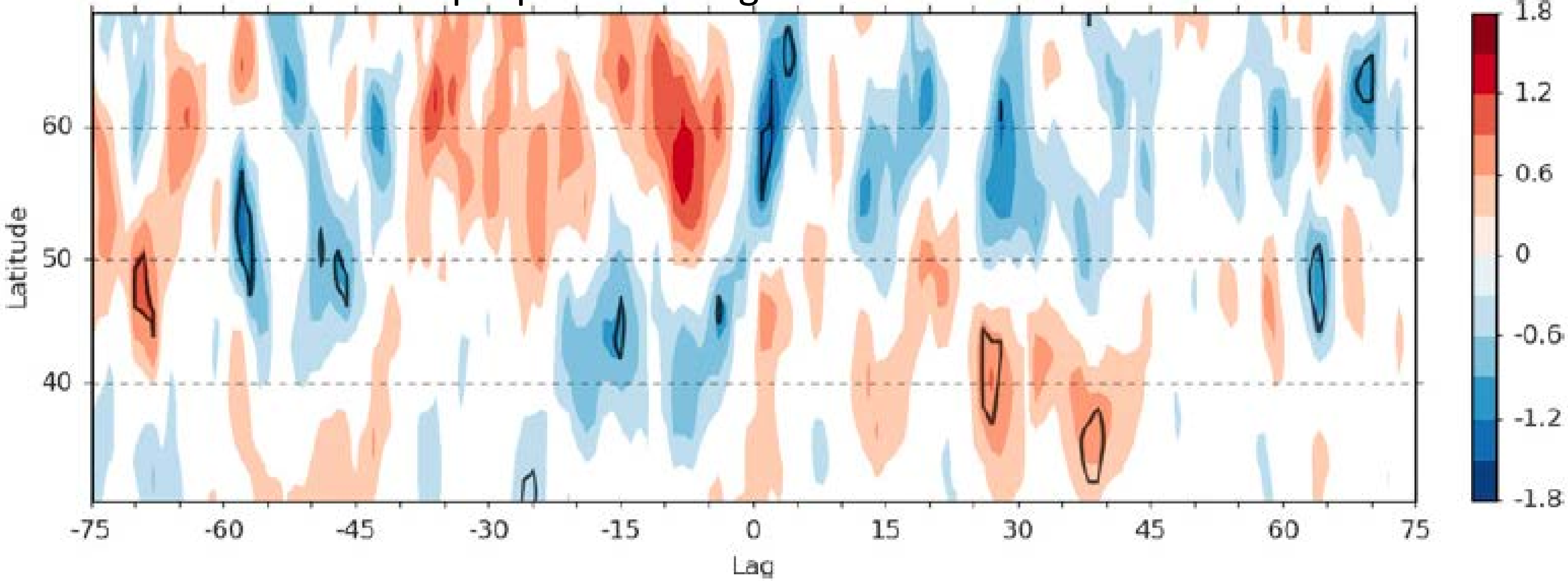
- Timing of the stratospheric vortex breakdown affects the tropospheric midlatitude jet; **tropospheric anomalies are completely different for early and late breakdown events**



Byrne, Shepherd, Woollings & Plumb (2017 J. Clim.)

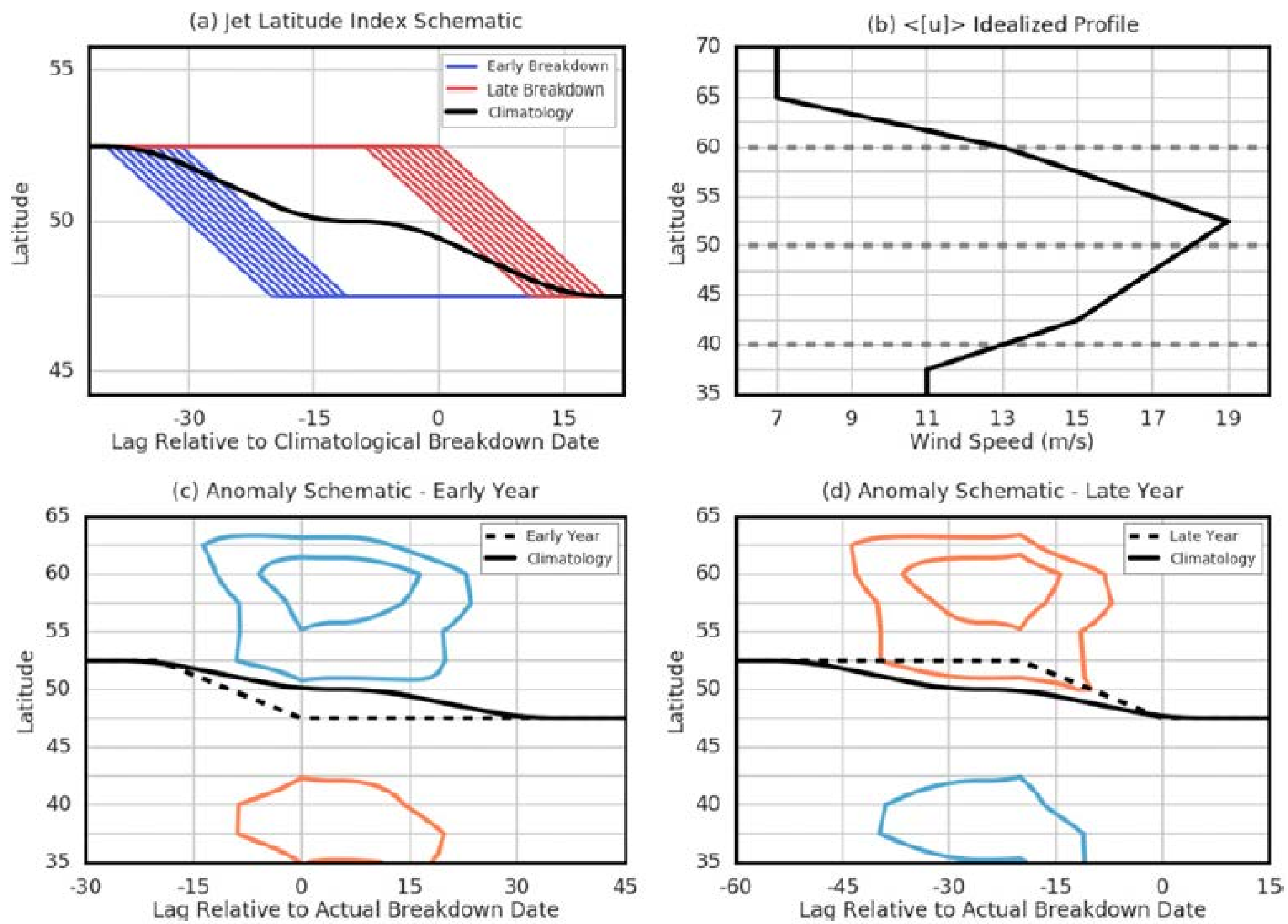
- When all anomalies are composited together (as in Black & McDaniel 2007 JAS), the very different features get diluted and lose statistical significance (note different colour scale)
  - This is *prima facie* evidence for **non-stationarity**

Tropospheric average zonal mean zonal wind



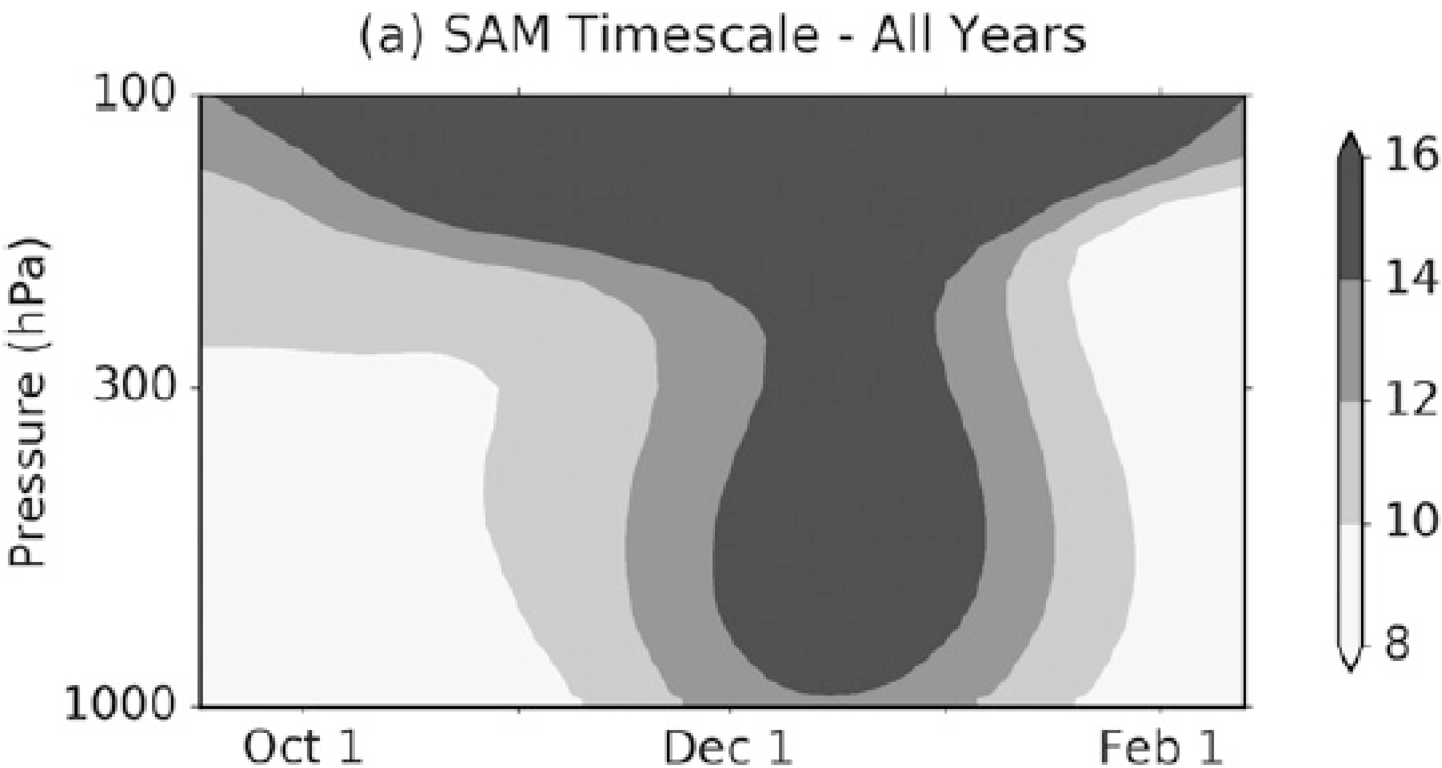
Byrne, Shepherd, Woollings & Plumb (2017 J. Clim.)

- The summertime equatorward shift of the tropospheric jet is a **regime transition**, mediated by the vortex breakdown
  - Explains anomaly patterns; the regime transition is a rapid phenomenon, but gets smoothed out in the climatology



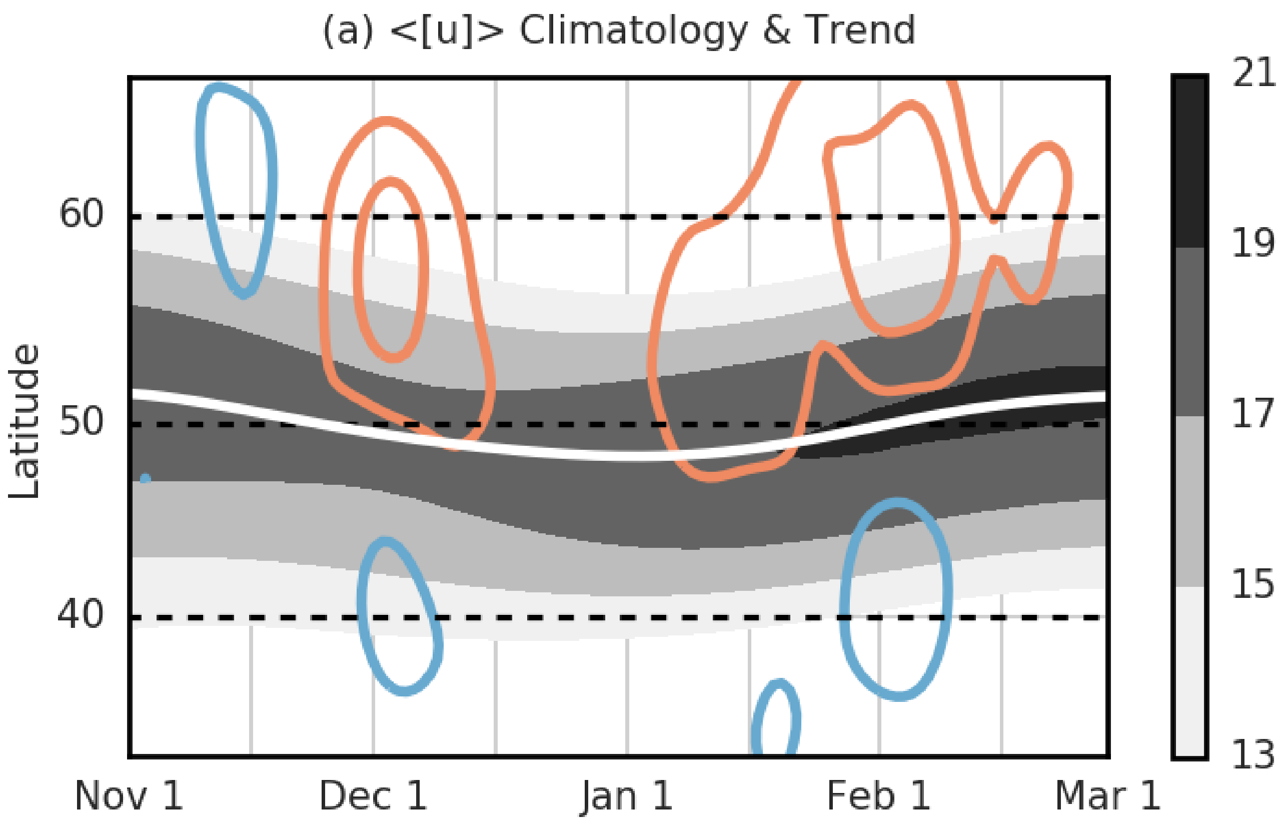
Byrne, Shepherd, Woollings & Plumb (2017 J. Clim.)

- This accounts for the **very long SAM persistence timescales** (deduced from anomaly autocorrelations) around the time of the vortex breakdown
  – No need to consider tropospheric eddy feedback mechanisms



Byrne, Shepherd, Woollings & Plumb (2017 J. Clim.)

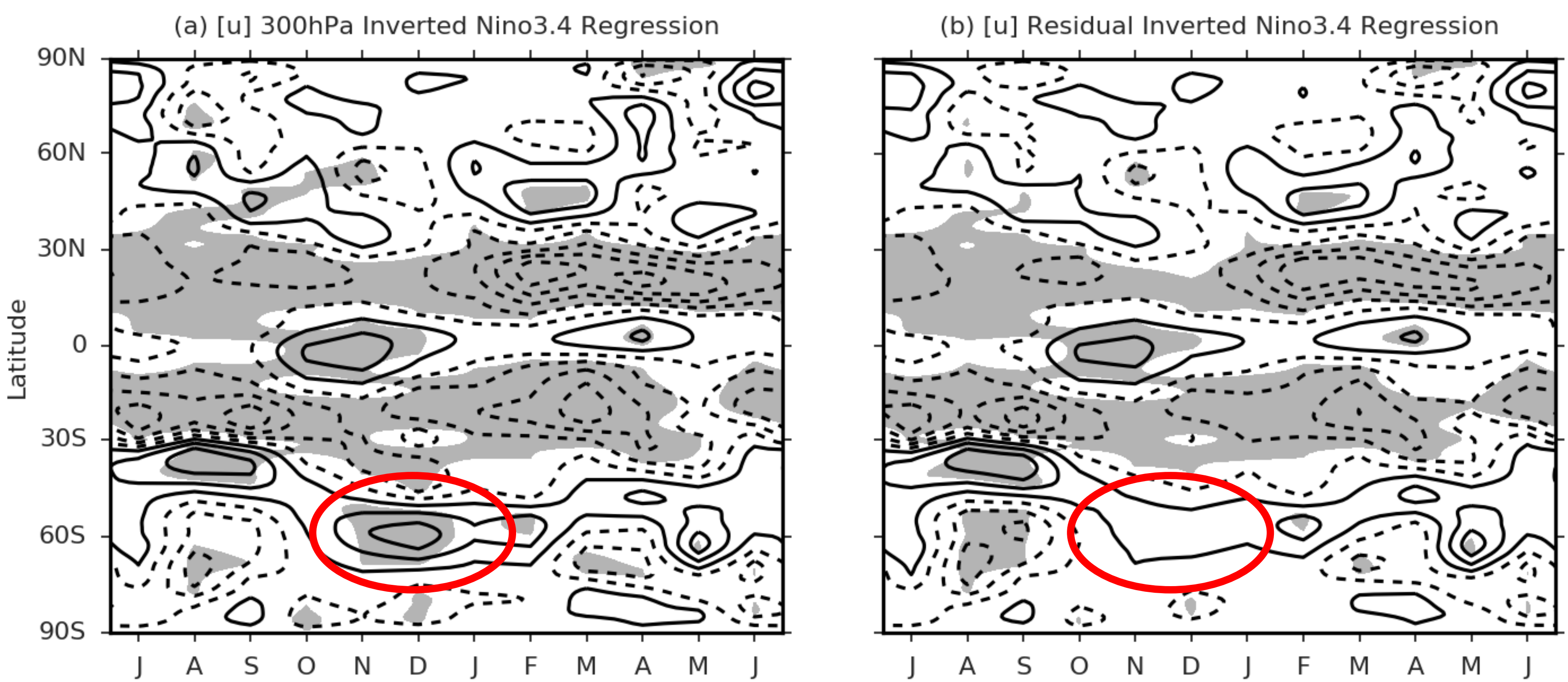
- The only observed circulation change that has been attributed to anthropogenic forcing is the poleward shift of the summertime SH eddy-driven jet (SAM) — and is attributed to the ozone hole
- Can be alternatively interpreted as a **delay of the seasonal equatorward transition**, induced by delayed vortex breakdown



Contours show climatology of tropospheric *u* from 1979-2016, contours the long-term change, C.I. 0.6 m/s/decade

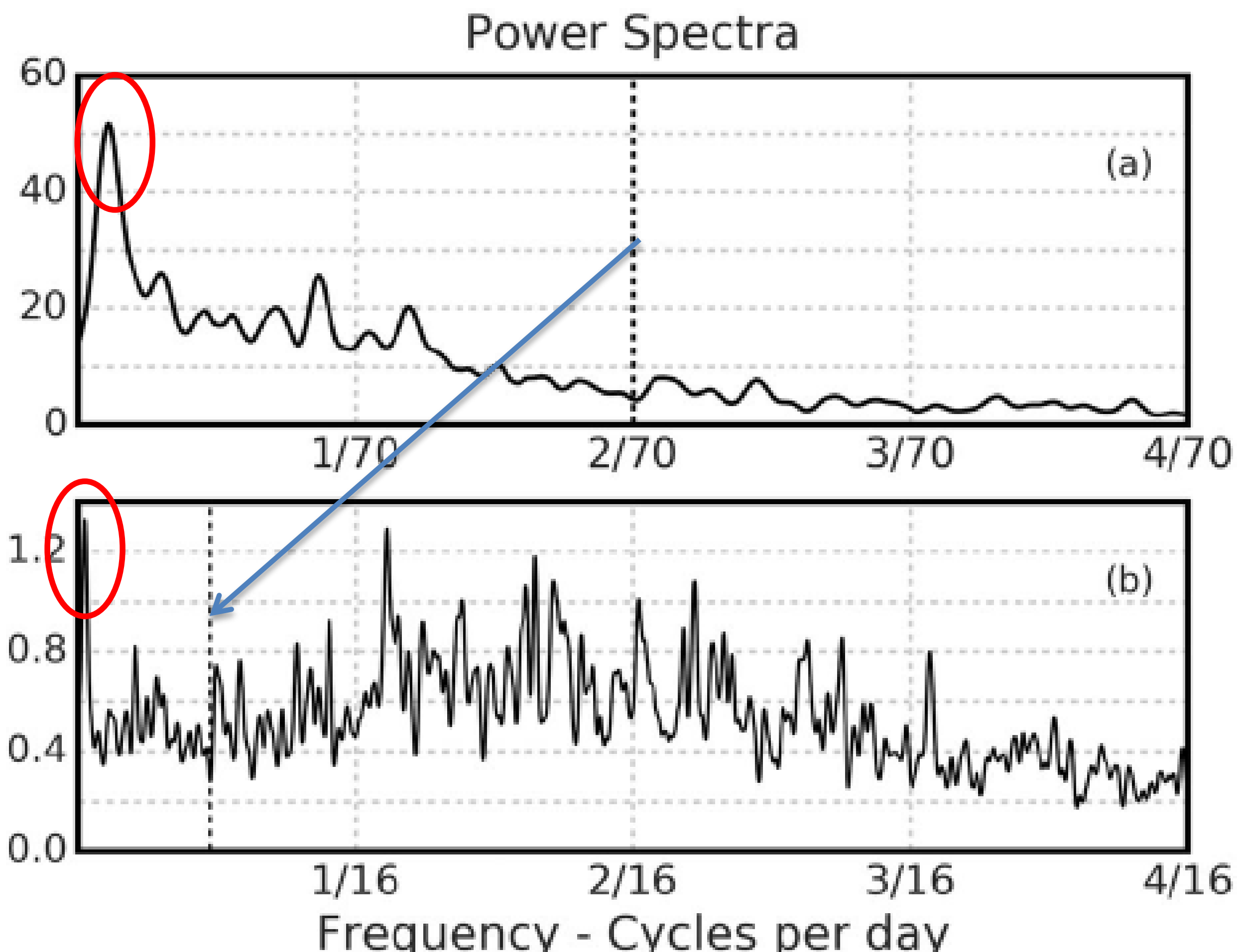
Byrne, Shepherd, Woollings & Plumb (2017 J. Clim.)

- The apparent observed **influence of ENSO** on SH summertime high-latitude zonal-mean 300 hPa wind (left) over 1979-2016 disappears once the influence of the stratospheric vortex breakdown is removed (right)
  - There is a strong correlation between ENSO and SH vortex breakdown (fortuitous or otherwise)



Byrne, Shepherd, Woollings & Plumb (2017 J. Clim.)

- Influence of variable SH vortex breakdown (confined to narrow time window) is ostensible reason for pronounced 2-year peak in SAM and eddy momentum flux convergence power spectra

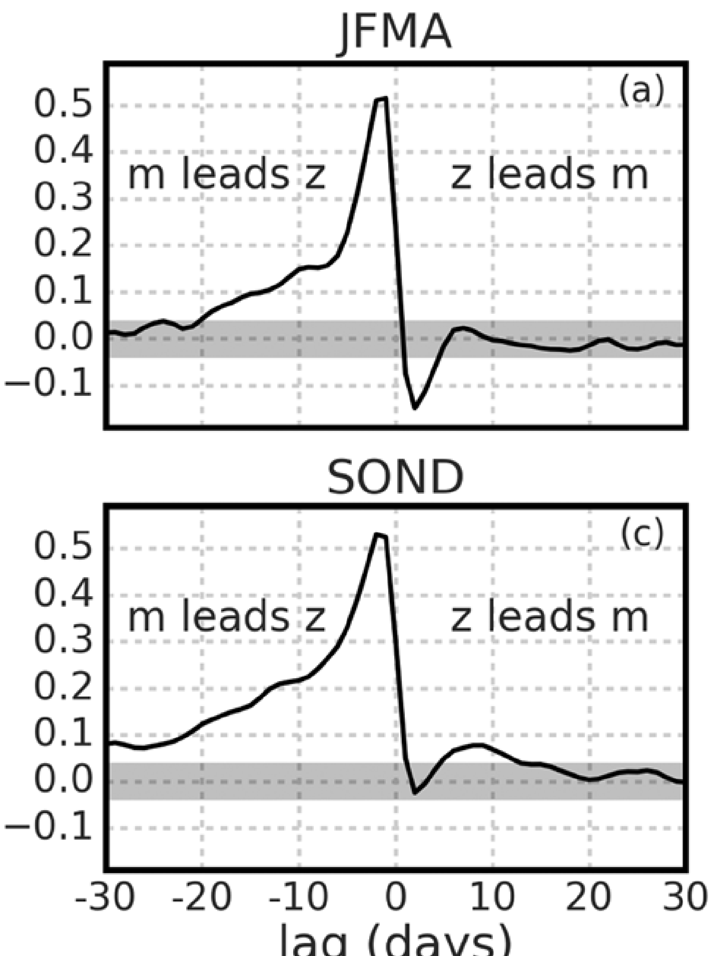


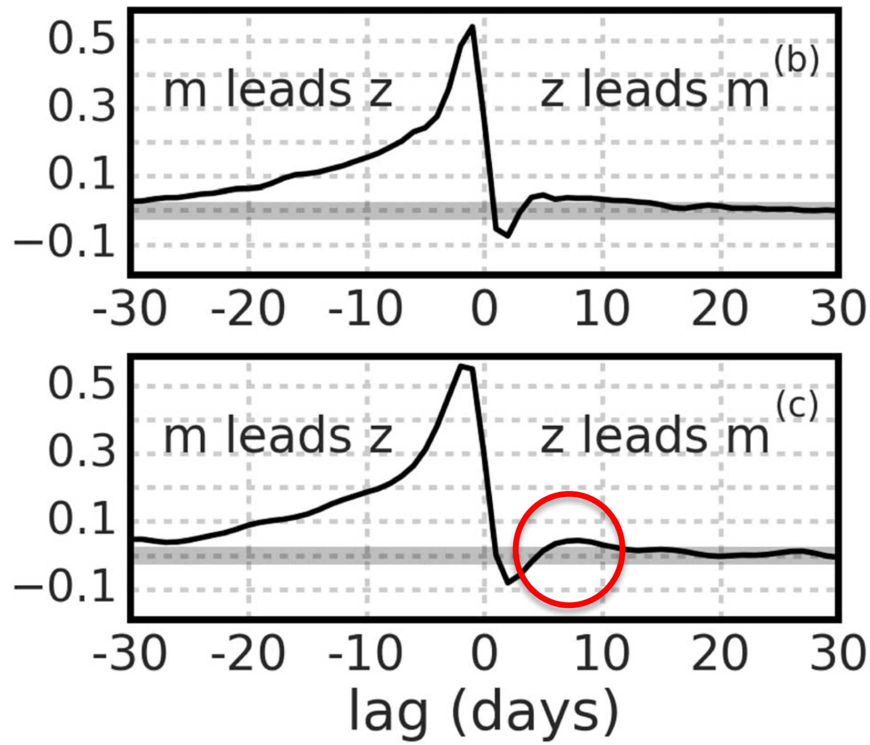
SAM

Eddy momentum flux convergence (note different horizontal scale)

Byrne, Shepherd, Woollings & Plumb (2016 GRL)

- Both the seasonal regime transition, and the 2-year peak in EMFC, introduce non-stationarity in the statistics of variability
- Apparent positive eddy feedback seen in SAM-EMFC cross-correlations appears to be an artefact of this non-stationarity

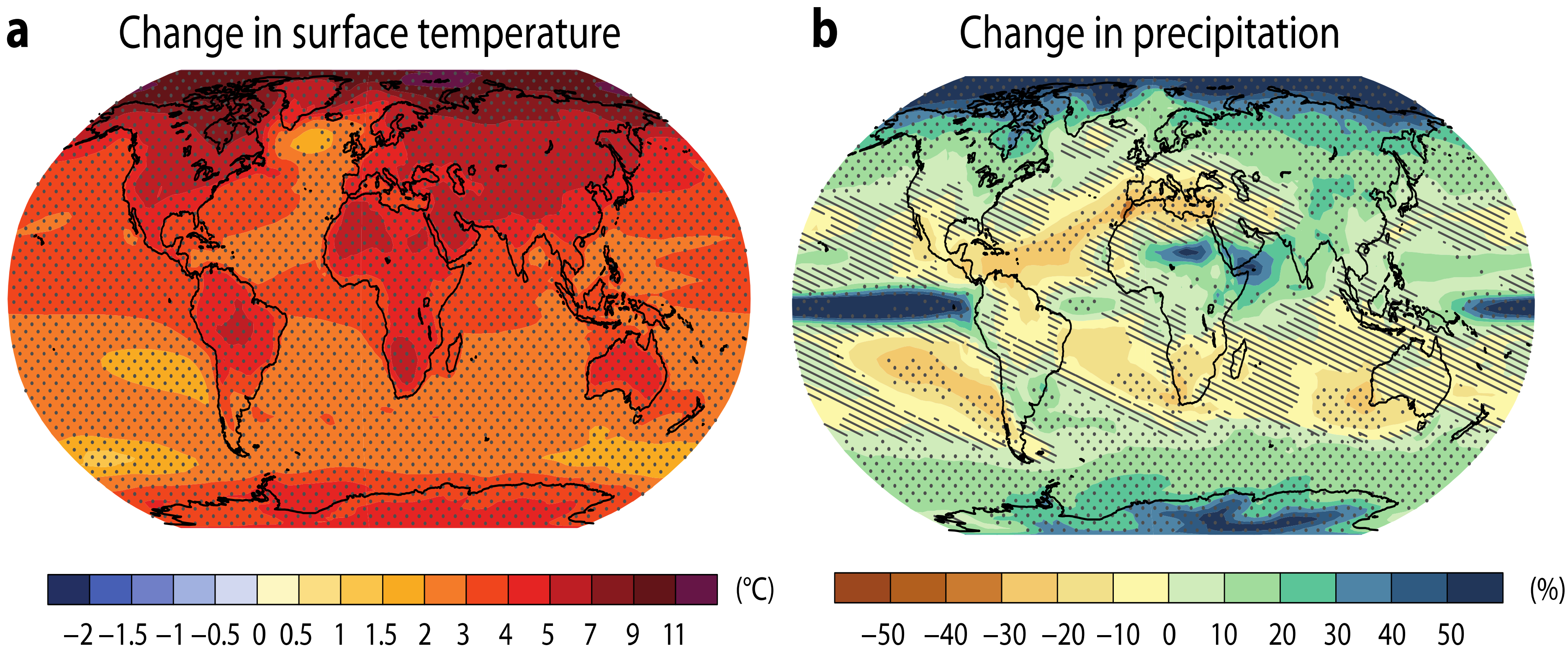




Synthetic model with no eddy feedback

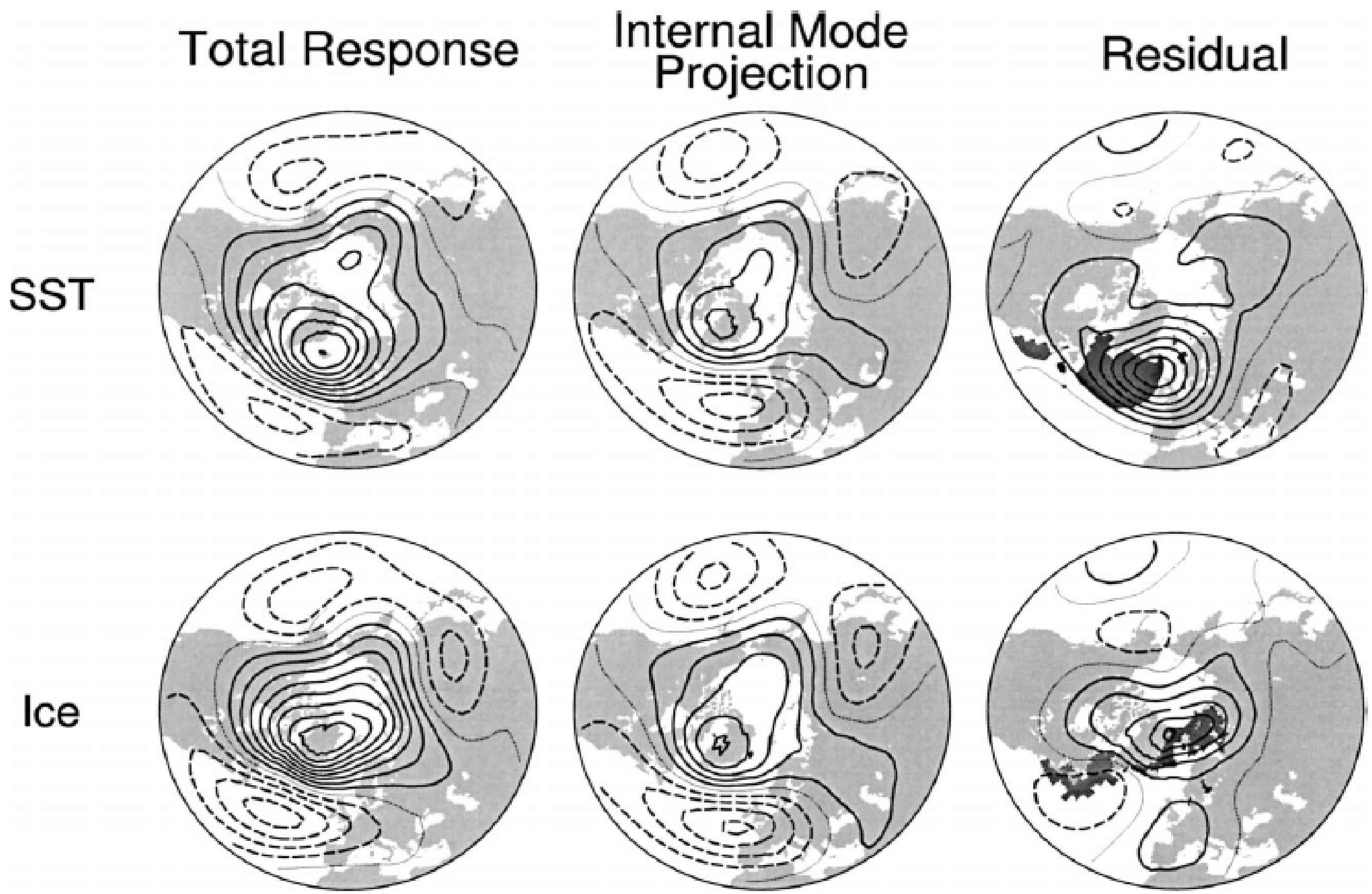
Byrne, Shepherd, Woollings & Plumb (2016 GRL)

- In contrast to temperature, **precipitation aspects of climate change are generally non-robust** in populated regions
- Here for model projections: robust changes are stippled; otherwise, either the models do not agree, or the changes are relatively small compared to internal variability (hatched)



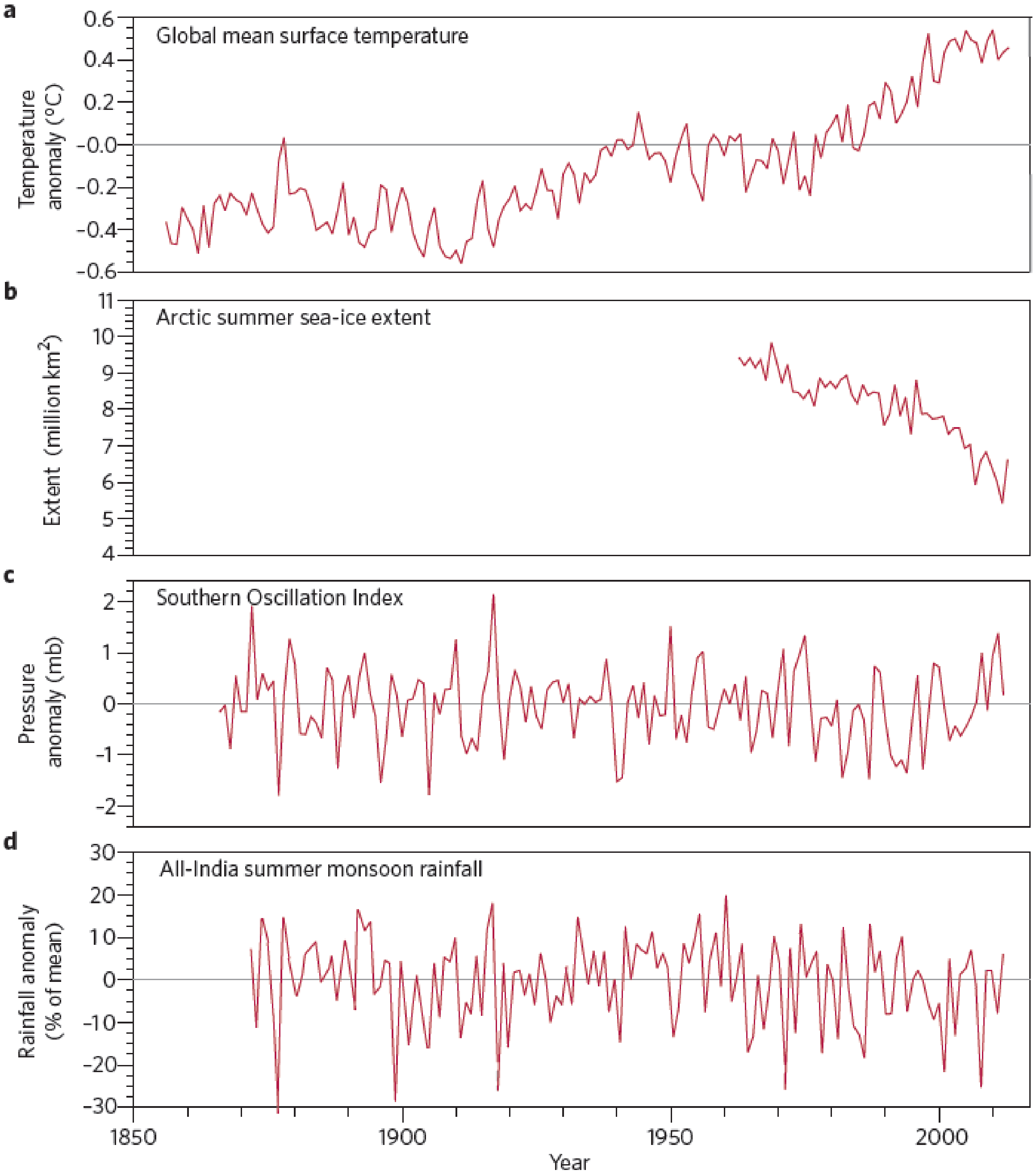
IPCC AR5 WGI (2013)

- In general, the **atmospheric response to a thermal forcing** consists of a **direct component and an indirect component** that projects on the dynamical modes of variability
  - Can be used to define ‘thermodynamic’ and ‘dynamic’ components of the response (many authors now doing this)



Wintertime 500 hPa geopotential height response to SST or sea-ice anomalies

Deser et al. (2004 J. Clim.)

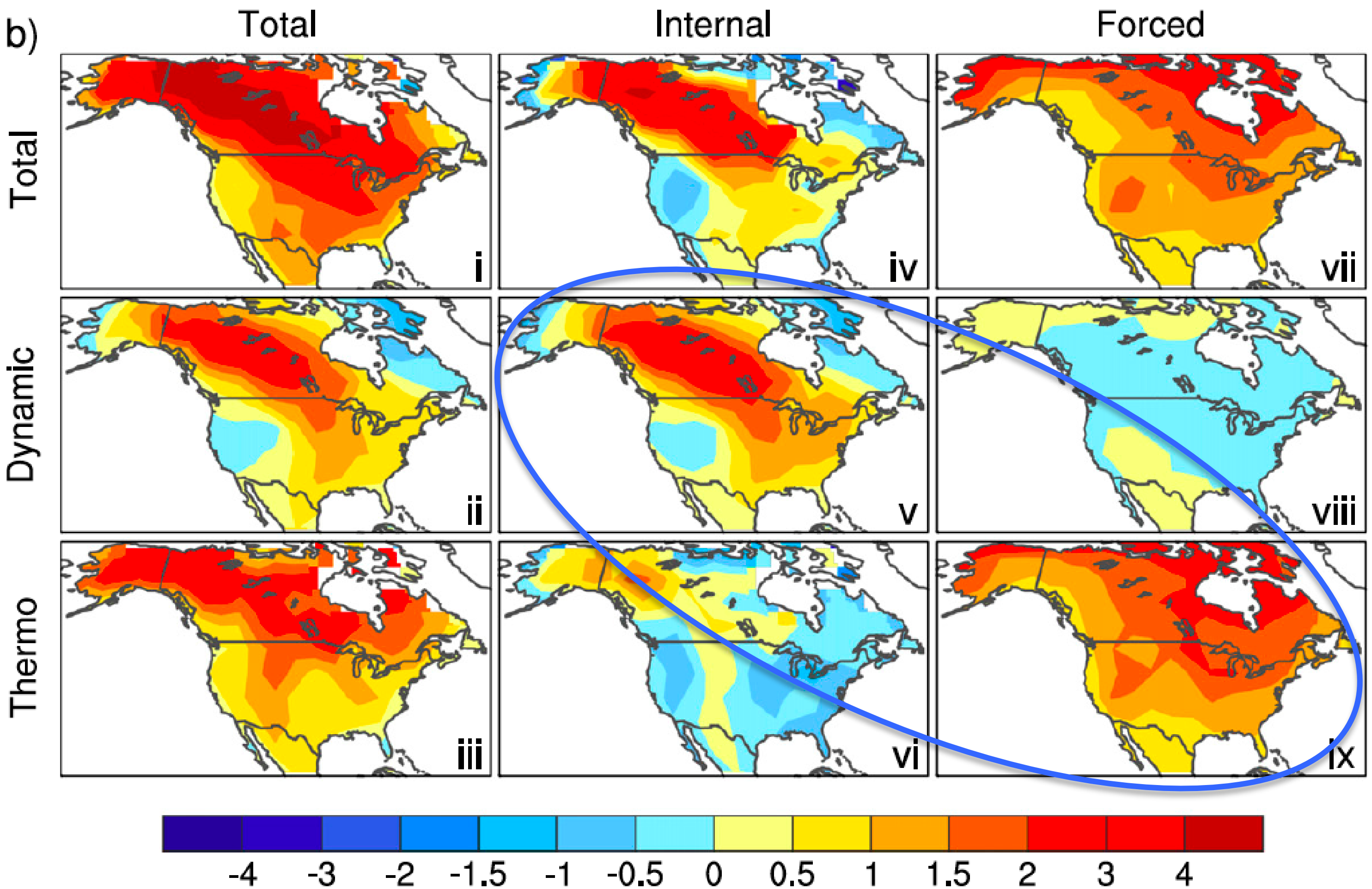


- Clear changes are evident in long-term observed records of temperature-related climate indices (high S/N ratio) ➔ D&A

- Indices of circulation generally do not show clear long-term changes, and there is no accepted theory of any such changes

Shepherd (2014 Nature Geosci.)

- **For surface temperature,** the forced response is dominated by the thermodynamic component, and the internal variability (which can be non-negligible) by the dynamic component

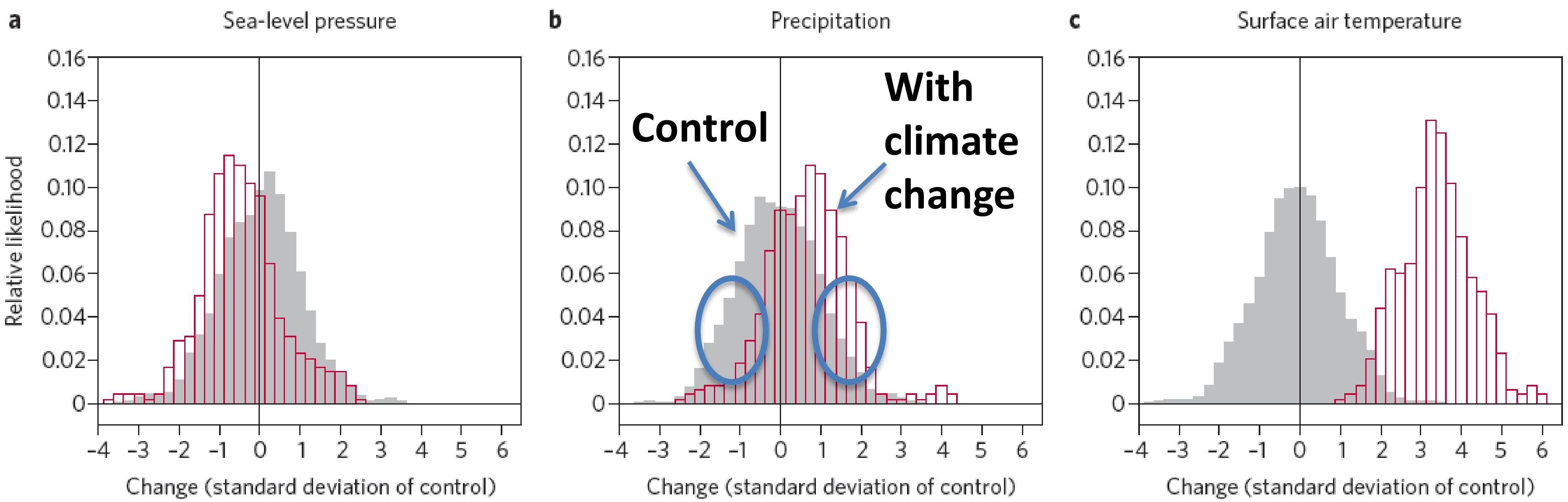


Observed DJF SAT changes over last 50 years, based on forced response in large-ensemble CESM

Deser et al. (2016 J. Clim.)

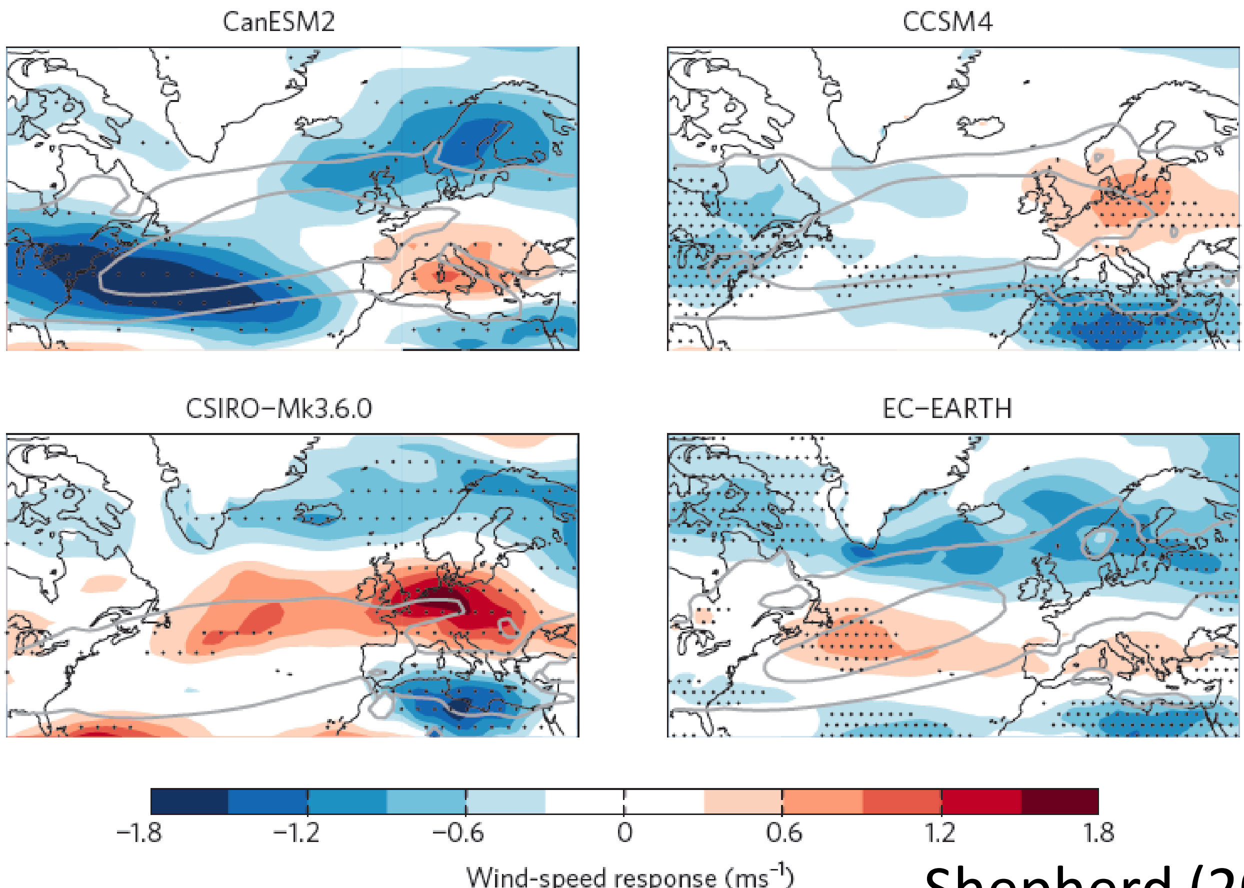
- In many regions, **precipitation** seems to be controlled much more by circulation than by pure thermodynamics, and **the signal-to-noise of the forced response is comparatively small**
  - Yet the change in risk is not small!

PDFs of DJF trends from 2005 to 2060 in the Eurasian/North Atlantic sector



Adapted from Deser et al. (2012 Clim. Dyn.)

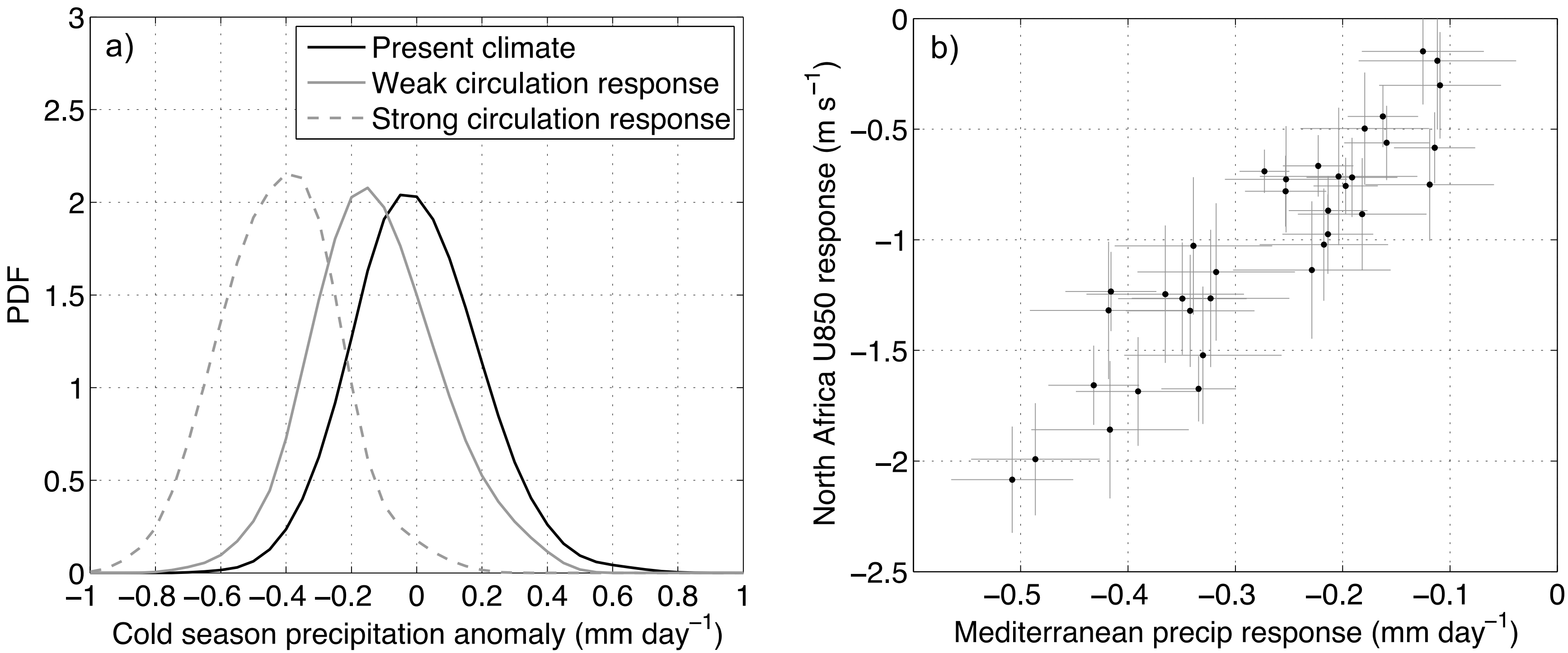
- Unfortunately, climate models can **disagree on the nature of the circulation response** to climate change
  - Has direct implications for precipitation and for weather-related extremes such as droughts and heat waves
  - The average of such different projections has no meaning!



Wintertime lower tropospheric zonal wind speed climatology (contours) and end-of-century response to RCP 8.5 (shading)

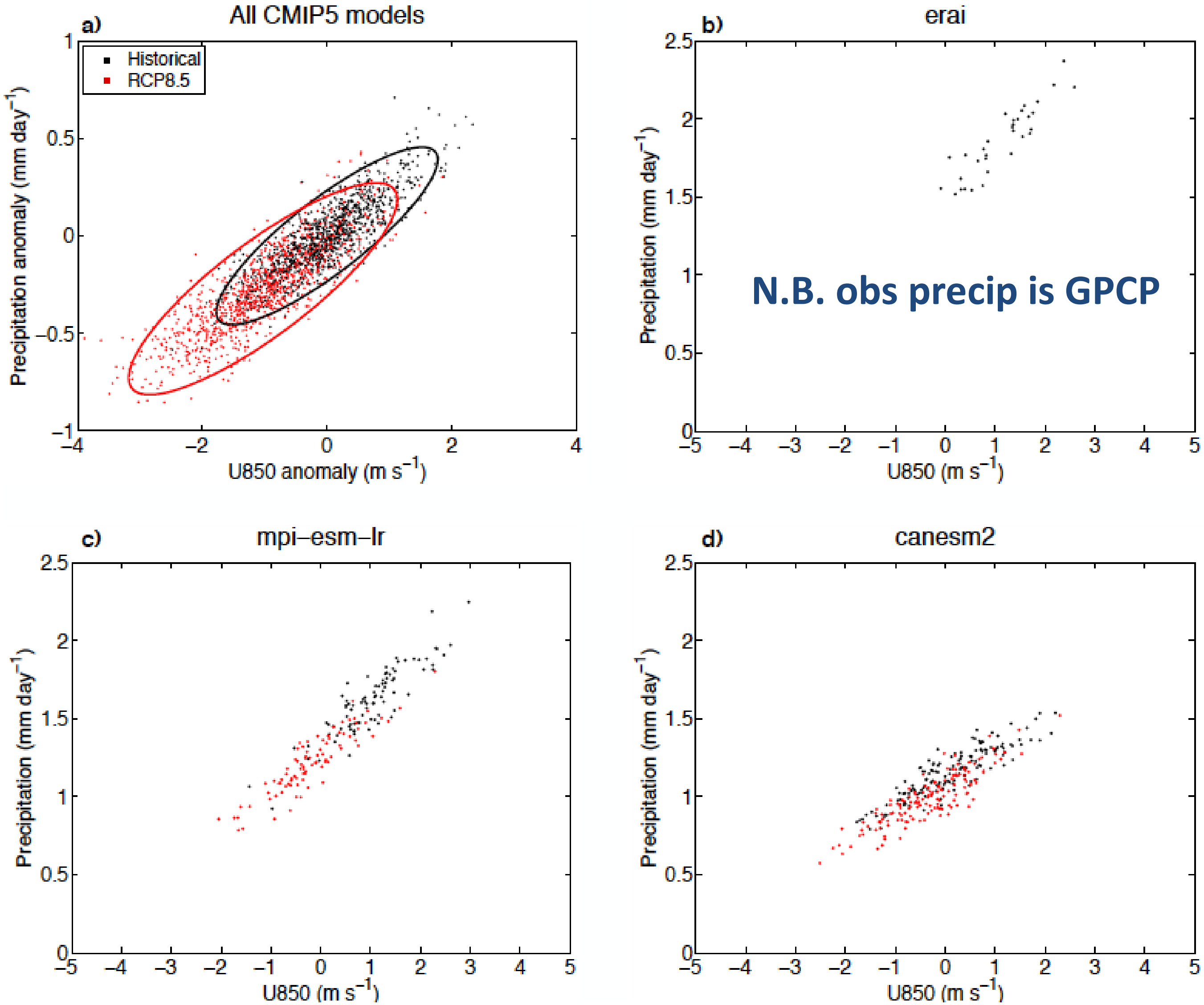
Shepherd (2014 Nature Geosci.)

- A consistent prediction of climate models is **wintertime drying over the Mediterranean** (still no theory for this)
  - Will have tremendous socio-economic implications
- 85% of the CMIP5 mean precipitation response, and 80% of the inter-model spread, are related to changes in circulation and are congruent with internal variability



Adapted from Zappa, Hoskins & Shepherd (2015 Env. Res. Lett.)

- Year to year variations in Mediterranean precip are correlated with variations in North Africa U850, in both obs and models

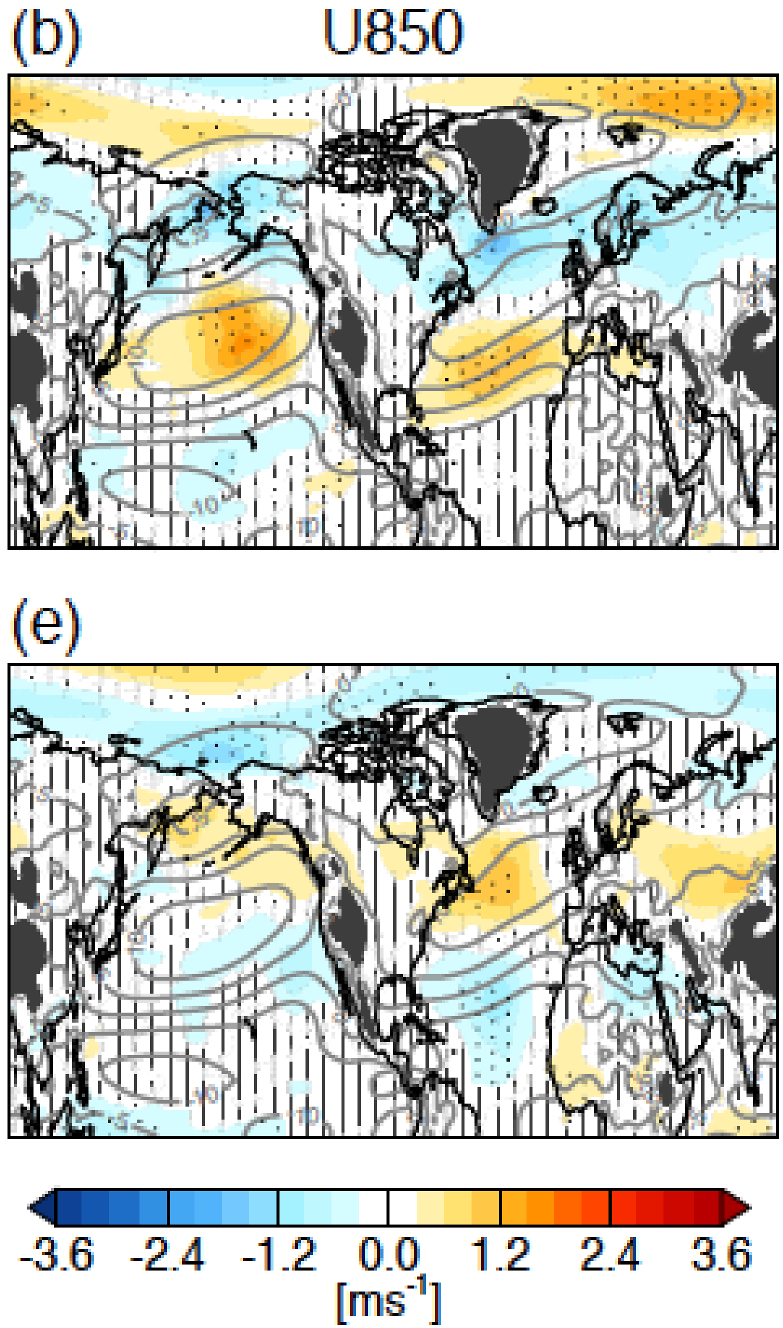


The projected changes seem mainly an extension of this relationship, plus some additional drying

Zappa, Hoskins & Shepherd (2015 Env. Res. Lett.)

Sensitivity to Arctic low-altitude warming

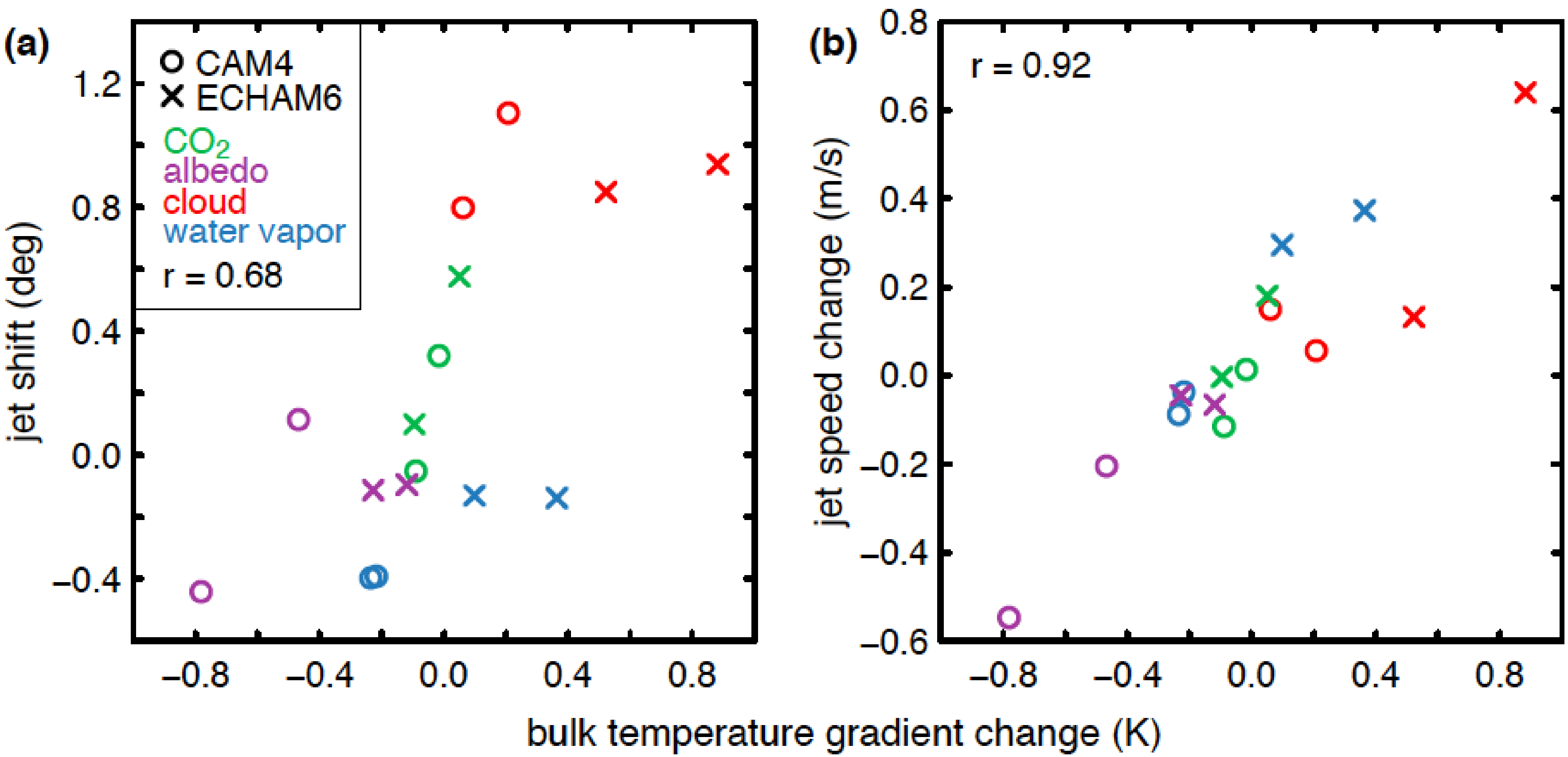
Sensitivity to tropical high-altitude warming



- One of the reasons for the divergence in model projections is the **‘tug of war’** between high-latitude and low-latitude warming (here for NH DJF)

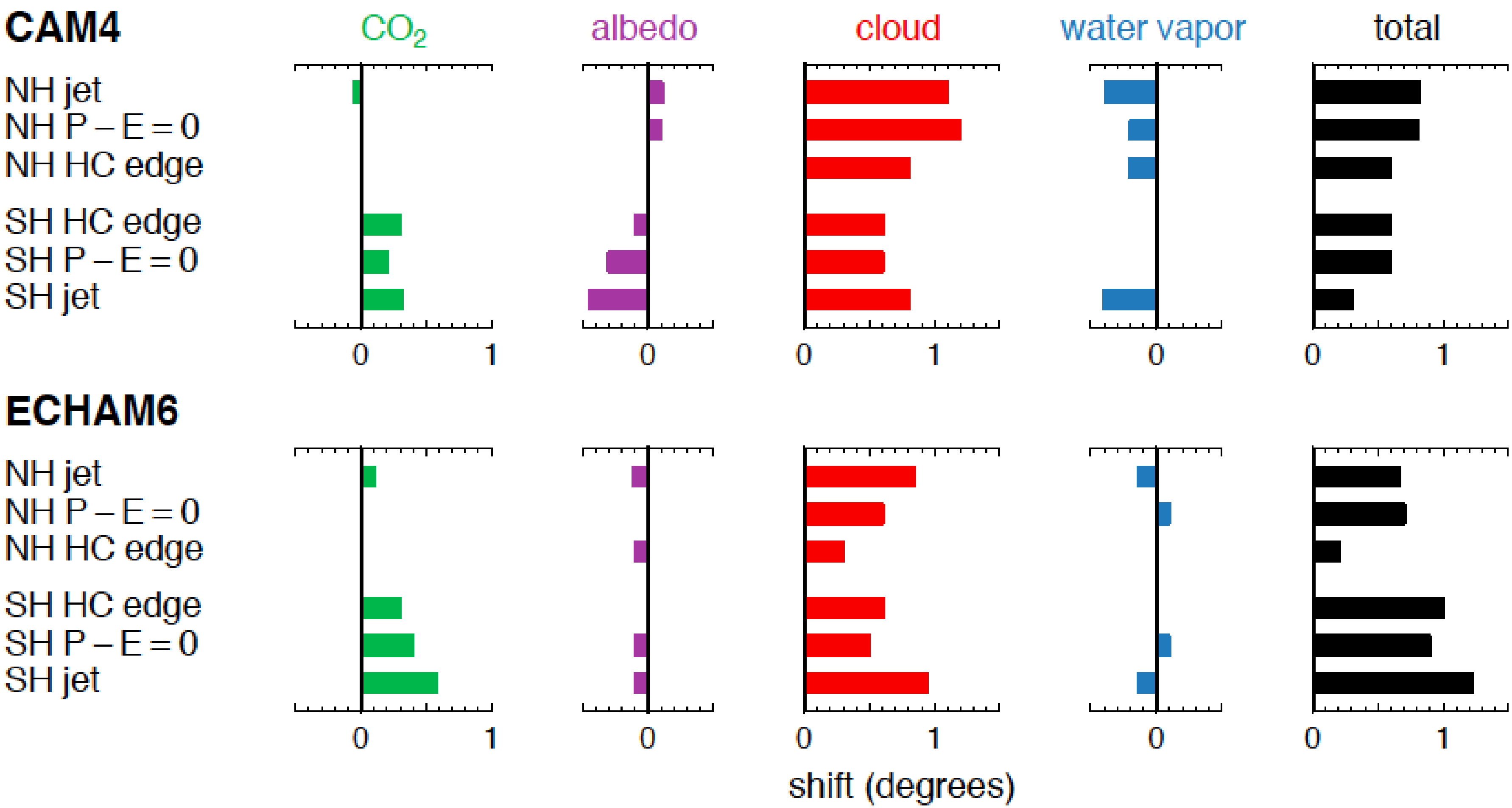
Harvey, Shaffrey & Woollings (2015 Clim. Dyn.)

- More generally, jet shifts have been widely understood as a response to **changing meridional temperature gradients**
  - Here expressed in terms of climate feedback processes
  - Seems to work better for jet speed than for jet latitude



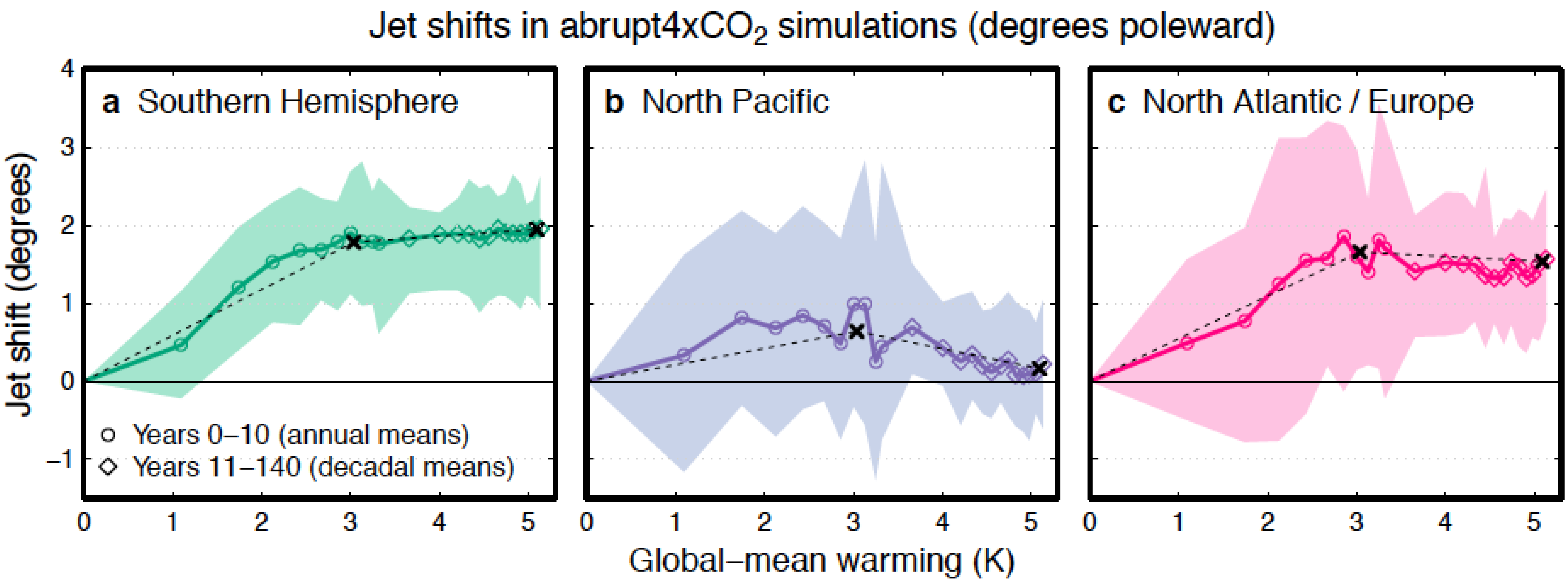
Ceppi & Shepherd (J. Clim., in press)

- Viewed in terms of radiative forcing and climate feedbacks, the dominant driver of a poleward shift comes from **clouds**
  - So causality is actually *opposite* to that stated in IPCC AR5



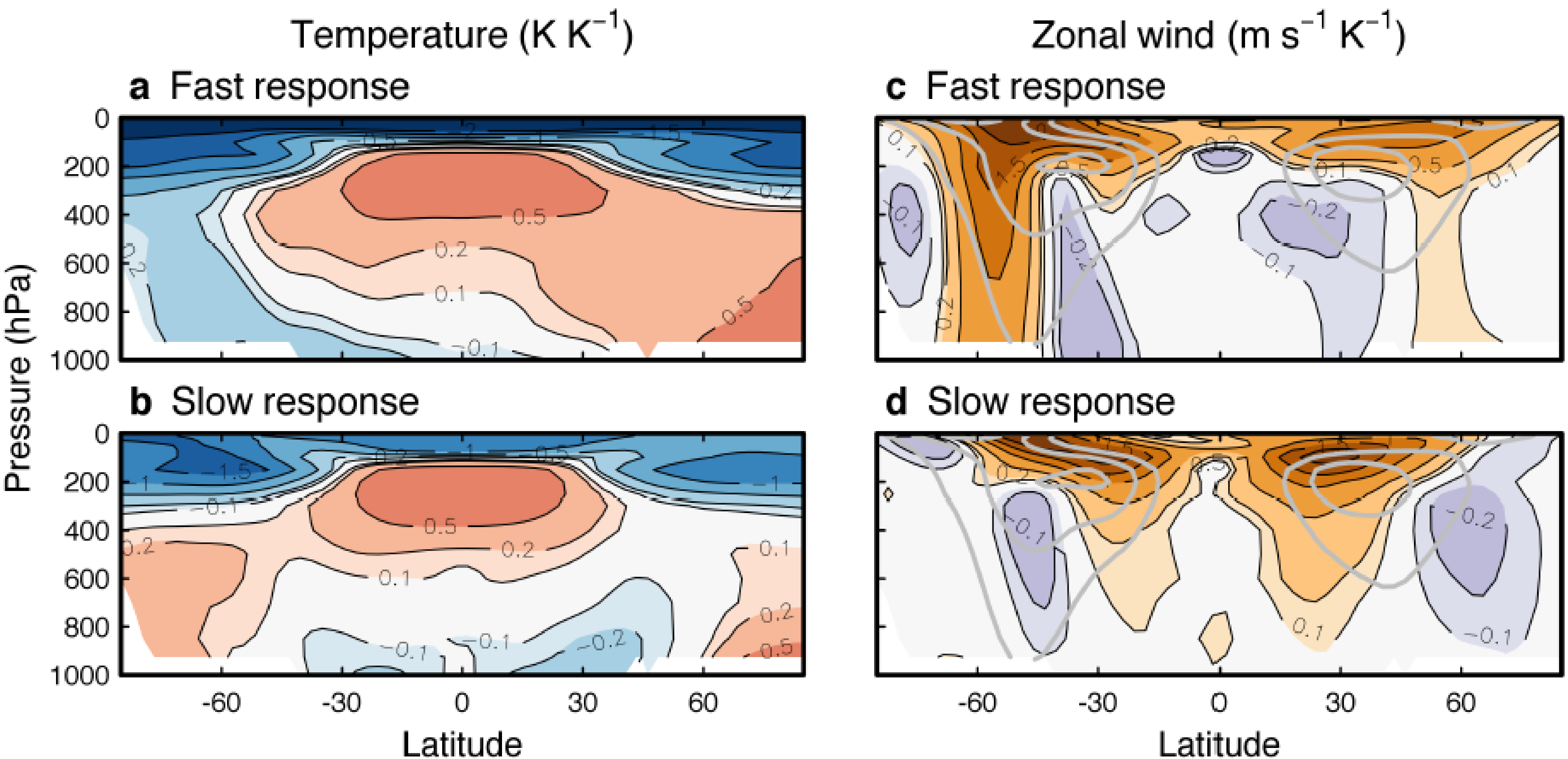
Ceppi & Shepherd (J. Clim., in press)

- There are **two distinct timescales of the circulation response** to an abrupt forcing (here CMIP5 abrupt $4xCO_2$ simulations)
  - Jet shifts are realized within the first 5-10 years (fast)
  - Shifts are zero, or reverse, on longer timescales (slow)



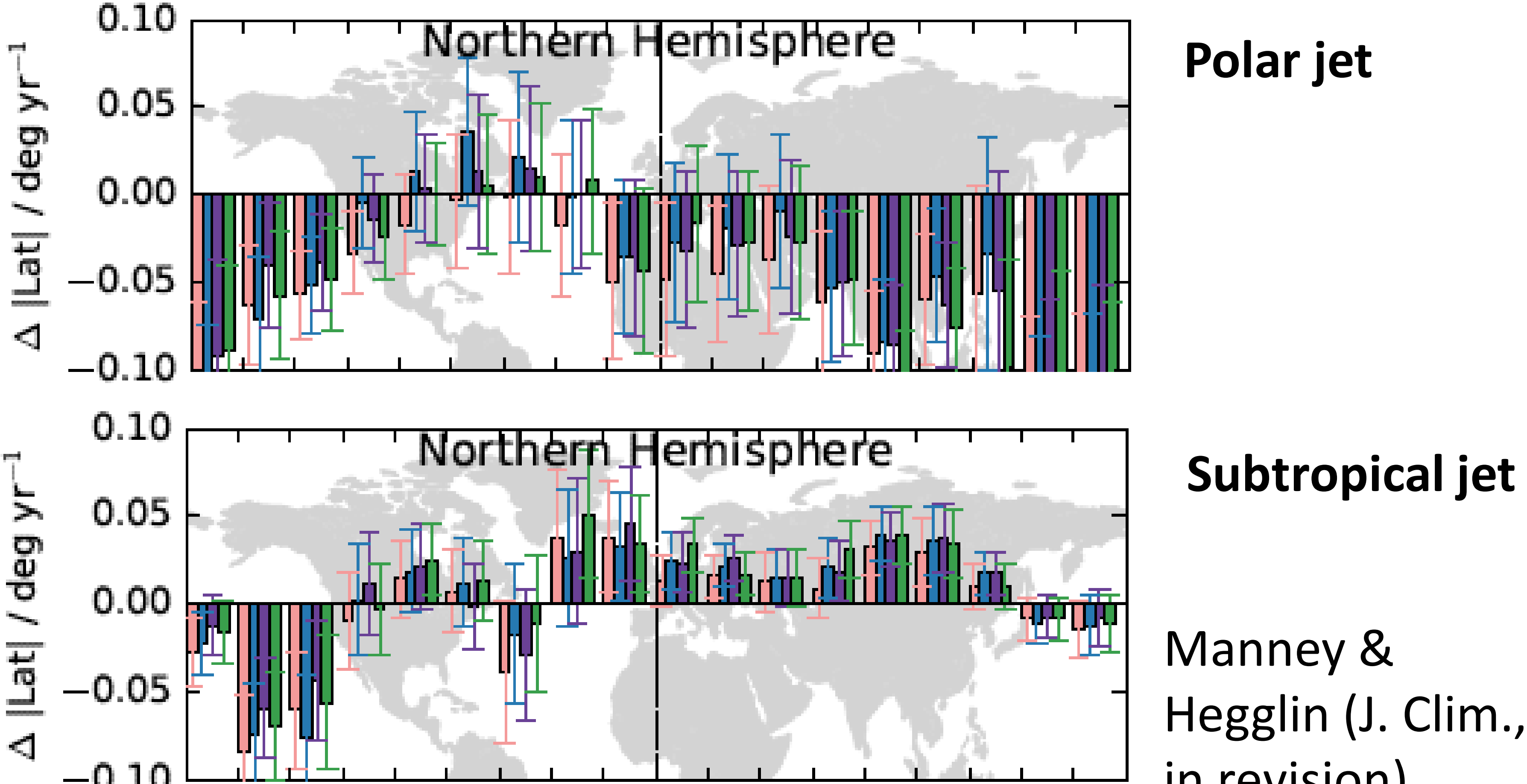
Ceppi, Zappa, Shepherd & Gregory (J. Clim., in press)

- The two timescales mainly reflect different timescales of the SST response, with **delayed warming at high latitudes**
  - Temperature shown is deviation from the global mean



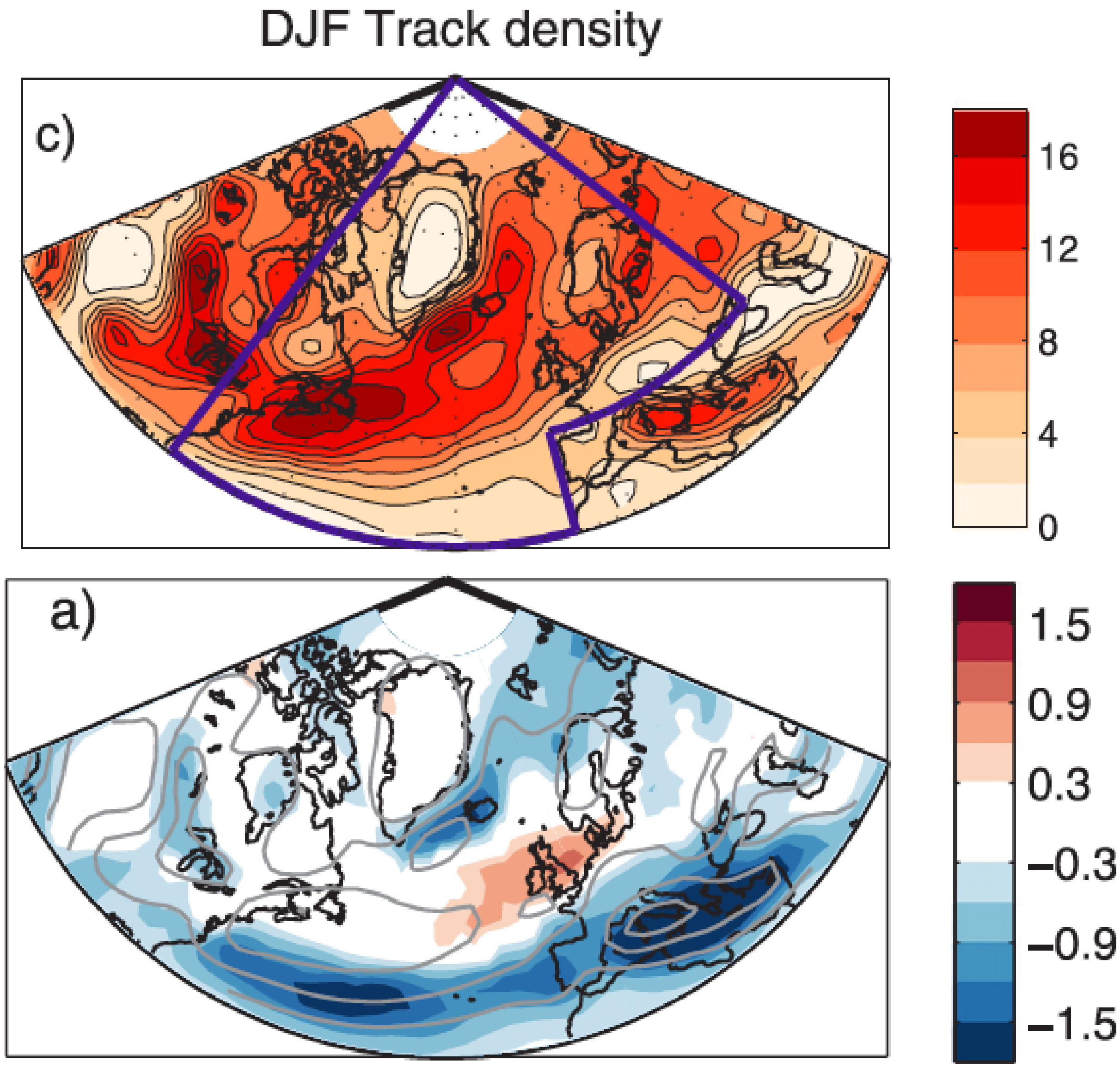
Ceppi, Zappa, Shepherd & Gregory (J. Clim., in press)

- Historical (1979-2014) NH DJF upper tropospheric jet shifts show generally **an equatorward shift of the polar jet, and a polar shift of the subtropical jet** — with lots of longitudinal structure!



Manney & Hegglin (J. Clim., in revision)

- The **projected North Atlantic storm track changes** may reflect such a squeezing together of the polar and subtropical jets



ERA-Interim climatology shows three preferred tracks

Mean CMIP5 response to RCP 8.5 in late 21st century

Zappa et al. (2013 J. Clim.)

Storylines/narratives/tales/scenarios

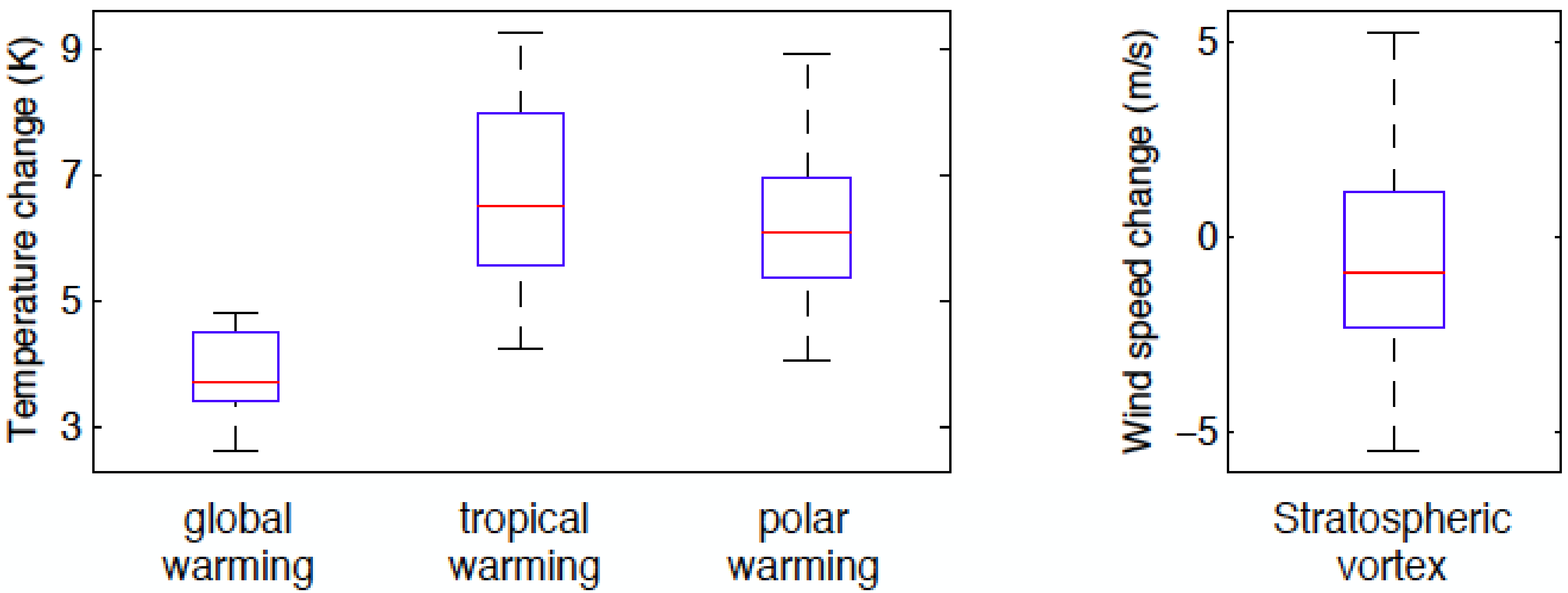
- Post-Paris, the demand for quantitative information about climate change has increased
- We have to accept that probabilistic quantification of climate change is ill-founded (even for known radiative forcings)
- We have to accept that climate information is not the same thing as climate predictions (or projections)
- Hence the need to consider storylines/narratives/tales:
  - A physically-based unfolding of past events, or of plausible future events
  - No probability of the storyline is assessed (not a prediction)
  - Emphasis is placed on the understanding of the factors involved, and the plausibility of those factors (or of changes in those factors)

The storyline approach to circulation change

- Formulation: $$\frac{p_1(E,C)}{p_0(E,C)} = \frac{p_1(E|C)}{p_0(E|C)} \times \frac{p_1(C)}{p_0(C)}$$ (cf. NAS 2016)
  - p_1 is factual, p_0 is counter-factual (i.e. without climate change)
  - E is the event of interest, C is the circulation regime conducive to that event
- The conditional probability ratio represents the purely thermodynamic effects of climate change, i.e. *for a given circulation regime*
  - This should be amenable to quantification (for a given ΔGMT)
- The second factor may be negligible (e.g. Deser et al. 2016 J. Clim.) or highly uncertain (e.g. Zappa et al. 2015 ERL), and in any case should be treated separately and non-probabilistically

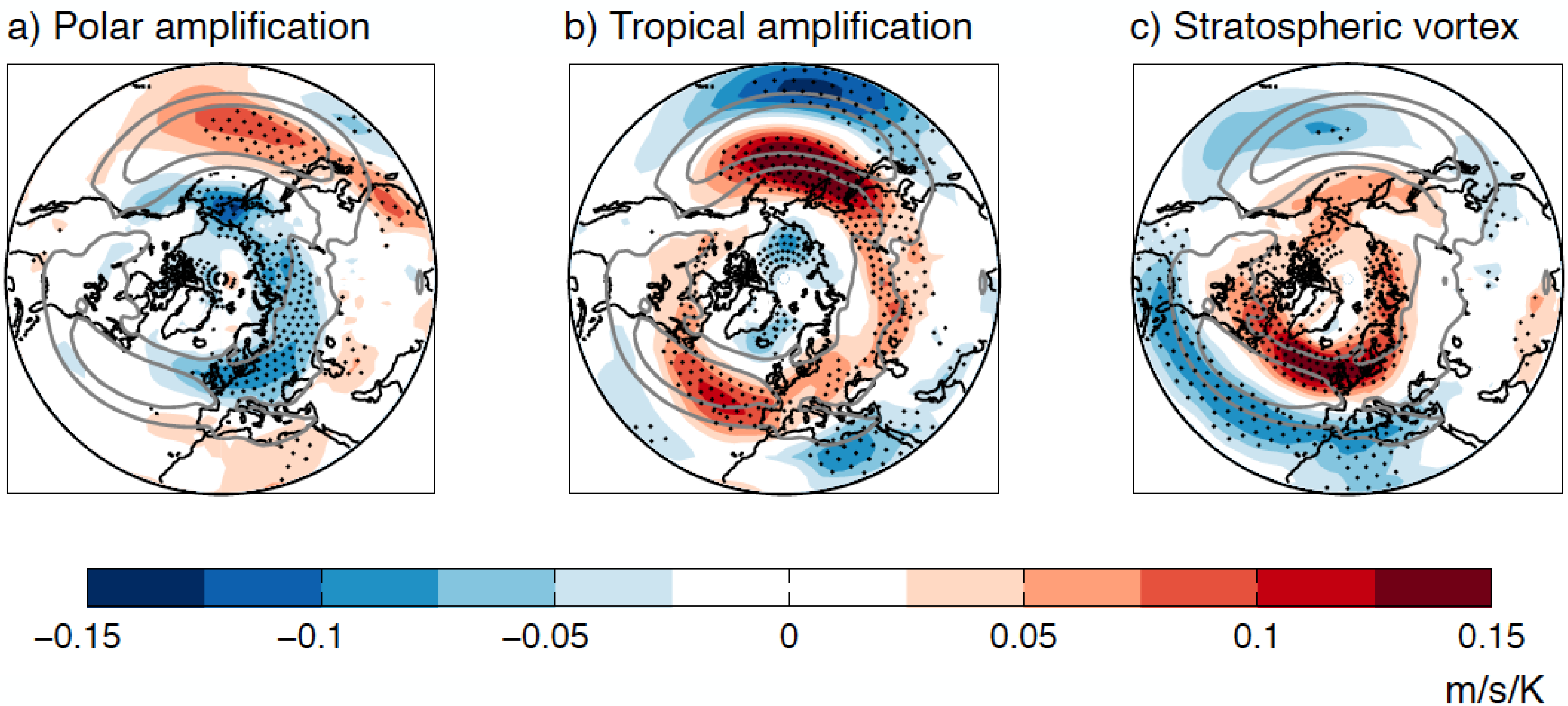
(See Shepherd 2016 Curr. Clim. Change Rep.)

- **Regional circulation response to climate change** can be characterized in terms of **storylines based on remote drivers**
  - There is uncertainty in particular aspects of climate change, which is independent (in the climate models) from the uncertainty in global warming itself
  - These particular aspects are known to exert a strong influence on regional climate (e.g. in climate variability)



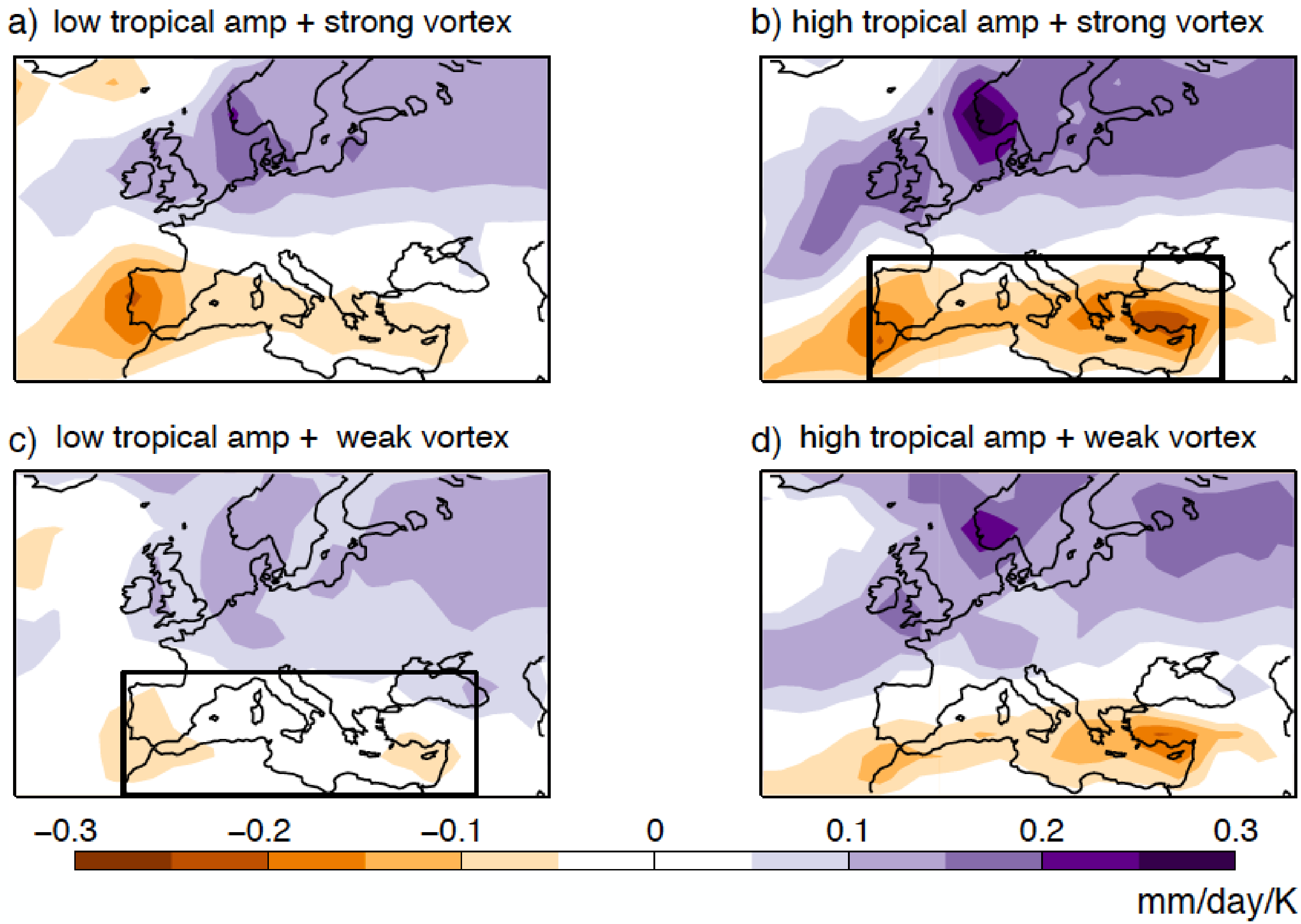
Zappa & Shepherd (2017 J. Clim.)

- The response of the storm tracks to climate change is affected by the uncertainty in these remote drivers
- The patterns (here for cold-season U850) are similar to those expected from single-forcing experiments
  - Also from seasonal prediction!



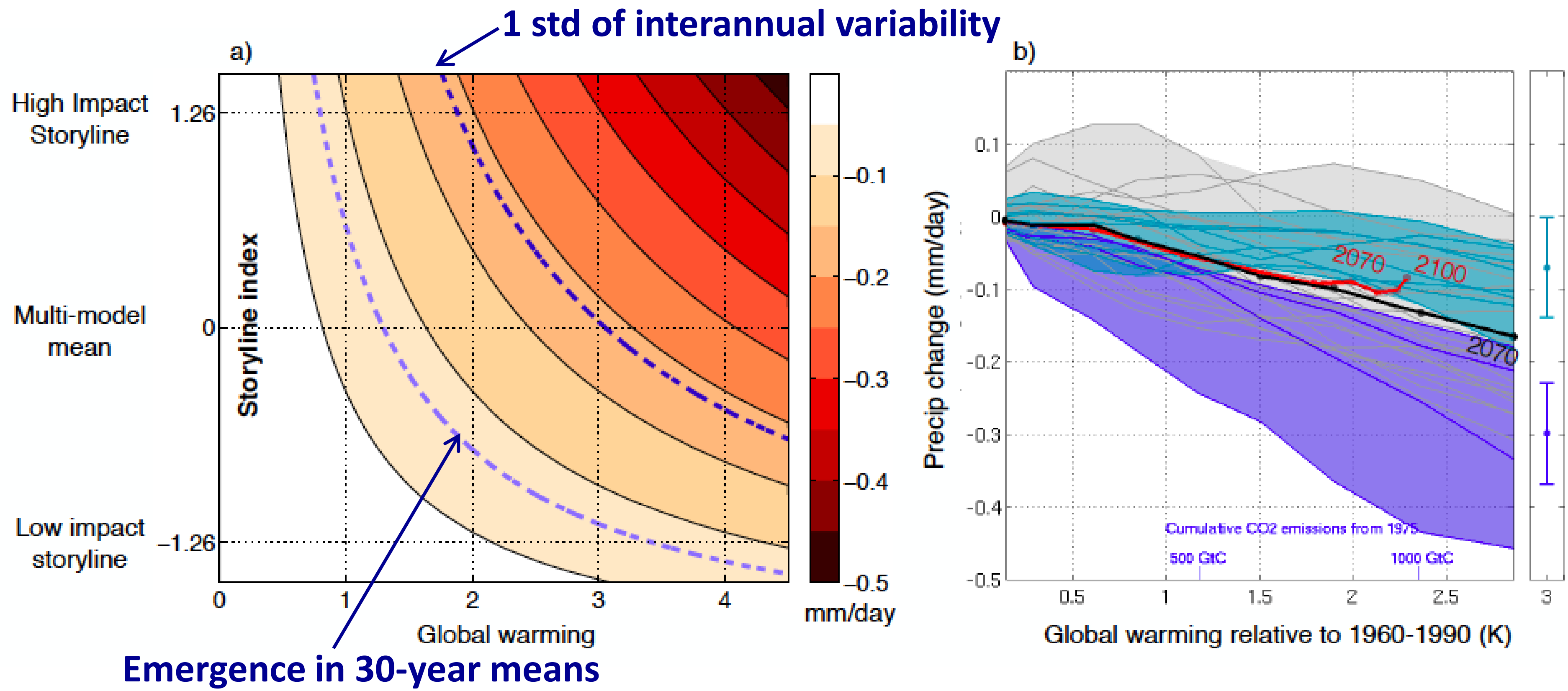
Zappa & Shepherd (2017 J. Clim.)

- Four **storylines of cold-season Mediterranean drying**
  - So far as we know, any one of these could be true



Zappa & Shepherd (2017 J. Clim.)

- Role of global warming, circulation uncertainty, and emission scenario on Mediterranean cold-season drying
  - **Circulation uncertainty is equivalent to several degrees of warming**



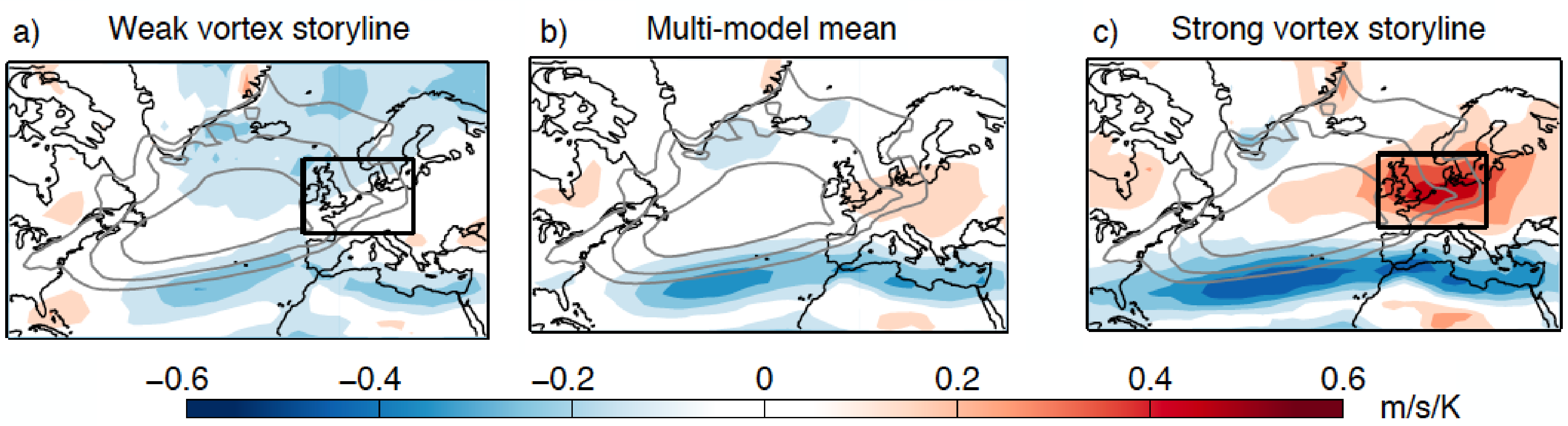
Zappa & Shepherd (2017 J. Clim.)

- **Storylines of European wintertime windiness changes**

  (95th percentile of daily mean windspeed at 850 hPa)

  – Uncertainty in the stratospheric vortex response to climate change is a major driver of CMIP5 model spread

  – So far as we know, any of these storylines could be true



Zappa & Shepherd (2017 J. Clim.)

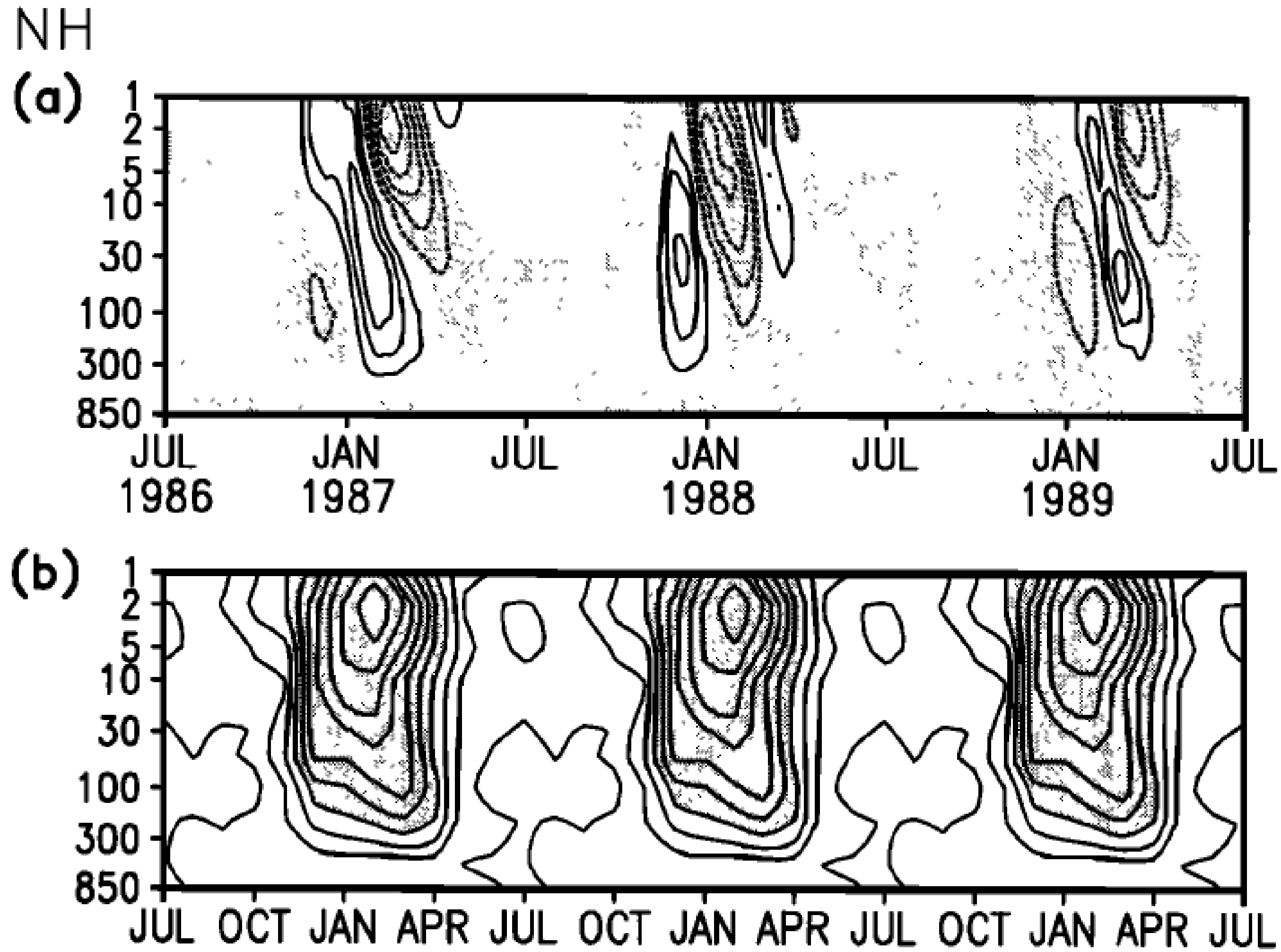
Summary

- Atmospheric teleconnections often lack causal attribution
  - Observations are rarely definitive because of insufficient data
  - Models are rarely definitive because of model error
- Treating variability as anomalies about a climatology — the standard approach — may not always be appropriate
  - Late-spring breakdown of the SH stratospheric polar vortex seems a case in point; introduces non-stationarity
  - Transition to summertime circulation is a regime shift
- Circulation aspects of climate change are generally congruent with internal variability, and exhibit teleconnections
  - There is non-robustness in midlatitude changes in part because of a ‘tug of war’ between different remote drivers
  - The multi-model mean makes no sense for circulation
  - Storylines are a promising way of dealing with uncertainty

- NH polar vortex disturbances propagate downwards, but there is only time for one oscillation in a winter

30 day running average polar T anomaly

Interannual std dev of monthly mean polar T

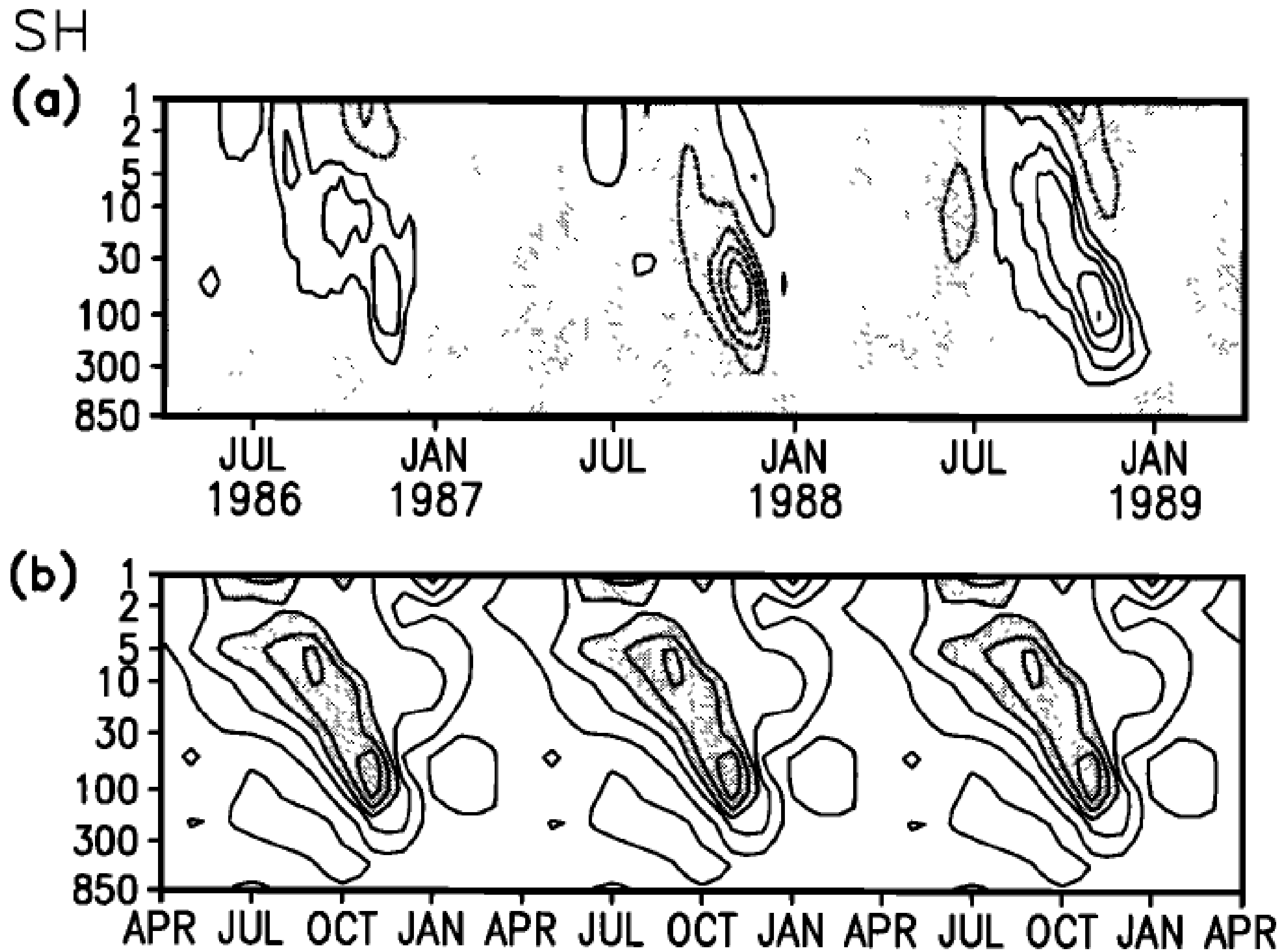


Kuroda & Kodera (2001 JGR)

- In the SH, the variability is (usually) confined to springtime and represents variability in the annual breakdown of the vortex

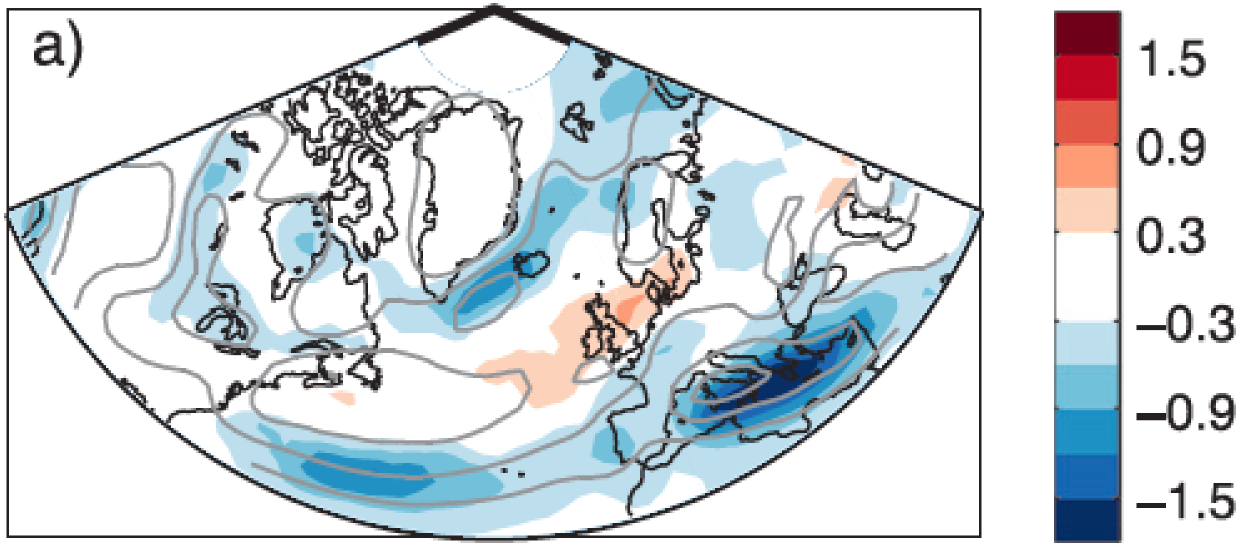
30 day running average polar T anomaly

Interannual std dev of monthly mean polar T

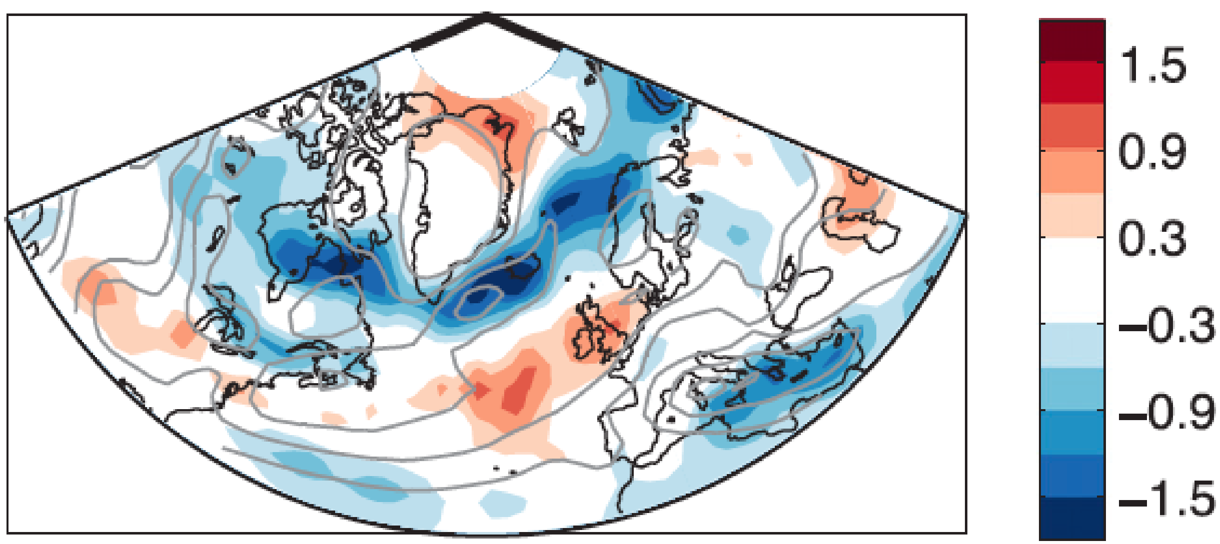


Kuroda & Kodera (2001 JGR)

- Locations of predicted Euro-Atlantic storm-track changes do not seem to depend on biases in storm-track location



Mean CMIP5 response of wintertime storm track density to RCP 4.5 in late 21st century



Mean response for the four models with the smallest biases

Zappa et al. (2013 J. Clim.)