The role of nonoceanic drivers on decadal climate predictability

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Key Points:

- Numerous extraoceanic processes active over the decadal scale are established
- Current ESMs underrepresent processes relevant for decadal predictability
- Predictive skill assessment is hampered by lack of observations

Advancements in decadal climate predictability: The role of nonoceanic drivers

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[Bellucci et al., 2015]

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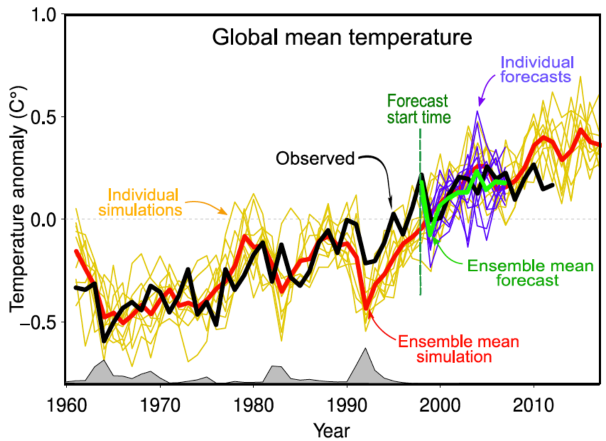
Drivers of decadal-scale predictability

OCEAN

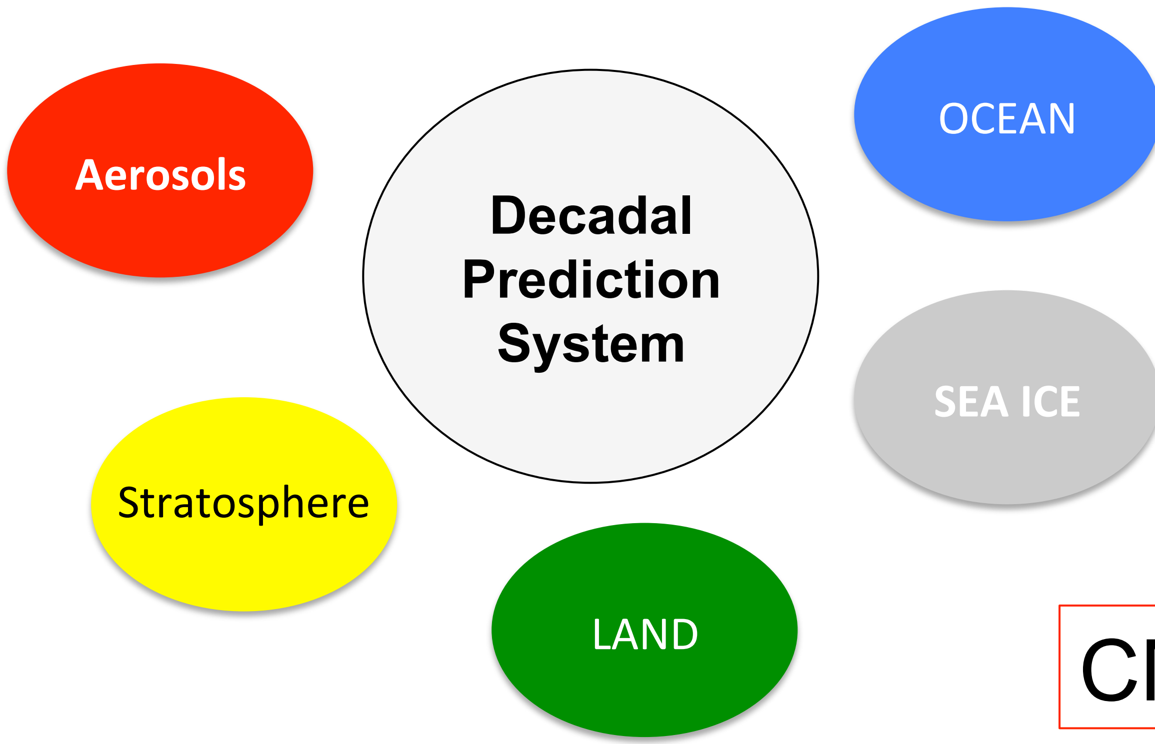
Decadal Prediction System



CMIP5

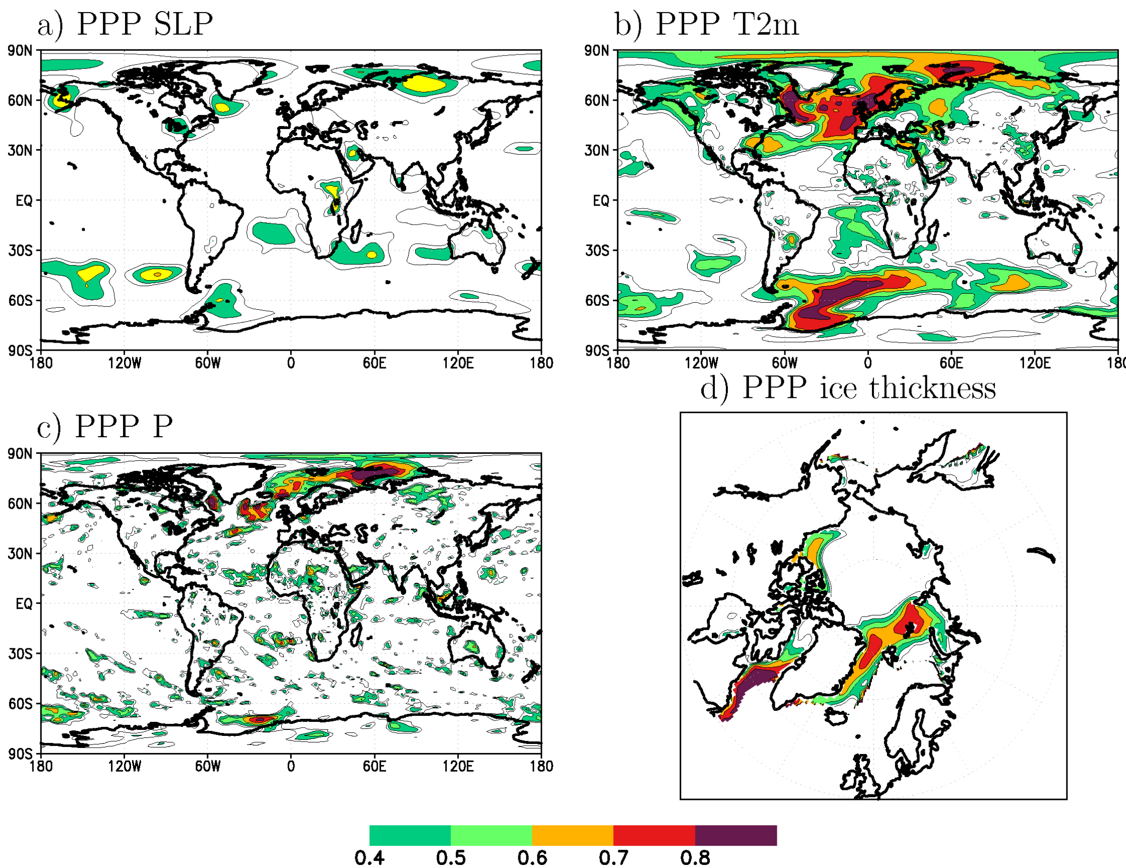
In CMIP5, most of the attention was dedicated to the oceans, as a primary source of predictability.

Drivers of decadal-scale predictability



CMIP-*N*

As the degree of complexity of Earth system models and our understanding of the physical processes at work increase, it is expected that DPS will follow, including additional sources of decadal predictability



[Koenigk et al., 2012]

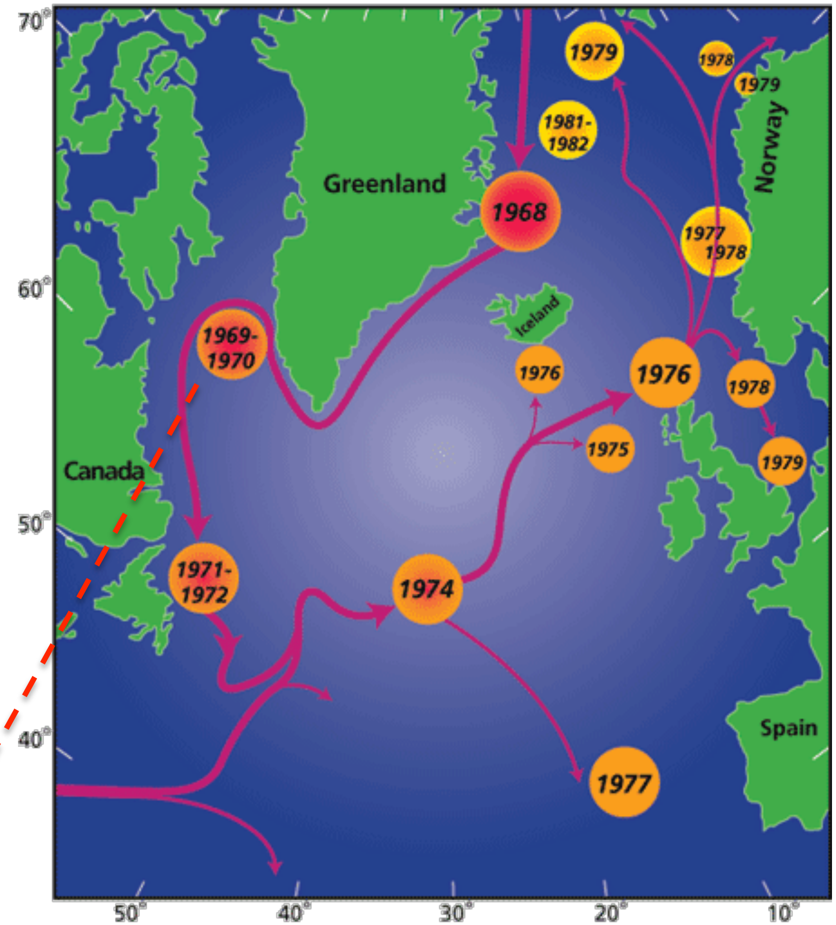
Potential Predictability in the Arctic

Results from a potential predictability study indicate that decadal averages of Arctic **sea ice thickness and area are well predictable along the ice edges** in the North Atlantic ice sector [Koenigk et al., 2012]. Connected to the ice variations, **air temperature and precipitation show a high potential predictability**, particularly in the Labrador and Barents/Kara Seas regions.

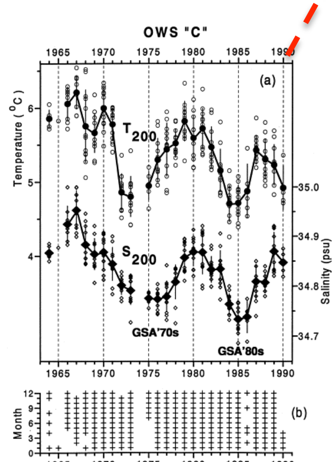
Ice export through the Fram Strait

Transport of sea ice contributes to predictability. This is particularly the case in the East Greenland Current: sea ice anomalies that propagate south from Fram Strait in the East Greenland Current, melt, and enter the Labrador Sea after about 2 years as freshwater anomalies. Positive freshwater anomalies reduce the deep water convection in the Labrador Sea, and this might **affect the Atlantic MOC.**

Great Salinity Anomalies (GSA) in the Labrador Sea provide a prominent example of this process.



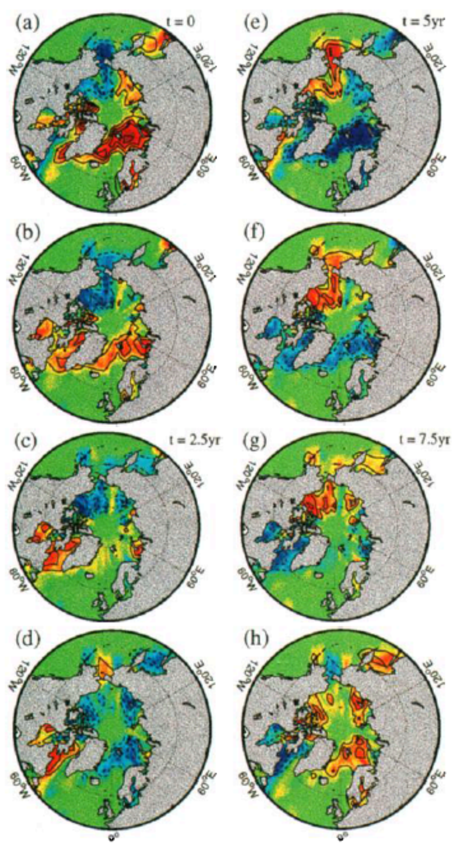
[Schmitt, 1996]

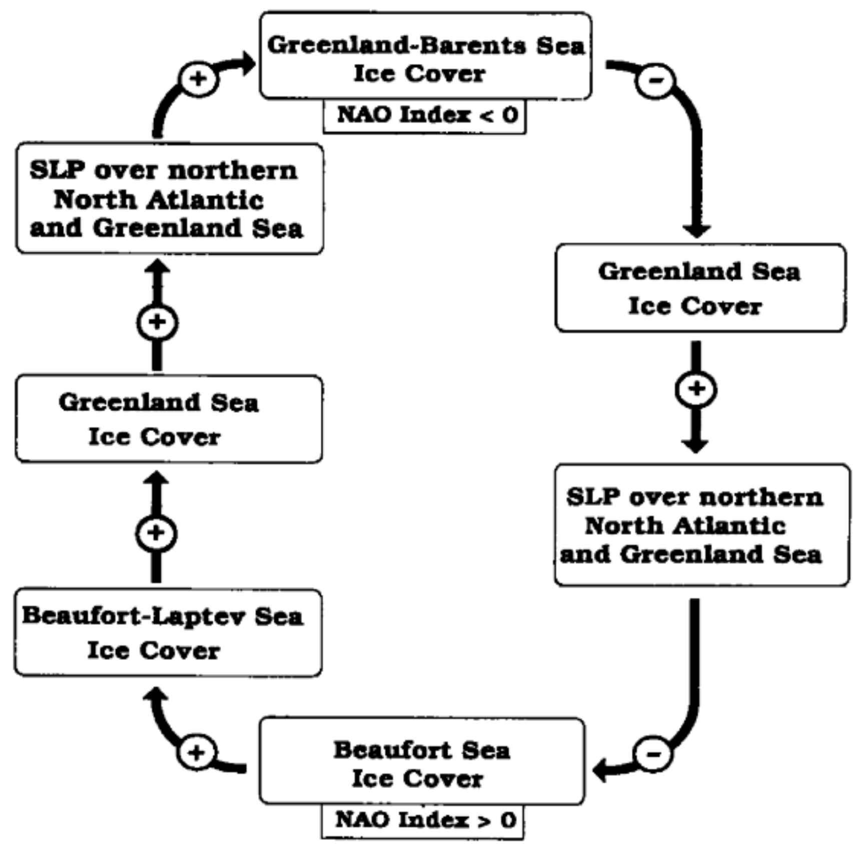


[Belkin et al., 1998]

Arctic sea ice/AO interactions

A number of studies suggest Arctic climate modes with time scales of 10–15 years, which fit well to the observed ice variations, involving the complex interplay between sea-ice extent anomalies and atmospheric circulation (**switch in the phase of the Arctic Oscillation**).





[Mysak and Venegas, 1998]

Arctic sea ice/AO interactions
A number of studies suggest Arctic climate modes with time scales of 10–15 years, which fit well to the observed ice variations, involving the complex interplay between sea-ice extent anomalies and atmospheric circulation (**switch in the phase of the Arctic Oscillation**).

Arctic sea ice/midlatitude atmospheric variability connection

- Evidence is accumulating that Arctic sea ice and midlatitude atmospheric variability are associated (Overland and Wang [2010]; Budikova [2009]).

- Relationship between the rapid Arctic sea ice decline and the recent chain of extreme winters and summers in midlatitudes remains controversial [Francis and Vavrus, 2012; Screen, 2014; Thomas, 2014; Barnes, 2013; Barnes et al., 2014].

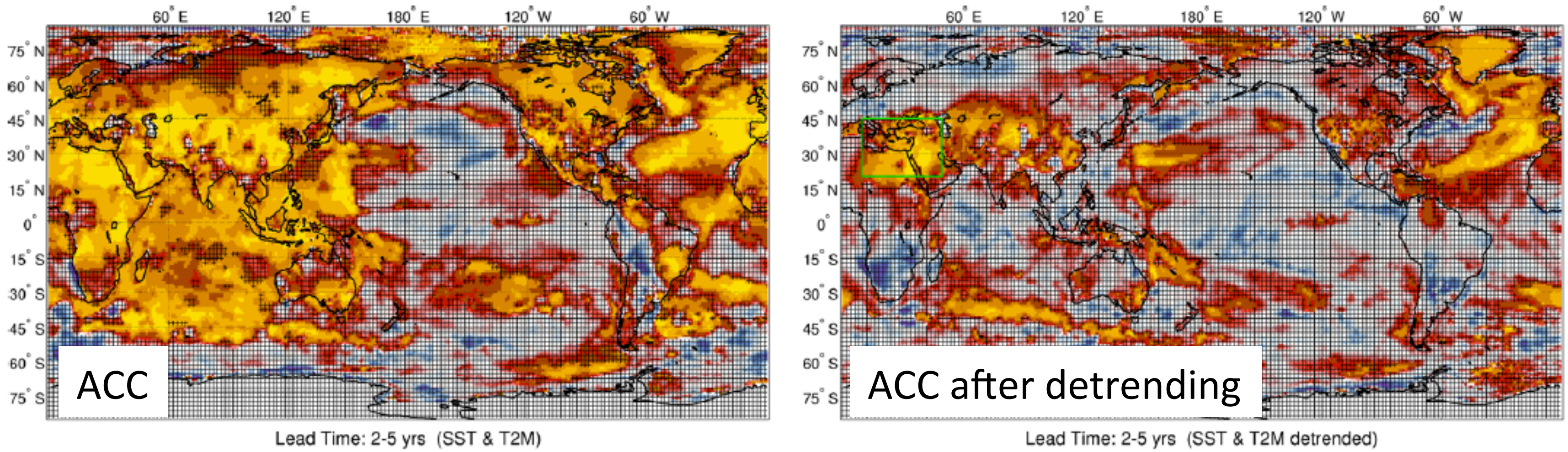
- Potential for sea ice initialization is known through potential prognostic predictability (PPP) experiments, but this potential has not been explored yet in real decadal predictions

- A fundamental limitation for assessing sea ice prediction skill is the lack of observations to perform adequately initialized hindcasts to robustly quantify predictability

- Physical consistency among sea-ice, atmosphere and ocean initial states needed to mitigate the initialization shock

- Role of sea ice initialization on the predictability of Southern Ocean climate has not been investigated yet

Land surface

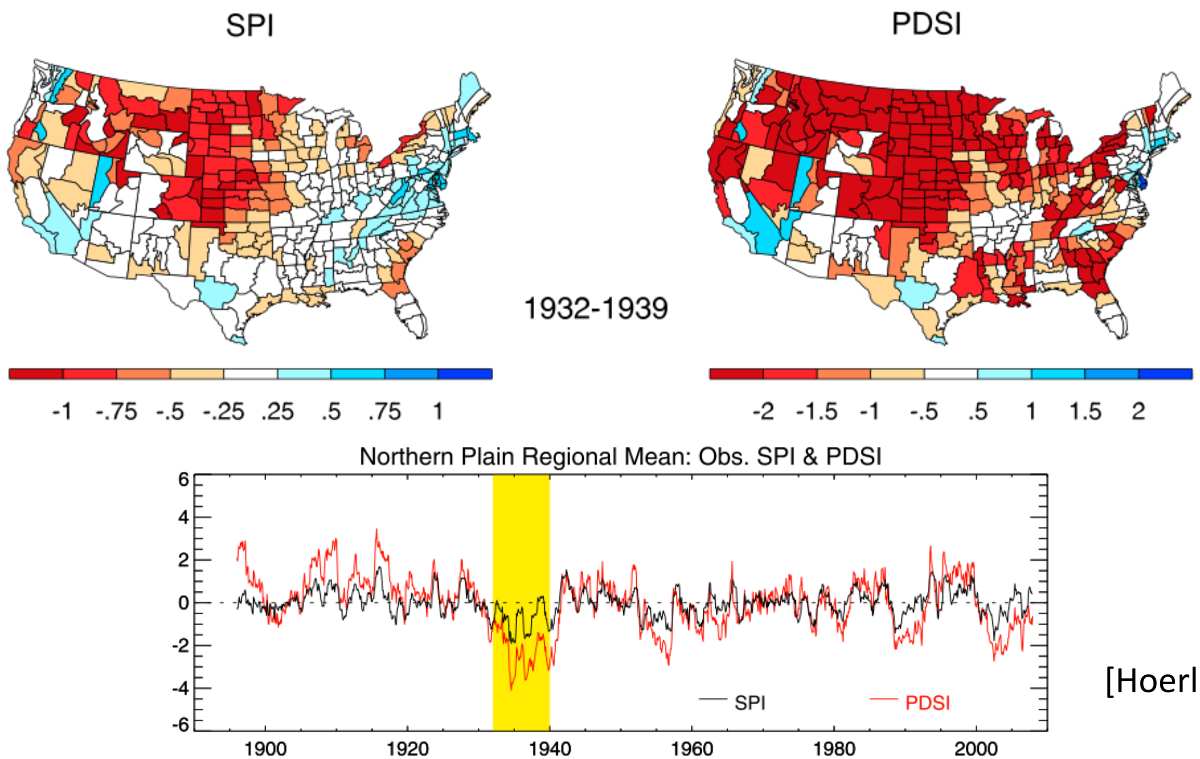


[Bellucci et al., 2014]

The skill of ocean-initialized decadal predictions over land drops drastically when linear temperature trends are removed, over most of the Earth's surface.

The land surface components featuring longer memory, such as **soil moisture and vegeation**, may be a meaningful source of information for predictability at decadal time scales.

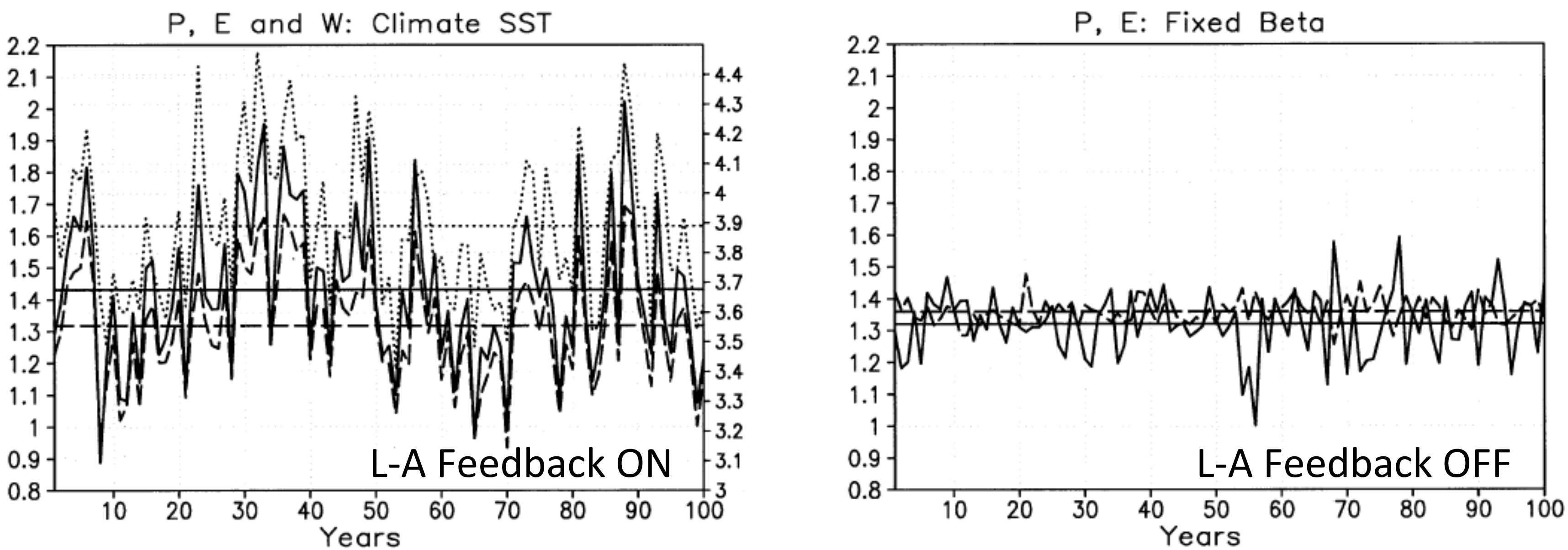
Land surface



[Hoerling et al., 2009]

Some studies point out that the 1930s Dust Bowl drought was triggered mostly by atmospheric variability, inducing low soil moisture that possibly initiated positive feedbacks with the land surface maintaining the dry condition.

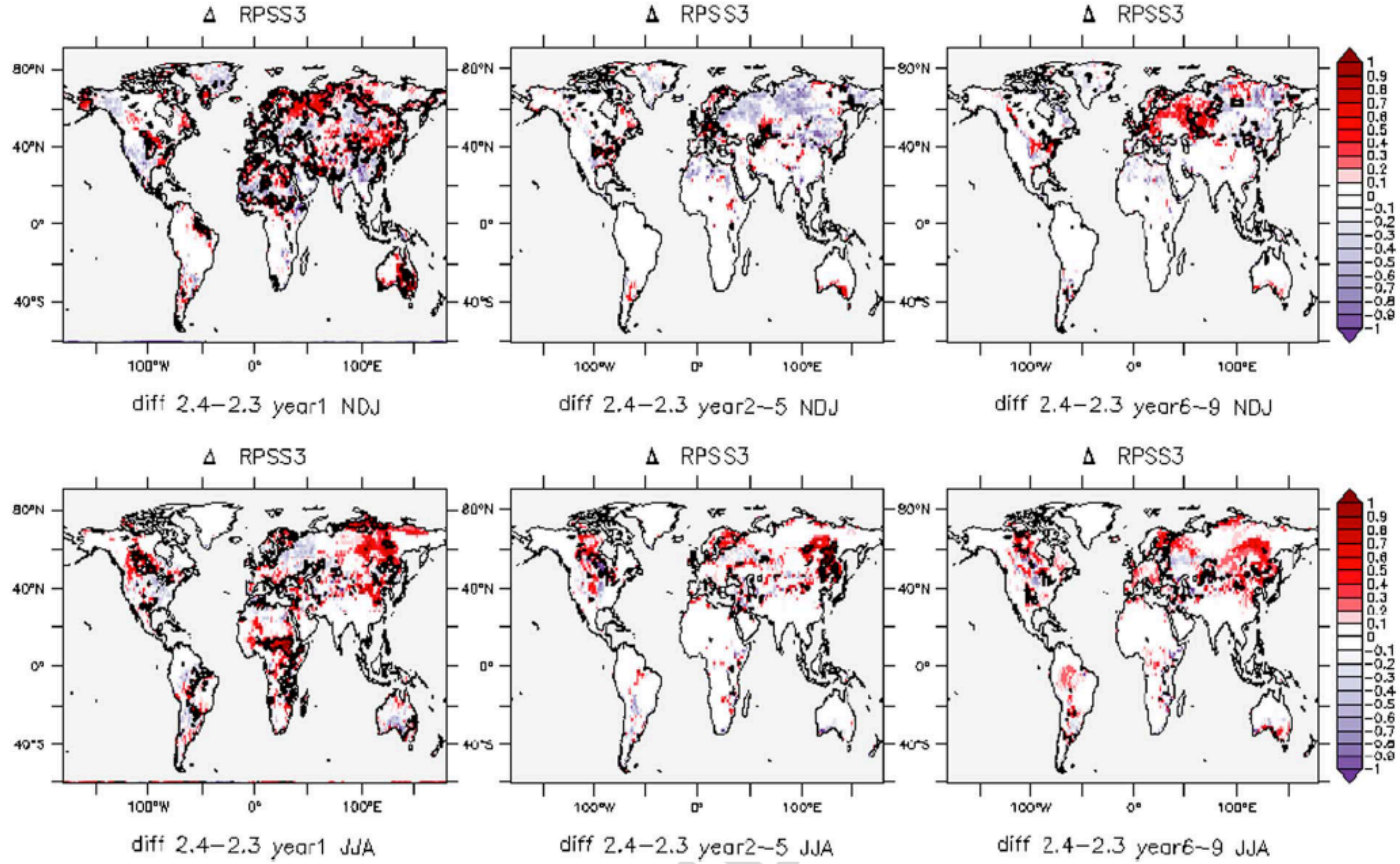
Role of **land-atmosphere feedback** on US Great Plains hydrological cycle decadal variability.



[Schubert et al., 2004]

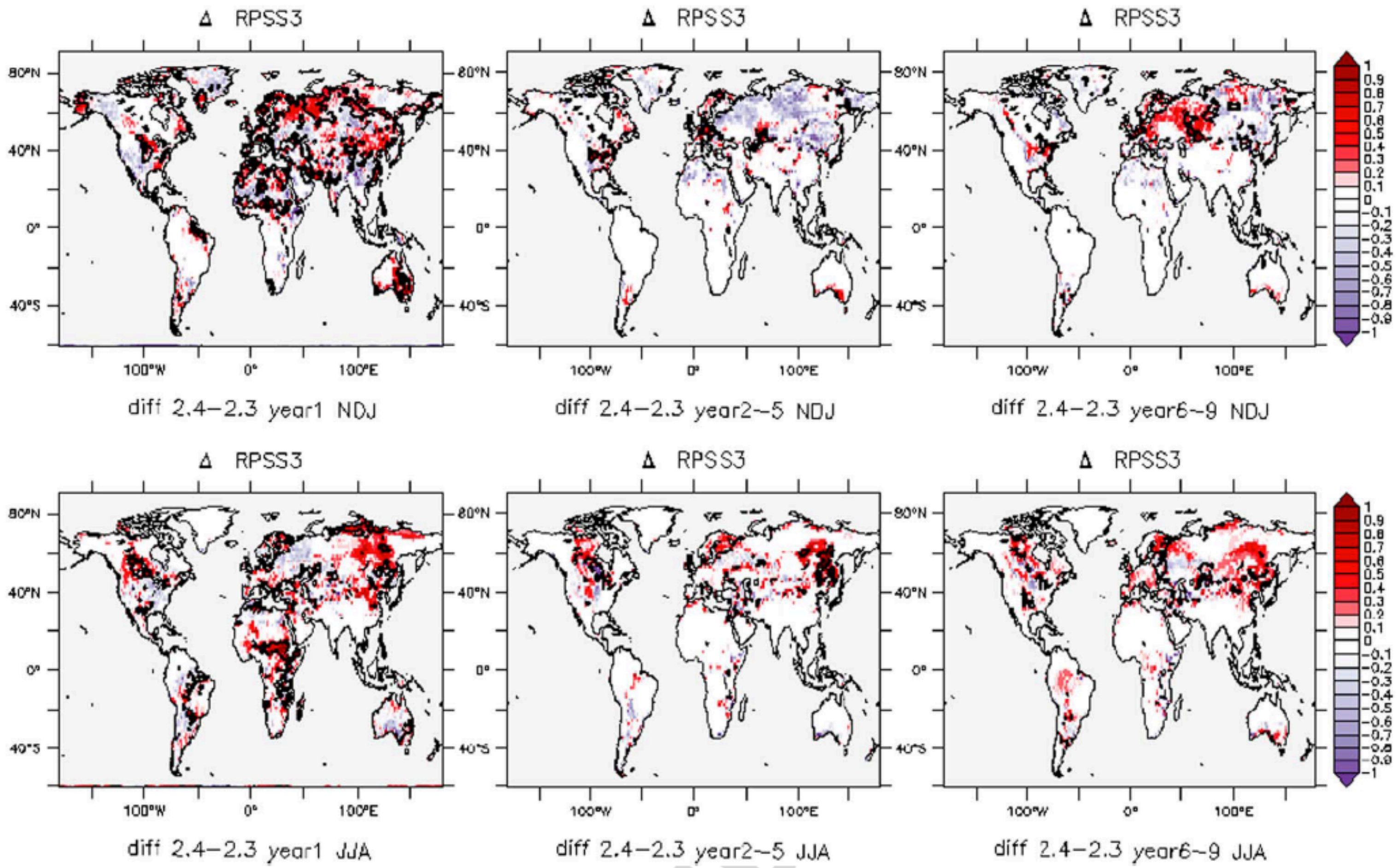
Schubert et al. [2004] have shown that **disabling the land-atmosphere coupling does not allow the reproduction of the low-frequency changes of precipitation over the Great Plains**, highlighting the importance of such a mechanism for the self-sustenance of the multiyear drought.

Impact of vegetation on proabilistic skill in a set of decadal hindcasts.



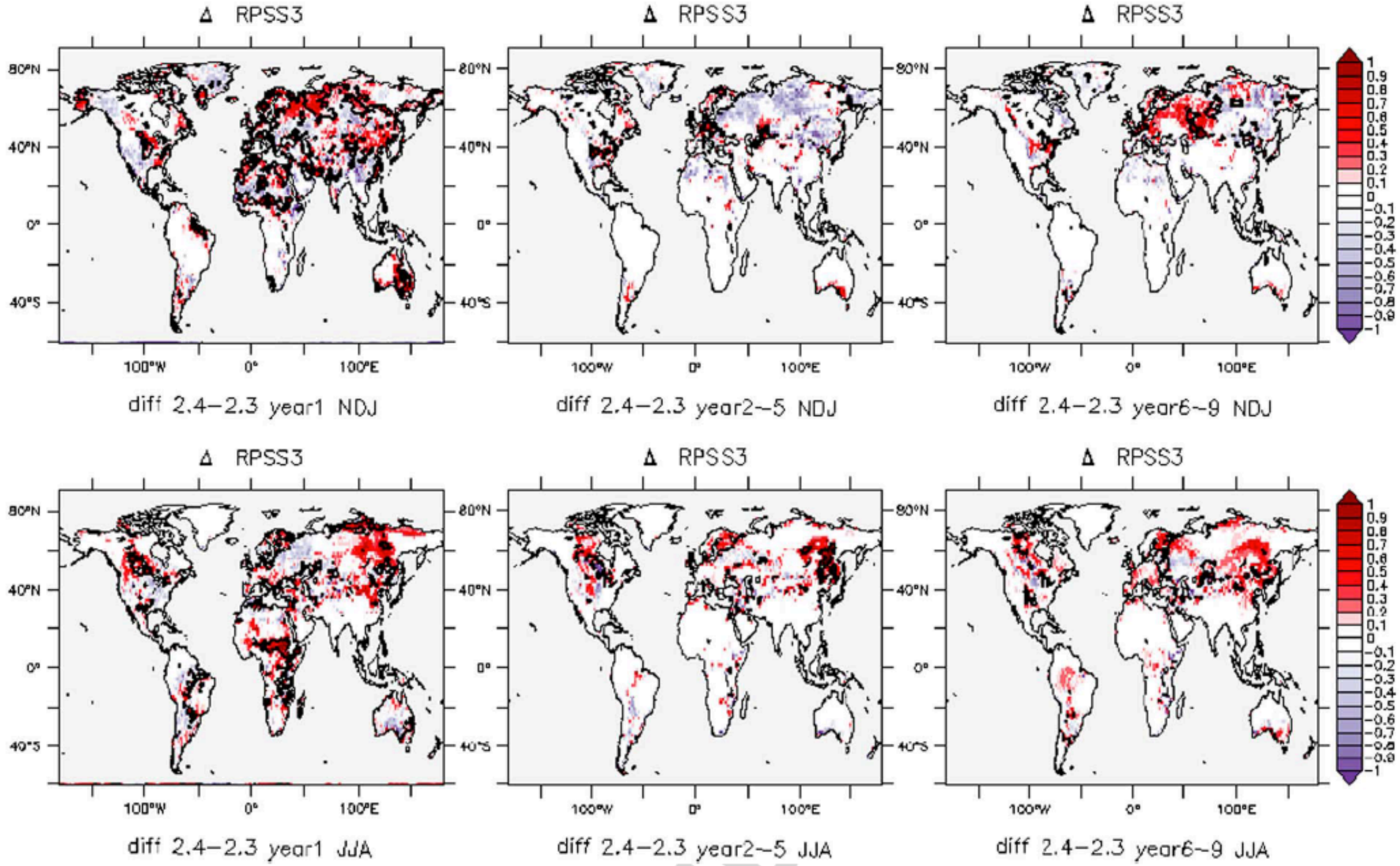
Weiss et al. [2014] analyse the impact of vegetation in a set of decadal hindcasts, and find an **improvement in the probabilistic skill in a few regions, especially in the first year after initialization**. In addition, the additional degrees of freedom introduced by the **interactive vegetation generate additional noise** to the model that does not necessarily translate into improved skill.

Impact of vegetation on proabilistic skill in a set of decadal hindcasts.



In order to explore the added value of a realistic initialization for vegetation, **start dates other than November** (as prescribed by the CMIP5 protocol) **should be considered** in the experimental design. Probably the **initial vegetation state in early Northern Hemisphere spring contains a lot more useful information**, for both the seasonal and the decadal time scale.

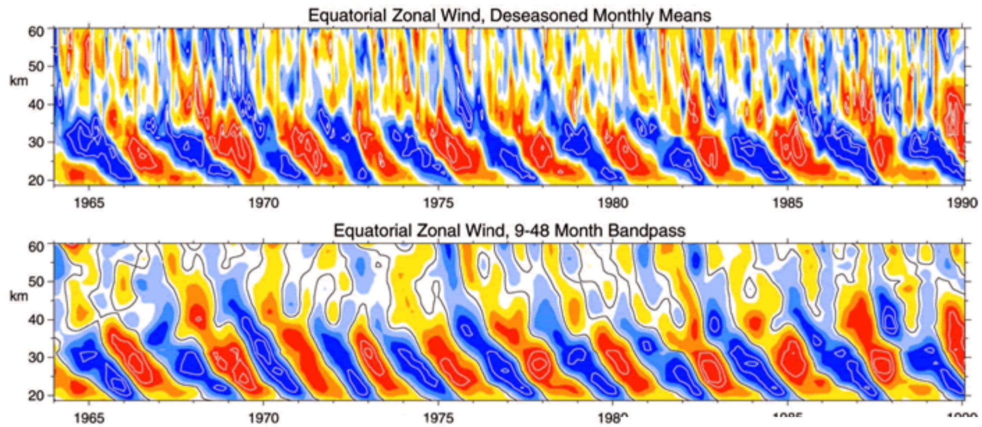
Impact of vegetation on proabilistic skill in a set of decadal hindcasts.



Predictable trends in **deforestation** may provide a source of predictability over the areas affected [e.g., Sampaio et al., 2007]

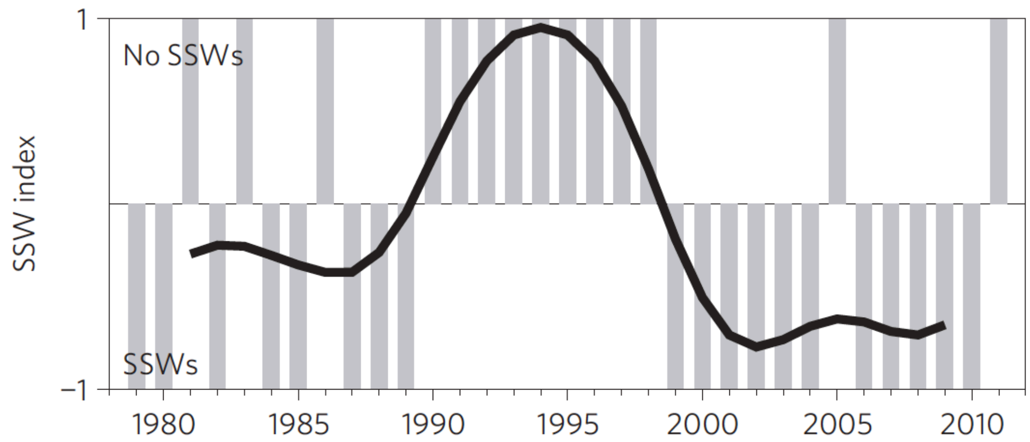
Stratosphere

QBO



[Baldwin et al., 2001]

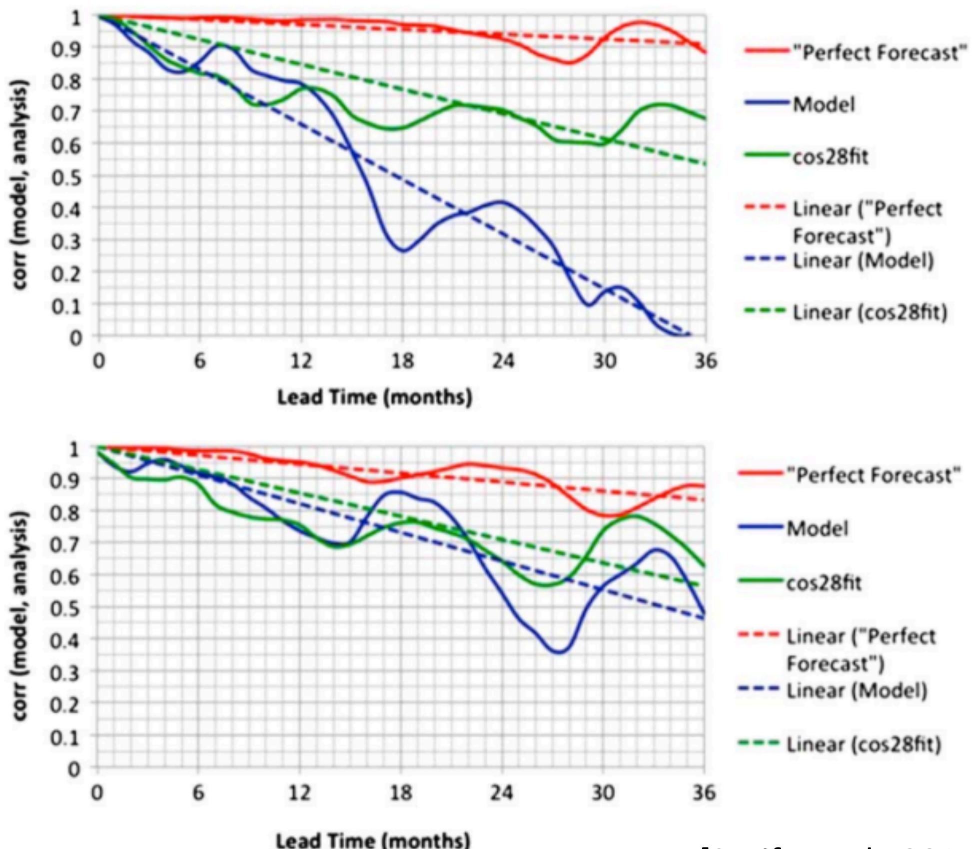
SSW



[Reichler et al., 2012]

The stratosphere features considerable energy over multi-annual (QBO) and multi-decadal timescales (SSW).

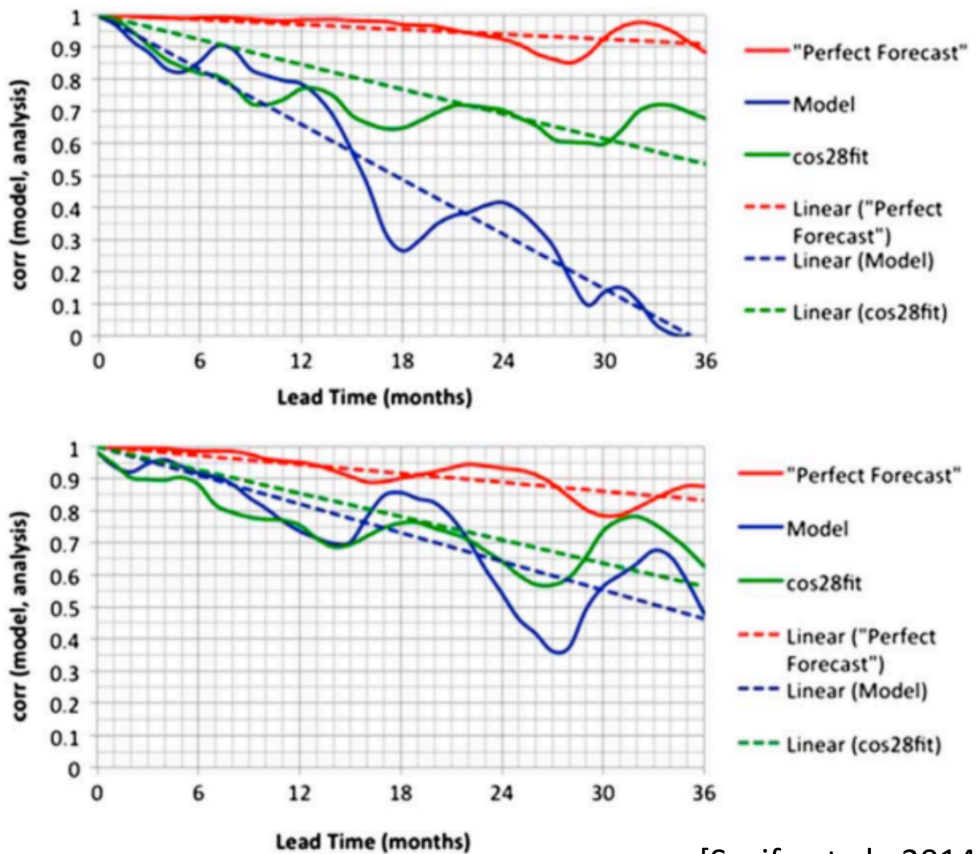
The impact of QBO on multi-year predictability



[Scaife et al., 2014]

Initialization of the tropical stratosphere can be beneficial for representing the correct phase and amplitude of the QBO for a few years following initialization (Scaife et al. [2014]).

The impact of QBO on multi-year predictability

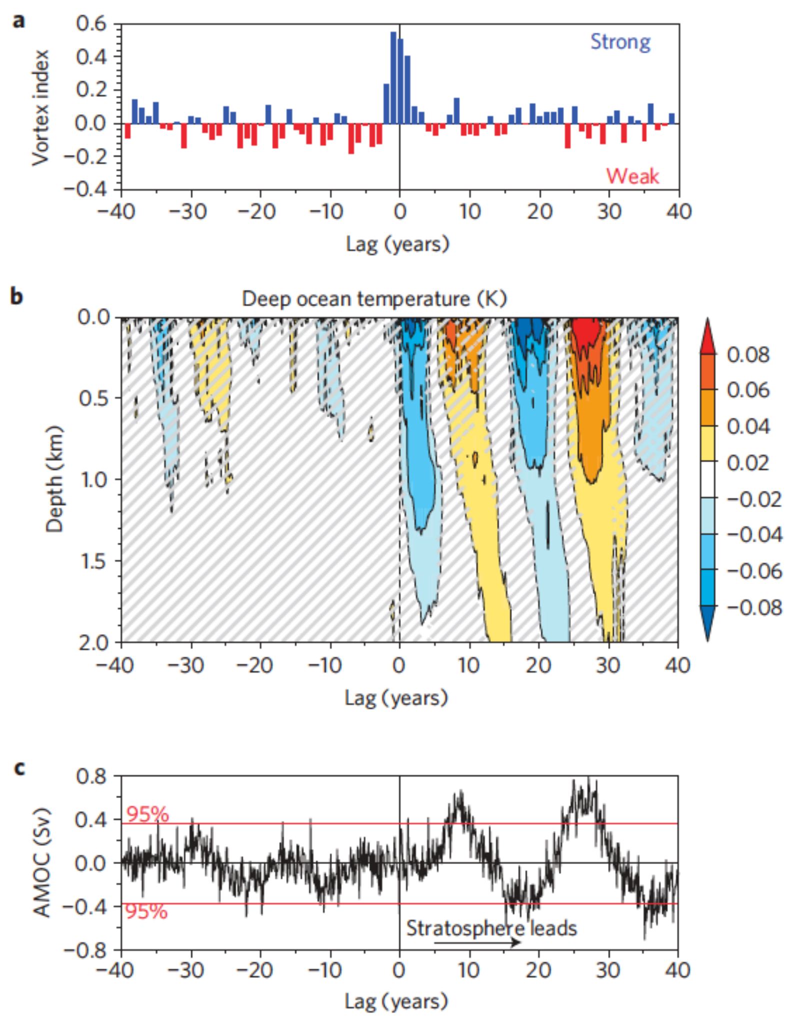


[Scaife et al., 2014]

QBO skill may potentially impact predictability of surface winter climate in the extratropics via the **Holton-Tan relationship.** This avenue has been poorly explored.

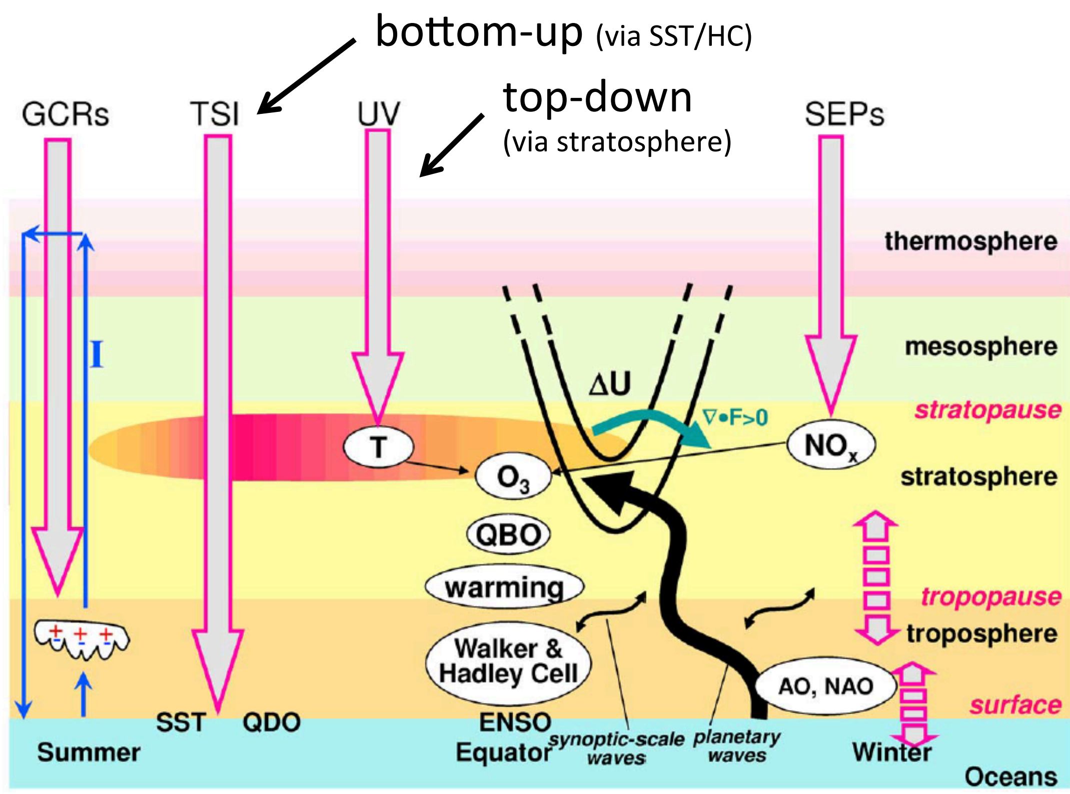
The stratosphere-troposphere-ocean coupled system.

Recent studies [Manzini et al., 2012; Reichler et al., 2012] based on stratosphere-resolving climate models, have provided **evidence of circulation anomalies propagating down from the stratosphere, finally affecting decadal variations in the North Atlantic Ocean circulation** (AMOC).



[Reichler et al., 2012]

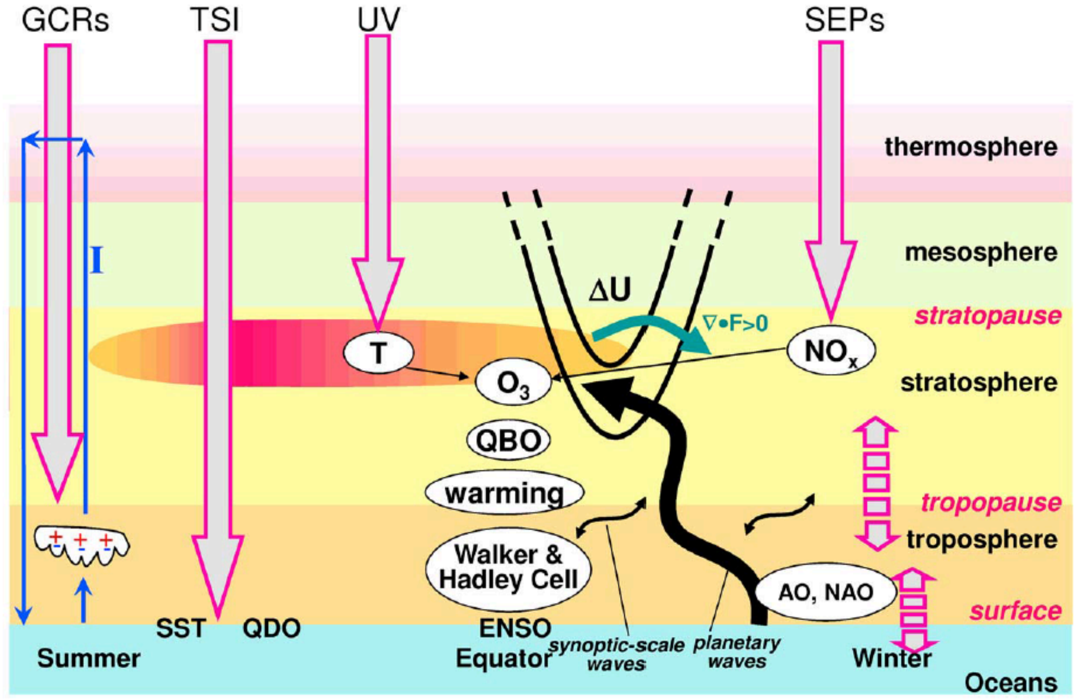
The 11-year solar cycle: top-down and bottom-up mechanisms.



[Gray, 2010]

Most current climate models include a representation of TSI variations, but their upper boundary does not extend sufficiently high to fully resolve the stratosphere, so most do not include the UV influence. Hence, the primary solar influence mechanisms in these models are ocean heat uptake and SST changes, which affect evaporation and low-level moisture in the atmosphere (*bottom-up* mechanism [Meehl et al., 2009]).

The 11-year solar cycle: top-down and bottom-up mechanisms.

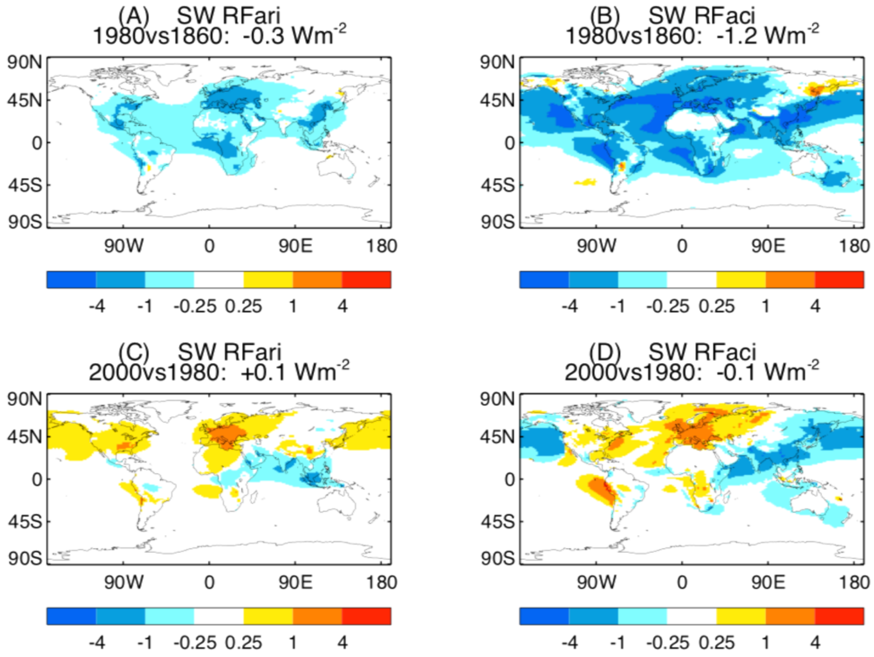


[Gray, 2010]

A correct simulation of the connection between solar variations and regional climate variability could provide predictability at the decadal scale. However, it has proved difficult for climate models to consistently reproduce solar cycle signal in the stratosphere and the troposphere, even though some of them have been successful [Matthes et al., 2006; Shindell et al., 2001].

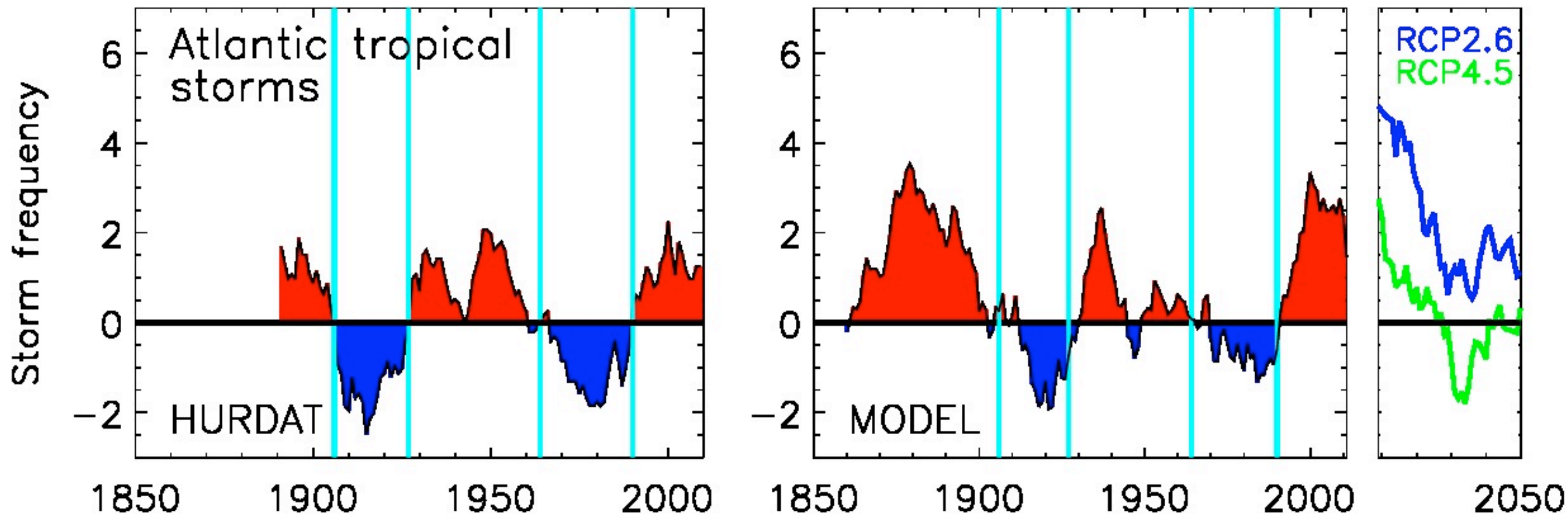
Aerosols

- Increasing body of literature linking aerosols to historical climate changes on decadal scales. There is a potential, therefore, for future emission changes to play an important role in regional and global climate.



[Bellucci et al., 2015]

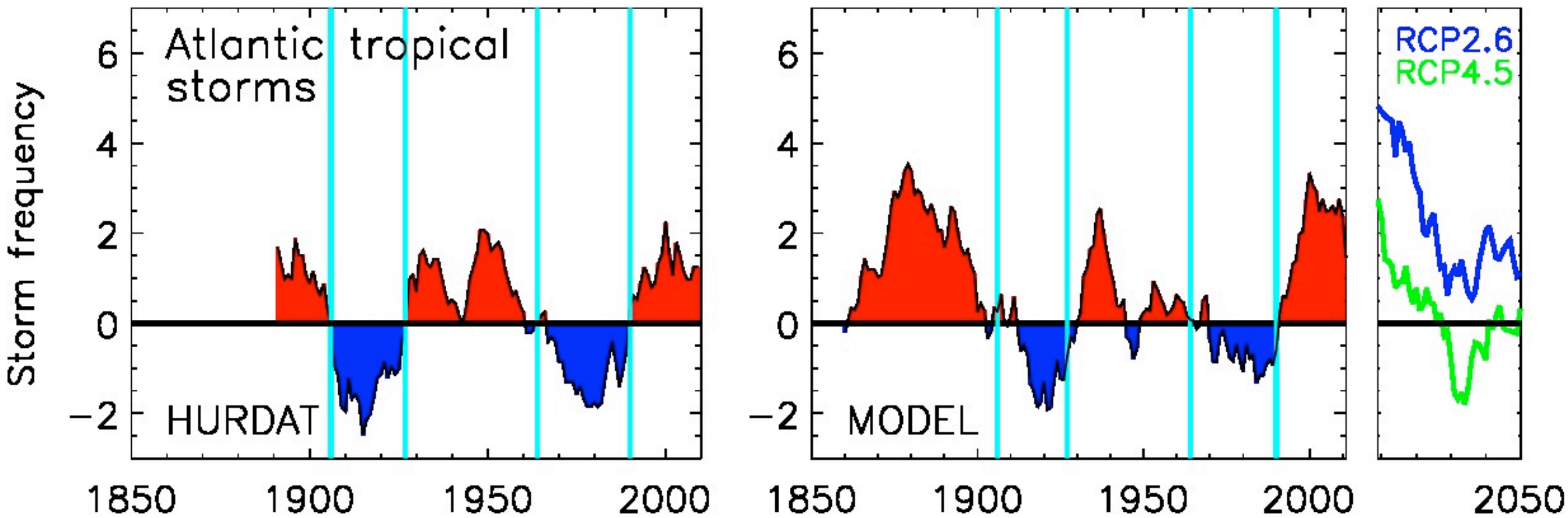
Impact of anthropogenic aerosols on Atlantic hurricanes



[Dunstone et al., 2013]

Sulfate aerosol differences (driven by different CO_2 mitigation pathways) imply two markedly different projected future changes in Atlantic tropical storms, in the HadGEM2 model [Dunstone et al., 2013]. **Under a scenario with aggressive mitigation of CO_2 emissions (RCP2.6) this model projects a record increase in tropical storm frequency over the next decade.**

Impact of anthropogenic aerosols on Atlantic hurricanes



[Dunstone et al., 2013]

However, there is a **large model-to-model uncertainty in the aerosols RF**: different models might feature markedly different decadal response to aerosol changes **(e.g, HadGEM2 features a strong globally averaged aerosols RF)**

Aerosols

- The **diversity in aerosol distributions** simulated by the state-of-the-art models that participated **in CMIP5 simulations is very large**, in spite of sharing the same aerosol emission data sets [Wilcox et al., 2013].

- This **diversity betrays the lack of knowledge and observational constraints** on aerosol processes and arises not only from differences in aerosol representation but also from different simulations of atmospheric or cloud processes

- CMIP5 models cover a **broad range of process complexity**. For example, only two models represent nitrate aerosols. **Nitrate aerosol** formation competes with that of sulfate. Similarly, **carbonaceous aerosols** are treated differently across models.

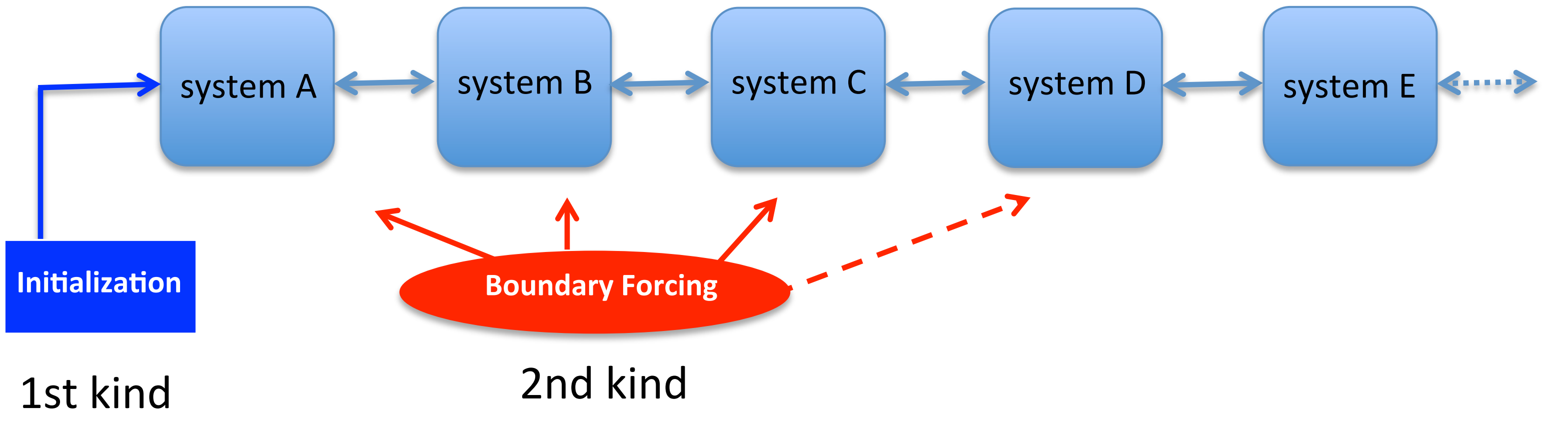
- The **challenge for decadal prediction systems is that as process understanding develops so does our understanding of the role of near-term aerosol changes** on the climate system.

- Importantly, **models with stronger total aerosol forcing show more marked climate impacts** [E.g., link aerosols increase/S-A Monsoon reduction in **GFDL CM3** (Bollasina et al., 2011); multi-decadal NASST/anthropogenic aerosols in **HadGEM2** (Booth et al., 2012)]

Systemic buffering

Sources of predictability are generally associated with knowledge of the initial state (predictability of the 1st kind) and boundary forcing (predictability of the 2nd kind).

A key role on the overall predictive ability of ESMs is expected to be played by an accurate representation of processes associated with specific components of the climate system. These act as "signal carriers," transferring across the climatic phase space the information associated with the initial state and boundary forcings, and dynamically bridging different (otherwise unconnected) subsystems.



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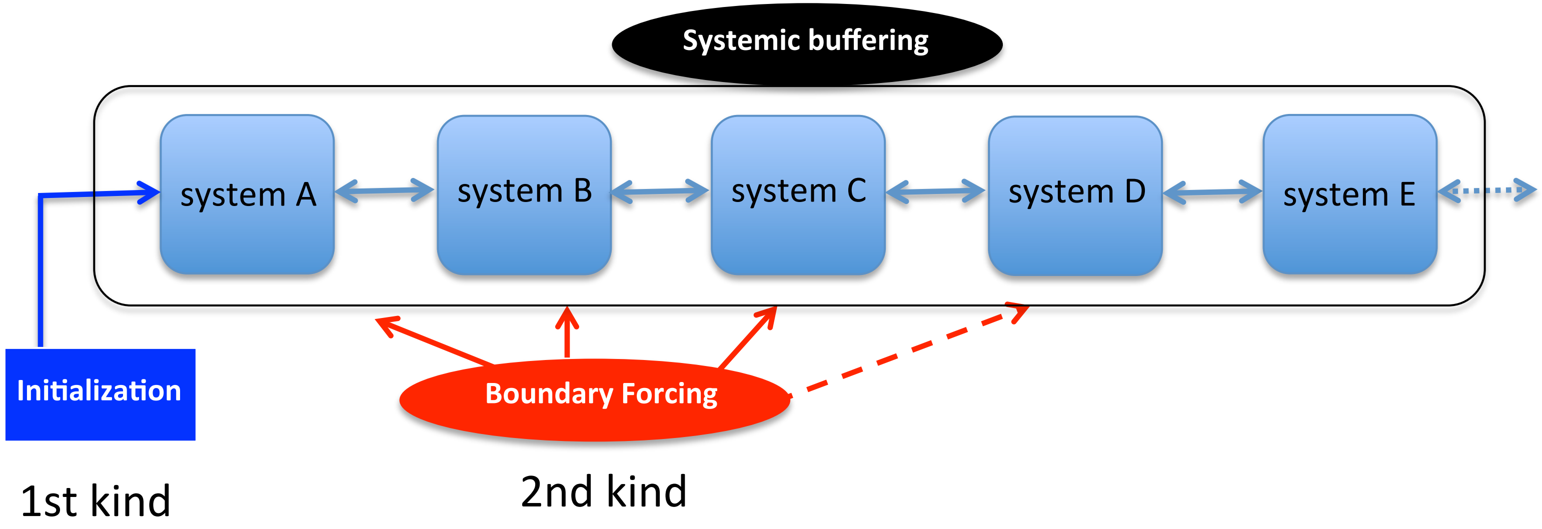

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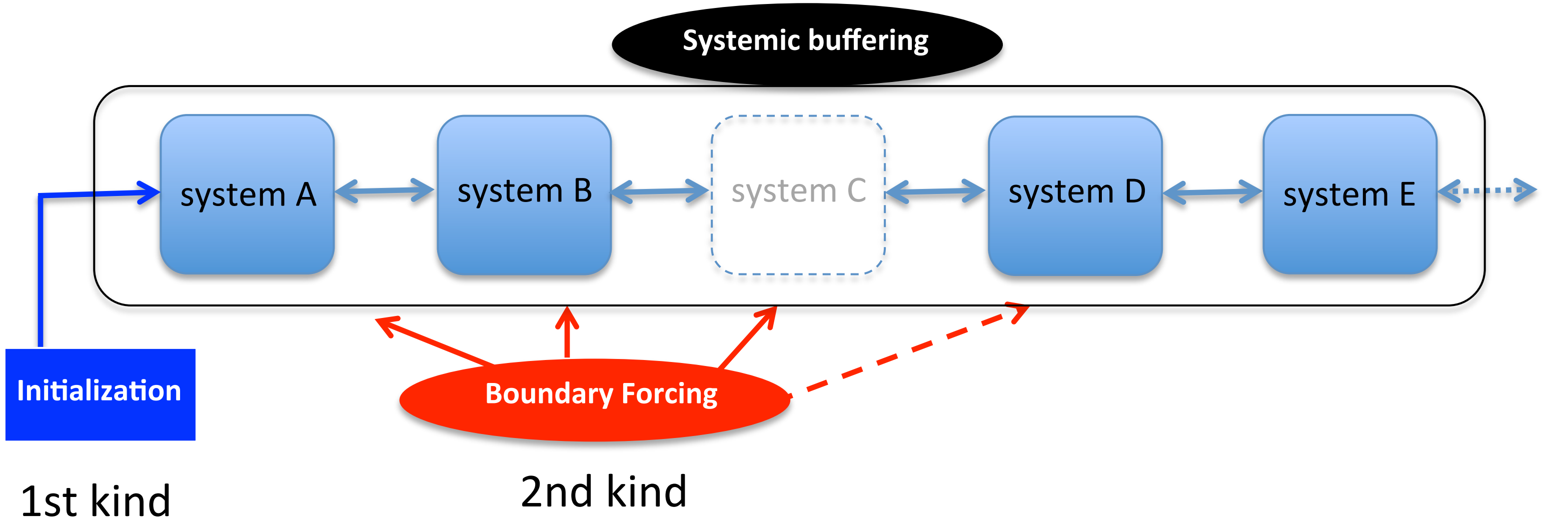
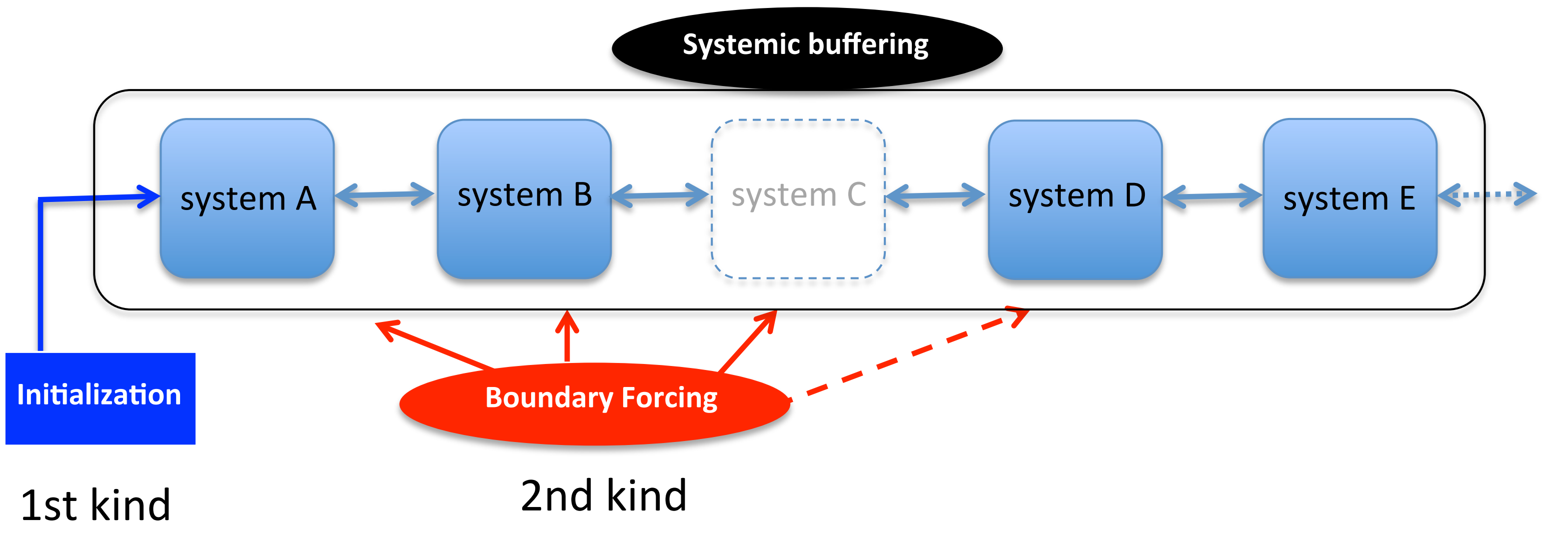


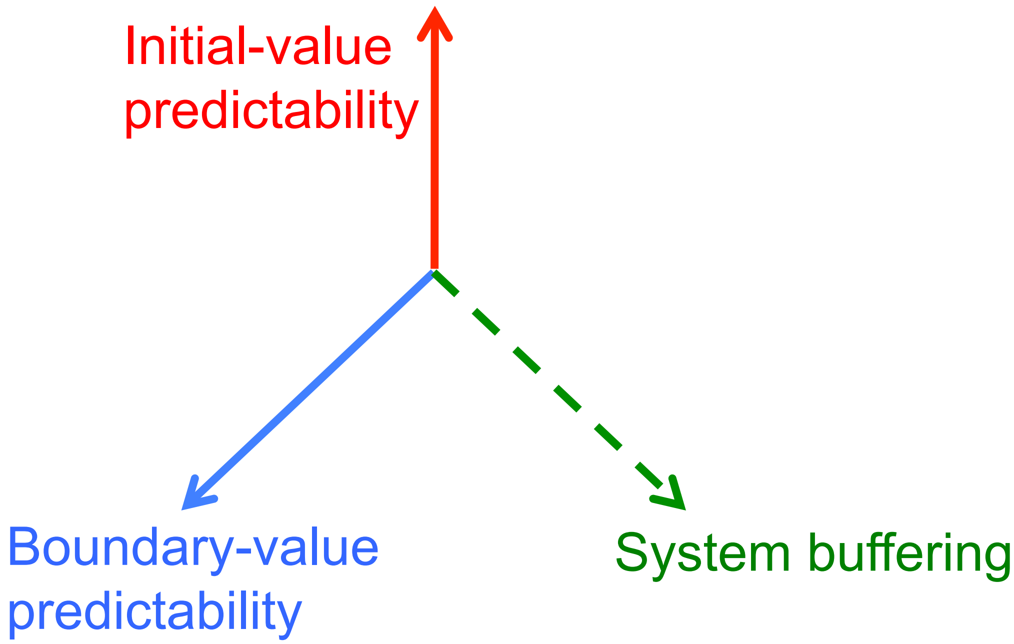
Systemic buffering

Nonoceanic components suffer from data scarcity. However, their predictability potential can be exploited through improvement/inclusion of key processes.

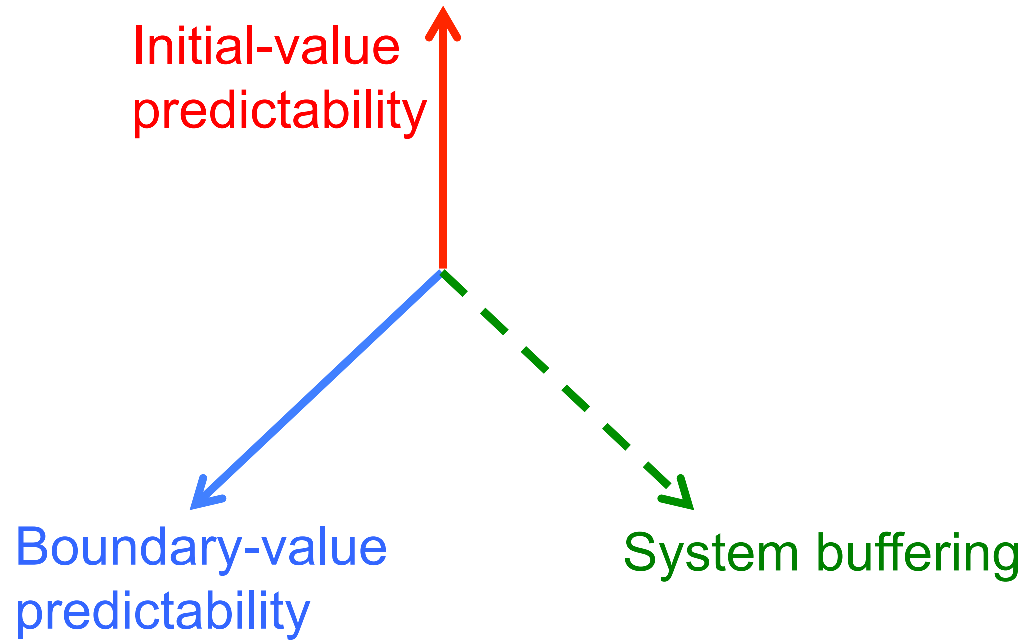
In fact, components that are NOT initialized but simply included/represented, contribute, through signal buffering, to enhance the predictive ability of a given Earth System Model.



Maximizing predictive capabilities of next generation ESMs

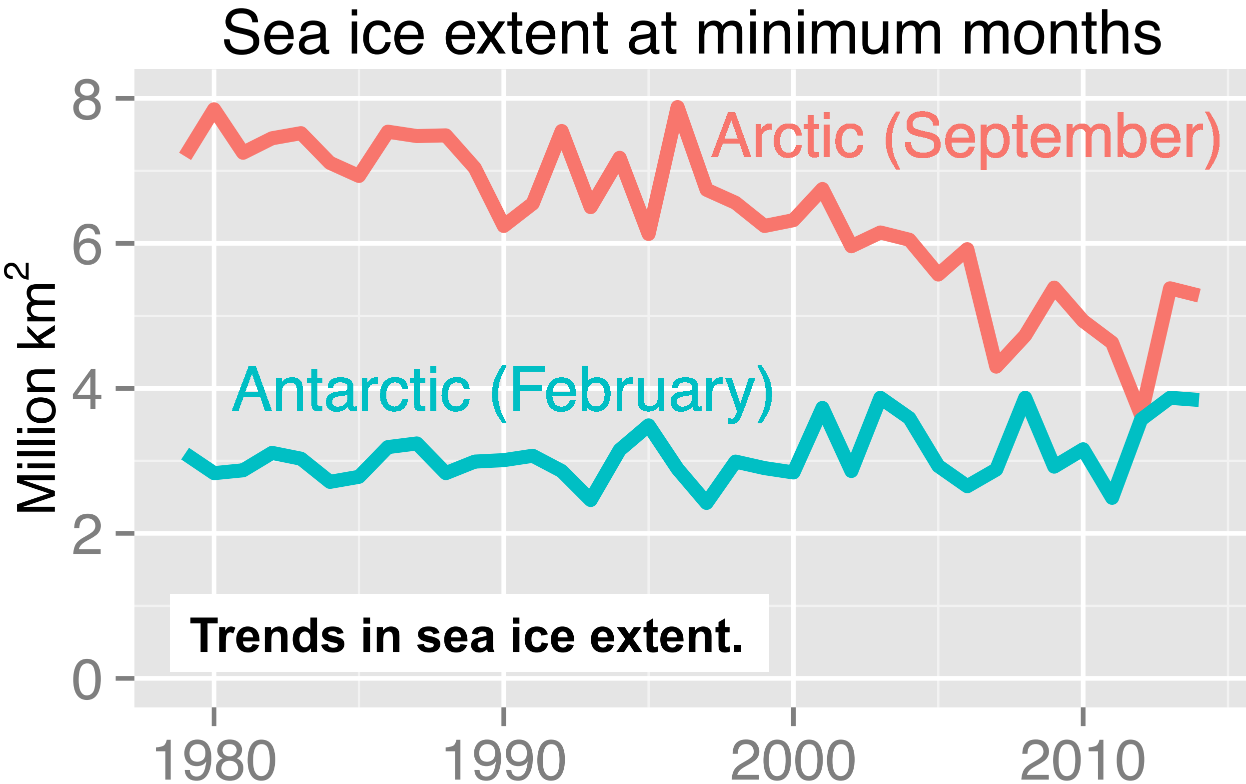


Maximizing predictive capabilities of next generation ESMs

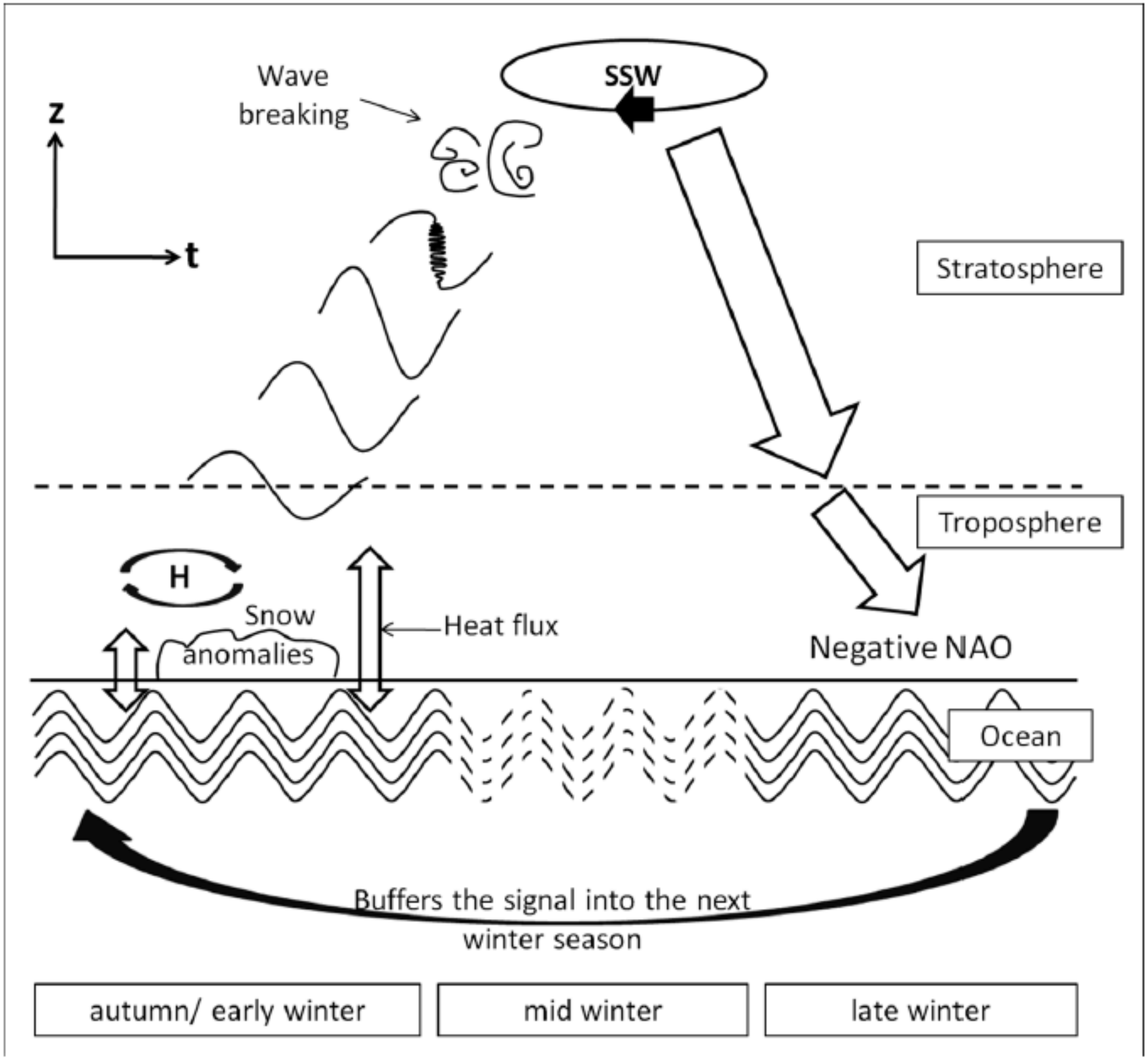


Thank you!

Sea ice



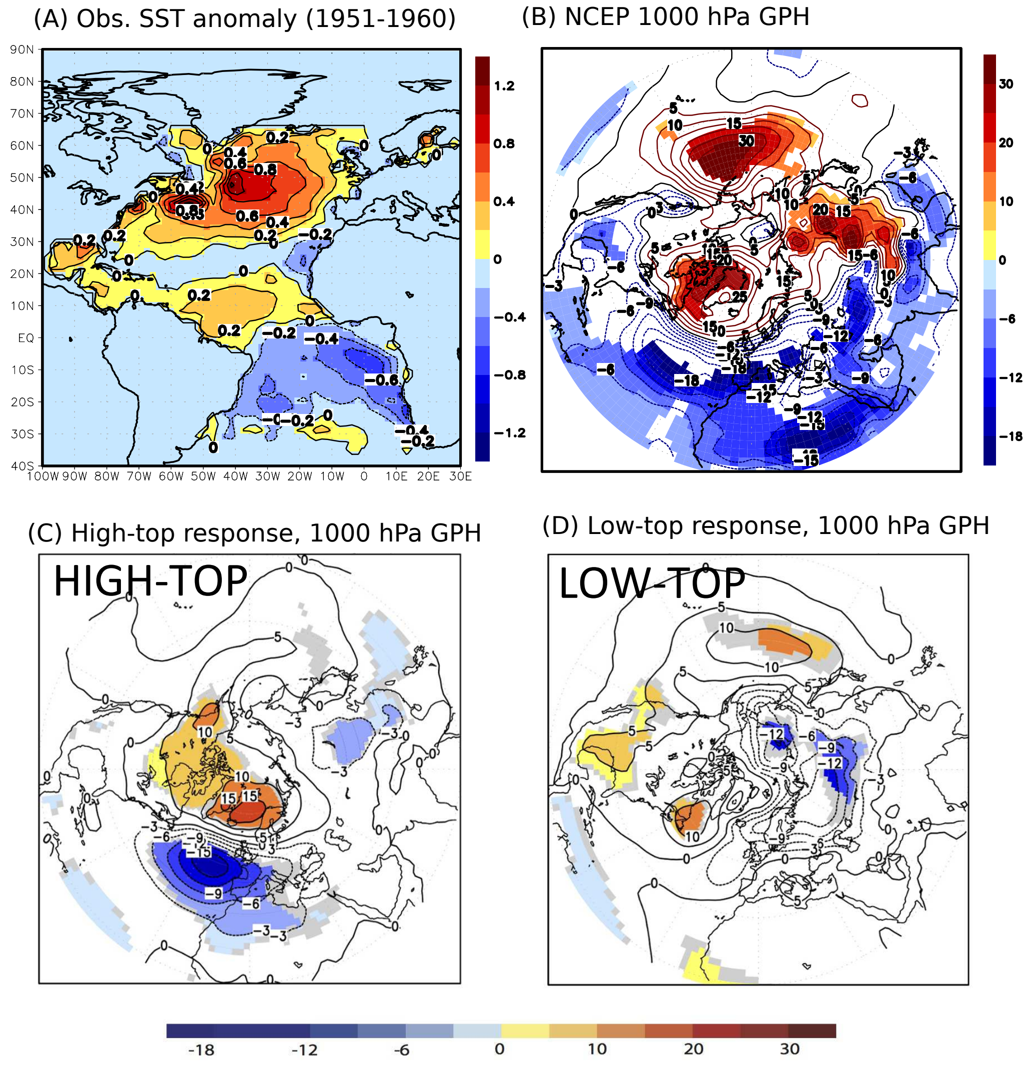
The mechanisms behind the **trend in sea ice do not only give rise to predictability of the ice itself but potentially also predictability for other variables** like air temperature, precipitation and atmospheric circulation, and also Arctic flora and fauna as well as socioeconomic factors.


Wave
breaking
SSW
z
t
Stratosphere
Troposphere
H
Snow
anomalies
Heat flux
Negative NAO
Ocean
Buffers the signal into the next
winter season
autumn/ early winter
mid winter
late winter

Issues

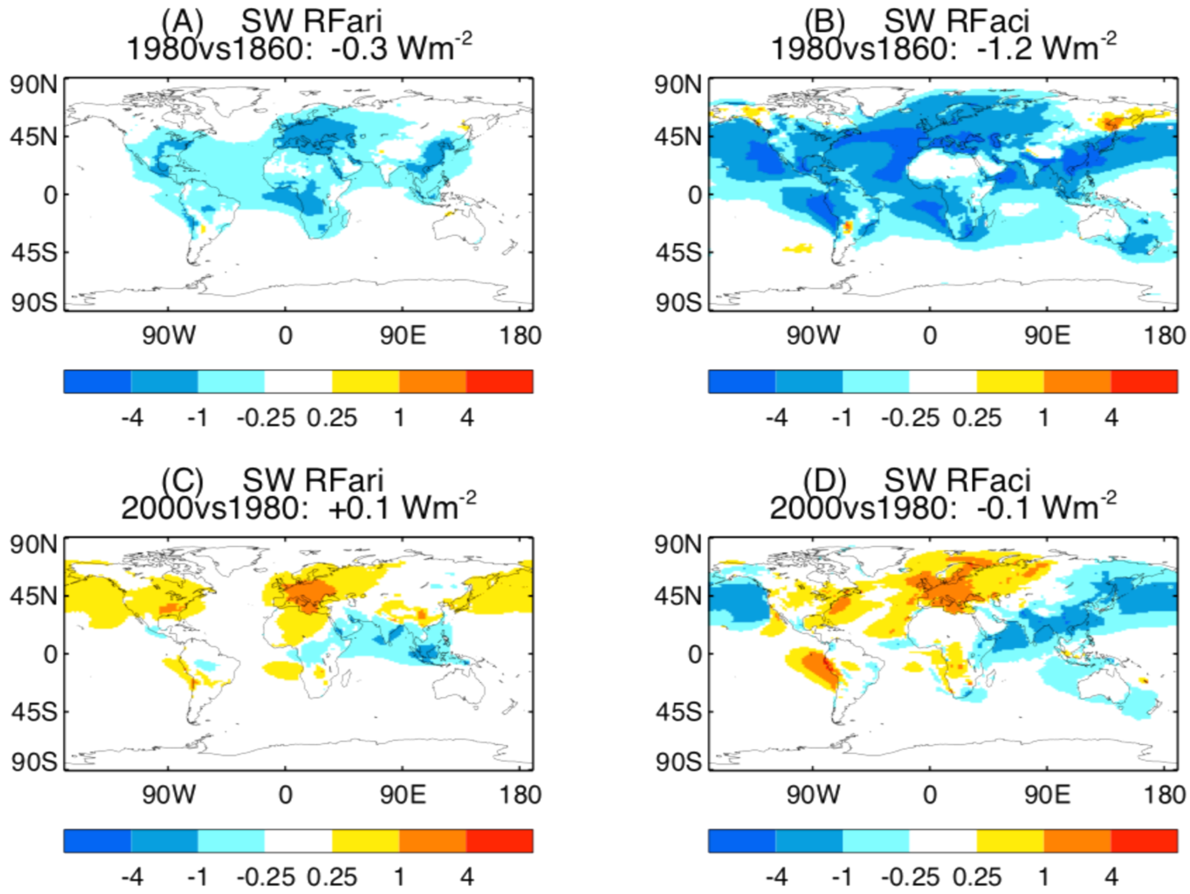
- Very few sensitivity experiments assessing the role of soil moisture and dynamic vegetation on decadal predictability
- Climate persistence induced by soil moisture memory and land-atmosphere coupling is amplified and extended through feedback mechanisms.
- Predictable trends in deforestation may provide a source of predictability over the areas affected [e.g., Sampaio et al., 2007]

Accurate representation of stratosphere-troposphere coupling is needed in order to faithfully reproduce the atmospheric response to low-frequency SST changes.



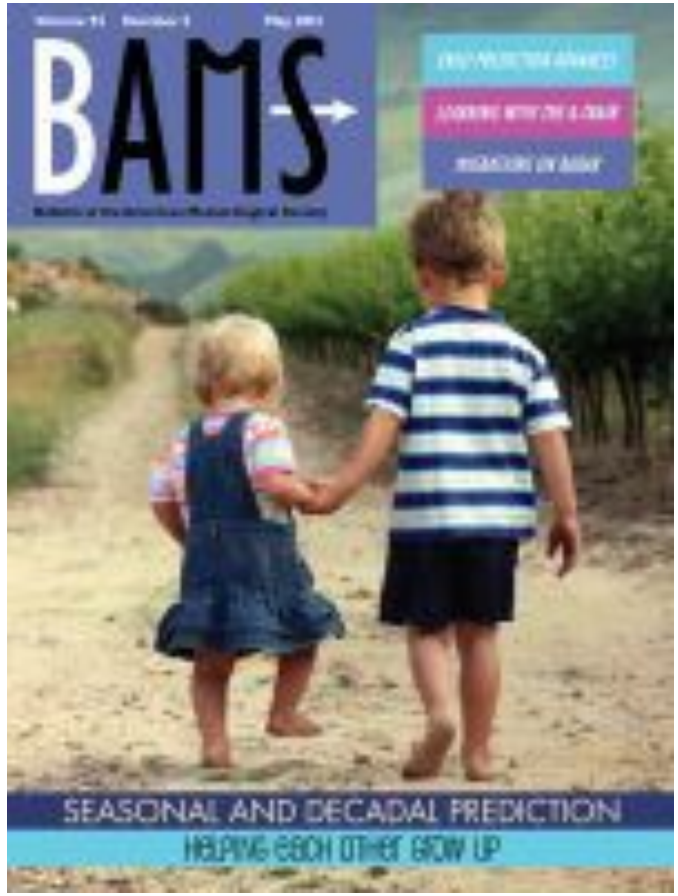
[Omrani et al., 2014]

Aerosols



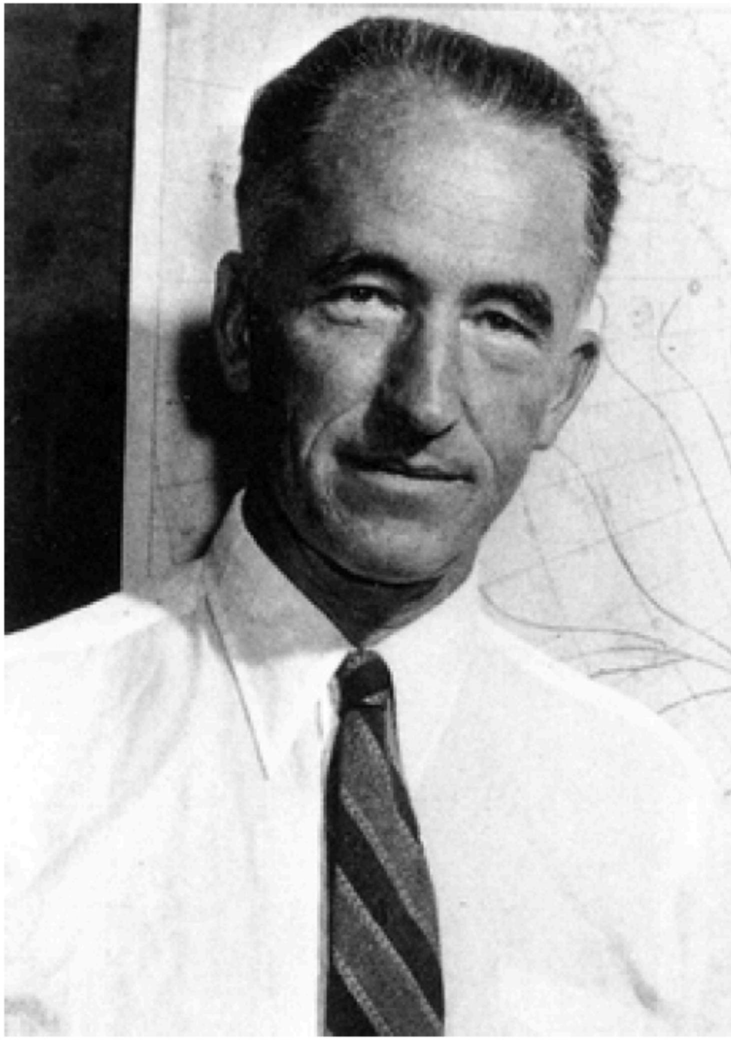
[Bellucci et al., 2015]

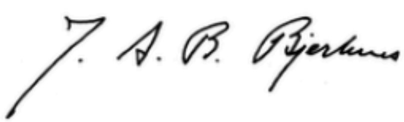
Distributions of radiative forcing from aerosol-radiation and aerosol-cloud interactions, simulated by the Hadley Centre climate model HadGEM2 between the years 1860 and 1980, and 1980 and 2000.



“Seasonal and decadal prediction: helping each other grow up”

[BAMS, May 2012]





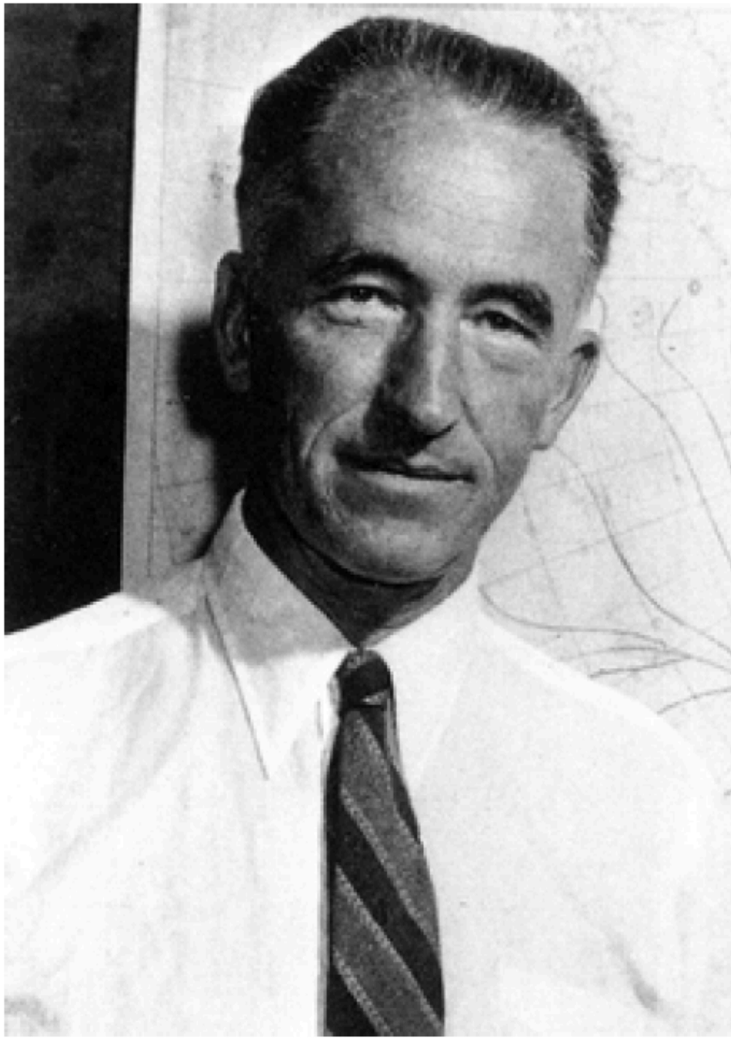
Jacob Bjerknes (1897 – 1975)

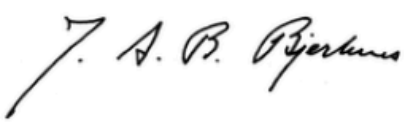
The roots

1964: Atlantic Air-Sea Interaction. Adv. Geophys., 10: 1-82.

1969: Atmospheric telecommunications from the equatorial Pacific. Mon. Weather Rev., 97: 163-172.

These two seminal papers contributed to set the foundations for our current understanding of air-sea interaction in mid-latitudes and ENSO, respectively.





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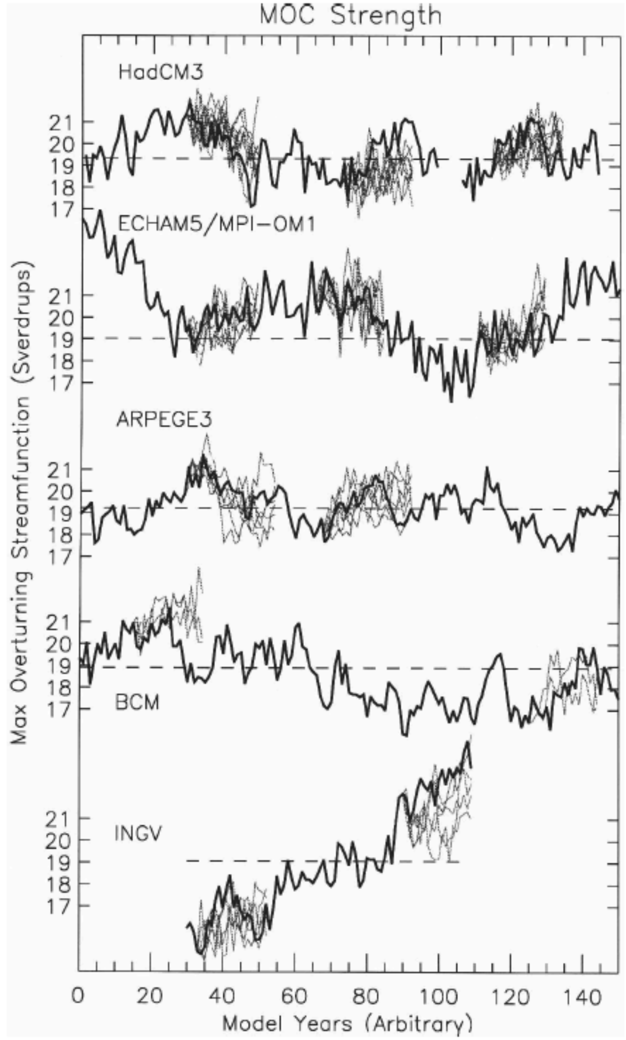
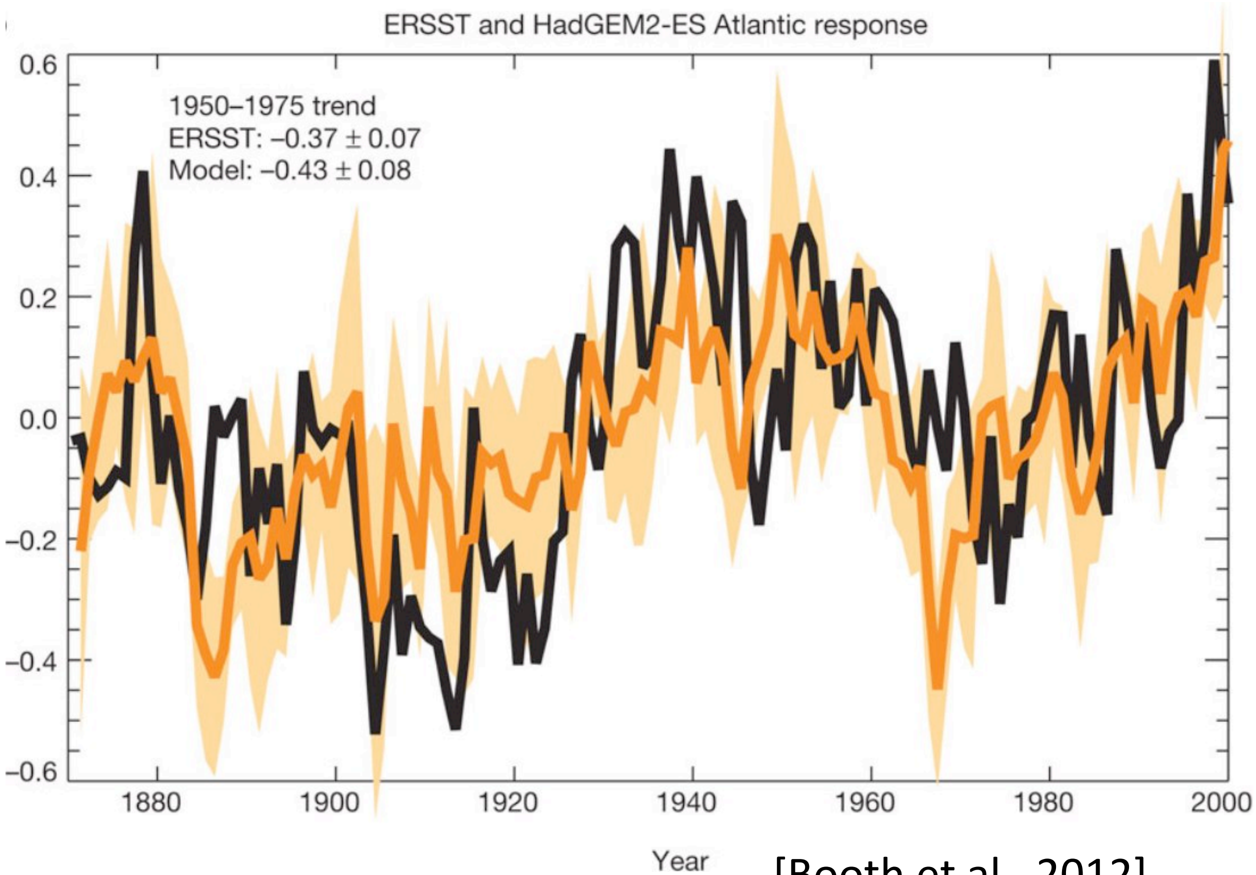
In his 1964’ paper, Bjerknes (1964) was the first to recognize the primary role played by ocean circulation in modulating SST anomalies (in the Atlantic) over decadal time scales.



[Collins et al., 2006]

Early potential predictability experiments mainly focussed on the role of the ocean.

Aerosols primary drivers of Atlantic Multidecadal Variability?



[Booth et al., 2012]