5th WGNE Workshop, June 22, 2017 [14:50-15:10]

Quantifying the Agreement Between Observed and Simulated Extratropical Modes of Interannual Variability

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LLNL-PRES-733259

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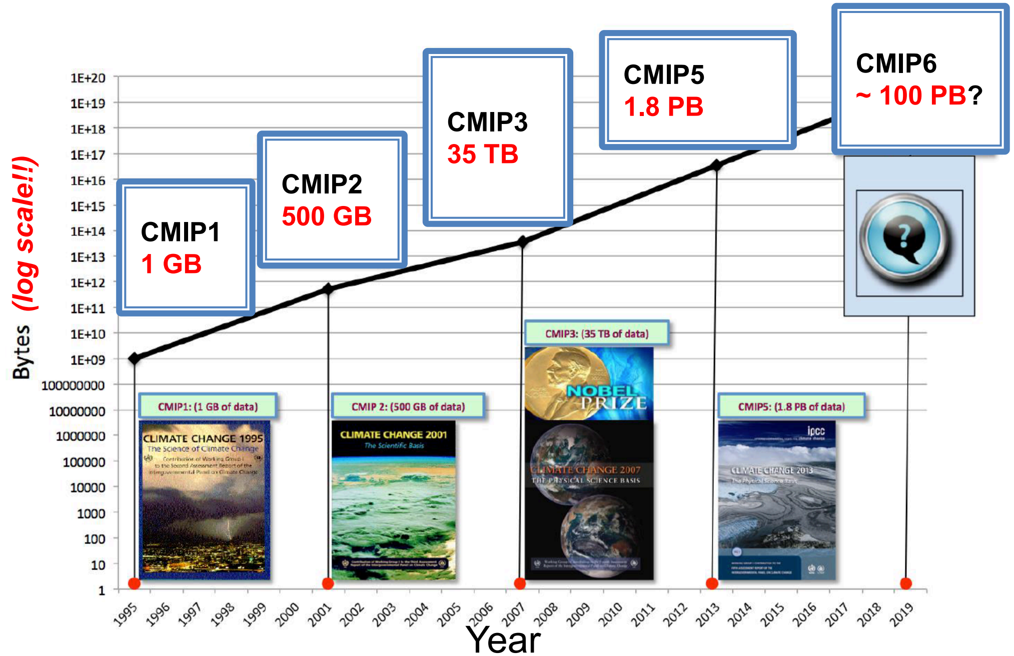
Objective: Routine Evaluation of Models

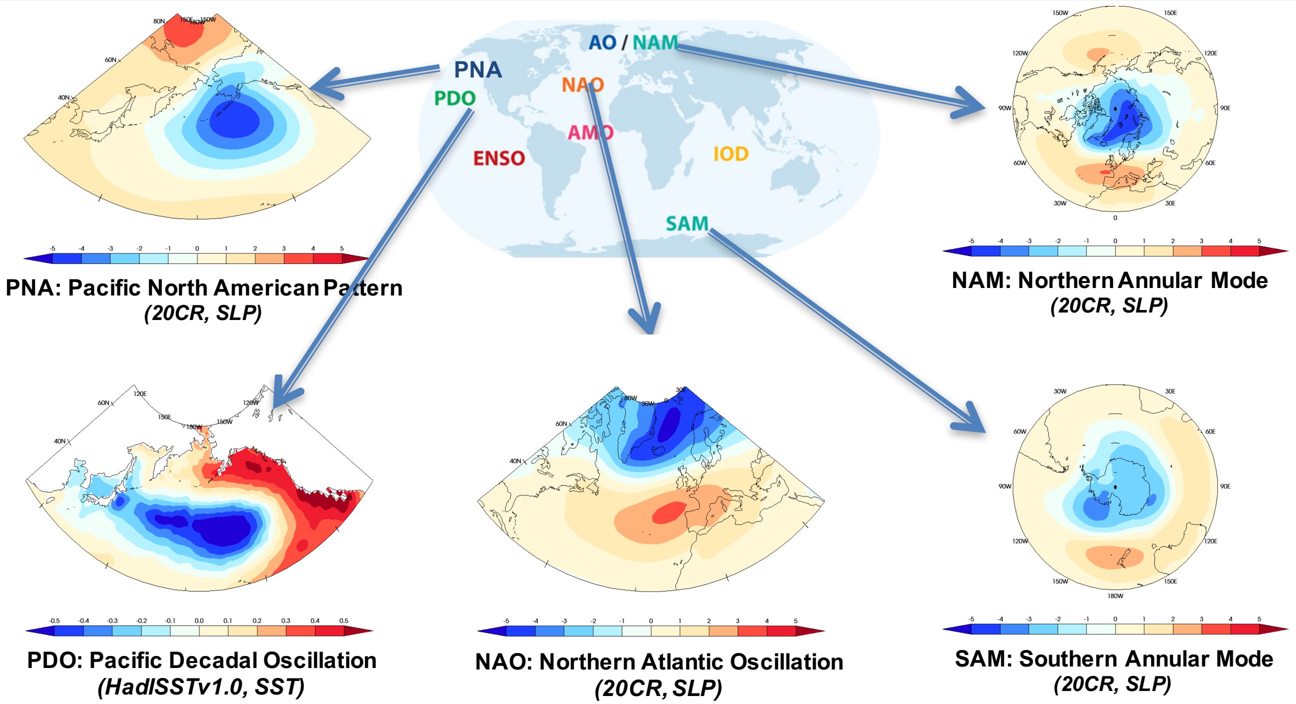
- **CMIP** has collected a massive volume of climate model output
- To have a better understanding of model *uncertainties and performance*, it is important to *evaluate models routinely in a systematic and collective way*
- PCMDI/LLNL is developing a metrics package (the PMP) to more directly contribute to model development (via quick feedback)

CMIP Data archived in ESGF Earth System Grid Federation



(Williams et al. 2015, BAMS)

Background (1): Modes of Variability



- Generally defined by the **leading EOF mode** in observations
- Represent **long-term large-scale** variance
- Important test for diagnosing model behavior, and detection & attribution

Background (2): Previous studies

- **The majority of previous studies have focused on one or two modes of variability**

- **A few studies have conducted systematic evaluation for a variety of modes, e.g.:**
  - *Stoner et al. (2009)* focused on the CMIP3 simulations
  - *Phillips et al. (2014)* has developed diagnostic package (NCAR CVDP) and released a repository for evaluating simulated modes in CMIP5

- **We expand these studies to develop *metrics* with an emphasis on how to:**
  - Objectively compare the models with observations, including seasonality
  - Test the skill sensitivity to: 1) multiple realizations from individual models
    2) choice of observations
    3) methodological consideration
  - Ascertain the role of pattern error versus amplitude error in assessing the fidelity of the simulations using ***skill metrics***

Datasets

- **CMIP5 Models**
  - Models: **180 historical simulations (45 models with their realizations)**
  - Time window: 1900-2005 (except SAM: 1956-2005)
  - Variables: 1) **Sea level pressure (SLP)**: Seasonal anomalies
    2) **Sea surface temperature (SST)**: Monthly anomalies (for PDO)
  - Area-weighted average over EOF domain was removed at each time step

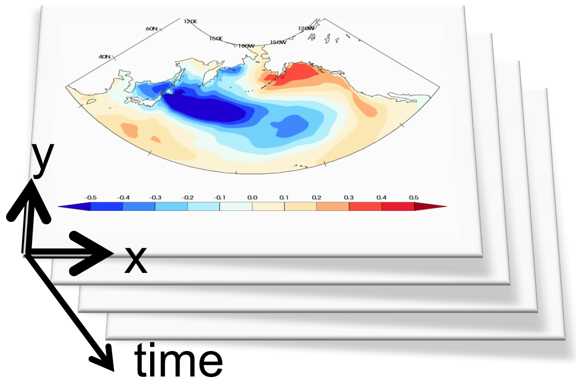
- **Observation based reference datasets**

	SLP	SST
OBS 1 *(default)*	NOAA CIRES 20CR	HadISST v1.1
OBS 2	ERA 20C	HadISST v2.1
OBS 3	HadSLP	ERSST v3.0

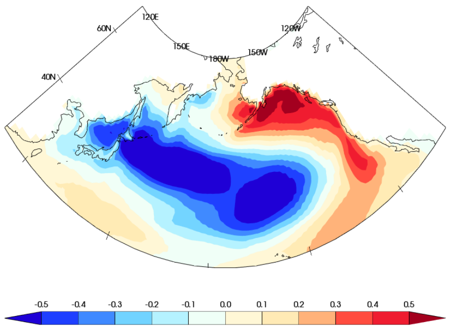
- **Tools**
  - ***PCMDI Metrics Package (PMP)***: Python based open-source tool *(Gleckler et al. 2016, EOS)*
  - ***UV-CDAT***: Python based large-scale data analysis and visualization tool *(Williams 2014, EOS)*
  - ***eofs***: Python library for EOF analysis *(Dawson 2016)*

Conventional EOF Approach

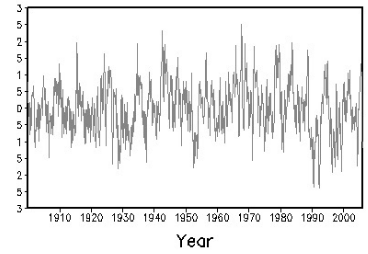
Anomaly field (OBS or Model)



Leading EOF Pattern



PC time series



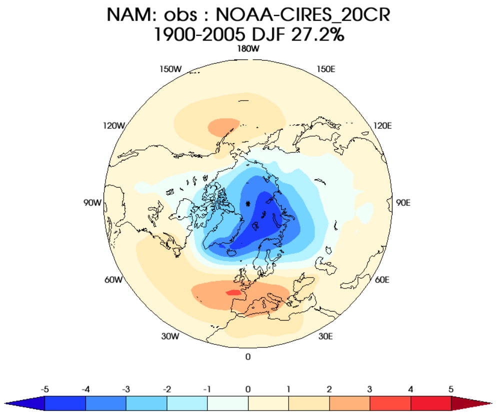
Limitations:

1. **Sign ambiguity**: EOF sign is arbitrary, sometimes it needs to be flipped
2. **EOF mode swapping**: Cases in which leading OBS EOF better corresponds to 2nd or 3rd mode of model

EOF mode swapping (1): Example

- **NAM (DJF) simulated by MIROC5 (r2i1p1)**

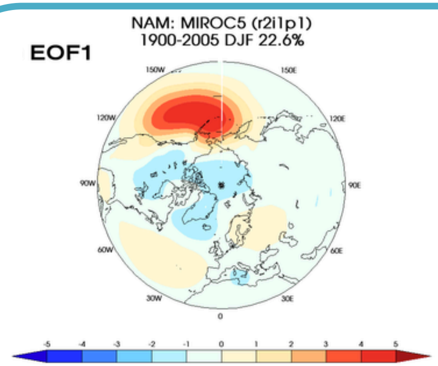
OBS



NAM: Northern Annular Mode
(20CR, SLP)

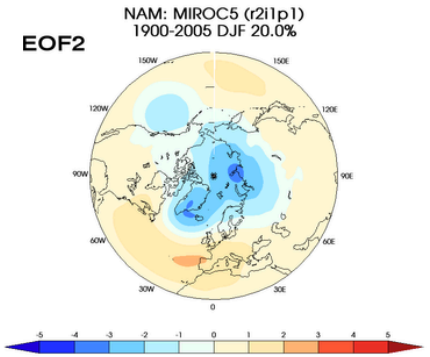
Model

EOF1

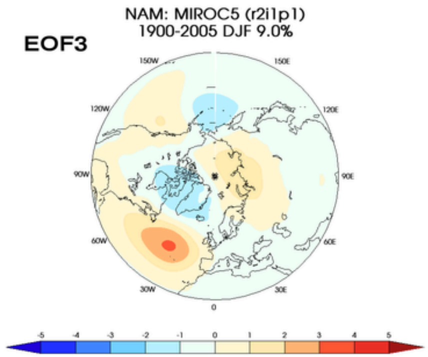


Best matching: EOF2

EOF2

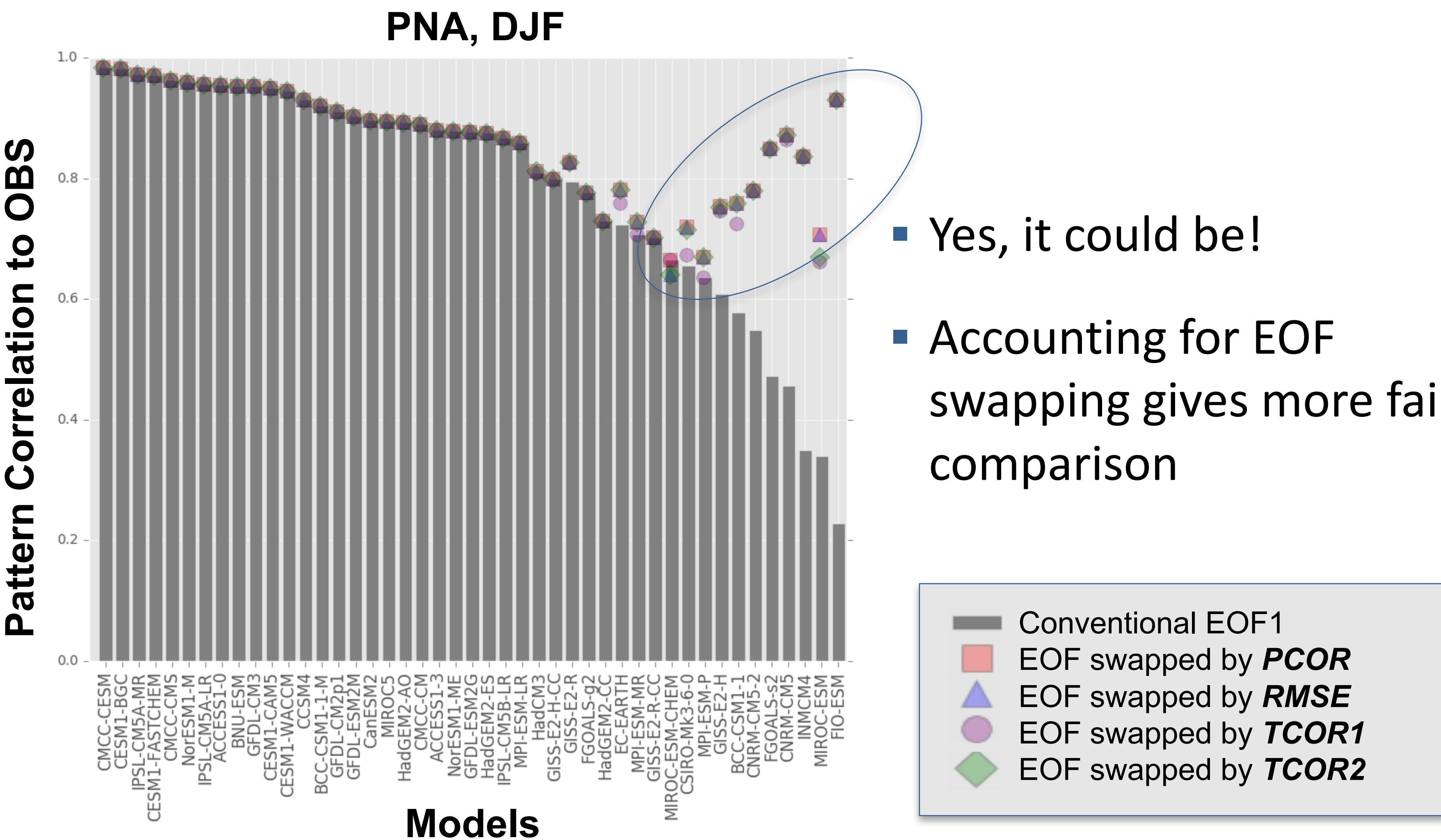


EOF3



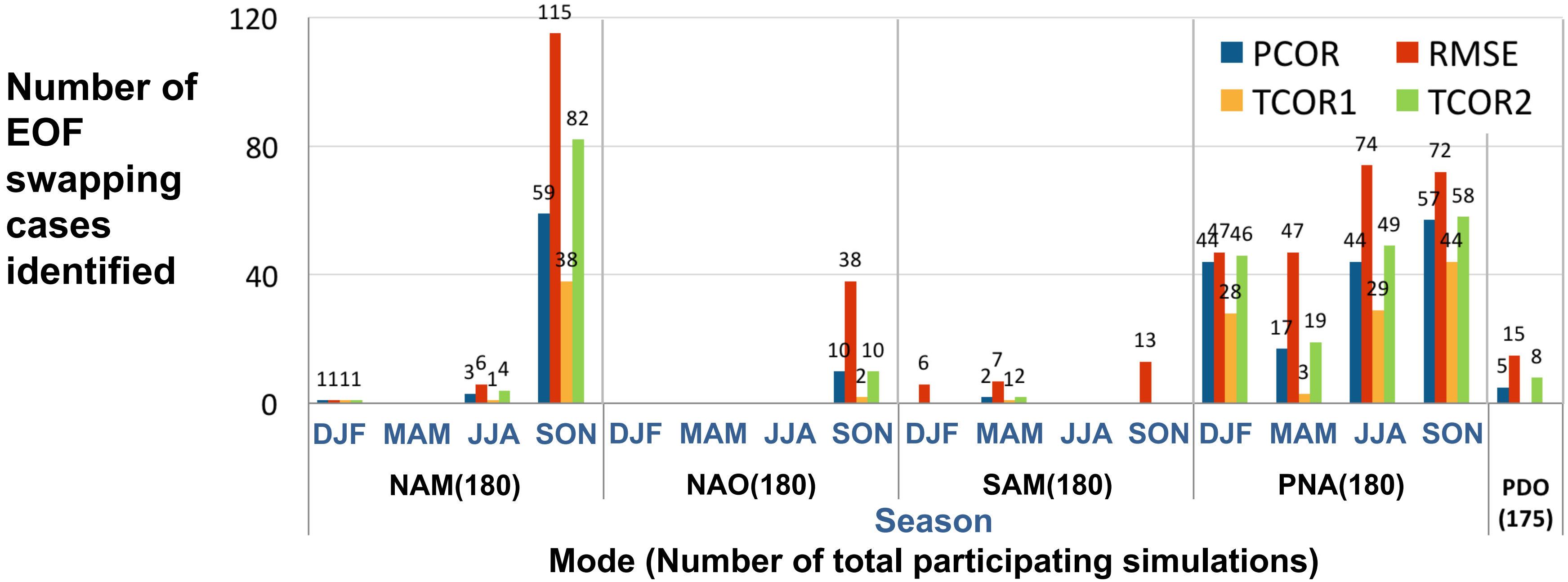
The leading OBS EOF corresponds best to model's 2nd EOF mode

EOF mode swapping (2): Is it significant?



- Yes, it could be!
- Accounting for EOF swapping gives more fair comparison

EOF mode swapping (3): How often it happen?



Applied criteria to decide best matching EOF:

Spatial:

- **PCOR**: Pattern correlation
- **RMSE**: Root mean square error

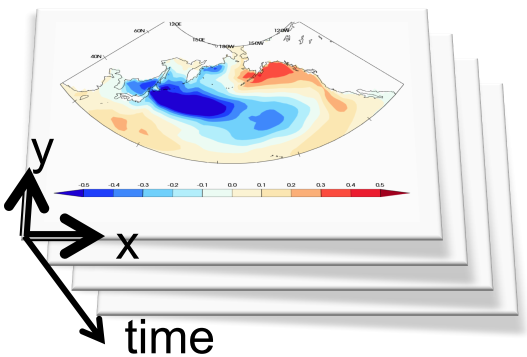
Temporal:

- **TCOR1**: CBF PC vs EOF PCs
- **TCOR2**: OBS PC vs tweaked CBF PCs

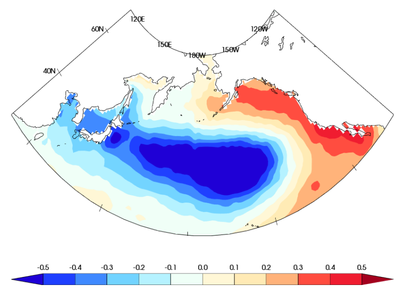
- Significant number of EOF swapping cases are identified
- There is no single best criteria

Common Basis Function (CBF) Approach

Model's anomaly field

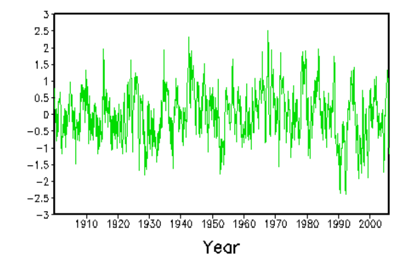


OBS leading EOF pattern



(1) Projection

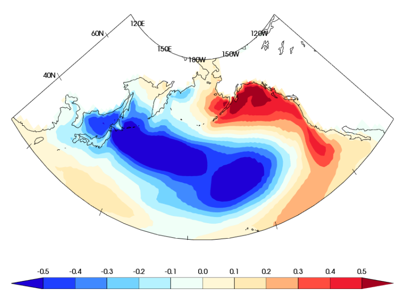
Model's CBF PC time series



Get PC time series by projecting OBS pattern into model's anomaly space

(2) Linear Regression

Model's CBF Pattern

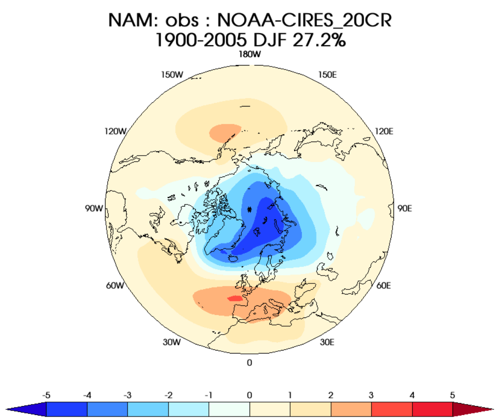


Reconstruct Pattern by linear regression between CBF PC & model field

CBF Result: Example

- **NAM (DJF) simulated by MIROC5 (r2i1p1)**

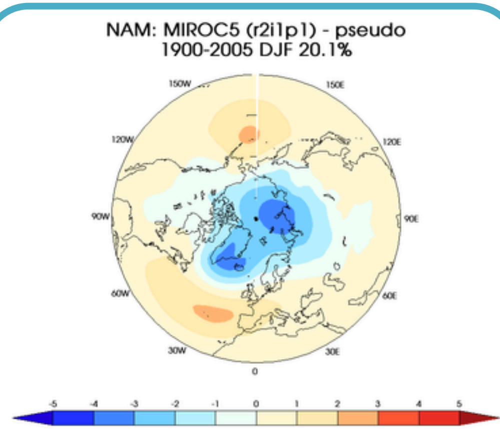
OBS



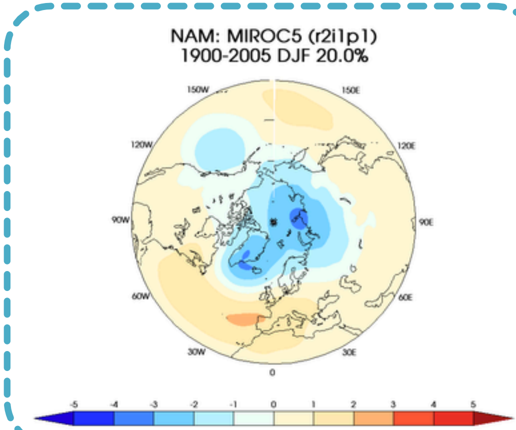
NAM: Northern Annular Mode
(20CR, SLP)

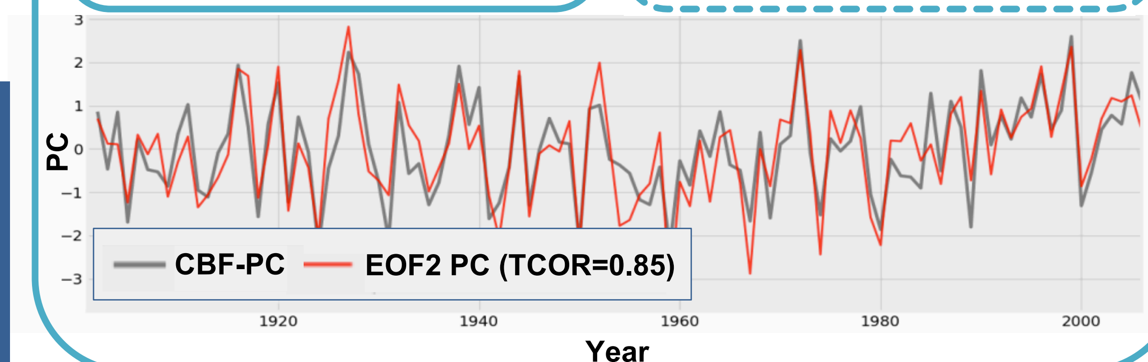
Model

CBF



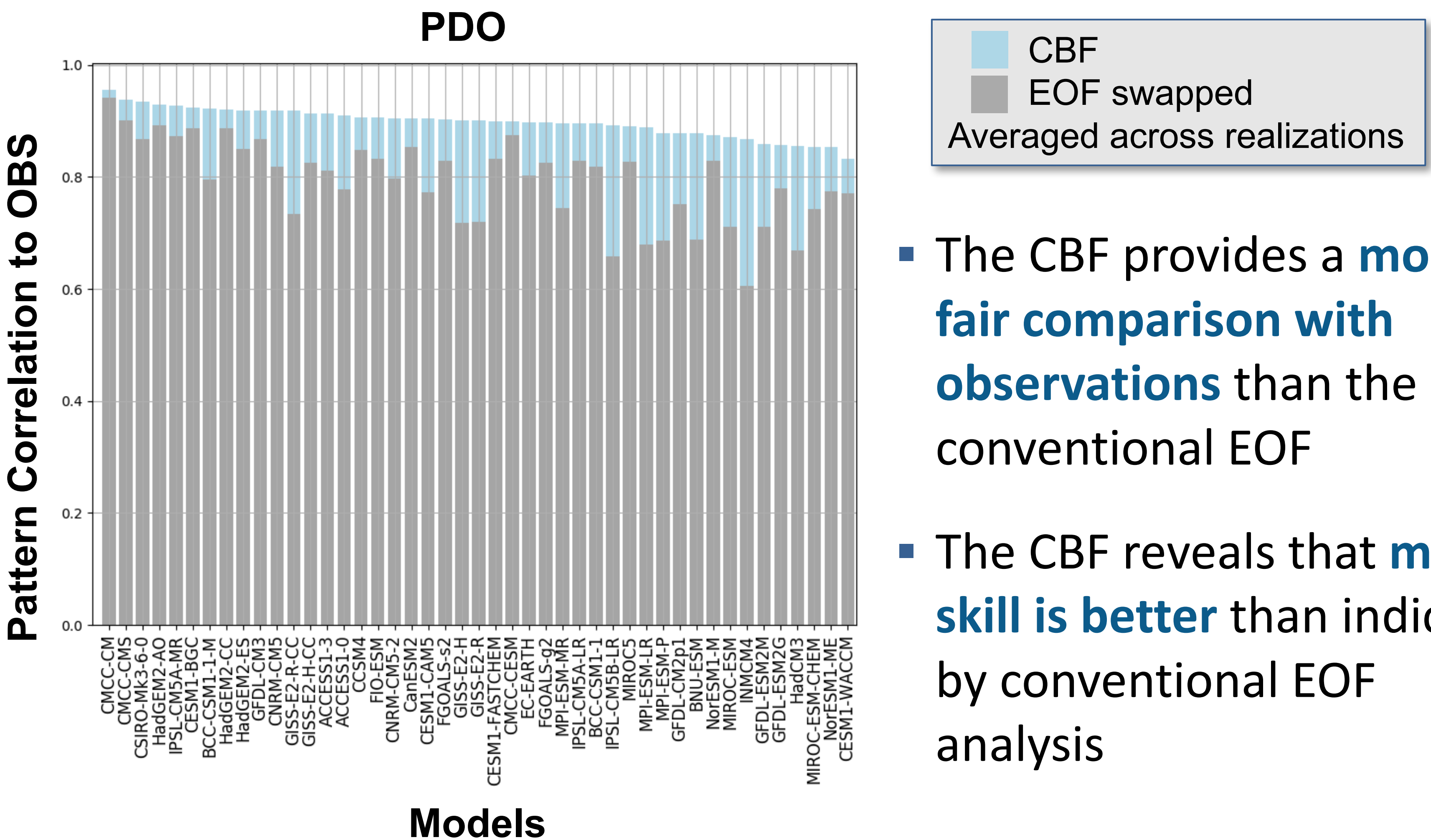
Best matching: EOF2





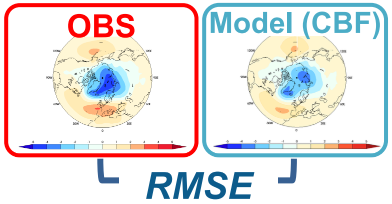
- CBF pattern better corresponds to OBS than the best-matching EOF mode
- CBF PC corresponds to PC of best-matching EOF mode

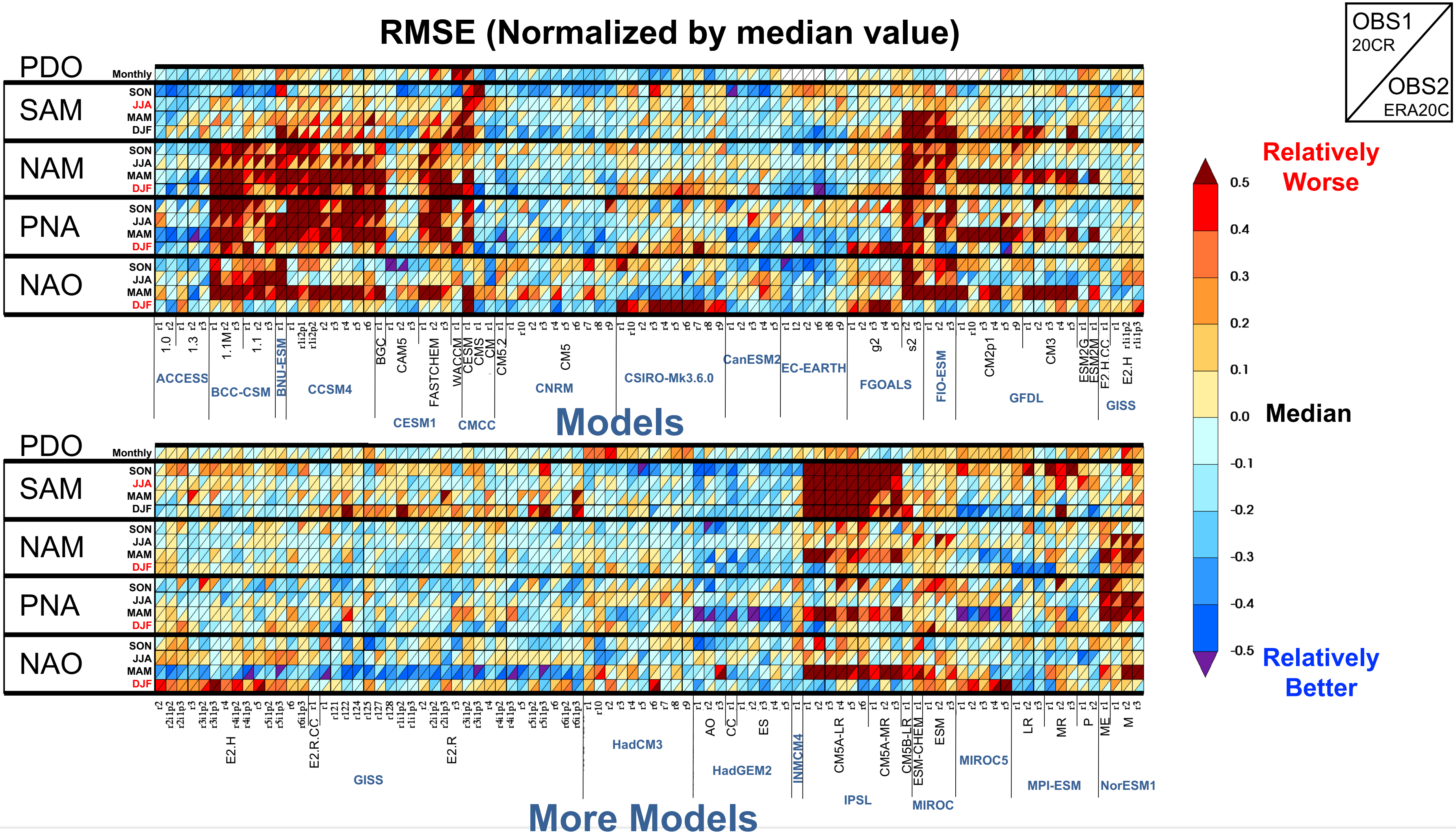
CBF vs. EOF swapping



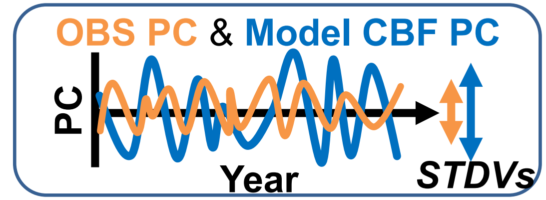
- The CBF provides a **more fair comparison with observations** than the conventional EOF
- The CBF reveals that **model skill is better** than indicated by conventional EOF analysis

Performance Diagnostics (1): Pattern + Amplitude

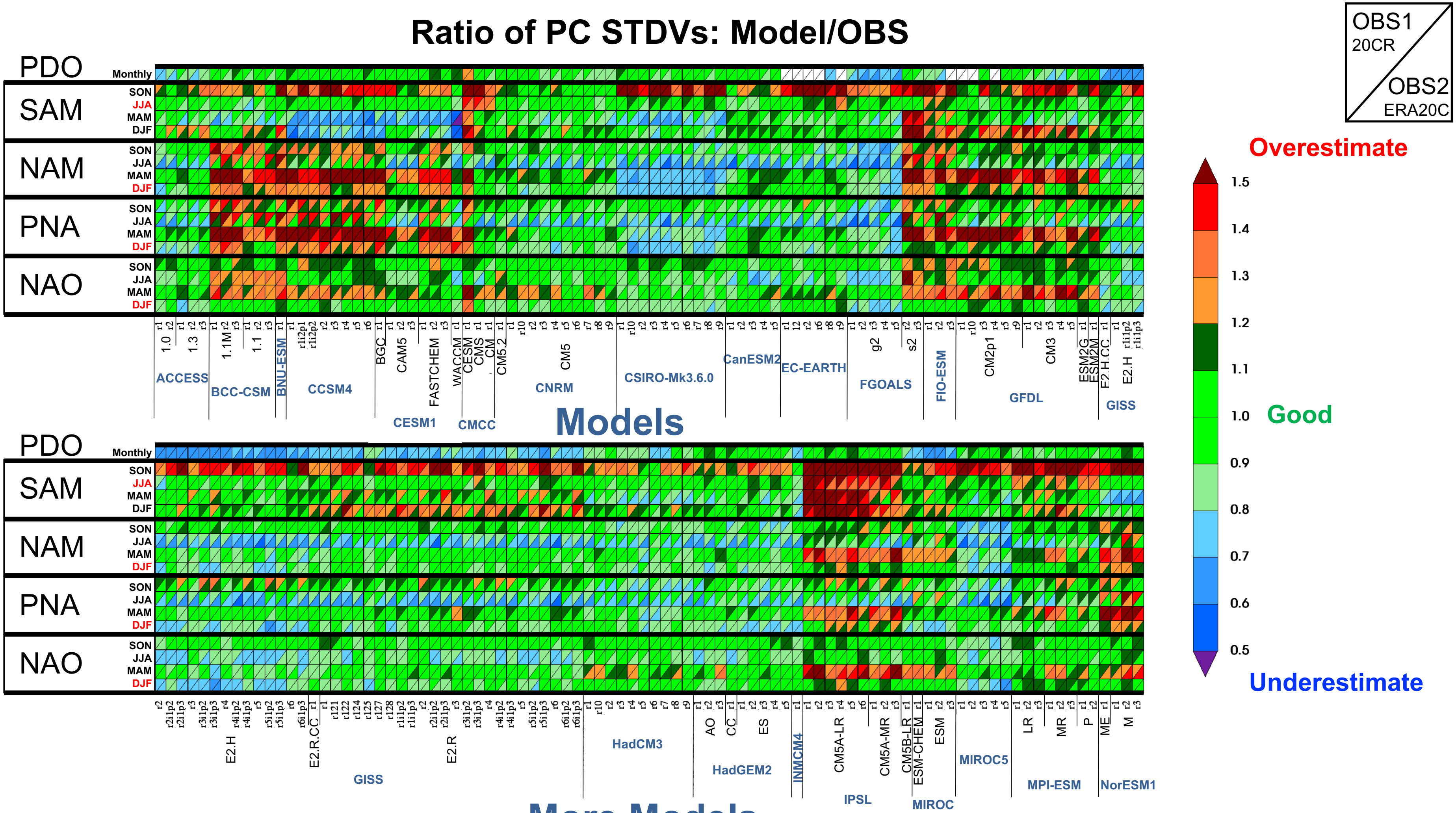




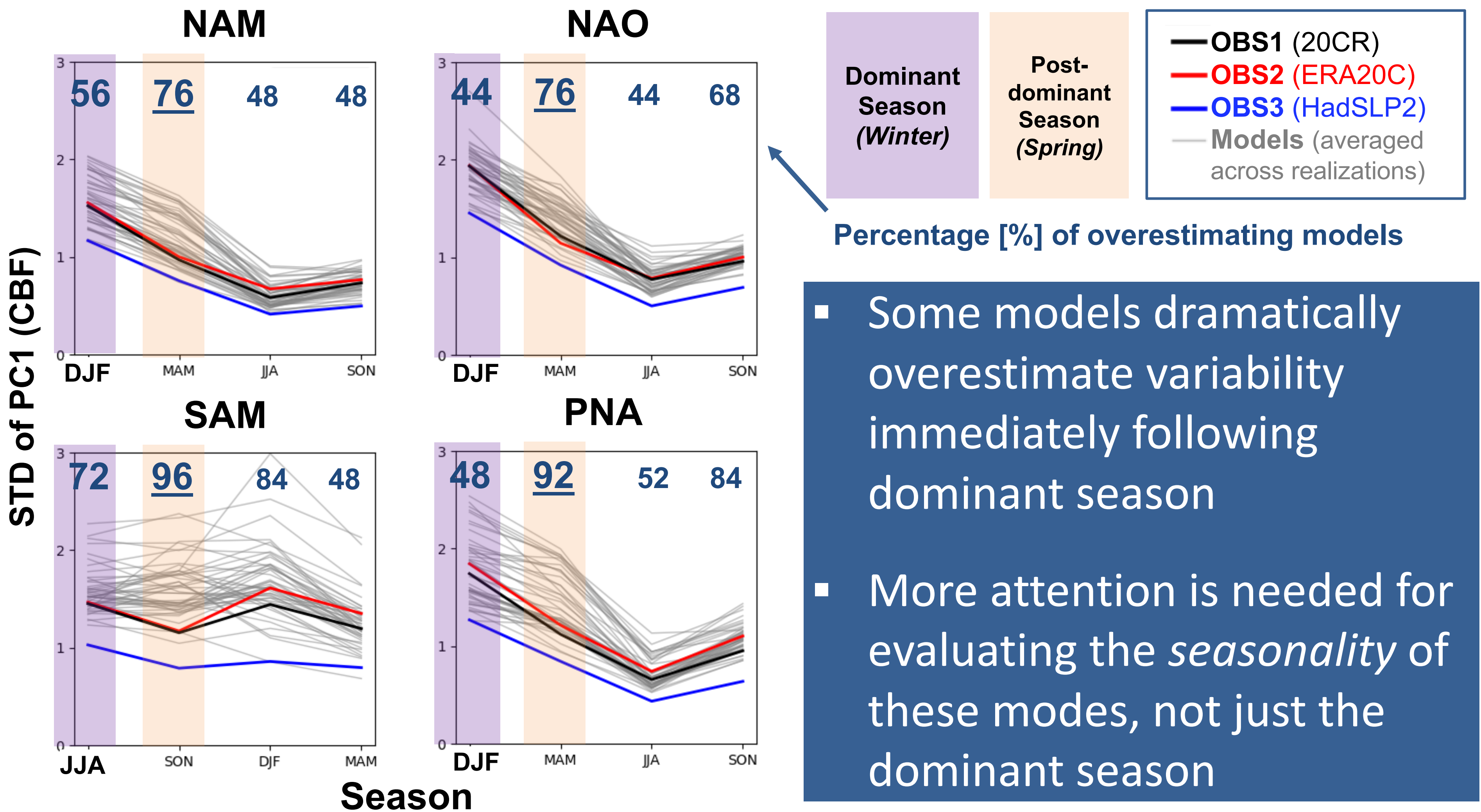
Performance Diagnostics (2): Amplitude



Ratio of PC STDVs: Model/OBS

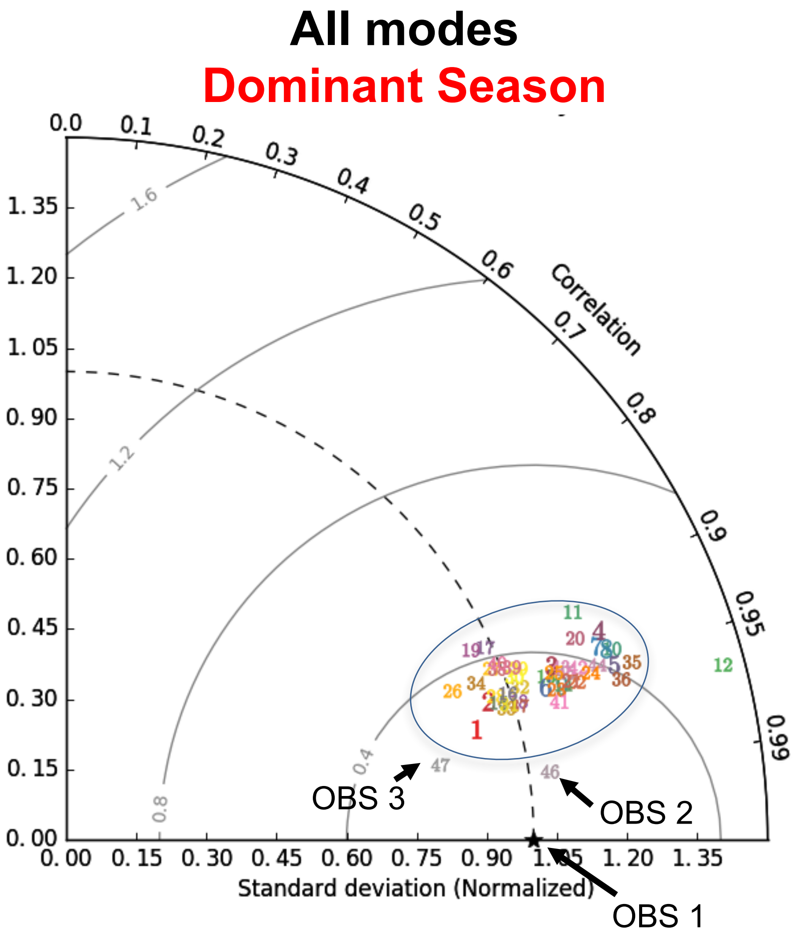


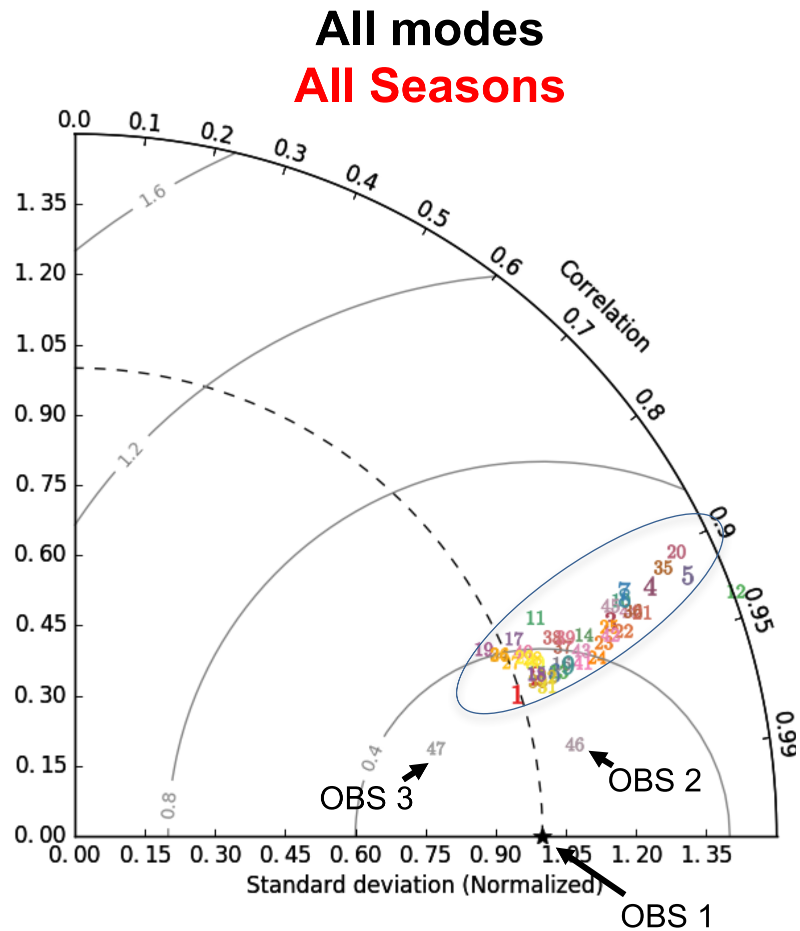
Seasonal Variation



- Some models dramatically overestimate variability immediately following dominant season
- More attention is needed for evaluating the *seasonality* of these modes, not just the dominant season

Taylor Diagrams





★ OBS 1
1 ACCESS1-0
2 ACCESS1-3
3 BCC-CSM1-1
4 BCC-CSM1-1-M
5 BNU-ESM
6 CanESM2
7 CCSM4
8 CESM1-BGC
9 CESM1-CAM5
10 CESM1-FASTCHEM
11 CESM1-WACCM
12 CMCC-CESM
13 CMCC-CM
14 CMCC-CMS
15 CNRM-CM5
16 CNRM-CM5-2
17 CSIRO-Mk3-6-0
18 EC-EARTH
19 FGOALS-g2
20 FGOALS-s2
21 FIO-ESM
22 GFDL-CM2p1
23 GFDL-CM3
24 GFDL-ESM2G
25 GFDL-ESM2M
26 GISS-E2-H
27 GISS-E2-H-CC
28 GISS-E2-R
29 GISS-E2-R-CC
30 HadCM3
31 HadGEM2-AO
32 HadGEM2-CC
33 HadGEM2-ES
34 INMCM4
35 IPSL-CM5A-LR
36 IPSL-CM5A-MR
37 IPSL-CM5B-LR
38 MIROC-ESM
39 MIROC-ESM-CHEM
40 MIROC5
41 MPI-ESM-LR
42 MPI-ESM-MR
43 MPI-ESM-P
44 NorESM1-M
45 NorESM1-ME
46 **OBS 2**
47 **OBS 3**

Post-dominant season (Spring) is the major contributor to the overestimation

Summary

Further detail:
J. Lee, K. R. Sperber, P. J. Gleckler, C. W. Bonfils, and K. E. Taylor (2017) Quantifying the Agreement Between Observed and Simulated Extratropical Modes of Interannual Variability. Climate Dynamics (in review)

- We have developed **evaluation metrics** for extra-tropical **modes of variability** using **CBF approach** – *projecting model anomalies onto the observational leading EOF*
- The CBF method leads to a more **consistent** approach for evaluation, overcoming limitations of conventional EOF
- The CBF reveals that **model skill** is better than indicated by conventional EOF analysis, even with swapping
- Our results are relatively **insensitive** to **sampling, observations, and processing choices**
- The **amplitude error** is the dominant contributor to systematic error in many models
- Models generally agree **better in the dominant season** of each mode,
  while many models systematically **overestimate** the variability in **post-dominant season**
  → ***More attention needs to be devoted to evaluating the seasonality of modes***

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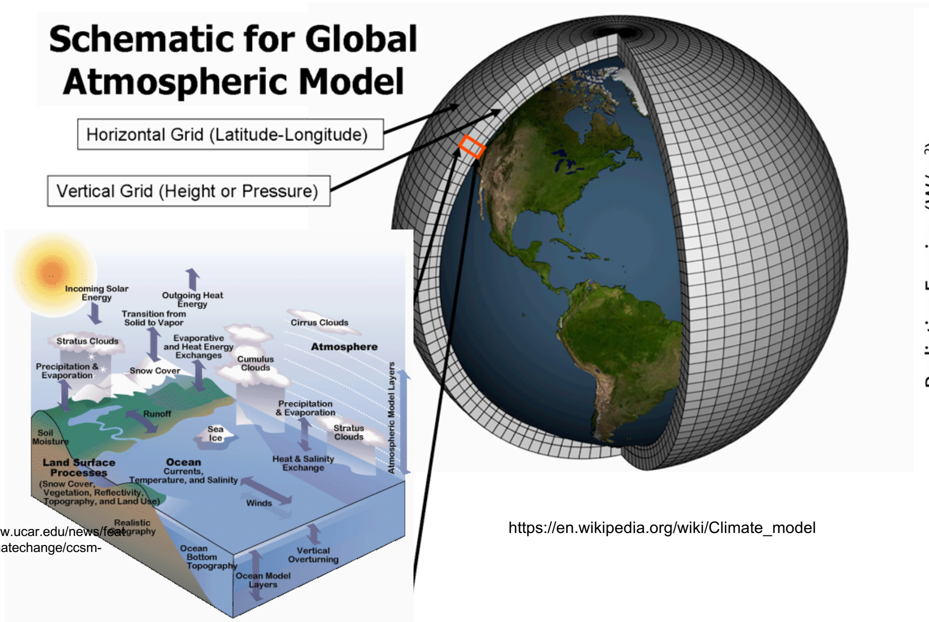
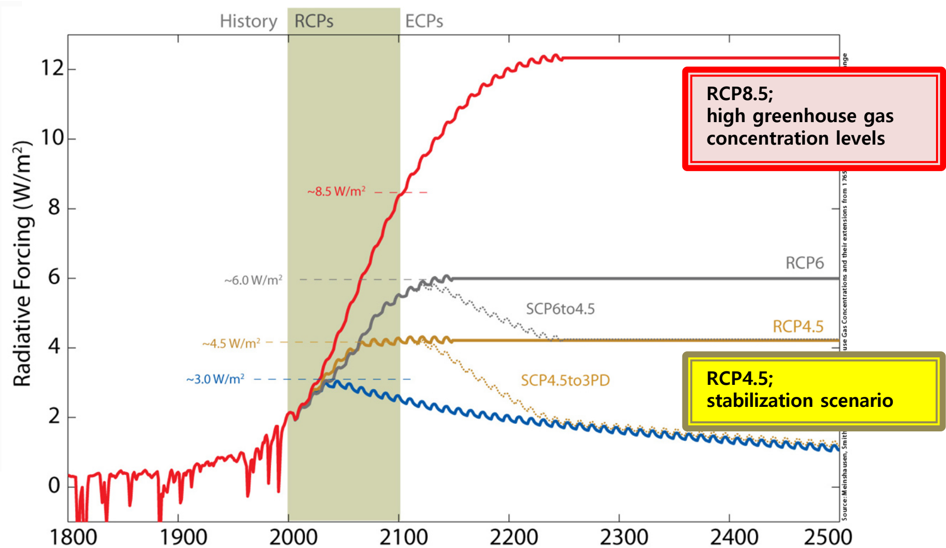
Extra Back-up Slides

Modeling Climate Under Future Possible Change Scenarios



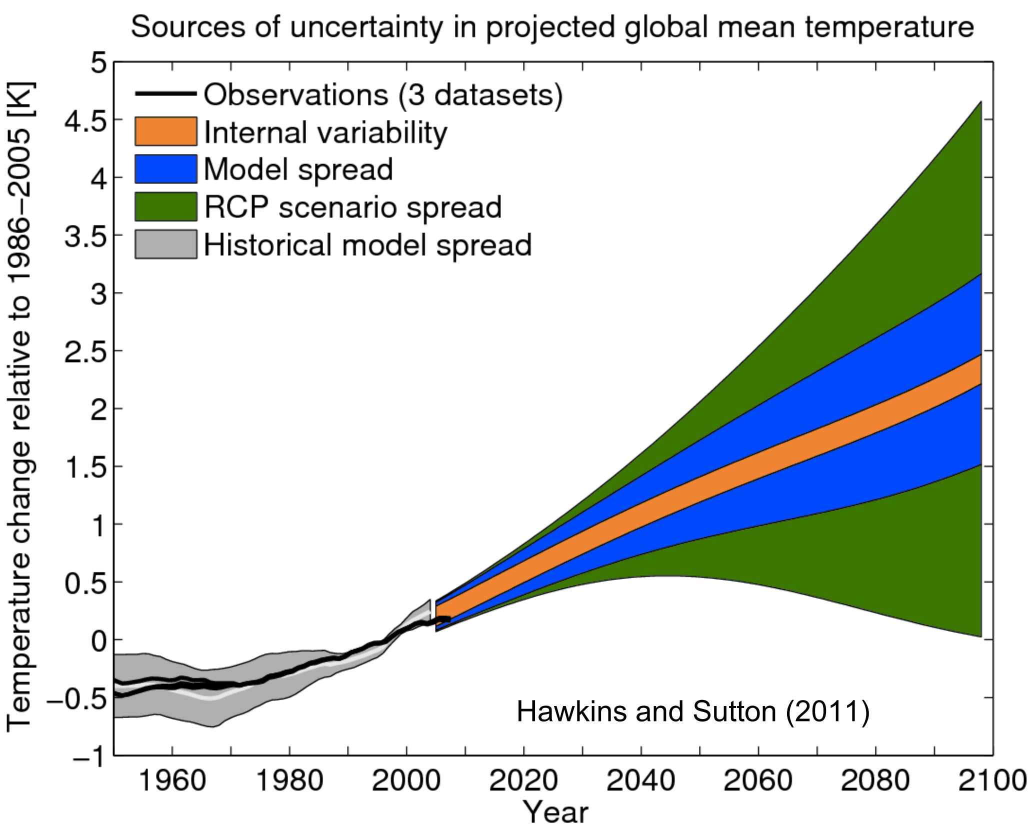
http://www.ucar.edu/news/features/climatechange/ccsm-text.jsp

https://en.wikipedia.org/wiki/Climate_model

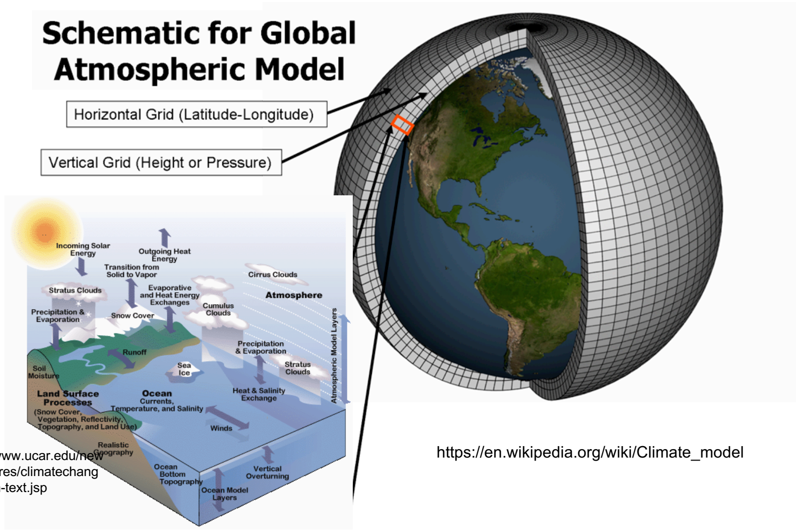


(Meinshausen et al. 2011)

Climate Model Inter-comparison



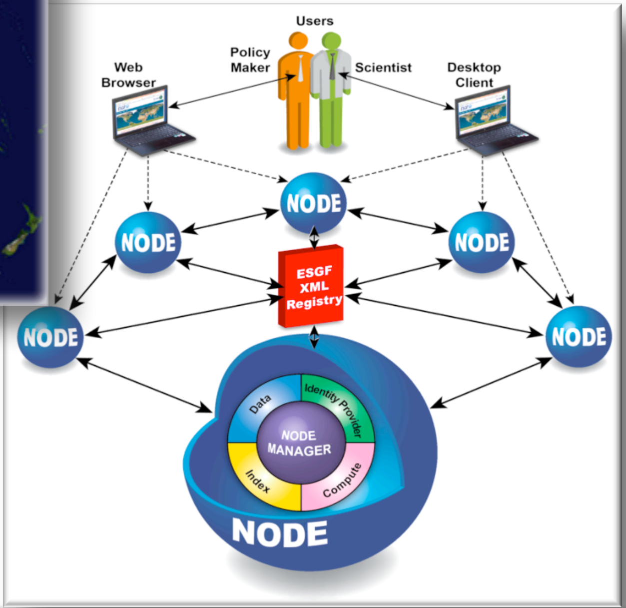
- Coupled Model Intercomparison Project Phase 5 (CMIP5)



http://www.ucar.edu/news/features/climatechange/ccsm-text.jsp

https://en.wikipedia.org/wiki/Climate_model

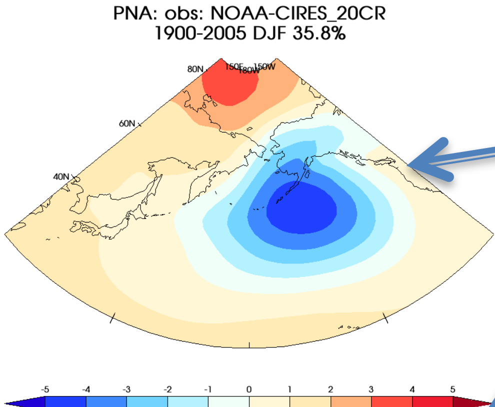
World-wide Climate Data Archive



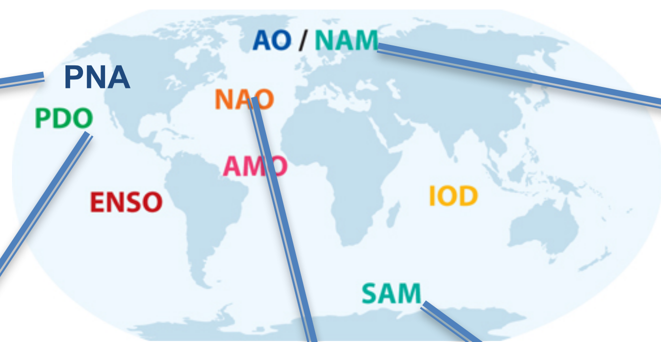
+ Data standardization, which open door to

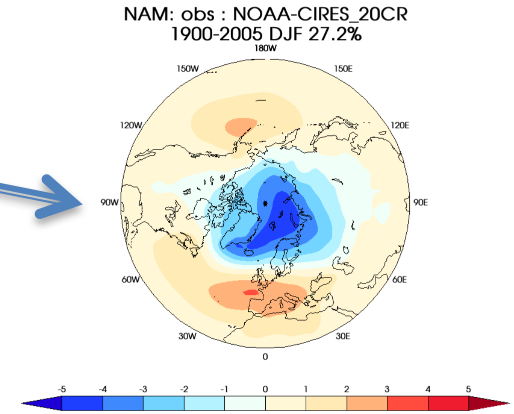
Climate Model Inter-comparison

Modes of variability (1)

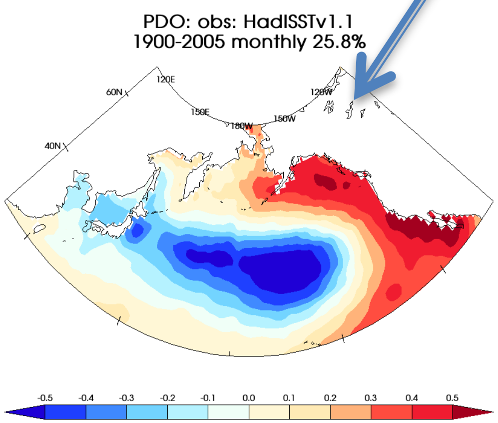


PNA: Pacific North American Pattern
(20CR, SLP)

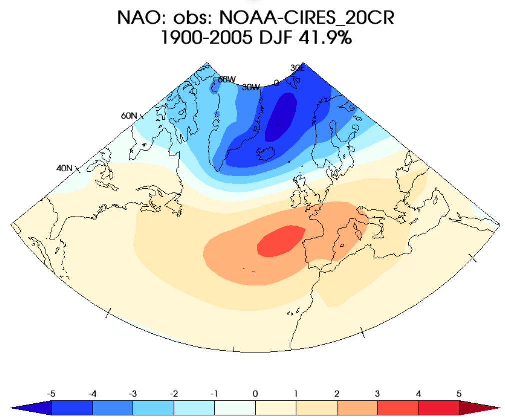




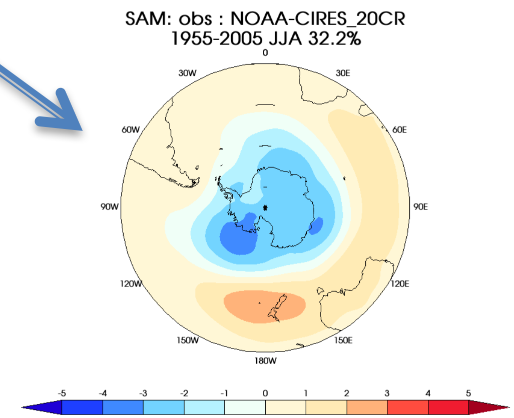
NAM: Northern Annular Mode
(20CR, SLP)



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



NAO: Northern Atlantic Oscillation
(20CR, SLP)



SAM: Southern Annular Mode
(20CR, SLP)

Modes of variability (2): NAO

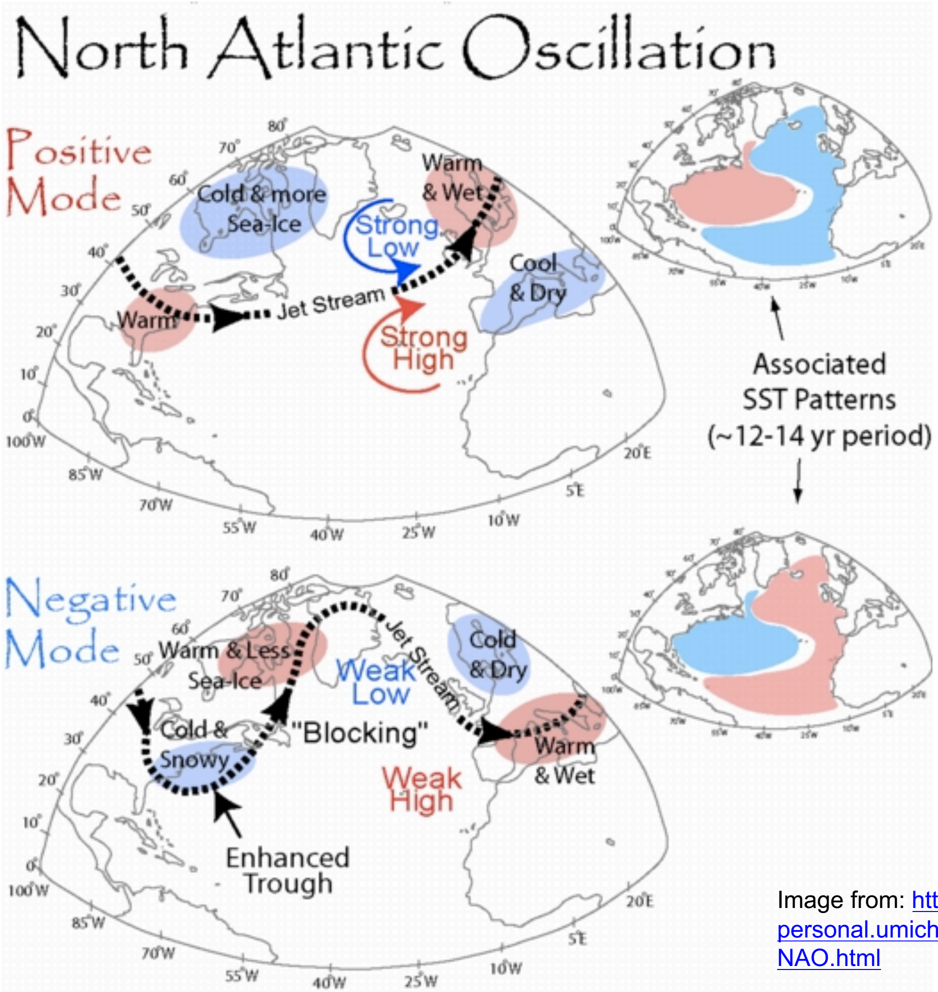
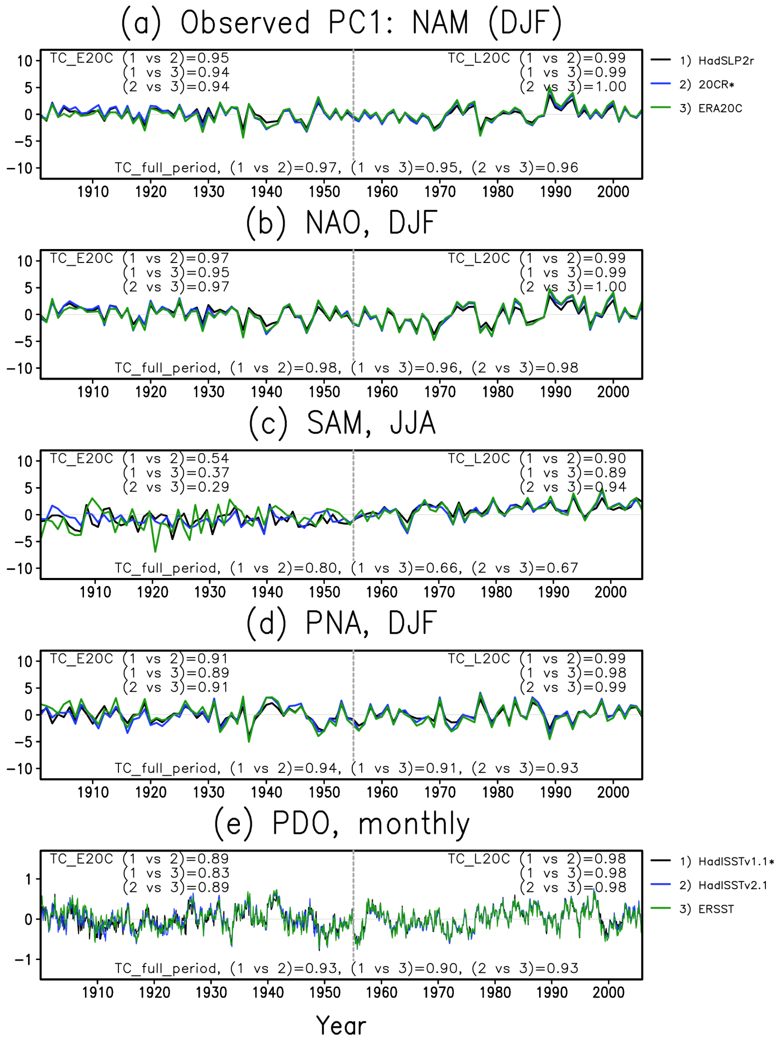
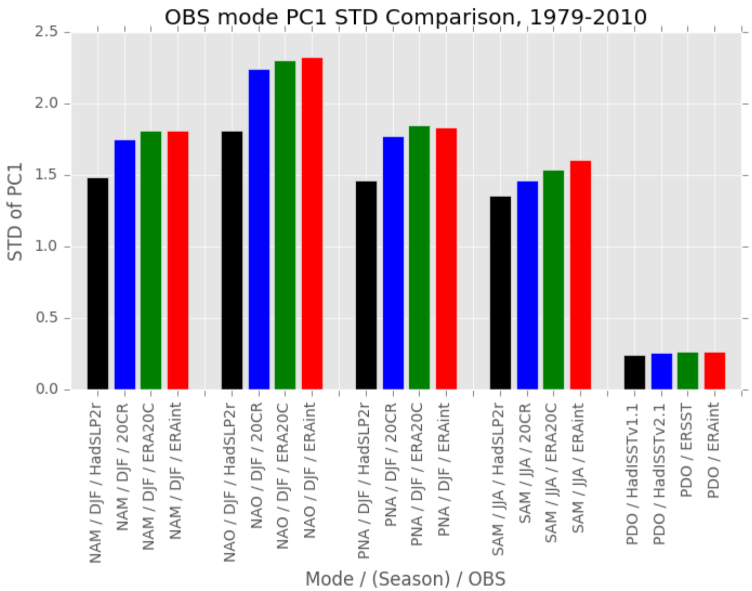


Image from: http://www-personal.umich.edu/~aurael/precipitation/pages/NAO.html

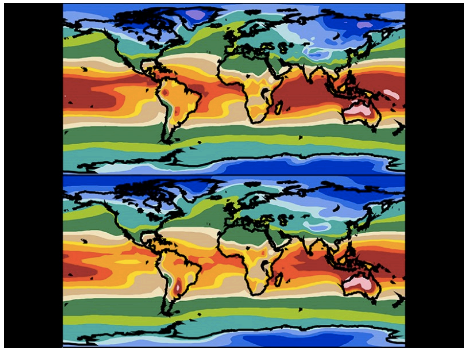
Observation

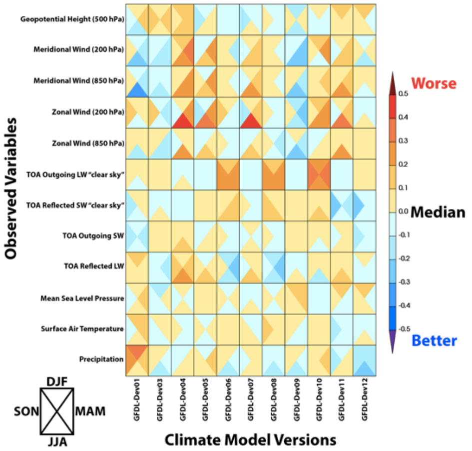




Software Development

- **Python (free of H/W System dependency)**
- **Built over:**
  - **PCMDI Metrics Package (PMP)**
  - **UV-CDAT**
  - **EOFs** (Dawson 2016)
- **Open source (Github)**
- **Reusable code**
  - user friendly designed
  - self-describing documentation

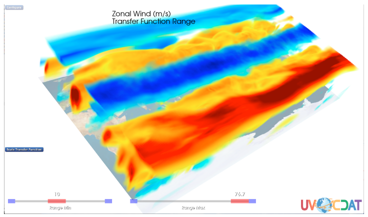


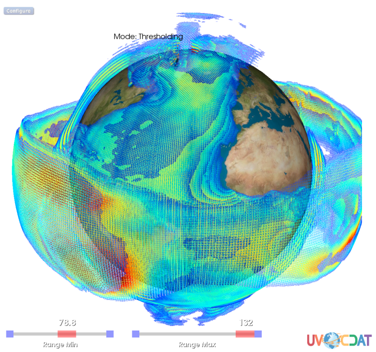


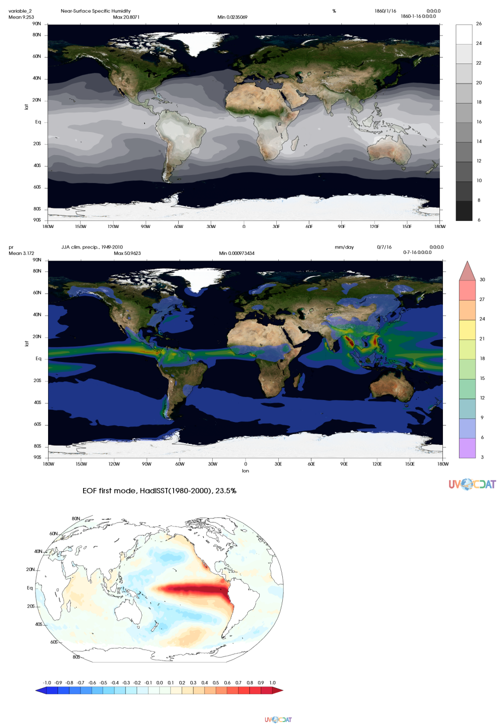
Gleckler, P. J., C. Doutriaux, P. J. Durack, K. E. Taylor, Y. Zhang, D. N. Williams, E. Mason, and J. Servonnat (2016), A more powerful reality test for climate models, Eos, 97, doi:10.1029/2016EO051663. Published on 3 May 2016.

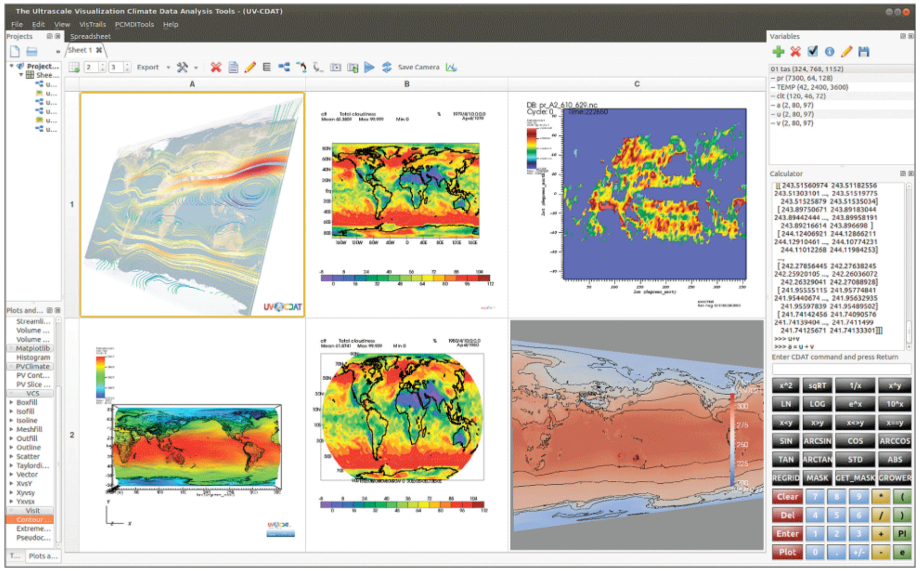
Ultra-scale Visualization Climate Data Analysis Tools (UV-CDAT)

- CDMS (Climate Data Management System)
  - Handle multi-dimensional climate variables
- VCS Graphics Module



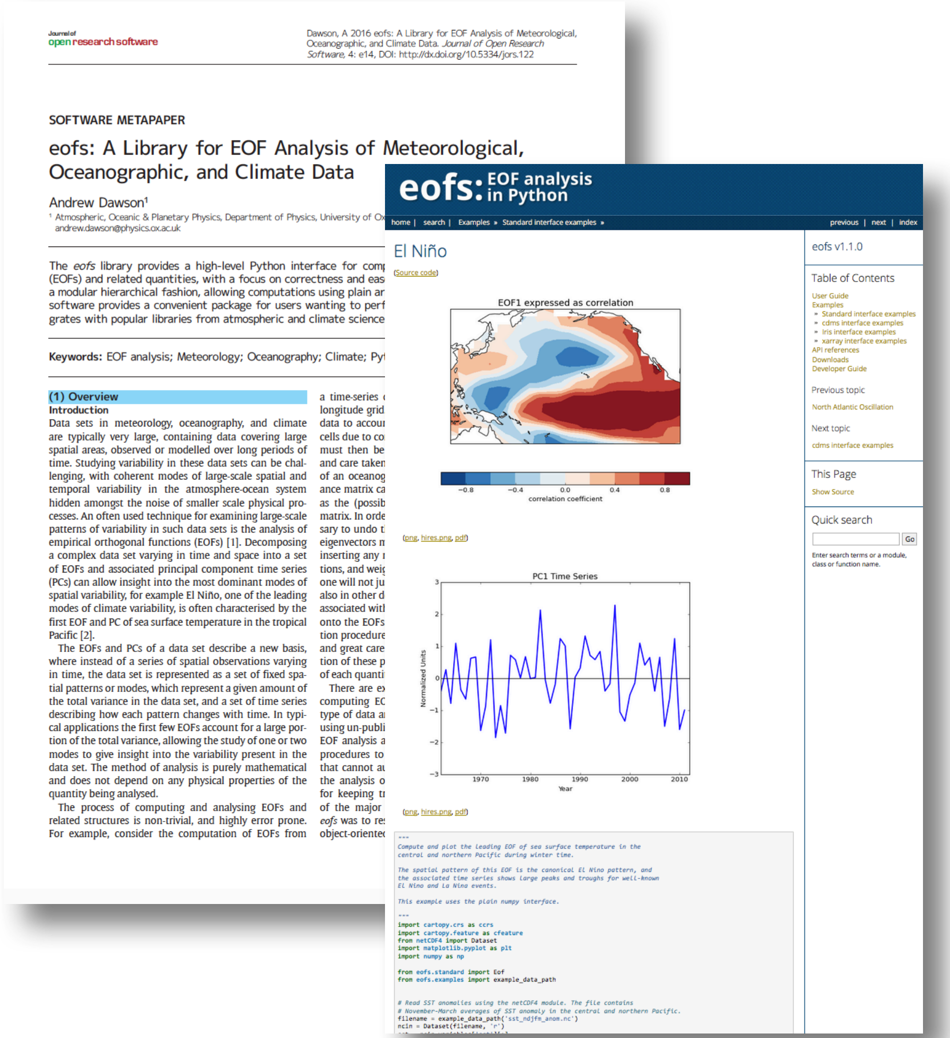






Python EOFs Library

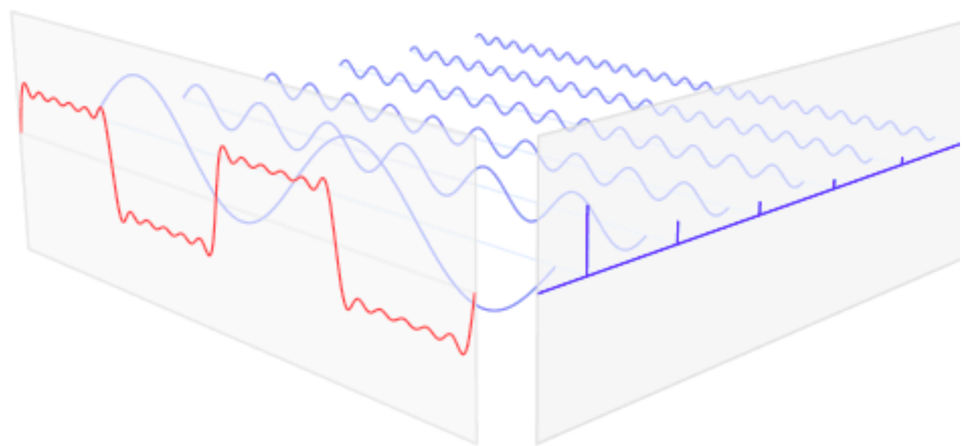
- High-level interface for computing empirical orthogonal functions (EOFs) and related quantities



Dawson, A., (2016). eofs: A Library for EOF Analysis of Meteorological, Oceanographic, and Climate Data. Journal of Open Research Software. 4(1), p.e14. DOI: http://doi.org/10.5334/jors.122

Empirical Orthogonal Function (EOF) analysis

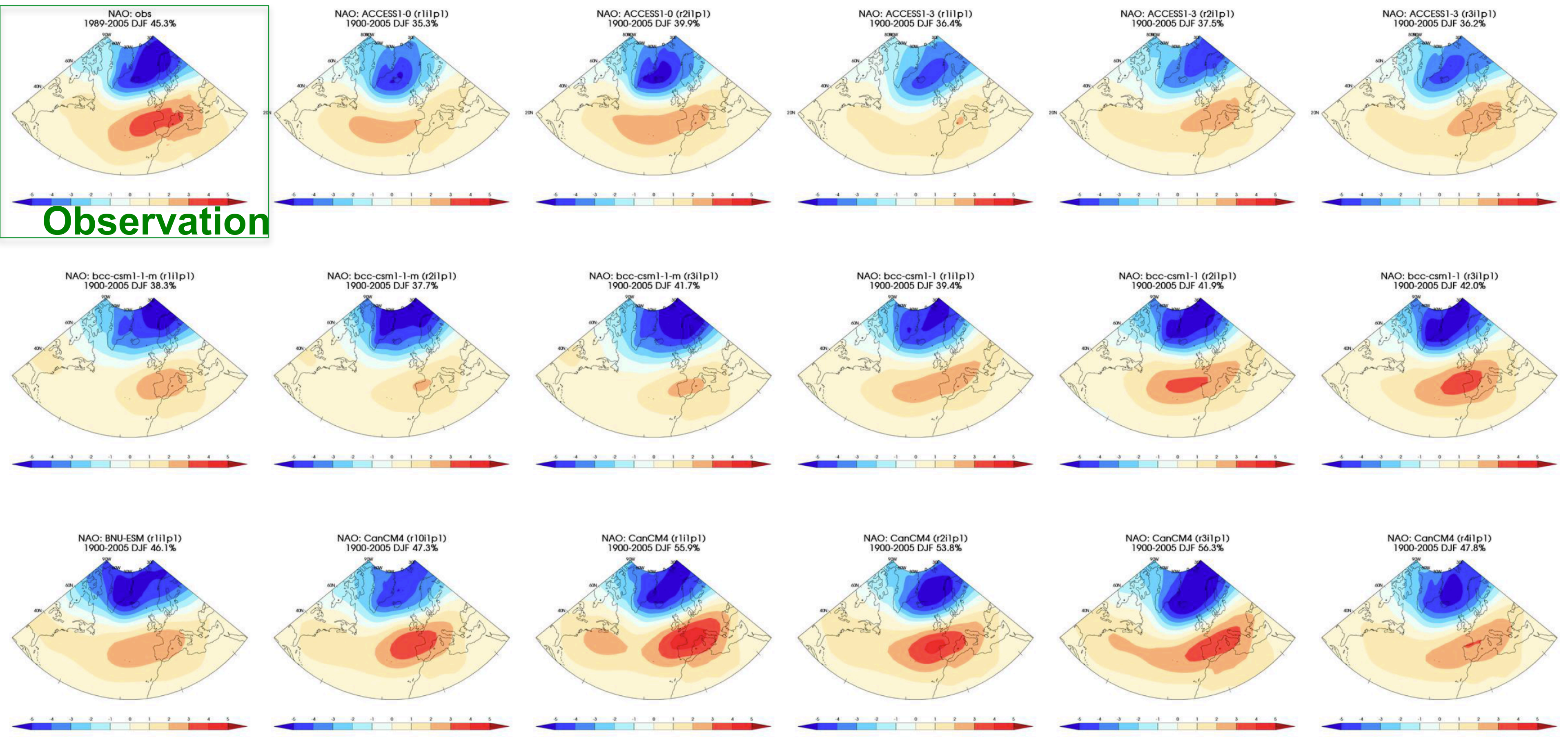
- **Fourier Transform:**



http://tex.stackexchange.com/questions/127375/replicate-the-fourier-transform-time-frequency-domains-correspondence-illustrati

- **EOF:**
  - Similar concept to FT, but separates modes based on orthogonality
  - It is more useful when time series has "jumps" in it

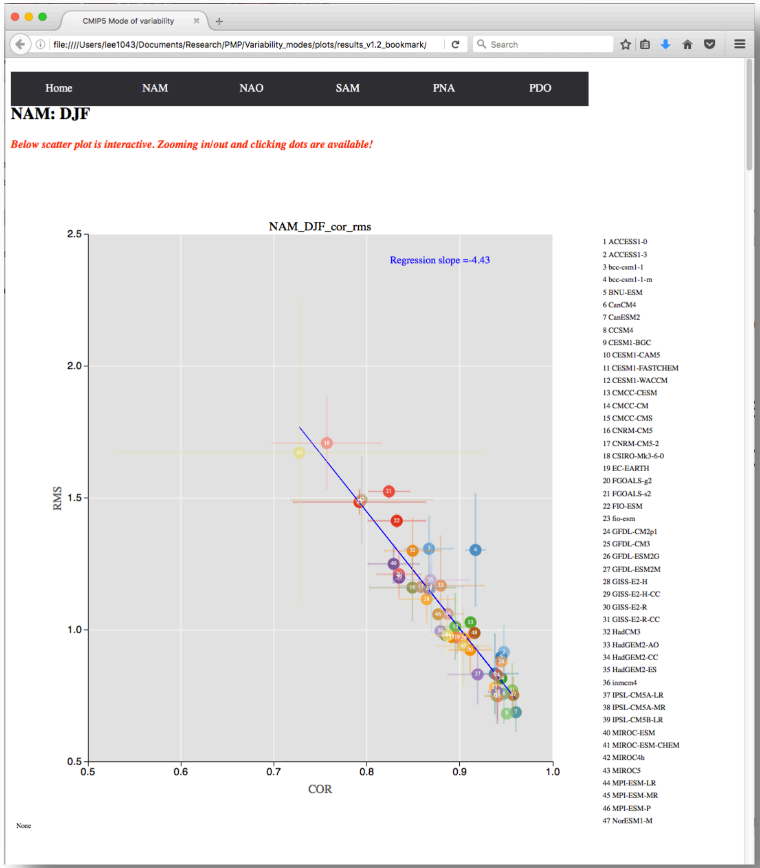
Loop through all CMIP5 simulations.. (e.g. NAO)



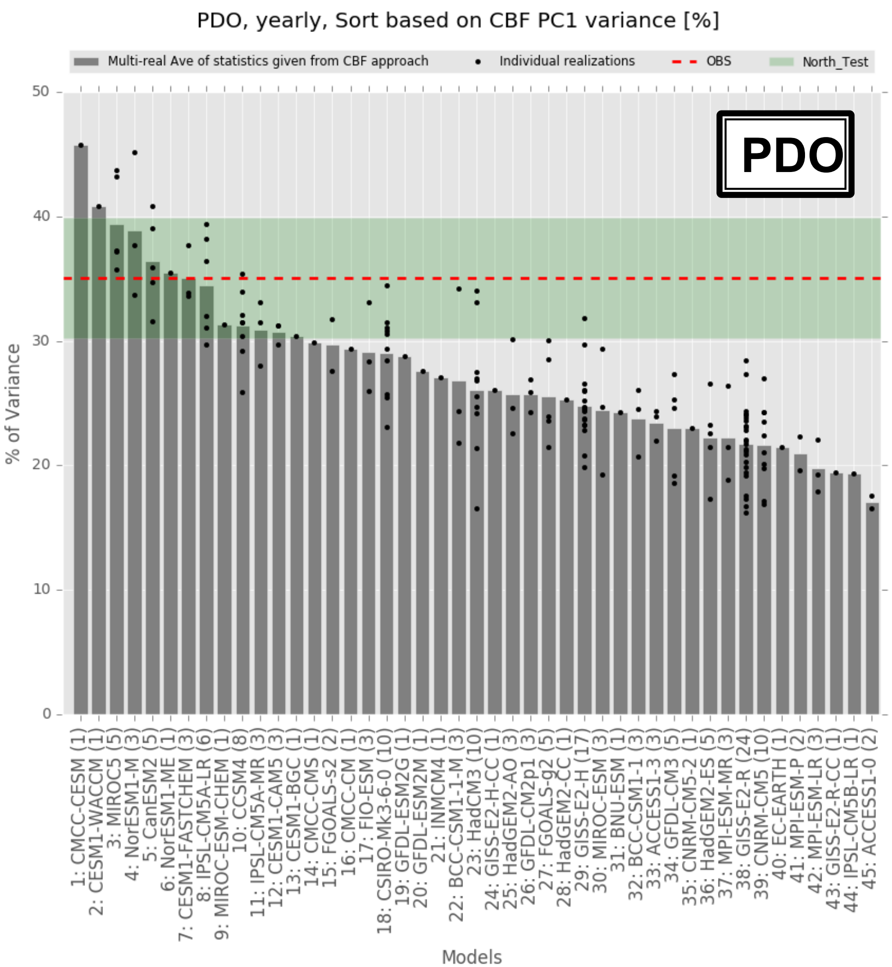
5 modes, 4 seasons, about 45 models with all available realizations (1~25 per model), various type of plots;
≈ 13,000 images at the end…

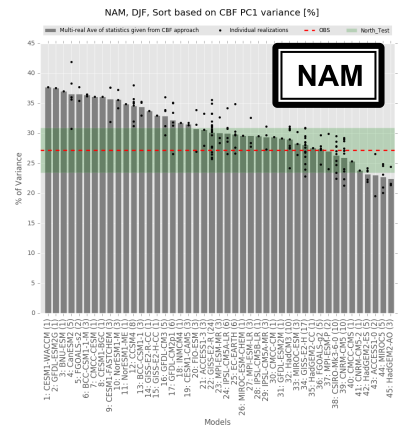
Database Construction

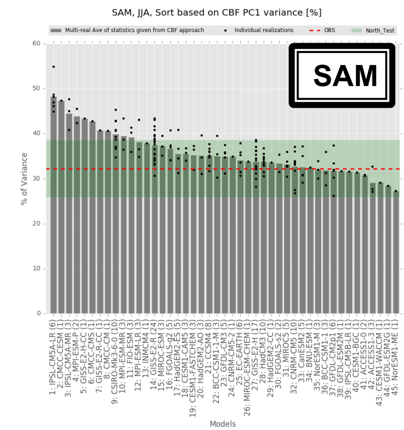
- Browsing available web-like navigation
- Statistics based Interactive plots (mpld3 Library)
- Starting version for PCMDI web service

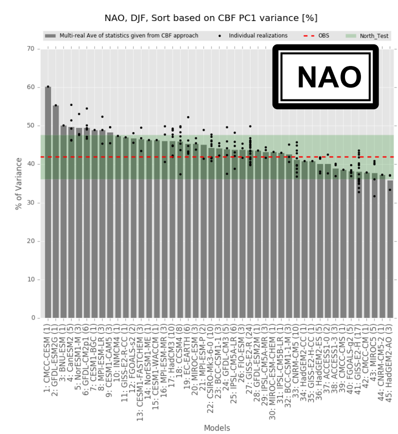


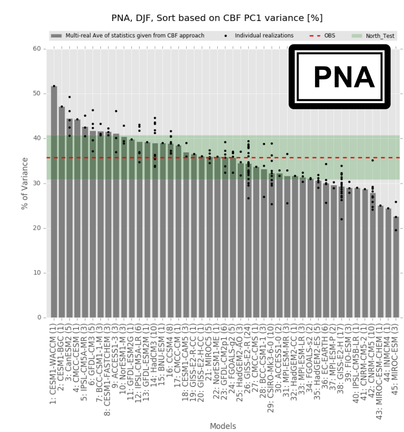
PDO and others - Variance in time





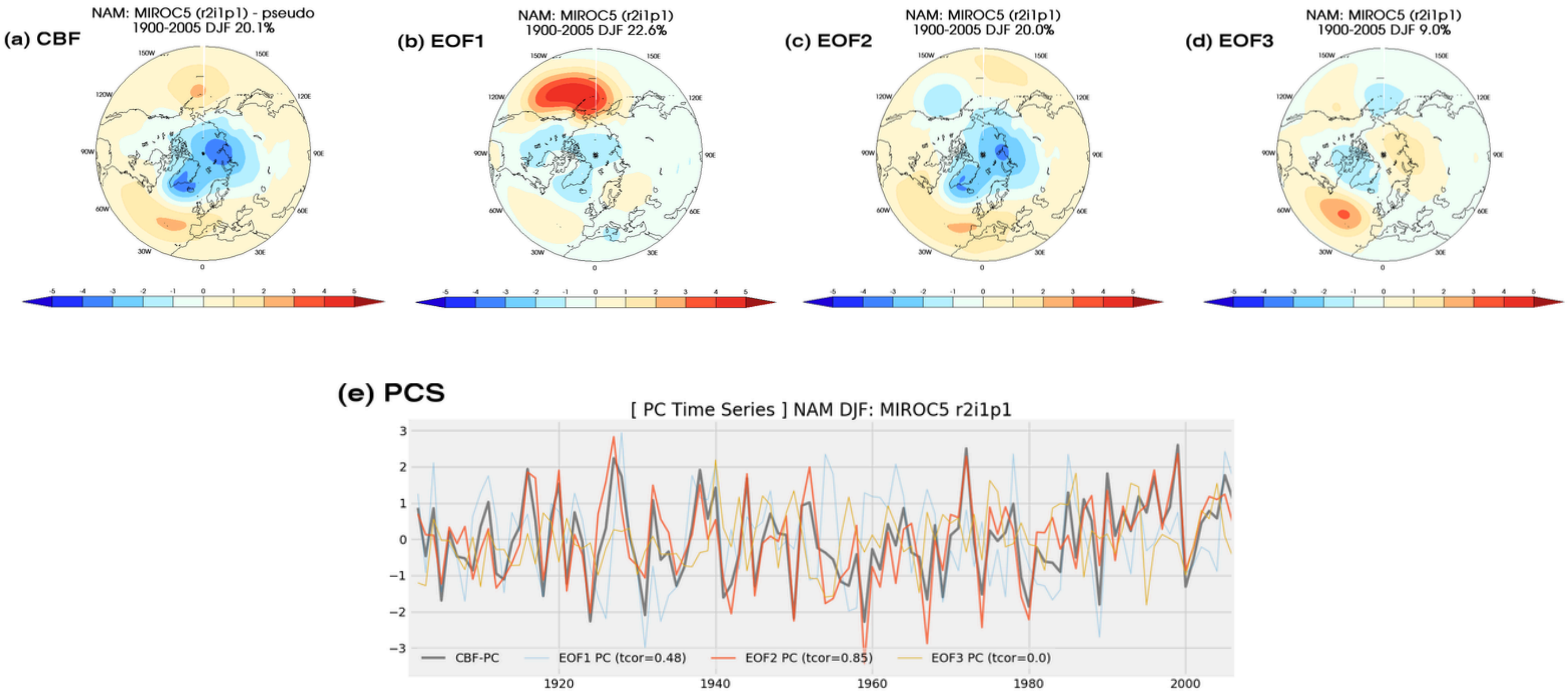






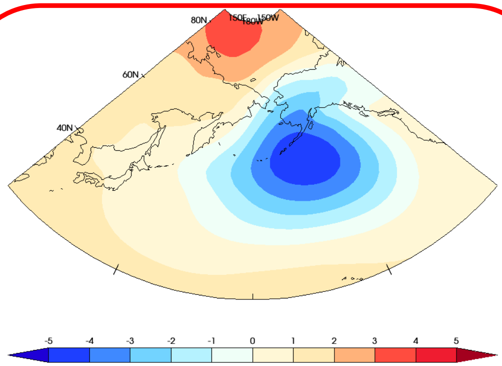
EOF mode swapping: NAM, DJF

- NAM in MIROC5 (r2i1p1)

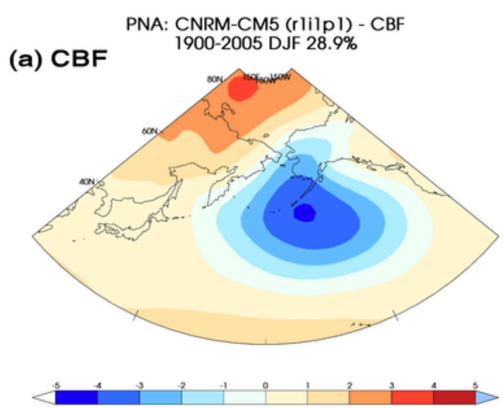


EOF mode swapping and CBF: PNA Example

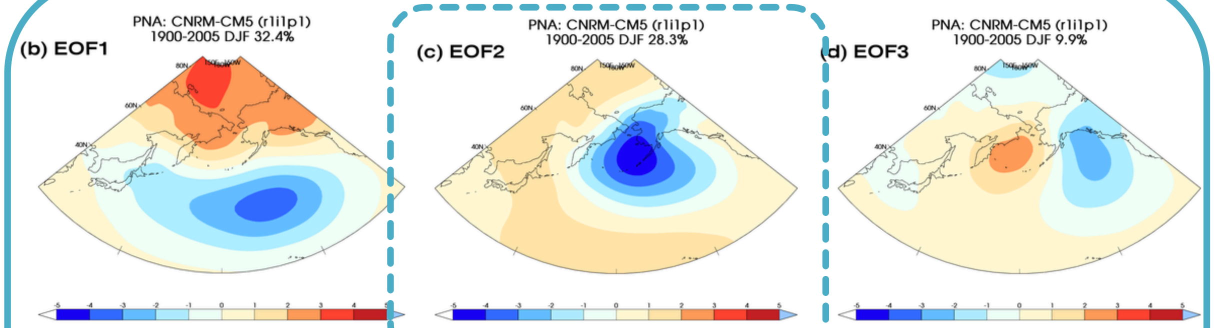
OBS



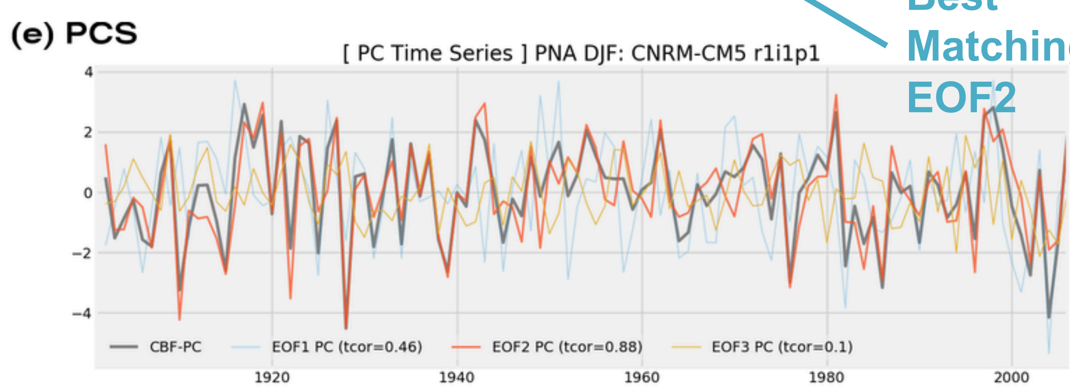
PNA: Pacific North American Pattern
(20CR, SLP)



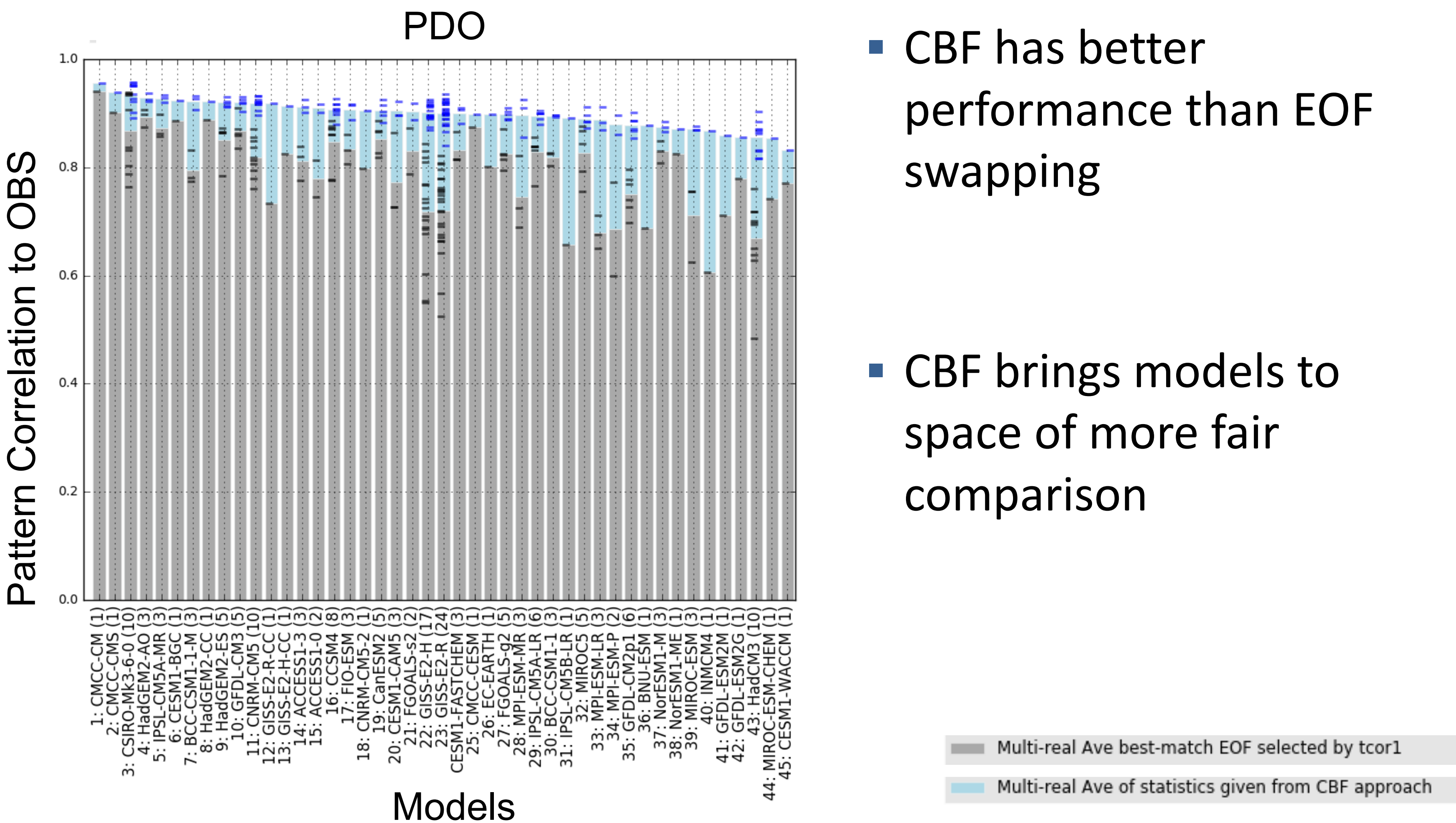
Model



Best Matching: EOF2

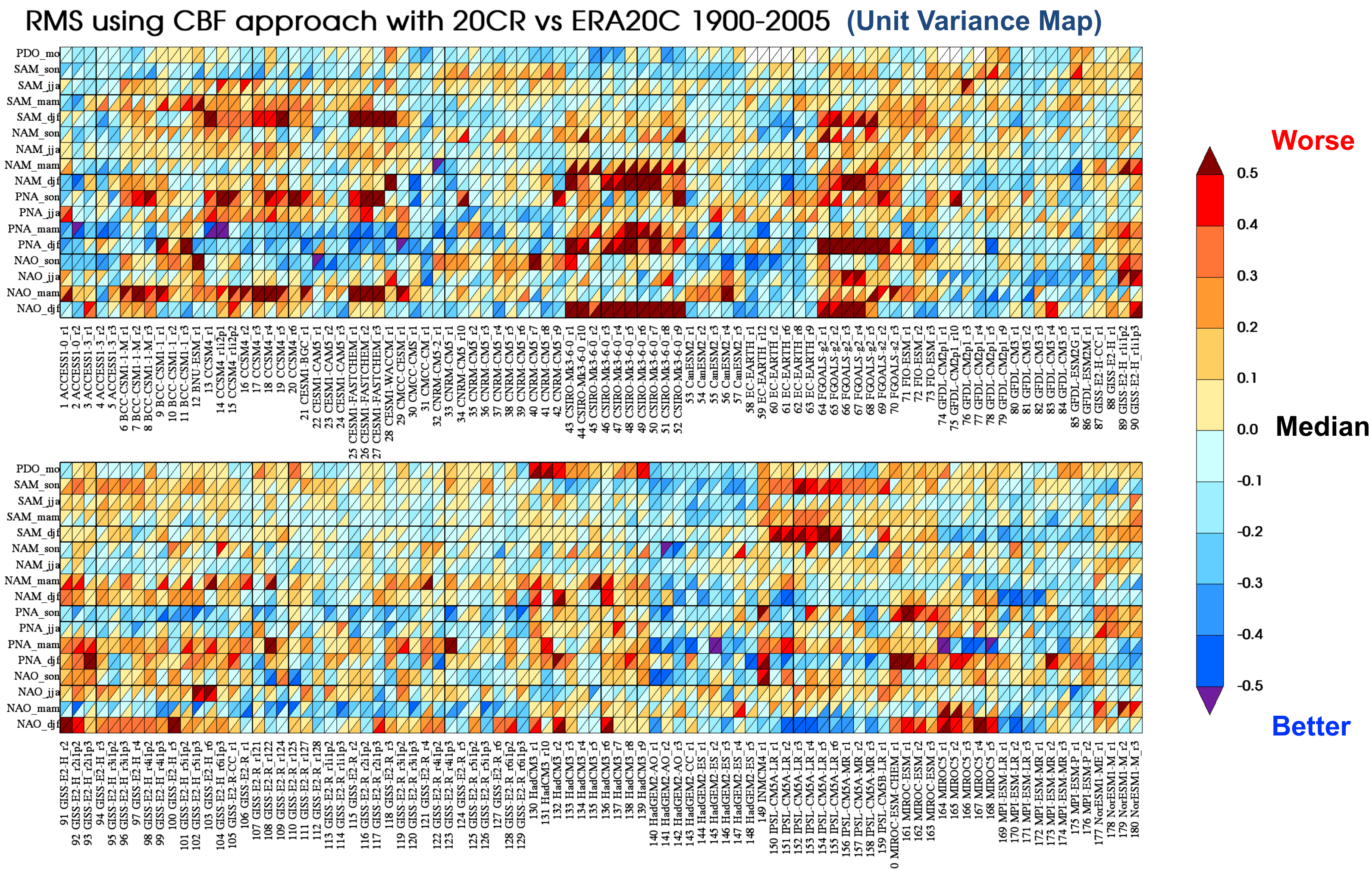


CBF vs. EOF swapping



- CBF has better performance than EOF swapping
- CBF brings models to space of more fair comparison

Performance Diagnostics: Pattern (RMSE) – Unit variance map



Amplitude comparison for CBF