



# **Systematic errors across space and time scales and their relevance to projections of climate change**

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# Systematic errors across space and time scales and their relevance to projections of climate change

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A companion topic:

**Progress on community-based capabilities to more effectively diagnose and document model errors**

# Outline

- Introduction
- An aspirational goal for the WCRP
- Model evaluation capabilities under development
- PCMDI's mean state and variability metrics package
- Some steps towards reaching that aspirational goal
- Closing thoughts

I'll be wearing several stylish hats...



I'll be wearing several stylish hats...



## Getting the most out of model intercomparisons (MIPs) ...

- CMIP and other MIPs have enabled an enormous body of research that has helped improve understanding of model behavior and been a foundation for IPCC and other assessments
- Direct benefits for model development and improvement less obvious
- **Can we make WCRP MIPs more useful for model developers?**

# Towards ongoing benchmarking of CMIP class models

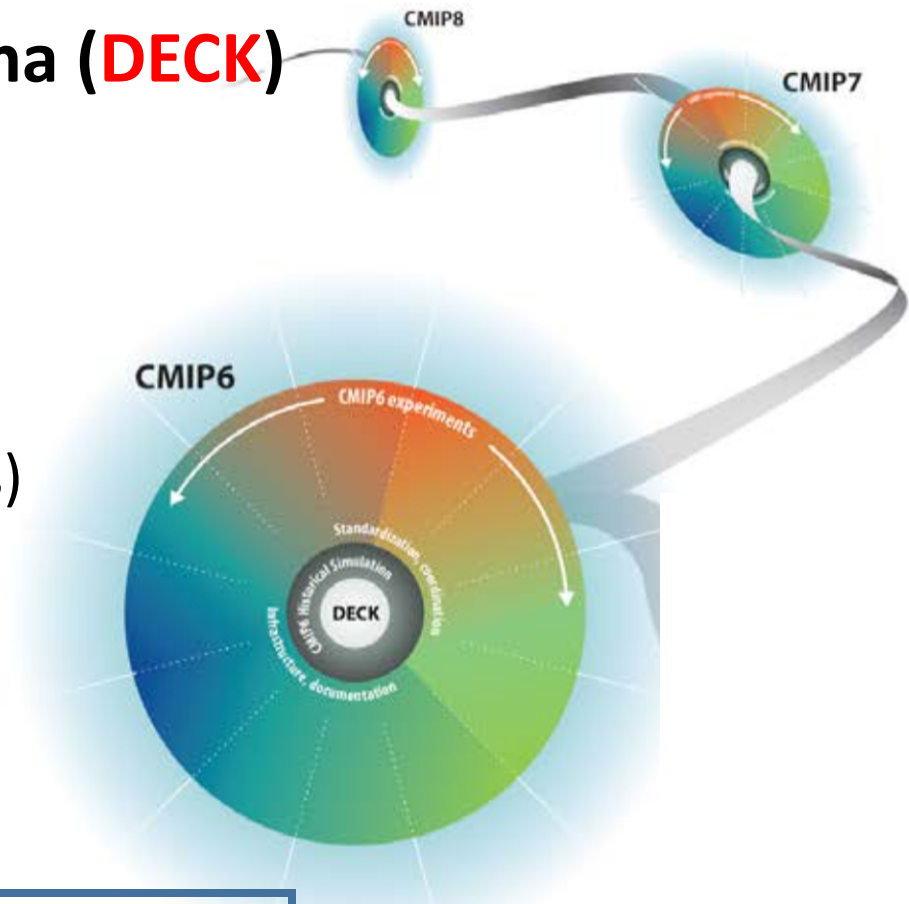
- **D**iagnosis, **E**valuation and **C**haracterization of **K**lima (**DECK**)

- AMIP (~1979-2014)
- Pre-industrial control
- 1%/yr CO<sub>2</sub> increase
- Abrupt change to 4xCO<sub>2</sub>
- Performed whenever new model is ready (no deadlines)

- **Historical run**

- Historical forcing updated for each CMIP phase

■ **DECK in part motivated to emphasize routine evaluation**



# Imagine if ... (where I hope we will be by CMIP7)

Modeling groups can access a catalogue of **easy to use and coordinated** community-based analysis capabilities

This could enable the diverse expertise in the CMIP analysis community to be of more direct benefit to model development

**WCRP** modeling analysis capabilities

World Climate Research Programme

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**Technical Support**

**Access to open source codes**

- Large scale climatology
- Interannual variability
- Interseasonal variability
- Clouds and aerosols
- Precipitation
- Process-oriented
- Land surface interactions
- Ocean physics
- Sea-ice
- Biogeochemical cycles

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**FAKE NEWS!**

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## An incomplete listing of developing analysis capabilities that may be relevant for routine evaluation of CMIP DECK simulations

- ESMValTool (Eyring et al, GMD, 2016) \*
- PCMDI Metrics Package (Gleckler et al., EOS, 2016) \*
- ARM Diagnostics and Metrics package
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- CFMIP diagnostics and metrics
- TECA (Prabhat et al., 2012)
- MJO diagnostics
- NOAA MAPP process-oriented task force
- Scales of precipitation (Klingaman et al., 2017)
- CLIVAR basin panels ....

**These complement but cannot  
replace CMIP research**

**\* These tools are built into ESGF nodes**

# The PCMDI Metrics Package (PMP)

[https://github.com/PCMDI/pcmdi\\_metrics](https://github.com/PCMDI/pcmdi_metrics)



- **Emphasizes a diverse suite of relatively robust high level summary statistics objectively comparing models and observations across space and time scales**
- End-to-end provenance to ensure reproducibility
- Open source python publicly available on github
- Designed to enable the research community to contribute
- Currently collaborating with 5 modeling groups

# A continuum of evaluation metrics

## Serving different purposes...

**“Holistic”**

**“Process-oriented”**

**Convolving multiple influences**

**Of more of interest to most end users**

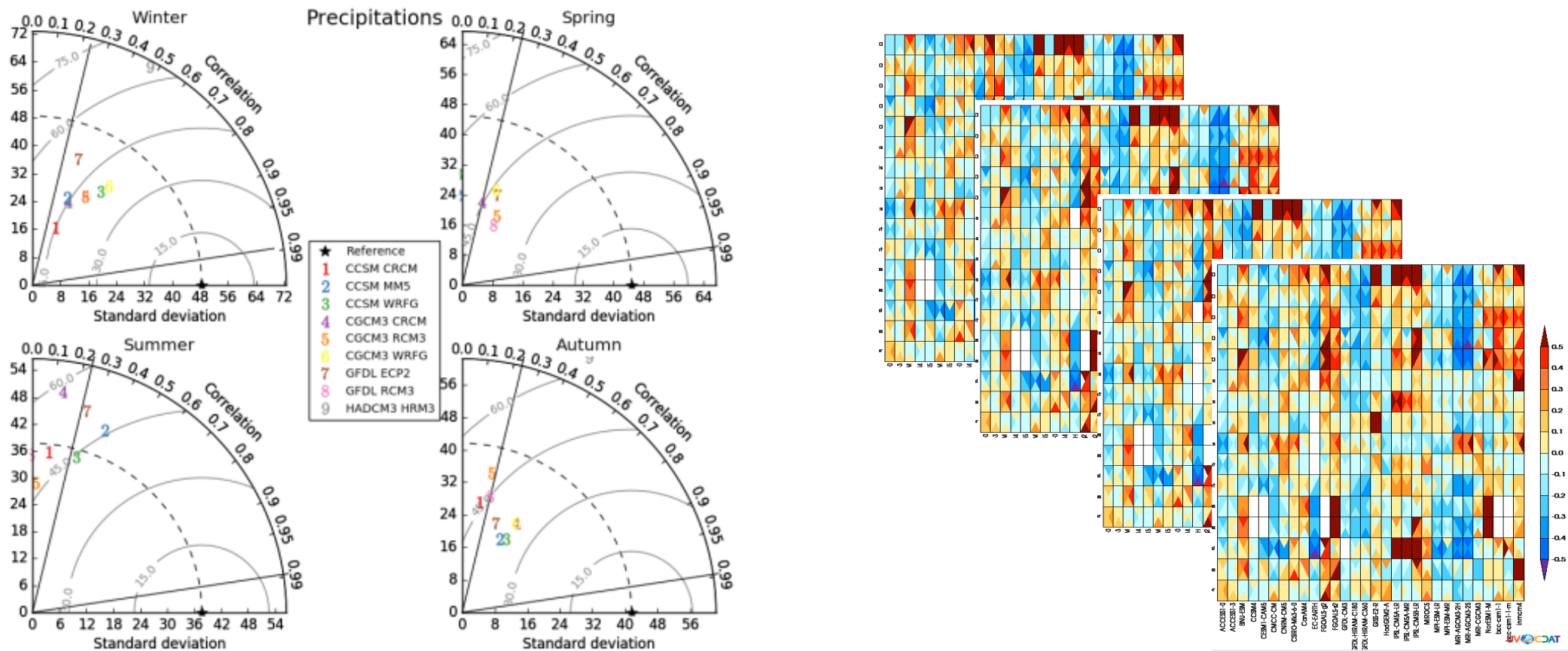
**Targeting particular processes, often as a case study with local to regional scale evaluation**

**Better for identifying the root causes of model errors**

# The PCMDI Metrics Package (v1.1x)

## Prototyped on climatological summaries

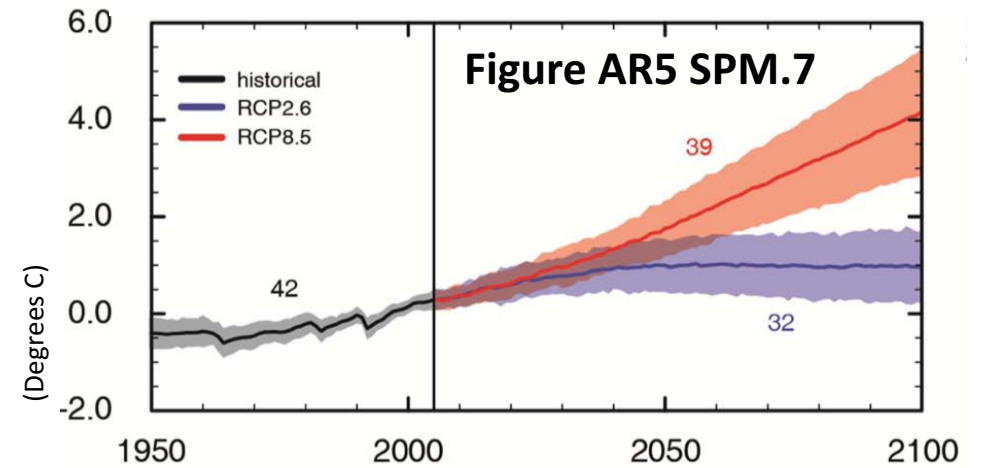
Taylor Diagrams and Portrait Plots:  
Orthogonal decompositions of large scale climatological error statistics



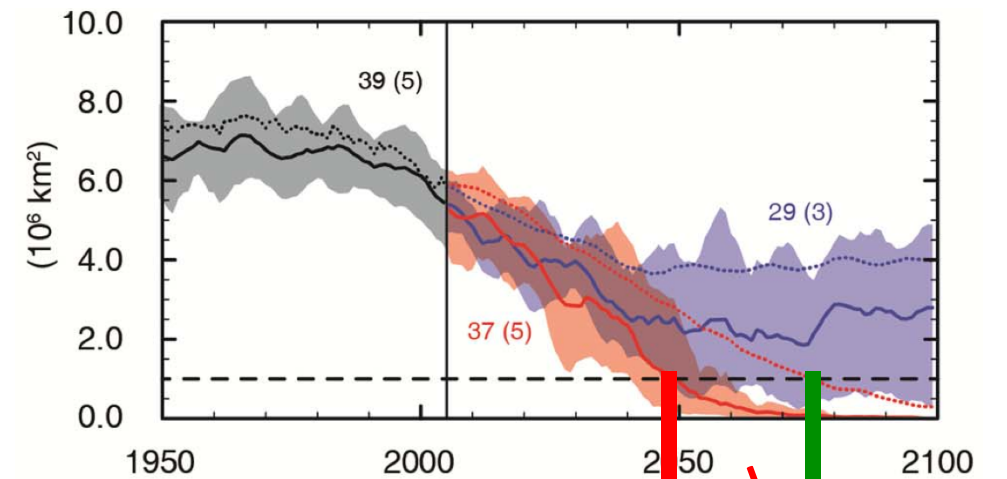
# The Quest for Moving beyond “One Model One Vote”

- For the first time in the IPCC, the AR5 CMIP5 multi-model projections involved weighting based on metrics of sea-ice extent (mean state and trend)
- A weighted MME results yields an “ice free” (<math><10^6\text{km}^2</math>) September Arctic nearly 3 decades earlier

Global Average Surface Temperature



N. Hemisphere September sea ice extent

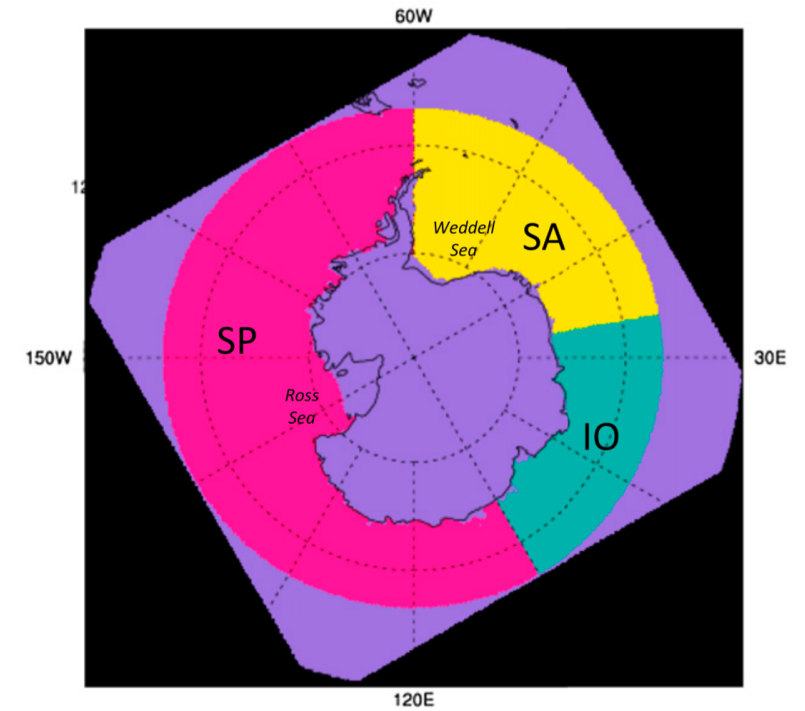
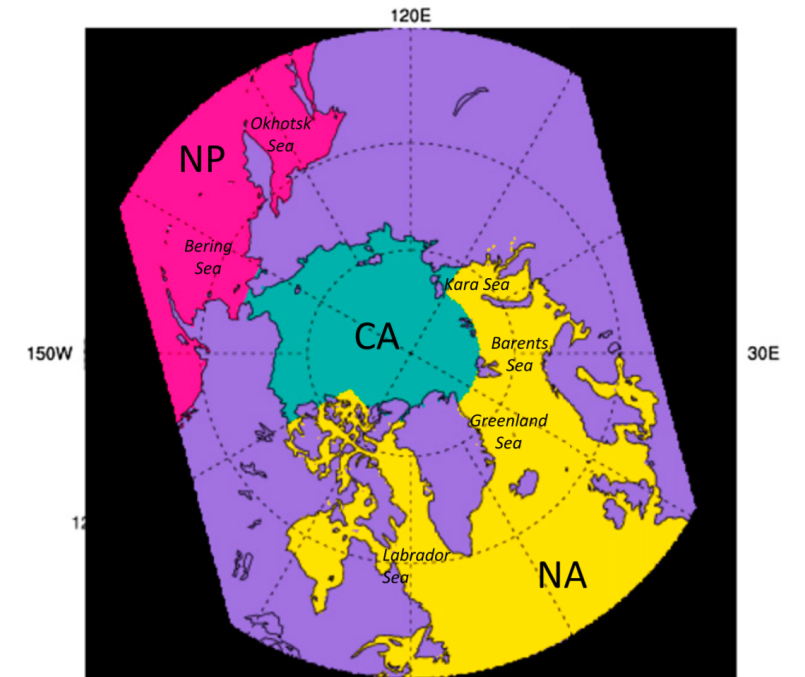


Projected year of “ice-free” Arctic

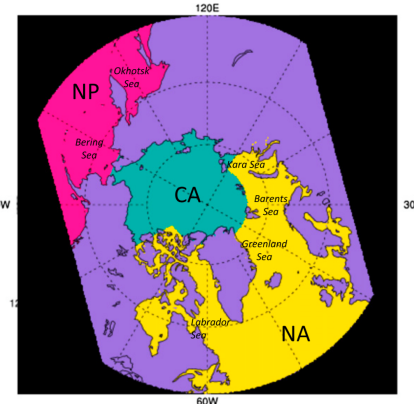
weighted  
Equal-weighted

Most sea-ice metrics used to date have been based on total sea ice area or extent

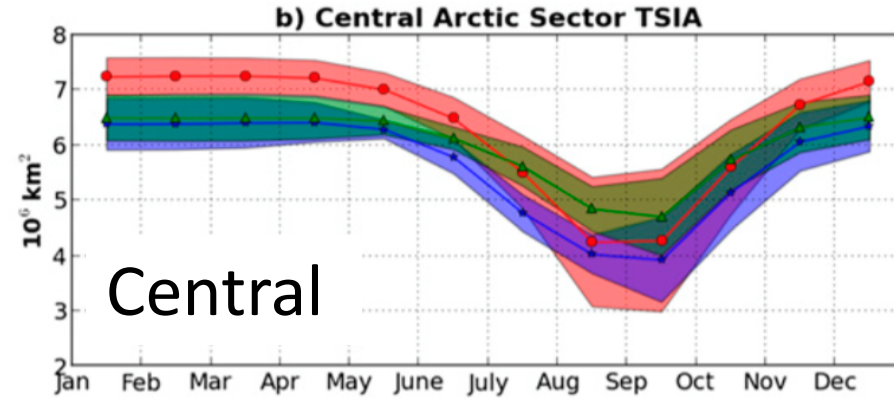
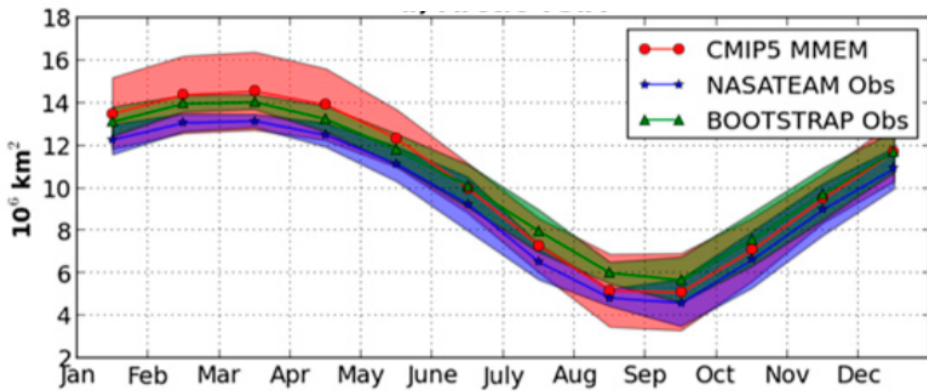
To address the possibility of error compensation we partition the Arctic and Antarctic into 3 commonly defined sectors



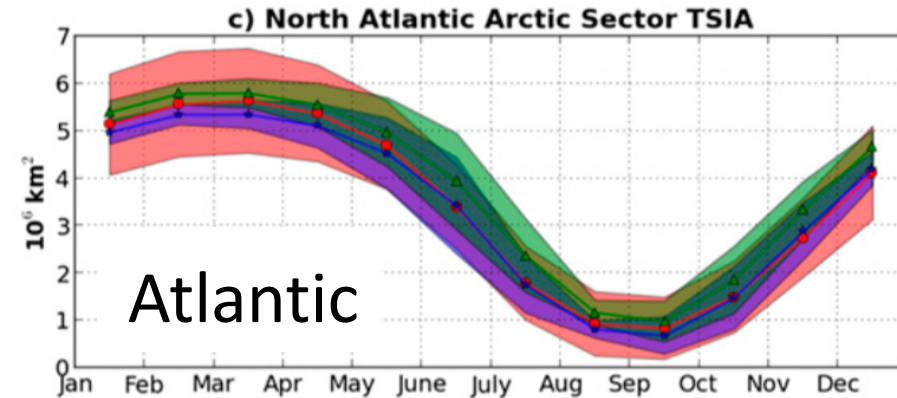
# Sector Scale Sea ice CMIP5 MME compared to 2 satellite based estimates (1979-2005)



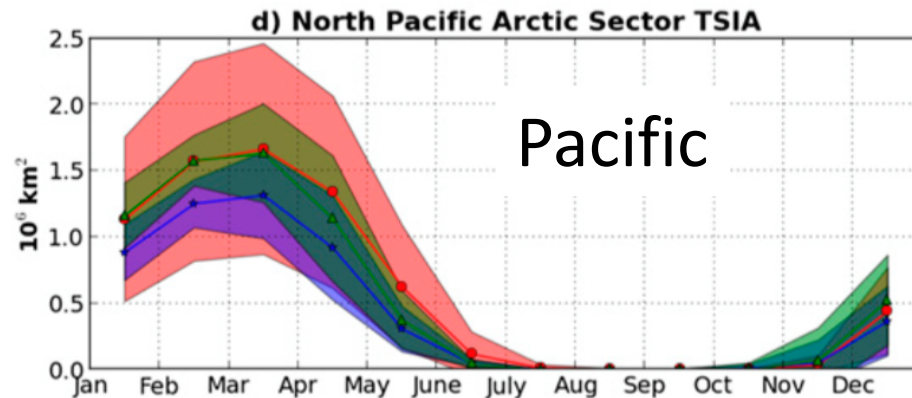
Total Arctic



Central



Atlantic



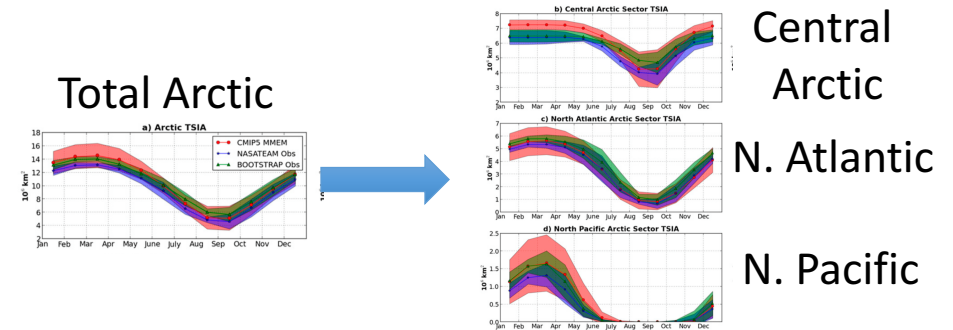
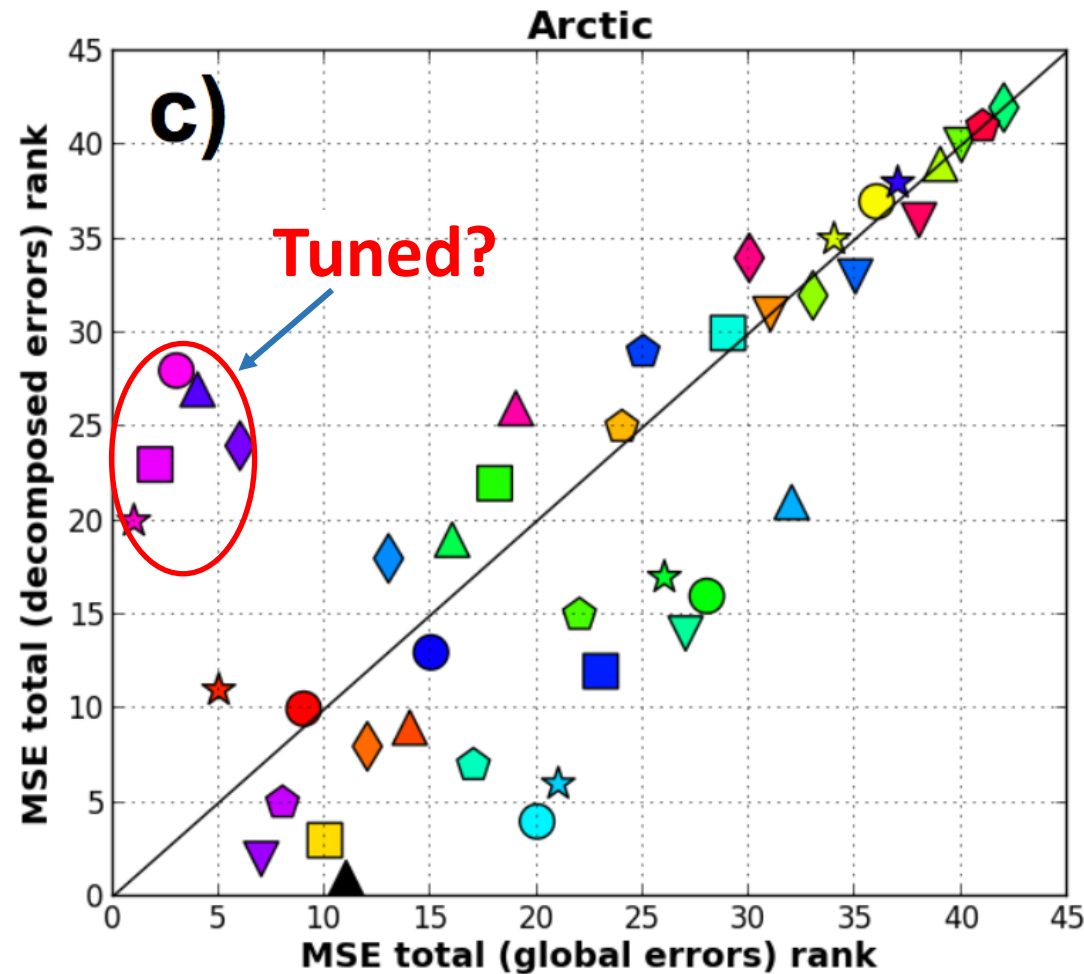
Pacific

Ivanova et al., J. Climate, 2016

Native grid sector scale combining "ice area" errors of N.Atl, N.Pac and central Arctic



# Sea ice metrics: Exposing compensating errors



- An orthogonal decomposition of MSE errors compare “global” vs “sector scale” total ice errors
- Substantial error compensation, especially in some “better” performing models
- Evidence of tuning in CMIP5 ?

# ENSO metrics: some high level results are fairly robust in a multi-model context

## ENSO Nino3 SST S.D. for CMIP5 piControl



Bar height represents variability for entire piControl

x non-overlapping 100 year segments of piControl

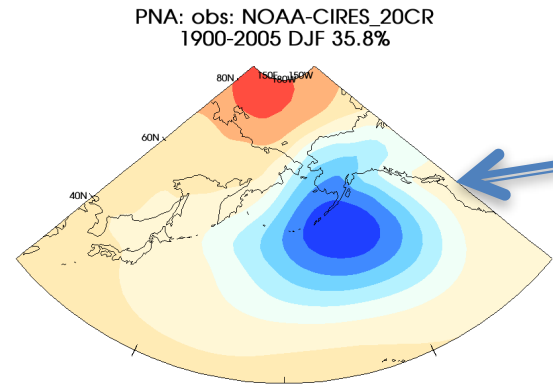
Some models have substantial century-to-century variability but generally less than inter model differences

A baseline ENSO metric (e.g., Belanger et al, 2014)

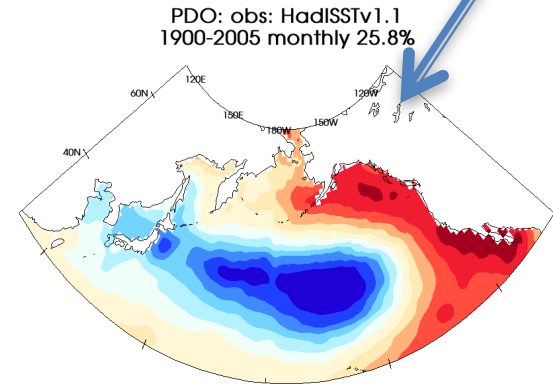
# Extra-tropical Modes of Variability

Excerpt from Jiwoo Lee's talk 14:50-15:10

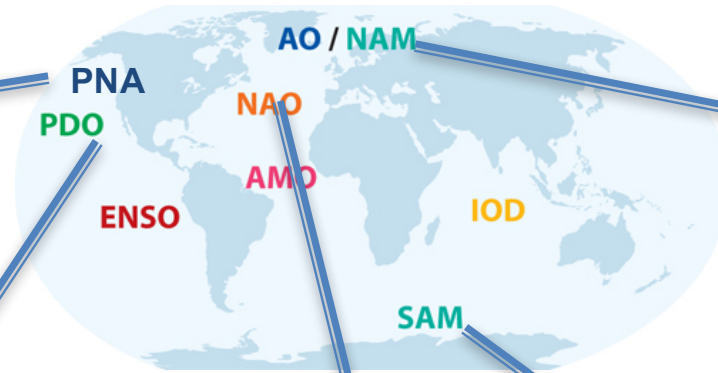
## Generally defined by EOF leading mode in observations



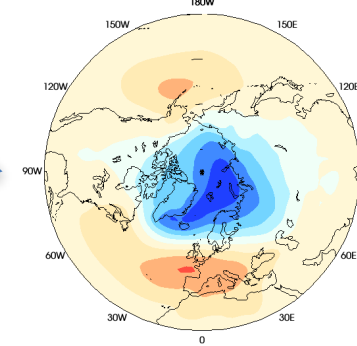
**PNA: Pacific North American Pattern**  
(20CR, SLP)



**PDO: Pacific Decadal Oscillation**  
(HadISSTv1.0, SST)

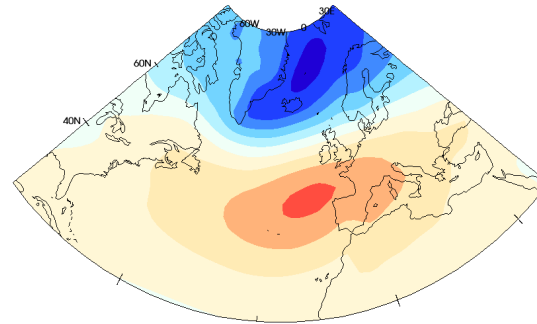


NAM: obs : NOAA-CIRES\_20CR  
1900-2005 DJF 27.2%



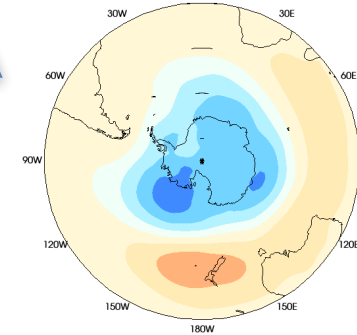
**NAM: Northern Annular Mode**  
(20CR, SLP)

NAO: obs: NOAA-CIRES\_20CR  
1900-2005 DJF 41.9%



**NAO: Northern Atlantic Oscillation**  
(20CR, SLP)

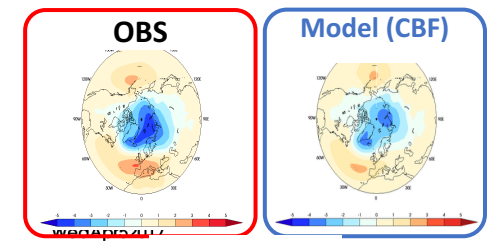
SAM: obs : NOAA-CIRES\_20CR  
1955-2005 JJA 32.2%



**SAM: Southern Annular Mode**  
(20CR, SLP)

# CMIP5 Historical Simulations (1900-2020) vs 20CR and ERA20C

## Relative model errors (pattern + amplitude)

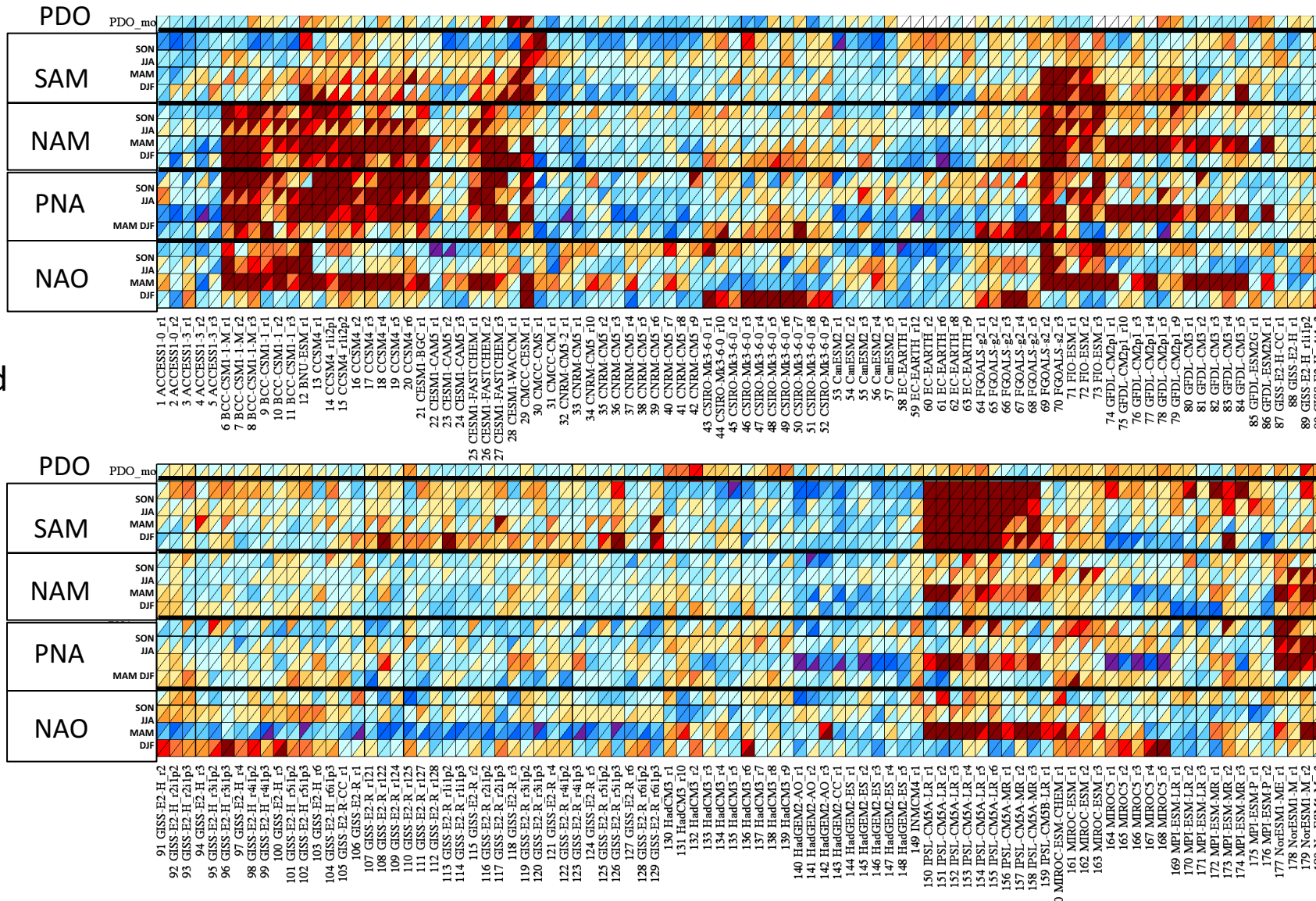


RMSE

Relatively large error

Median error

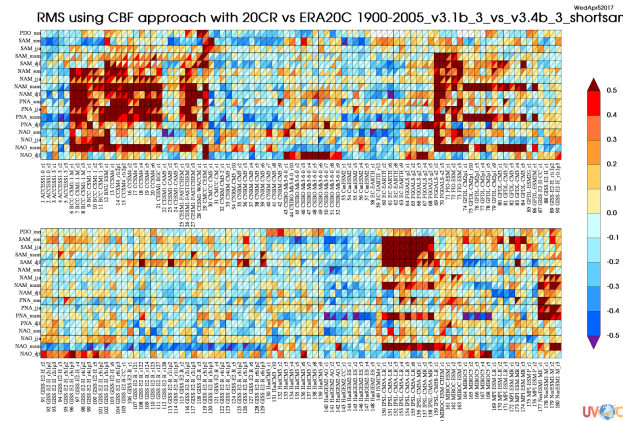
Relatively small error

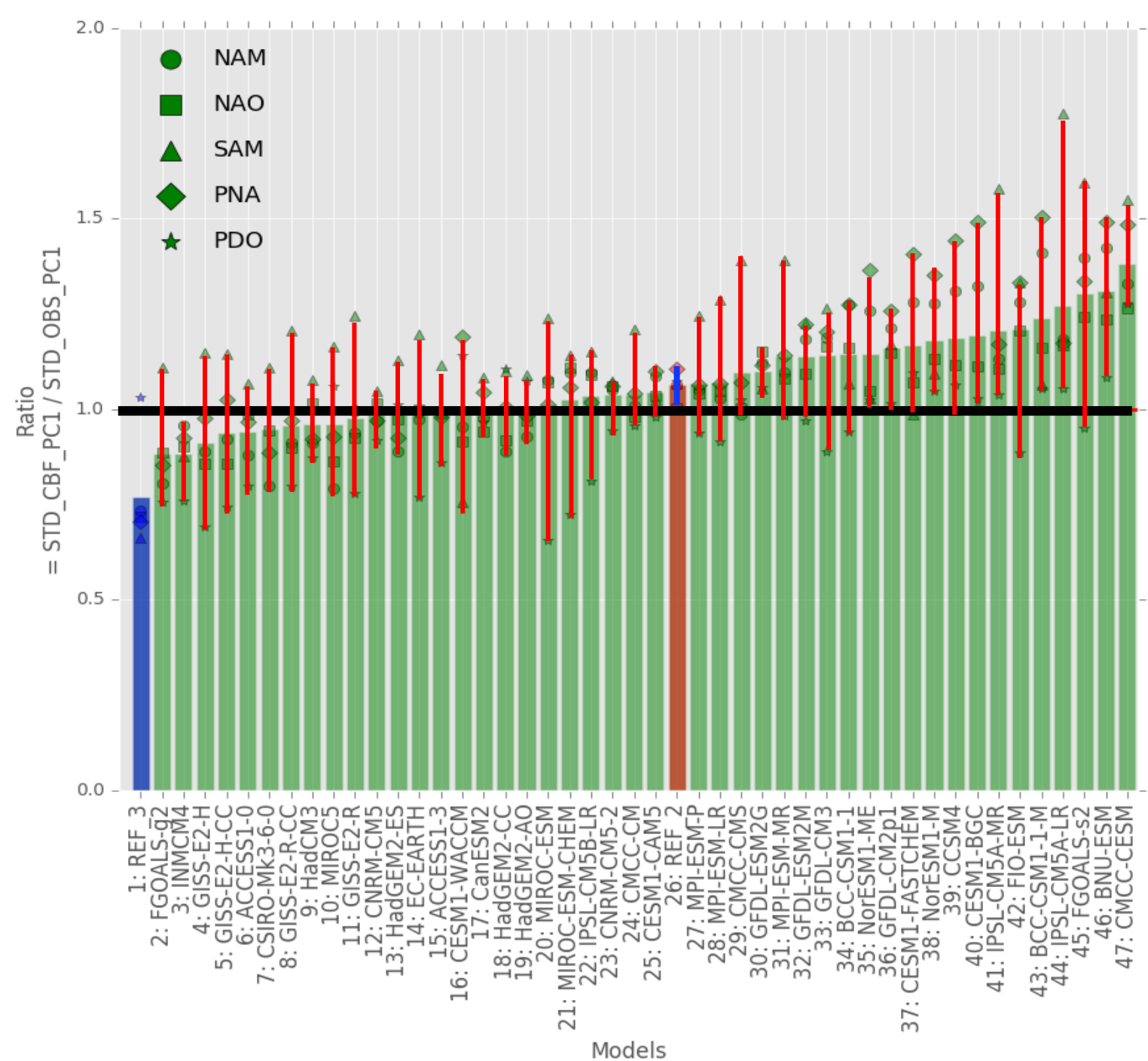


# Metrics for extra tropical modes of variability

General conclusions are fairly robust to:

- Selection of reference data (e.g., 20CR vs ERA20C)
- Internal variability (consistent results across realizations)
- Methodological considerations (**Jiwoo Lee's talk 14:50-15:10**)





# Overall Amplitude Behavior

Simulated/Observed amplitude ratios (derived from SD of PC tseries)

Averaged across realizations, seasons

Bar height: averaged across modes

Inconsistencies in model behavior (e.g., most models overactive in SAM, muted PDO)

Error compensation (across modes) is substantial in most modes

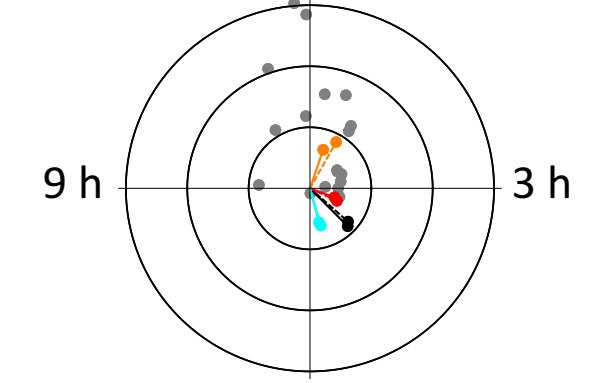
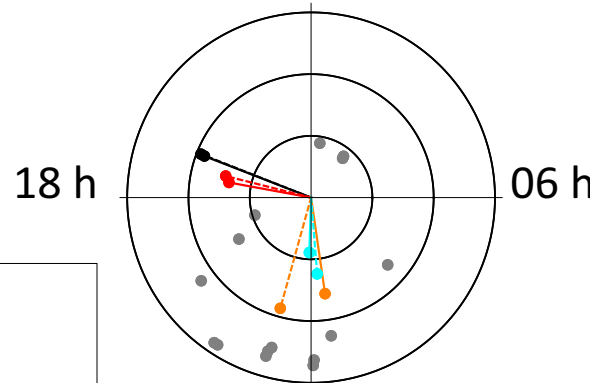
# Harmonic-dial Metric for Mean Amplitude and Phase

Covey et al., *J Climate* (2016).

Diurnal Component

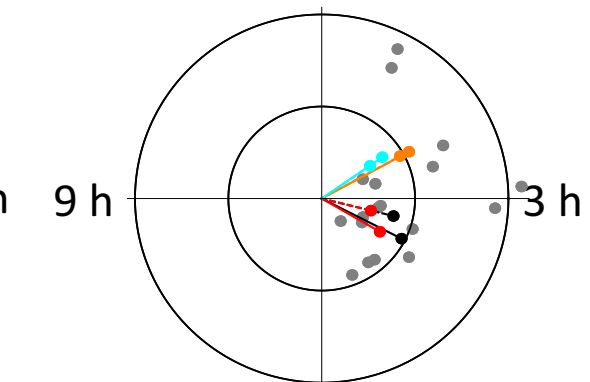
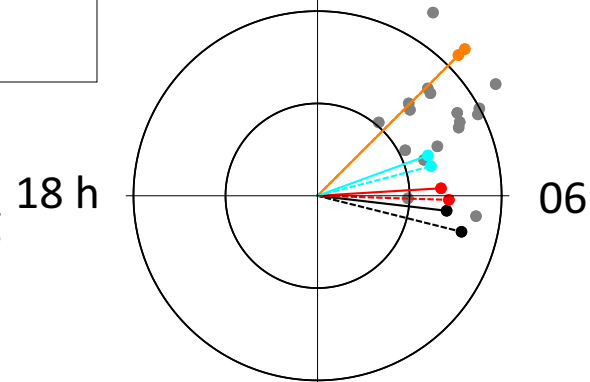
Semidiurnal Component

Vector-averaged over LAND:  
0/24 h



6 h

Vector-averaged over OCEAN:  
0/24 h



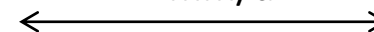
6 h

Solid lines: Januarys  
Dashed lines: Julys  
TRMM3B/Obs4MIPs = black pts/lines  
CMORPH = red "  
CCSM499-05 = lt blue "  
MIROC599-05 = orange "  
other CMIP599-05 = gray (July only)

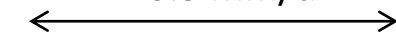
After "correcting" the observed phases by subtracting 2-3 hours (Dai et al. 2007, Kikuchi & Wang 2008)

**Models are still raining too early, at least over land**

1 mm/d



0.5 mm/d



# PMP progress and plans

- Currently implementing a diverse suite of relatively robust high level summary statistics across space and time scales
- We plan to document and make available results for all generations of AMIP and CMIP with end-to-end provenance to ensure reproducibility
- In the queue:
  - monsoon onset/decay
  - ARGO based T&S
  - selected cloud properties
  - additional variability



## For modeling groups interested in using PMP results

- Simulation summaries will be provided to modeling groups soon after their DECK + Historical simulations are made available via ESGF
- We provide support to modeling groups interested in using the package

### *A possible aid to modelers*

- Help identify unexpected degradation against backdrop of general improvement
- Determine if these “red flags” are significant (in the context of the MME), to help decide if they should influence development/tuning priorities

## An incomplete listing of developing analysis capabilities that may be relevant for routine evaluation of CMIP DECK simulations

- ESMValTool (Eyring et al, GMD, 2016) \*
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- Scales of precipitation (Klingaman et al., 2017)
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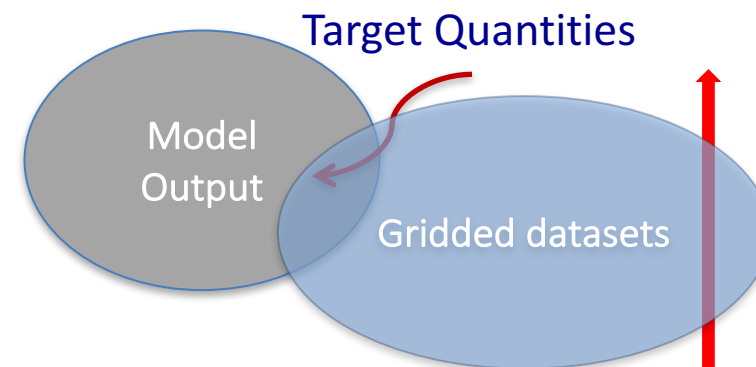
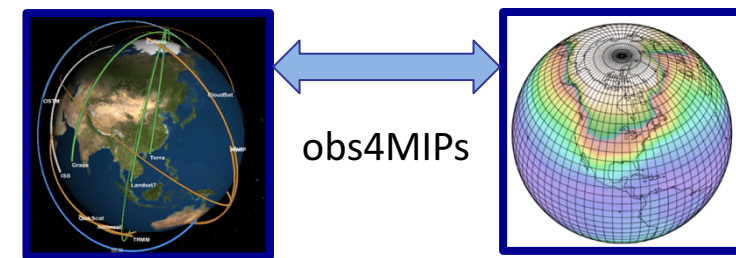
**These complement but cannot  
replace CMIP research**

**\* These tools being designed to be integrated with ESGF nodes**

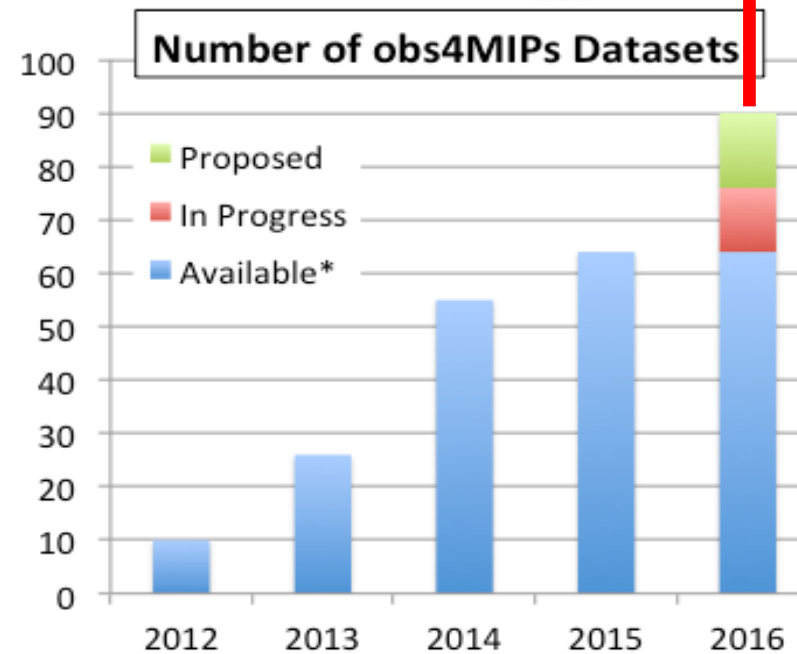
**What do all of these developing “community based” capabilities have in common?**

**A need to access well documented and readily usable reference data (obs and reanalysis)**

- A project for identifying, documenting and disseminating observations for climate model evaluation in WCRP model intercomparisons, notably CMIP
- Data accessible with the distributed CMIP model output, adhering to same conventions
- Guided by the WCRP Data Advisory Council obs4MIPS Task Team

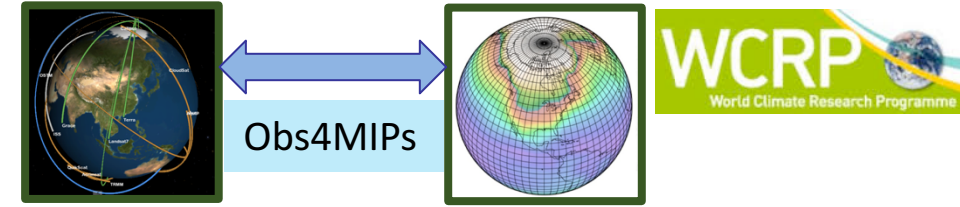


**Complete (~125\*)**  
**In Progress\* (~15)**  
**Proposals from Data Call (~90)**



...and growing!

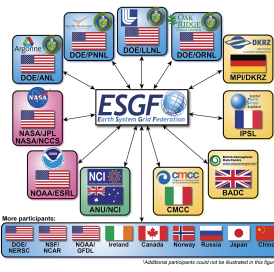
# obs4MIPs: The 4 Commandments



1. Use the CMIP\* Standard Model Output as guideline for selecting observations
2. Observations to be structured in coordination with the CMIP output (e.g. NetCDF, CF Convention, common vocabularies)
3. Hosted side by side on the ESGF with CMIP model output
4. Include a Technical Note for each variable describing observation and use for model evaluation (at graduate student level)

**\* obs4MIPs conventions are being updated to be consistent with CMIP6**

# Potential benefits of obs4MIPs



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How to contribute data  
Planning Meeting Report

### Products

Satellite Products  
Reanalysis Products  
In-situ Products (sample)  
Technical Notes

### Visitors

List All News  
List All Files

## Observations for Climate Model Intercomparisons

Obs4MIPs (Observations for Model Intercomparisons) is an activity to make observational products more accessible for climate model intercomparisons.

*To Get Data - Please go to the "Search Data" box or "Advanced Data Search" link to the right.*

A wide variety of observationally-based datasets are used for climate model evaluation. Obs4MIPs refers to a limited collection of well-established and documented datasets that have been organized according to the 5th Coupled Model Intercomparison Project (CMIP5) model output requirements and made available on the Earth System Grid Federation (ESGF). Each Obs4MIPs dataset corresponds to a field that is output in one or more of the CMIP5 experiments. This technical alignment of observational products with climate model output can greatly facilitate model data comparisons. Guidelines have also been developed for Obs4MIPs product documentation that is of particular relevance for model evaluation. This effort was initiated with support from NASA and the U.S. Department of Energy (DOE) and has now expanded to include contributions from a broader community including CFMIP-OBS and products that rely on ESA satellites.

To summarize, products currently available via Obs4MIPs are:

1. Directly comparable to a model output field defined as part of CMIP5
2. Open to contributions from all data producers that meet the Obs4MIPs requirements
3. Well documented, with traceability to track product version changes
4. Served through ESGF (and directly available through this COG).

Efforts are underway to coordinate obs4MIPs with CMIP6

Last Update: Nov. 7, 2014, 4:57 p.m. by Robert Ferraro



No Comments

Project Activity

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Obs4MIPs-CMIP6 Planning Meeting Final Report is now available  
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Obs4MIPs

Child projects (0)

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Start typing, or use the 'Delete' key to show all available tags.

- Make documented observational data more accessible to CMIP analysts
- Inspiring improved uncertainty estimates
- Provide design target for developing analysis capabilities
- Increasing cohesion across different observational communities

# **A nascent effort to benchmark simulated precipitation in CMIP/AMIP class models**

C. Jakob, P. Gleckler and about a dozen others with diverse expertise

Team to identify a broad range of performance tests, assemble them into a supported package, apply them to current generation of models, and assess/document state-of-the-art

Package to be provided to modeling groups who will be encouraged to use it to help guide their improvement of simulated precipitation

Assessment will be repeated after 5-7 years to document improvement

# Imagine if ... (where I still hope we will be by CMIP7)

University of Colorado Boulder

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## WCRP modeling analysis catalogue

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### Access to open source codes

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- .....

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CoG version 2.10.0  
ESGF P2P Version 1.7.1-phoenix-release-master

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A WGNE/WGCM metrics panel struggled for a long time to address important but difficult science questions (e.g., what are the most important metrics?), and a rapidly evolving science

Priorities have been revised for the panel to help advance towards this “community-based capability”, leaving many science considerations to grass roots expert teams

**First steps can be an “as is” catalogue**



# Closing perspectives

Peer-reviewed publications will continue to be the primary outcome of CMIP, but

Some capabilities will soon be providing fast and increasingly comprehensive evaluation feedback to modeling groups participating in CMIP

Standards/conventions and ultimately some governance will be needed as these capabilities promulgate – this is going to take substantial (likely volunteer) work

Its going to take time to reach that aspirational goal