Skillful climate forecasts using model-analogs

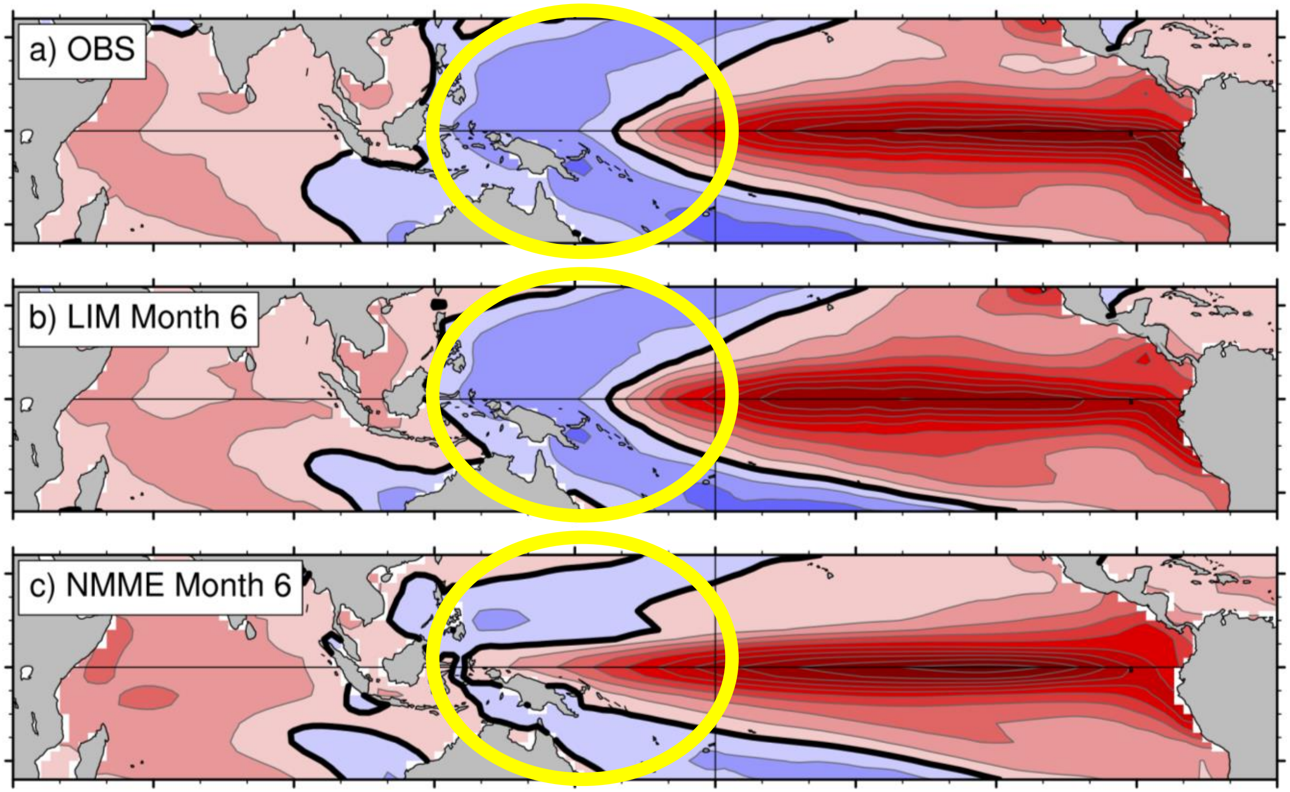
Hui Ding[1,2], Matt Newman[1,2], Mike Alexander[2], and Andrew Wittenberg[3]

1. CIRES, University of Colorado Boulder
2. NOAA ESRL PSD
3. NOAA GFDL

NCEP operational multi-model ensemble (NMME) forecast ENSO pattern is too far west

NMME forecast ENSO looks like coupled model ENSO as early as Month 2: *phase error in western tropical Pacific*

Leading EOF of observations and Month 6 forecasts



Some known climate model forecast issues

- Model drift: model's mean climate ≠ observed mean climate
  - *Fixes: bias correction (a posteriori), flux correction, anomaly model, nudging*
- Model states not in observed phase space
  - *Fixes: model output statistics, inflation of spread*
- Initialization shock: initialization not in model phase space
  - *Fixes: coupled data assimilation, anomaly model*
- This problem may be even worse for longer-range forecasts where deep ocean initialization matters

Alternative:
Initialize model in its phase space, not nature's phase space

Our stupid idea

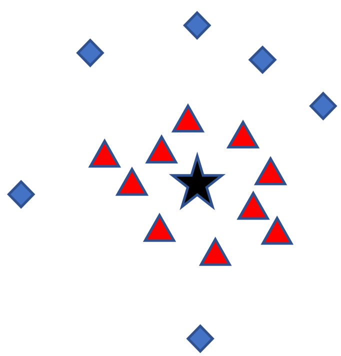
- Initialize the forecast with an ensemble of ***model states*** that are closest to the observed state
- Take these initial states from a long control run of a coupled GCM used to make climate forecasts
- In which case, since these states are fully in balance in the model, we already know how they will evolve

That is: *construct an analog model of the model itself from its long control run*

But then: *we don't need to run forecast model at all*

"Model-analog" technique

Analog training period (n years) | Remaining verification period (m years)



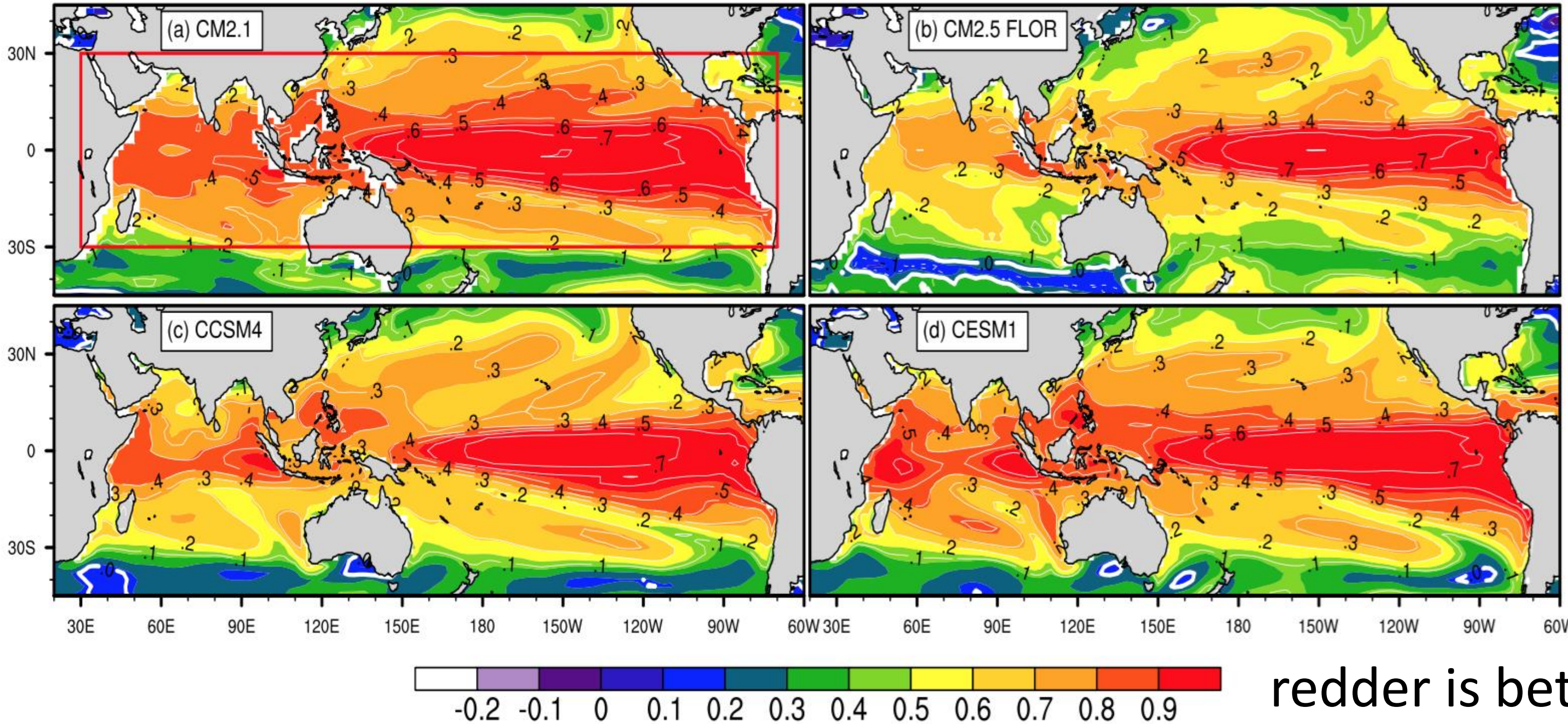
★ : a target state

▲ : analogs defined as the nearest *k* states to the target state

◆ : other states in the training period

- For a target state, analog ensemble is the *k* nearest states, defined by root-mean-square (RMS) distance (used grid space; PC space instead is similar)
- No weighting of members: forecast is evolution of ensemble mean
- Analogs defined from monthly sea surface height (SSH) and sea surface temperature (SST) anomalies from the tropical Indo-Pacific (30E-80W, 30S-30N); variables are equally weighted.
- Analogs are constrained to be from the same calendar month.

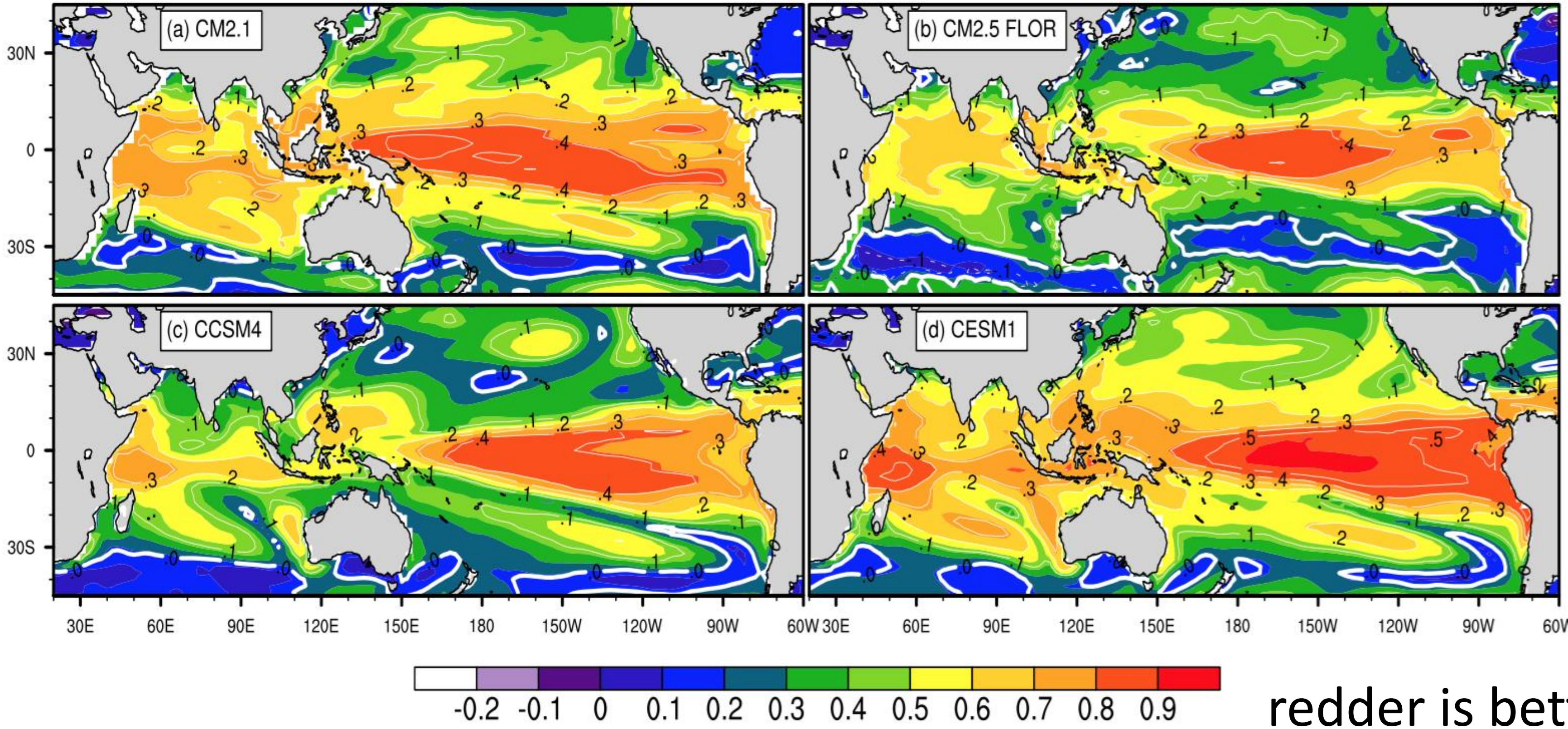
Ensemble mean analog representation of target anomalies is just ok…



redder is better

Correlation (shaded) and rms skill score (contours; 1=no error) of ensemble mean analog initial condition with target anomaly

… but model-analog captures perfect model skill



redder is better

Correlation (shaded) and rms skill score (contours ; 1=no error) of ensemble mean analog forecasts with verification anomaly at 6 month lead

For perfect model skill, AC^2 + standard $error^2$ = 1. Mostly true within 1%.

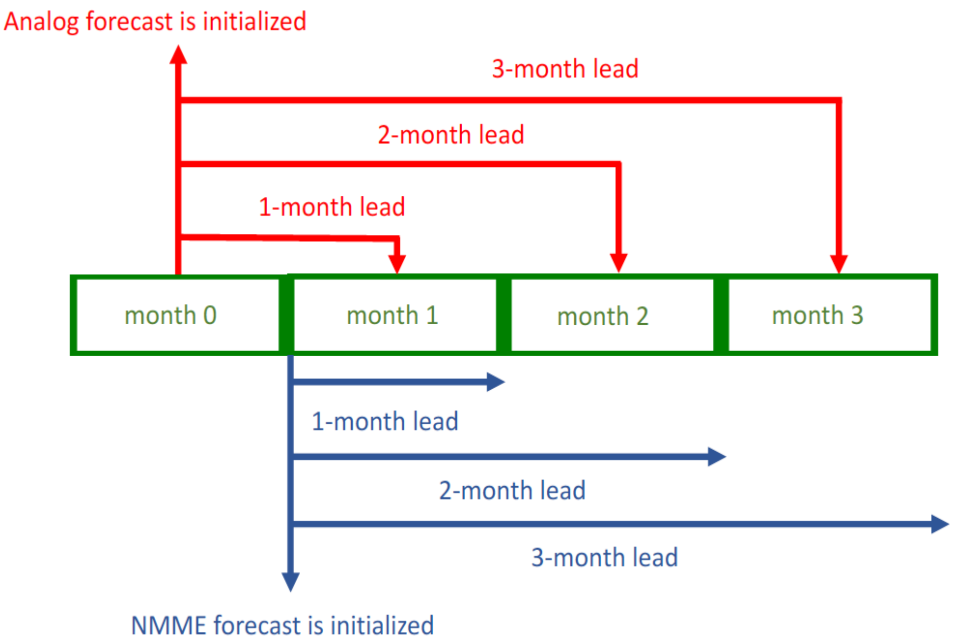
Model-analog hindcasts, 1982-2009

<u>For each CGCM control run:</u>

Analog ensembles found for observed target states (Dec 1981 - Nov 2009 monthly anomalies, ORA-S4 SSHs / NOAA OISST.v2 SSTs)

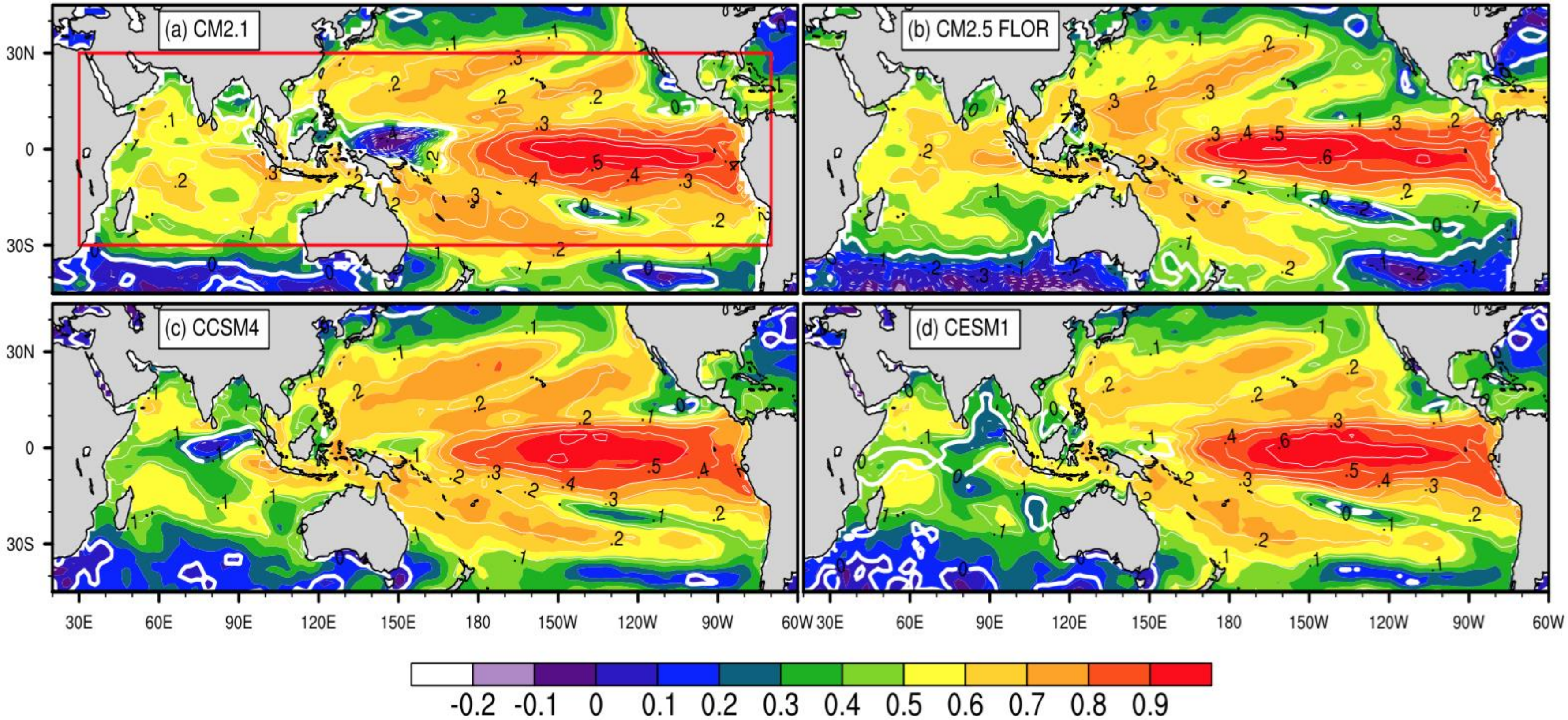
Hindcasts are the ensemble mean model-analog evolution.

Compare the hindcast skill of the model-analogs to the (roughly) corresponding CGCM hindcast skill in the NMME database.



Schematic of forecasts from the analog method and the NMME

Ensemble mean analog representation of observed target anomalies is still ok…



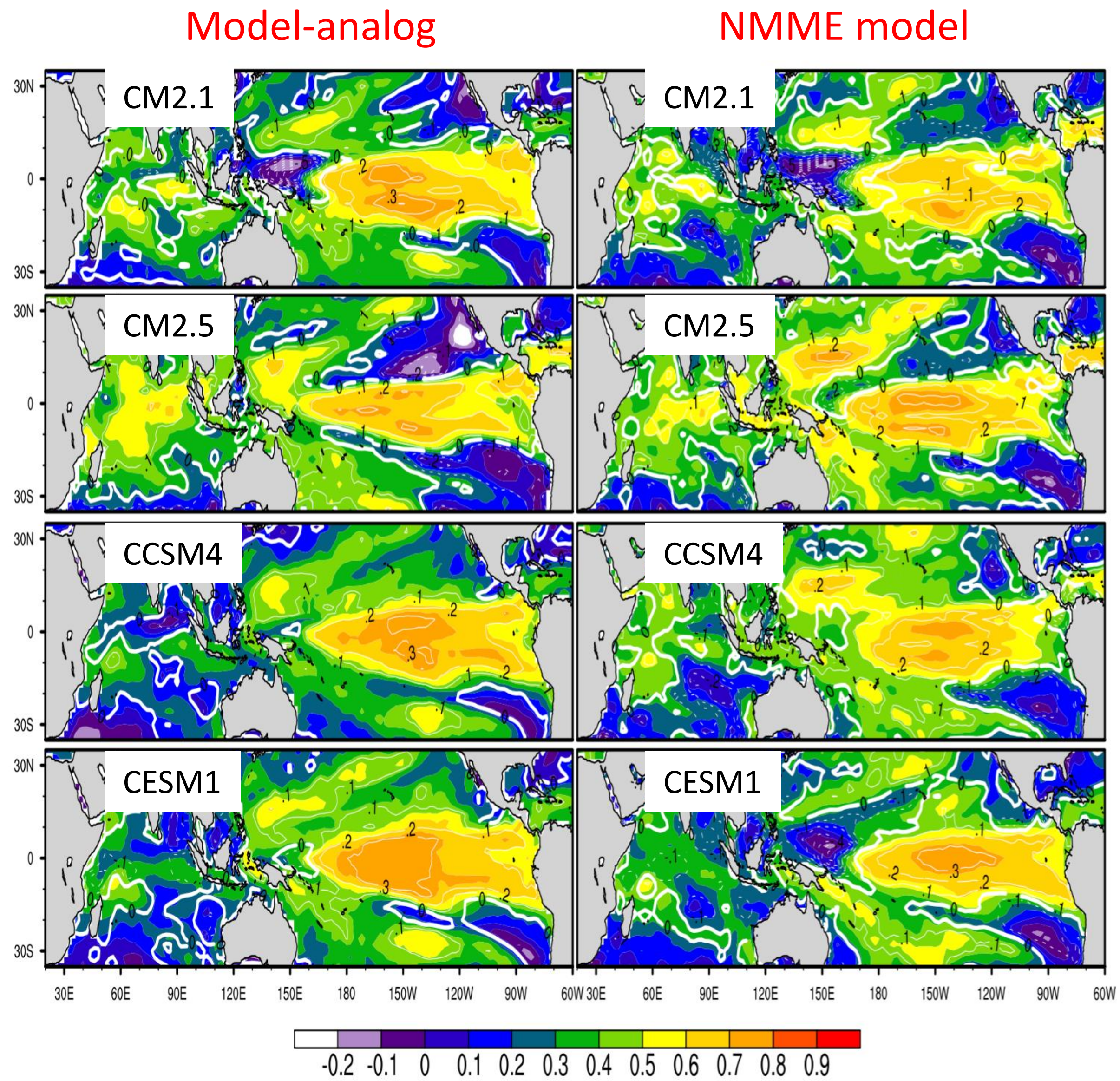
Correlation of ensemble mean analogs with target anomaly

Training run is entire control run for each model (varies in length)

… and model-analog skill compares well with corresponding model hindcast skill

Month 6 AC skill, 1982-2009

NMME hindcasts are bias-corrected



Equatorial SST skill, all models, Months 1-12

Correlation skill as function of forecast lead, SST averaged between 5ºS-5ºN

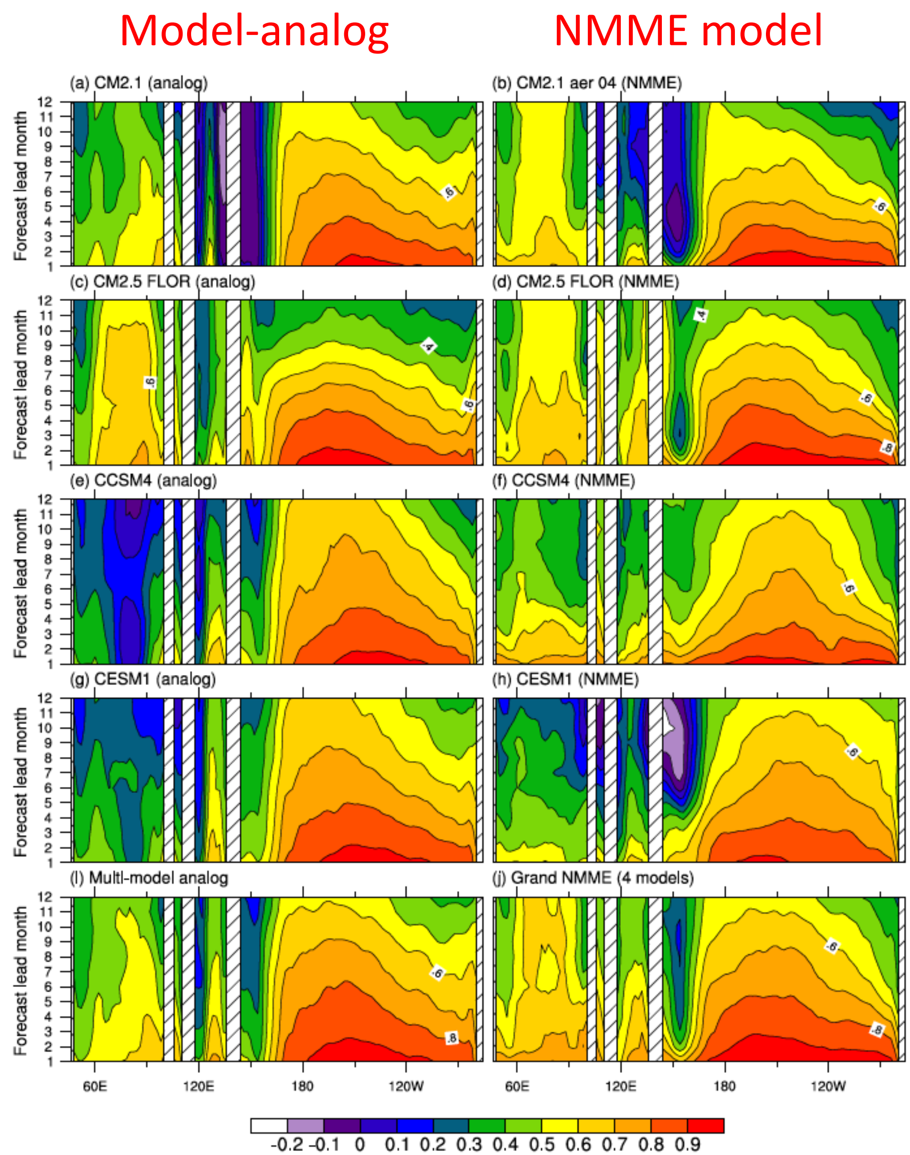
CM2.1

CM2.5 FLOR

CCSM4

CESM1

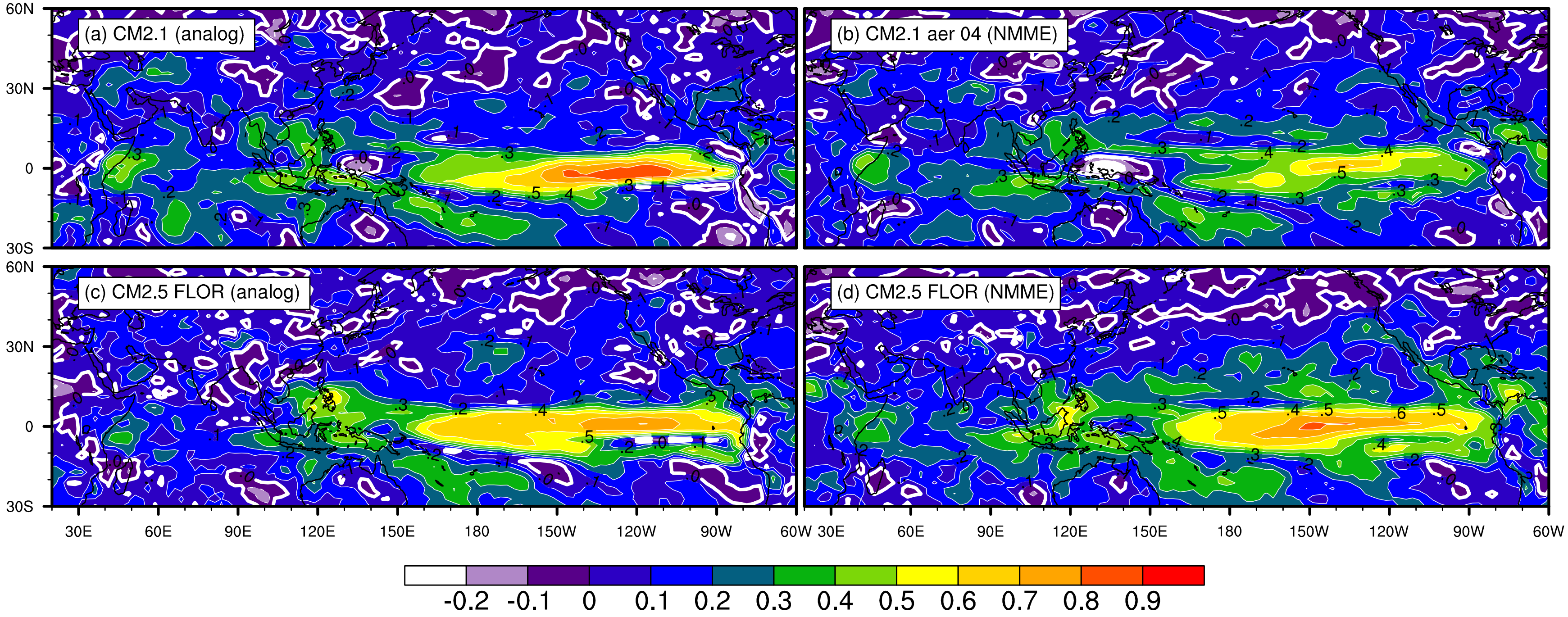
ensemble mean



Model-analogs capture Month 3 hindcast precipitation skill

Model-based analog forecasts

NMME hindcasts



Correlation (shaded) of precipitation forecasts with verification (CMAP) at 3 month lead

Note that analog is still based only on tropical SST/SSH

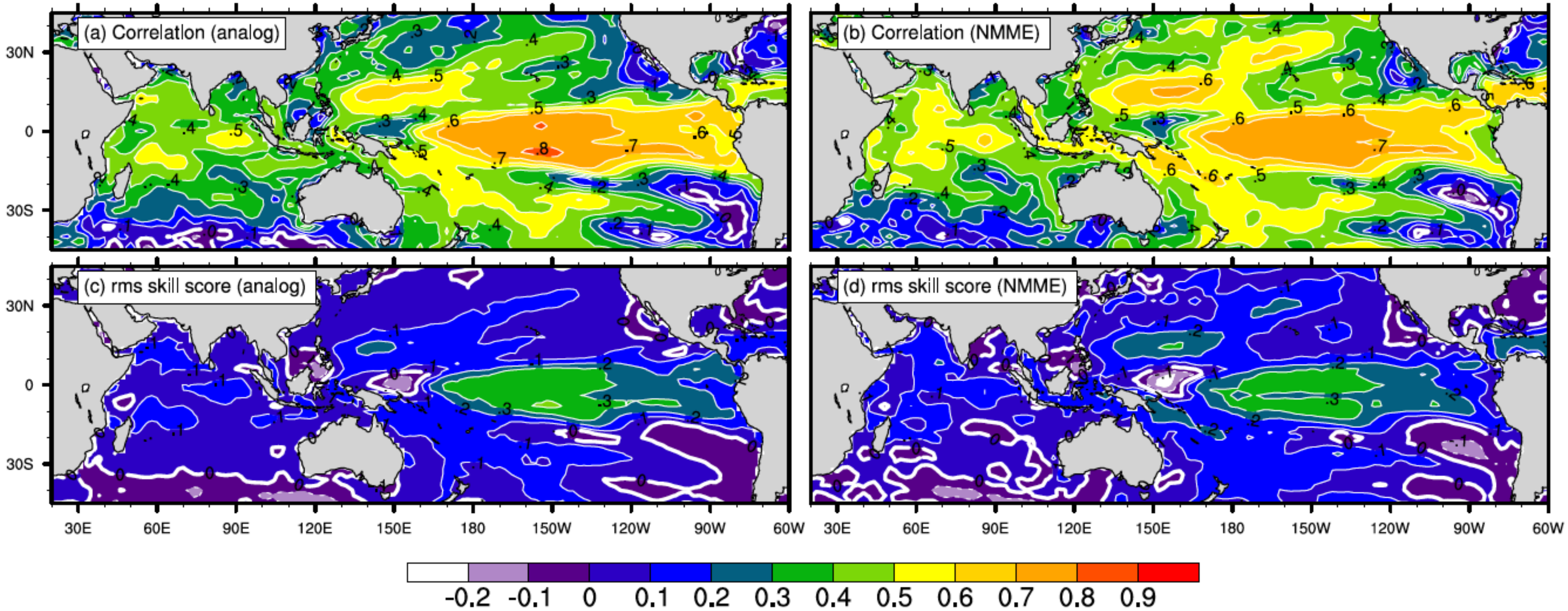
Concluding remarks

- Monthly tropical SST forecasts can be made from model-analogs of a long control run alone
- Questions:
  - Is greater model-analog skill due to better bias correction or reduced initialization shock?
  - Will this work for other variables, regions, and/or time scales?
  - Can any CGCM with a sufficiently long control run (500 years appears enough) produce skillful forecasts?

Month 6 multimodel hindcast SST skill

Model-based analog forecasts

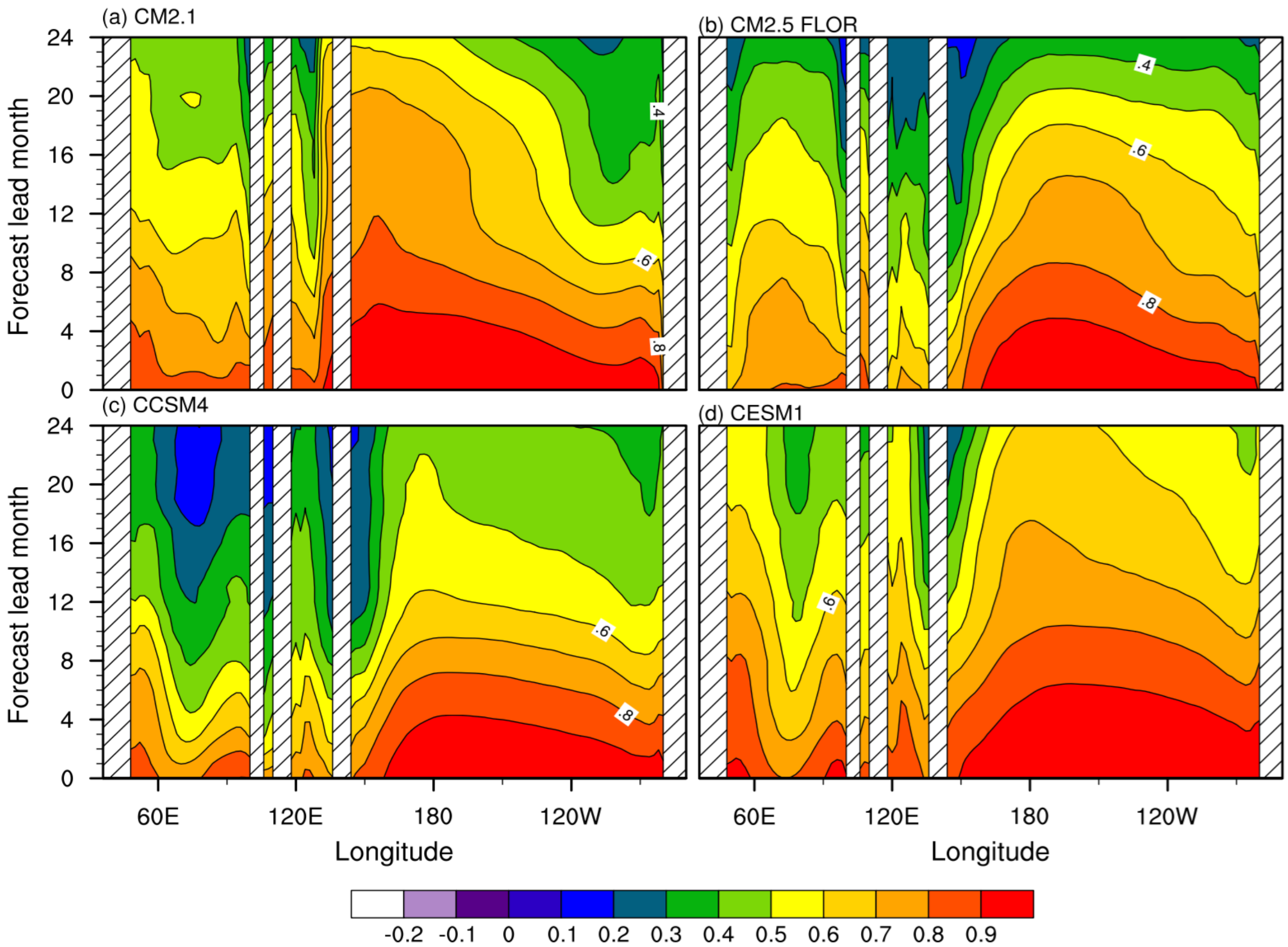
grand NMME-mean



- Model-analog ensemble mean: 10 members from each model (CM2.1, CM2.5 FLOR, CCSM4 and CESM1) = 40 ensemble members per forecast.
- Grand NMME mean: CM2.1, CM2.5 FLOR, CCSM4 and CESM1 NMME hindcasts

Equatorial model-analog perfect skill, all models

Correlation skill as function of forecast lead, SST averaged between 5ºS-5ºN



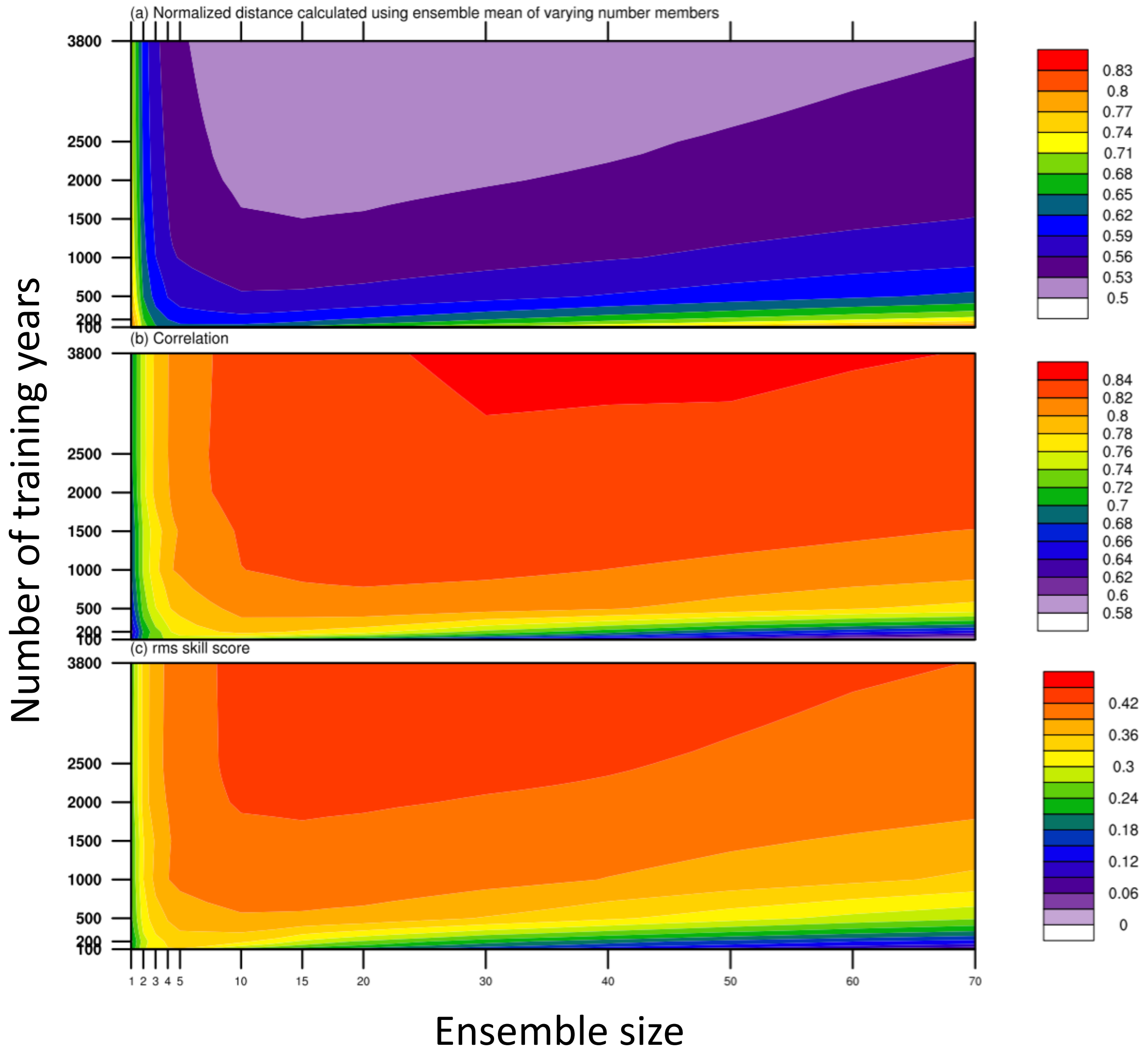
Sensitivity to ensemble and library size

GFDL CM2.1

Top: Average distance between target and ensemble mean

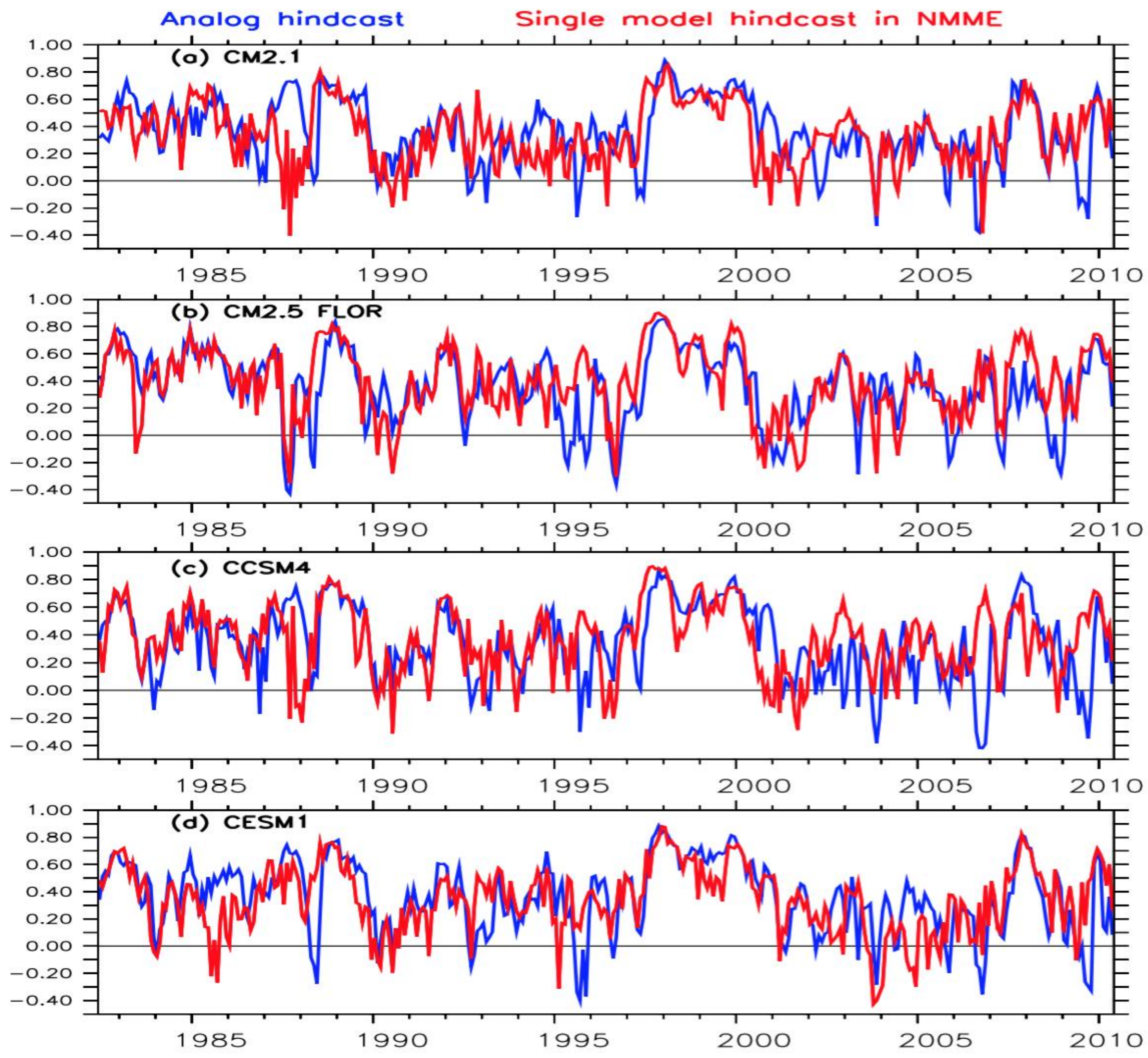
Middle: Pattern correlation skill at 6 month lead

Bottom: Domain rms skill score at 6 month lead



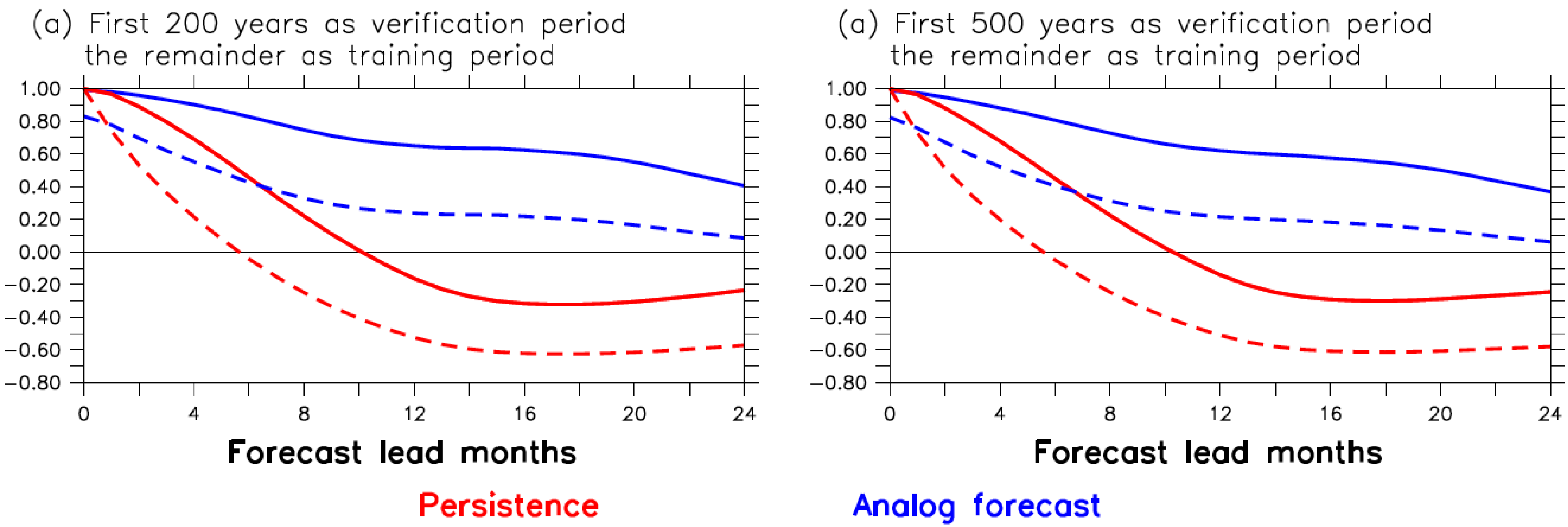
Time dependence of Month 6 skill

Pattern correlation of Month 6 hindcast and verification anomalies in the tropical IndoPacific



Tuning the length of verification period and testing robustness

Evaluation of analog forecasts in Nino3.4 SST by correlation (solid) and RMS skill score (dashed)



Evaluation of CM2.1-based analog reconstruction at initial conditions

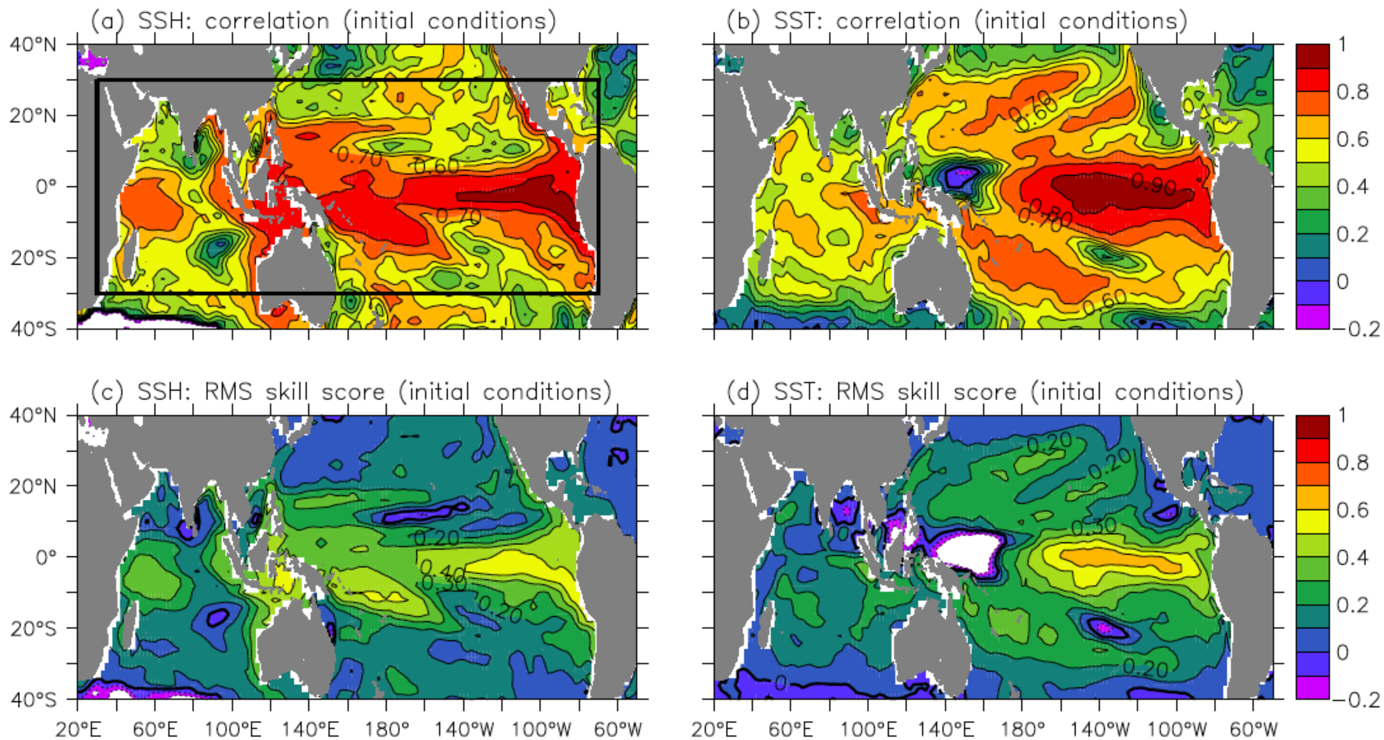
Analog are evaluated against ORA-S4 SSH (left) and NOAA OISST (right)

SSH

SST

Correlation

RMS skill score

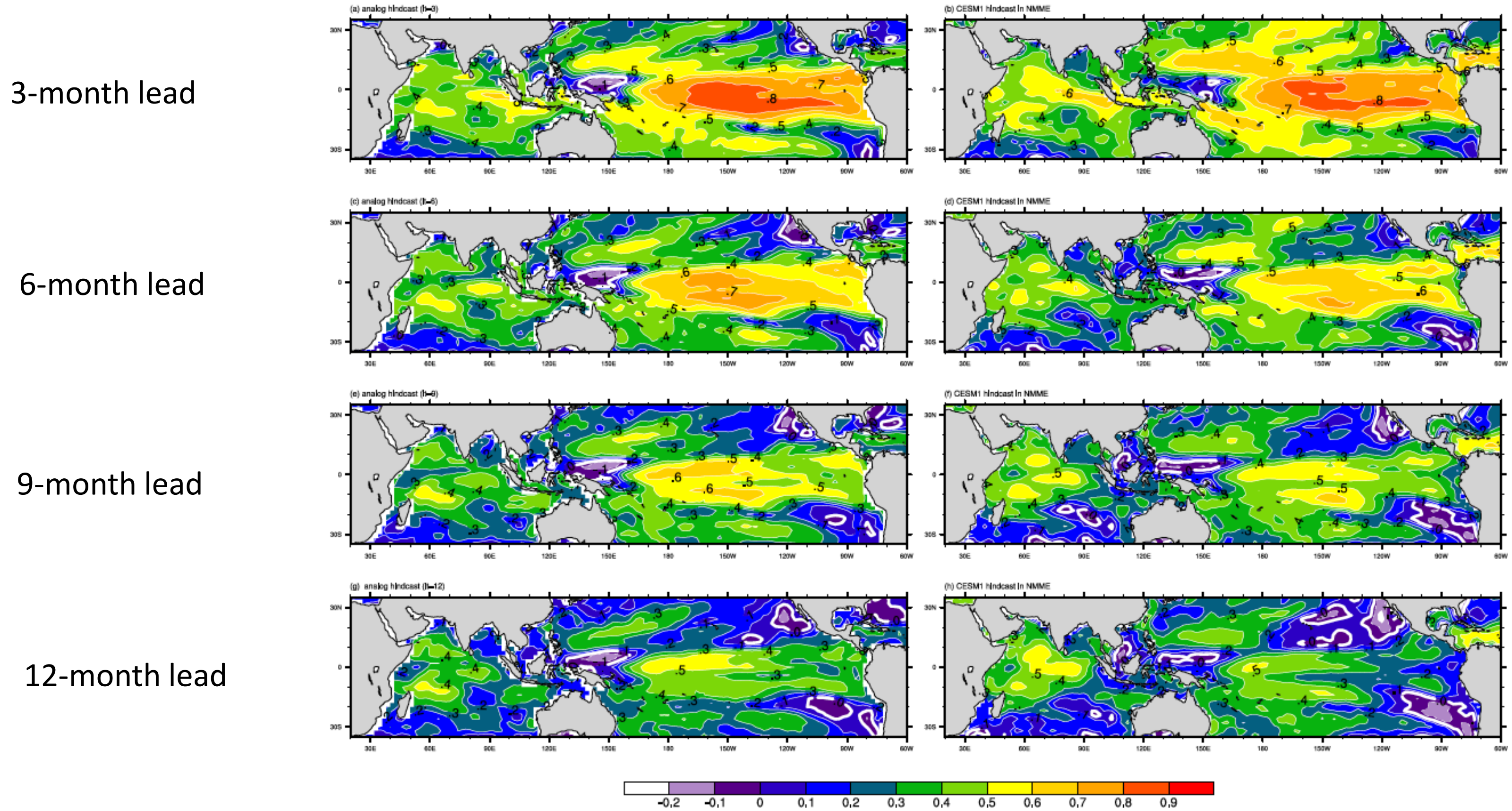


RMS skill score = 1 – standardized RMS error

SST forecast skill using correlation: CM2.1-based analog forecast vs CM2.1 aer 04 forecast in NMME

Analog forecast initialized between Dec 1981 and Nov 2009

CM2.1 aer04 forecast in NMME initialized between Jan 1982 and Dec 2009



SST-only observations-based analogs