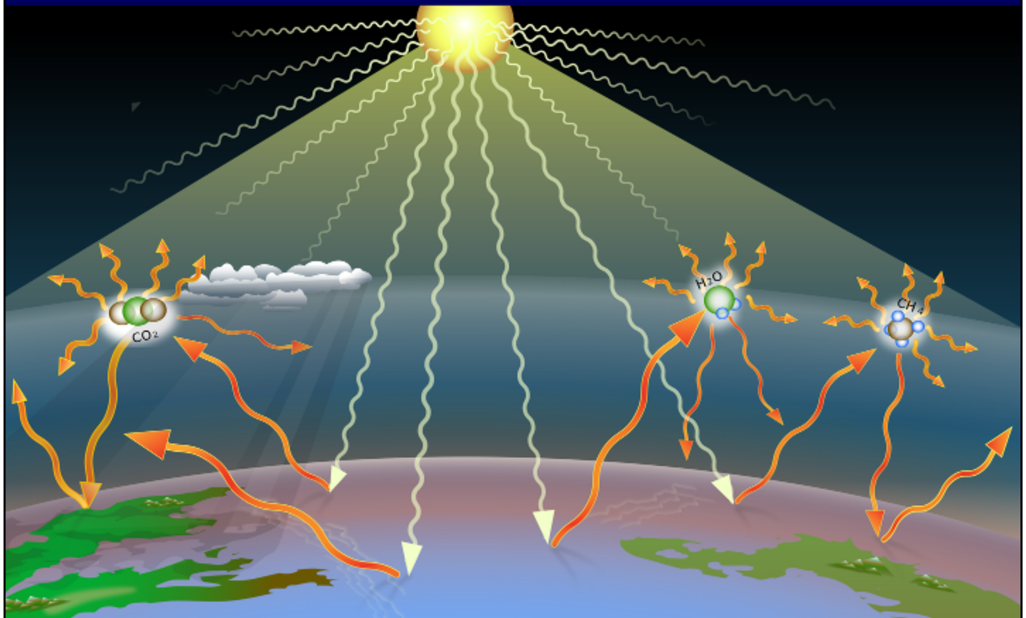
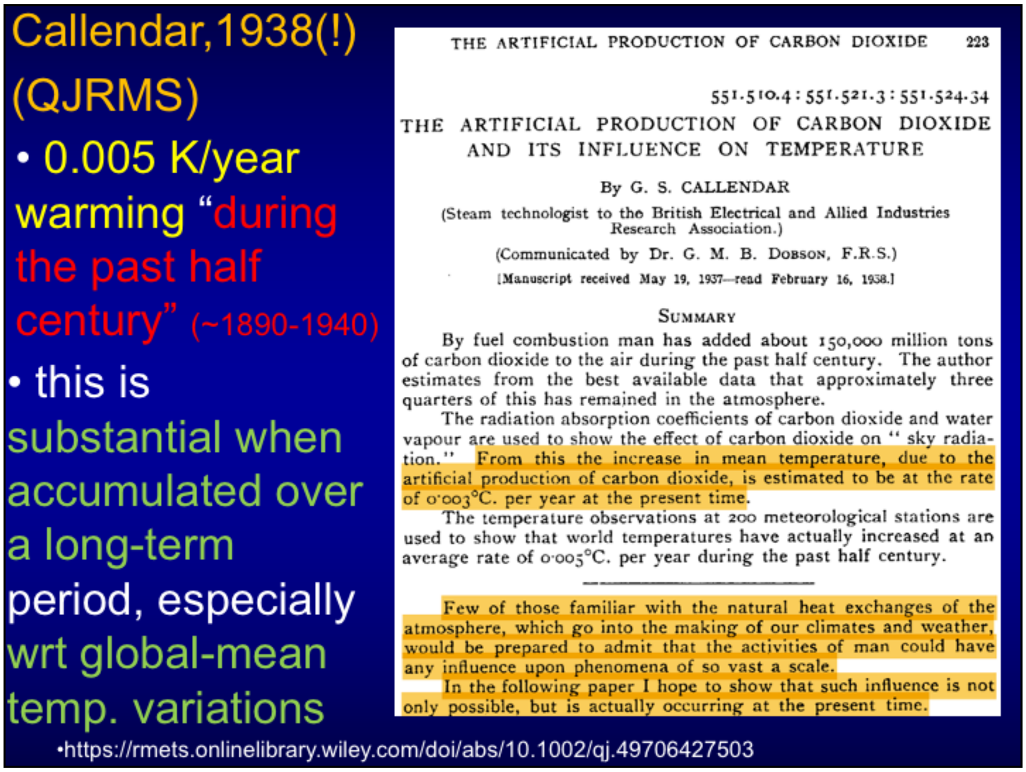
Invited presentation at the Greater Milwaukee Chapter of American Meteorological Society meeting

Greenhouse effect

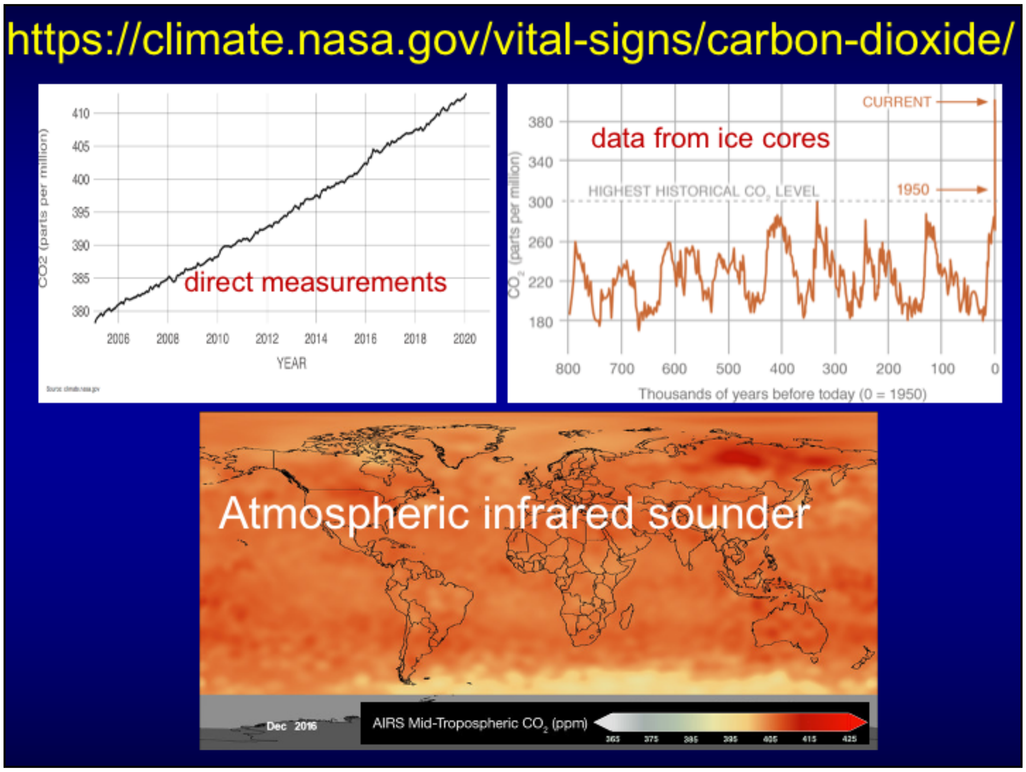


• https://en.wikipedia.org/wiki/Greenhouse_effect#/media/File:Greenhouse-effect-t2.svg

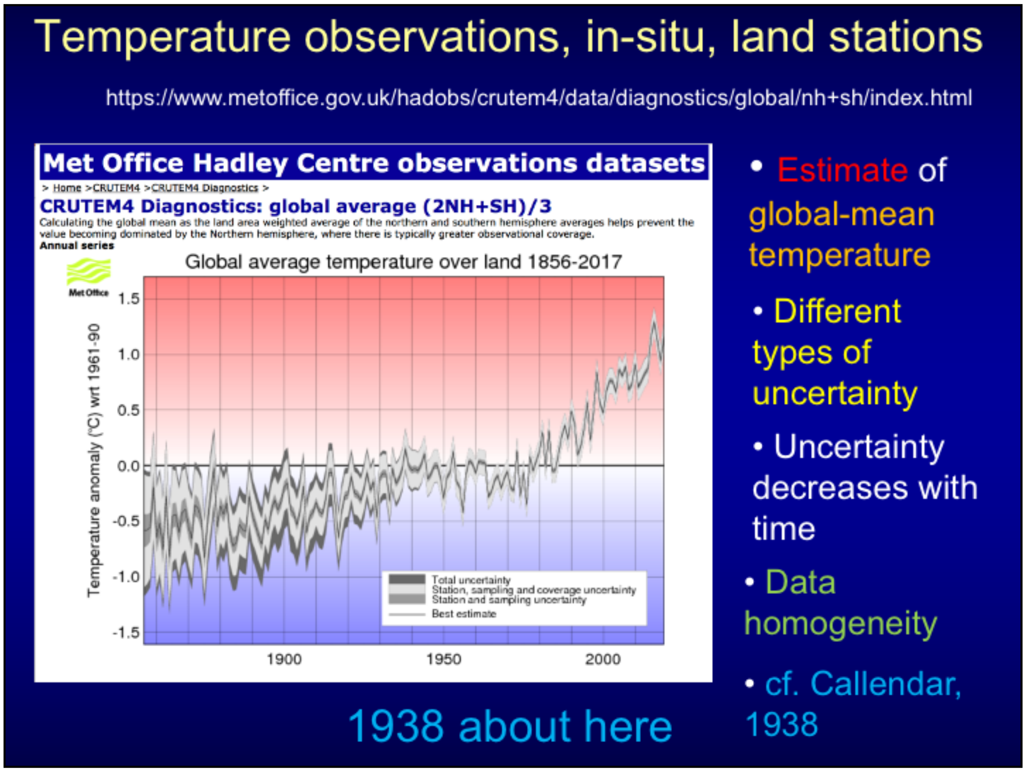
Greenhouse gases transmit (most of) shortwave radiation and absorb long-wave back-radiation from the Earth's surface. This absorption warms the atmosphere, which then sends additional downward longwave radiation toward the Earth's surface. The net downward radiation flux in the presence of the greenhouse gases (solar + atmospheric downward radiation) is therefore larger than in the absence of greenhouse gasses (solar only), so the surface must warm to a larger temperature to achieve equilibrium.



This is a pioneering work using theoretical and observational analyses to suggest human-induced long-term climate trends. Note that the 0.005K number appears to be tiny compared to day-to-day or even year-to-year temperature variations at a single location, but it translates into a substantial temperature warming over long term, especially compared to spatially averaged (e.g. global-mean) variability.



… and, indeed, CO2 is increasing and is now way above the pre-industrial levels (based on proxy data). Also, it is pretty uniformly distributed horizontally (bottom panel), and it's a "good news" for our ability to detect temperature trends radiatively forced by the CO2 increase, since we can do it for multiple stations all over the world. Why is it a good news? – because we can reduce signal contamination due to internal atmospheric "noise" (which is different for any two stations that are far apart) by averaging the temperature trends measured all over the world (cf. Callendar's paper above).



This illustrates the analysis of global temperature using one of the state-of-the-art observational in-situ data sets. It currently streams information from about 5500 weather stations worldwide (much fewer stations in the beginning of the instrumental record, leading to large uncertainty in computing the global-mean). Each station also has gaps in data and errors associated with measurement accuracy. Data homogeneity is an important issue when addressing long-term trends (because different observational techniques can result in bogus climate “jumps”). Note the non-uniformity of warming, with global temperatures steady before 1880 and decreasing from about 1940 to 1970. This decrease was a major factor for Callendar’s work being under-appreciated at that time (apparently, his predictions failed to verify, right!) Why? – because CO_2 is only a part of the story, we’ll get to that later.

Marine instrumental observations

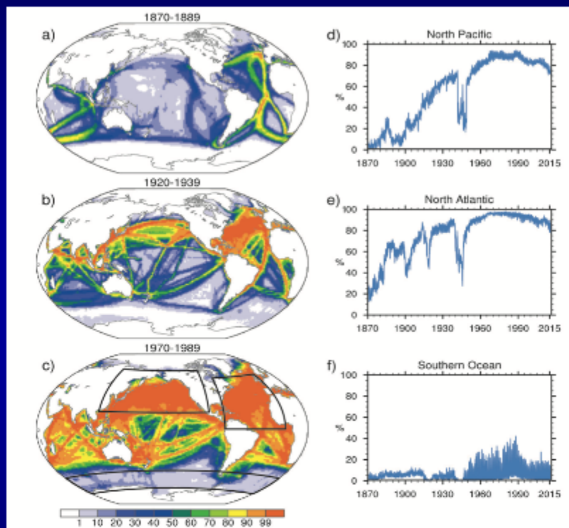


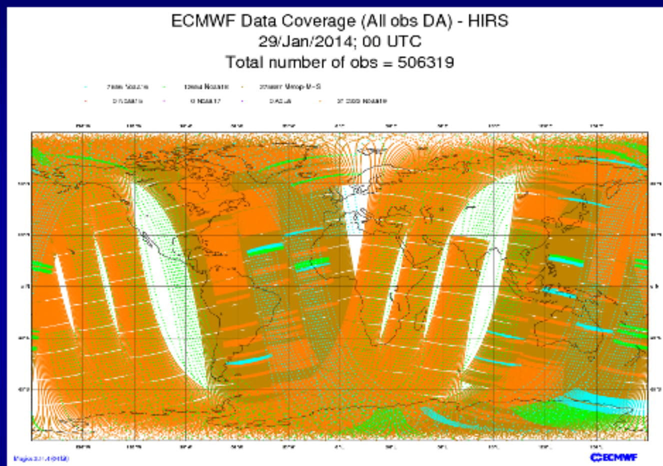
Figure 1: Distribution of sea surface temperature observations from the International Comprehensive Ocean Atmosphere Data Set. Maps show the percentage of months with at least one measurement in a 2 degree latitude by 2 degree longitude

- Incomplete coverage for sure, especially in the past
- Better coverage now, still poor over Southern Ocean
- Don't forget about data homogeneity!

Deser and Phillips, 2017, CLIVAR Exchanges, doi:10.22498/pages.25.1.2

Similar (or even more challenging!) issues exist with regards to instrumental data over the oceans!

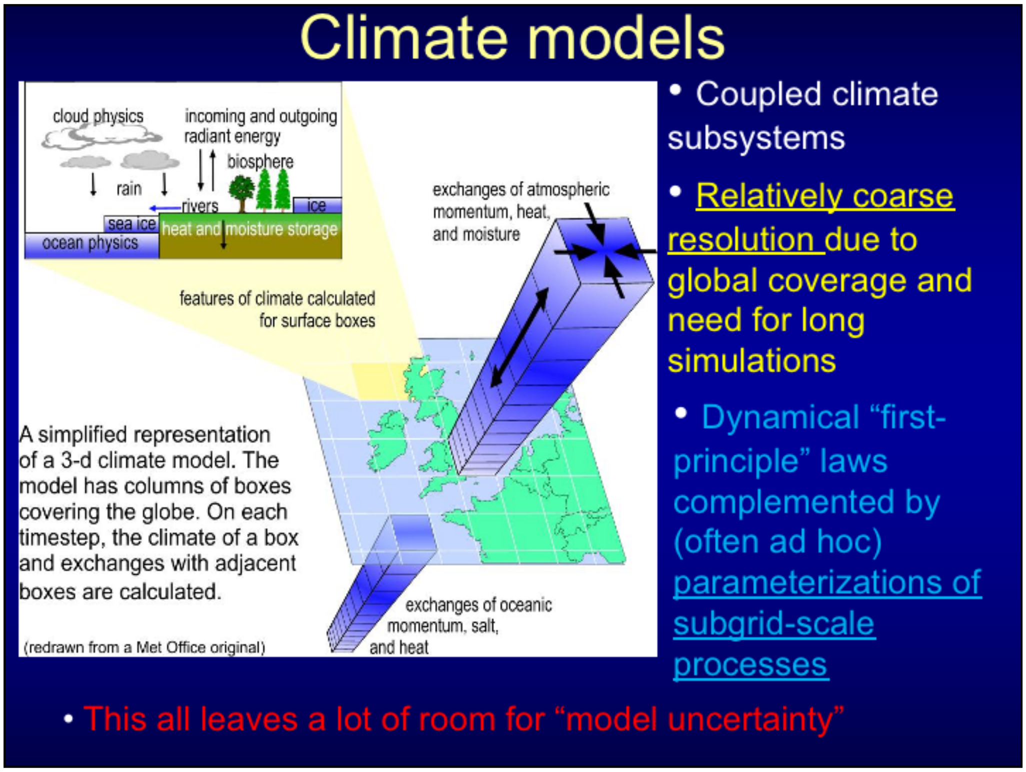
Satellite observations



- started recently - in earnest, since late 20th century (so now we have ~50 yr of data)
- Lots of data!
- There exist various issues with space/time coverage, presence of clouds, inhomogeneities at the surface over land etc., but they can be effectively dealt with to provide faithful estimates of climate variability over a range of time scales.

http://weather.mailasail.com/Franks-Weather/Weather-Observations-Nwp

Satellite data provided observations with unprecedented coverage since about 1970s.



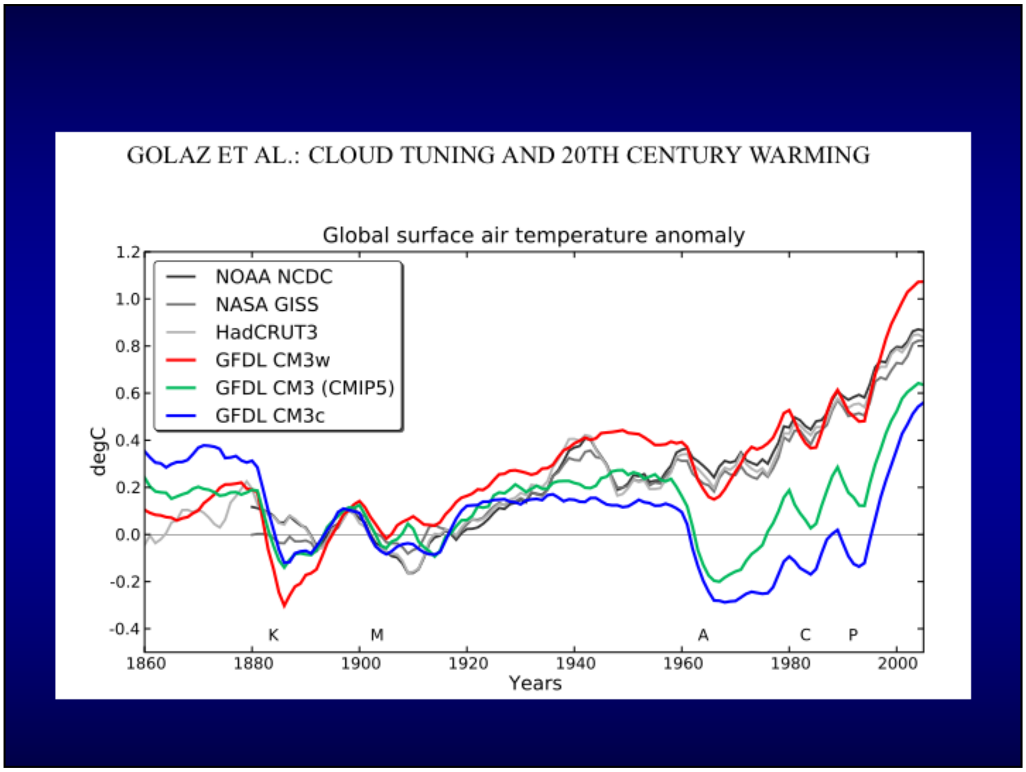
State-of-the-art climate models are complex (yet incomplete!), but (and) prone to uncertainty due to ad hoc parameterizations of subgrid-scale ("unresolved") processes (for example, the production of and effects of clouds on the climate of an individual atmospheric box). This uncertainty is not a small thing (e.g., see the next two slides).

Cloud tuning in a coupled climate model: Impact on 20th century warming

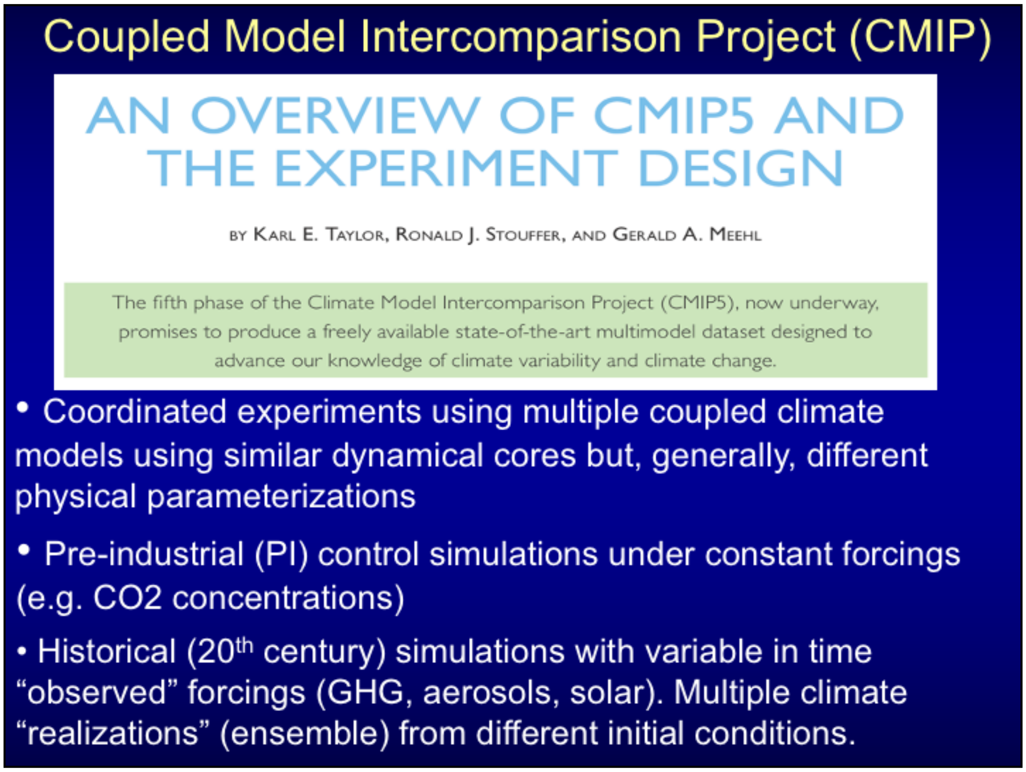
Jean-Christophe Golaz,[1] Larry W. Horowitz,[1] and Hiram Levy II[1]

[1] Climate models incorporate a number of adjustable parameters in their cloud formulations. They arise from uncertainties in cloud processes. These parameters are tuned to achieve a desired radiation balance and to best reproduce the observed climate. A given radiation balance can be achieved by multiple combinations of parameters. We investigate the impact of cloud tuning in the CMIP5 GFDL CM3 coupled climate model by constructing two alternate configurations. They achieve the desired radiation balance using different, but plausible, combinations of parameters. The present-day climate is nearly indistinguishable among all configurations. However, the magnitude of the aerosol indirect effects differs by as much as 1.2 Wm^{-2}, resulting in significantly different temperature evolution over the 20th century. **Citation:** Golaz, J.-C., L. W. Horowitz, and H. Levy II (2013), Cloud tuning in a coupled climate model: impact on 20th century warming, *Geophys. Res. Lett.*, *40*, 2246–2251, doi:10.1002/grl.50232.

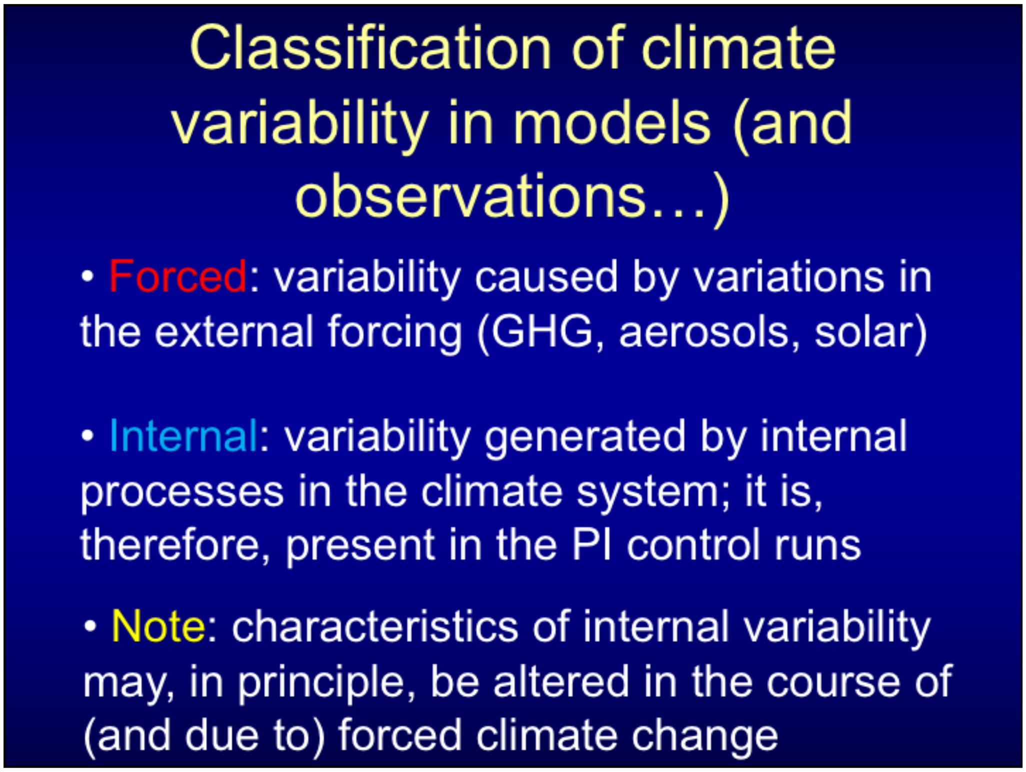
The process of choosing model parameters entering parameterization of subgrid-scale processes to make sure the model best matches the observed climate is called tuning. The problem is multiple combinations of model parameters may be used to achieve essentially the same model climate, but different responses to variable forcing.



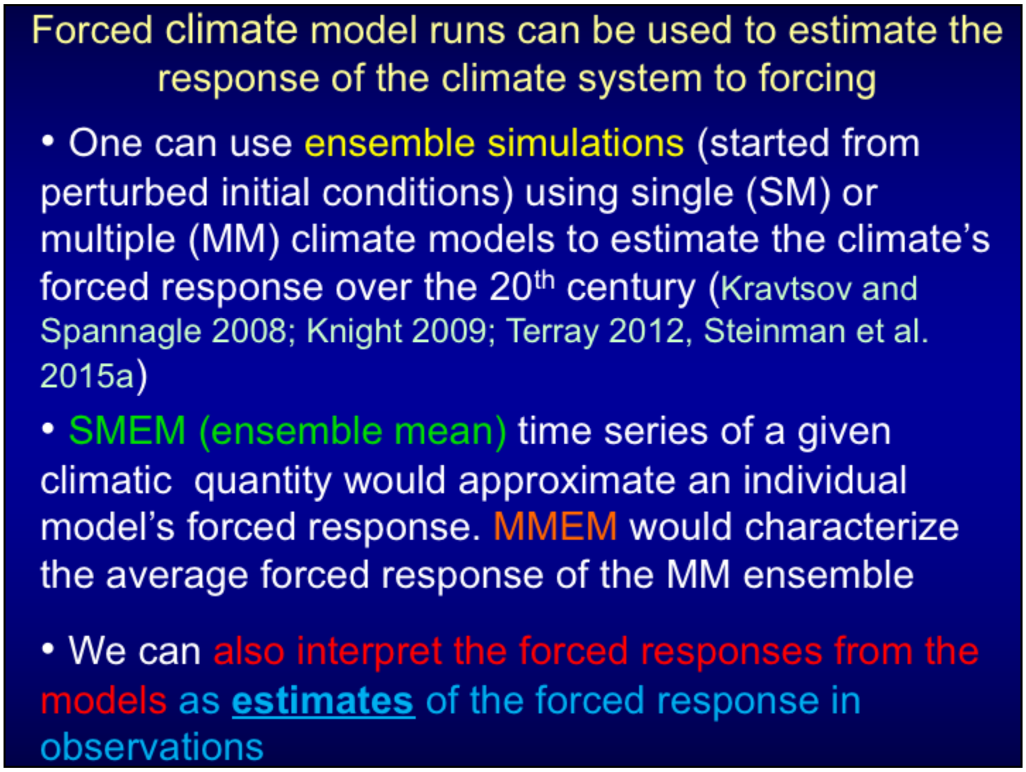
Here is how it looks! Changing, slightly, a couple of adjustable parameters in a model may result in major changes in the long-term climate trends simulated by the model (Black-to-gray: observational data sets; color lines – model simulations with different cloud-scheme parameters).



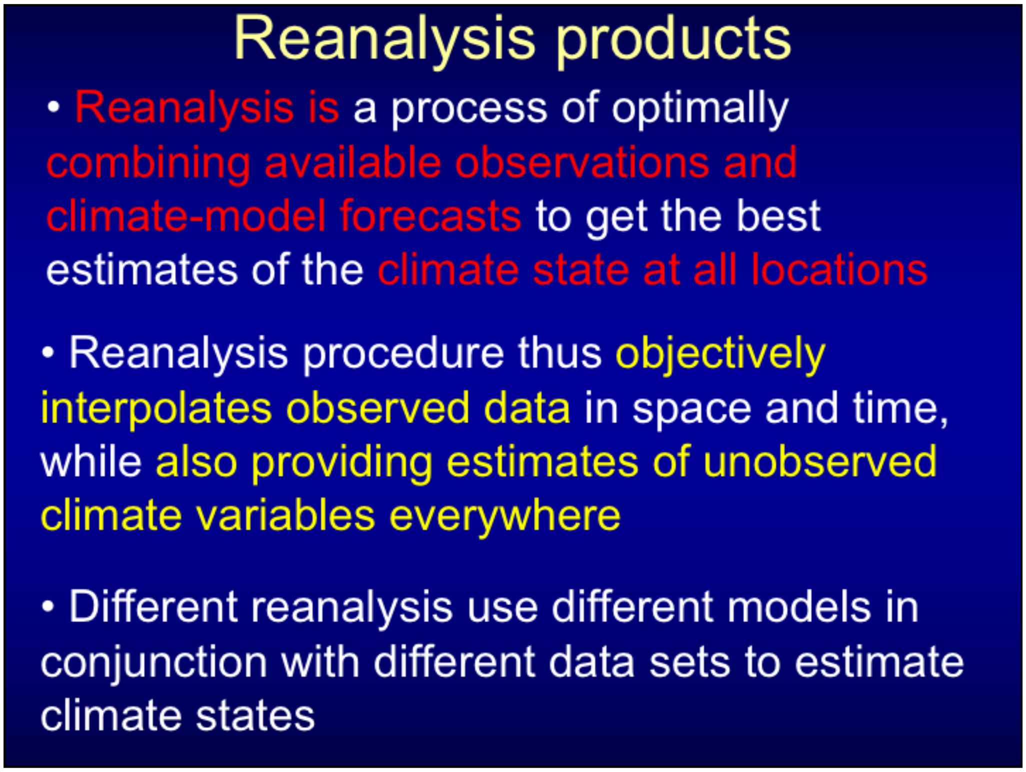
One way of accounting for uncertainties in physical parameterizations within climate models is to use ensemble of models with different such parameterizations… Such models are developed and run by major climate research centers all over the world, producing a massive database for analyzing the dynamics of climate change.



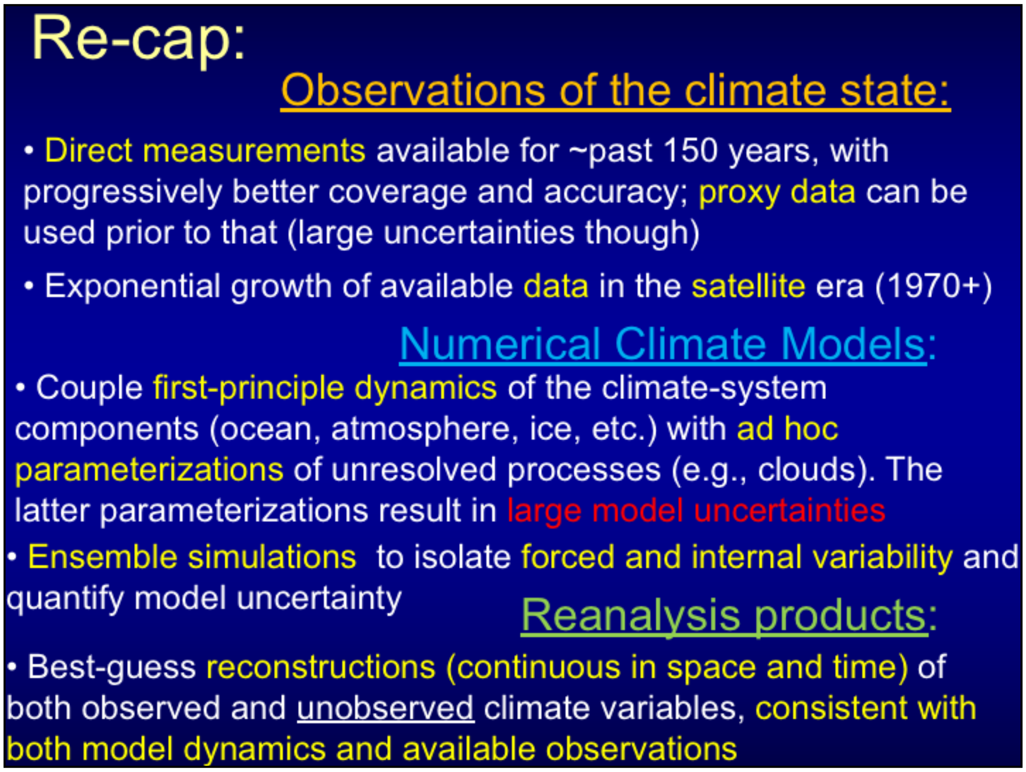
Climate variations may be due to climate system's response due to variability in external forcing(s) or be internal to the climate system (and, hence, exist under constant-forcing conditions).



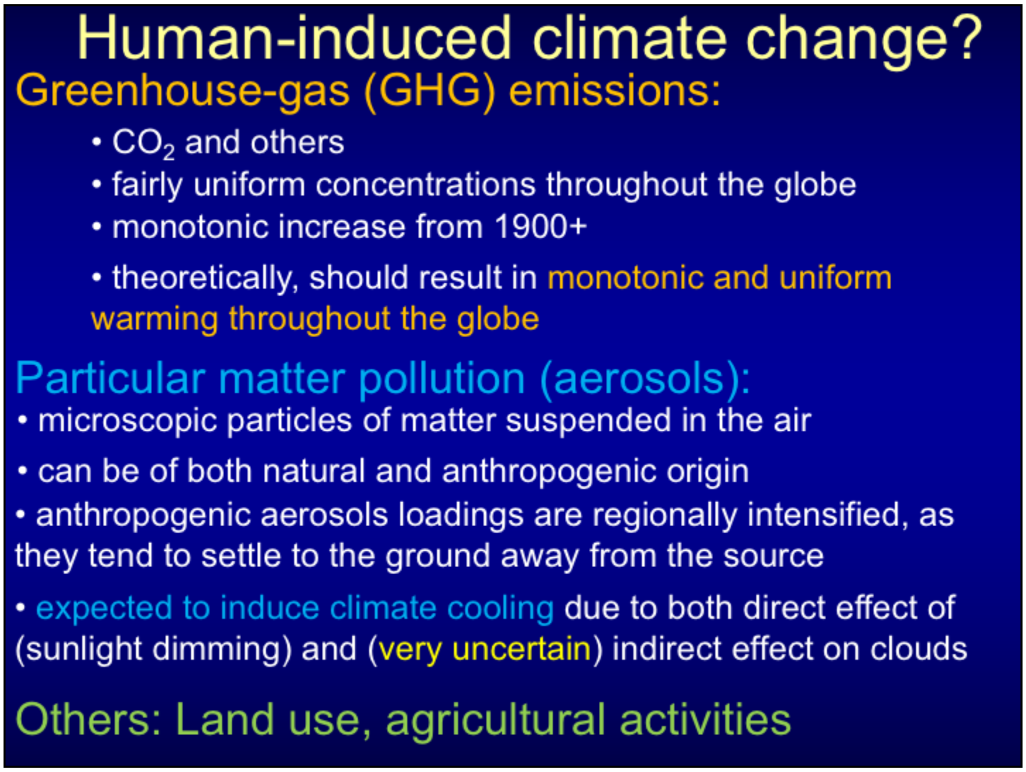
Ensemble simulations provide means to isolate forced signal by averaging over multiple forced runs of an individual model started from different initial conditions, since these runs would be characterized by the same forced signal, but uncorrelated realizations of internal variability.



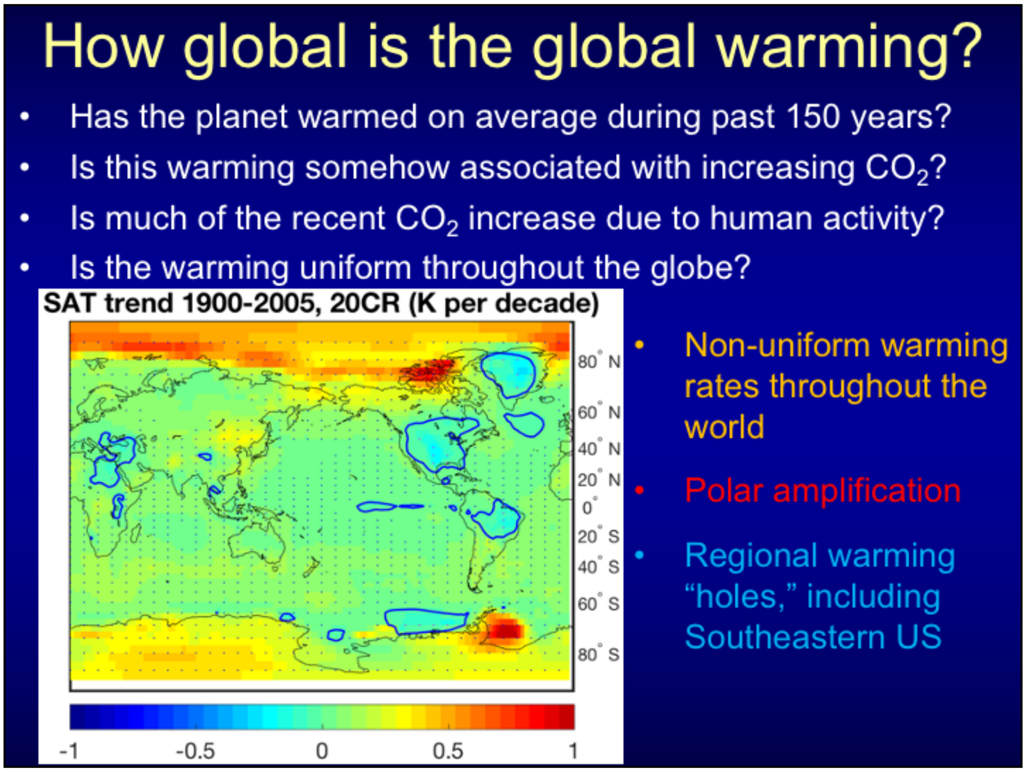
Reanalysis products is our best guess(es) of the climate variability over the duration of the observational record, providing essentially continuous information in space and time. Different reanalyses combine different models with different observational data sets and may result in different estimates of climate states and their evolution. Note that the models used to produce reanalysis are also imperfect and model errors may be an issue as well.



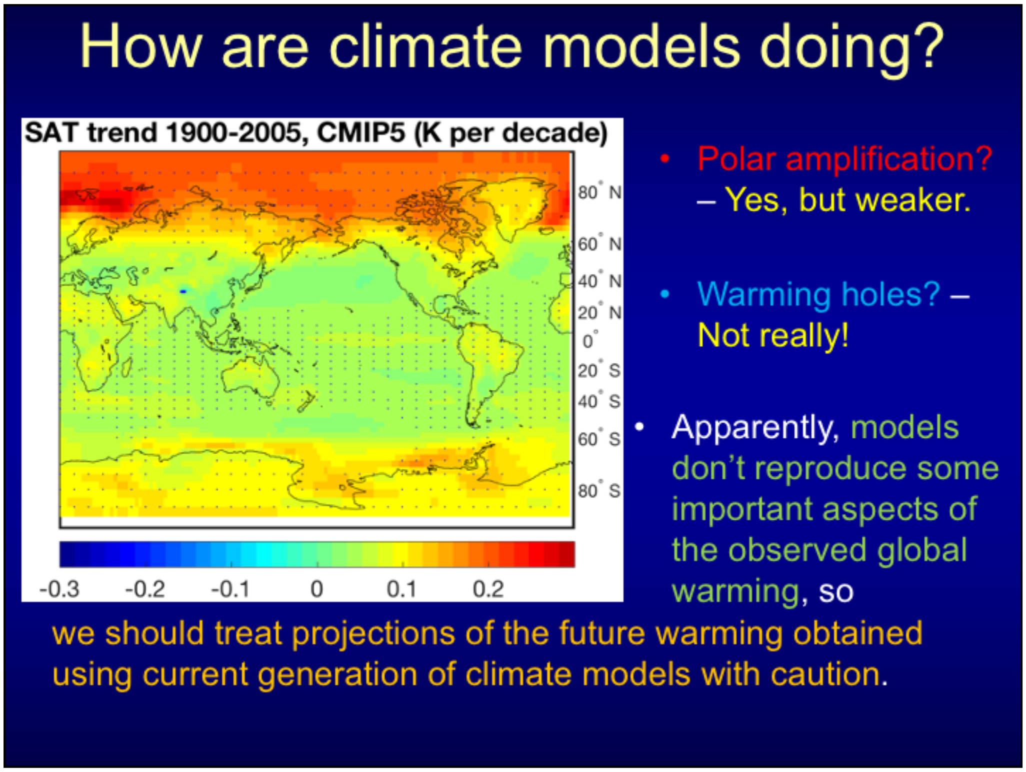
Climate science is a data-driven science, but numerical climate models is its main analysis tool!



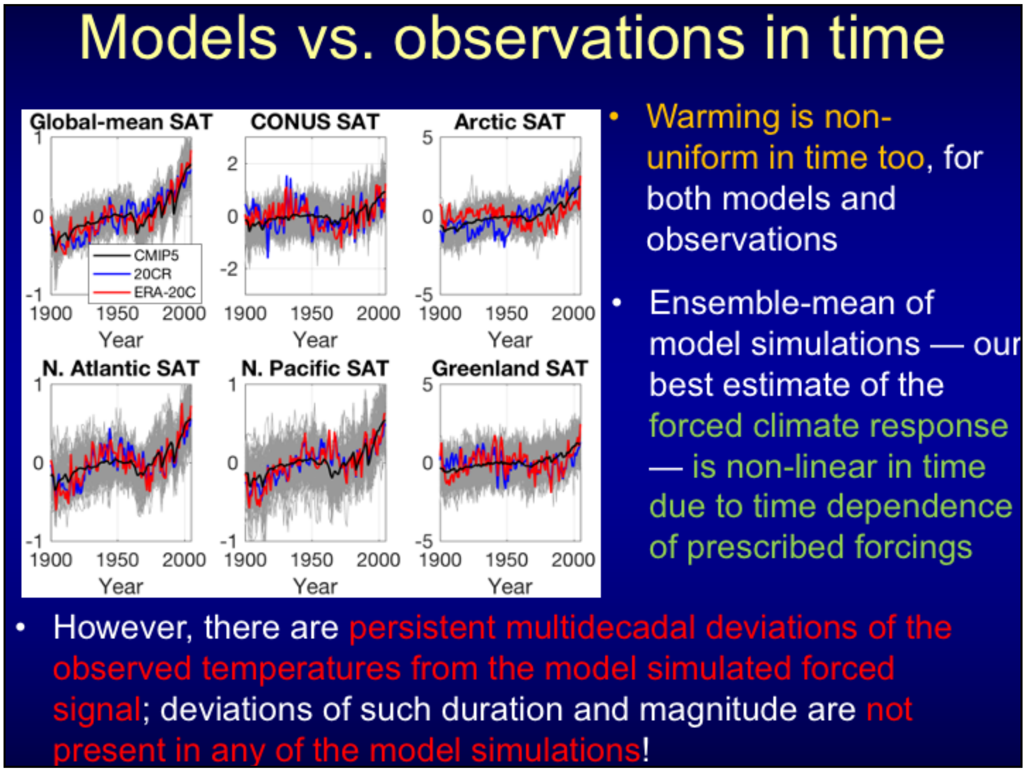
Human induced climate change is to be categorized as the response of the climate system to variability in the external (to cilmate system) forcing.



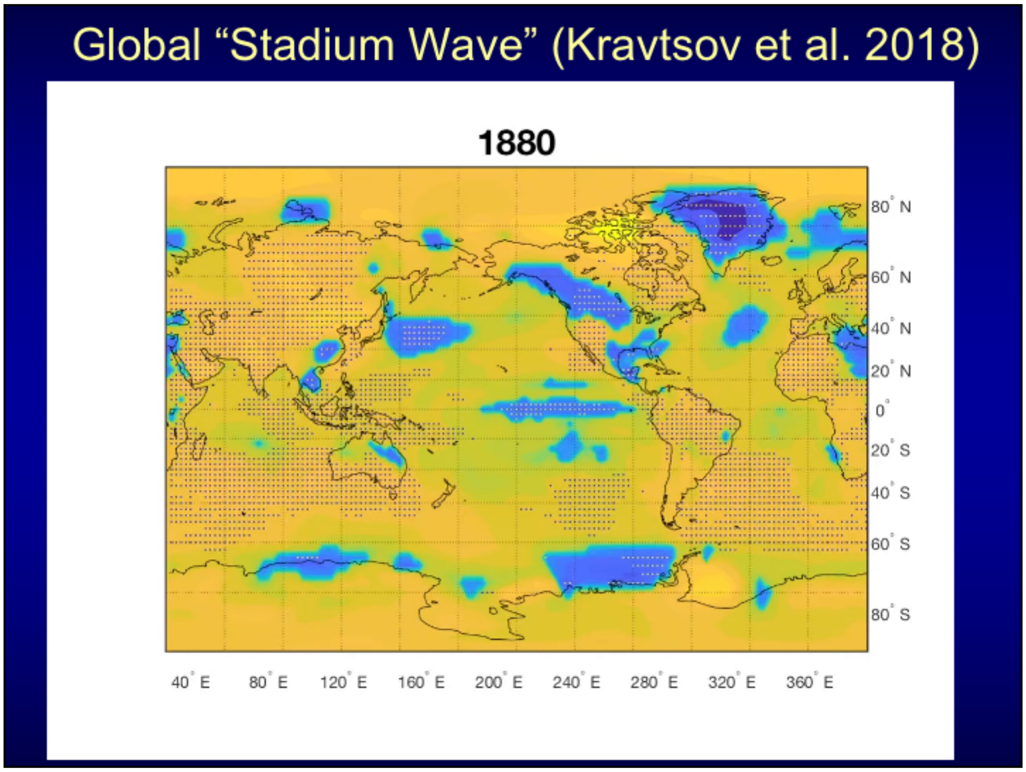
Using theories, observations and models, we can address various questions associated with the problem of global warming. Is there a warming of a planet on average over the past 150 years? – Sure, we saw the observational evidence before. Is it somehow associated with increasing carbon dioxide in the atmosphere? – Very likely: after all, the CO2 concentration increased to levels unprecedented in at least several thousand centuries in the past and the net rate of warming is consistent with theoretical estimates based on greenhouse effect physics. Is much of this CO2 increase due to human activity? – Perhaps: industrial revolution is the major phenomenon delineating the 20th century from the 19th. Is the warming uniform throughout the globe? For example, do you think Milwaukee warmed from 1900 to 2000? No! For example, polar regions warmed much faster than the rest of the world, and there are regional warming "holes."



While models do reproduce well the global-mean warming (next slide), they miss some important features of the observed regional dependence of the global warming.



The same applies to the apparent non-uniformities of global warming in time. Smoothed multidecadal deviations of individual CMIP5 runs from their forced signals are much smaller than the observed deviations, which exhibit an oscillatory-like globally propagating signal, the so-called stadium wave (Kravtsov et al. 2018, next slide).



Stadium wave originates as a temperature anomaly in the North Atlantic Ocean, and propagates to the North Pacific, Southern Ocean and Antarctica, and, finally, to the Arctic, requiring a few decades to complete half-cycle (from positive to negative phase). These spatial patterns and their sequence are absent from CMIP5 models (Kravtsov et al. 2018).

What causes multidecadal deviations of observed and model simulated climates?

- One possibility is that the forced signals estimated by models are wrong
- Indeed, model uncertainties, for example, those associated with parameterizations of indirect aerosol effects, are large
- Other misrepresented dynamical mechanisms may also be at work (see next slide)

REVIEW ARTICLE
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nature climate change

Divergent consensuses on Arctic amplification influence on midlatitude severe winter weather

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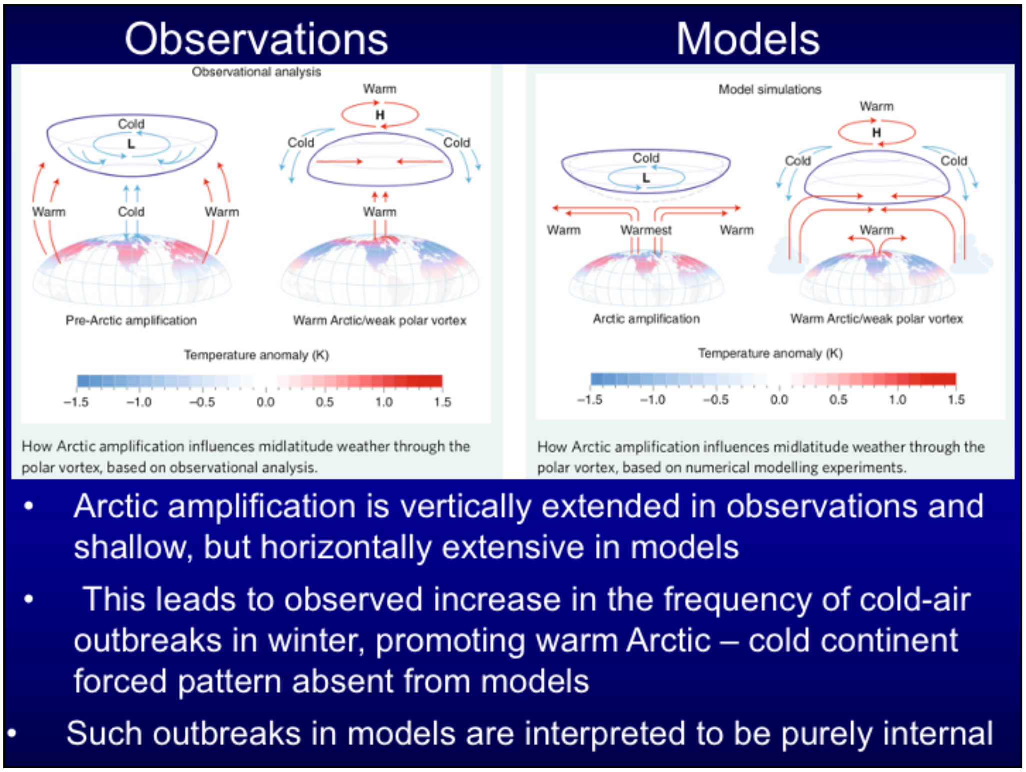
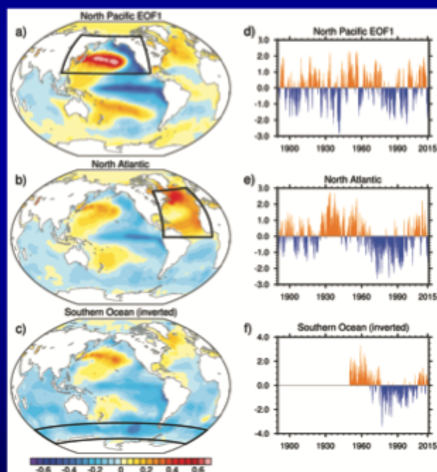
The Arctic has warmed more than twice as fast as the global average since the late twentieth century, a phenomenon known as Arctic amplification (AA). Recently, there have been considerable advances in understanding the physical contributions to AA, and progress has been made in understanding the mechanisms that link it to midlatitude weather variability. Observational studies overwhelmingly support that AA is contributing to winter continental cooling. Although some model experiments support the observational evidence, most modelling results show little connection between AA and severe midlatitude weather or suggest the export of excess heating from the Arctic to lower latitudes. Divergent conclusions between model and observational studies, and even intramodel studies, continue to obfuscate a clear understanding of how AA is influencing midlatitude weather.



One hypothesis of why the response of models to Arctic amplification of global warming is different from the observed response is misrepresentation, in models, of the interactions between the troposphere and stratosphere.

What causes multidecadal deviations of observed and model simulated climates?

- Another possibility is that these differences are due to model's lacking multidecadal internal variability rooted in slow ocean dynamics



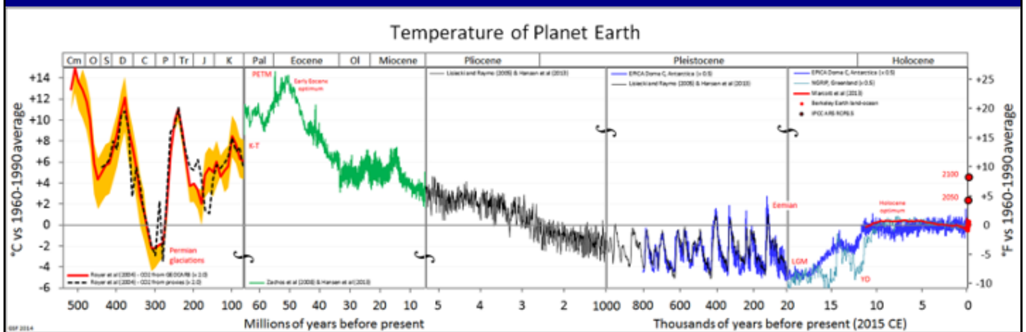
- Indeed, the coherence in time of the temperature deviations from the global-mean warming trend is striking. How can it be forced?

- This figure (from Deser and Phillips 2017) basically illustrates the stadium wave using different data set and different methodology of subtracting the forced signal

Conclusions

- CO_2 is increasing, overall climate is warming
- Warming rate is consistent with that expected, theoretically, from GH effect
- Warming is geographically non-uniform and, in some regions, negative (ha-ha:)
- The dynamics of these regional effects are complex
- State-of-the-art climate models are uncertain due to ad hoc parameterizations of unresolved processes and do not quite capture the geographical pattern of global warming
- The future GW projections using these models should be treated with caution, especially at regional level

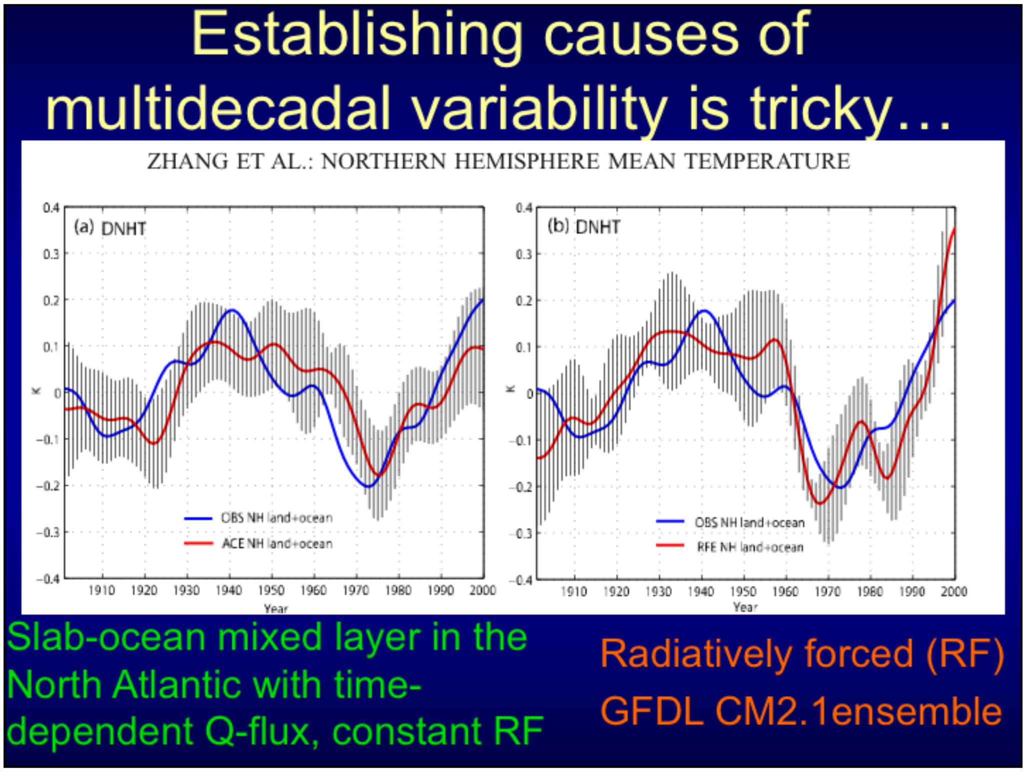
… and just to put things into perspective



https://www.reddit.com/r/conspiracy/comments/55v4m1/the_truth_about_global_warming/

Climate variability in the past exhibited various regimes. Keep in mind though that the processes operating in the past could be very different from those dominating the present climate variability.

Back up slides

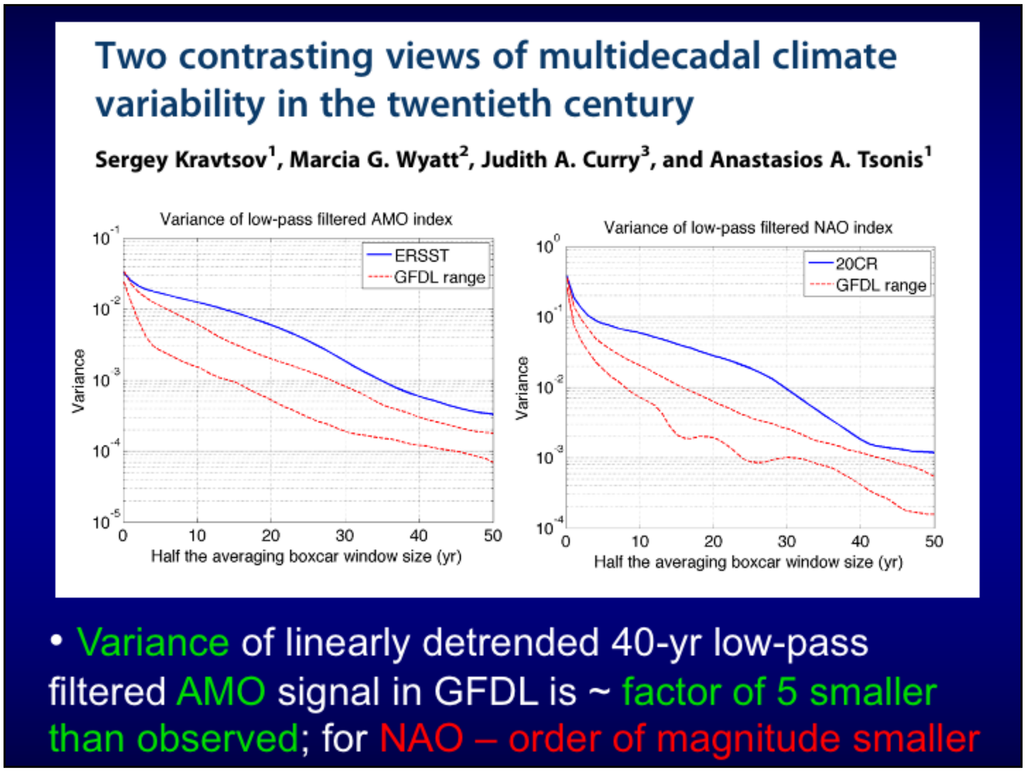


…since the internally generated SST anomalies (e.g. due to variations in AMOC) and non-uniform (in time) radiative forcing may both be responsible for the observed non-uniformities in the NH warming!

…so, multidecadal deviations of NH surface temperature from linear trend may well be rationalized as being either due to the climate's response to the ocean-driven heat-flux forcing from the North Atlantic SSTs, or due to the response to non-linear trends in the radiative forcing

Notes:

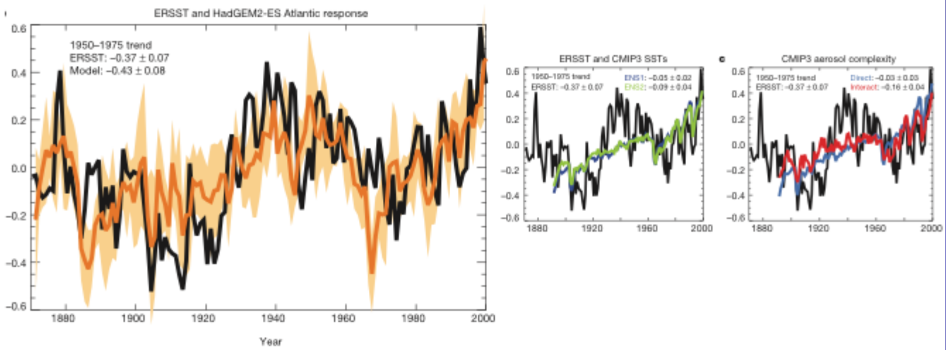
- in both setups, the climate response is forced
- the ensemble spreads (due to internal variability) are similar too, and are fairly narrow: this suggests that in the coupled setting, GFDL2.1's internally generated decadal-scale SST anomalies in the North Atlantic have a smaller magnitude than the observed SST anomalies



The multidecadal deviations from the linear trend in GFDL2.1 simulated North Atlantic SSTs are indeed much smaller than observed, but this is even more so for NAO (which, incidentally, has essentially no forced component in the CMIP5 model simulations). Note that the linearly detrended NHT variance is similar to the observed, consistent with Zhang et al. (2007).

Aerosols implicated as a prime driver of twentieth-century North Atlantic climate variability

Ben B. B. Booth[1], Nick J. Dunstone[1]*, Paul R. Halloran[1]*, Timothy Andrews[1] & Nicolas Bellouin[1]



- Lack of multidecadal SST variability in the North Atlantic was suggested to be due to underestimation of aerosol indirect effects in coupled climate models
- In this interpretation, multidecadal variations of the North Atlantic SSTs are forced (cf. Zhang et al. 2007)

Aerosols?

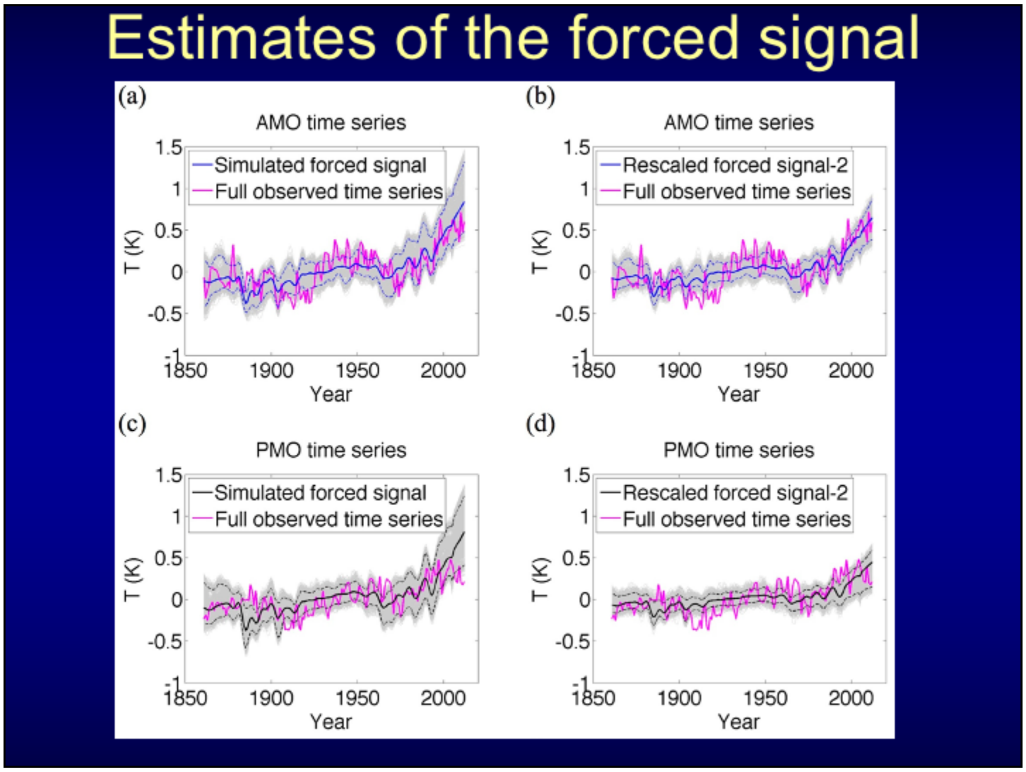
Have Aerosols Caused the Observed Atlantic Multidecadal Variability?

RONG ZHANG,* THOMAS L. DELWORTH,* ROWAN SUTTON,+ DANIEL L. R. HODSON,+ KEITH W. DIXON,* ISAAC M. HELD,* YOCHANAN KUSHNIR,# JOHN MARSHALL,@ YI MING,* RYM MSADEK,* JON ROBSON,+ ANTHONY J. ROSATI,* MINGFANG TING,# AND GABRIEL A. VECCHI*

- major discrepancies between HadGEM2-ES simulations and observations in terms of the 3-D structure of multidecadal upper-ocean temperature and salinity in the North Atlantic, as well as in various fields outside of North Atlantic (we'll see some of that later in the talk)

- Still, if observed multidecadal deviations of North Atlantic SSTs from linear trend are internally generated, why is their magnitude so much larger than that in CMIP5 coupled runs?

Well, maybe not, but what would then be the explanation for the insufficient simulated amplitude of multidecadal variability?...



Left – no rescaling; right – rescaled signals. Linear growth of uncertainty at the end of the record is due to linear extrapolation of model time series from 2005 through 2012.

Summary

- We used Monte-Carlo approach to estimate forced signals from multi-model ensemble of CMIP5 historical simulations
- These forced signals were subtracted from individual model runs and, after rescaling, from observed time series to derive the internally generated component of the observed and simulated climate variability
- Internal climate variability in models has a smaller amplitude and different spatiotemporal structure wrt the observed variability
- The differences between models and observations are dominated by a low-dimensional multidecadal mode of the observed climate variability, which is apparently absent from models