The Indo-Pacific MJO Pathway:

Coupling, Physics and Continental Barriers to Propagation

Rich Neale and Cecile Hannay

Climate and Global Dynamics

National Center for Atmospheric Research (NCAR)

6th WGNE Workshop on Systematic Errors in Weather and Climate Models

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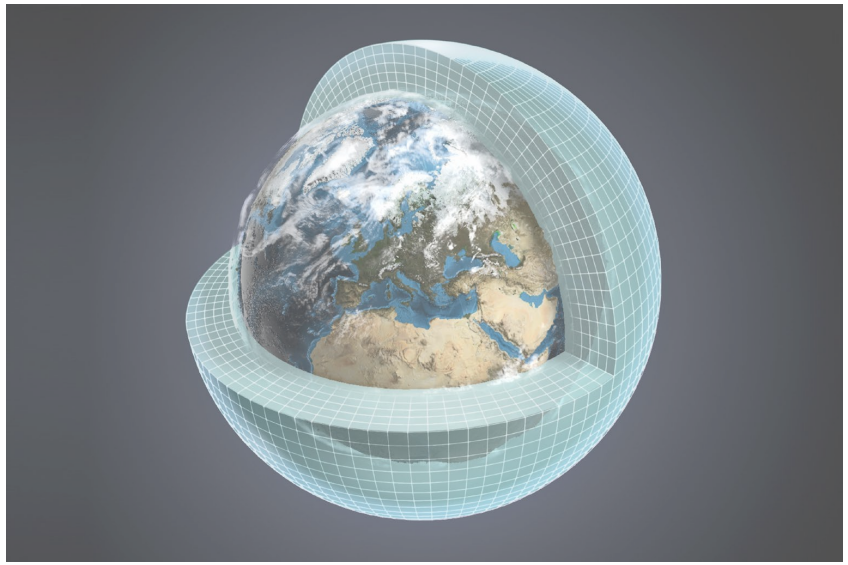
Outline

- The Madden Julian Oscillation
  - Largest-scale mode of convectively variability in the tropics
  - Envelope of multiple scales and phenomena
  - Tropical cyclones, equatorial waves, monsoons
  - Heating drives the global circulation
  - Teleconnections, Rossby wave, jet modulation
  - How will the MJO change in the future?
  - S2S (weeks->months) prediction and predictability

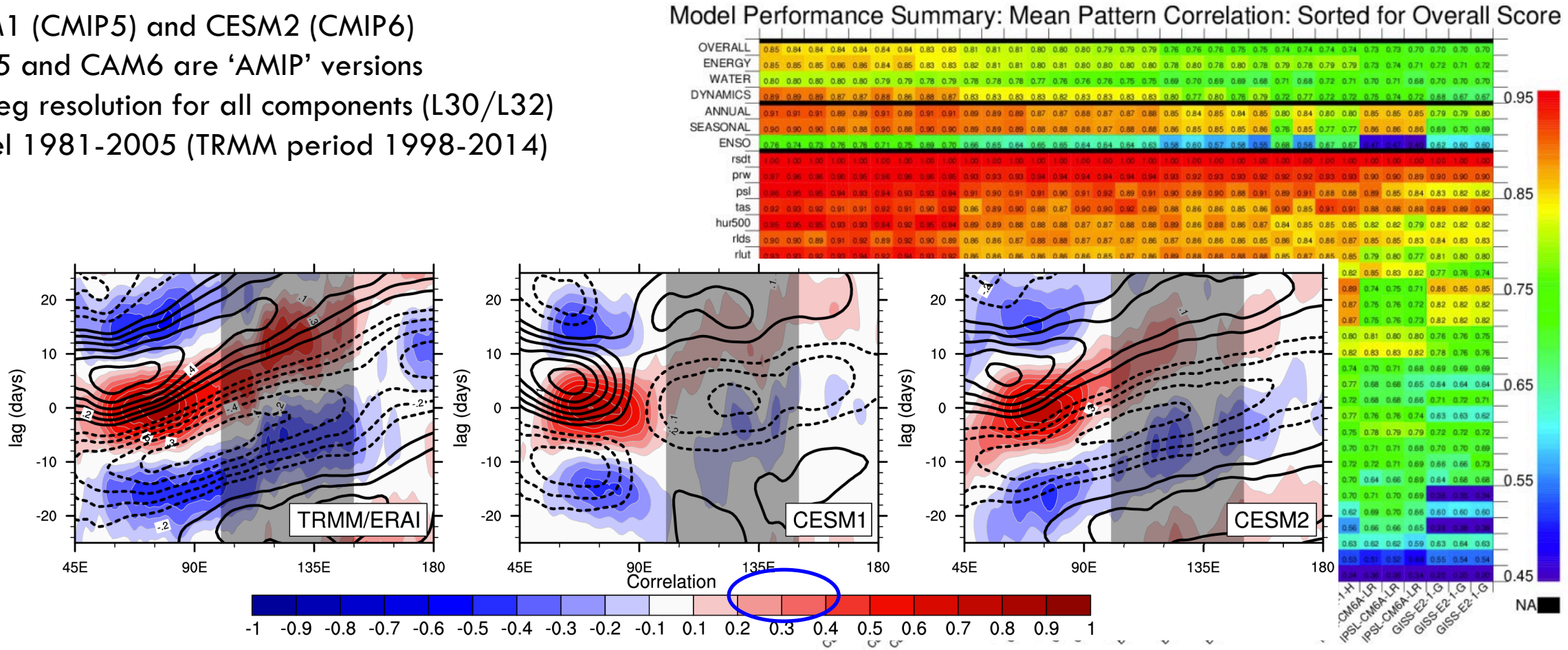


- Systematic errors
  - Frequency, amplitude, speed, growth, decay, coupling
  - Downstream impacts
  - Traversing maritime continent

The MJO in the Community Earth System Model (CESM)

Madden Julian Oscillation

- CESM1 (CMIP5) and CESM2 (CMIP6)
- CAM5 and CAM6 are 'AMIP' versions
- ~1 deg resolution for all components (L30/L32)
- Model 1981-2005 (TRMM period 1998-2014)

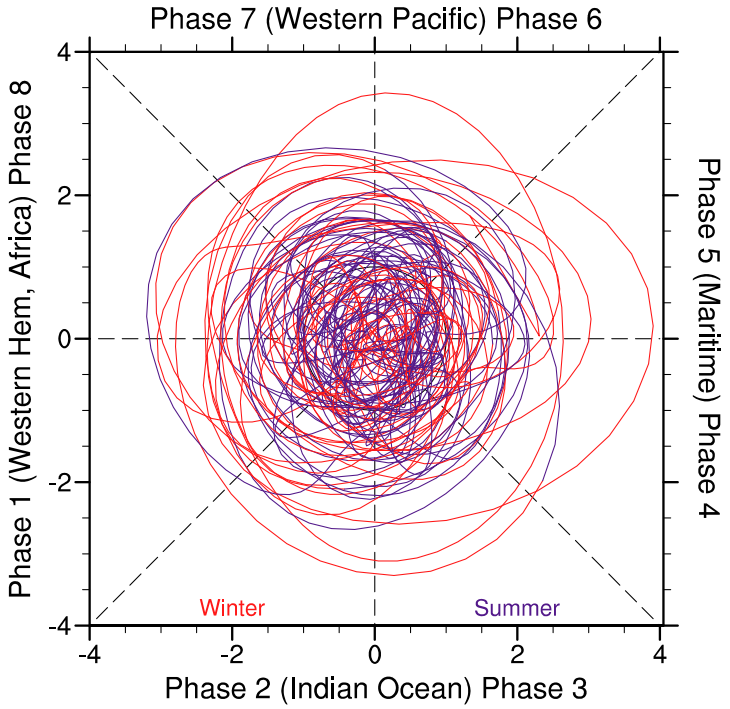


Lag-lead correlation of intraseasonal filtered precipitation (in the Indian Ocean) and U850

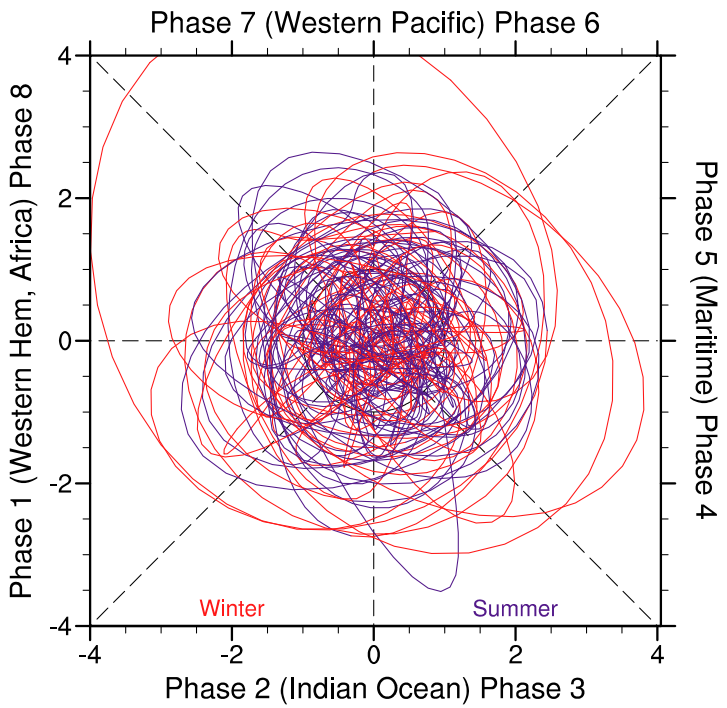
From Fasullo; Climate Model Analysis Tool (CMAT)

MJO Event Circuits (1990-1999)

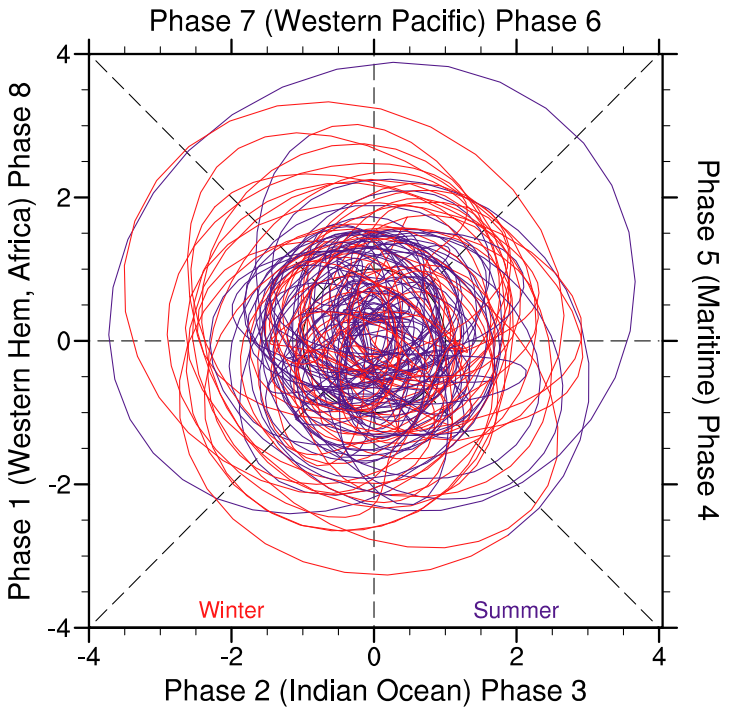
ERA-interim



CESM1



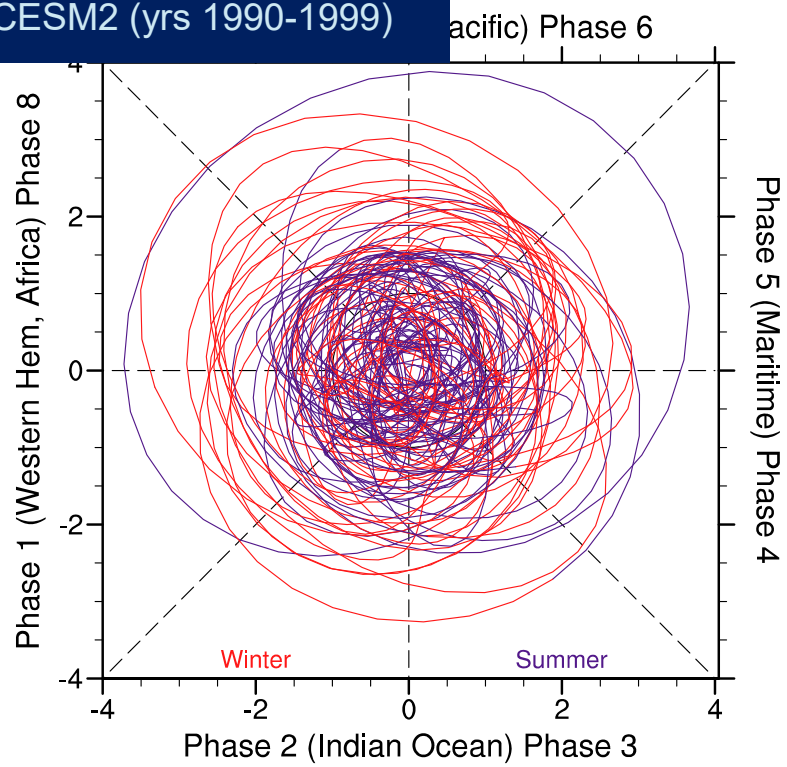
CESM2



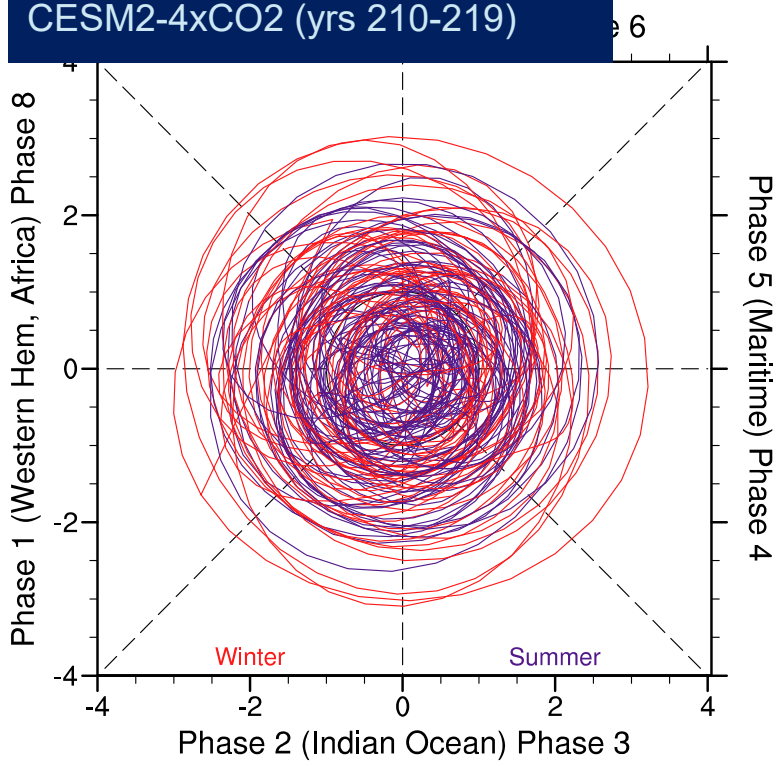
- CESM2 more complete/continuous circuits; dominance of Winter over Summer
- CESM1 fewer continuous events; more Summer events on the whole
- **BUT:** large continuous events are possible: Implies physics can support an MJO

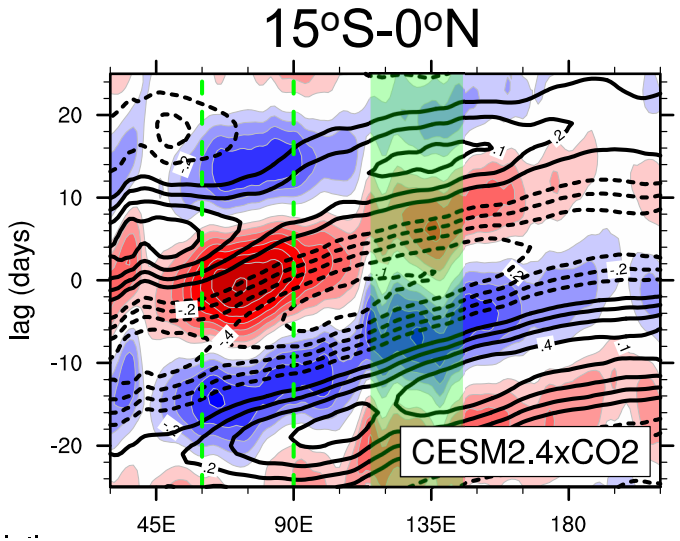
MJO Event Changes (Future)

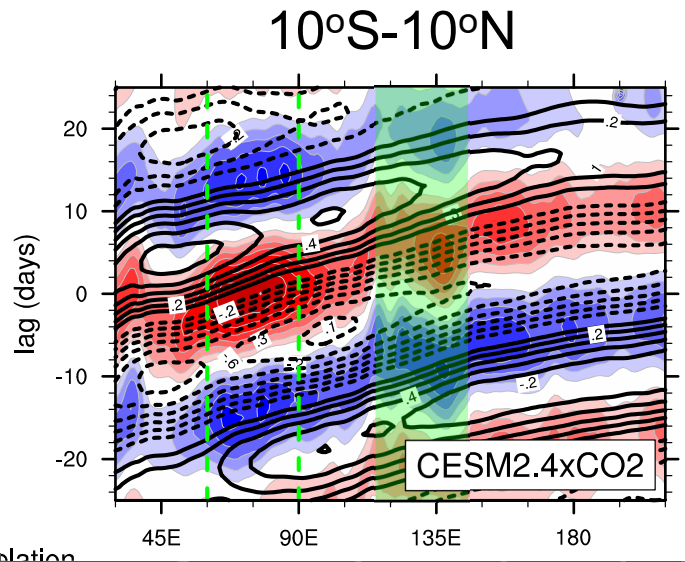
CESM2 (yrs 1990-1999)



CESM2-4xCO2 (yrs 210-219)



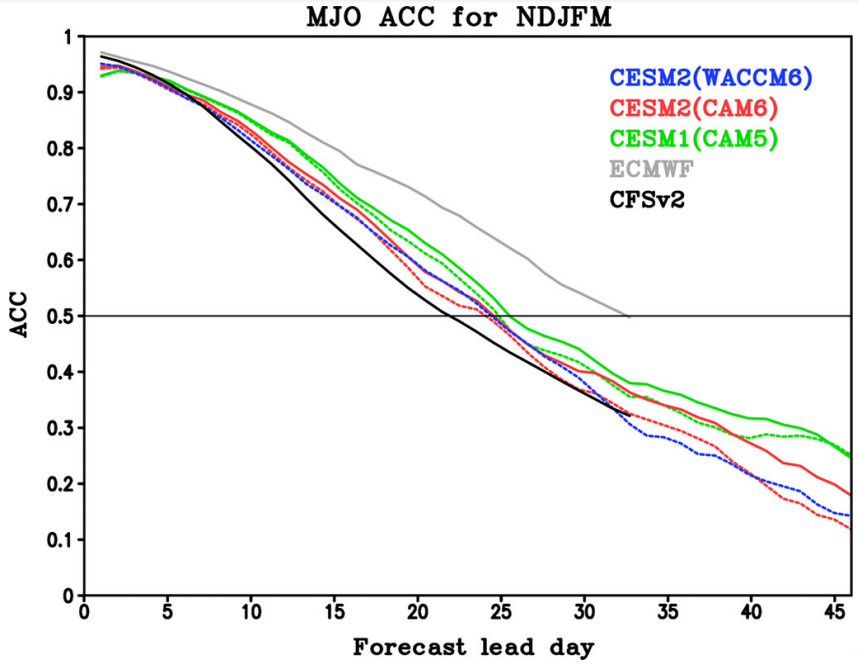




- 4xCO2
- More frequent complete circuits (predictability)
- Fewer very large events

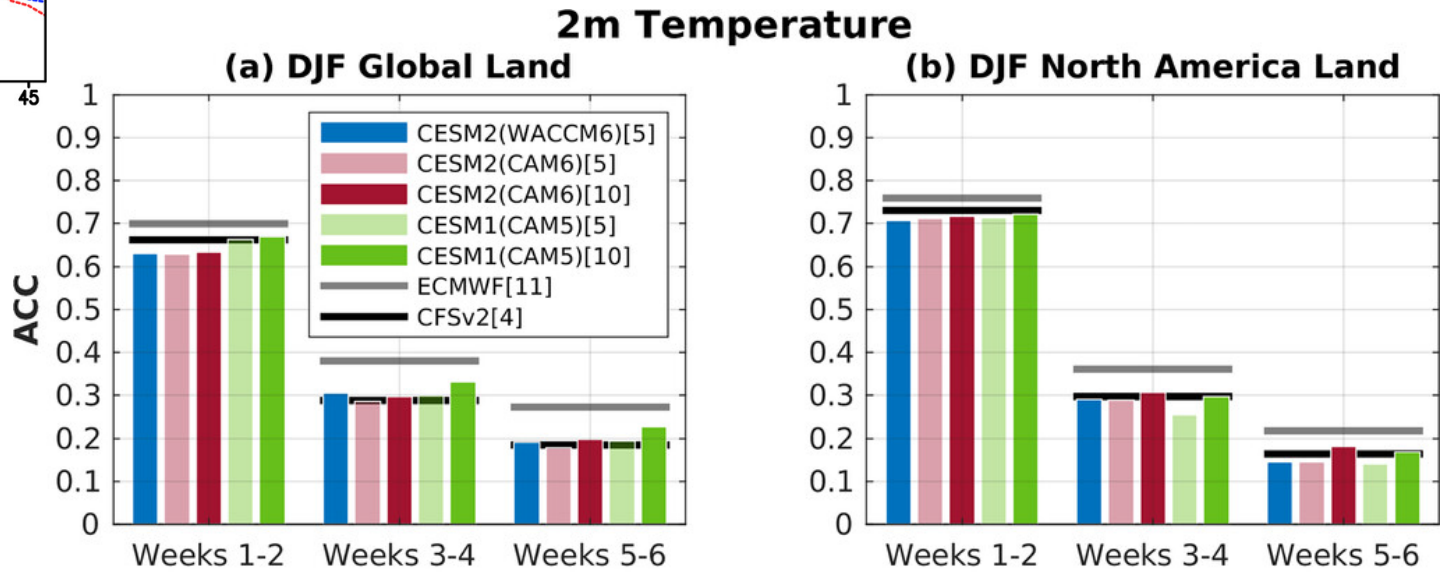
Bacmeister et al., 2021, *JAMES*

MJO and S2S Skill in CESM



Prediction Skill

- CESM1 (CAM5) and CESM2 (CAM6/WACCM6)
- 10 Ensemble members each
- Paradoxically CAM5 more skillful than CAM6 (MJO)
- North American TS skill contribution from the MJO?

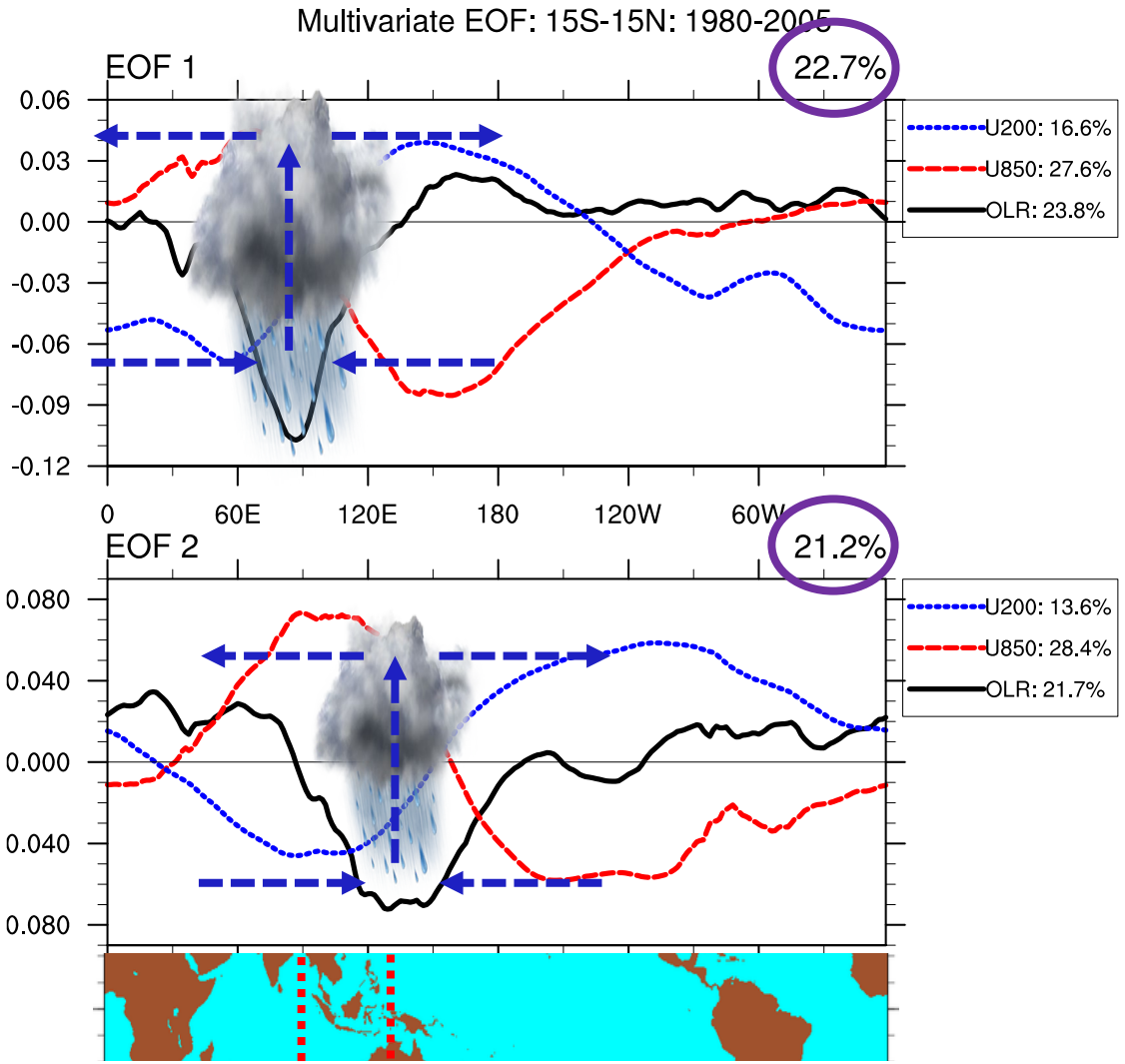


Richter et al., 2022: https://doi.org/10.1175/WAF-D-21-0163.1

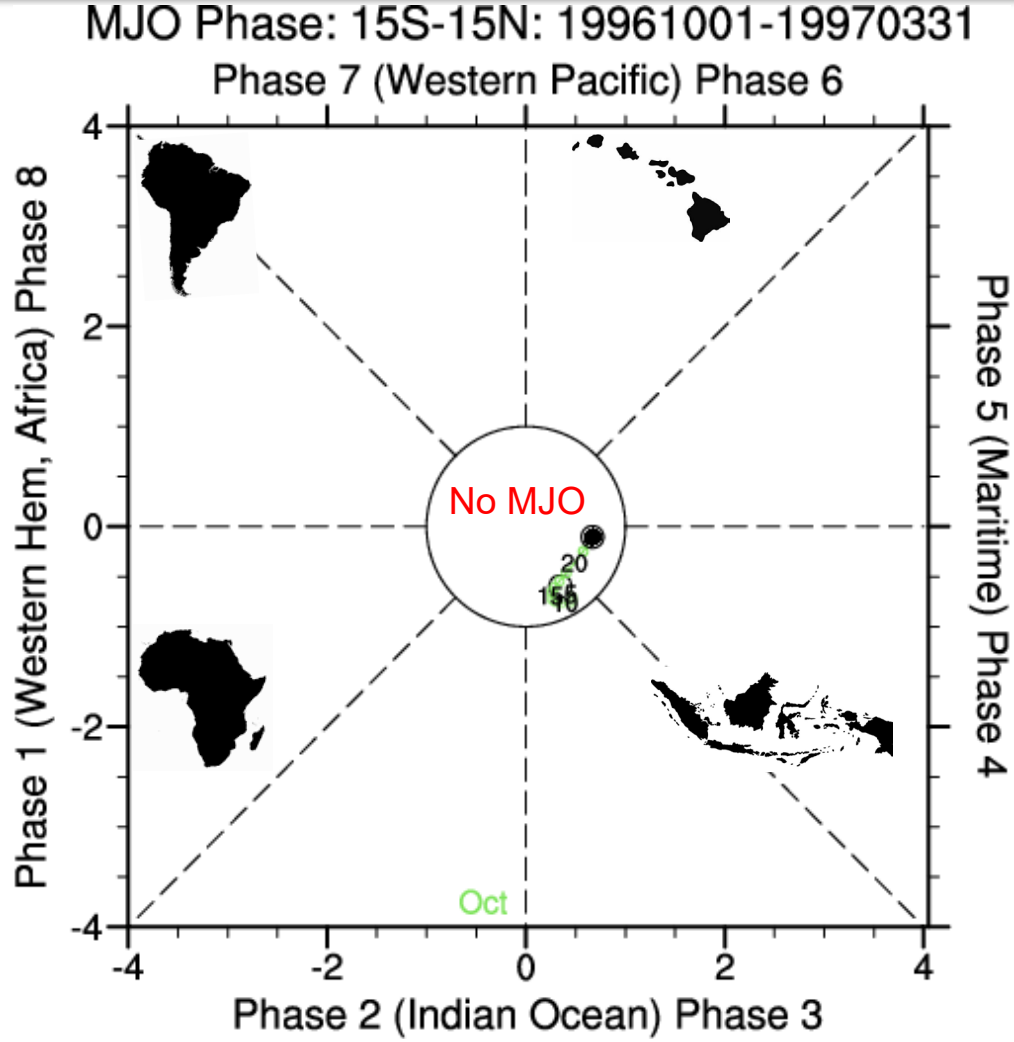
General Hypotheses (CESM1 -> CESM2)

- Indo-Pacific SST Gradients are important for the MJO
- The morphology of the Maritime Continent Impacts MJO characteristics
- Model physics 'configurations' modulate the MJO

MJO Metrics

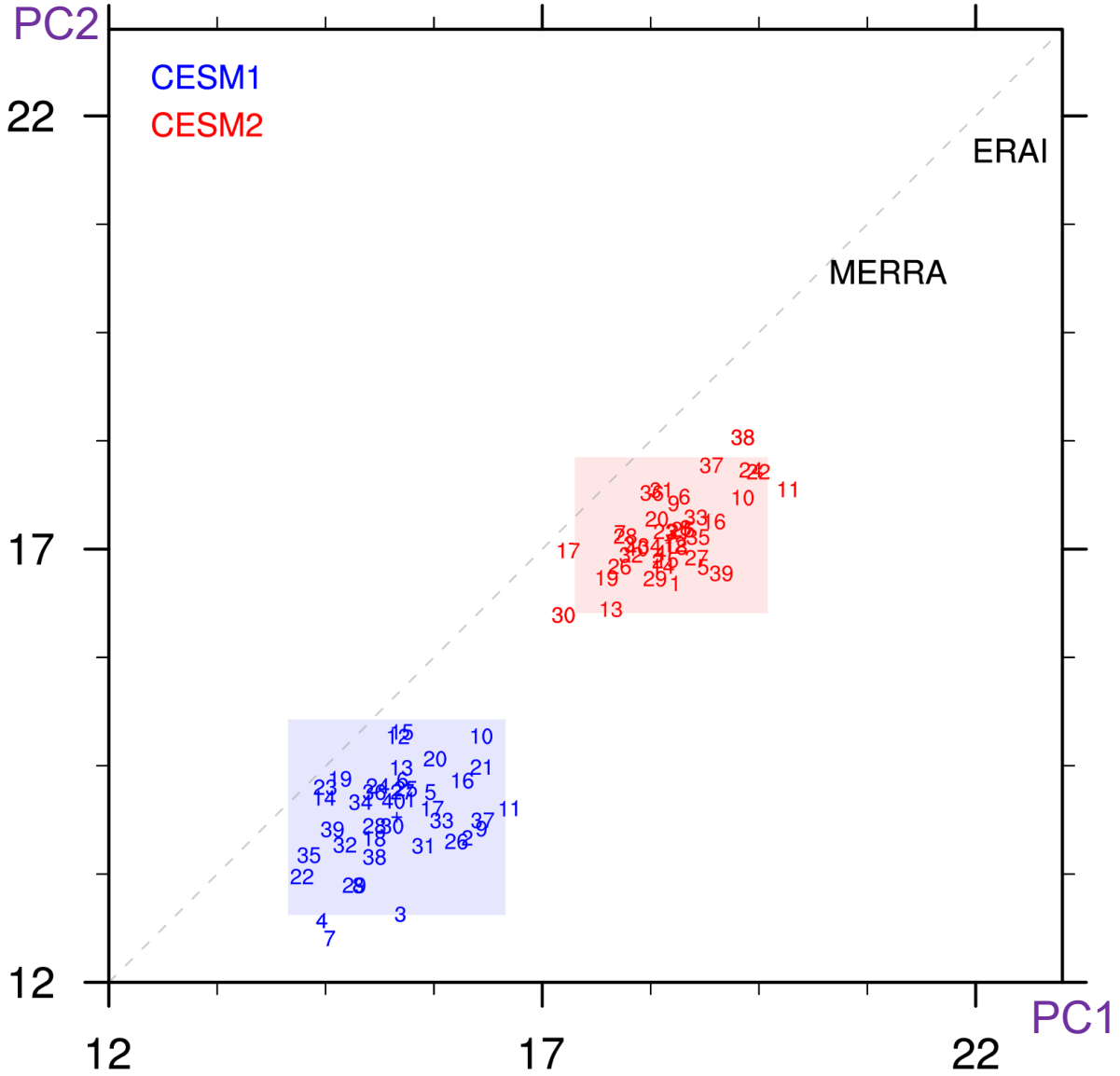


Kim et al., (2009) J. Climate (MJO Task Force)



ERA-interim: U850/200
NOAA: OLR

Coupled Model MJO



Large Ensembles (LENS)

- CESM1 (LENS) and CESM2 (LENS2)
- 40 Ensemble members each
- Historical simulations (small surf. pres. perturbation)
- 1981-2005 (start 1850/1920)

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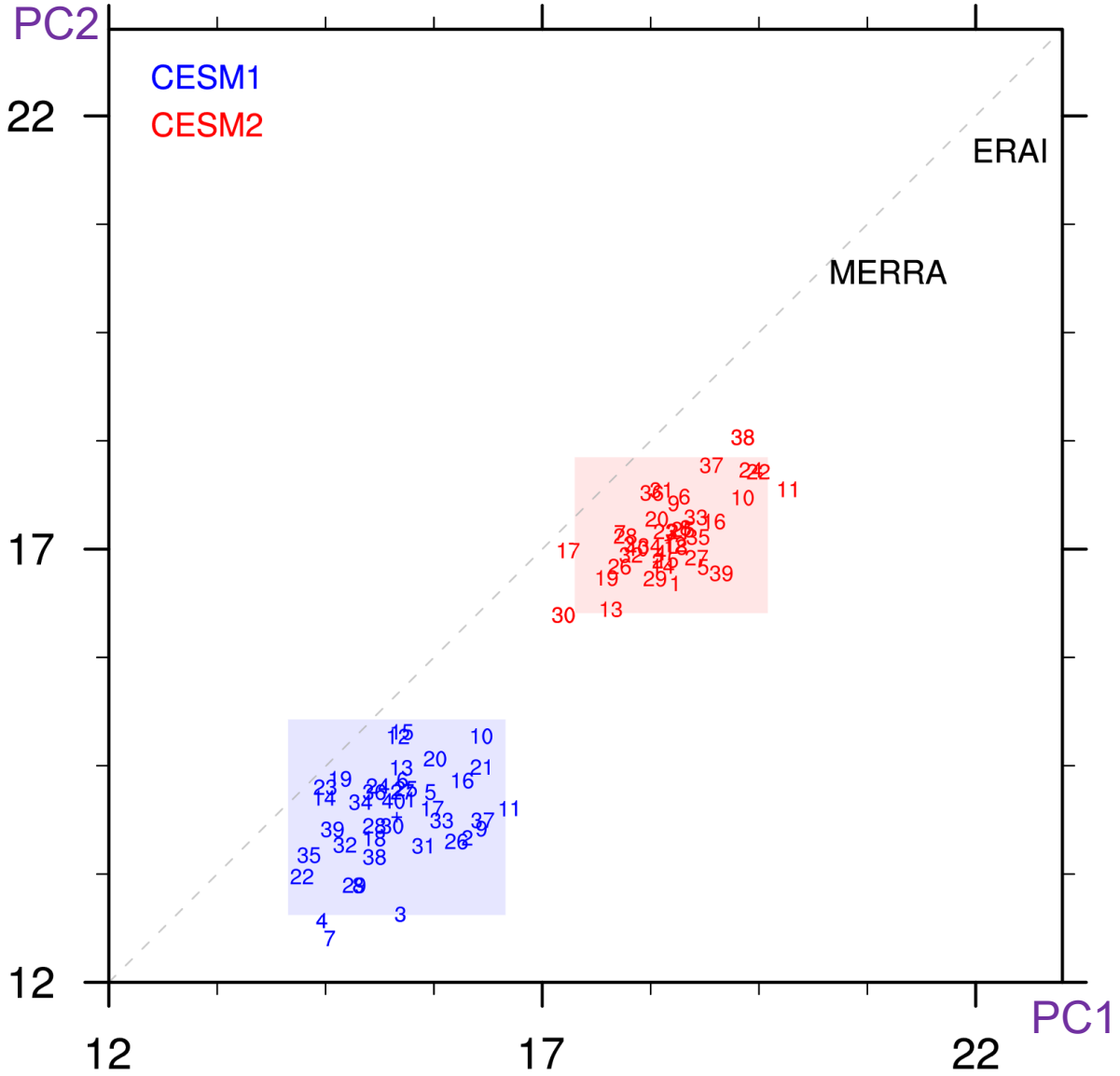

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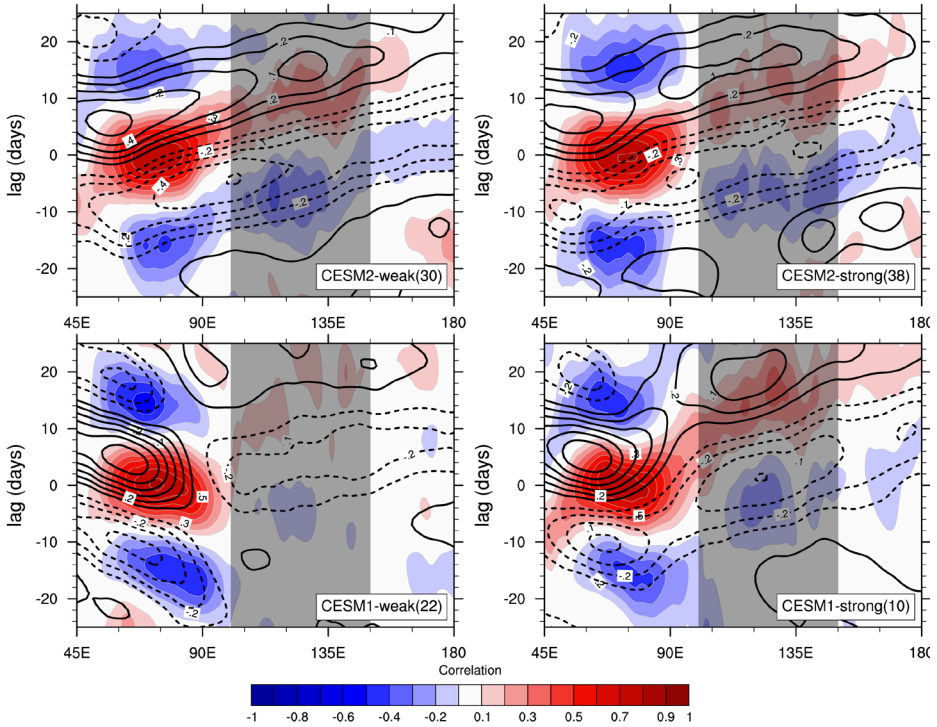
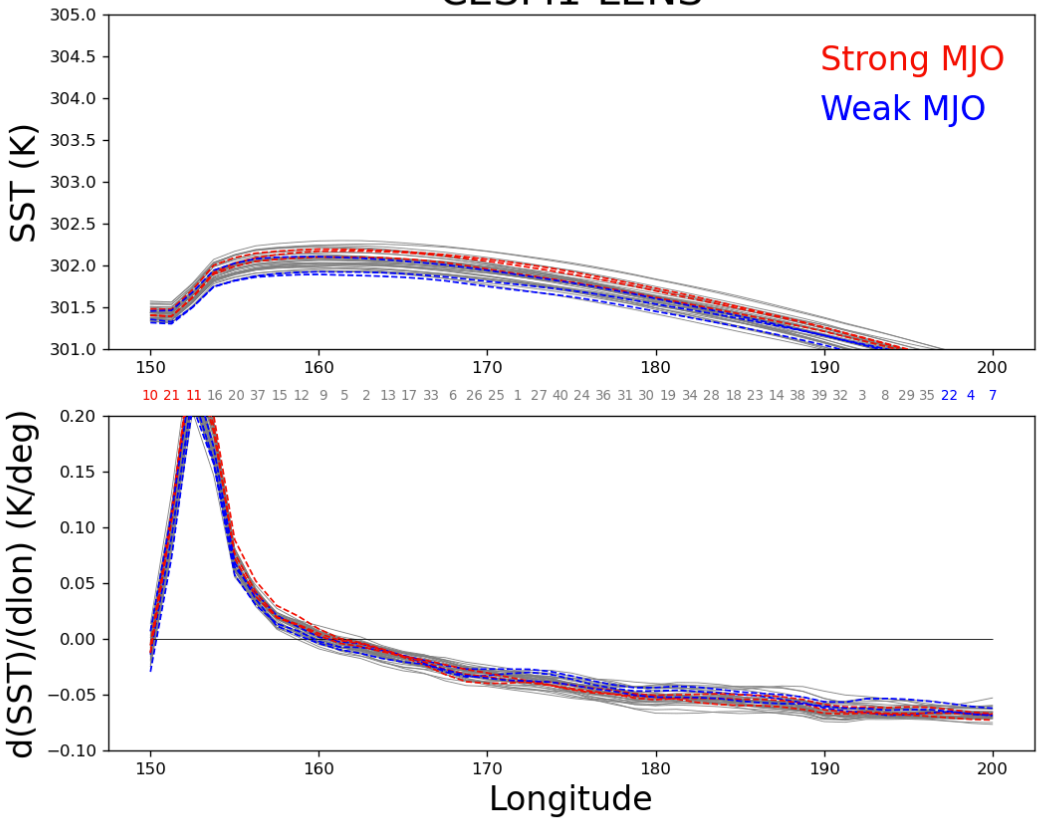


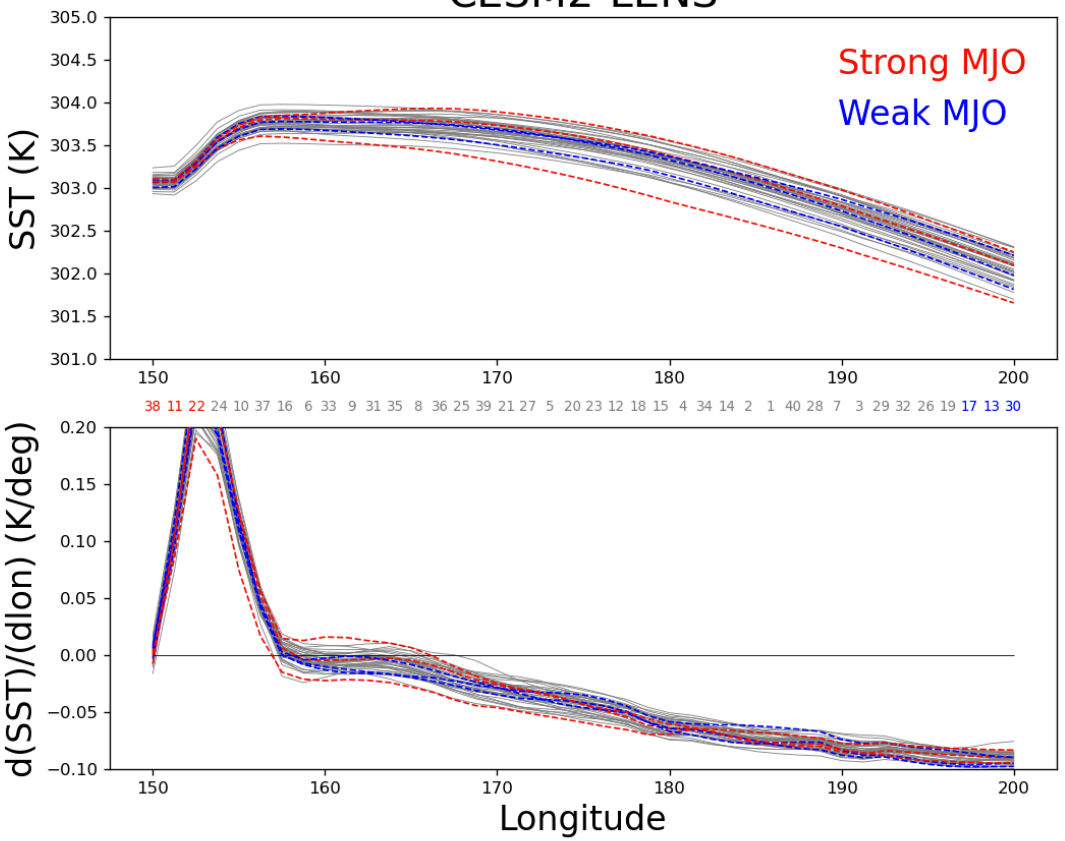
Sea Surface Temperature Dependent Variability?

WEST PACIFIC

CESM1-LENS

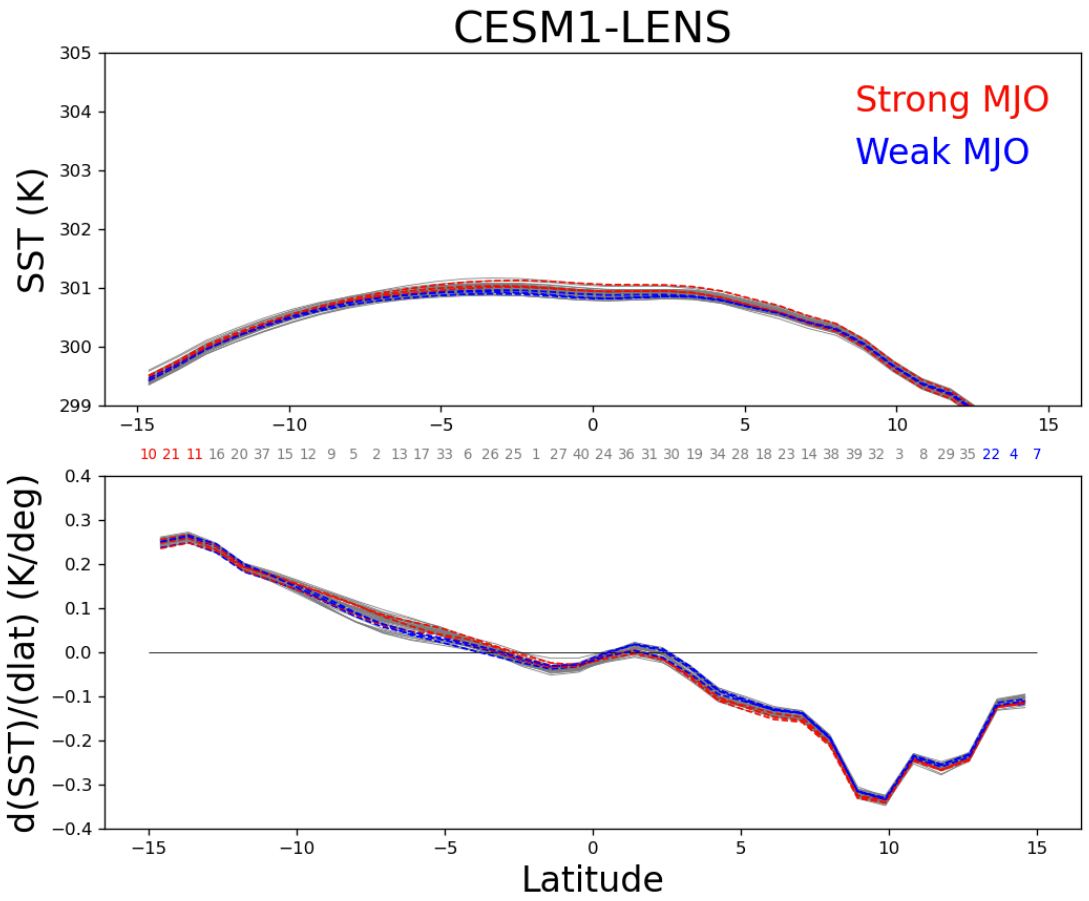


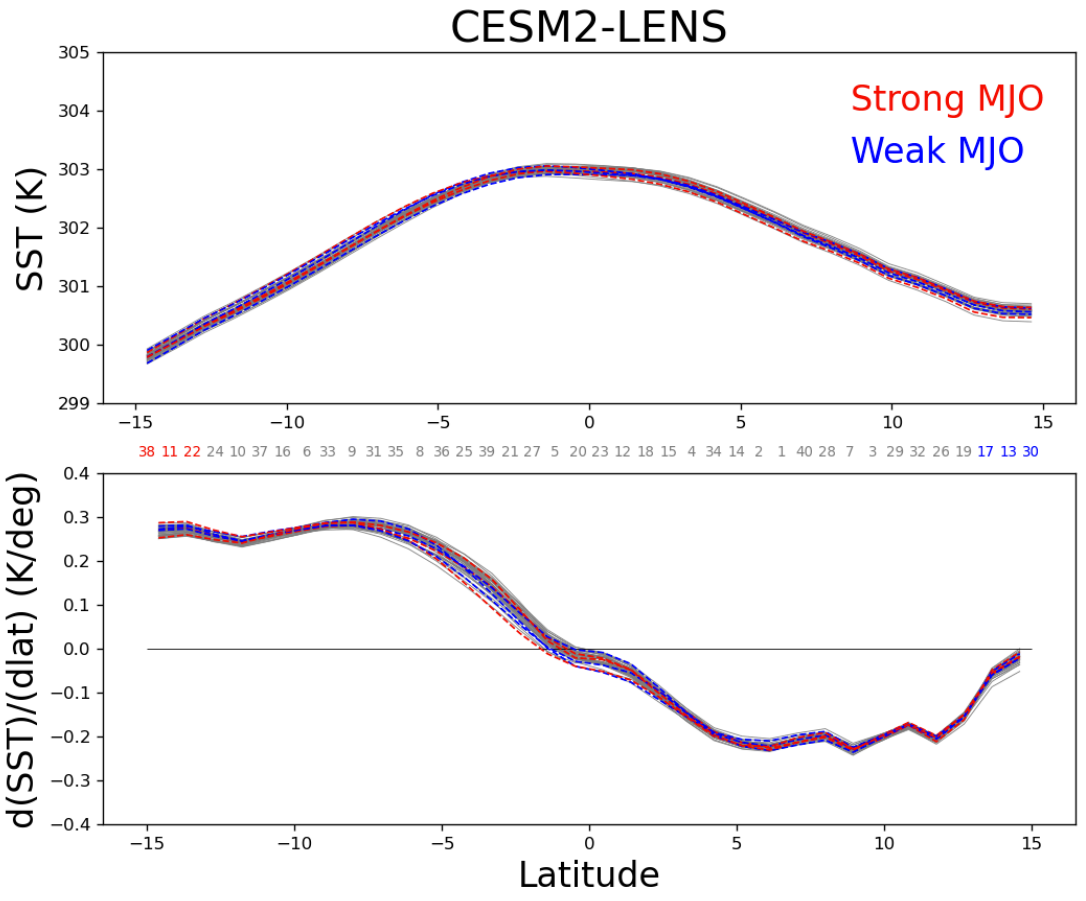
CESM2-LENS



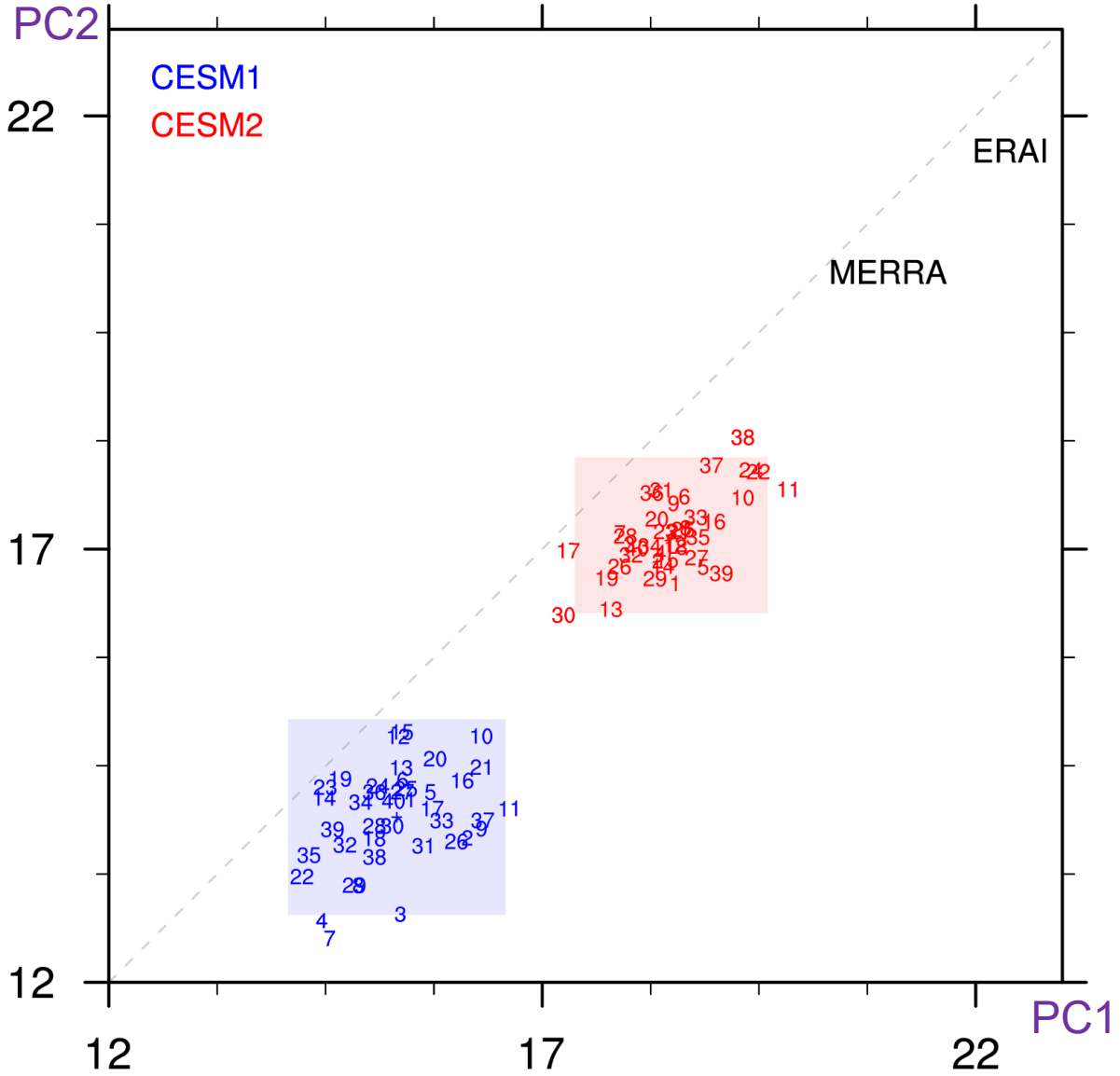
Sea Surface Temperature Dependent Variability?

INDIAN OCEAN





Coupled Model MJO



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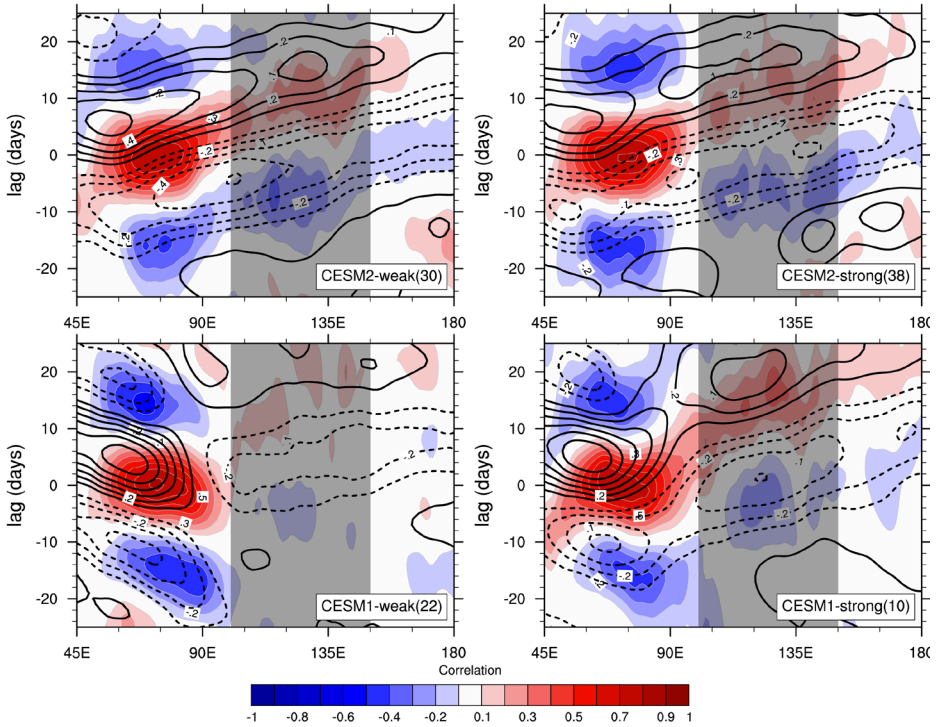

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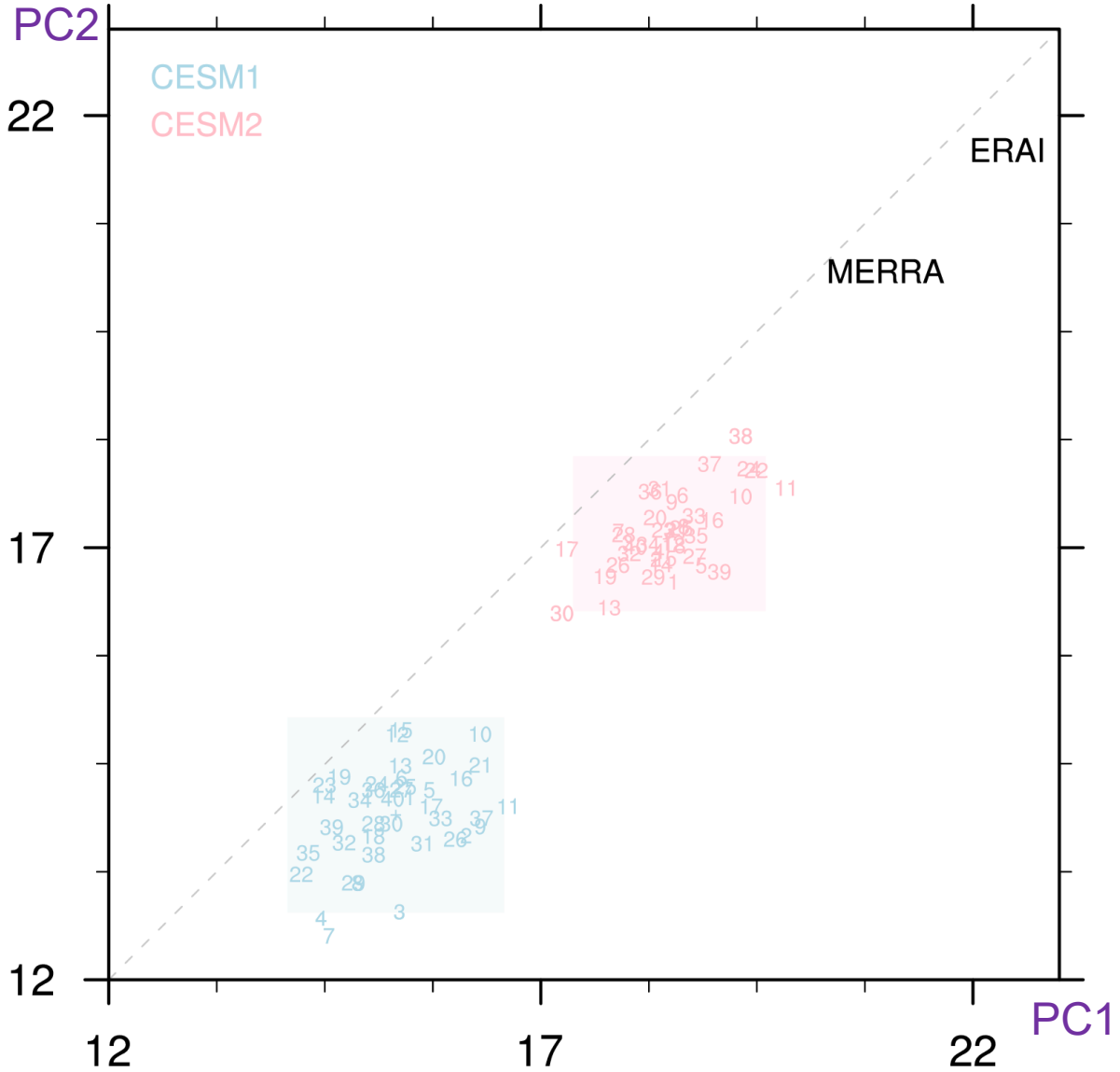

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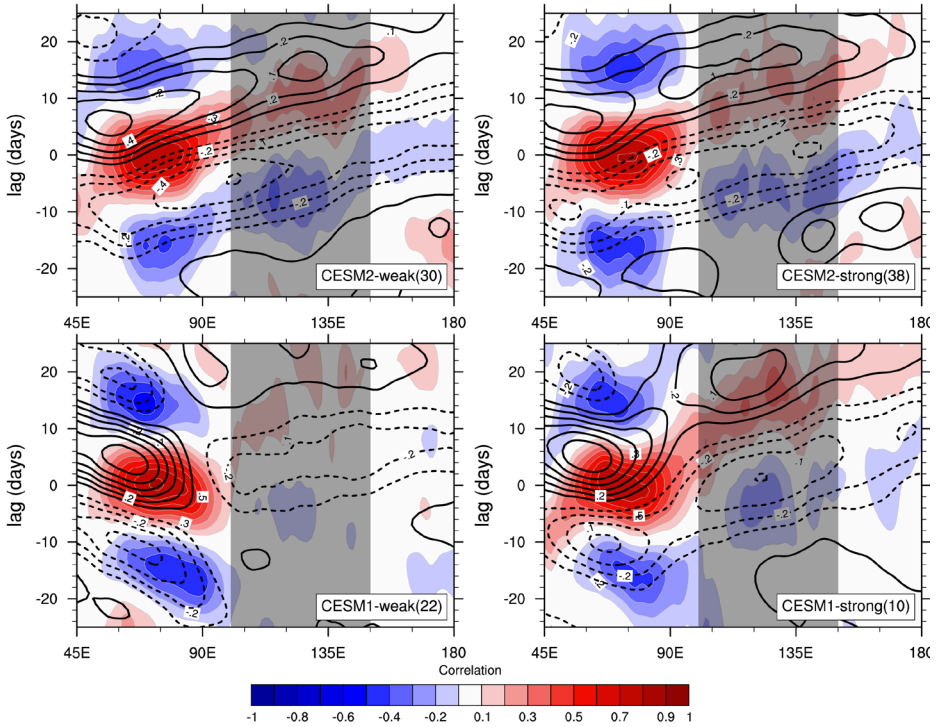
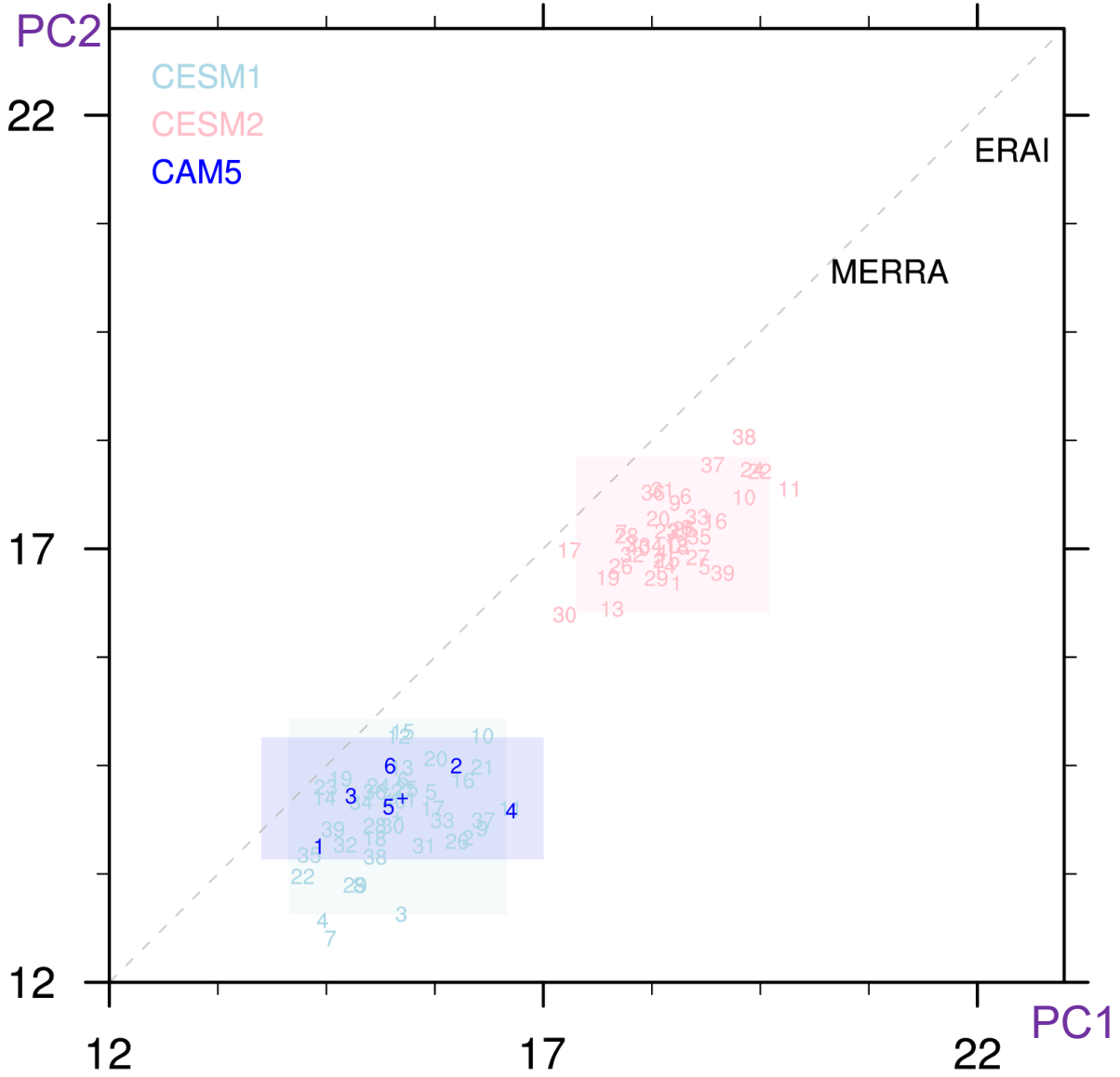


Forced vs. Prescribed SSTs



AMIP Ensembles

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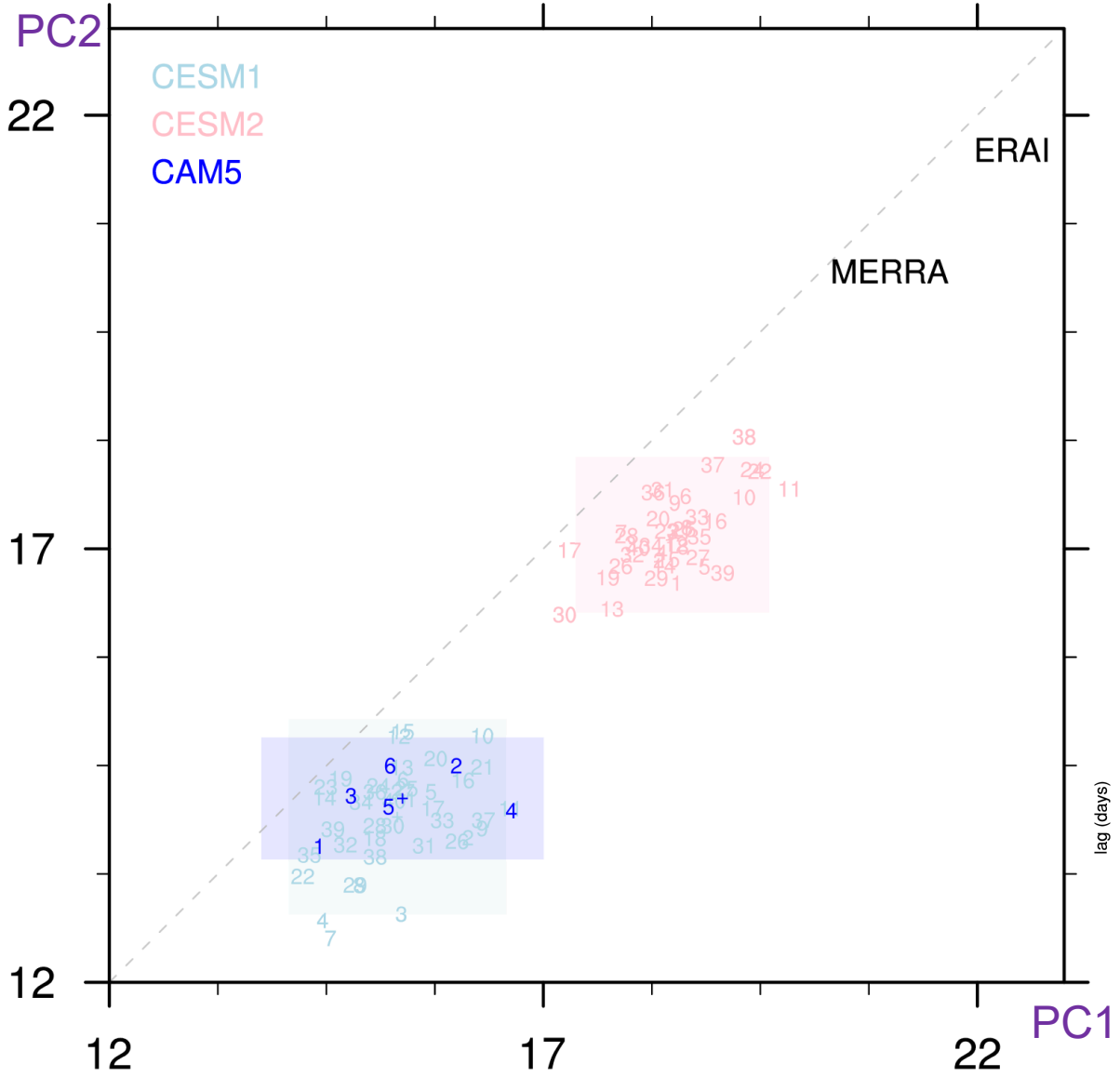

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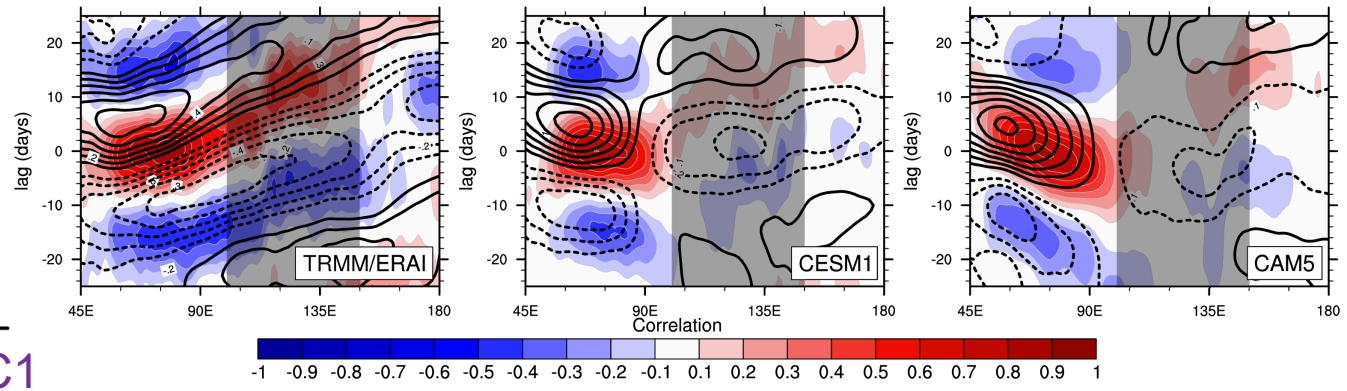

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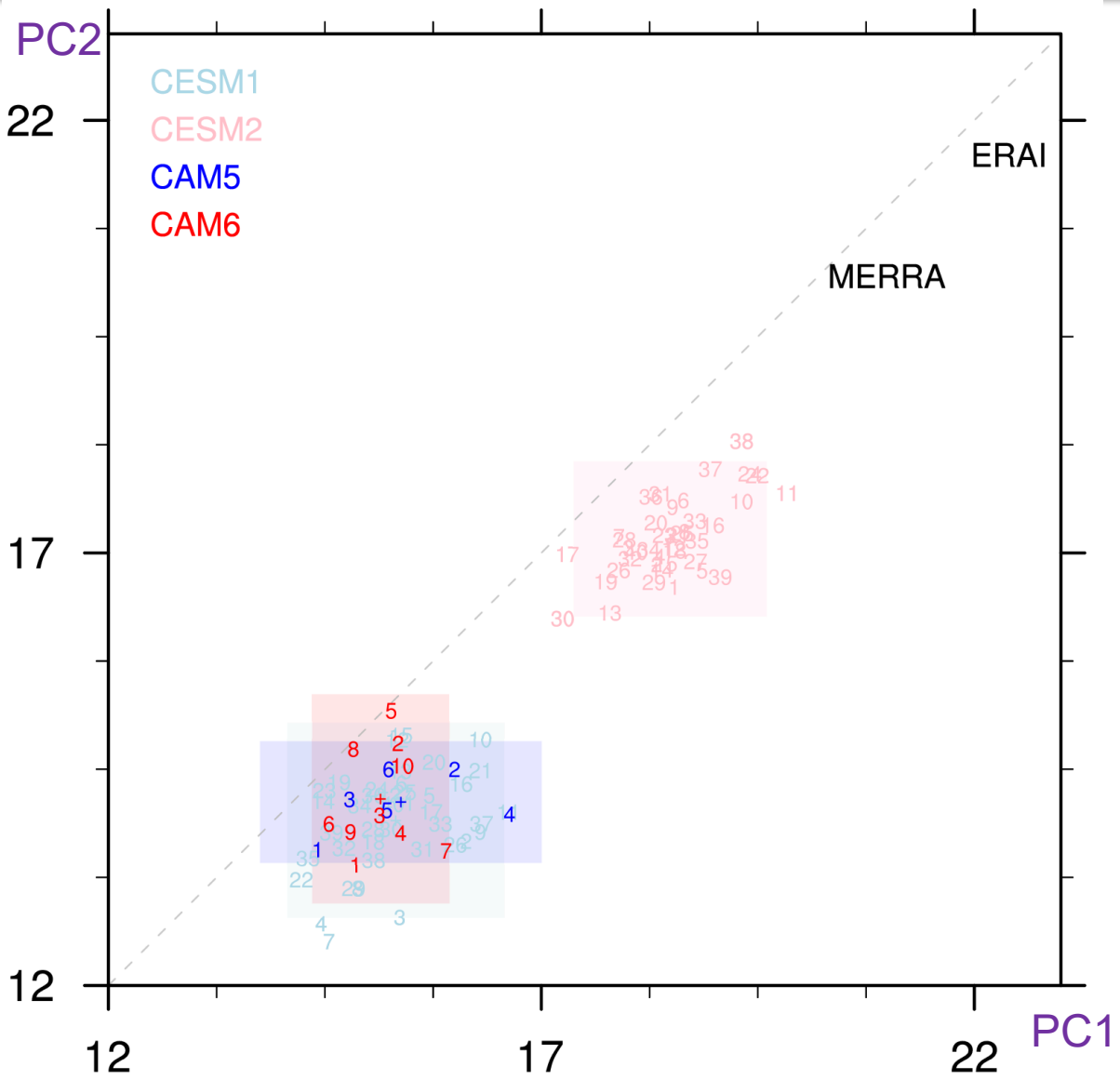

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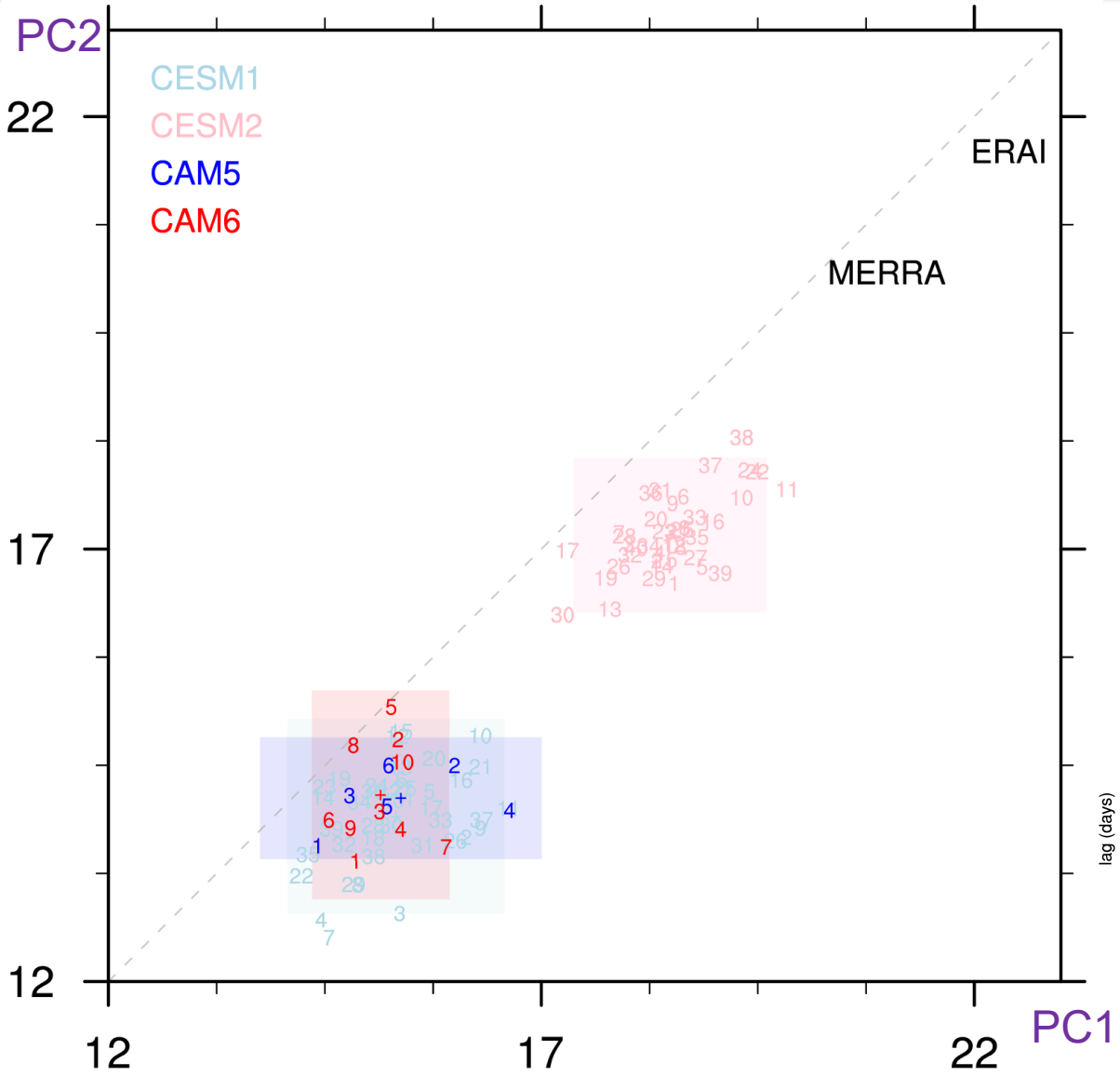

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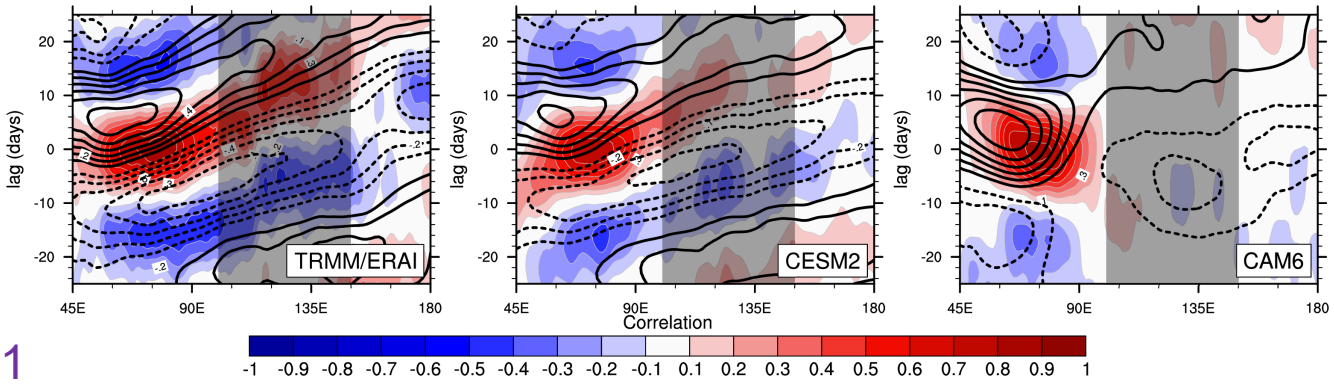
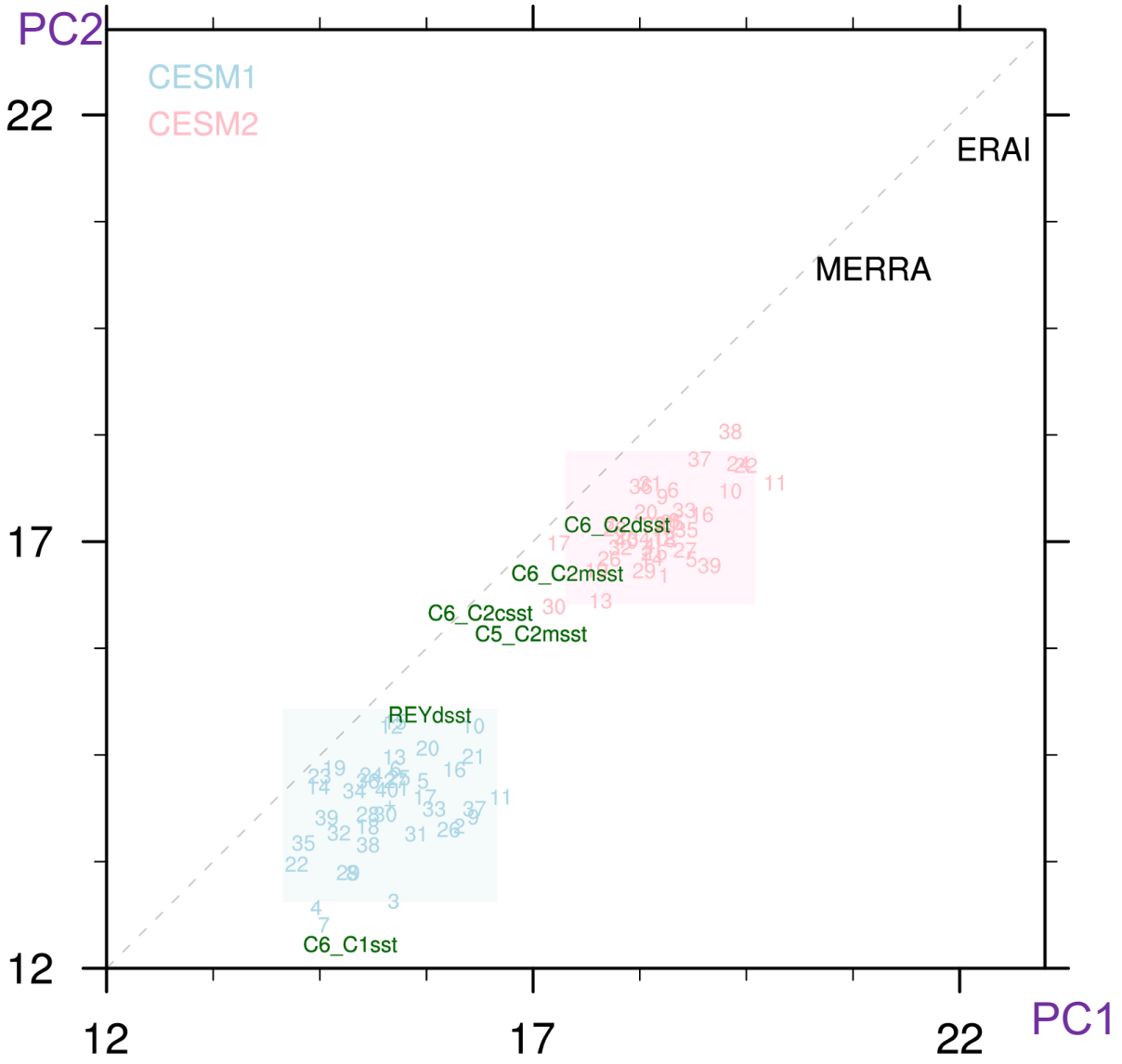


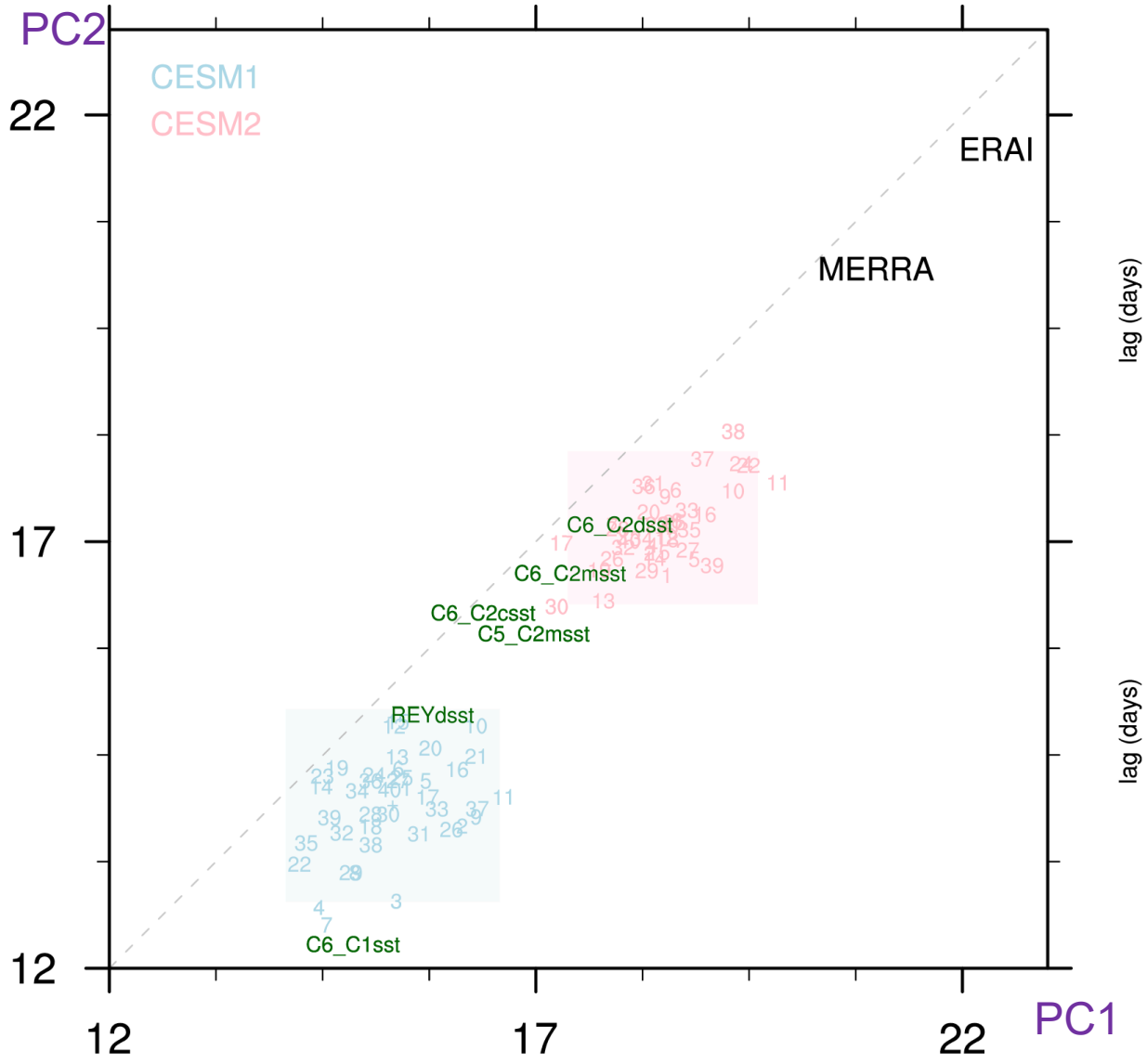
Prescribing SST Patterns



Temporal Coupled SSTs

- Daily Reynolds SSTs have little impact: REYdsst
- CAM5/CAM6 with prescribed coupled SSTs
- High frequency vs. seasonal climatology
- Using CESM2 (C2) SSTs amplifies MJO
- Even when used in CAM5: C5_C2msst
- Using daily frequency has most impact: C6_C2dsst
- Using CESM1 (C1) SSTs gives weakest MJO: C6_C1sst

Prescribing SST Patterns



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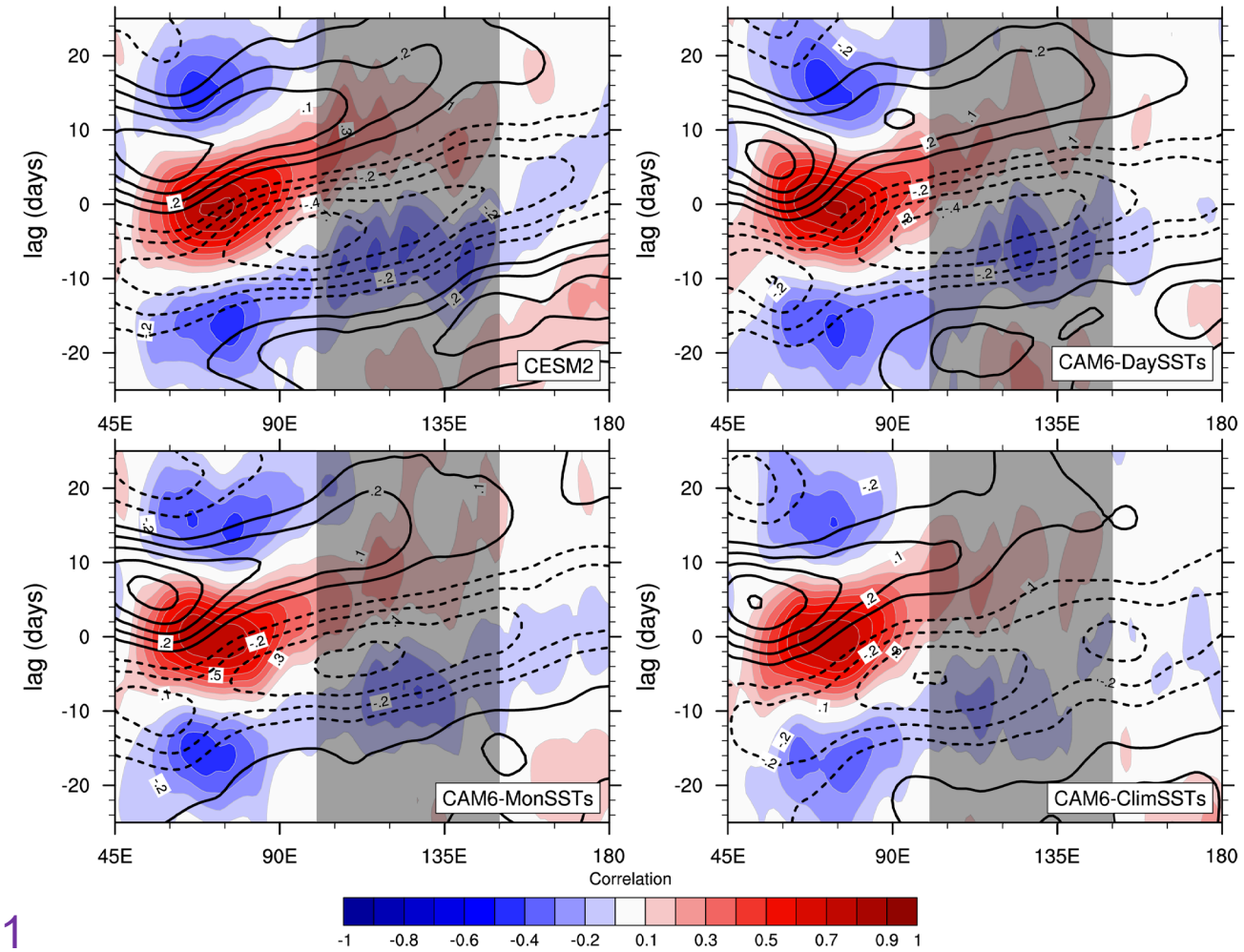
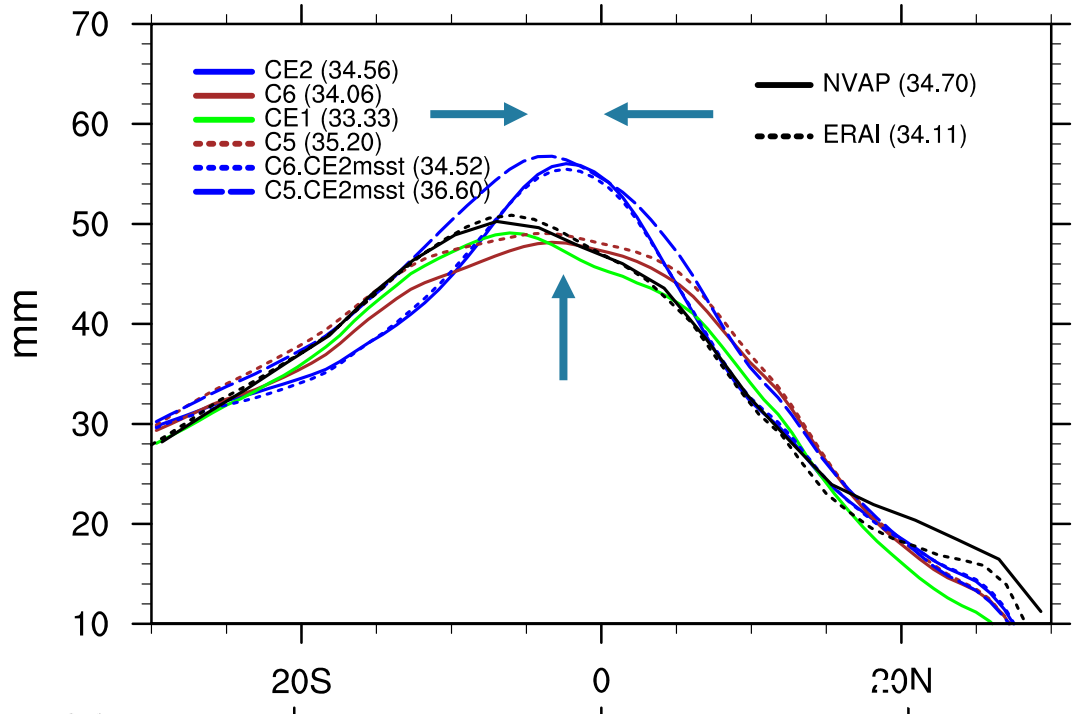
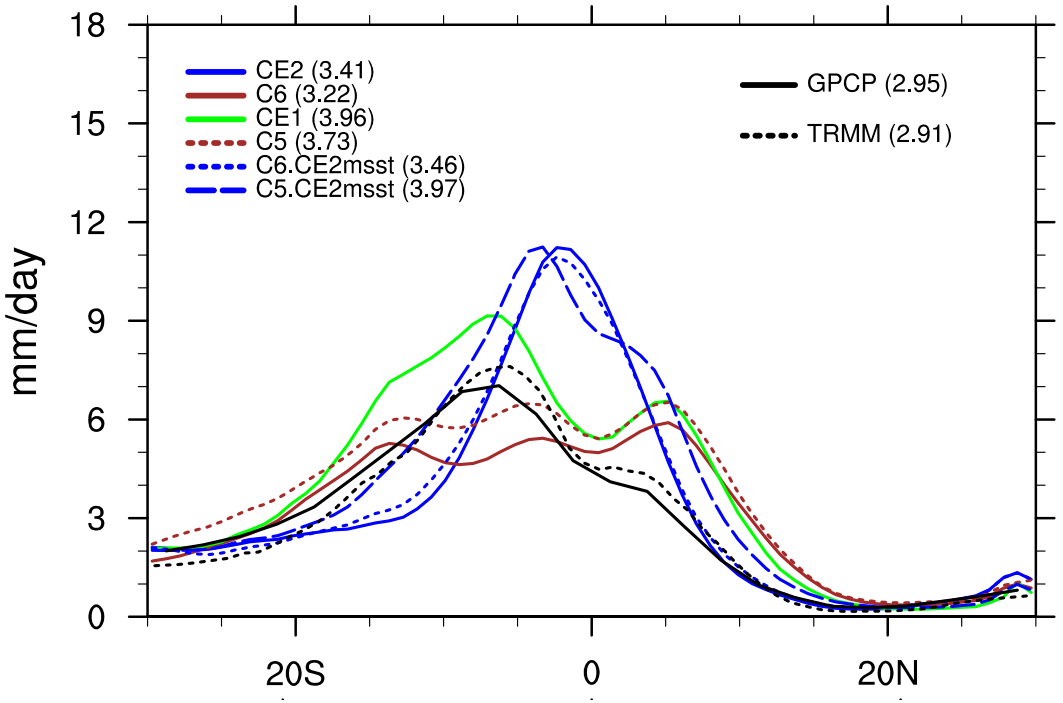


DJF Indian Ocean SST Gradient

Precipitable Water (45-100E)

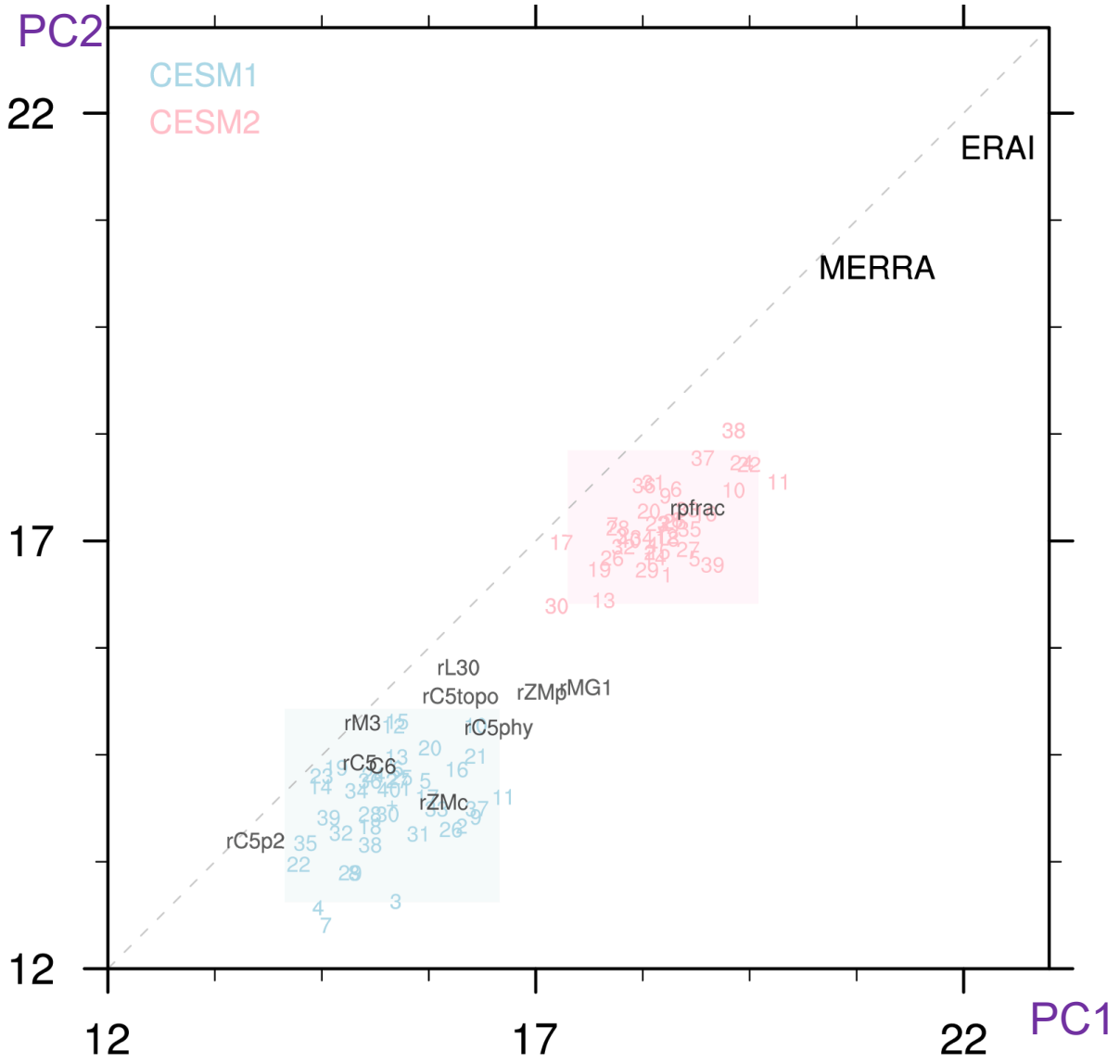


Precipitation (45-100E)



Observed, CESM1, CESM2

Physics Sensitivities



Parameterization 'Revert' Experiments

- Stepping back changes from CAM6 (C6) to CAM5 (rC5)
- Includes whole schemes, pieces of schemes and tuned settings
- 1->2 Moment Microphysics revert: rMG1
- In general changes secondary to SST changes
- What is special about: rpfrac ?

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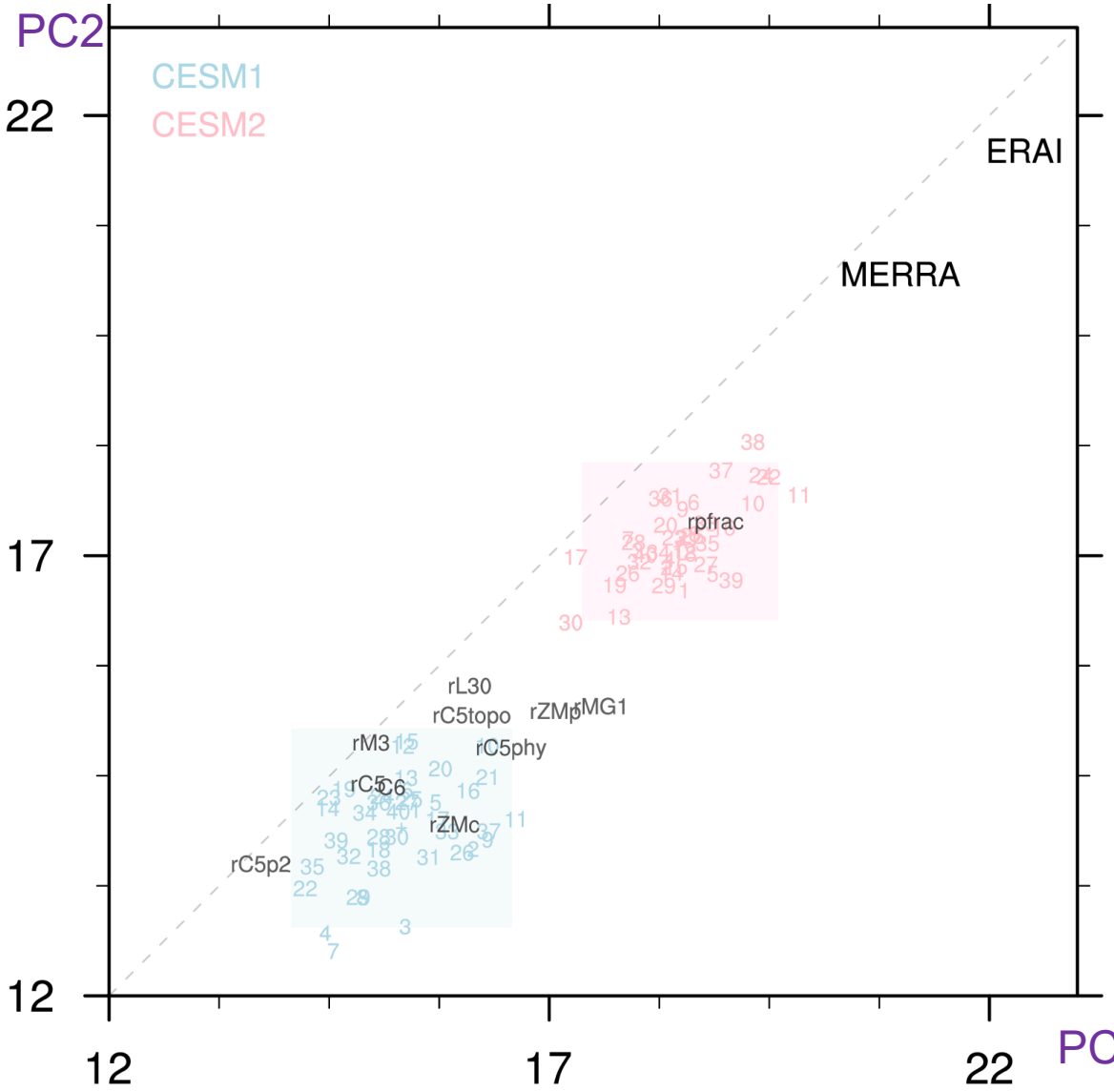

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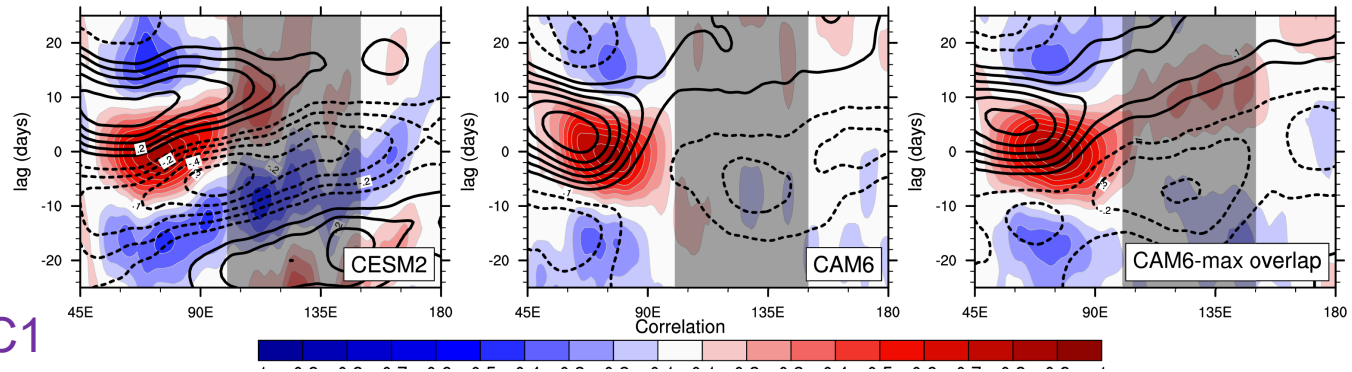

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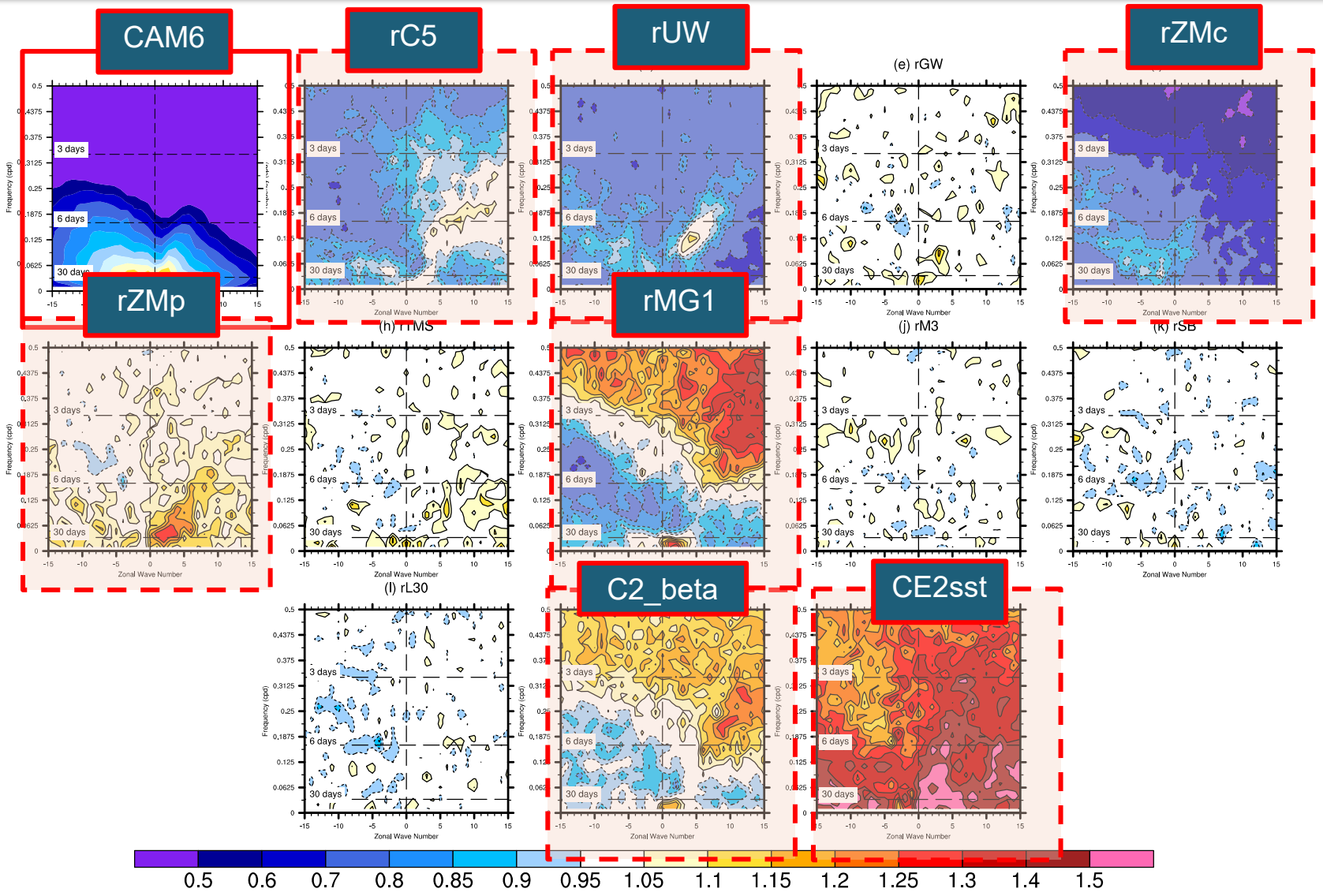
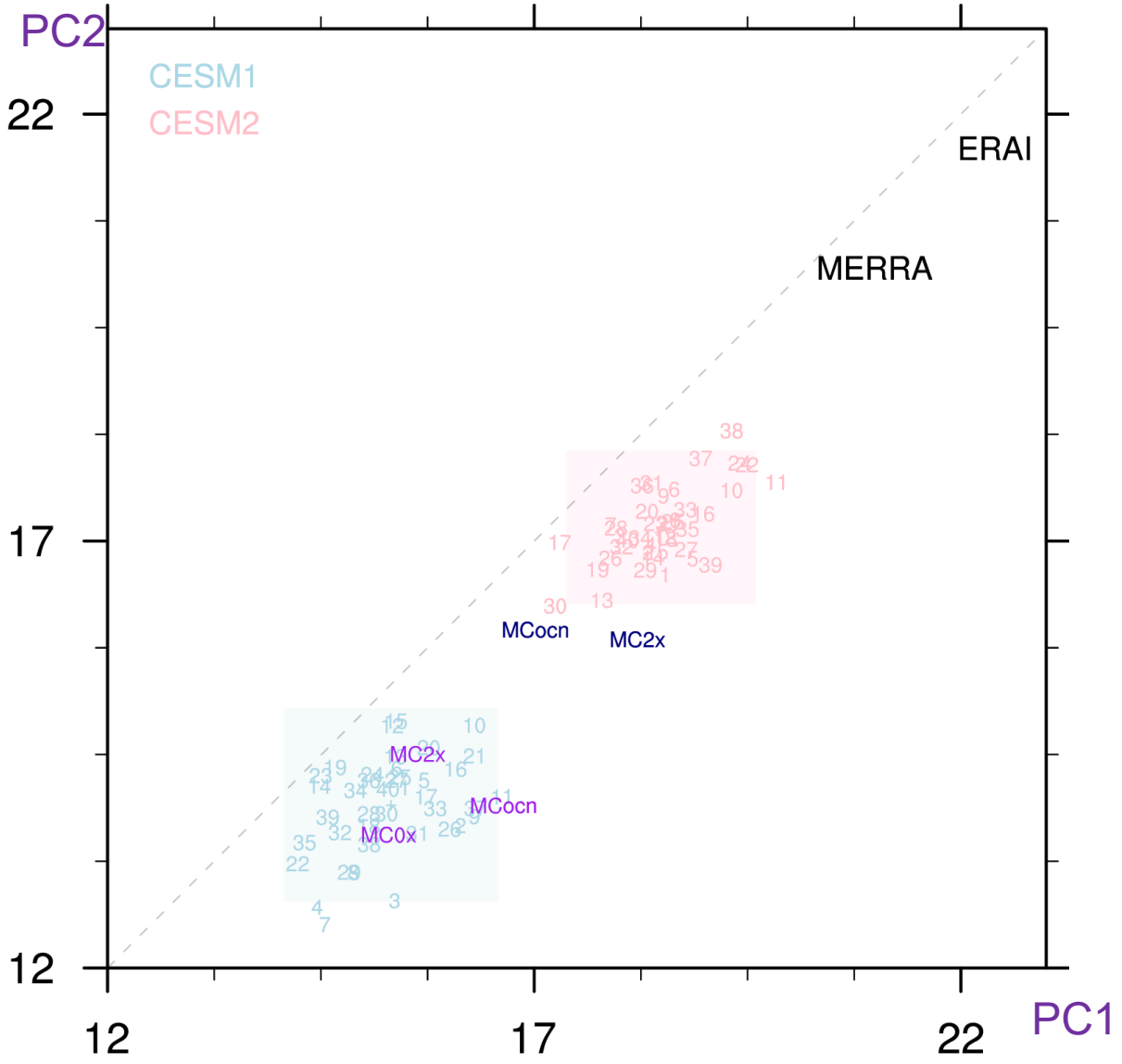


- Blues: weaker power
- Reds: stronger power
- Changes across spectra

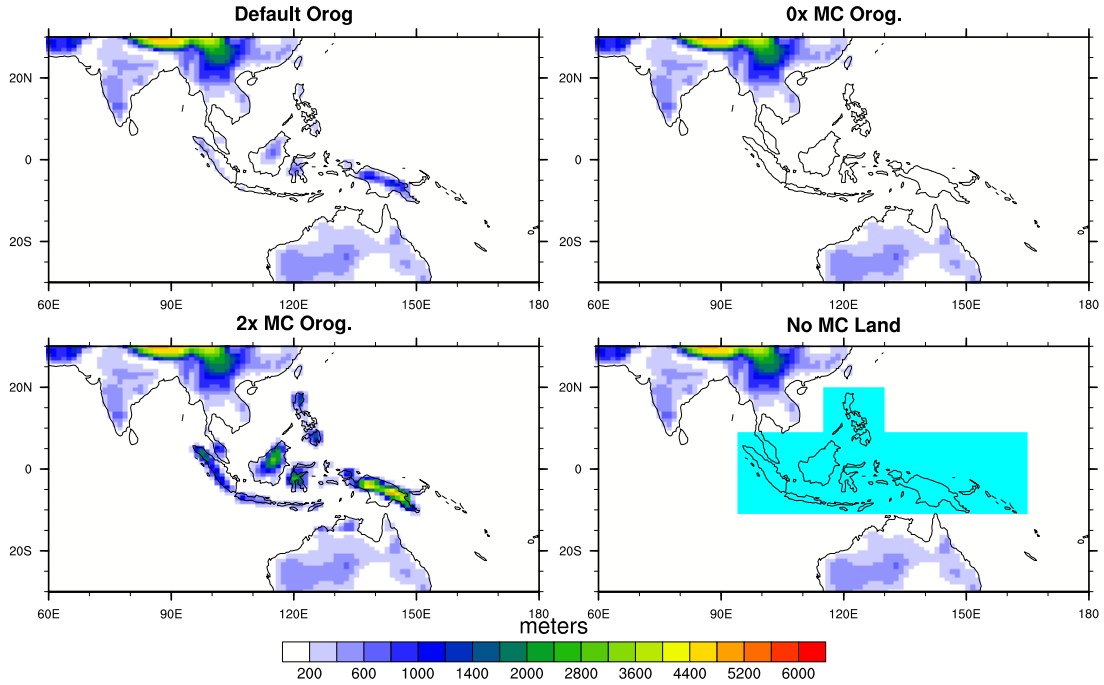
- Most sensitive schemes
  - UW PBL scheme
  - ZM stable layer/parameters
  - MG microphysics
- Non-linear effects of combinations
- All sensitivities much smaller than applying CESM SSTs

Influence of the Maritime Continent



MC Modification Experiments

- Experiments with Observed and CESM2 SSTs
- Flatten the topography: MC0x
- Double topography height: MC2x ,MC2x
- Replace with interpolated SSTs: MCocn, MCocn
- Investigate barrier and surface flux effects



Neale and Slingo, 2003 https://doi.org/10.1175/1520-0442(2003)016<0834:TMCAIR>2.0.CO;2

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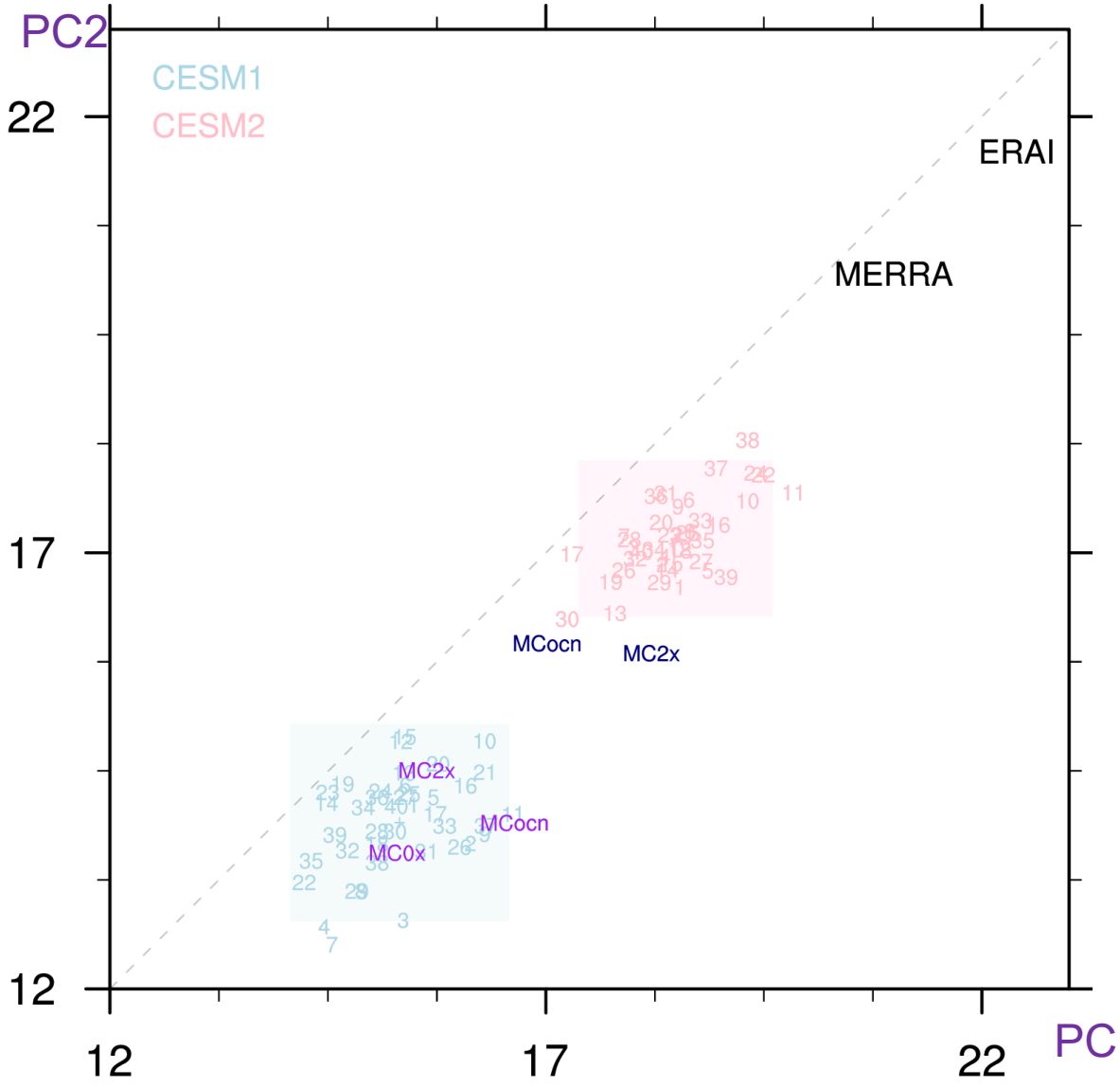

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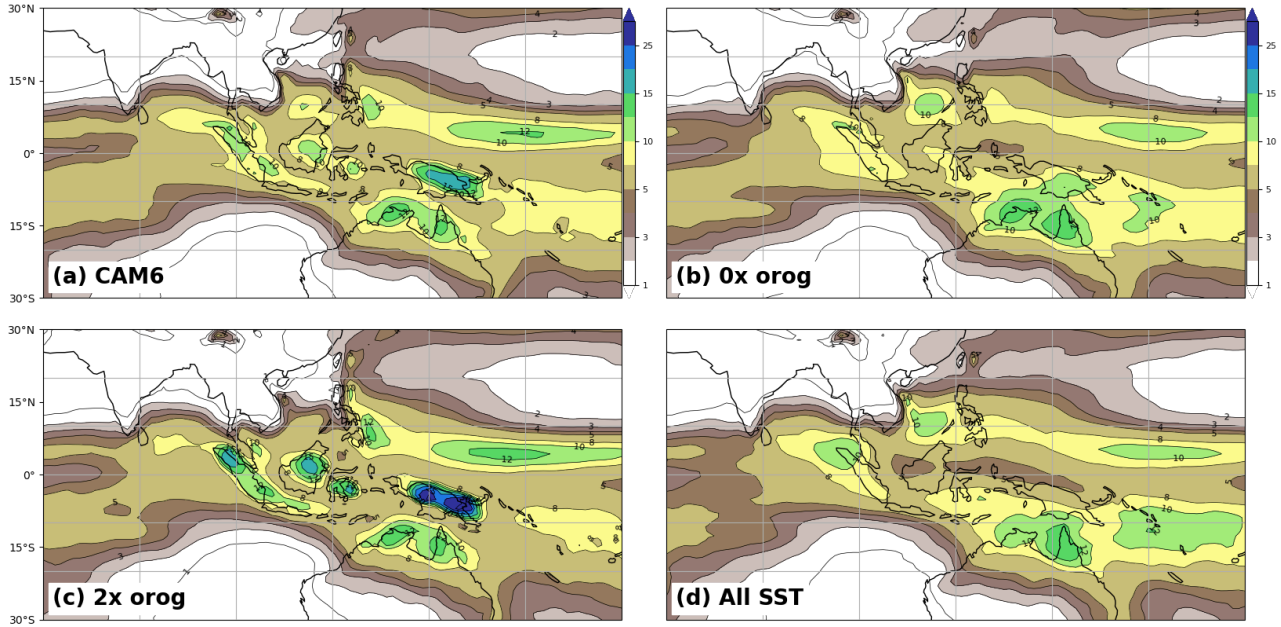

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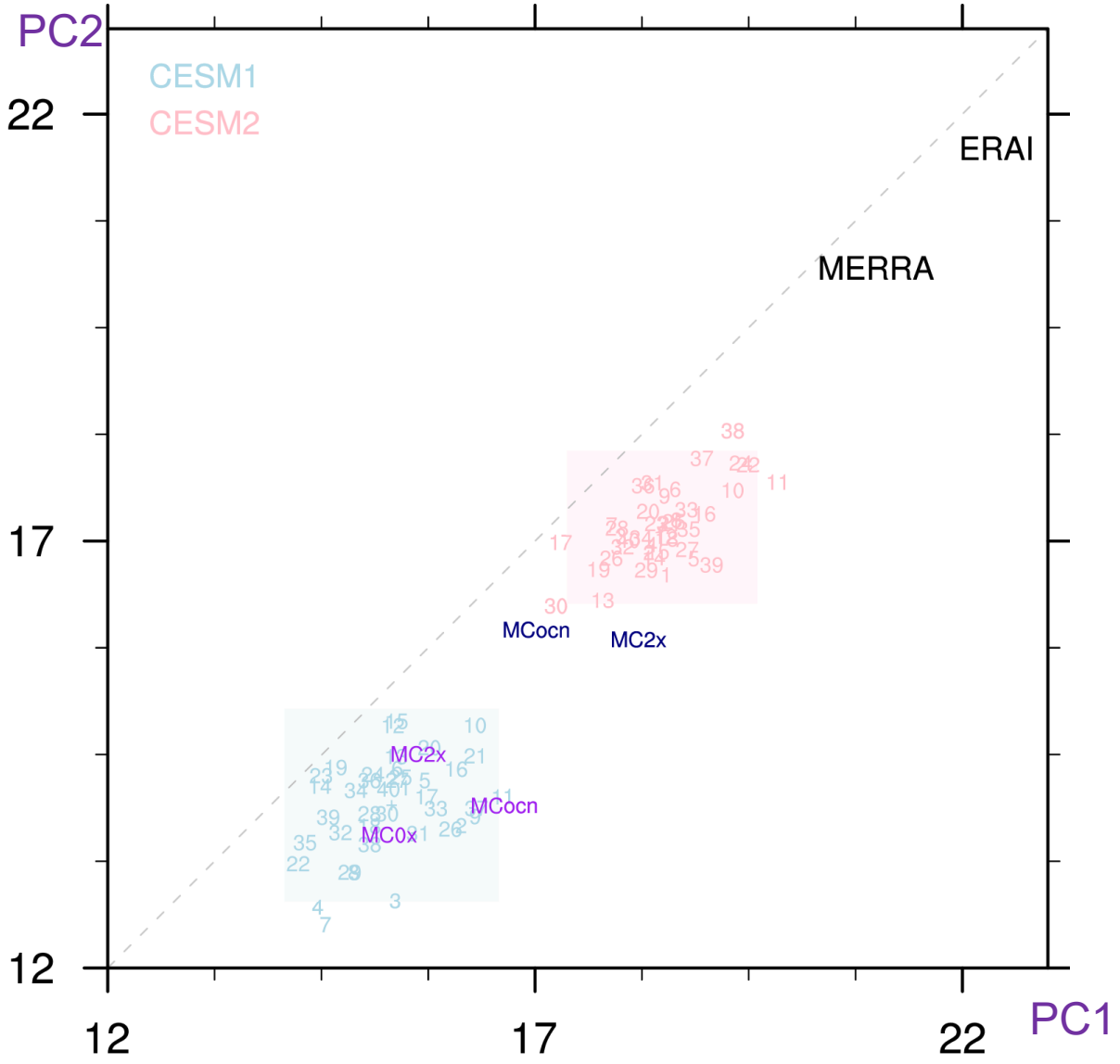

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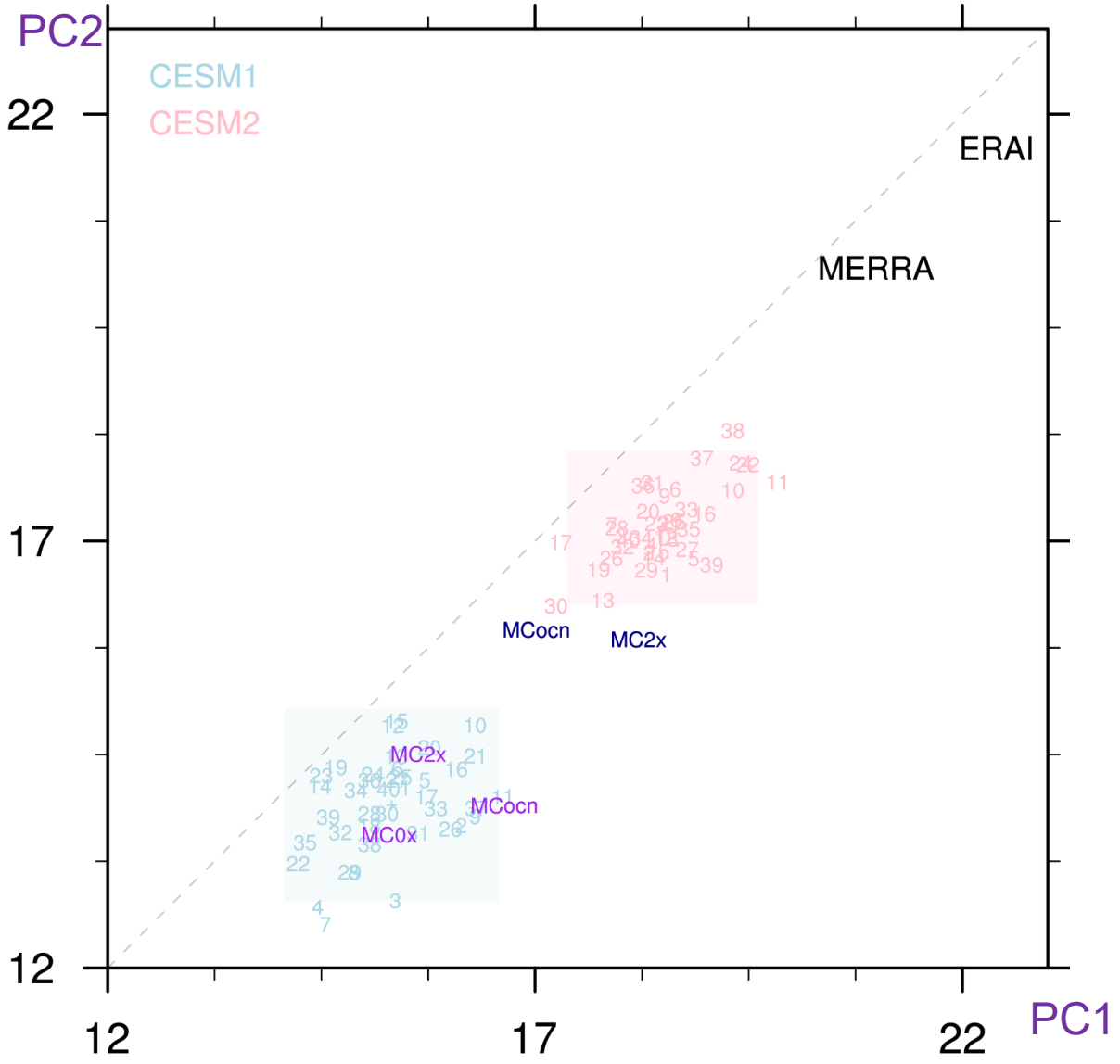

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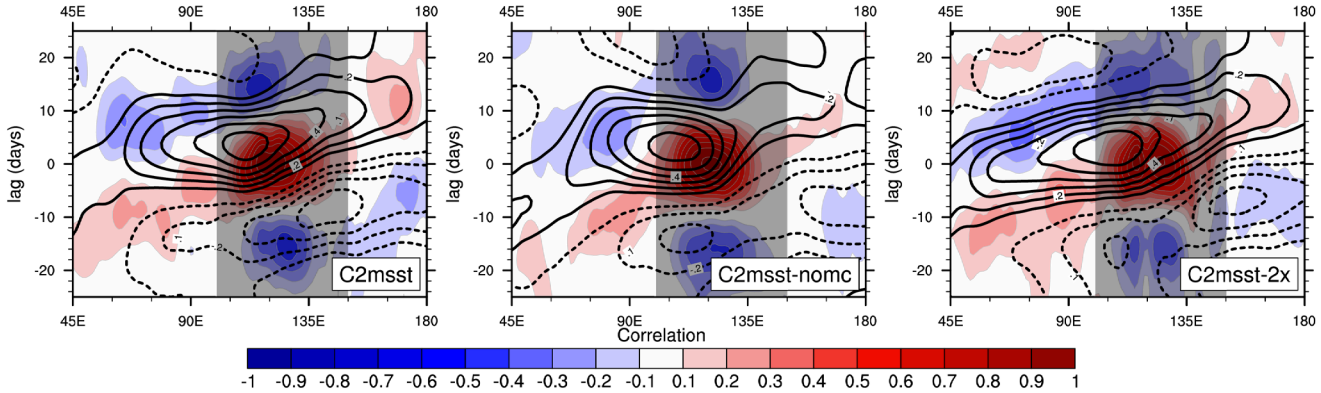

Now for Events starting near the maritime Continent

Summary

- CESM2 has a better MJO than CESM1 in response to erroneous surface forcing

- MJO modulation can come from a number of different factors
  - SST is clearly the dominant factor in this model -> Meridional gradient in Indian Ocean
  - With an intra model set though, variations mostly result from MC and W. Pacific sensitivities
  - Physics matters (of course!), but subtle interplays can mask desired/undesired sensitivities
- Other factors
  - Ocean-atmos. coupling frequency (hourly vs. daily – this was important for CESM2)
  - Resolution (vertical matters more than horizonal – with convection parameterization)
  - Near surface important in a model with convective parameterization
- Paths forward
  - Merging initial value versus boundary forced (climate) simulations
  - Perturbed parameter simulations
  - Include more continuous physics parameterizations (CAM7: CLUBB-MF)

Questions?