Impact of the 11-yr Solar Cycle at the Earth's Surface

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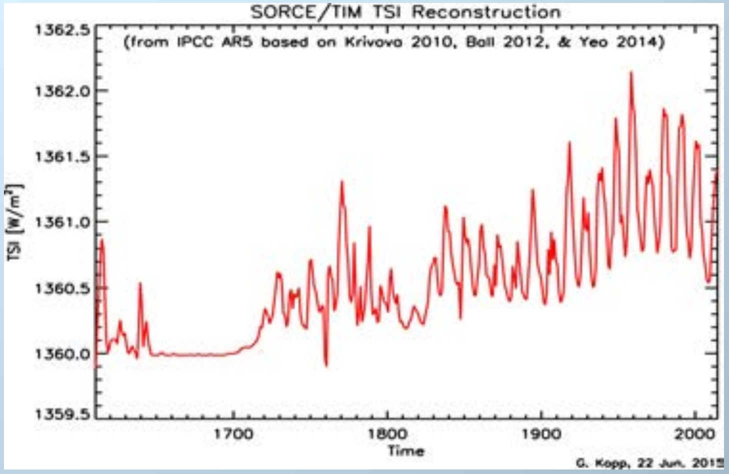
(Met Office)

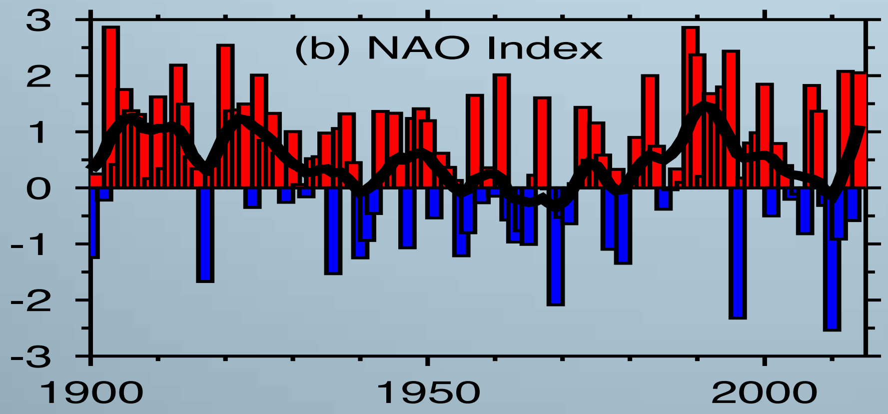
Solar Variability and Climate

1. Mechanisms and tools for analysis of surface observations

2. The North Atlantic Response
   - North Atlantic Oscillation (NAO),
   - Role of ocean feedback?

3. Pacific Response (Walker circulation)

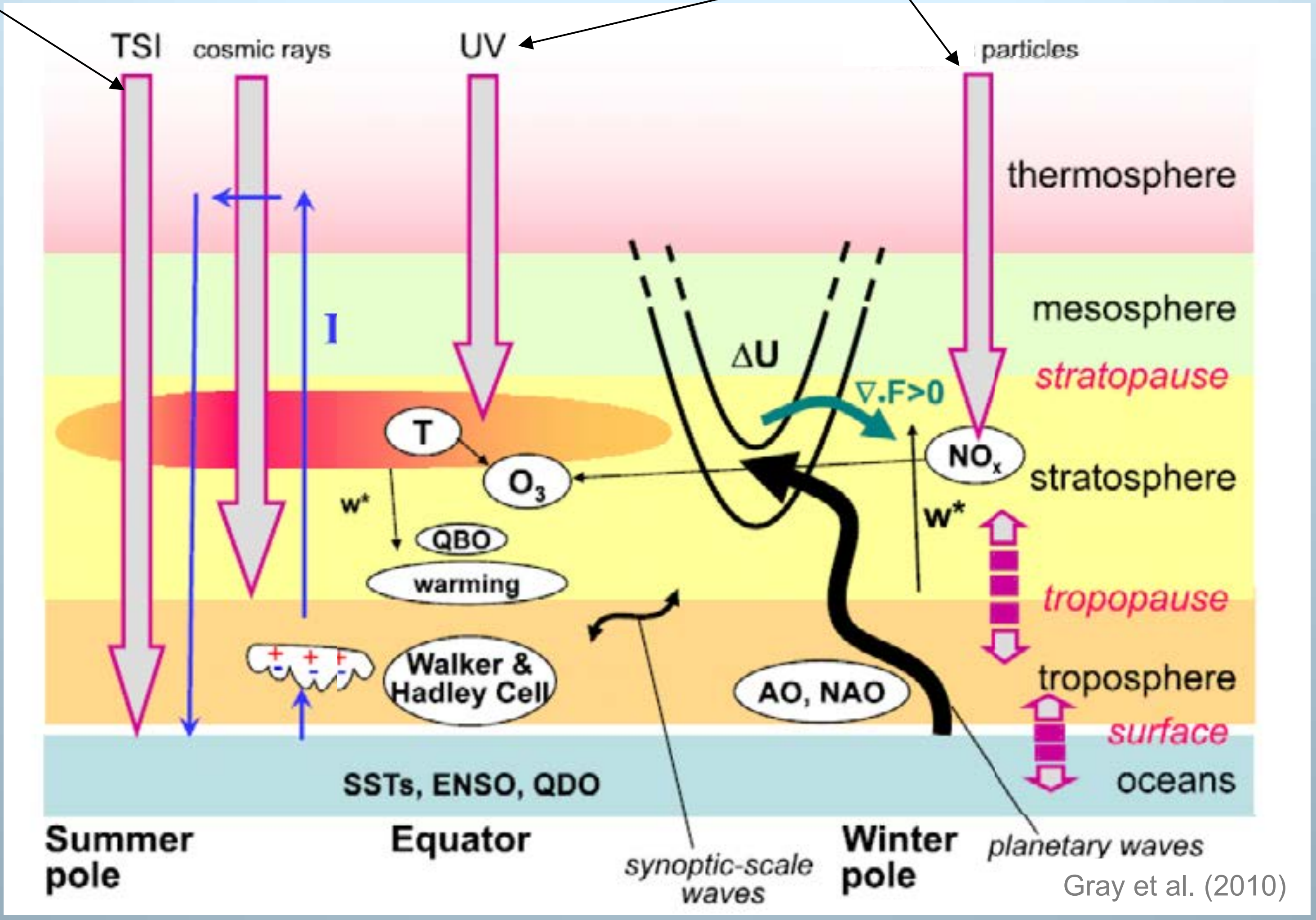




Potential mechanisms

Bottom-up

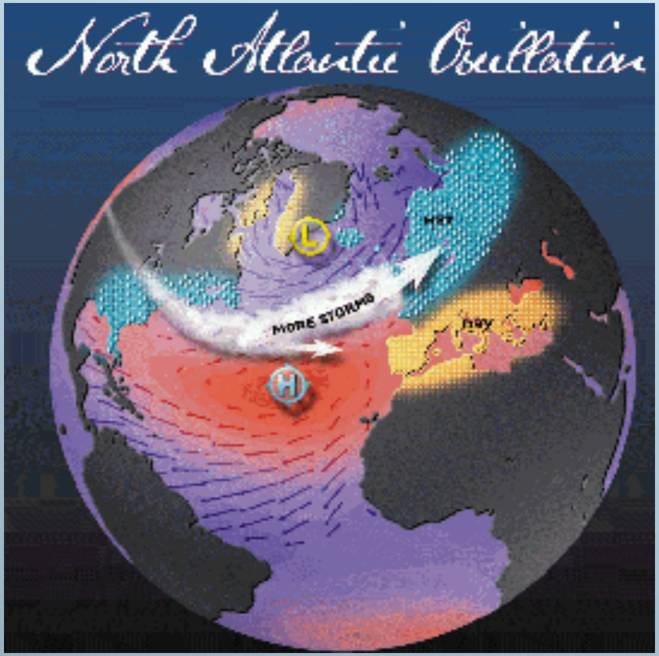
Top down



NORTH ATLANTIC OSCILLATION (NAO)

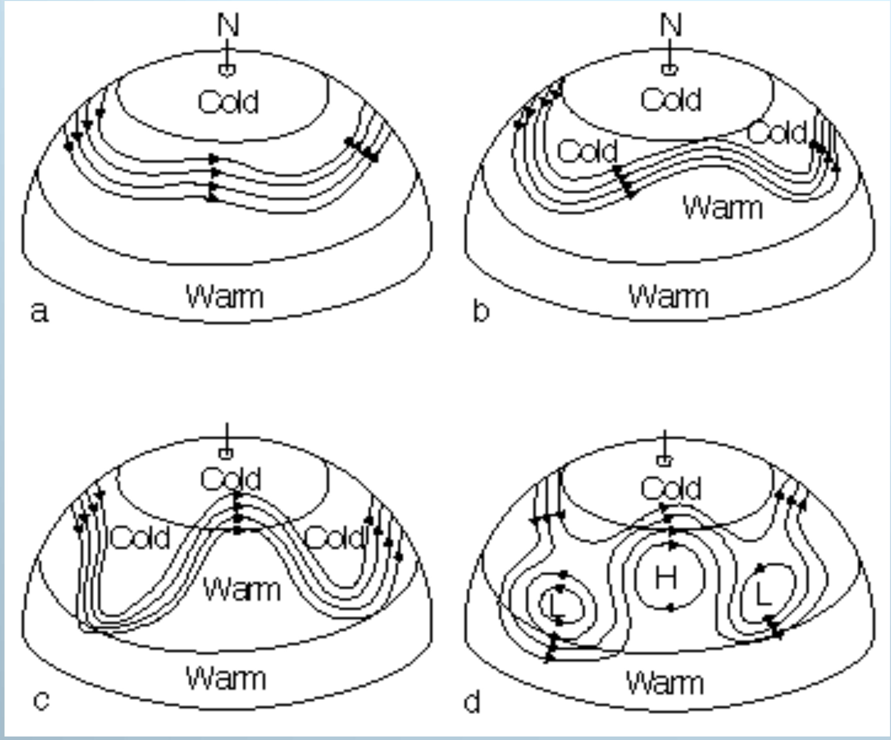
- Dominant pattern of North Atlantic variability (Walker and Bliss 1932)
- Related to changes in the position and strength of the Atlantic storm track
- Azores – Iceland sea level pressure difference (mean ~20 hPa, s.d. ~7 hPa)

NAO+



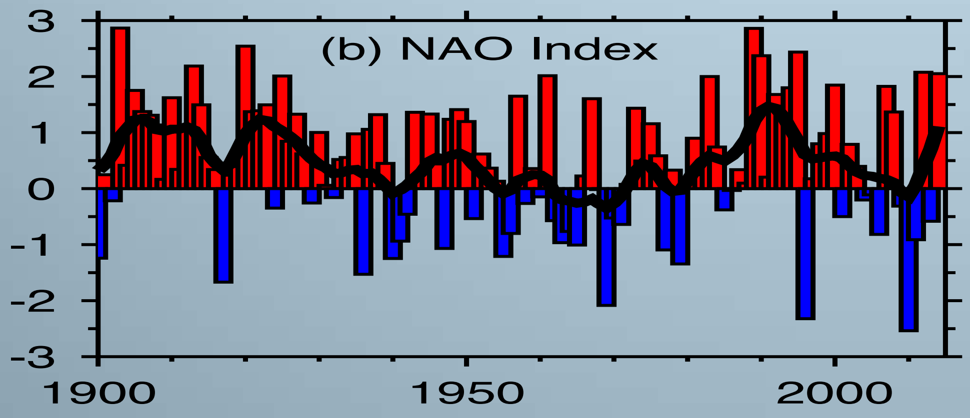
NAO-

Schematic of the mid-latitude jet-stream



The NAO is highly variable, influenced by many different factors

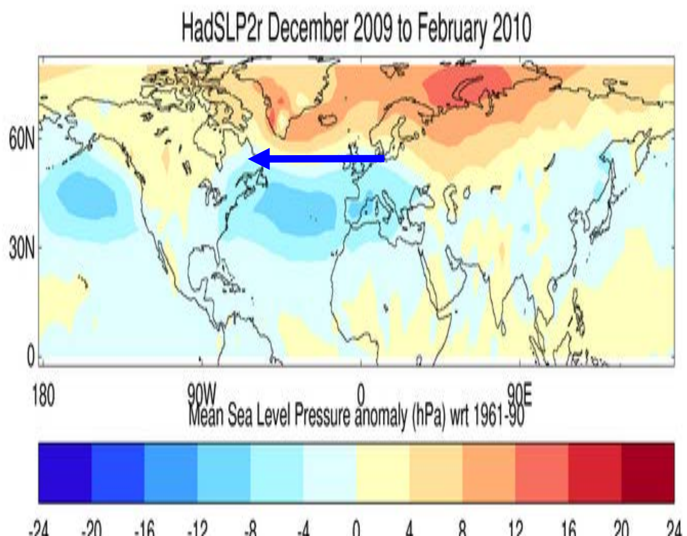
- natural internal variability
- Pacific North America (PNA) wave train from the tropics
- ENSO
- Sea ice extent
- Tropical rainfall
- stratospheric polar vortex
- ocean circulation feedback

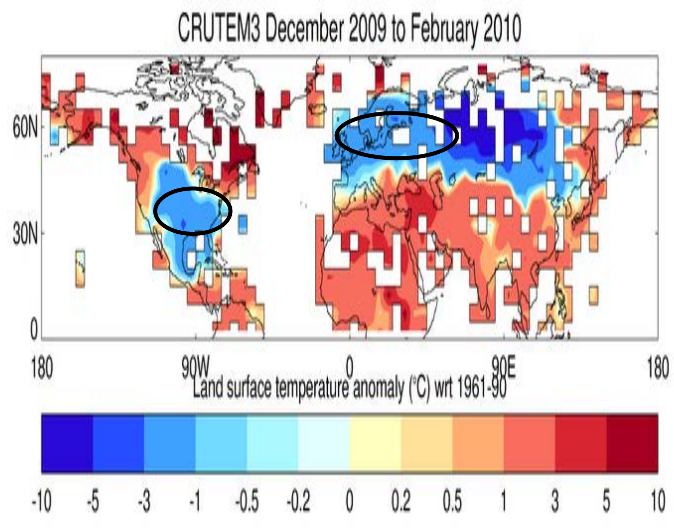


Is there an 11-yr solar signal in this NAO index?

Winters depend on which way the wind blows (i.e. the phase of the NAO)

Winter 2009/10





Weak P Gradient
(NAO-)

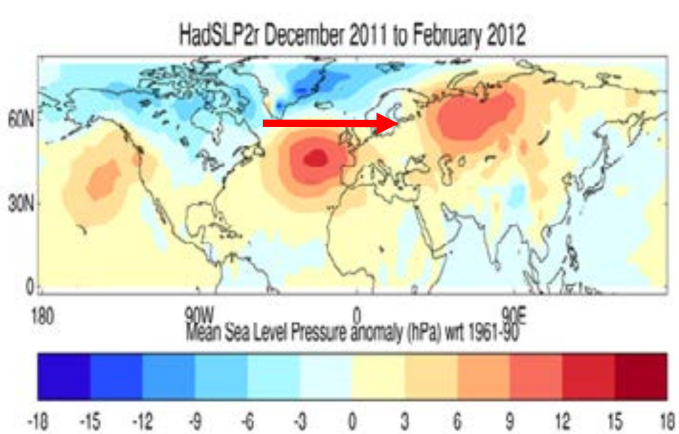
Cold advection into N. Europe

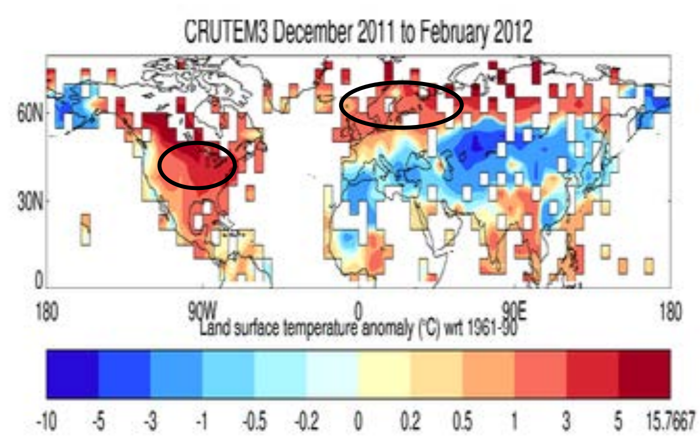
Cold, calm and dry in N Europe

Sea level pressure anomaly

Winter 2011/12

Surface temperature anomaly





Strong P Gradient
(NAO+)

Warm advection into N. Europe

Mild, wet and stormy in N Europe

Multi-Linear Regression Analysis

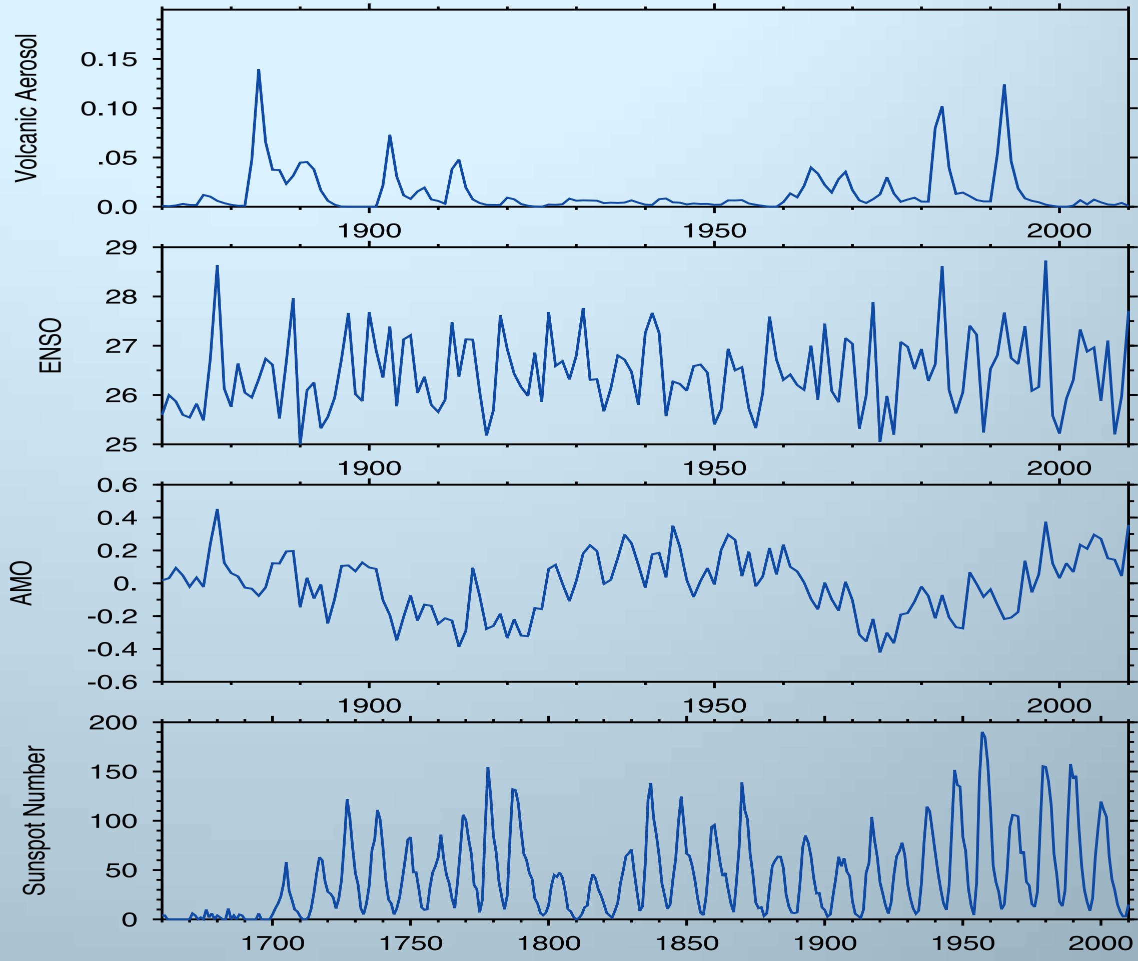
Volcanic

ENSO

AMO
(Atlantic Multidecadal Oscillation)

Solar

+ Long-term trend, (QBO)



Huge drawback: assumes indices are independent and climate signals can be characterised by linear combinations

Future: improved techniques e.g. machine learning to detect teleconnections; causal effects networks (Potsdam Institute)

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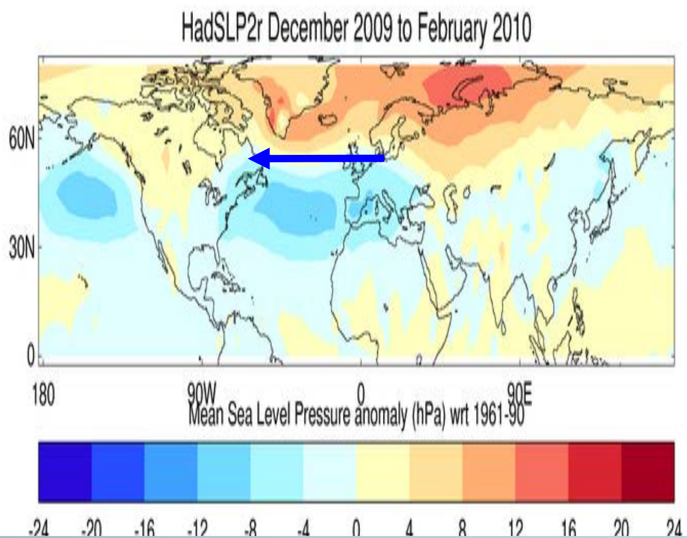

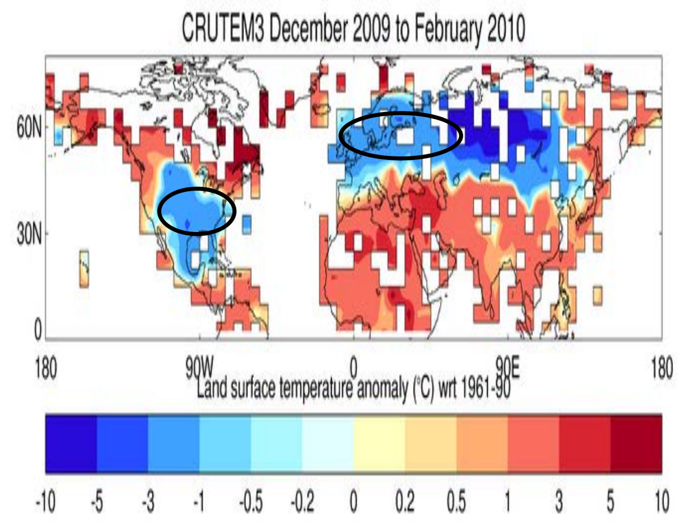

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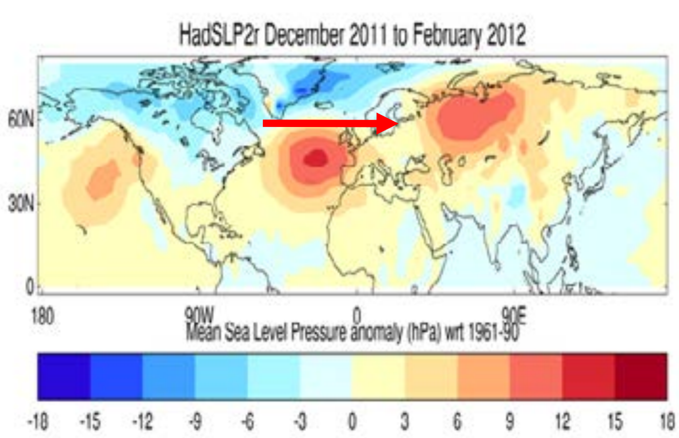

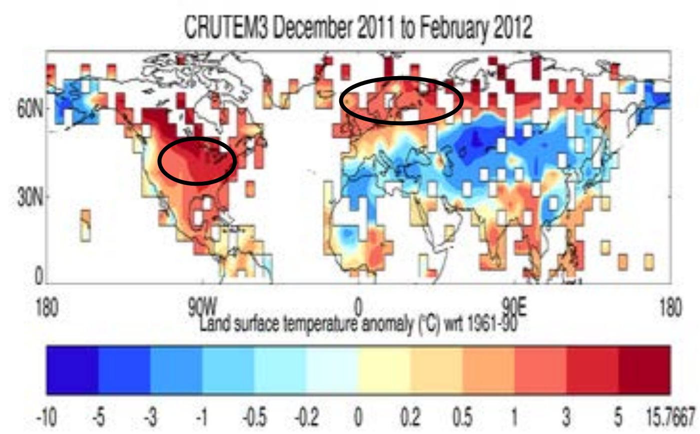

Strong P Gradient
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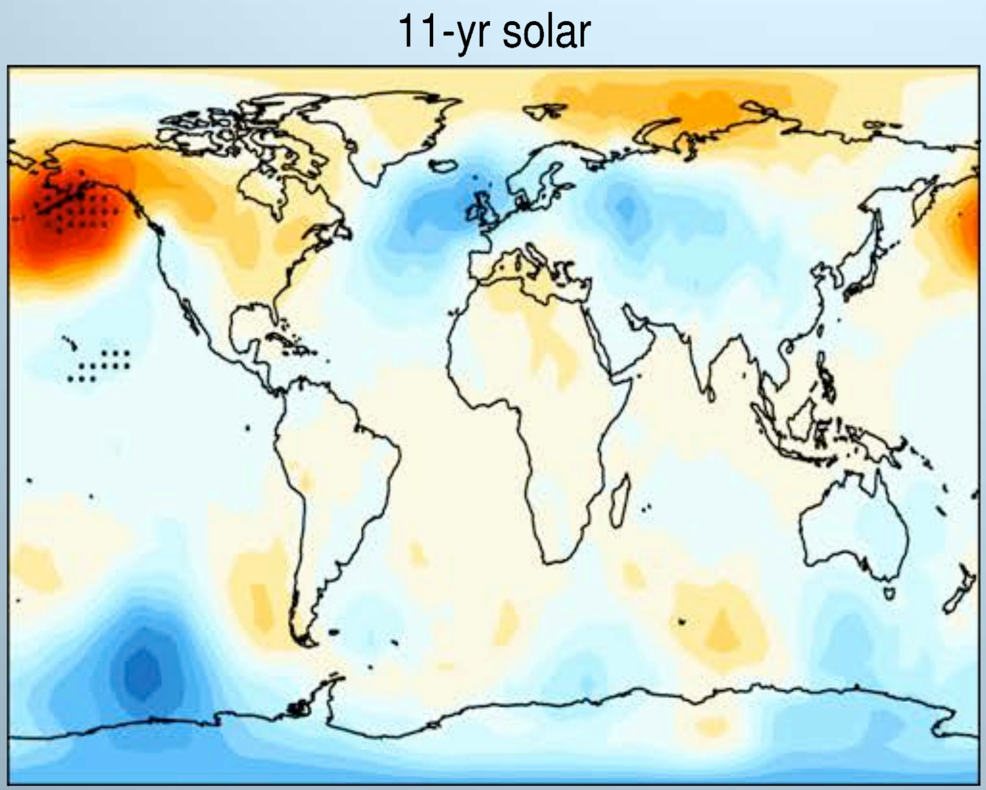
Warm advection into N. Europe

Mild, wet and stormy in N Europe

HadSLP mean sea level pressure

1870-2012 (approx 13 solar cycles)



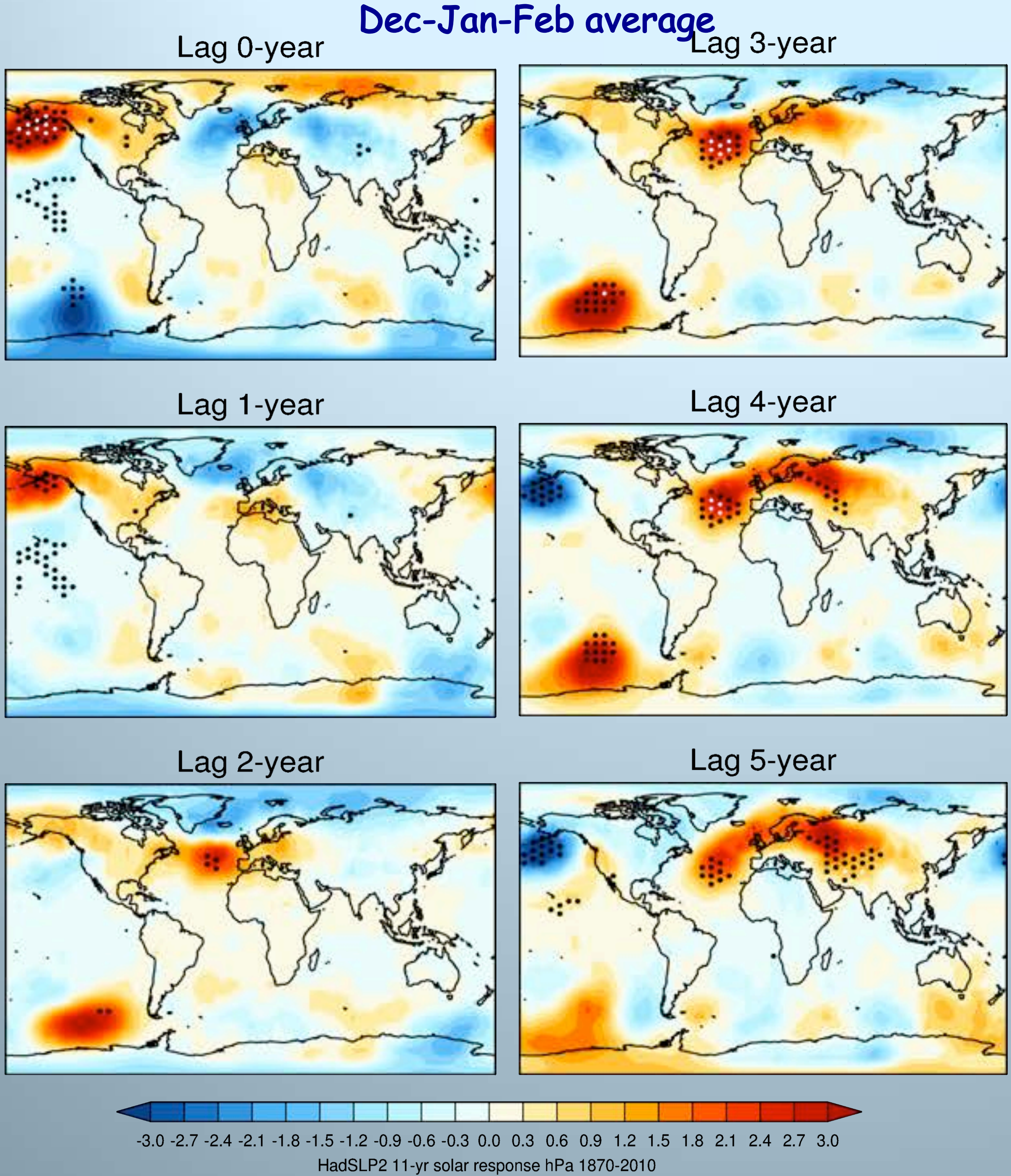
Black dots: 99% statistical significance

- Roy and Haigh 2010
- See also Tung and co-workers; Lean and Rind;

multiple regression analyses

Dec-Jan-Feb average
Smax minus Smin

No statistically significant NAO response



Regression analysis of mean sea level pressure (HadSLP) 1870-2015 (13 solar cycles)

Gray et al. 2013 JGR

No significant NAO response at zero lag BUT a signal emerges at 3-4 year lags

Black dots: 95%
White dots: 99% statistical significance

DJF
mslp response over Atlantic / European sector

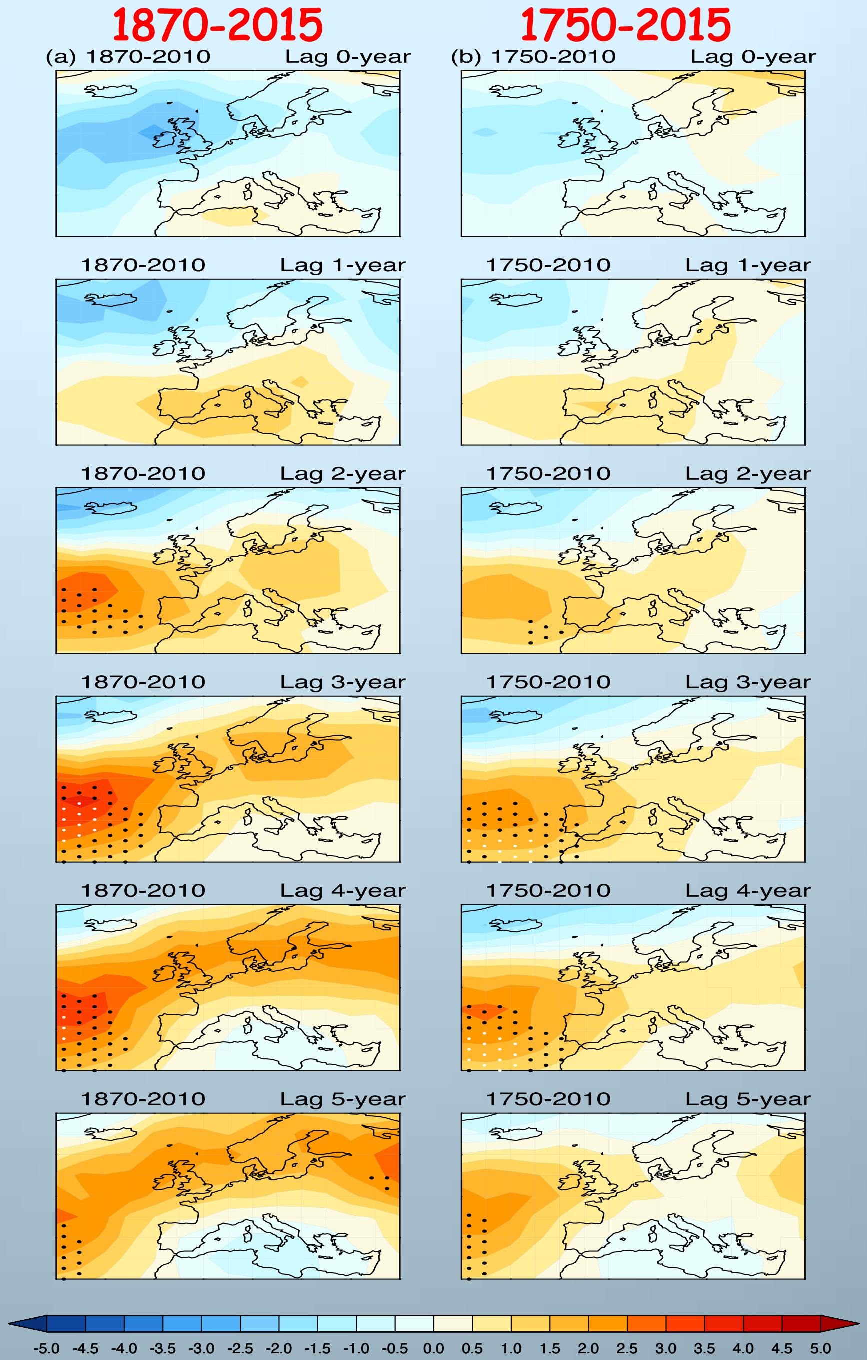
1750-2015
~24 solar cycles

1870-2015: HadSLP2

1750-1870: Luterbacher et al. 2002 reconstruction

Gray et al. QJRMS 2016

see also Brugnara et al. 2009



Where does the lag come from?

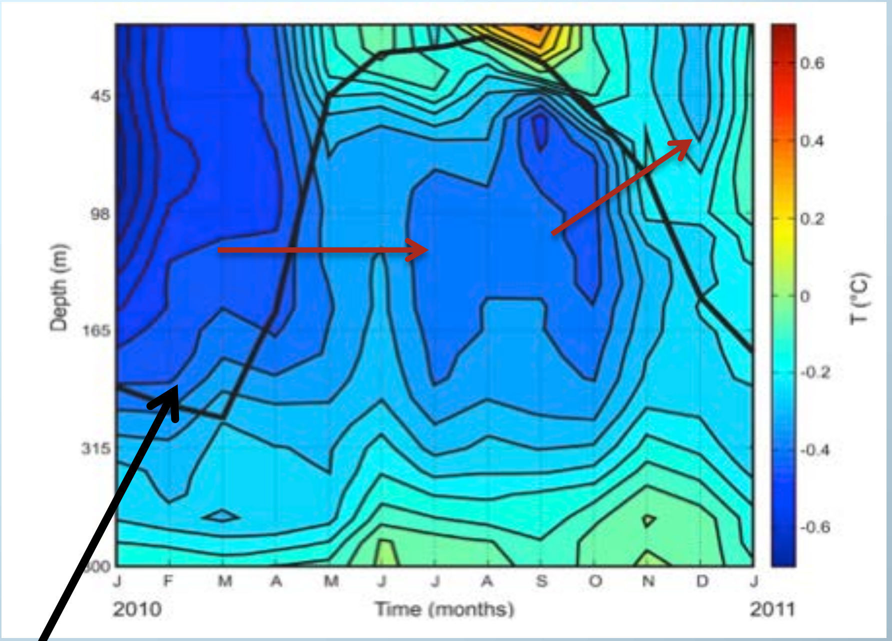
Is it the atmosphere? No – the atmosphere has insufficient 'memory' and the observed stratospheric response is at lag-zero

Is it the ocean? The North Atlantic Ocean is a more likely source of the memory

- 'top-down' mechanism via stratospheric vortex forces +ve NAO at Smax and SSTs respond to this via wind stress and heat flux anomalies
- *Sequestration and re-emergence of SST anomalies*
- Demonstrated in non-solar contexts
- Seasonal variation of mixed-layer-depth is the key.

Scaife et al. GRL, 2013;

Andrews et al. ERL 2015



Mixed-layer depth

Taws et al., 2011 (35-60N, 45W-10E)

So we propose **two processes** occur:

Firstly: direct (top-down) forcing via stratosphere with max response at zero-lag

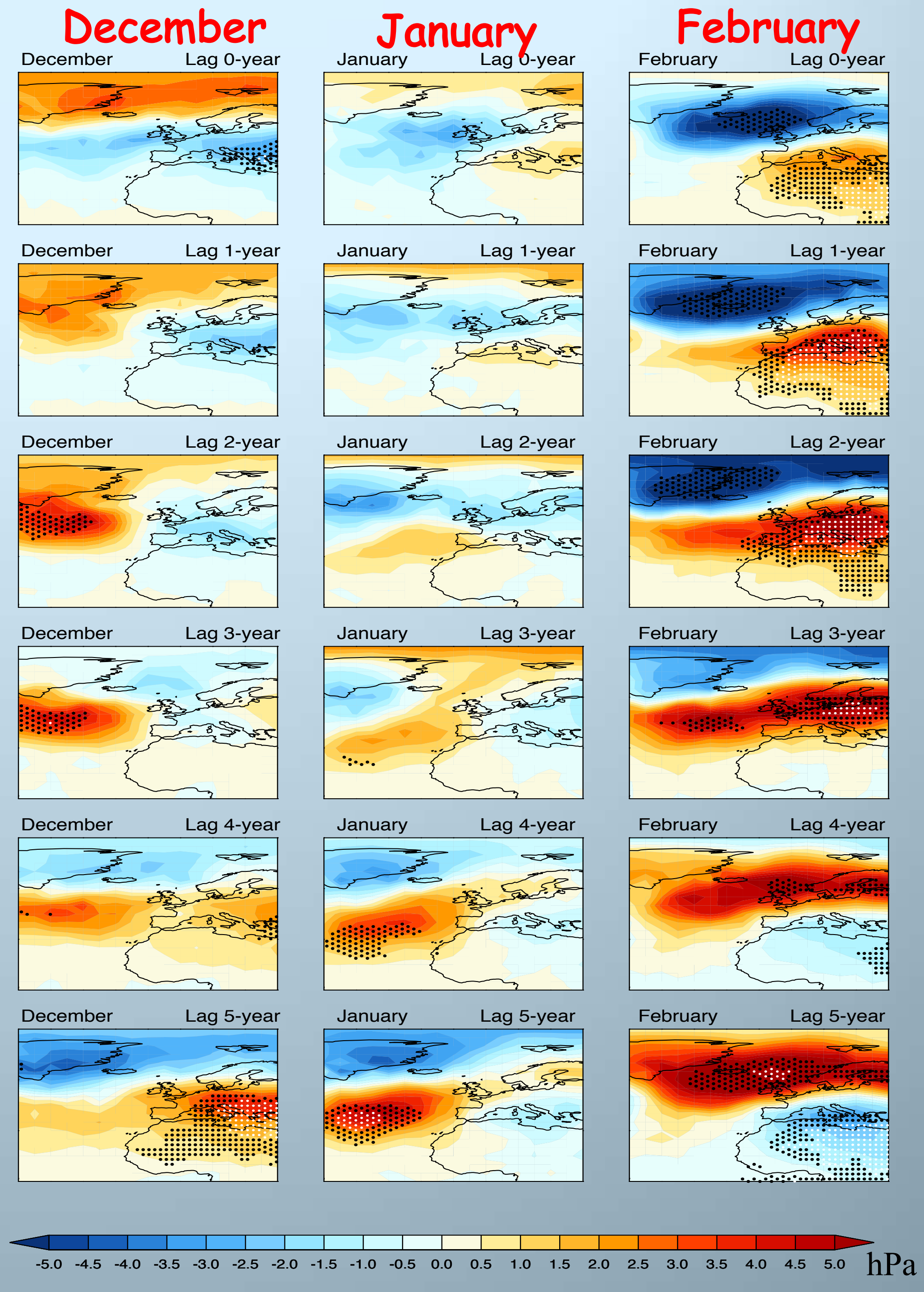
Followed by: indirect (bottom-up) forcing via mixed-layer ocean amplification with max response at 3-4 yr lag

If we carry out the regression analysis for individual months: we see possible evidence of both mechanisms operating

February: shows a lag-zero response

December: ~3-yr lagged response

11-yr solar cycle mslp response 1870-2015

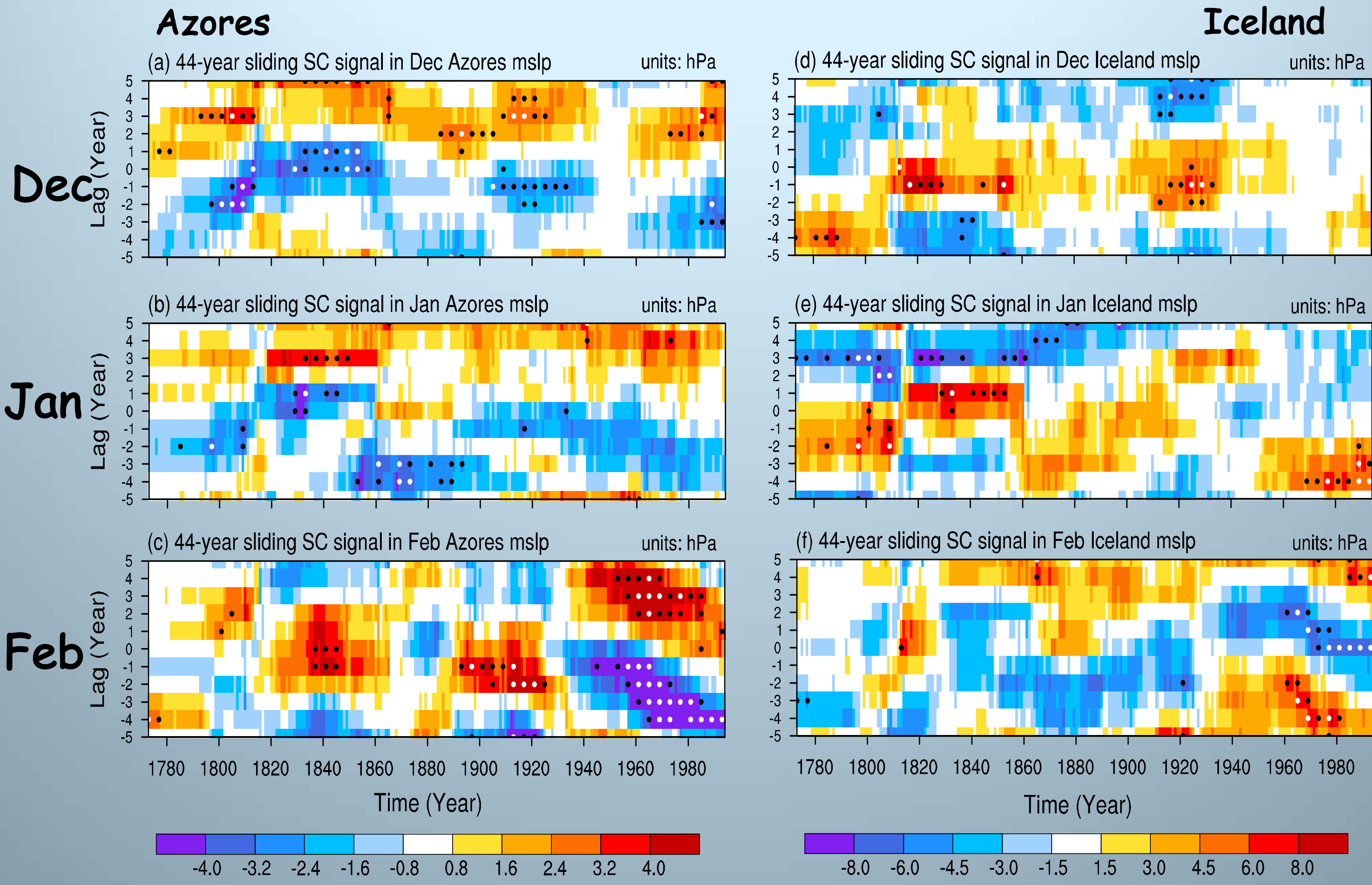


Statistical significance:
Black dots: 95%
White dots 99%

Gray et al. 2016, Q.J. Roy. Met. Soc

33-yr sliding NAO response to 11-yr solar cycle

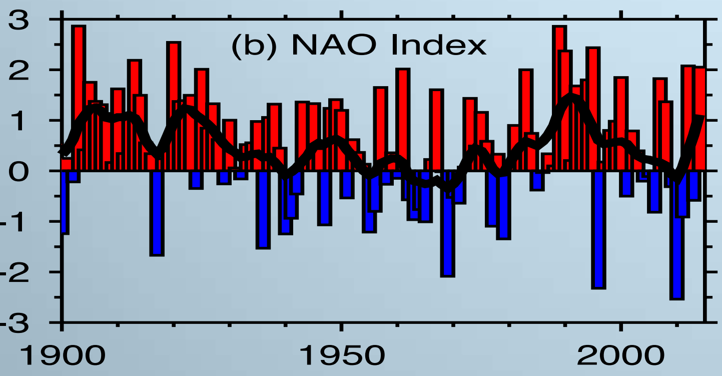
(Ma et al. 2018 Env. Res. Letts.)

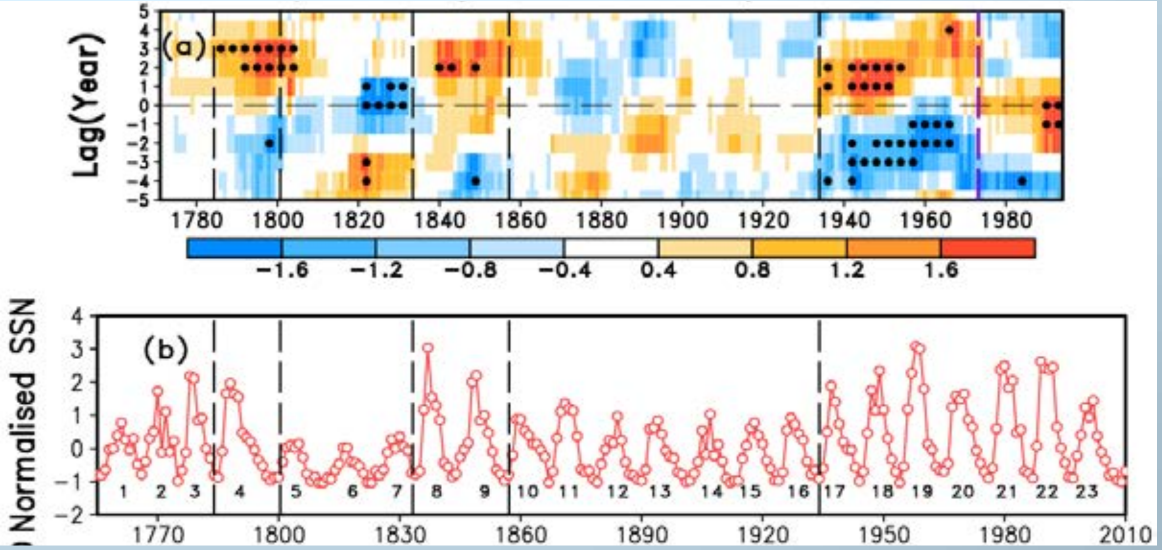


Can we understand why the sign of the solar response seems to vary in time?

(Ma et al. 2018 Env. Res. Letts.)

Solar cycle signal in DJF NAO index





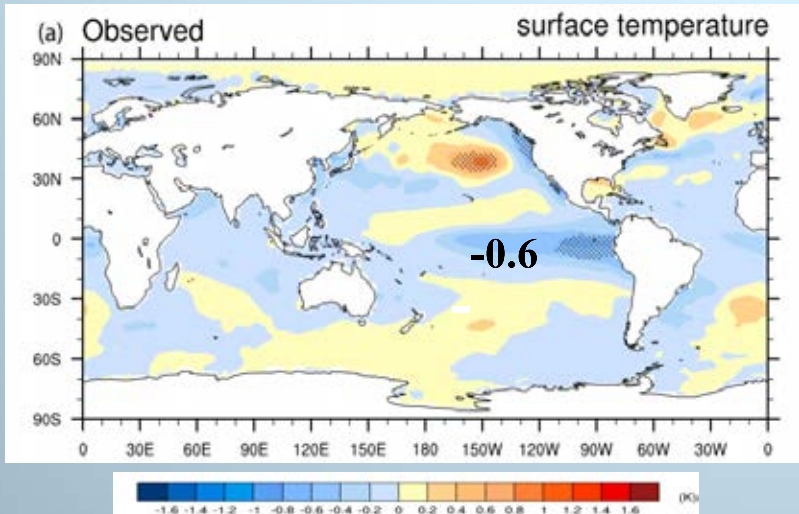
1. The lagged response is sporadic

2. The response appears to be proportional to the amplitude of the sunspot variations – perhaps partly explains why the response is sporadic

3. There's a strong response from 1940s to the present, corresponding to the strong solar forcing, but ~1970s the lag shifts from 3-4 years to zero-lag; this explains why studies of most recent observations since 1979 show a lag-zero solar response – but why?

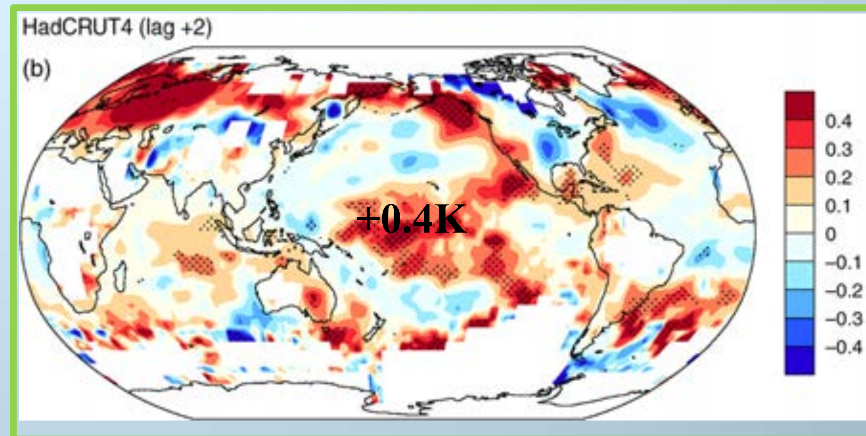
The case of the Tropical Pacific

Observations: Composite
1870- lag zero



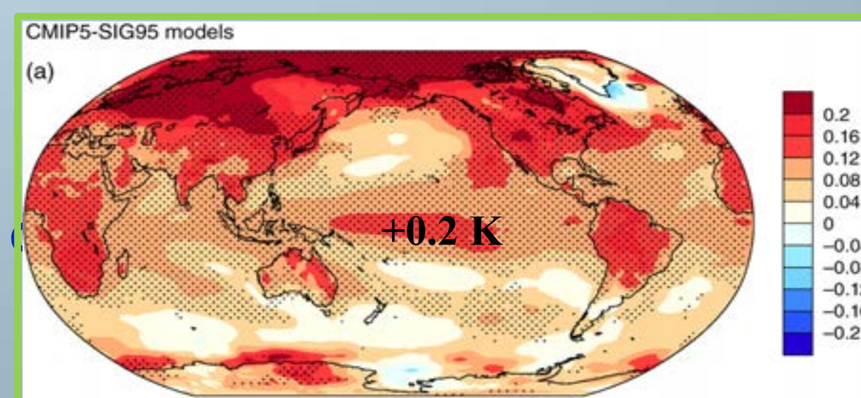
Meehl et al., 2009

Observations: Regression
1950- lag-2 yrs



Misios et al., 2015

CMIP5 models 1850- ~lag 2-yrs



- Is there any solar signal in the tropical Pacific?
- How to filter out ENSO?
- CMIP5 models show a tendency for warmer equatorial Pacific.

Mechanisms: bottom-up

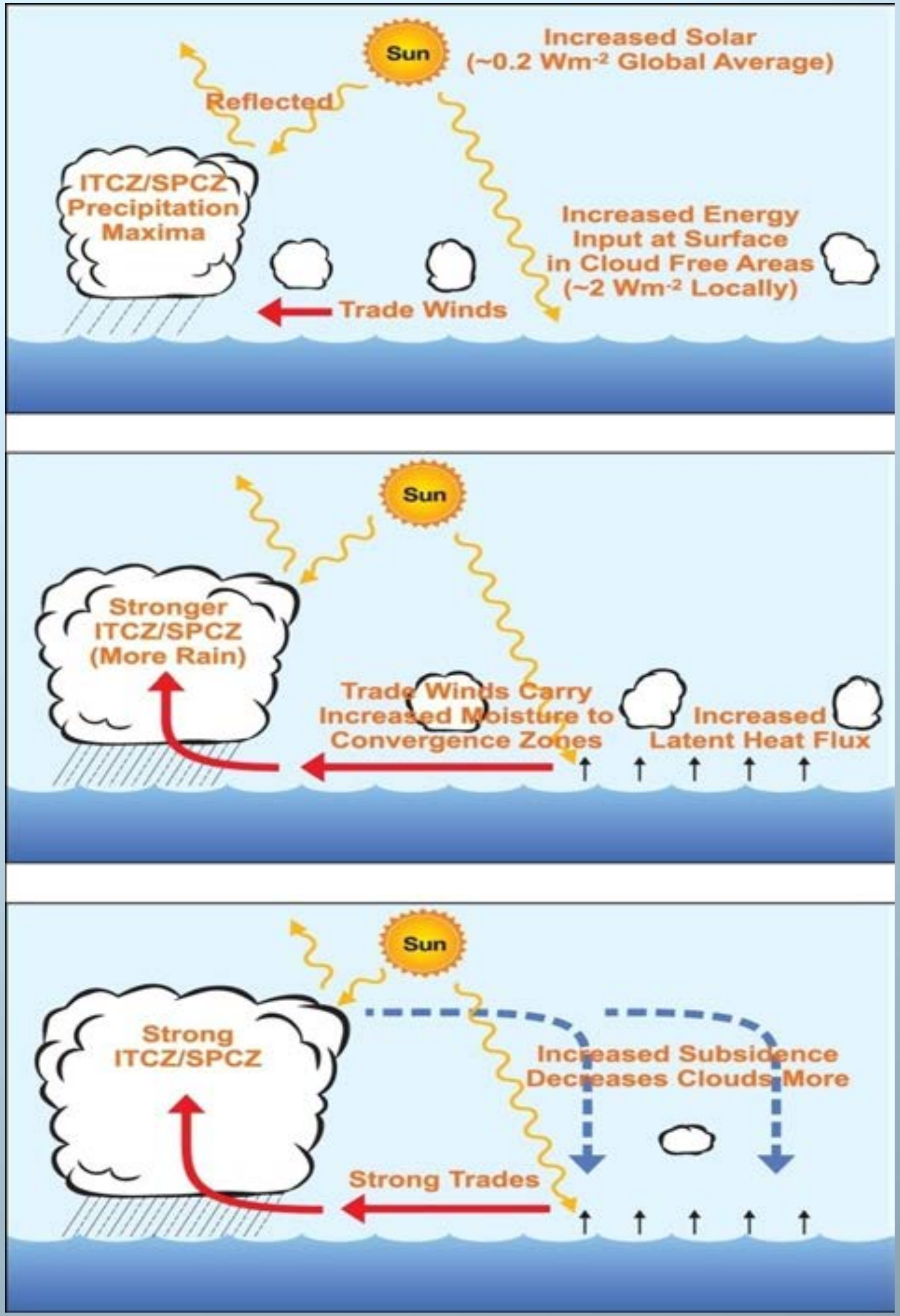
The 'bottom-up' mechanism through total solar irradiance (TSI):

1. Increased solar absorption at Smax in cloud-free subtropical oceans, increases evaporation;

2. increased moisture converges into precipitation zones, intensifies precipitation and upward vertical motions, which strengthens Hadley and Walker circulations;

3. stronger subsidence in subtropics gives positive feedback that reduces clouds and allows increased solar forcing.

Cubasch, van Loon, Meehl, White

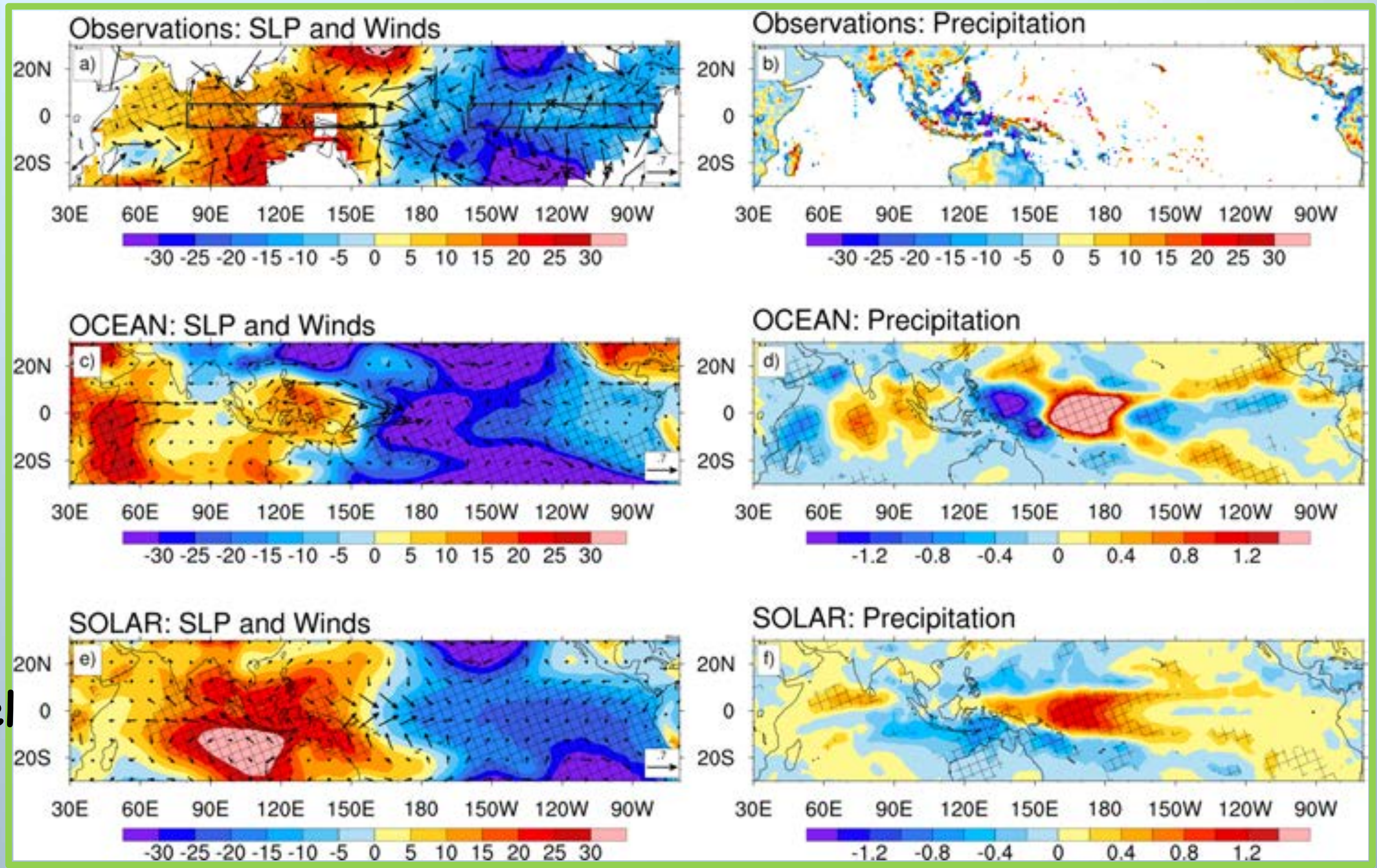


SC influence in the Tropics

Obs mslp

Atmospheric model forced only by SSTs

Fully coupled ocean / atm model with repeated 11-yr solar forcing



In the Indo-Pacific:

Misios et al., 2018 (submitted)

- SLP gradient weakens; easterly winds weaken; Walker circulation slows down
- Precipitation shifts to the east
- Signals are driven by the surface warming to solar cycle heating (bottom up)
- Proposed mechanism: as with GHG warming, water vapour content increases proportionately more than precipitation increases

Summary

- The surface response to solar variability is complex, in both the Atlantic (NAO) region and the Pacific; we don't yet have adequate tools to disentangle this complexity
- The NAO response to 11-year solar forcing is sporadic, causing much scepticism
- Overall the maximum response occurs at 3-4 year lag, but this varies with time and recent periods show a lag-zero response
- A possible ocean-atmosphere coupling mechanism is proposed that amplifies the NAO signal and produces the 3-4 year lag – but this is difficult to model and there may be other explanations
- The NAO response appears to depend on the amplitude of the solar forcing, which helps to explain some of the sporadic nature of the response
- It's also possible that the amplification mechanism may be state-dependent, which could also give rise to a sporadic response
- There is still a lot of controversy about the Pacific response – very difficult to disentangle it from ENSO
- The Walker circulation appears to slow down in response to solar max, in same way as models predict a slow-down of the Walker circulation in response to GHG warming.