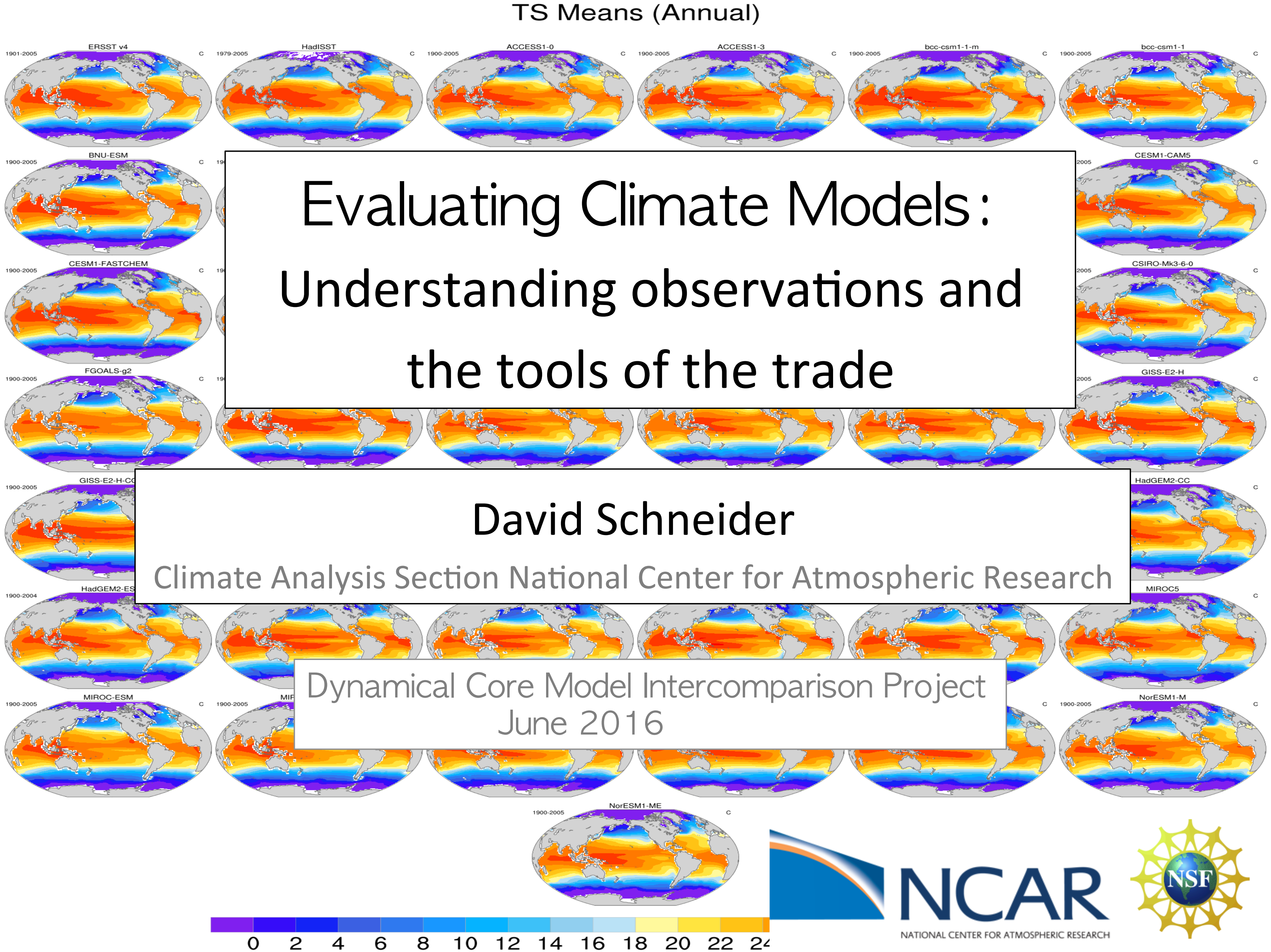

Evaluating Climate Models: Understanding observations and the tools of the trade

David Schneider

Climate Analysis Section National Center for Atmospheric Research

Dynamical Core Model Intercomparison Project
June 2016

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NSF

Acknowledgements

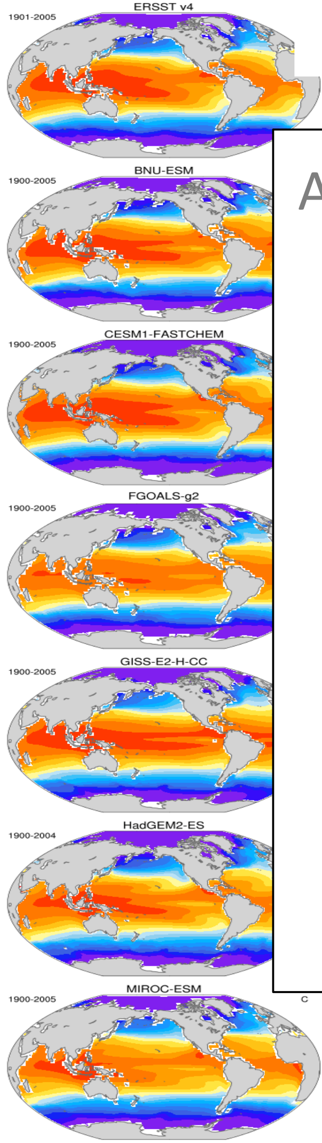
Alice Bertini: CESM Software Engineering Group, NCAR

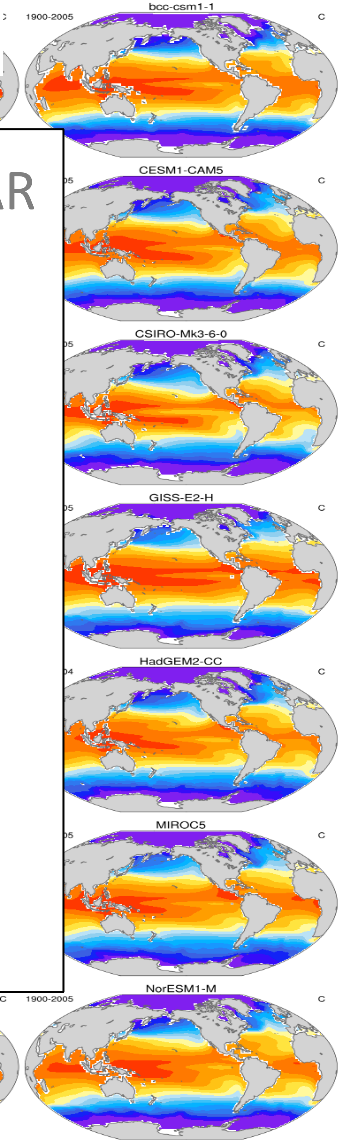
Clara Deser: Climate Analysis Section, NCAR

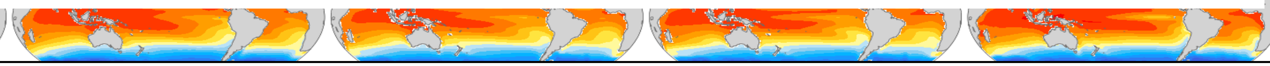
Jennifer Kay: University of Colorado

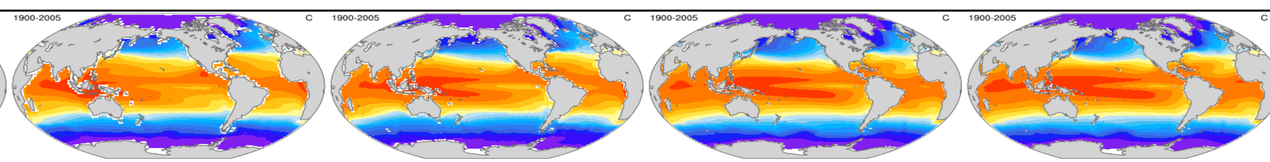
Adam Phillips: Climate Analysis Section, NCAR

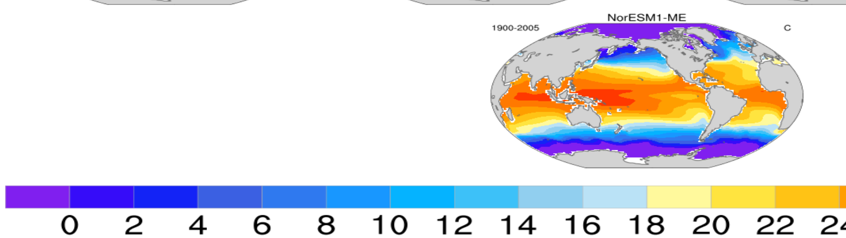
Kevin Trenberth: Climate Analysis Section, NCAR











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Outline

1. Motivation & Intro to model evaluation

a) Major types of uncertainty:

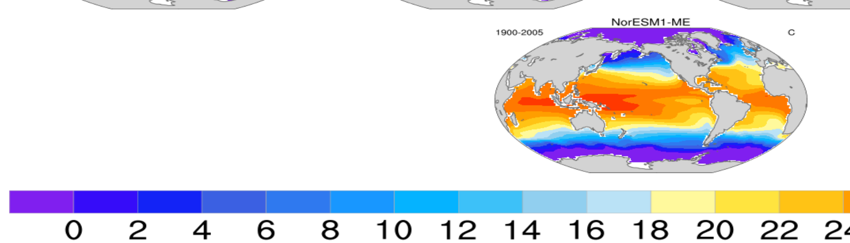
Observational uncertainty, structural uncertainty, natural variability, forcing/scenario uncertainty

b) Case study: Antarctic sea ice increase (why models and observations disagree)

2. Tools for model evaluation

a) Climate Variability (and other) Diagnostics Packages

b) Climate Data Guide



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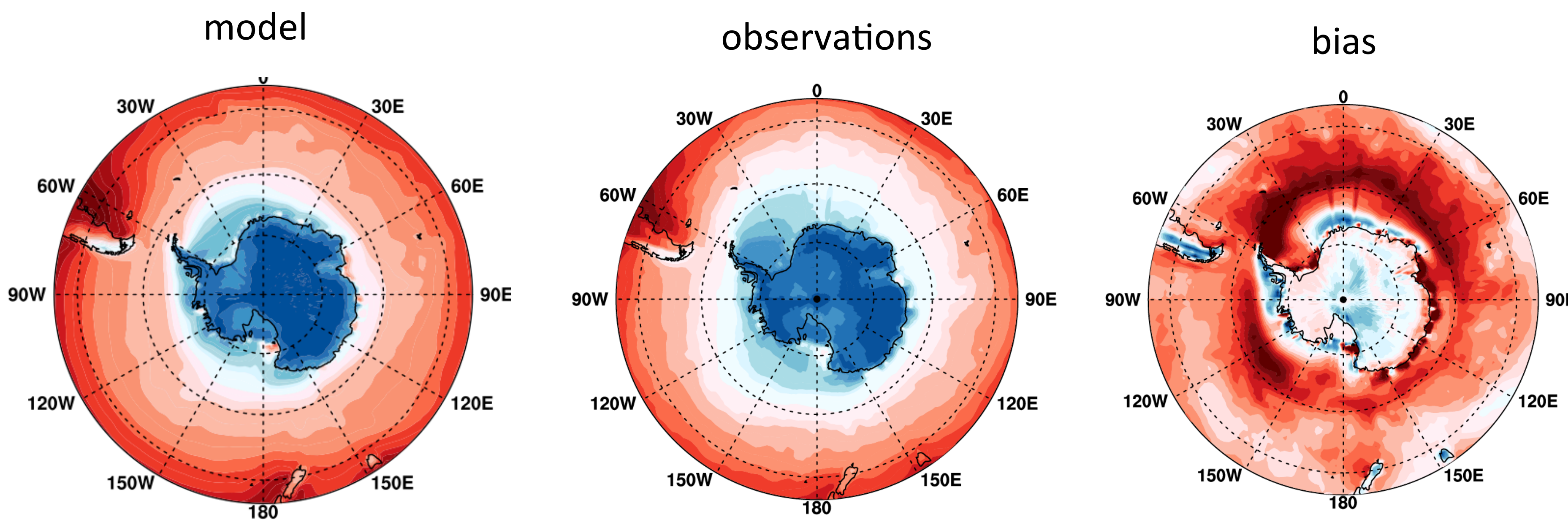
characterizing uncertainty

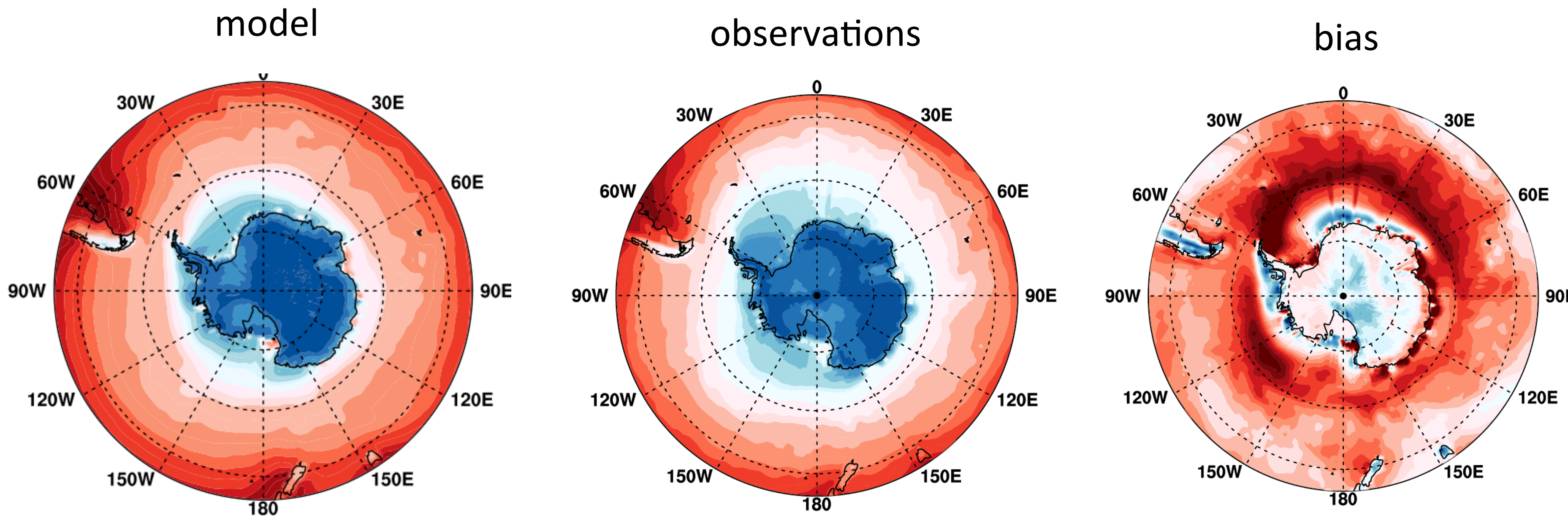


1. Structural uncertainty – the models are wrong

physical parameterizations, model resolution, dynamical core, parameter values, missing physics

<u>How to address</u>: multi-model ensembles (like CMIP5); perturbed physics ensembles, hierarchical modeling, model tuning

characterizing uncertainty

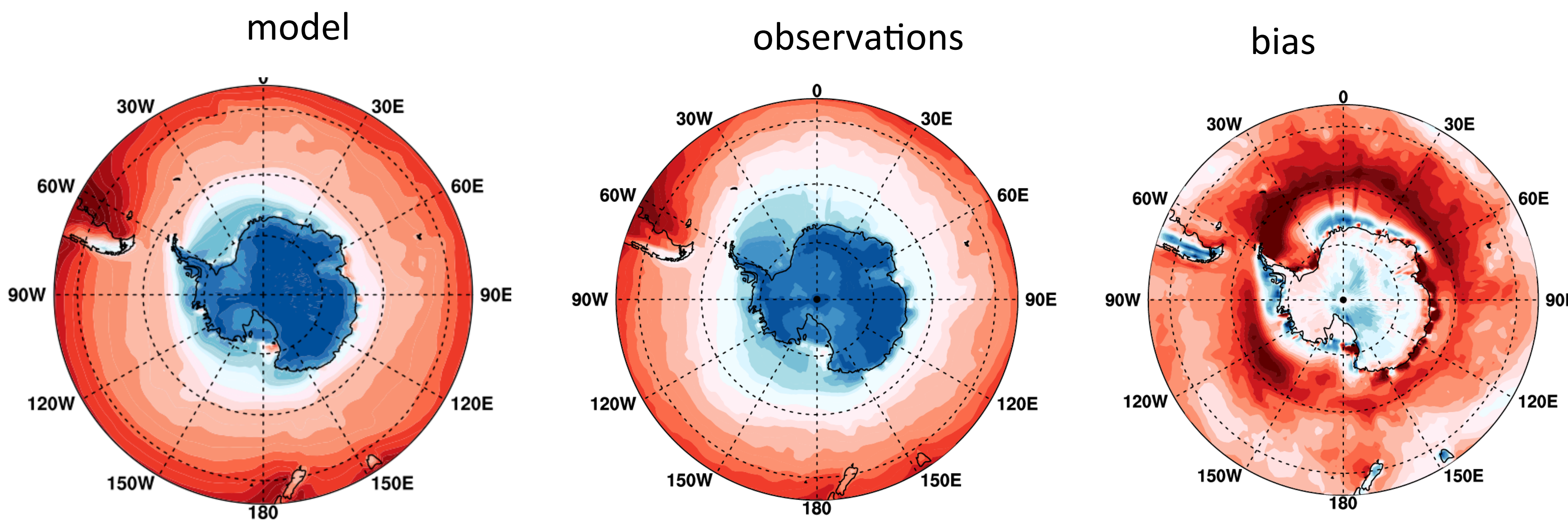


2. Observational uncertainty – the observations are wrong

sparse spatial and temporal sampling, changing instrumentation practices, time-of-day sampling, satellite drift, sensors and instruments come and go, different definitions between models and obs

<u>How to address</u>: consider multiple observational datasets, average datasets together, use multiple physically related variables, try different or longer time periods (sampling), satellite simulators

characterizing uncertainty

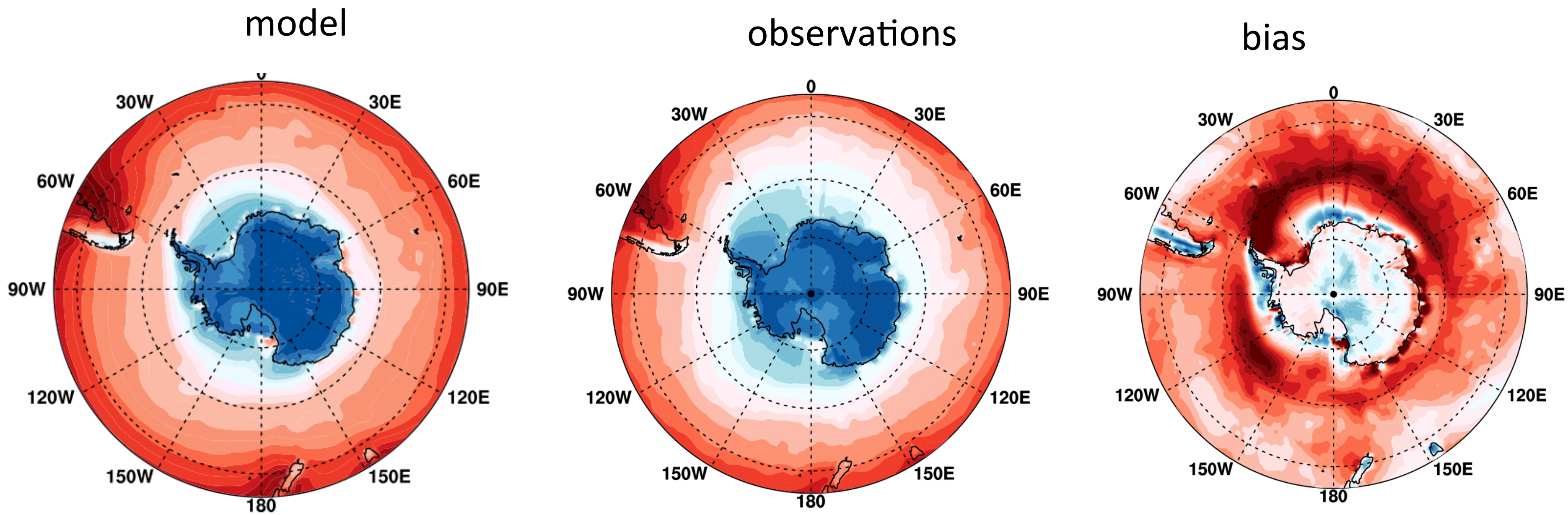


3. Forcing/scenario uncertainty – wrong or missing external forcing

knowledge of time-evolving forcing is incomplete, competing hypotheses about what is important

> <u>How to address</u>: compare results from different scenarios (e.g. RCP 4.5 and 8.5); change forcing datasets; conduct single-forcing or 'leave-one-out' ensembles

characterizing uncertainty



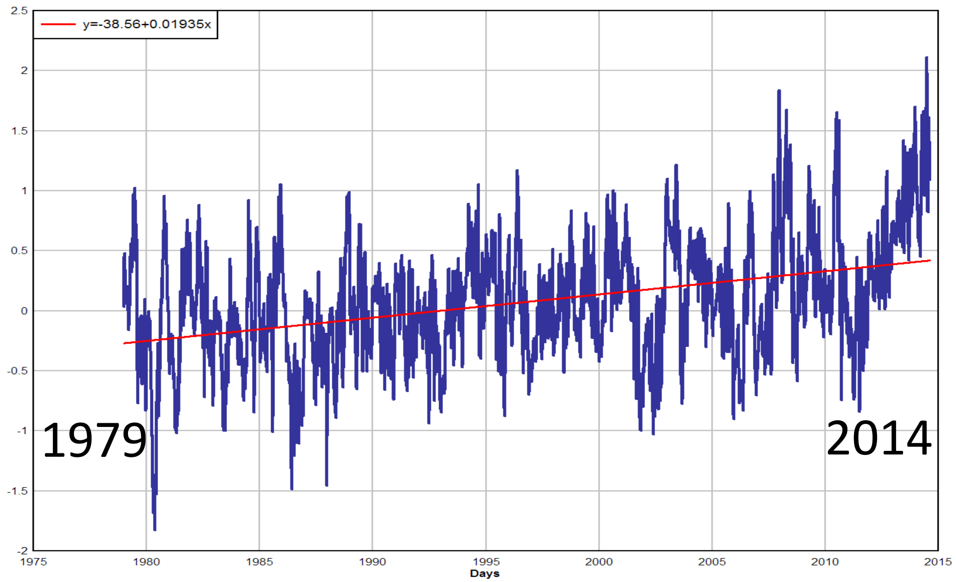
4. Internal variability – model and obs are correct, but are sampling different realizations of internal variability

arises from atmospheric, oceanic, land and cryospheric processes and their coupled interactions

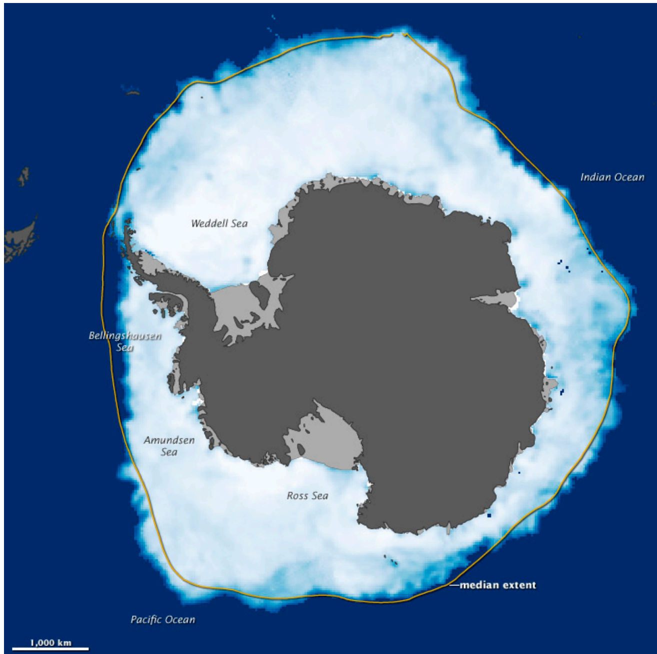
<u>How to address</u>: sample multiple time periods in obs and models; use large, initial condition ensembles (like CESM Large Ensemble)

Case study: Antarctic sea ice expansion

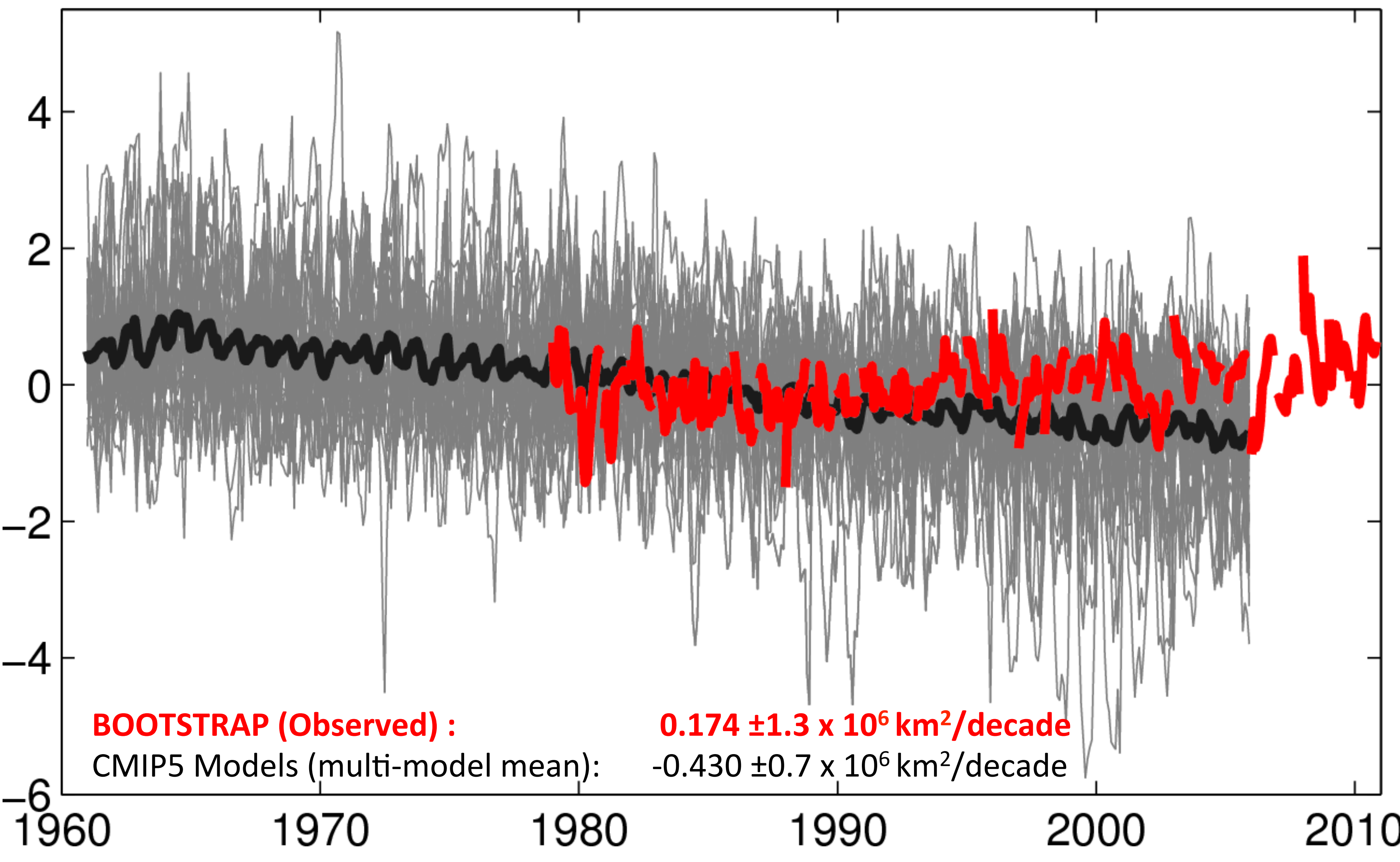
Antarctic Sea Ice Extent (observed)



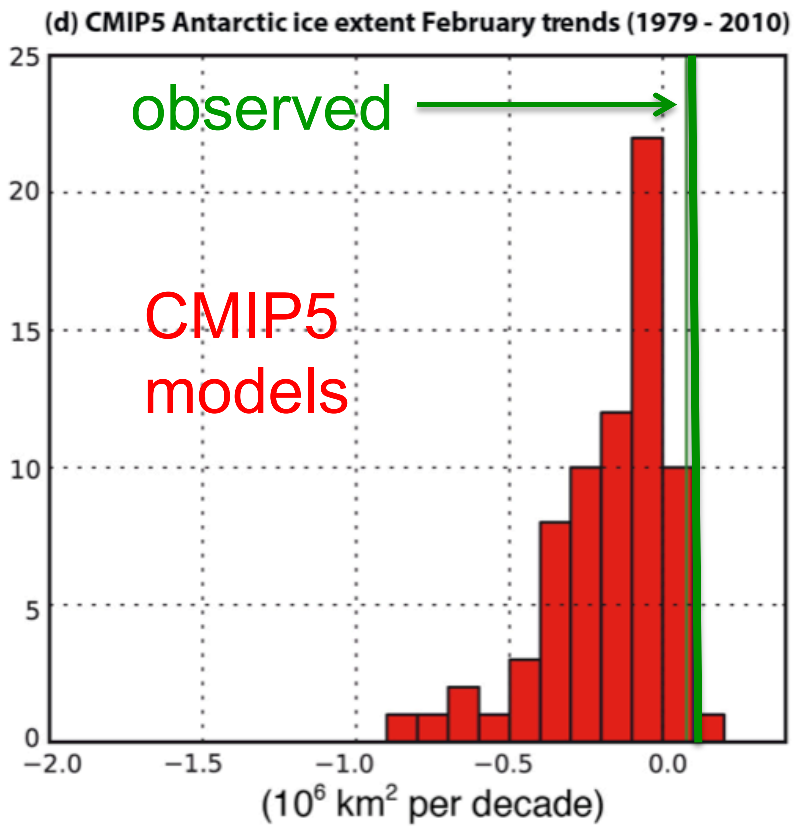
Antarctic sea ice expansion in a warming world

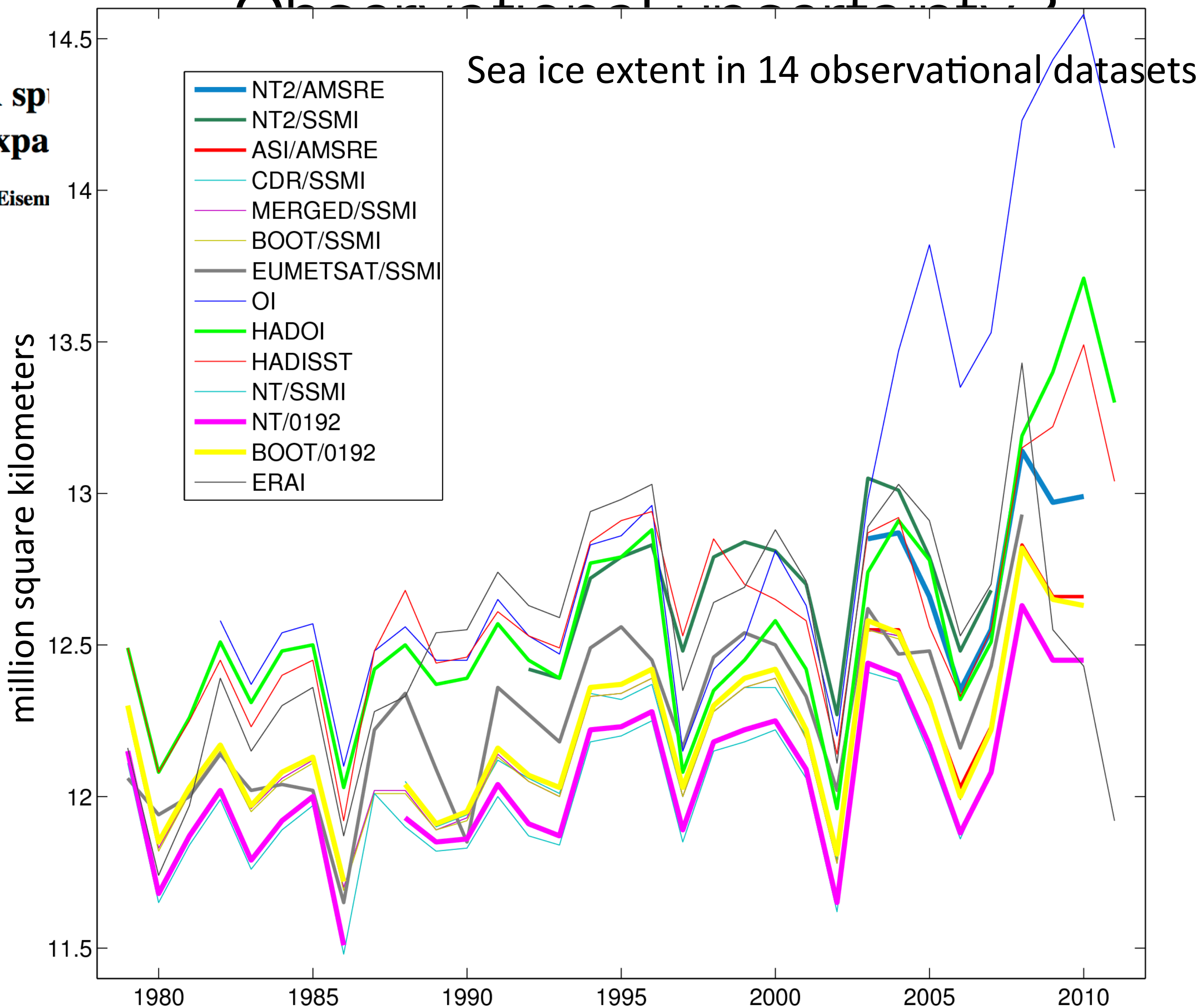


Case study: Antarctic sea ice expansion

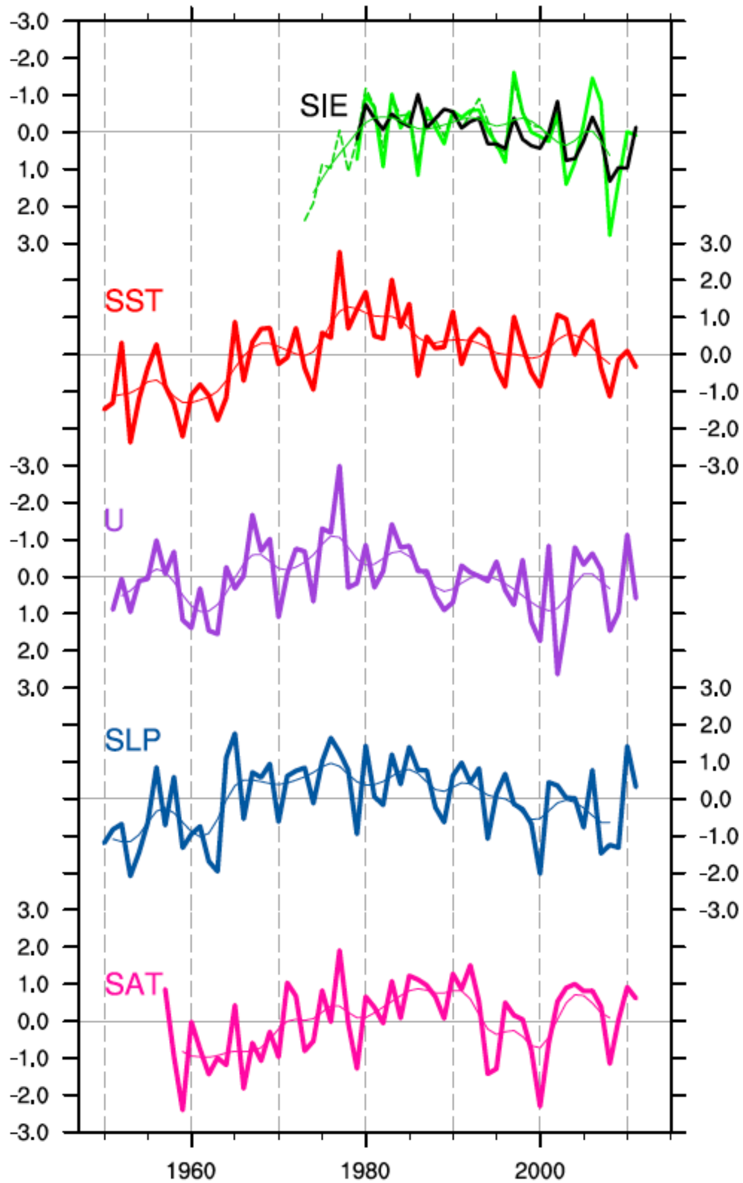


Case study: Antarctic sea ice expansion




Sea ice extent in 14 observational datasets
NT2/AMSRE
NT2/SSMI
ASI/AMSRE
CDR/SSMI
MERGED/SSMI
BOOT/SSMI
EUMETSAT/SSMI
OI
HADOI
HADISST
NT/SSMI
NT/0192
BOOT/0192
ERAI
million square kilometers
14.5
14
13.5
13
12.5
12
11.5
1980
1985
1990
1995
2000
2005
2010

Observational uncertainty?



sea ice extent increase

consistent with

sea surface temperature (SST) decrease
(50°S-70°S)

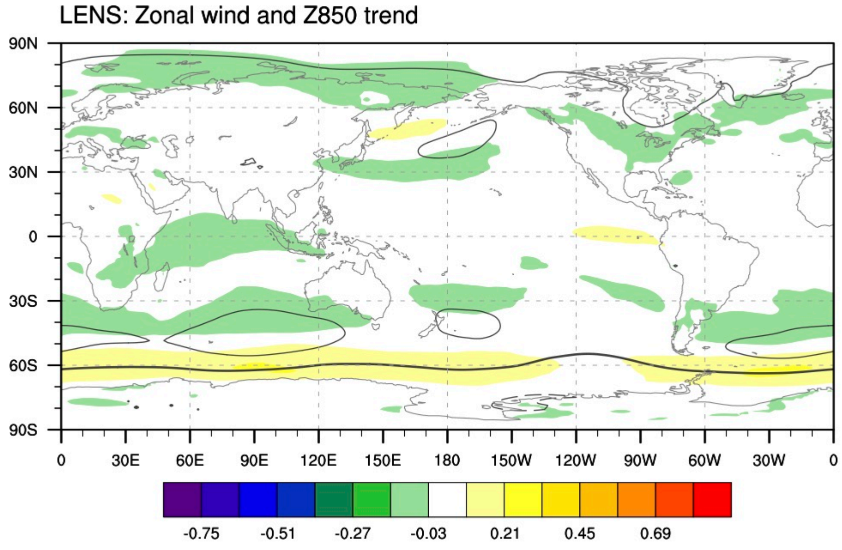
Fan et al., 2014, GRL.

Natural variability?

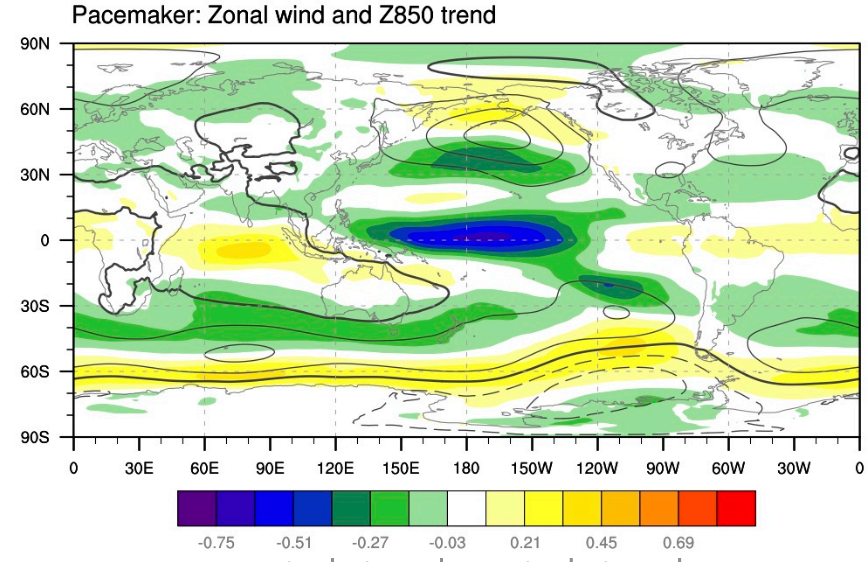
Southern Ocean Sea Ice and wind trends in:

- CESM Large Ensemble (>30 ensemble members, historical forcing)
- CESM "Pacemaker" Ensemble (10 ensemble members, historical forcing plus model nudged to observed SSTs in eastern tropical Pacific)

Large Ensemble (ensemble-mean)
1979-2013 zonal wind trend

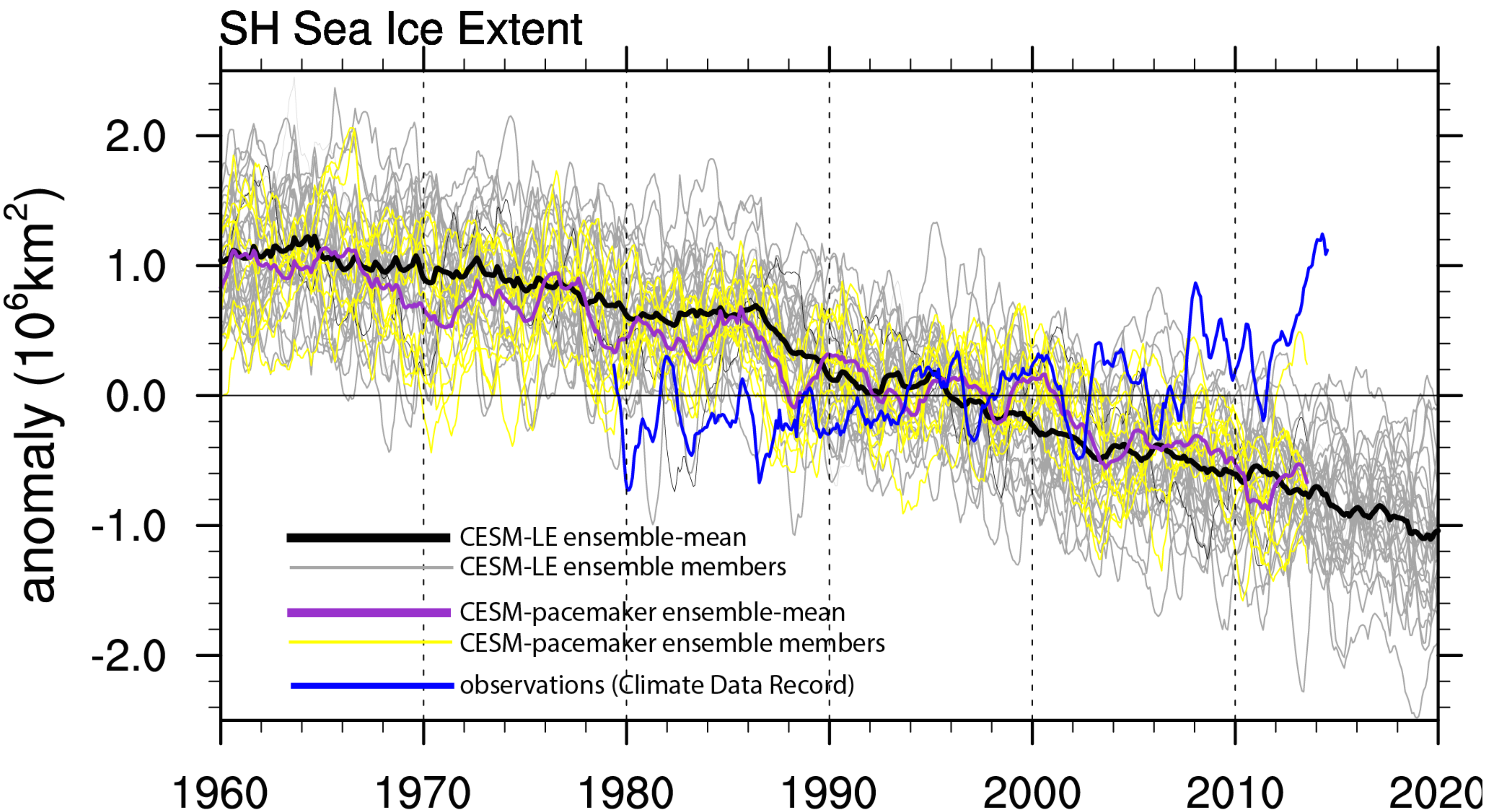


Pacemaker (ensemble-mean)
1979-2013 zonal wind trend



<-- easterly trend westerly trend -->

Natural variability?



Forcing/scenario uncertainty?

Missing Forcing: Freshwater discharge from melting ice shelves not represented in models

Important role for ocean warming and increased ice-shelf melt in Antarctic sea-ice expansion

R. Bintanja*, G. J. van Oldenborgh, S. S. Drijfhout, B. Wouters and C. A. Katsman

The influence of recent Antarctic ice sheet retreat on simulated sea ice area trends

N. C. Swart[1] and J. C. Fyfe[2]

"our simulations show that the freshwater effect on sea ice trends over the historical period is small and fails to reproduce the observed regional patterns of trends, when using observationally consistent rates of freshwater forcing"

Forcing/scenario uncertainty?

Inadequate wind trend because stratospheric ozone forcing is too weak (Purich et al., 2016; Mahlstein et al., 2013)

However,

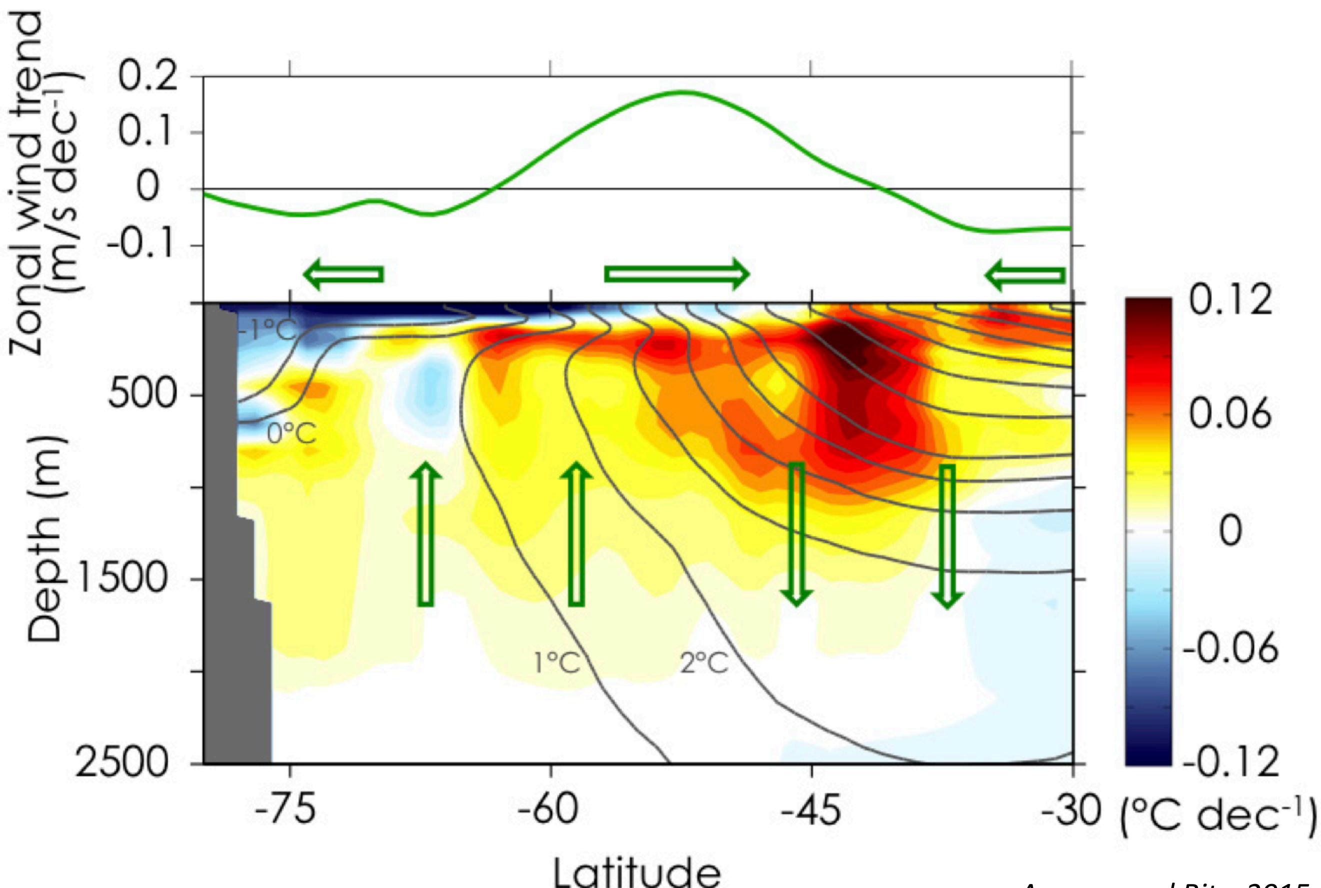
the choice of ozone dataset has little impact on the simulated wind trend (Schneider et al., 2015);

the response to ozone forcing in all CMIP5 models is sea ice loss (Sigmond and Fyfe, 2014);

and

even strong wind trends lead to sea ice loss (Pacemaker ensemble)

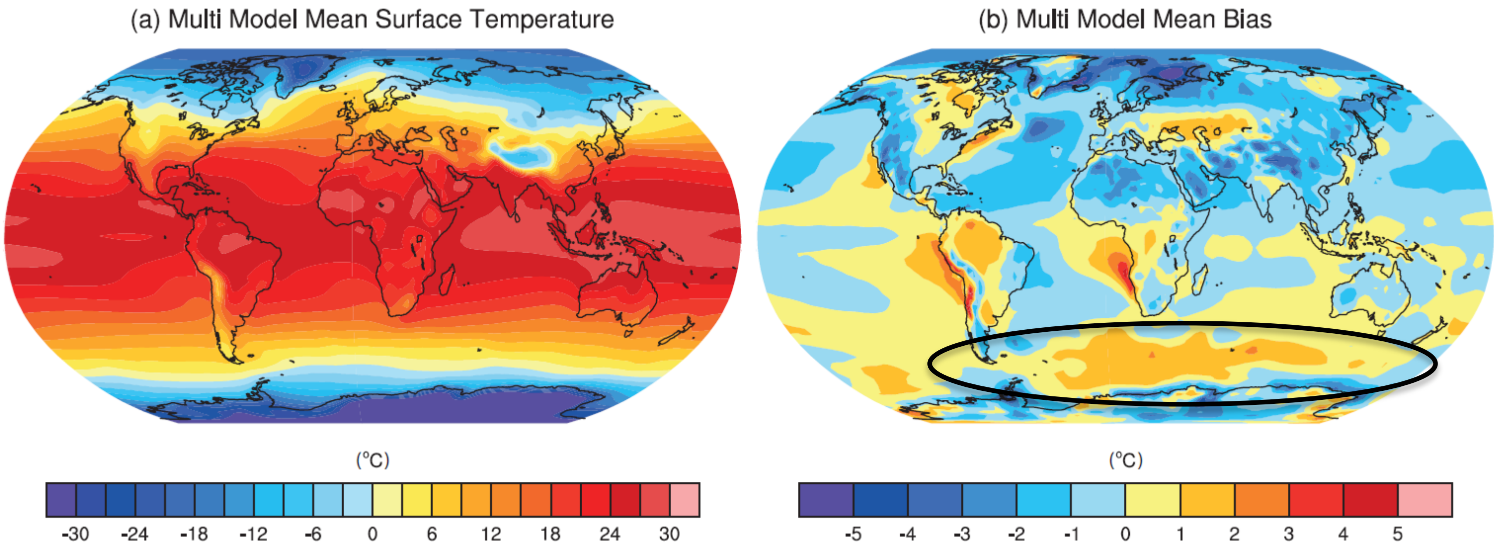
Structural uncertainty?



Armour and Bitz, 2015.

The response of sea ice to stronger winds depends on horizontal and vertical temperature gradients in the ocean

Structural uncertainty?

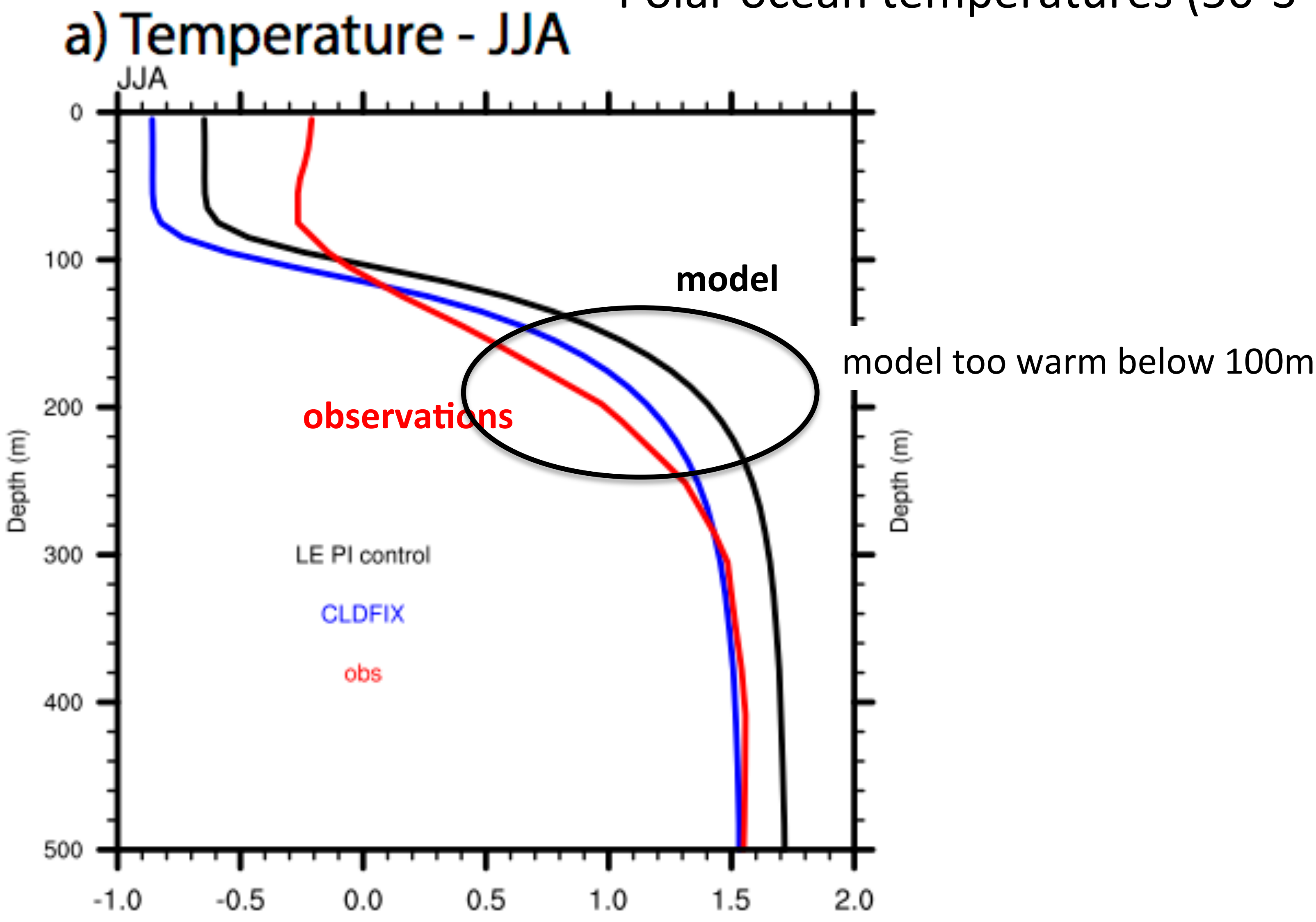


Models are warm-biased in Southern Ocean

2013 IPCC Report, Chapter 9

Structural uncertainty?

Polar ocean temperatures (50°S-70°S)

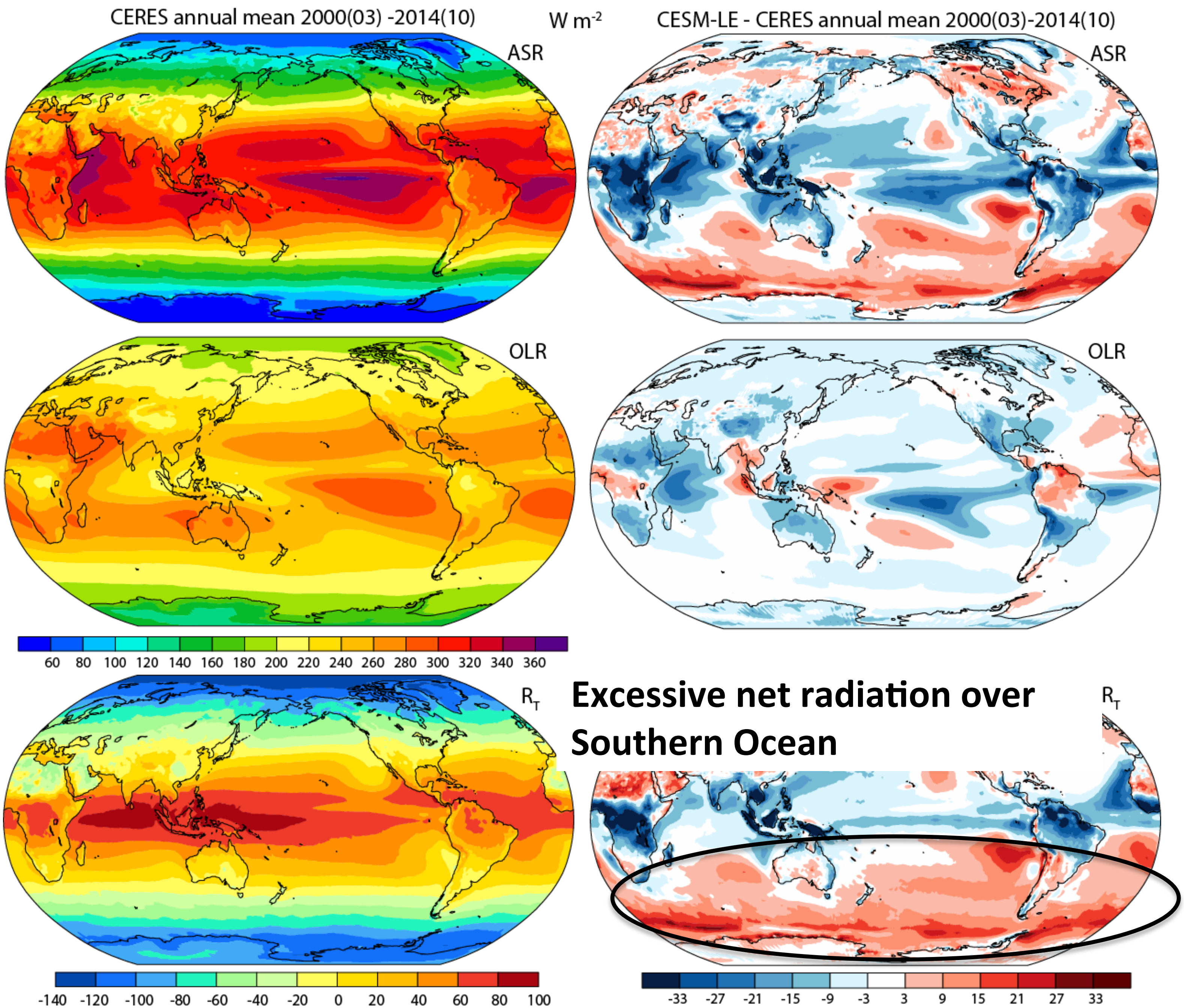


CERES TOA radiation CESM-LE

Obs.
&

Diffs

2000-2
014

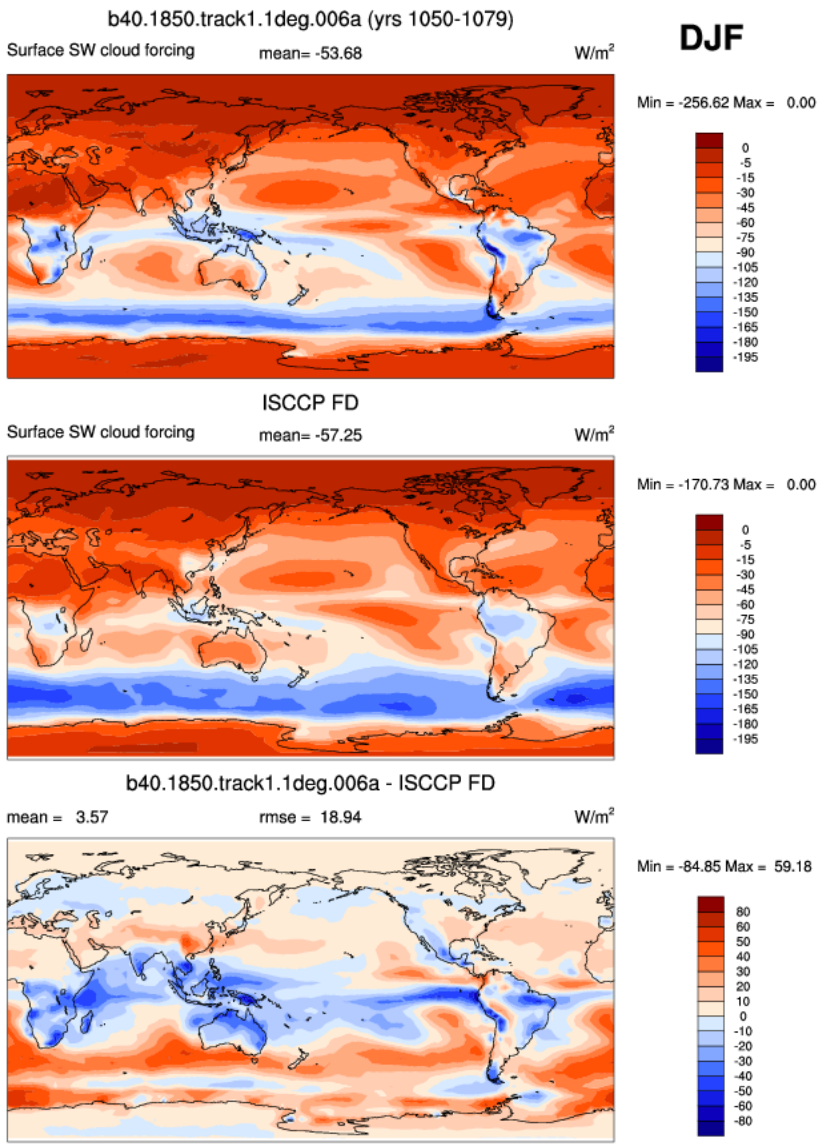


ASR

OLR

R_T

Shortwave Cloud Forcing (SWCF) bias

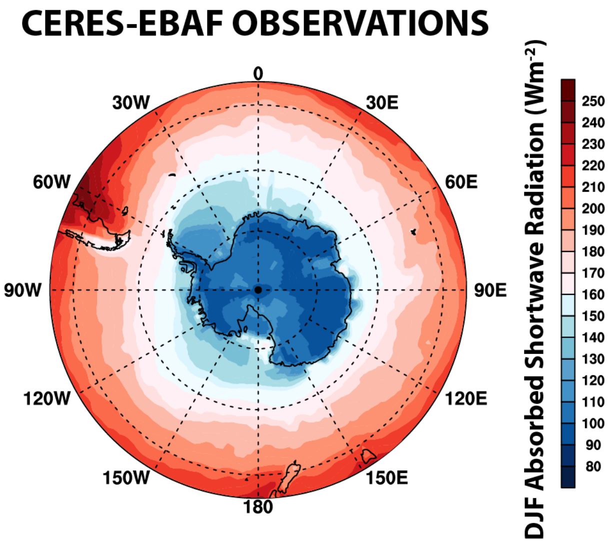


model (CESM)

obs

model-obs

What if we fix SWCF biases?

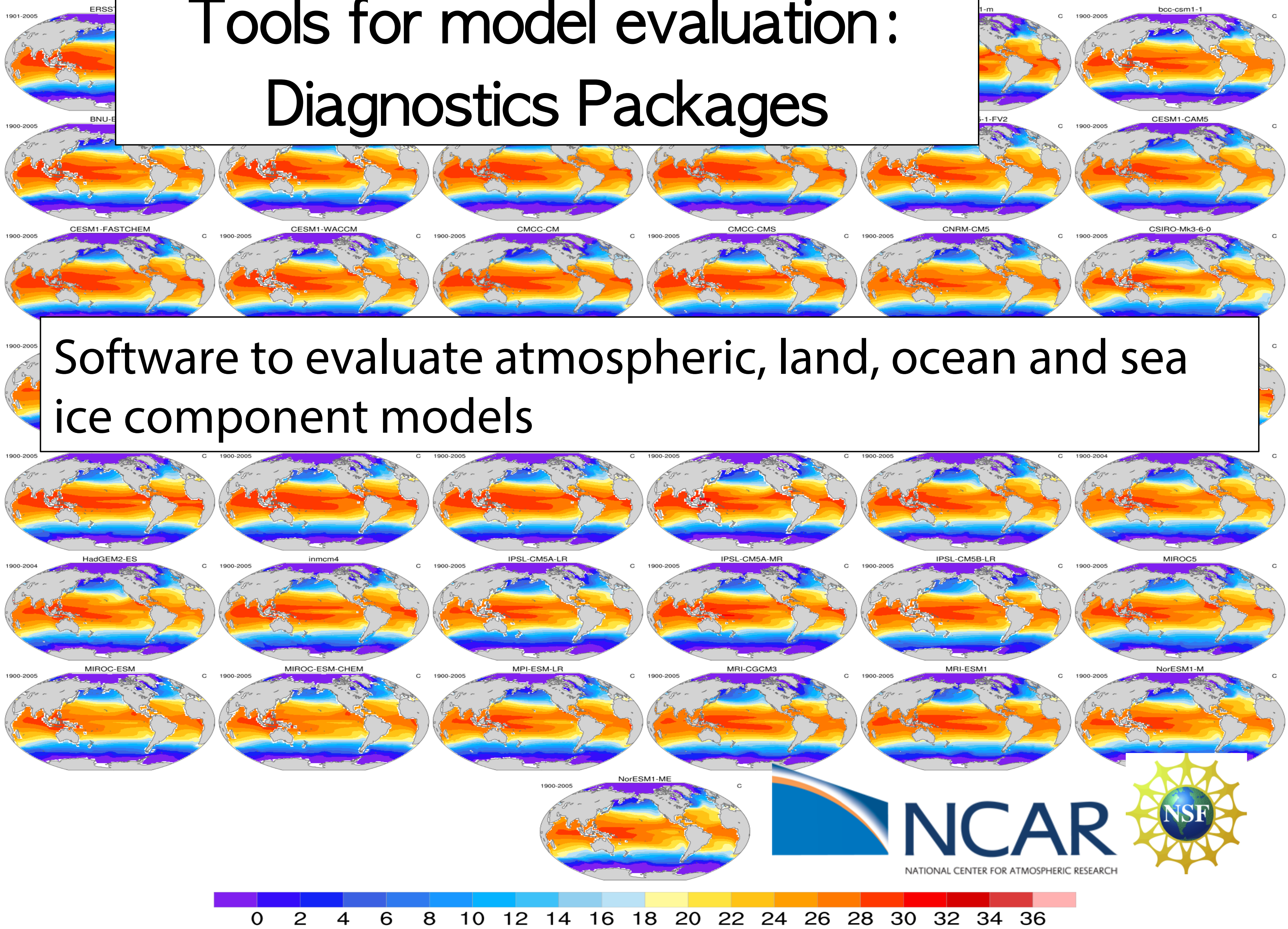


Hypothesis: The Antarctic sea ice response to stronger winds (induced by stratospheric ozone depletion and greenhouse gas increases) depends on the climatology of the ocean, especially the horizontal and vertical temperature gradients.

This is a *structural uncertainty* issue. Stay tuned for results!!

Tools for model evaluation: Diagnostics Packages

Software to evaluate atmospheric, land, ocean and sea ice component models



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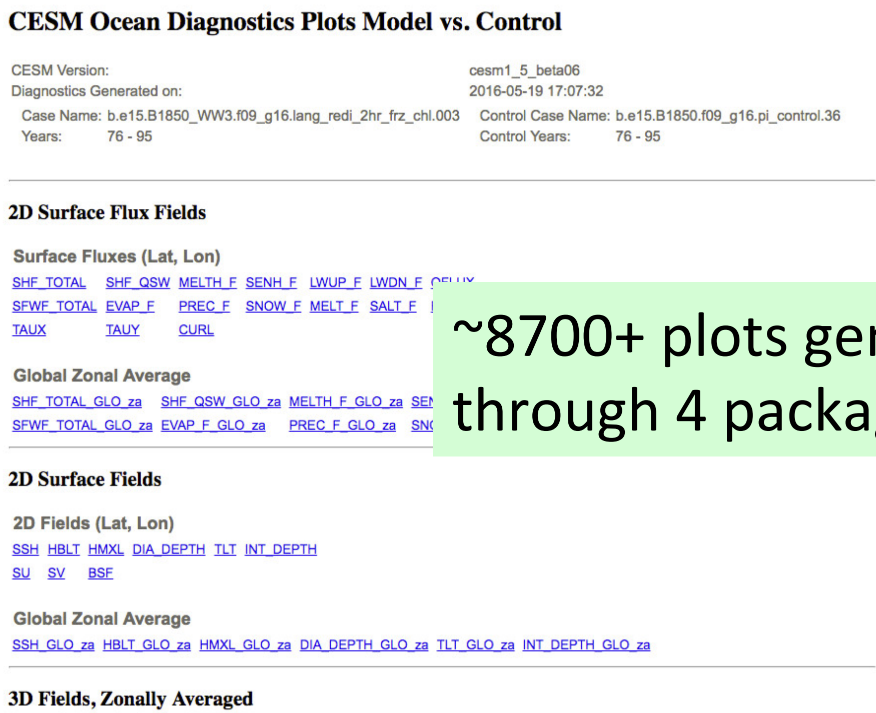
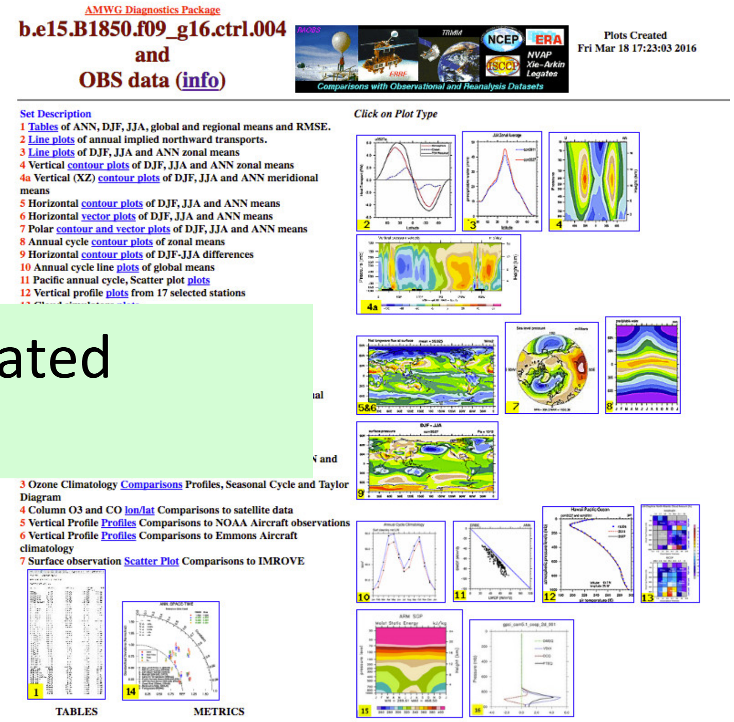
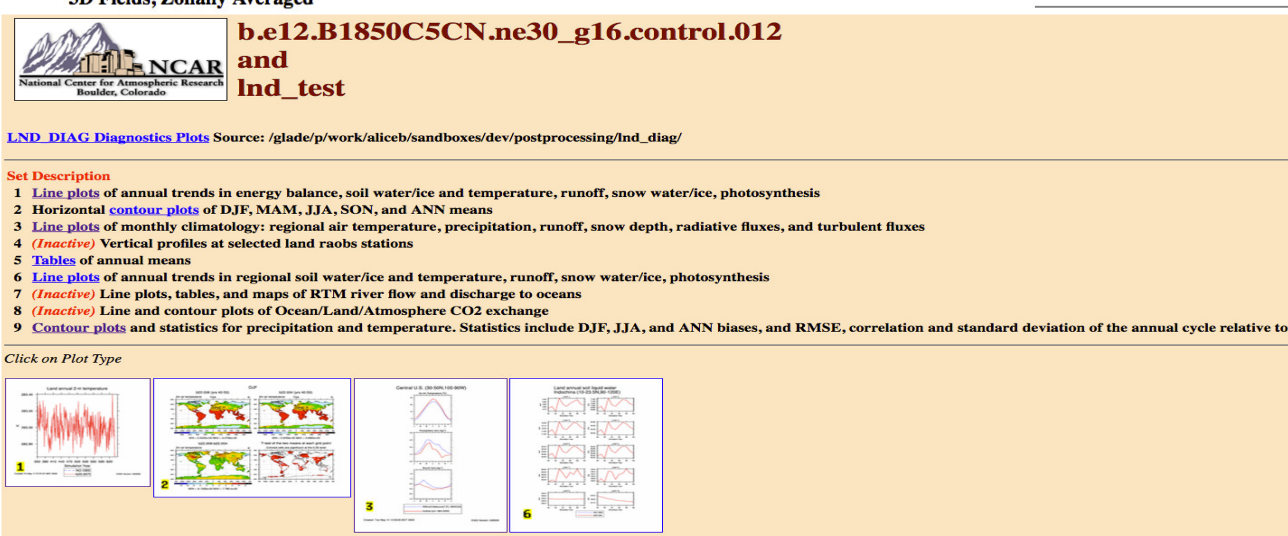
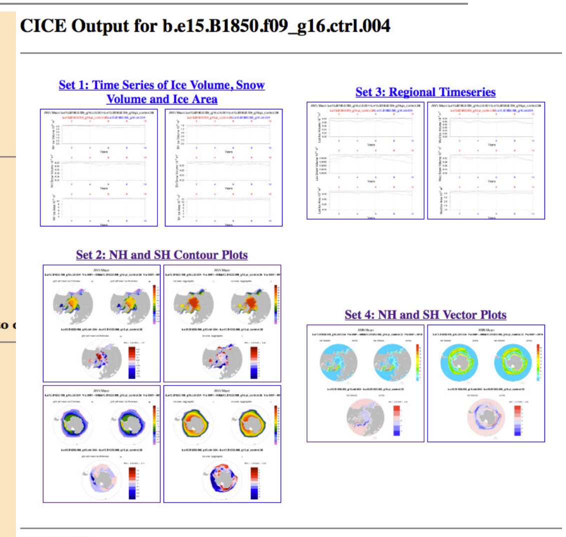
Diagnostics Packages



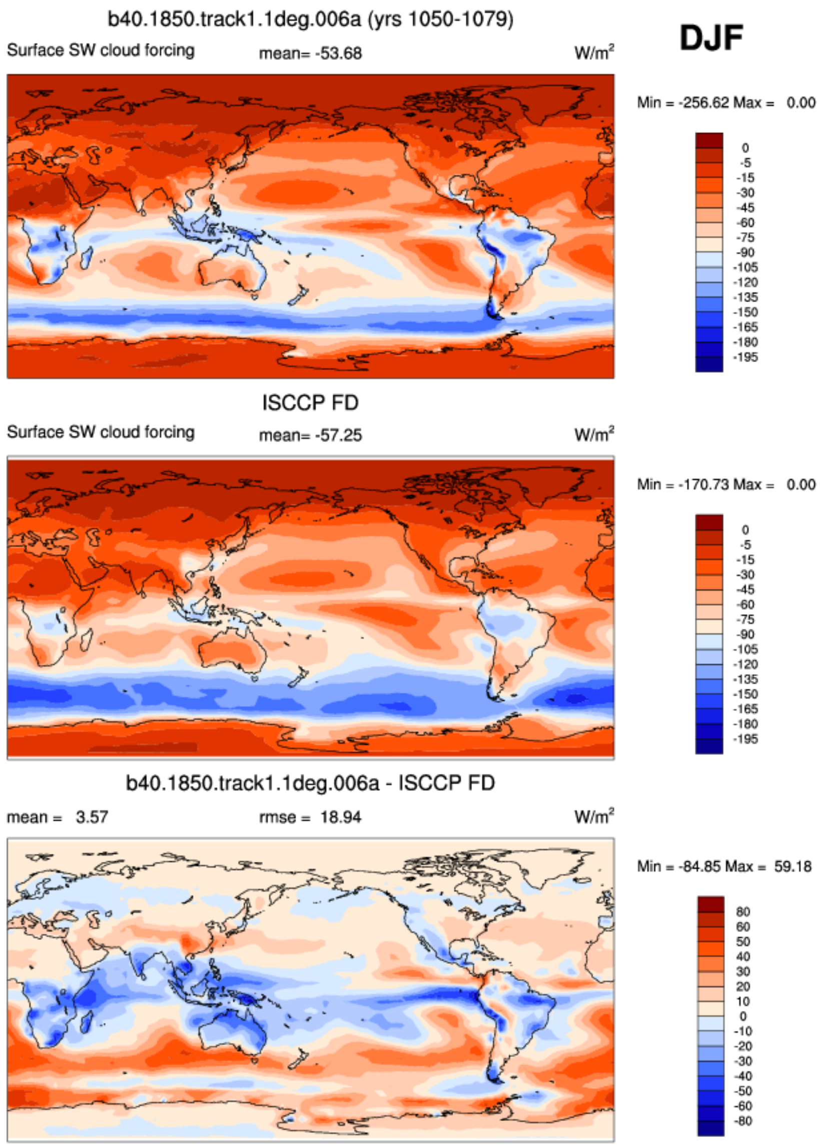


~8700+ plots generated through 4 packages





Diagnostics Packages (AMWG example)

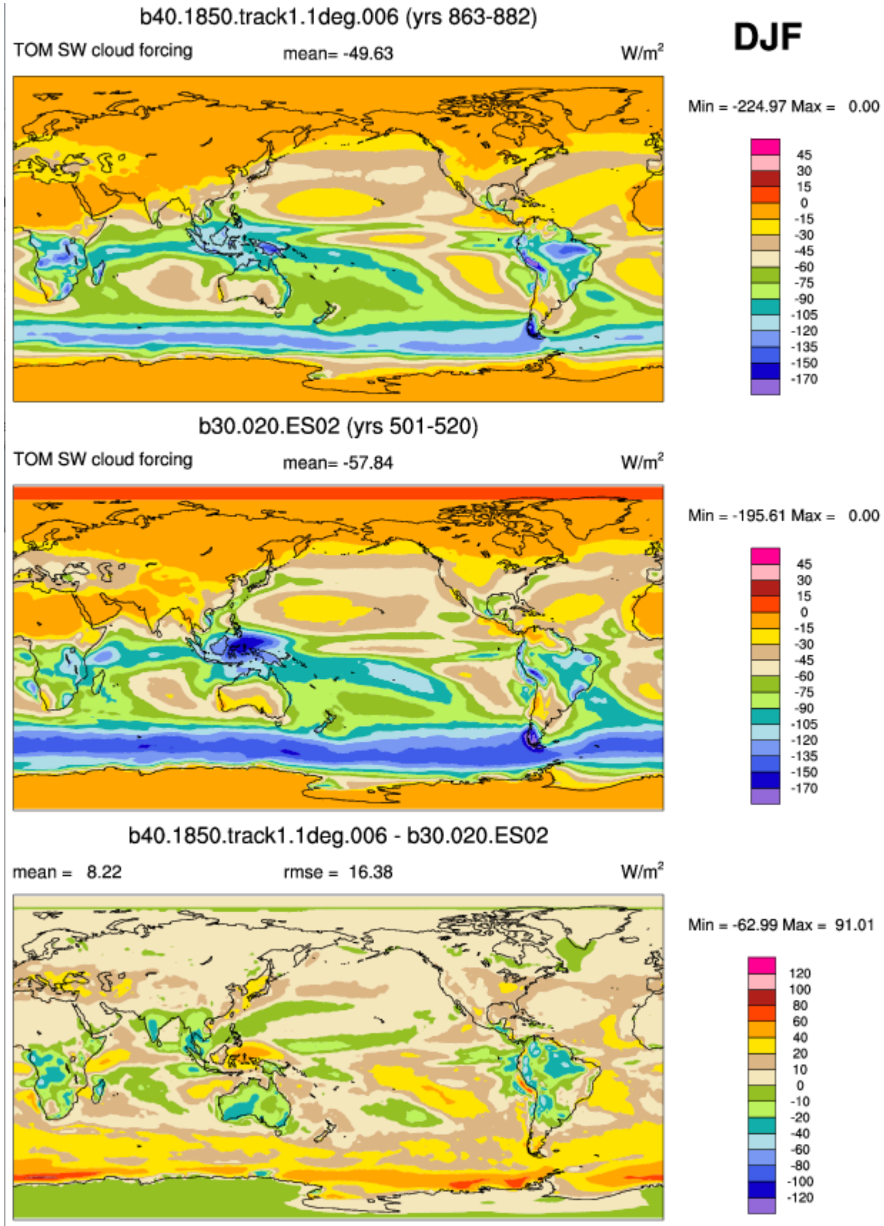


model

obs

model-obs

Diagnostics Packages (AMWG example)



run 1

run 2

run1-run2

run 1 vs run 2 or
run1 vs obs or
run 2 vs obs

useful for development

no ensemble capability (yet)

specific to CESM formatted files

geared towards climatology

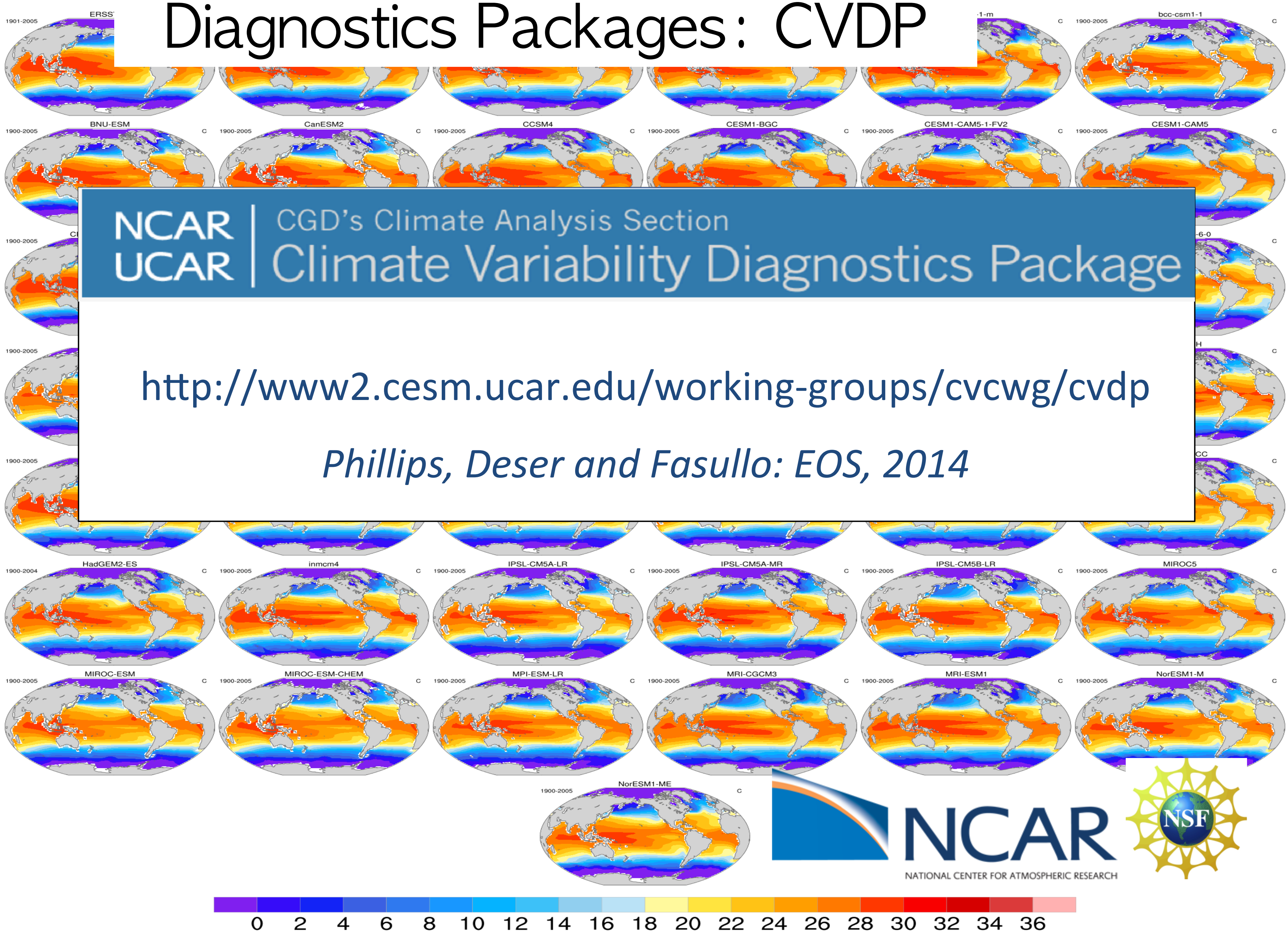
Diagnostics Packages: CVDP

NCAR UCAR | CGD's Climate Analysis Section

Climate Variability Diagnostics Package

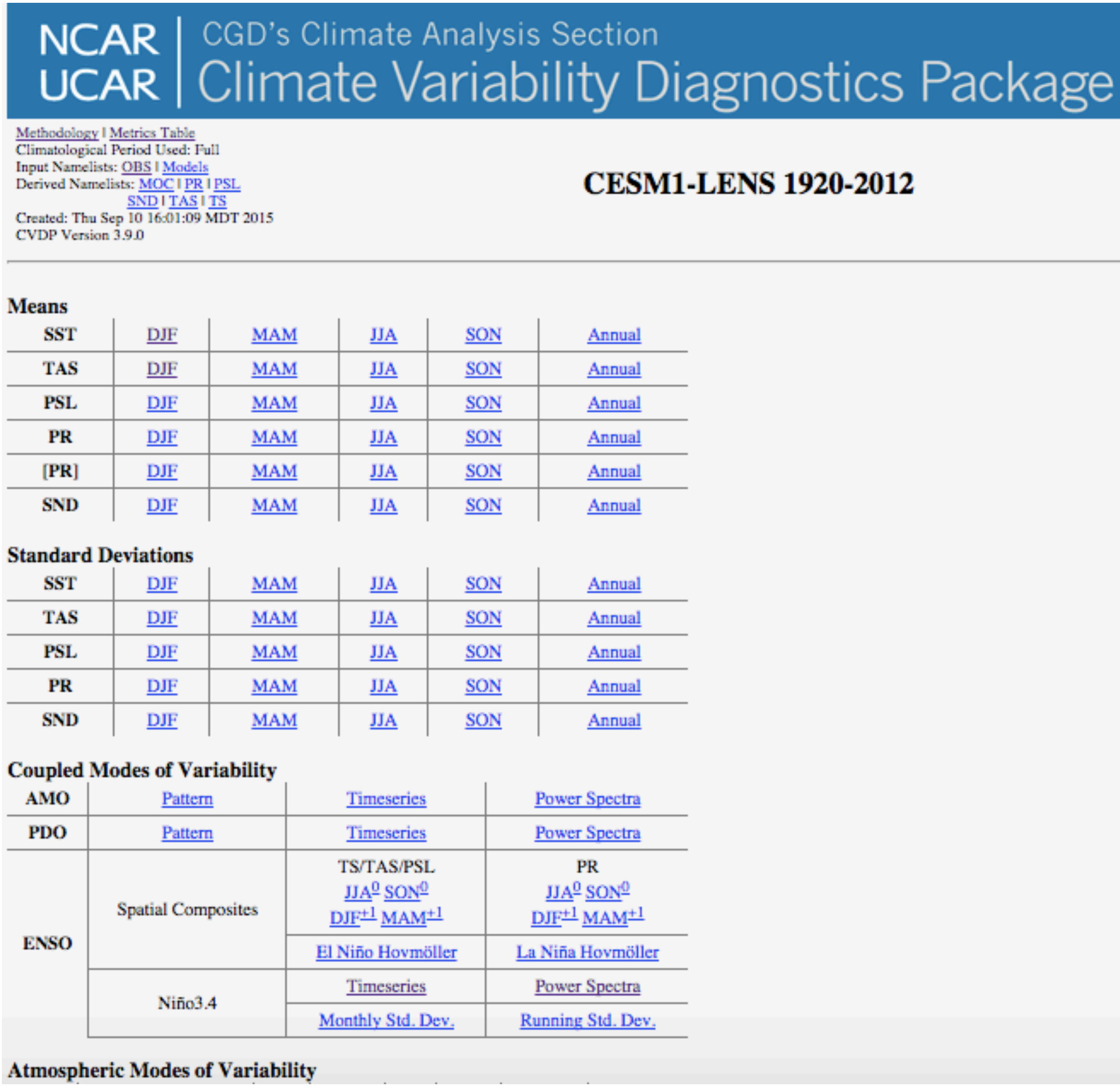
http://www2.cesm.ucar.edu/working-groups/cvcwg/cvdp

Phillips, Deser and Fasullo: EOS, 2014



CVDP Overview

- Focus on the coupled climate system
- Calculations: Coupled and atmospheric modes, trends, timeseries, means and variances w/limited input variables
- Analyze multi-model ensembles and observations at once with distinct time periods
- All calculations written to NetCDF files
- Support, code and selected output available online



NCAR UCAR | CGD's Climate Analysis Section

Climate Variability Diagnostics Package

Methodology | Metrics Table
Climatological Period Used: Full
Input Namelists: OBS | Models
Derived Namelists: MOC | PR | PSL
SND | TAS | TS
Created: Thu Sep 10 16:01:09 MDT 2015
CVDP Version 3.9.0

CESM1-LENS 1920-2012

Means

SST	DJF	MAM	JJA	SON	Annual
TAS	DJF	MAM	JJA	SON	Annual
PSL	DJF	MAM	JJA	SON	Annual
PR	DJF	MAM	JJA	SON	Annual
[PR]	DJF	MAM	JJA	SON	Annual
SND	DJF	MAM	JJA	SON	Annual

Standard Deviations

SST	DJF	MAM	JJA	SON	Annual
TAS	DJF	MAM	JJA	SON	Annual
PSL	DJF	MAM	JJA	SON	Annual
PR	DJF	MAM	JJA	SON	Annual
SND	DJF	MAM	JJA	SON	Annual

Coupled Modes of Variability

AMO	Pattern	Timeseries	Power Spectra
PDO	Pattern	Timeseries	Power Spectra
ENSO	Spatial Composites	TS/TAS/PSL JJA^0 SON^0 DJF^{+1} MAM^{+1}	PR JJA^0 SON^0 DJF^{+1} MAM^{+1}
		El Niño Hovmöller	La Niña Hovmöller
	Niño3.4	Timeseries	Power Spectra
		Monthly Std. Dev.	Running Std. Dev.

Atmospheric Modes of Variability

CVDP Overview : specifying datasets

User Supplied: namelist_obs (list of observational datasets to use by variable)

TS | ERSST v3b | /project/cas/asphilli/Dsets/ersstv3b.ts.185401-201401.nc | 1900 | 2005
PSL | 20thC_ReanV2 | /project/cas/asphilli/prmsl.mon.mean.187101-201212.nc | 1900 | 2005
TREFHT | MLOST | /project/cas/asphilli/DSets/mlost.v3.5.3.188001-201312.nc | 1900 | 2005
PRECT | GPCP | /project/cas/asphilli/GPCP/gpcp.mon.mean.pr.197901-201411.nc | 1979 | 2005

User Supplied: namelist (list of model simulations)

CESM-LENS EM | /project/yampa01/asphilli/CESM1-LE/b.e11.B*C5CNBDRD.*.EM.* 1979 | 2018
CESM-LENS #34 | /project/yampa01/asphilli/CESM1-LE/b.e11.B*C5CNBDRD.*.034.* 1979 | 2018
BNU-ESM | /project/cmip5/ETH/cmip5/{historical,rcp85}/Amon/*/BNU-ESM/r1i1p1/ | 1900 | 2020
CanESM2 | /project/cmip5/ETH/cmip5/historical/Amon/*/CanESM2/r1i1p1/ | 1900 | 2005
CESM1-BGC | /project/cmip5/ETH/cmip5/historical/Amon/*/CESM1-BGC/r1i1p1/ | 1900 | 2005
CESM1-CAM5 | /project/cmip5/ETH/cmip5/historical/Amon/*/CESM1-CAM5/r1i1p1/ | 1900 | 2005
CMCC-CM | /project/cmip5/ETH/cmip5/historical/Amon/*/CMCC-CM/r1i1p1/ | 1900 | 2005

User Modified: driver.ncl (CVDP options)

CVDP Overview: specifying datasets

User Supplied: namelist_obs   (list of observational datasets to use by variable)

PSL | 20thC_ReanV2 | /project/cas/asphilli/20thCRV2/prmsl.mon.mean.187101-201212.nc | 1900 | 2012
PSL | HadSLP2r | /project/cas/asphilli/DSets/hadslp2r.185001-201312.nc | 1900 | 2012
PSL | ERA20C | /project/cas/asphilli/ERA20C/msl.mon.mean.190001-201012.nc | 1900 | 2010
PSL | 20thC_ReanV2 | /project/cas/asphilli/20thCRV2/prmsl.mon.mean.187101-201212.nc | 1979 | 2012
TS | ERSST v4 | /project/cas/asphilli/DSets/ersstv4.185401-201512.nc | 1900 | 2012
TS | HadISST | /project/cas/asphilli/DSets/hadisst.187001-201312.nc | 1900 | 2012
TS | ERSST v3b | /project/cas/asphilli/DSets/ersstv3b.185401-201401.nc | 1900 | 2012
TS | HadSST 3.1 | /project/cas/asphilli/DSets/HadSST.3.1.0.0.median.185001-201309.nc | 1900 | 2012
TREFHT | GISTEMP | /project/cas/asphilli/DSets/gistemp.tas.188001-201512.nc | 1900 | 2012
TREFHT | MLOST | /project/cas/asphilli/DSets/mlost.v3.5.3.188001-201312.nc | 1900 | 2012
TREFHT | HadCRUT 4.2 | /project/cas/asphilli/DSets/HadCRUT.4.2.0.0.t.185001-201312.nc | 1900 | 2012
TREFHT | GISTEMP | /project/cas/asphilli/DSets/gistemp.tas.188001-201512.nc | 1979 | 2015
PRECT | GPCC | /project/cas/asphilli/DSets/GPCC/full_data_v6_precip_10.190101-201012.nc | 1901 | 2010
PRECT | GPCP | /project/cas/asphilli/DSets/gpcp.mon.mean.197901-201411.nc | 1979 | 2012
PRECT | GPCP | /project/cas/asphilli/DSets/gpcp.mon.mean.197901-201411.nc | 1979 | 2013

CVDP examples

Applied to a 10-member CAM5-1°AMIP ensemble (observed SSTs and radiative forcings, 1952-2002)

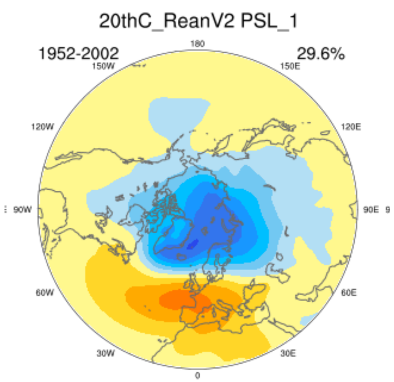
- Standard 30-level version
- New 46-level version (better stratospheric representation)

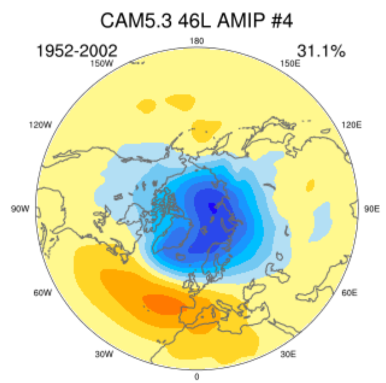
Northern Annular Mode (EOF1 DJF SLP 20-90°N, 1952-2002)

Observations
(20CR)

Model
46L CAM5

30%

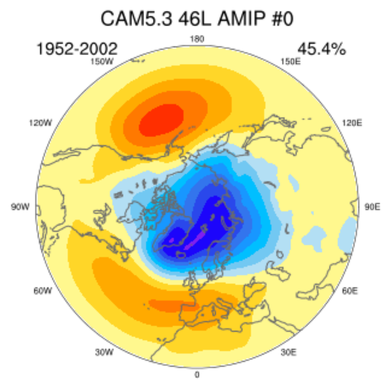




Run 4
31%

Northern Annular Mode (EOF1 DJF SLP 20-90°N, 1952-2002)

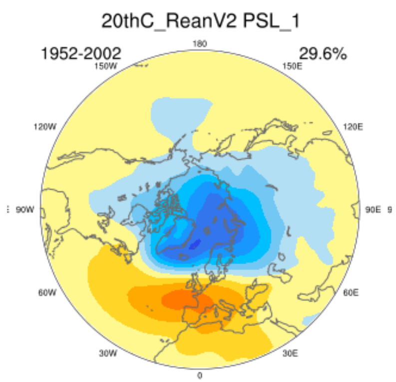
46L CAM5

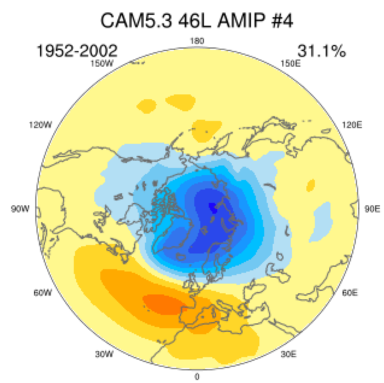


Run 1
45%

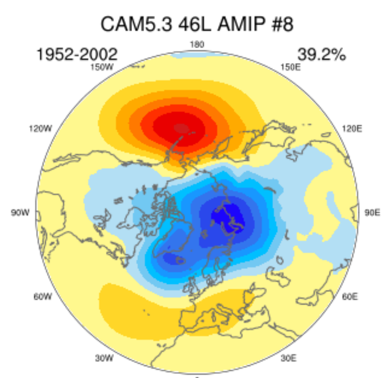
Observations
(20CR)

30%





Run 4
31%

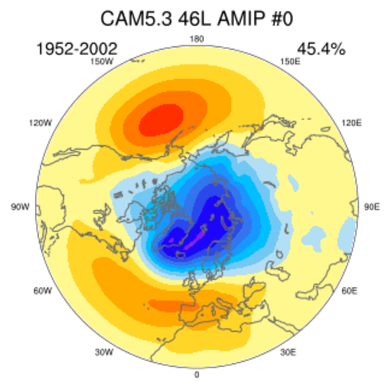


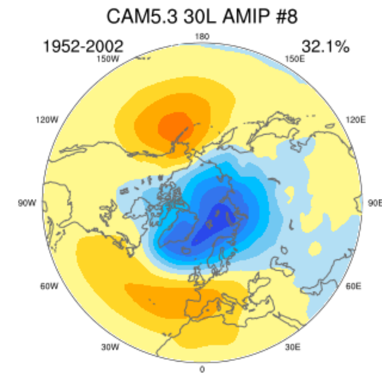
Run 8
39%

Northern Annular Mode (EOF1 DJF SLP 20-90°N, 1952-2002)

46L CAM5

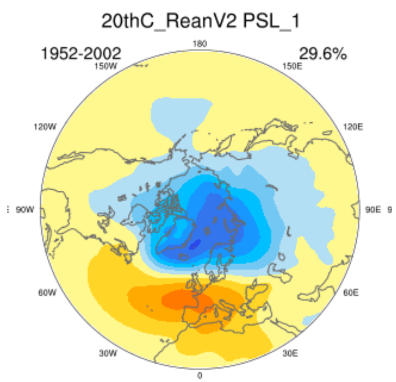
30L

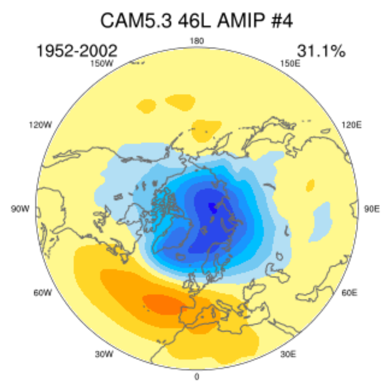


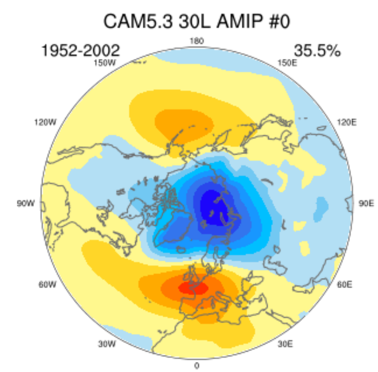


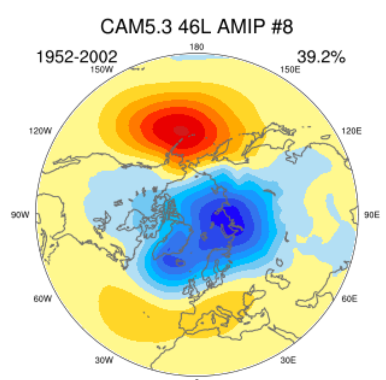
Observations (20CR)

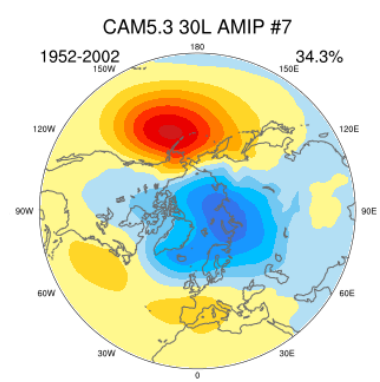
30%





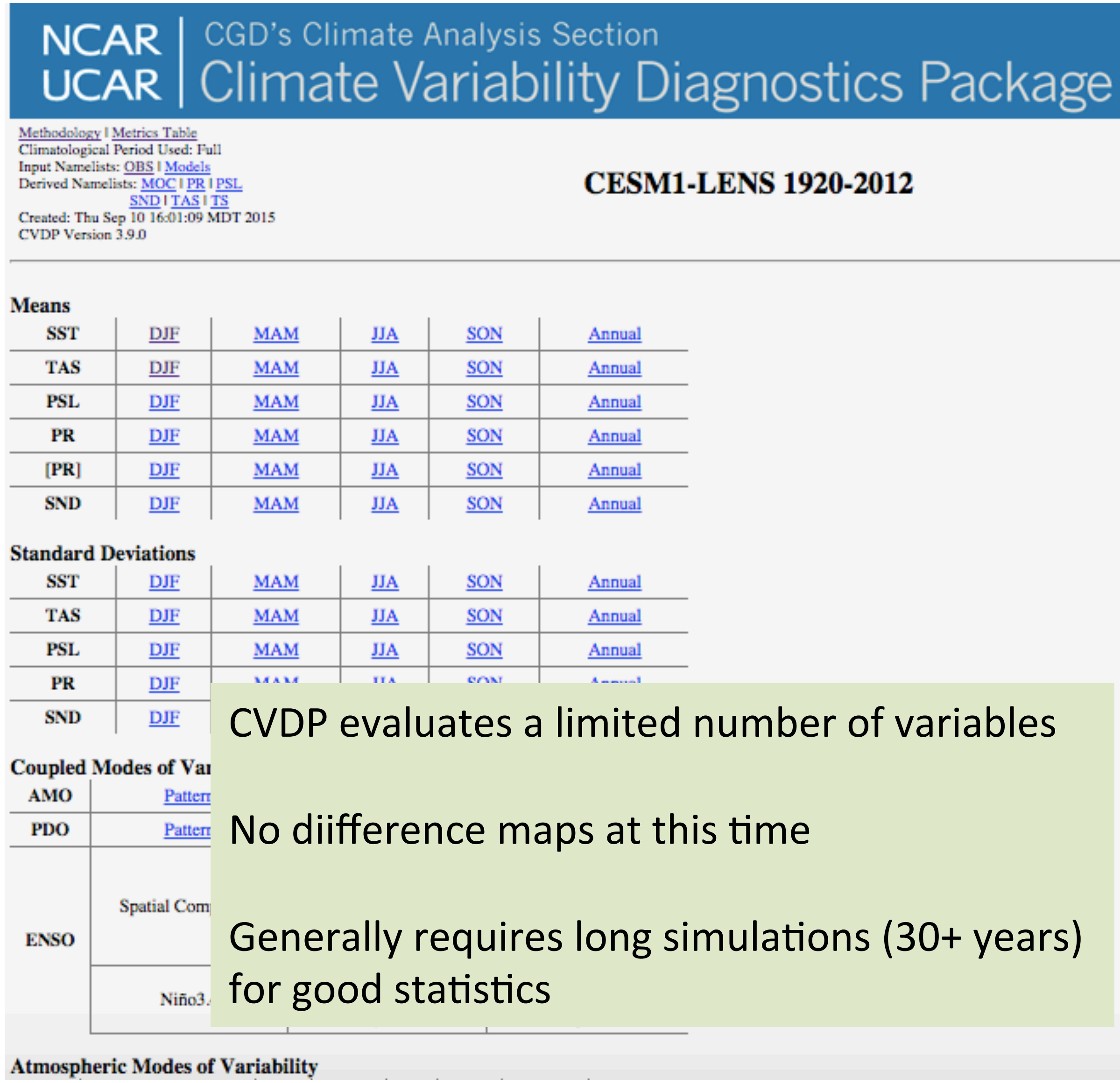






CVDP Overview

- Focus on the coupled climate system
- Calculations: Coupled and atmospheric modes, trends, timeseries, means and variances w/limited input variables
- Analyze multi-model ensembles and observations at once with distinct time periods
- All calculations written to NetCDF files
- Support, code and selected output available online



CVDP evaluates a limited number of variables

No diifference maps at this time

Generally requires long simulations (30+ years) for good statistics

Tools for model evaluation: Climate Data Guide

observational uncertainty

structural uncertainty	natural variability	forcing/scenario uncertainty
observations needed for parameterizations and parameter values	range of natural variability incompletely sampled; not all processes sampled	poorly sampled history of forcing factors such as aerosols, volcanic sulfate, solar, ozone, etc.

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Schneider et al., 2013 EOS

Concise expert guidance on the strengths, limitations and applications of climate data…

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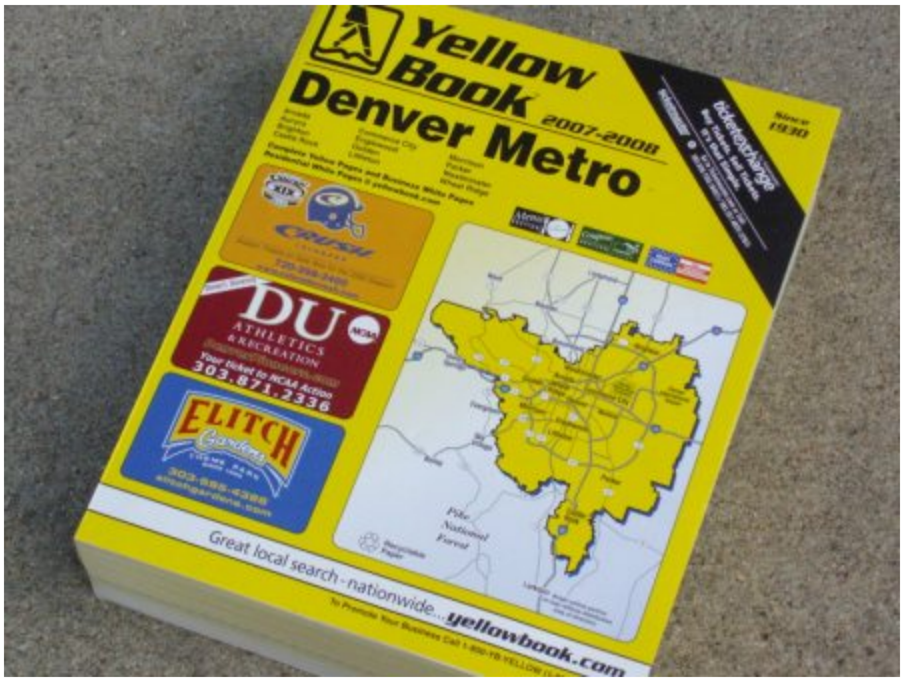
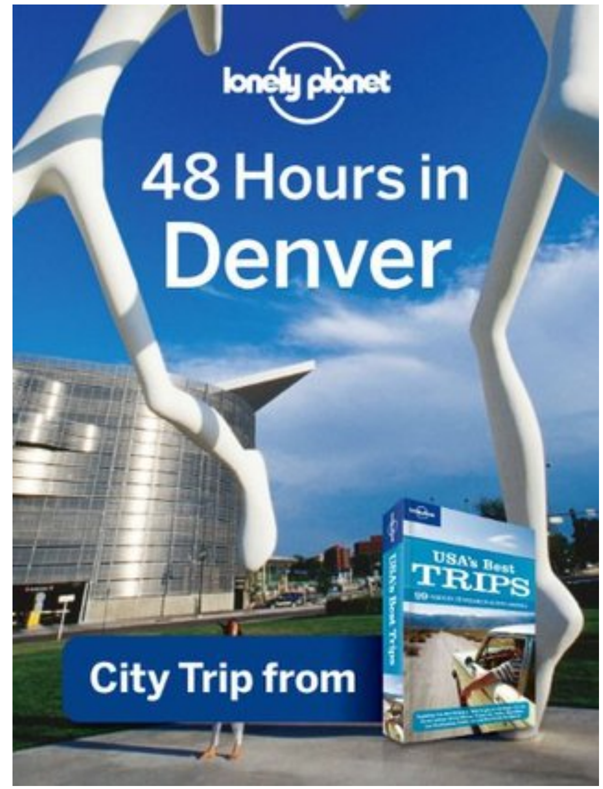
Typical data portal



Climate Data Guide



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Concise expert guidance on the strengths, limitations and applications of climate data…

Do we trust the obs? (e.g. spurious trends, different sensitivities of satellite algorithms)

Which dataset to use? (out of a dozen precipitation datasets, which is the best one for me?)

Are the data comparable with model output? (e.g. clouds in a model vs. clouds in satellite obs)

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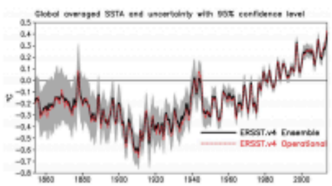
SST DATA: NOAA EXTENDED RECONSTRUCTION SSTS, VERSION 4

Summary | Expert Guidance | Metadata | Get Data (External) | References



The NOAA Extended Reconstruction Sea Surface Temperature (ERSST) provides global, spatially complete SST data at a monthly timestep for 1854-present. Compared to the previous version, Version 4 uses the more extensive ICOADS Release 2.5 data and revised quality control, bias adjustment, and infilling procedures. The resolved signals are rather damped prior to 1880 and more consistent after 1880. The data are distributed as anomalies; climatologies (absolute values) are available for 1981-2010. As a globally infilled dataset, ERSST v4 is generally suitable for basin-scale and global studies of climate variability and change, and has been used as boundary conditions for atmospheric models.

KEY STRENGTHS:

- Long record spanning 1854-present; global coverage
- Uses more extensive input data and revised quality control and bias adjustment procedures compared to previous versions
- Uncertainty estimates provided

KEY LIMITATIONS:

- Coarse spatial resolution and low temporal resolution; some features are highly smoothed or damped
- Large uncertainties in the Arctic and Southern Oceans
- Resolved signal degrades back through time, especially before 1880

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SST DATA: NOAA EXTENDED RECONSTRUCTION SSTS, VERSION 4

Summary | Expert Guidance | Metadata | Get Data (External) | References

EXPERT DEVELOPER GUIDANCE

The following was contributed by **Dr. Boyin Huang**, NOAA National Climatic Data Center, January, 2016:

1. Data Description

The most recent version of the Extended Reconstruction of Sea Surface Temperature (ERSST) analysis is v4 (ERSST v4). The analysis is based on the International Comprehensive Ocean-Atmosphere Data Set (ICOADS) Release 2.5. At the end of every month, the ERSST analysis and its uncertainty are updated with the available GTS ship and buoy data for that month. The anomalies are computed with respect to a 1971-2000 climatology.

The monthly analysis extends from January 1854 to the present, but because of sparse data in the early years, the analyzed signal is damped before 1880. After 1880, the strength of the signal is more consistent over time. ERSST is suitable for long-term global and basin wide studies; local and short-term variations have been smoothed in ERSST. The spatial resolution is 2° in latitude and longitude, and temporal resolution is monthly.

2. Key strengths

ABOUT THE EXPERTS

pages with Expert Guidance by *Dr. Boyin Huang at NOAA NCDC.*

SST data: NOAA Extended Reconstruction SSTs, version 3 (ERSSTv3 & 3b)

SST data: NOAA Extended Reconstruction SSTs, Version 4

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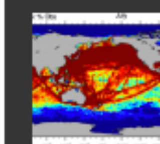
SST DATA: NOAA EXTENDED RECONSTRUCTION SSTS, VERSION 4

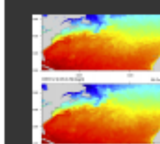
Summary | Expert Guidance | Metadata | Get Data (External) | References

1. Huang, B., and coauthors, 2016: Further exploring and quantifying uncertainties for Extended Reconstructed Sea Surface Temperature (ERSST) version 4 (v4). J. Climate, doi:10.1175/JCLI-D-15-0430.1.
2. Huang, B. and coauthors, 2015: Extended Reconstructed Sea Surface Temperature version 4 (ERSST.v4), Part I. Upgrades and intercomparisons. J. Climate, 28, 911-930, doi:10.1175/JCLI-D-14-00006.1.

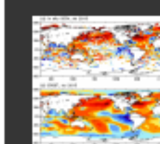
RELATED PAGES



ICOADS Surface Marine Weather Observations



SST Data Sets: Overview & Comparison Table



SST data: NOAA Extended Reconstruction SSTs, version 3 (ERSSTv3 & 3b)

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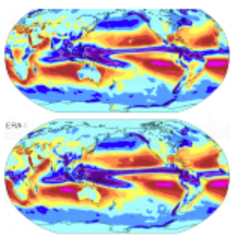
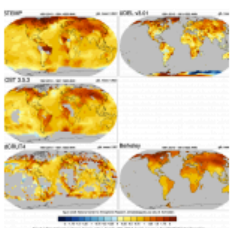
Data Set Overviews > >

Compare the attributes, strengths and limitations of multiple data sets.

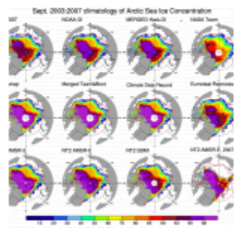


Atmospheric Reanalysis: Overview & Comparison Tables

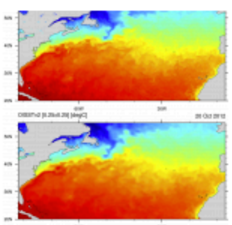


Global Temperature Data Sets: Overview & Comparison Table

Precipitation Data Sets: Overview & Comparison table



Sea Ice Concentration data: Overview, Comparison table and graphs



SST Data Sets: Overview & Comparison Table

currently: SSTs, air temperature, precipitation, atmospheric reanalysis, sea ice concentration

coming soon: clouds, climate indices

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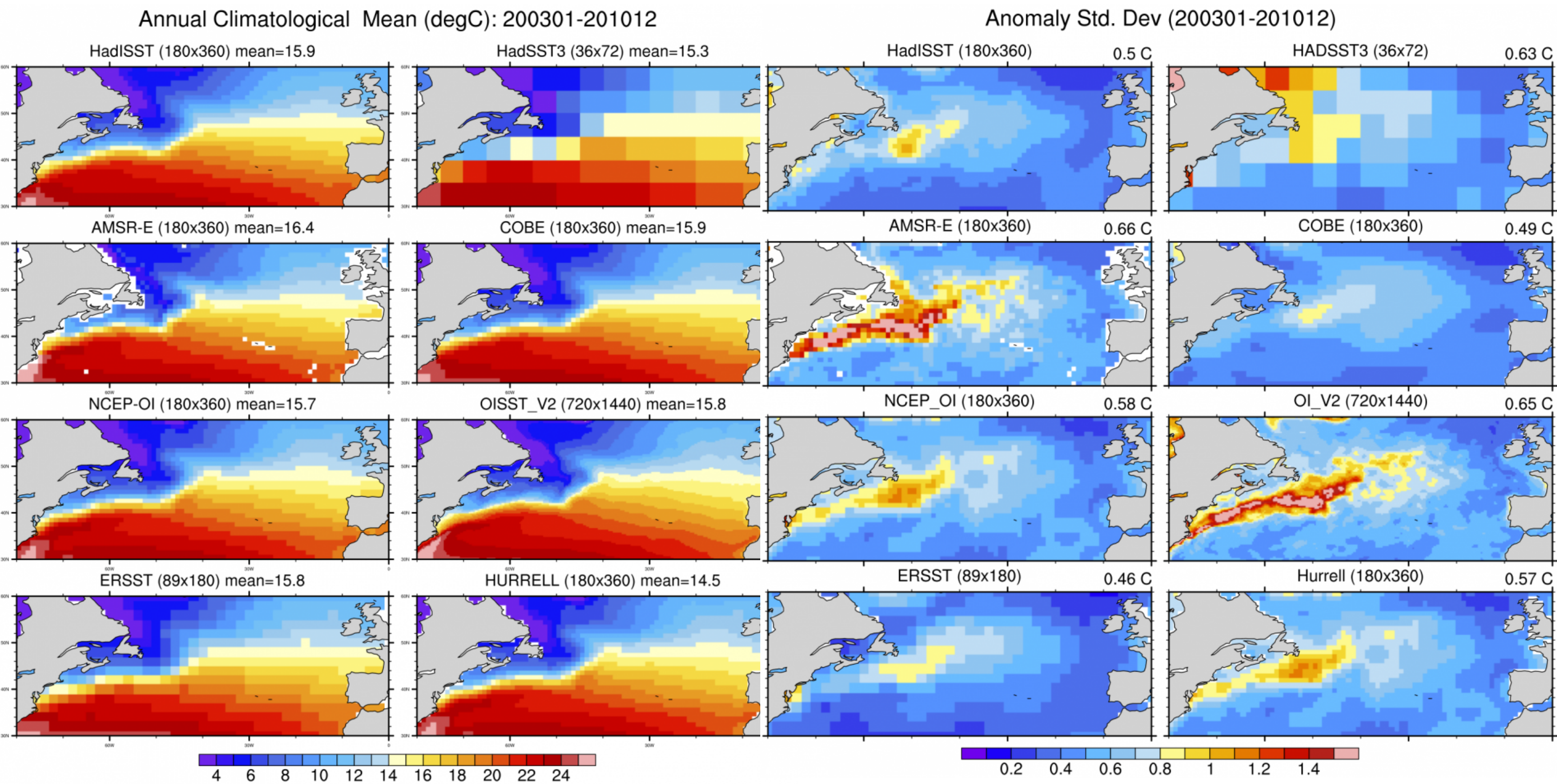

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Summary of Atmospheric Reanalysis products

Name	Source	Domain	Period of Record	available timestep(s)	available resolution	available format(s)	Model Resolution	scheme & model vintage
Arctic System Reanalysis (ASR)	Byrd Polar Research Center, The Ohio State University/ David Bromwich,NCAR,CIRES,U Illinois	Arctic	2000/01 to 2012/12	Sub-daily, Monthly	30 km; 71 levels; 10hPA top, 10 km	netCDF	30 km and 10 km	WRF-VAR
Climate Forecast System Reanalysis (CFSR)	NCEP	Global	1979/01 to 2011/01	Sub-daily, Monthly	.5°x.5° & 2.5°x2.5°, 0.266 hPA top	GRIB	T382 x 64 levels	3DVAR | 2009
ERA-15	ECMWF	Global	1979/01 to 1993/12	Sub-daily, Monthly	T106, 2.5 x 2.5	GRIB	T106 (1.125)	
ERA-20C: ECMWF's atmospheric reanalysis of the 20th century (and comparisons with NOAA's 20CR)	ECMWF	Global	1900/01 to 2011/01	Sub-daily, Daily, Monthly	~ 125km; 160 x 320; 91 model levels/ 37 pressure levels / 16 potential temperature levels, and the 2 PVU potential vorticity level	netCDF, GRIB		4DVAR
ERA-Interim	ECMWF	Global	1979/01 to 2016/03	Sub-daily, Daily, Monthly	0.75°x0.75°x60 lev 0.1 hPA top	netCDF, GRIB	T255, 60 levels	4DVAR | 2006
ERA40	ECMWF	Global	1957/09 to 2002/08	Sub-daily, Monthly	2.5°x2.5° / 1.125°x1.125°; 60 levels 0.1 hPA top	netCDF, GRIB	T159, 60 levels	3DVAR | 2004
JRA-25	Japanese Meteorological Agency	Global	1979/01 to 2004/12	Sub-daily, Monthly	1.125x1.125/2.5x2.5; 0.4 hPA top	GRIB	T106, 40 levels	3DVAR | 2004
	Japanese Meteorological		1957/12	Sub-daily,	T319 x 60 levels, 0.1 hPA		T319 x 60	4DVAR |

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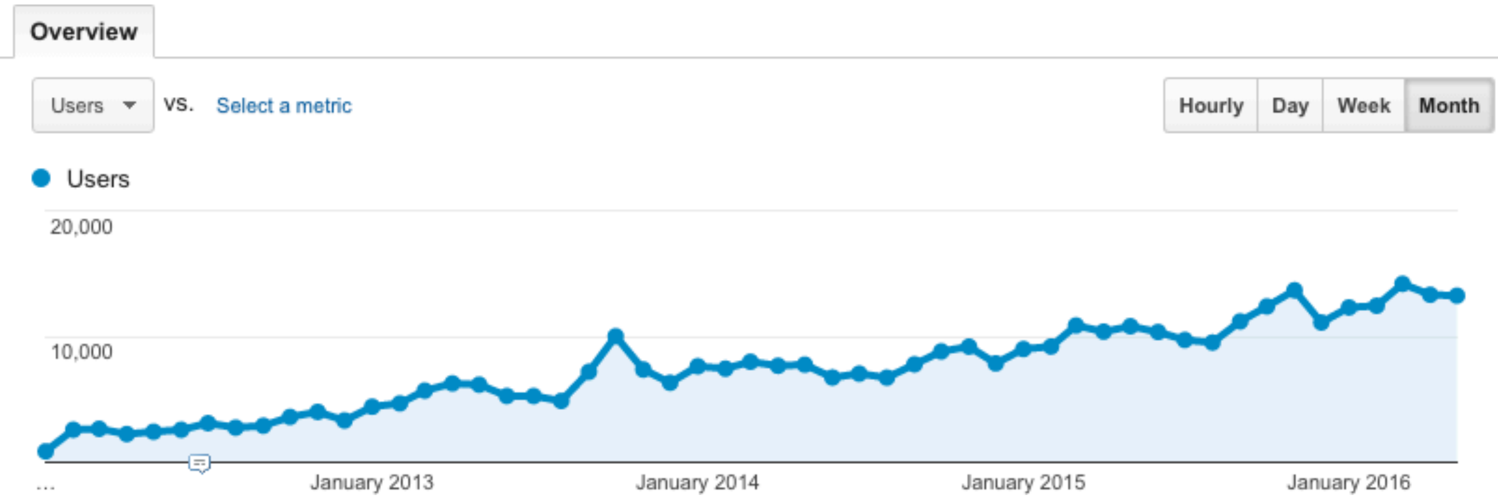

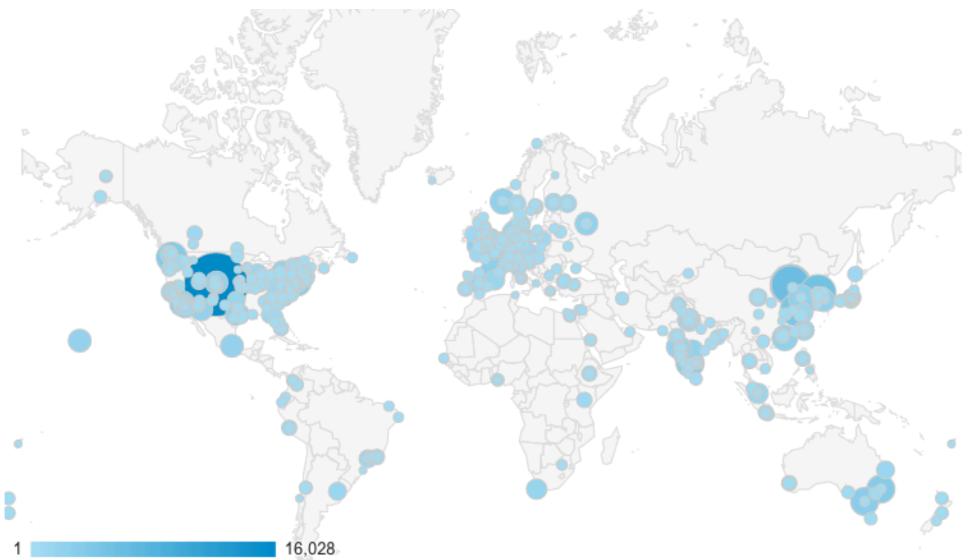

Summary

Model evaluation is an effort to characterize uncertainty

Four main types of uncertainty: Observational, Structural, Forcing/Scenario, Internal Variability

Data-model disagreement in Antarctic sea ice trends has been a thorny problem...

After considering observational uncertainty, forcing uncertainty, and internal variability, we conclude that structural uncertainty plays a major role...

Climate Variability Diagnostics Package and Climate Data Guide are excellent tools available to you to facilitate model evaluation.

The end