



**NATIONAL  
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# Impact of ocean stochastic physics on the UFS subseasonal to seasonal forecast

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1.IMG at NOAA/NWS/NCEP/EMC

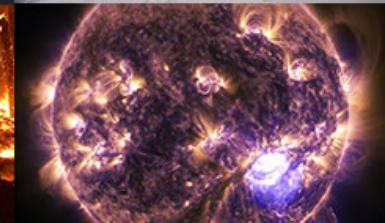
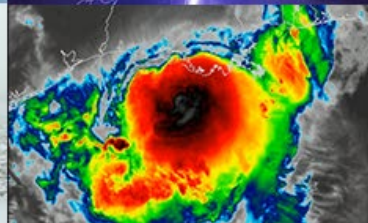
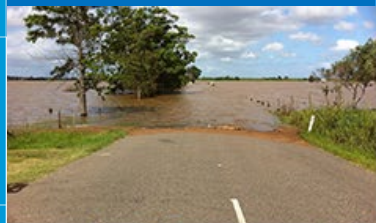
2.NOAA/NWS/NCEP/EMC

3.NOAA/ESRL/PSL

4.SRG at NOAA/NWS/NCEP/EMC

ECMWF workshop on model uncertainty, ECMWF Reading, UK, MAY 9-12

Acknowledgements: EMC coupled model group





# Outline



- Introduction and motivation



- Ocean stochastic physics schemes:

- Ocean SPPT
- Ocean ePBL



- Ocean stochastic physics in the UFS coupled model

- Subseasonal forecast
- Seasonal forecast



- Summary



# Review of SPPT and SKEB

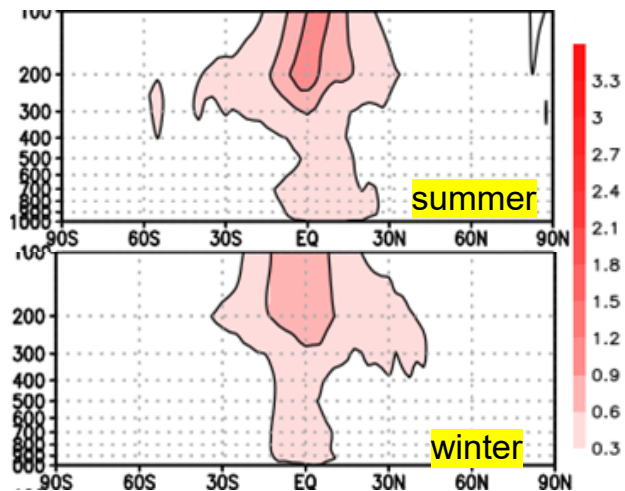
- Stochastic physics schemes (SPPT and SKEB) has been implemented in NOAA's operational global ensemble forecast system (GEFSv12) to account for model uncertainty.
- SPPT
  - `sppt = 0.8,0.4,0.2,0.08,0.04`
  - `sppt_lscale = 500.E3,1000.E3,2000.E3,2000.E3,2000.E3`
  - `sppt_tau = 2.16E4,2.592E5,2.592E6,7.776E6,3.1536E7`
  - `iseed_sppt =`  
`20210101000103,20210101000104,202101000105,20210101000106,20210101000107`
- SKEB
  - `skeb = 0.6`
  - `skeb_lscale = 500.E3`
  - `skeb_tau = 2.16E4`
  - `iseed_skeb = 20210101000101`

# SPPT - Stochastically Perturbed Physics Tendencies

Example of 5-scale random patterns

## Concept:

- Subgrid variability in physical processes, along with errors in the parameterizations result in an under spread and biased model.
- Stochastically perturbed physics tendency (u, v, t, q)



SPPT contributions (U wk1-ave)

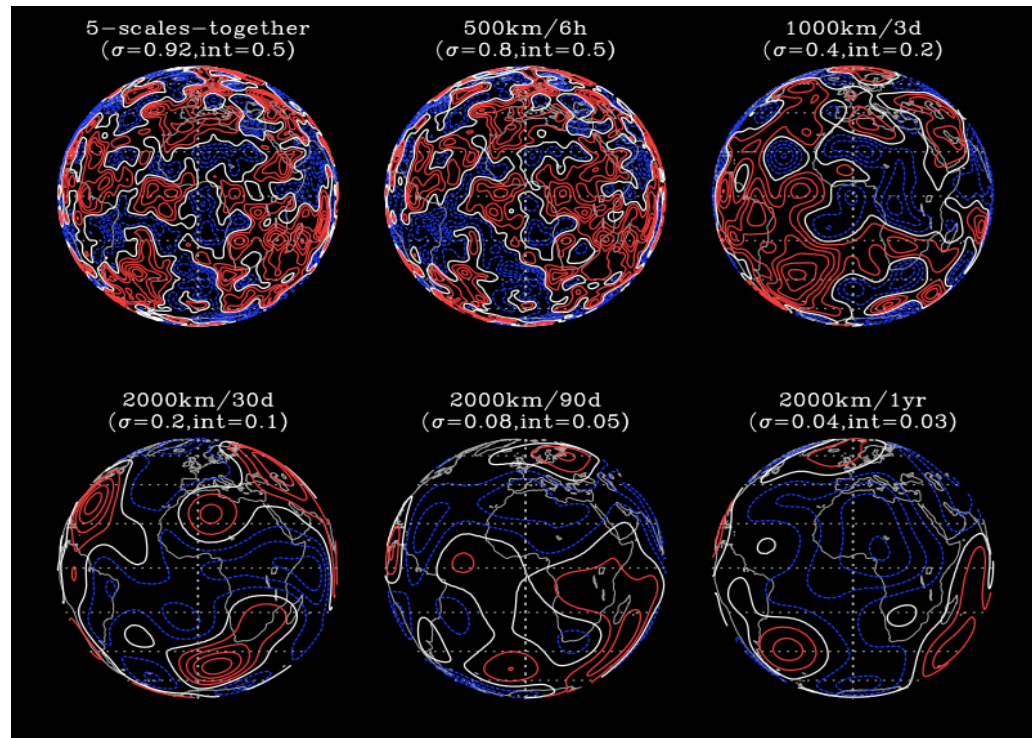


Fig. 2: 5-scale random patterns used in Stochastic Perturbed Physics Tendencies (SPPT). On the top of each plot, the numbers (except for upper left) represent the scales of spatial and temporal perturbations with the maximum amplitude and contour intervals in the bracket.

# SKEB - Stochastic Kinetic Energy Backscatter

A fraction of the **dissipated energy** is backscattered upscale and acts as streamfunction forcing for the resolved-scale flow (Shutts and Palmer 2004, Shutts 2005, Berner et al 2009)

Streamfunction forcing is given by:

$$F_{\Psi}(\lambda, \mu, \eta, t) = \sqrt{b_R D_{tot}} F(\lambda, \mu, \eta, t)$$

Random pattern

Streamfunction forcing

Backscatter ratio

Total dissipation rate

Rotational Component

Divergent Component

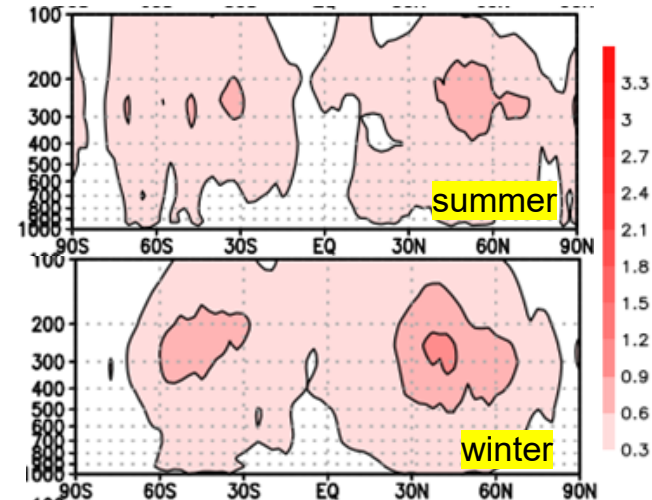
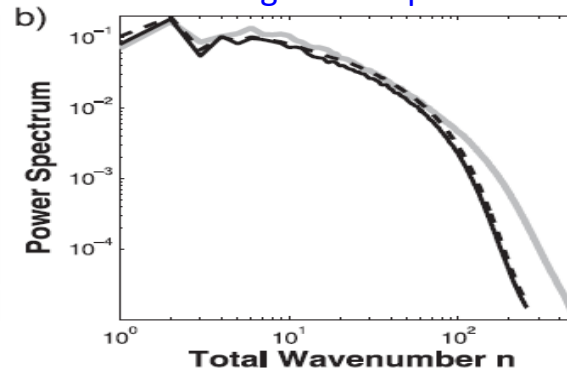
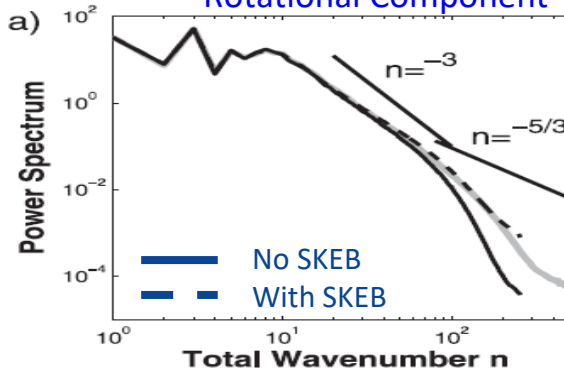


Figure 6 from Berner et al. (2009)



# Motivation of adding ocean stochastic physics



- NOAA's next global model upgrade is aiming for a fully coupled model under Unified Forecast System (UFS) framework. In preparation for the upgrade, a series of UFS coupled model prototypes have been developed at the EMC by the scientists from various NOAA labs/centers and communities.
- In a coupled model, uncertainty due to subgrid processes in other model component like ocean model needs to be accounted for too.
- It is interesting and also important to understand what is the impact of ocean stochastic physics on subseasonal to seasonal forecast in a fully coupled model.



# Uncertainties in OCN model

- Vertical mixing – Energetic PBL
- Surface fluxes, thermodynamic structure
- Subgrid scale dynamics (unresolved eddies)
- Equation of state
- Flux from ATM model at ocn upper boundary (if coupled)





# Ocean SPPT and ePBL schemes



*Following Juricke et al 2017 (Journal of Climate), energetic PBL perturbations and ocean SPPT were developed at NOAA/PSL.*



- **OCN SPPT** scheme: perturbs tendency of three ocean variables: potential temperature, salinity and layer thickness.
- **OCN ePBL** scheme: perturbs production and dissipation terms of Ocean Planetary Boundary Layer (PBL) Total Kinetic Energy (TKE)





# Ocean stochastic physics setting

- Ocean SPPT
  - `ocnsppt = 0.8,0.4,0.2,0.08,0.04`
  - `ocnsppt_lscale = 500.E3,1000.E3,2000.E3,2000.E3,2000.E3`
  - `ocnsppt_tau = 2.16E4,2.592E5,2.592E6,7.776E6,3.1536E7`
  - `iseed_ocnsppt =`  
`20150601001501,20150601001502,20150601001503,20150601001504,20150601001505`
- Ocean ePBL
  - `epbl = 0.8,0.4,0.2,0.08,0.04`
  - `epbl_lscale = 500.E3,1000.E3,2000.E3,2000.E3,2000.E3`
  - `epbl_tau = 2.16E4,2.592E5,2.592E6,7.776E6,3.1536E7`
  - `iseed_epbl =`  
`20150601001506,20150601001507,20150601001508,20150601001509,20150601001510`

# Subseasonal forecast experiment

## CTL:

FV3(0.25)+MOM6(0.25)+CICE6(0.25)+WW3(0.5) (UFS coupled model P5)  
+ ATM stochastic physics

## EXP:

FV3(0.25)+MOM6(0.25)+CICE6(0.25)+WW3(0.5) (UFS coupled model P5)  
+ ATM stochastic physics + **OCN stochastic physics**

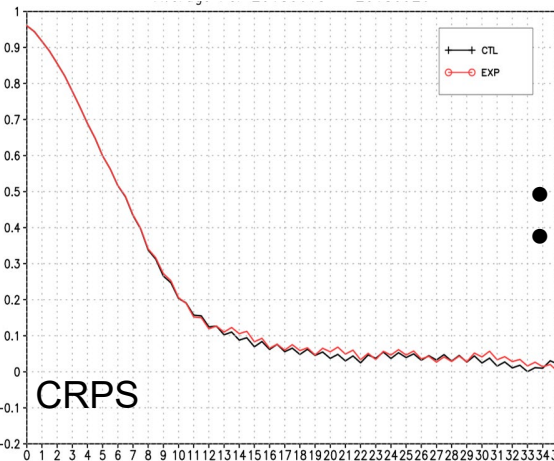
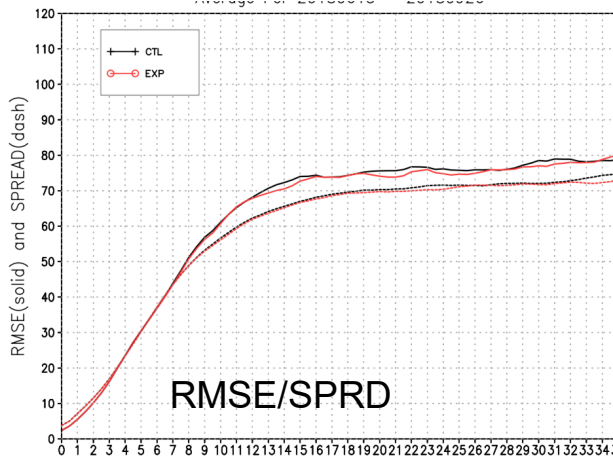
- 16 summer cases (weekly run, 2018 summer)
- 16 winter cases (weekly run, 2018/19 winter)
- 11 members (ATM: 1 unperturbed, and 10 perturbed members)
- 35-day forecast



# Subseasonal forecast skills (NH Z500)

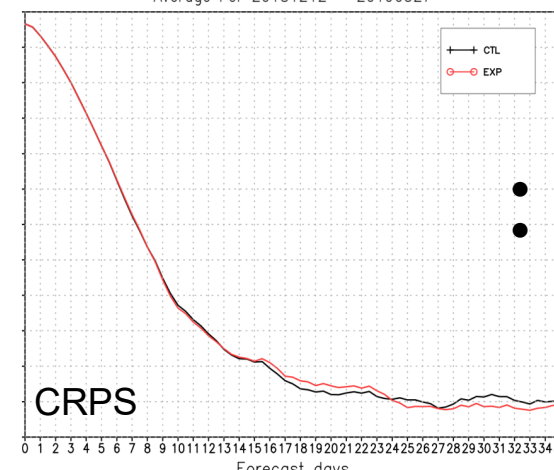
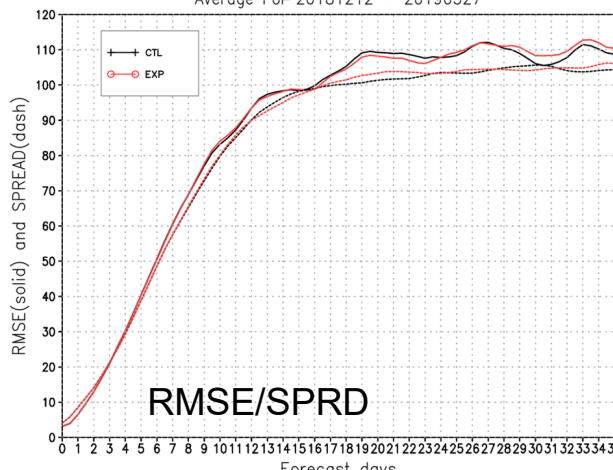
Black: CTL  
Red: EXP

SUMMER



- Week-1 very similar
- Week-2 and after, slightly reduced RMSE; slightly improved CRPS

WINTER

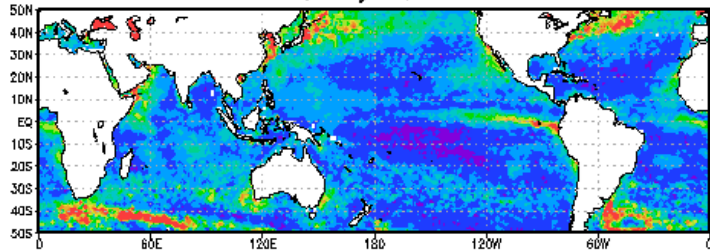


- Week-1, very similar
- Week-2 and after, skills score mixed along the forecast time.

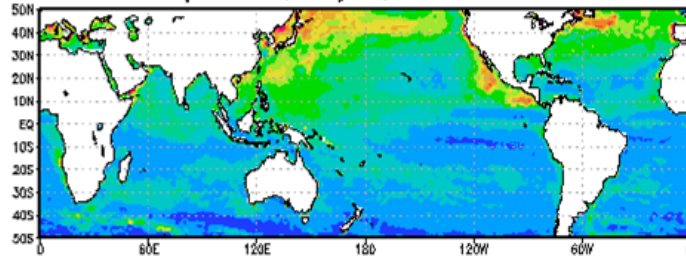


# SST RMSE/SPRD (day11) changes from ocean stochastic (summer)

SST rms c384, Day11, Ocean=0.57522

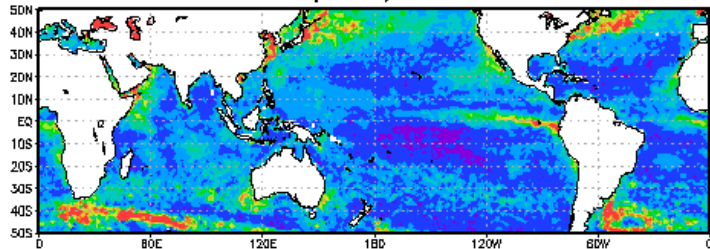


SST spr c384, Day11, Ocean=0.272321

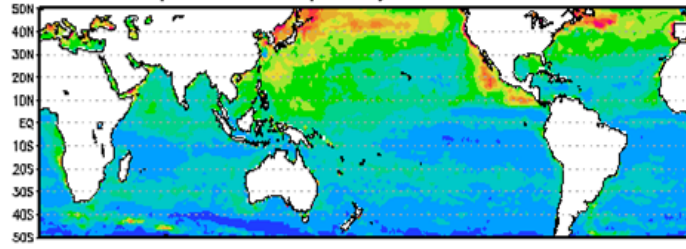


CTL

SST rms c384fullsp, Day11, Ocean=0.574599

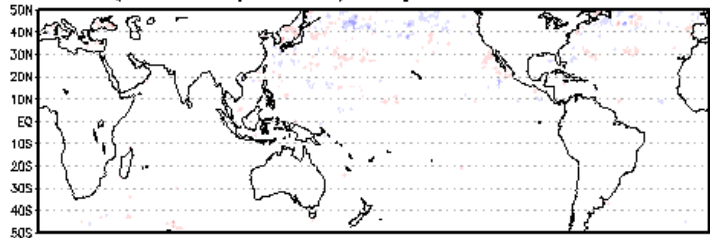


SST spr c384fullsp, Day11, Ocean=0.29468

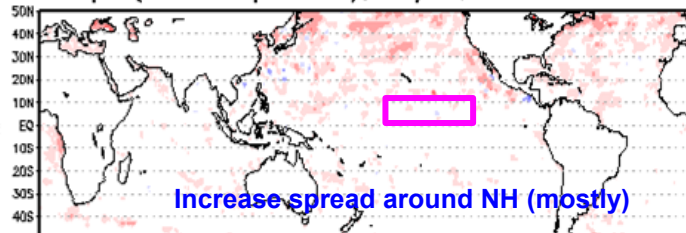


EXP

SST rms (c384fullsp-c384), Day11, Ocean=-0.000621342



SST spr (c384fullsp-c384), Day11, Ocean=0.0223596

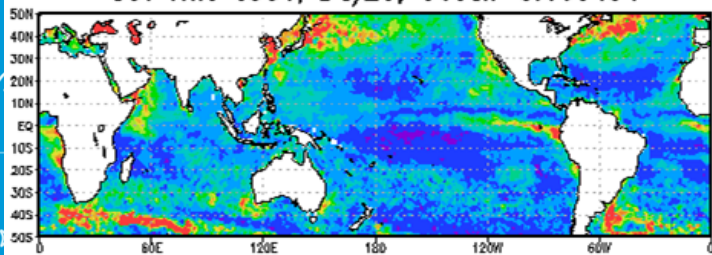


EXP - CTL

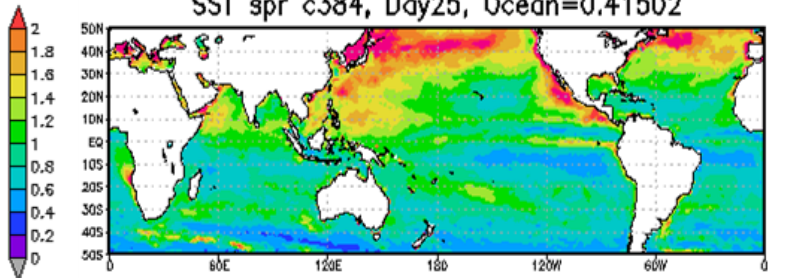


# SST RMSE/SPRD (day25) changes from ocean stochastic (summer)

SST rms c384, Day25, Ocean=0.663494

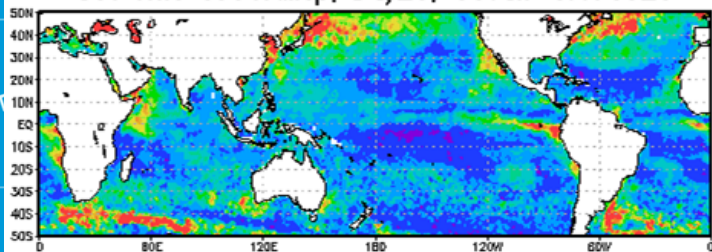


SST spr c384, Day25, Ocean=0.41502

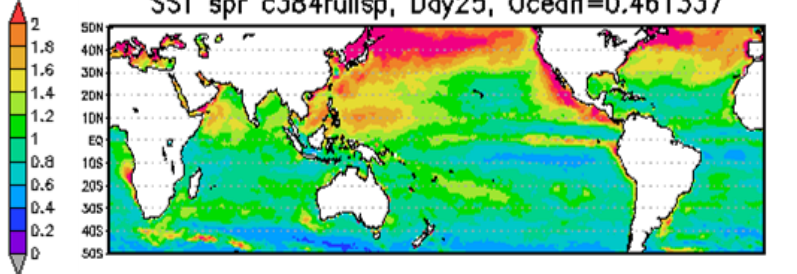


CTL

SST rms c384fullsp, Day25, Ocean=0.675528

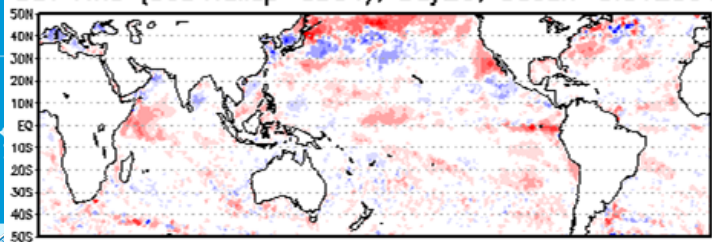


SST spr c384fullsp, Day25, Ocean=0.461337

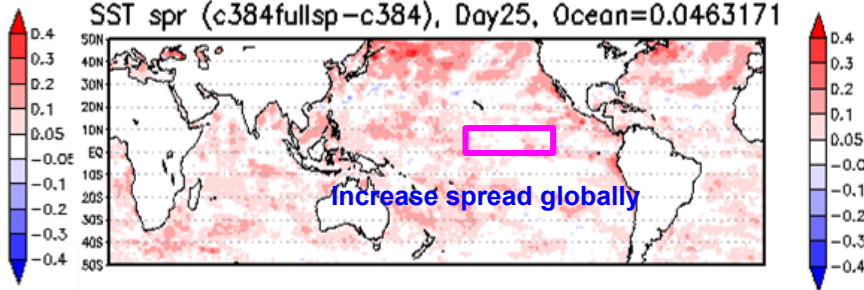


EXP

SST rms (c384fullsp-c384), Day25, Ocean=0.0120344



SST spr (c384fullsp-c384), Day25, Ocean=0.0463171



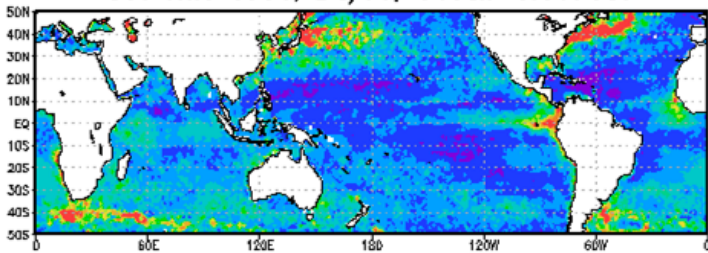
EXP - CTL



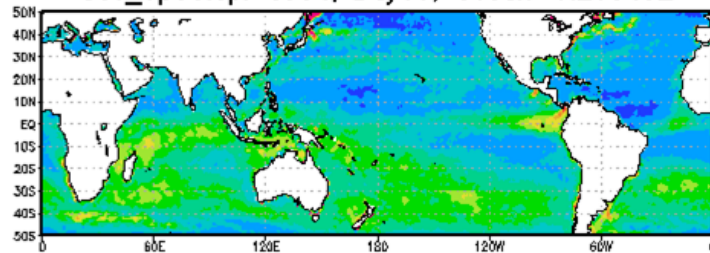


# SST RMSE/SPRD (day11) changes from ocean stochastics (winter)

SST rms c384, Day11, Ocean=0.567887

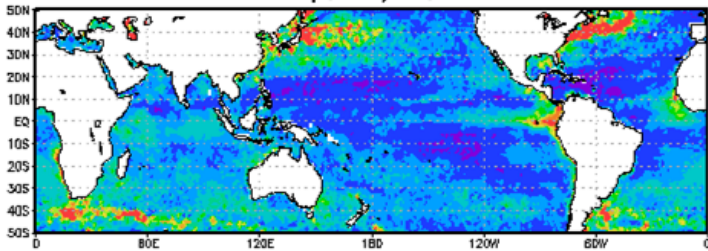


SST\_1p00.spr c384, Day11, Ocean=0.299492

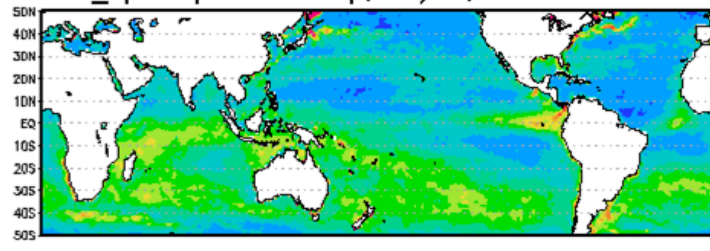


CTL

SST rms c384fullsp, Day11, Ocean=0.569127

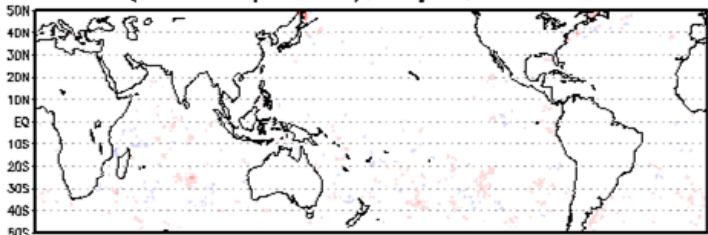


SST\_1p00.spr c384fullsp, Day11, Ocean=0.325065

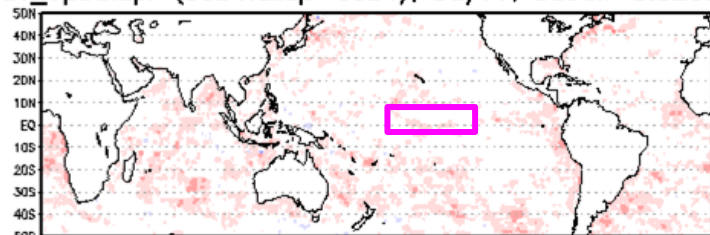


EXP

SST rms (c384fullsp-c384), Day11, Ocean=0.00124024



SST\_1p00.spr (c384fullsp-c384), Day11, Ocean=0.0255732

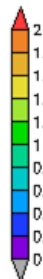
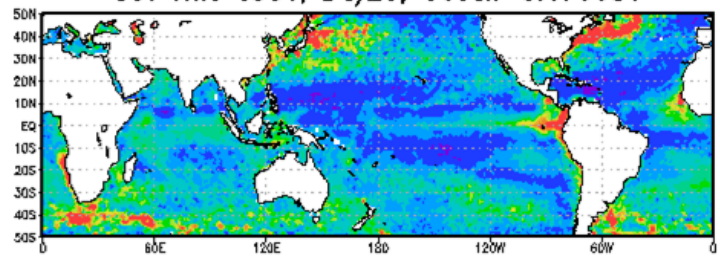


EXP - CTL

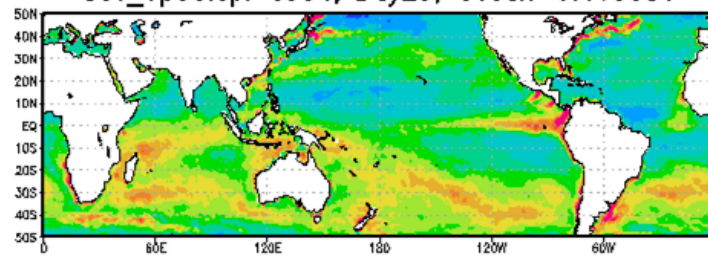


# SST RMSE/SPRD (day25) changes from ocean stochastics (winter)

SST rms c384, Day25, Ocean=0.679381

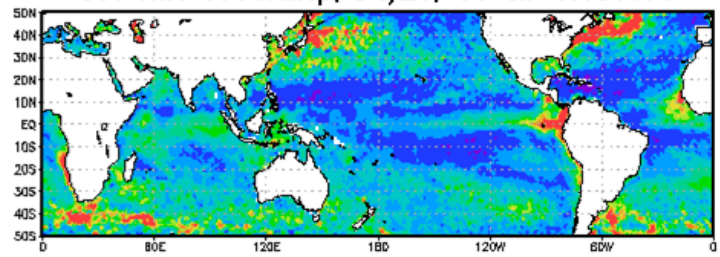


SST\_1p00.spr c384, Day25, Ocean=0.465081

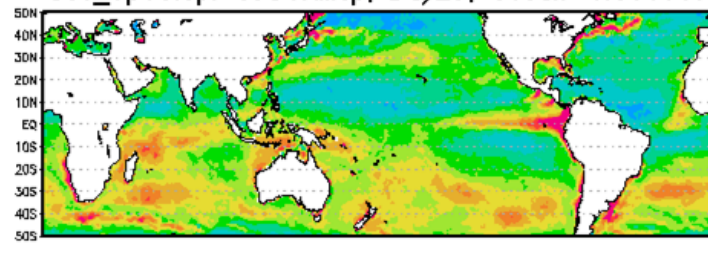


CTL

SST rms c384fullsp, Day25, Ocean=0.686671

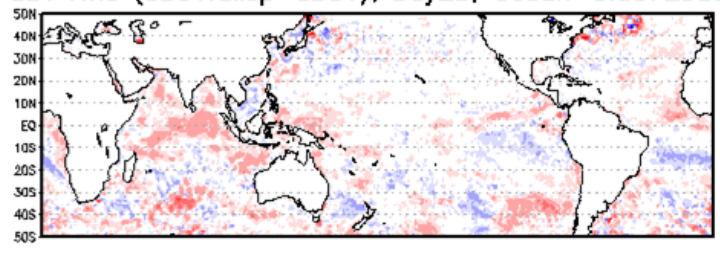


SST\_1p00.spr c384fullsp, Day25, Ocean=0.510917

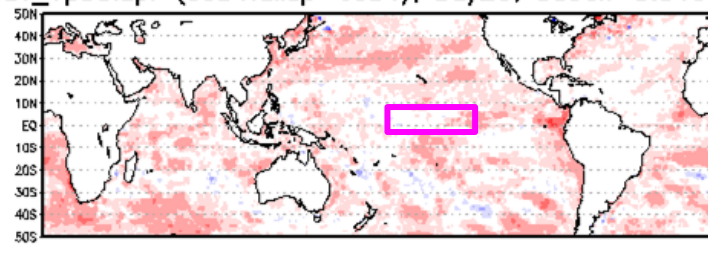


EXP

SST rms (c384fullsp-c384), Day25, Ocean=0.00729004



SST\_1p00.spr (c384fullsp-c384), Day25, Ocean=0.0458354

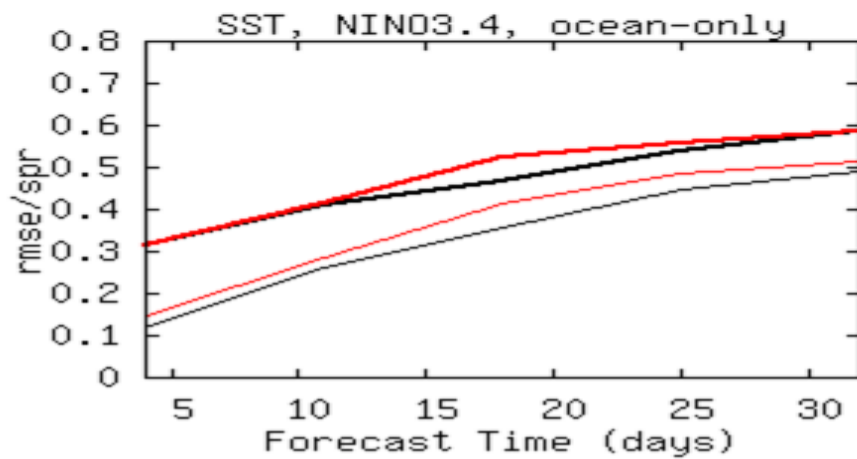
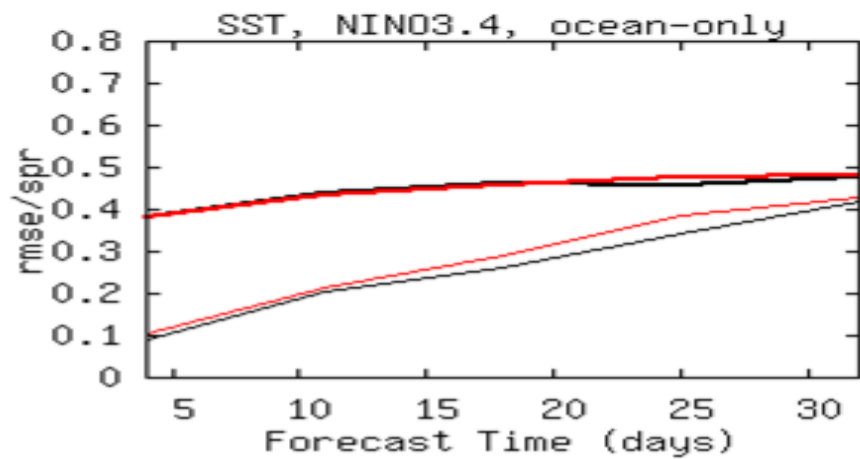
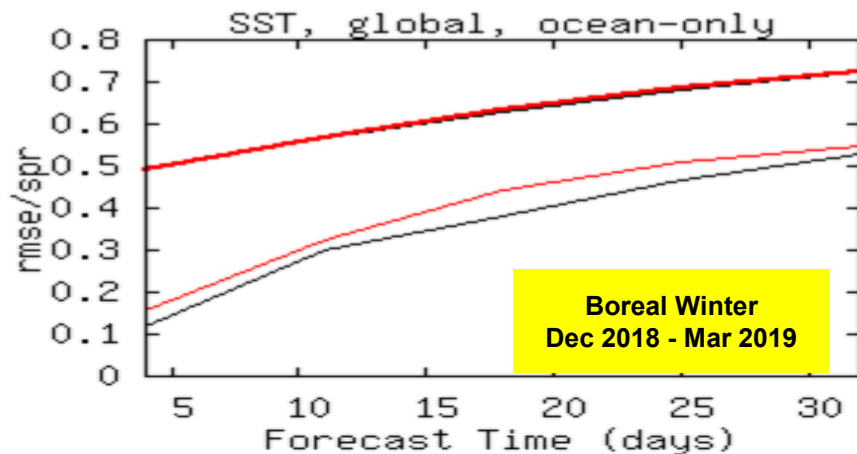
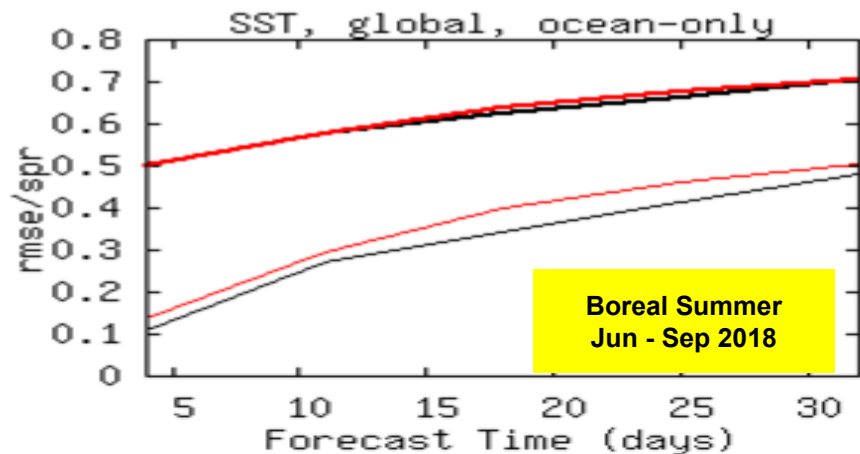


EXP - CTL



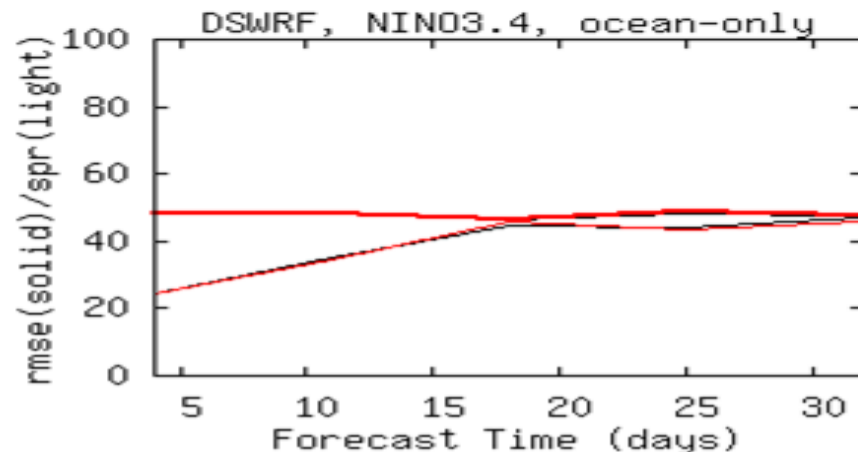
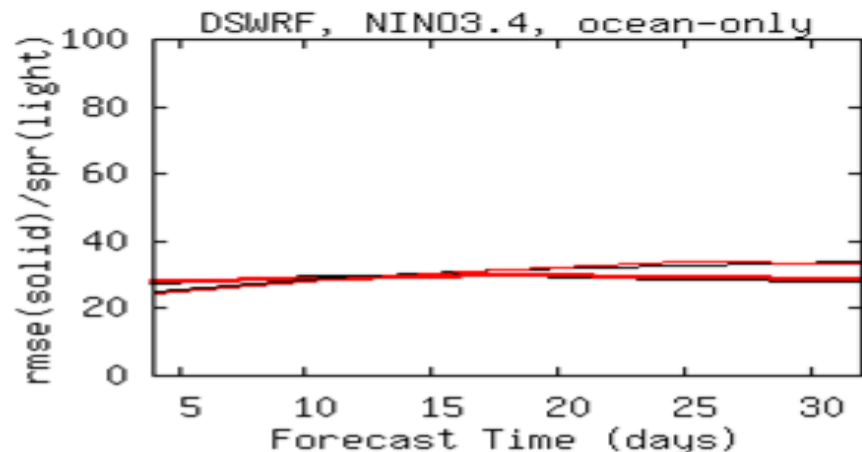
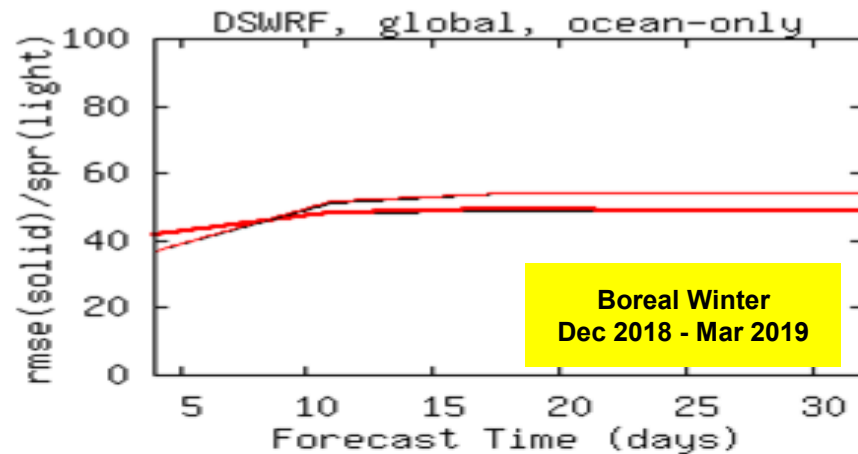
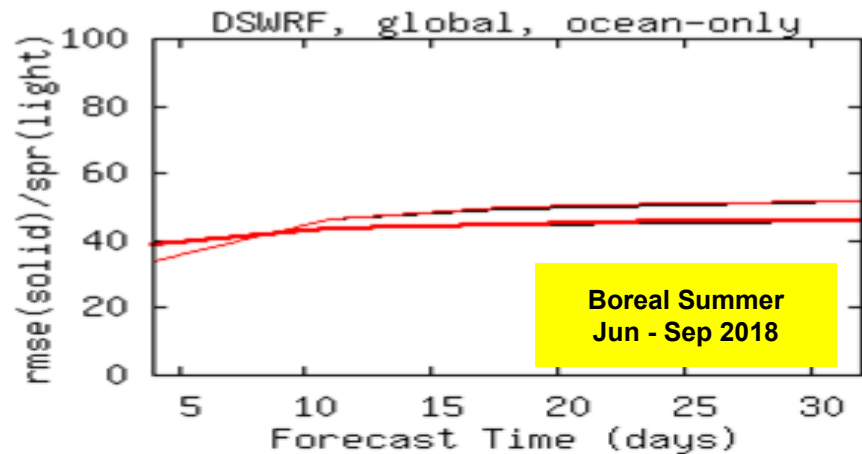


# SST RMSE/SPRD changes from ocean stochastics



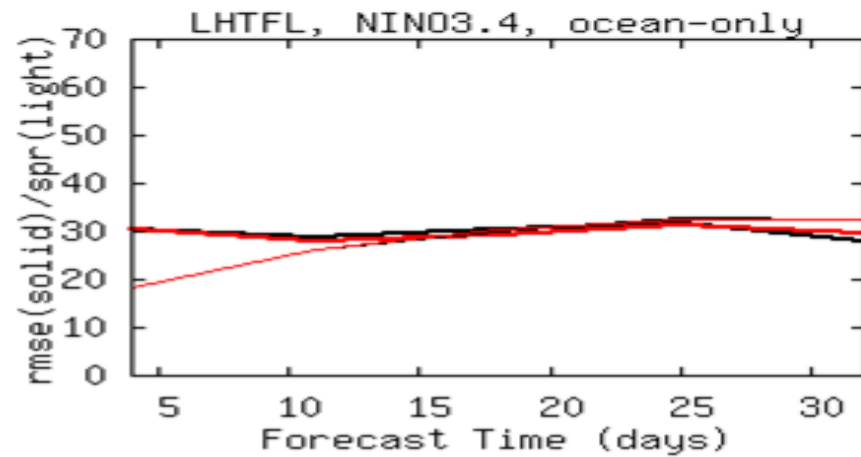
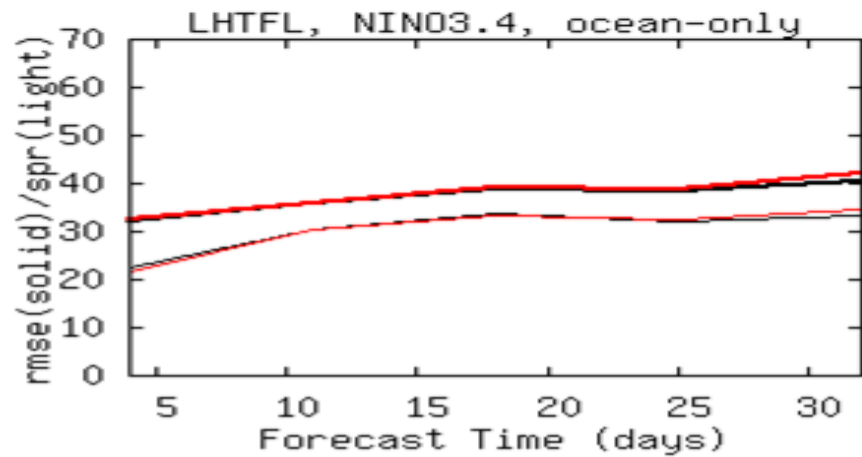
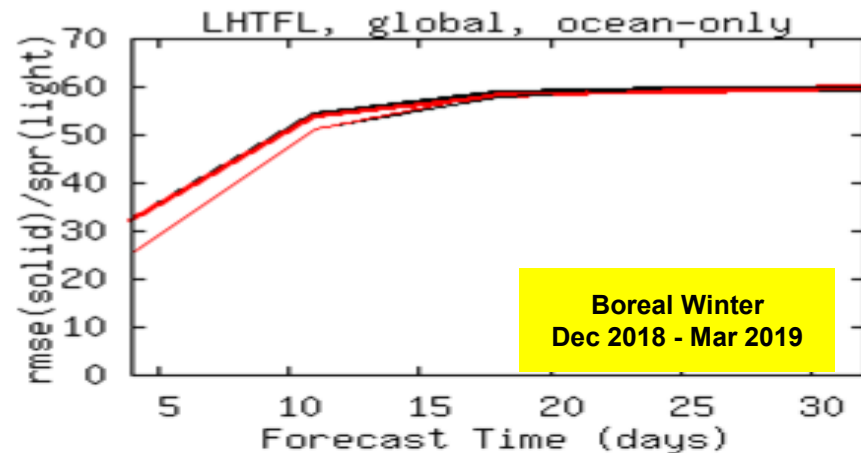
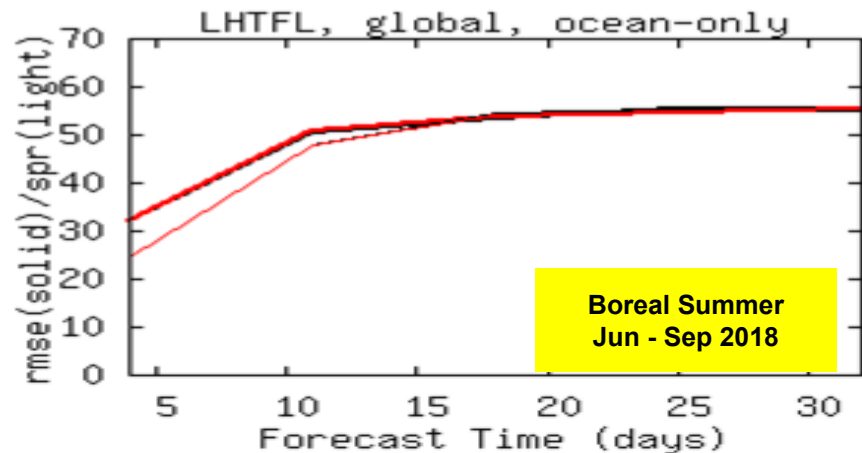


# DSWRF RMSE/SPRD changes from ocean stochastic





# LHTFL RMSE/SPRD changes from ocean stochastic



# Seasonal forecast experiment

## CTL:

FV3(0.5)+MOM6(0.5)+CICE6(0.5) (UFS coupled model P5)

## EXP:

FV3(0.5)+MOM6(0.5)+CICE6(0.5) (UFS coupled model P5)

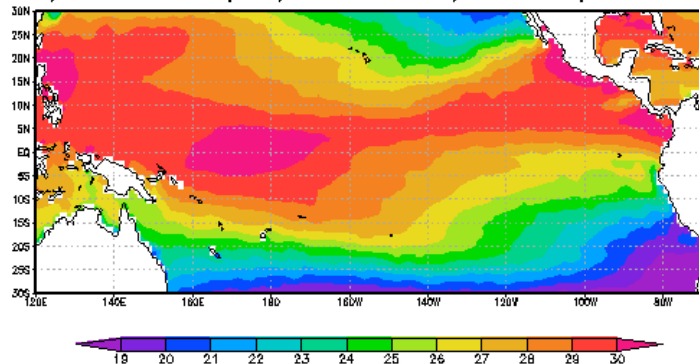
+ OCN stochastic physics

- One single El Nino case (2015-16 El Nino)
- Init time: 20150601 00Z
- 41 members (ATM: 1 unperturbed, and 40 perturbed members)
- 9 months forecast

# SST weekly mean and difference of w/wo ocean stochastic

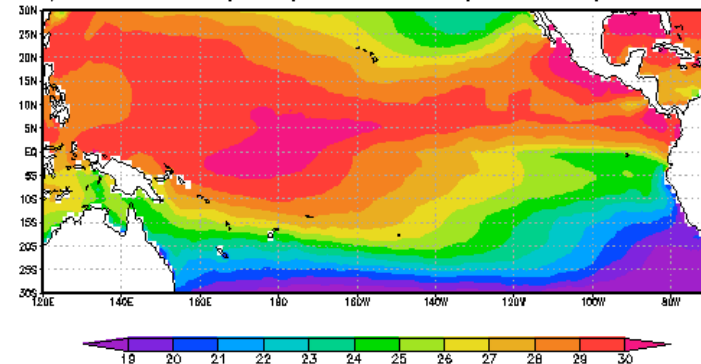
wk 5 fcst

SST,init.2015060100,WK5,ensemble mean,OceanStocs,Ocean=26.68

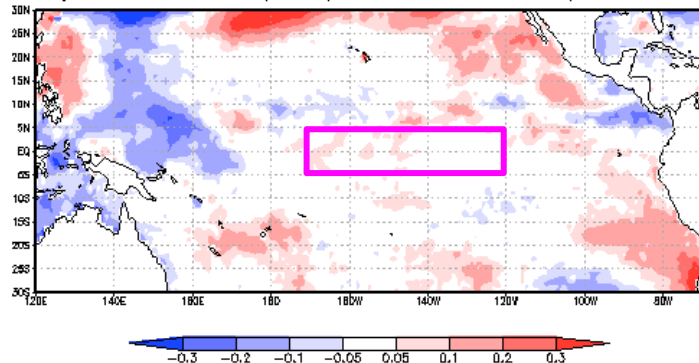


wk 10 fcst

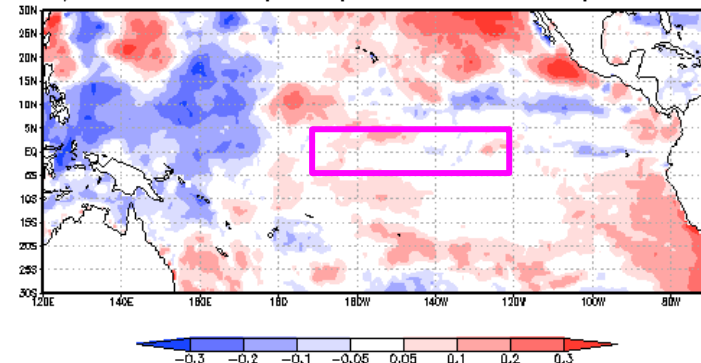
SST,init.2015060100,WK10,ensemble mean,OceanStocs,Ocean=26.63



SST, init. 2015060100, WK5, OceanStocs-NoStocs, Ocean=0.00



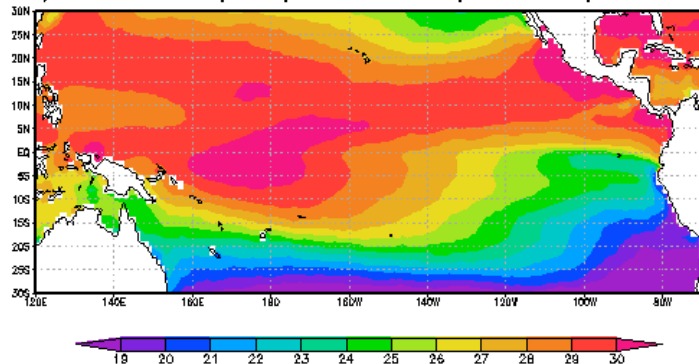
SST, init. 2015060100, WK10, OceanStocs-NoStocs, Ocean=0.00



# SST weekly mean and difference of w/wo ocean stochastic

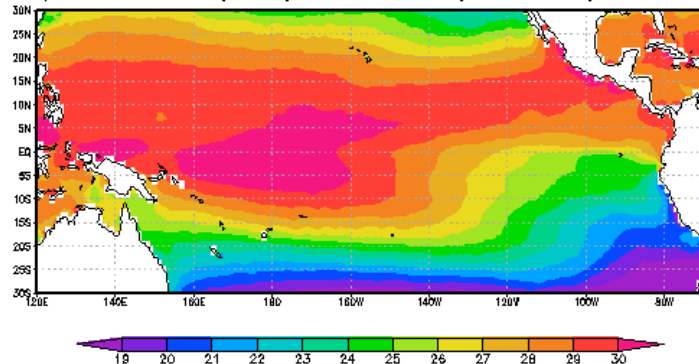
wk 15 fcst

SST,init.2015060100,WK15,ensemble mean,OceanStocs,Ocean=26.74

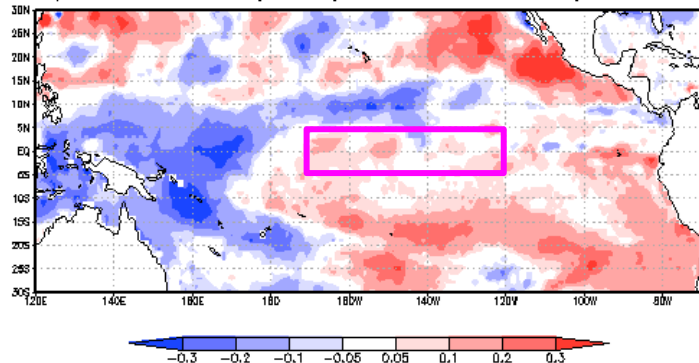


wk 20 fcst

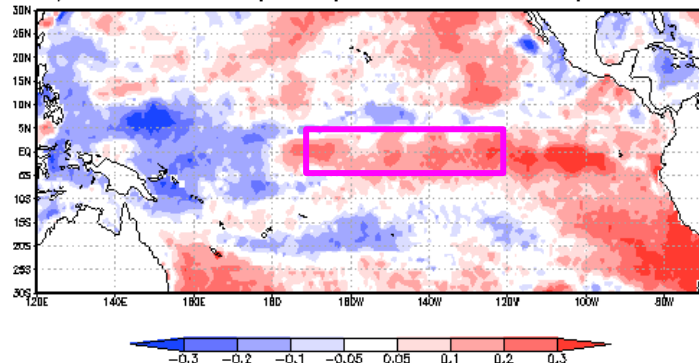
SST,init.2015060100,WK20,ensemble mean,OceanStocs,Ocean=26.84



SST, init. 2015060100, WK15, OceanStocs-NoStocs, Ocean=0.00



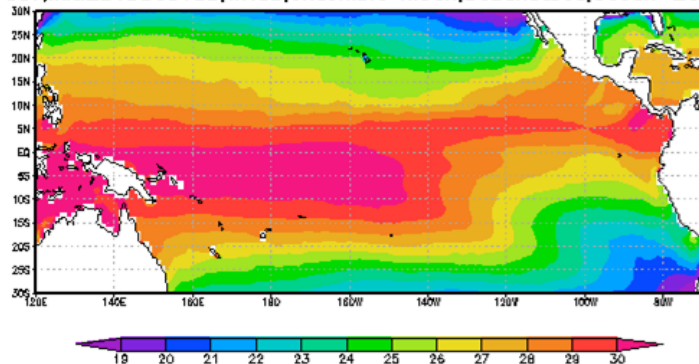
SST, init. 2015060100, WK20, OceanStocs-NoStocs, Ocean=0.02



# SST weekly mean and difference of w/wo ocean stochastics

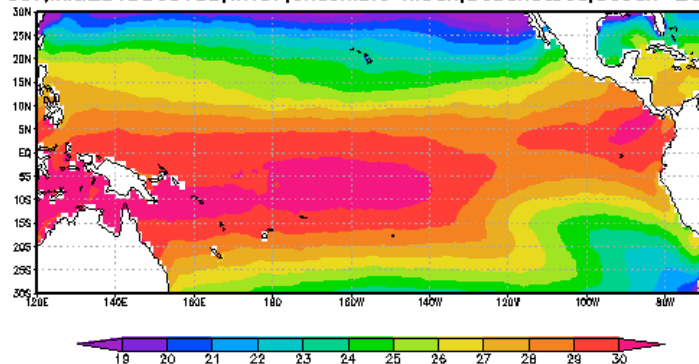
wk 30 fcst

SST,init.2015060100,WK30,ensemble mean,OceanStocs,Ocean=26.72

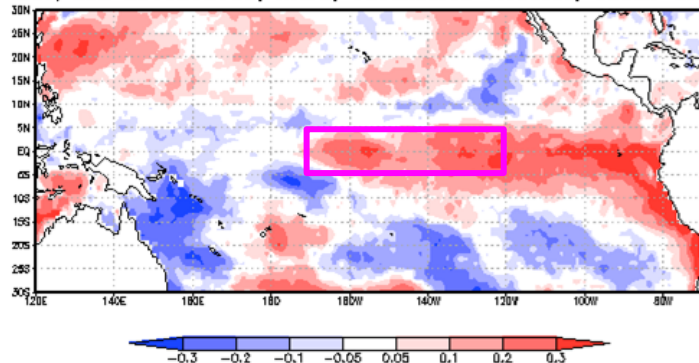


wk 37 fcst

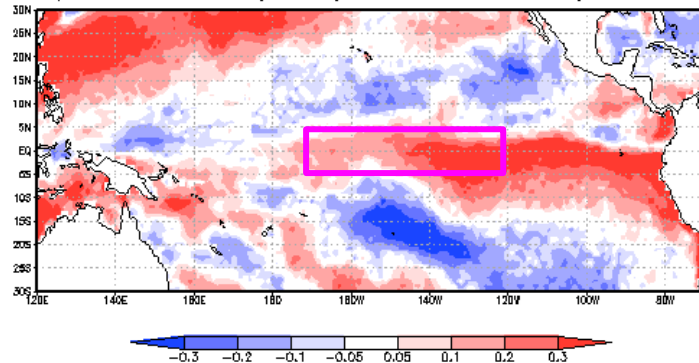
SST,init.2015060100,WK37,ensemble mean,OceanStocs,Ocean=26.71



SST, init. 2015060100, WK30, OceanStocs-NoStocs, Ocean=0.02



SST, init. 2015060100, WK37, OceanStocs-NoStocs, Ocean=0.04

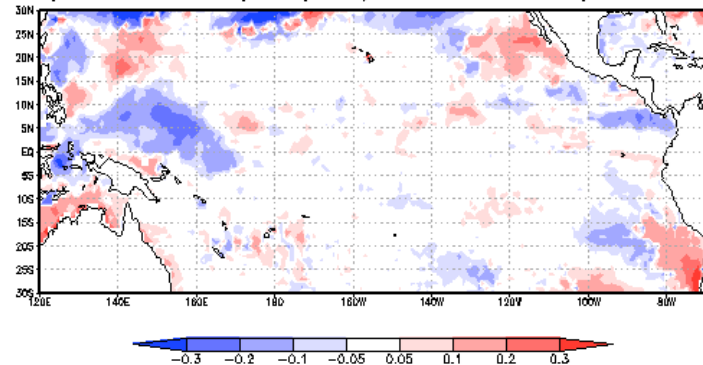




# Difference of SST RMSE/SPRD w/o ocean stochastics

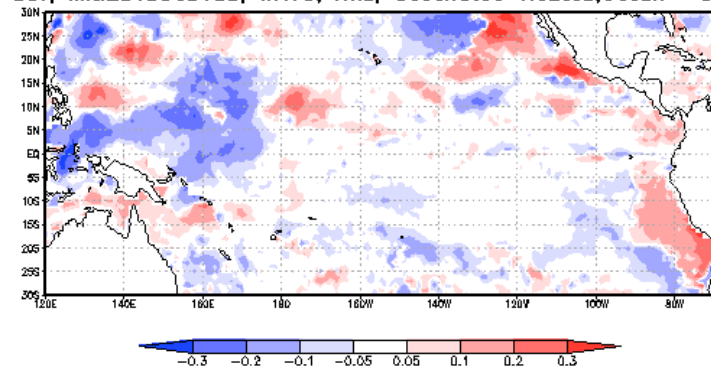
wk 5 fcst

SST, init.2015060100, WK5, rms, OceanStoc-NoStoc,Ocean=-0.00

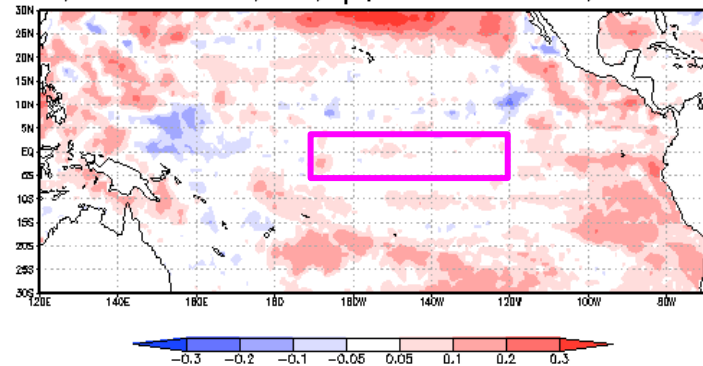


wk 10 fcst

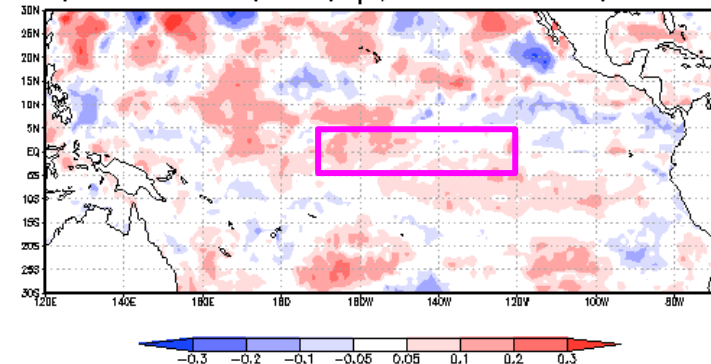
SST, init.2015060100, WK10, rms, OceanStoc-NoStoc,Ocean=-0.01



SST, init.2015060100, WK5, spr, OceanStoc-NoStoc,Ocean=0.03



SST, init.2015060100, WK10, spr, OceanStoc-NoStoc,Ocean=0.02

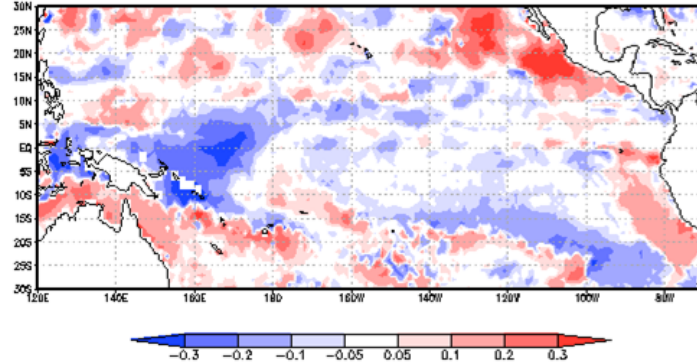




# Difference of SST RMSE/SPRD w/wo ocean stochastics

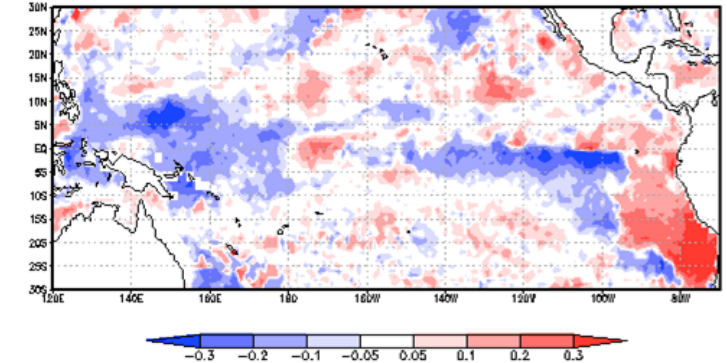
wk 15 fcst

SST, init.2015060100, WK15, rms, OceanStoc-NoStoc,Ocean=-0.00



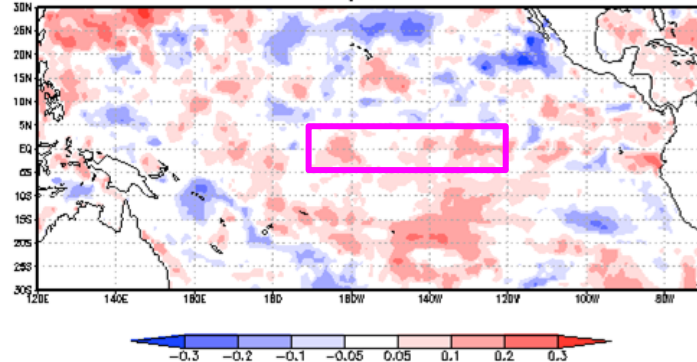
wk 20 fcst

SST, init.2015060100, WK20, rms, OceanStoc-NoStoc,Ocean=-0.01

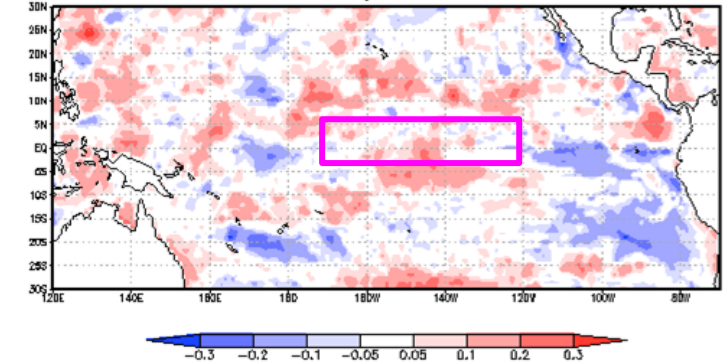


RMSE

SST, init.2015060100, WK15, spr, OceanStoc-NoStoc,Ocean=0.01



SST, init.2015060100, WK20, spr, OceanStoc-NoStoc,Ocean=0.01



SPRD

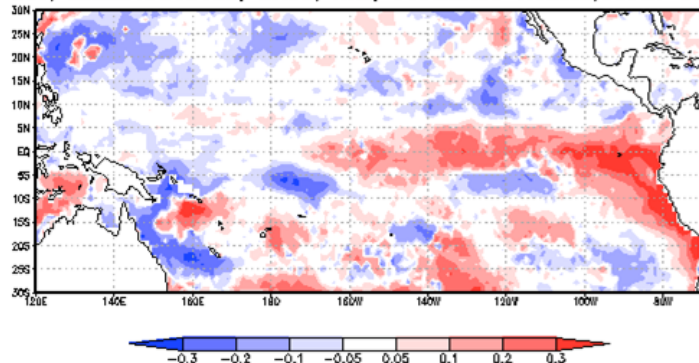


# Difference of SST RMSE/SPRD w/wo ocean stochastics

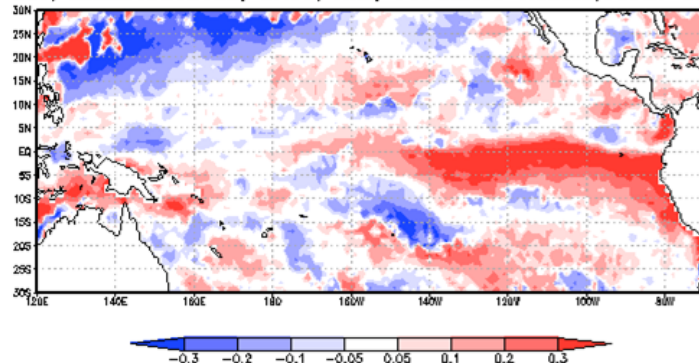
wk 30 fcst

wk 37 fcst

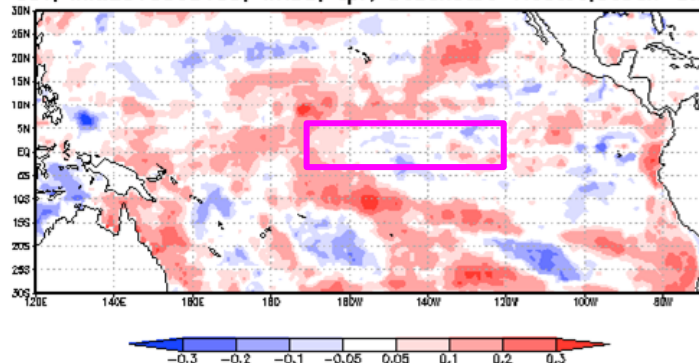
SST, init.2015060100, WK30, rms, OceanStoc-NoStoc,Ocean=0.00



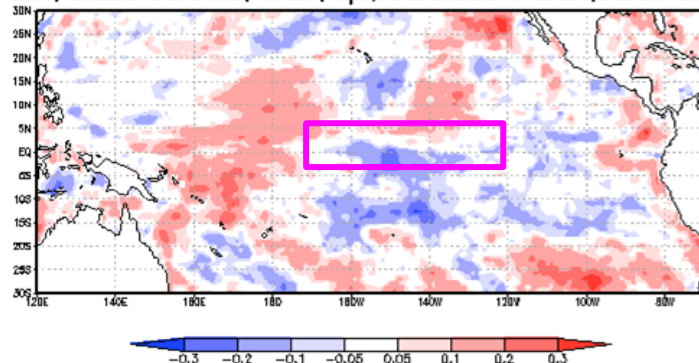
SST, init.2015060100, WK37, rms, OceanStoc-NoStoc,Ocean=0.02



SST, init.2015060100, WK30, spr, OceanStoc-NoStoc,Ocean=0.03



SST, init.2015060100, WK37, spr, OceanStoc-NoStoc,Ocean=0.01

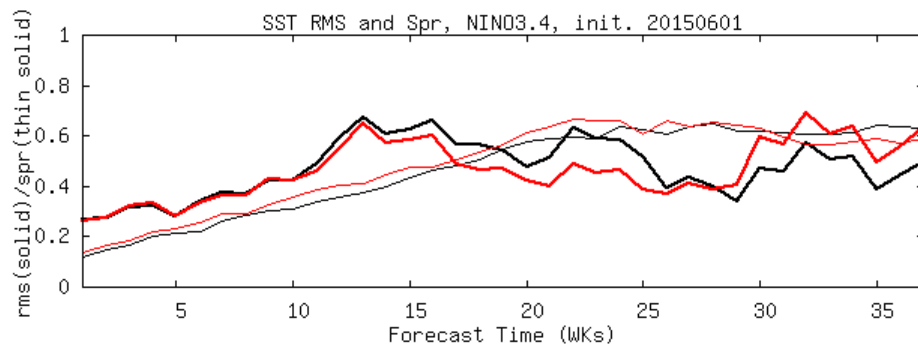
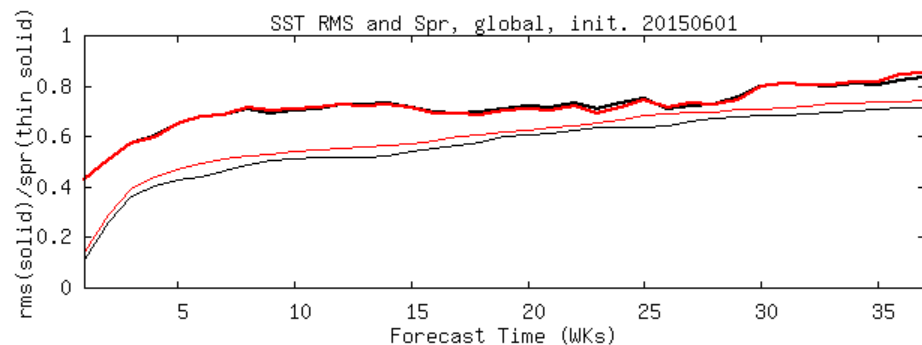
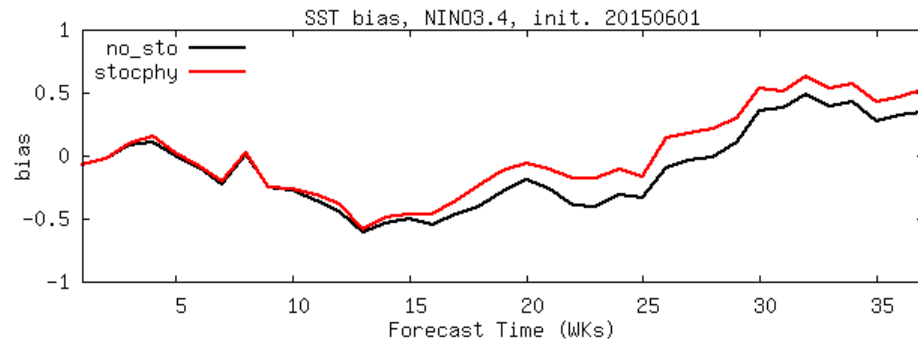
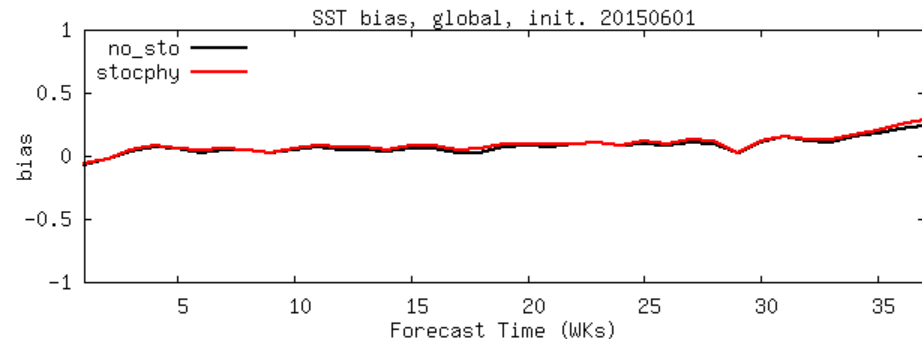


RMSE

SPRD



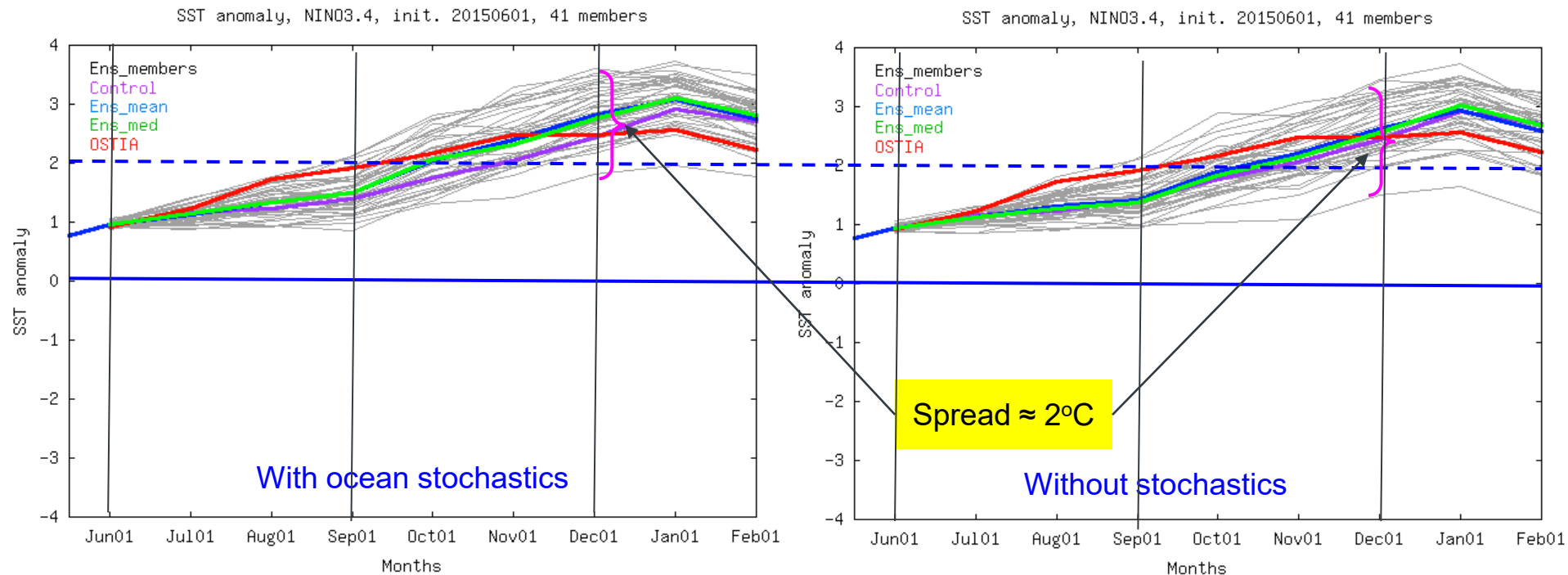
# Weekly average SST performance (reference: OSTIA)



- Spread is larger with ocn stochastic physics for both global and nino 3.4 region
- RMSE is reduced for mon4-6 forecast in Nino 3.4 region
- Warm bias in Nino 3.4 region for longer lead time forecast



# Nino 3.4 index (monthly average) comparison:



- The spread and forecast trend are very similar
  - Mon1-3, similar; Mon4-6, exp > ctl; Mon6-9, exp < ctl
  - The distribution of ensemble plumes is near normal after turning off stochastics (ctl=mean=medium?)
- ENSO signal is too strong?



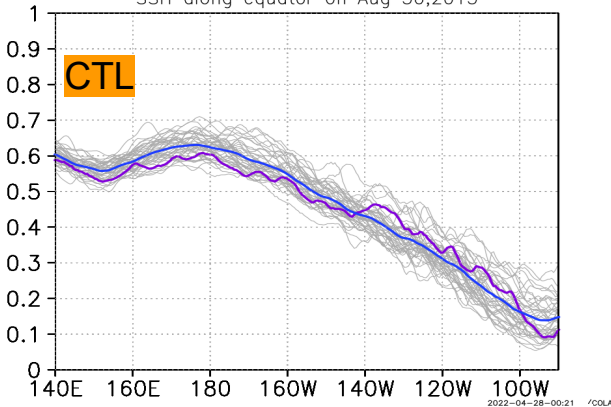




# Predicted SSH along equator at 3/6/9 month

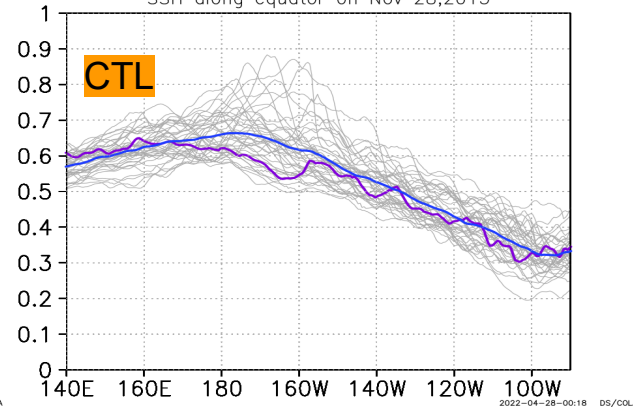
Month 3

SSH along equator on Aug 30,2015



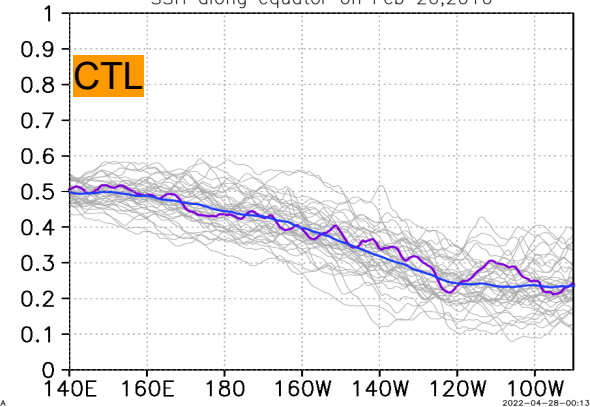
Month 6

SSH along equator on Nov 28,2015

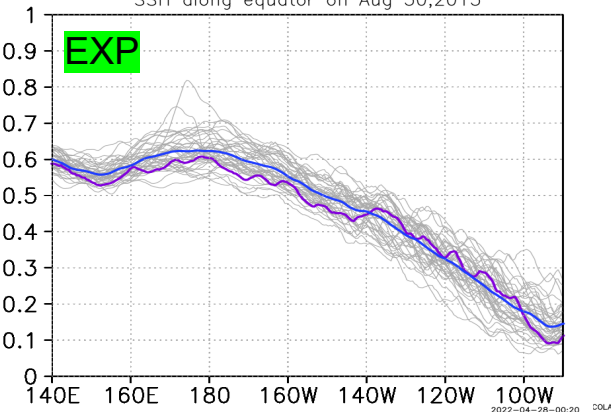


Month 9

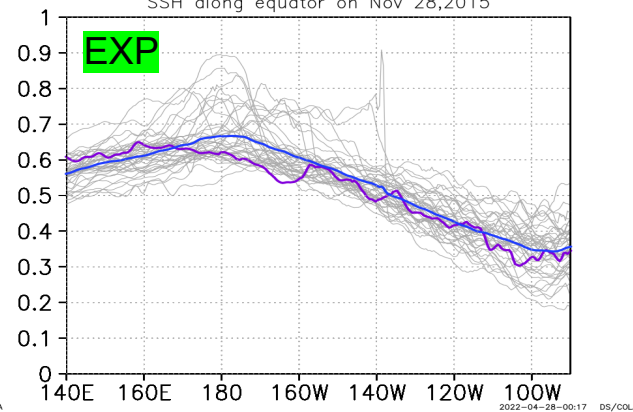
SSH along equator on Feb 26,2016



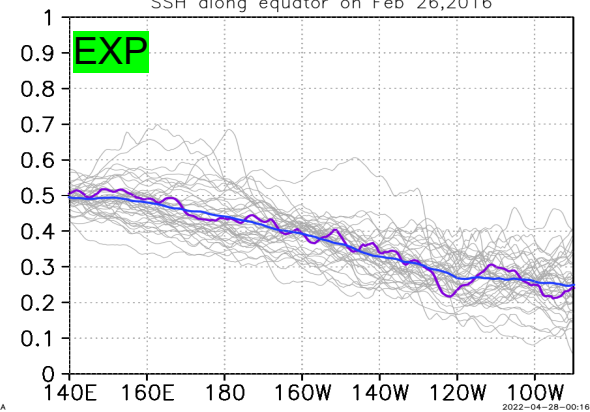
SSH along equator on Aug 30,2015



SSH along equator on Nov 28,2015



SSH along equator on Feb 26,2016





# Predicted D20 along equator at 3/6/9 month

Month 3

— ens Mean  
— unpert member

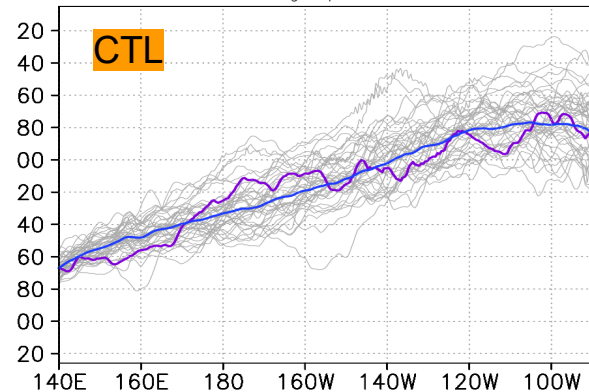
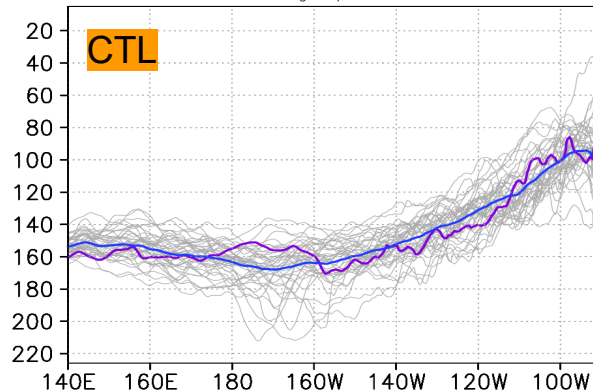
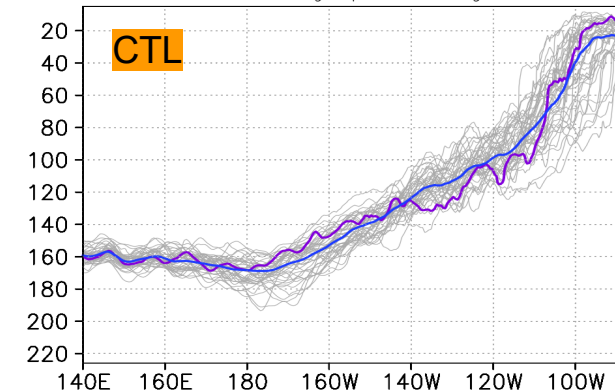
Month 6

Month 9

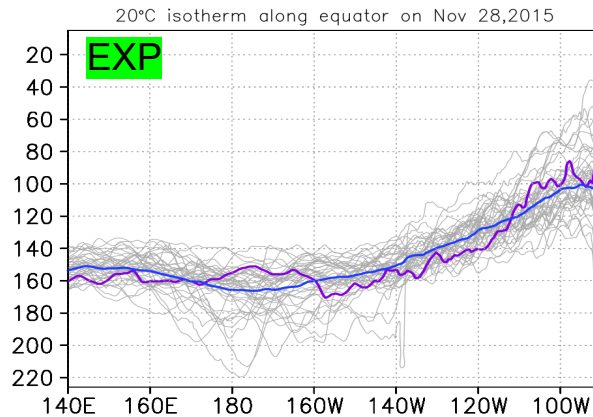
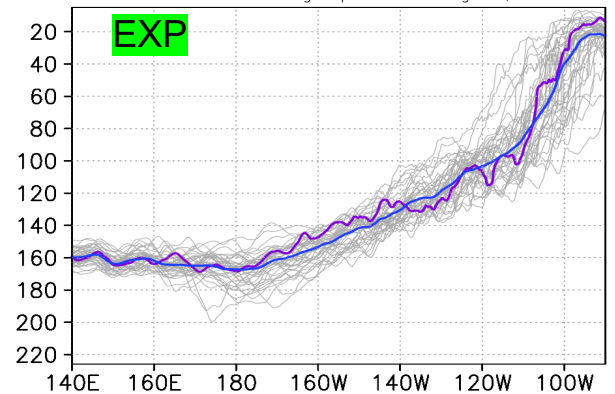
20°C isotherm along equator on Aug 30, 2015

20°C isotherm along equator on Nov 28, 2015

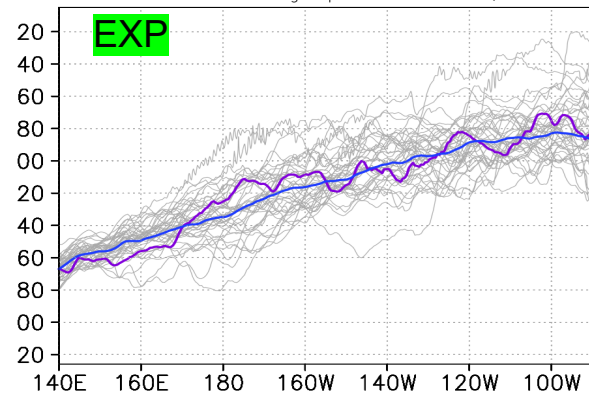
20°C isotherm along equator on Feb 26, 2016



2022-04-28-00:21



2022-04-28-00:14







# Summary

- Ocean SPPT and ePBL schemes have been implemented in the UFS coupled model to evaluate the impact on S2S forecast
- Increase of SST spread can be clearly observed
- Minor improvements in summer subseasonal forecast. The ocn stochastic physics has more impact on the summer hemisphere
- Neutral to positive impact on 2015/16 El Nino prediction up to 6 months. A slight warm bias in Nino3.4 is also noticed



# Future investigation and challenges

- What is the combined impact if we add ocean initial perturbations? especially for short-range to subseasonal forecast.
- How the uncertainty in atmosphere and ocean interact with each other (uncertainty in coupled model)?
- How to connect the changes of ocean dynamics and physics such as ocean waves, ocean eddies and latent heat flux to the impact of ocean stochastic physics?



**Thank you!**

