Evaluation of CMIP5 dynamic sea surface height multi-model simulations against AVISO satellite observations

Felix W. Landerer[1] , Peter J. Gleckler[2] & Tong Lee[1]

[1]Jet Propulsion Laboratory, California Institute of Technology;

[2] Program for Climate Model Diagnosis and Intercomparison, Lawrence Livermore National Laboratory, Livermore, CA, U.S.A.

Contact: landerer@jpl.nasa.gov

Paper now in press @ Climate Dynamics!

Summary - Take Home Points

- We evaluate the representation of dynamic sea surface height (SSH) fields of 33 CMIP5 global coupled models (GCMs) against observations from satellite altimetry;
- Basic performance metrics to quantify the ability of the GCMs to replicate observed SSH of the time-mean, seasonal cycle, and inter-annual variability patterns;
- Time-mean SSH (**reference data set**: Maximenko-MDT; 10-year mean SSH):
  - biases markedly improved from CMIP3 to CMIP5 (reduced RMSDs & GCM ensemble spread);
  - Tropical Pacific and Indian Ocean biases are consistent with wind stress biases in the GCMs;
  - Southern Ocean biases not related to wind stress, but reflect eddy parameterization;
  - Performance skill not sensitive to analysis time period;
- Annual Cycle & Interannual variability (**reference data set**: gridded AVISO 1993-2012):
  - Considerable spread across the CMIP5 models;
  - Performance sensitive to analysis time period;

1. Overview

Projections that regional sea level changes due to ocean dynamic changes can deviate from the global mean by up to 100%. However, the projections form different coupled models are not very consistent with each other: the spread in the multi-model ensemble is often as large as the mean projected change, adding considerable uncertainty to the projections. Therefore, we examine here how GCMs perform compared to observations to (1) to reveal underlying processes and mechanisms, and (2) to assess if model skill can be used to discriminate between model projections. The analysis reveal that overall, current CMIP5 models can capture the time-mean dynamic SSH well, and the spread among the model-ensemble is small. However, the spread grows when comparing annual and interannual SSH changes from CMIP5 to observations. The relatively short time period of observations (20 years) presents a significant challenge, and limits the analysis to 10-year variability. We also find that in contrast to the time-mean SSH, the interannual model performance metric are quite sensitive to which particular 18-year window is used from the model.

2. Mean Dynamic Topography

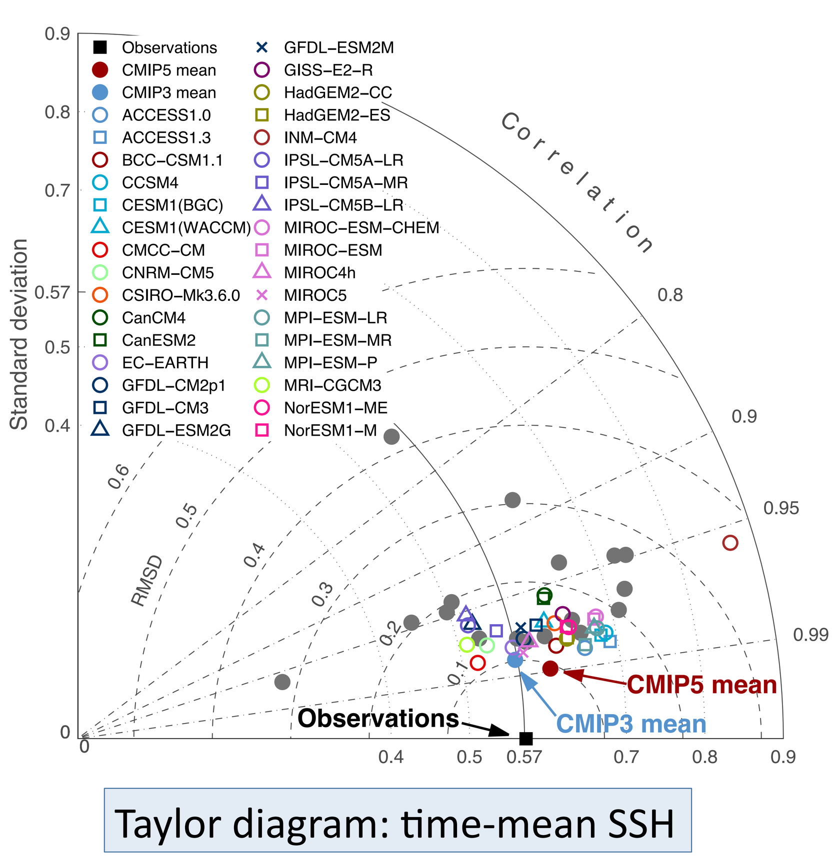


Fig. 1 Taylor diagram of the CMIP3 (grey dots) and CMIP5 (colored symbols, see legend) mean dynamic topographies (MDTs) compared against the observed MDT. The CMIP3 and CMIP5 ensemble averages (shown as stars) show the best agreement with observations.

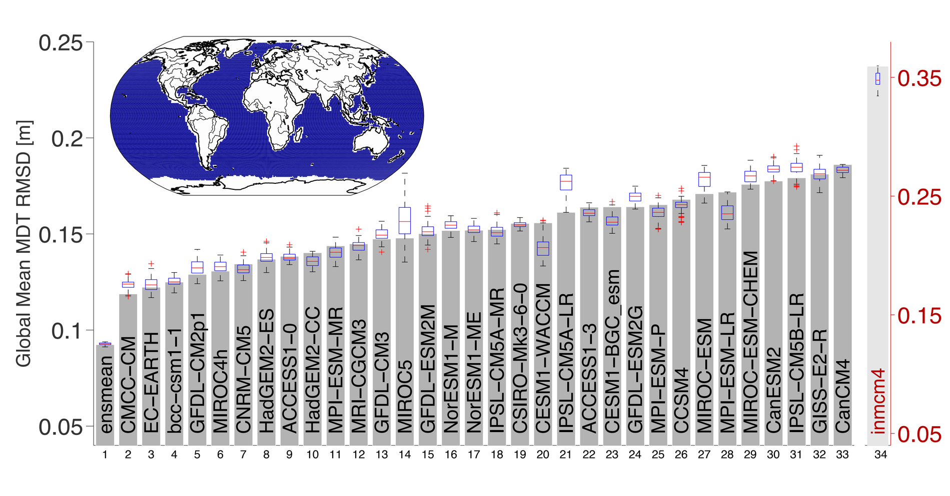
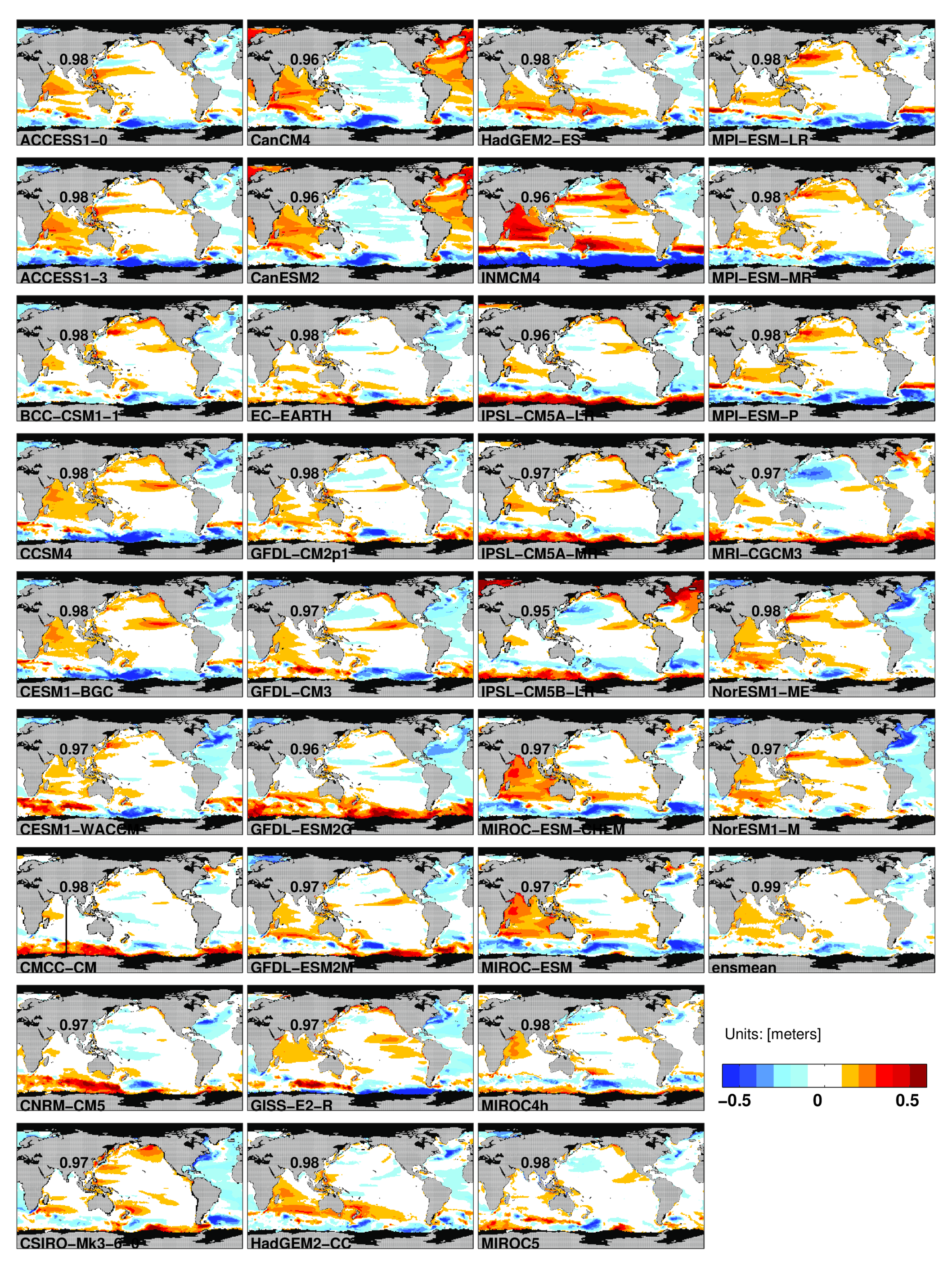


Fig. 2 Global mean RMSD of CMIP5 models. Grey bars represent the model/observations RMSD value for the time-period 1993-2002, and the whiskers the distribution of RMSDs between the observed MDT and 10-year sliding windows for each CMIP5 GCM for the 'historical' 20th century runs (central red mark is the median, box edges are 25th and 75th percentiles). The map inset shows the ocean area over which the model statistics were computed for all CMIP5 GCMs; marginal seas have been excluded.

Fig. 3 Individual CMIP5 model MDT biases, computed over a ten-year period 1993 – 2002.



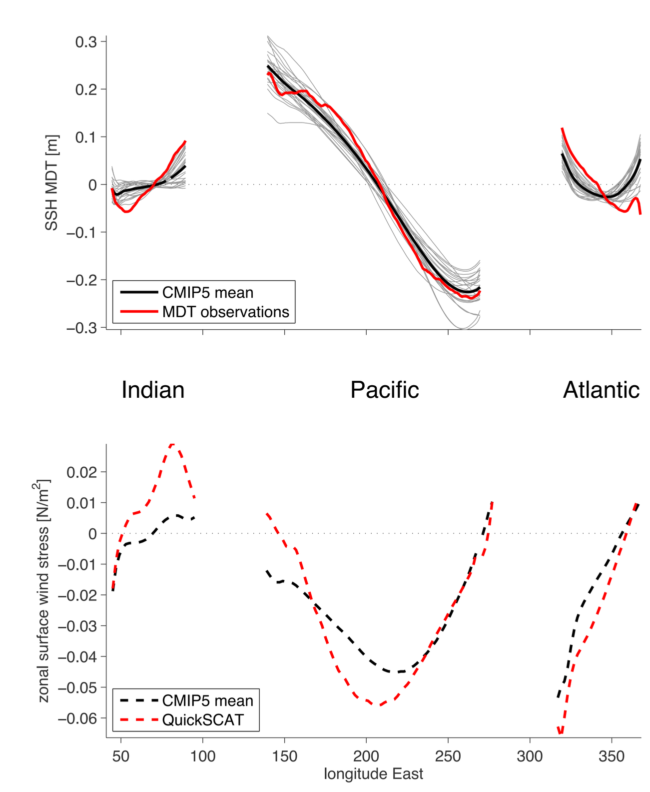


Fig. 4 *(top)* Absolute MDT bias between individual CMIP5 models (grey), the CMIP5 model mean, and the MDT observations. The biases were computed between 2S-2N over the time-mean SSH for model years 1992-2002, matching the observations. *(bottom)* Equatorial zonal wind stress (2S-2N) of the CMIP5 ensemble and QuickSCAT.

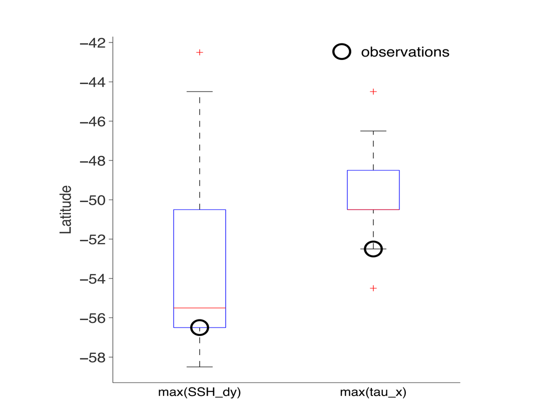


Fig. 5 Both maximum zonal wind stress and the location of maximum meridional SSH gradient are biased equatorward in the CMIP5 models.

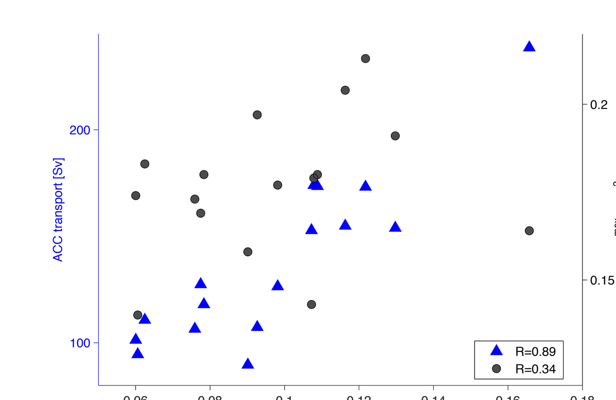


Fig. 6 Scatter plot of the maxima of westerly surface wind stress (gray circles), and maximum ACC transports through Drake Passage (blue triangles) in CMIP5 models as a function of the zonal mean maxima of the Southern Ocean meridional SSH gradients. This plot shows that Southern Ocean MDT biases are not related to wind stress biases, but reflect eddy parameterization.

3. Interannual Variability Patterns

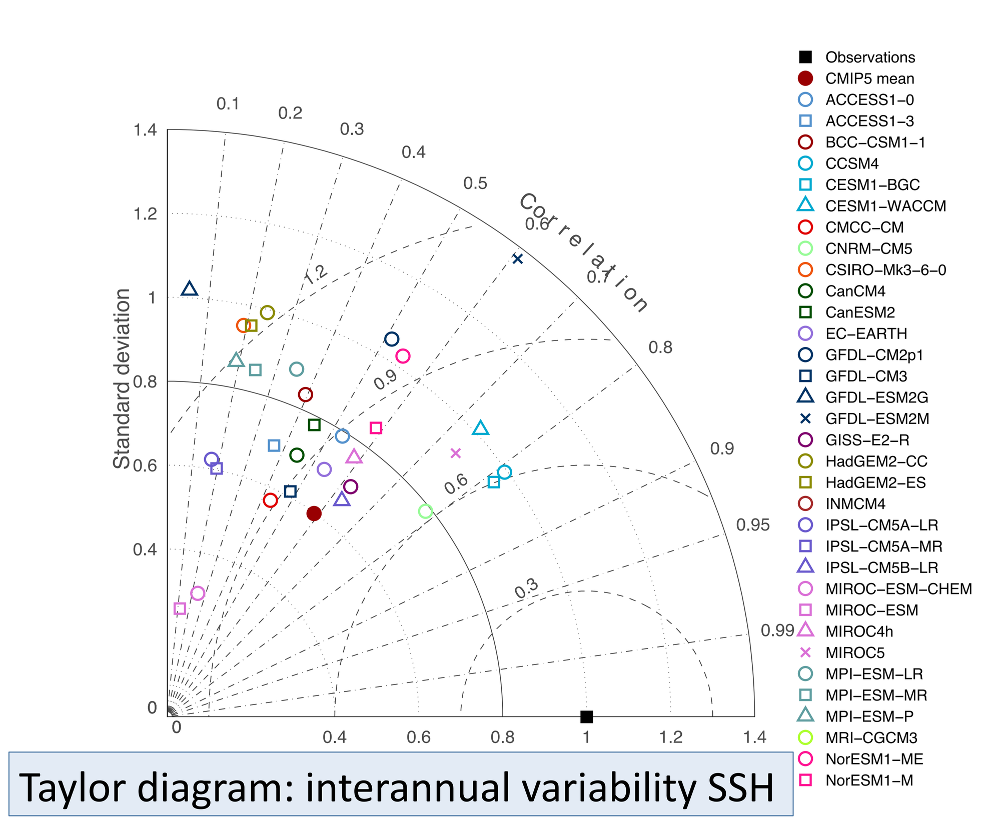


Fig. 7 Taylor diagram summarizing the normalized statistics of interannual SSH variability patterns of the CMIP5 models over the tropical Pacific Ocean area (between 20S and 20N). The monthly mean climatology has been subtracted, the data have been detrended, and a band-pass filter (1-10 years) has been applied. The inter-annual variability pattern is then simply the RMS over a 18-year window (here: 1993-2010). Compare the performance here against the performance for the MDT (Fig. 1).

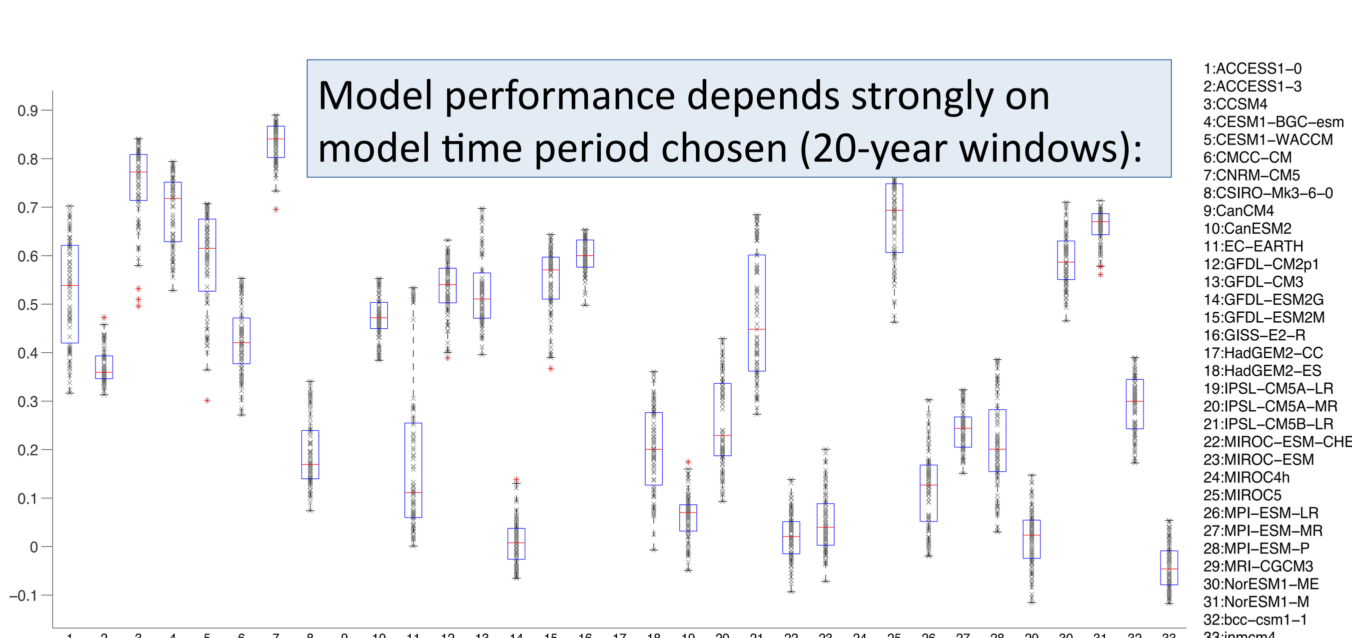


Fig. 8 Spread of pattern correlation between interannual SSH variability of the CMIP5 models and observations over the tropical Pacific Ocean area (between 20S and 20N). For each model, the data points are derived by sliding a 20-year window over the historical run, and computing the pattern correlation to the observed interannual variability (the latter remains the same). Data processing and filtering is as in Fig. 7.

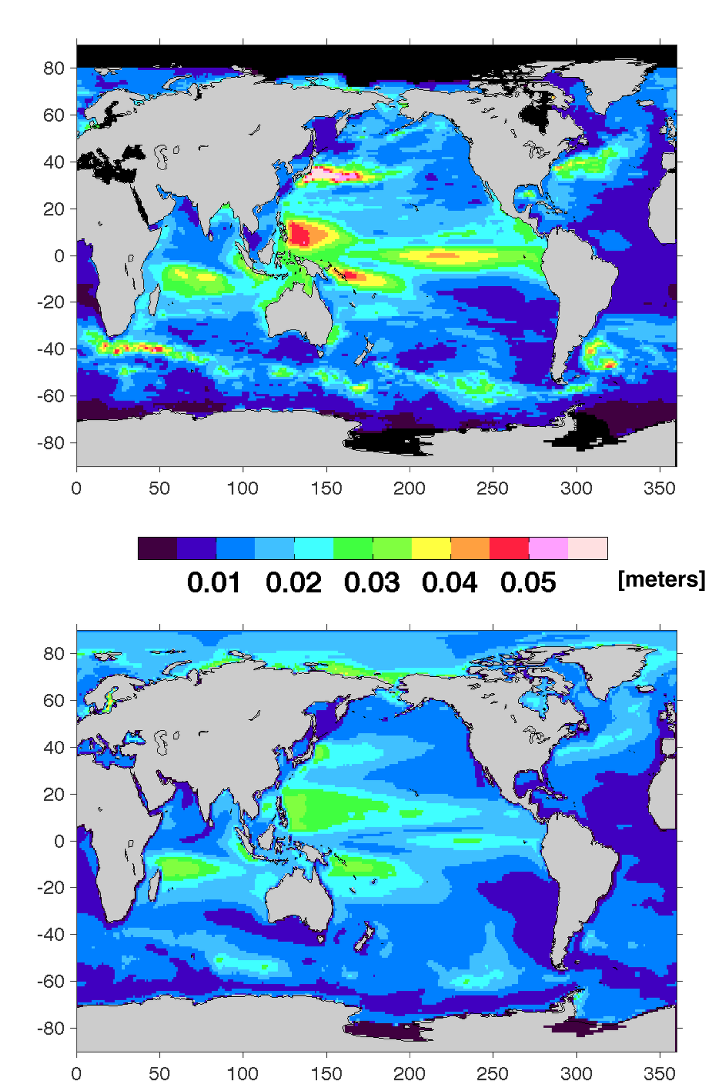


Fig. 9 Spatial patterns of interannual SSH variability of the AVISO observations (top) and the mean of the interannual variability patterns of the CMIP5 models (bottom). The monthly mean climatology has been subtracted, the data have been etrended, and a band-pass filter (1-10 years) has been applied.

4. Mean Annual Cycle SSH Amplitudes

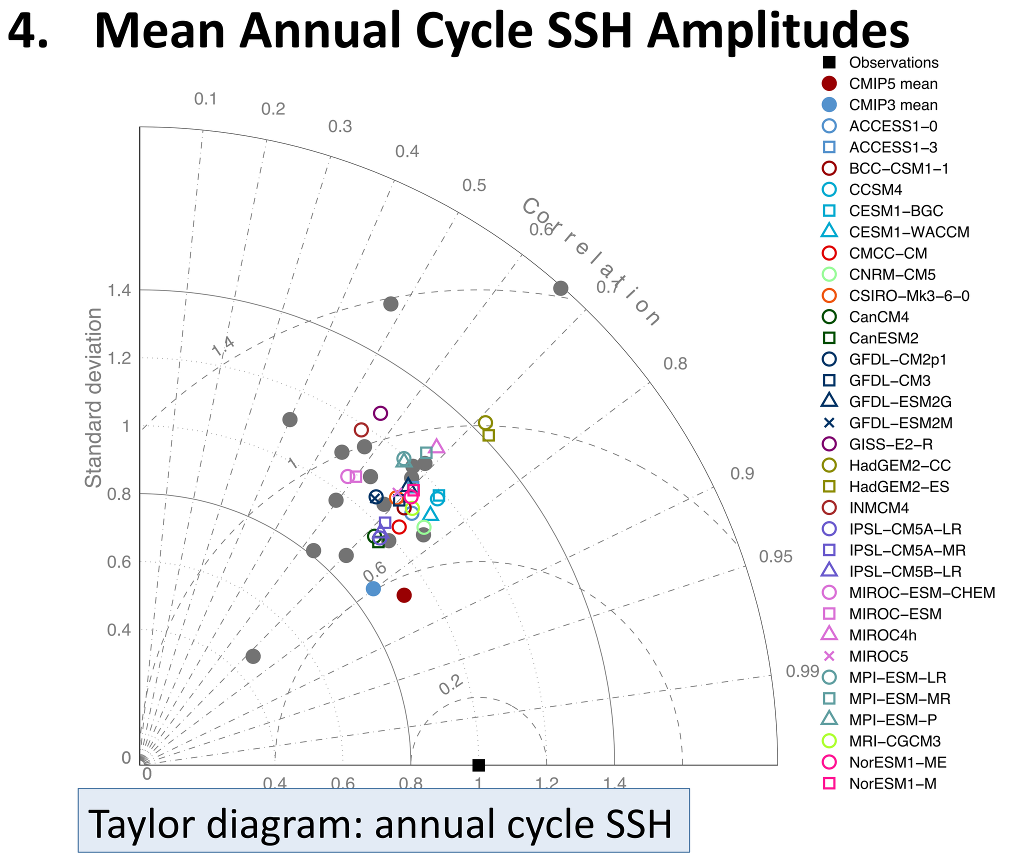


Fig. 10 Taylor diagram summarizing the normalized statistics of the mean monthly climatology SSH fields of the CMIP5 models (see legend), and CMIP3 models (grey dots). For each model, 12 monthly maps (from 20 years of data & observations) are used to compute the Taylor statistics.

Acknowledgements

We acknowledge the modeling groups, the Program for Climate Model Diagnosis and Intercomparison (PCMDI) and the WCRP's Working Group on Coupled Modelling (WGCM) for their roles in making available the WCRP CMIP3 & CMIP5 multi-model dataset. Support of this dataset is provided by the Office of Science, U.S. Department of Energy.

F.W.L.s work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.