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On the role of models and observations in climate analysis and research

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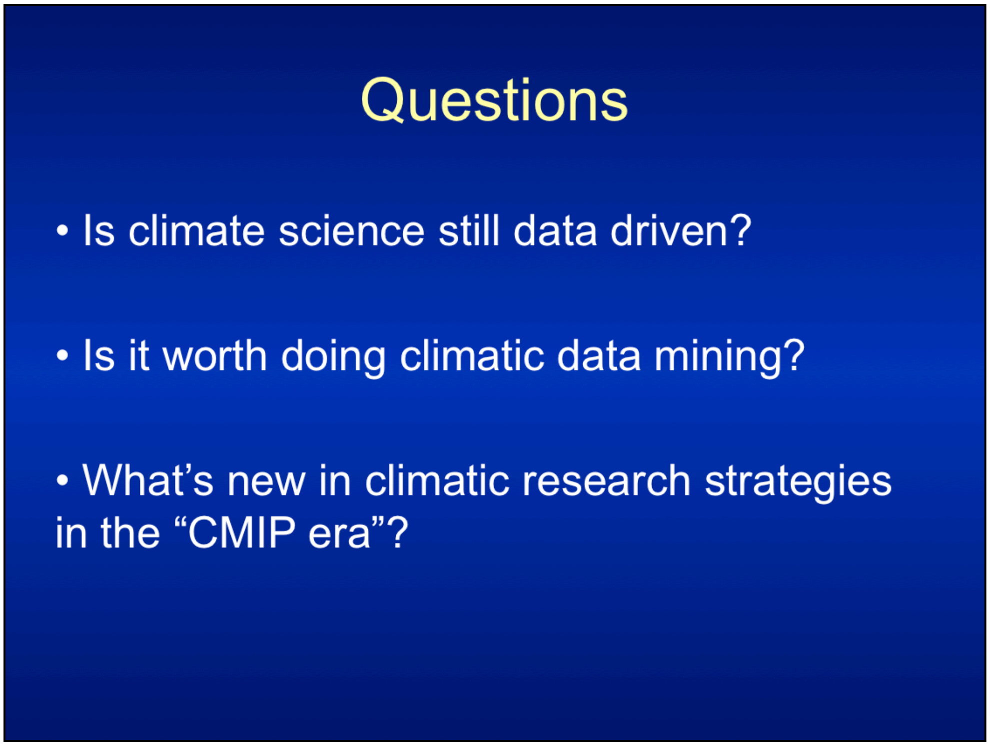


Is climate science still data driven? Is it worth doing climatic data mining? What's new in climatic research in the "CMIP era"? I'll use an example of some of my own research and recent discussion with the reviewers on that issue to spin things up - but hope to hear a lot of feedback from attendees.

Scientific Method

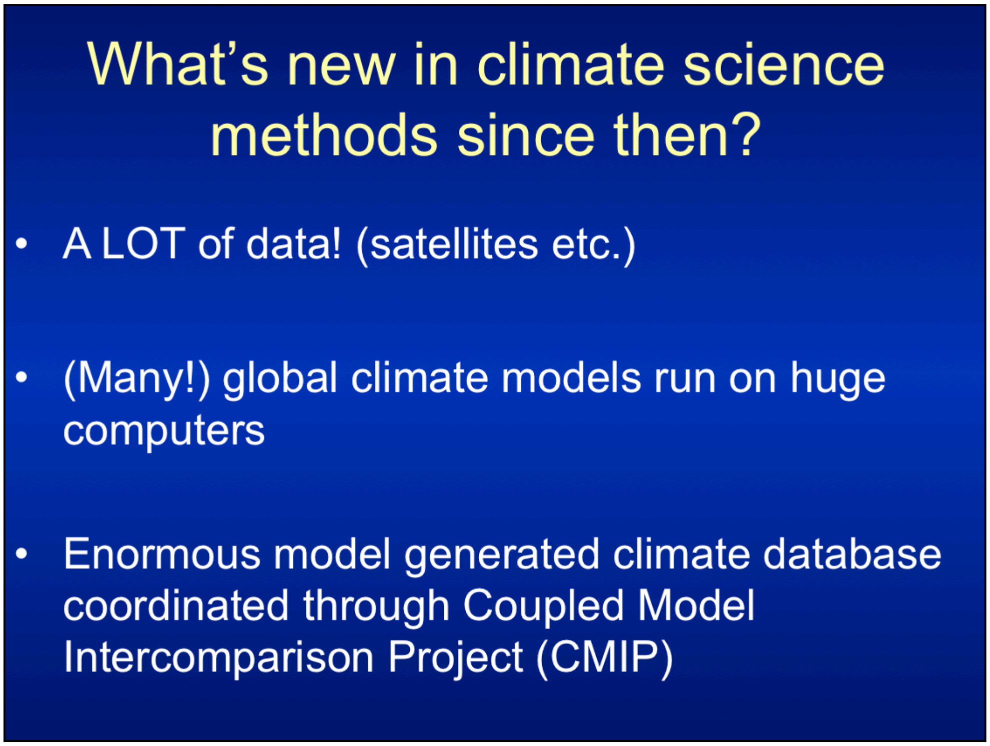
- a method or procedure consisting in systematic observation, measurement, and experiment, as well as the formulation, testing, and modification of hypotheses (Oxford English Dictionary)
- All hypotheses and theories must be tested against observations of the natural world (from the wiki article on empiricism)
- Popper: scientific theories are abstract in nature, and can only be tested (and falsified) indirectly, by reference to observations of their implications (wiki article on Popper)

Scientific theories only make sense as long as they refer to the *observed* natural world phenomena!

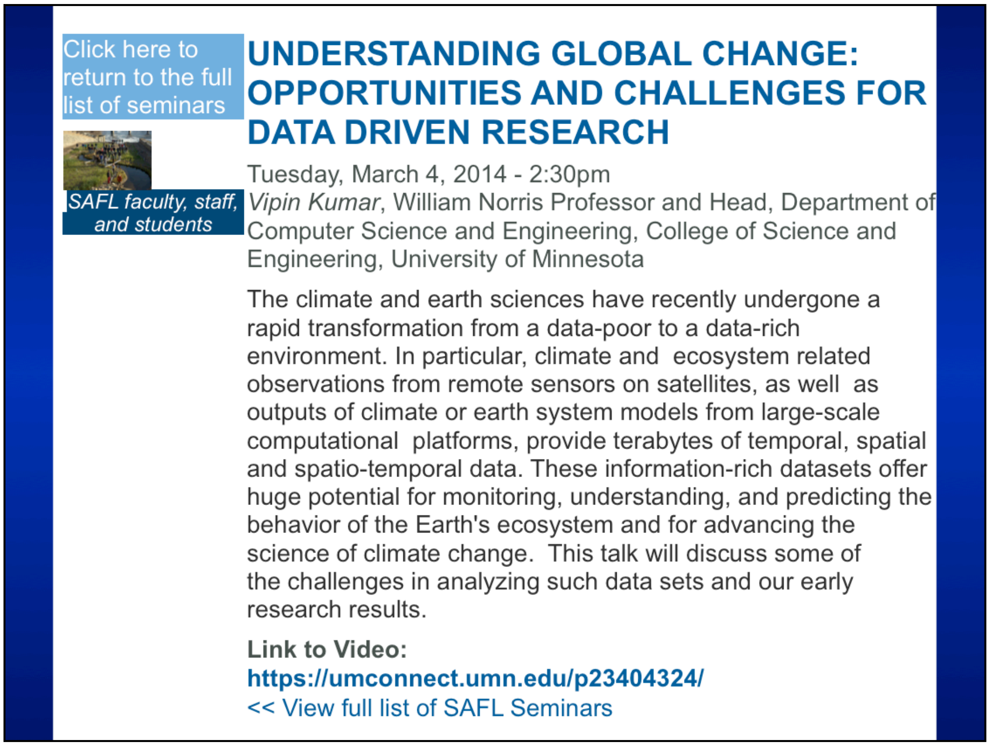
Climate research example: ENSO

- Zebiak and Cane (1987): "With no anomalous external forcing, the coupled model reproduces certain key features of the observed phenomenon, including the recurrence of warm events at irregular intervals with a preference for three to four years"
- "A theory for this variability and the associated transitions between El Niño and La Niña states is presented"
- A long history of observations and idealized uncoupled modeling prior to this study!..

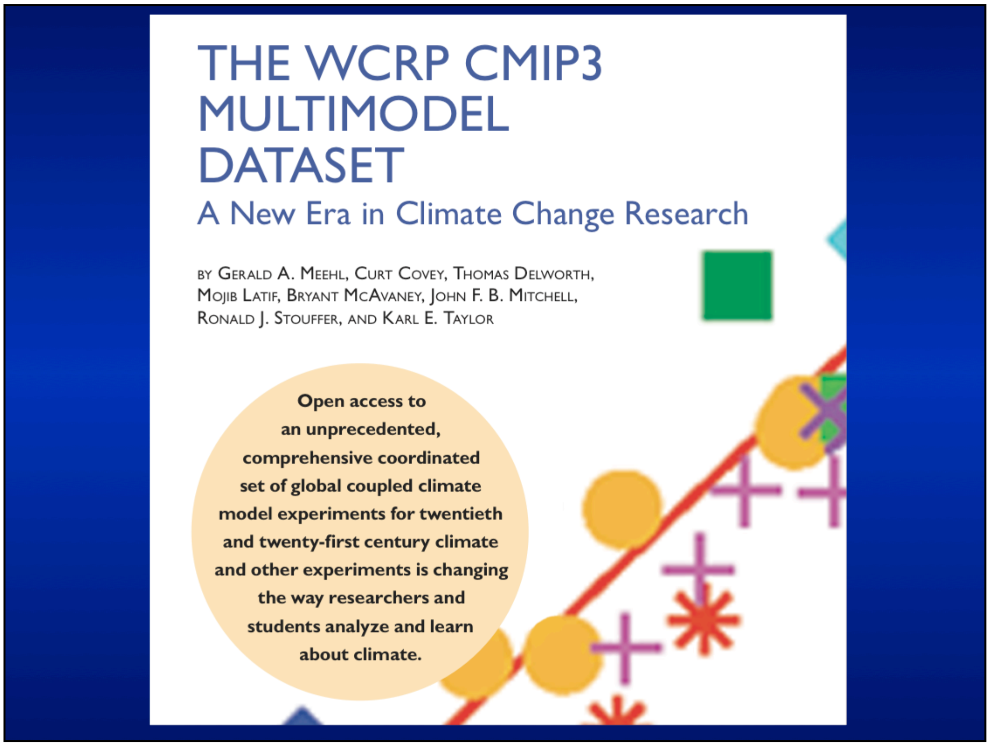
The role of observations in climatic research is especially important, as the climate science is *data driven*: We see something in observations and try to explain it, rather predicting something and then looking for signs of our prediction in observations. So, observations go first, theories (often based on parameterized models incorporating some of the basic first principles) follow.



With the advent of satellites and powerful computers, we have to deal with huge observational and model generated data sets. Climatic phenomena have now to be identified with advanced signal detection methods, while the models produce behaviors as complex as in the real world and *do not target a specific isolated phenomenon of interest*.



This set up creates a vibrant research environment full of challenges on both “observational” and “theoretical” side.



The "new era" of Coupled Model Intercomparison Project is in that the model generated climates are now publicly available, although it's not clear what the immediate impact of that could be, given an enormously data intensive character of actual and virtual "observations." Let's see how Meehl et al. (2007) comment on utility of CMIP database.

Utility of CMIP database

• The availability of such a large number of models provides considerable opportunity to explore model simulation capability of various aspects of twentieth-century climate (model verification)

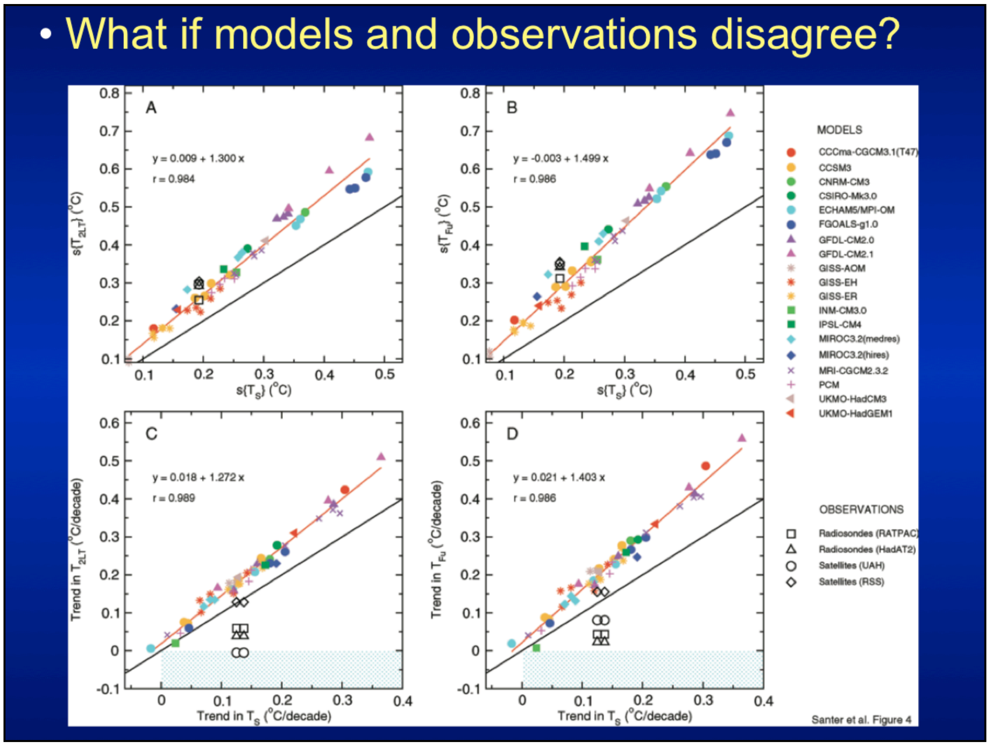
This type of quantification of model simulation capability of what we have already observed provides a baseline for the degree of confidence we can place in the models and how they may simulate future changes.

In the Meehl et al. paper this paragraph describes an illustration of how models simulate the observed leading pattern of 20th century sea-ice variability. They see the overall agreement between the observed and simulated patterns and conclude that this "overall agreement in the basic pattern of variability between the models and the observations builds confidence that sea ice variability in a future warmer climate can be usefully studied." Note the connection that is explicitly spelled out here between models and observations, consistent with an implied continued primary importance of observations in climate science.

Utility of CMIP database

- The CMIP3 multimodel dataset has also been used to help understand climate changes that have already been observed (!) during the twentieth century (analysis tool). For example, model results for the twentieth century have been analyzed, in concert with additional single forcing datasets from some of the models, to show that the signature from large volcanic eruptions, such as Krakatoa in the late nineteenth century, persist and are manifested by reduced ocean heat content for decades after the event (e.g., Delworth et al. 2005; Gleckler et al. 2006).

If models and observations agree, further analysis of the models can be used to disentangle causes of complex climatic phenomena.



This figure from Meehl et al. (originally from Santer et al.) shows comparison between models and observations of the ratio of tropospheric to surface temperature variability in tropics. The results for different CMIP models are shown with colored symbols, while observational results — as black symbols. The magnitude of surface temperature variability is a variable on the horizontal axis, while the magnitude of tropospheric variability is on the y-axis. The model results exhibit a wide range of tropospheric and surface amplitudes, but are aligned along a straight line, thus showing that the ratio of tropospheric-to-surface variability is consistent between the models (black line is the ratio of 1). Upper panels show the variance of monthly data, while lower panels – the variance for the smoothed, decadal-scale data.

For the monthly data the models and observations show consistent ratio of tropical to surface variability, with tropospheric variability being stronger. However, for the decadal-scale variability the models and observations suggest the opposite results…

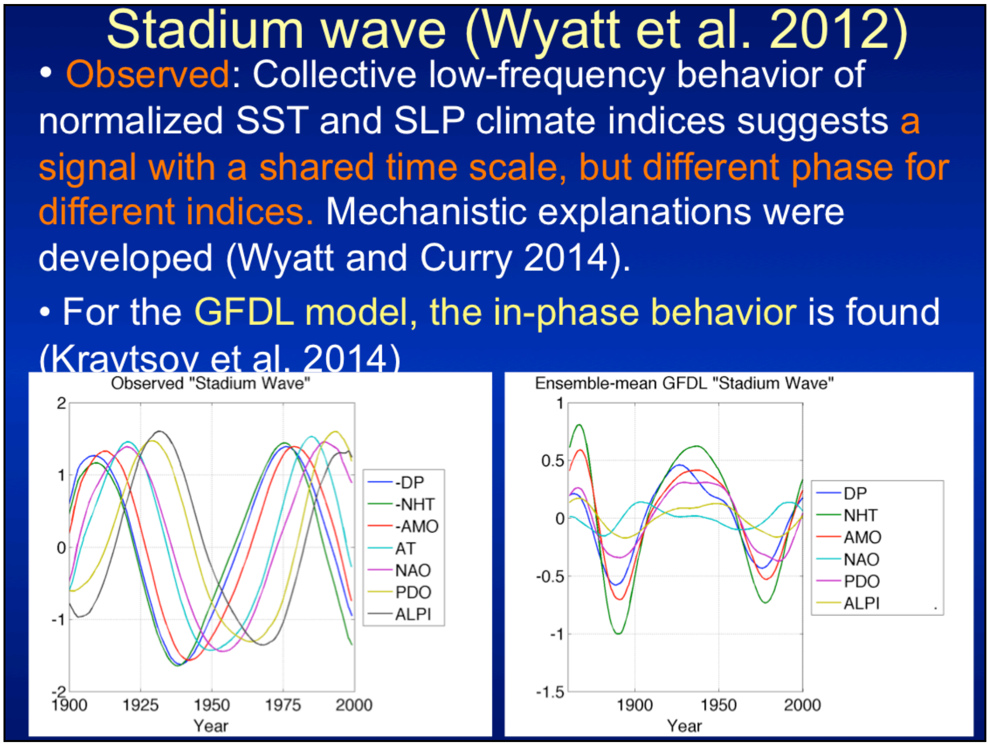
Meehl et al. conclusion:

- "Therefore, either there are different physics operating at monthly and trend time scales in the observations (whereby there can somehow be good agreement on the monthly time scale and less agreement on the trend time scale)"

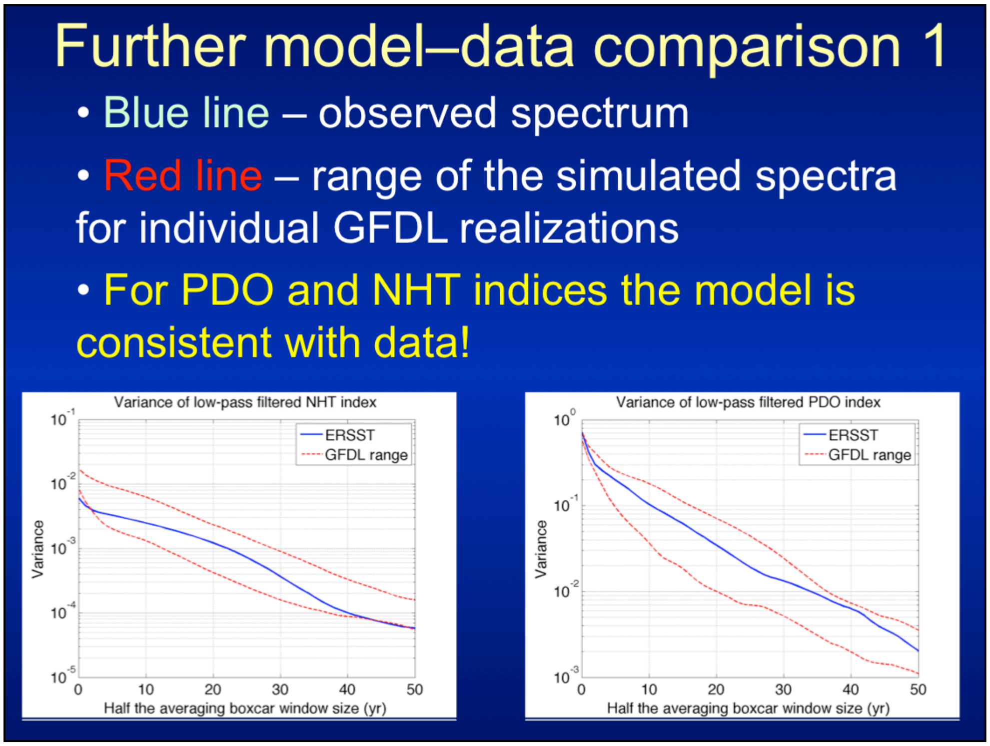
- "or this result points to the difficulties of constructing accurate small trends with disparate observed data with associated discontinuities in observing systems over time."

Notice how carefully crafted the Meehl et al.'s conclusions regarding these results are. Neither of these conclusions suggests that something in the models may be wrong and needs to be improved. This implies that the authors tend to think that the data is bad, rather than to consider a possibility of a fairly sound assumption that "the different physics" operate on monthly and decadal time scales, as suggested by observations. To be fair, the rationale for their skepticism regarding the quality of decadal data is also clear — limited length of observational record and only a few realizations of decadal variability available make the data suspect.

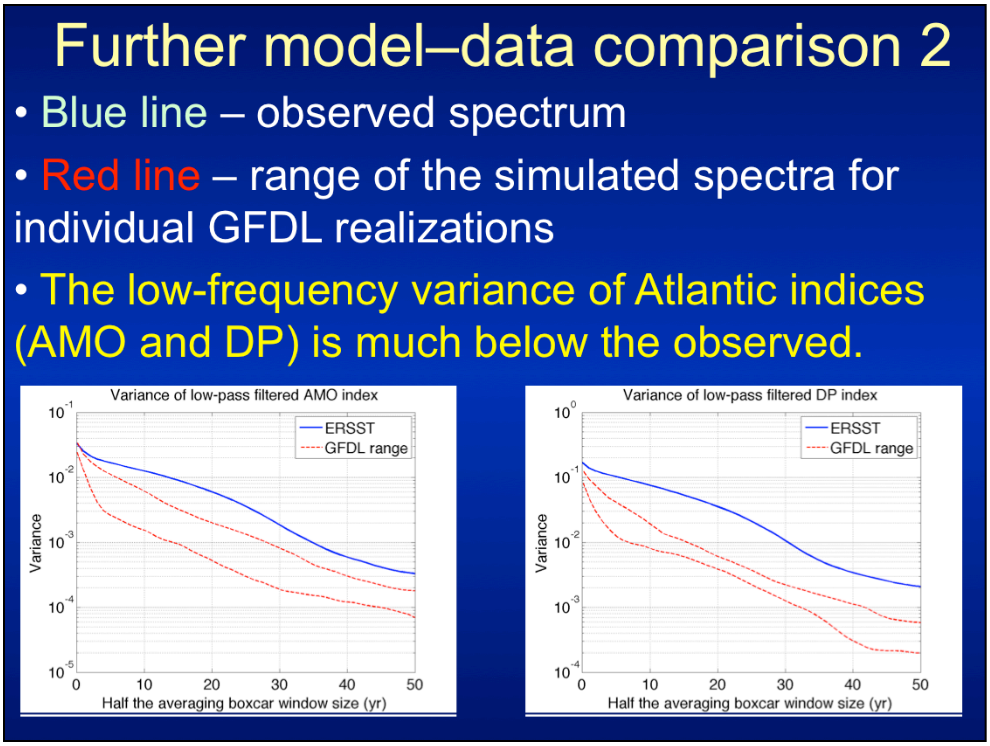
However, as I will try to further illustrate below, there may be a developing tendency for the scientists in the modeling community to be biased toward an opinion that model simulations, especially when consistent between different models, can somehow be used as tools to falsify observations rather than vice versa. To do so, consider a recent example from my own research.



Wyatt et al. (2012) following Tsonis et al. (2007) in considering a network of distinct climate indices to study the collective climate behavior in the Northern Hemisphere. They used an objective filtering technique to isolate the leading low-frequency signal in a linearly detrended data, and presented evidence for statistically significant propagation (phase shifts) of this “stadium wave” across the space of climate indices. Wyatt and Curry (2014) proposed a mechanistic explanation for this observed behavior. In contrast, applying the same technique to the data sets simulated by CMIP models (Wyatt and Peters 2012; Kravtsov et al. 2014) identifies in-phase, stationary signals devoid of such propagation.



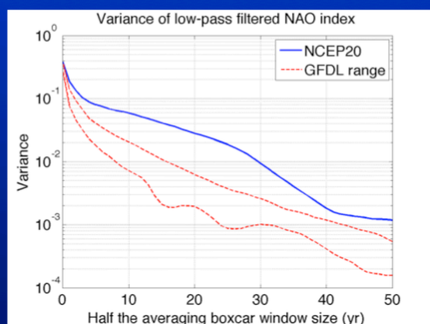
The observed and simulated “spectra” of PDO (Pacific Decadal Oscillation) and NHT (Northern Hemisphere temperature) indices shown in this slide were computed as the variances of the running-mean filtered data, for different sizes of the averaging window. “0” on the horizontal axis corresponds to raw annual data, while the non-zero numbers correspond to half of the window size (e.g., “10” corresponds to the window size of 21 yr). The observed and simulated spectra are consistent.

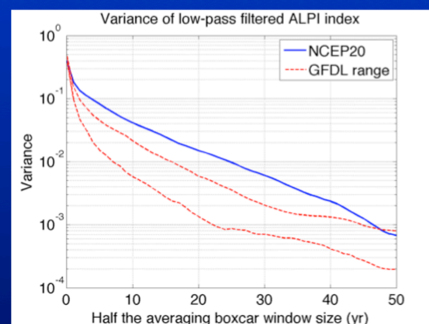


However, a tremendous, order-of-magnitude difference in variance is seen between the observed and simulated Atlantic Ocean SST indices (AMO – Atlantic Multidecadal Oscillation, and DP – “Atlantic dipole” index used as a proxy for the variability of the Atlantic Meridional Overturning Circulation [AMOC]).

Further model–data comparison 3

- Blue line – observed spectrum
- Red line – range of the simulated spectra for individual GFDL realizations
- The low-frequency variance of SLP indices (NAO and ALPI) is also much below the observed.





The same is true for both atmospheric indices used, NAO (North Atlantic Oscillation) and ALPI (Aleutian Low Pressure Index).

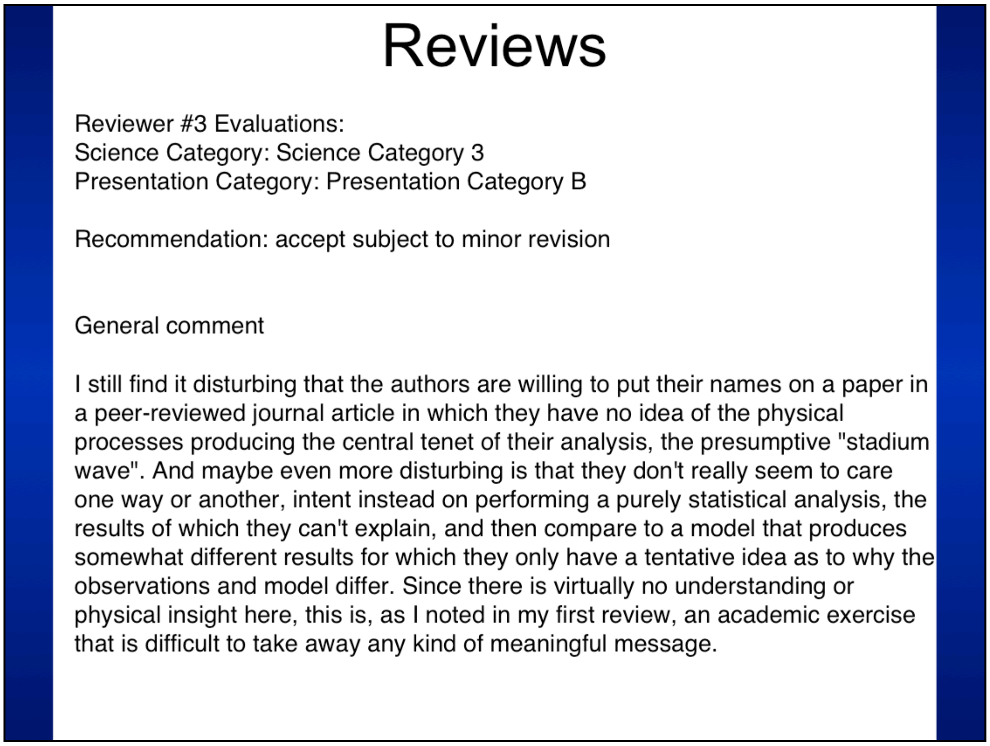
Implications (Kravtsov et al. 2014)

- Is statistical analysis faulty? (e.g., Mann et al.) — doesn't seem to be the case:

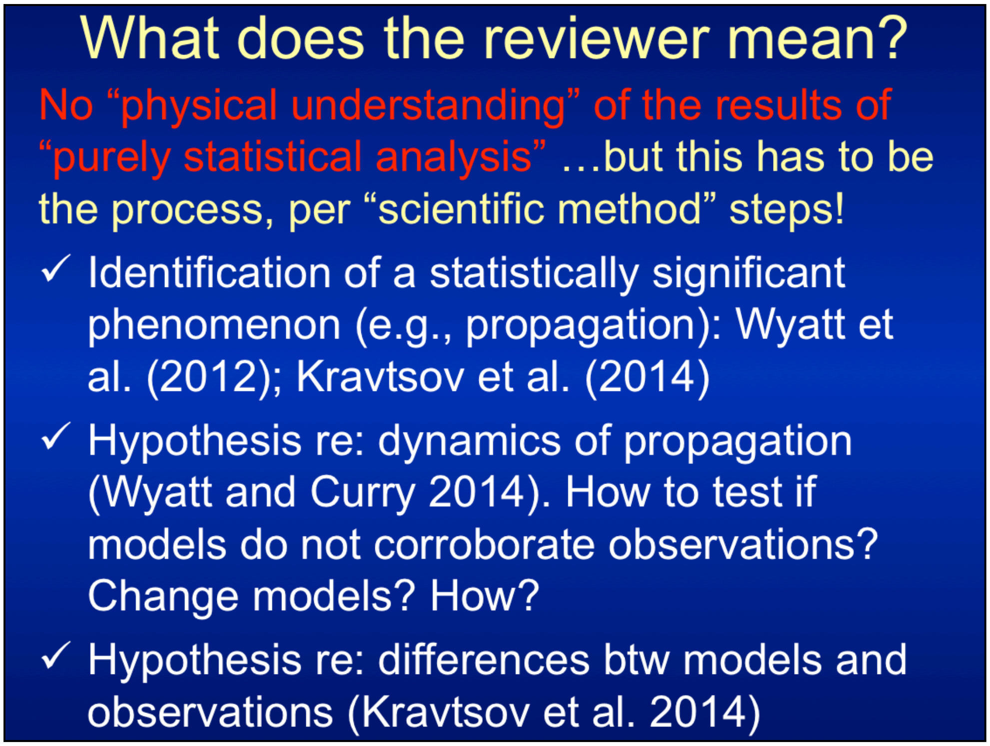
✓ Propagation is stat. significant at 5% level

✓ Leading-order differences in the level of North Atlantic and atmospheric decadal variance, well above the level of uncertainty

- Alternative: Are models wrong? — seems to be a reasonable assumption warranted by the results of statistical analysis



Despite an obvious conclusion of the previous slide, the Kravtsov et al. (2014) paper has been in review for over three months (a long time for fast-track GRL journal!). Here is the closing statement by the most critical reviewer of the paper.

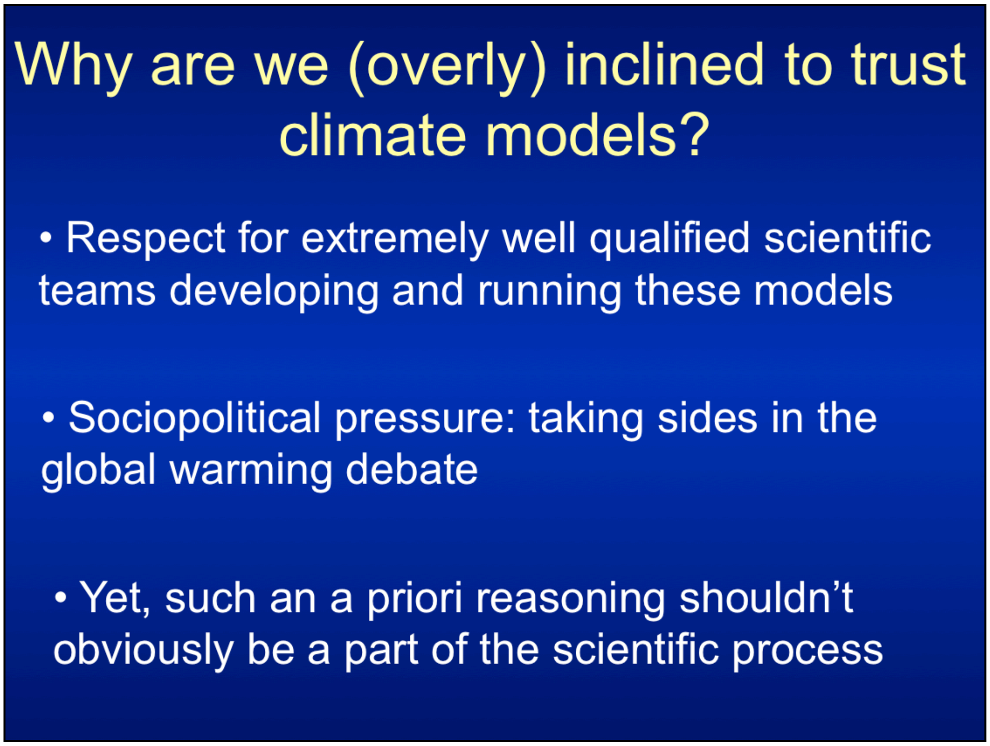


The reviewer's main critique of the paper is that the hypothesized sequence of dynamical feedbacks leading to the stadium wave (Wyatt and Curry 2014) is, well, hypothetical as of yet. We are at an impasse here, since the climate models – the major tool that one could use to test this hypothesis (Meehl et al. 2007) — do not seem to reproduce the observations. Other results by Kravtsov et al. (2014) are suggestive of potential areas for the model development that can be looked at with regards to this problem (most notably, the apparent lack of multidecadal atmospheric sensitivity to what the surface climate does, more on that later). However, who will do this analysis and how? Given the way the climate models are developed and run (see the next slide), there has to be a two-way collaboration between climatologists and climate modelers that would target *specific* observed phenomena.

Climate models

- Run by climate centers; hundreds of climatologists, numerical modelers and computer scientists are involved in developing and maintaining the models and their outputs
- The models are expensive to develop and run
- The models consist of the "first principles" dynamical core and multiple physical parameterizations of subgrid-scale processes
- The models produce virtual climates as complex as reality. They don't target a specific phenomenon, but rather model "everything"
- But, are "virtual climates" = "real climate"? – No!

Models are a tool to analyze observations, not vice versa! So disagreement of models with observations does not (and cannot be used to) disprove observations. On the contrary, the models may need to be modified to bring their results in consistency with observations, then physical processes behind the observed features of climate can be meaningfully studied using these improved models. Once again, it seems that a useful research strategy would be to look at models as ever-developing climate analysis tools to understand specific climate observations, rather than virtual (implicitly=real) climate laboratories.



Climate models incorporate some of the essential first-principle dynamics, and turned out to be an extremely useful tool for climate analysis. They are developed and run by dedicated scientists who deserve all the respect. It is psychologically more difficult to challenge the results of the model simulations managed by a large team of skilled professionals. Yet, it's no secret that the models are prone and will undoubtedly stay prone to errors, due to, for example, lack of resolution and the necessity to parameterize subgrid-scale processes.

Furthermore, in recent years the global warming debate splashed out of its scientific niche and became public. A person criticizing the ability of climate models to faithfully describe the observed decadal variability is somewhat automatically regarded to be, in some sense, "non-consensus" (and the "non-consensus" people gladly talk back about "climate alarmists" or "warmists").

However, a priori trust into the collective effort of climate modeling centers (vs. individual researchers) or personal beliefs in whether there is a human induced global warming or not have no place in the scientific method approach to analyzing natural phenomena.

Areas for model improvement

• Atmospheric sensitivity to SST anomalies (Kushnir et al. 2002), especially on decadal time scale. Can be as simple as turning up the resolution to the scale of ocean thermal fronts (Feliks et al. 2004) – mesoscale-resolving atmospheric components?

• Eddy-resolving ocean model components (Kravtsov et al. 2011) – or stochastic parameterizations for efficiency?

• Better resolving sea-ice dynamics (Kwok 2011; Wyatt and Curry 2014)?

Summary

- In a data-rich environment of modern climate science, advanced statistical detection methods can and should be used to search for climate signals
- The absence of an observed signal in a climate model cannot be used to falsify observations
- This discussion calls for a two-way collaboration between climatologists and climate modelers in which climate models are further developed to address specific targeted phenomena, rather than implicitly being treated as truth — virtual, but still somehow equal to the real climate

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