

Ocean a klimat:

wczoraj, dziś i jutro

Wykład 5:

Zmienność klimatu w skali dekadальной
(*AMO, NAO, PDO*)

Jacek Piskozub

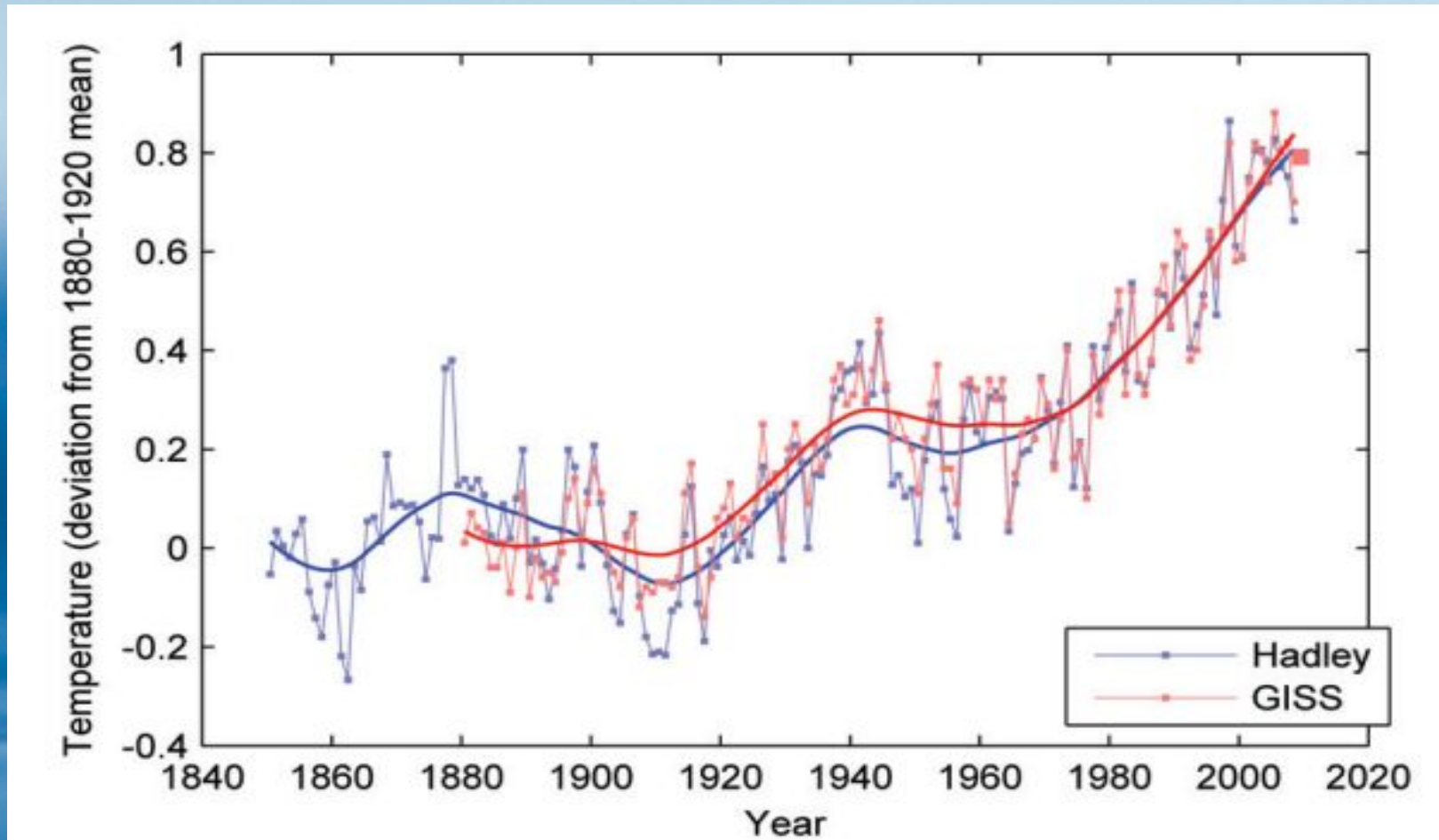
Studium Doktoranckie IOPAN, semestr zimowy 2010/11 r.

<http://www.iopan.gda.pl/~piskozub/klimat/>

Jacek Piskozub “Klimat a ocean: wczoraj, dziś i jutro”, kurs wykładów dla doktorantów 11.10.2010 - ???.02.2011

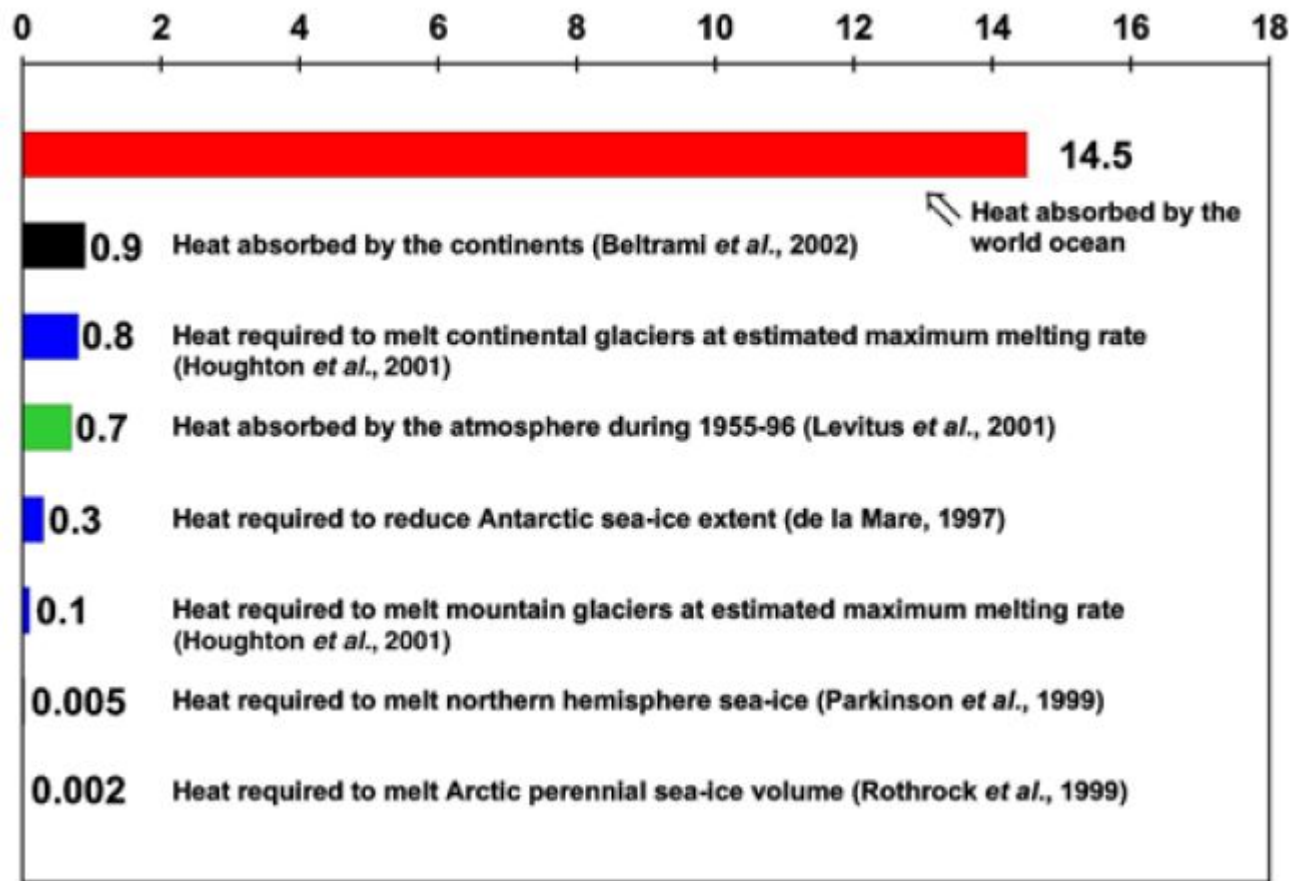
- ✓ Maszyna klimatyczna Ziemia (*zmienność w skali geologicznej*)
- ✓ Epoka lodowa w której żyjemy (*zmienność w skali astronomicznej*)
- ✓ Gwałtowne zmiany klimatu (*deglacjacja, zmienność “suborbitalna”*)
- ✓ Holocen: klimat, ocean a cywilizacja, (*stała słoneczna i wulkanizm*)
- ✓ Północny Atlantyk – kuźnia klimatu (*cyrkulacja termohalinowa*)
- ✓ **Zmienność klimatu w skali dekadalej (AMO, NAO, PDO)**
- ✓ Tropiki a zmienność klimatu (*ENSO, huragany, monsuny*)
- ✓ Aerosol: wielka niewiadoma klimatyczna
- ✓ Gazy o znaczeniu klimatycznym (*cykl węgla, CO₂, metan, DMS*)
- ✓ Globalne ocieplenie a ocean (*zmienność antropogeniczna*)
- ✓ Zmiany klimatyczne w rejonach polarnych

What causes the multidecadal variability of global temperature?



On top of the global warming trend, the instrumental temperature records show significant multidecadal variability. To better learn the actual climate sensitivity to greenhouse gases, we need to understand how much of it is caused by changing forcing (natural and anthropogenic) and how much by natural variability? And what this variability actually is?

How can we explain any multiannual climate oscillations?



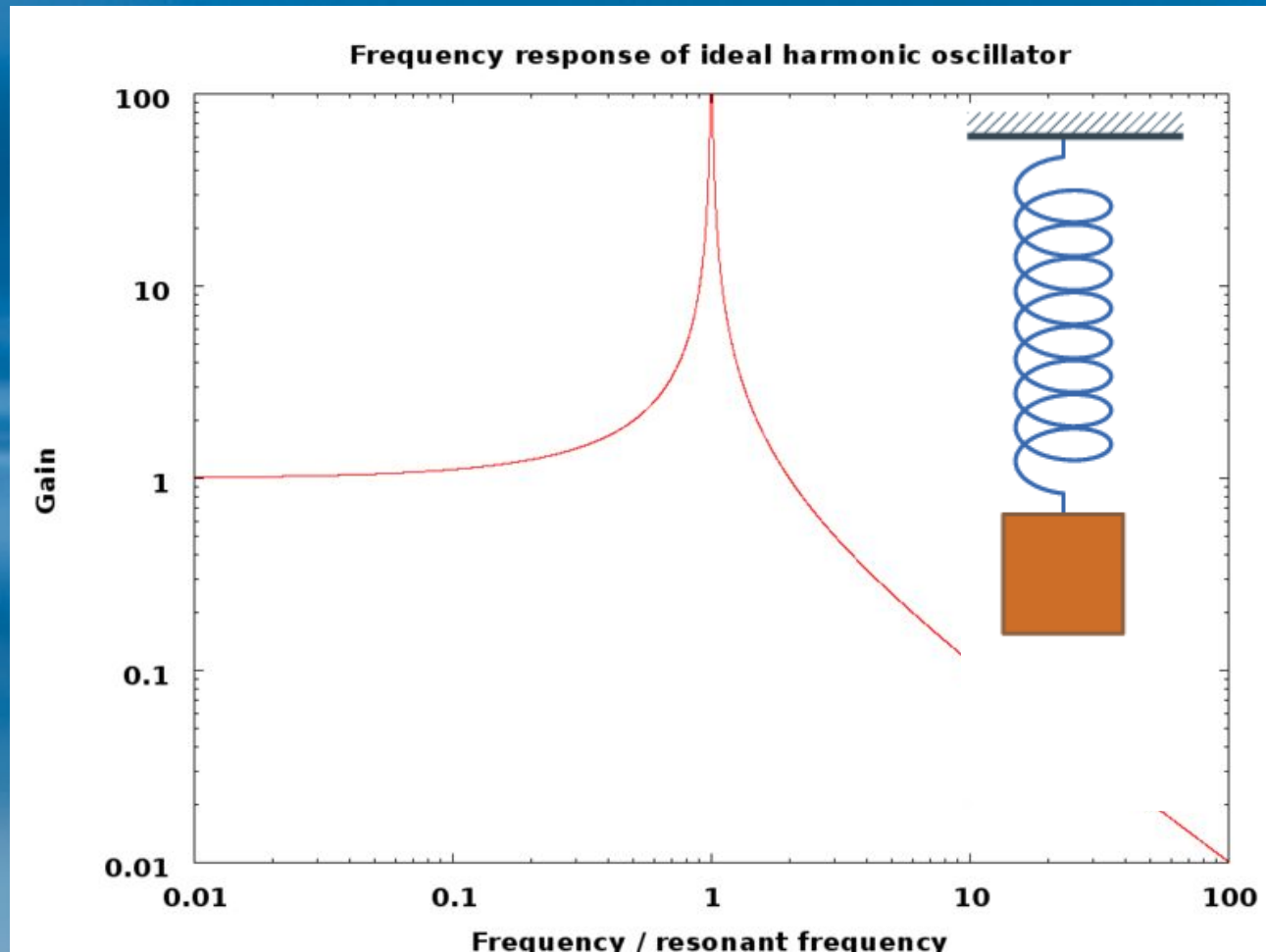
The absorbed amount of heat (in 10^{22} J) by various components of Earth climate machine: ocean absorbed 84%, land 4% and atmosphere 5%. The missing 7% is the latent heat of ice-sheets and sea ice. The actual heat content share of the ocean even bigger share of the pie as ocean has a long relaxation time for heat fluxes (hundreds of years) and has not yet adjusted to the present greenhouse forcing.

*Levitus, Antonio, Boyer 2005
(Geophysical Res. Letters)*

There are many known or suspected multiannual climate oscillations (examples will be shown soon) but it is not possible to explain any of them without air-sea interaction because the heat content of land and atmosphere is too small for a multiannual climate “memory” (and continental moisture can barely explain biannual variability).

What are the possible mechanisms of interannual climate oscillations?

If we observe climate oscillations with a period of multiple years we can suspect either a forced (driven) oscillator, with a periodic forcing controlling its period, or a stochastically forced oscillator (possibly bistable) with a period close to its resonant period. In any case it is very hard to force oscillations when the resonance period is longer than the forcing period (low gain).



Frequency response of an ideal harmonic oscillator. Real climate systems are neither harmonic (nonlinearities) nor ideal (they have damping) but the main conclusions are still true.

en.wikipedia.org

What need we to do?

To understand any interannual climate oscillation we need to identify either the person pushing the swing (external periodical forcing) or the way someone on the swing can keep it in motion (internal physics of the phenomenon).



Jean-Honore Fragonard: "The Swing"

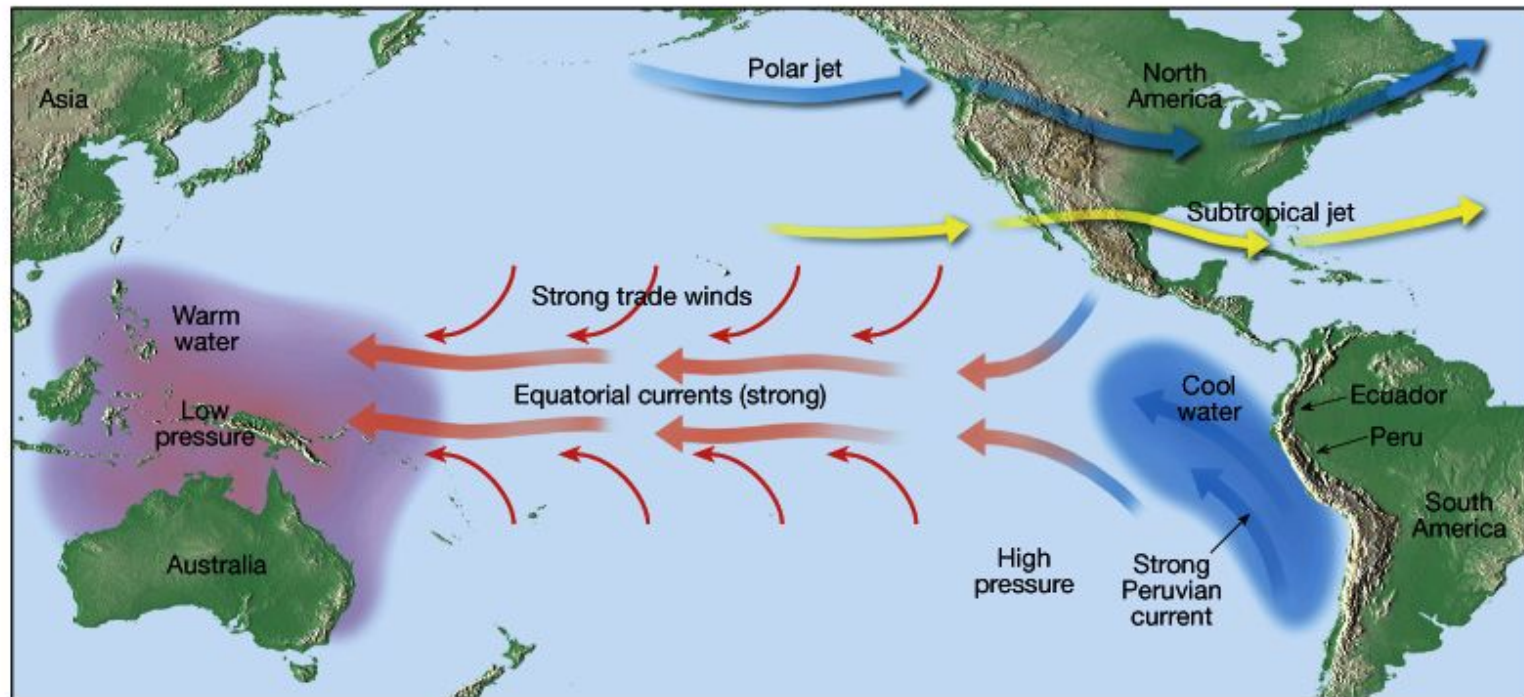
Two phases of ENSO

La Niña (top)

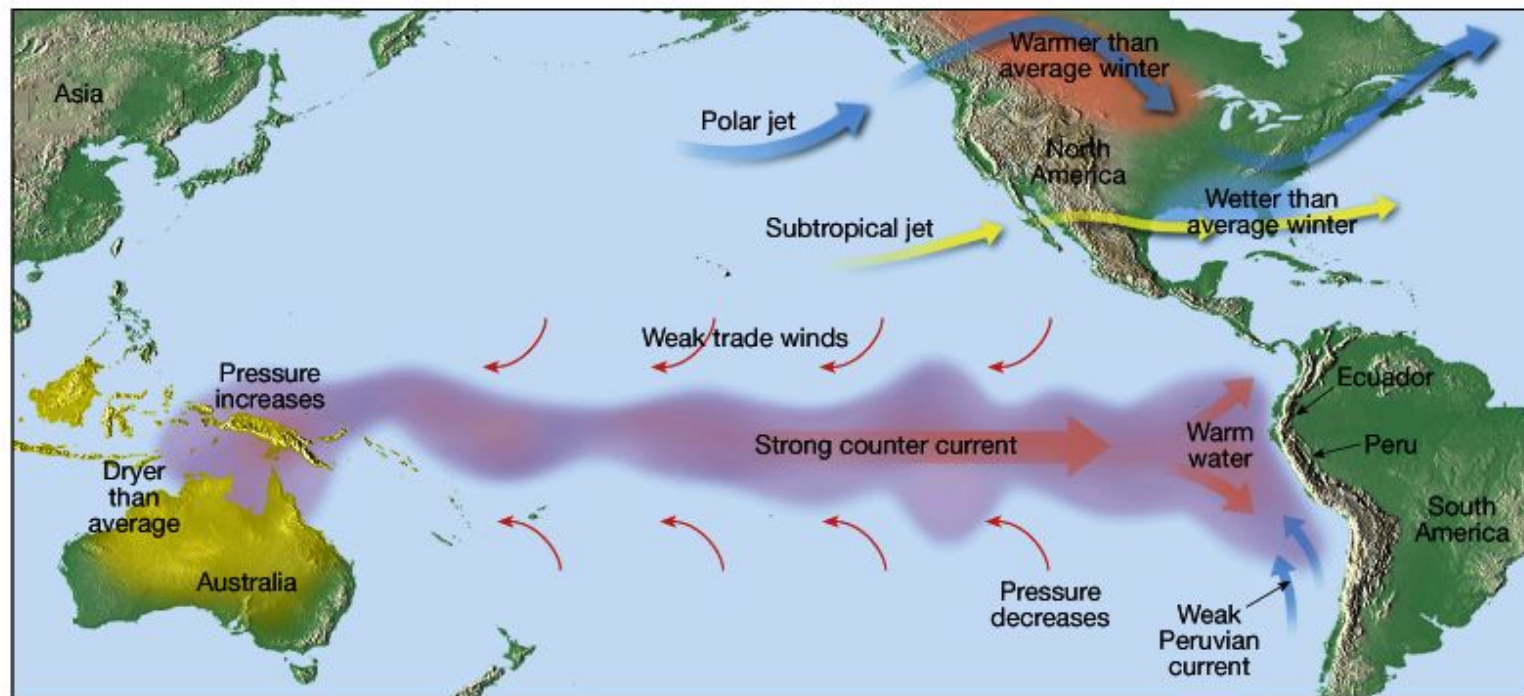
and

El Niño (bottom)

El Niño-Southern Oscillation (ENSO): a quasi bistable ocean-atmospheric system of 3 to 7 year period with stochastic forcing?

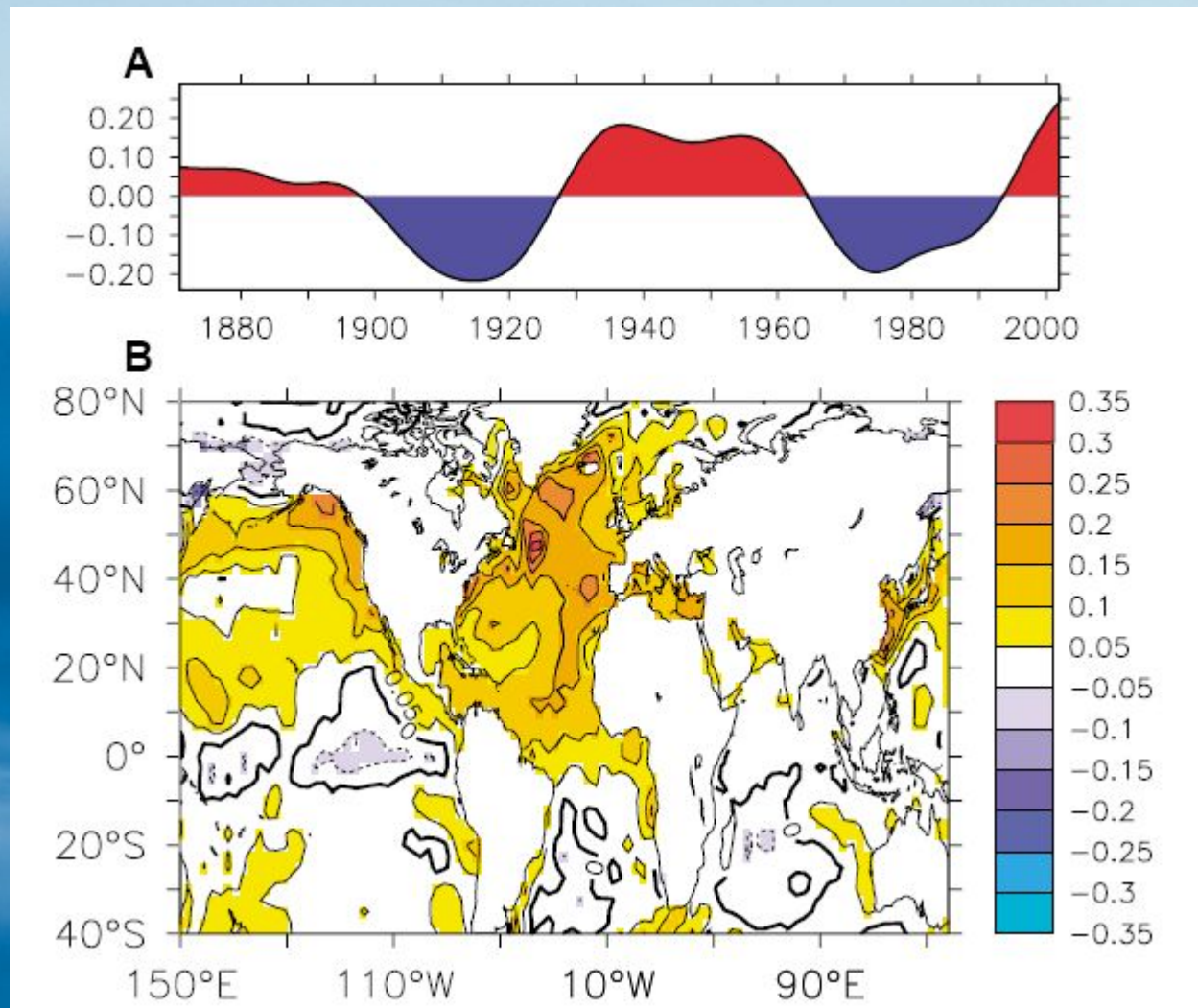


A. Normal conditions



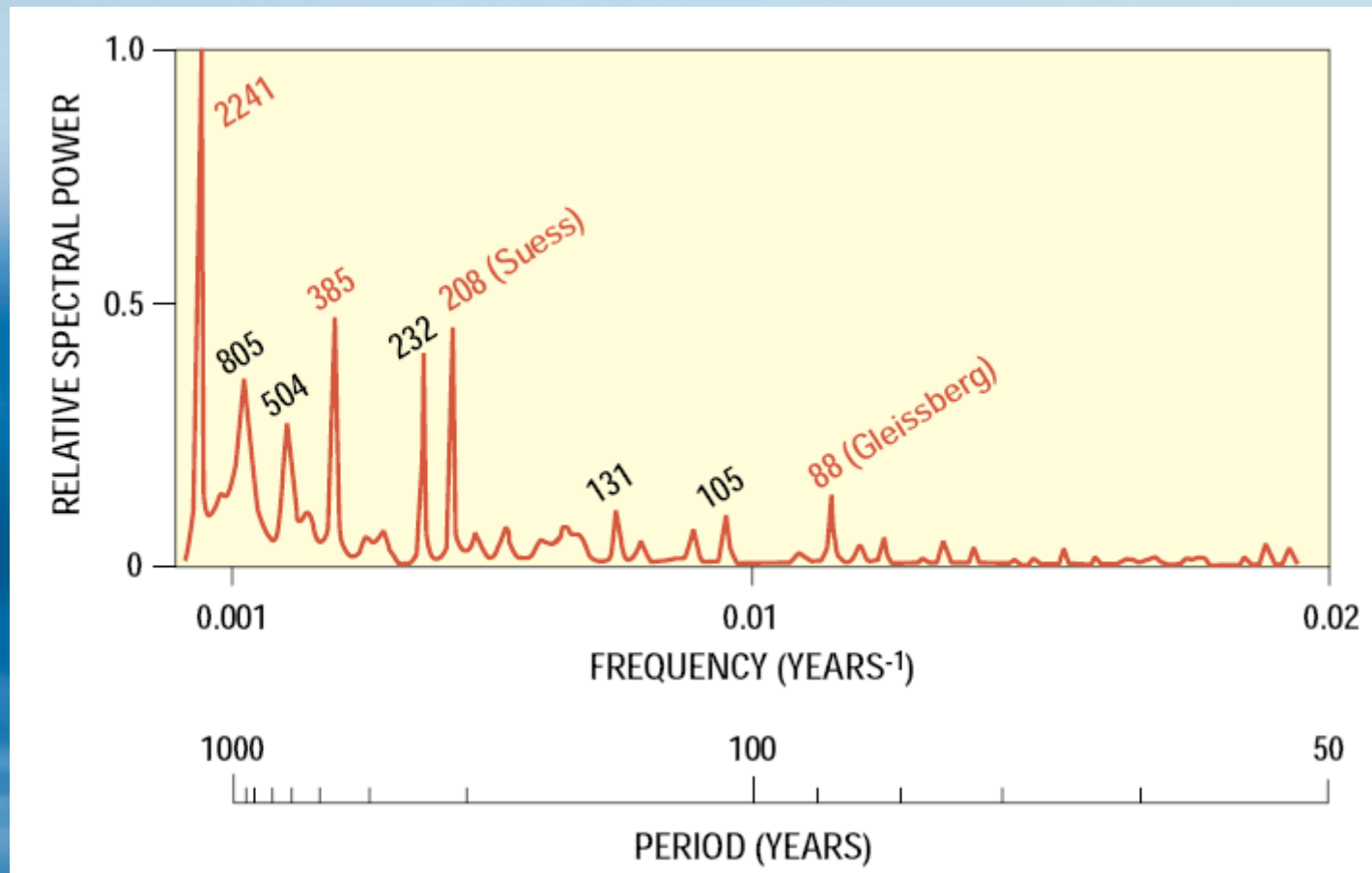
B. El Niño

Atlantic Multidecadal Oscillation



Atlantic Multidecadal oscillation is a periodical (60-70 years) warming and cooling of North Atlantic. The temperature anomaly of North Atlantic (top) is used as the AMO index.

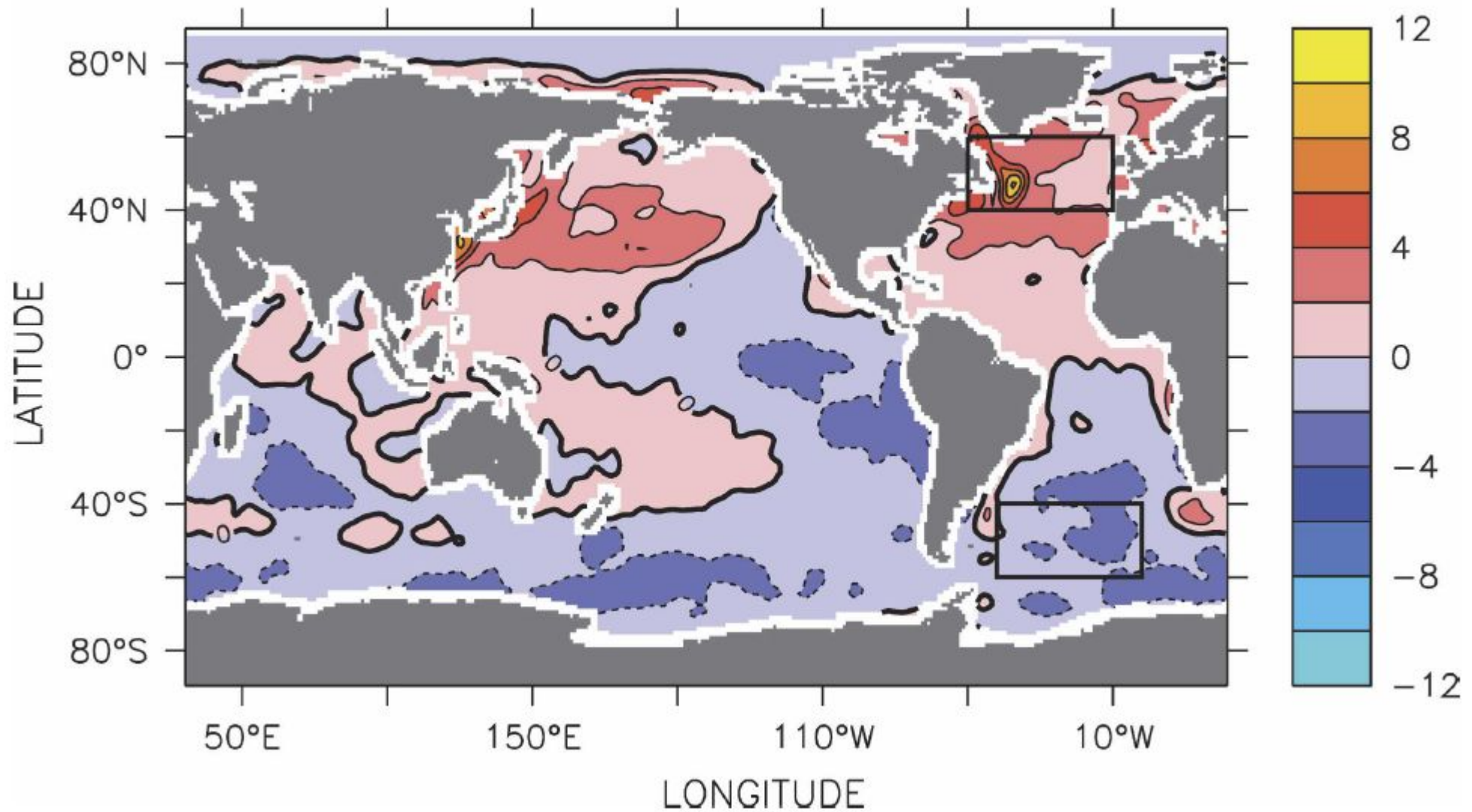
Solar forcing: sun activity spectrum from tree ring C^{14}



Solar activity from tree ring ^{14}C shows many cycles but the shorter important one is 88 year long. It is difficult to explain any multiannual or multidecadal variability of a shorter period by sun only. We also know of no other external decadal periodical forcings.

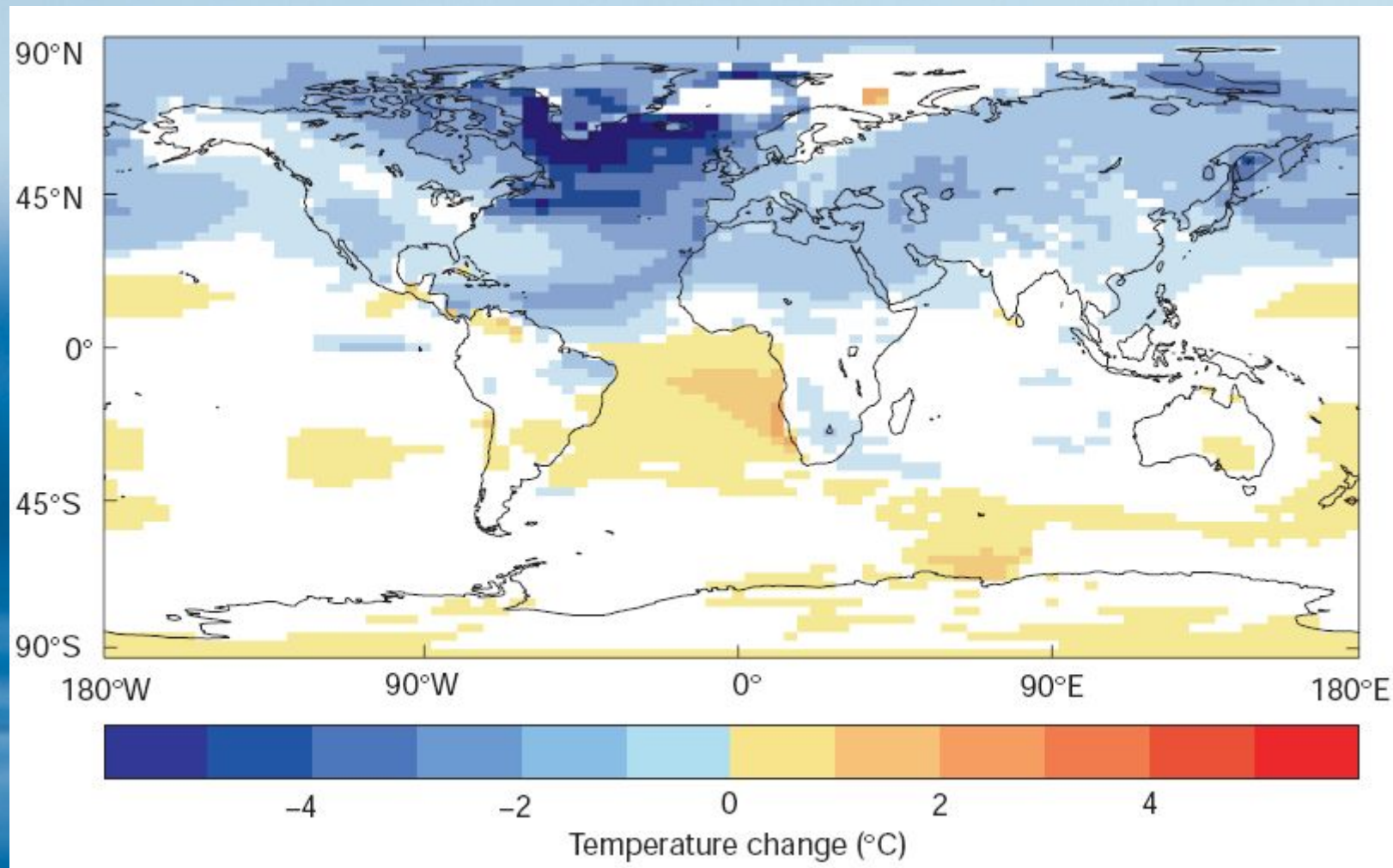
Observed AMO pattern

1980–2004



Linear SST trend (in °C) between AMO low (1980) and high (2004) values, after subtracting global SST increase trend.

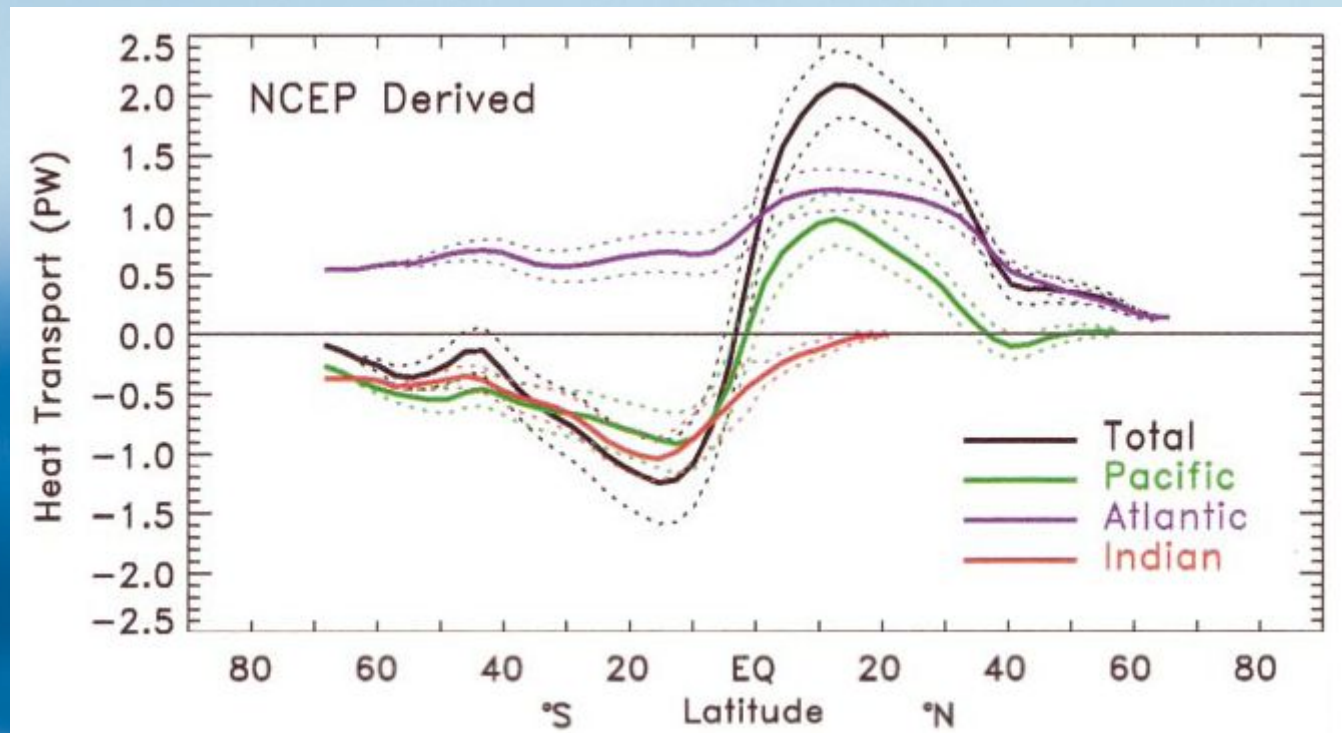
Meridional overturning climate effect



General circulation models (here HadCM3 model) show that stopping MOC would create a characteristic climate pattern of northern cooling (especially in North Atlantic) and southern warming (more diffuse). Strengthening MOC has an inverse effect.

Rahmstorf 2002

Meridional transport of heat: the Atlantic exception

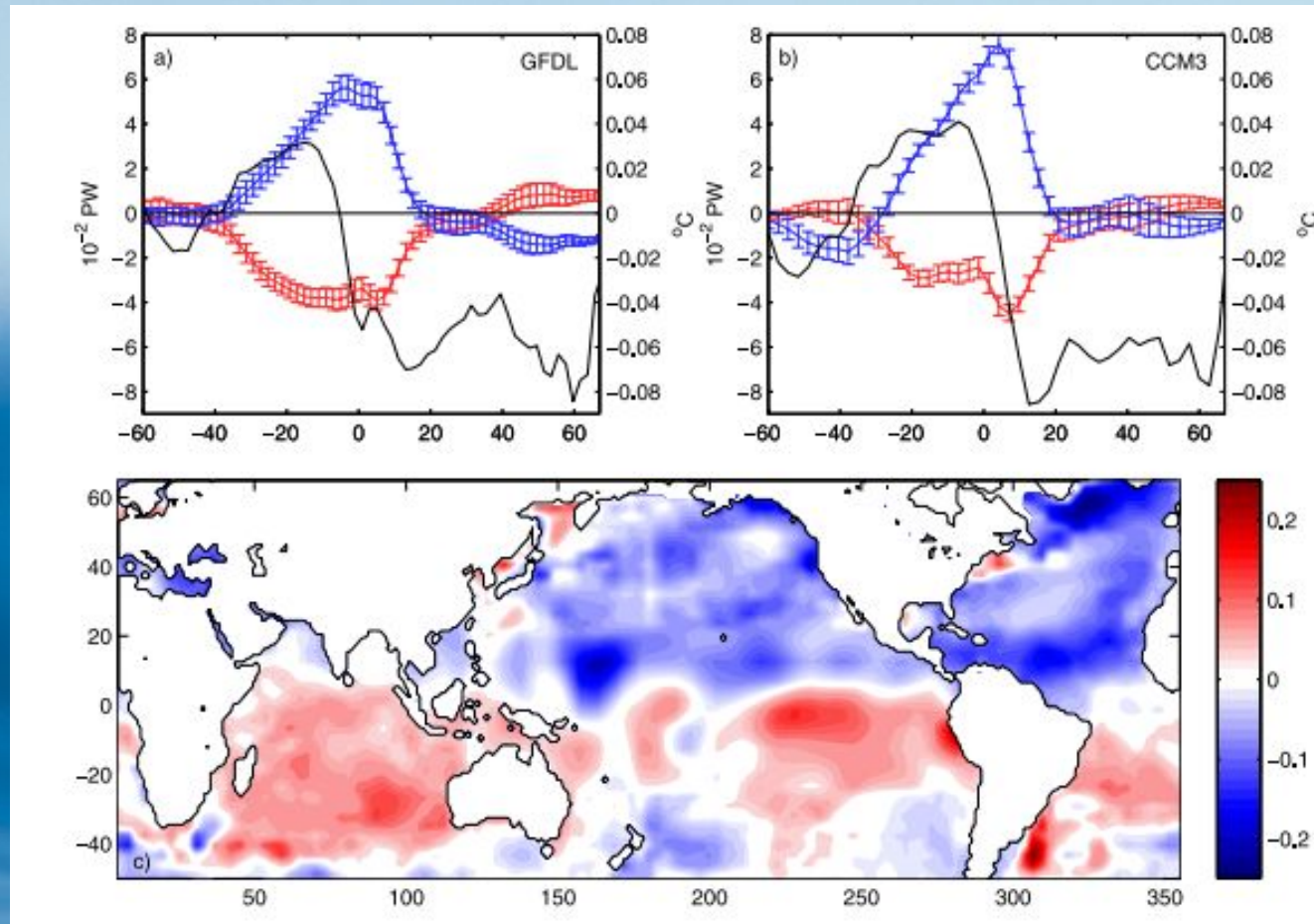


Ocean heat transport (positive means Northward, negative Southward)

The Atlantic is the only ocean where thanks to THC, the heat transport crosses the equator and reaches much further North than in the Pacific. With the exception of Indian Ocean monsoon (transporting heat southward), it is the only significant mechanism coupling the climate of Northern and Southern Hemispheres.

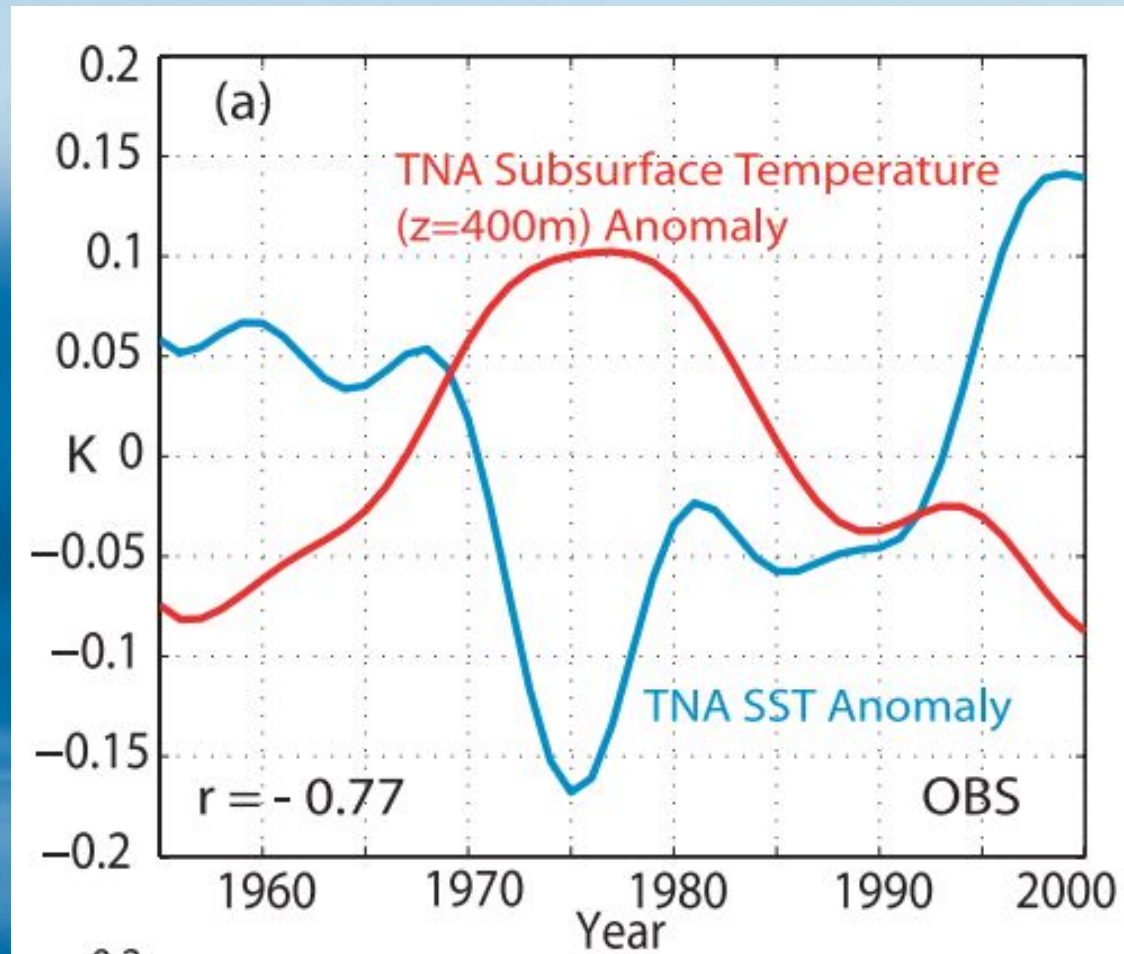
Trenberth & Caron, 2001 (Journal of Climate)

Ocean and atmospheric MOC heat transport variability



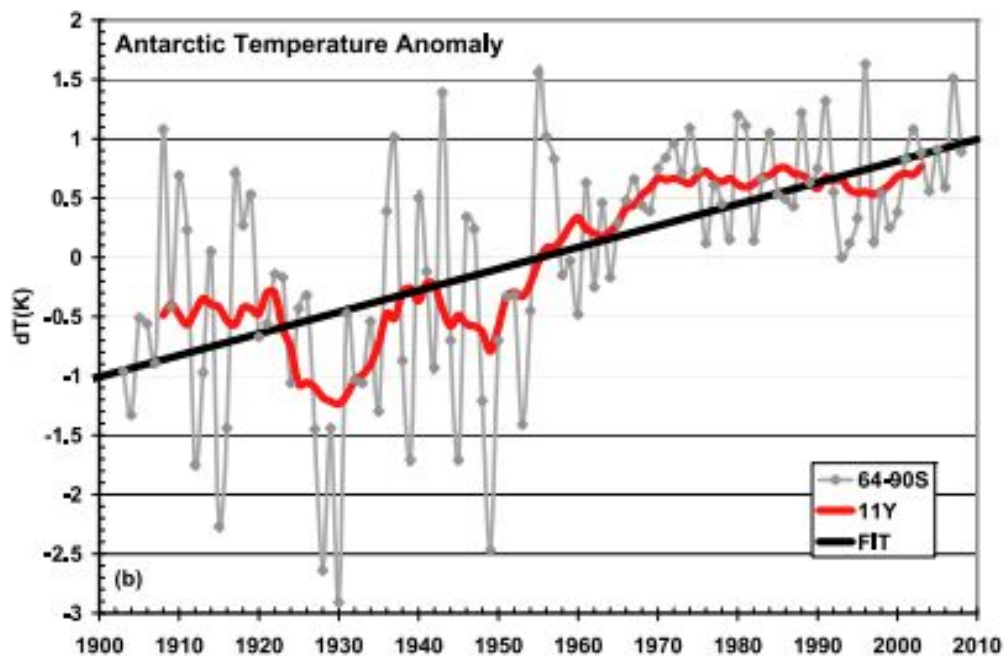
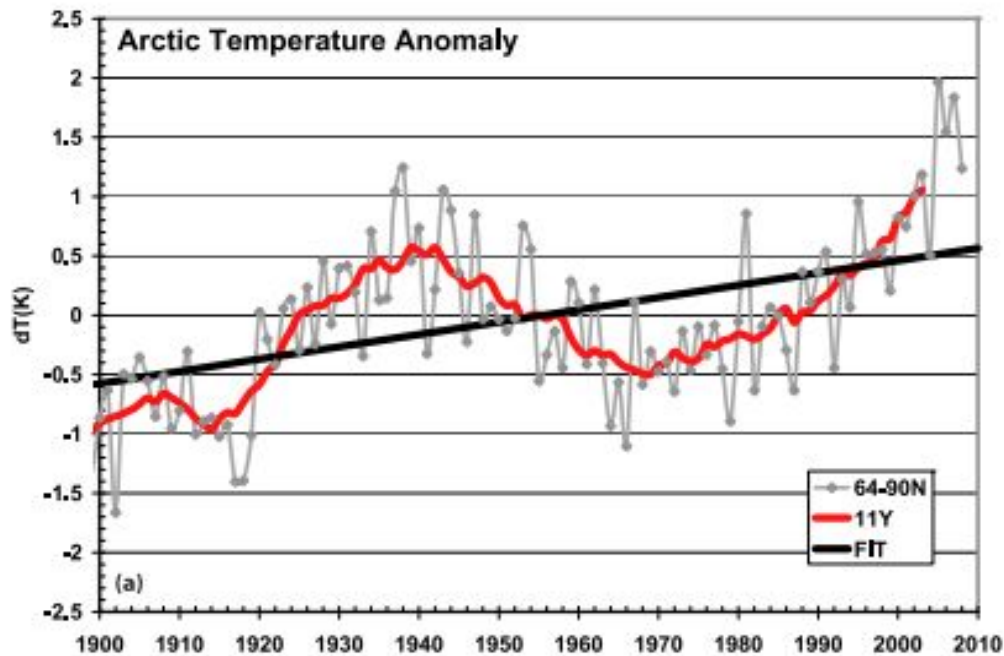
(a)–(b) Regressions of the anomalous heat transport for the ocean (red), atmosphere (blue), with one standard deviation ensemble member spread, and the zonal mean SST anomaly (black) on the normalized V-index. (c) Spatial distribution of the regression of the SST's on the normalized V-index (CCM3 model only). Results are multiplied with -1.

AMOC exchanges heat between ocean and the atmosphere on decadal scales



The temperature of subsurface tropical North Atlantic and surface waters are anticorrelated on decadal scales showing that AMOC exchanges heat not only between the hemispheres but also between the ocean and the atmosphere with an AMO-like timescale

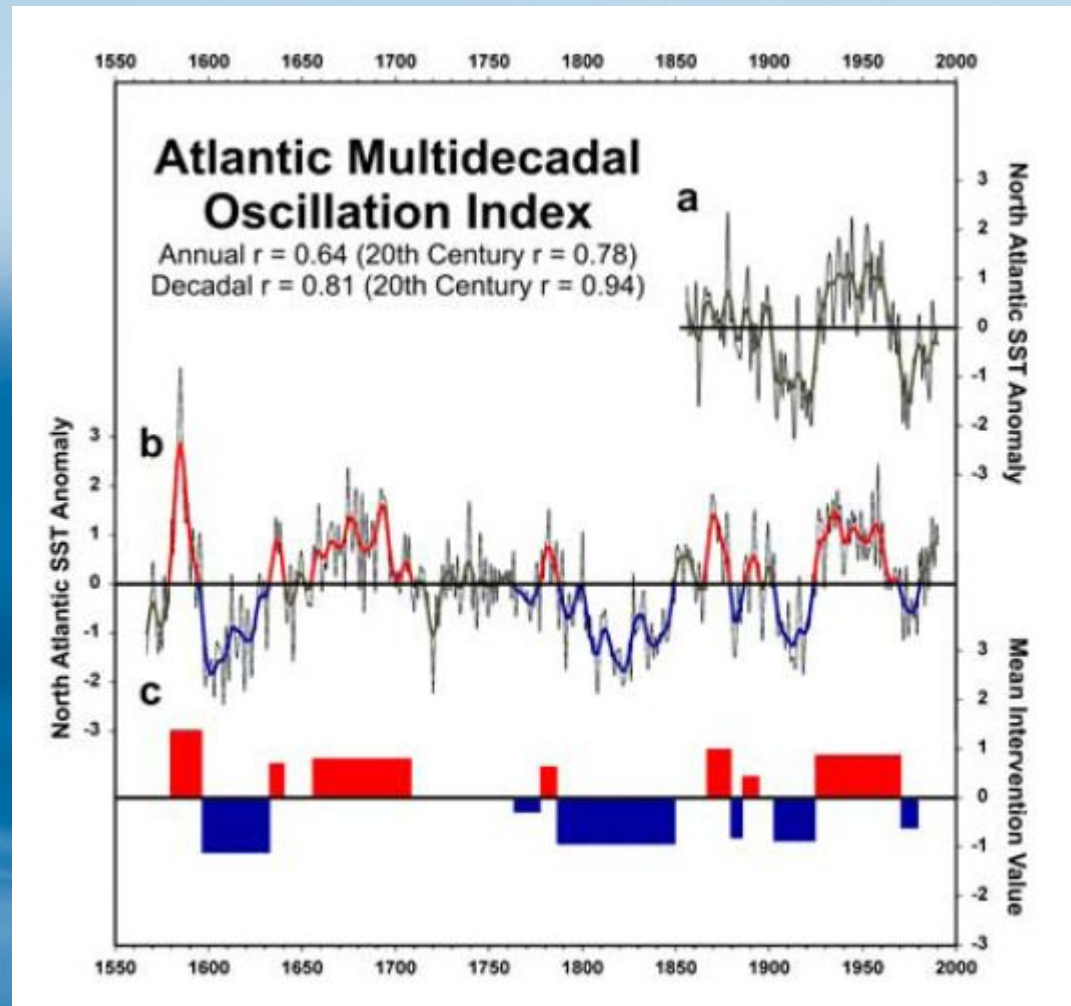
The bipolar see-saw was active also in the 20th century



The bipolar “see-saw” first discovered in the glacial era paleodata was also active in the 20th century.

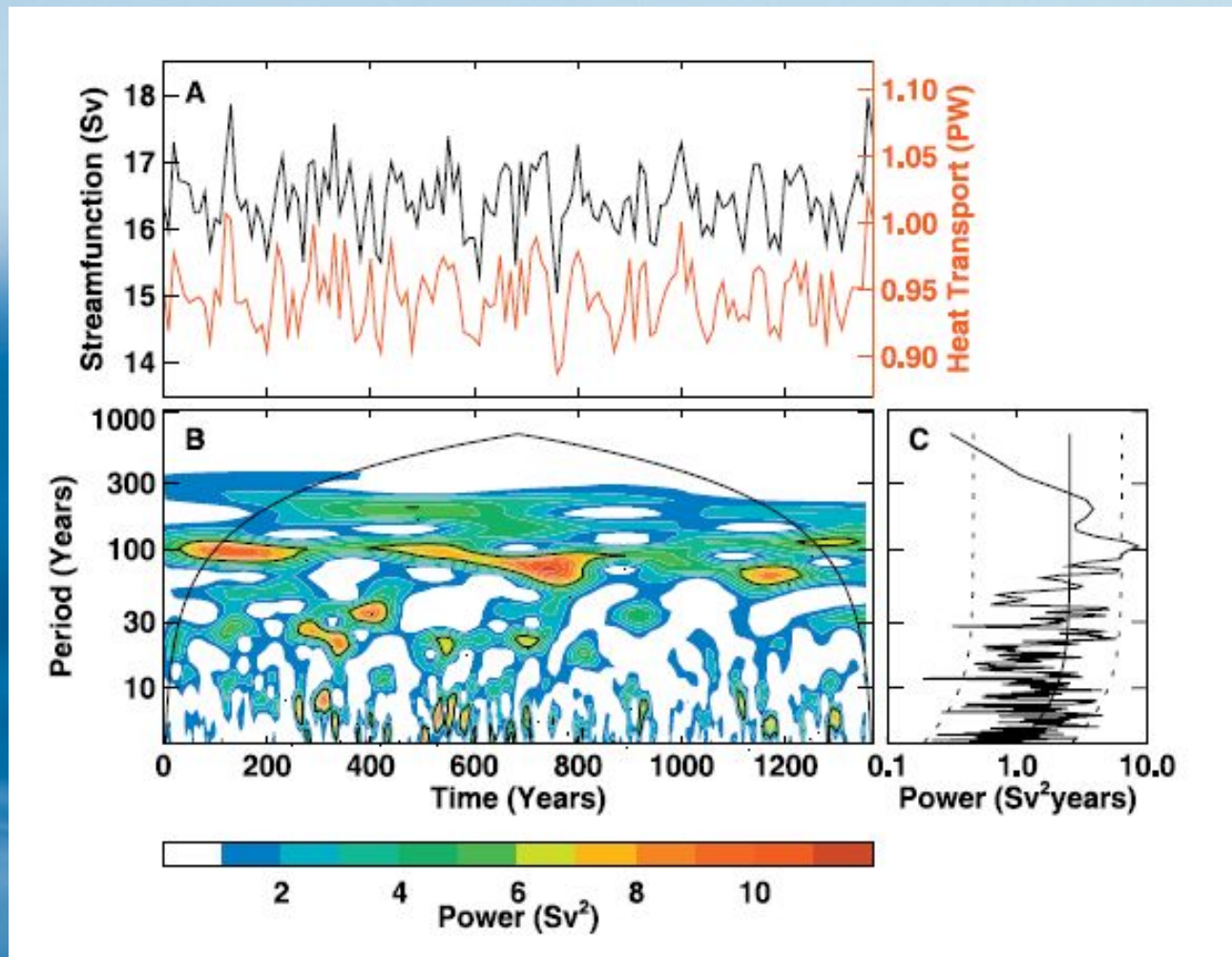
The Arctic and Antarctic temperature anomalies (from NASA GISS dataset) seem to have inverse phases strongly suggesting a MOC related interhemispherical heat transport. The linear trend is similar for both hemispheres and therefore related to global forcings (greenhouse gases and solar variability).

Observed and reconstructed values of AMO



Using tree-ring width it was possible to reconstruct AMO of past four centuries (caveat: or at least something that well correlates with AMO during the time we could observe it directly)

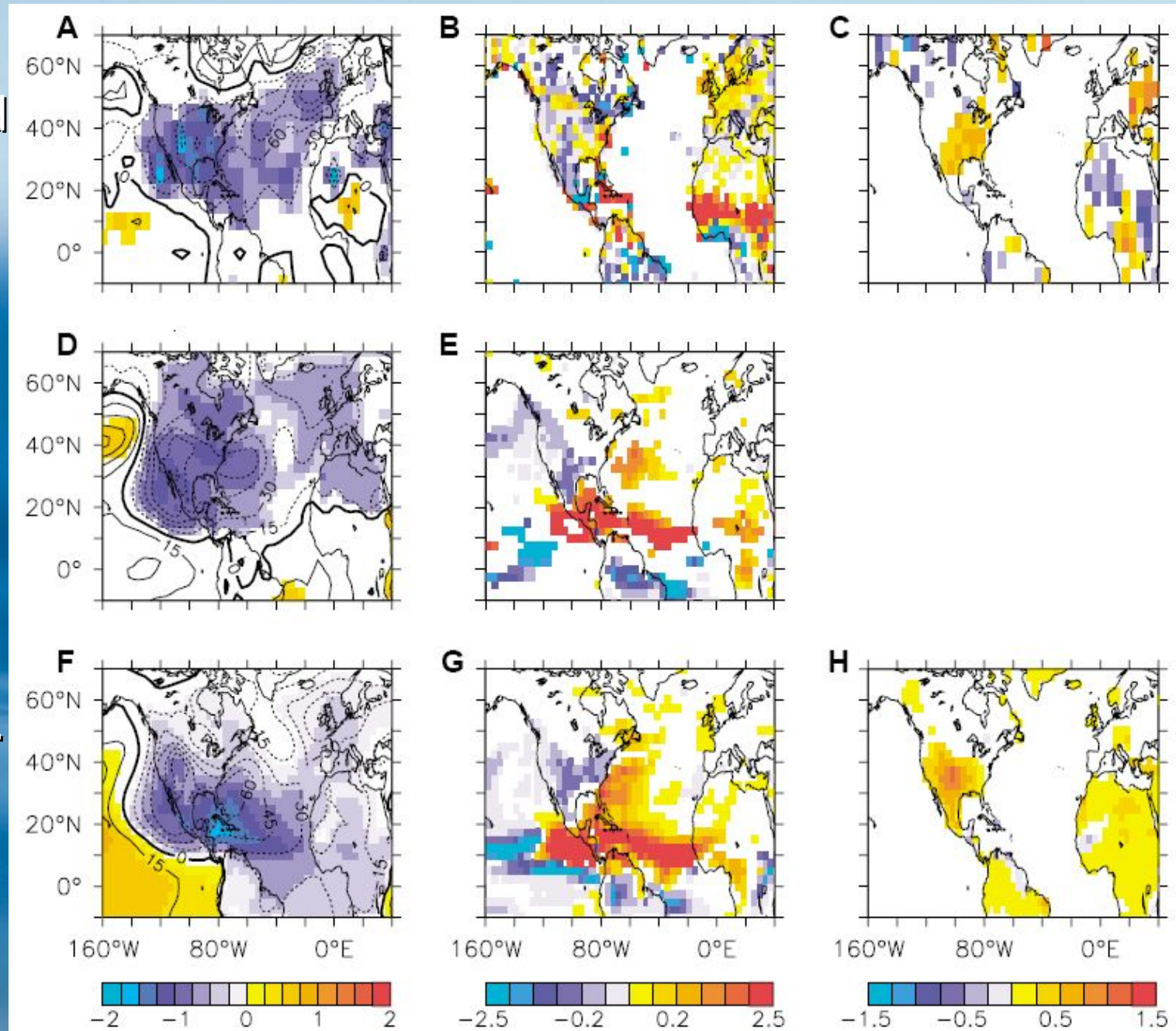
Modeled AMO: wavelet analysis



Wavelet analysis of modeled 1400 years of AMO (HadCM3 model) showing a 70-120 year period of AMO.

Observed and modeled AMO climate effects

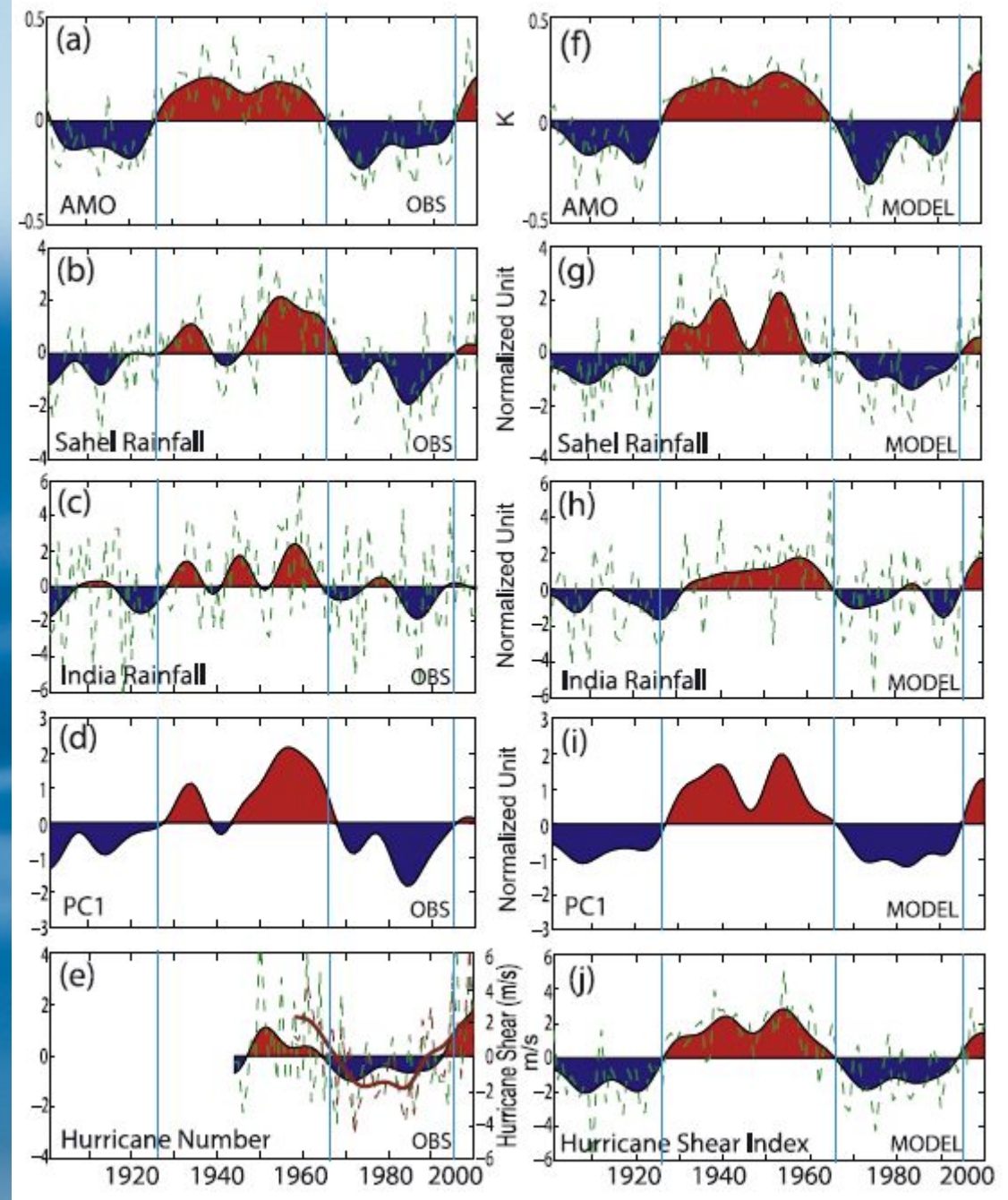
Observed (top) and modeled using as a forcing observed SST (middle) and ideal AMO SST values (bottom) decadal variability of air pressure (left), precipitation (center) and surface temperature (right). The plots should be interpreted as positive – negative phase of AMO values.



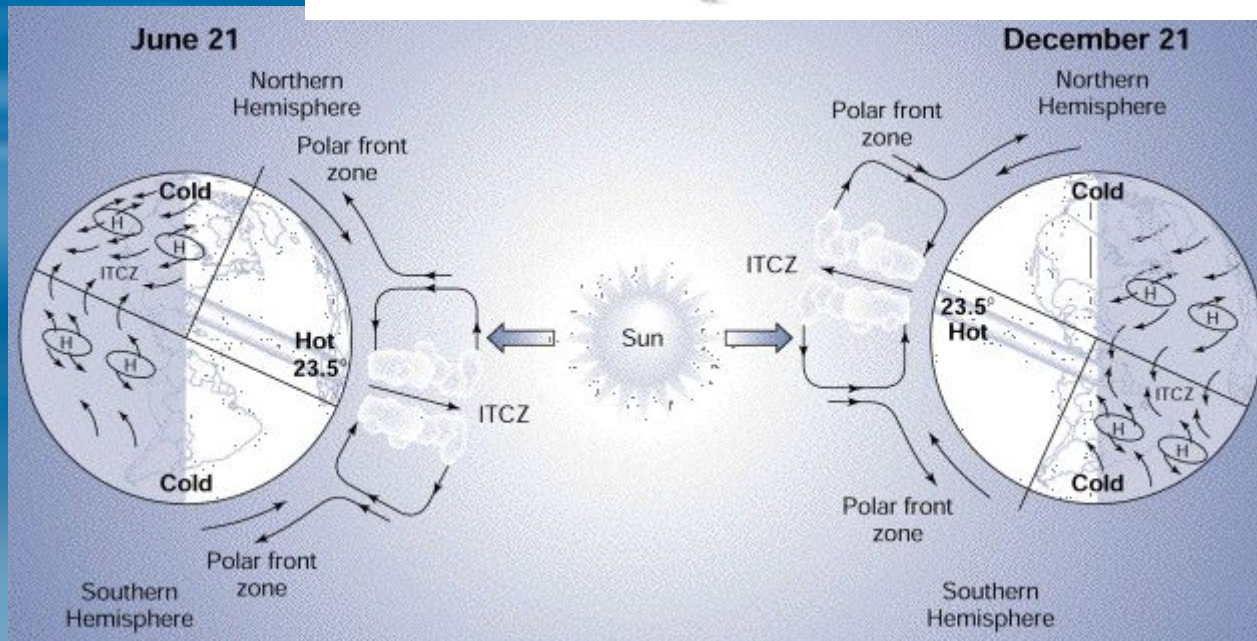
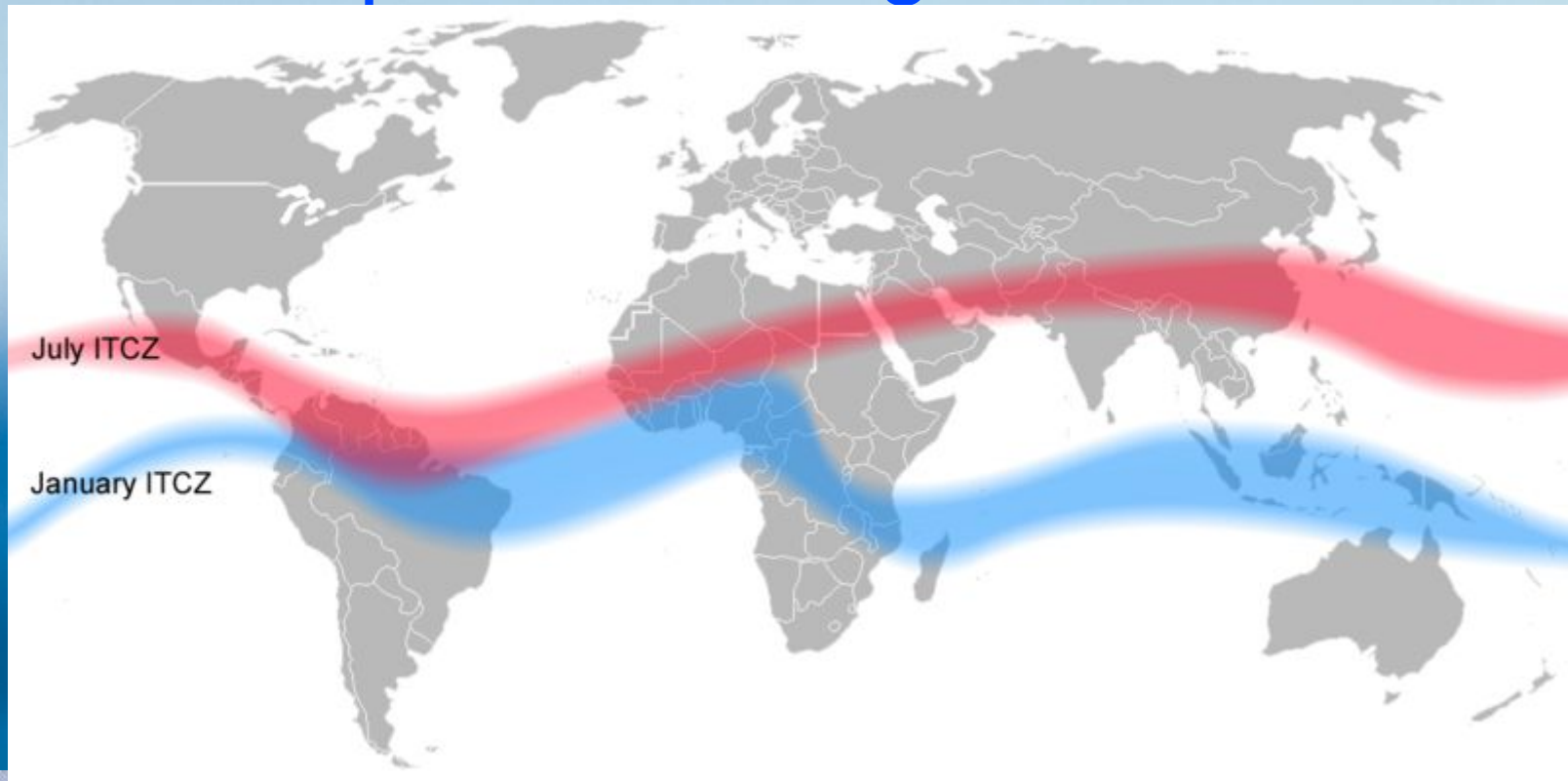
Observed and modeled AMO influences

AMO correlates very well with summer Sahel and India rainfall (even better with its low-pass filtered first principal component) and with Atlantic hurricane numbers both for observations (left) and with model (right), for a general circulation model (GFDL CM2.1) forced with measured Atlantic heat fluxes .

Is it easy to explain the relationships?



Intertropical Convergence Zone



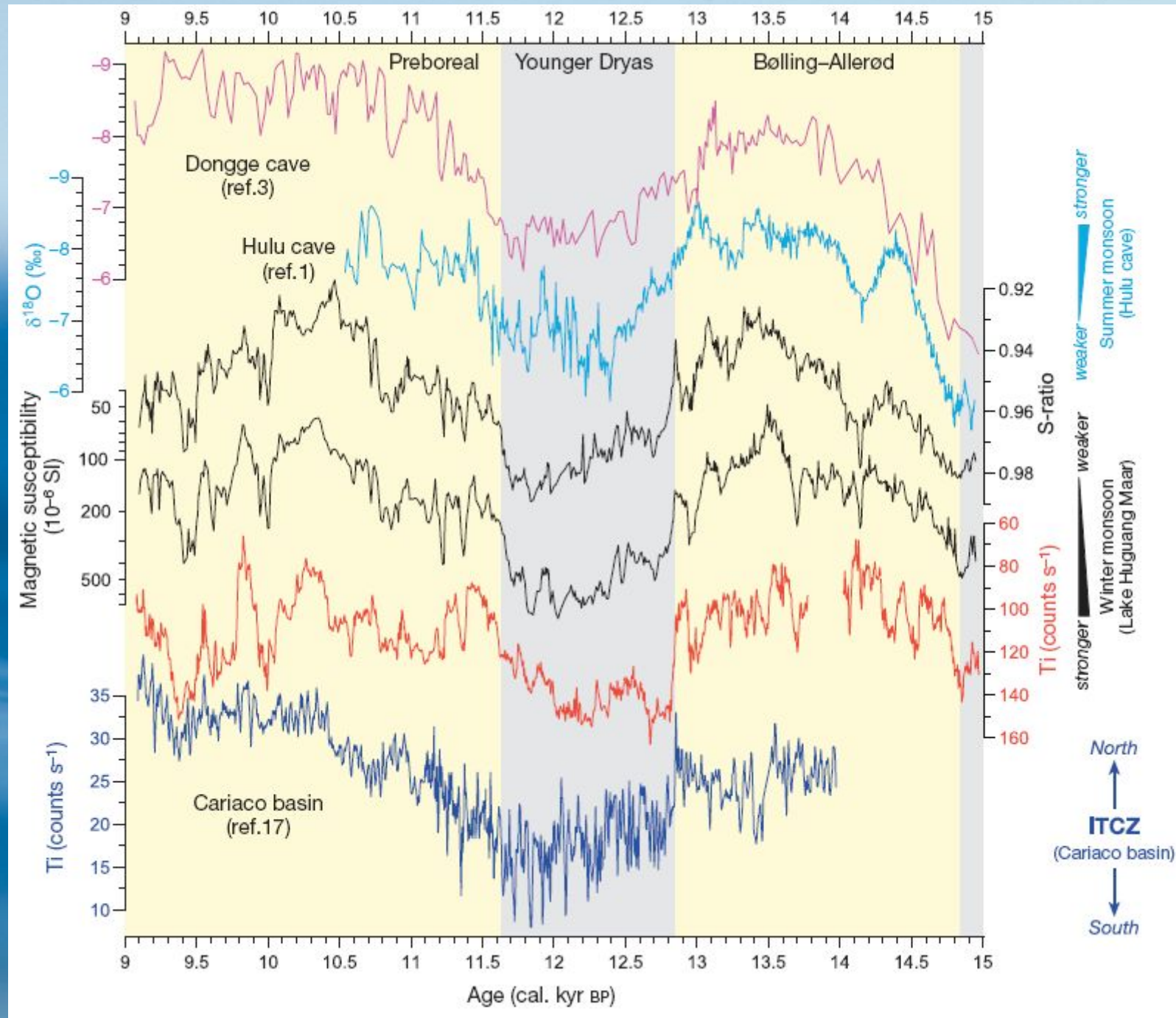
In the yearly cycle, ITCZ moves always to the hemisphere which receives more heat from the sun (see lower panel).

Variability of Asia monsoon and Caribbean precipitation

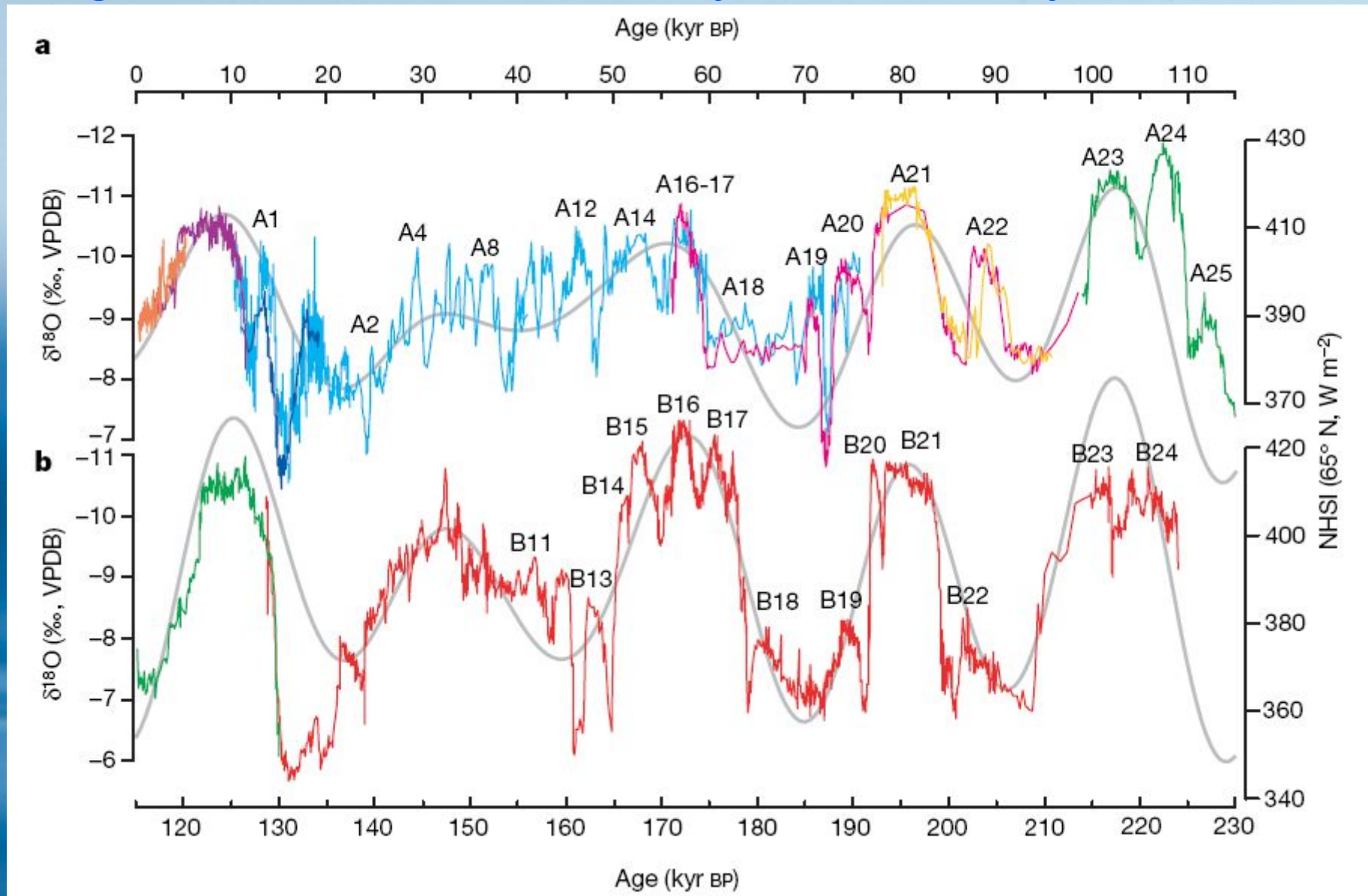
During the deglaciation (right) and glacial era (not shown), changes of the tropical climate were highly synchronous.

Common denominator?

THC regulated northward and southward movements of ITCZ.



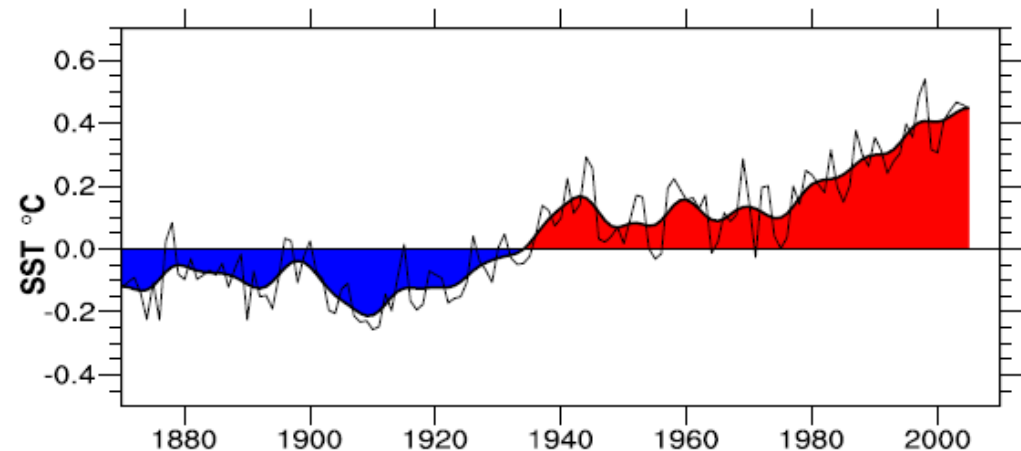
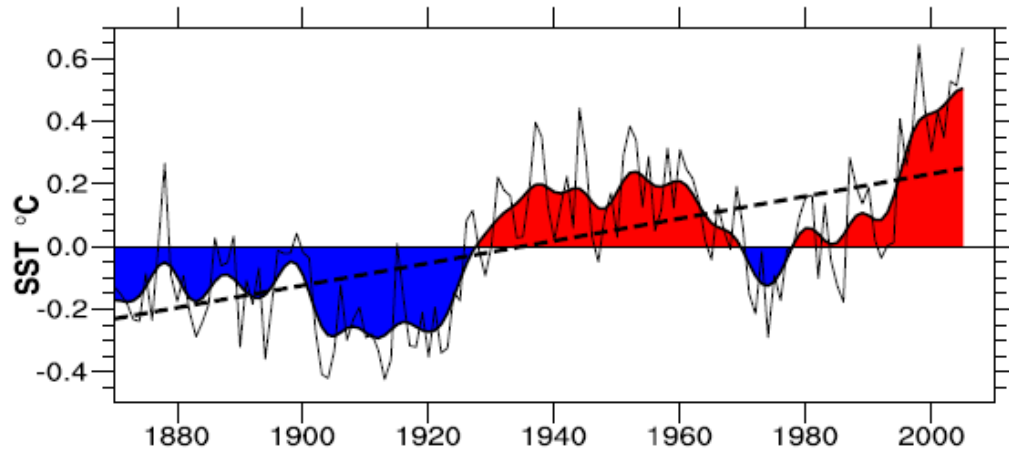
Long term monsoon variability controlled by NH insolation



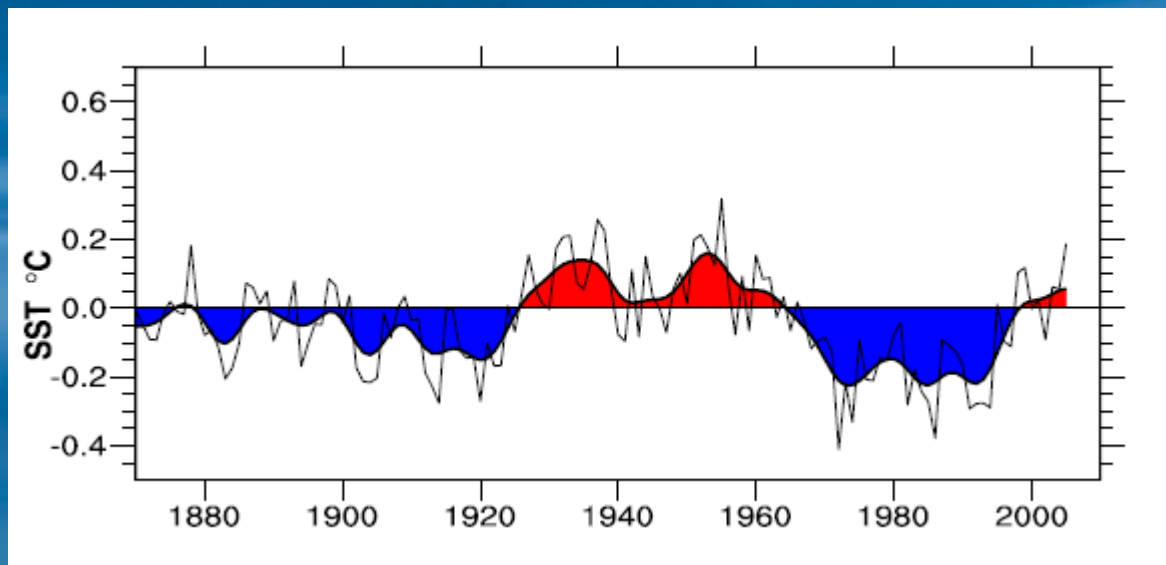
Monsoon intensity over last 230ka from south China stalagmites compared with summer insolation at 65° N. AI named “wiggles” correspondent to THC related North Atlantic events. It is clear that the ITCZ position is controlled by North-South temperature difference.

Wang et al. 2008 (Nature)

Is AMO another name for global warming?



SST changes of North Atlantic [0° to 60° N] (left) and global oceans [60° S to 60° N] (right) show similar temporal variability. Is one of them due to the other?



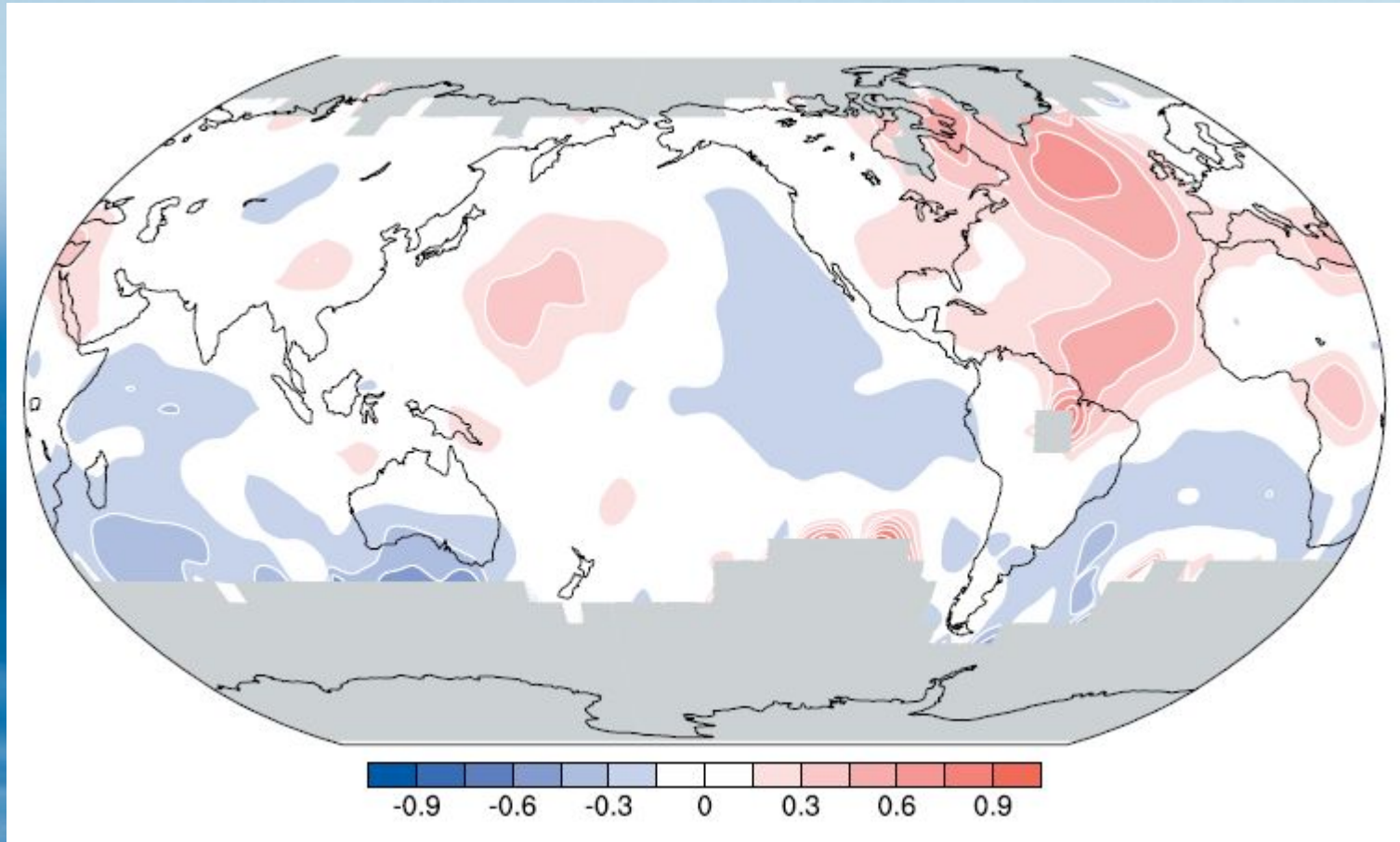
SST changes of North Atlantic with the global trend subtracted. This can be treated as an improved AMO index.

Subtracting the global trend from North Atlantic SST time series shows the residual AMO. But isn't it strange that it is in phase with global temperature variability?

However it nicely explains the hurricane correlation if Vecchi & Soden 2007 are right.

Trenberth Shea 2006 (Geophysical Research Letters)

Is AMO another name for global warming? The spatial pattern.

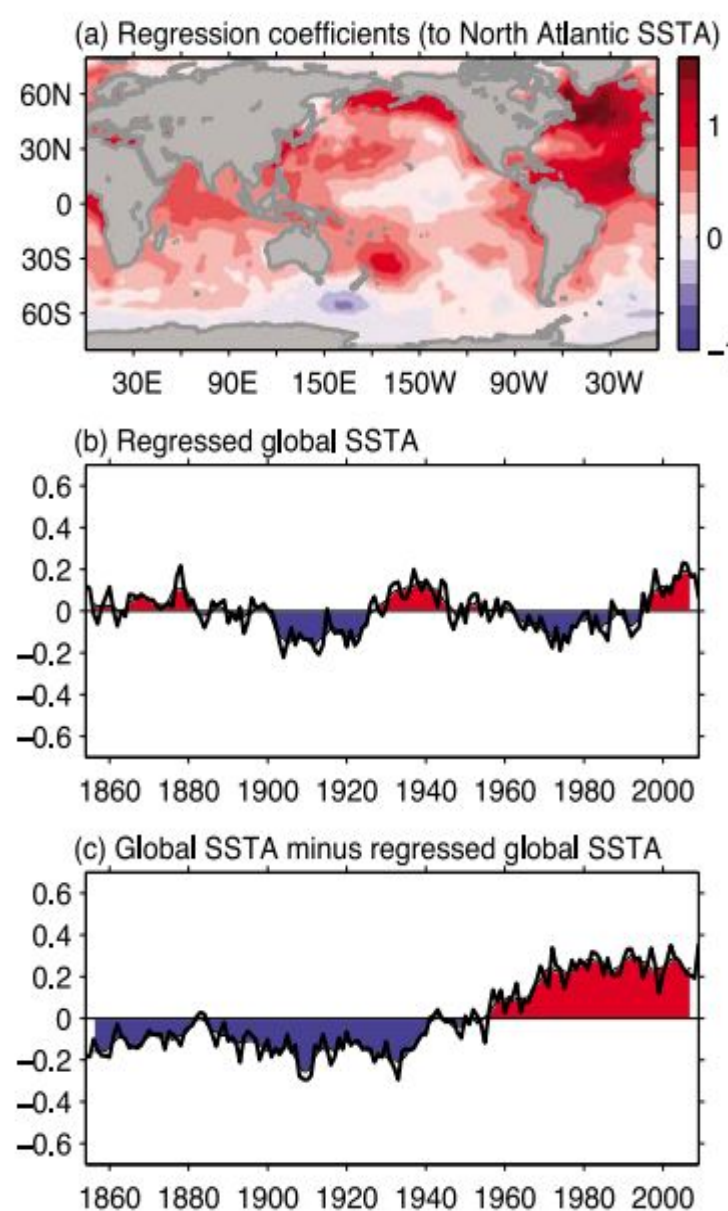
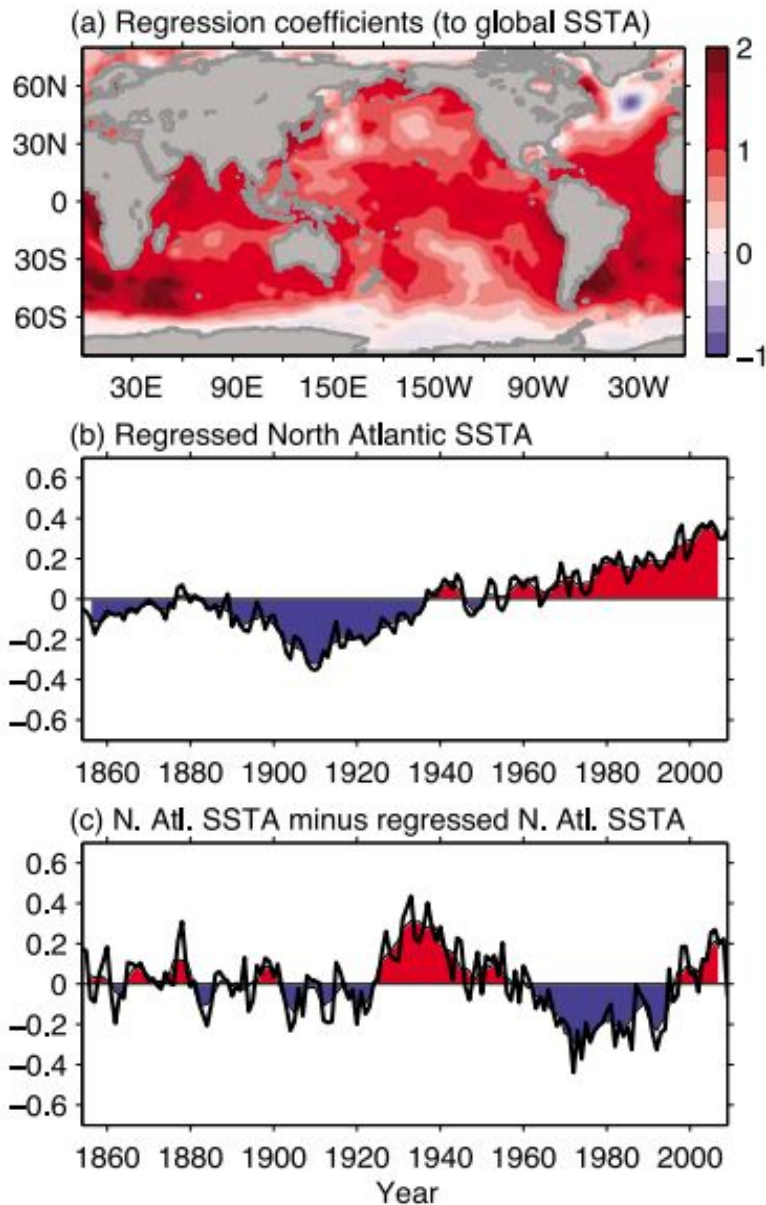


Correlation of the revised AMO index with global surface air temperatures for 1900 to 2004 based on annual values. Only values in the North Atlantic can be considered significant.

Is there a good reason for AMO to be in phase with global temperature?

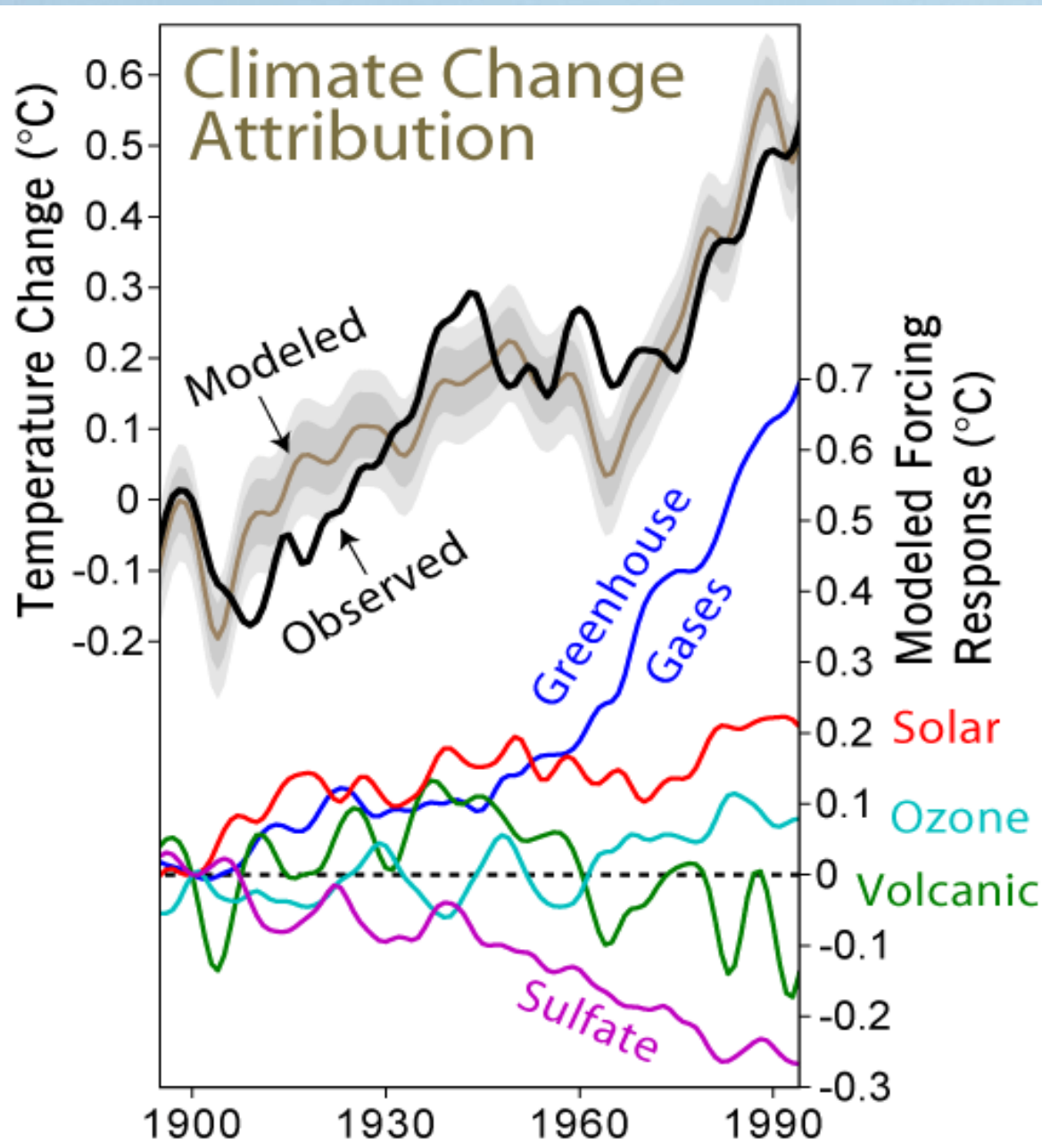
Trenberth Shea 2006 (Geophysical Research Letters)

Global SST and AMO indices are not fully independent



Influence of global SST on NA SSTs and the resulting “cleaned” AMO index (left) and the influence of AMO on world temperatures and the AMO-free global temperature data series.

There is only one problem...



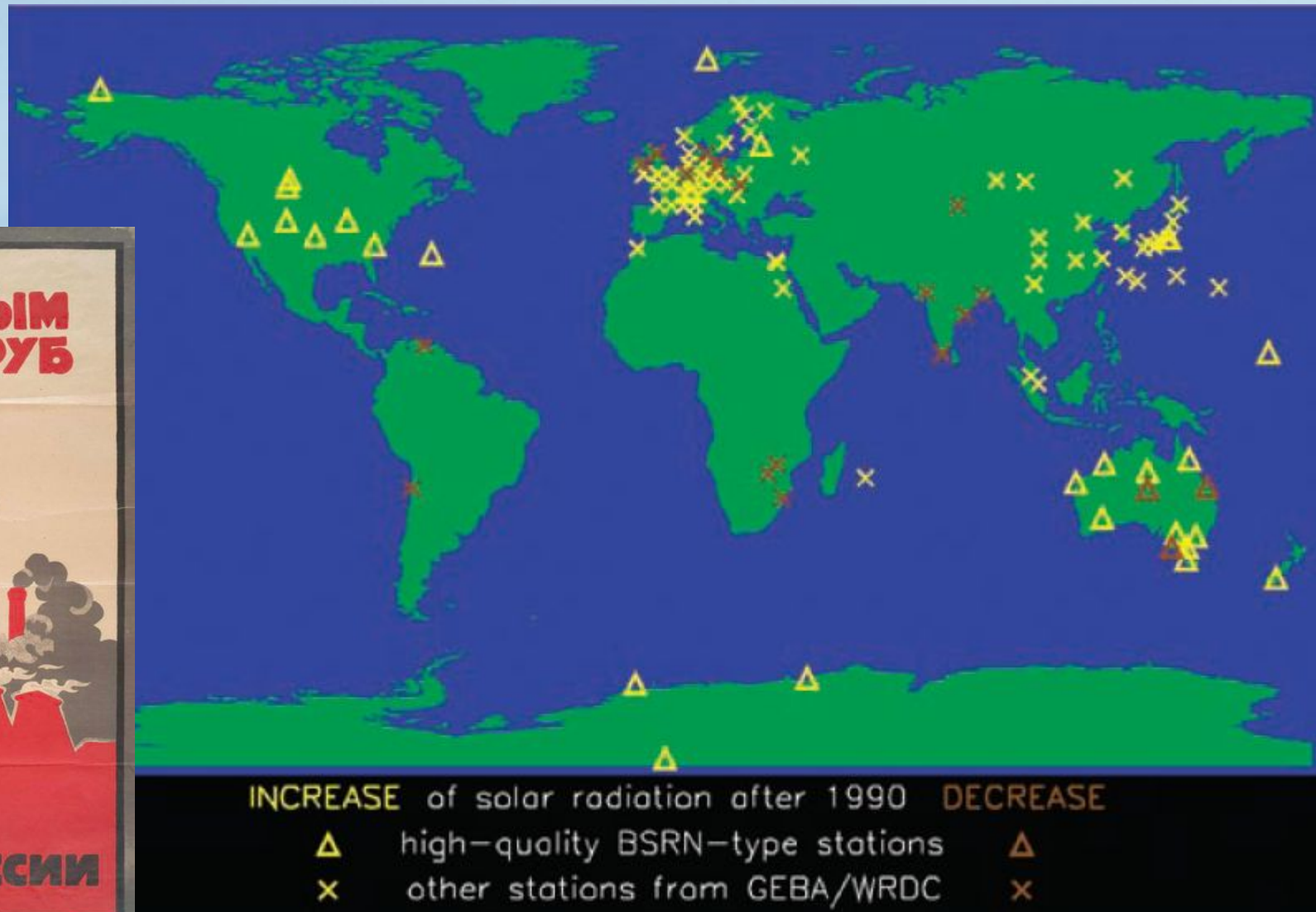
It seems we do not need THC to explain the average changes of Earth temperature.

Warming of the 1920s and 1930s was caused by increasing solar activity and green house gases and a break in volcanism.

The cooling of 1950s and 1960s was due to more aerosol emission (industrial sulfur rich smoke) and increase of volcanism.

The last 30 years were dominated by greenhouse gases increase.

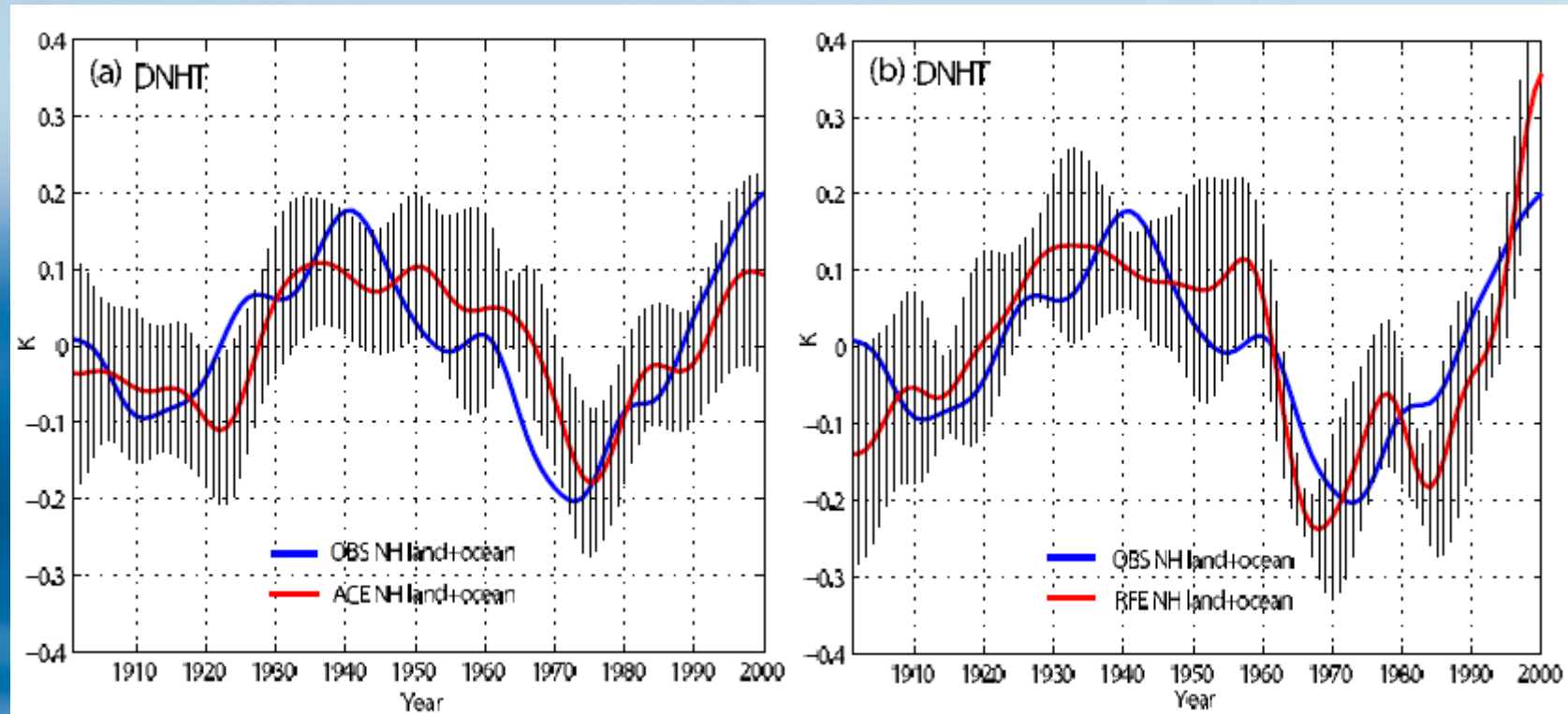
Brightening of Earth (since 1990)



Most stations measuring aerosol optical thickness note **increasing** irradiation (less aerosol) since 1990. Only tropical stations in India subcontinent, Africa and South America show **decrease** of irradiation. Especially the Northern Hemisphere became clearer since the fall of Soviet era heavy industry.

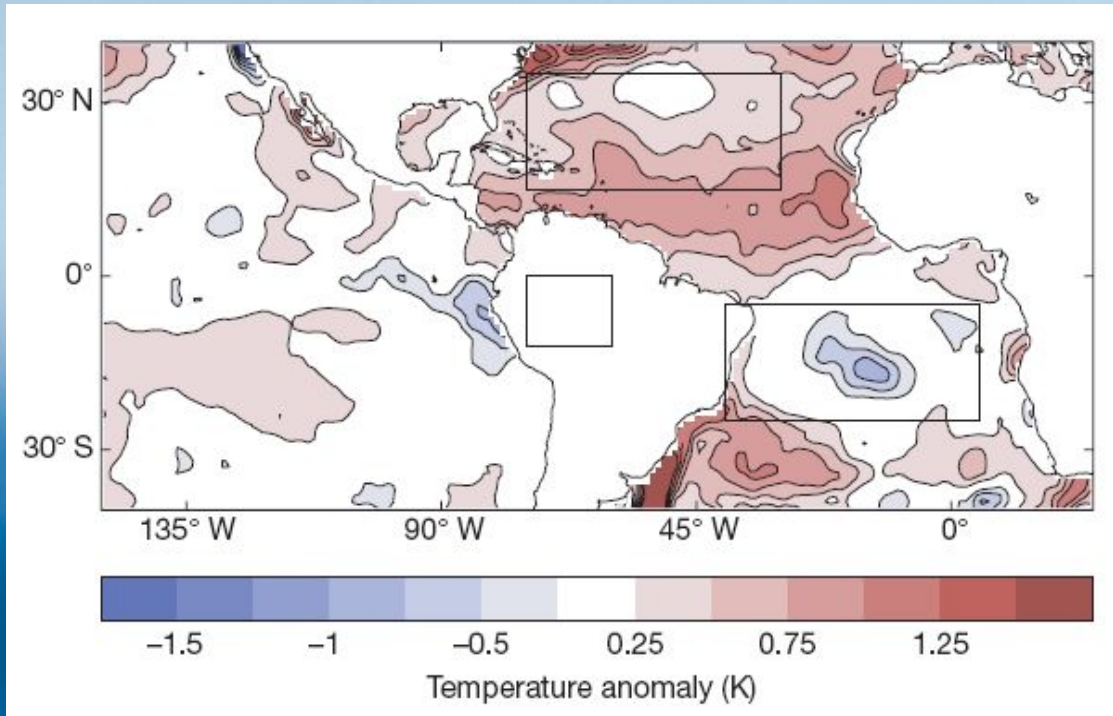
Wild et al. 2005 (Science)

Again: why is AMO in phase with greenhouse and aerosol forced global warming?



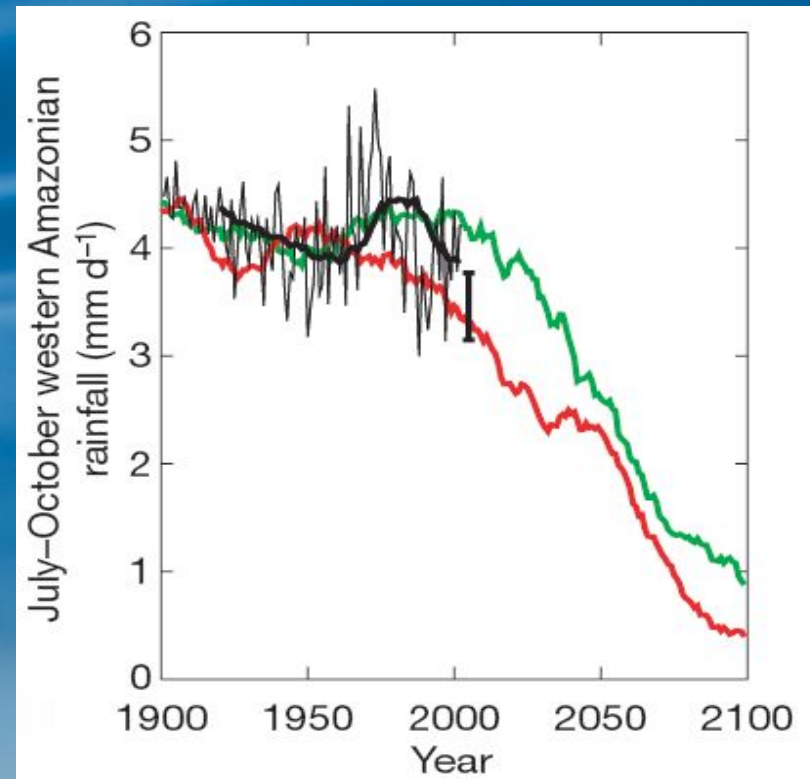
Northern Hemisphere temperatures **measured** and **modeled** using AMO forced (left) and greenhouse gas forced (right) general circulation model. Both allegedly explain the observed variability. This looks too good to be true. Unless...

Apparently other people are thinking too...

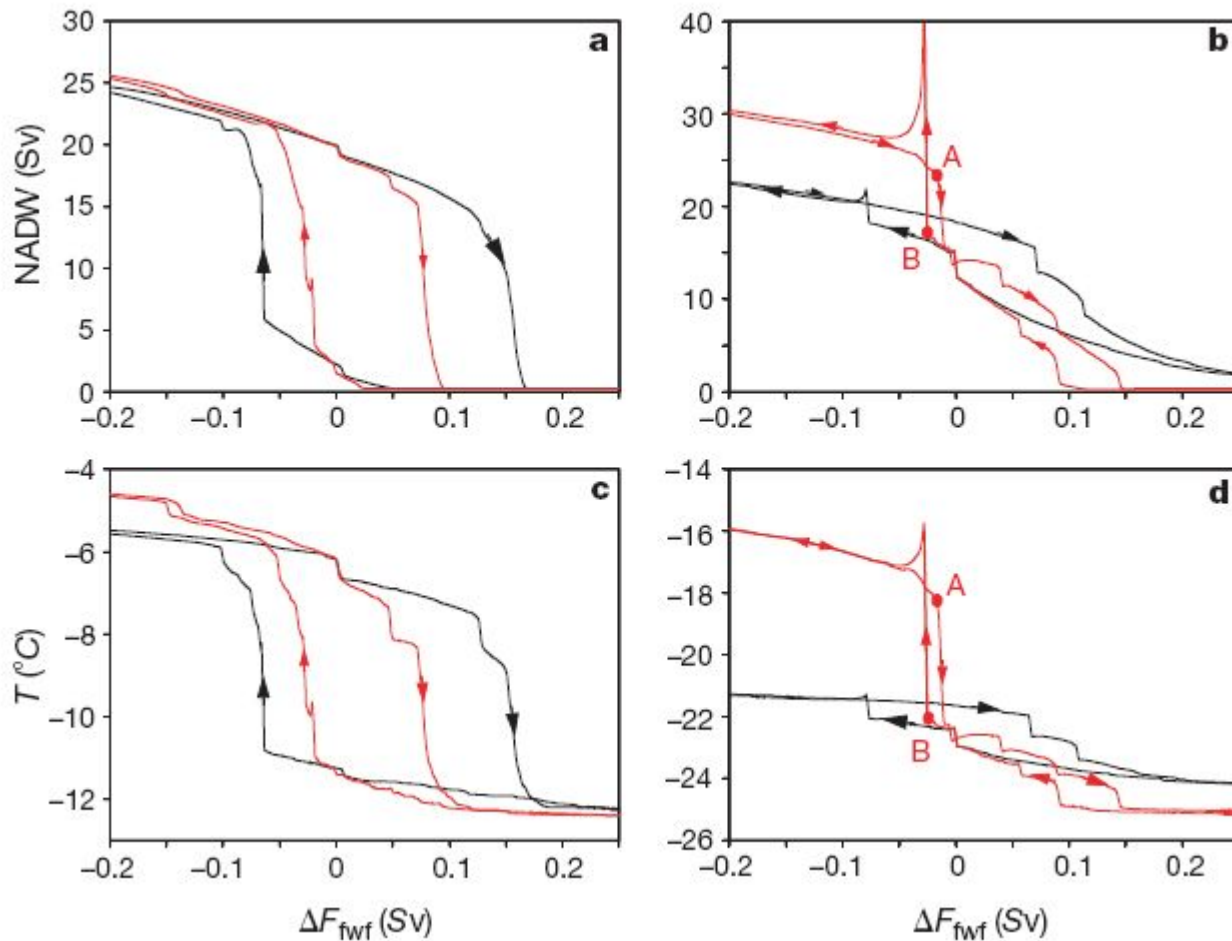


Met Office Hadley Centre has the only operating global model with interactive aerosol and carbon cycle: HadCM3LC. A recent study of droughts in the Amazonia (left: 2005 drought) links them to ITCZ shifts... caused by hemisphere differences in aerosol forcing.

Right: July-October western Amazonian rainfall (black) with 20 year average, results of HadCM3LC model runs with greenhouse gases only (red) and greenhouse gas + aerosol (green). The future part of the runs suggests dry western Amazon in the greenhouse world.



A reminder: THC volume depends on the inflow of fresh water to North Atlantic

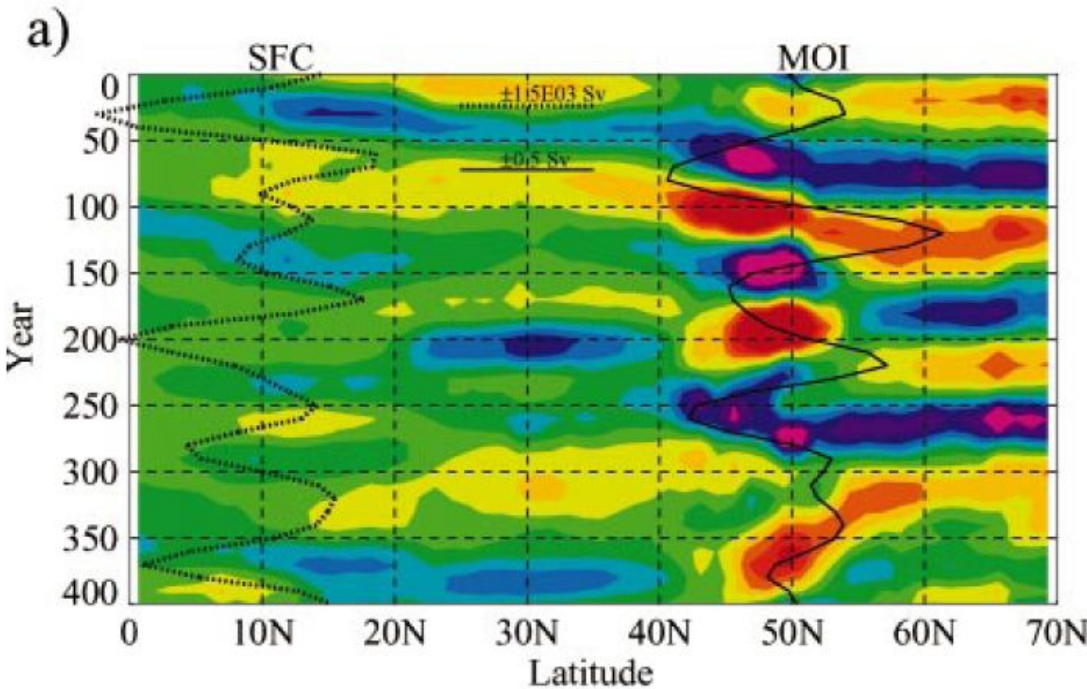


Model of NADW production (top) and SST (bottom) of present day North Atlantic (left) and glaciation era Atlantic (right) as a function of fresh water inflow flux into Subarctic (red) and Polar (black) Atlantic

Climate models show that fresh water influences NADW production in non-linear way (with a hysteresis). In order to stop THC, nature needs more fresh water added far from the Arctic (in the Tropical Atlantic) or less added in the Subarctic. In the glacial times the hysteresis loop was narrower (due smaller NADW producing basins) which caused the climate to be unstable.

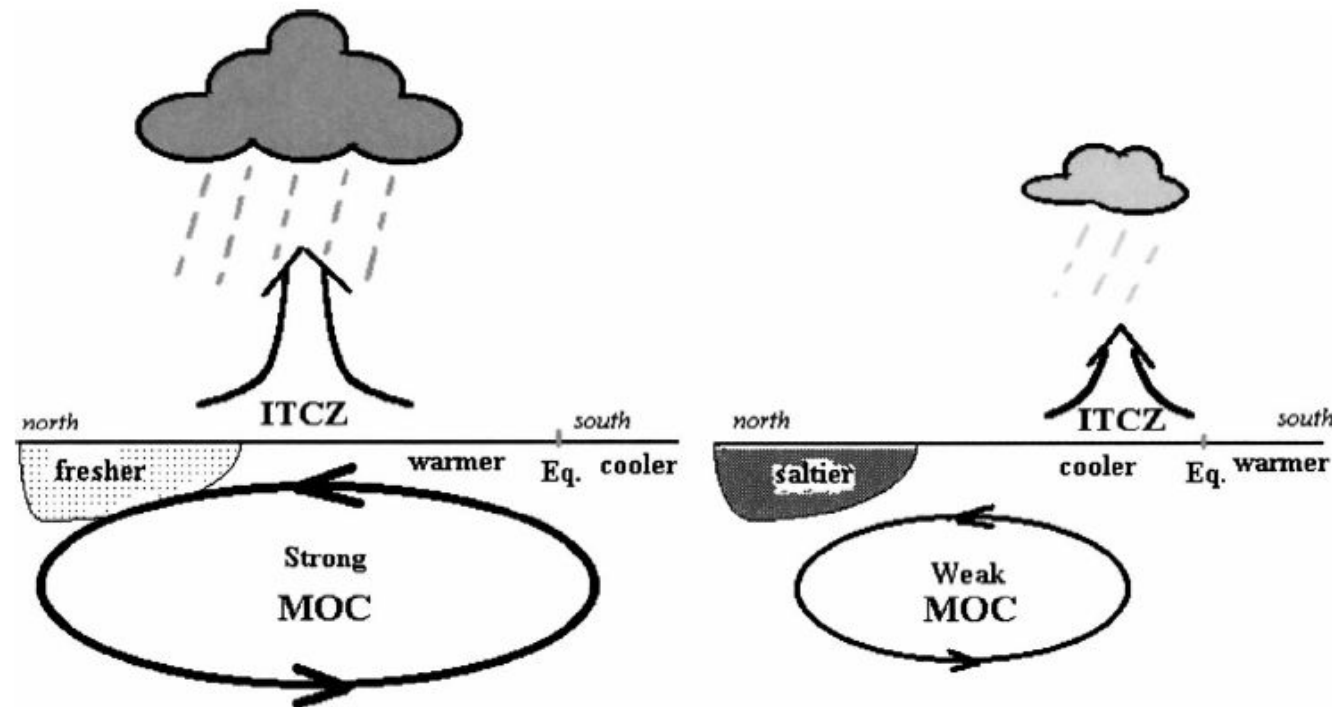
Ganopolski & Rahmstorf 2001 (Nature)

We have a mechanism for AMO



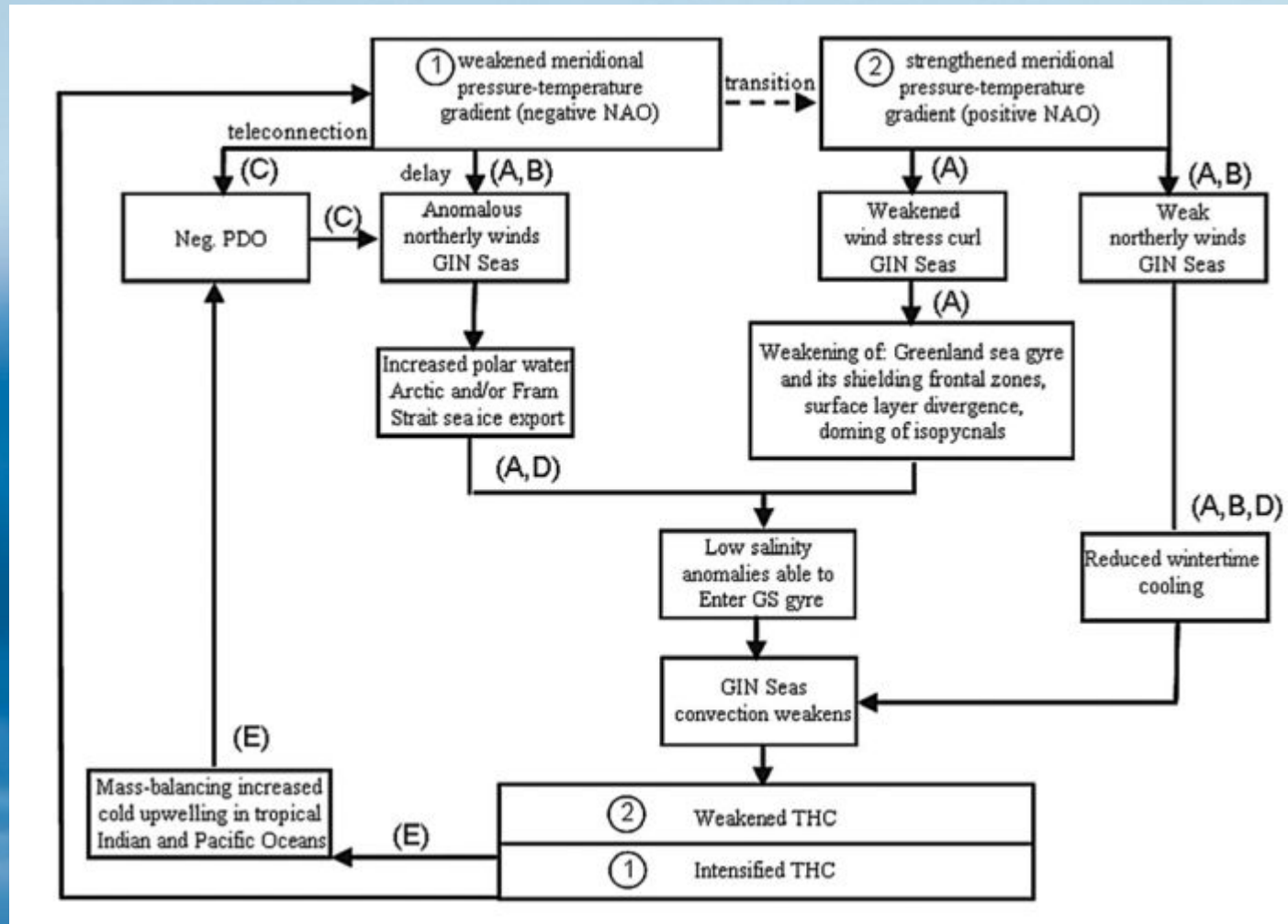
Unforced modeling with HadCM3 general circulation model shows a salinity pulse followed by freshwater pulse traveling from tropics northwards with a period of about 100 years. The mechanism is as follows:

decreased THC →
south shifted ITCZ →
less rain in TAO →
salty impulse →
increased THC →
north shifted ITCZ →
more rain in TAO →
freshwater impulse →
decreased THC



*Velliniga Wu 2004
(Journal of Climate)*

We have even more than one possible mechanism



Dima and Lohmann proposed a more complicated mechanism involving NAO changes influencing freshwater inflows from the Arctic. The above graph is supposed to explain at least part of it.

Grossmann & Klotzbach 2009 (JGR) explaining the mechanism proposed by Dima & Lohmann 2007 (or rather part of it)

So why is AMO in phase with “global warming”?

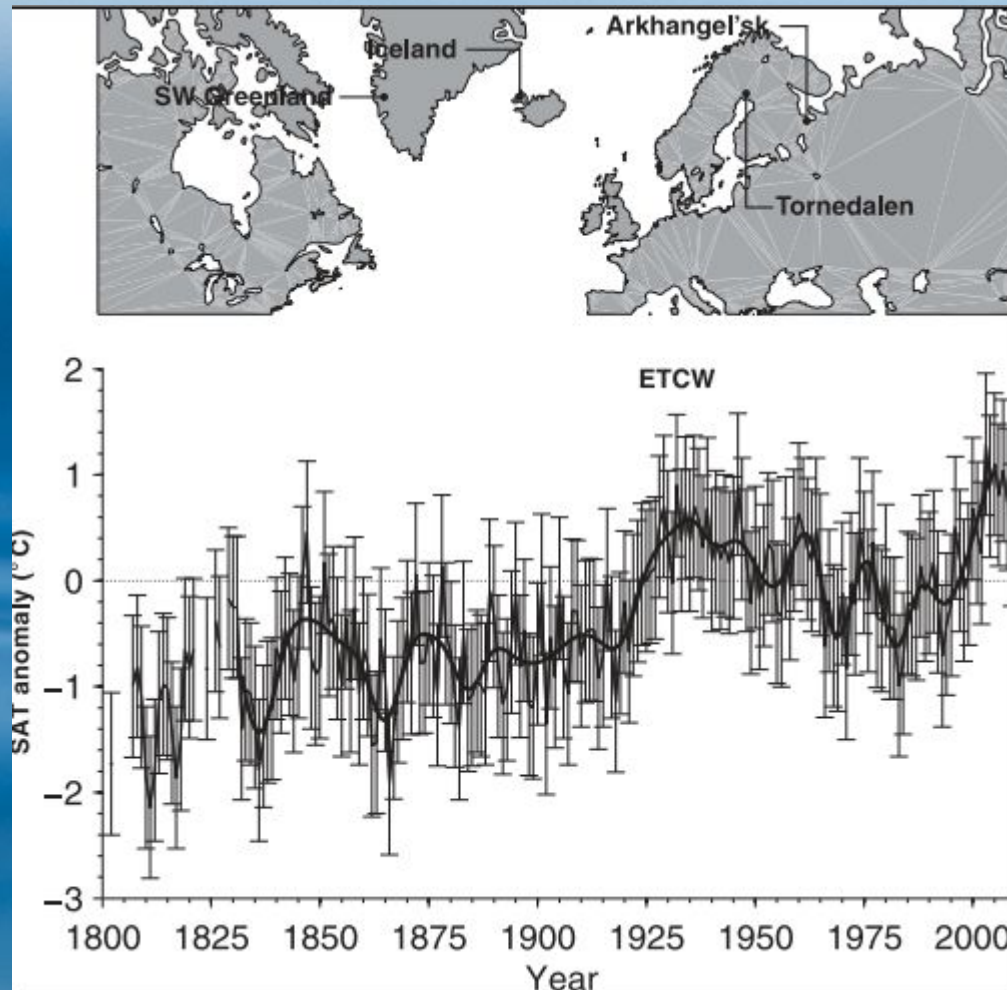


Because the anthropogenic forcings (especially aerosol related but also, to a lesser degree greenhouse gases) are stronger in the Northern Hemisphere, they create a inter-hemisphere temperature gradients. This moves ITCZ, influencing THC in similar manner as AMO itself. I believe it possible that we created a forced oscillator AMO pattern, forcing its phase to be in step with the sum anthropogenic forcings.

How could we possibly test the hypothesis? Only by using coupled general circulation models.

Some proof that AMO may be still a side-product of the 20th century anthropogenic forcings?

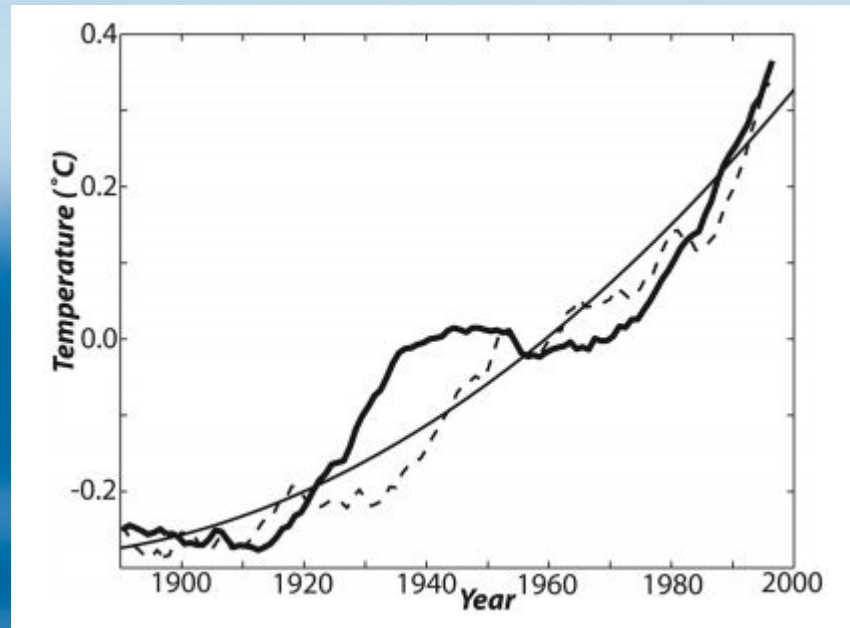
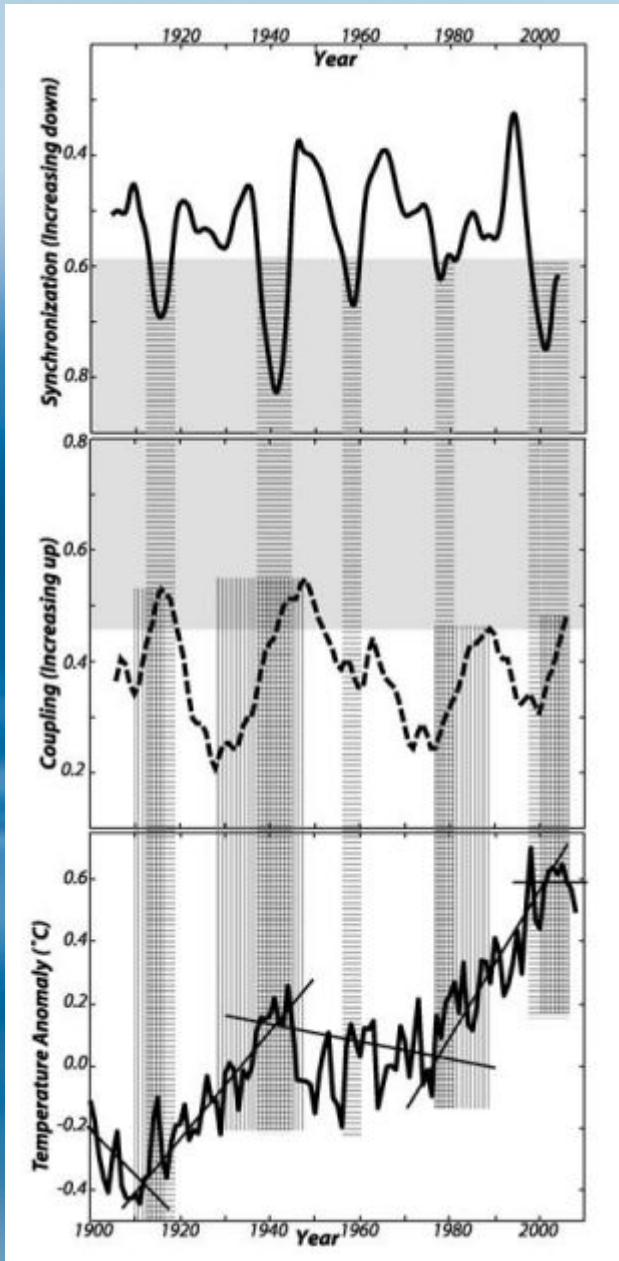
“Remember, no cycles!”
Jim Overland



A new reconstruction of North Atlantic surface air temperatures from meteorological records going back to 1802 does not show a 60-70 year cycle before the beginning of the 20th century.

This leaves open the possibility that even as the cycle is a natural oscillation, it was put in motion only by anthropogenic forcing (most probably North Hemisphere aerosol load).

What it all means for our future (two different views by the same authors)



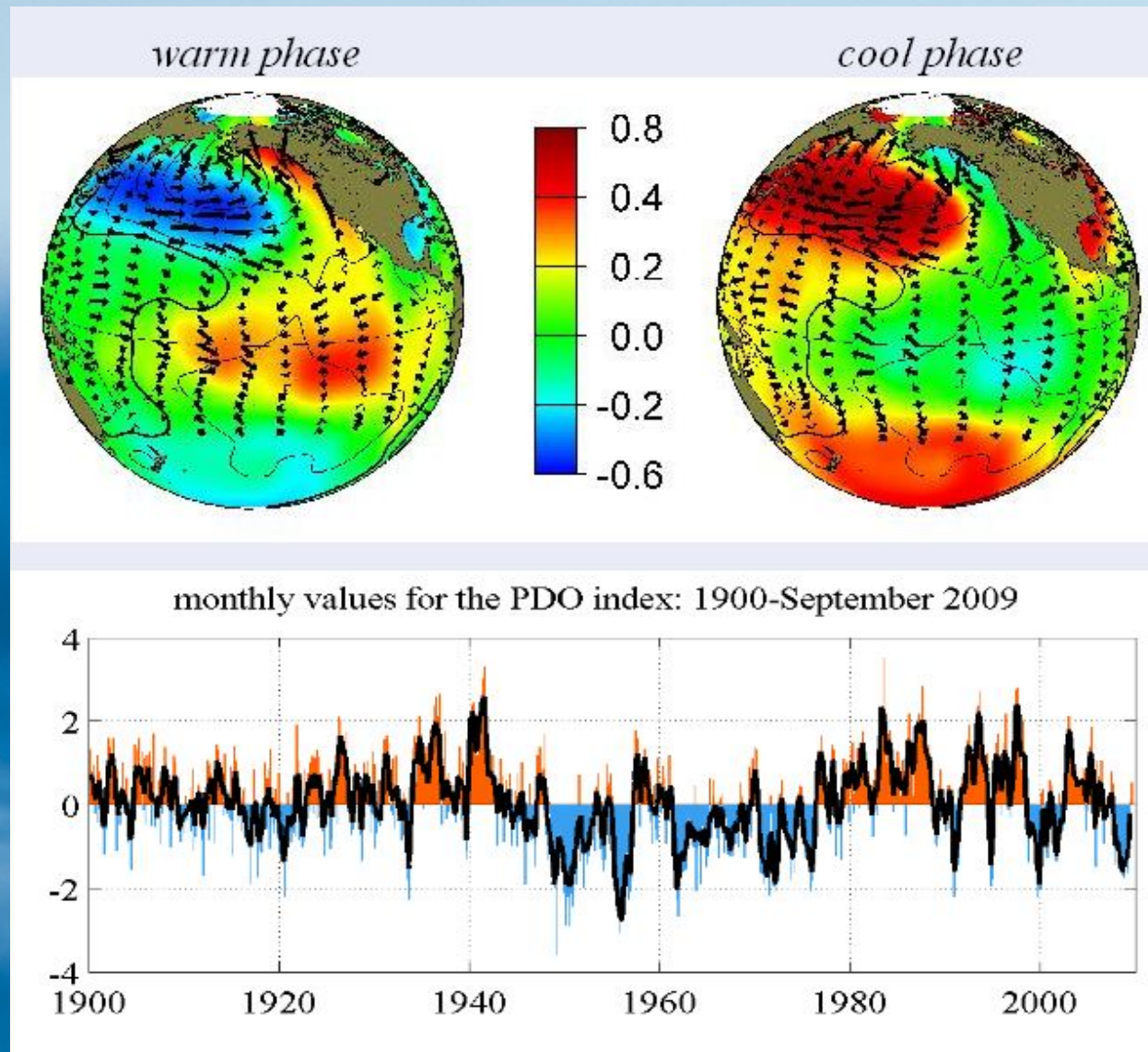
A statistical analysis of multiple climate indices (but not AMO) told Swanson and Tsonis that a climate shift has recently happened. However adding one oceanographer to the team (and AMO) changed the story. Now the record (heavy solid) can be explained by AMO related variability and a greenhouse gases driven trend (dashed line – temperature with the variability is subtracted, thin solid – quadratic fit).

Swanson & Tsonis 2009 (GRL); Swanson, Sugihara & Tsonis 2009

Podsumowanie 1/3

- Jednym z głównych elementów zmienności temperatury XX wieku jest cykl o okresie ok. 70 lat, związany z regionem wokół Północnego Atlantyku, zwany Atlantycka Oscylacją Multidekadową (AMO).
- Wzorzec przestrzenny AMO, a szczególnie odwrotna faza zmian w okolicy Arktyki i Antarktydy świadczy, że związany jest on ze zmianami intensywności cyrkulacją termohalinowej
- Jesteśmy w stanie wytłumaczyć taki cykl zmianami opadów w rejonie tropikalnego Atlantyku Północnego wymuszonymi różnicą temperatur obu półkuli i spowodowanymi tym zmianami zasolenia Atlantyku.
- Jednak podobne różnice temperatur między półkula północna i południową mogliśmy wywołać zadymiając tę pierwszą w pierwszej połowie XX wieku
- Czy zatem “rozkołysaliśmy” naturalny mod zmienności THC przy pomocy aerozolu?

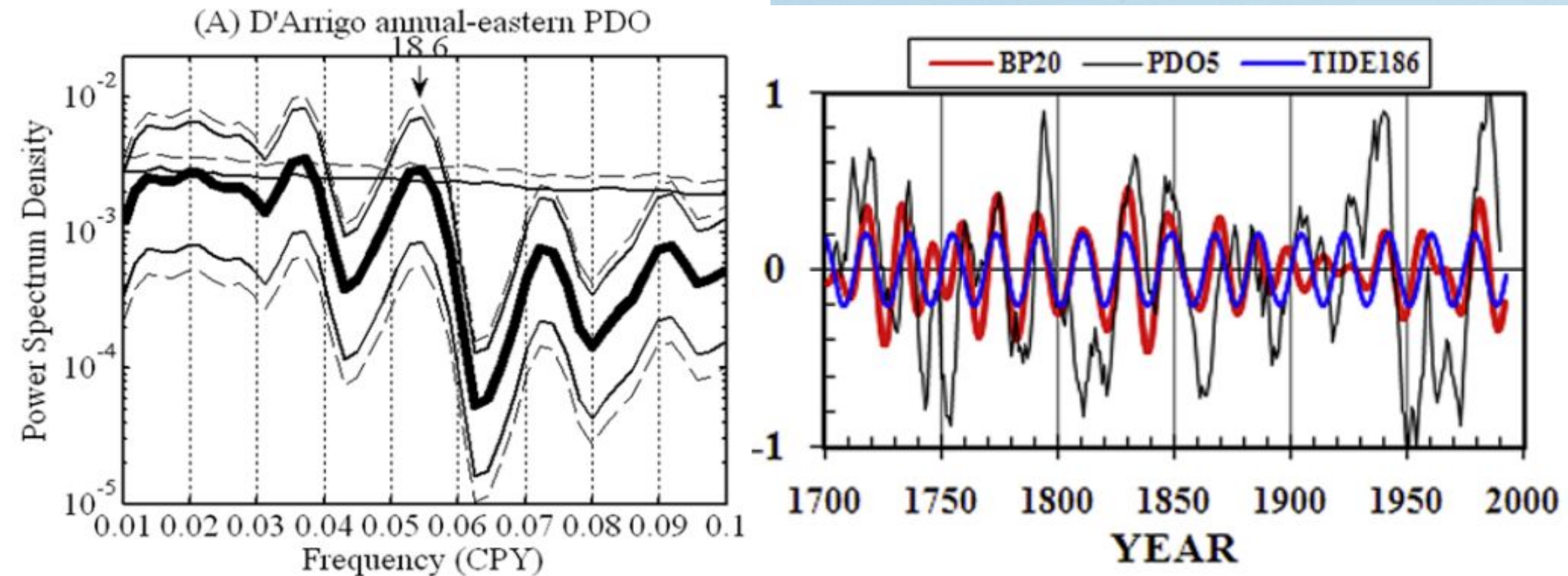
Pacific Decadal Oscillation (PDO)



Odpowiednikiem AMO na Pacyfiku jest PDO, o okresie cyklu ok. 20 lat, zidentyfikowany przez Latifa i Barnetta (1994) i zdefiniowany jako pierwszy EOF zmienności temperatury Pn. Pacyfiku przez Mantuę i innych (1997).

<http://jisao.washington.edu/pdo/>

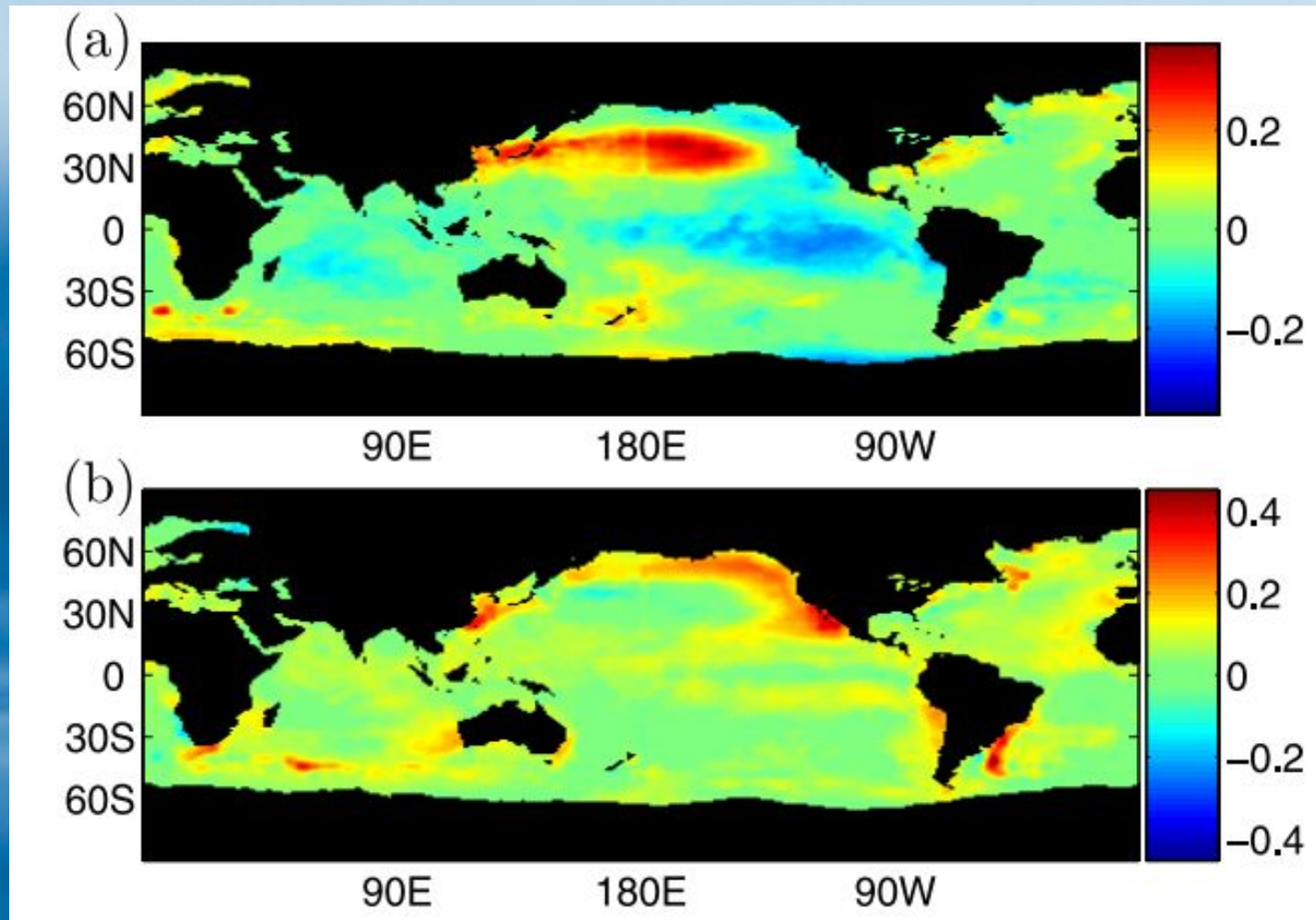
PDO is phase-locked to Lunar tidal cycle



PDO FFT-spectrum shows a prominent 18.6 year maximum which is identical to the Lunar induced nodal tidal cycle (left). The right panel is time-series of 5-year running mean PDO (PDO5: thin black curve), bi-decadal (BP20: 15.5–23.3year) component of the PDO (red) and inverted-18.6-year period moon cycle (TIDE186: blue) where the maximum corresponds to the minimum diurnal tide.

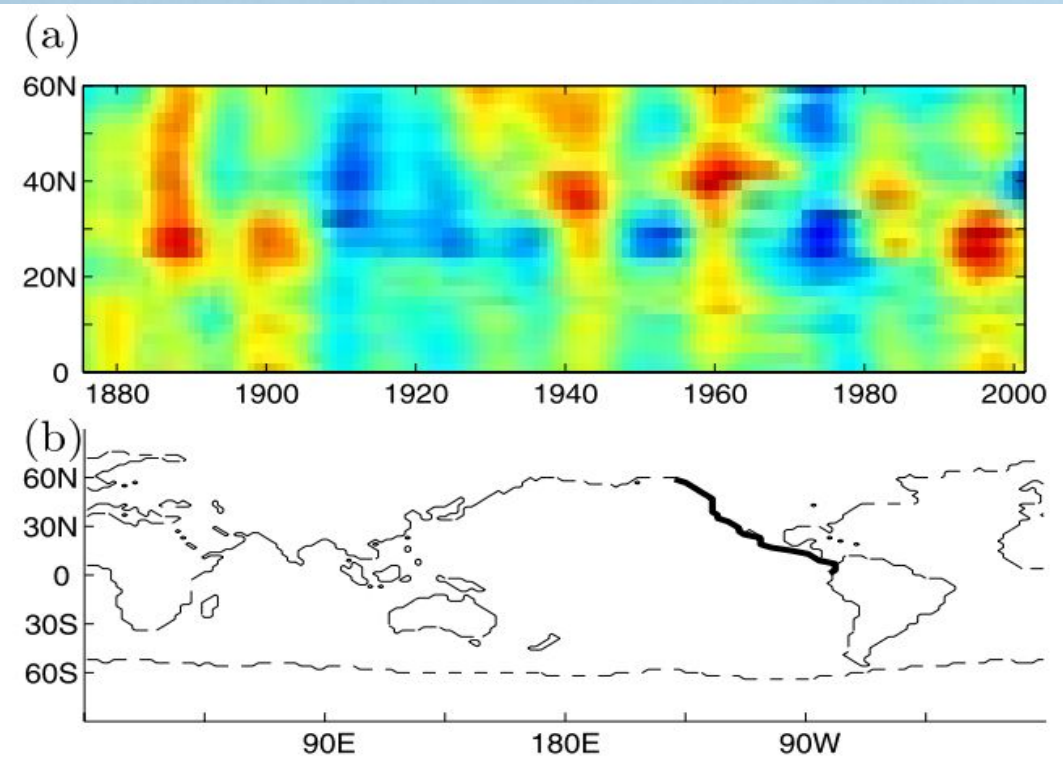
The tidal cycle seems to weak to create PDO but it may be able to phase-lock a natural oscillation of North Pacific of roughly 20-year period.

However PDO seems to have two independent components



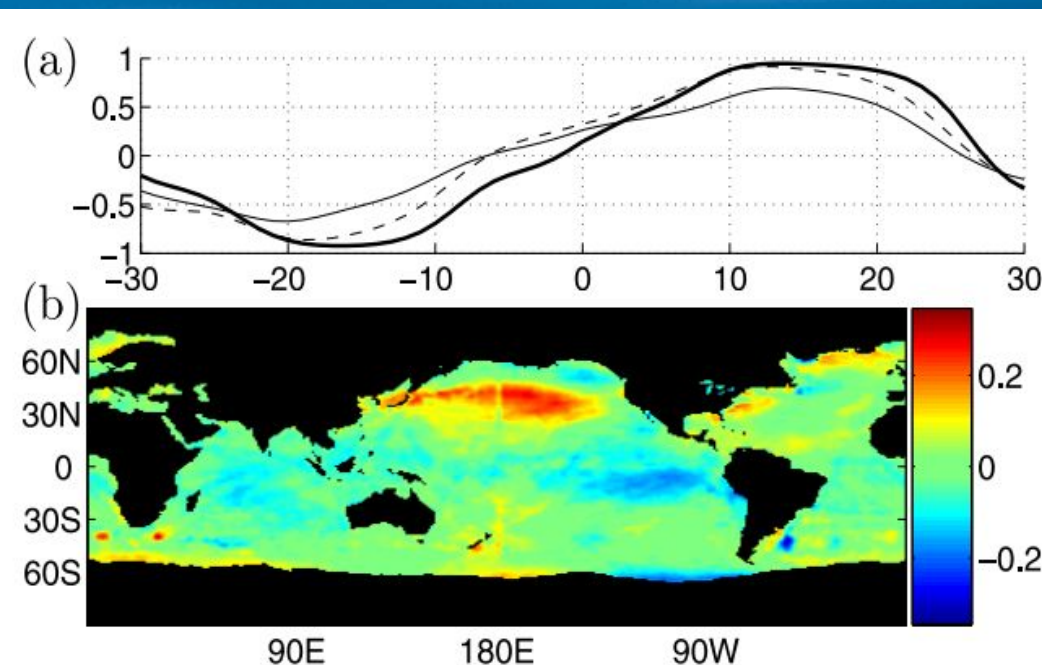
Two first EOFs of North Pacific SST variability since 1870.

However PDO seems to have two independent components

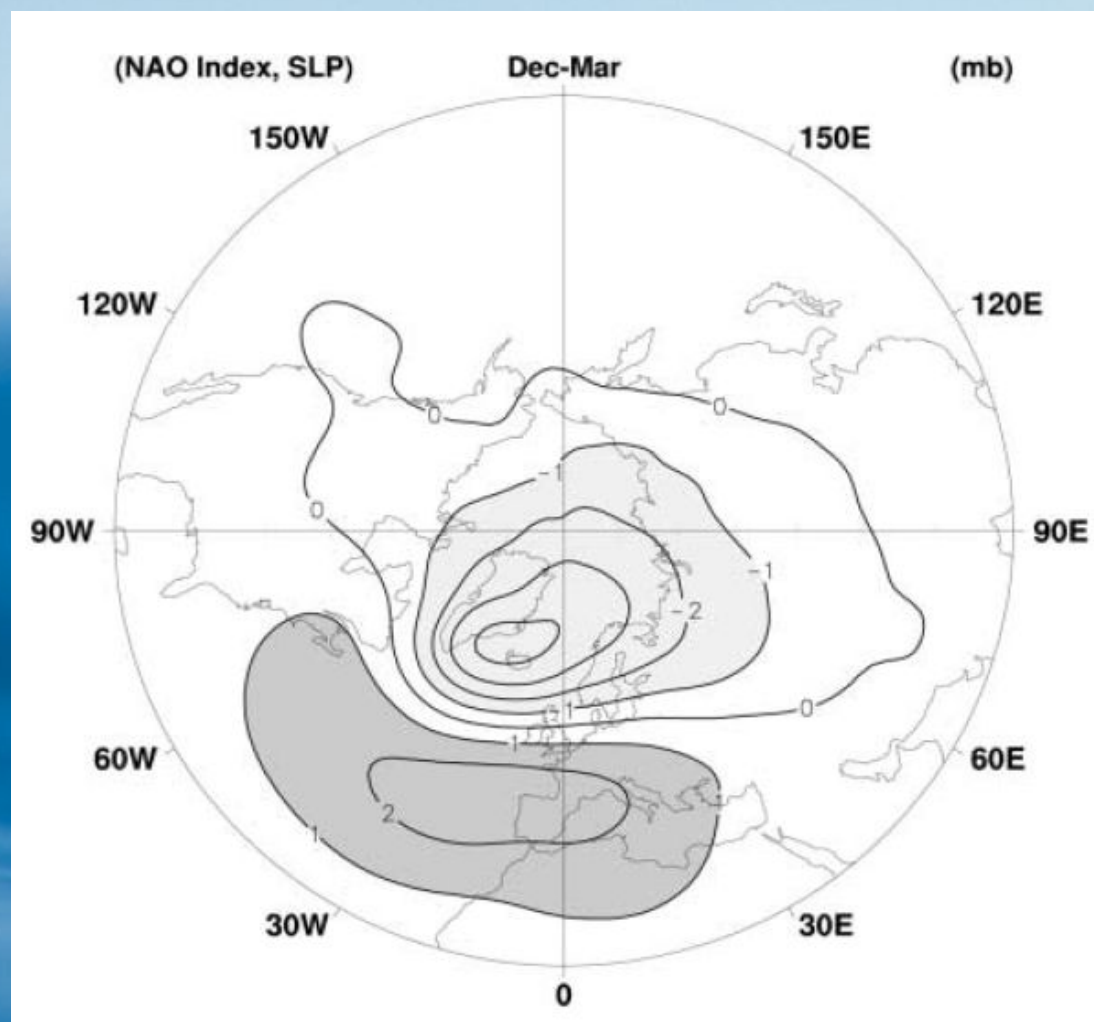


One of the EOFs seem related to Eastern boundary SST anomalies with the Lunar tidal cycle of 18.6 years (top).

The other (bottom) seems to be mirroring AMO with a 13 year time lag. The bottom figure consists of (a) Spatial correlation between the PDO and the time-lag regression on the AMO index. (b) Spatial structure of the time-lag correlation on the AMO index at lag of 13 years



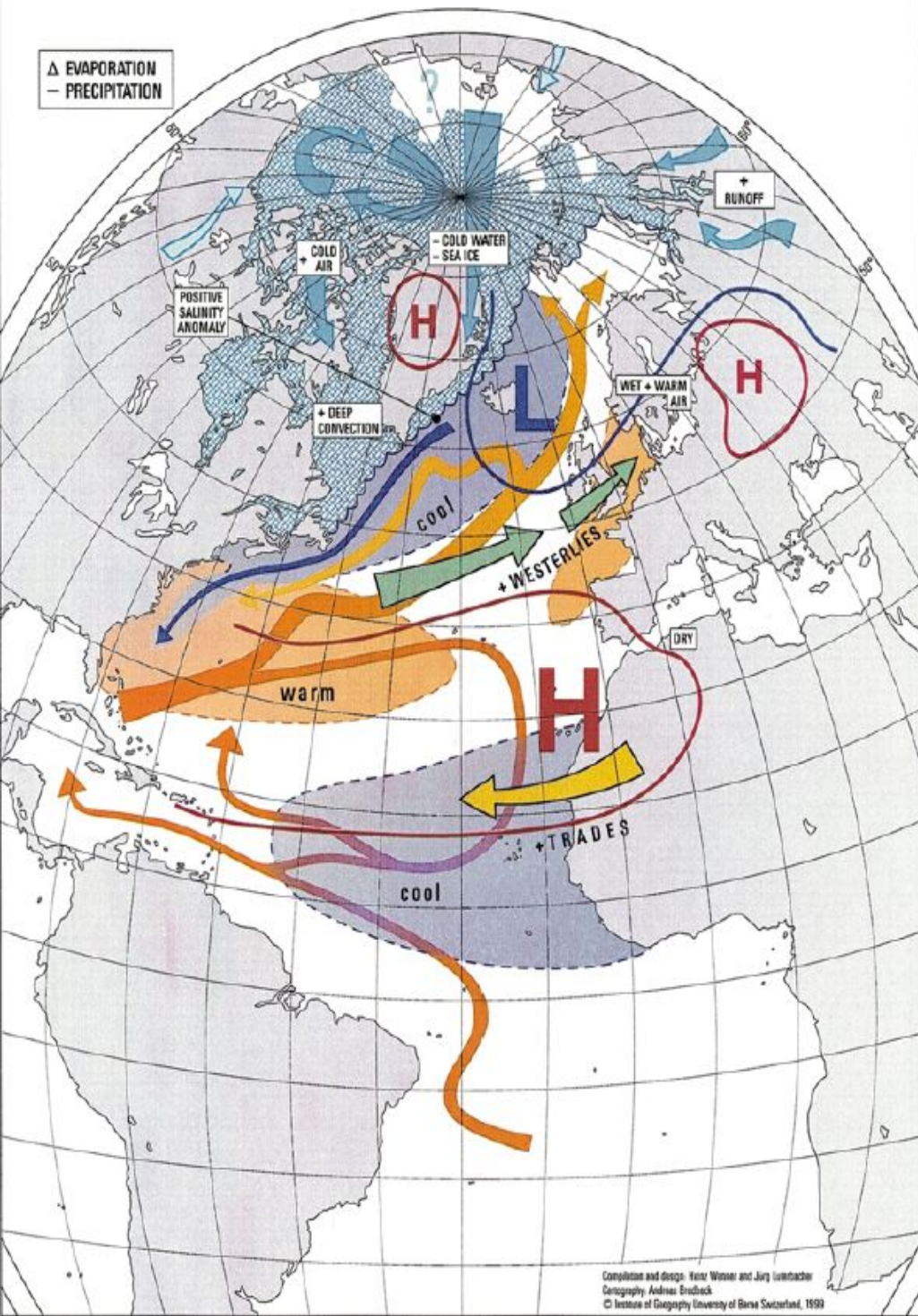
North Atlantic Oscillation (NAO)



Indeks NAO, zidentyfikowany przez Walkera (1924), najczęściej definiowany jako różnica ciśnień między Lizboną a Reykjavikiem (na rysunku sytuacja dodatniego NAO). Indeks ten tłumaczy 31% zróżnicowania zimowych temperatur na północ od 20° N.

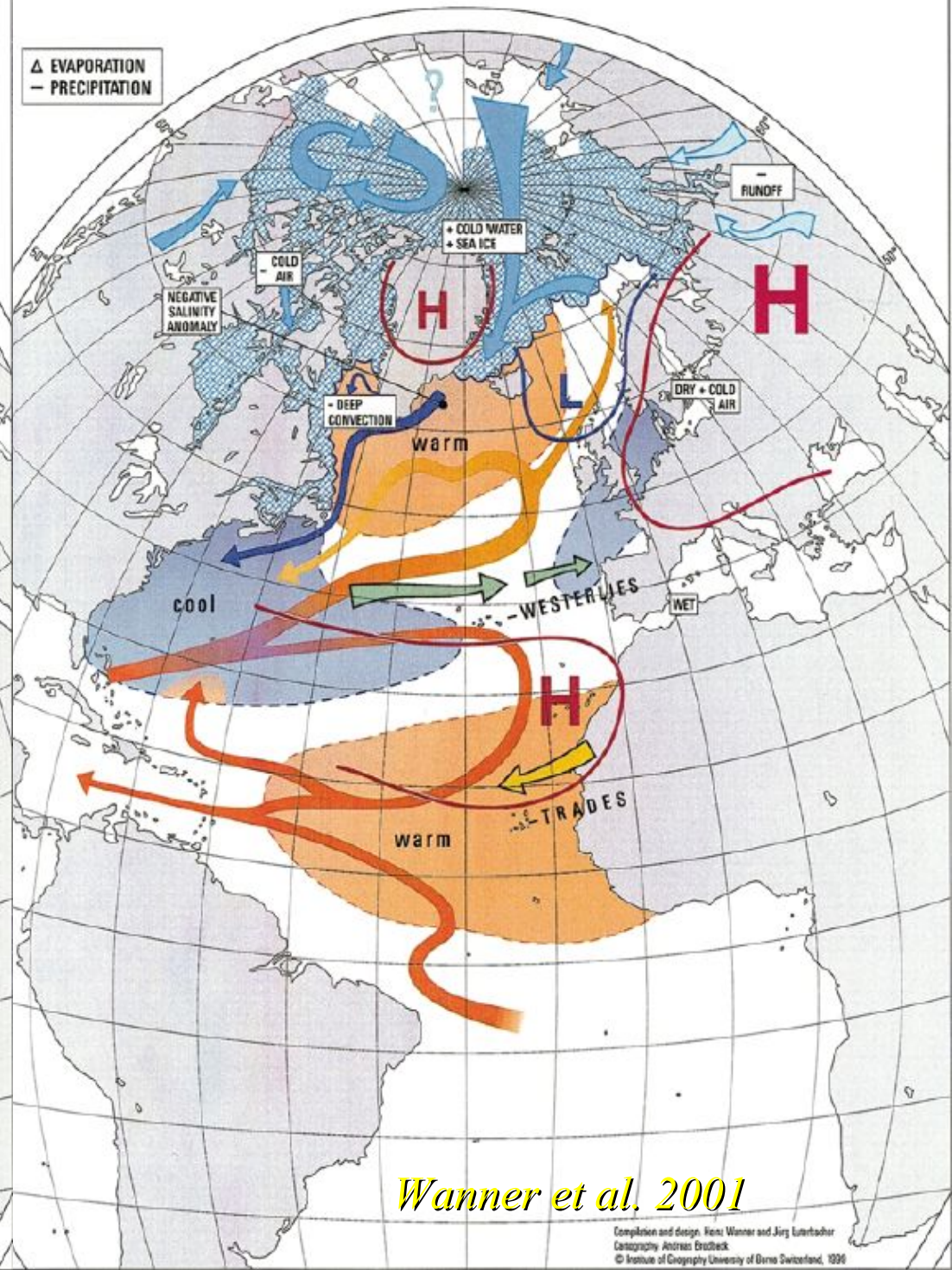
NAO +

Δ EVAPORATION
- PRECIPITATION



NAO -

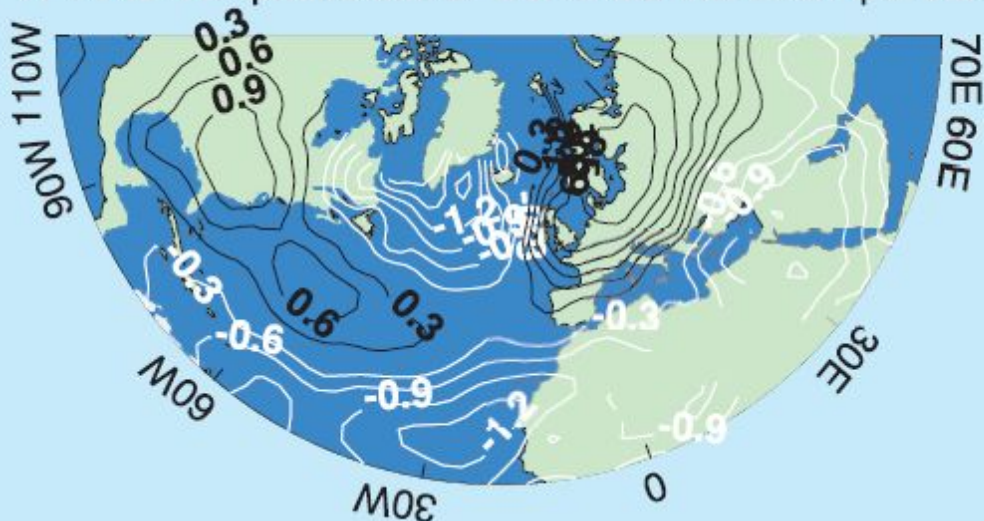
Δ EVAPORATION
- PRECIPITATION



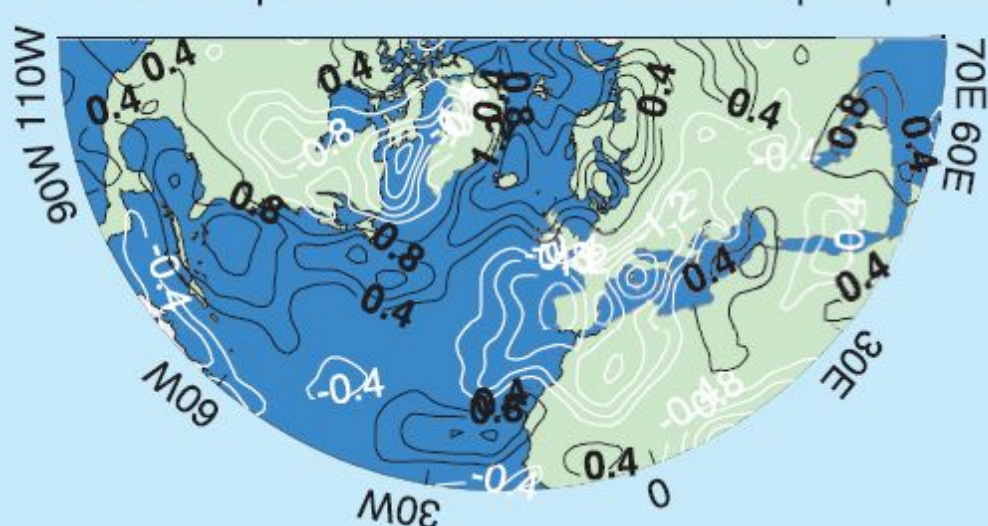
Wanner et al. 2001

Jak NAO wpływa na pogodę wokół Atlantyku?

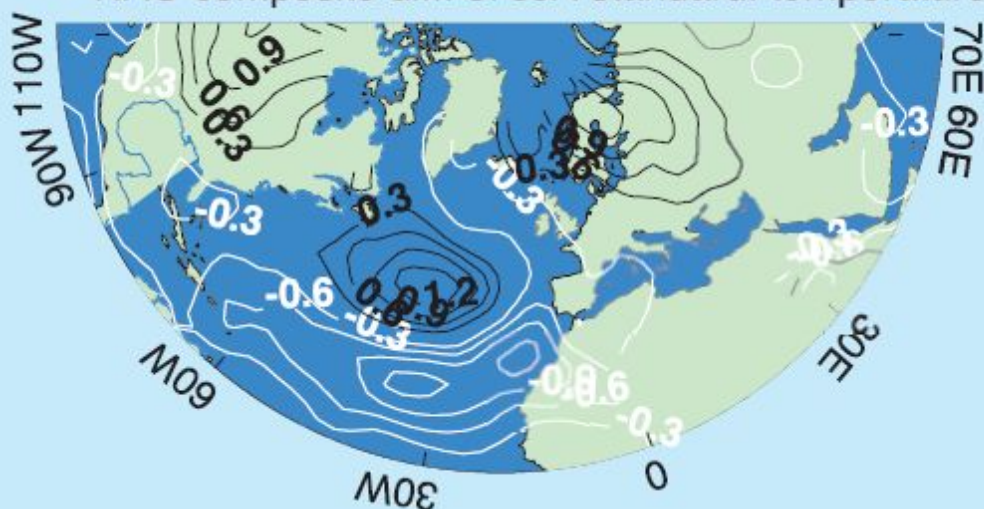
A NAO composite diff. of DJFM standard. temperature



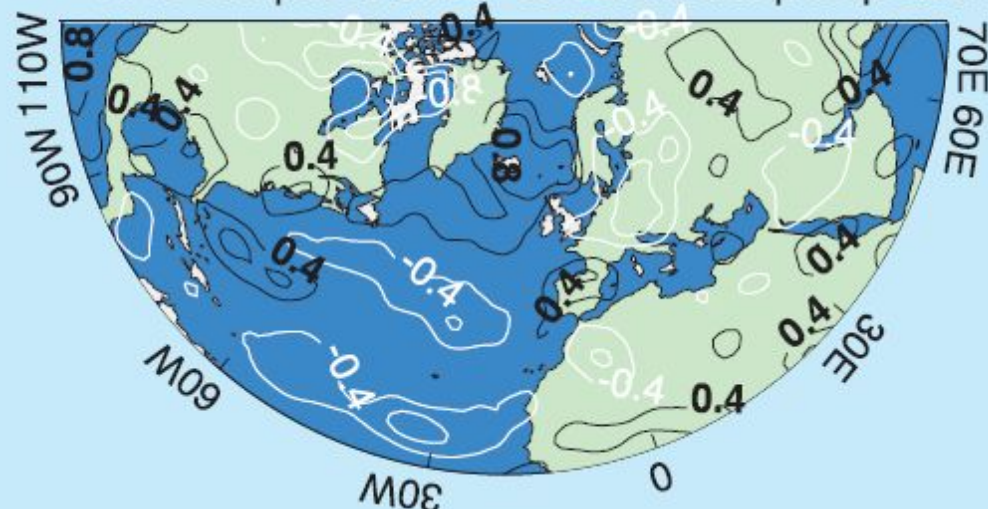
C NAO composite diff. of DJFM standard. precipitation



B NAO composite diff. of JJA standard. temperature

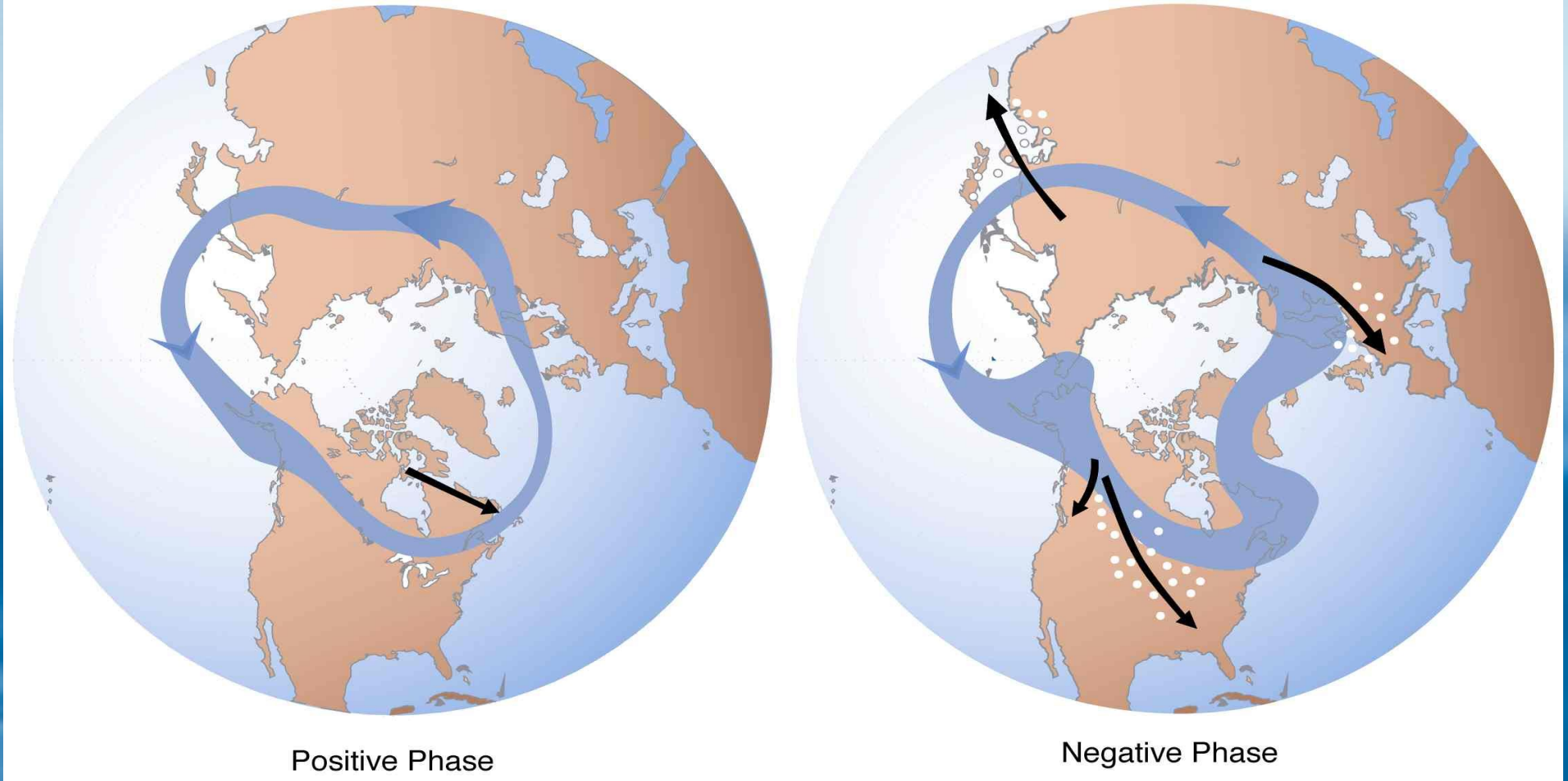


D NAO composite diff. of JJA standard. precipitation



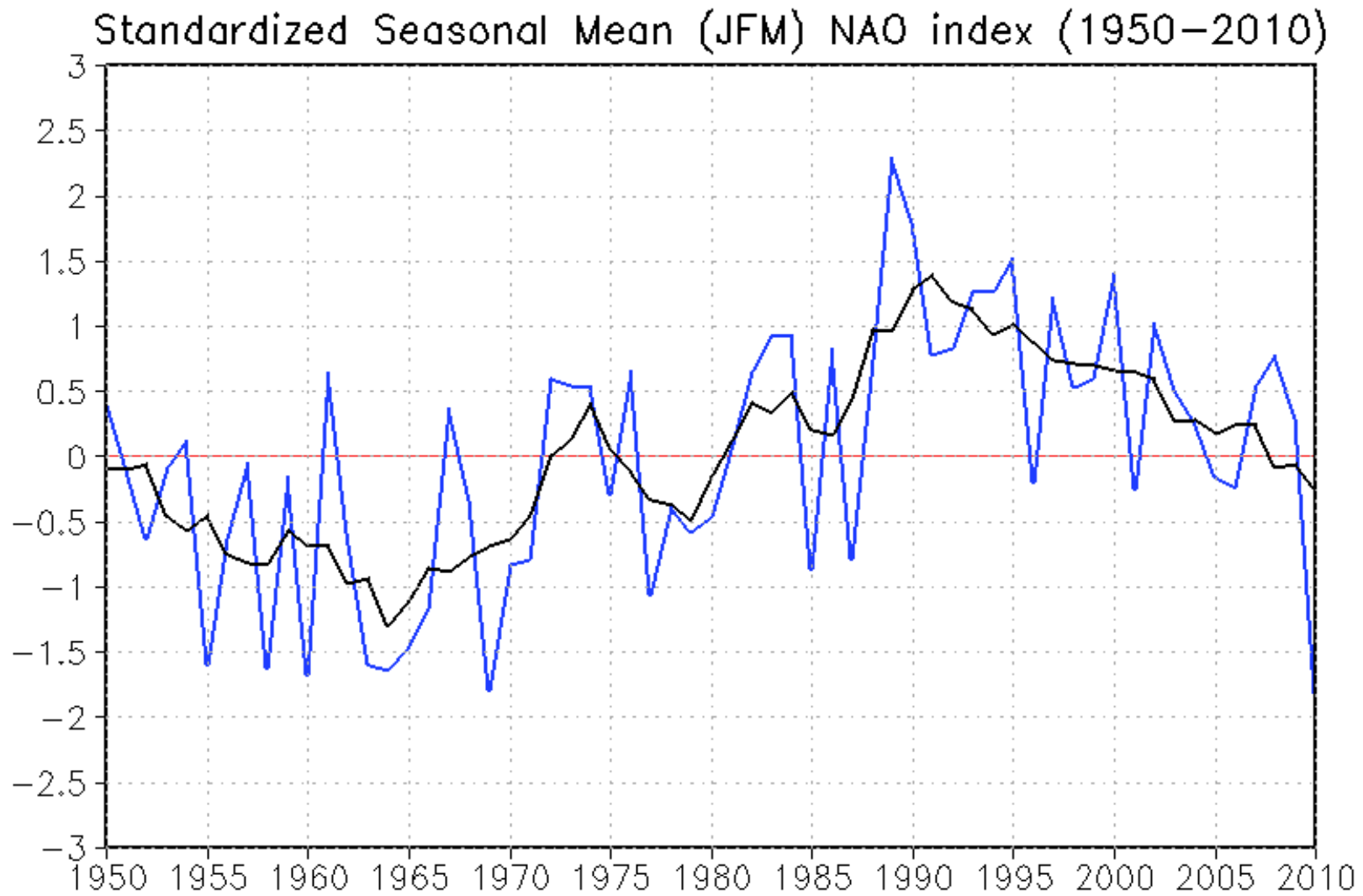
Odchylenie wartości temperatury (lewe panele) i opadów (prawe) w stosunku do średniej wielorocznej zimą (góra) i latem(dół) – różnica między dodatnimi i ujemnymi NAO.

Wartość Arctic Oscillation (AO) i zasięg niżów



Innym indeksem wysoce skorelowanym z NAO jest Arctic Oscillation – różnica ciśnienia między szerokościami 37° - 45° N a polarnymi, a zatem miara intensywności niżu polarnego. Przy ujemnych wartościach AO (czyli zazwyczaj i NAO) front polarny (*“jet stream”*) odsuwa się od bieguna sprawiając, że trasy niżów, a zatem i strefy opadów przesuwają się na południe.

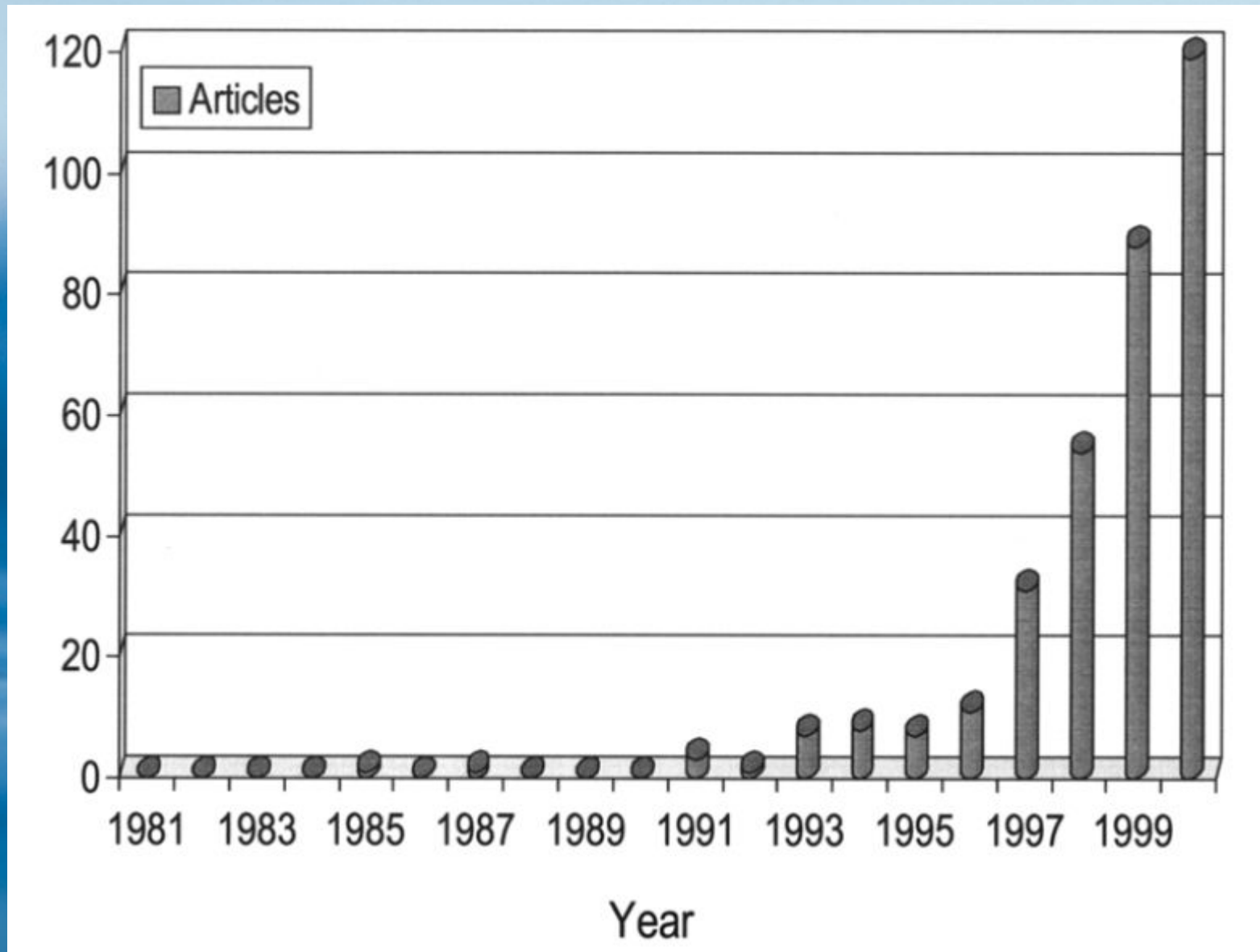
Zimowe wartości indeksu NAO od 1950



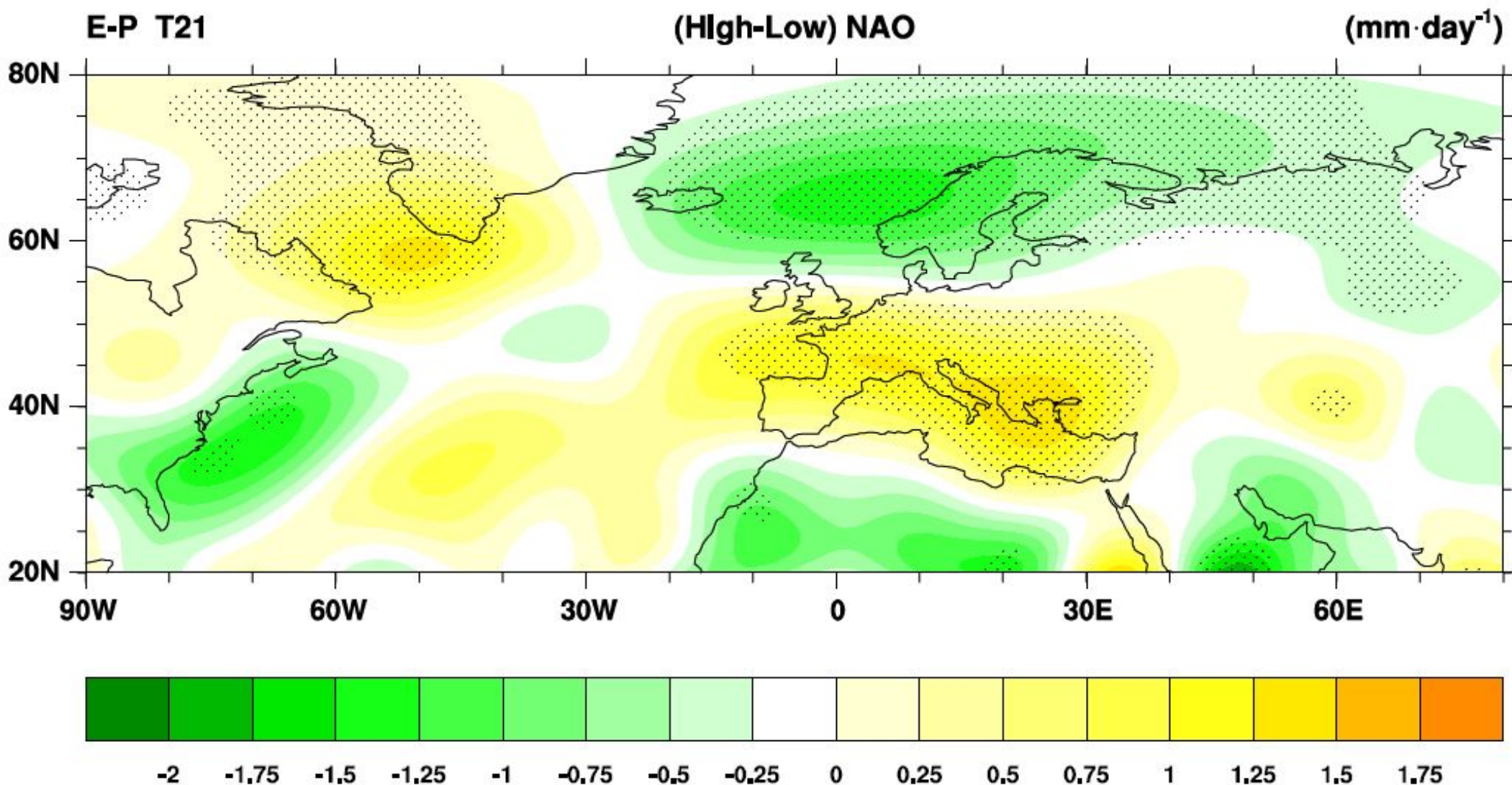
Zwraca uwagę okres niskich wartości w latach 60-tych i wysokich w 90-tych oraz malejąca wartość w ostatnich latach.

<http://www.cpc.ncep.noaa.gov/products/precip/CWlink/pna/season.JFM.nao.gif>

Ilość artykułów naukowych na temat NAO



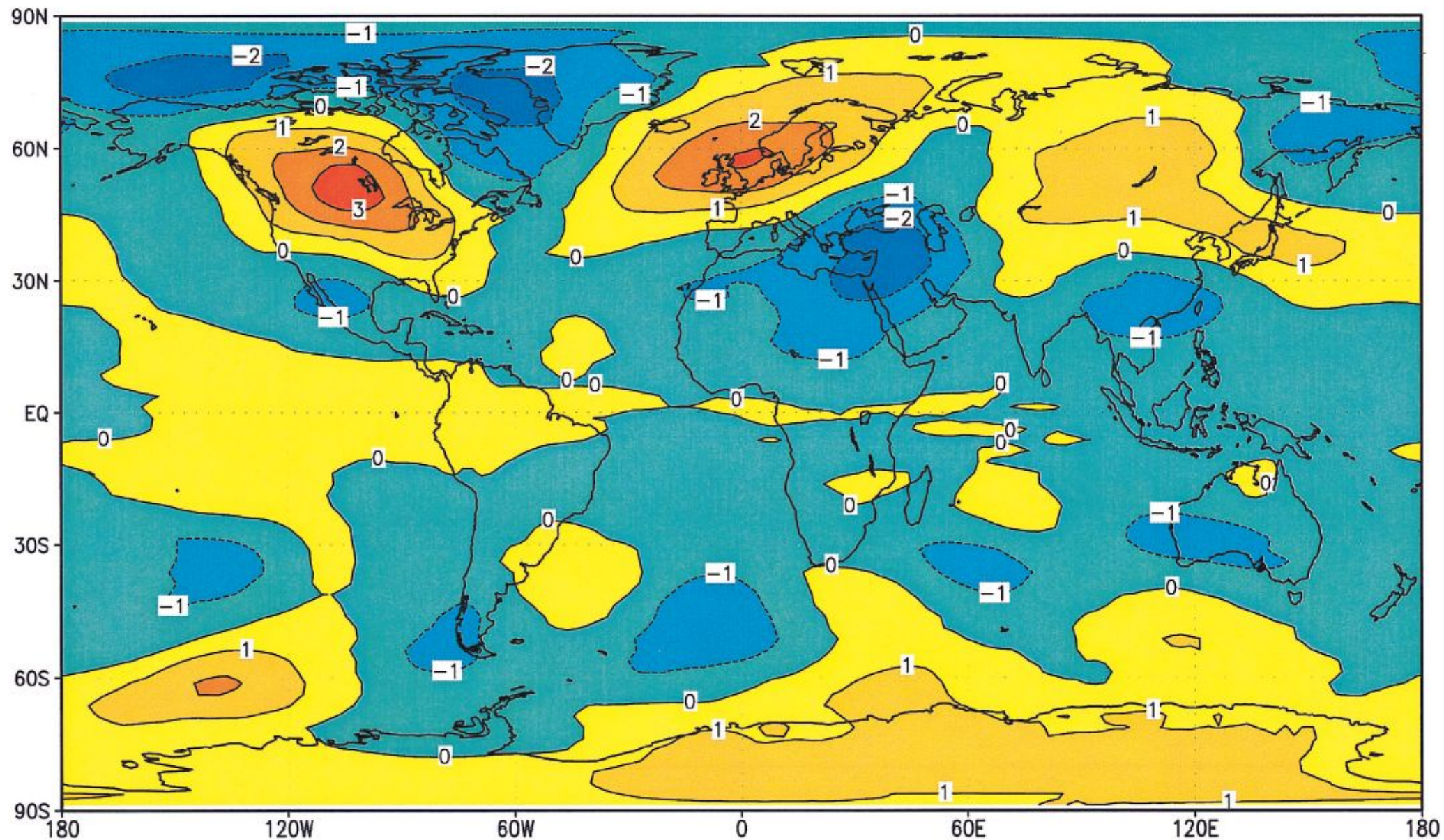
Wpływ NAO na opady



Anomalie opadów związane z zimowym indeksem NAO [mm/dzień]: średnia dla zim z dodatnim NAO minus średnia dla zim z ujemnym. Wygląd układu identyczny jak efekt wybuchu wulkanu na temperaturę zimą (uwaga: znak przy skali na dole ewidentnie pomyłony!)

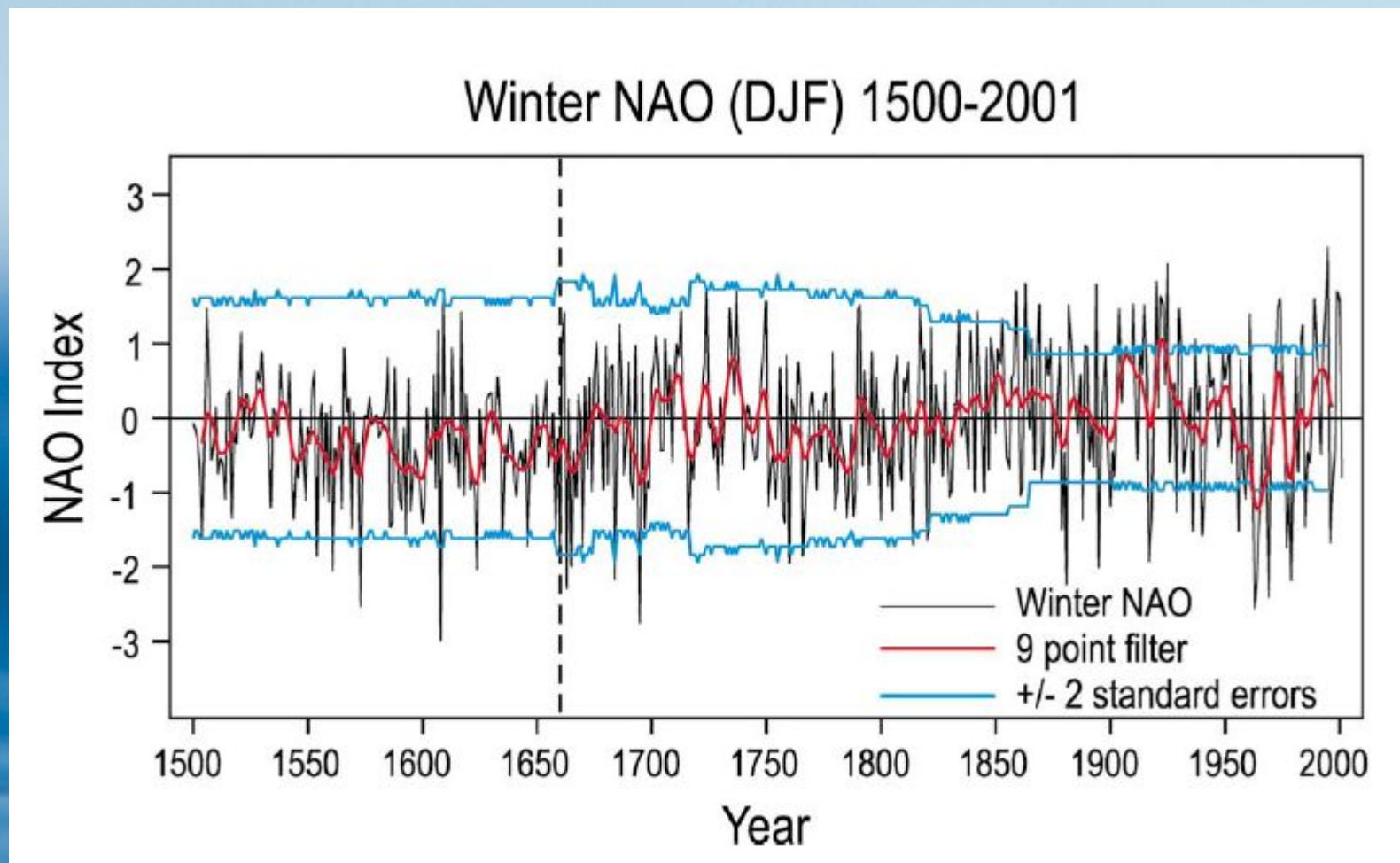
Za Hurrell 1995 (Science)

Przypomnienie: anomalie temperatury zimą po Pinatubo



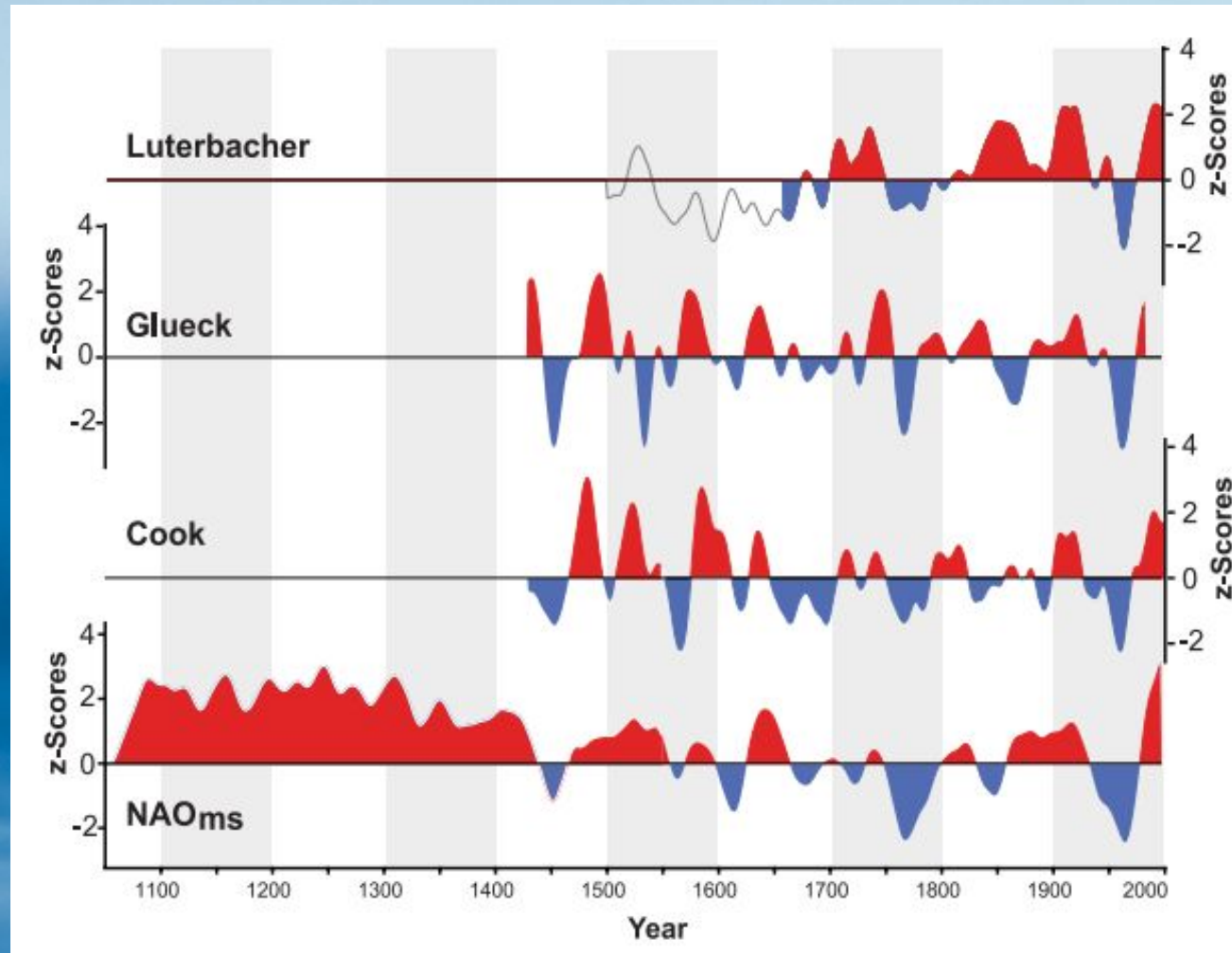
Po wybuchu wulkanów tropikalnego pierwsza zima typowo jest ciepła m. in. w Pn. Europie a zimny na Bliskim Wschodzie.

Przypomnienie: wartości NAO w ciągu ostatnich 500 lat



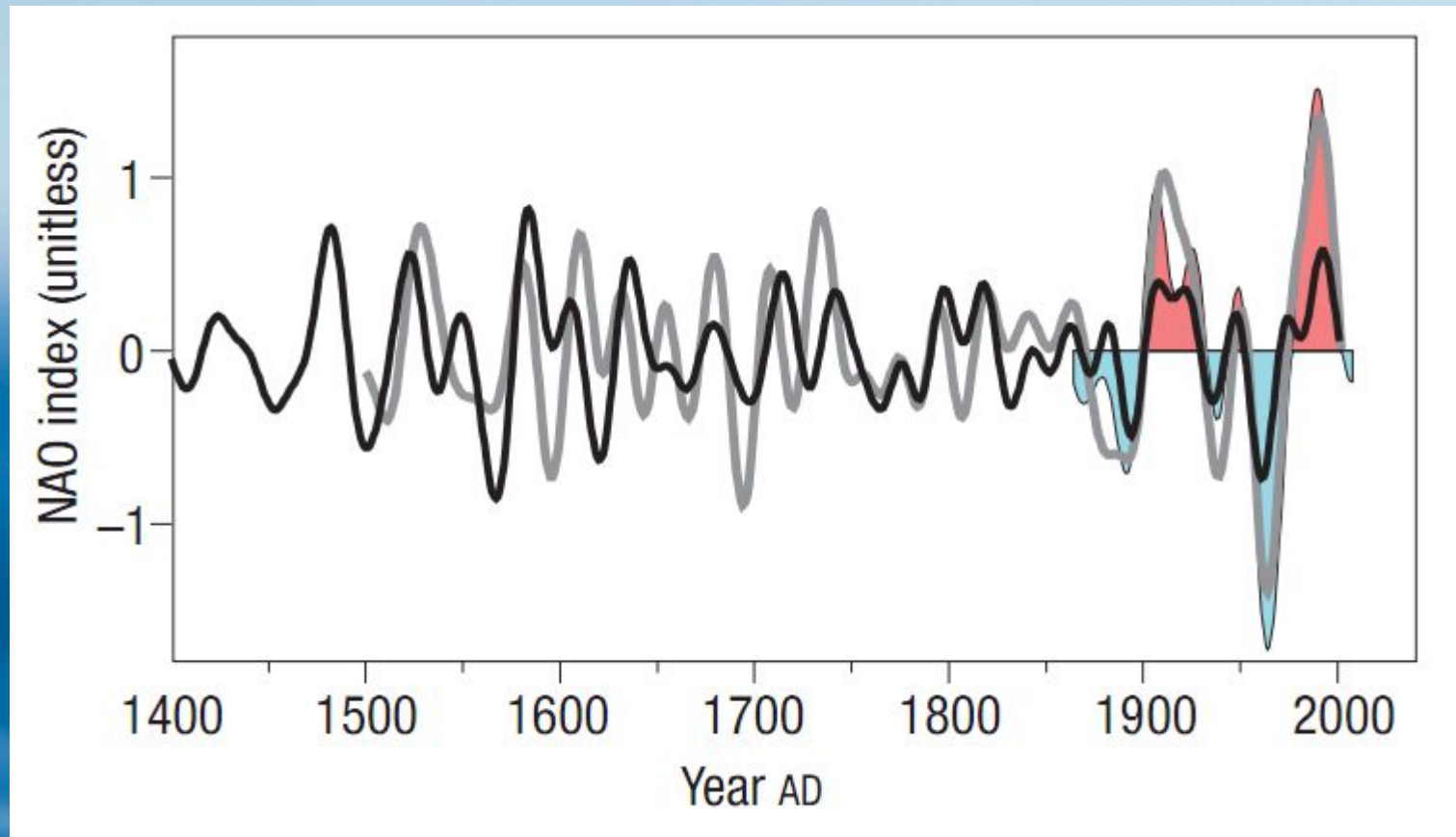
Indeks NAO jest wysoki gdy produkcja wód głębinowych (THC) jest wysoka (i odwrotnie). Co jest przyczyną? NAO, THC czy aktywność słońca. Zatem dlaczego przez ostatnie kilkadziesiąt lat THC malała gdy NAO rósł? Odpowiedź: malała tylko na Morzach Nordyckich.

Nieustające dodatnie NAO w czasie „ciepłego średniowiecza”?



Rekonstrukcja indeksu NAO na podstawie wartości izotopowych stalaktytów ze Szkocji i słoï drzew z Maroka (czyli opadów w rejonach zależnych od znaku NAO) świadczy o istnieniu okresu około 300 lat (1100-1400 n.e.) z nieustająco dodatnim indeksem NAO.

Zmienność NAO silniejsza w „okresie przemysłowym”?



Rekonstrukcja indeksu NAO na podstawie wartości izotopowych koralu z Bermudów (jakkolwiek ryzykowna!) pokazuje zwiększoną amplitudę zmian NAO od późnego XIX wieku. Nawet jeśli autorzy mierzyli bardziej AMO niż NAO jest to ciekawy wynik.

Timm 2008 using data of Goodkin et al 2008 (Nature Geoscience)

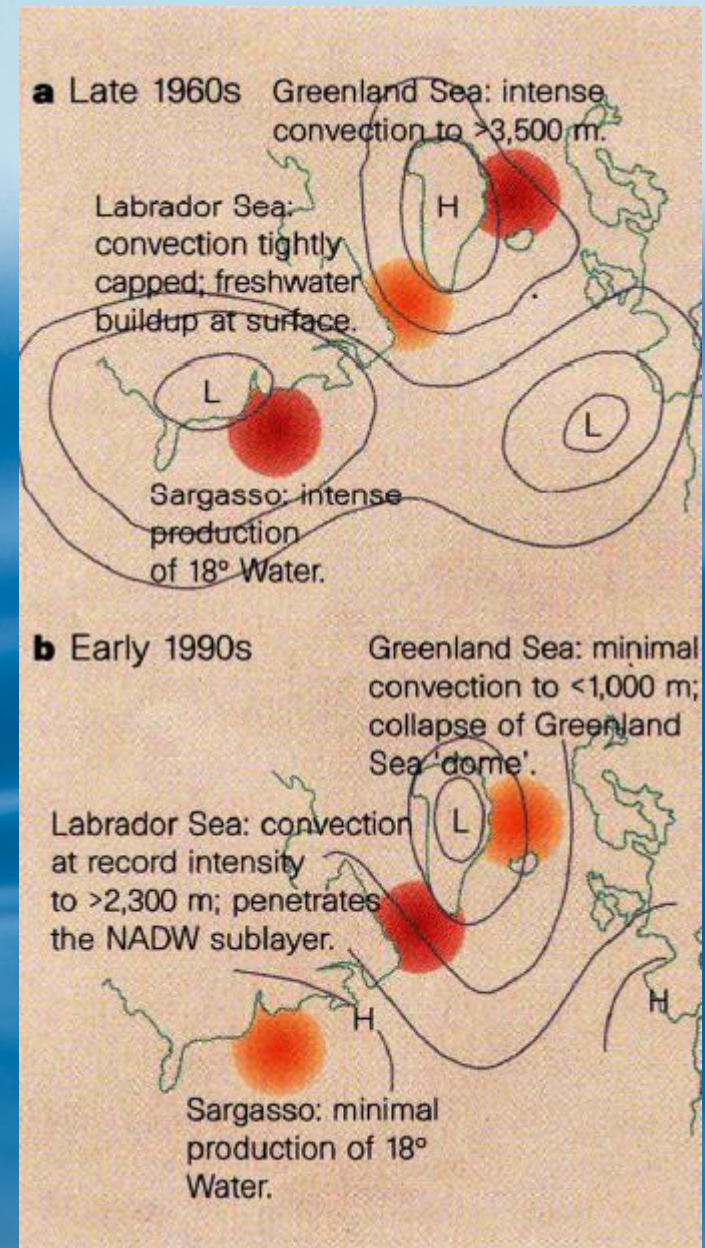
Zmiany w produkcji wód głębinowych

Zmienność NAO wpływa na miejsce (i zapewne ilość) produkowanych wód głębinowych.

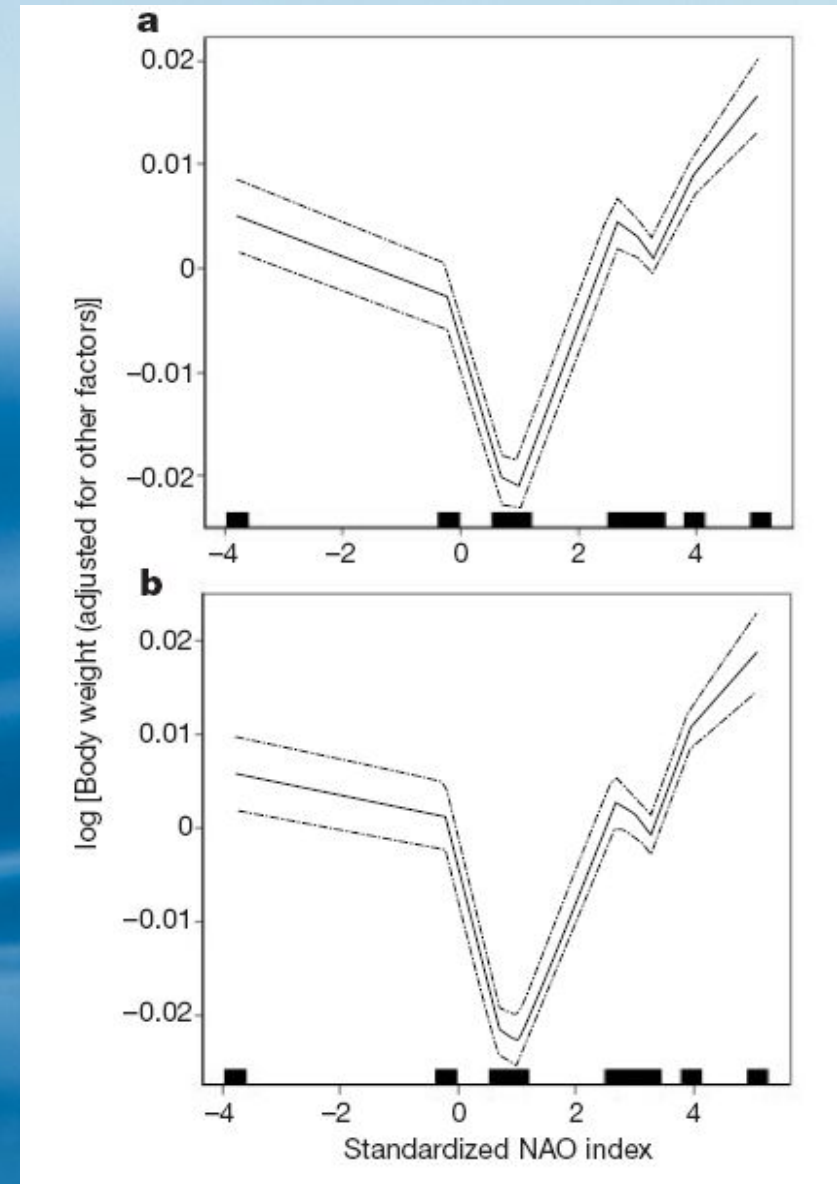
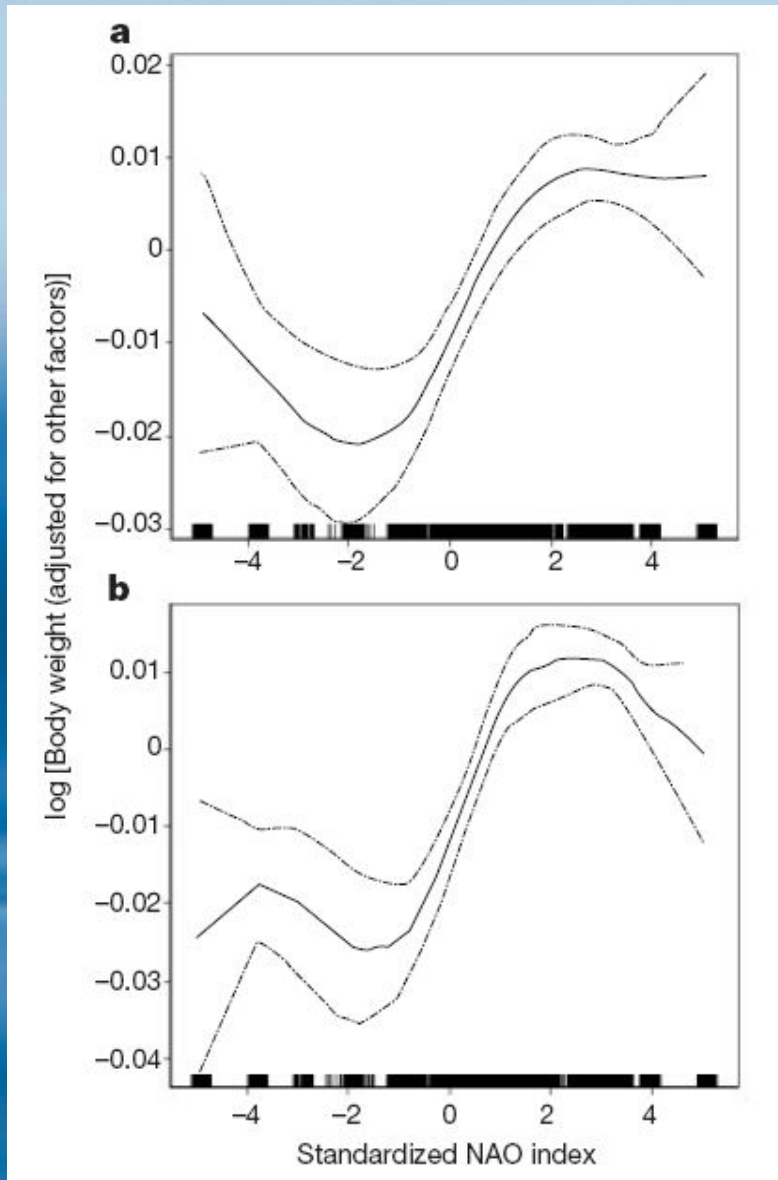
Przy ujemnych wartościach NAO (lata 60-te) zmalała produkcja wód głębinowych na Morzu Labradorskim a zwiększyła się na Morzach Nordyckich.

Przy dodatnim NAO (lata 90-te) zaszło zjawisko odwrotne.

Zmiana ta tłumaczy zmniejszenie się przepływu wód głębinowych z Mórza Nordyckiego do właściwego Atlantyku od lat 60-tych.



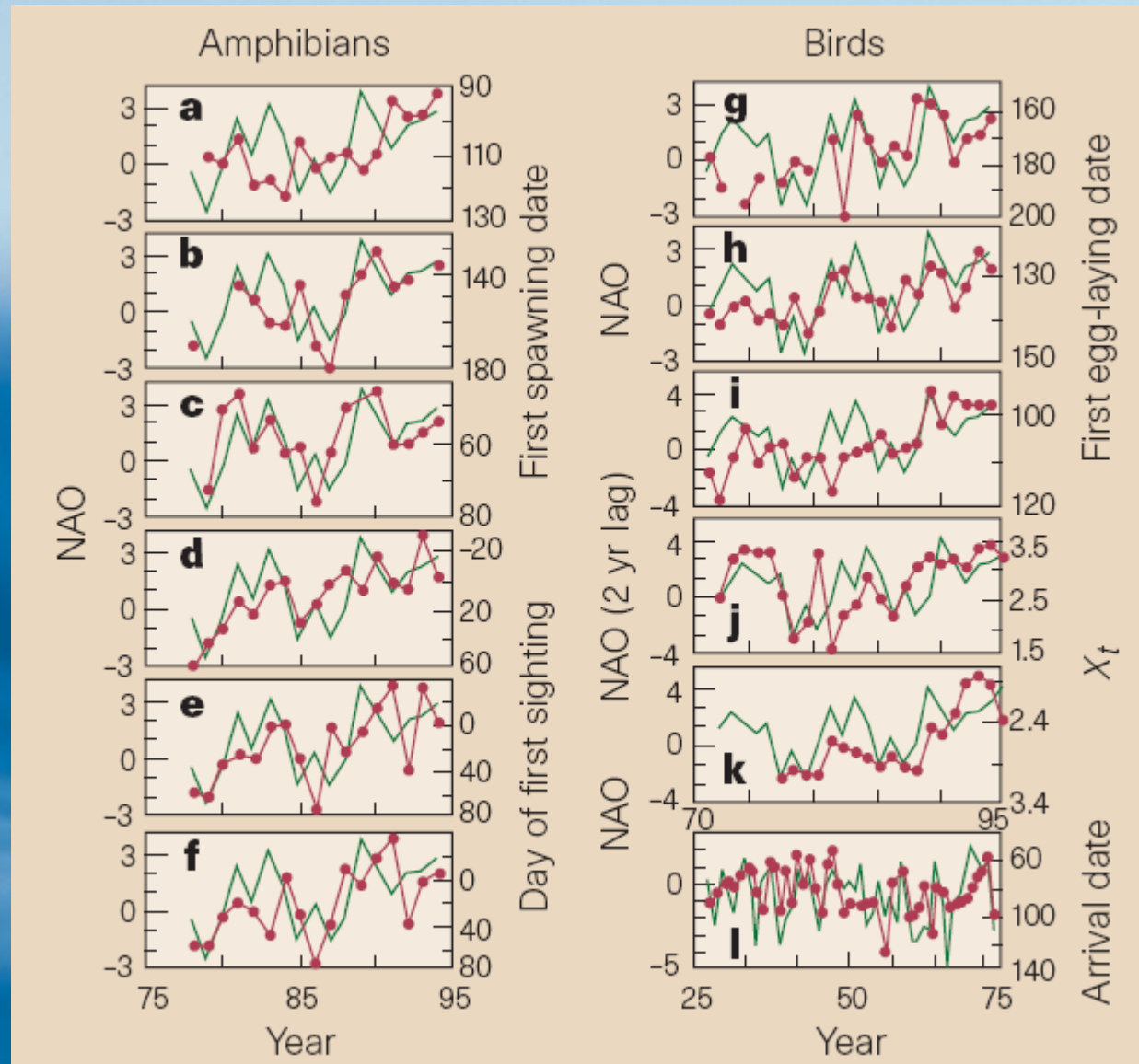
Wpływ NAO na przyrodę Europy: przykład pierwszy



Wpływ wartości NAO na wagę samic (górną) i samców (dolną) skandynawskich jeleni (lewa) i owiec (prawa).

Myrsterud et al. 2001 (Nature)

Wpływ NAO na przyrodę Europy: przykład drugi



Wpływ wartości NAO na datę składania jaj przez płazy (lewe) i ptaki brytyjskie – *uwaga skala dni odwrócona*.

Forchhammer et al. 1998 (Nature)

Podsumowanie 2/3

- Temperatura i opady zimą w Europie zdeterminowane są głównie wartością indeksu NAO. Dla całej półkuli północnej tłumaczy on ponad 30% zmienności klimatu.
- W czasie Małej Epoki Lodowej indeks ten był średnio ujemny. Czy w skutek małej objętości produkowanych wód głębinowych (THC)?
- Lata 60-te to okres ujemnych wartości NAO, 90-te dodatnich. W pierwszym tych okresów wody głębinowe produkowane były głównie na Morzu Labradorским a w drugim na Morzach Nordyckich.
- Ujemne NAO spowodowało tzw. Wielką Anomalię Zasolenia. Jednak zasolenie północnego Atlantyku maleje od lat 60-ych prawie stale (prawdopodobnie równolegle z napełnianiem Arktyki słonymi wodami Atlantyckimi).
- Indeks NAO zależy od temperatury wód Atlantyku z poprzedniego roku co daje szansę tworzenia wielomiesięcznych prognoz pogody Europy.

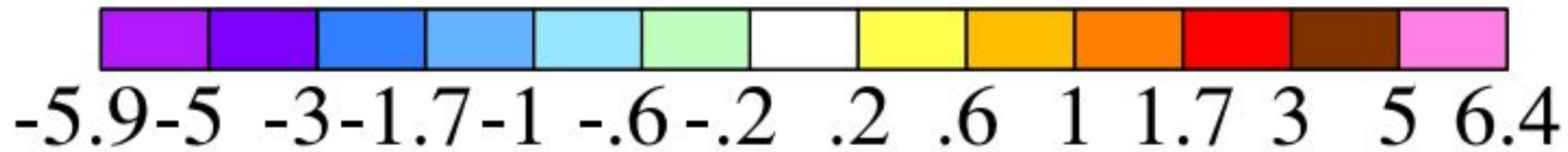
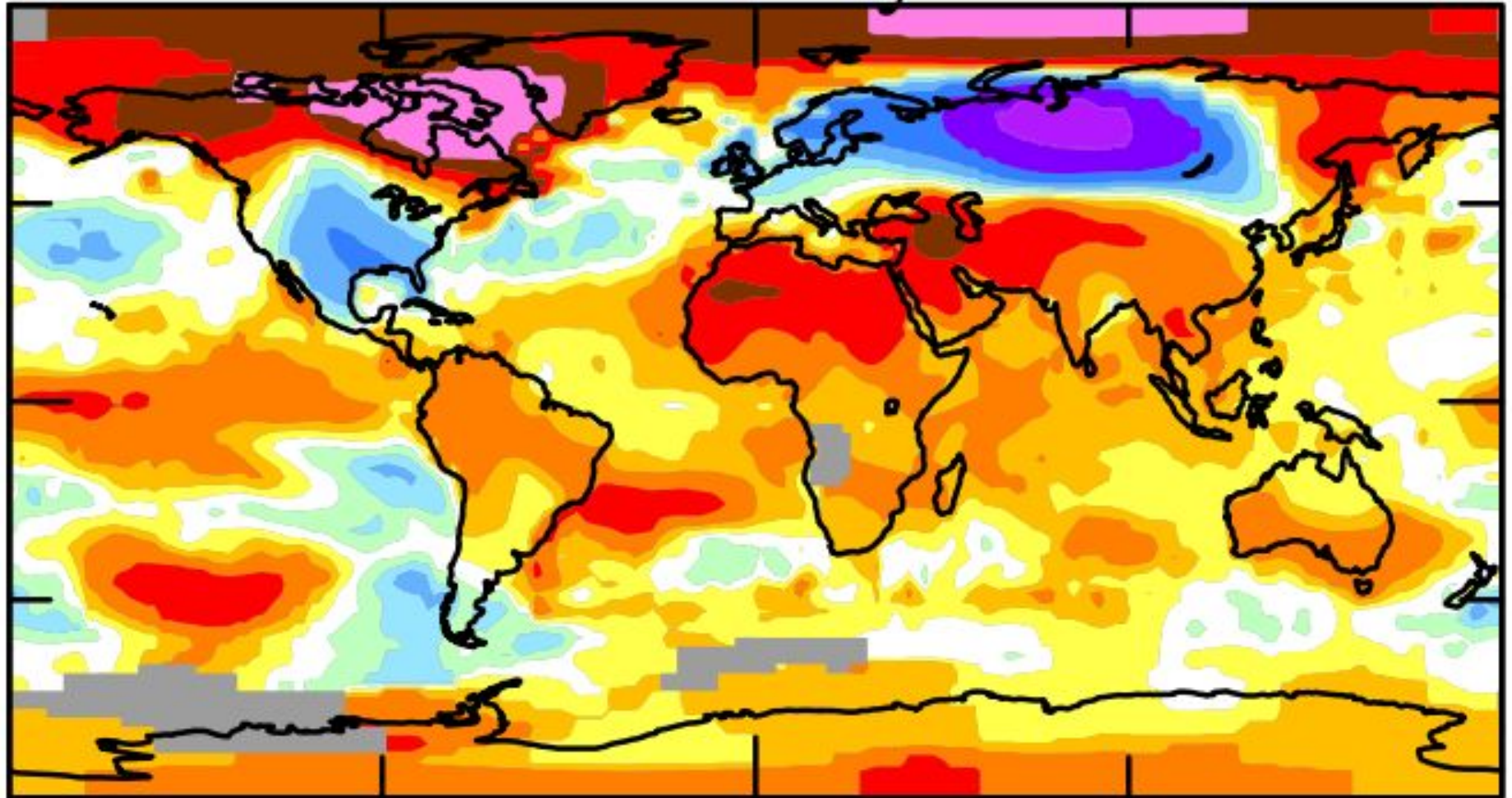


Jeleń szlachetny – jego jakość życia zależy od indeksu NAO?

N.H. Winter (Dec-Jan-Feb)

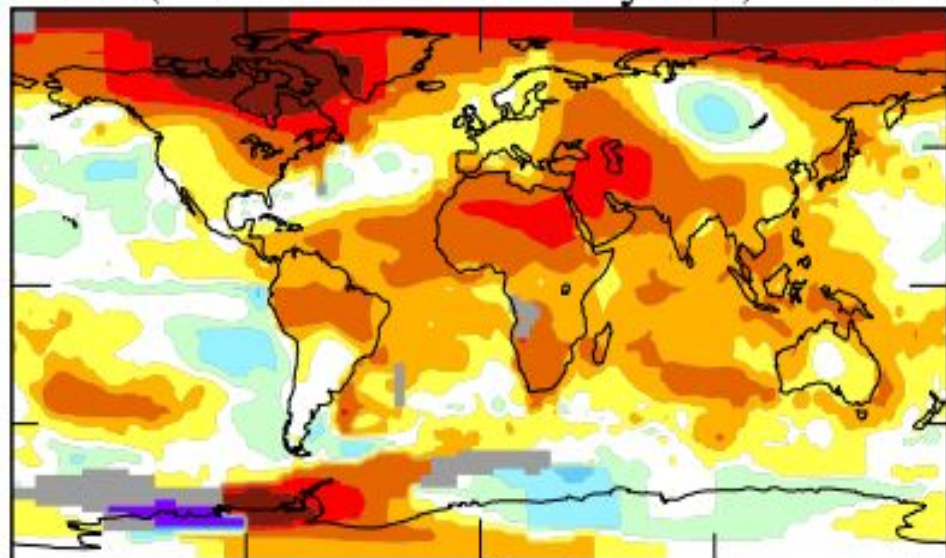
2nd warmest of 130 years 0.68

2010

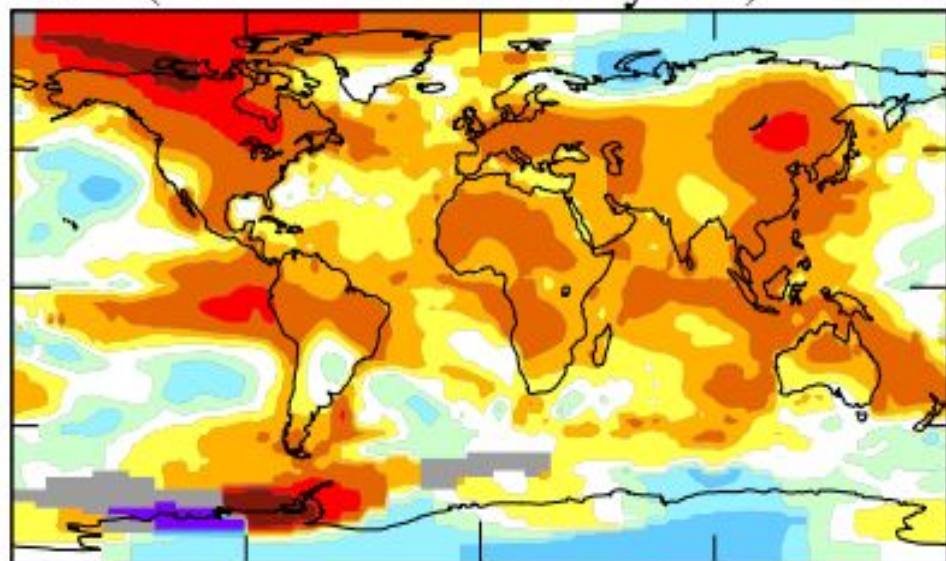


January-October Mean Surface Temperature Anomaly ($^{\circ}\text{C}$)

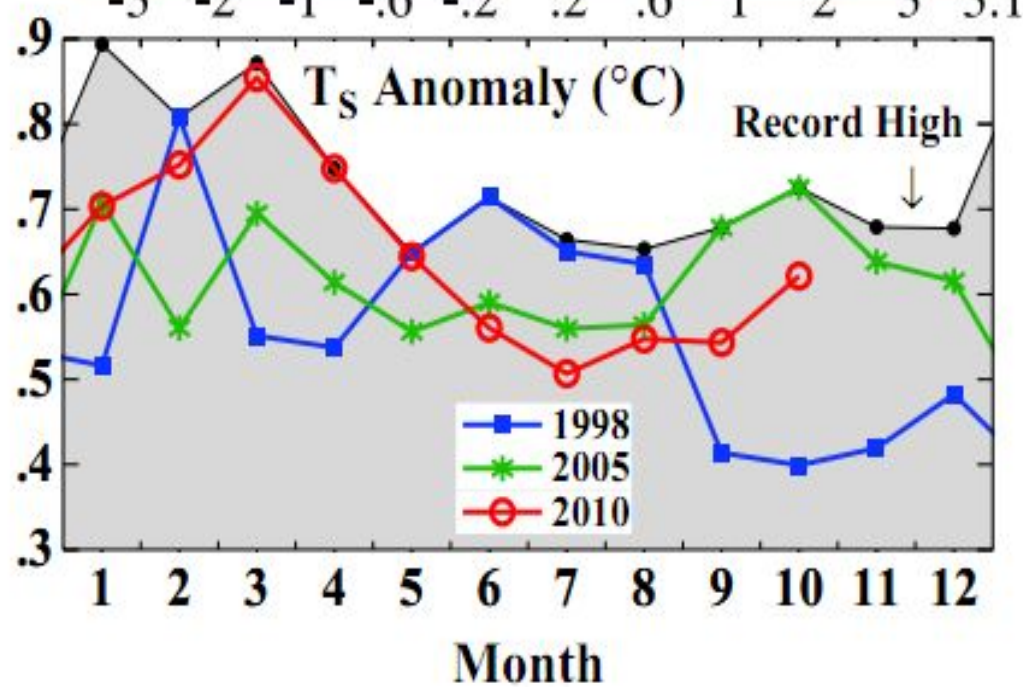
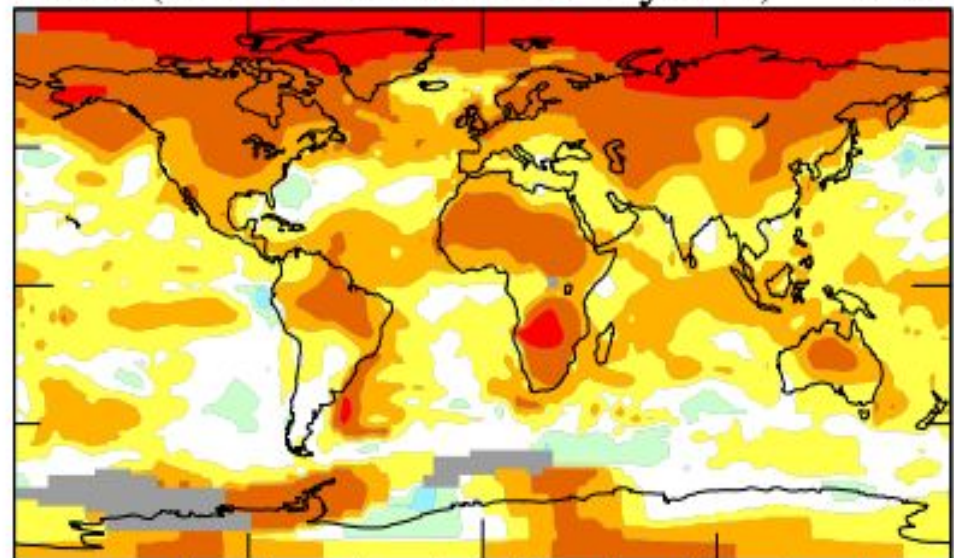
2010 (the warmest of 131 years) 0.65



1998 (4th warmest of 131 years) 0.59

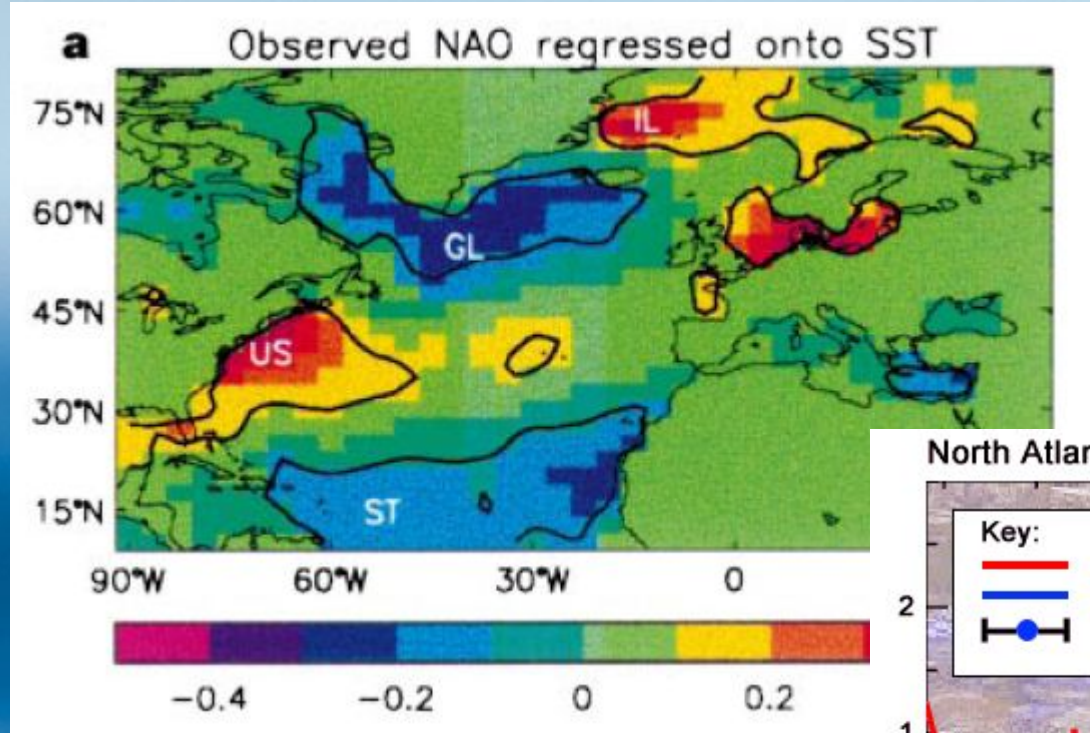


2005 (2nd warmest of 131 years) 0.62



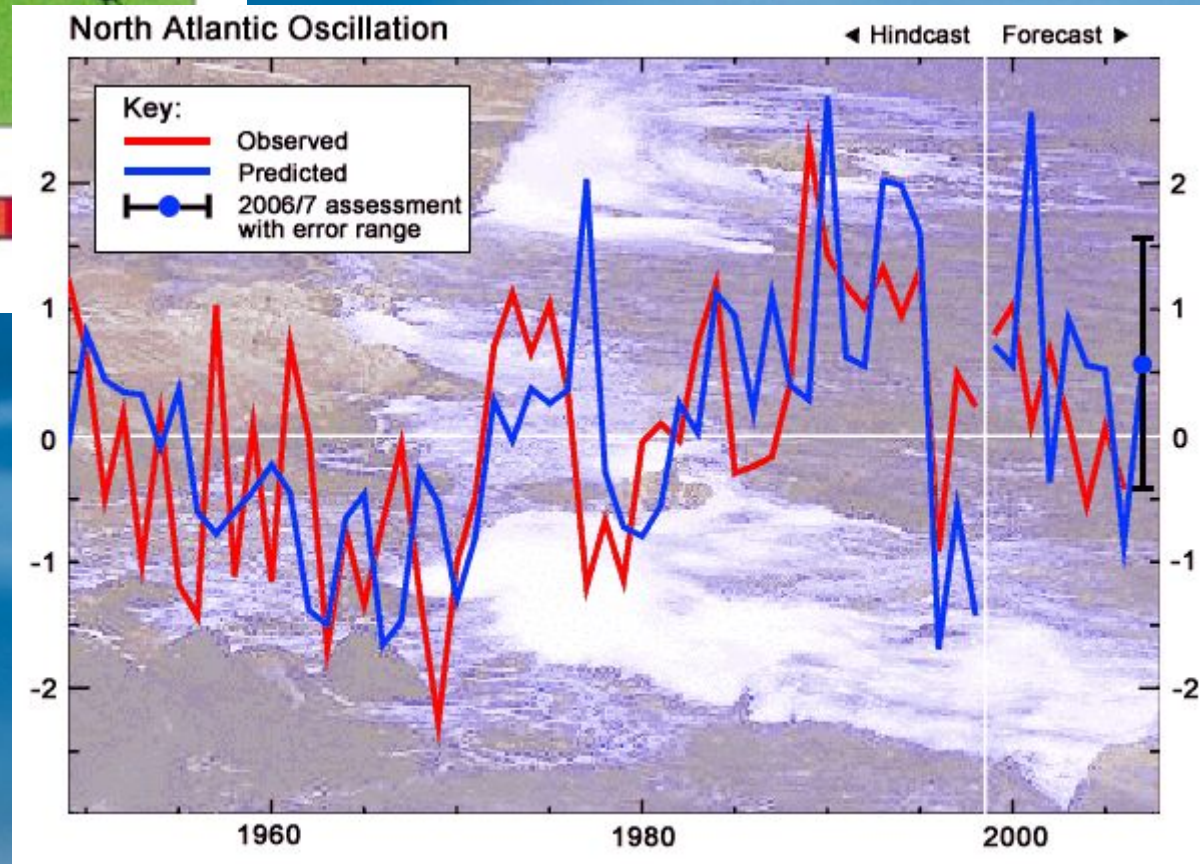
Base Period: 1951-1980

Can we predict NAO values?

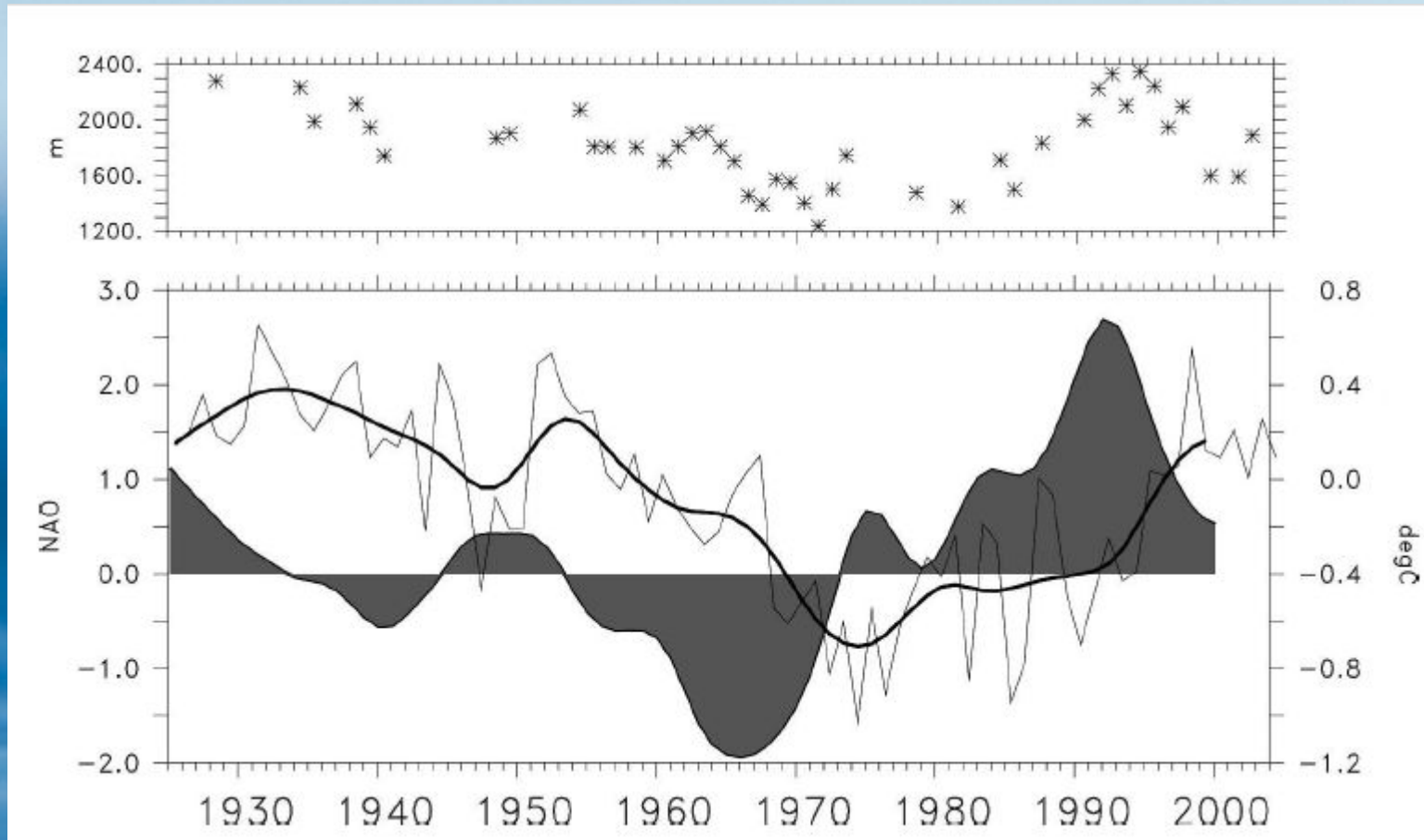


Correlations of summer ocean SST with NAO index of the following winter (Rodwell et al. 1999)

British Met Office has a hindcasting 2/3 successful prediction of winter NAO sign from North Atlantic SST of the previous summer.



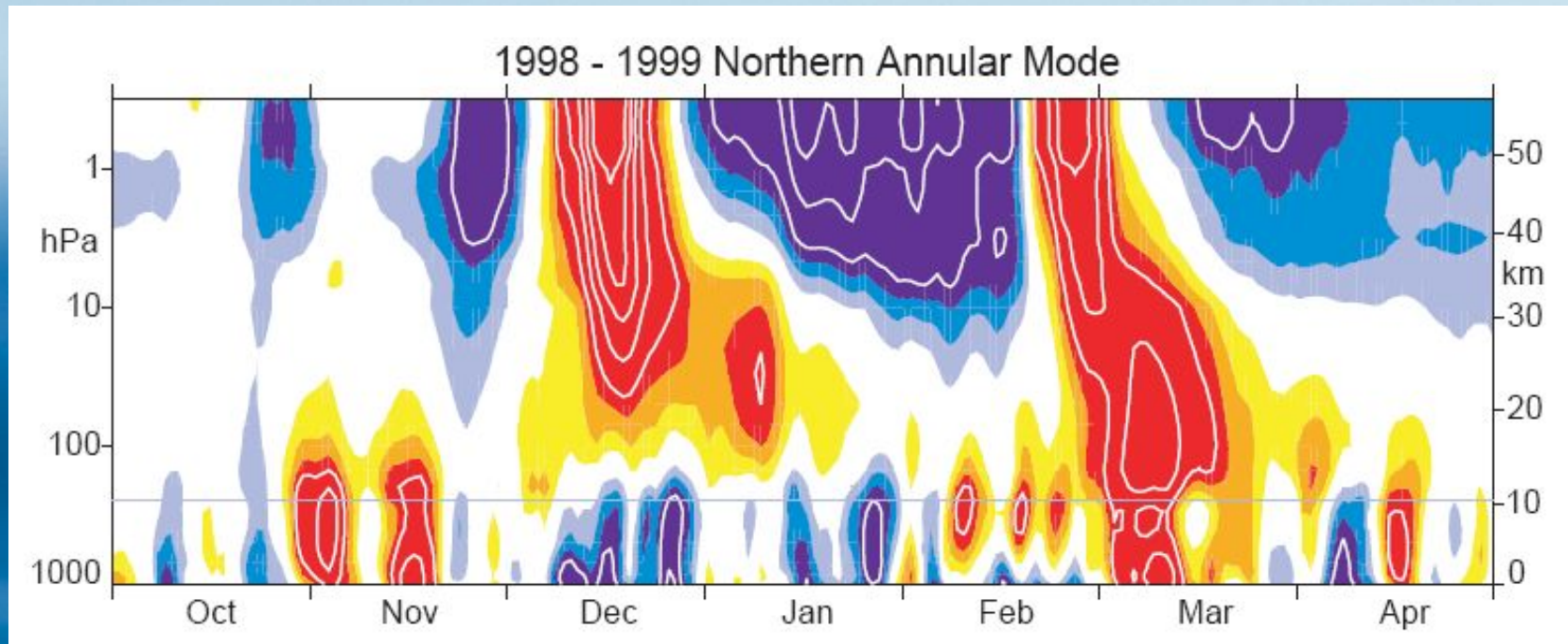
NAO leads THC by 10 years!



NAO index (shaded) seems to lead North Atlantic temperature (a simple measure of THC volume) by 10 years (thick line is a 11-year running mean). The mechanism explaining the phenomenon is supposed to be the NAO effect on Labrador Sea deep convection (top is Labrador Sea Water thickness in meters).

Latif et al. 2006 (Journal of Climate)

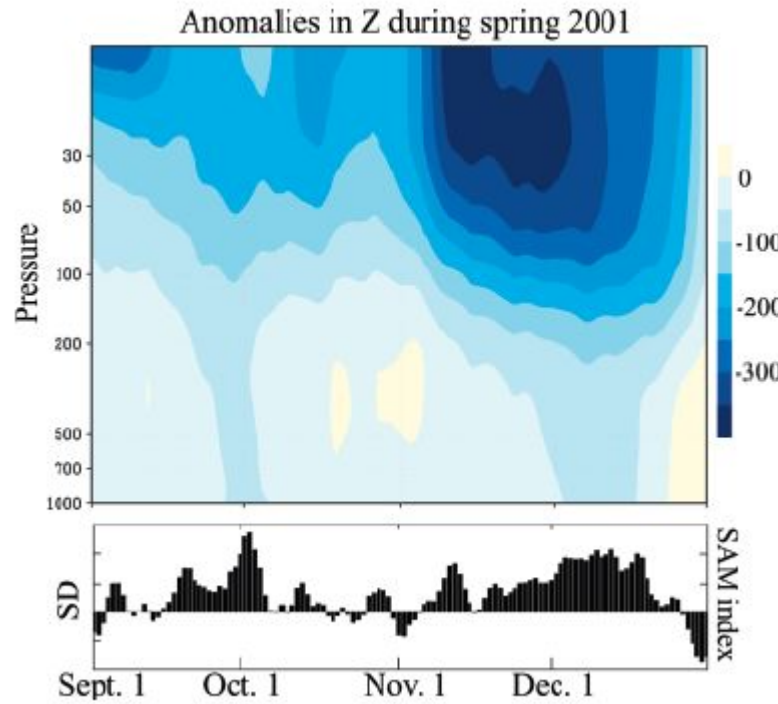
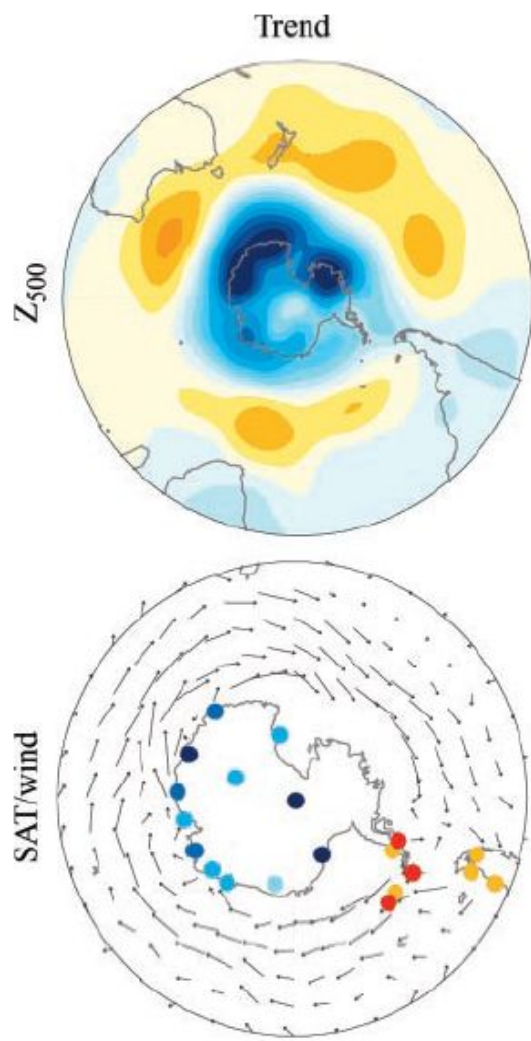
But then, NAO starts in the stratosphere



It seems NAO-like vortex circulation starts in the stratosphere and descends from the 50 km altitude within 60 days to the surface level.

Northern Annular Mode is another name of NAO / AO
(compare <http://ao.atmos.colostate.edu/introduction.html>).

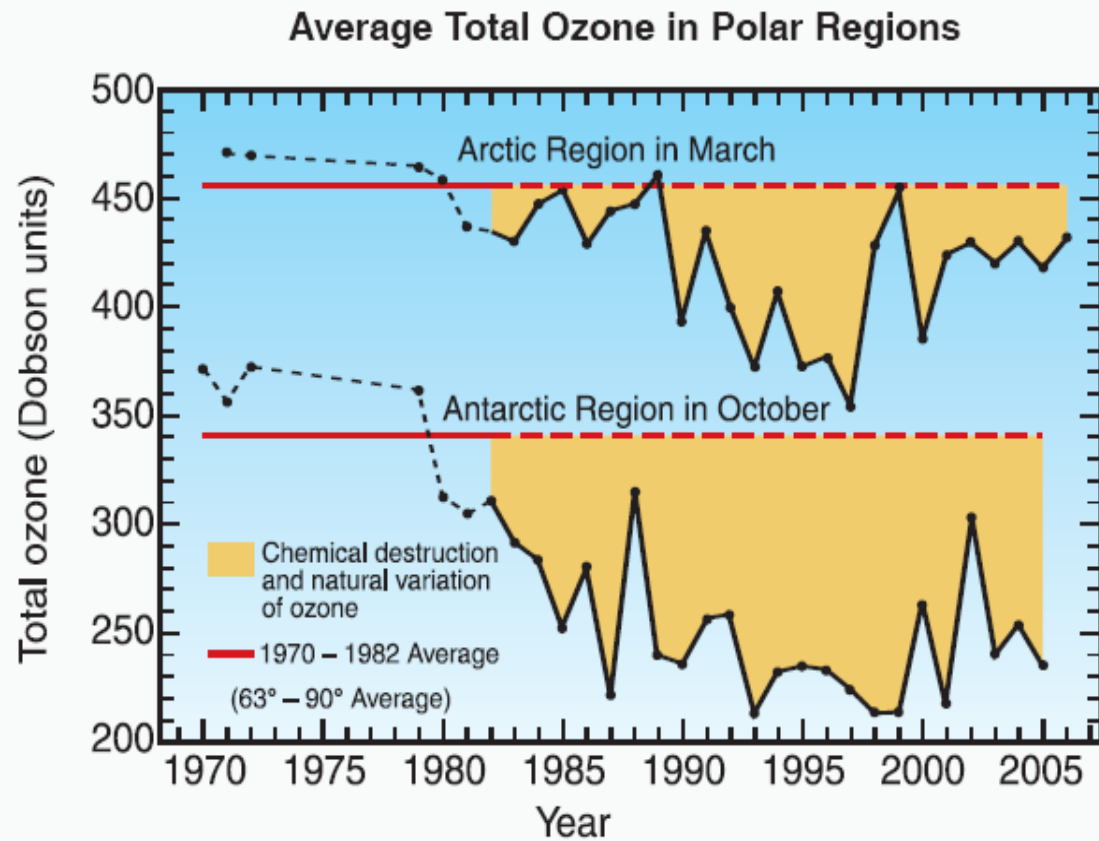
Ozone controls SAM („southern NAO”)?



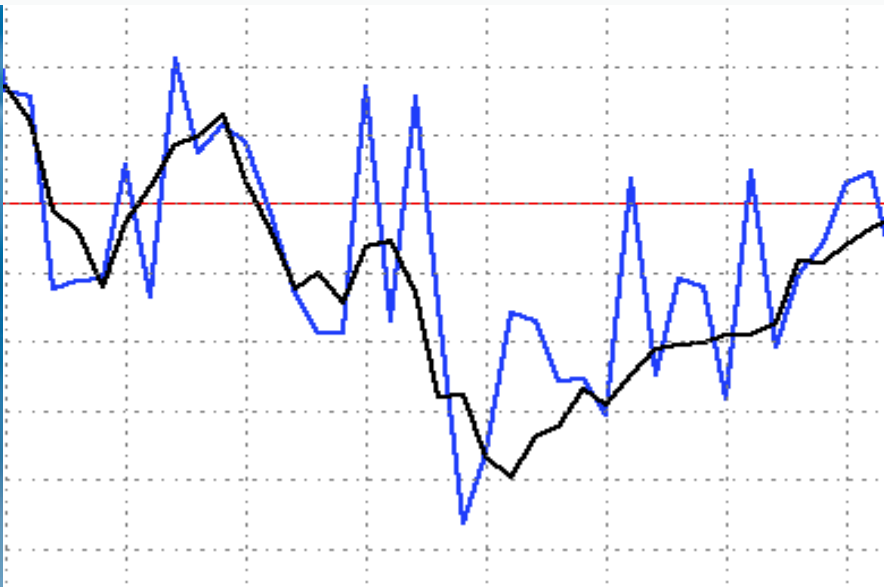
The trend (1979-2000) of deepening low pressure and the Antarctic vortex is consistent with observed increase of Southern Annual Mode (SAM – the southern counterpart of AO). This deepens the thermal isolation of the Antarctic. Anomalies of geopotential height (an inverted measure of AO) start from stratosphere which temperature is influenced by the presence of ozone. The isolation of the polar vortex deepens the ozone hole. The covariance of stratospheric ozone and SAM seem an established fact. But does it prove causality?

Thompson & Solomon 2002 (Science)

Ozone and NAO

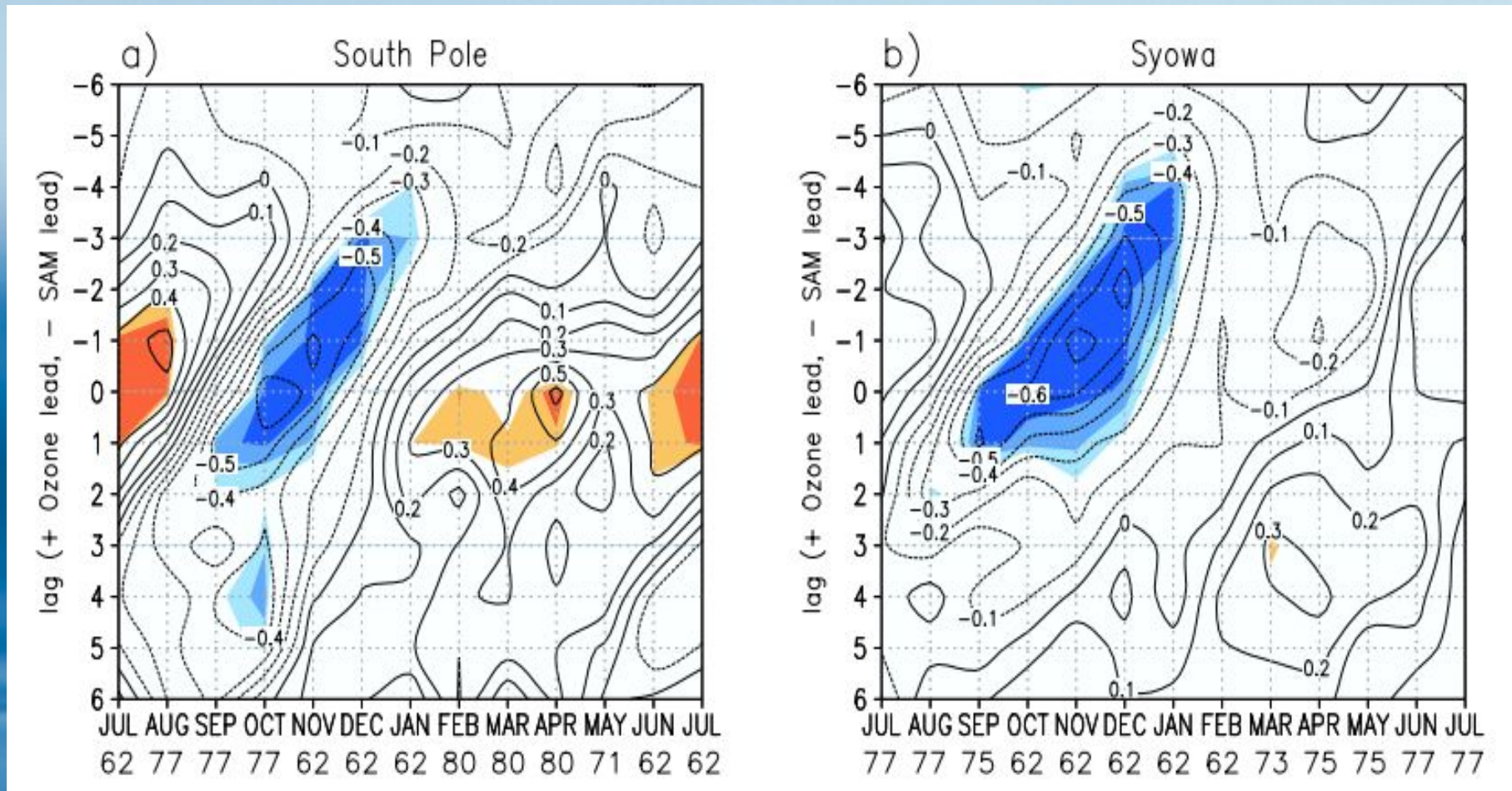


Polar stratospheric ozone for Northern and Southern 63°-90° polar areas (top) and inverted NAO index (bottom) – with the same time scale.



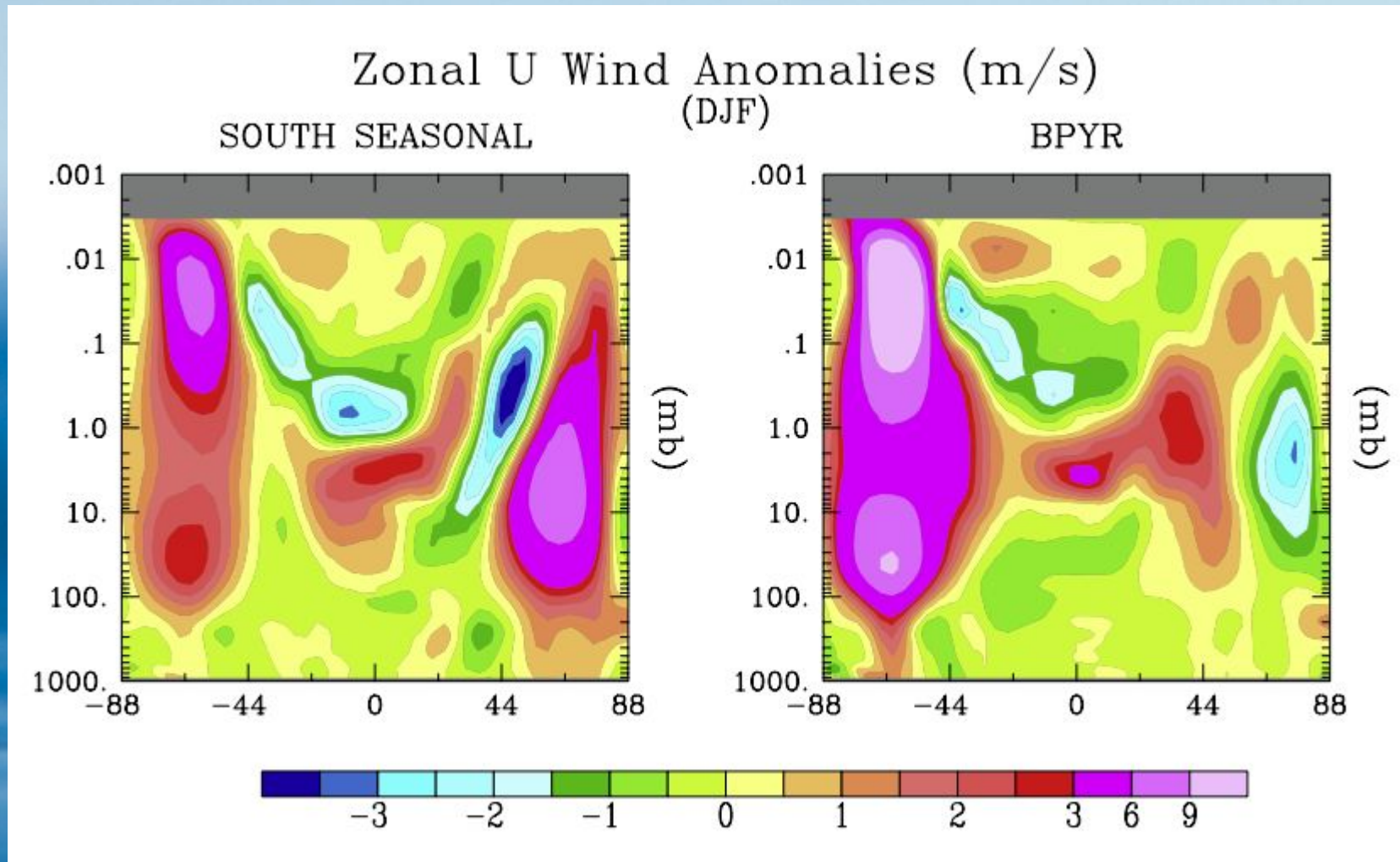
Is the covariance accidental? If not, which controls which? The effect can be “explained” qualitatively both ways. But which is true? Or maybe both?

Ozone and SAM



Observations show that at least in short time scale ozone anomalies over Antarctica precede the Southern Annular Mode by up to 4 months (in SH Spring). This does not prove causation but...

The WTF result: Antarctic ozone and NAO !?



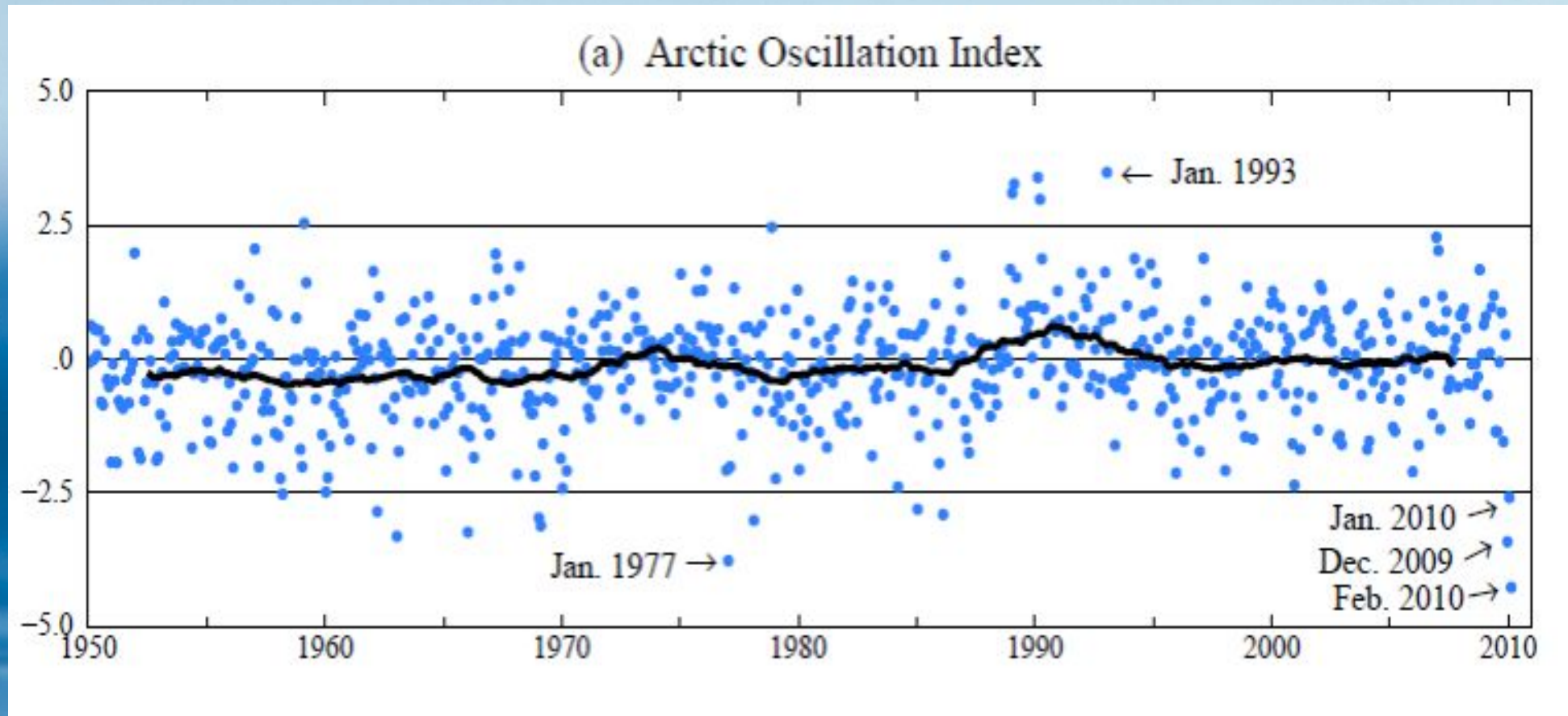
Rind et al 2009 made modelling “experiments” of checking the atmospheric circulation effect of removing all ozone over the Antarctic in SH spring or on both hemispheres (BPYR = Both Poles Year Round). It seems northern ozone does not have much effect but removing the southern one makes both SAM and NAO (yes!) stronger. Hard to believe? Yes, but...

So what will be the weather of the next decades?

- Of course with increasing atmospheric CO₂, it will be generally warmer everywhere but especially in the Arctic (with positive feedback caused by sea-ice loss)
- We should expect more precipitation in North Europe (and less in the South), including more extreme precipitation (almost everywhere)
- The 60-70 AMO oscillation index seems to be decreasing implying decreasing Atlantic overturning circulation. This should slow down a little the warming around North Atlantic but not stop it.
- At the same time the NAO index went into negative values implying the possibility of several cold winters in North Europe.

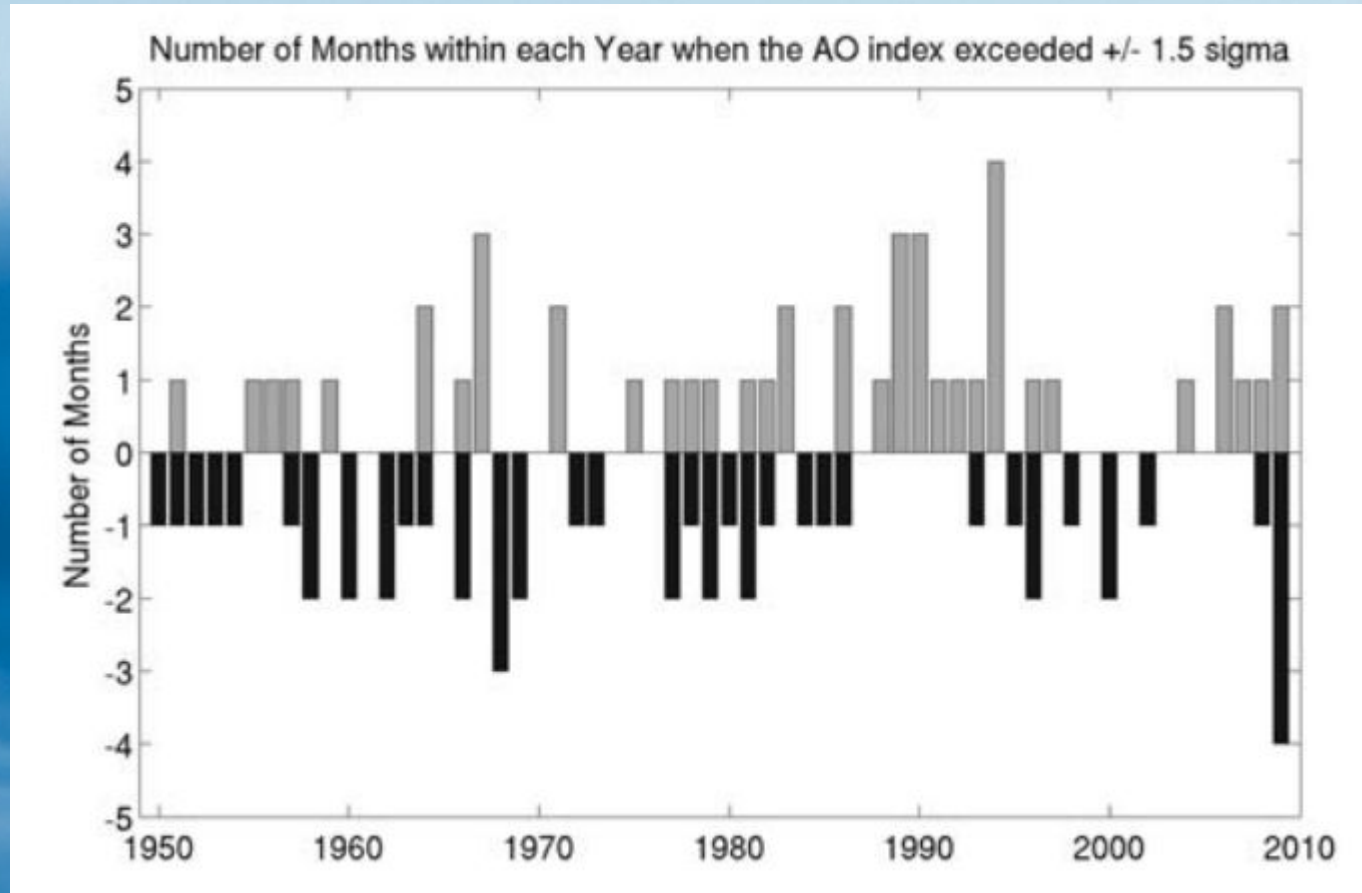
So do we understand it all? Certainly not as well as we would like. There are many unknowns (including how much of AMO variability is actually anthropogenic). But it starts to make some sense.

Why did we have such a cold winter?



The winter AO values of 2010 were the lowest since 1977. Blue dots are monthly means and black curve is the 60-month (5-year) running mean.

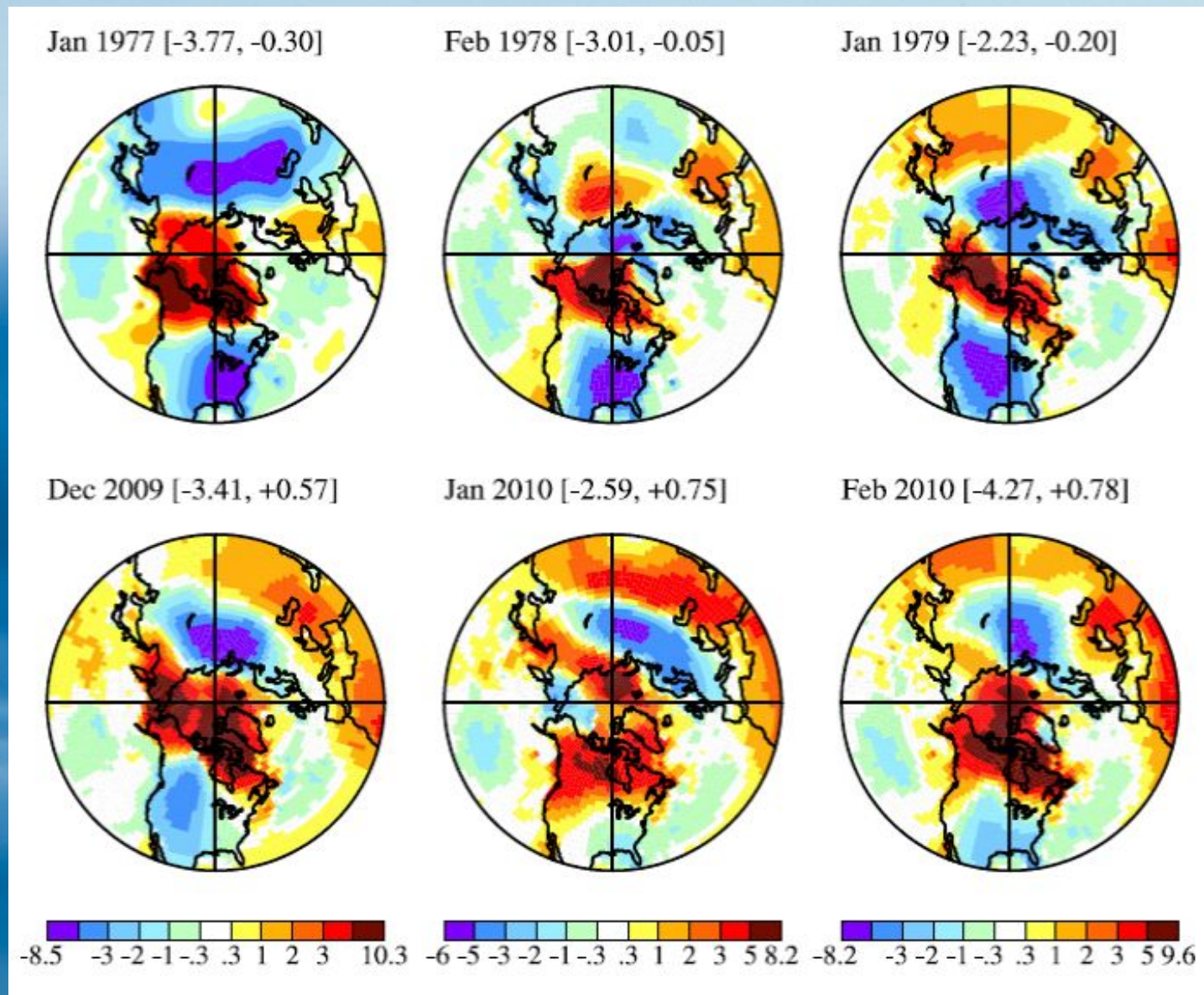
2009 had a record number of low NAO months



Even before the winter started, AO had three months of extremely low NAO values (June, July and October). December was the fourth (and as we know the next months continued the trend). The values itself were the lowest in 60 years. It may be noted that 2009 had also two months of very high NAO values (May and September).

L'Heureux et al 2010 (GRL)

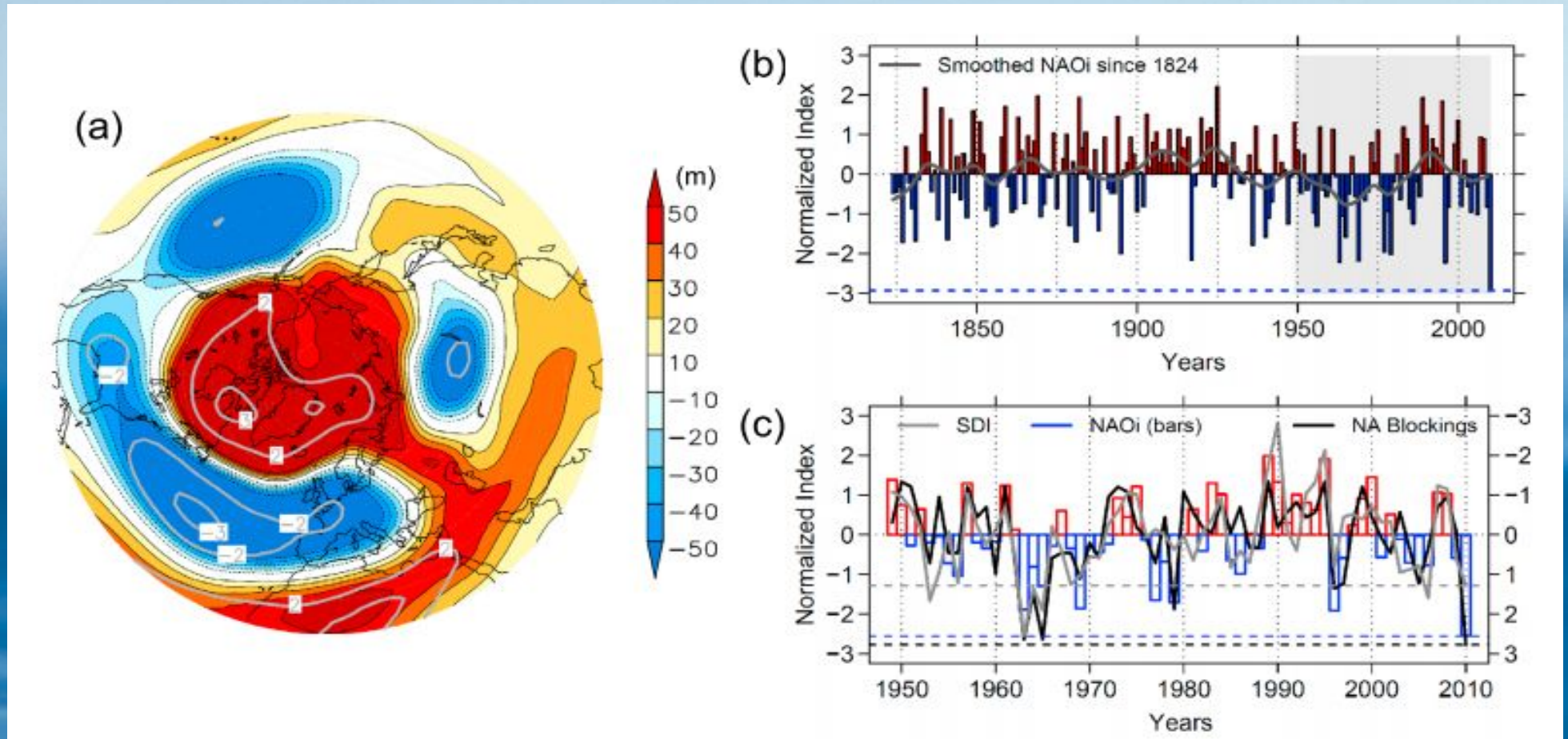
Low AO values lead to this kind of winters



90-24 N temperature anomaly for months with extremely negative AO Index

Hansen 2010 (unpublished)

We had the winter with lowest NAO in history?

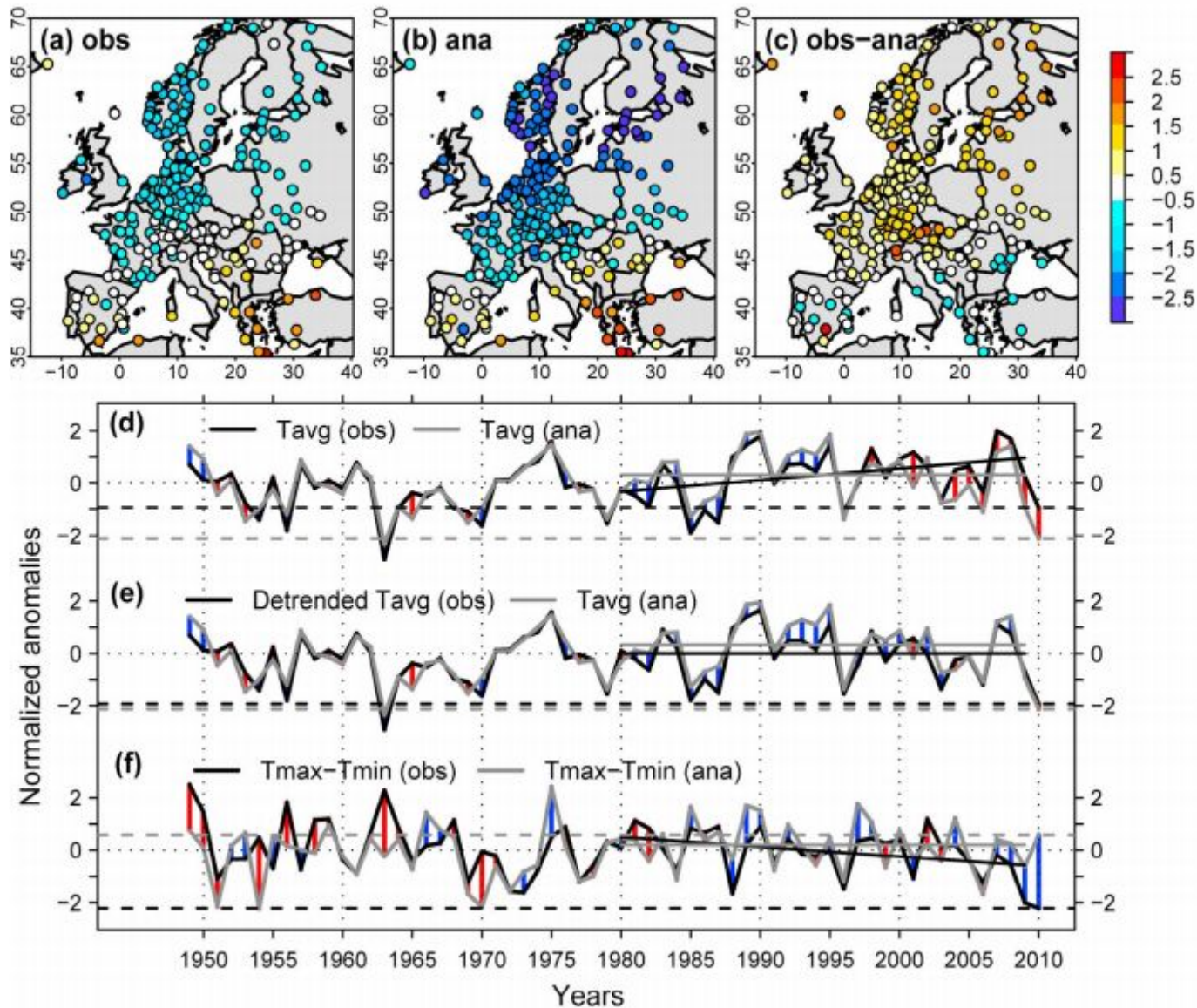


It seems we had not only the lowest winter NAO values since meteorology started but also the second longest blockings (see panel a) since 1949 (the longest were in 1963).

Cattiaux et al 2010 (GRL)

“Winter 2010 in Europe: A cold extreme in a warming climate” published on October 22

But it was only the 13th coldest one. Why?

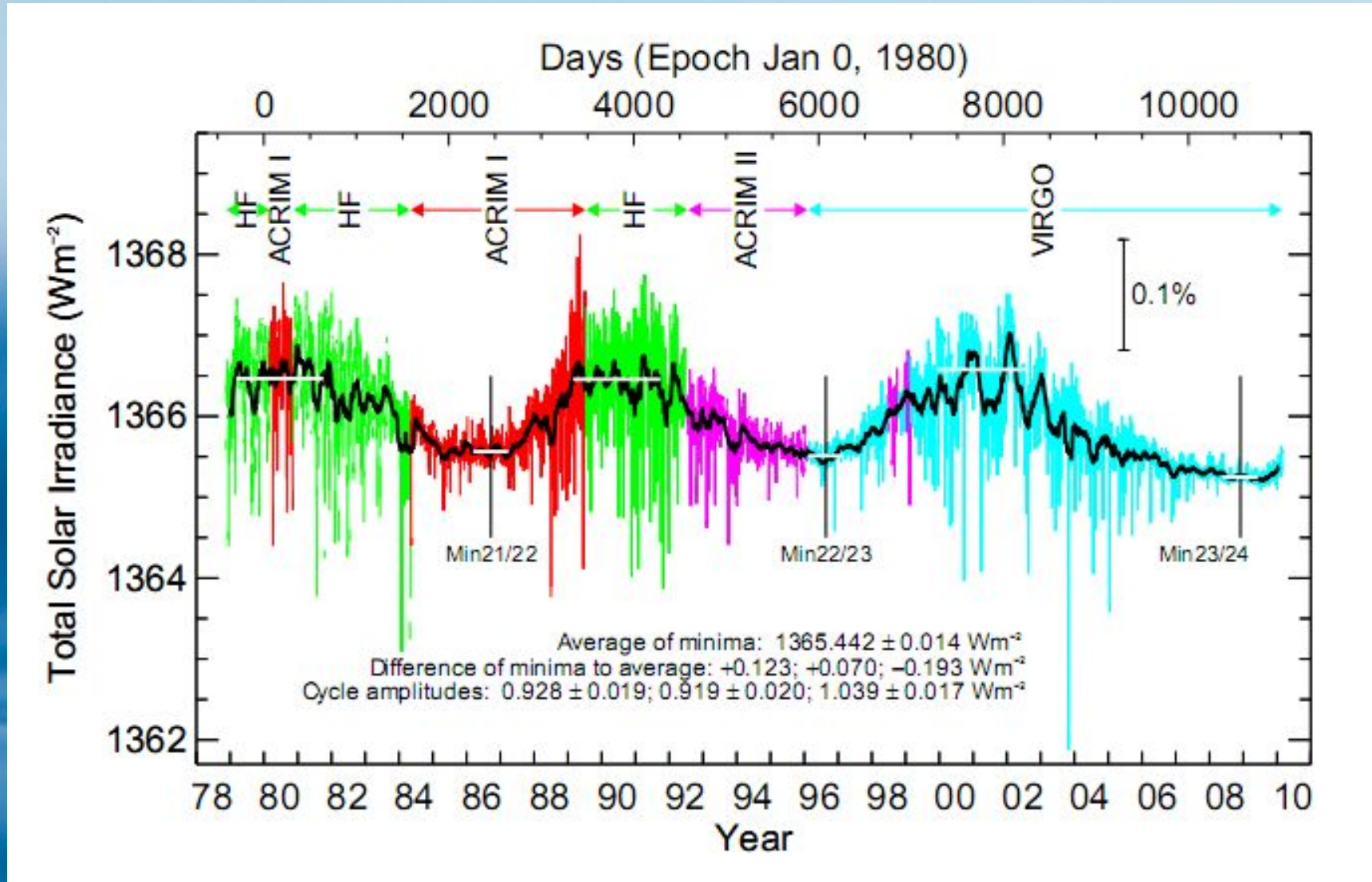


Comparing the synoptic situation of every winter day with most similar (analogous) days in 1949-2009 shows that the observed “obs” values started to diverge from “ana” since 1980. This may be interpreted as the effect of global warming making winters less cold than similar ones in the past and decreasing day-night amplitudes (f)

Cattiaux et al 2010 (GRL)

“Winter 2010 in Europe: A cold extreme in a warming climate” published on October 22

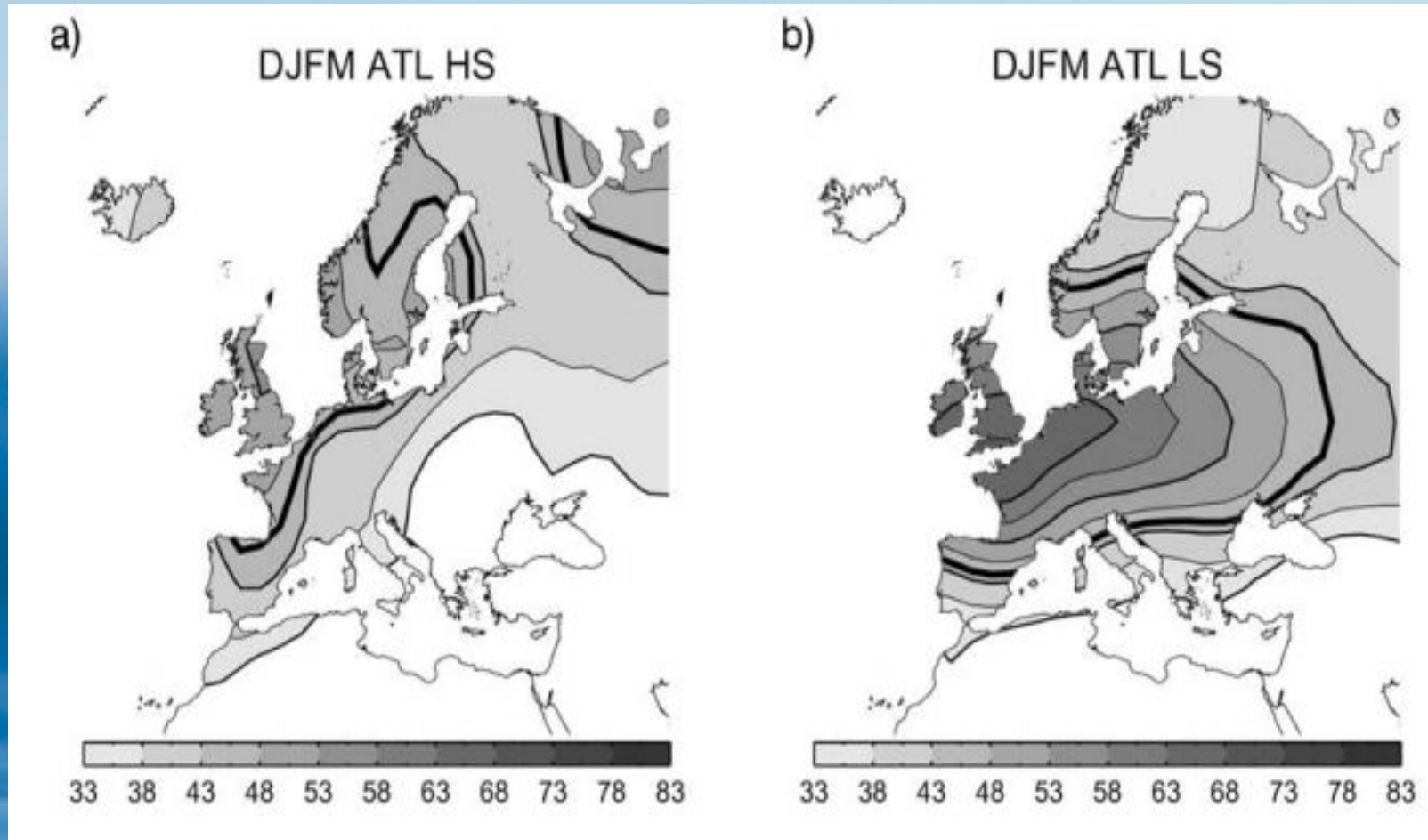
Solar activity in 2009/10 lowest since 1913



The PMOD composite Total Solar Irradiance as daily values plotted in different colors for the different originating experiments. The difference between the minima values is also indicated, together with amplitudes of the three cycles

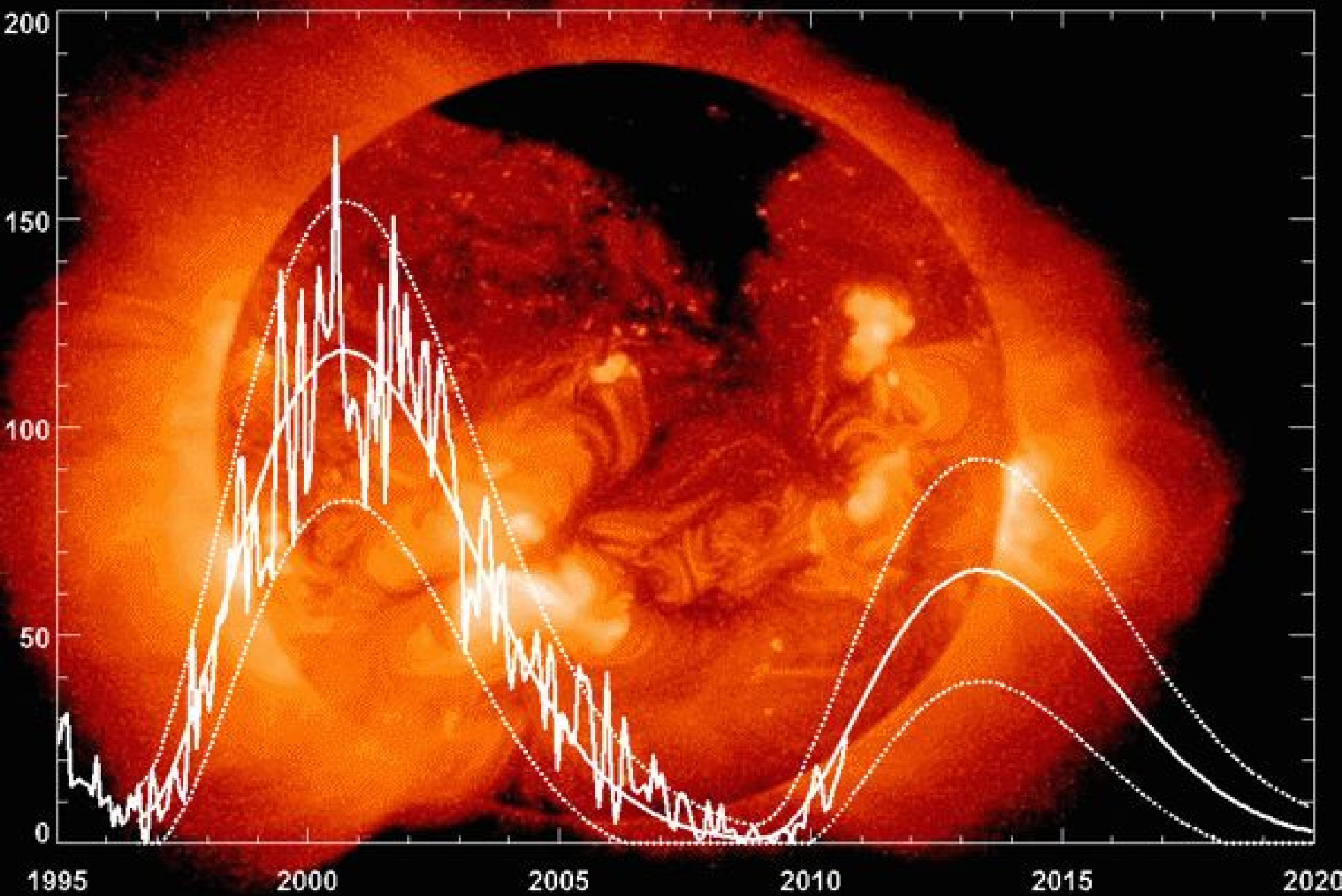
<http://www.pmodwrc.ch/pmod.php?topic=tsi/composite/SolarConstant>

Blocking is more effective with low solar activity



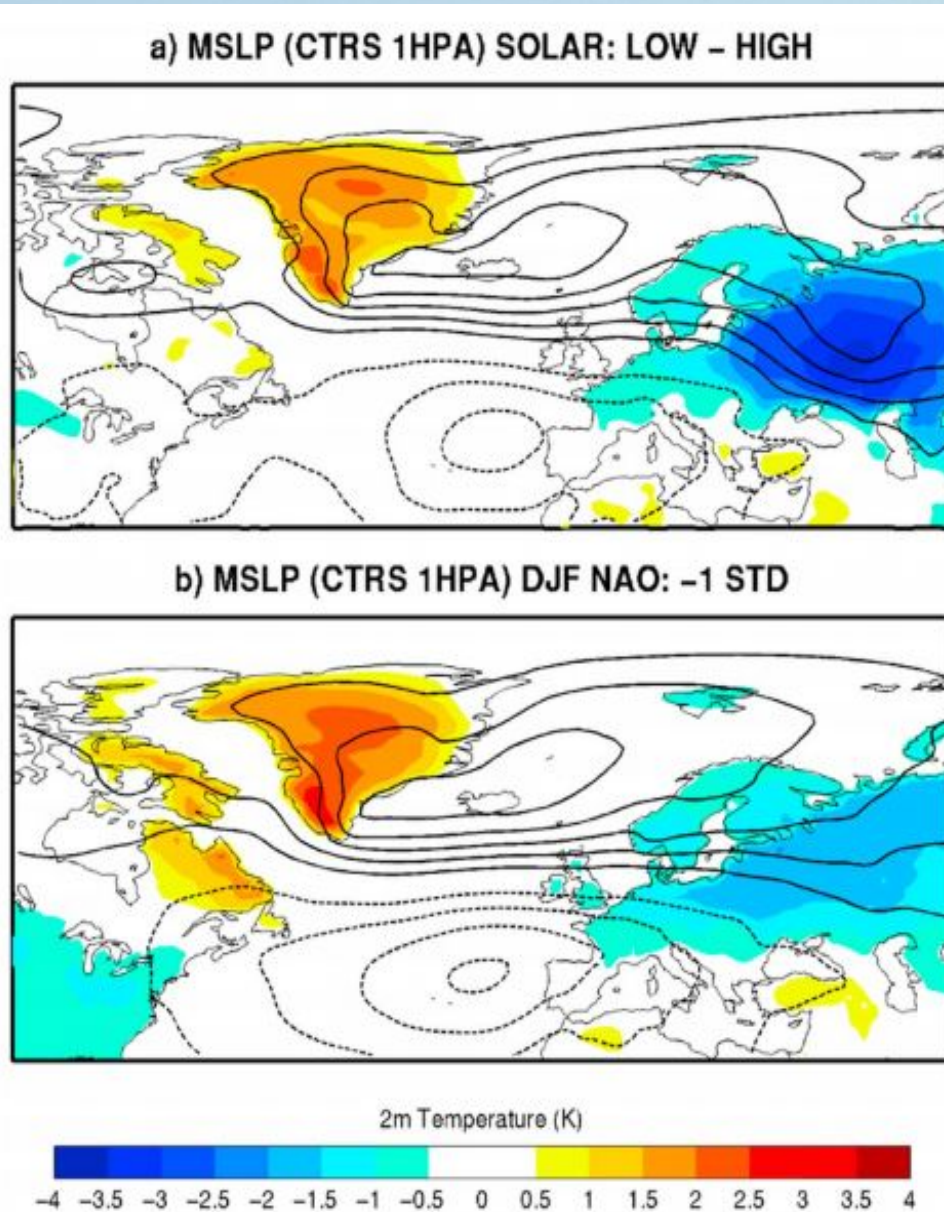
Solar modulation of the blocking impacts in the temperature distribution. Percentage of Atlantic blocking days with daily mean 2-m temperature anomalies in the lower tercile of its winter distribution under: (a) HS and (b) LS. Solid lines and shaded areas denote those values exceeding the expected value (33.3%) with 5% contour interval. The thick solid line denotes the 95% confidence threshold based upon a binomial test. The quartile solar stratification is used *Barriopedro et al. 2008 (JGR)*

Cycle 24 Sunspot Number Prediction (October 2010)



Hathaway/NASA/MSFC

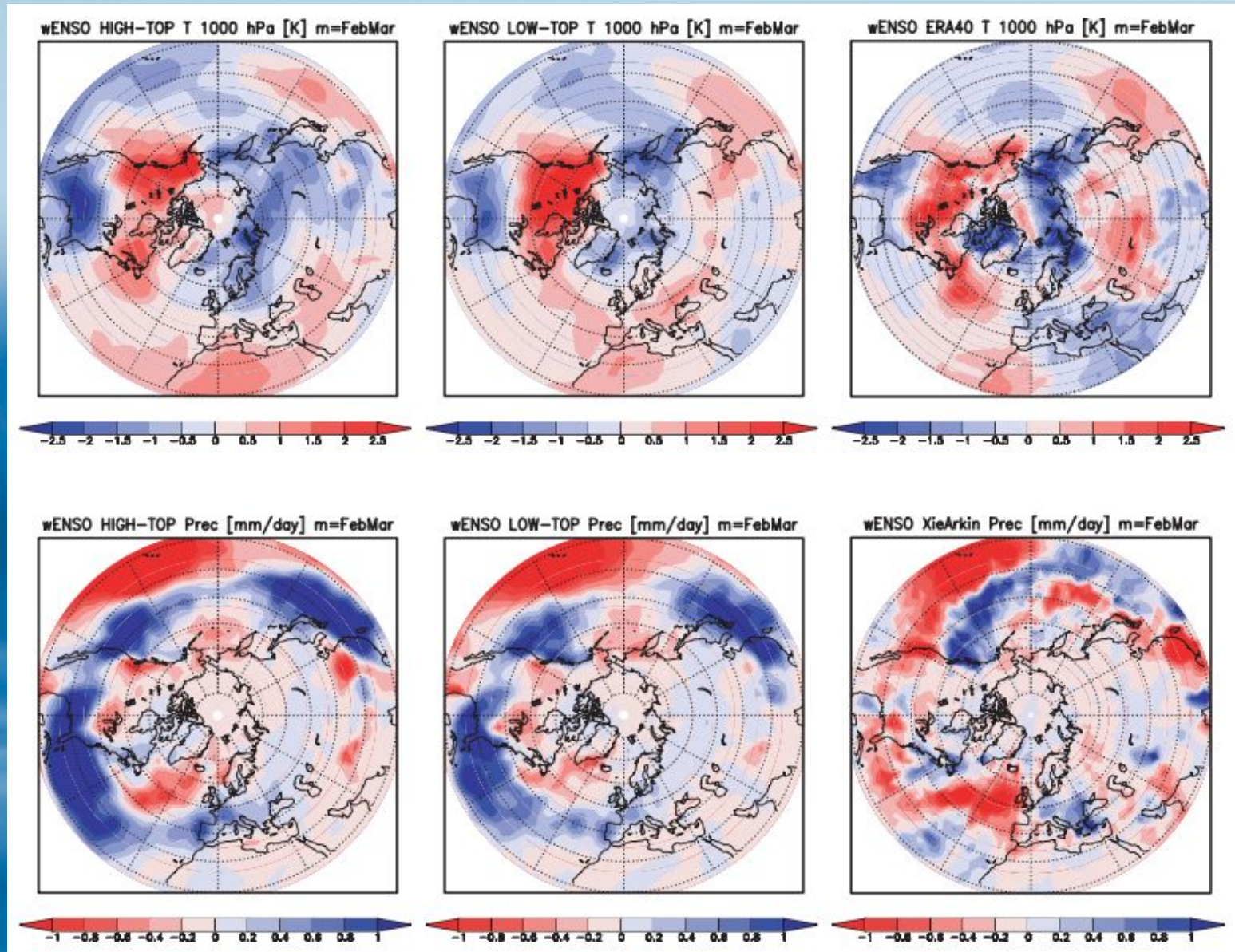
Is the effect of Solar activity similar but distinct from NAO?



Comparison of mean winter surface pressure (contours) and 2m temperature (colors) between low- and high- solar activity years (upper panel) and low and high NAO (lower panel).

The patterns are similar but the effects of low solar activity extend more to the East towards Central Europe. The two patterns seen statistically different.

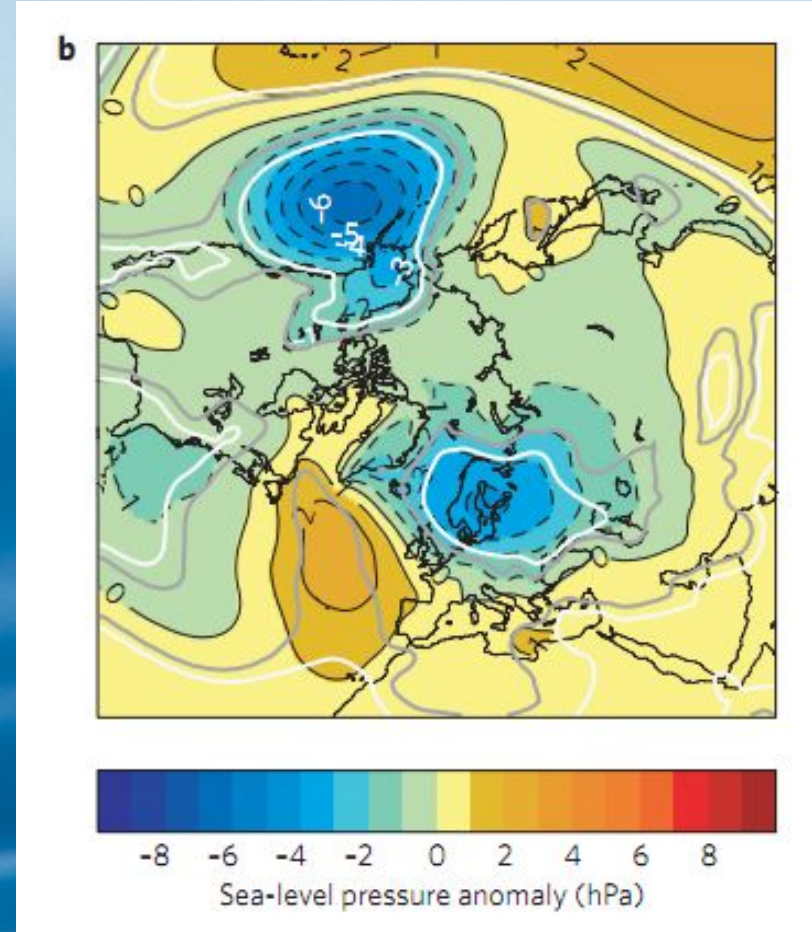
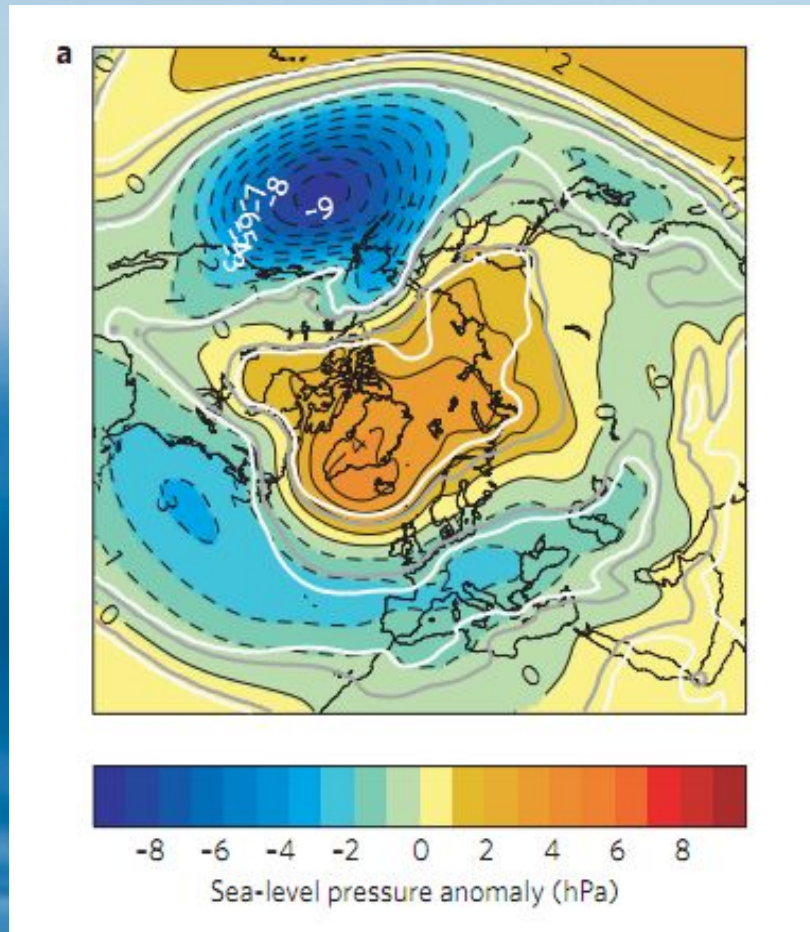
ENSO also influences North Hemisphere winter?



FM ENSO anomaly in (top) 1000-hPa temperature (K), and (bottom) precipitation (mm day⁻¹) for (left) high-top model, (middle) low-top model, and (right) ERA-40 data for SLP and 1000-hPa temperature; precipitation data from observations.

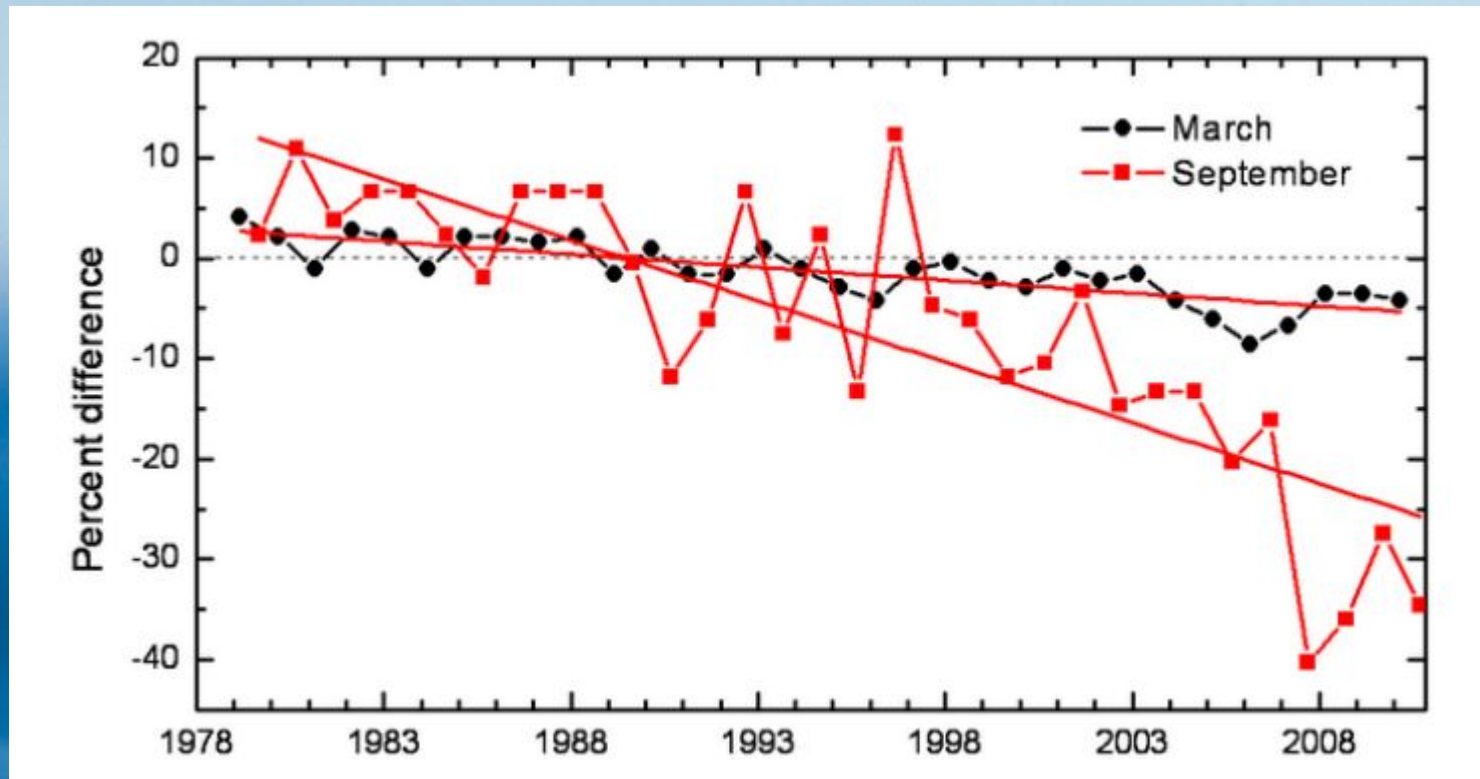
Cagnazzo & Manzini 2009 (J. Climate)

Yes but only in years with Sudden Stratospheric Warmings



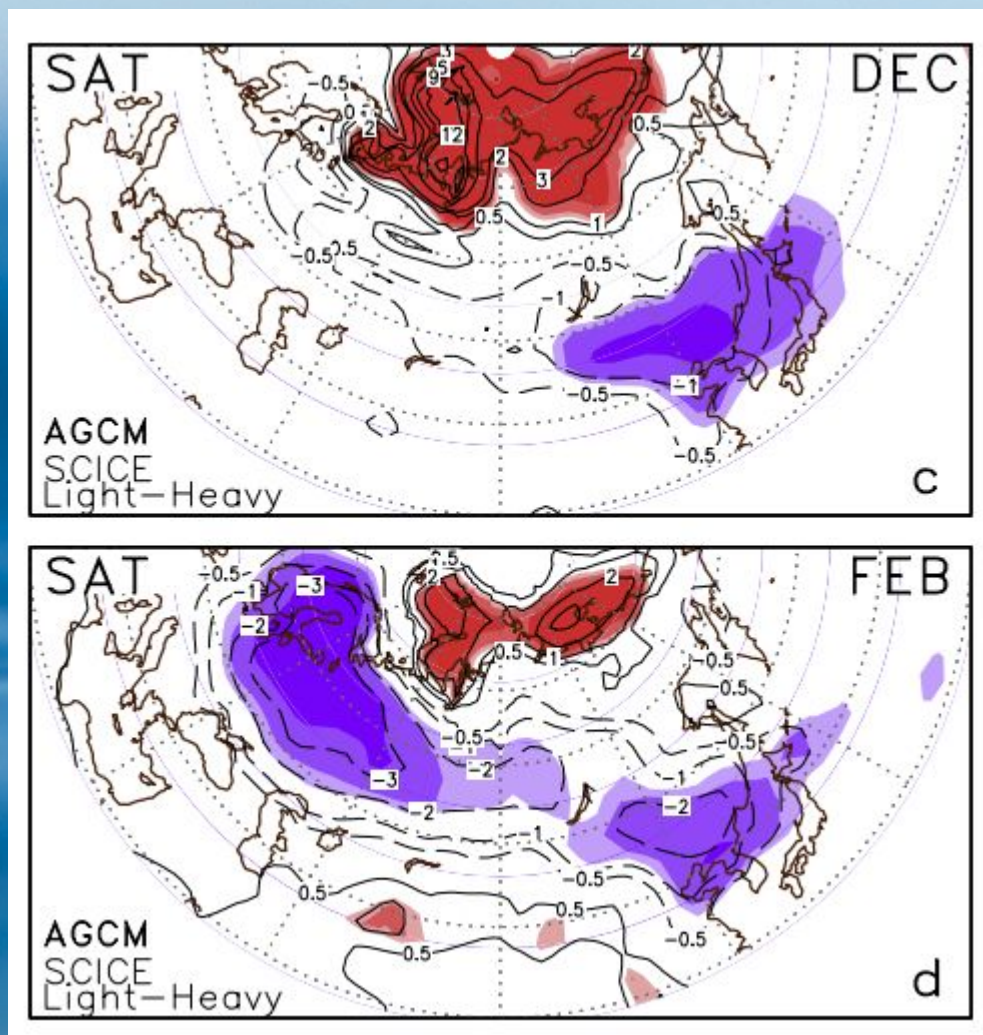
Modelled surface climate response to El Niño associated with a weak and strong polar vortex. Composite sea-level pressure anomaly (hPa) for El Niño years with sudden stratospheric warmings (a) and El Niño years with no sudden stratospheric warmings (b). Anomalies are for January–March. Grey and white contours indicate significance at the 95% and 99% confidence levels.

Arctic sea-ice loss



Time series of the percent difference in ice extent in March (the month of ice extent maximum) and September (the month of ice extent minimum) relative to the mean values for the period 1979–2000. Based on a least squares linear regression for the period 1979–2009, the rate of decrease for the March and September ice extents is -2.7% and -11.6% per decade, respectively.

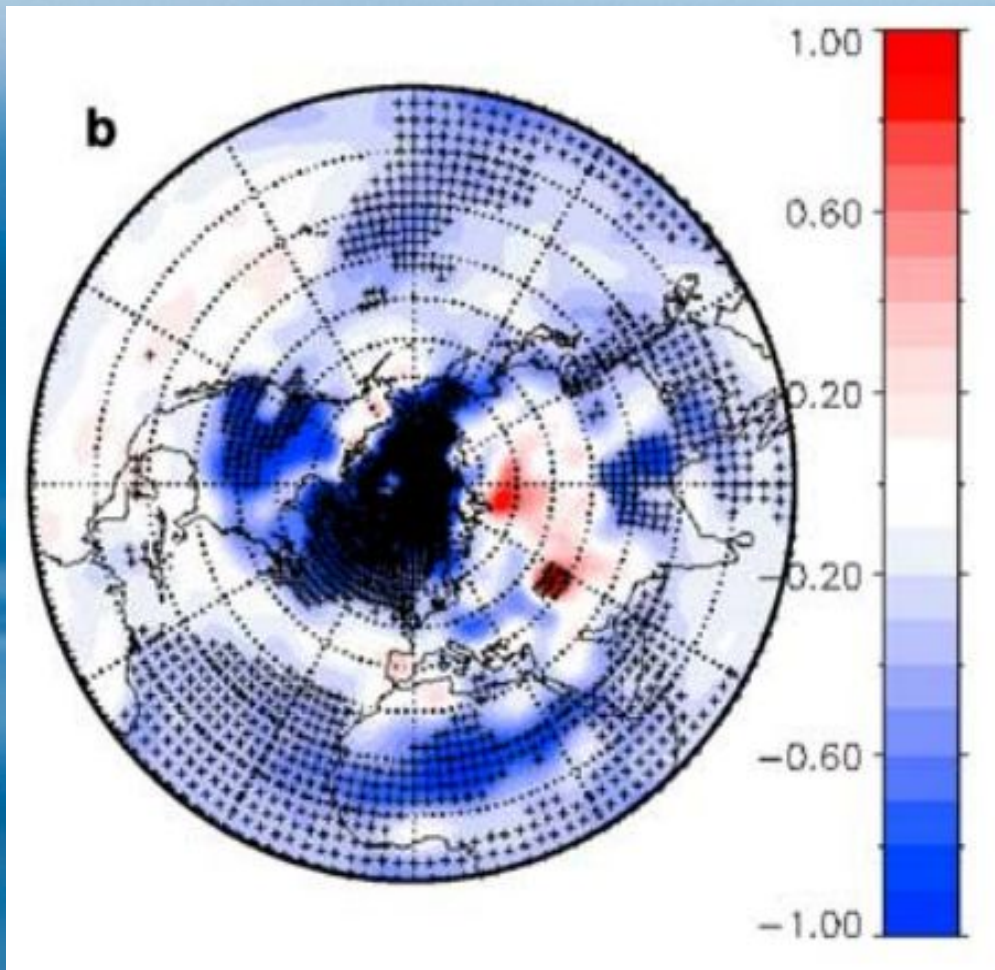
Less summer Arctic sea-ice means colder Eurasian winter?



Maps of monthly near-surface temperatures for December and February (1978/9 – 2005/6) regressed on sea-ice concentration in previous September (with reversed signs!).

Less Summer sea-ice means warmer wintertime Arctic and colder Eurasia in a zonal area similar to the 2009/10 winter anomaly (especially in February).

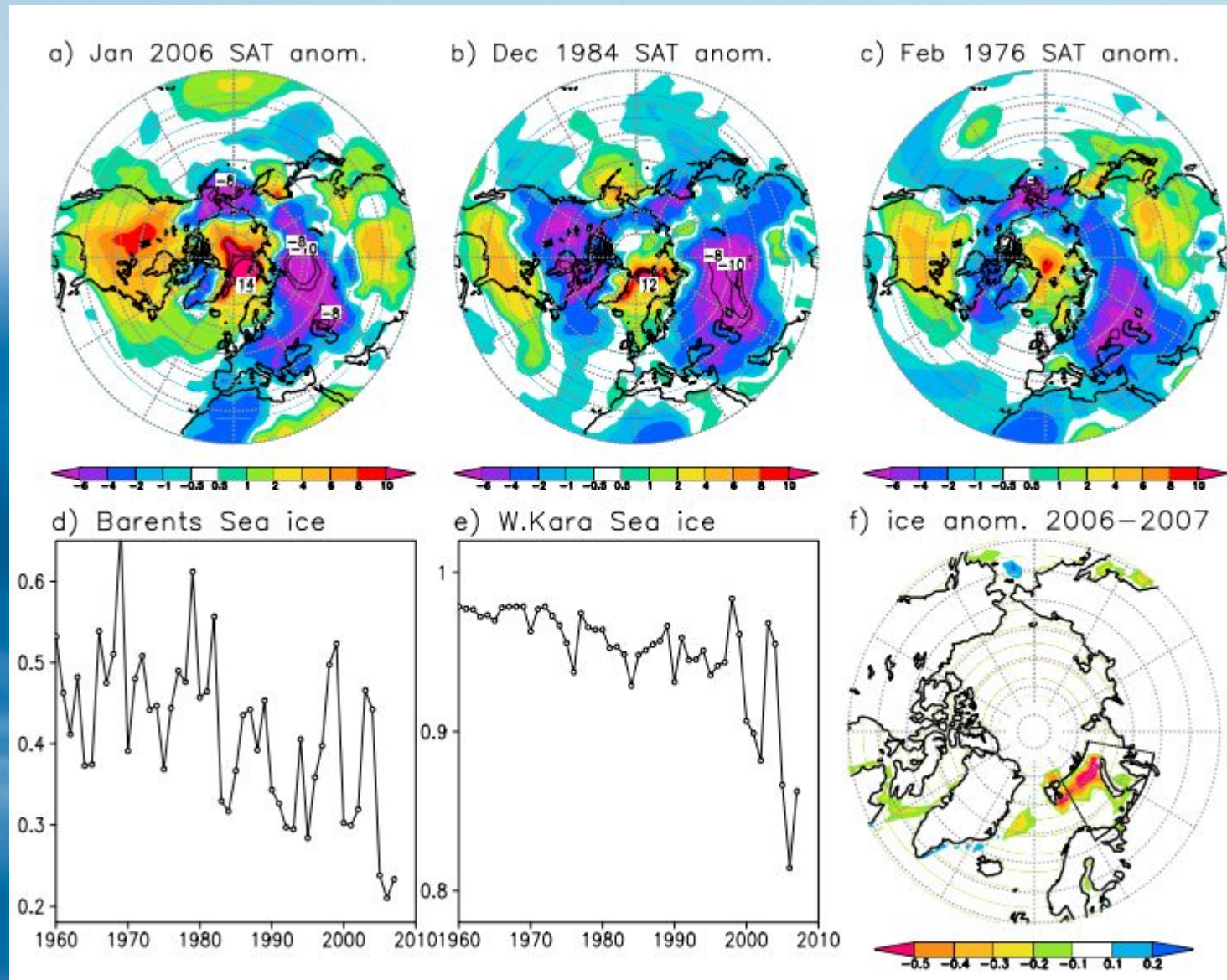
Less summer Arctic sea-ice means colder Eurasian winter?



Linear regressions between actual September sea-ice extent and the surface air temperature in $\text{K}/10^6 \text{ km}$ during the following winter (Nov – Jan)

Here the sign of the correlation is not changed!

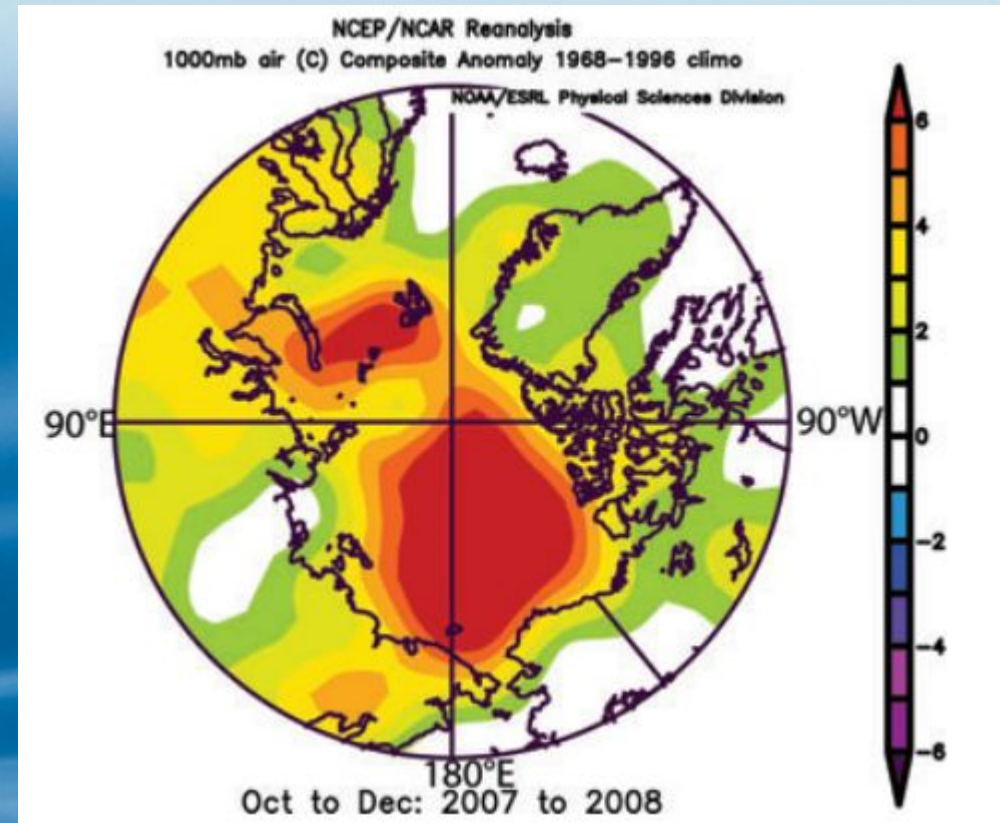
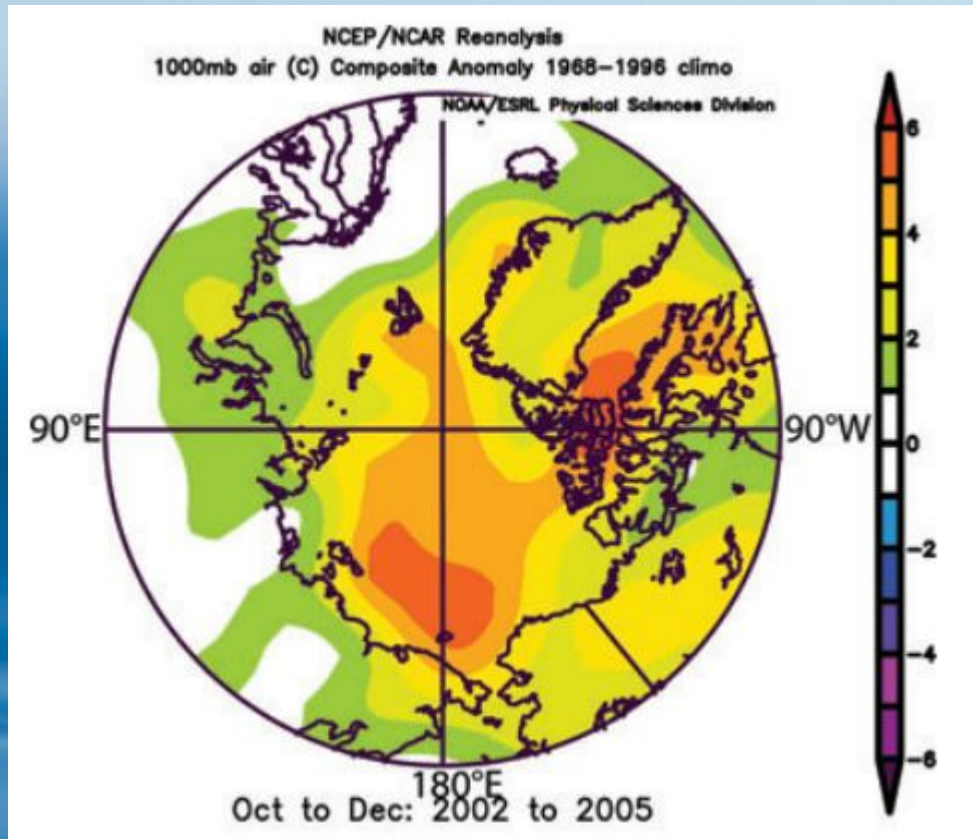
Possibly it is also the Barents-Kara sector sea-ice loss



Petoukhov and Semenev (2010) explain extremely cold Eurasian winters by the loss of sea-ice in Barents and Kara Seas. Interestingly they submitted their paper **before** the cold 2010 winter!

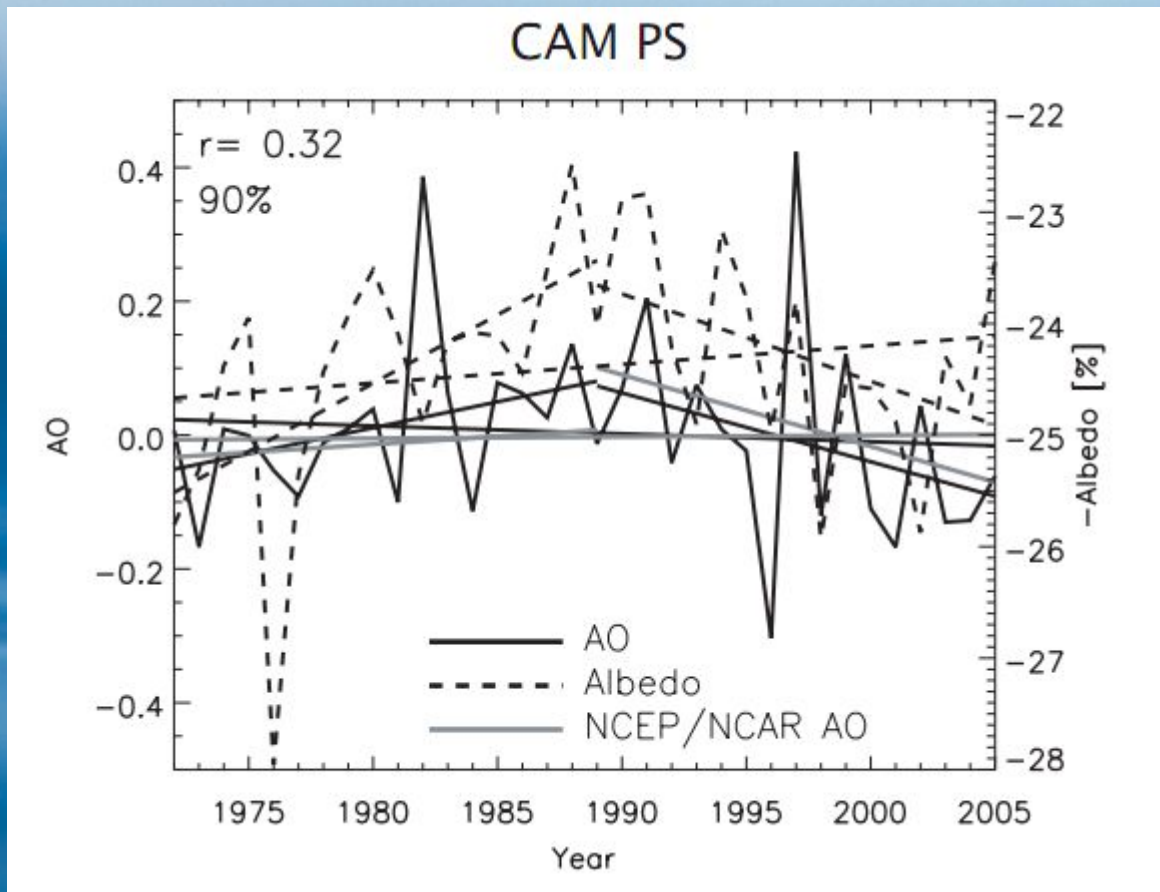
Petoukhov Semenov 2010 (GRL)

Arctic October-December near-surface air temperature anomaly



Near surface air temperature anomaly multiyear composites (°C) for (left panel) October–December 2002–2005 and (right panel) October–December 2007–2008,

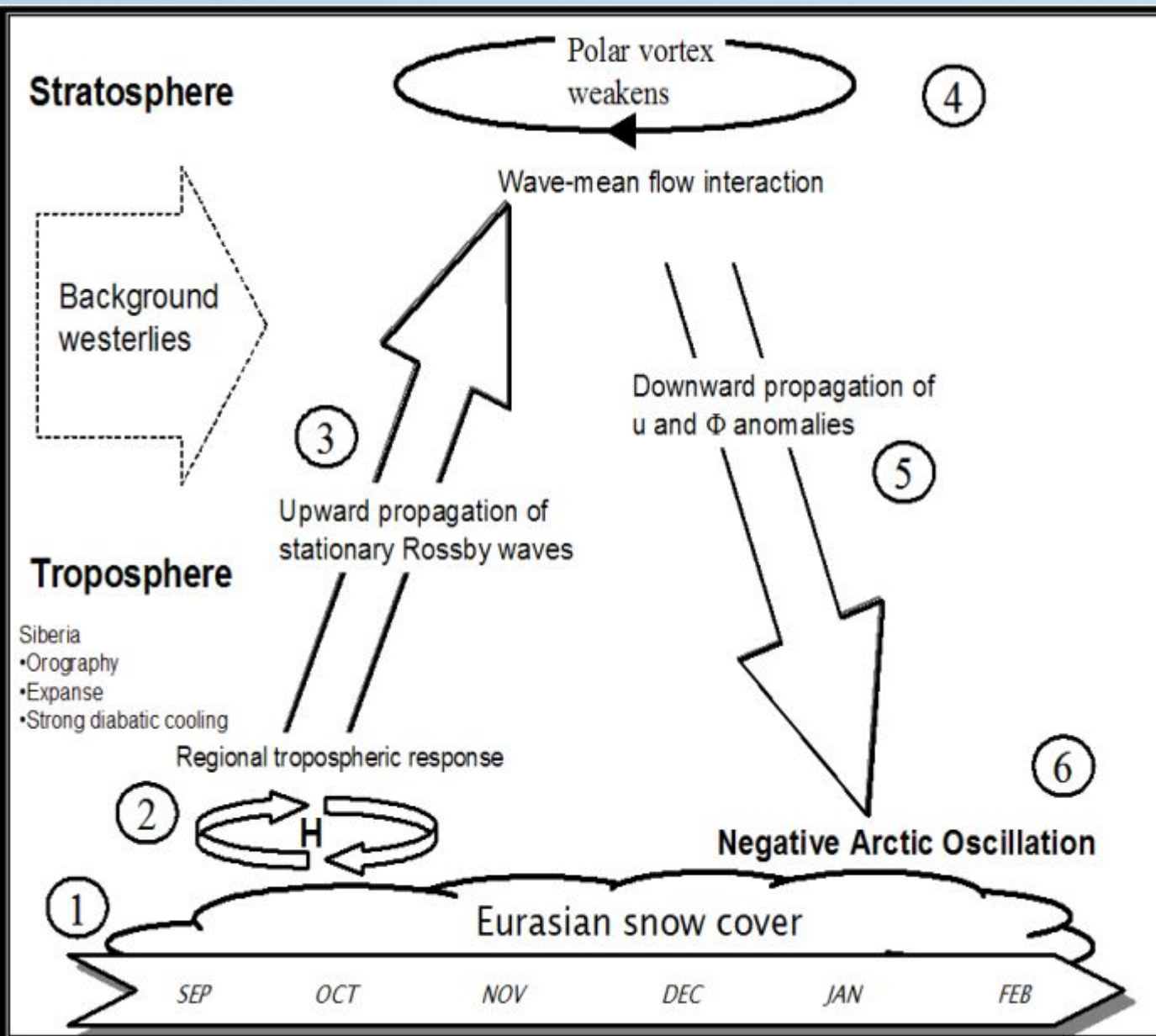
More Eurasian snow means lower NAO/AO?



Forcing a climate model (CAM3) with satellite derived wintertime snow extent and calculating the corresponding albedo (inverted!) one can obtain AO wintertime values similar to observations.

Does it mean the Eurasian snow cover really drives the winter AO/NAO values? Maybe, but both can also respond to the same forcings. For example the Arctic sea ice?

The proposed mechanism of Eurasia autumn snow cover on winter NAO index

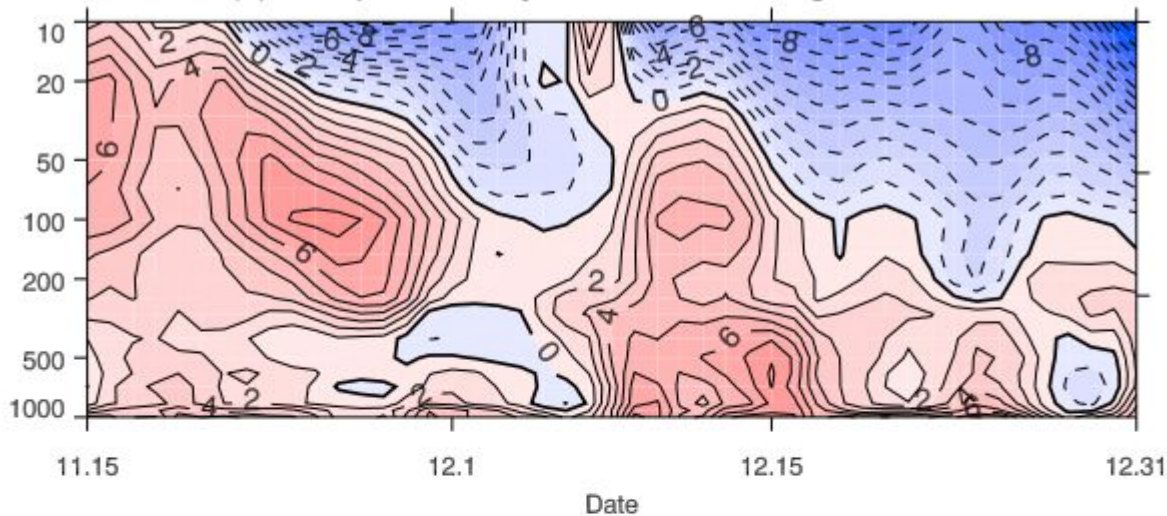


The mechanism, involving a stratospheric sudden warming (3) and downward propagation of zonal wind and potential temperature anomalies (5) seems well documented.

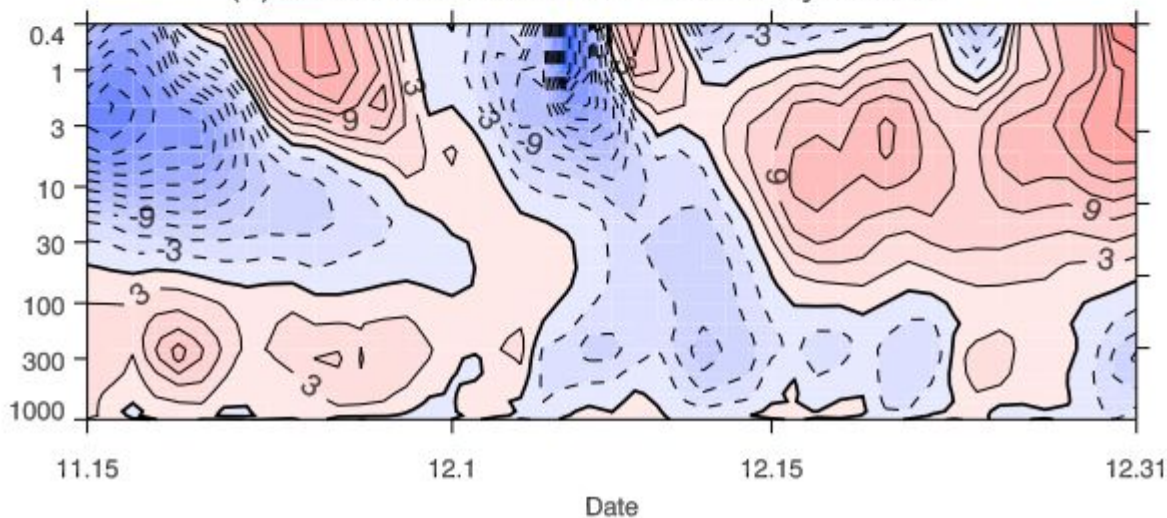
However it does not exclude the possibility of a (0) phase: summer Arctic sea-ice anomaly results in an Autumn SST anomaly, influencing Siberian snowfall.

The stratospheric link has been observed

(a) Temp. anomaly in North Pole region



(b) Zonal mean zonal wind anomaly at 60°N

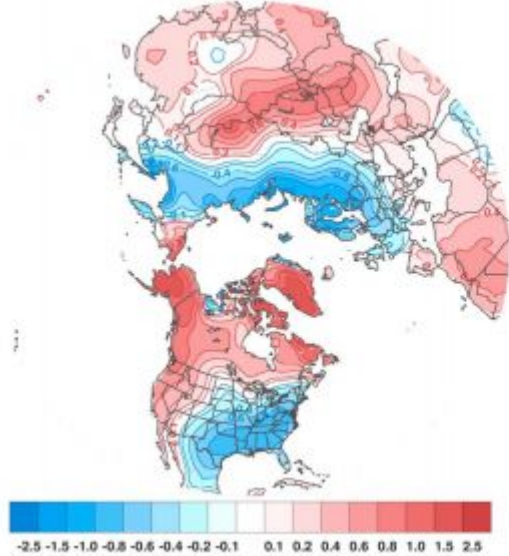


The changes in temperature and zonal winds anomalies during the 2010 winter did start from the stratosphere.

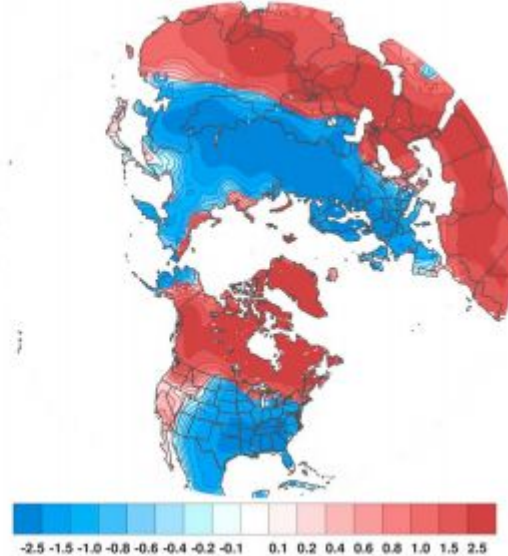
One can observe two events starting in mid-November and early December

Eurasian snow as a good winter predictor

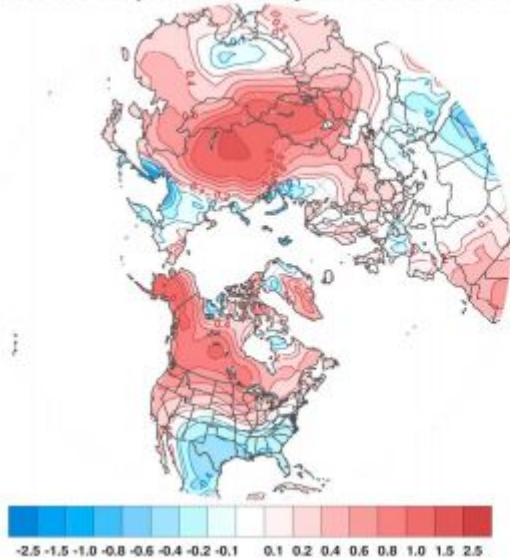
c) Forecast Temperature Anomaly Jan-Feb-Mar 2010



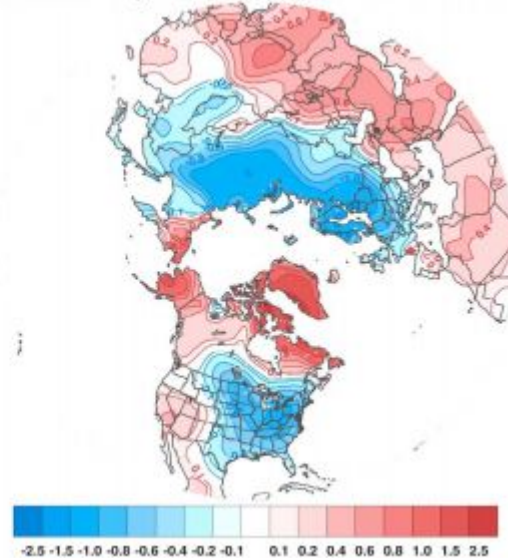
d) Observed Temperature Anomaly Jan-Feb-Mar 2010



e) Forecasted Temperature Anomaly Jan-Feb-Mar 2010 ENSO



f) Forecasted Temperature Anomaly Jan-Feb-Mar 2010 SNOW



Cohen et al 2010 predicted c) the 2010 winter temperatures d) using only three parameters: Eurasian snow extent, surface pressure and an ENSO index.

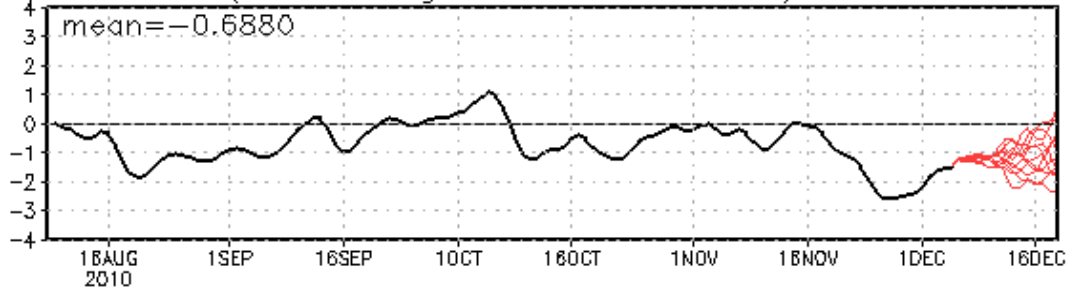
Because the model is linear it is possible to discern the effect of the predictors. While an ENSO only e) prediction was clearly wrong, an Eurasian snow extent one f) was surprisingly good.

But is snow the real climate forcing here?

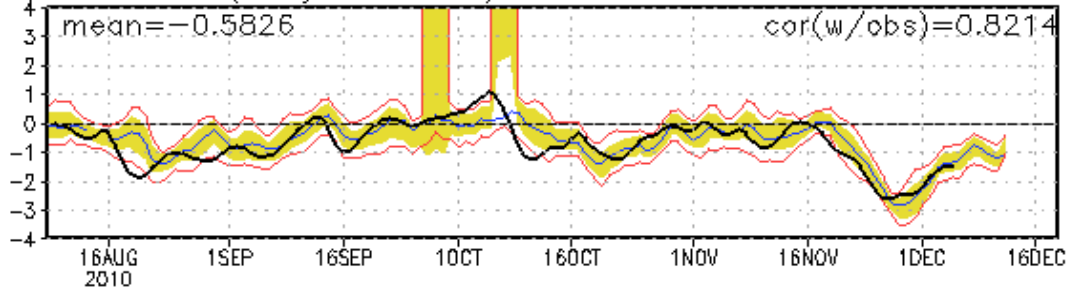
And what about this winter?

NAO: Observed & ENSM forecasts

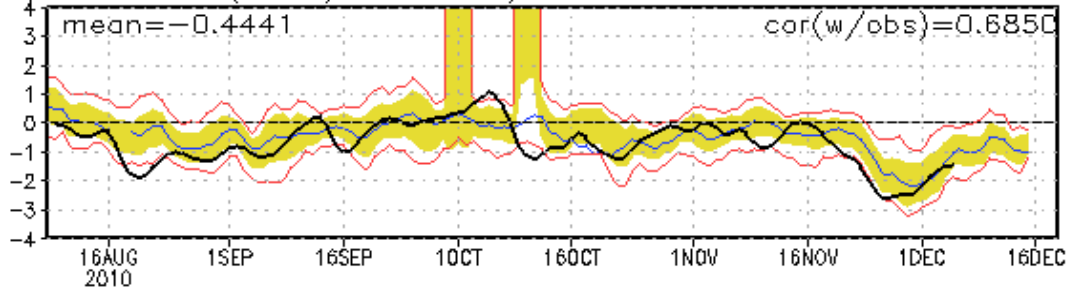
500mb Z (Obs: 08Aug2010 – 05Dec2010) NAO index



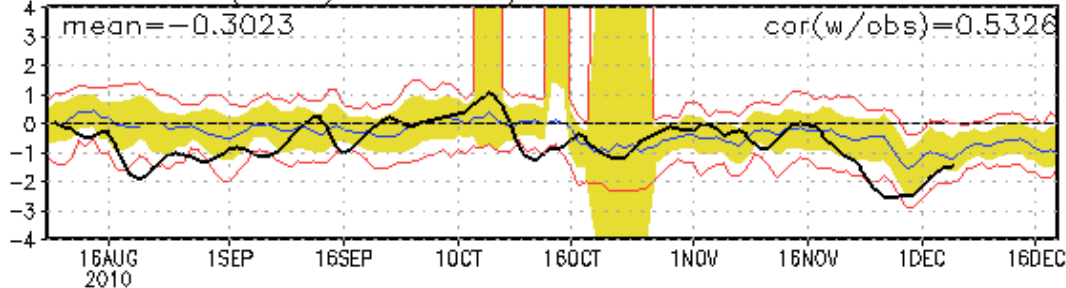
500mb Z (7day Forecast) NAO index



500mb Z (10day Forecast) NAO index

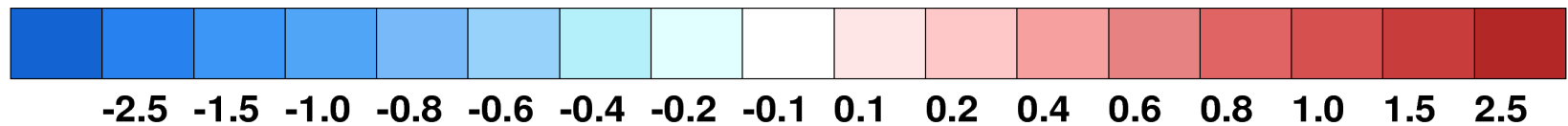
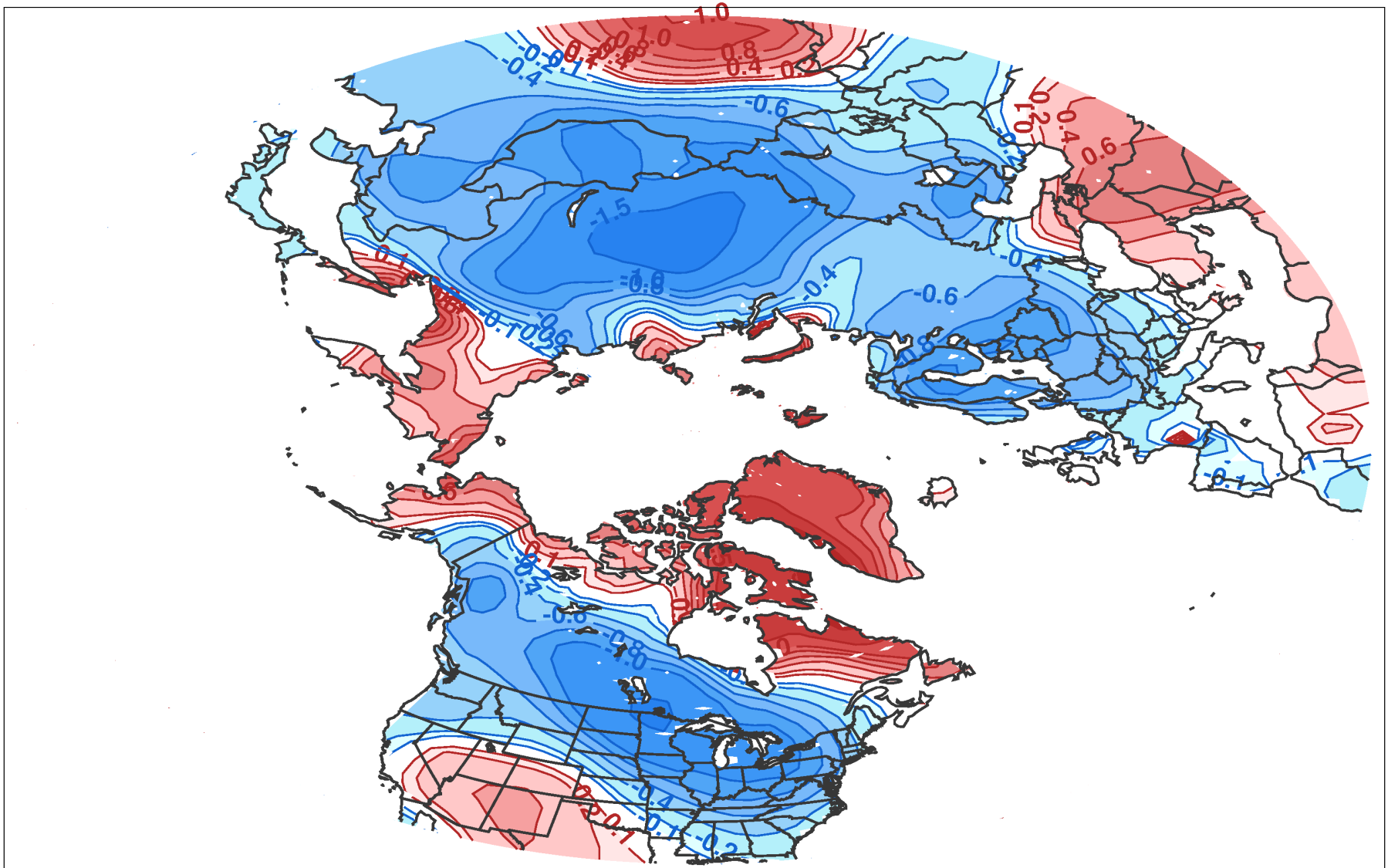


500mb Z (14day Forecast) NAO index



The observed NAO values for August 2010 to present day and forecasts for the next weeks.

Forecast Temperature Anomaly Dec-Jan-Feb 2011



Zatem jaka będzie zima 2010/11?

- Zeszłej zimy sprzysięgło się przeciw nam wszystko: niska aktywność słońca, El Nino, mało lodu w Arktyce i malejący AMO
- Lód w Arktyce, AMO (i ozon) nie zmieniają się z roku na rok ale obecnie mamy La Ninę i większą aktywność słońca
- Jednak NAO lubi mieć podobne wartości w sąsiednich latach
- Zatem czego się spodziewać?

Moja prognoza: będzie zimniej niż przeciętnie ale cieplej niż zeszłej zimy. Szczególnie druga połowa zimy powinna być ciepła gdy dojdzie do naszych szerokości efekt rozpoczynającej się obecnie La Ninii.

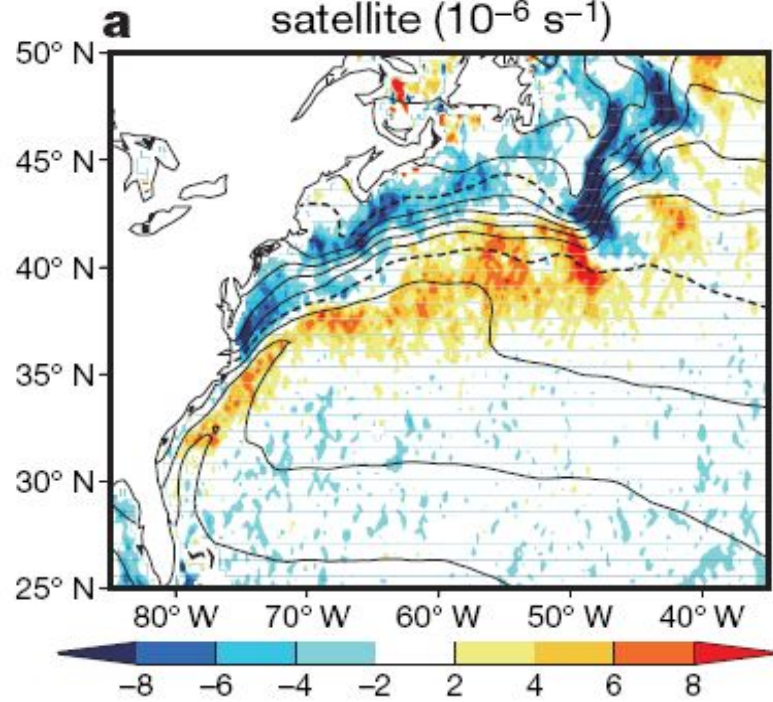
Dziękuję za uwagę

Za tydzień (13.12.2010 r.):

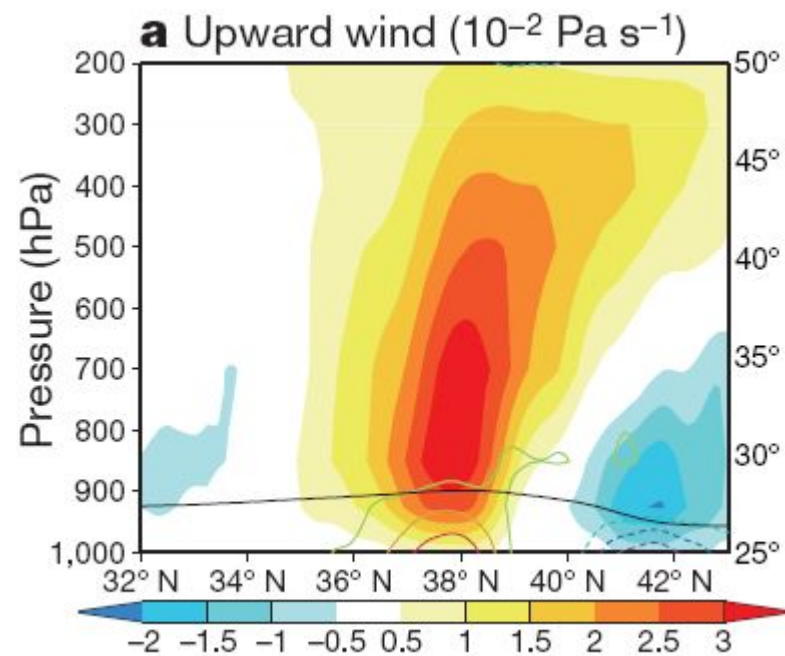
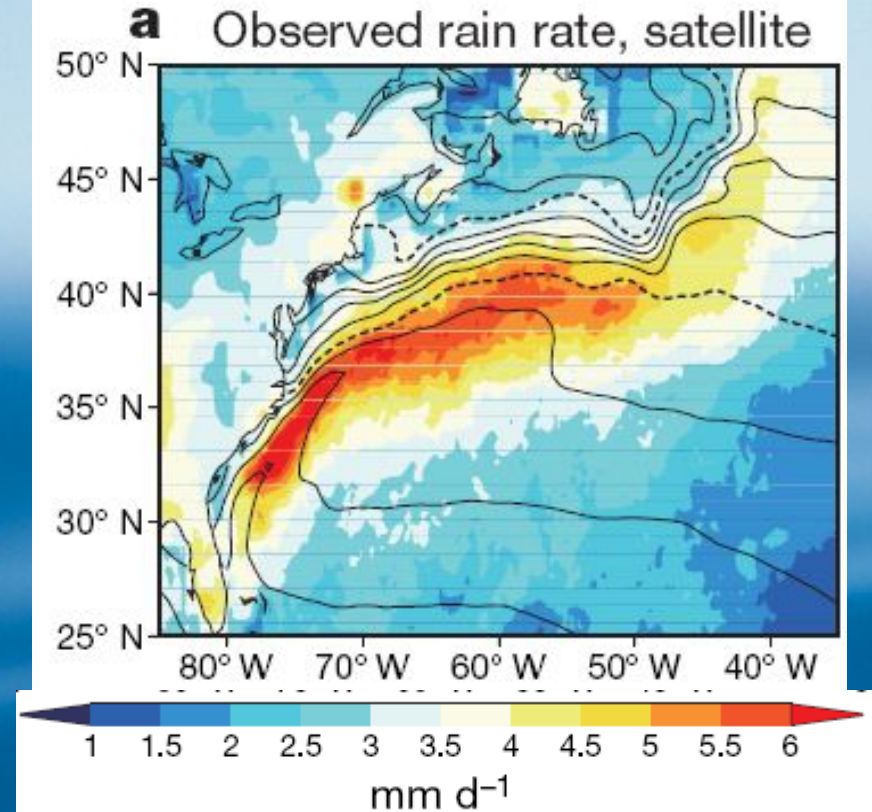
Tropiki a zmienność klimatu (ENSO, huragany, monsuny)

The Gulf Stream influences the whole troposphere

Wind convergence,
satellite (10^{-6} s^{-1})



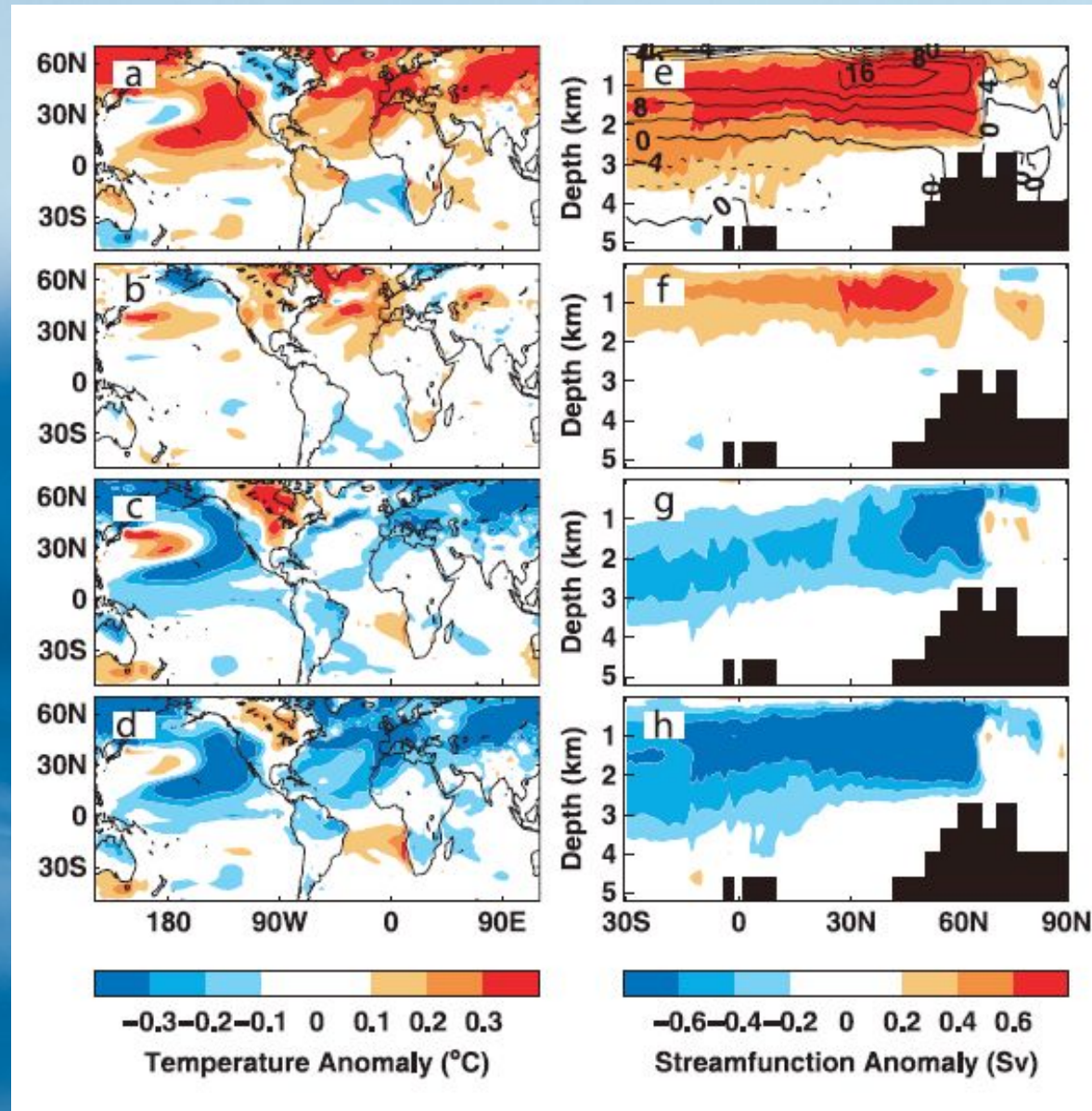
Observed rain rate, satellite



The observed average yearly surface wind convergence and rain rates along the Gulf Stream as well as the vertical wind cross-section (upward is positive) with the boundary layer marked as a black line.

Minobe et al. 2008 (Nature)

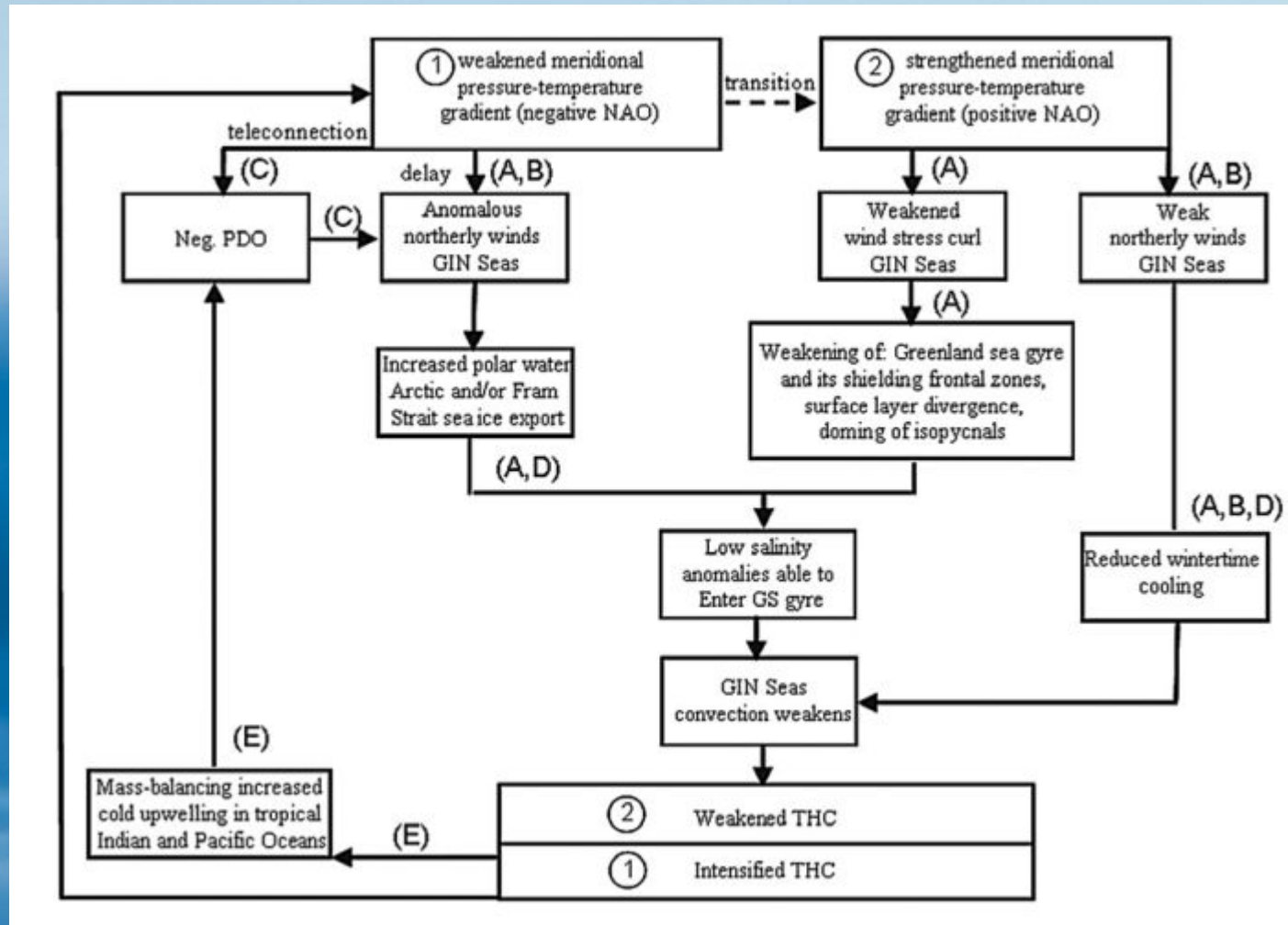
Modeled AMO: surface temperature and THC



Simulated temperature and THC anomalies at 0°, 60°, 120° and 180° of the modeled cycle.

Knight et al. 2005 (Geophysical Research Letters)

We have even more than one possible mechanism

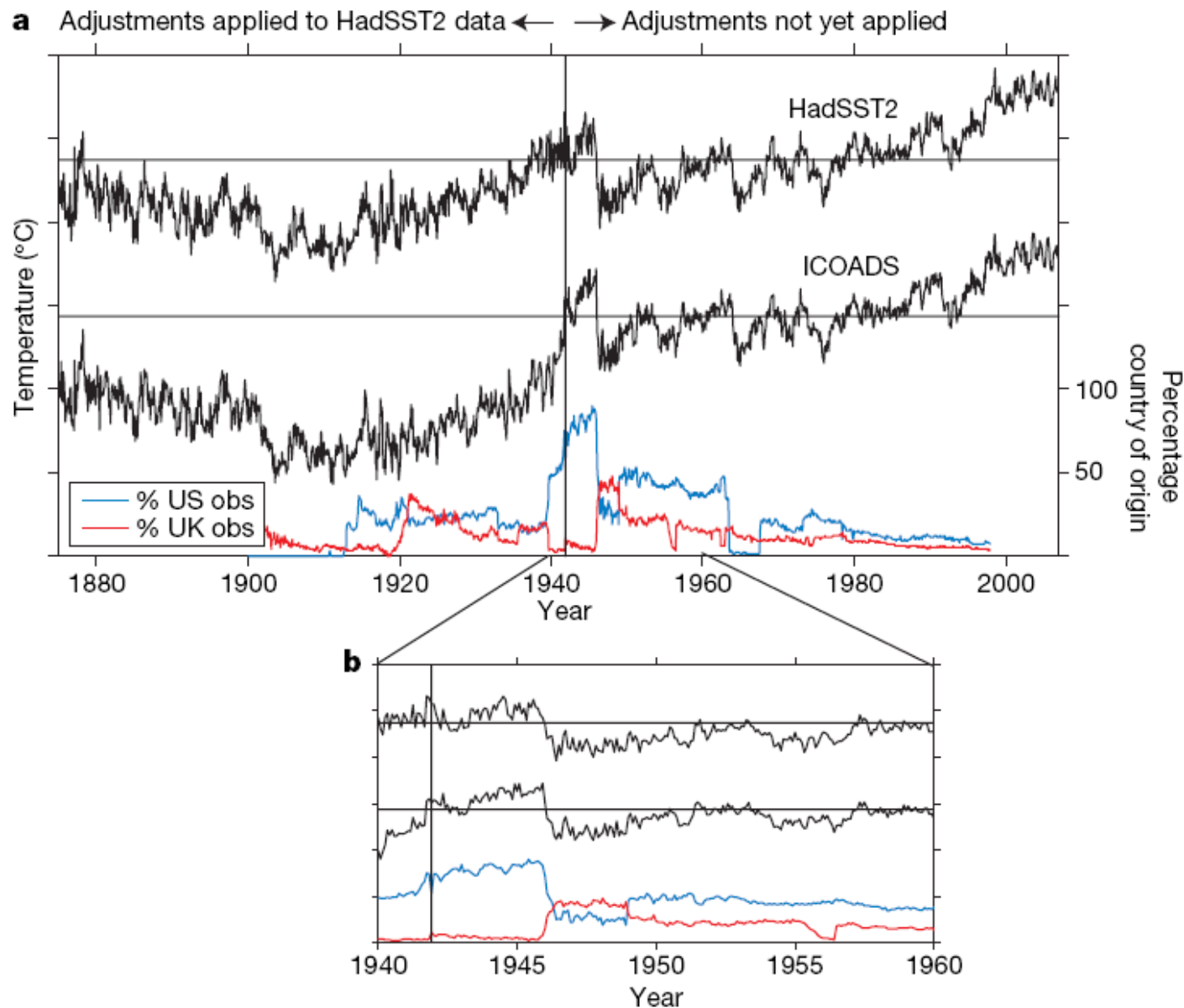


Dima and Lohmann proposed a more complicated mechanism involving NAO changes influencing freshwater inflows from the Arctic. The above graph is supposed to explain at least part of it.

Grossmann Klotzbach 2009 (JGR) explaining the mechanism proposed by Dima & Lohmann 2007 (or rather part of it)

Back to square one?

Published on May 29, 2008

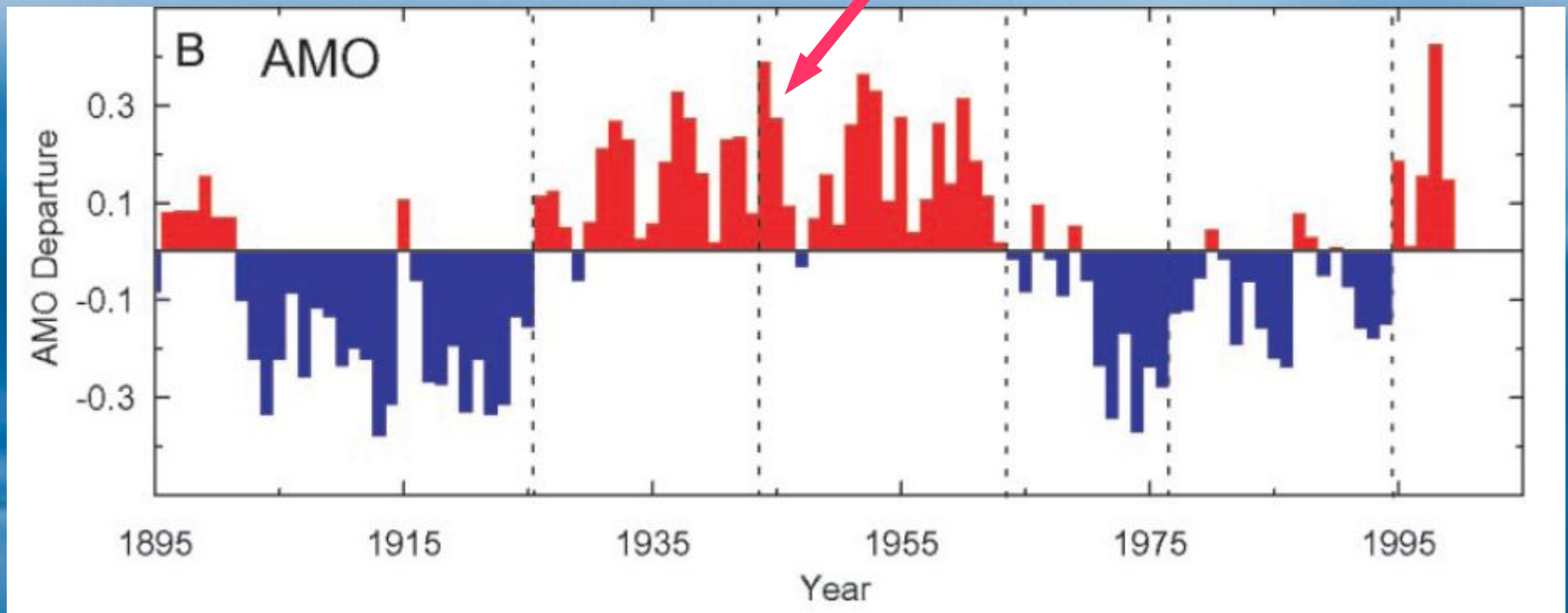


It seems that the mid-20th century SST discontinuity (not visible in land data), a 0.3°C drop in 6 months from August 1945, was an artifact caused by the British not measuring SST during the war. The British open bucket method was biased down while the US engine room intake method biased up.

If continuation of the HadSST2 reanalysis of original (but ENSO “cleaned”) ICOADS dataset erases out the 1940-1945 bulge, would there be still any 20th century AMO to explain? *Thompson et al. 2008 (Nature)*

Probably AMO is still with us

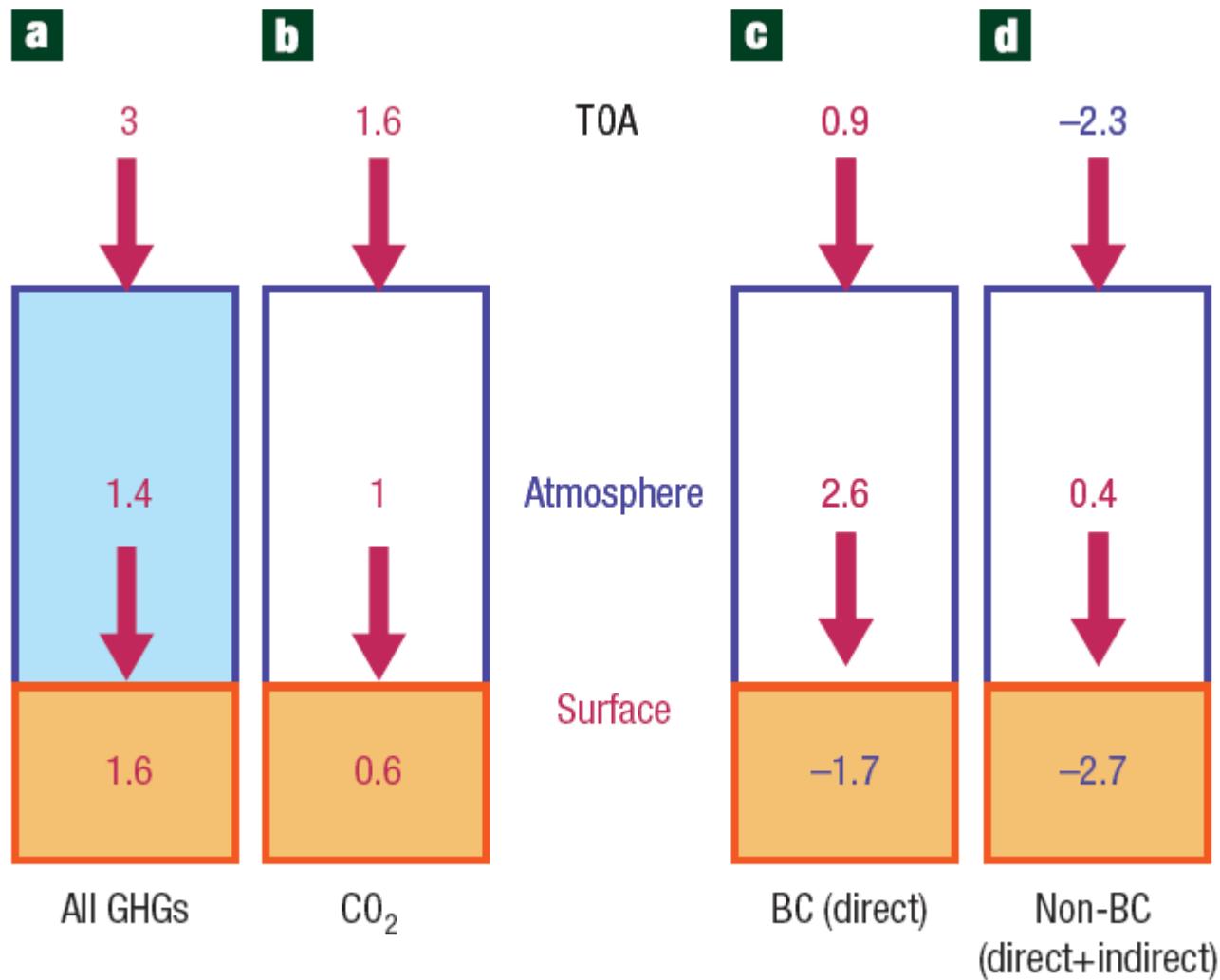
The “British bucket” dip ?



Filling out the 0.3°C “British bucket” dip would seem to make the AMO signal even stronger. Moving the left (“pre-dip”) part of the graph down by 0.3°C would make an even bigger minimum in the 1970s (after correcting the detrending). So it seems there is still an AMO to account for.

McCabe Palecki McCourt 2004 (PNAS)

... then suddenly black carbon enters the scene.



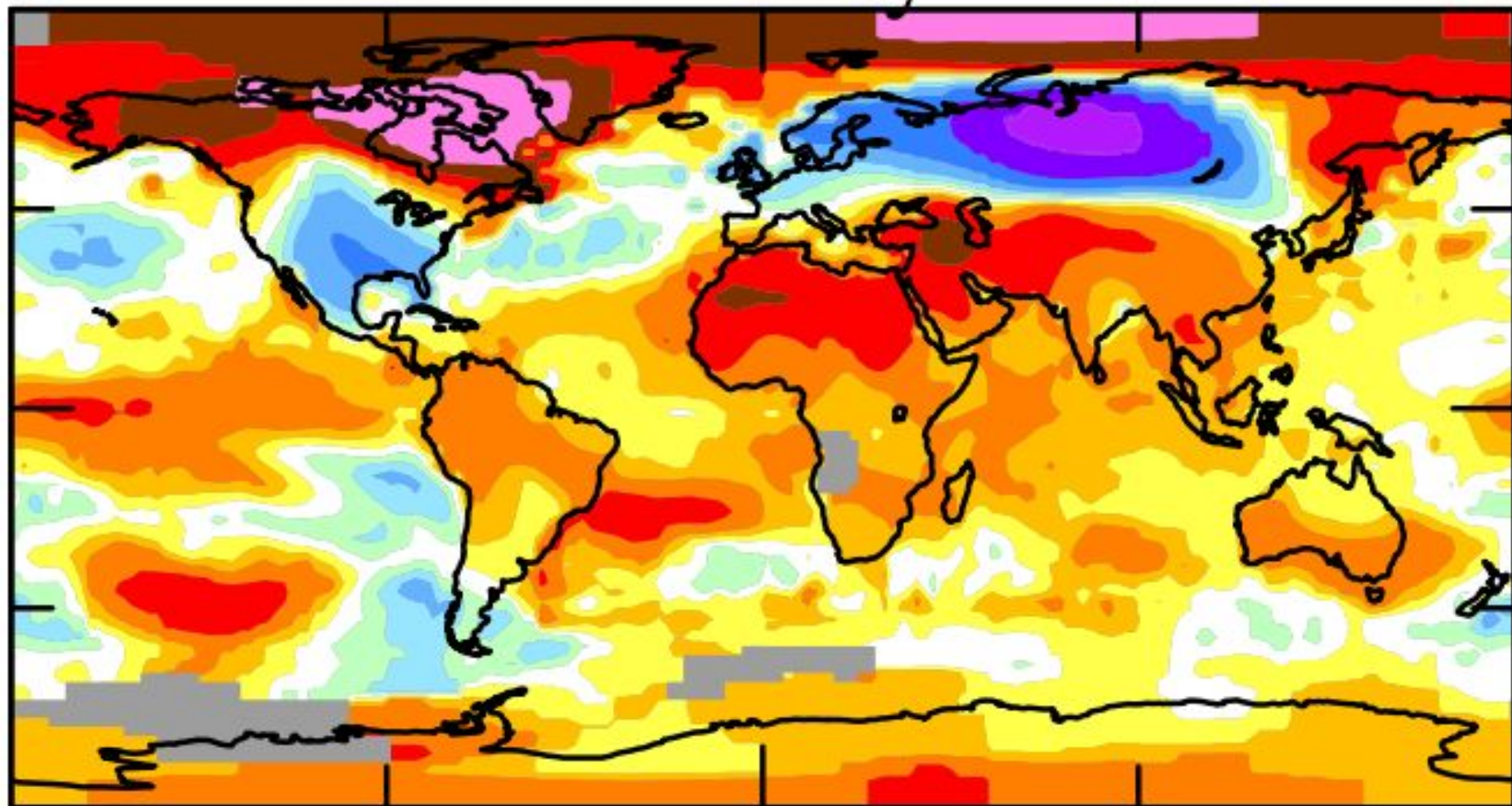
Radiative forcing (W m^{-2}) of:
a) all greenhouse gases, b) CO_2 only,
c) black carbon (soot), d) other aerosols.

This additional warming of the planet (see TOA values) with direct surface cooling and troposphere warming complicates the aerosol $\rightarrow$ climate influence even more.

N.H. Winter (Dec-Jan-Feb)

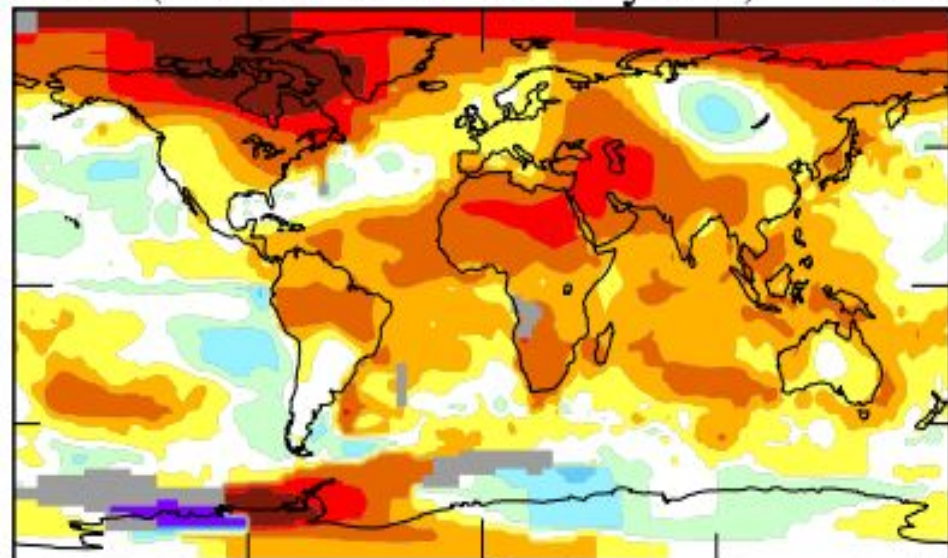
2nd warmest of 130 years 0.68

2010

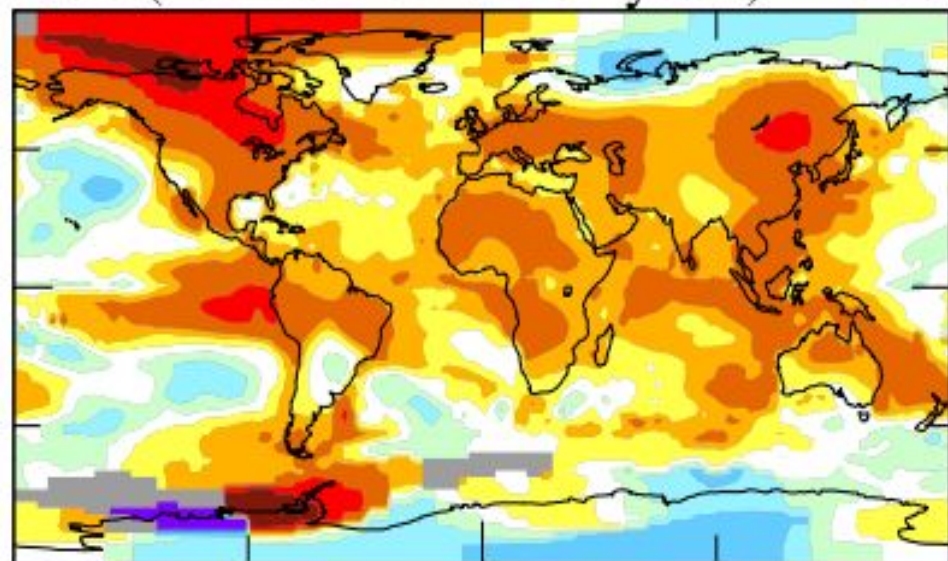


January-October Mean Surface Temperature Anomaly ($^{\circ}\text{C}$)

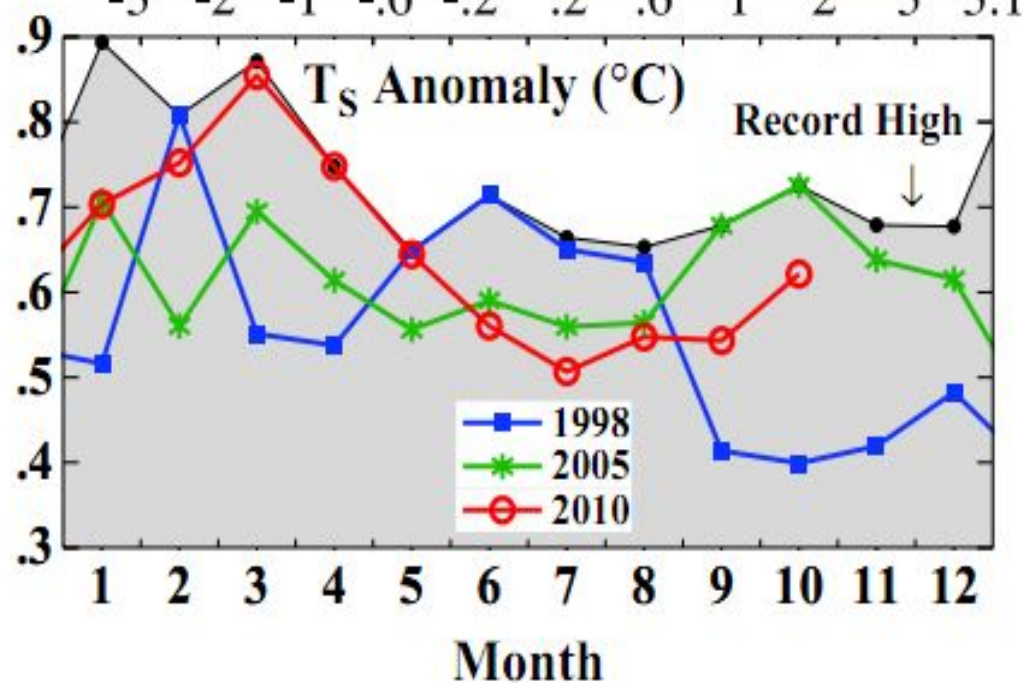
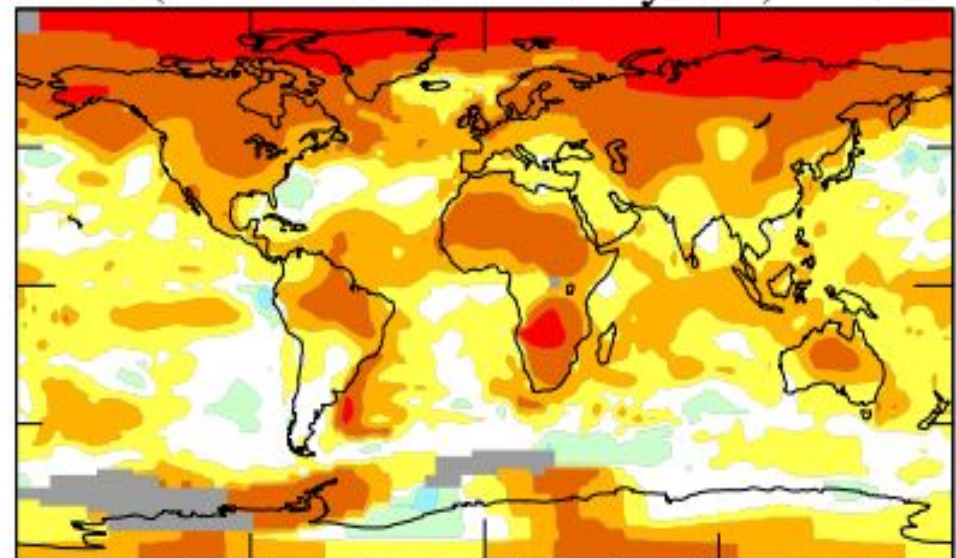
2010 (the warmest of 131 years) 0.65



1998 (4th warmest of 131 years) 0.59

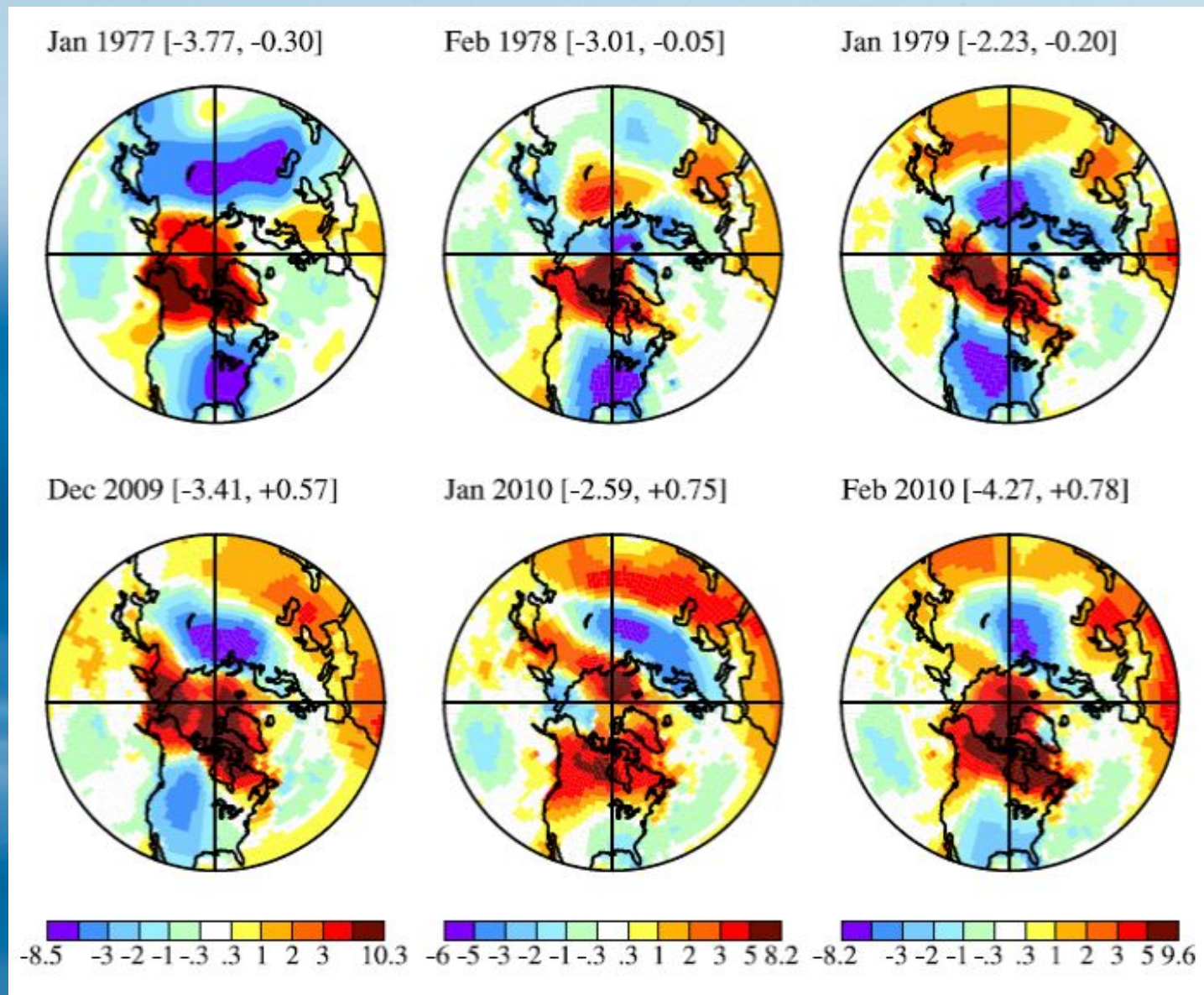


2005 (2nd warmest of 131 years) 0.62



Base Period: 1951-1980

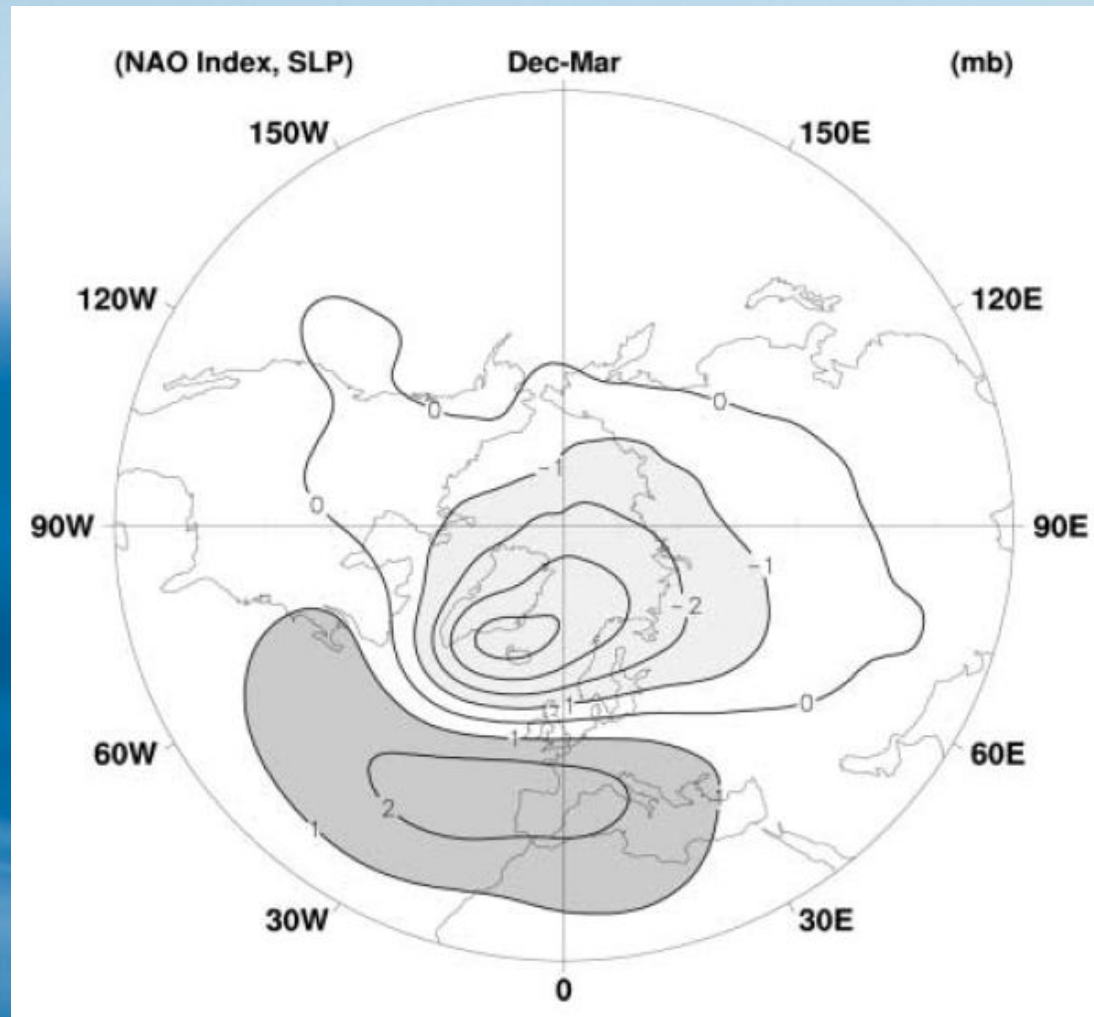
Low AO values lead to this kind of winters



90-24 N temperature anomaly for months with extremely negative AO Index

Hansen 2010 (unpublished)

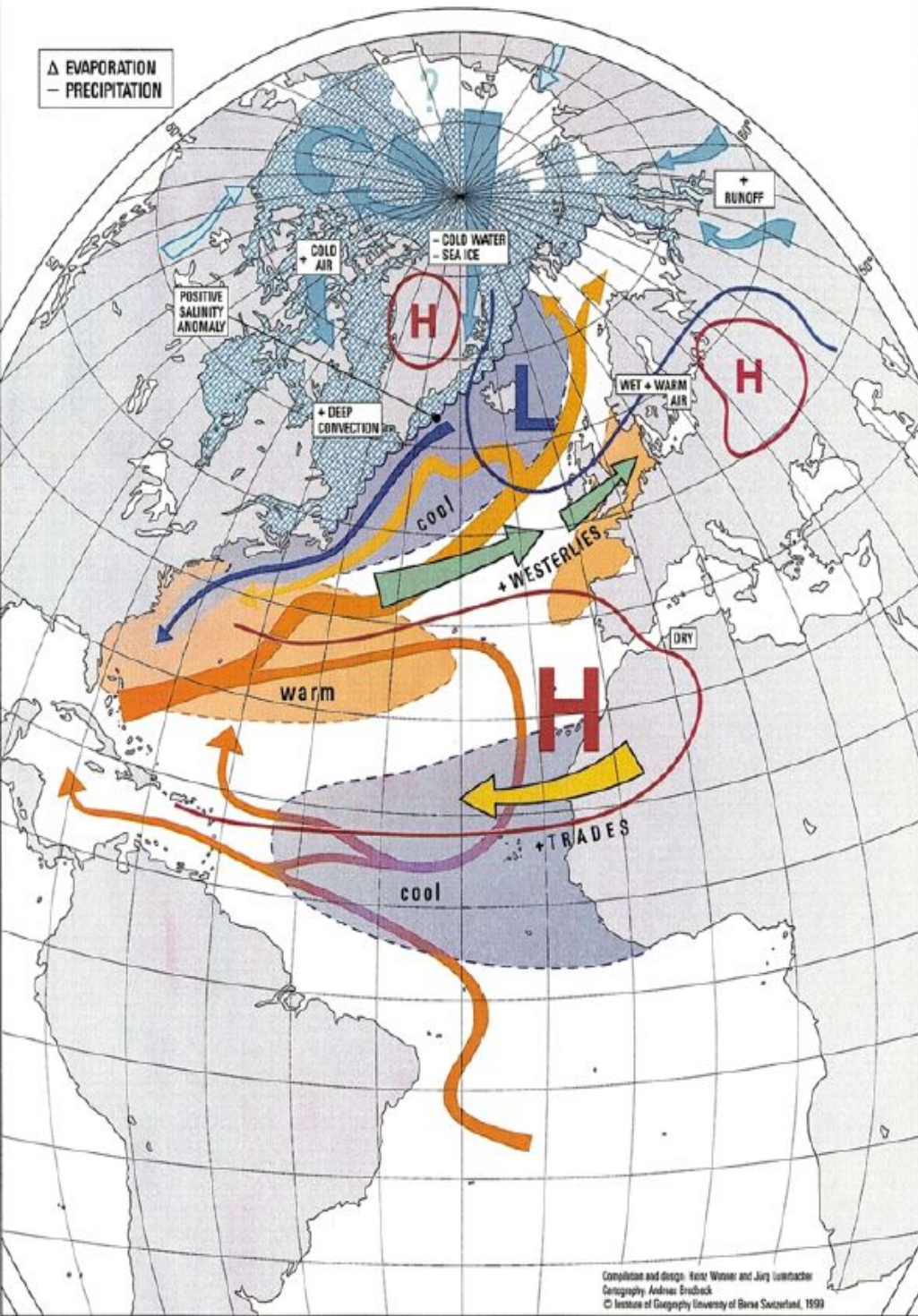
North Atlantic Oscillation (NAO)



NAO index, identified by Walker (1924), was historically defined as the surface air pressure difference between Lisbon, Portugal and Reykjavik, Iceland (the graph shows a positive NAO pressure pattern). NAO explains 31% variability in winter temperatures north of 20° N.

NAO +

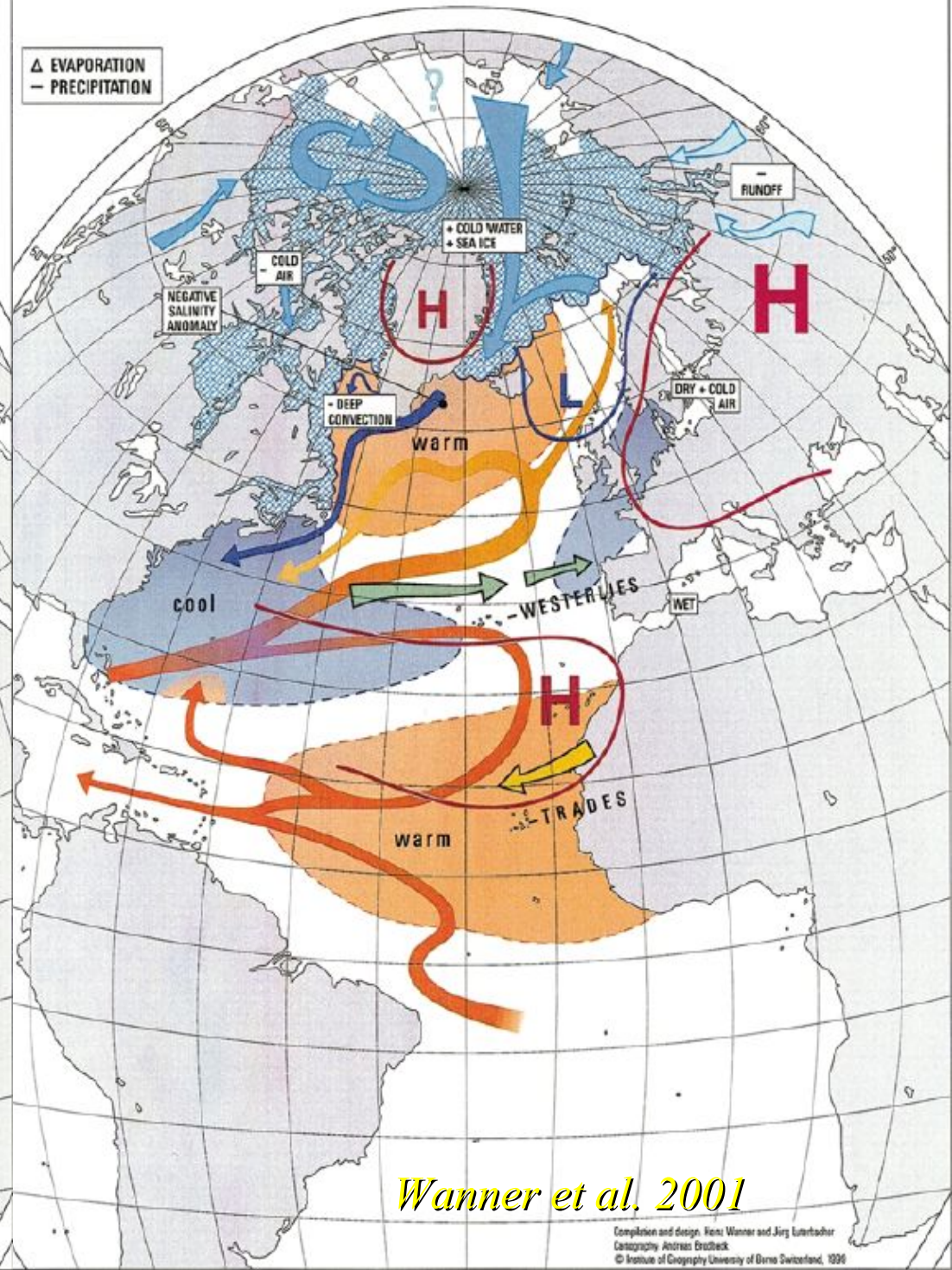
Δ EVAPORATION
- PRECIPITATION



Compilation and design: Rens Wanner and Jürg Luterbacher
Cartography: Andreas Brückner
© Institute of Geography University of Bern Switzerland, 1998

NAO -

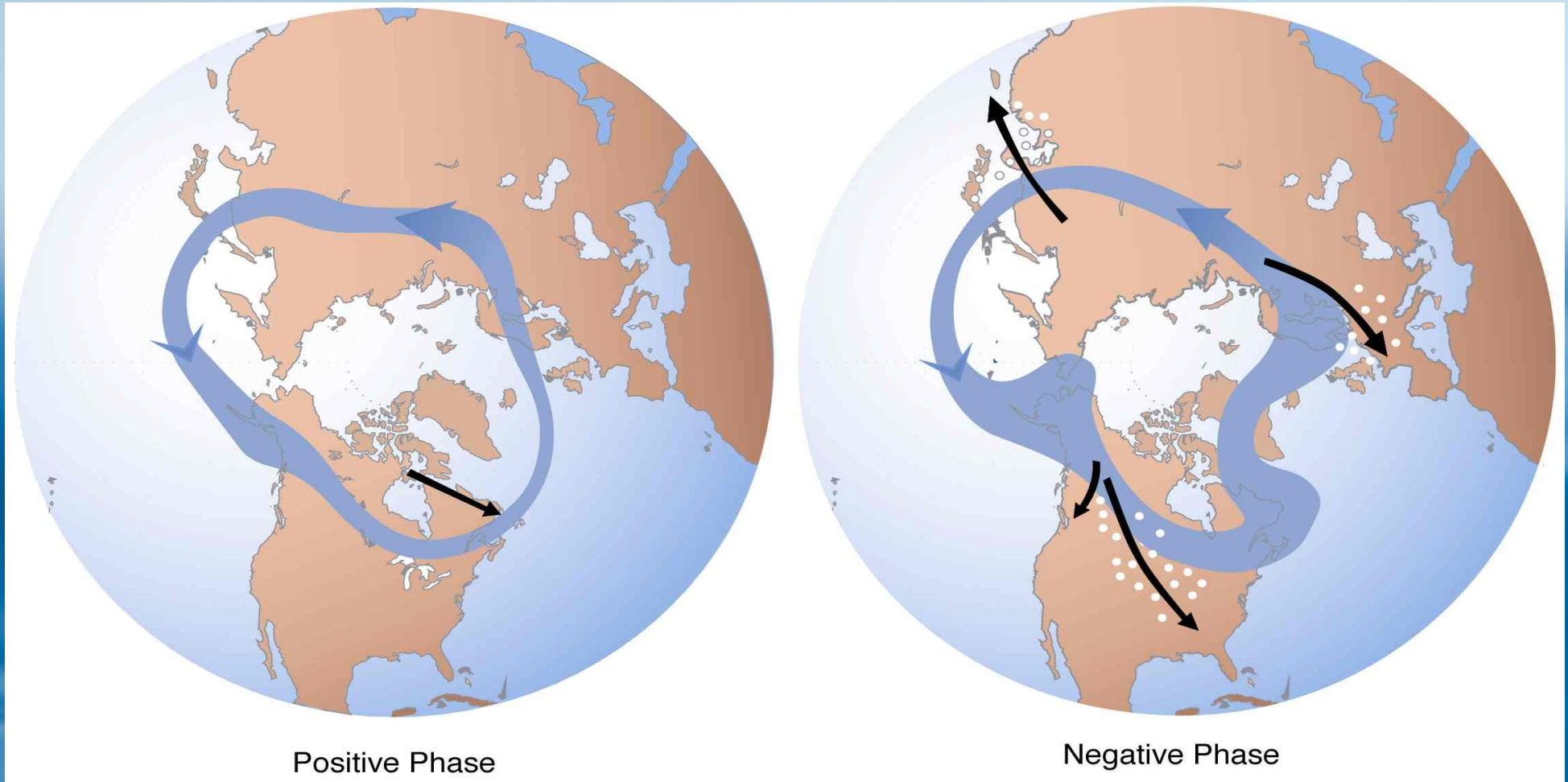
Δ EVAPORATION
- PRECIPITATION



Compilation and design: Rens Wanner and Jürg Luterbacher
Cartography: Andreas Brückner
© Institute of Geography University of Bern Switzerland, 1998

Wanner et al. 2001

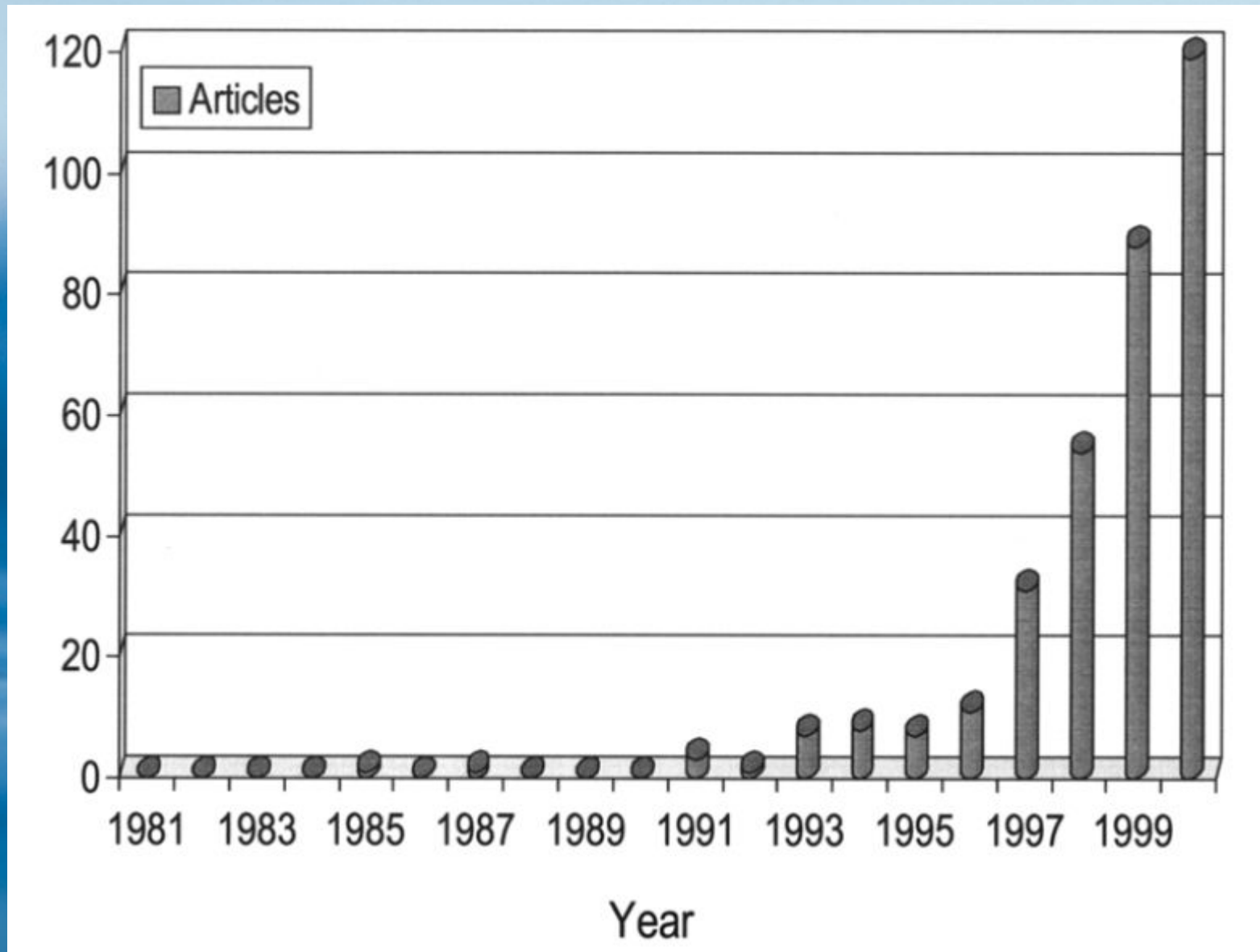
Arctic Oscillation (AO) and storm tracks



Another index, highly correlated with NAO is Arctic Oscillation – difference of air pressure between 37°-45° N zone and the polar vortex (and therefore a measure of its intensity). With positive AO, polar vortex is stronger and the storm tracks are closer to the pole.

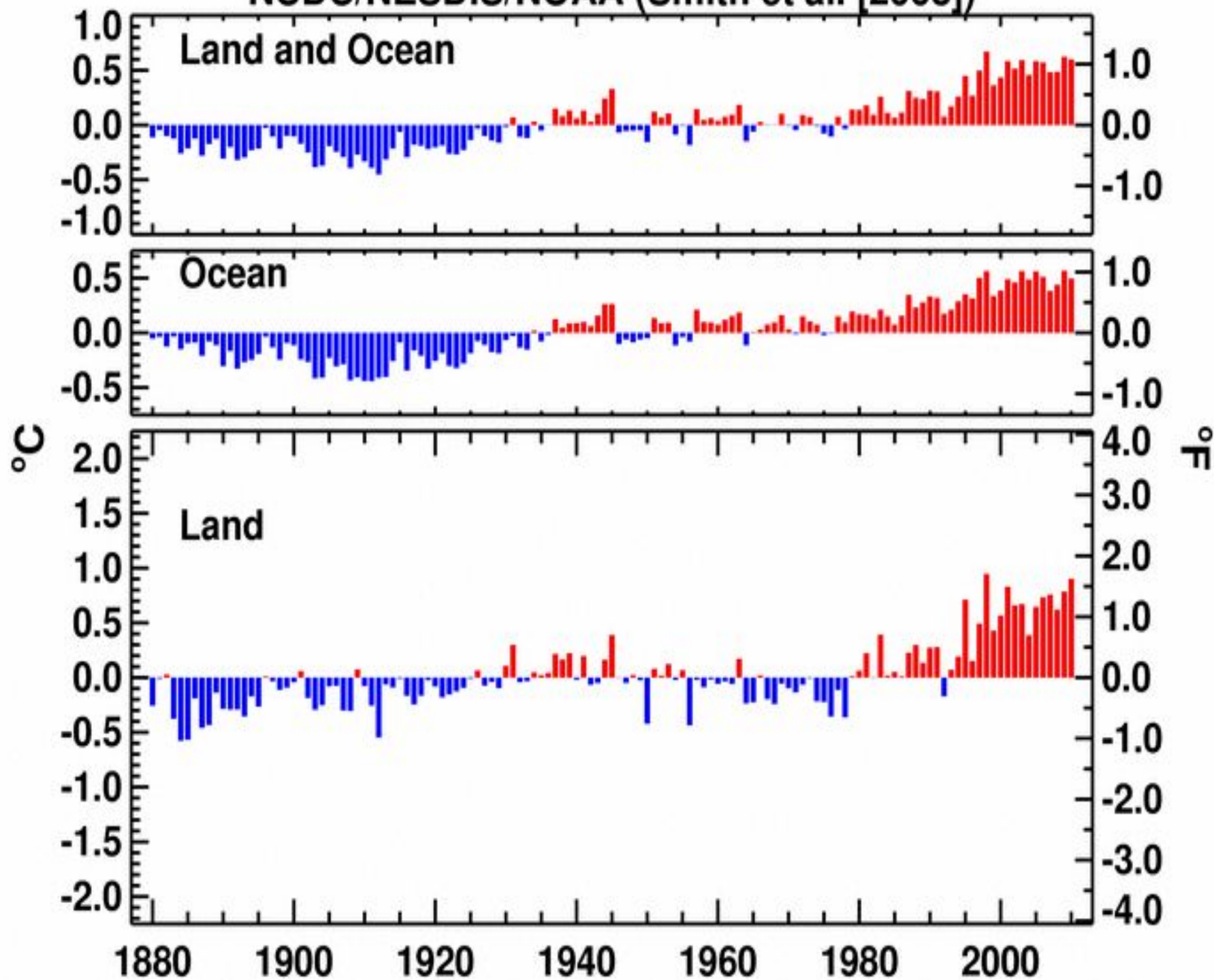
Most researchers treat NAO as the local Atlantic chapter of AO.

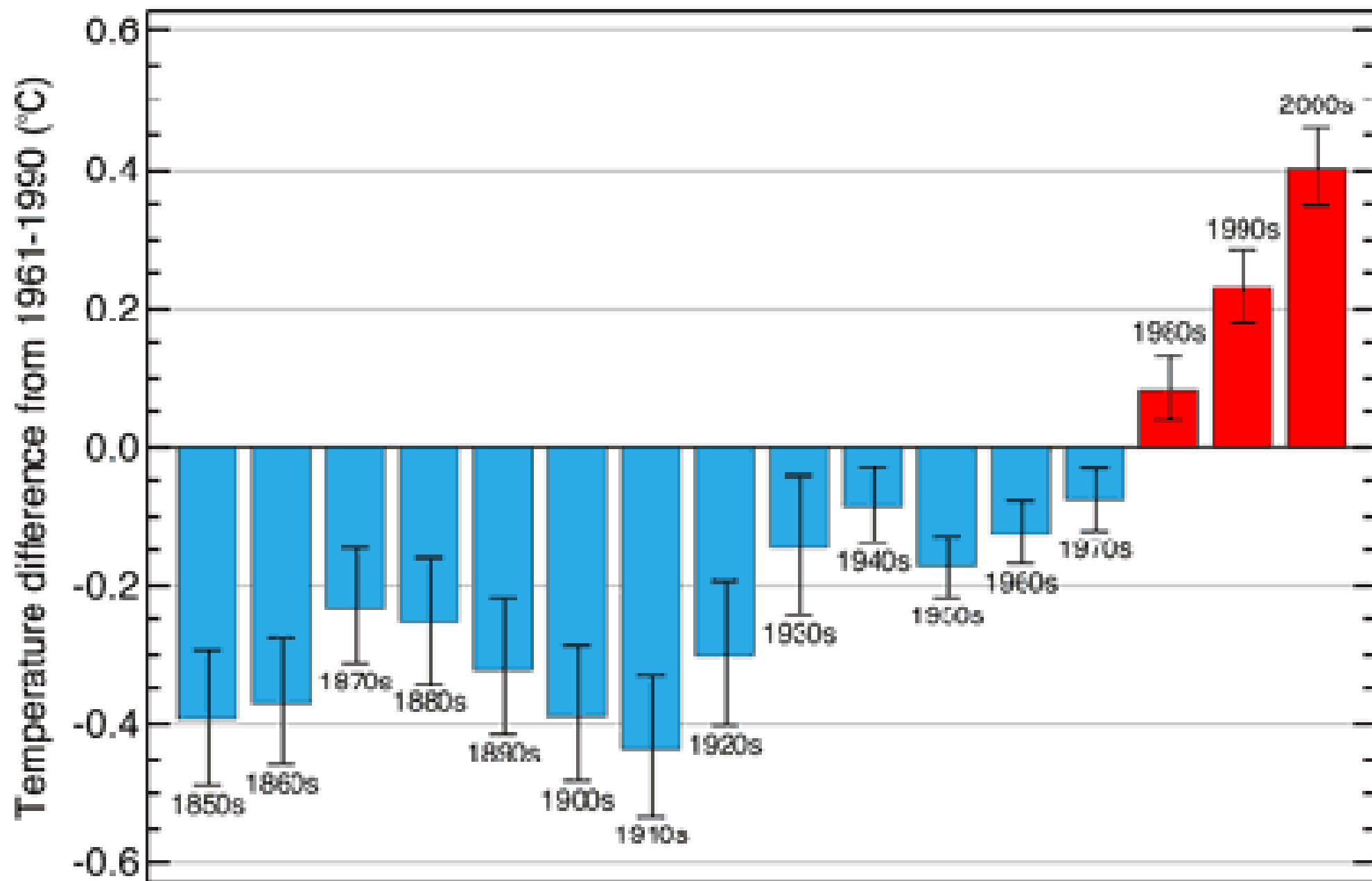
The number of scientific articles on NAO



August Global Surface Mean Temp Anomalies

NCDC/NESDIS/NOAA (Smith et al. [2008])

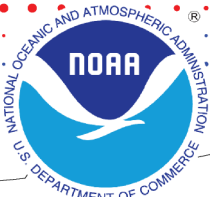
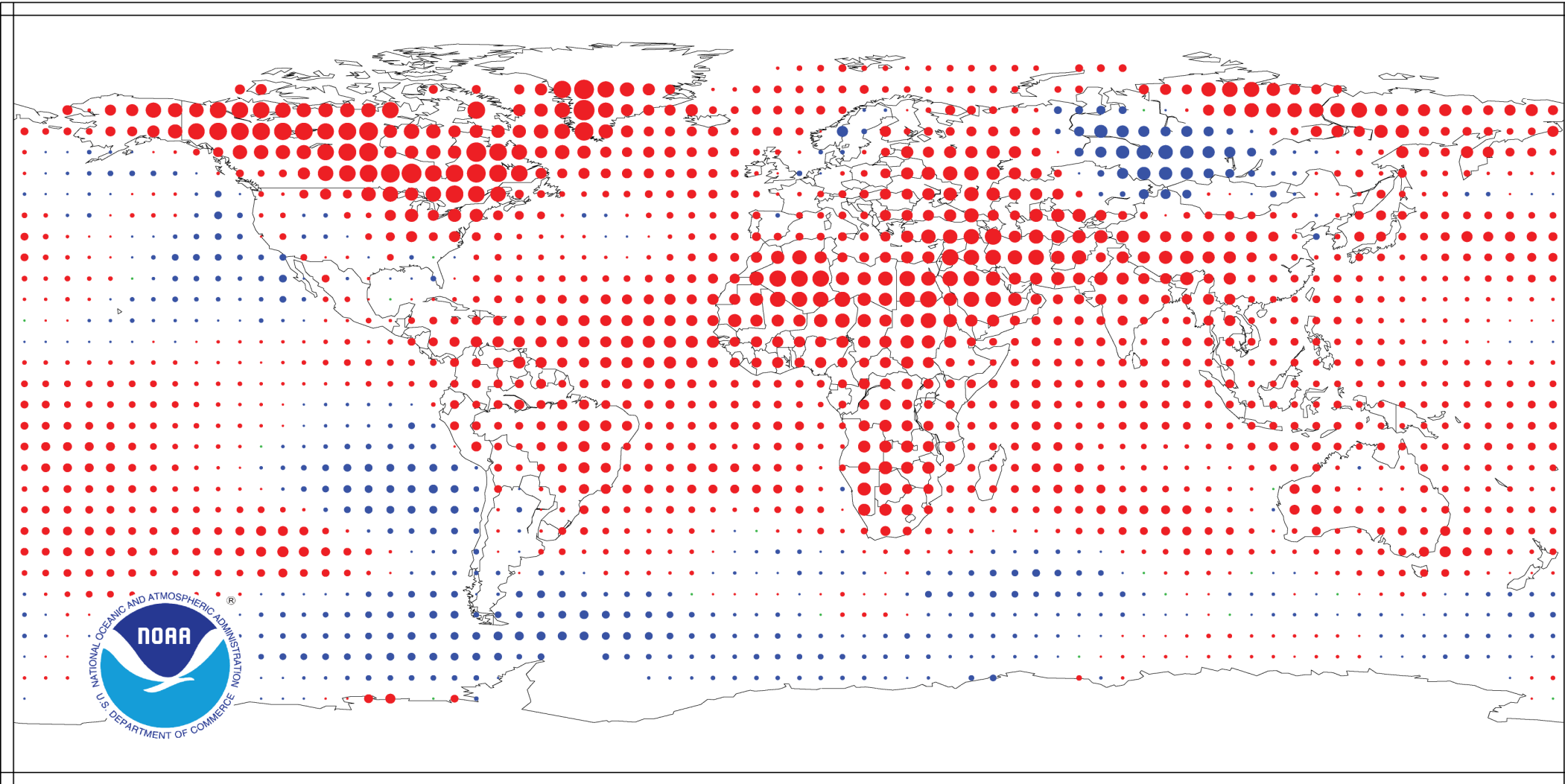




Temperature Anomalies Jan-Aug 2010

(with respect to a 1971-2000 base period)

National Climatic Data Center/NESDIS/NOAA

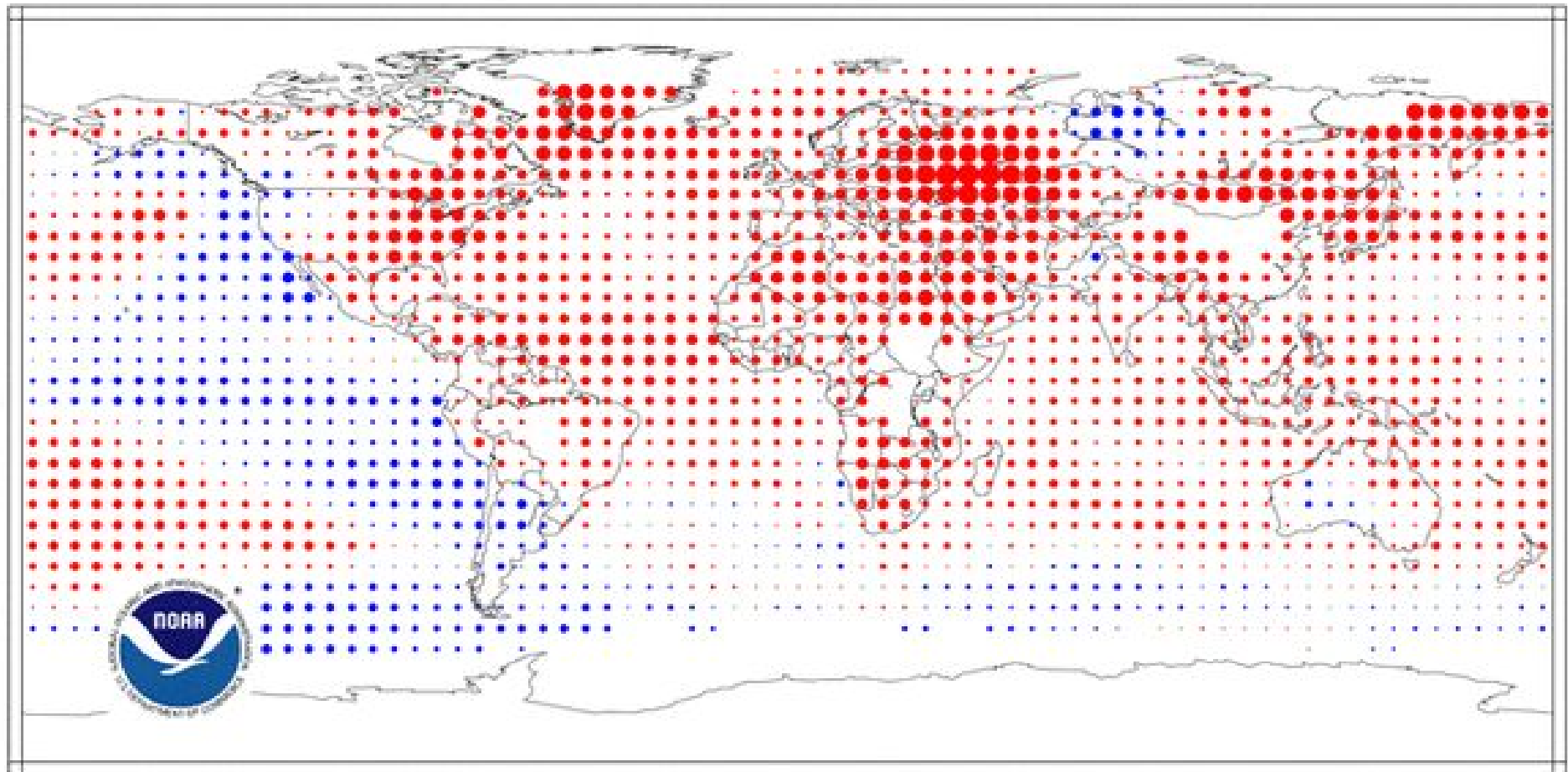


Degrees Celsius

Temperature Anomalies Jun-Aug 2010

(with respect to a 1971-2000 base period)

National Climatic Data Center/NESDIS/NOAA

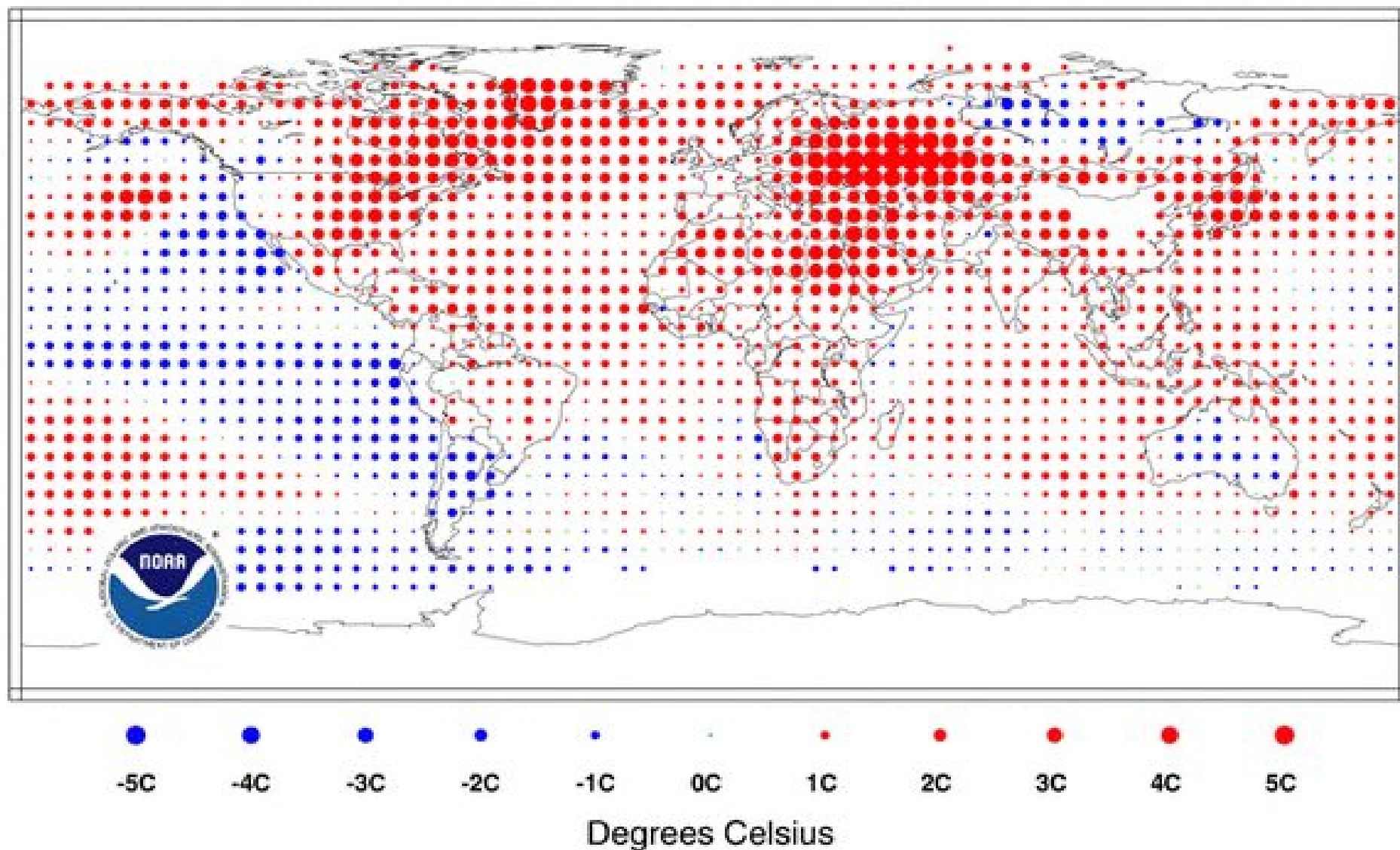


Degrees Celsius

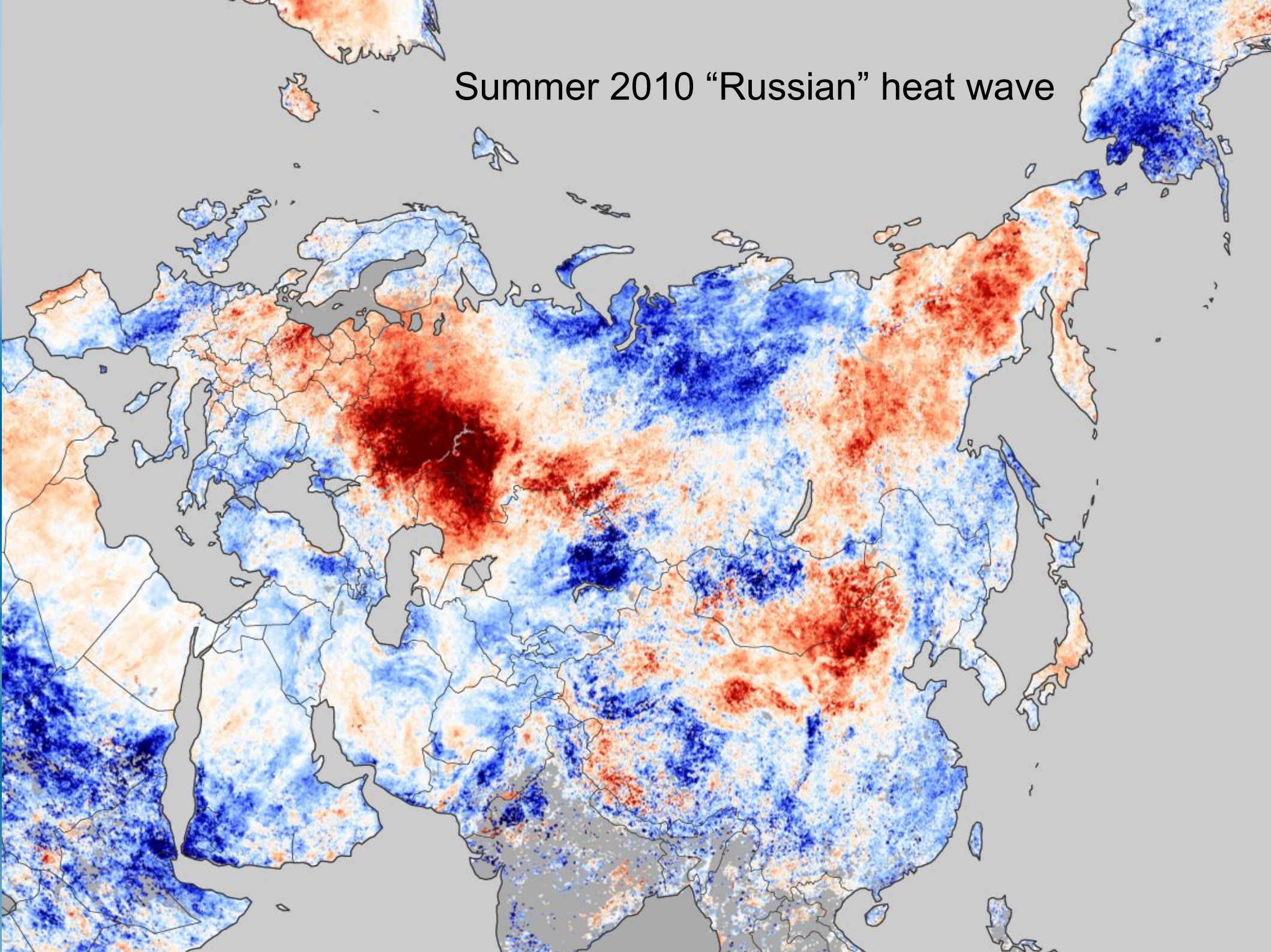
Temperature Anomalies August 2010

(with respect to a 1971-2000 base period)

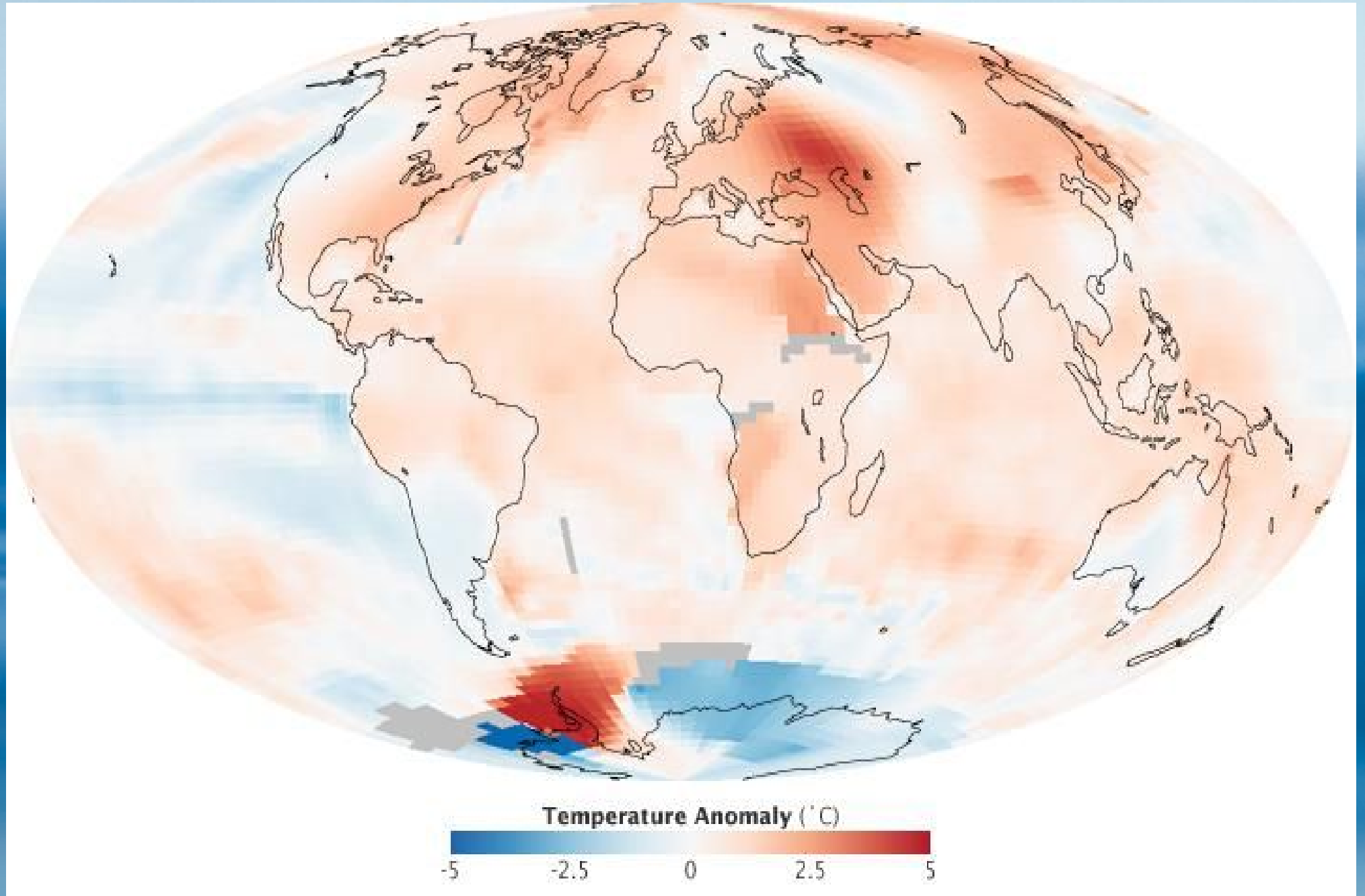
National Climatic Data Center/NESDIS/NOAA



Summer 2010 “Russian” heat wave



A global summer 2010 heat wave ?



Possibly to add in future:

- Evan et al 2009
- Park & Latif 2008
- Hofman Maqueda 2009 (to the previous one)
- Thompson et al 2010