



# Reducing Tropical Cyclone Biases in the Navy Earth System Prediction Capability

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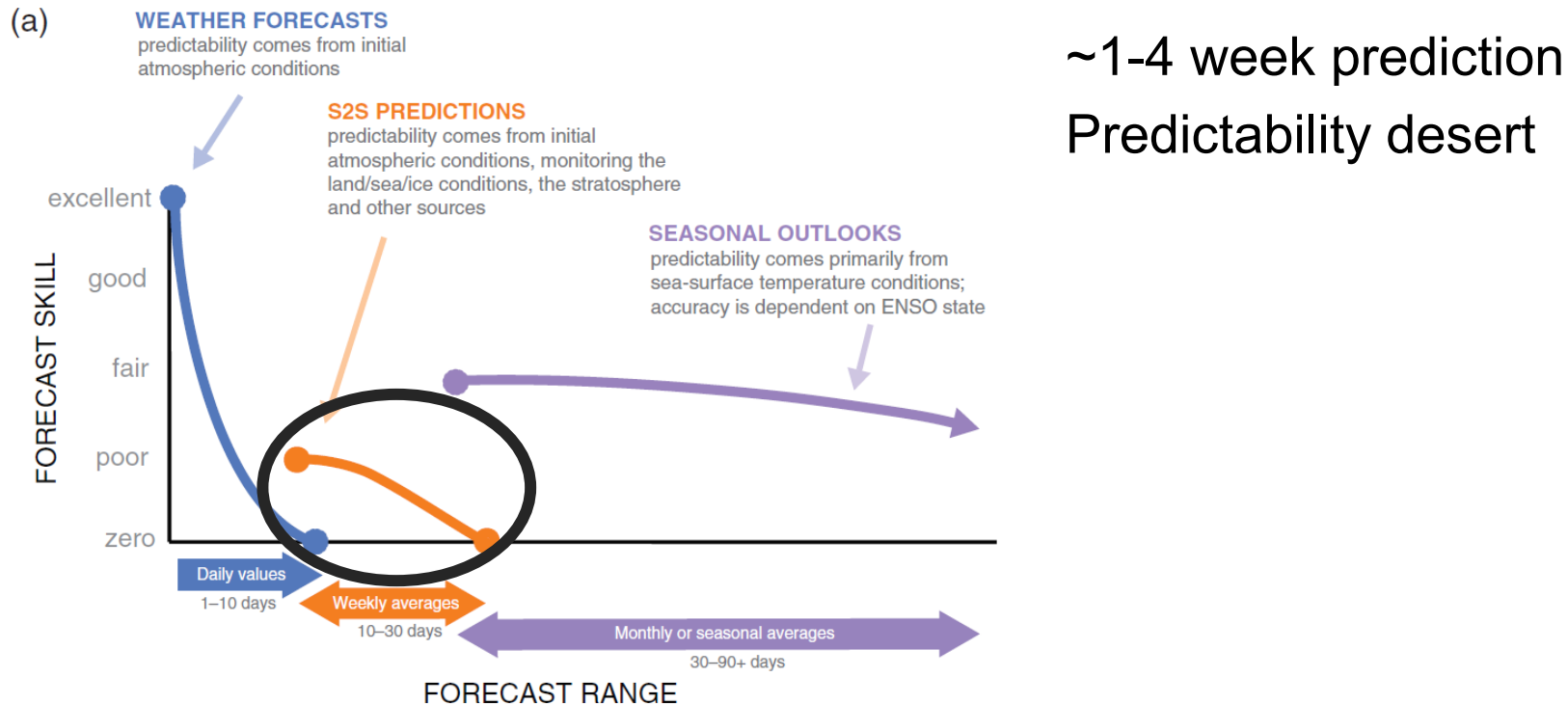
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6<sup>th</sup> WGNE Workshop on Systematic Errors in Weather and Climate Models

10/31/2022

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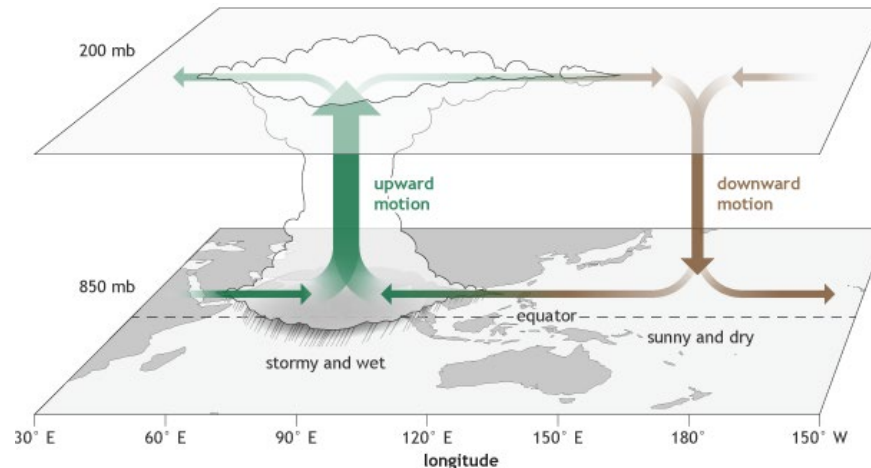
# Subseasonal-to-Seasonal Forecasting



(White et al., 2017)

# Madden-Julian Oscillation (MJO)

- Dominate mode of intraseasonal variability
- Convectively coupled equatorial disturbance
- Planetary scale
- Slow eastward propagating



# MJO-TC Relationship

- Enhanced likelihood for TC formation during strong convective phase of the MJO
- MJO-associated Rossby-like gyres create anomalous relative vorticity, low vertical wind shear, and poleward moisture advection
- Genesis Potential Index (GPI)
  - $\eta$ : Absolute Vorticity at 850hPa
  - $V_{shear}$ : Vertical Shear between 850hPa and 200hPa
  - $\mathcal{H}$ : Relative Humidity at 700hPa
  - $V_{pot}$ : Potential Intensity,  $f(SST, mslp, T, q)$

$$GPI = |10^5 \eta|^{3/2} \left( \frac{\mathcal{H}}{50} \right)^3 \left( \frac{V_{pot}}{70} \right)^3 (1 + 0.1 V_{shear})^{-2}$$

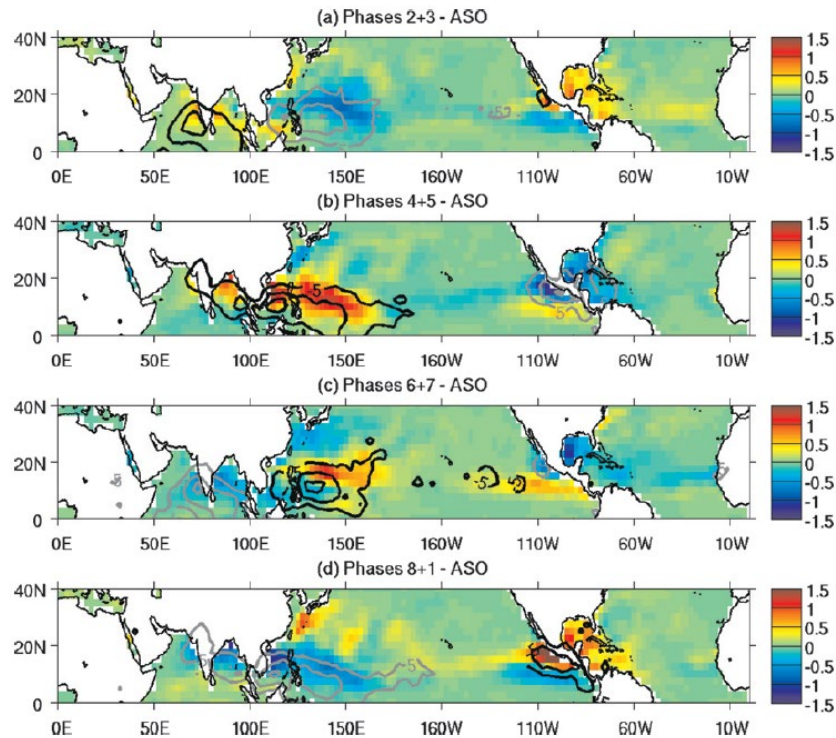


FIG. 2. As in Fig. 1, but for ASO.

Contours: MJO OLR Anomaly Composites  
(Camargo et al., 2009)

# Successful uses of S2S Forecasting

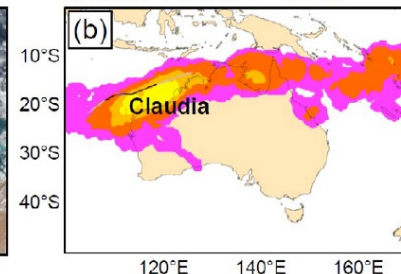
- Case studies using the ECMWF Ensemble S2S Hindcast:
  - Heat waves with lead times 3-4 weeks
  - Cold air outbreaks with lead times 2-3 weeks
  - TC cases were predicted with 3-4 weeks lead time
    - High TC predictability is attributed to strong and well predicted MJO events**

(Domeisen et al., 2022)

Cyclone Claudia – 2020/01/13



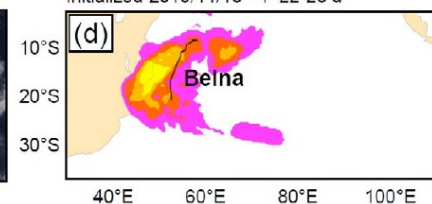
Initialized 2019/12/30 – F 15-21 d



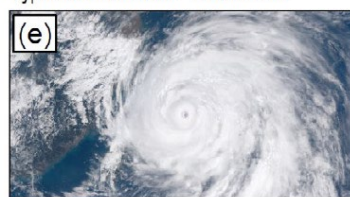
Cyclone Belna – 2019/12/07



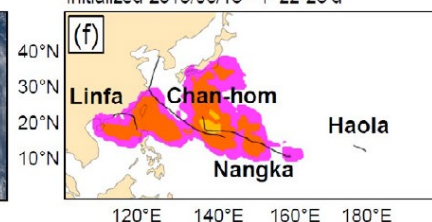
Initialized 2019/11/18 – F 22-28 d



Typhoon Chan-hom – 2015/07/10



Initialized 2015/06/15 – F 22-28 d



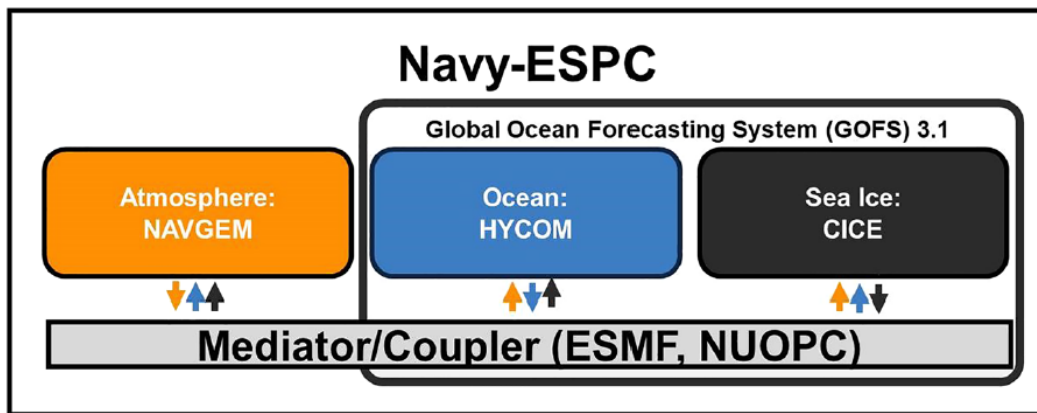
(Domeisen et al., 2022)

Probability of TC occurrence



# Navy Earth System Prediction Capability (ESPC)

- Atmosphere: NAVy Global Environmental Model (NAVGE M)
- Ocean: HYbrid Coordinate Ocean Model (HYCOM)
- Sea Ice: Community Ice Code (CICE)



**Sub-seasonal eXperiment (SubX) Version**

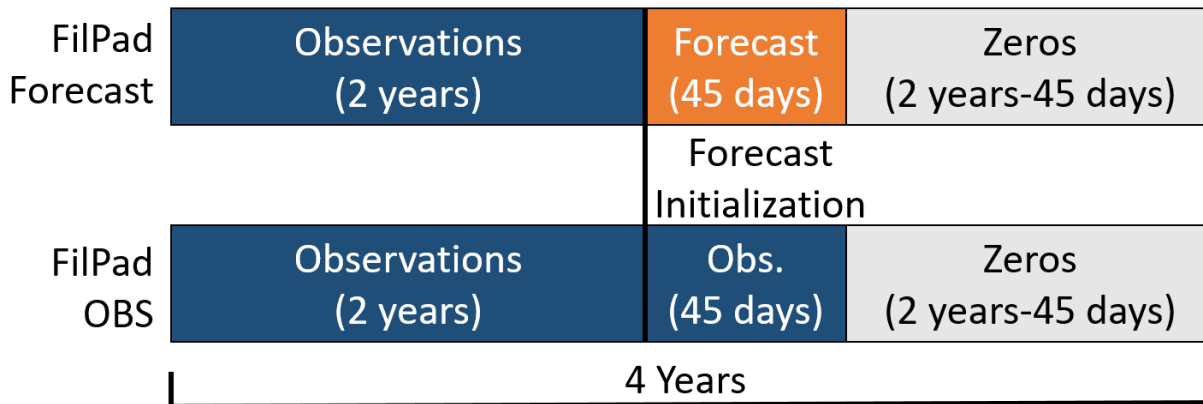
# SubX Version of the Navy ESPC

- Single member
- Initialized four times weekly
- 45-day forecasts
- 2009-2015
- May-November (MJJASON)



# MJO Filtering

- Wavenumber-frequency filtering
  - 30-90 day periods
  - Eastward wavenumbers 1-6



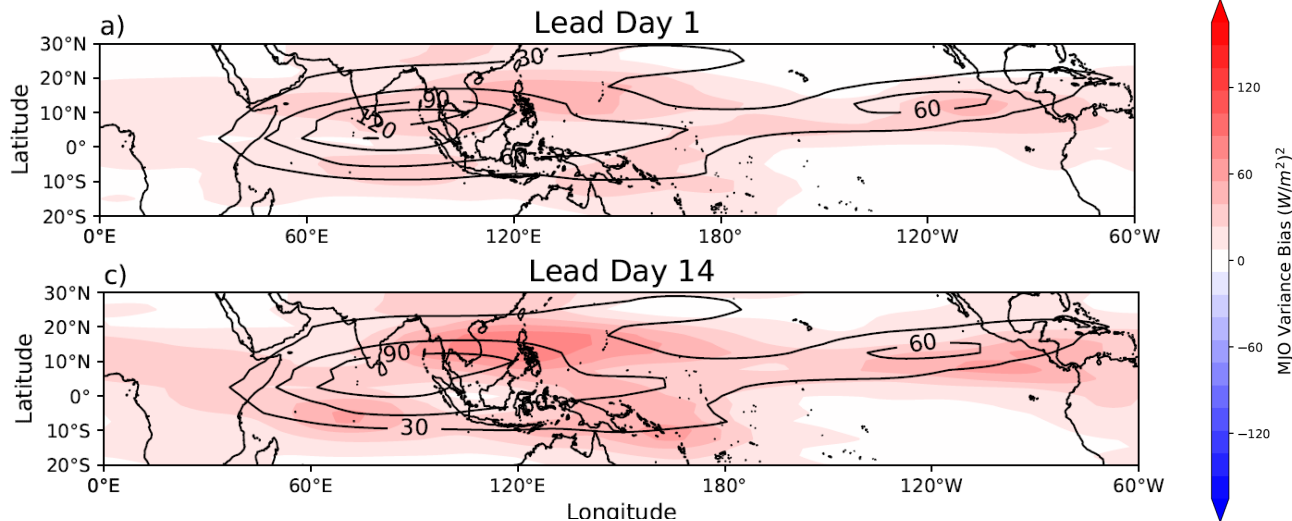


## MJO is too strong

- 1) A faster convective moisture adjustment timescale
- 2) Stronger vertical moisture advection

**See poster for more information**

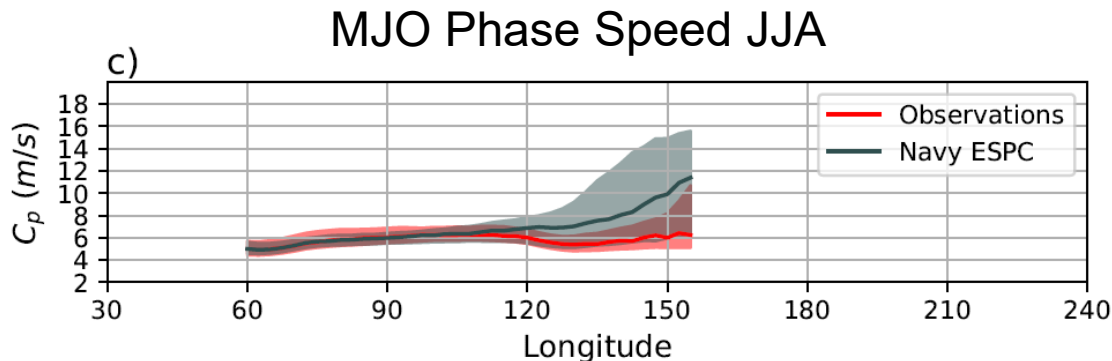
MJO Amplitude Bias MJJASON



## MJO propagates too quickly

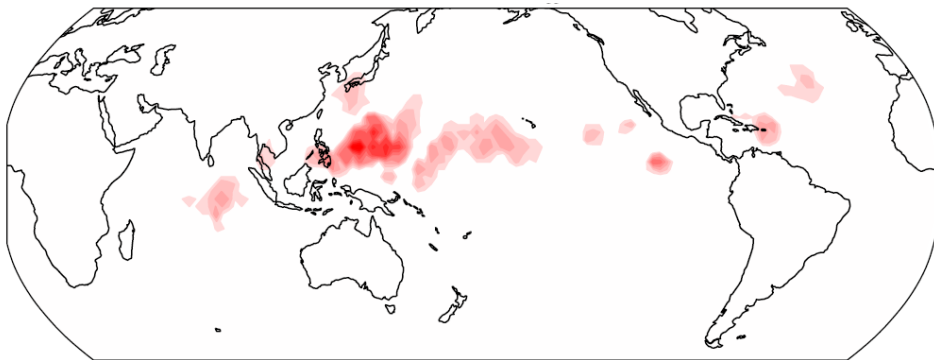
- Stronger horizontal moisture advection in the Western Pacific driven by steeper mean meridional and zonal moisture gradients, increases the moisture tendency

See poster for  
more information

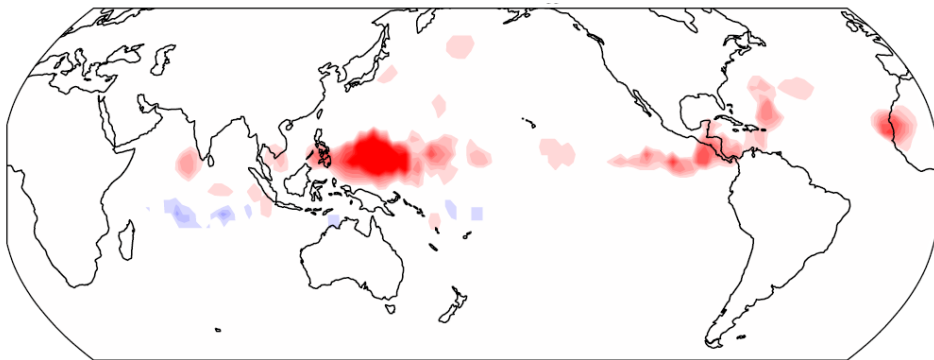


# TC Genesis Biases

**TC Genesis Bias MJJASON Lead Day 1**



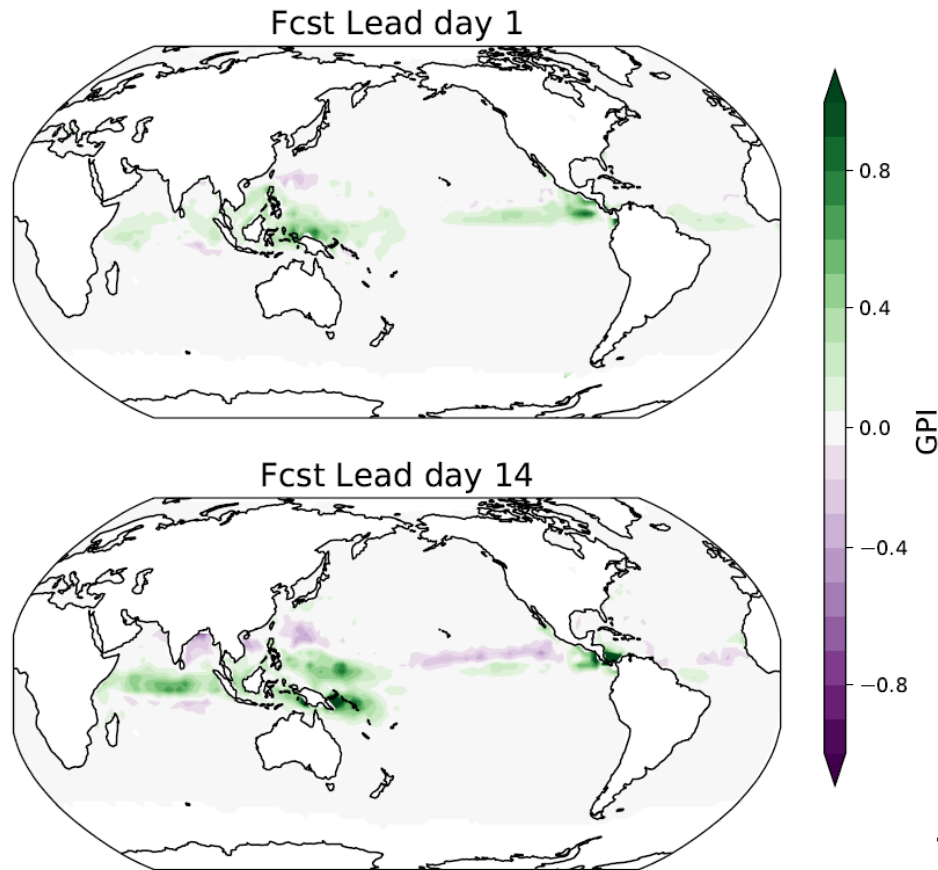
**TC Genesis Bias MJJASON Lead Day 14**



Genesis Bias

- More TC genesis in the Navy ESPC
- More genesis in the Northwestern Pacific, Eastern Pacific, Atlantic Basins

- Positive GPI bias at lead day 1
- Stronger positive bias in Indo-Pacific Warm pool and Eastern Pacific at lead day 14



**How does the MJO-TC skill in the Navy ESPC change with the addition of bias correction methods?**

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**Analysis Correction-based Additive Inflation (ACAI) Version**

# ACAI Version of the Navy ESPC

- Works to reduce systematic and random errors
- Applies perturbations to the model tendency to account for model error
  - Mean bias calculated from analysis corrections from the data assimilation model to account for systematic biases
  - Stochastic model errors using random analysis increments to represent model uncertainty

$$\delta x_i = \underbrace{\frac{1}{N_s} \sum_{k=1}^{N_s} \delta x_k^a}_{\text{3-month seasonal average analysis correction}} + \alpha \underbrace{\left( \delta x_{r_i}^a - \frac{1}{N_e} \sum_{j=1}^{N_e} \delta x_{r_j}^a \right)}_{\text{Stochastic perturbation}},$$

Tendency perturbation

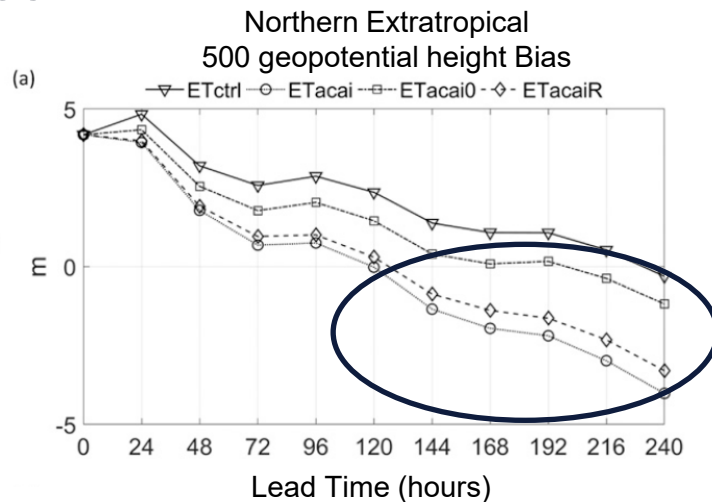
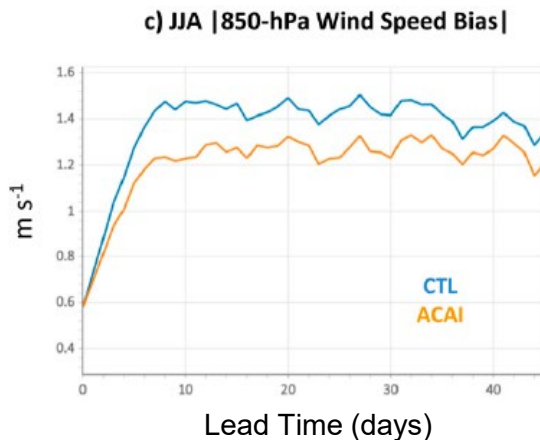
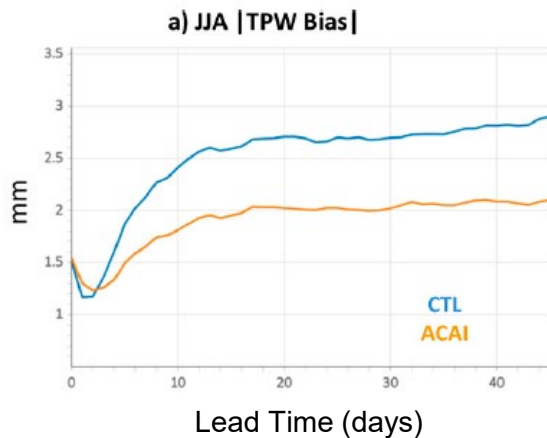


# ACAI Version of the Navy ESPC

- Stochastic perturbations pulled from:
  - Static Archive of analysis increments from 2011
  - Running Archive of 60-day leading analysis increments
- Perturbations applied to:
  - Surface pressure
  - Temperature
  - Humidity
  - Zonal and meridional wind speed

# ACAI Version of the Navy ESPC

- Improves non-linear model forecasts
- Significantly improves forecast skill
- Over-correction of bias at longer lead times

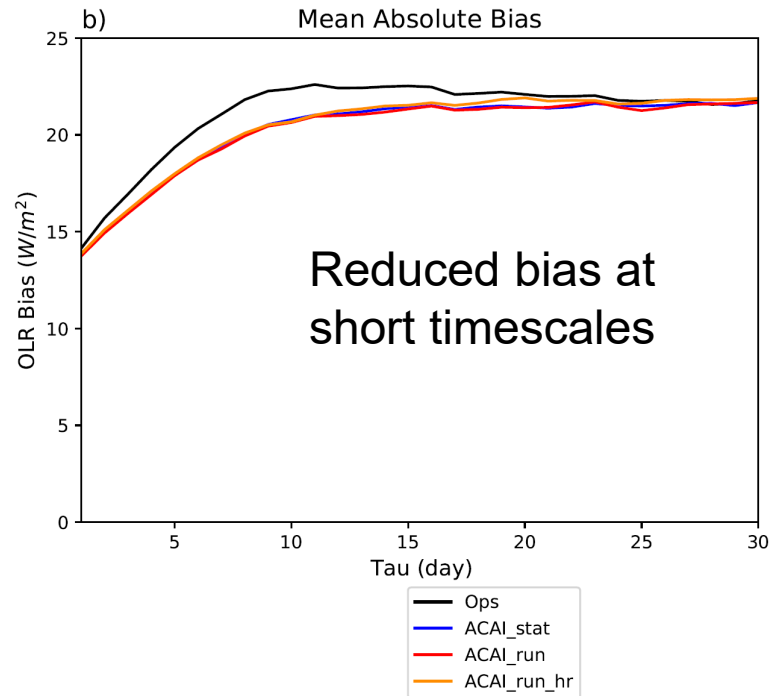
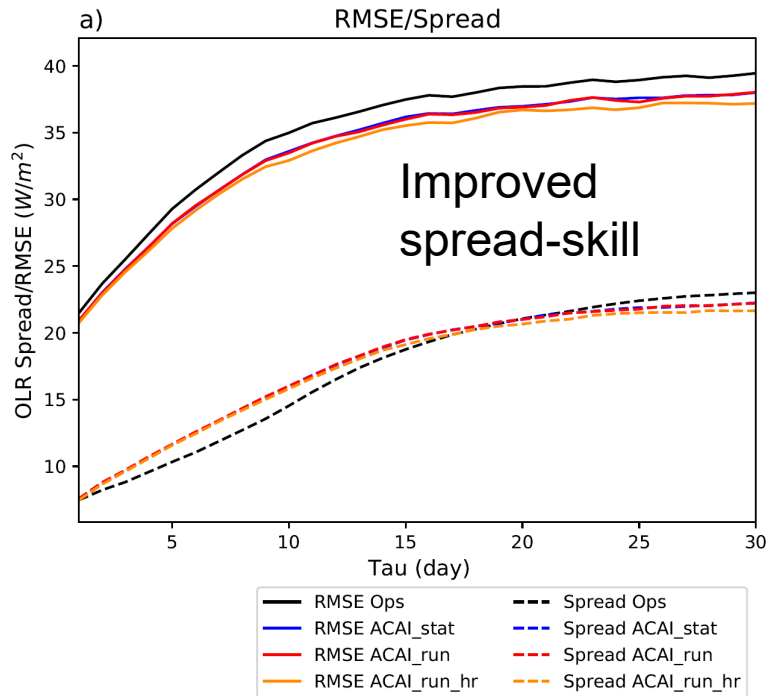


- Feb. 1, 2017- Jan. 31, 2018
- 45-day forecasts
- May-November (MJJASON)

Ensemble Name	Ensemble Size	Simulation	Perturbation Method	HYCOM Grid	CICE Version
Ops	16*	Operational	None	1/12°	4
ACAI_stat	7	ACAI	Static Archive	1/4°	5
ACAI_run	7	ACAI	Running Archive	1/4°	5
ACAI_run_hr	7	ACAI	Running Archive	1/12°	5

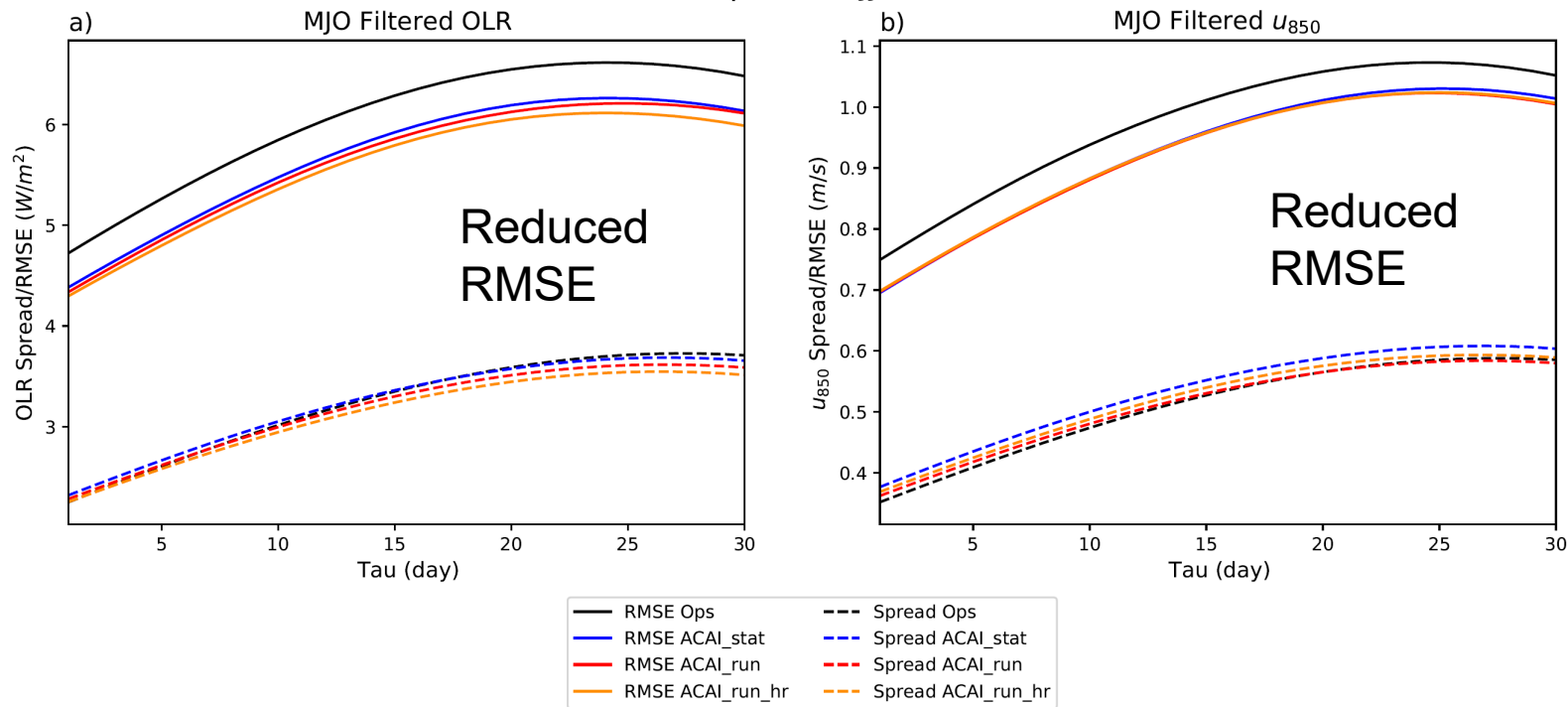
\*Note: Spread for Ops simulation calculated using a bootstrap resampling to 7 members

## OLR Anomalies MJJASON

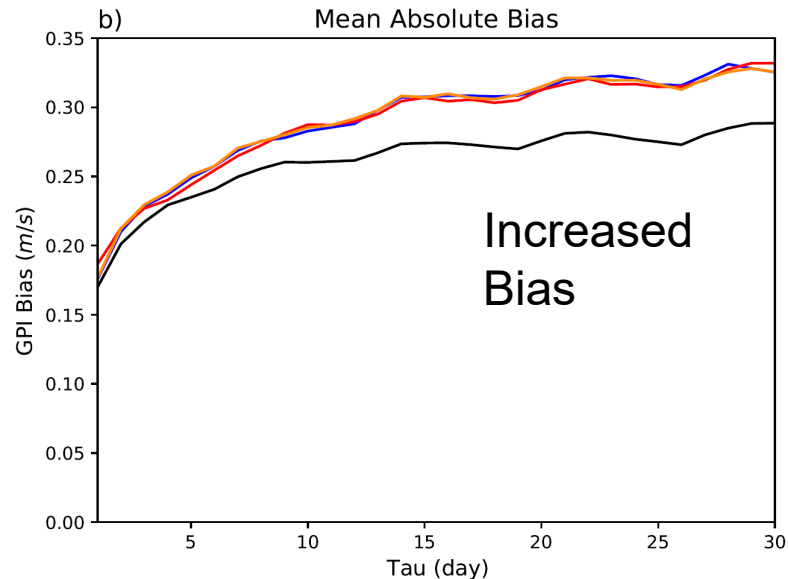
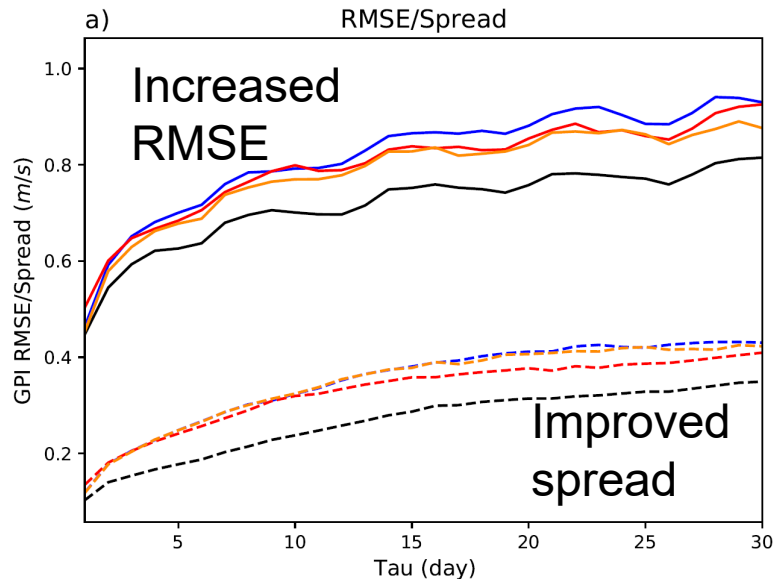


Similar results for  $u_{850}$

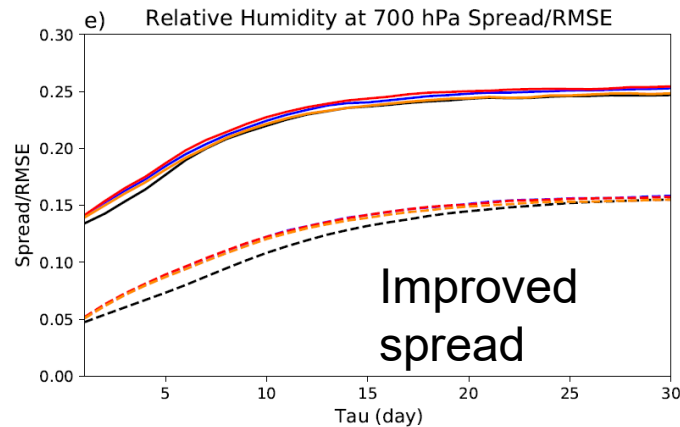
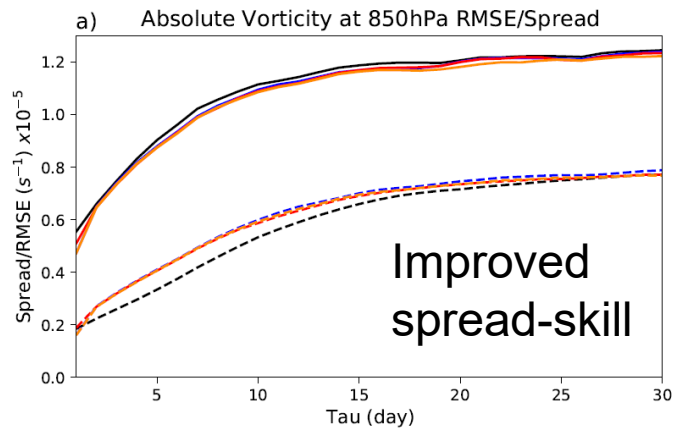
## RMSE/Spread MJJASON



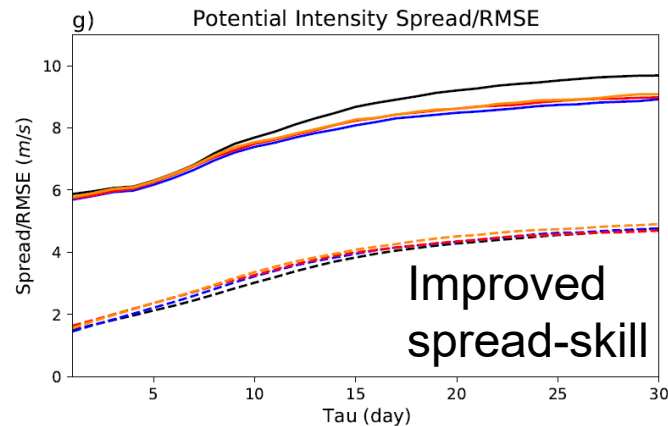
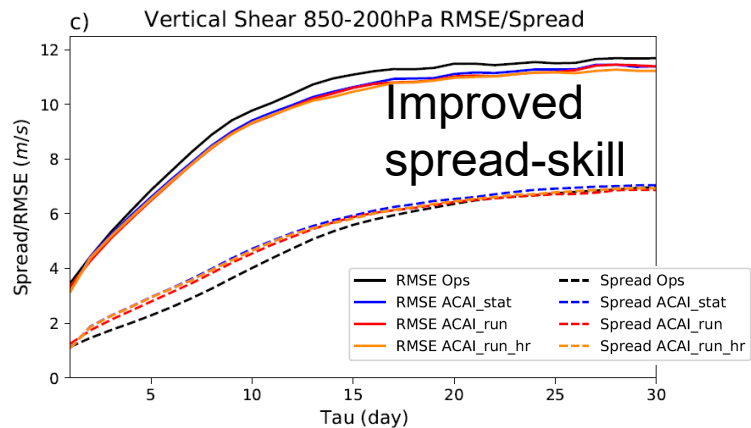
## GPI Anomalies MJJASON



# Skill of GPI Components

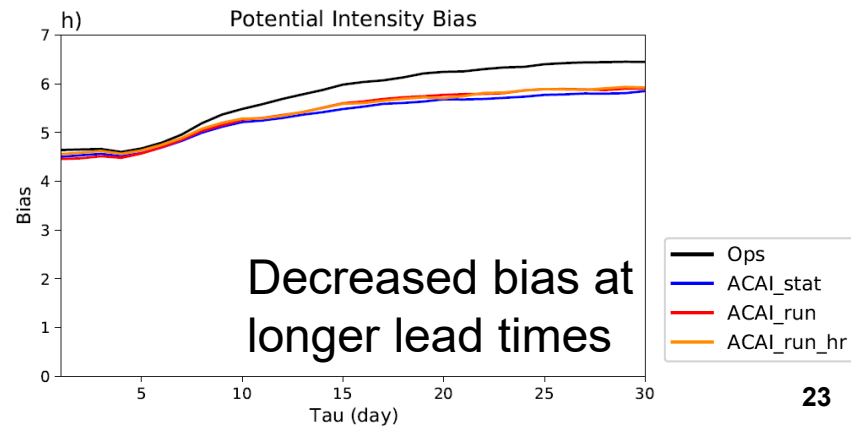
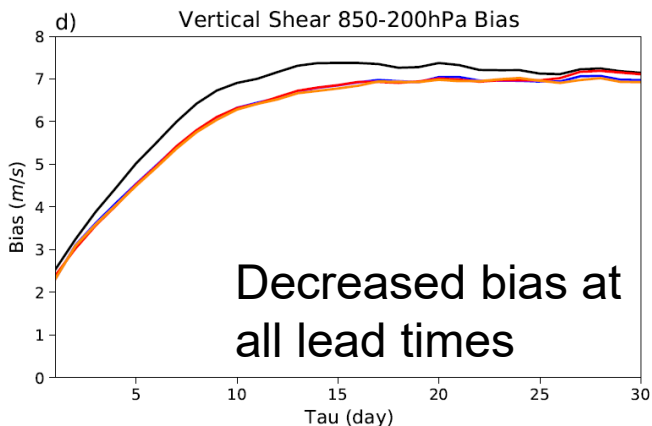
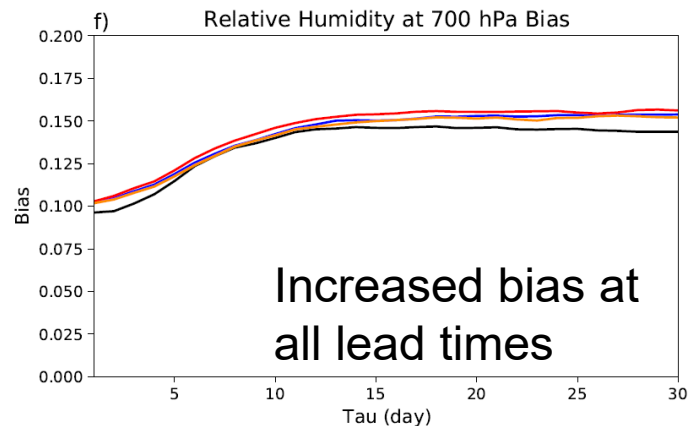
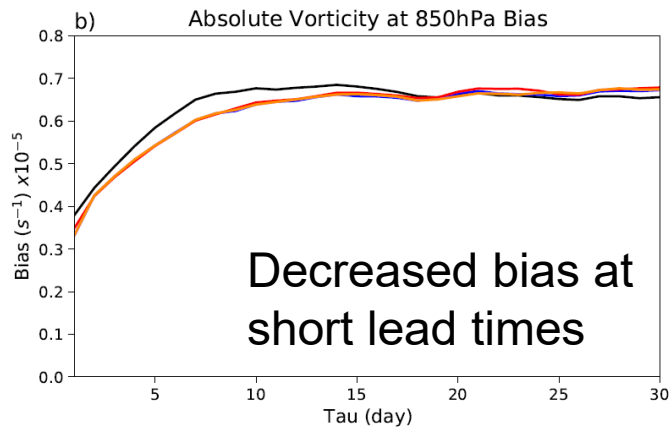


Increased  
RMSE

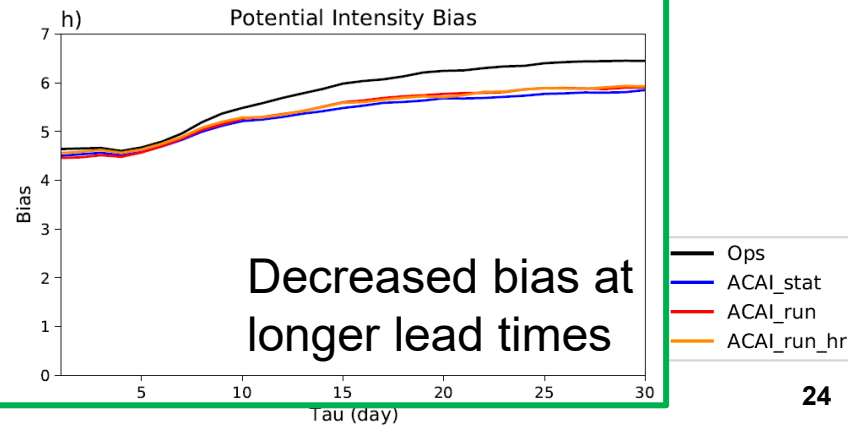
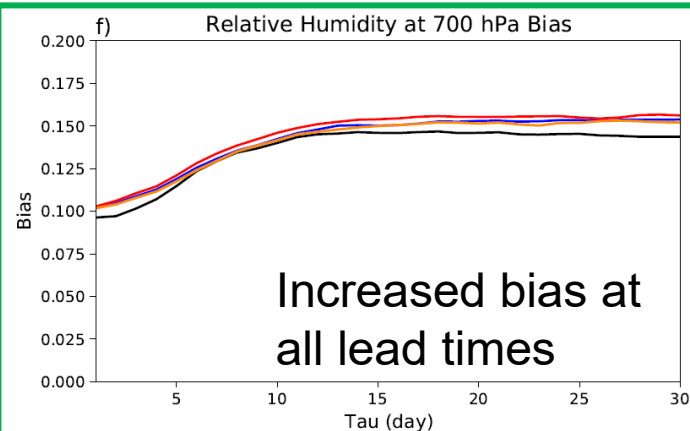
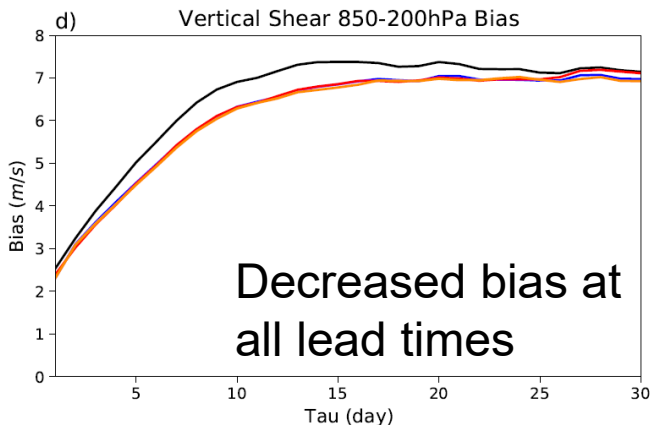
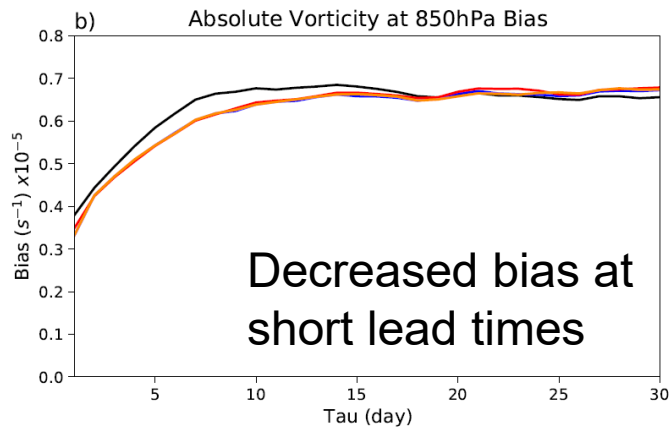




# Bias of GPI Components



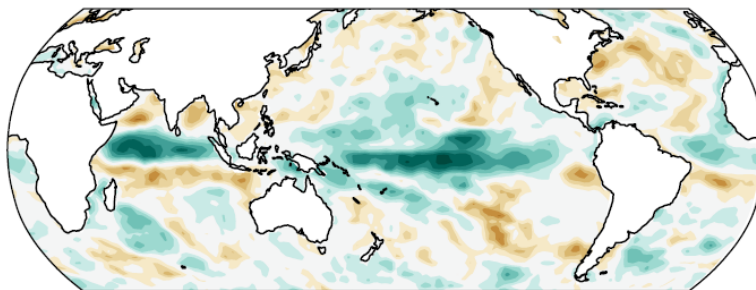
# Bias of GPI Components



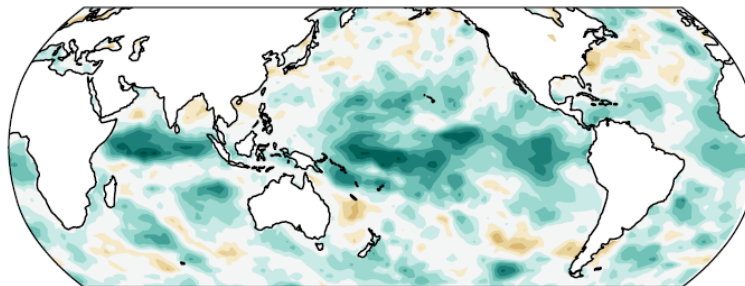
Ops  
ACAI\_stat  
ACAI\_run  
ACAI\_run\_hr

# Relative Humidity

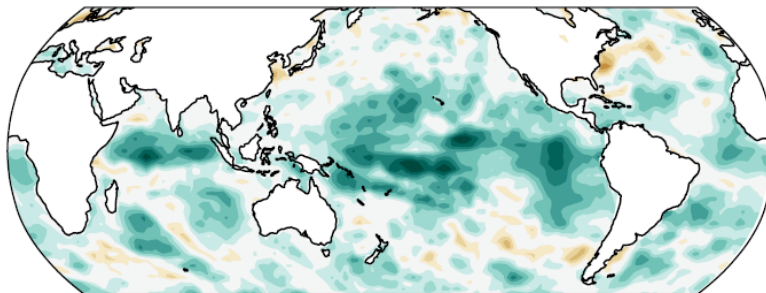
Ops Bias Lead Day 14



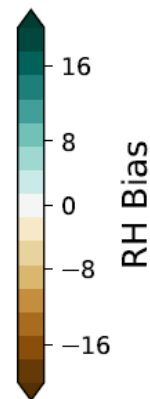
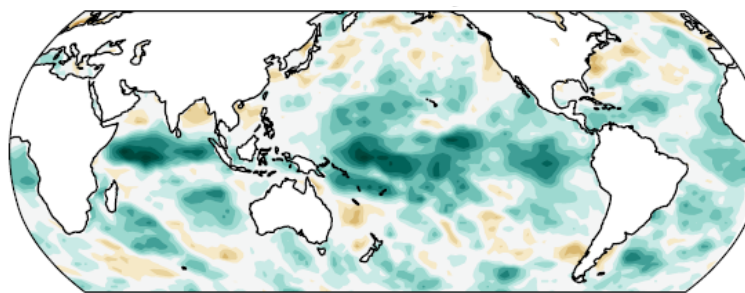
ACAI\_stat Bias Lead Day 14



ACAI\_run Bias Lead Day 14

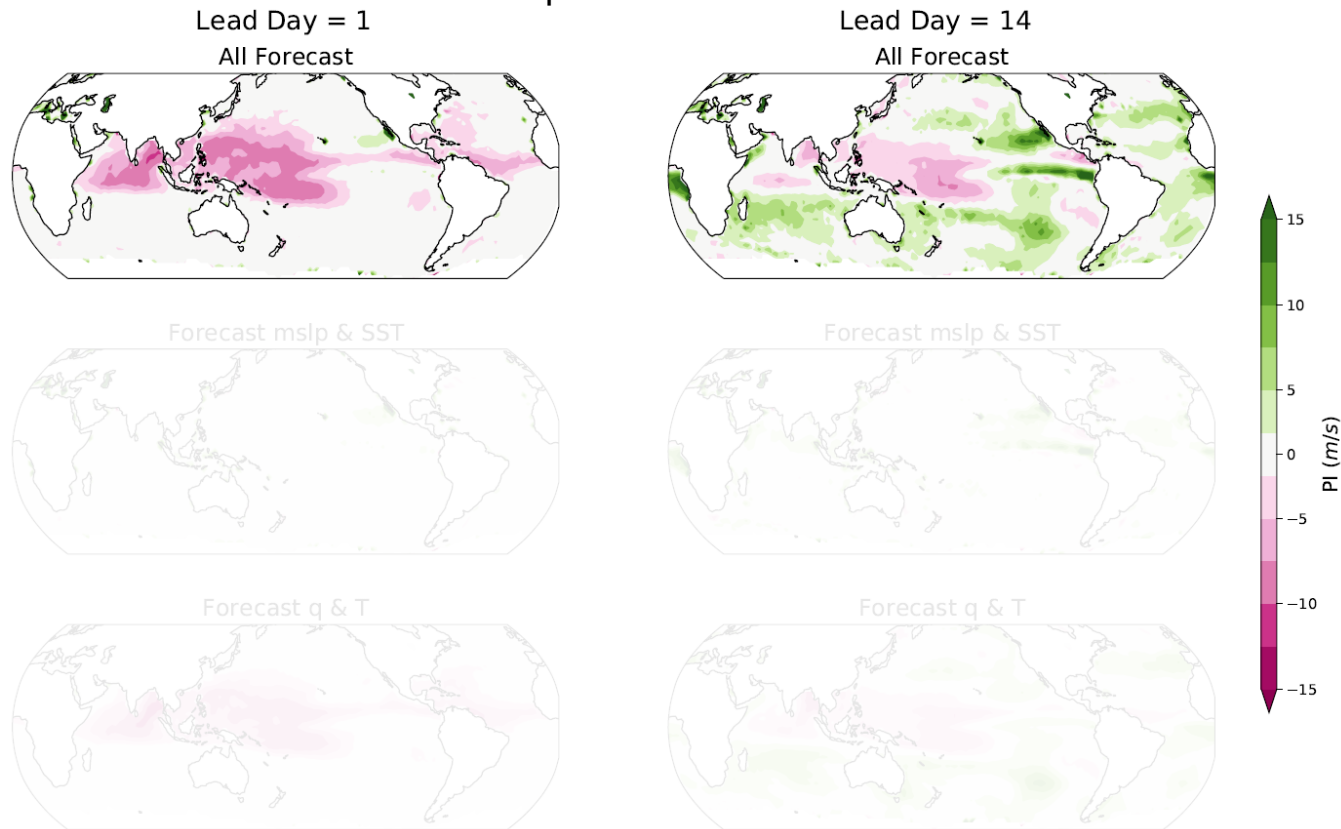


ACAI\_run\_hr Bias Lead Day 14



# Potential Intensity

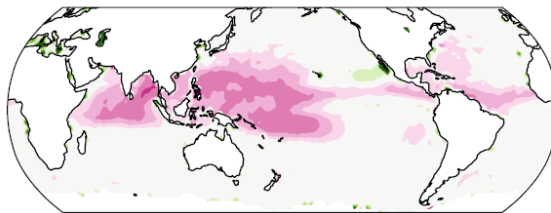
## Ops Bias



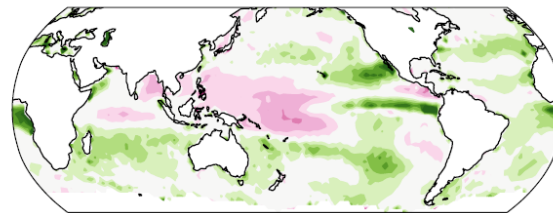
# Potential Intensity

## Ops Bias

Lead Day = 1  
All Forecast



Lead Day = 14  
All Forecast



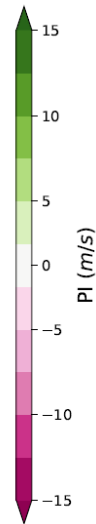
Forecast mslp & SST

Forecast mslp & SST

$$PI = f(SST, mslp, T, q)$$

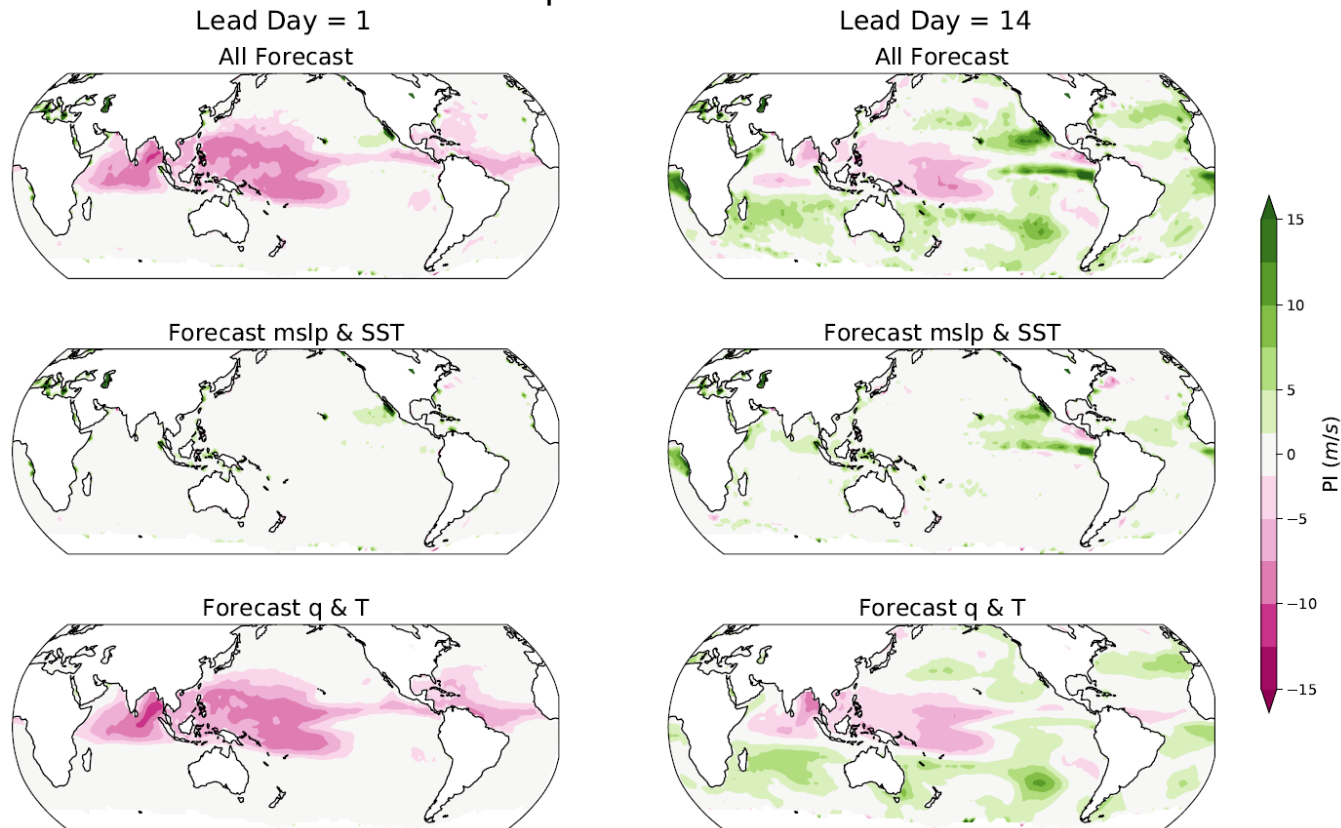
$$PI_{sfc} = f(SST_{fcst}, mslp_{fcst}, T_{obs}, q_{obs})$$

$$PI_{col} = f(SST_{obs}, mslp_{obs}, T_{fcst}, q_{fcst})$$



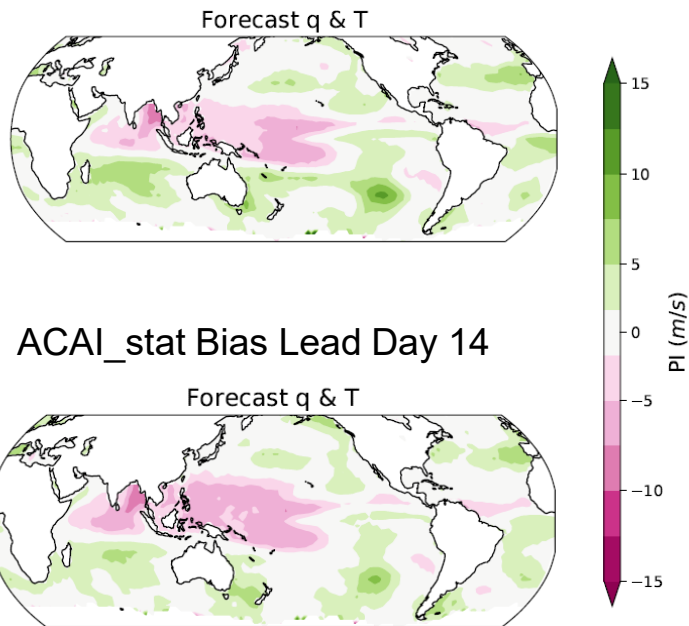
# Potential Intensity

## Ops Bias

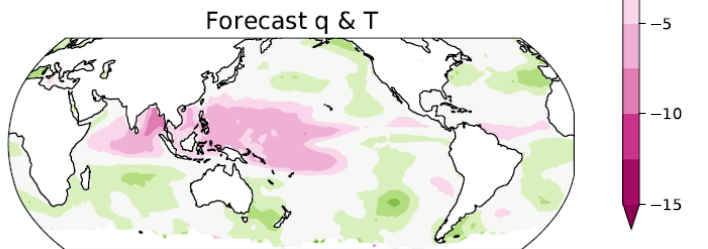


# Potential Intensity

Ops Bias Lead Day 14



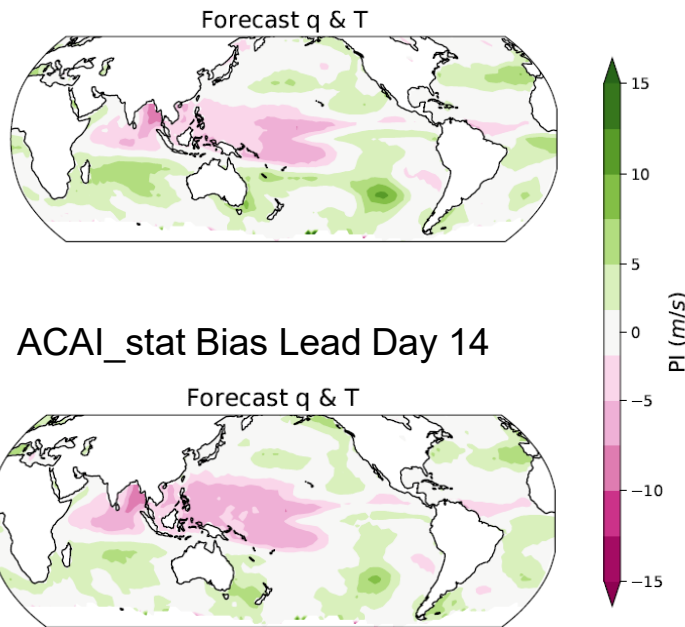
ACAI\_stat Bias Lead Day 14



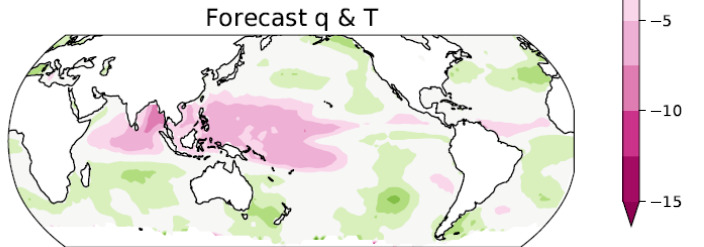


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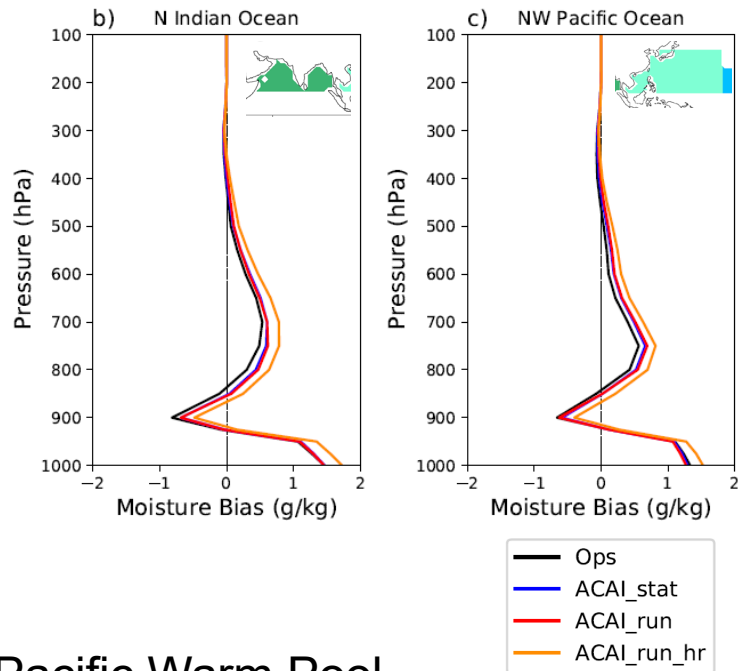
Ops Bias Lead Day 14



ACAI\_stat Bias Lead Day 14



## Mean Moisture Bias



Possibly due to moisture biases in the Indo-Pacific Warm Pool

# Conclusions

- The MJO in the Navy ESPC is too fast and too strong, related to the convection schemes and representation of moisture
- ACAI improves the MJO prediction skill
- Degradation of the GPI skill, ACAI increases errors in moisture
- ACAI improves the prediction skill of absolute vorticity, potential intensity, and vertical shear

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**See poster in Monday Session for more information**

# Questions?

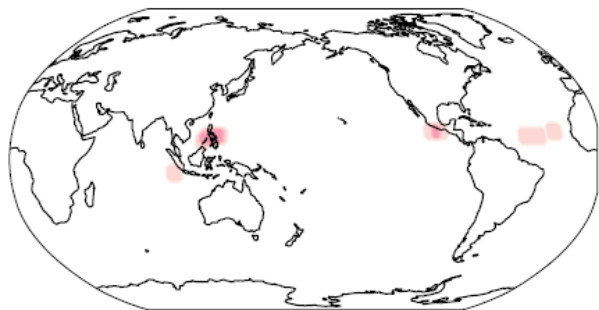
**email: [stephanie.rushley.ctr@nrlmry.navy.mil](mailto:stephanie.rushley.ctr@nrlmry.navy.mil)**



We gratefully acknowledge the support of the Chief of Naval Research through the NRL Base Program, Extended-Range Tropical Cyclone Prediction 6.2 (PE 62435N). Computational resources were supported in part by a grant of HPC time and resources from the Department of Defense High Performance Computing Modernization Program, Stennis Space Center, MS. This research was performed while the author held an NRC Research Associateship award at the Naval Research Laboratory.

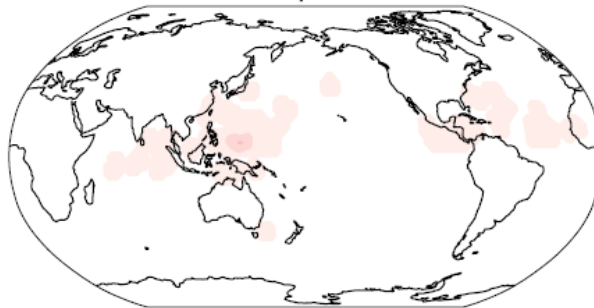
## TC Genesis MJJASON 2017

Observations

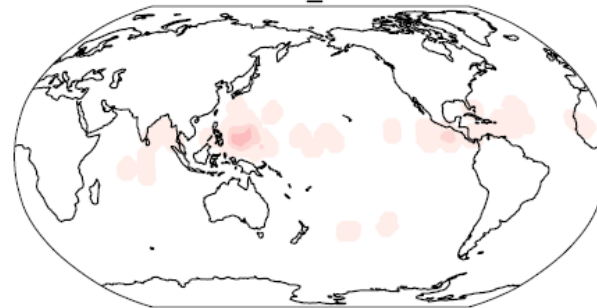


## TC Genesis Lead Day 14

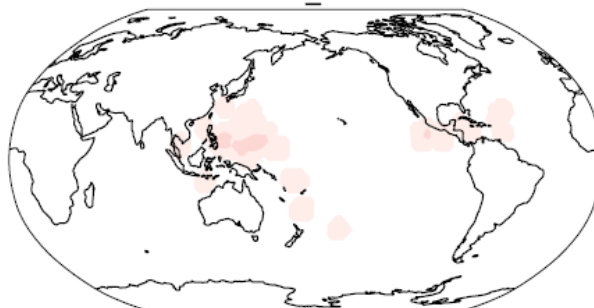
Ops



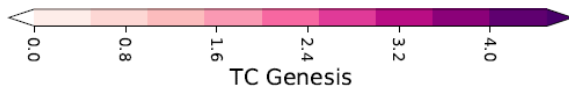
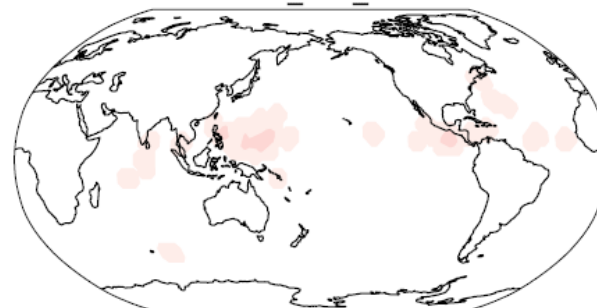
ACAI\_stat



ACAI\_run



ACAI\_run\_hr



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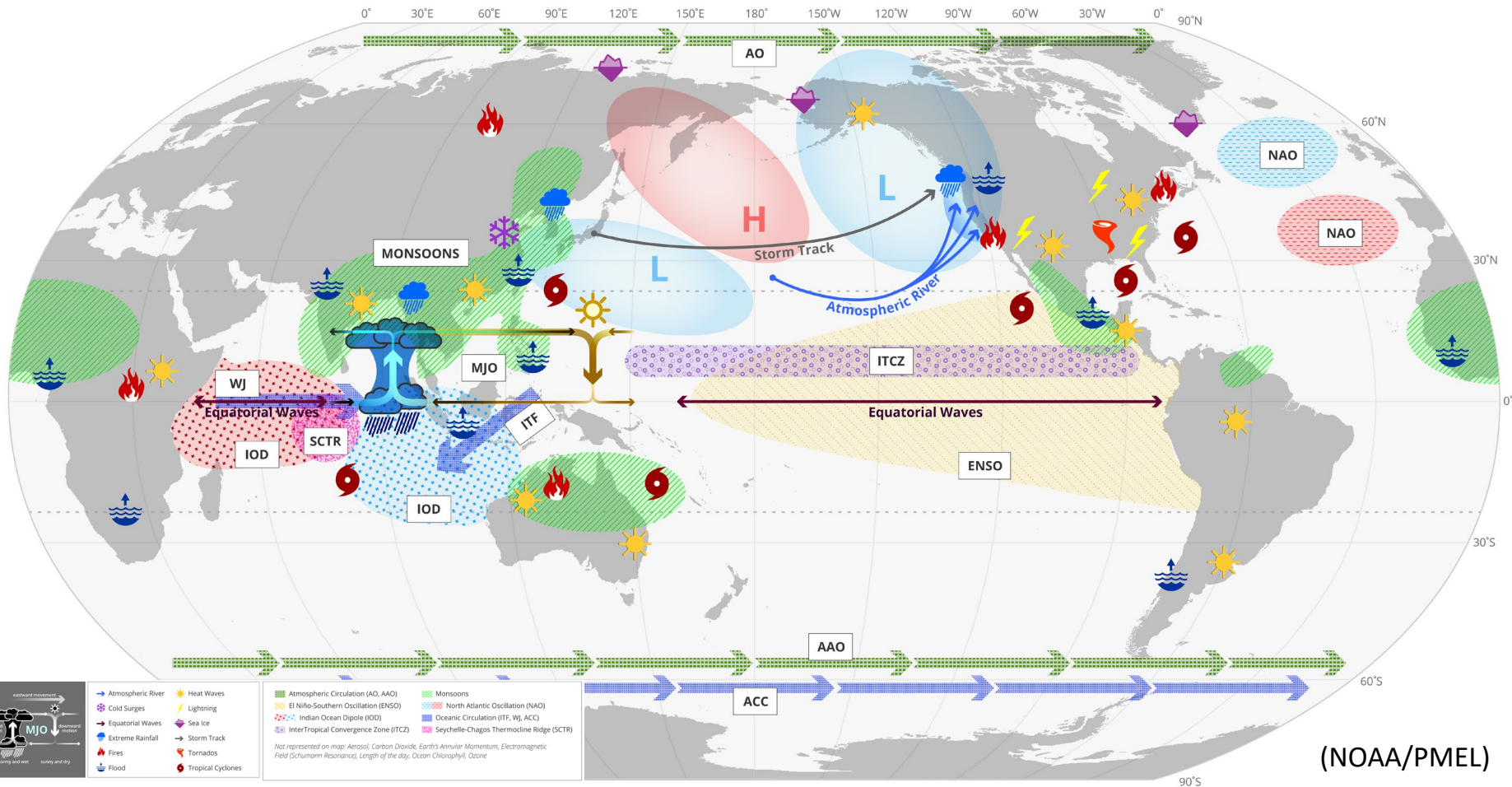
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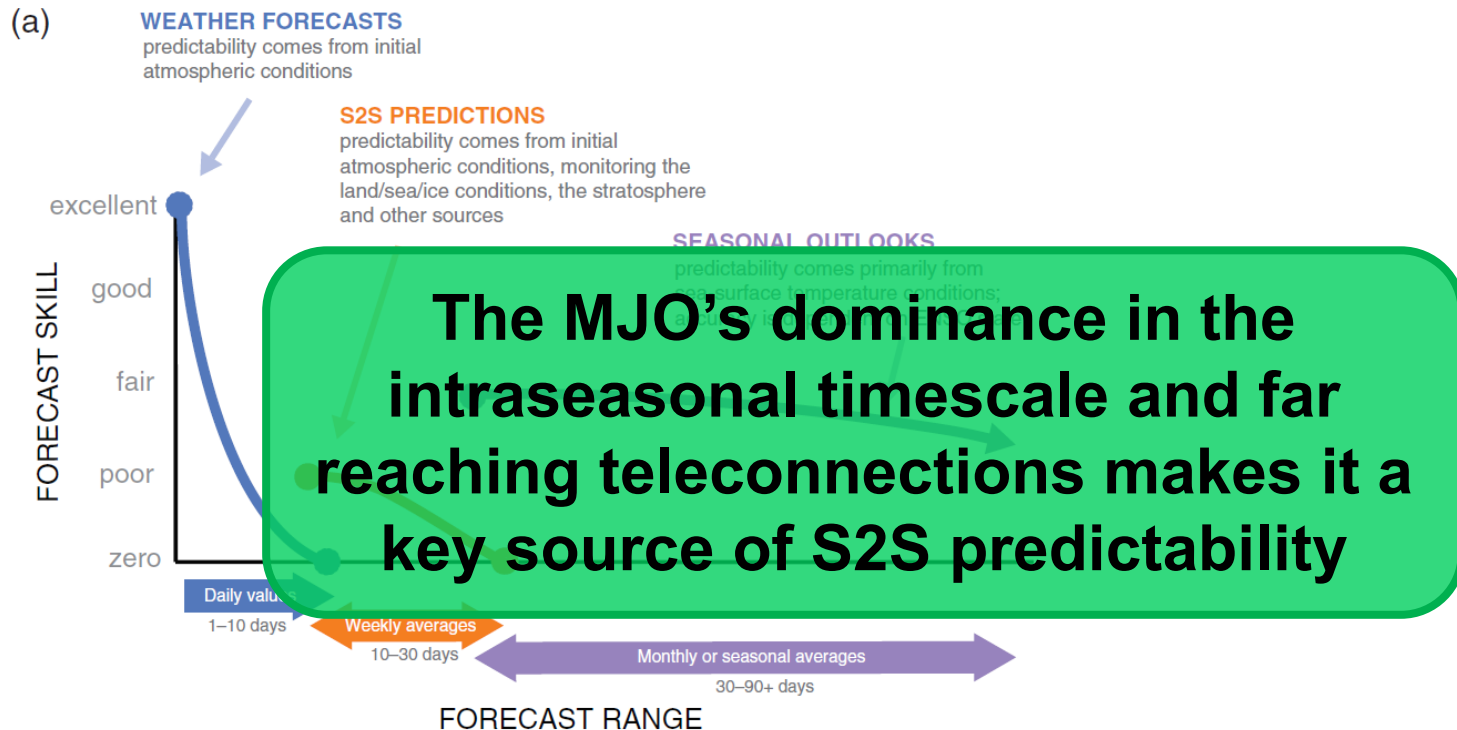


# MADDEN-JULIAN OSCILLATION (MJO): GLOBAL IMPACTS



(NOAA/PMEL)

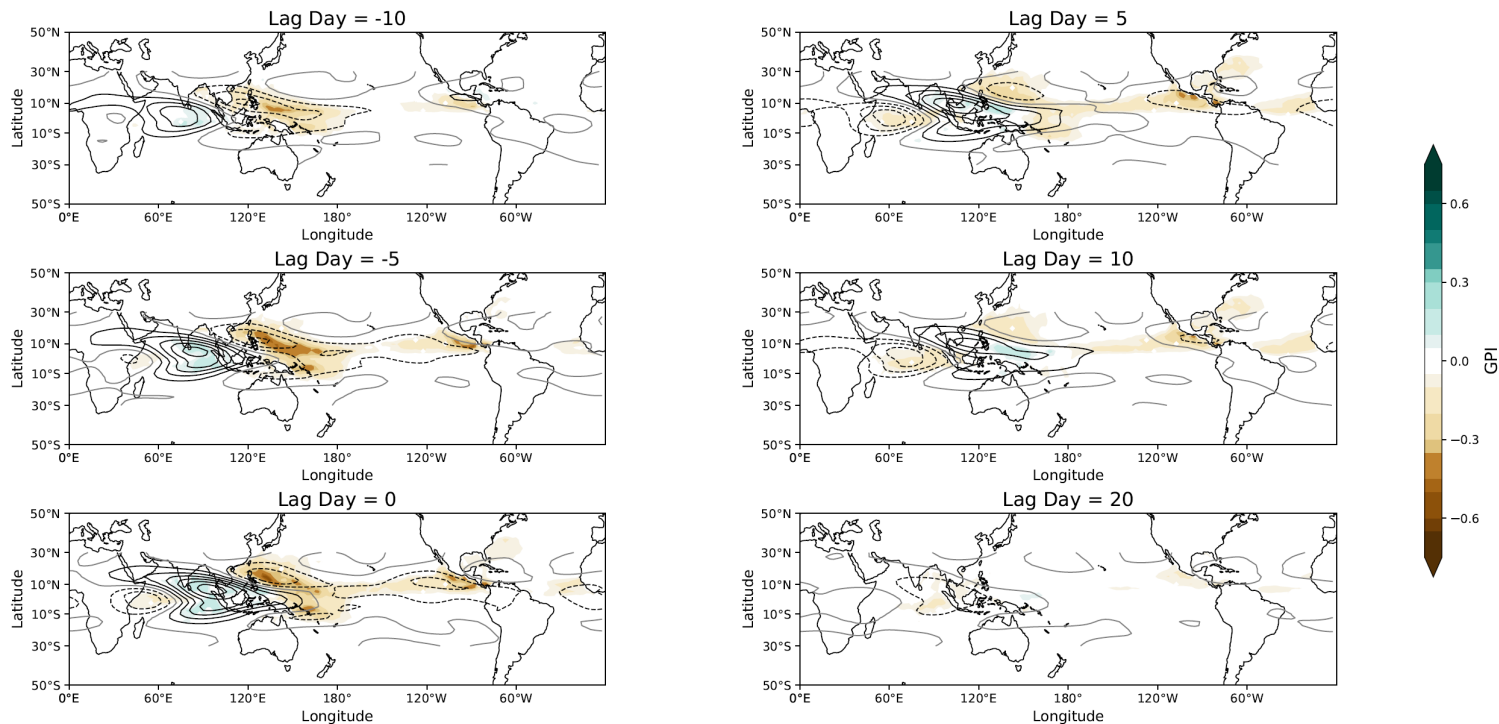
# Subseasonal-to-Seasonal Forecasting



(White et al., 2017)

# L10 FCST Absolute Vorticity GPI

**GPI w/ Navy ESPC Absolute Vorticity MJJASON 2009-2015**



# Leave One Out (L1O) GPI Biases

Role of Vertical Shear:  $GPI = |10^5 \eta|^{3/2} \left( \frac{\mathcal{H}}{50} \right)^3 \left( \frac{V_{pot}}{70} \right)^3 (1 + 0.1 V_{shear})^{-2}$

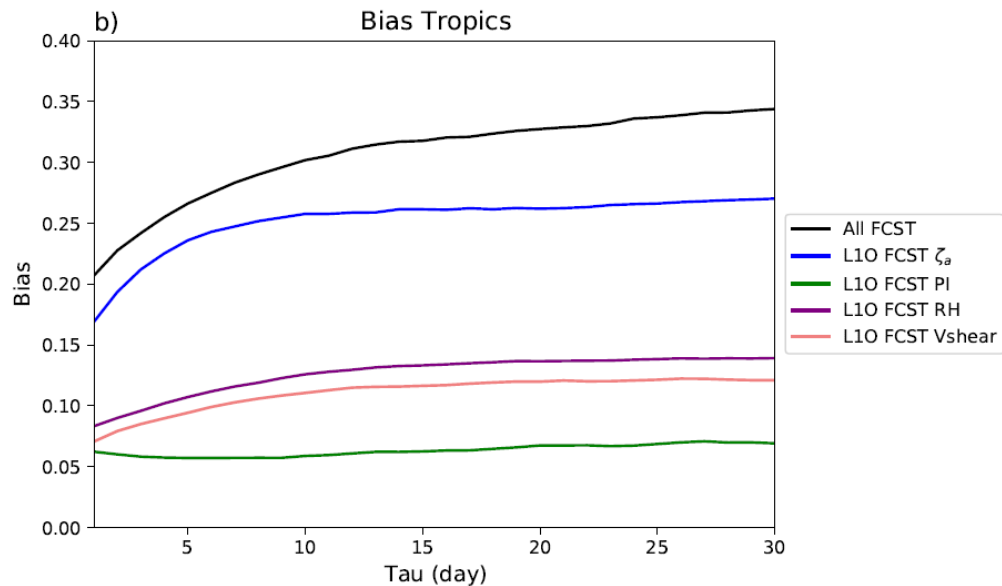
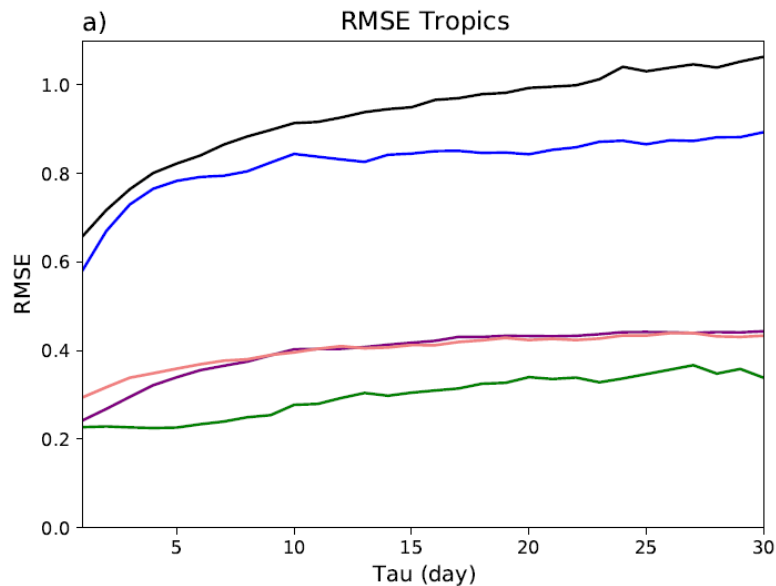
OBS  
FCST

Role of Relative Humidity:  $GPI = |10^5 \eta|^{3/2} \left( \frac{\mathcal{H}}{50} \right)^3 \left( \frac{V_{pot}}{70} \right)^3 (1 + 0.1 V_{shear})^{-2}$

OBS  
FCST

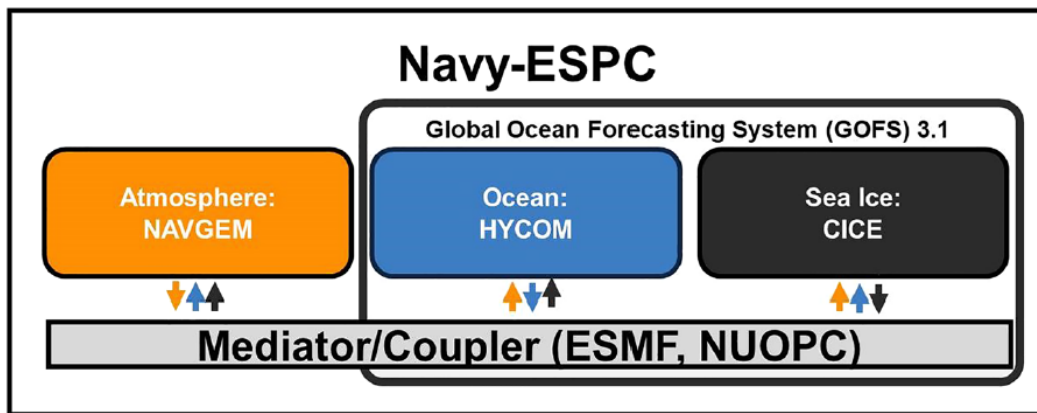
# L10 GPI Bias

## GPI MJJASON



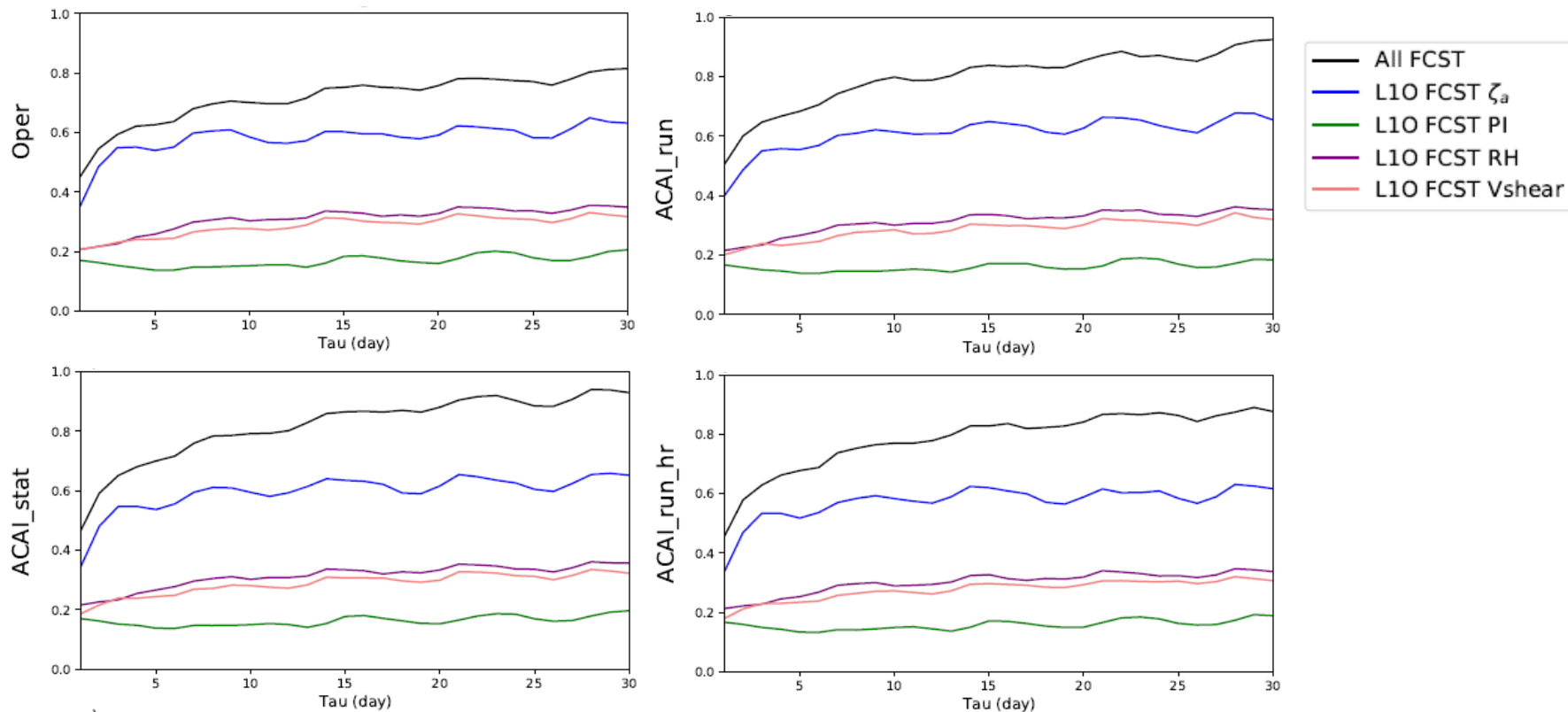
# Navy Earth System Prediction Capability (ESPC)

- Atmosphere: NAVy Global Environmental Model (NAVGE M)
- Ocean: HYbrid Coordinate Ocean Model (HYCOM)
- Sea Ice: Community Ice Code (CICE)



**Analysis Correction-based Additive Inflation (ACAI) Version**

# L10 GPI RMSE

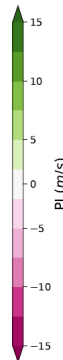
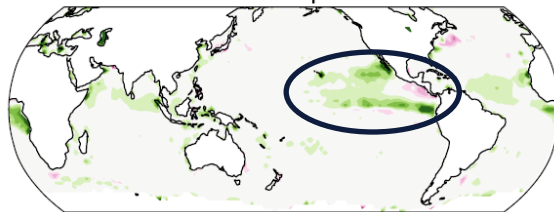




# Potential Intensity

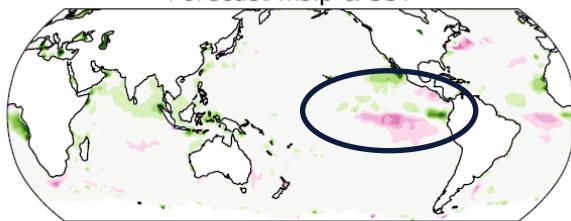
Ops Bias Lead Day 14

Forecast mslp & SST



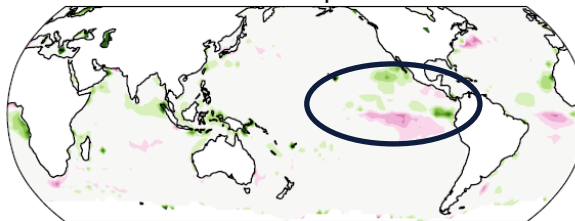
ACAI\_stat Bias Lead Day 14

Forecast mslp & SST



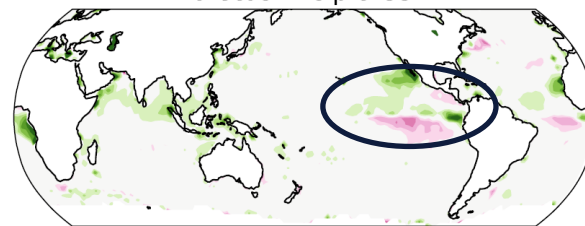
ACAI\_run Bias Lead Day 14

Forecast mslp & SST



ACAI\_run\_hr Bias Lead Day 14

Forecast mslp & SST



Likely SST driven in the East-Central Pacific



## $u_{850}$ Anomalies MJJASON

