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Global-scale Multidecadal Variability Missing in State-of-the-Art Climate Models

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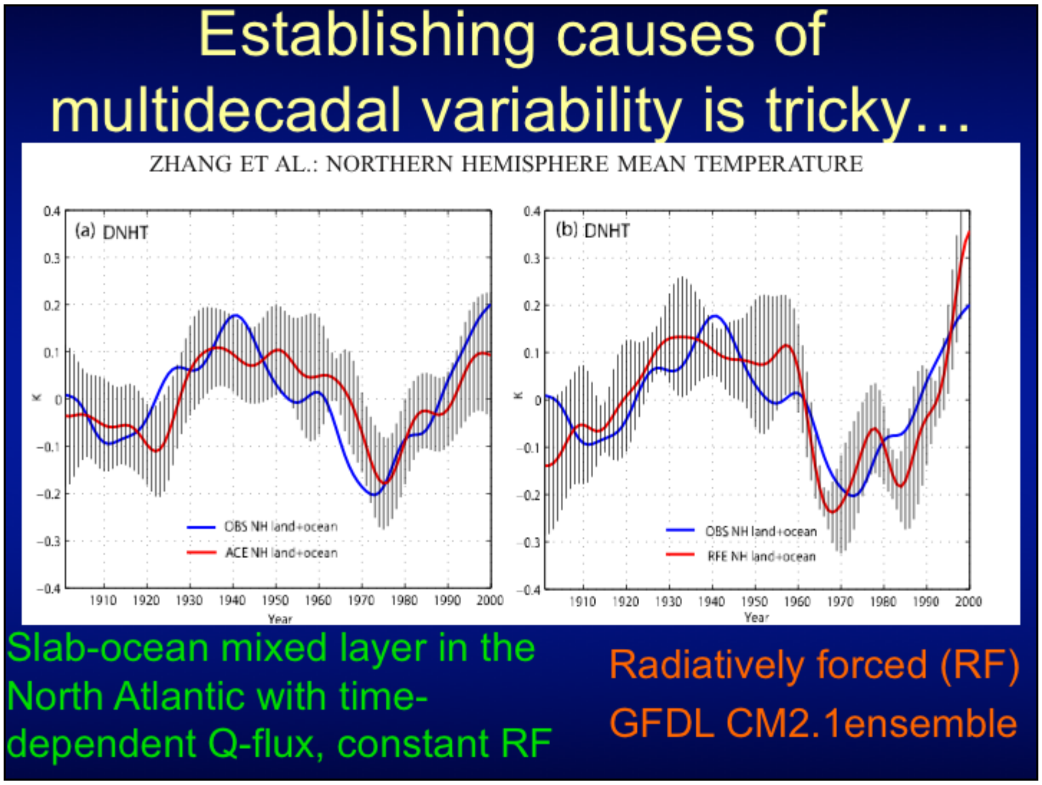
https://people.uwm.edu/kravtsov/



…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! Other pacemaker experiments (e.g., SSTs prescribed in the Pacific, Indian Ocean) show analogous results.

…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

This (underestimating the magnitude of internal variability) turns out to be a common problem for many CMIP5 models. Not only that, but also — timescales and patterns of multidecadal climate variability turn out to be different!

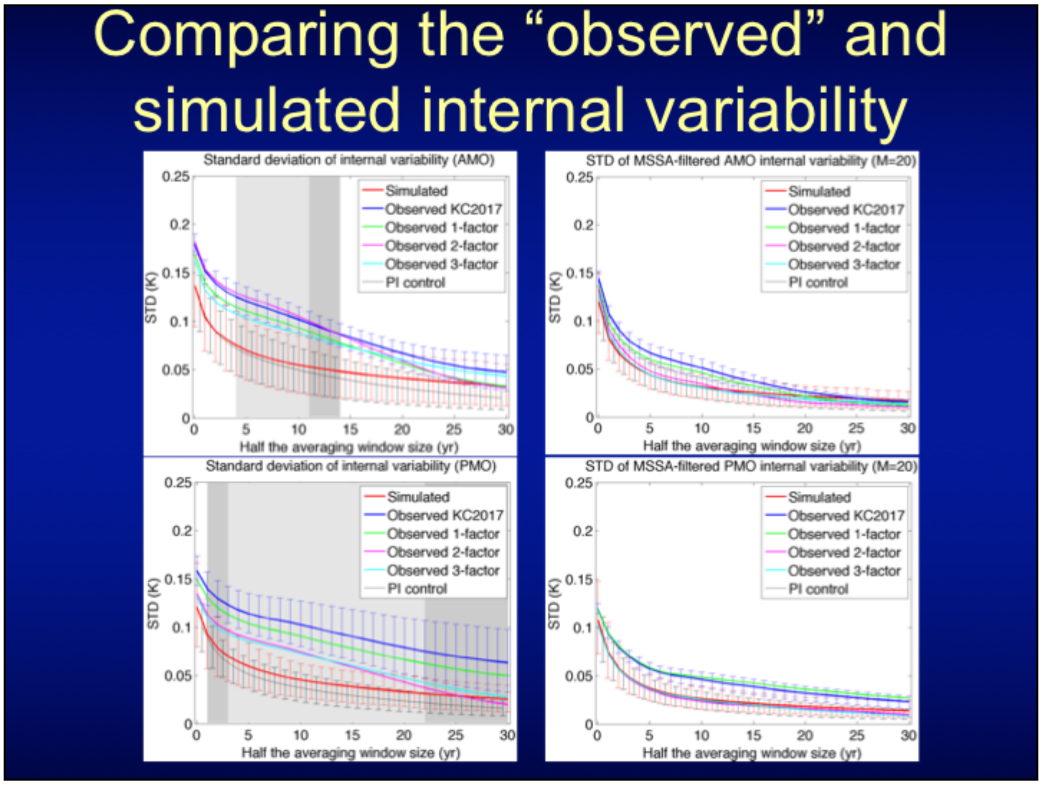
Kravtsov (2017) GRL

- Estimate forced signal and its uncertainty from CMIP5 multi-model ensemble, for several climate indices: AMO, PMO, NMO, NAO, ALPI

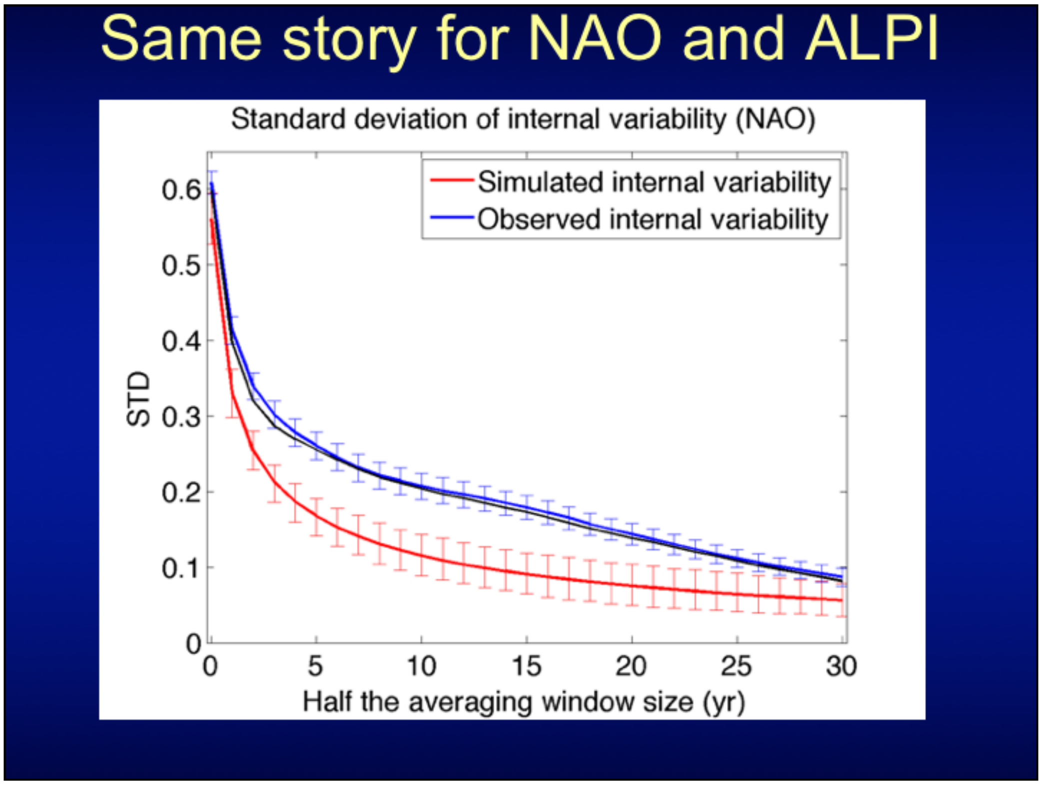
- Combine these forced-signal estimates with individual model simulations as well as observations to obtain estimates of internal climate variability

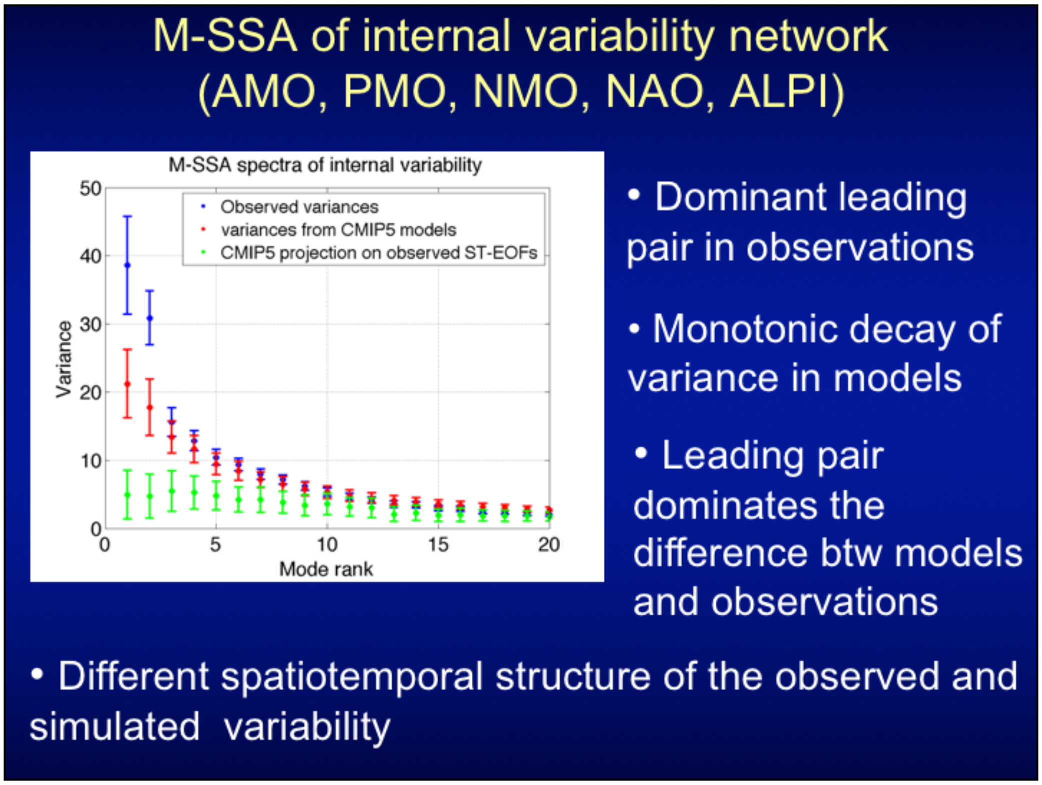
- Compare characteristics of the simulated and "observed" (semi-empirical) internal variability

AMO – SST averaged over North Atlantic, PMO – SST averaged over North Pacific, NMO – surface air temperature averaged over the entire Northern Hemisphere (ocean+land), NAO – leading EOF of SLP over North Atlantic, ALPI – leading EOF of SLP over North Pacific.

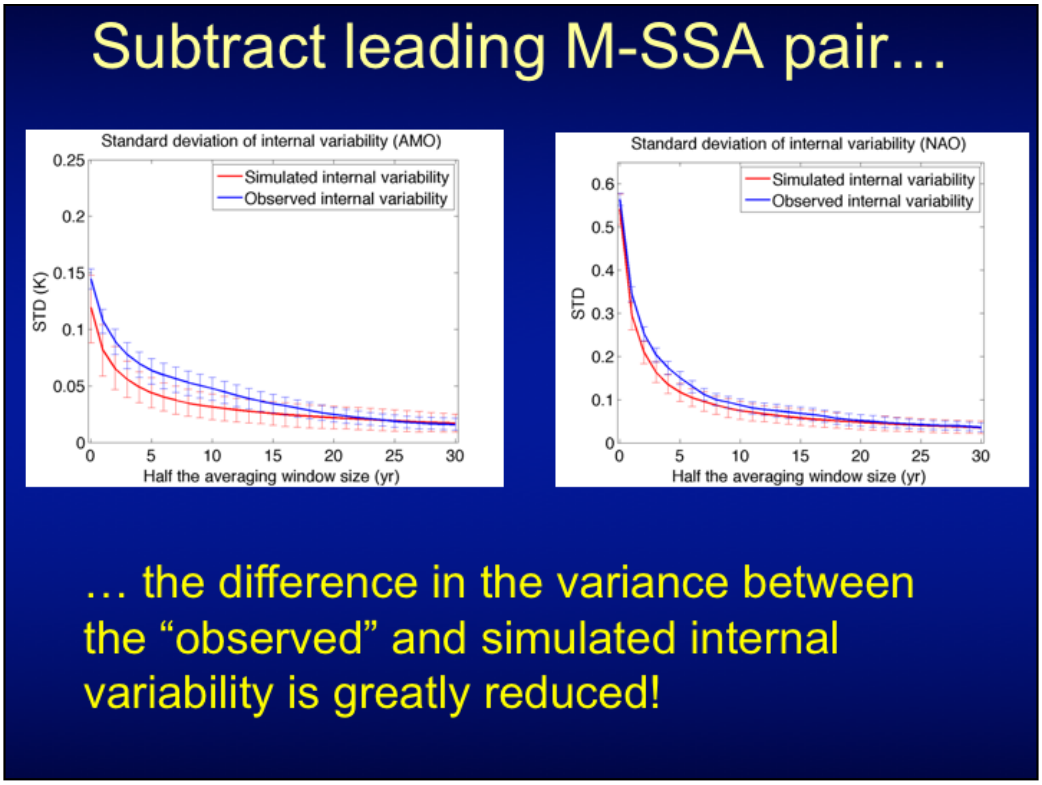


Inflation factors have been developed and applied to account for a small number of realizations and insufficient averaging of internal variability in the ensemble averaged “forced” signal. Even inflated internal variability in CMIP5 simulations is significantly smaller than observed estimates!


Same story for NAO and ALPI
Standard deviation of internal variability (NAO)
Simulated internal variability
Observed internal variability
STD
0
0.1
0.2
0.3
0.4
0.5
0.6
0
5
10
15
20
25
30
Half the averaging window size (yr)



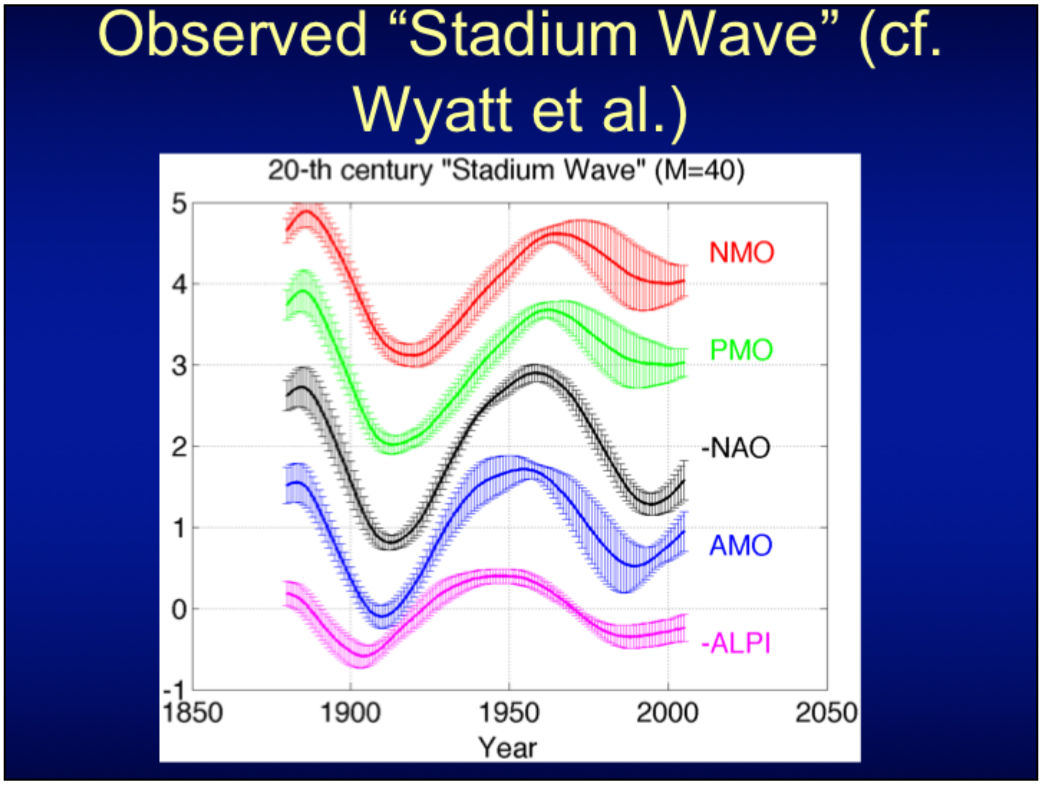
Blue – observed, red – simulated, green – variance of projections of the simulated trajectory matrices onto the observed T-EOFs. Dominant leading pair in observation, with the variance much larger than that of the dominant pair in models. Model's projections onto observed T-EOFs are tiny: different spatiotemporal structure of the simulated variability compared to the observed.



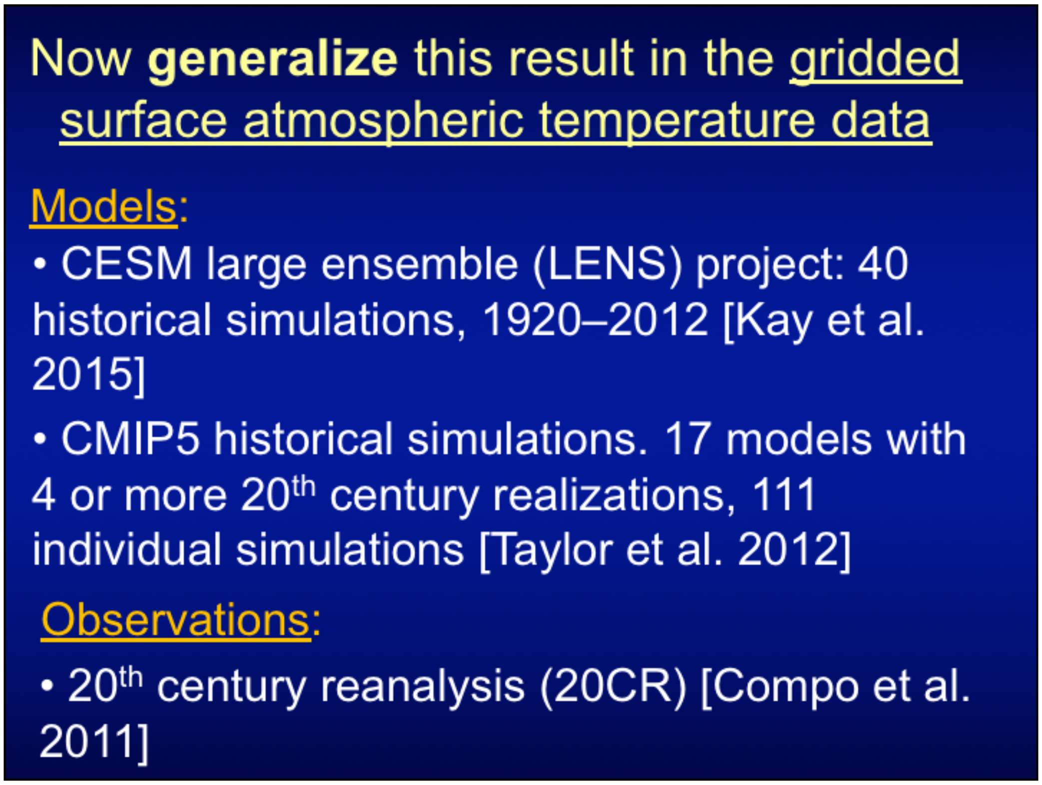
So comparing semi-empirical internal variability in models and observation recovers the results based on comparing the deviations from the linear trends in observations and model simulations: lack of multidecadal variance and different spatiotemporal structure of variability in the models relative to observations.

Summary (Kravtsov 2017)

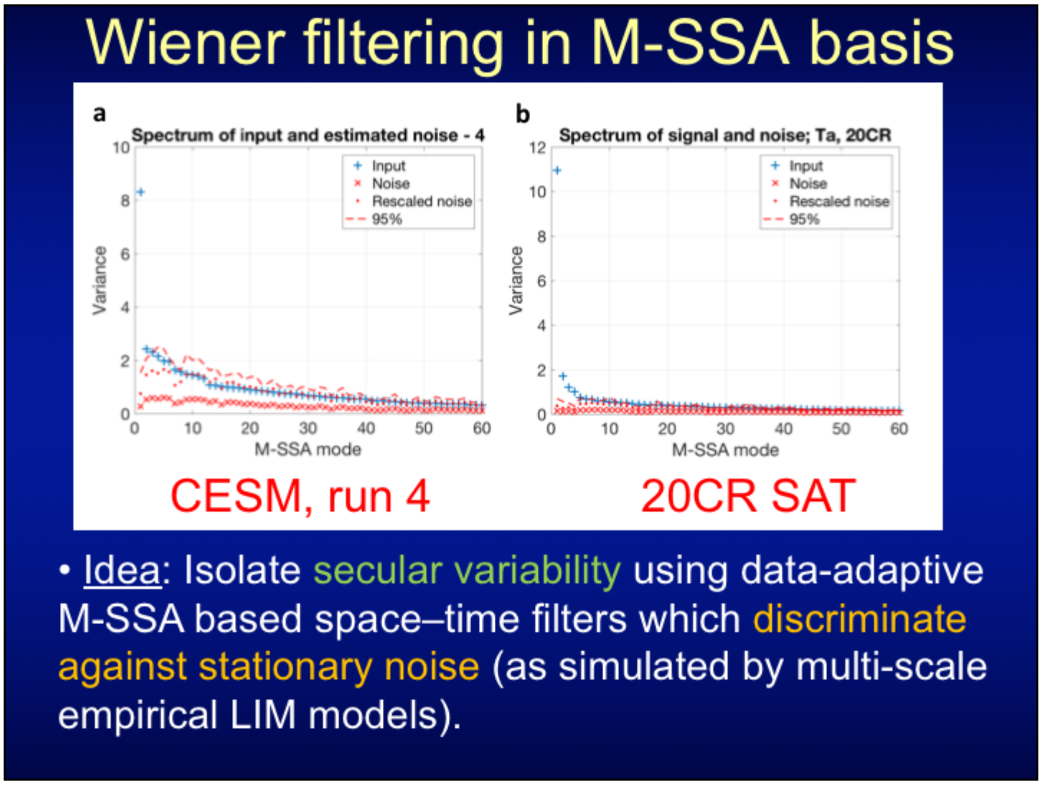
- We estimated forced signals from multi-model ensemble of CMIP5 historical simulations
- These forced signals were subtracted from individual model runs and, after rescaling, from observed time series to derive the internally generated component of the observed and simulated climate variability
- Internal 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 has a hemispheric character and is apparently absent from models



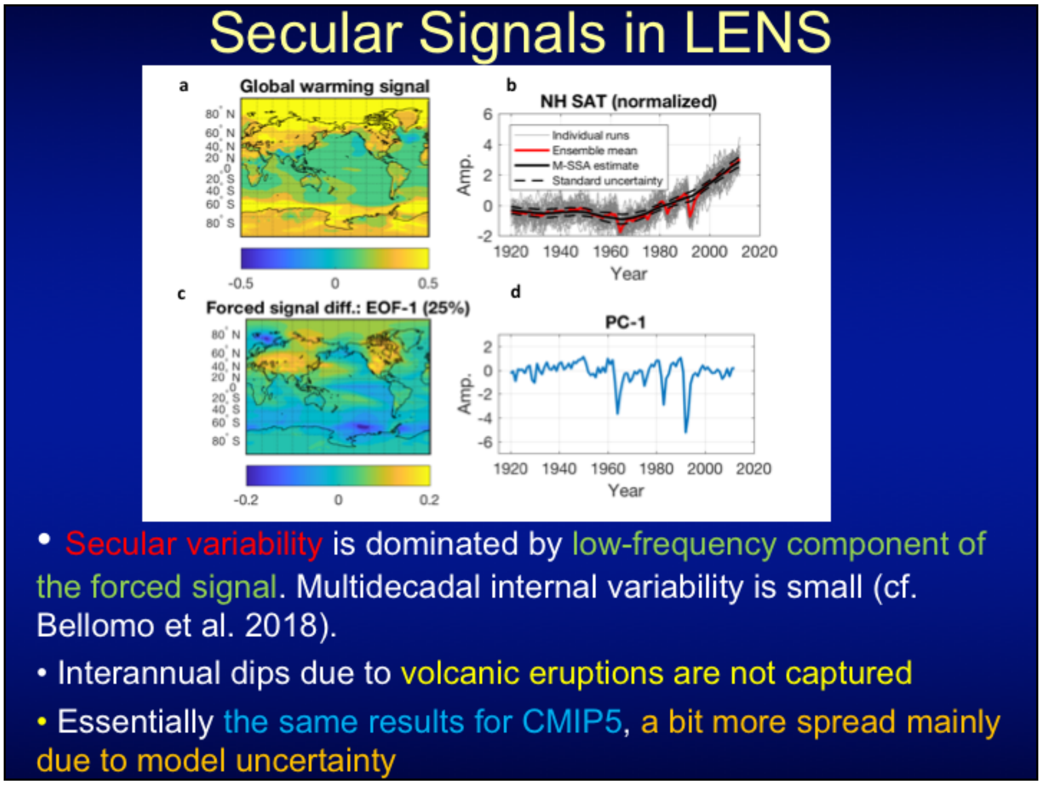
Here is how this observed mode of variability — absent from the models — looks like, in the five indices considered.



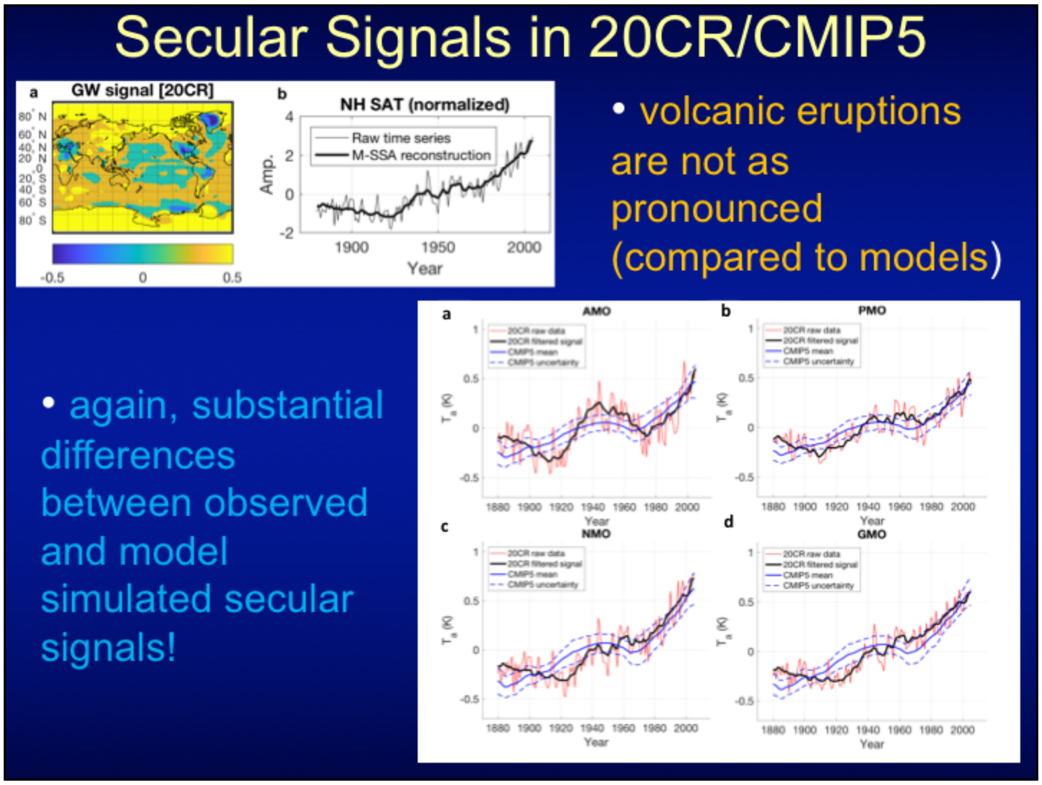
Since the emphasis is on the large-scale low-frequency variability, simply applying the above analysis at the level of individual grid points (where the noise is much larger than in the regional averages) won't work: we need to filter the data to focus on the appropriate time and spatial scales.



(a) Input/noise spectra for one of the simulations of the CESM model; (b) The same for 20CR SAT data. Statistically significant M-SSA modes are multiplied by signal-to-input variance ratio and their sum is reconstructed in physical space. Inflation factors (based on comparing filtered and raw time series) are needed, since both signal and noise tend to get attenuated in Wiener filtering.

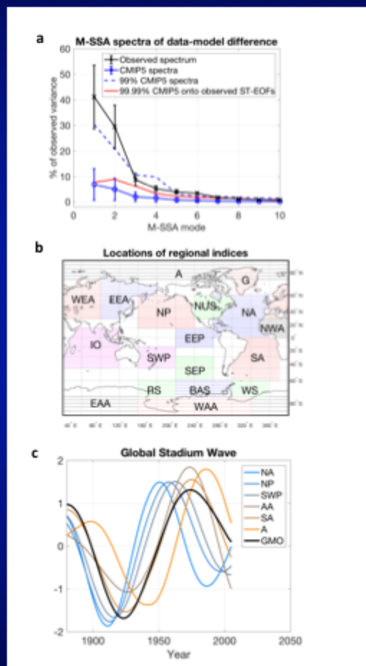


Note narrow uncertainty range of the secular signal in NH SAT, meaning that essentially the same (forced) signal is isolated in each individual CESM run. In CMIP5, the spread is a bit more (model uncertainty) - see backup slides.



Now take the difference (at each grid point) between secular signals in observations and each (scaled) model simulation, and do M-SSA analysis to isolate dominant data-model differences. Since secular signals in models are dominated by forced variability, the data-model difference can be thought of as an estimate of internal climate variability in observations. We also analyze the differences between secular signals in individual simulations and this model's ensemble-mean secular signal. This would be an estimate of the internal secular variability in models.

Data–model differences



- The M-SSA results are completely analogous to Kravtsov (2017) work, which considered a few climate indices: dominant M-SSA pair in observations, flatter spectrum and lack of observed ST-EOFs in the models
- Regional reconstructions indicate global "stadium wave" (Wyatt et al. 2012), which originates in the North Atlantic (cf. Moron et al. 1998) and then "propagates" to North and South Pacific, South Atlantic and Southern Ocean/Antarctica, and, finally, the Arctic (see animation)

Reconstructions are consistent with Kravtsov (2017). In reconstructions, the ocean indices are scaled by 0.1K and land indices – by 0.6K. This is why the animation shows stretched signals to better visualize the sequence of anomaly propagation. Movie here.

Summary

Reliability of future global warming projections depends on how well climate models reproduce the observed climate change over the twentieth century. In this regard, deviations of the model simulated climate change from observations, such as a recent "pause" in global warming, have received considerable attention[1–3]. Such decadal mismatches between model simulated and observed climate trends present a systemic problem throughout the twentieth century, and their causes are still poorly understood[4–10]. Here we use a new objective filtering method to show that the discrepancies between the observed and simulated climate variability on decadal and longer time scale have a coherent structure suggestive of a pronounced global multidecadal oscillation. Surface temperature anomalies associated with this variability originate in the North Atlantic and spread out to the Pacific and Southern oceans and Antarctica, with Arctic following suit in about 40 years. While climate models exhibit various levels of decadal climate variability and some regional similarities to observations, neither of the simulations considered match the observed signal in terms of its magnitude, spatial patterns and their sequential time development. These results highlight a substantial degree of uncertainty in our interpretation of the observed climate change using current generation of climate models.

Discussion

Multidecadal signals originating in the North Atlantic Ocean and exerting some influence on the Northern Hemisphere climate have been observed and simulated before[35, 36]. They are thought to be rooted in the variability of the Atlantic Meridional Overturning Circulation (AMOC) (ref. 37). Recent observational[15, 38–40] and modelling studies[41, 42] highlighted global character of such DCV, especially its connections to the Southern Ocean, which is also consistent with our findings. These global DCV modes are likely to be due to a combination of multiple slow, regional-to-basin-scale oceanic processes defining dynamical memory of the climate system in the presence of fast, large-scale atmospheric processes. The latter fast processes can both supply energy for DCV and provide means for intra- and inter-basin communication and synchronization of decadal climate modes[43–45].

Although some of the climate models are able to simulate certain qualitative features of the observed DCV[8, 54], our results summarize and rigorously document pronounced quantitative discrepancies between models and observations, which should help guide further DCV research[14].

References

1. Yan, X.-H., Boyer, T., Trenberth, K., Karl, T. R., Xie, S.-P., Nieves, V., Tung, K.-K. & Roemmich, D. The global warming hiatus: Slowdown or redistribution? *Earths Future* **4**, 472–482 (2016). https://doi.org/10.1002/2016EF000417
2. Xie, S.-P. & Kosaka, Y. What caused the surface warming hiatus from 1998–2013? *Curr. Climate Change Rep*. **3,** 128 (2017). https://doi.org/10.1007/s40641-017-0063-0
3. Hedemann, C., Mauritsen, T., Jungclaus, J. & Marotzke, J. The subtle origins of surface-warming hiatuses. *Nat. Climate Change* **7,** 336–339 (2017). doi:10.1038/nclimate3274
4. Dai, A., Fyfe, J. C., Xie, S.-P. & Dai, X. Decadal modulation of global surface temperature by internal climate variability. *Nat. Clim. Change* **5,** 555–559 (2015). doi:10.1038/nclimate2605
5. Kravtsov, S. & Callicutt, D. On semi-empirical decomposition of multidecadal climate variability into forced and internally generated components. *International J. Climatology* **37**, 4417–4433 (2017). doi:10.1002/joc.5096
6. Swanson, K., Sugihara, G. & Tsonis, A. A. Long-term natural variability and 20th century climate change. *Proc. Nat. Acad. Sci*. **106**, 16120–16123 (2009). www.pnas.org/cgi/doi/10.1073/pnas.0908699106
7. DelSole, T., Tippett, M. K. & Shukla, J. A significant component of unforced multidecadal variability in the recent acceleration of global warming. *J. Clim*. **24**, 909–926 (2011). doi:10.1175/2010JCLI3659.1
8. Knutson, T. R., Zhang, R. & Horowitz, L. W. Prospects for a prolonged slowdown in global warming in the early 20th century. *Nat. Comm.* **7**, 13676 (2016), doi:10.1038/ncomms13676.
9. Meehl, G. A., Hu, A., Santer, B. D. & Xie, S.-P. Contribution of the Interdecadal Pacific Oscillation to twentieth-century global surface temperature trends. *Nat. Clim. Change* **6**, 1005–1008 (2016). https://doi.org/10.1038 /nclimate3107
10. Kravtsov, S. Pronounced differences between observed and CMIP5-simulated multidecadal climate variability in the twentieth century. *Geophys. Res. Lett.* **44**, 5749–5757 (2017). doi:10.1002/ 2017GL074016.

14. Cassou, C., Kushnir, Y., Hawkins, E., Pirani, A., Kucharski, F., Kang, I.-S. & Caltabiano, N. Decadal climate variability and predictability: Challenges and opportunities. *Bull. Amer. Meteor. Soc.* **99**, 479–490 (2018). https://doi.org/10.1175/BAMS-D-16-0286.1

15. Deser, C. & Phillips, A. An overview of decadal-scale sea surface temperature variability in the observational record. *CLIVAR Exchanges* **72**/*PAGES Magazine* **25**, joint issue, 2–6 (2017). https://doi.org/10.22498/pages.25.1.2

25. Moron, V., Vautard, R. & Ghil, M. Trends, interdecadal and interannual fluctuations in global sea-surface temperatures. *Clim. Dyn.* **14**, 545–569 (1998). doi:10.1007/s003820050241

26. Ghil, M. & Coauthors. Advanced spectral methods for climatic time series. *Rev. Geophys.* **40**, 1003 (2002). doi:10.1029/2000RG000092

27. Kay, J. E., Deser, C., Phillips, A. & co-authors. The Community Earth System Model (CESM) Large Ensemble Project: A community resource for studying climate change in the presence of internal climate variability. *Bull. Amer. Met. Soc.* **96**, 1333–1349 (2015). doi:10.1175/BAMS-D-13-00255.1

28. Bellomo, K., Murphy, L. N., Cane, M. A., Clement, A. C. & Polvani, L. M. Historical forcings as main drivers of the Atlantic multidecadal variability in the CESM large ensemble. *Clim. Dyn.* **50**, 3687–3698 (2018). doi:10.1007/s00382-017-3834-3

29. Compo, G. P. & Coauthors. The Twentieth Century Reanalysis Project. *Quart. J. Roy. Meteor. Soc.* **137**, 1–28 (2011). doi:10.1002/qj.776

38. Chen, X. Y. & Tung, K. Varying planetary heat sink led to global-warming slowdown and acceleration. *Science* **345**, 897–903 (2014). doi:10.1126/science.1254937.

39. Drijfhout, S. S., Blaker, A. T., Josey, S. A., Nurser, A. J. G., Sinha, B. & Balmaseda, M. A. Surface warming hiatus caused by increased heat uptake across multiple ocean basins. *Geophys. Res. Lett.* **41,** 7868–7874 (2014). https:// doi.org/10.1002/2014GL061456.

40. Fan, T., Deser, C. & Schneider, D. P. Recent Antarctic sea ice trends in the context of Southern Ocean surface climate variations since 1950. *Geophys. Res. Lett.* **41**, 2419–2426 (2014). https://doi.org/10.1002/2014GL059239.

41. Latif, M., Martin, T. & Park, W. Southern Ocean sector centennial climate variability and recent decadal trends. *J. Clim.* **26**, 7767-7782 (2013). doi: 10.1175/ JCLI-D-12-00281.1.

42. Zhang, L., Delworth, T. L. & Zeng, F. The impact of multidecadal Atlantic meridional overturning circulation variations on the Southern Ocean. *Clim. Dyn.* **48**, 2065–2085 (2016). doi: 10.1007/s00382-016-3190-8

43. Tsonis, A. A., Swanson, K. & Kravtsov, S. A new dynamical mechanism for major climate shifts. *Geophys. Res. Lett.* **34**, L13705 (2007), doi: 10.1029/2007GL030288.

44. Dommenget, D., Latif, M. Generation of hyper climate modes. *Geophys. Res. Lett.* **35**, L02706 (2008). doi:10.1029/2007GL031087

45. Newman, M. & Coauthors, The Pacific decadal oscillation, revisited. *J. Clim.* **29**, 4399–4427 (2016). doi:10.1175/ JCLI-D-15-0508.1

46. Zhang, R. & Delworth, T. L. Impact of the Atlantic multidecadal oscillation on North Pacific climate variability. *Geophys. Res. Lett.* 34, L23708 (2007) doi:10.1029/2007GL031601

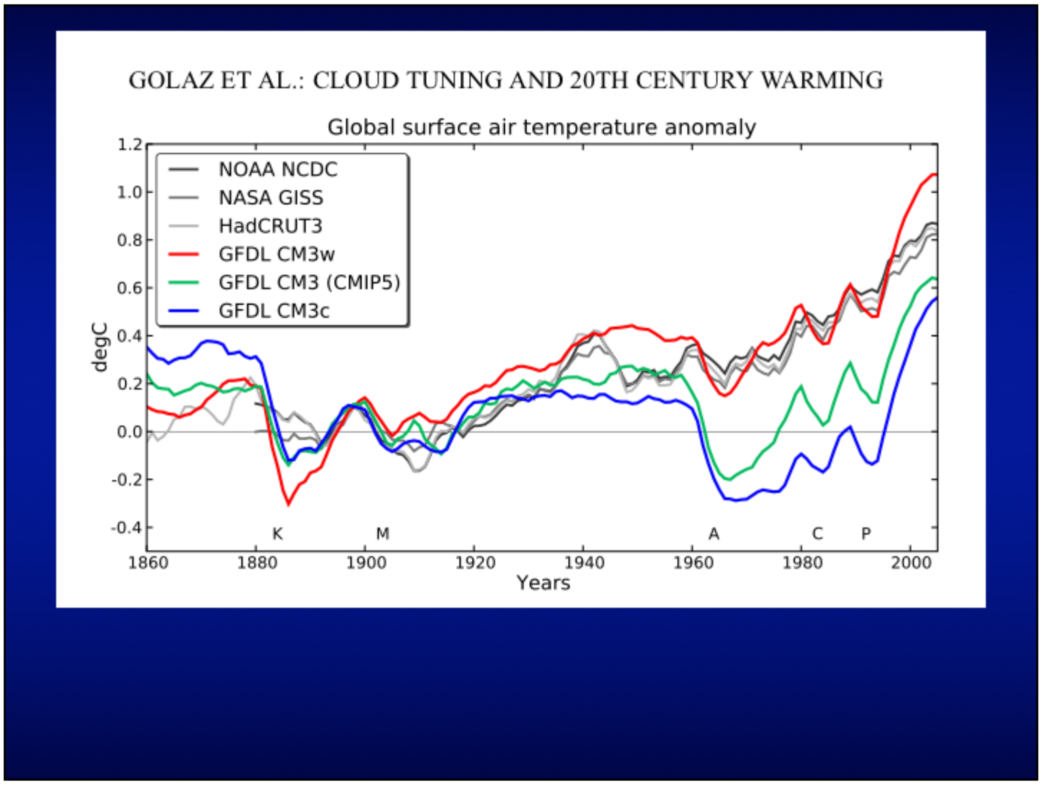
47. Zhang, R., Delworth, T. & Held, I. M. Can the Atlantic Ocean drive the observed multidecadal variability in Northern Hemisphere mean temperature? *Geophys. Res. Lett.* **34**, L02709 (2007). doi:10.1029/2006GL028683

54. Barcikowska, M. J., Knutson, T. R. & Zhang, R. Observed and simulated fingerprints of multidecadal climate variability and their contributions to periods of global SST stagnation. *J. Clim.* **30**, 721–737 (2016). doi: 10.1175/JCLI-D-16-0443.1

Back-up slides

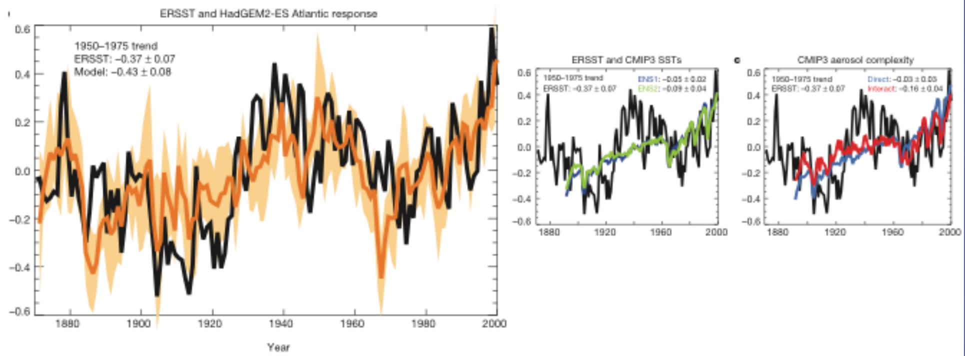
For further info:

- Kravtsov, S., 2017: Pronounced differences between observed and CMIP5 simulated multidecadal climate variability in the twentieth century. *Geophys. Res. Lett.*, DOI: 10.1002/2017GL074016.
- Kravtsov, S., and D. Callicutt, 2017: On semi-empirical decomposition of multidecadal climate variability into forced and internally generated components. *International J. Climatol.,* DOI: 10.1002/joc.5096.
- Kravtsov, S., 2018: Paper submitted to npj Climate and Atmospheric Science


GOLAZ ET AL.: CLOUD TUNING AND 20TH CENTURY WARMING
Global surface air temperature anomaly
NOAA NCDC
NASA GISS
HadCRUT3
GFDL CM3w
GFDL CM3 (CMIP5)
GFDL CM3c
degC
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
K
M
A
C
P
1860
1880
1900
1920
1940
1960
1980
2000
Years

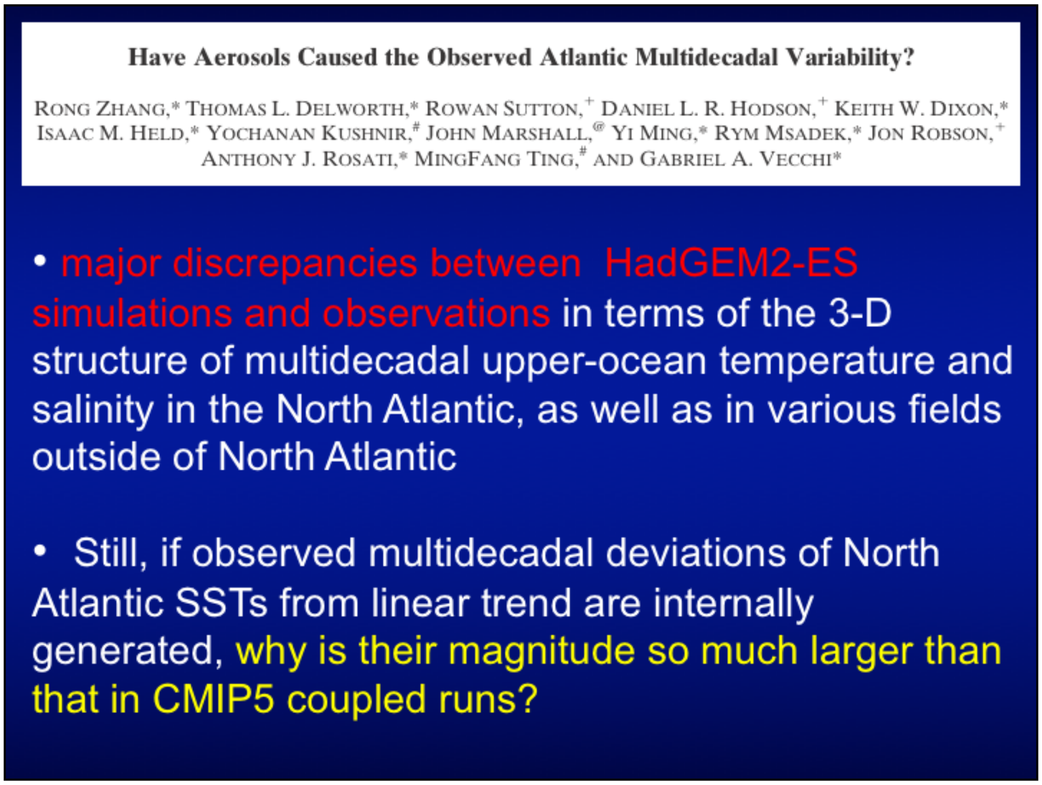
Aerosols implicated as a prime driver of twentieth-century North Atlantic climate variability

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?



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

Model #	Model acronym	# of runs
1	CanESM2	5
2	CCSM4	6
3	CNRM-CM5	10
4	CSIRO-MK3-6-0	10
5	GFDL-CM2.1	10
6	GFDL-CM3	5
7	GISS-E2-Hp1	6
8	GISS-E2-Hp2	6
9	GISS-E2-Hp3	6
10	GISS-E2-Rp1	6
11	GISS-E2-Rp2	6
12	GISS-E2-Rp3	6
13	HadCM3	10
14	HadGEM2-ES	5
15	IPSL-CM5A-LR	6
16	MIROC5	5
17	MRI-CGCM3	3
Total:	17 models	111 simulations

Wiener Filtering in CMIP5