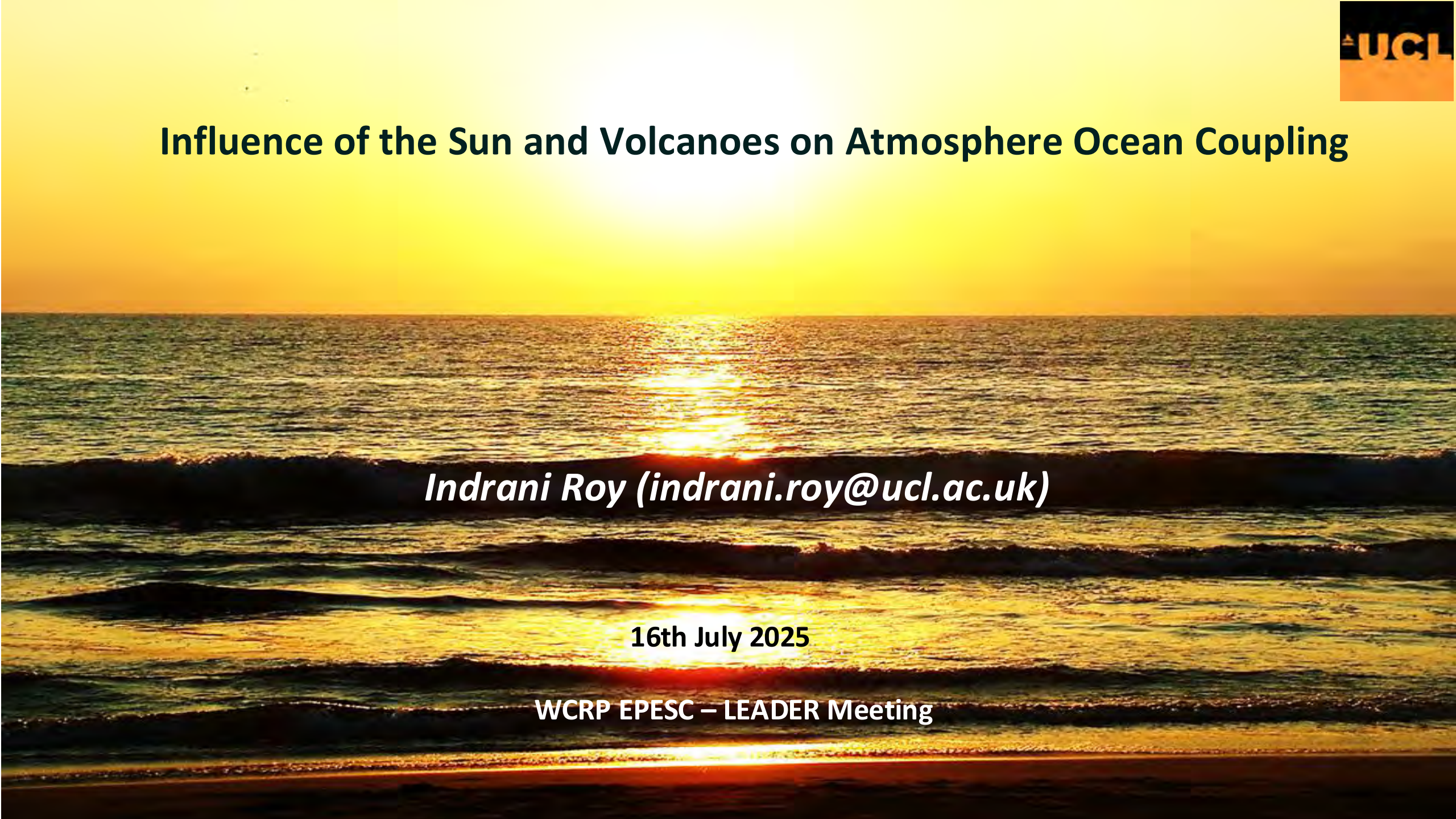


Influence of the Sun and Volcanoes on Atmosphere Ocean Coupling

Indrani Roy (indrani.roy@ucl.ac.uk)

16th July 2025

WCRP EPESC – LEADER Meeting

Outline

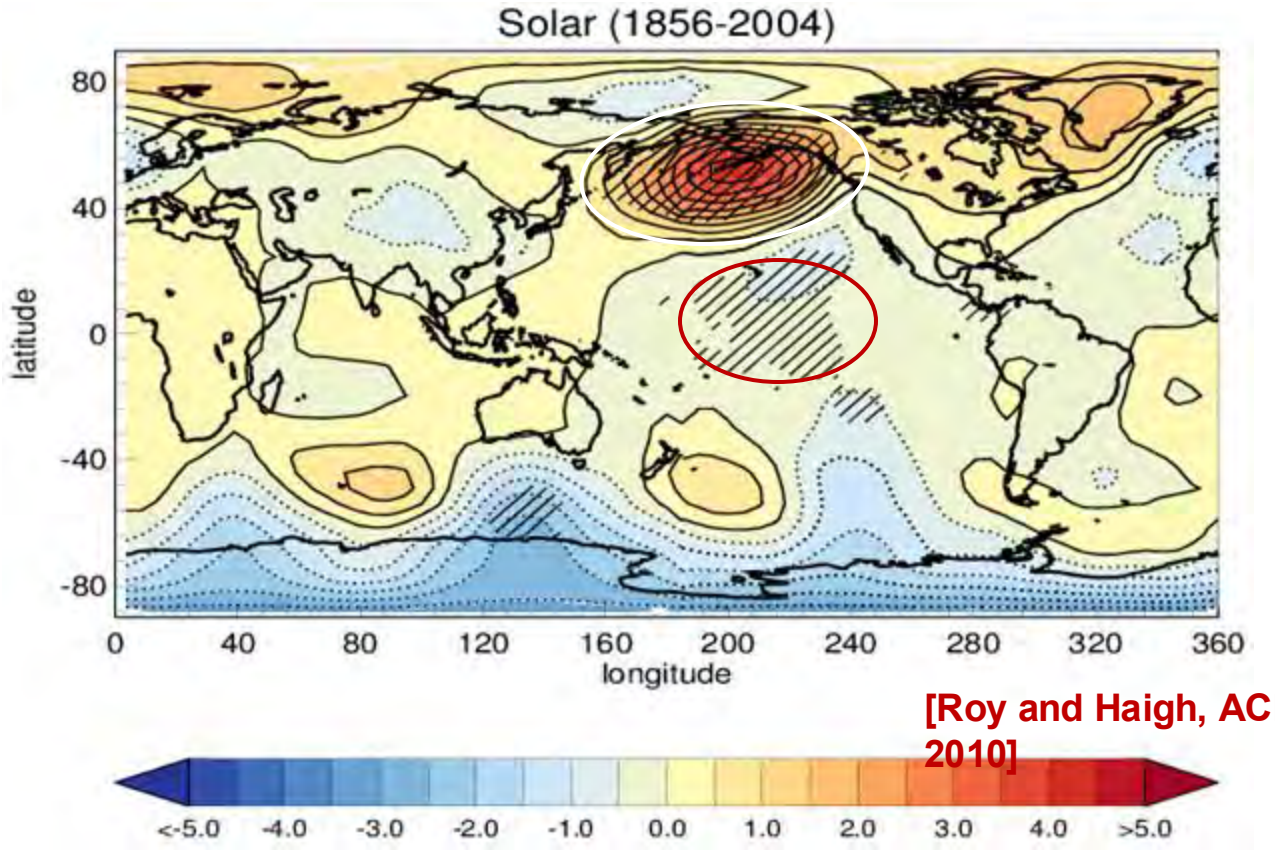
- **Solar influence on climate**

  Main mechanisms: Ozone variation ~6% in stratosphere between solar min to max.

- **Influence of strong Volcanoes**

  Mechanisms: Ozone changes ~5% in stratosphere after strong volcanos

Robust Solar signal on Climate



[Roy and Haigh, ACP, 2010]

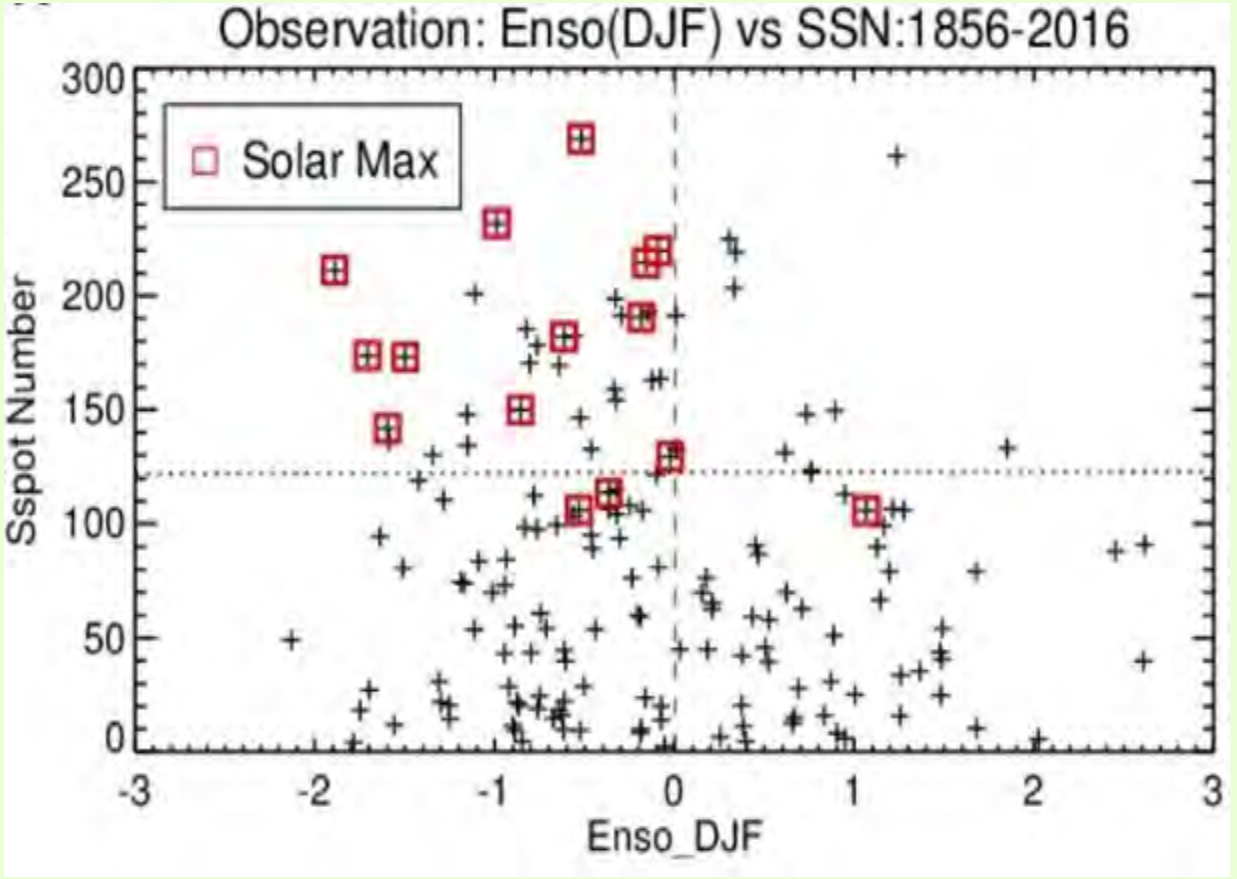
Signal on observed **Sea Level Pressure data, HadSLP2** (DJF) using **Multiple Linear Regression:**

- Robust around Aleutian Low (Place of PDO) using different time periods. Decadal signal similar to Cold event of ENSO.
- Significant signal around tropical Pacific to incite Trade wind.
- No significant pattern of NAO.

Interested in Details

Roy, I. and Haigh, J.D., 2010, 'Solar cycle signals in sea level pressure and sea surface temperature', *Atmospheric Chemistry and Physics (ACP),* 10, 6, 3147–3153.
Impact Factor: 6.54; **Citations: 140**

SSN vs. ENSO (DJF)



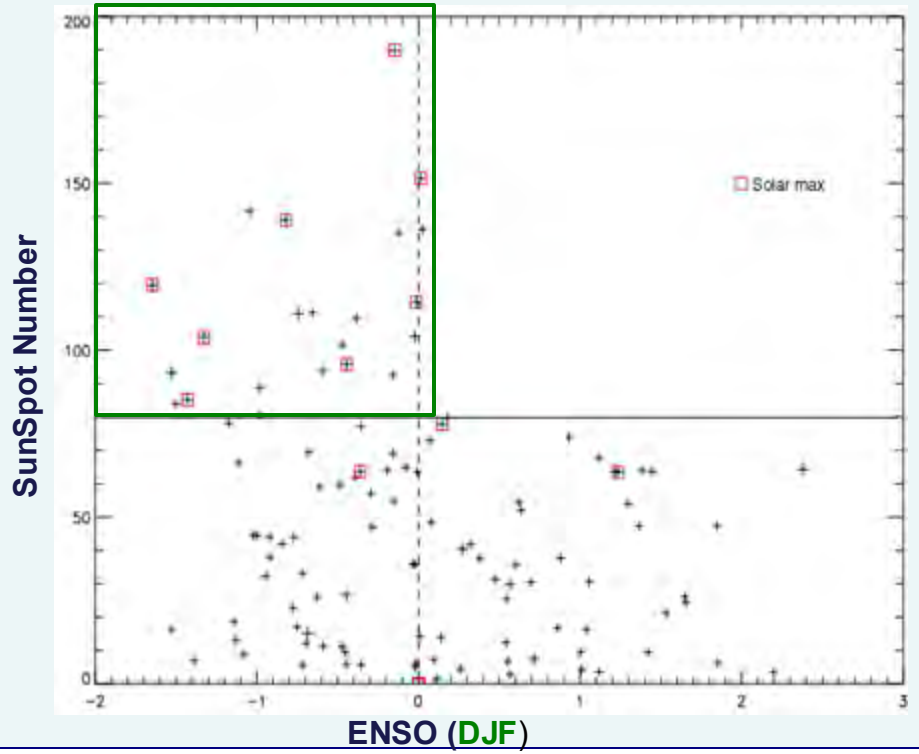
Solar Max (peak) years for high solar cycles (SSN>120, using version 2) are biased towards **Cold event side of ENSO**. Not seen in models.

SSN is now above that threshold and 2025 (DJF) was Cold event type of ENSO

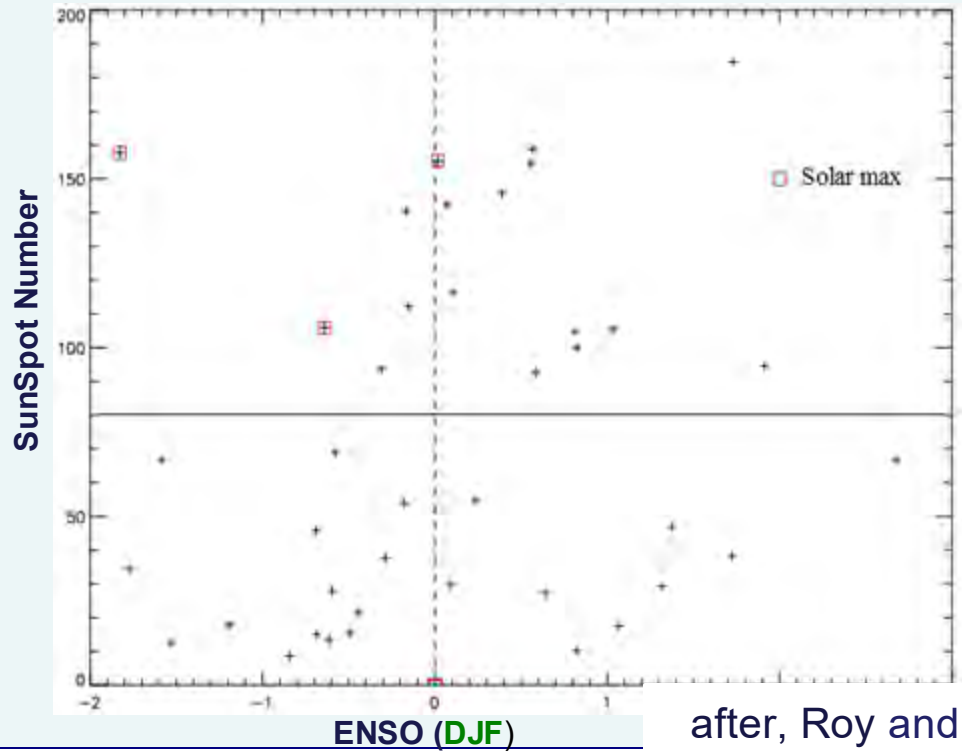
Sun-ENSO connection was different before 1950s (and after 1997)

- Strong **decrease** in strength of shallow meridional overturning circulation (MOC) around tropical Pacific after 1950s
- Modest **intensification** since 1998
- Also true for Walker and Hadley circulation; more in Walker. (McPhaden and Zhang,2004;Vecchi and Soden 2007)

(1856-1957) & (1998-2007)



(1958-1997)



after, Roy and Haigh (2012)

Before 1958 and after 1997

- All years with higher S.S numbers (say, above 80, using version 1) are with –ve ENSO index
- Possibly, active sun influences SSTs but this is overwhelmed by innate strong ENSO variability at lower solar activity

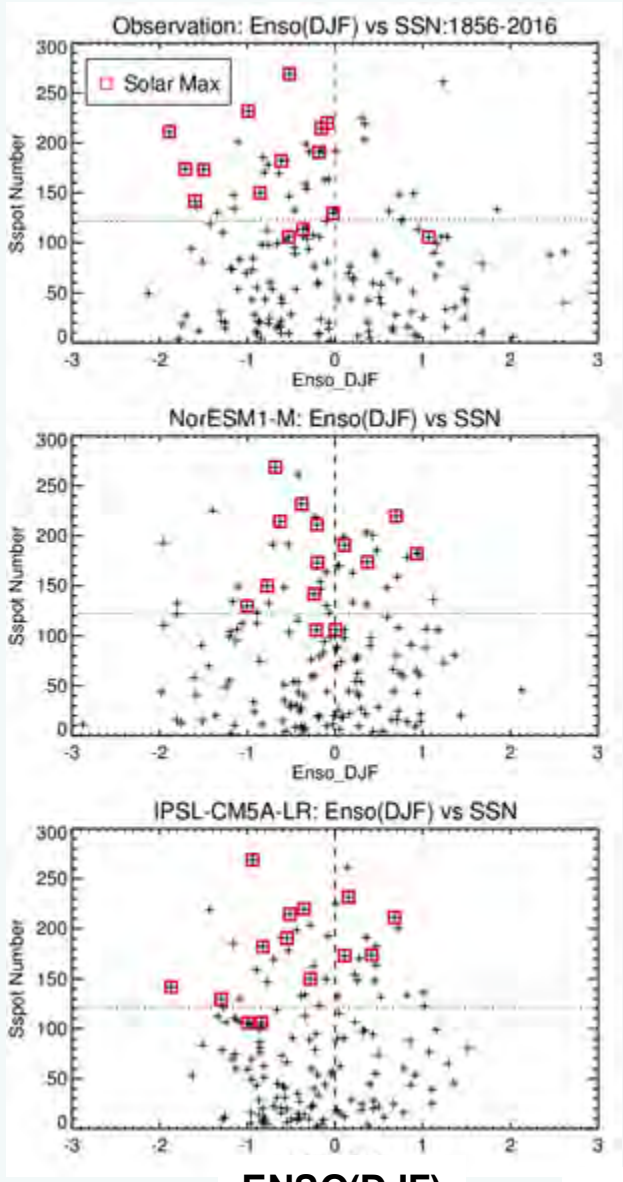
SSN vs. ENSO (DJF) updated result

1856-2016

1856-1957 & 1998-2016

1958-1997

SSN



ENSO(DJF)

OBS

- **Obs:** Top

Sun and ENSO (DJF) different connections (cold event) after 1998 and before 1957 in all active solar years (SSN >120), not only Max yrs.

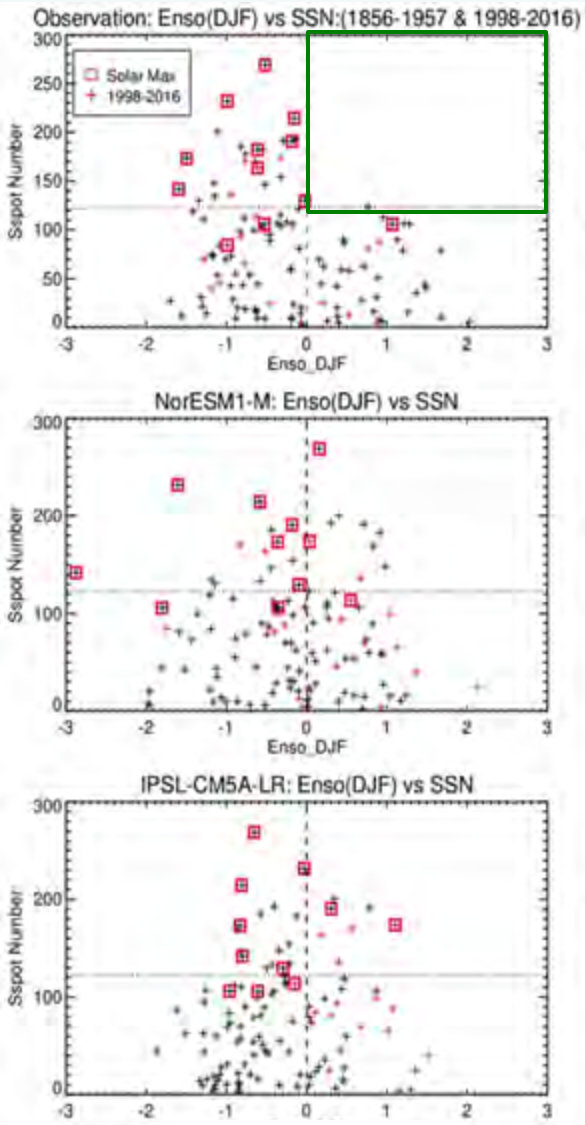
NorESM1-M

- **Model:** Bottom Two

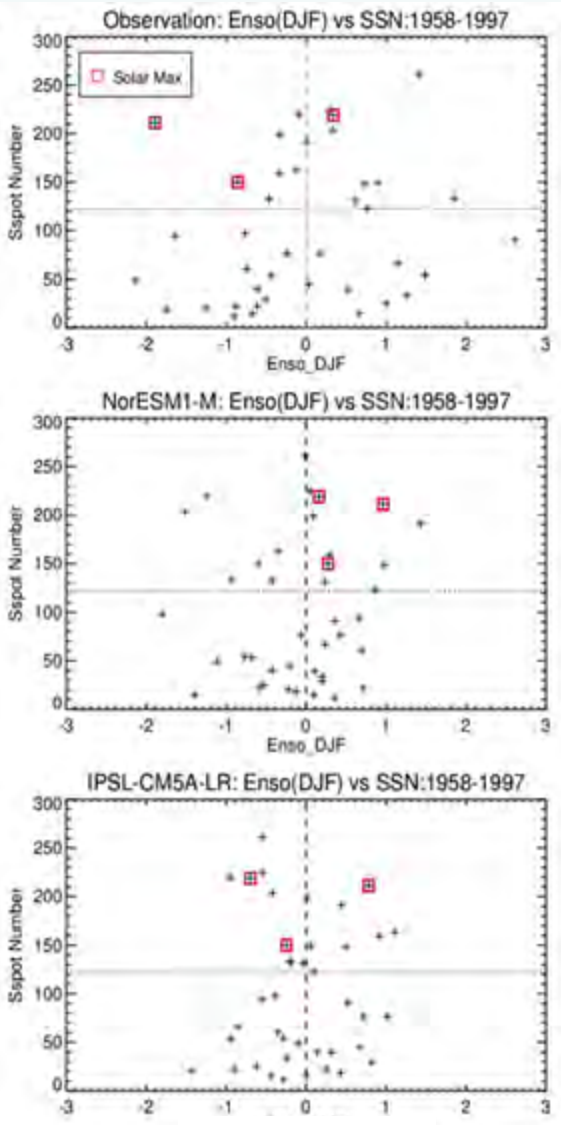
Solar contribution of warming as observed (Top) via ENSO in later decades of 20th century is missing in all CMIP models.

IPSL-CM5A-LR

[Roy, Frontiers in Earth Sci, 2018]

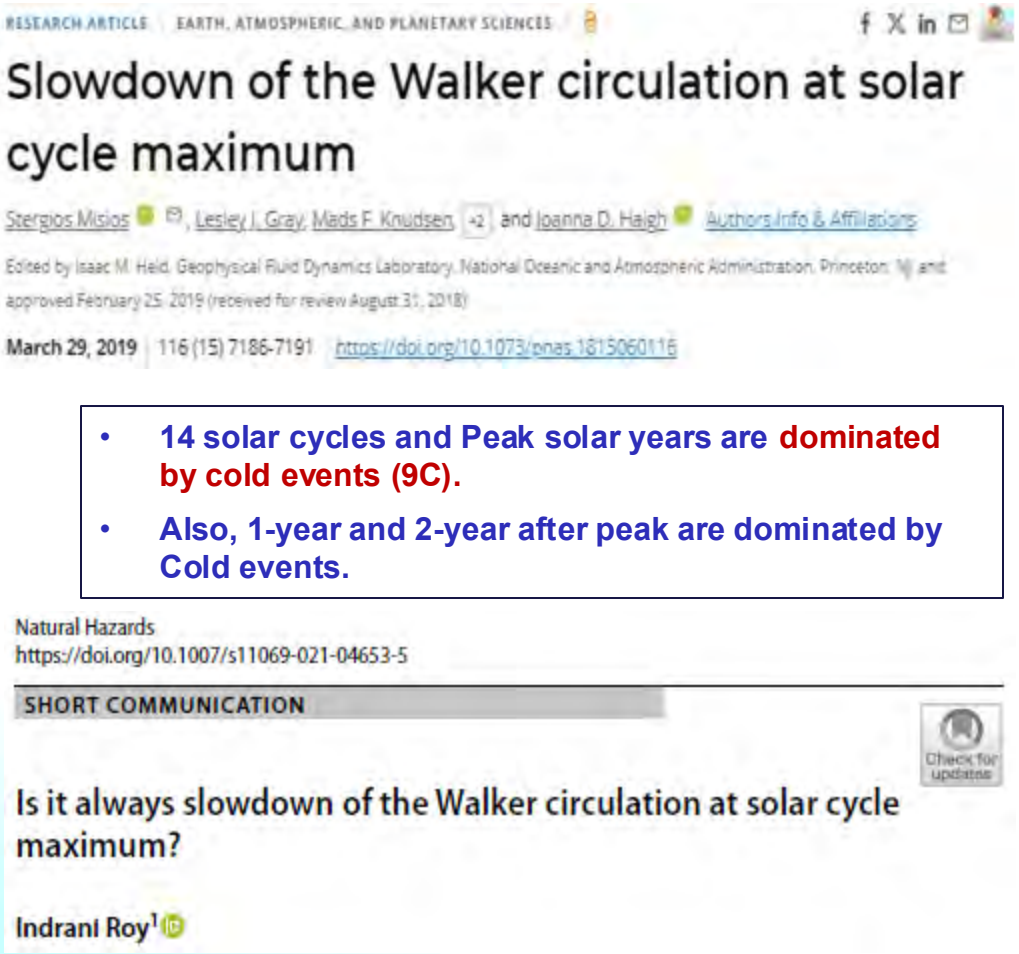


ENSO(DJF)



ENSO(DJF)

Sun-ENSO connection: Peak year and Lag year since 1856



RESEARCH ARTICLE | EARTH, ATMOSPHERIC, AND PLANETARY SCIENCES

Slowdown of the Walker circulation at solar cycle maximum

Stergios Misios, Lesley J. Gray, Mads F. Knudsen, +2 and Joanna D. Haigh Authors Info & Affiliations

Edited by Isaac M. Held, Geophysical Fluid Dynamics Laboratory, National Oceanic and Atmospheric Administration, Princeton, NJ, and approved February 25, 2019 (received for review August 31, 2018)

March 29, 2019 | 116 (15) 7186-7191 https://doi.org/10.1073/pnas.1815060116

- **14 solar cycles and Peak solar years are dominated by cold events (9C).**
- **Also, 1-year and 2-year after peak are dominated by Cold events.**

Natural Hazards
https://doi.org/10.1007/s11069-021-04653-5

SHORT COMMUNICATION

Check for updates

Is it always slowdown of the Walker circulation at solar cycle maximum?

Indrani Roy[1]

Solar cycle no	Years	Peak year	State of ENSO (DJF)		
			peak year	1 y after peak y	2 y after peak y
10	1856-1867	1860	C	C	C
11	1867-1878	1870	C	C	C
12	1878-1890	1883	C	-	W
13	1890-1901	1893	C	C	C
14	1901-1913	1905	W	W	C
15	1913-1923	1917	C	C	W
16	1923-1933	1928	W	C	W
17	1934-1944	1937	-	C	C
18	1944-1954	1947	-	W	C
19	1955-1964	1957	C	W	W
20	1964-1976	1968	C	W	W
21	1976-1986	1979	-	W	C
22	1986-1996	1989	C	W	W
23	1996-2007	2000	C	C	C
	Total		**9 C 3 – 2 W**	**7 C 1 – 6 W**	**8 C 0 – 6 W**

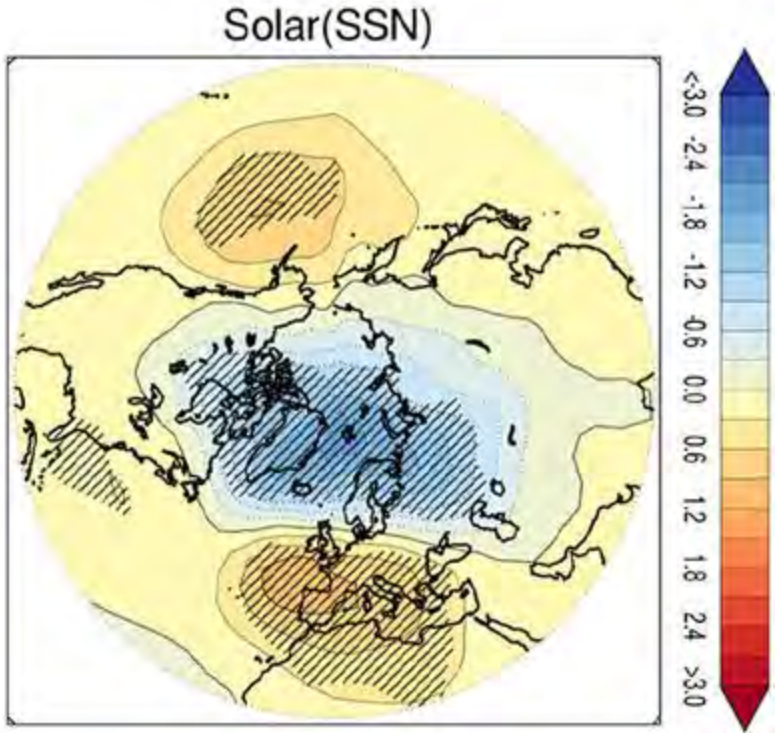
[Roy, 2021, Natural Hazards]

- **Cold event means Walker circulation strengthens. Whereas, warm events or El Nino like situation mean Walker circulation weakens.**
- **Hence, do not indicate in Observation that in high solar years Walker circulation weakens**

Insignificant influence of the 11-year solar cycle on the North Atlantic Oscillation

Gabriel Chiodo, Jessica Oehrlein, Lorenzo M. Polvani, John C. Fyfe & Anne K. Smith

Nature Geoscience **12**, 94–99 (2019) | Cite this article



Positive sun-NAO connection quite distinct since 1970s

Multiple Linear Regression (MLR) technique using Hadley SLP data (hPa), separating ENSO, QBO, Linear trend, Volcanoes.
True using various data and different methodology

Pure Appl. Geophys.

https://doi.org/10.1007/s00024-020-02564-3

Pure and Applied Geophysics

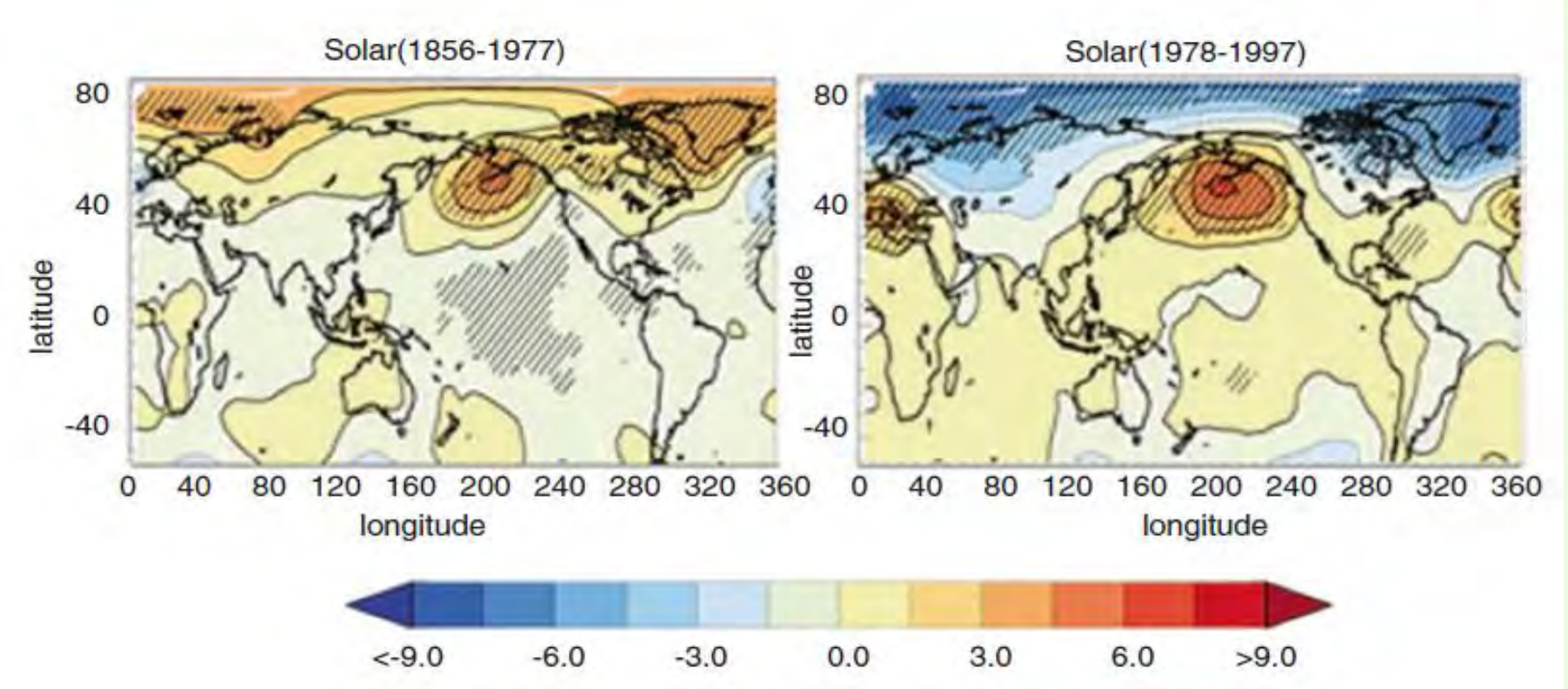
Check for updates

Solar Signals in Observation Indeed Implied Enhanced Predictability Since 1977

Indrani Roy[1]

Sun and NAO

(Observation, Simultaneous relation)

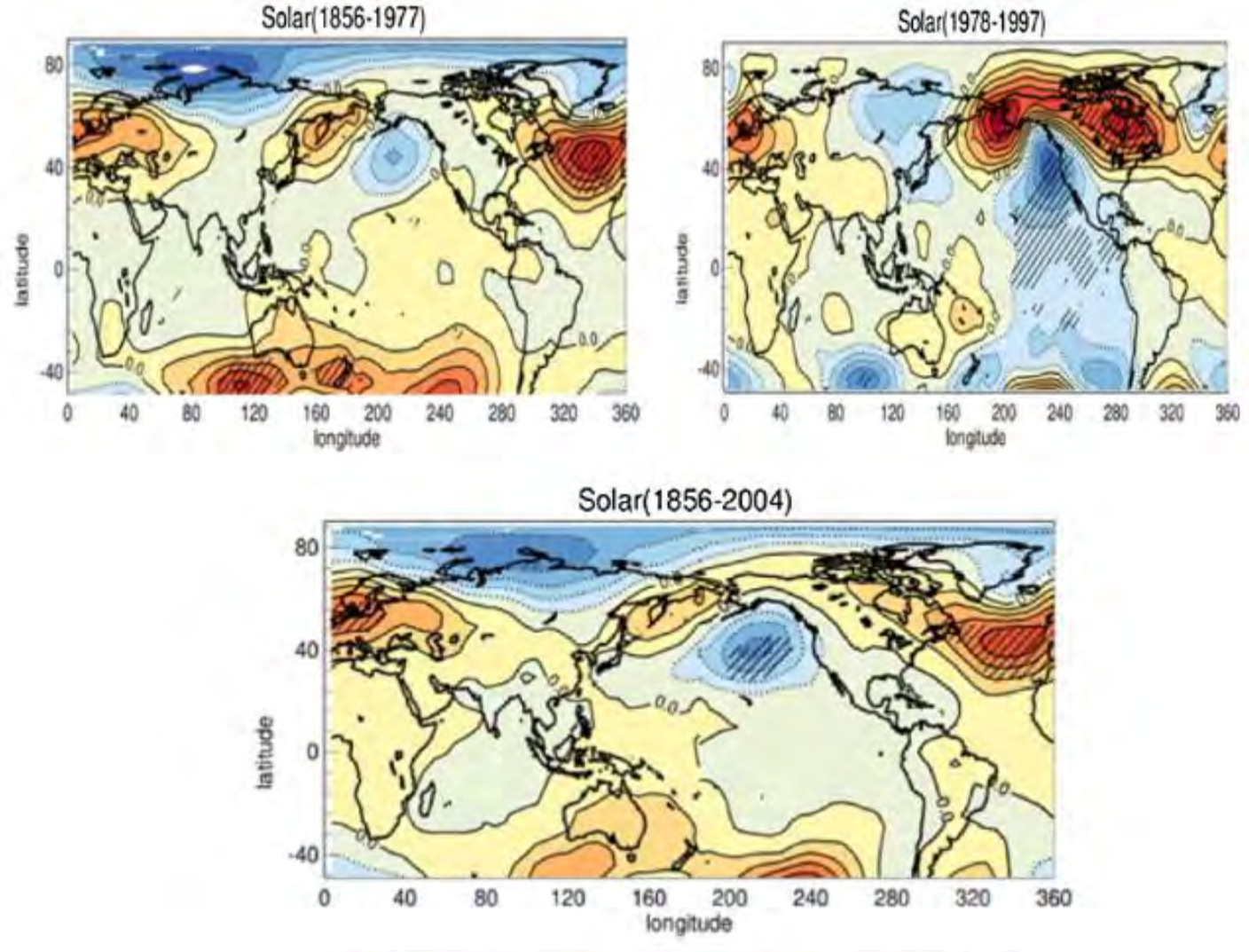


Roy I, (2015, 2020), *Pure Appl. Geophys*

- Sun and NAO very strong positive connection during 1978-1997 in HADSLP2 data (right). Method: Multiple Linear Regression AR1 Noise Model, separating effects of ENSO, linear trend, QBO and volcanoes. Also, captured in UK Met Office model [Ineson, et al., 2011].
- However, signal is not present in earlier period (left)!

Sun and NAO

(Observation, Lag relation)



- Same Hadslp2 data for 1870-2010 suggests strong positive signature around **Azore High** in 3 years lag from peak solar years (Gray et al 2013).

But….

- If again separate period 1978-1997 and period before 1978 - lag response around Azore High is not the same.

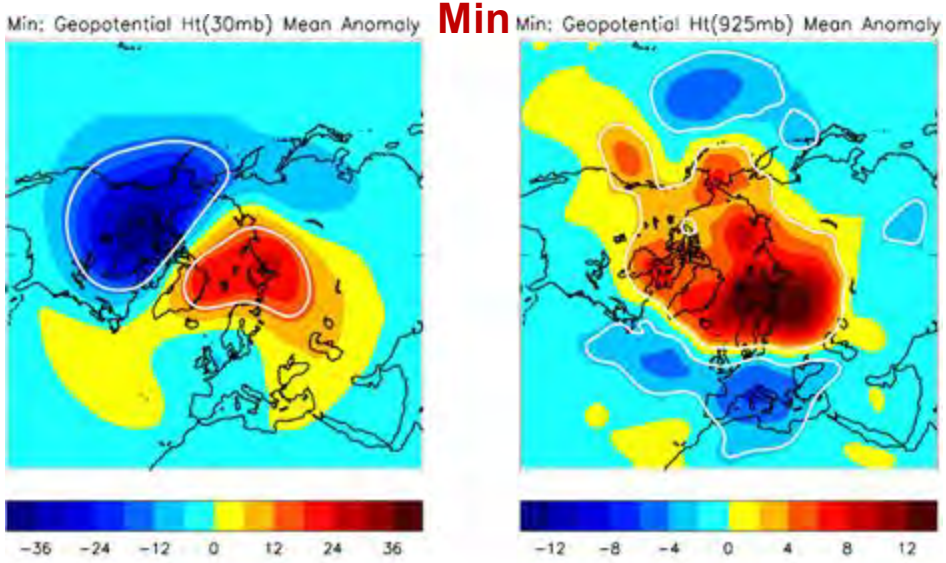
Roy I, (2015, 2020), *Pure Appl. Geophys*

Sun-Arctic connection: During years, when winter Sun Spot Number falls below mean (**Min**), **warming** in **Arctic** extends from surface to high up in upper stratosphere (upto 50 km high); **vice versa** when SSN is above mean (**Max**).

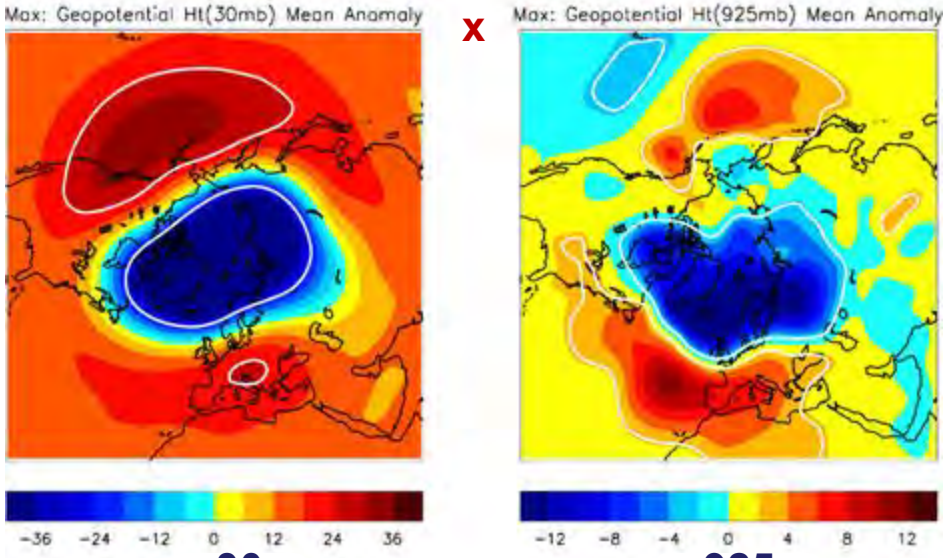
Roy, I., 2018, 'Solar cyclic variability can modulate winter Arctic climate', *Scientific Reports,* 8,4864, doi:10.1038/s41598-018-22854-0.

Composite Study: Geopotential height anomaly- Solar **Min** vs. **Max**

Min



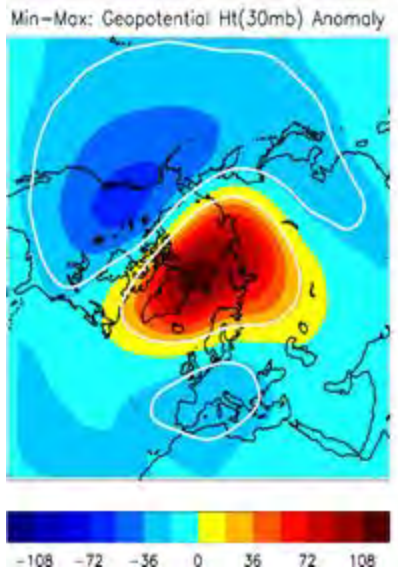
Max

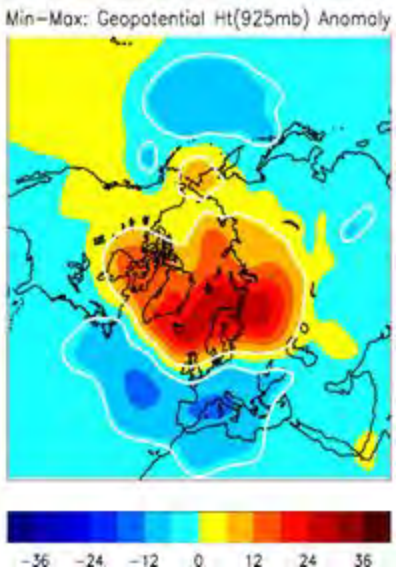


30 mb

925 mb

Min-Max





30 mb

925 mb

- **Min**: +ve Geo.pot. Height (gph) in Arctic for 30mb and 925 mb.
- **Max**: -ve gph.

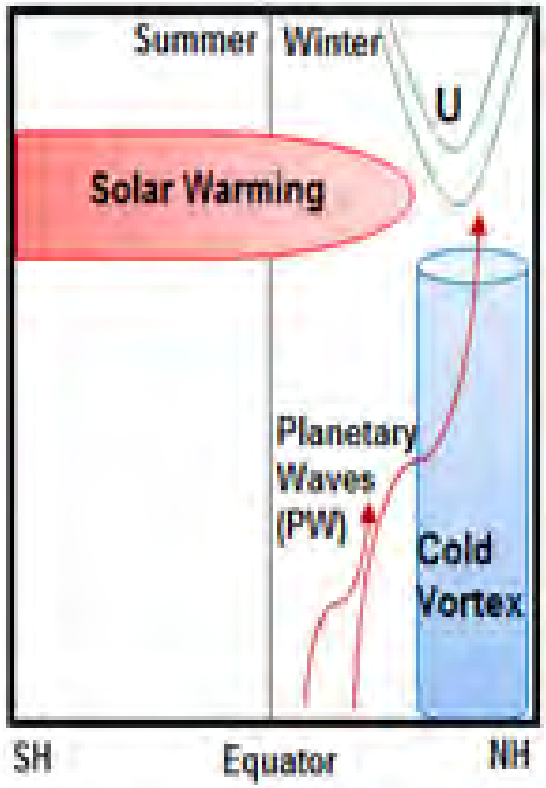
- **Min-Max**: gph diff. 30 mb -108m; 925 mb - 24m.

Mechanism
(Solar Top-Down)

UV 205 nm increases ~6% Solar Min to Max

More ozone heating in upper stratosphere(DJF), SH causes stronger jet (U) in NH– follows Thermal Wind Balance Relationship

Planetary waves (PW) (long say no ~1-3) from troposph--ere reach stratopause

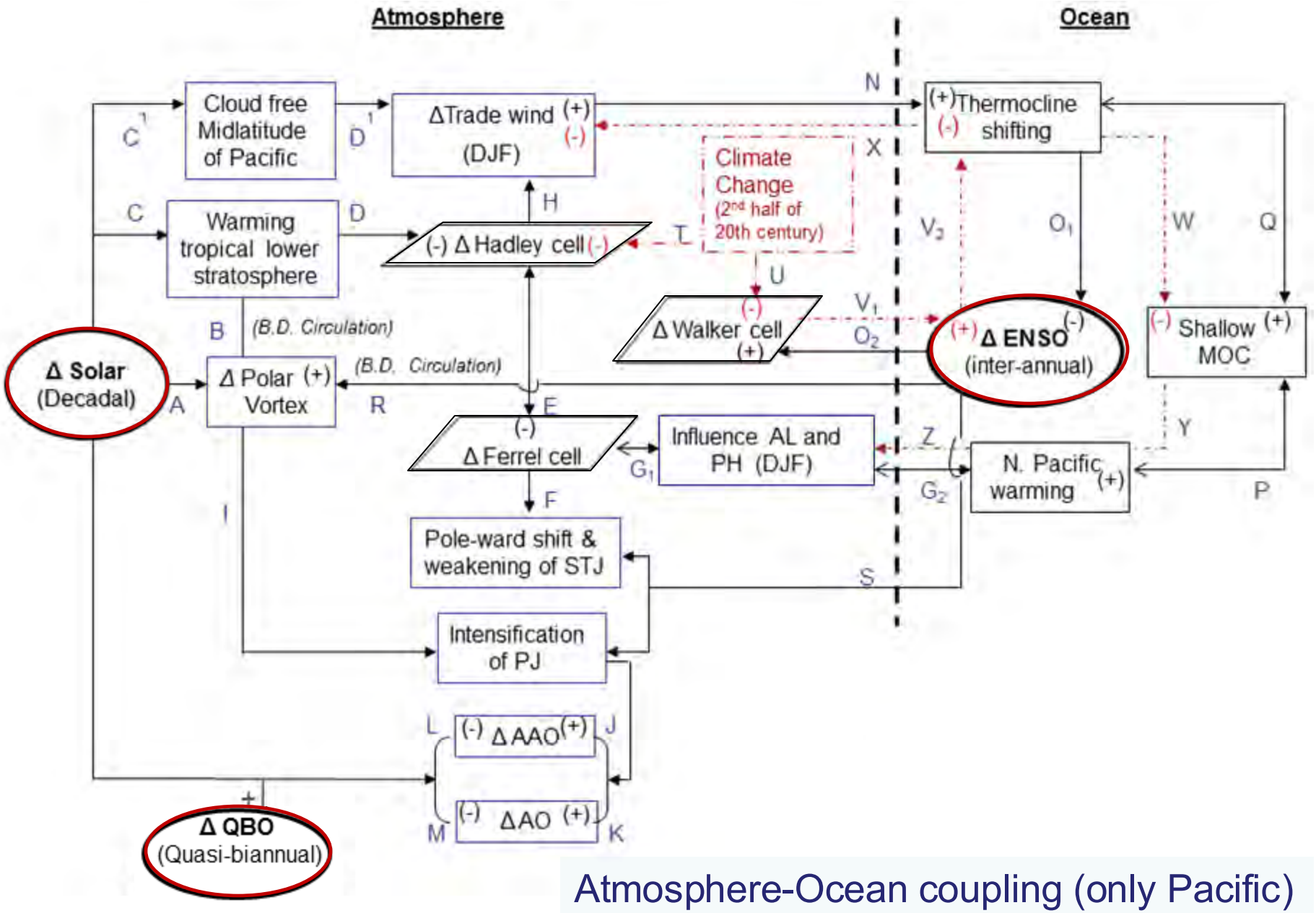


Charney Drazin Criteria: PW cannot break strong U. Hence, in Max, vortex stronger, constricted, colder. In Min, it breaks, mixes with airs, causes warm vortex.

Perturbation of stratospheric vortex are transported down to surface via NAM (Baldwin et al. 1999).

Thus, Cold (Warm) Arctic for Solar Max (Min).

An overview of solar influence on climate



Atmosphere-Ocean coupling (only Pacific)

Summary

- Overview of Solar influence on climate in a form of flow chart.
- Description: Three major variability; viz. solar, QBO and ENSO with oval outlines; major circulations, responsible for modulating the effect shown by non-rectangular parallelograms.
- Pathways of signals marked by 'A' – 'Z'; direction of change in behaviour by '+' (for increase) or '-' (for decrease).
- Subscripts indicate steps of same process; Superscripts same effect but different forcing - radiative or dynamical.

Main Points:

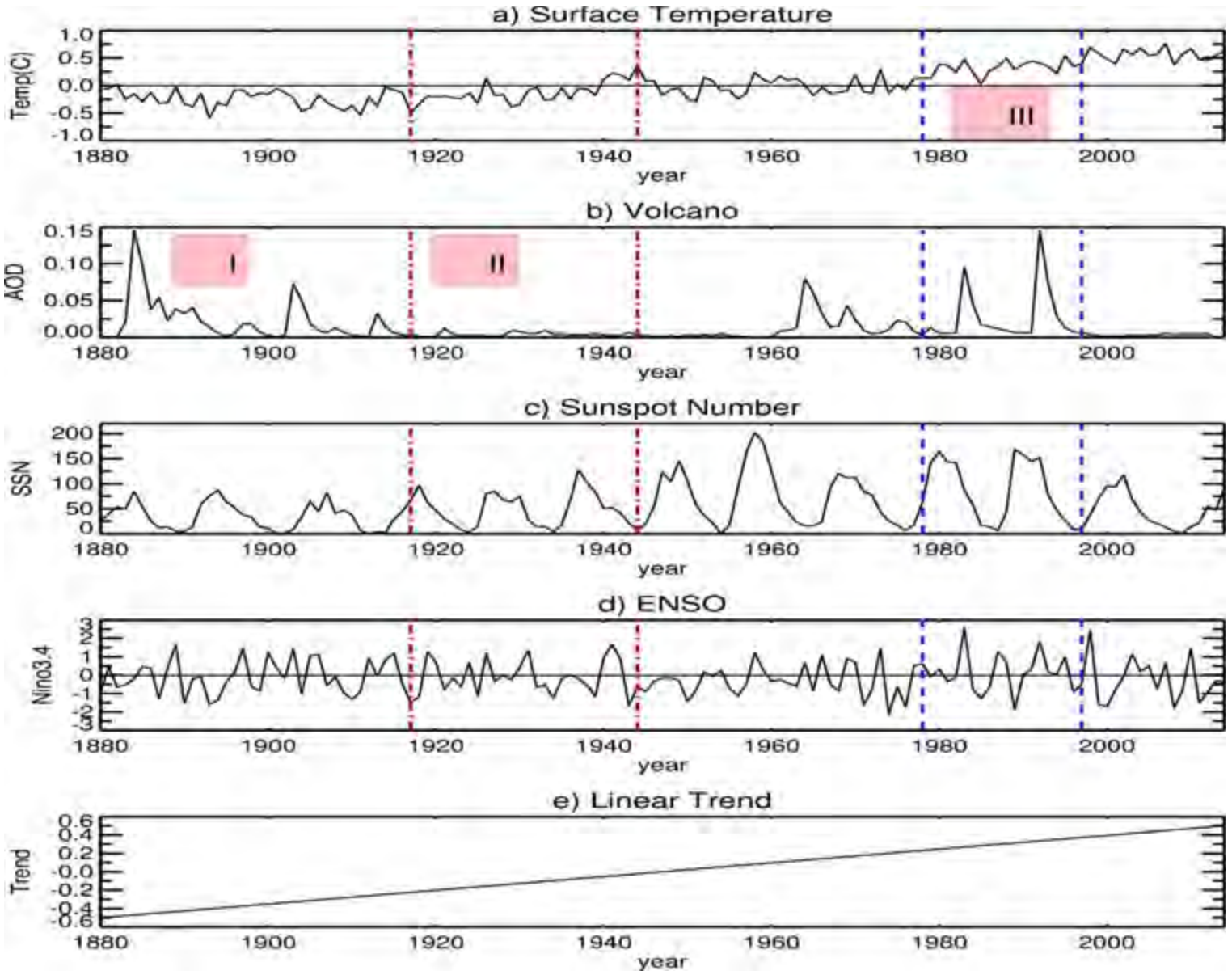
- Holistic Representation: An overview how atmosphere and ocean is influenced by solar variability.
- How it is disturbed during last half of 20th century.
- Why true quantification of solar signal is so difficult.

Interested in Details

Roy, I., 2014, 'The role of the sun in atmosphere-ocean coupling' *International Journal of Climatology,* 34 (3), 655-677, doi:10.1002/joc.3713. Citations: 46.

Future Scope: Teleconnection, Stratosphere-Troposphere coupling, Monsoon, Decadal and seasonal prediction, ENSO, Ocean-Atmosphere coupling, Climate Change

Background: Timeseries of Various Parameters (DJF)



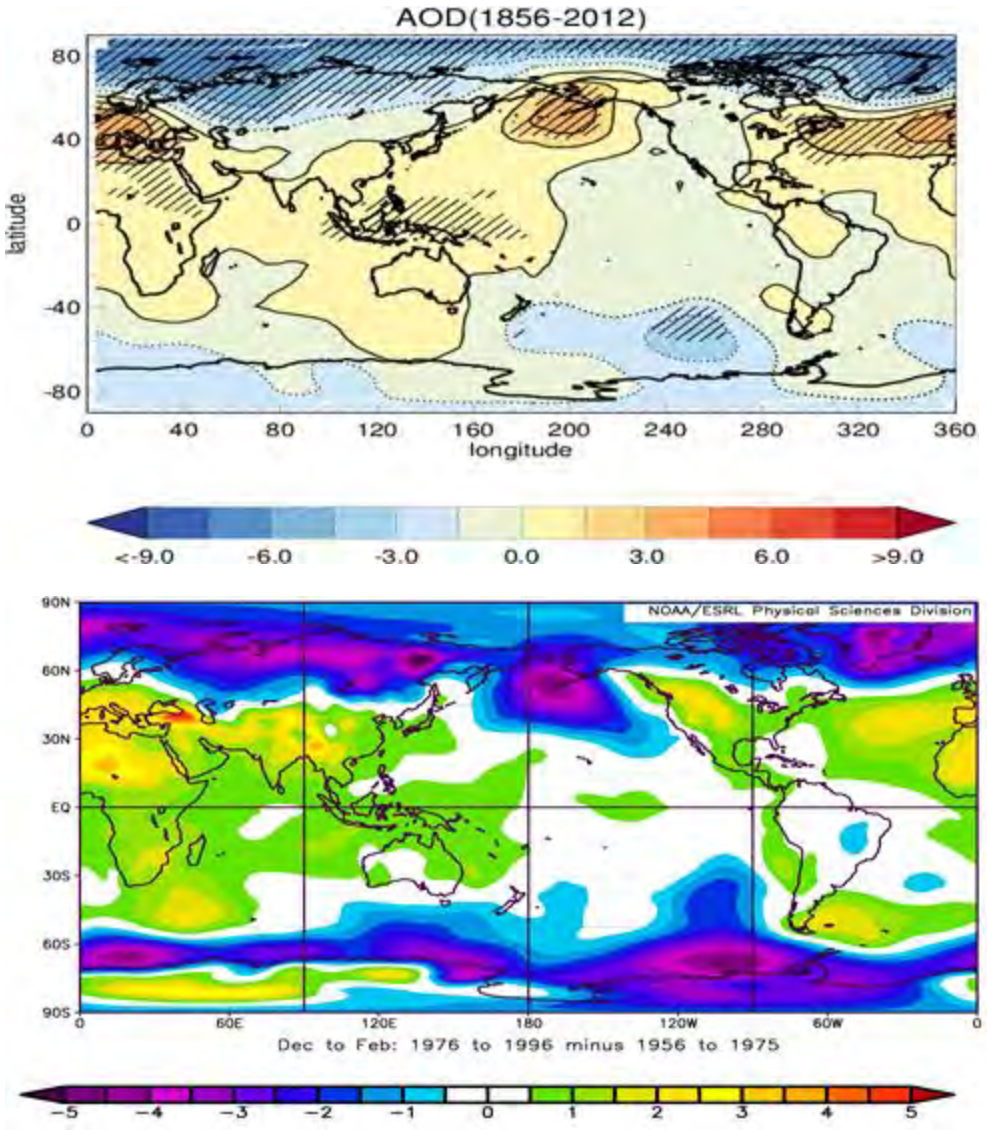
Global temperature anomaly in later two decades of last century and after (prior to strong El Nino of 2015)

- **Period:** III and after (prior to big El Nino of 2015) .
- **III:** Two major volcanos erupted in active phase of strong solar cycles.
- **ENSO in III:** Strongest in terms of amplitude and variability.
- **Global Temp:** GISS and CRU. 0.07ºC/decade in overall period; but Period II and III, 0.13ºC/decade

Roy I, 2020

Influence of very strong Volcanic Eruption

Sea Level Pressure (SLP), DJF



Signal of Volcano in Multiple Linear Regression (MLR), (ENSO, solar, trend removed) HadSLP2

Volcano: very strong Influence in N. Atlantic

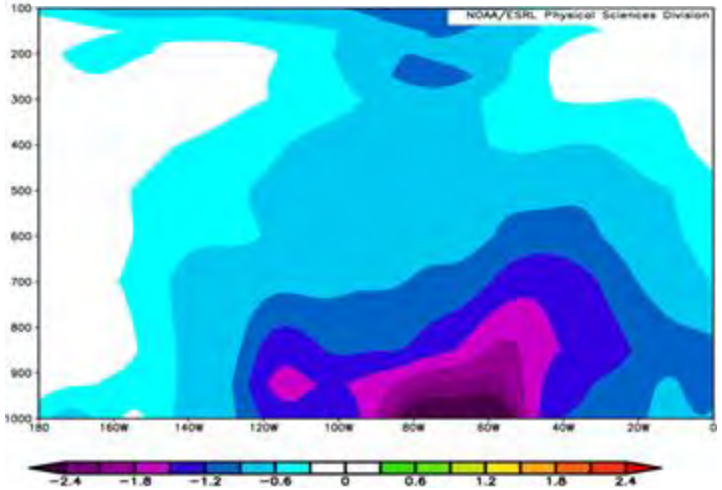
- **SLP: MLR (top)**
- **SLP: Anomaly in '1976-1996' (bottom)**

SLP anomaly, (1976-1996) w.r.t. (1956-1975), NCEP

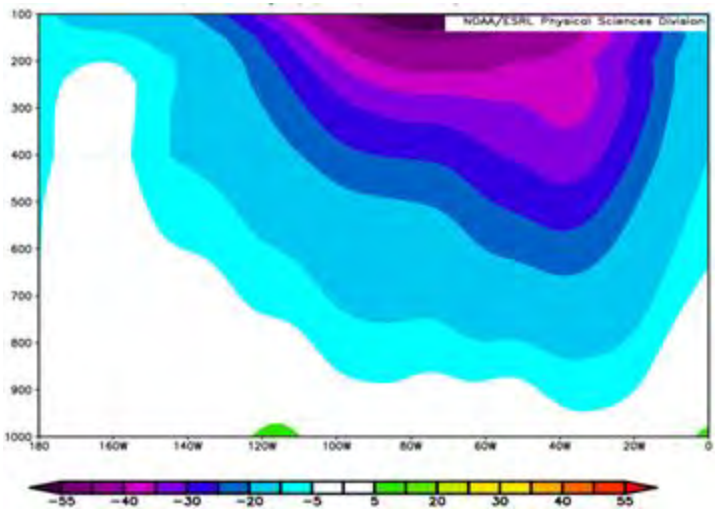
Influence of very strong Volcanoes those matched active phases of sun

Longitude vs. Height Anomaly plot (DJF)

(1979-1996) w.r.t. (1999-2017) over 50ºN to 70ºN



Air Temperature



Geopotential Height

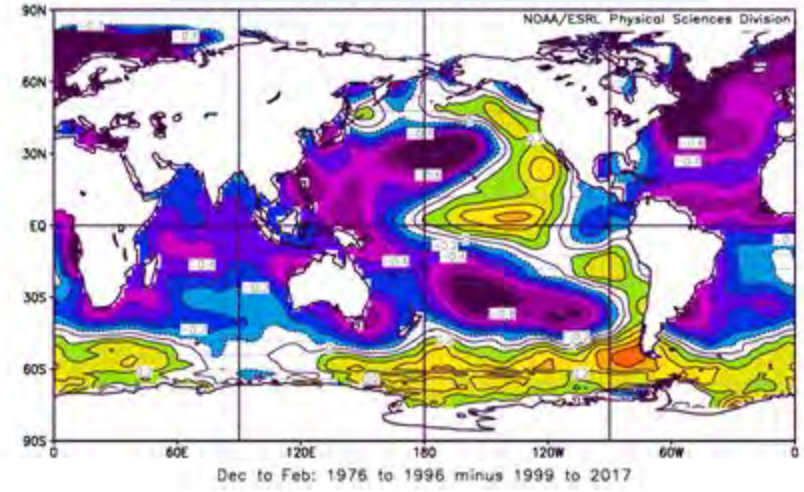
- **Longitude -Height:**

Anomaly very strong in (1979-1996) that extended even upto stratosphere

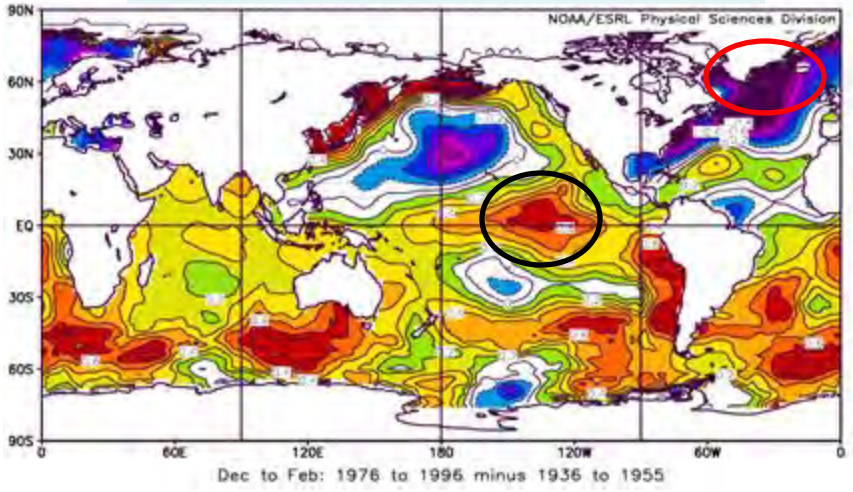
- **Air Temp (top)**
- **Geopotential Ht (bottom)**

SST (ºC, NOAA, ERSST) Anomaly, DJF during (1976-1996) w.r.t. other arbitrary periods

w.r.t. (1999-2017)

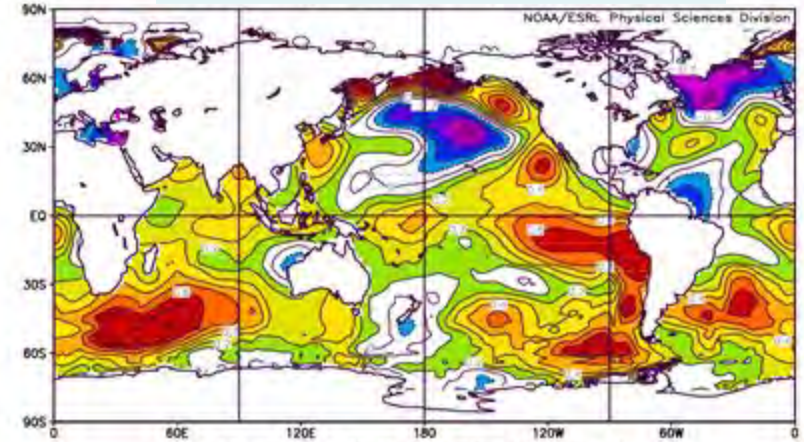


w.r.t. (1936-1955)

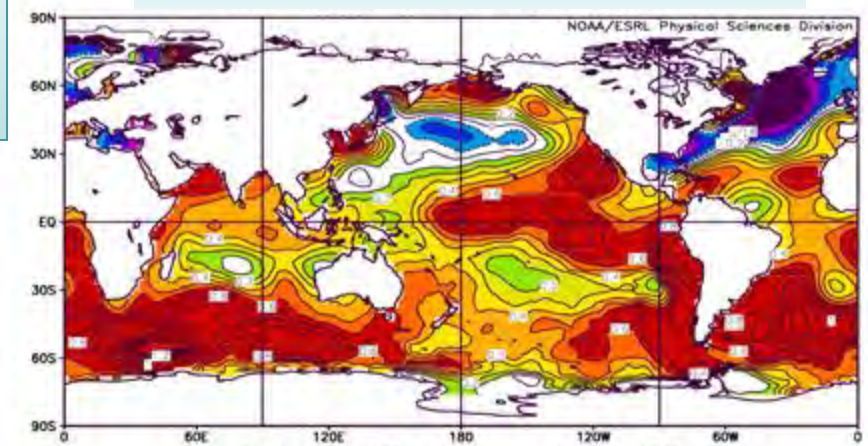


- **Central Pacific: Warming**
- **North Atlantic: Cooling**
- True for: **GISTEMP air temp**

w.r.t. (1956-1975)

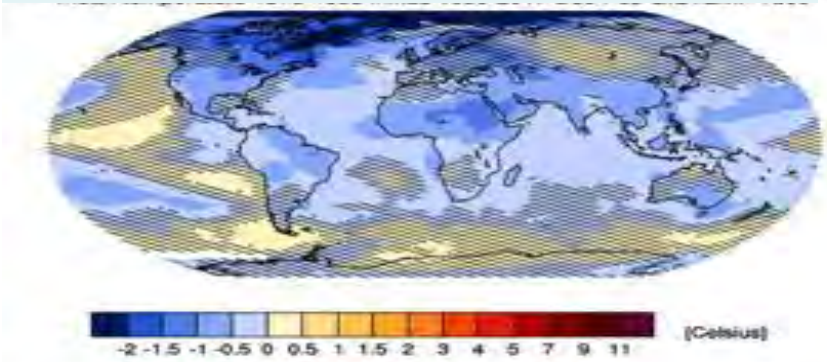


w.r.t. (1916-1935)

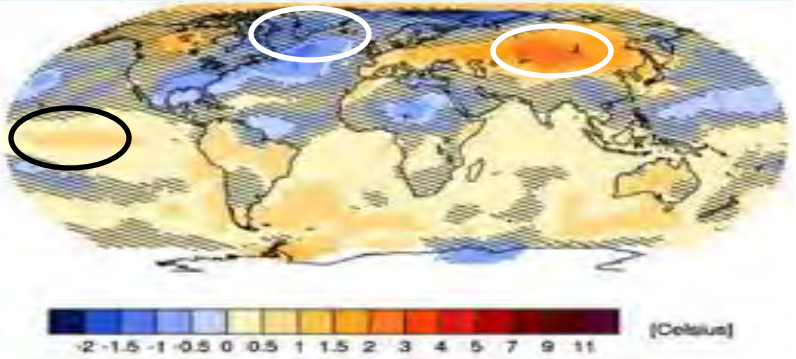


GISTEMP Anomaly, DJF during (1976-1996) w.r.t. other arbitrary periods

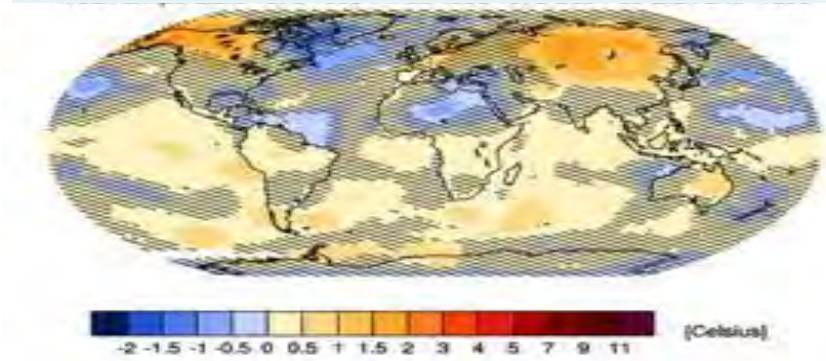
w.r.t. (1999-2017)



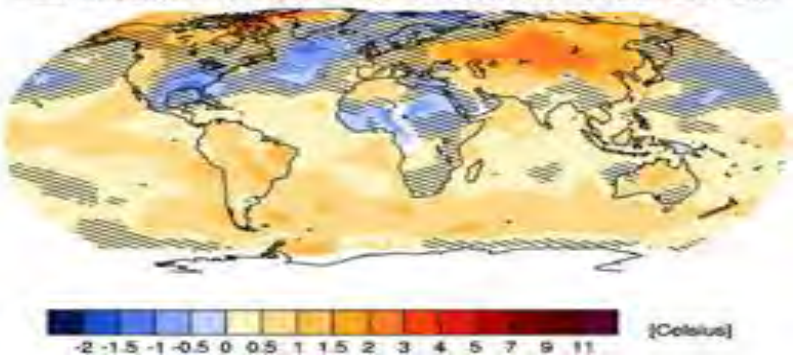
w.r.t. (1936-1955)



w.r.t. (1956-1975)



w.r.t. (1916-1935)



- **Central Pacific: Warming**
- **North Atlantic: Cooling**

Additional feature

Eurasian Sector: Surface Warming

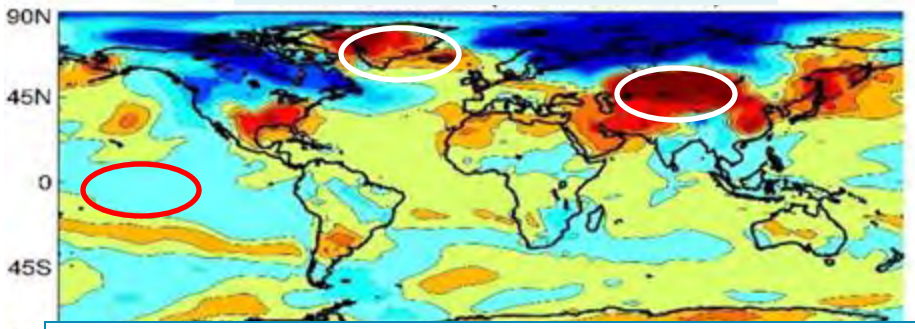
Performance of Individual Models

Anomaly of Surface Temperature (DJF) in 1976-1996

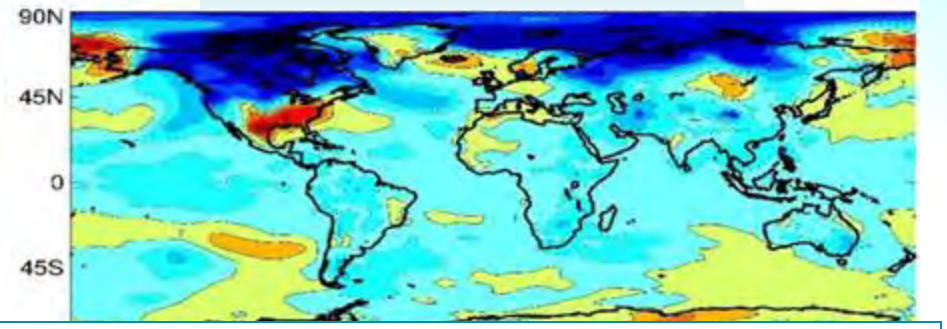
IPSL-CM5A-LR

A

w.r.t. (1956-1975)



w.r.t. (1999-2017)

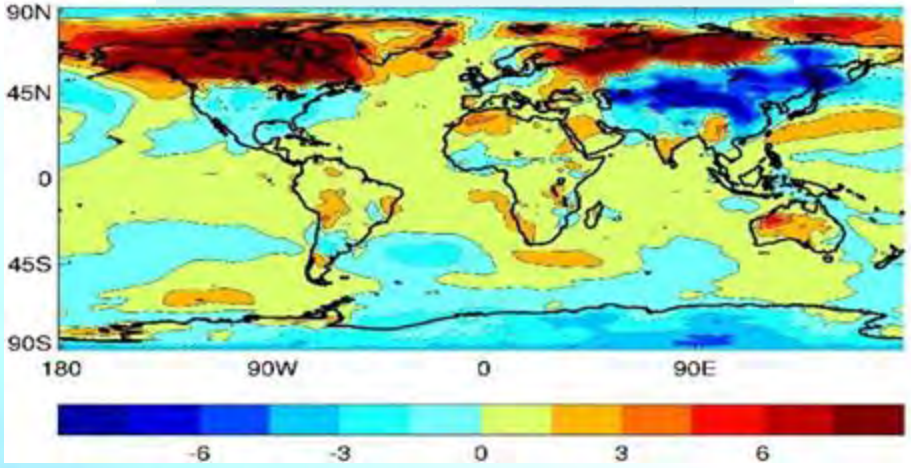


- Some models capture signature in Eurasian Sector, but not in North Atlantic or Central Pacific and vice versa. True for all models.
- Not matching with observation. No Consistency among models.

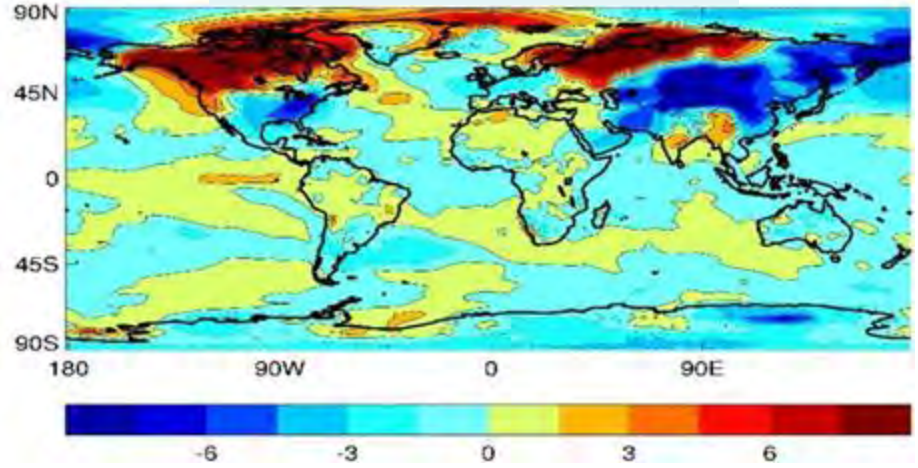
NorESM1-M

C

w.r.t. (1956-1975)



w.r.t. (1999-2017)



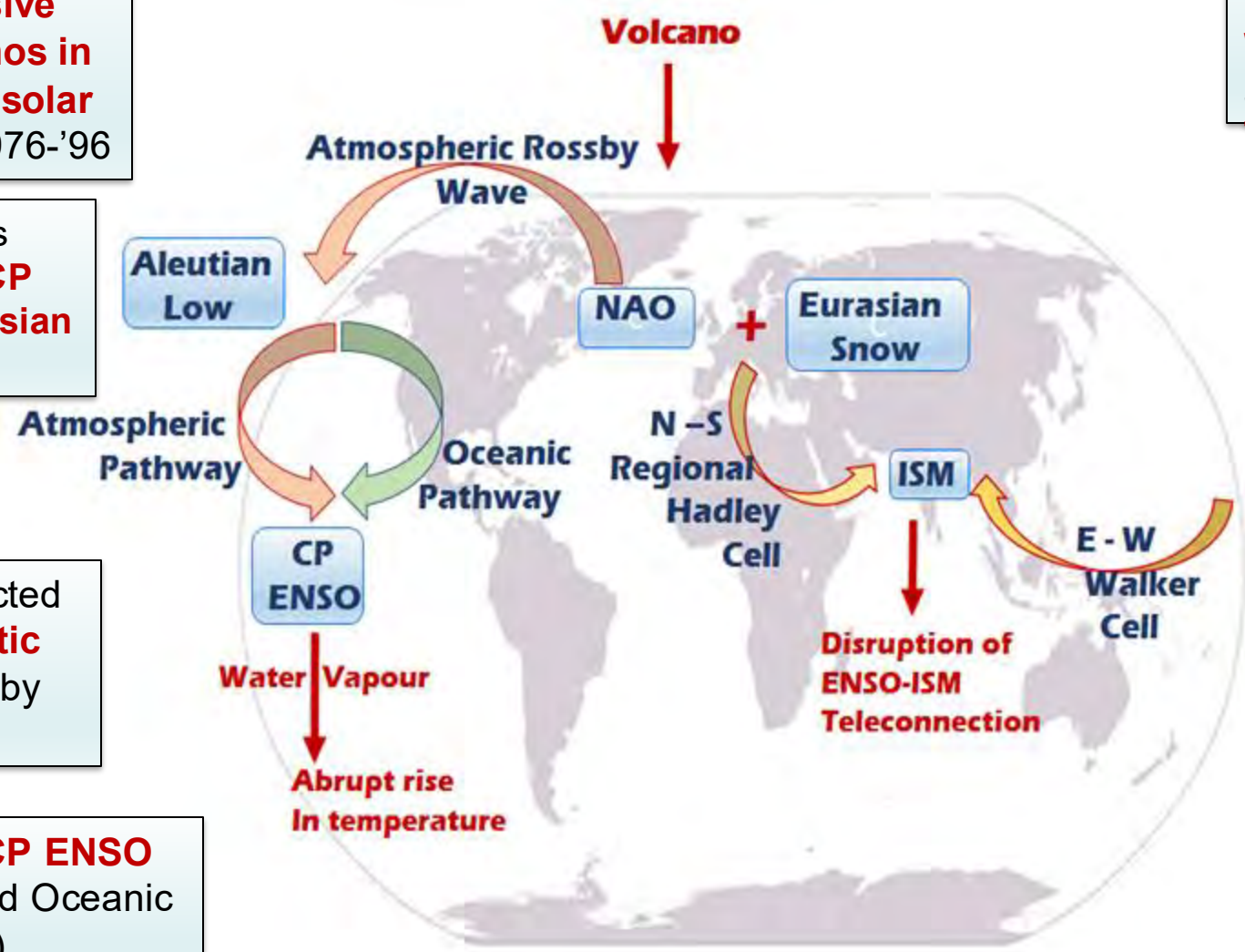
Mechanisms

1. Initiated by **explosive volcanos in active solar yrs**, 1976-'96

2. Modulates **NAO, ISM, CP ENSO, Eurasian Snow**

3. AL is impacted from **N. Atlantic** via Atm. Rossby waves (Pink).

4. Signal trigger **CP ENSO** via Atm. (pink) and Oceanic pathways (Green).



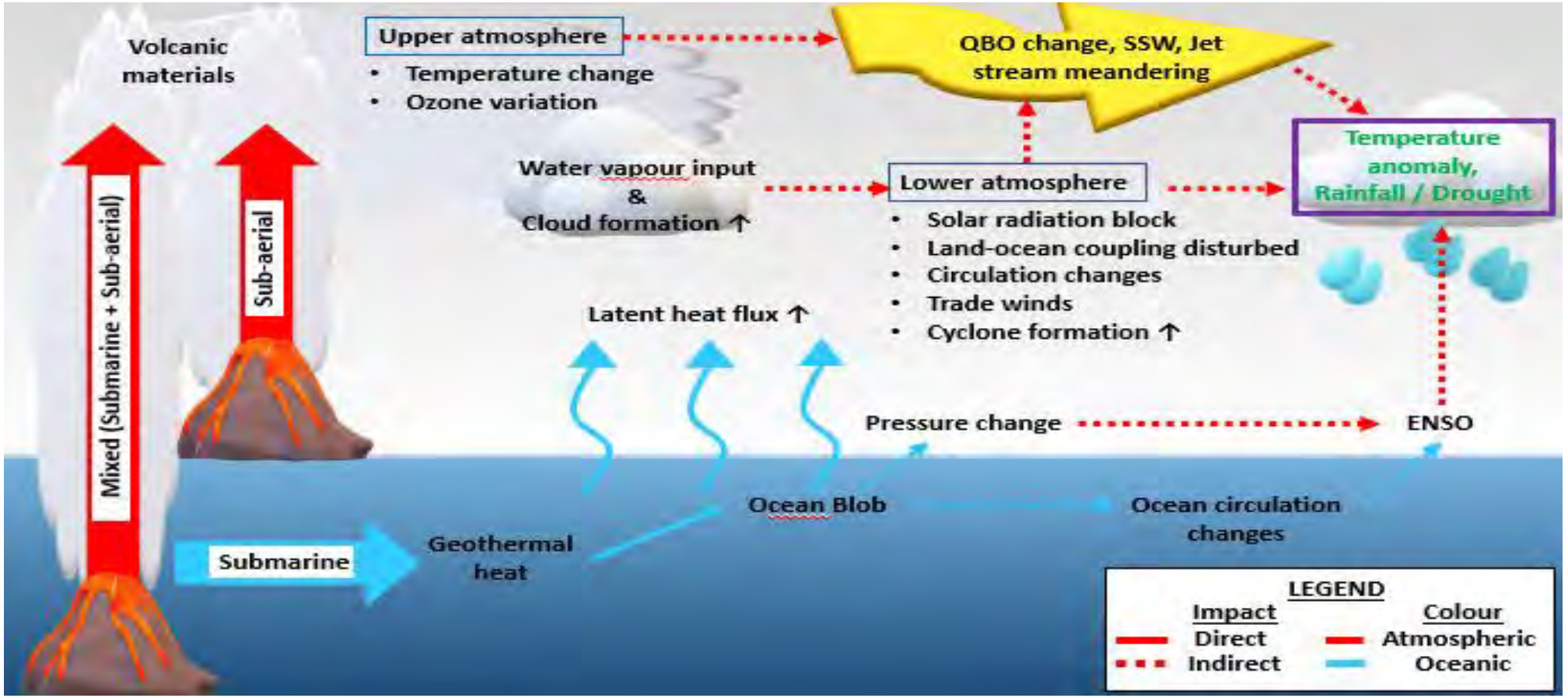
[Roy, Frontiers in Earth Sci, (2018), Roy, (2023)]

5. CP ENSO increases atm. **Water Vapour**-abrupt rise in **Global Temp** (Red).

6. NAO, Eurasian Snow modulate regional Hadley cell (Yellow) & **ISM.**

7. ENSO-ISM teleconn. via Walker cell (yellow) over taken ->**Disruption ENSO-ISM telecon-nection** (Red).

Schematic with direct and indirect influences of strong volcanos (submarine, sub-aerial and mixed) on climate



[Alvin, Roy et al. 2025]

Summary

- **Robust Solar Signal on Climate:** Significant signal around places of **Aleutian Low** and Central Pacific. Discussed **Sun-ENSO, Sun-NAO** and **Sun-Arctic Connection.**
- **Holistic Representation of Atmosphere-Ocean Coupling initiated by the sun:** Presented an overview of Solar influence on climate in the form of flow chart. **Why true quantification of solar signal is so difficult.**
- **Strong Volcanic Eruption and Influence (DJF): Very strong** influence around **N. Atlantic in 1976-1996,** by MLR and anomaly plot. **Change also seen in upper troposphere and stratosphere.**
- **Temperature Anomaly (1976-1996):** Temp changed compared to any similar period earlier or later of last 150 years. **Warming in central Pacific, cooling in N. Atlantic, warming in Eurasian sector. Used different observed data sources.**
- **Mechanisms Proposed:** Initiated by **explosive volcanos** in 1976-'96 with **sun**. It modulates **NAO, AL, Eurasian Snow, CP ENSO and ISM.** Abrupt warming and disruption of ISM-ENSO teleconnections.
- **CMIP Models and observations suggest different:** Some areas identified.
- **Various Direct and Indirect Effects of Individual strong volcanoes**: Schematic with a general overview is presented.

Thank You