# Seasonal Prediction with the Unified Forecast System

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# Introduction

- NOAA is in the process of developing a Seasonal Forecast capability using the UFS framework to replace the aging Climate Forecast System version 2 (CFSv2).
- CFSv2 went operational in the spring of 2011, generating an ensemble of 9 month forecasts with a fully coupled model every day.
- Components consists of T126/L64 GFS (~1-degree) atmosphere and the Noah land model, MOM4 with a 2-layer ice model (½-degree grid, refining to ¼ in the tropics)
- Atmospheric Physics in the CFSv2 is from a 2007 version of the GFS (17-years old!).

# Introduction continued

- We are in the first year of focused development of the UFS
- In the spring of 2023, scientists from NCEP, the NOAA research labs, and the development testbed center (DTC) drafted a development plan outlining the goals of the project and organized the Seasonal Forecast System (SFS) application team.
- The target configuration of the SFS is
  - ½-degree atmosphere (C192L127) with interactive aerosols
  - ¼-degree ocean/ice/waves
- The starting point for focused development with be the tagged version which will become GEFSv13

# In the meantime…

- With support from the Weather Program Office, we coordinated experiments to compare the impact of stochastic physics on S2S timescales between NOAA and NCAR.
- Both groups generated long coupled simulations (50-100 years) with and without stochastic physics.
- Simulations are compared using NCAR's Climate Variability Diagnostics Package (CVDP)
- Additional diagnostics on the UFS simulations was performed with the Model Diagnostics Task Force (**MDTF**)-Diagnostics package

# Interannual Results: SST variability [K]

Observations (historical)

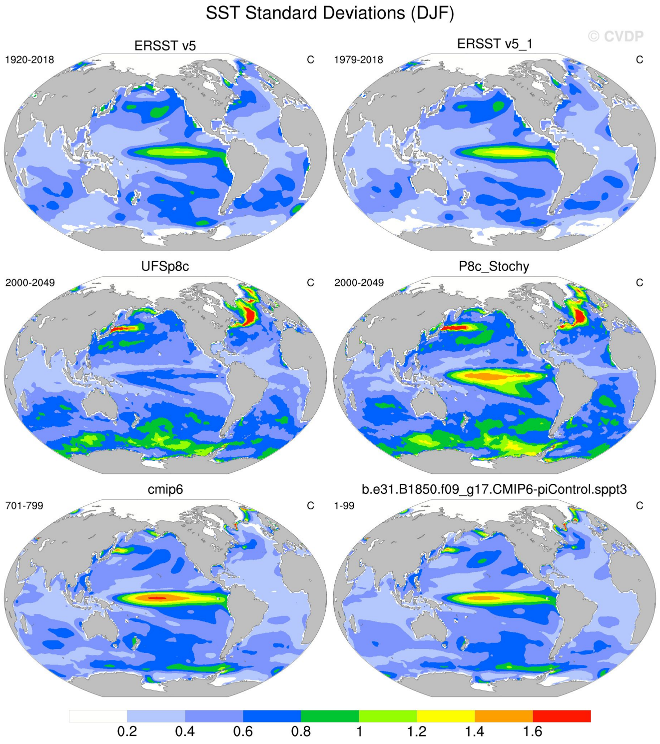
Observations (satellite era)

UFS-P8

UFS-P8-stoch

CESM2

CESM2-stoch

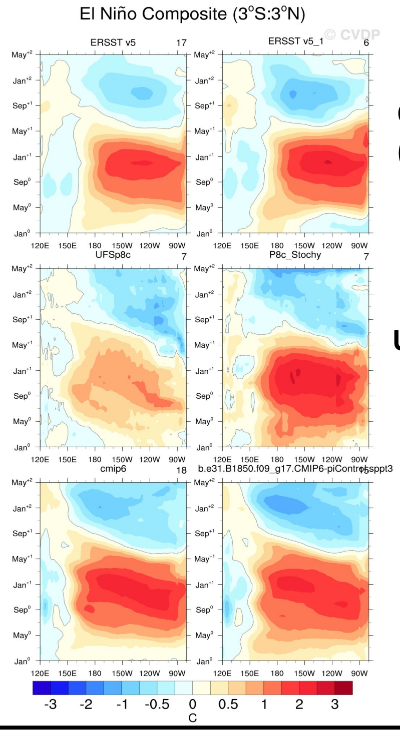



The UFS with deterministic physics lacks tropical variability. With stochastic physics the UFS has too much tropical variability.

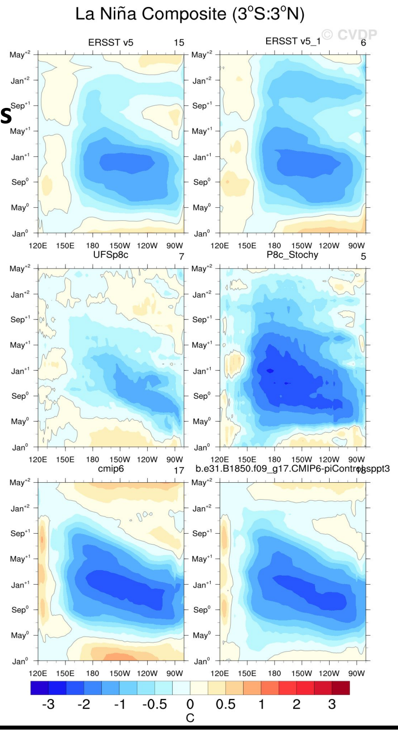
CESM has the opposite problem. ENSO is too strong with deterministic physics, and is a little weaker with stochastic physics.

# Composite ENSO Evolution

Observations (historical) | Observations (satellite era)
UFS-P8 | UFS-P8-stoch
CESM2 | CESM2-stoch




Observations (historical) | Observations (satellite era)
UFS-P8 | UFS-P8-stoch
CESM2 | CESM2-stoch

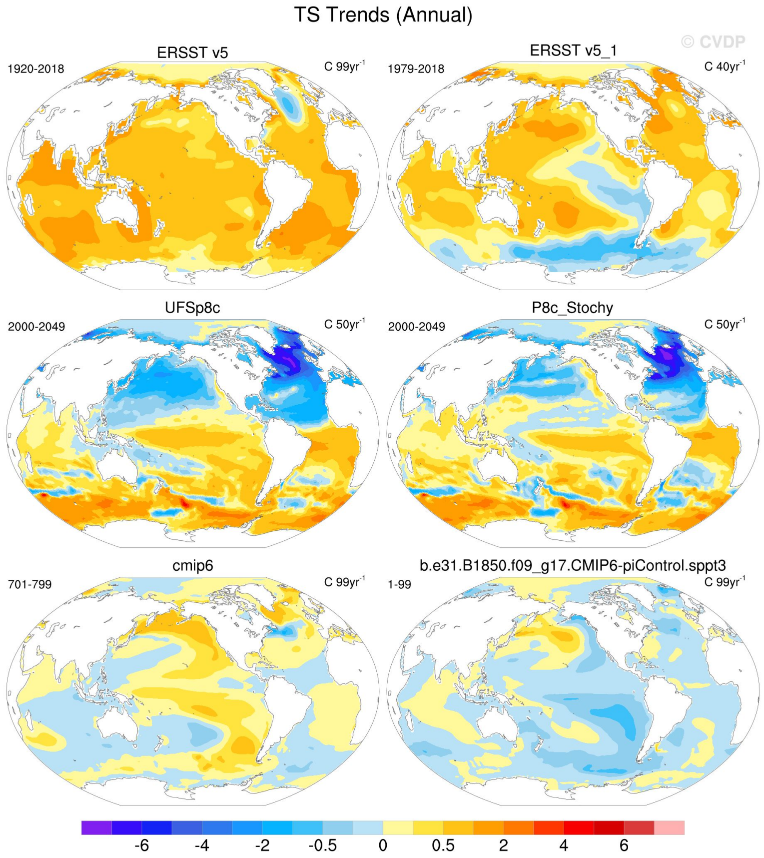



UFS with stochastic physics exhibits too early of an ENSO onset, but shows a good decay phase, including the likelihood of a multi-year La Niña.

# Long Term trend in Sea Surface Temperature [K]

Observations (historical)

Observations (satellite era)




The UFS drifts towards a cold state over the Northern Hemisphere.

UFS-P8

UFS-P8-stoch

CESM2

CESM2-stoch

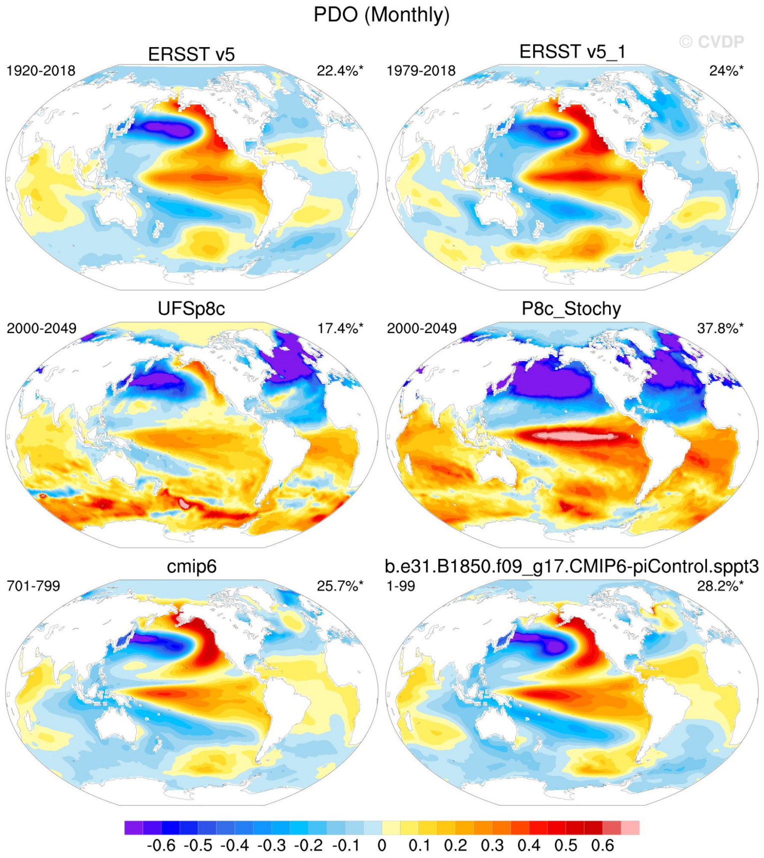
CESM shows little trend which is expected since this is a pre-industrial control run.

# The Pacific Decadal Oscillation

Observations (historical)

UFS-P8

CESM2



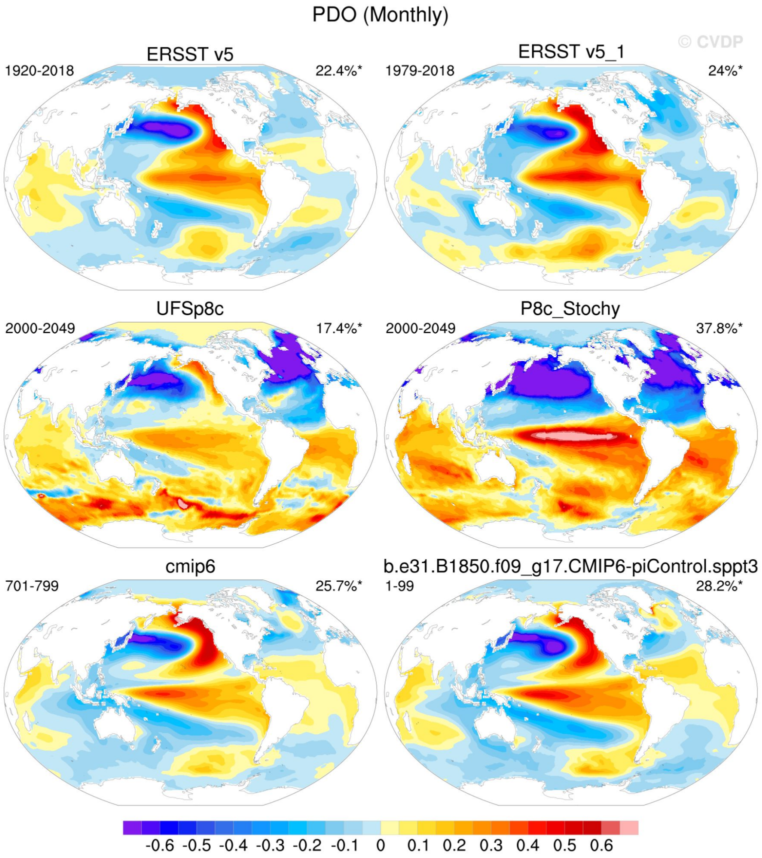

Observations (satellite era)

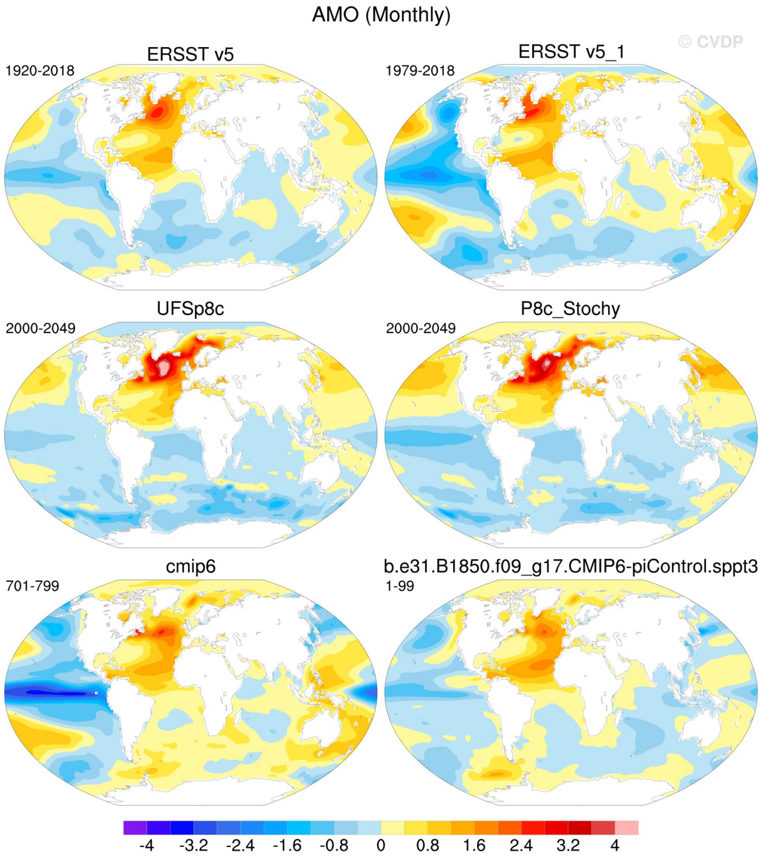
UFS-P8-stoch

CESM2-stoch

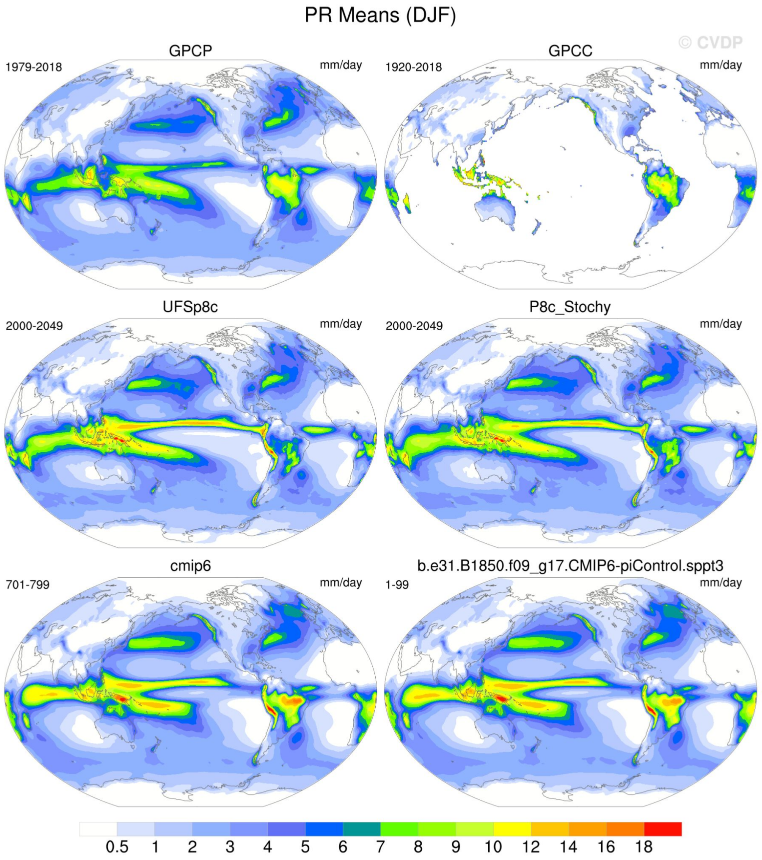
The PDO looks *really bad* with stochastic physics

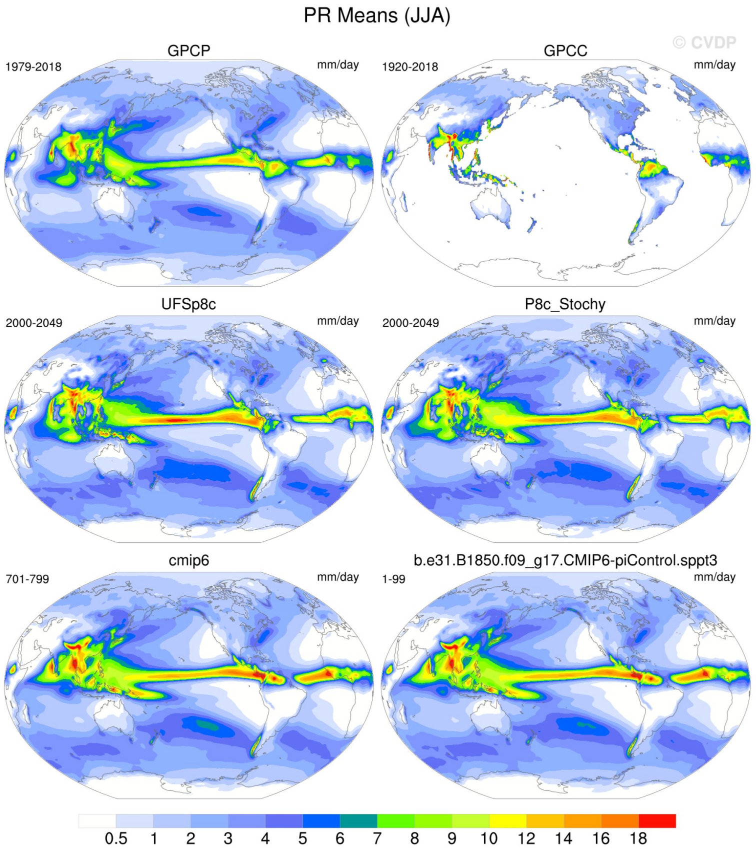
# The PDO/AMO


PDO (Monthly)
© CVDP
ERSST v5
1920-2018
22.4%*
ERSST v5_1
1979-2018
24%*
UFSp8c
2000-2049
17.4%*
P8c_Stochy
2000-2049
37.8%*
cmip6
701-799
25.7%*
b.e31.B1850.f09_g17.CMIP6-piControl.sppt3
1-99
28.2%*
-0.6 -0.5 -0.4 -0.3 -0.2 -0.1 0 0.1 0.2 0.3 0.4 0.5 0.6

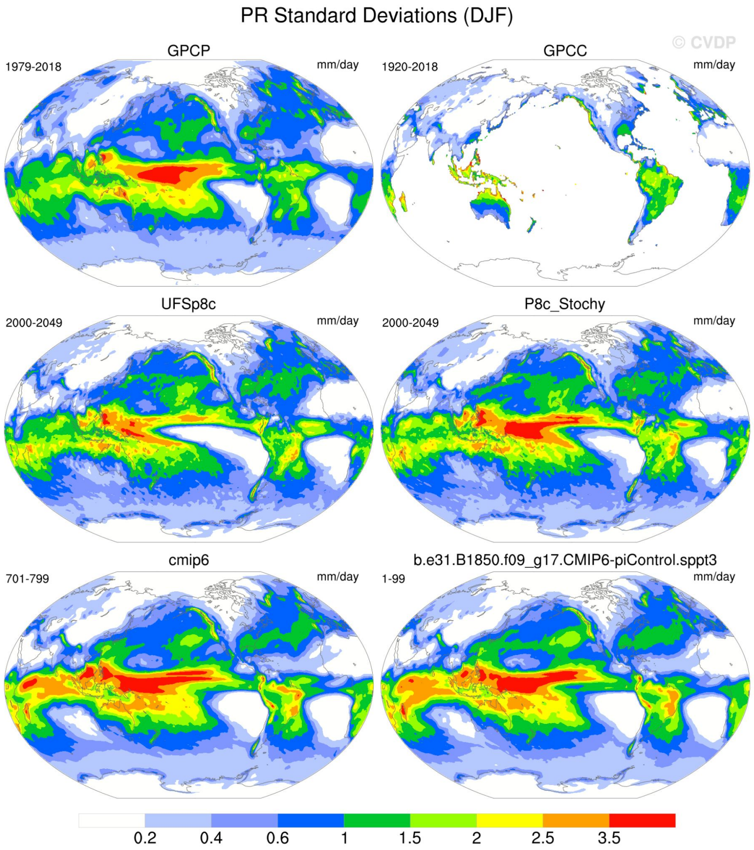

AMO (Monthly)
© CVDP
ERSST v5
1920-2018
ERSST v5_1
1979-2018
UFSp8c
2000-2049
P8c_Stochy
2000-2049
cmip6
701-799
b.e31.B1850.f09_g17.CMIP6-piControl.sppt3
1-99
-4 -3.2 -2.4 -1.6 -0.8 0 0.8 1.6 2.4 3.2 4

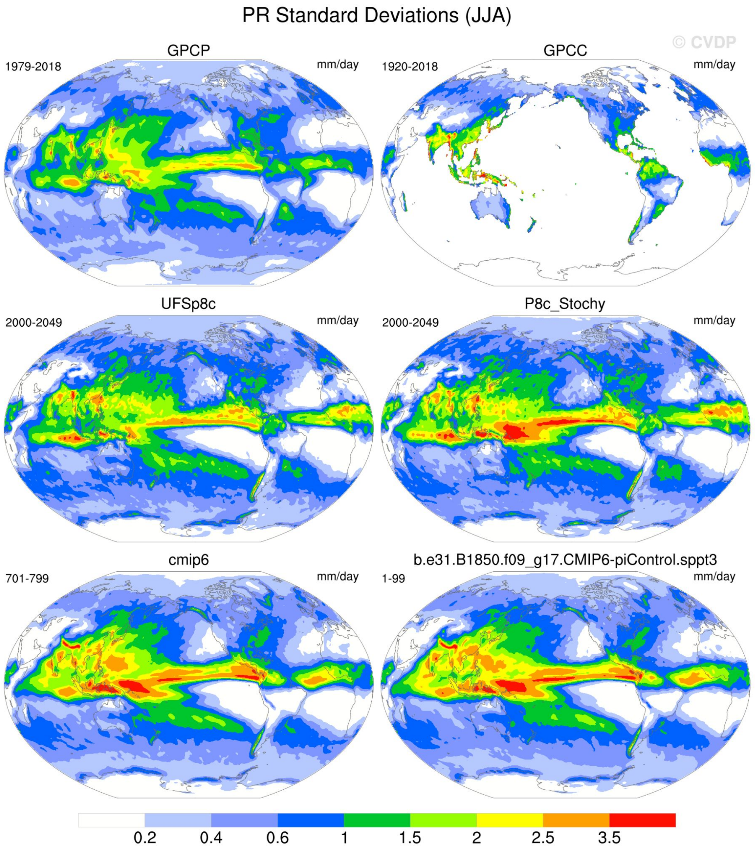
# Precipitation Climatology [mm day$^{-1}$]



# Interannual variability of precipitation



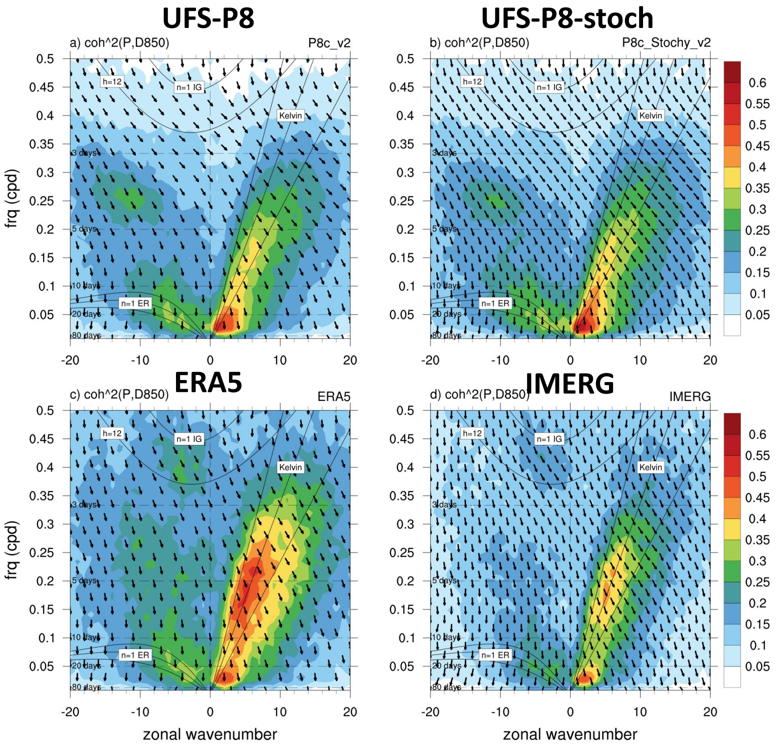
# Summary Metrics from CVDP



| Pattern Correlations | ENSO TAS ($DJF^{+1}$) | ENSO PSL ($DJF^{+1}$) | El Niño Hovmöller | La Niña Hovmöller | AMO | PDO | NAM (DJF) | SAM (DJF) | SST std dev (Ann) | PSL std dev (Ann) | PR std dev (Ann) | Mean Score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OBS 2 | 0.86 | 0.94 | 0.96 | 0.92 | 0.83 | 0.91 | 0.98 | 0.96 | 0.95 | 0.96 | 0.94 | 0.94 |
| UFSp8c | 0.34 | 0.37 | 0.79 | 0.81 | 0.74 | 0.44 | 0.95 | 0.98 | 0.57 | 0.97 | 0.83 | 0.81 |
| P8c_Stochy | 0.74 | 0.83 | 0.92 | 0.86 | 0.73 | 0.50 | 0.91 | 0.97 | 0.70 | 0.95 | 0.90 | 0.86 |
| cmip6 | 0.71 | 0.74 | 0.91 | 0.87 | 0.64 | 0.84 | 0.96 | 0.93 | 0.76 | 0.93 | 0.90 | 0.86 |
| 1850.f09_g17.CMIP6-piControl.sppt3 | 0.74 | 0.82 | 0.91 | 0.90 | 0.68 | 0.87 | 0.90 | 0.90 | 0.77 | 0.93 | 0.90 | 0.86 |

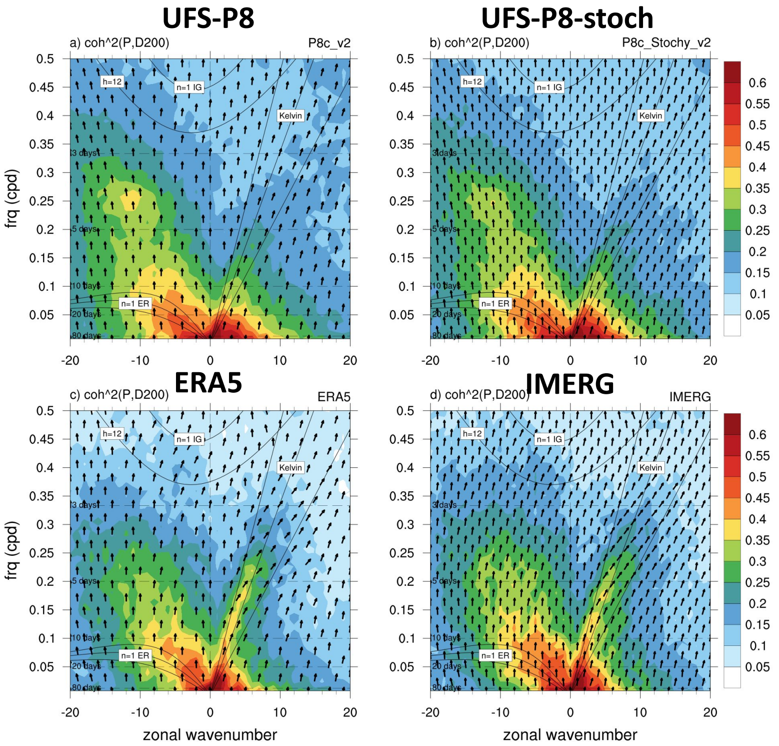
0.99, 0.95, 0.9, 0.85, 0.8, 0.75, 0.7, 0.65, 0.6, 0.55, 0.5

# Subseasonal Results:
# Coherence of Precipitation-Divergence at 850 hPa



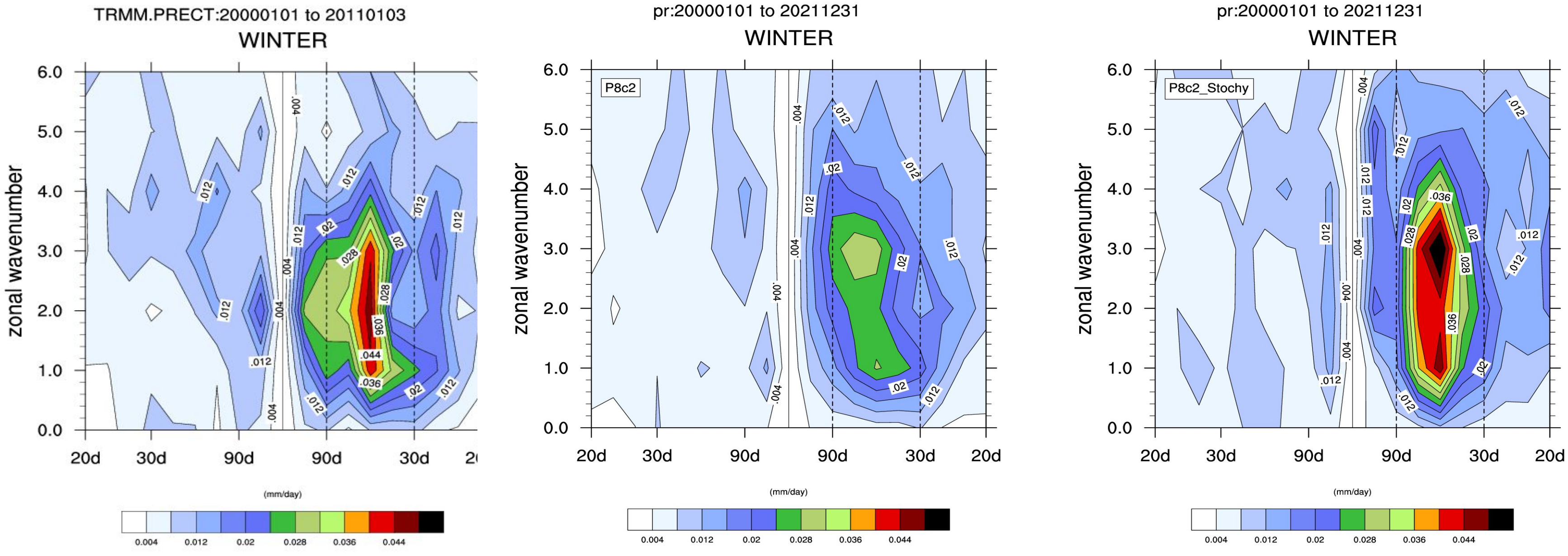

The coherence between low-level divergence and precipitation is well represented in the UFS. With the low-level convergence leading the precipitation by 1/8$^{th}$ of a cycle for eastward propagating waves.

# Subseasonal Results:
# Coherence of Precipitation-Divergence at 200 hPa




But the upper-level divergence in response to the precipitation is weak in the kelvin wave band.

# Wavenumber/frequency diagram

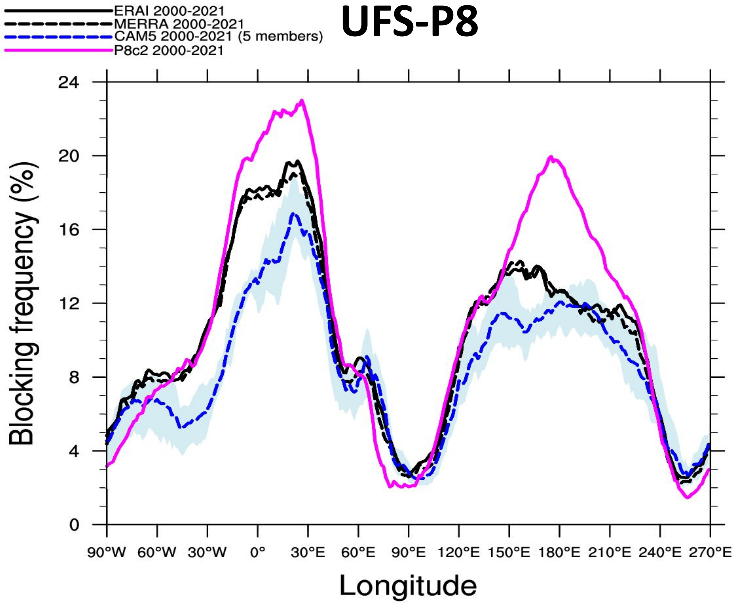


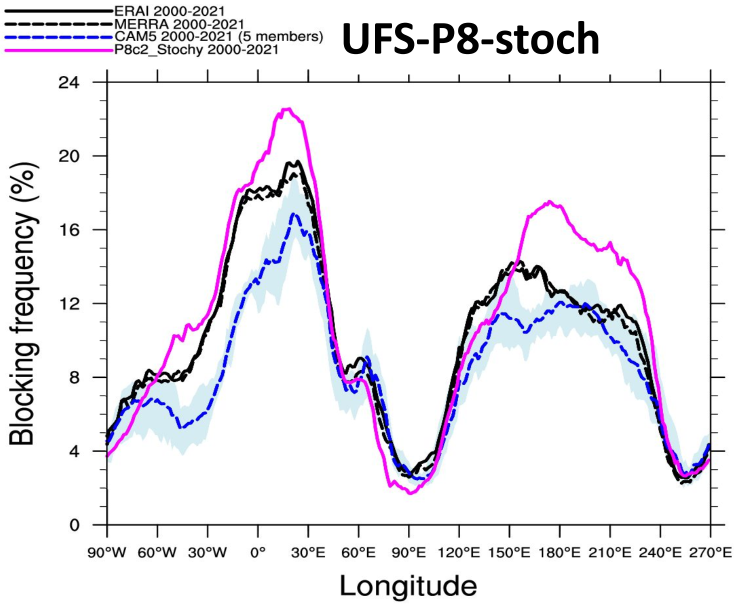

**Observations**

**1-deg UFS deterministic**

**1-deg UFS stochastic**

# Subseasonal Results: N.H. Blocking frequency



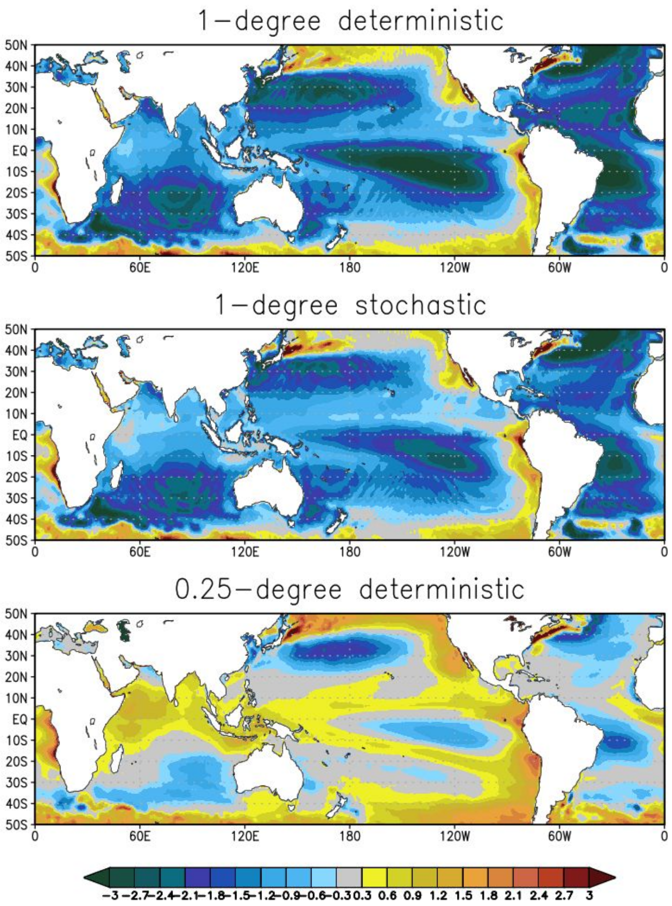




UFS with deterministic physics had too much blocking over both the Atlantic and Pacific Sectors. Stochastic physics slightly improves the frequency over the Pacific.

# Does stochastic physics help a low resolution model behave like a higher-resolution model?

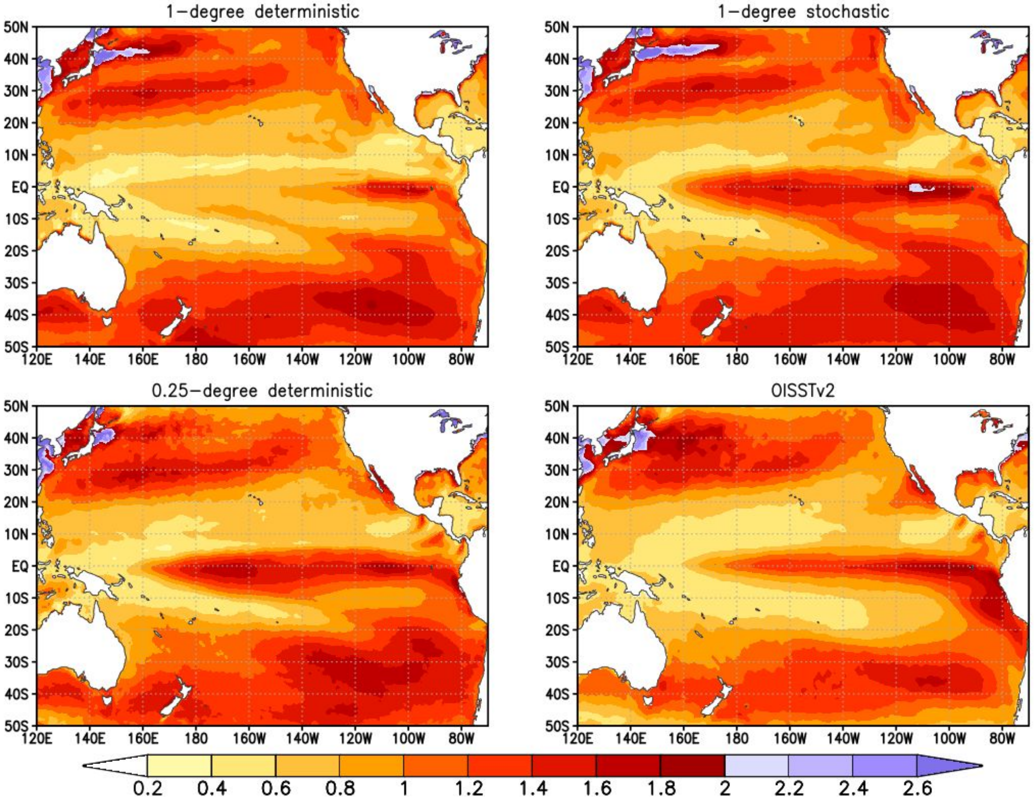
- We also ran 30-years of the ¼-degree P8 tag so we can attempt to answer this question.

# Mean bias of surface temperature vs OISSTv2




Stochastic physics does reduce the cold bias in the cold run, but model is much colder than ¼-degree version

# Standard Deviation of DJF mean surface temperature [K]



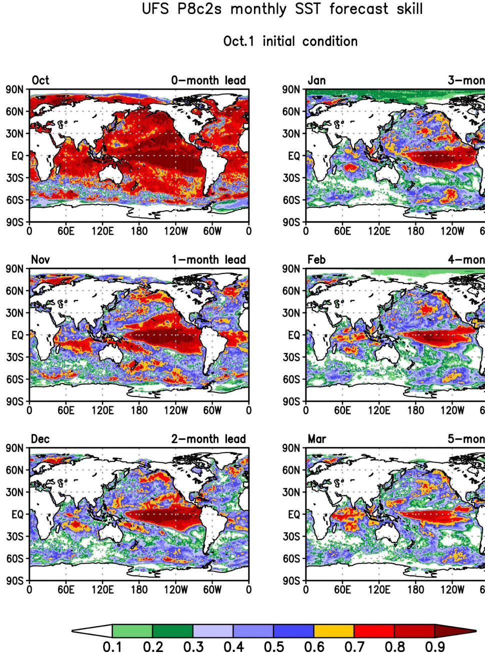

In terms of the inter-annual variability, stochastic physics does makes the 1-degree model look more like the higher resolution in the Niño region.

# Initialized Predictions

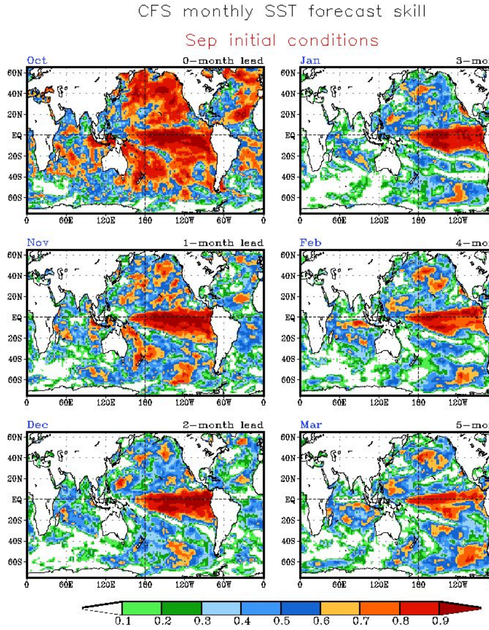
- We also ran 30-years of 10-ensemble member reforecasts initialized on Oct. 1 and run out 6-months
- Initial conditions for the reforecasts are from a 1-degree ‘replay’ to ERA5 and ORAS5.
- Initial condition perturbations to both the atmosphere and ocean
- Stochastic physics is on

# SST forecast skill
# Anomaly Correlation based on 29 years

## Development version of UFS



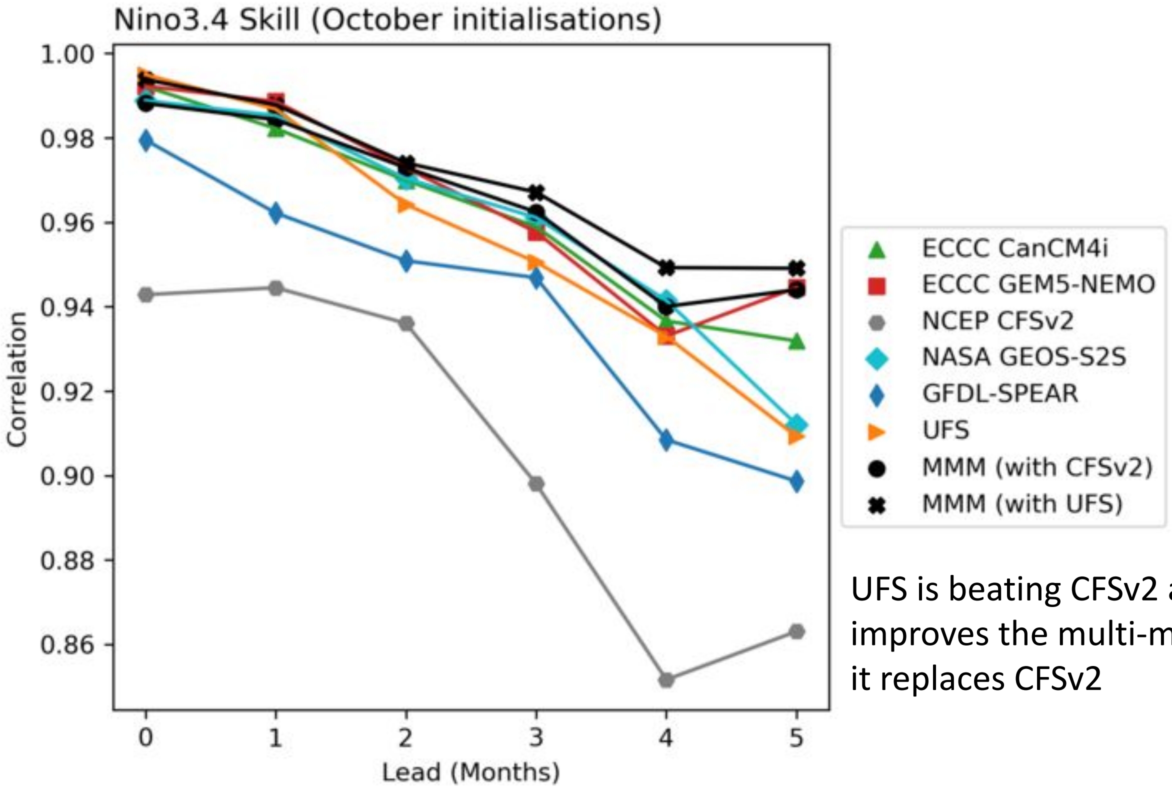

NWS/NCEP **CFSv2**




CFSv2 is a lagged ensemble initialized at the end of Sept. UFS is a burst ensemble initialized on Oct .1

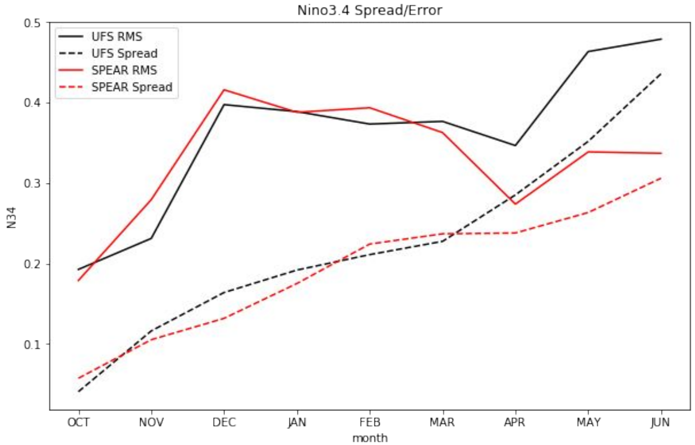
This initial test shows that the skill of SST forecasts is higher in the first month with the new model, and comparable at month-6

# Nino3.4 Skill compared to NMME

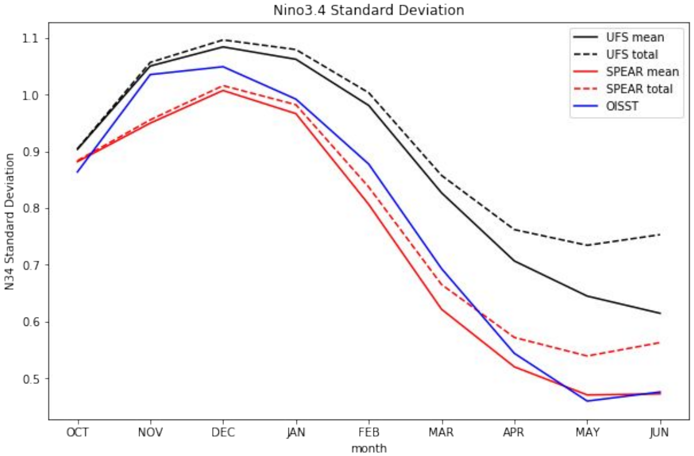



UFS is beating CFSv2 and SPEAR, and also improves the multi-model ensemble when it replaces CFSv2

# Nino3.4 Ensemble Spread/RMS Error for Oct initializations

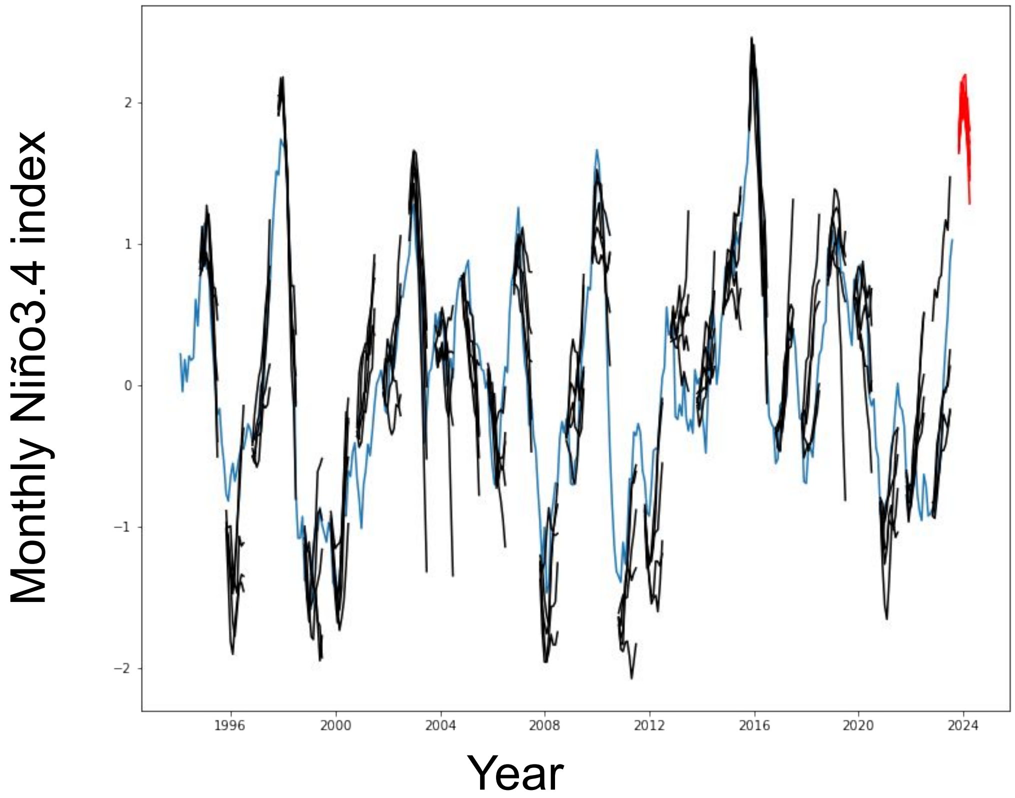



Both models are underdisperive

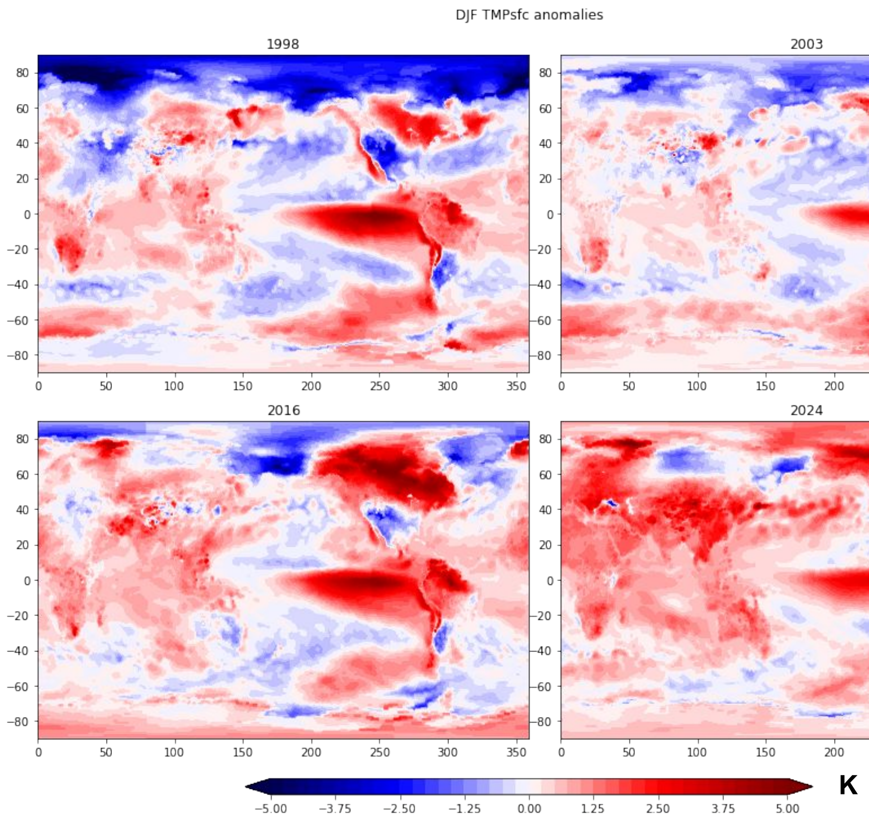



The UFS has too much variance

# UFS Nino3.4 re-forecasts (black), forecast for 2023/2024 (red) and observations (blue)

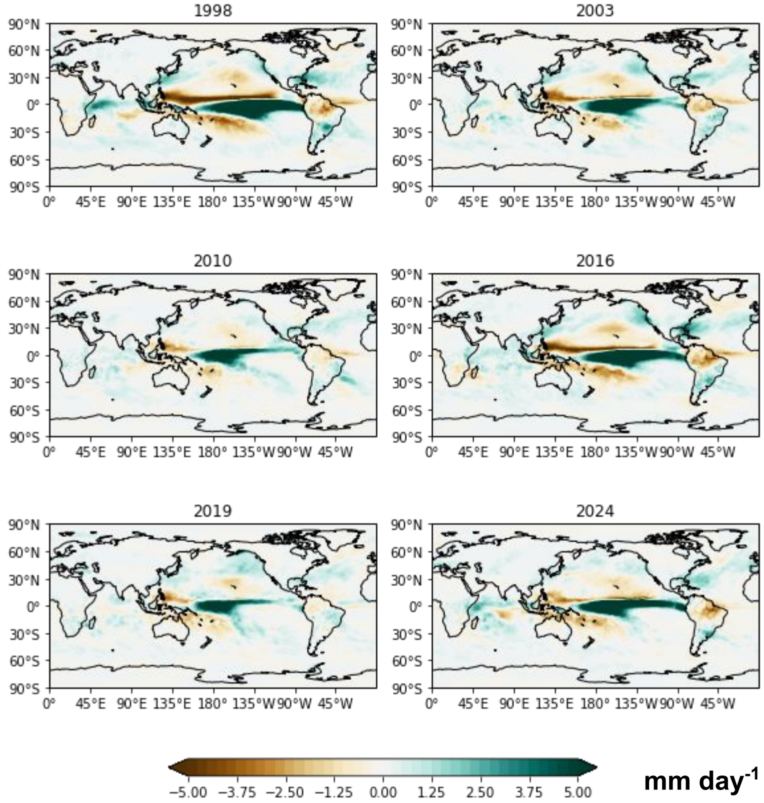


# Ensemble mean DJF surface temperature anomalies for select El Niño events

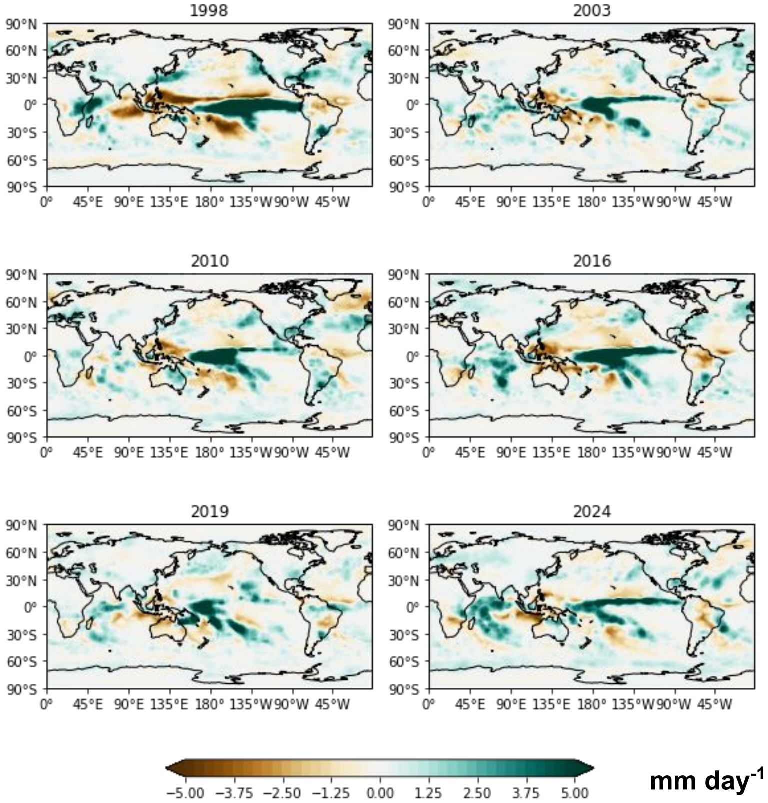


# DJF precipitation anomalies for select El Niño events

## SFS ensemble mean

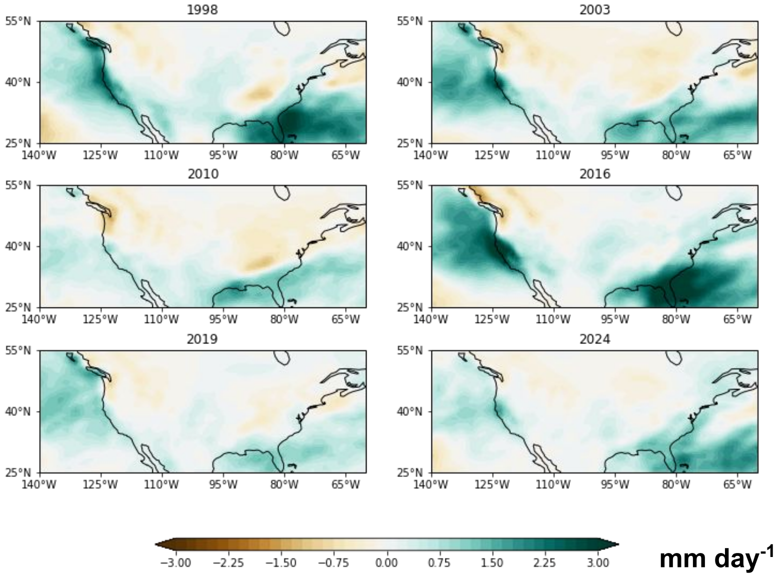



## GPCP ‘observations’



# DJF precipitation anomalies for select El Niño events

## SFS ensemble mean

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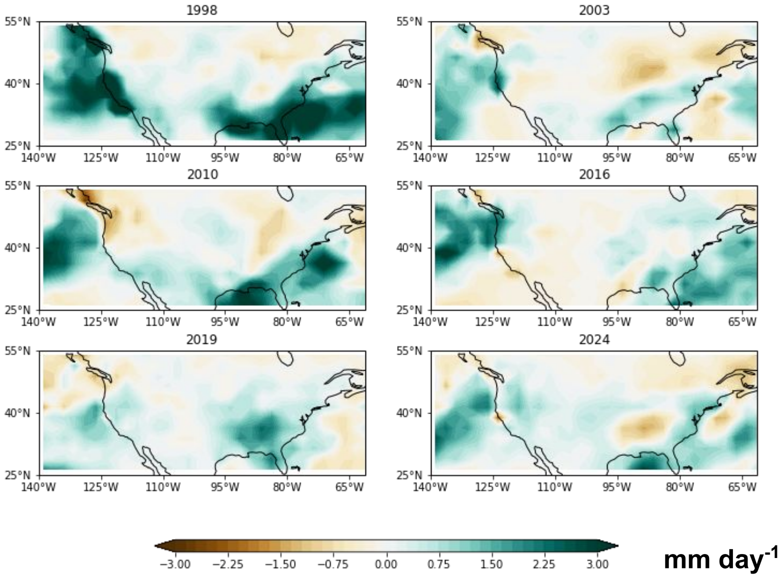

# Summary

- 1-degree UFS with stochastic physics has good internal variability
- Both versions of the UFS has a strong cooling trend in the Northern Hemisphere
- The UFS is missing the coherence between precipitation and upper-level divergence. This is also apparent at the higher resolution.
- UFS re-forecasts initialized with replay are outperforming CFSv2 and SPEAR for NINO3.4 prediction.
- The current state of the UFS is a really good starting point for developing a seasonal forecast system.
- We intend to release the SFS development plan soon, and will be soliciting feedback.
- NOAA is organizing two upcoming meetings:
    - S2S Community Meeting on **June 5-7**, Boulder, CO
    - UFS S2S Applications Workshop on **Sep 4-6**, College Park, MD