



A mechanistic approach to analyzing bias in climate models. Is climate, like all politics, local?

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Thanks to G. Bala (LLNL) and C. Drui (U o' M)



Definition of Climate

- The **climate** (from ancient [Greek](#): κλίμα, "[clime](#)") is commonly considered to be the [weather](#) averaged over a long period of time, typically 30 years. Somewhat more precisely, the concept of "climate" also includes the statistics of the weather — such as the degree of day-to-day or year-to-year variation expected. The [Intergovernmental Panel on Climate Change](#) (IPCC) glossary definition is:
 - Climate in a narrow sense is usually defined as the “average weather”, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period is 30 years, as defined by the World Meteorological Organization ([WMO](#)). These quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description, of the climate system. Wikipedia



Definition of Climate (continued)

- Within most definitions of climate is the idea of an average. Which raises the questions of
 - what area do we average over?
 - what time do we average over?
- This idea of an average impacts how we think about the problem, how we analyze climate models. *
 - We are drawn to mean quantities and how these mean quantities change as a function of model formulation.
 - We start to think of climate as, in fact, the average of weather.
- How do we determine cause and effect?



A nuance or something that matters?

- Weather represents a subset of the mechanisms that make up climate.
 - From the point of view of climate, “weather” represents an array of transport processes.
 - Transport in the atmosphere tends to be episodic, and strongly correlated to specific features.
 - There is a lot of sloshing back and forth ... (suitable to averaging)
 - Important events are related to something that causes irreversibility ... something that interferes with the sloshing ... (not suitable to averaging)
- Climate as an accumulation of weather?

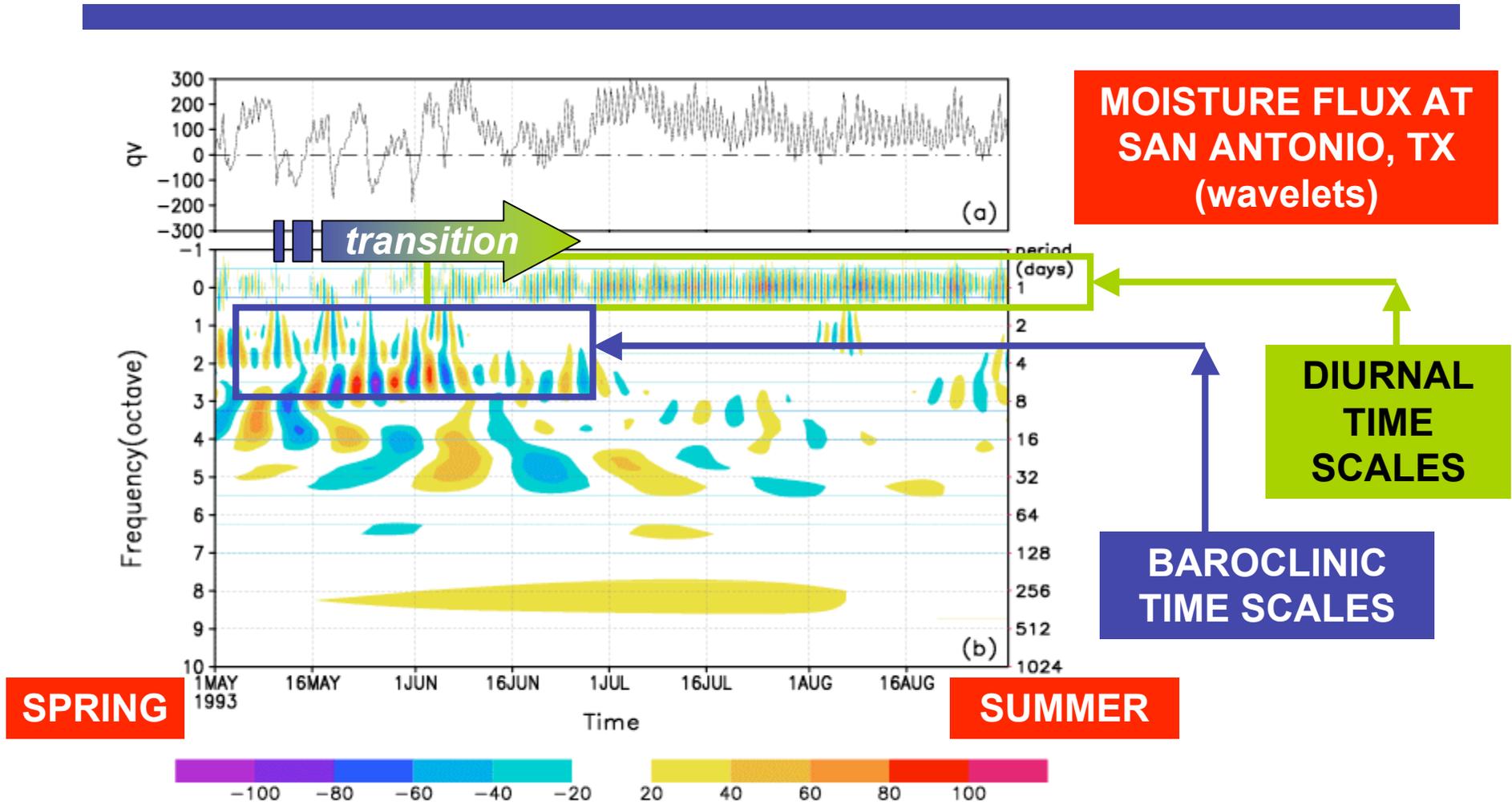


The problem

- There is a class of biases in climate models that has defied our efforts to correct them.
- Hypothesis: There is a subset of these problems which are caused by local processes, by a misrepresentation of mechanisms, by a deficiency in our ability to represent weather.
 - Which is not the same as our ability or inability to forecast weather.



My original motivation came from the first reanalysis data sets



See Helfand and Schubert, *J. Clim.* 1995 *



What comes from this figure?

- Distinct dynamical features which are mechanisms responsible for the continental moisture budget.
- Distinct seasonal change in mechanism.
- Mechanism in summer is
 - Relatively small scale
 - Anchored by topography
- What is the robustness of the representation of the mechanisms in climate models, and how do the attributes of the mechanisms change in the next century?

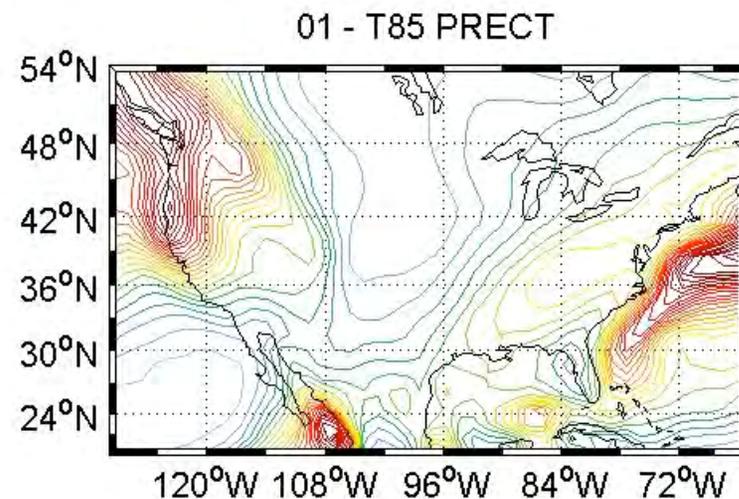
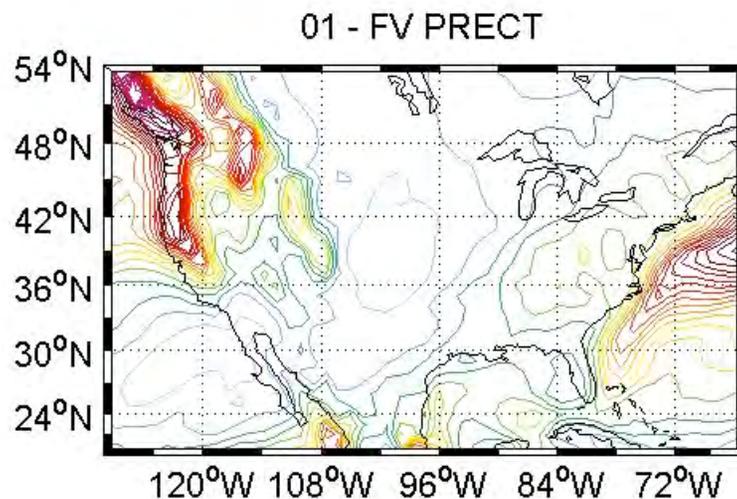


Can this mechanistic, weather-scale, approach be productively applied to bias in climate models?



- Two climate model simulations.

- Both use Community Climate System Model, Version 3.
 - One uses spectral dynamical core. T85 ~ > 1 degree resolution (+ filters, etc.)
 - global basis functions
 - One uses finite volume dynamical core (+ filters, etc.)
 - local representation of dynamics





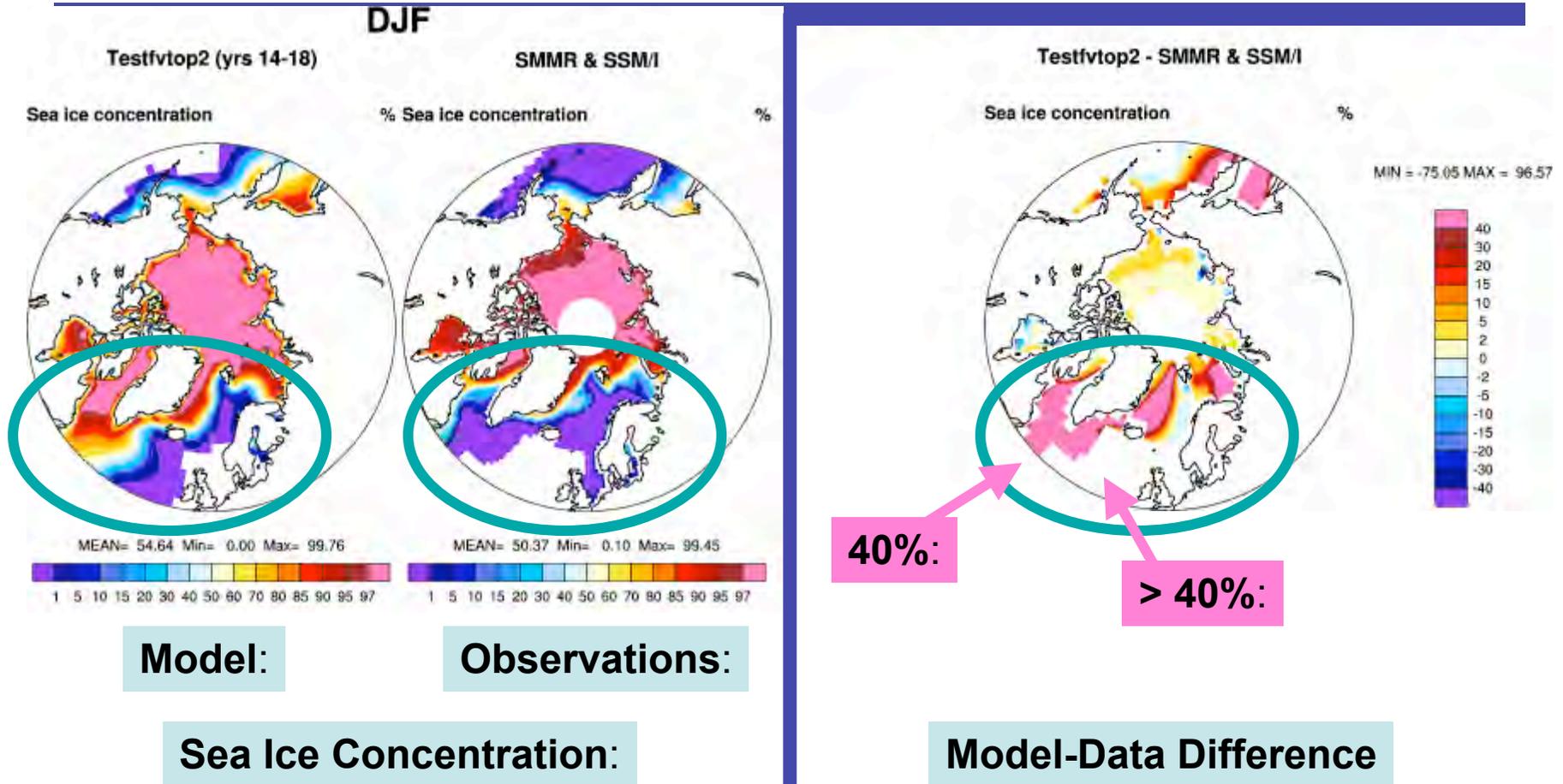
The Problem

- Sea ice extent in the North Atlantic in the coupled model using the finite volume dynamical core in the atmospheric model was far in excess of that from the runs with the spectral model dynamical core, which was already in excess of observations.

Bala, Rood, many others, Manuscript in Preparation



Sea-ice in North Atlantic (finite volume run vs observations)





Set of Experiments to Address the Problem

- The first assumption was that the change in the dynamical core caused some subtle change in the large-scale dynamics that changed the balances in the sea ice budget
 - Series of thermodynamic experiments
 - Albedo
 - Cloud cover
 - Sensitivity to wind stress over ocean
 - Gravity wave drag (influence on Icelandic low?)
 - Ice drag experiments
 - Turn off ice dynamics.

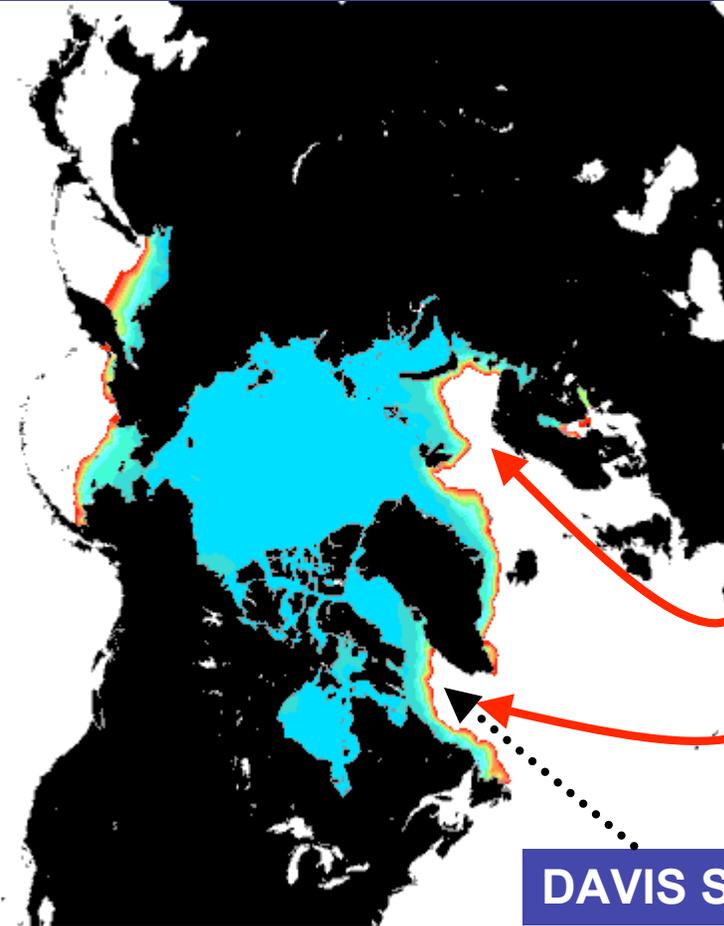


Result of these experiments

- Most of these experiments made under the assumption that average distribution was related to the average atmospheric circulation.
 - Albedo // radiative balance negatively impact seasonal cycle
 - With the exception of the no ice dynamics, there was very little sensitivity to the model changes.



Closer look at sea ice in N. Atlantic



Observed January mean sea ice concentration

Note that much of the North Atlantic is, in fact, ice free.

Clear north of Scandinavia

Clear in the eastern part of the Davis Strait

Suggest local control?

DAVIS STRAIT

<http://polar.ncep.noaa.gov/seaice/climatology/>

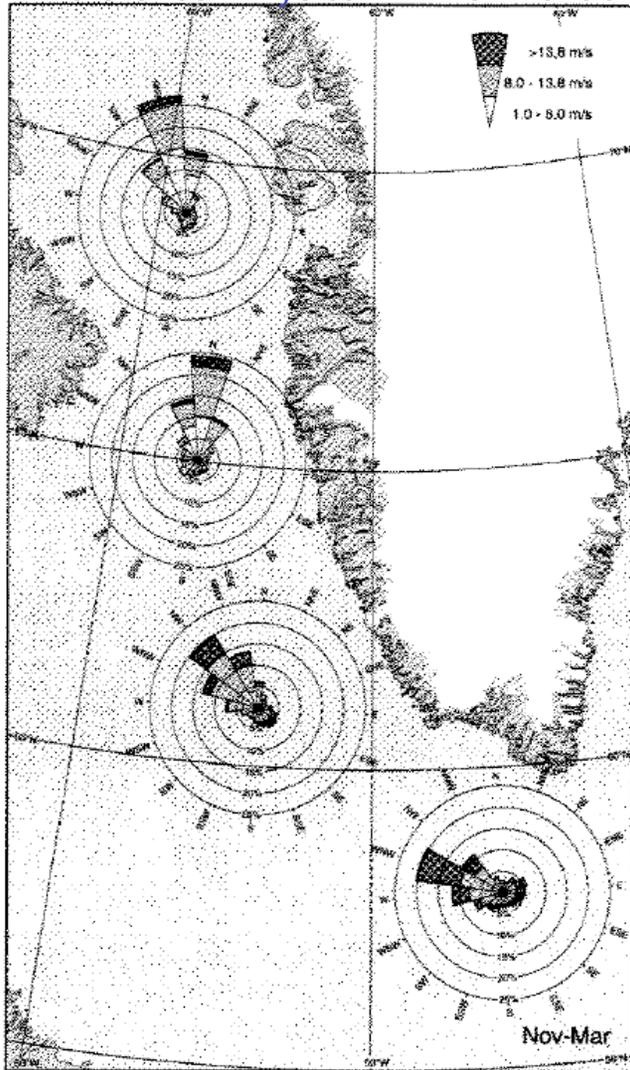


More process-oriented analysis of model

- No ice dynamics experiment suggest that the problem is, to zero order, related to ice dynamics.
 - What are the basic mechanisms of ice dynamics in the Davis Strait
 - Transport by ocean currents
 - Transport by wind blowing ice
- Sea ice bias developed in winter, but did not persist through summer.
 - Hence, related to wintertime circulation.

Summary of observations

Reference: Physical Environment of Eastern Davis Strait and the Labrador Sea (Govt of Denmark)



Analyzed winds



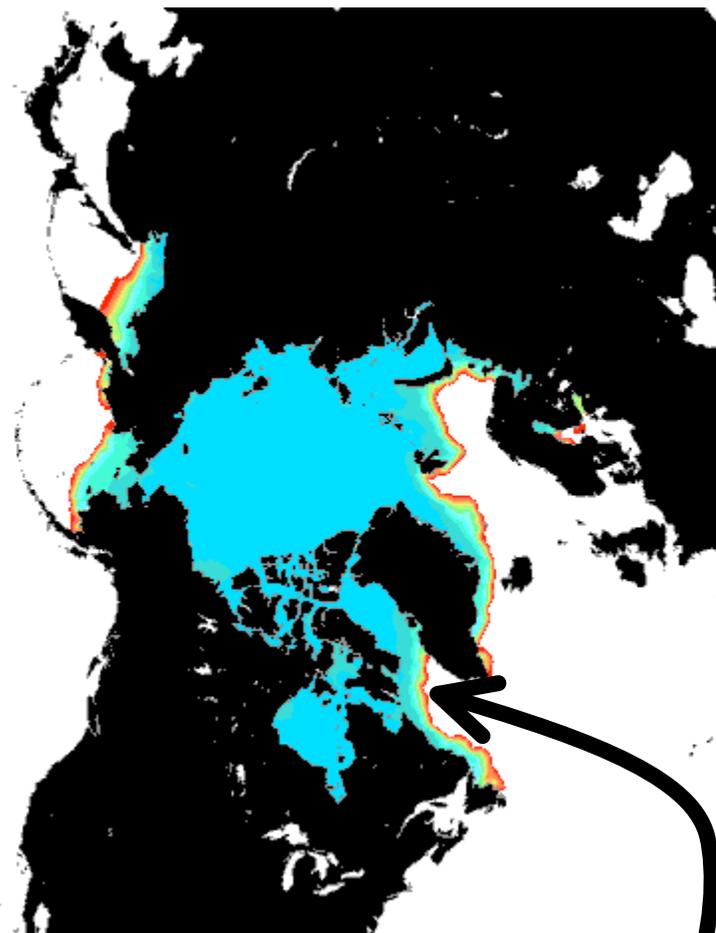
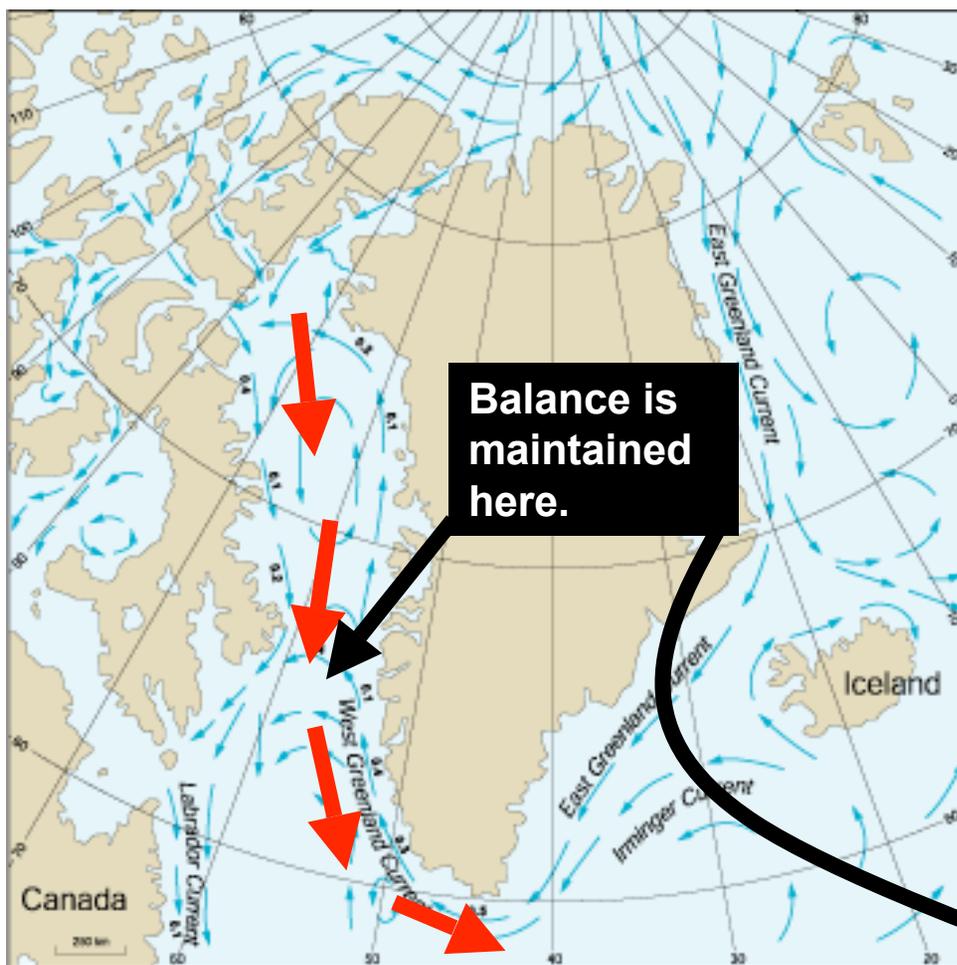
Observed winds: Gales > 25% of time. Topography is important



From observations what controls sea ice in Davis Strait and Labrador Sea?

- Ice formed and transported from north and west.
 - Ocean surface currents (Labrador, Baffin Island Current)
 - Atmospheric wind.
- Ice is melted in warm(ish) waters from surface ocean currents (West Greenland).
- Ice is dominated by first year ice.
- Reference: Physical Environment of Eastern Davis Strait and the Labrador Sea (Govt of Denmark) —

Ice is in dynamic balance



Observed winds: Gales > 25% of time. Topography is important

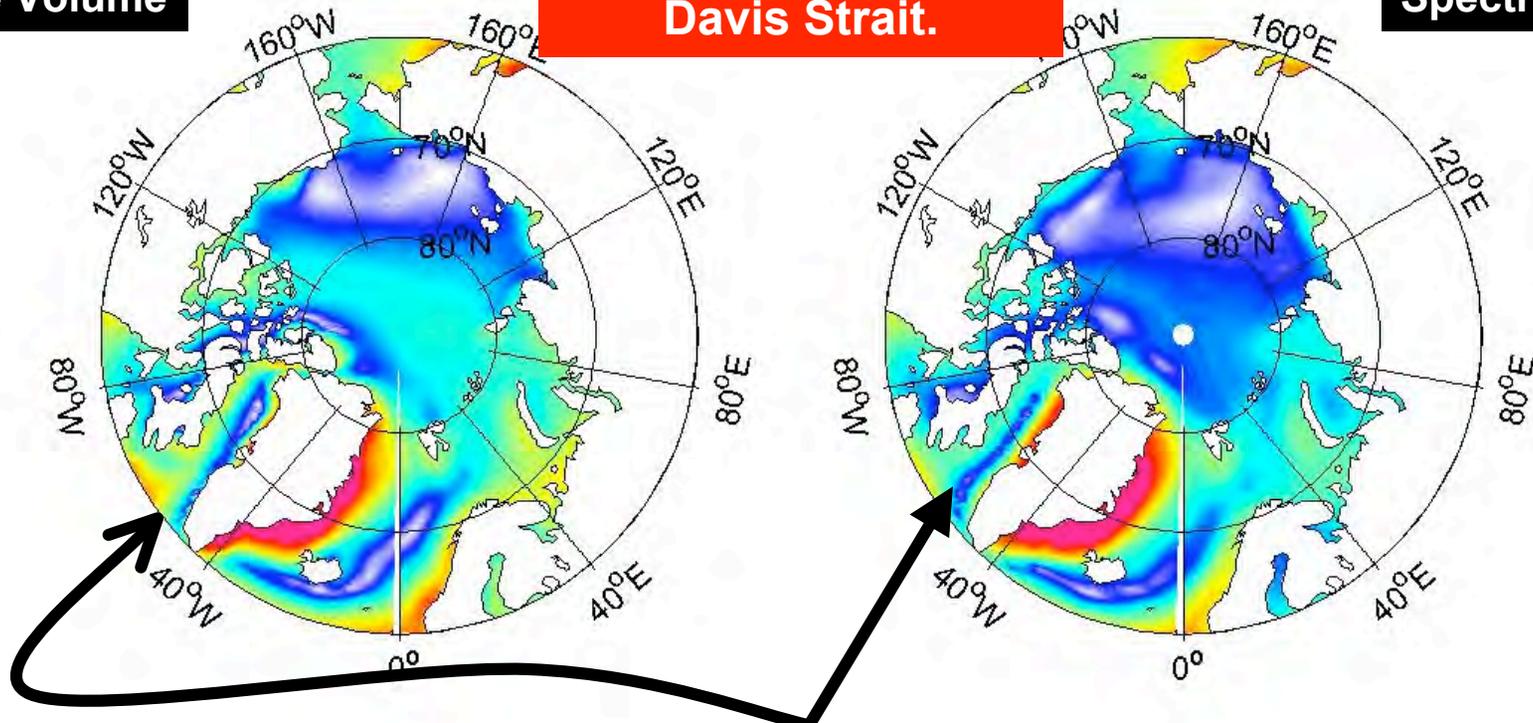


What is the modeled wind?

The observed winds are maximum in Davis Strait.

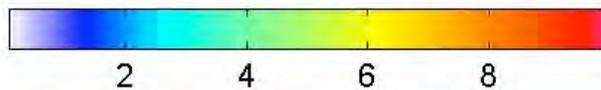
Finite Volume

Spectral

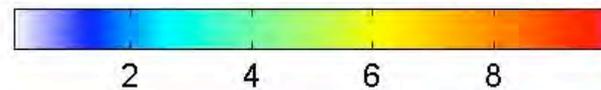


In both model simulations minimum of wind in the Davis Strait. (January, 20 year average) (That's why there was no sensitivity in ice stress experiments)

01 - FV Near Surface Wind Speed [m/s]

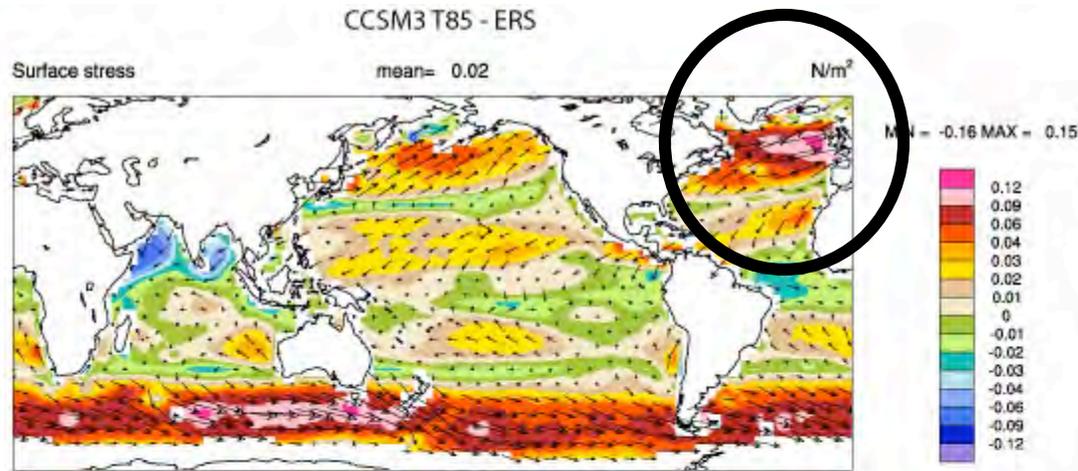


01 - T85 Near Surface Wind Speed [m/s]

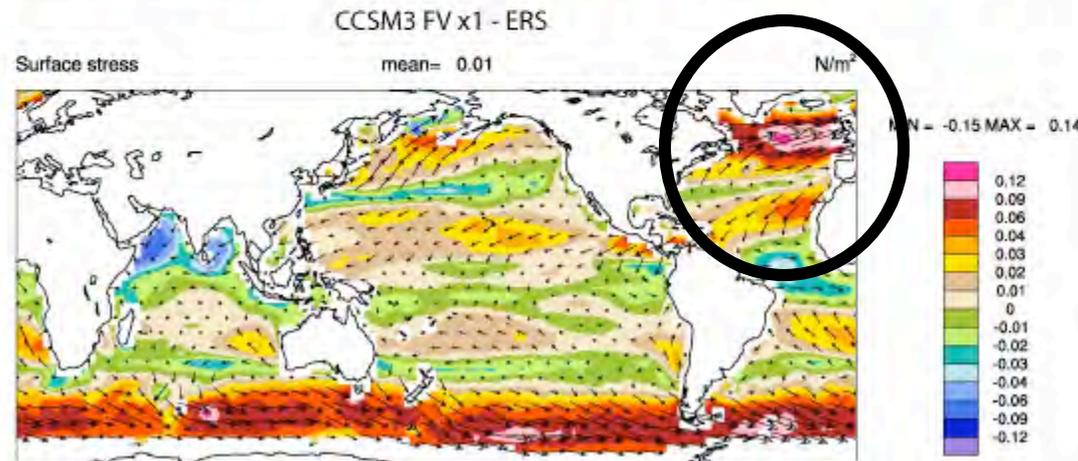




Wind stress?



Spectral - Scatterometer



Finite Volume - Scatterometer



From looking at the winds

- In both models there are major errors in Davis Strait winds and North Atlantic wind stress.
- In both cases the finite volume is slightly closer to observations, but still far from observations.
- If there was a better simulation of the atmosphere in the Davis Strait, critical for the sea ice balance, the sea ice distribution would be much worse.
 - For the wintertime, North Atlantic sea ice balance, better atmosphere dynamics worse sea ice.



What does this mean?

- The better North Atlantic sea ice in the spectral model simulation is not due to better atmospheric dynamics.
 - In fact, the balance is not maintained by the correct geophysical mechanisms.
- Examine the other mechanisms at the balance point in the Davis Strait.
 - West Greenland Current
 - Labrador Current
 - Gyre to the north



What does it lead?

- Ocean dynamics
 - Resolution of ocean model
 - Ocean topography
 - Ocean viscosity

**RECENT EXPERIMENTS AT NCAR HAVE SHOWN HIGH SENSITIVITY TO SMAGORINSKY NONLINEAR DIFFUSION IN OCEAN MODEL.
(over diffusion of near shore currents, especially at low resolution)
(MARKUS JOCHUM AND BILL LARGE)**



Result

(Bala, Rood, et al. Manuscript in Preparation)

- With the change of the diffusion in the ocean model, the sea ice bias in the finite volume atmosphere version of the Community Climate System Model is remedied.
 - Still, though we now have evidence that the wintertime sea ice distribution of the North Atlantic sea ice is not maintained for the correct reasons. I am confident that improved meteorology in this region would degrade the sea ice.
- Different things are true for different regions.
 - Cannot extend conclusions to regions where different mechanisms, different weather, maintains the balance.



Can we extend these ideas to other biases?

- The answer is yes:
 - Near coast features in the oceanic precipitation.
 - Numerous anomalies in continental precipitation.
 - Tropical clouds?



Weather and Climate (1)

- Thinking of weather as representing a mechanism of climate, a subset of climate model biases can be successfully analyzed and understood.
 - Can this subset be characterized?
 - Behavior as a function of resolution
 - Behavior as a function of parameterization
 - Regional spatial structure
 - Seasonal structure



Weather and Climate (2)

- Thinking of weather as representing a mechanism of climate, are there new ways of analyzing climate models based on small scale structure?
 - Perhaps, for example tropical cloud objects.
 - Xu, K.-M., *et al.*, *J. Climate*, 2005.
 - Xu, K.-M., *Mon. Wea. Rev.*, 2006.
 - Xu, K.-M., *et al.*, *J. Climate*, (conditionally accepted), 2006.
 - (we have a proposal)
 - Organization of summertime continental precipitation
 - ...



Weather and Climate (3)

- Thinking of weather as representing a mechanism of climate, what does it mean for climate predictions.
 - More robust prediction and analysis of local changes that will impact resilience and adaptation to climate change.
 - Representation and analysis of local dynamical structures important to climate predictions.



Backup Viewgraphs





Some experiments

Here is the list of 25-yr experiments:

Test 1- 4 : albedo reduction experiments

Test 5: wind stress over ocean is multiplied by 1.2

Test 6 : wind stress over ocean is multiplied by 0.8

Test 7: Wind drag on ice doubled

Test 8: Wind drag on ice halved

Test 9: Wind drag on ice reduced by a factor of 10

Test 10: Same as 5, but the multiplication factor is 2

Test 11: no dynamic sea ice



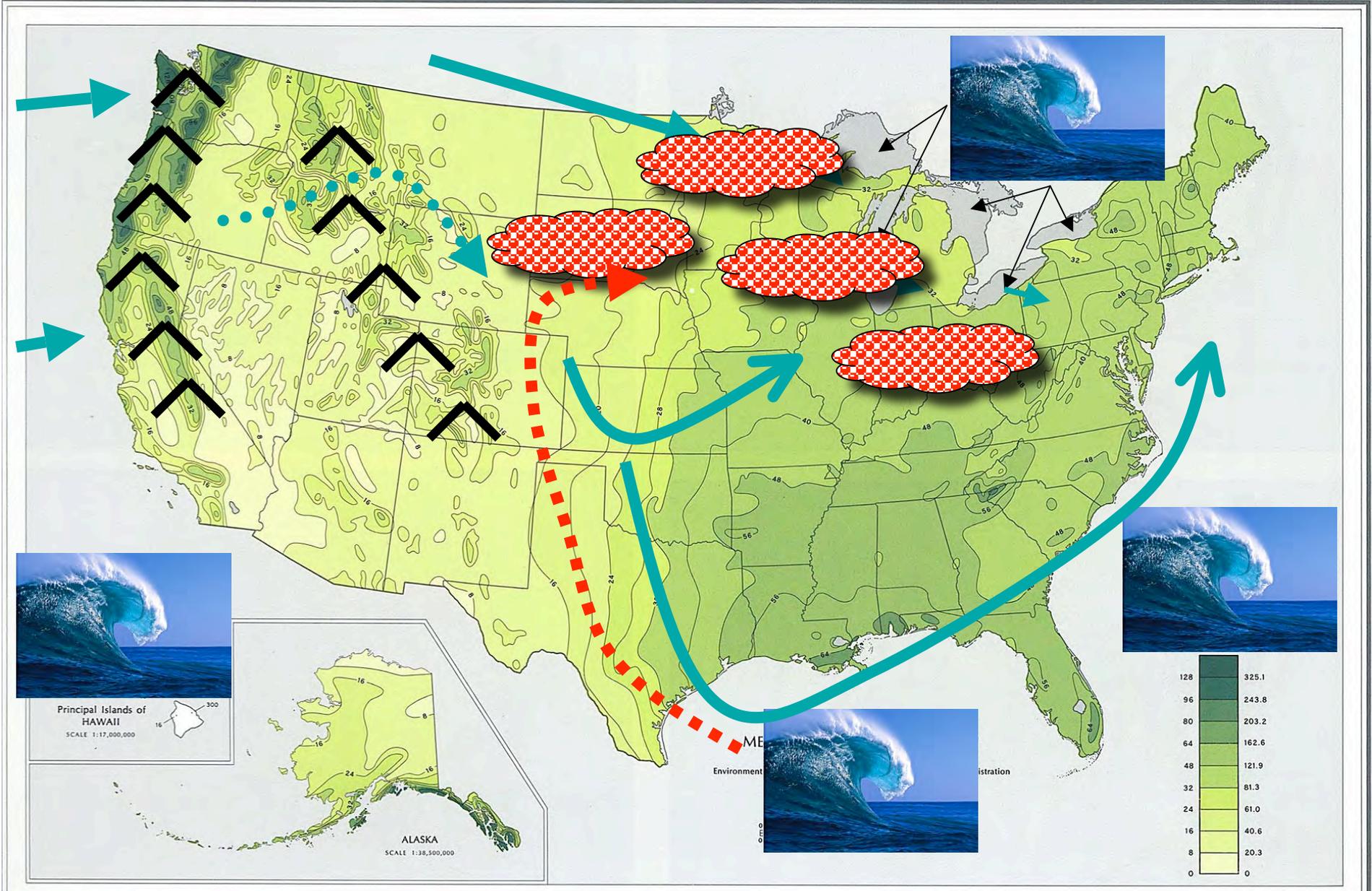
Long as I remember the rain been comin' down



[from the National Atlas (1970)]

(1930-1961)

PRECIPITATION





A proposal

-
- There is a class of climate change problems which require the credible representation of local weather if climate predictions are to be used with confidence in adaptation, geo-engineering, and abrupt climate change applications.



Changing of the definition of climate

- When Allstate Insurance stops writing homeowners insurance on the Atlantic Coast
- When the mayor of Seattle starts to adhere to the Kyoto Protocol
- When what really matters is what happens in my city?