Towards Creating an Ensemble of Global Ocean Analysis: Ensemble GIOPS

Environment and Climate Change Canada | Environnement et Changement climatique Canada

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Environmental Numerical Prediction Research Section

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In Collaboration with

Environment and Climate Change Canada

Environnement et Changement climatique Canada

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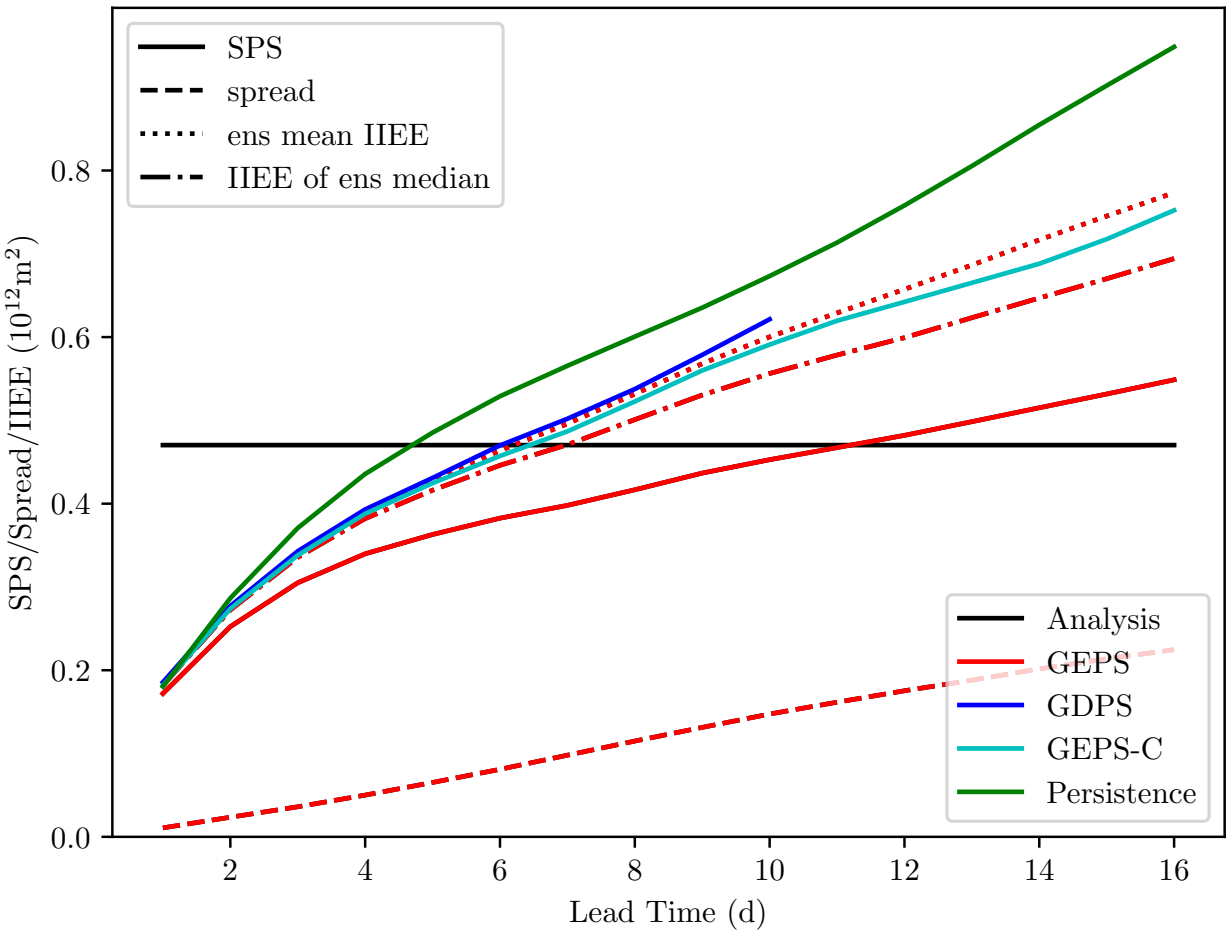
GEPS Coupled Forecast Spread/Error – Sea Ice

Arctic Sea Ice SPS / Spread



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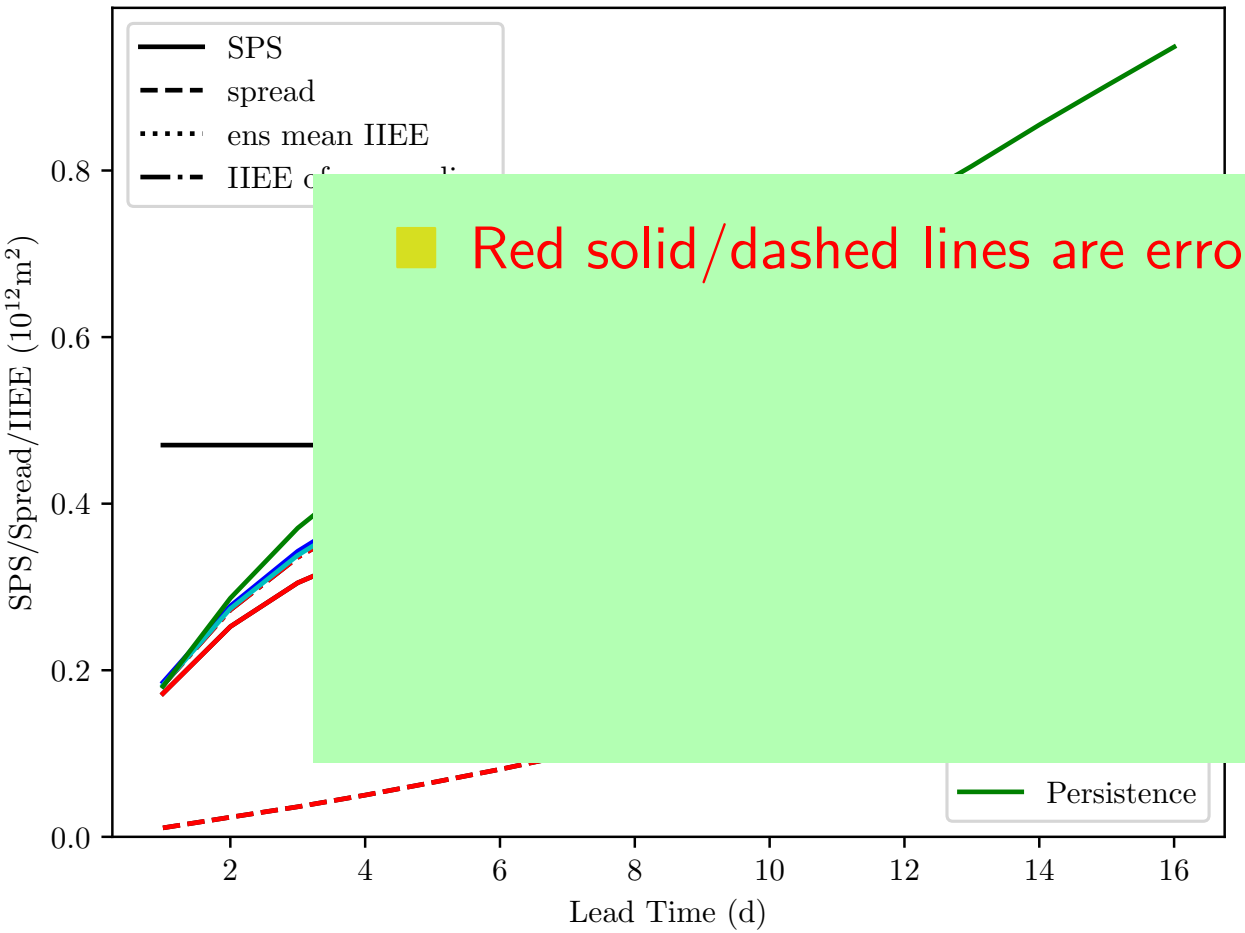

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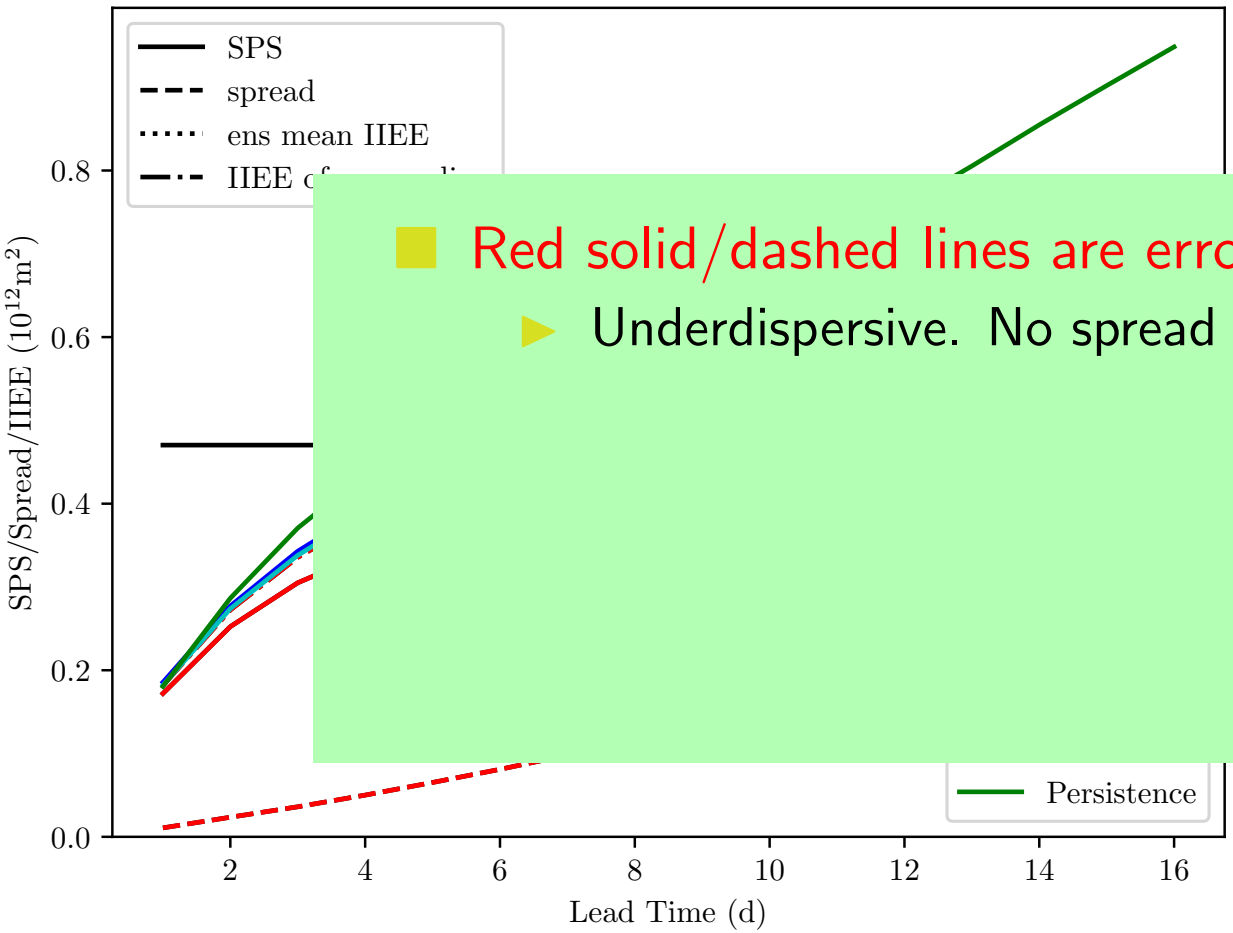

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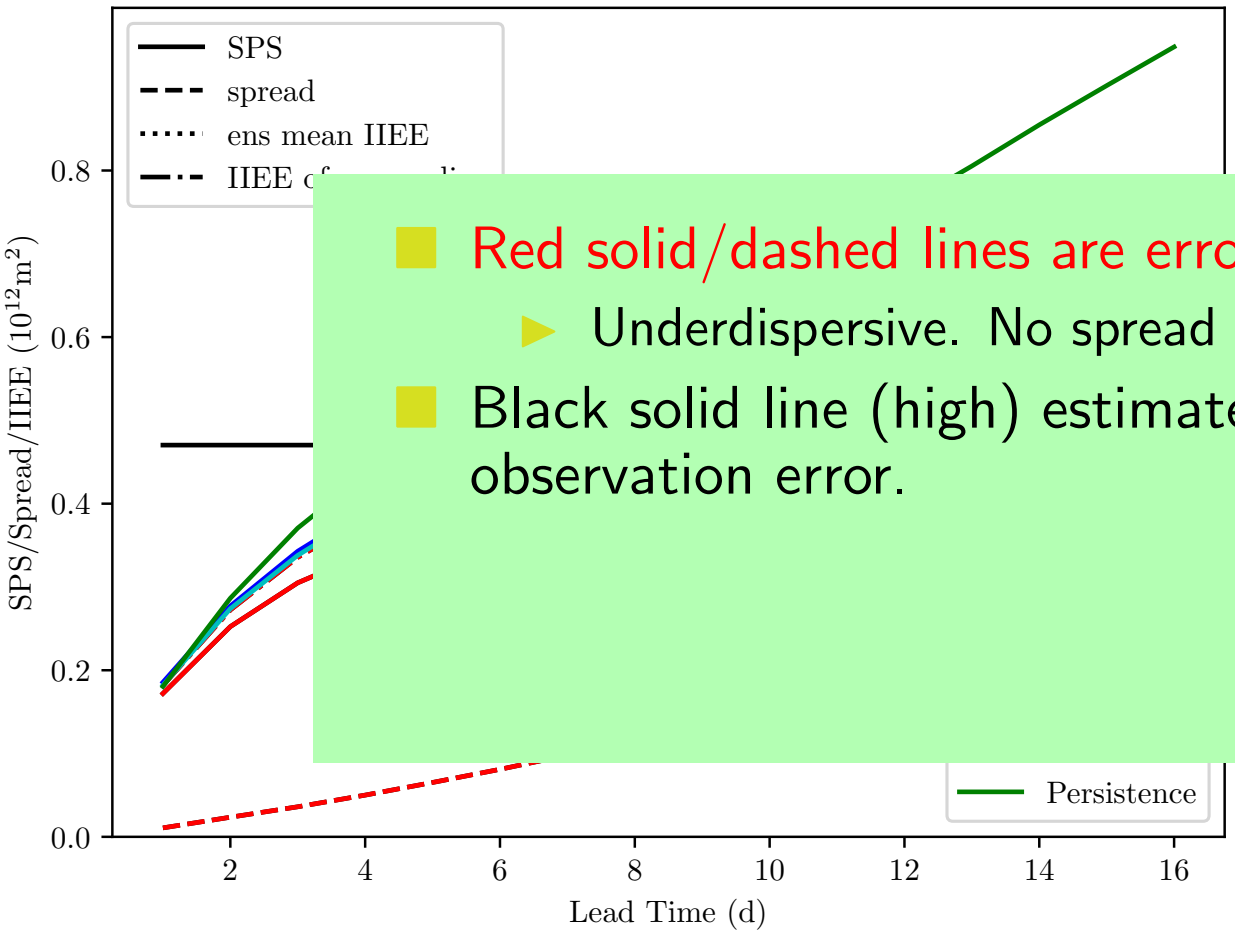

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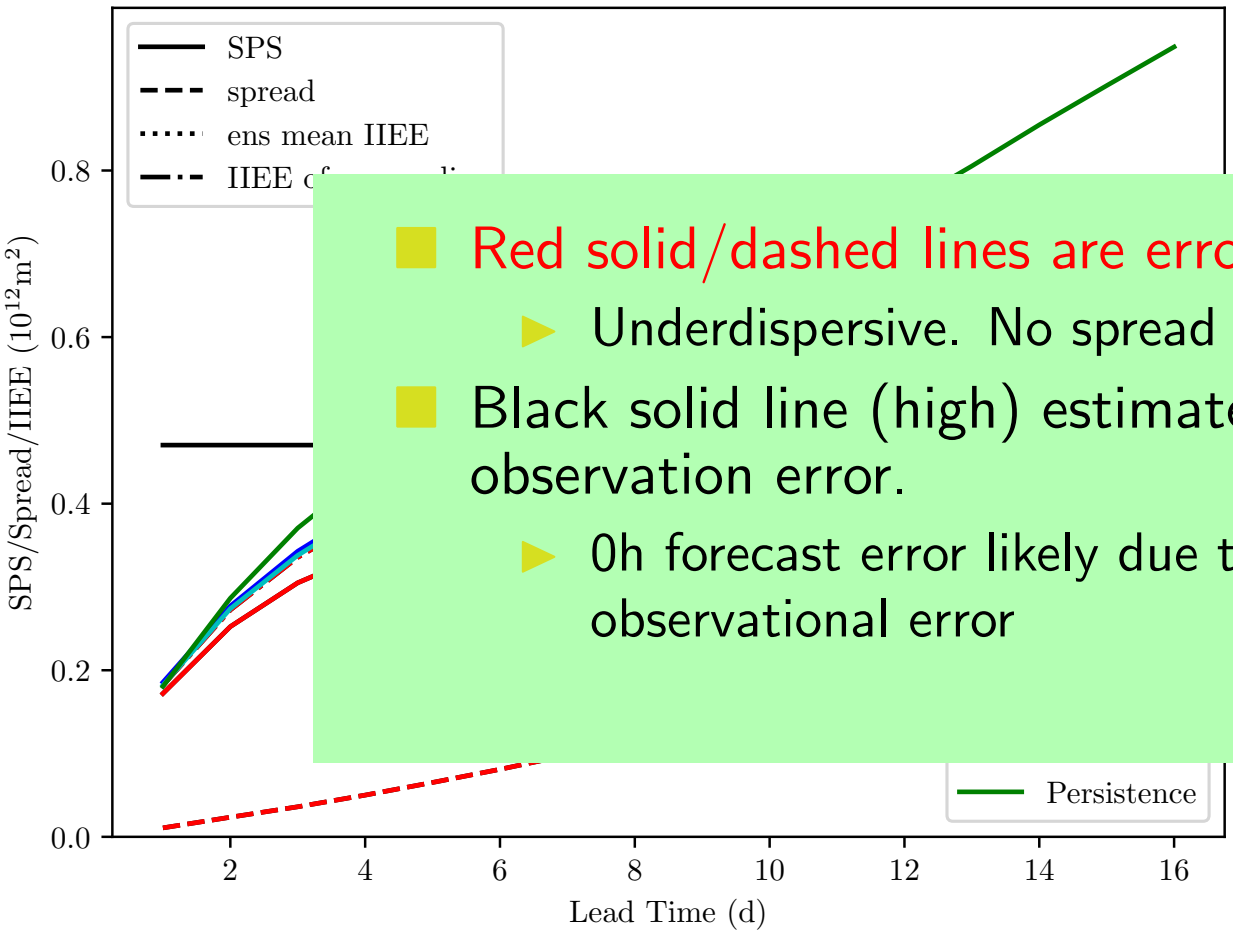

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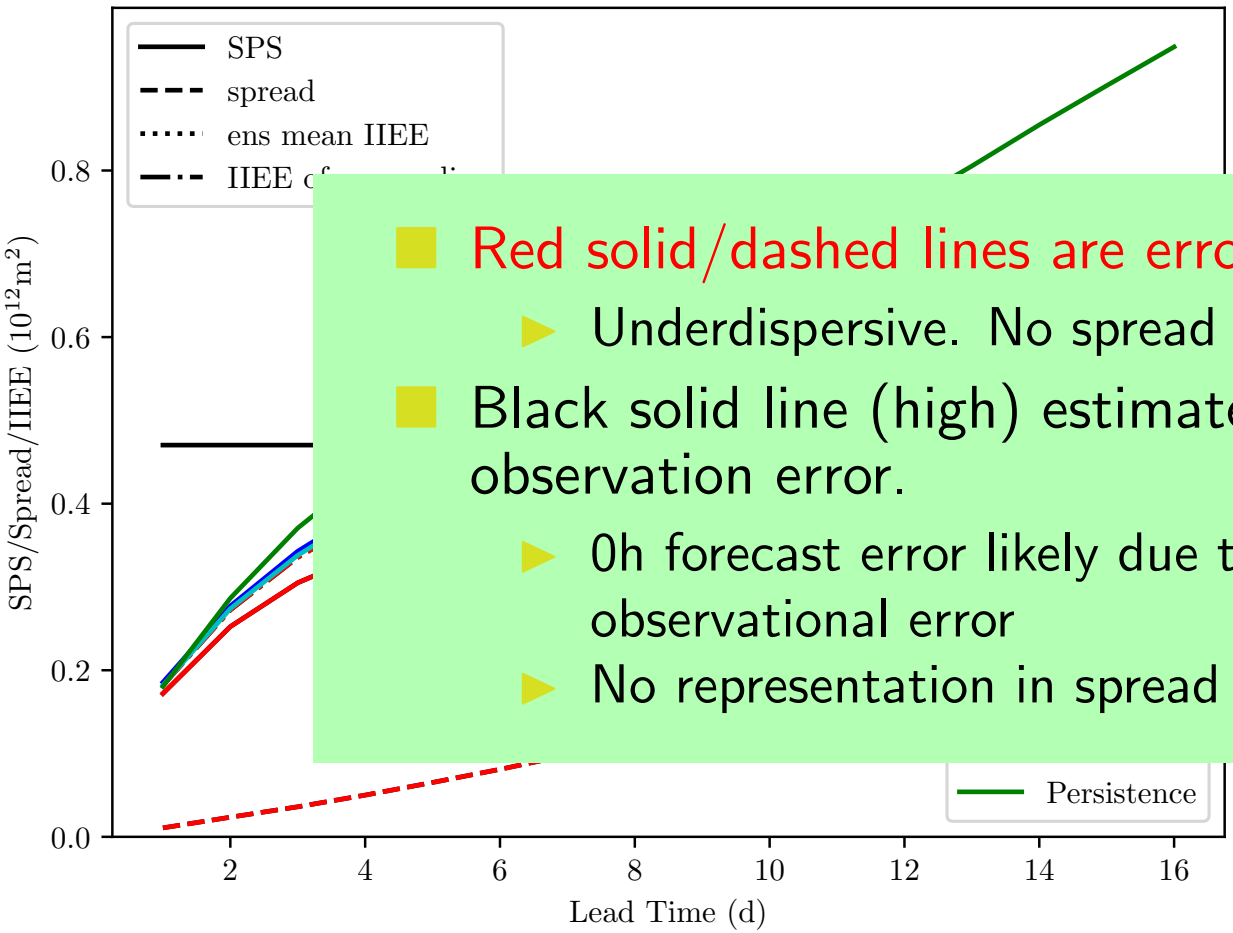

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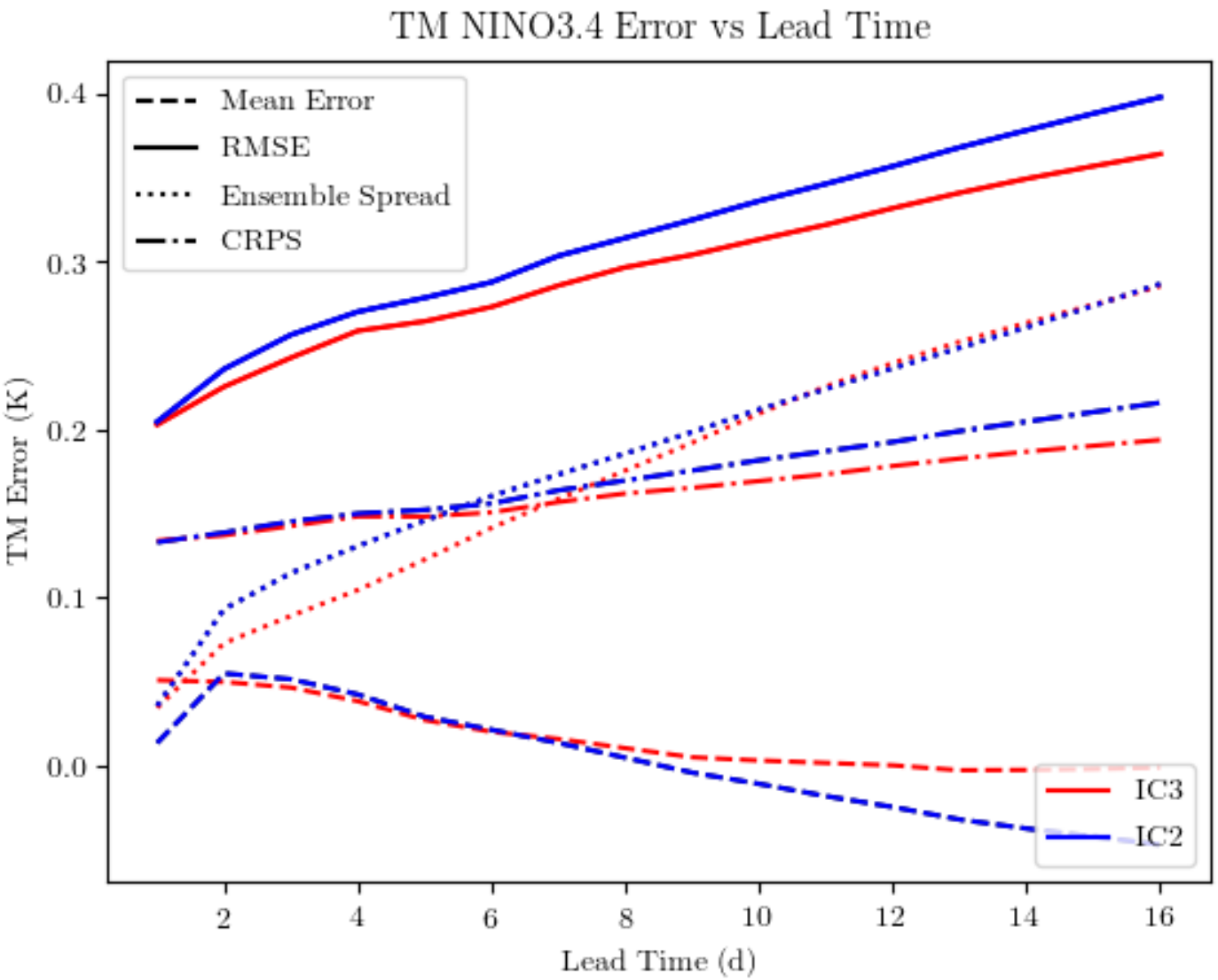
GEPS Coupled Forecast Spread – SST NINO3.4

NINO3.4 Error/Spread



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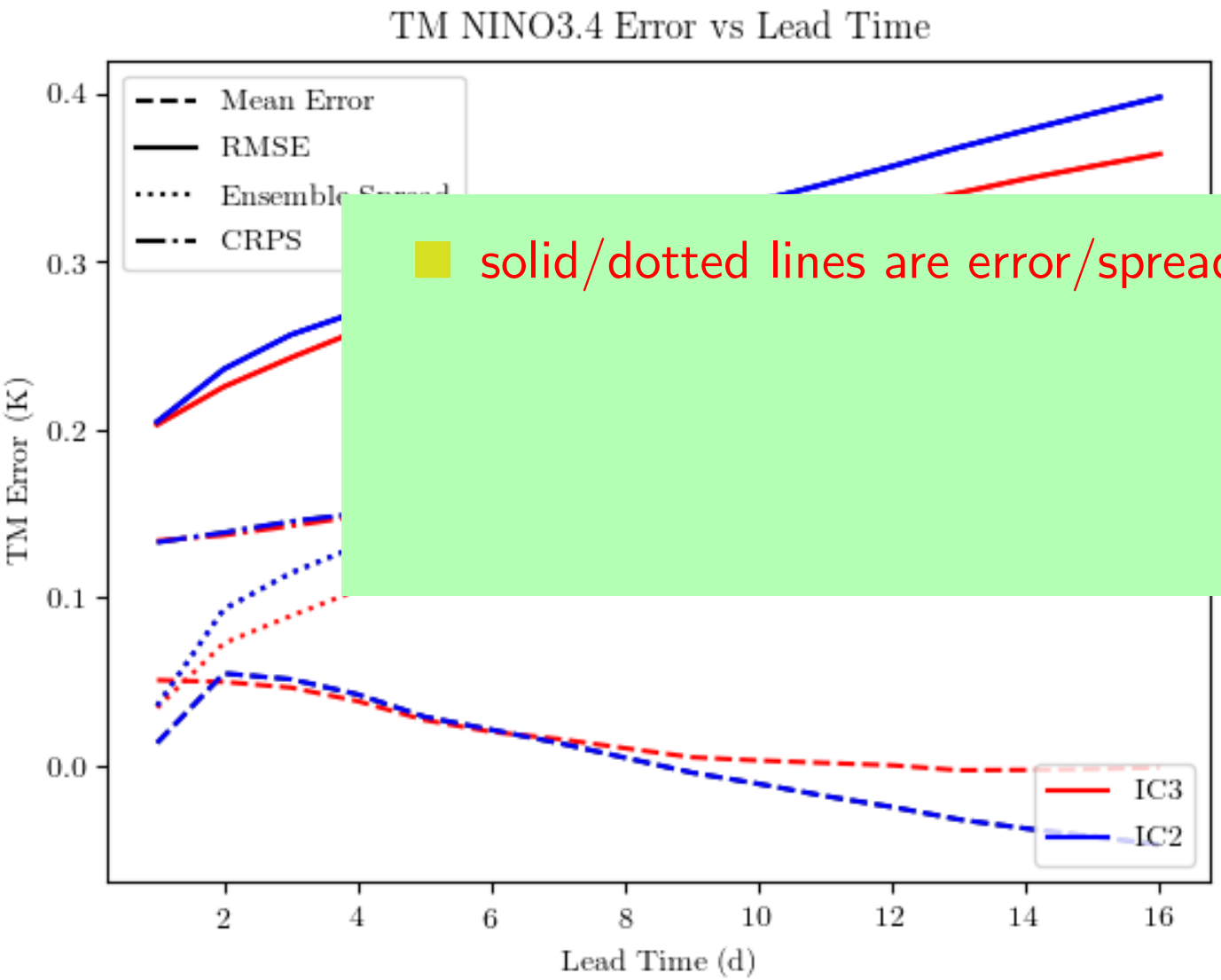

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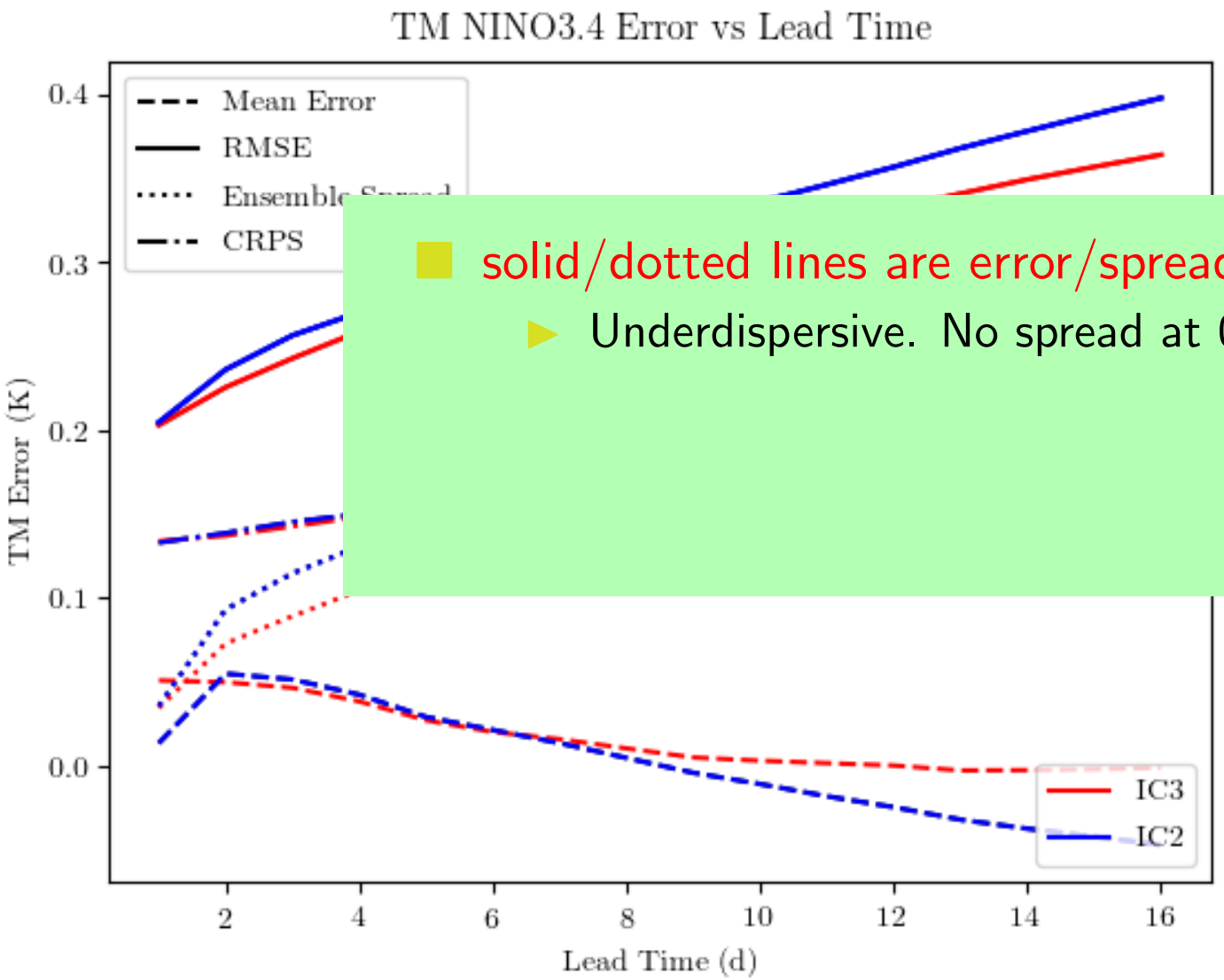

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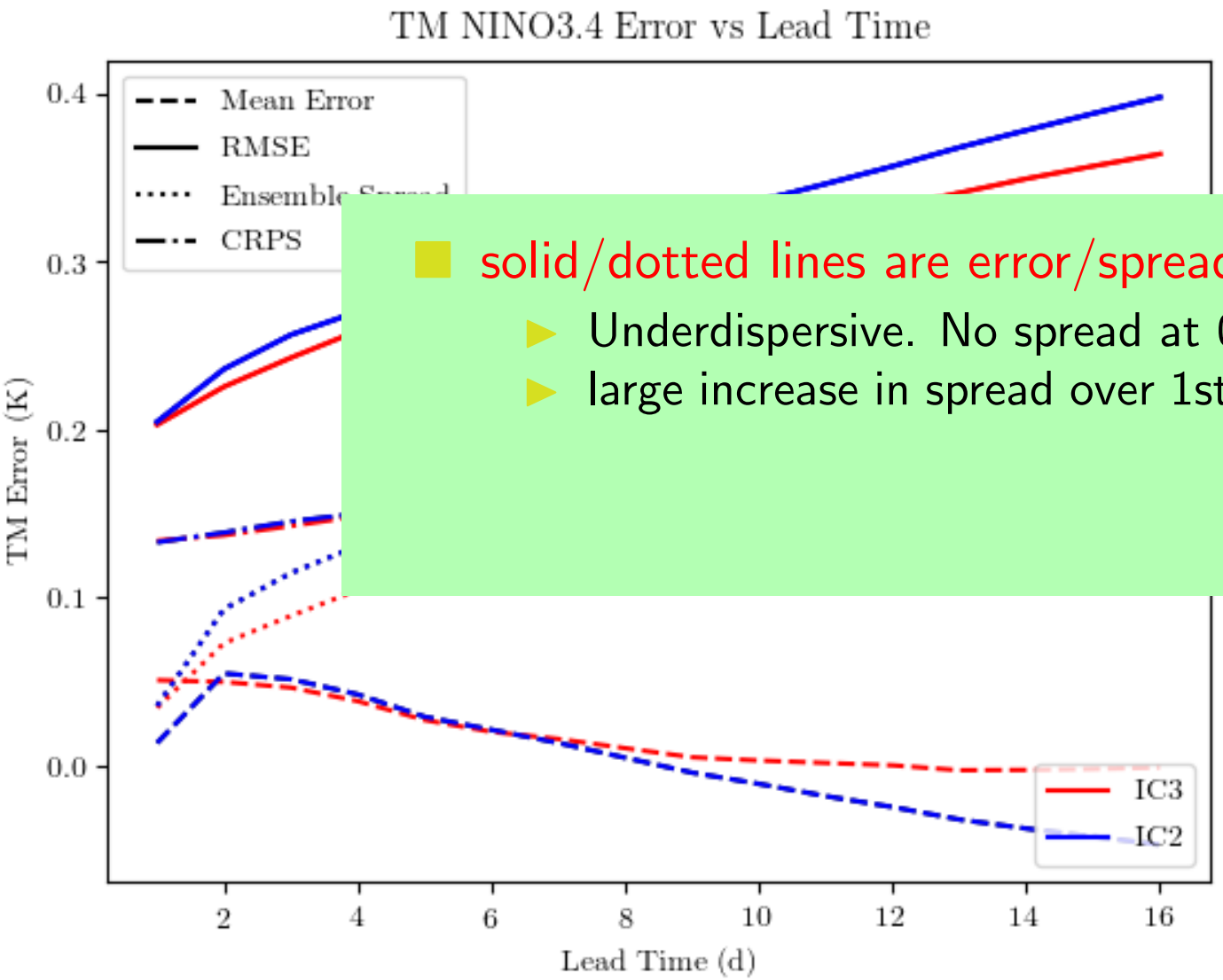

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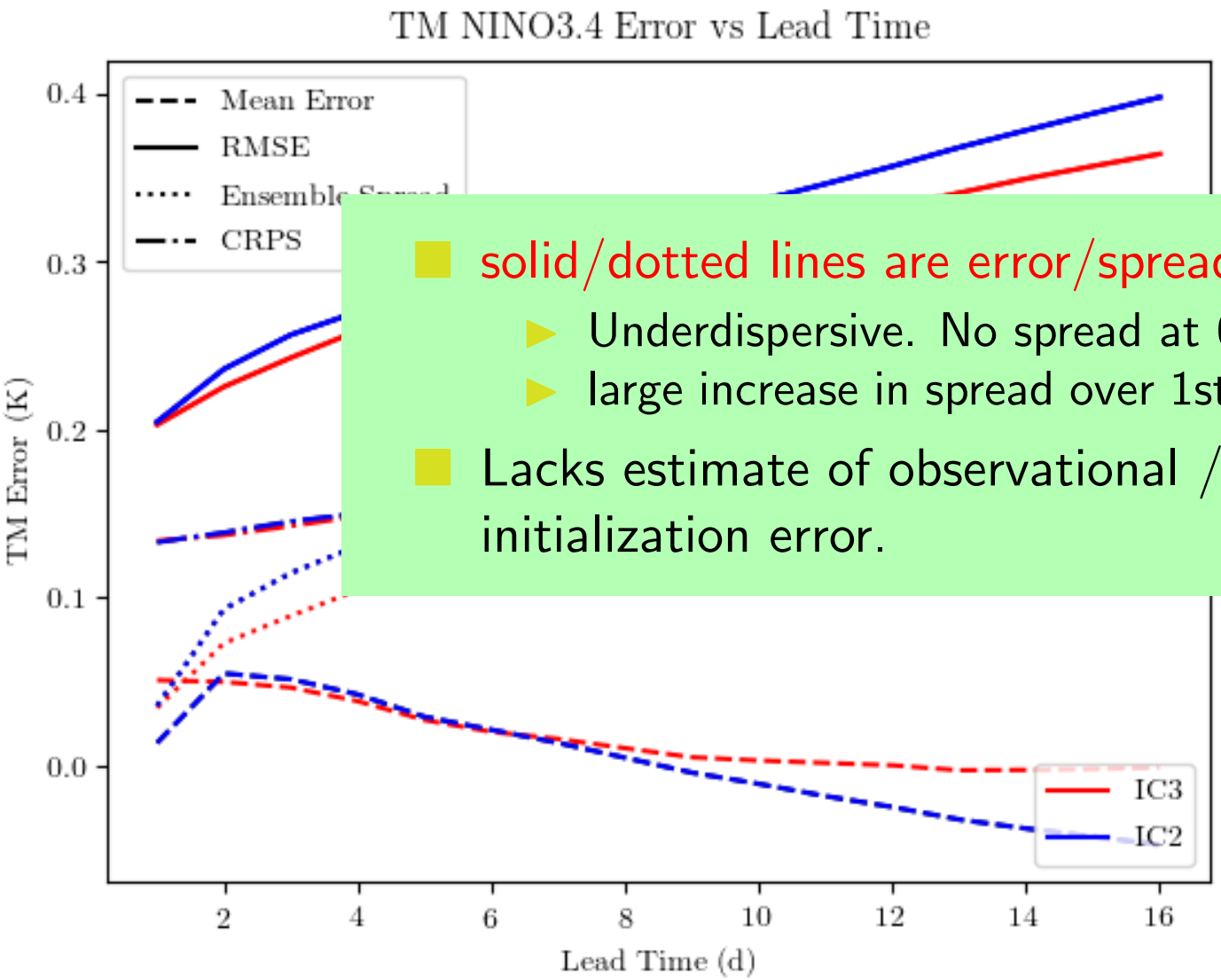

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- Lacks estimate of observational / initialization error.

GIOPS

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- Atmospheric forcing from Global Deterministic Prediction System (GDPS) IAU step
- Ocean model is NEMO

Ensemble GIOPS

- replace GDPS forcing with GEPS Ensemble Atmospheric Forcing (21 members)
  - From 12-36h forecast

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    - Increases spread in quiescent (gyre) areas with small errros.

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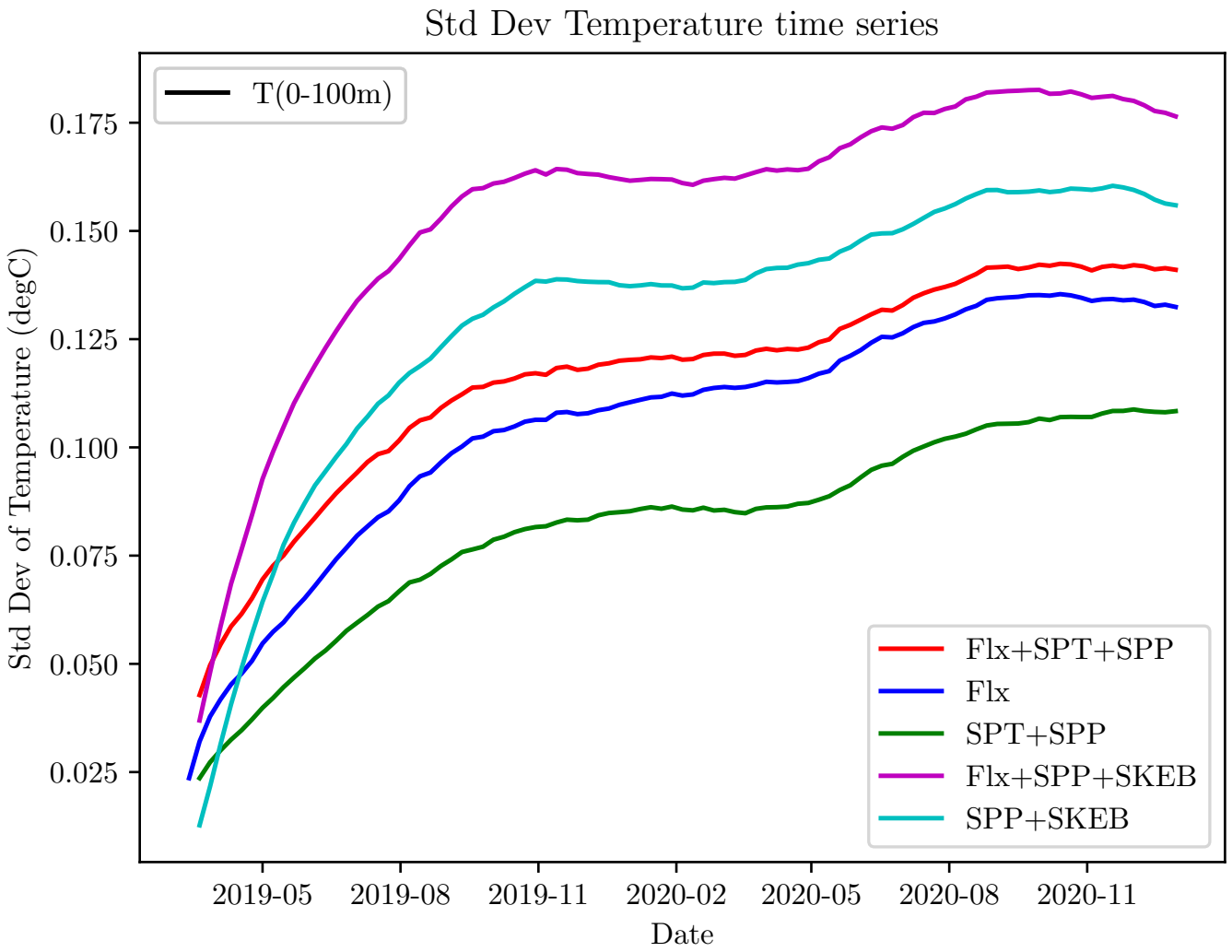
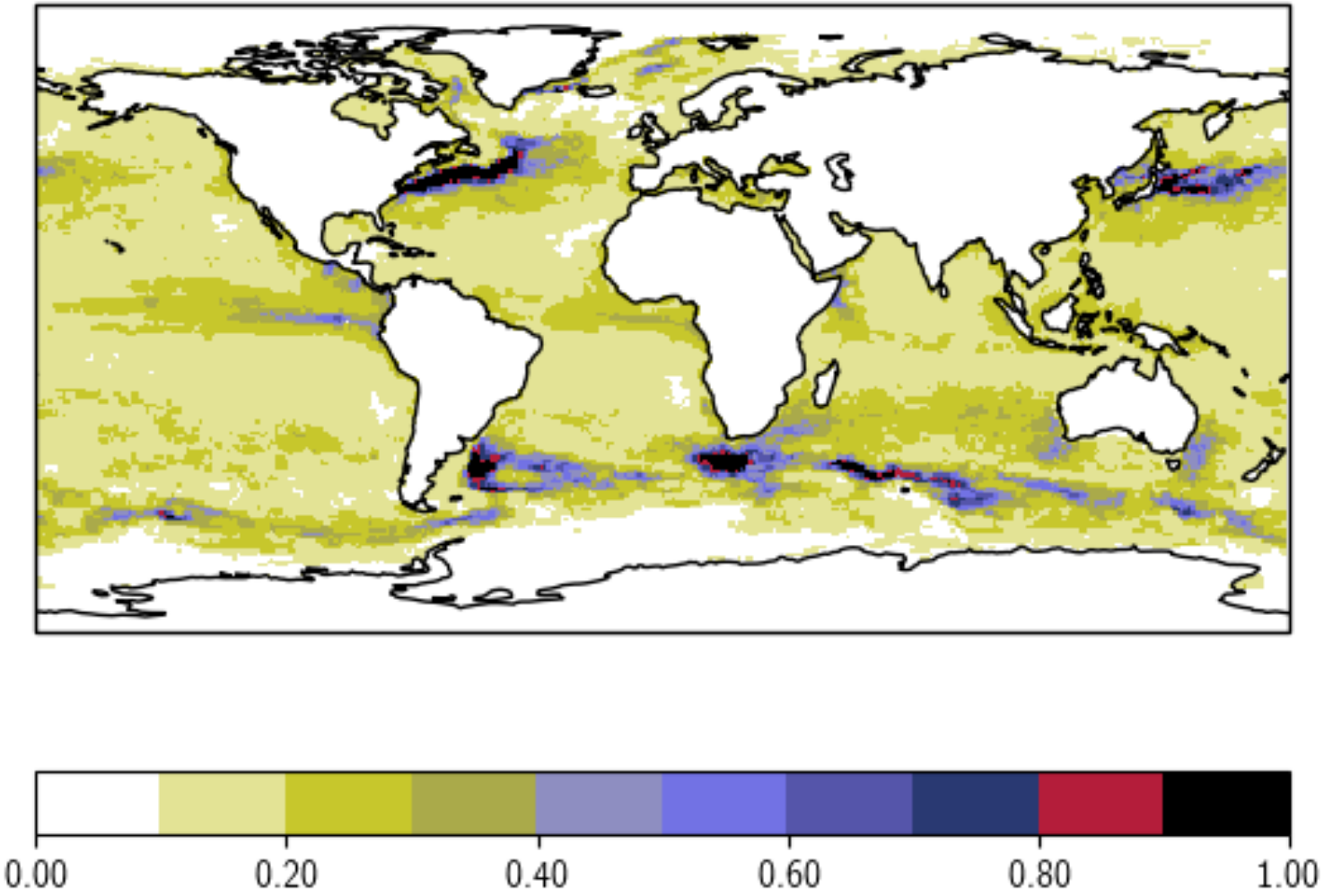
  - Additional Details in Extra Slides.

Spread Induced in System – T(0-100m)



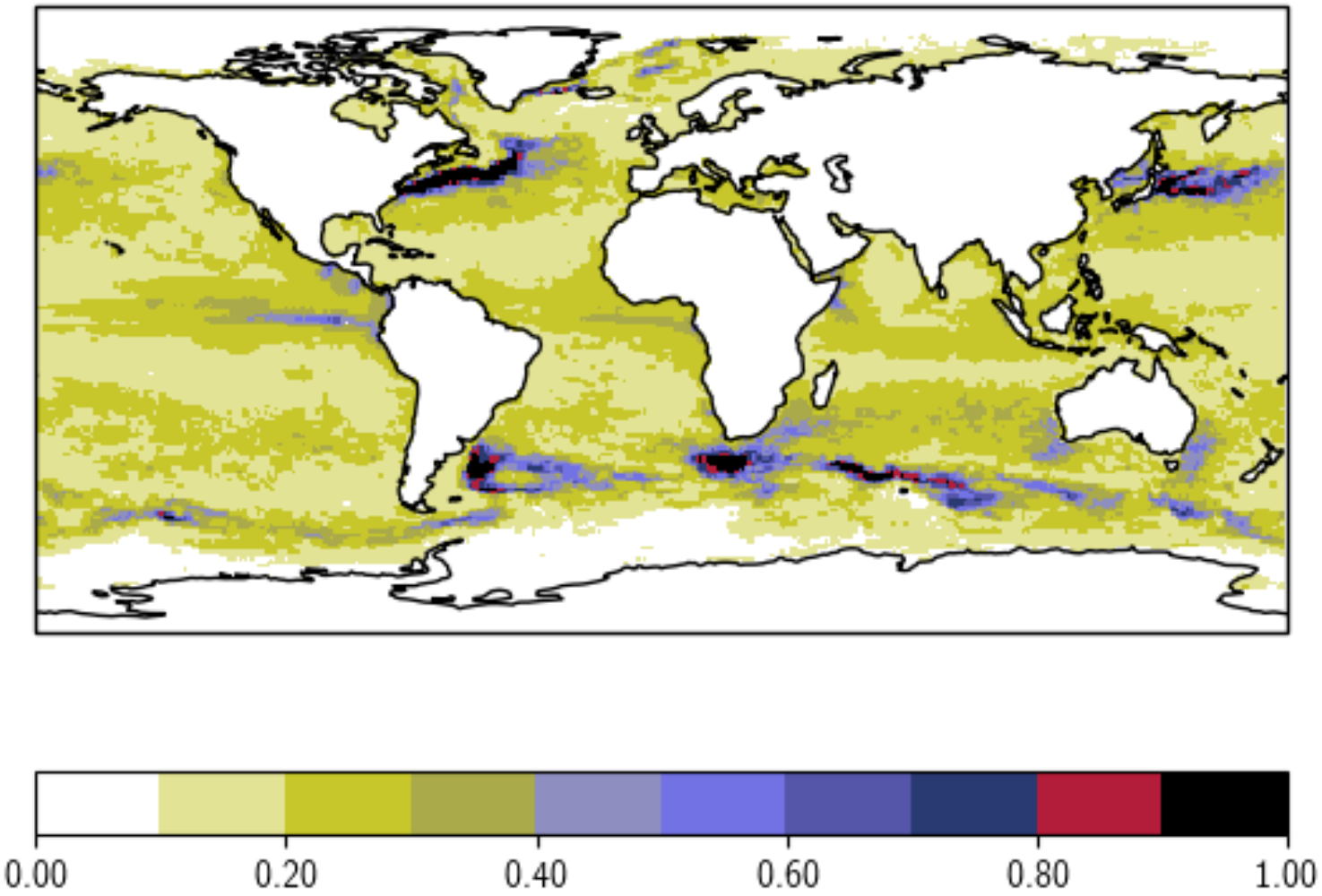
SST Ensemble Spread (Std. Dev.)

GEPS Fluxes only – 2020



SST Ensemble Spread (Std. Dev.)

Flux + SPPT + SPP – 2020



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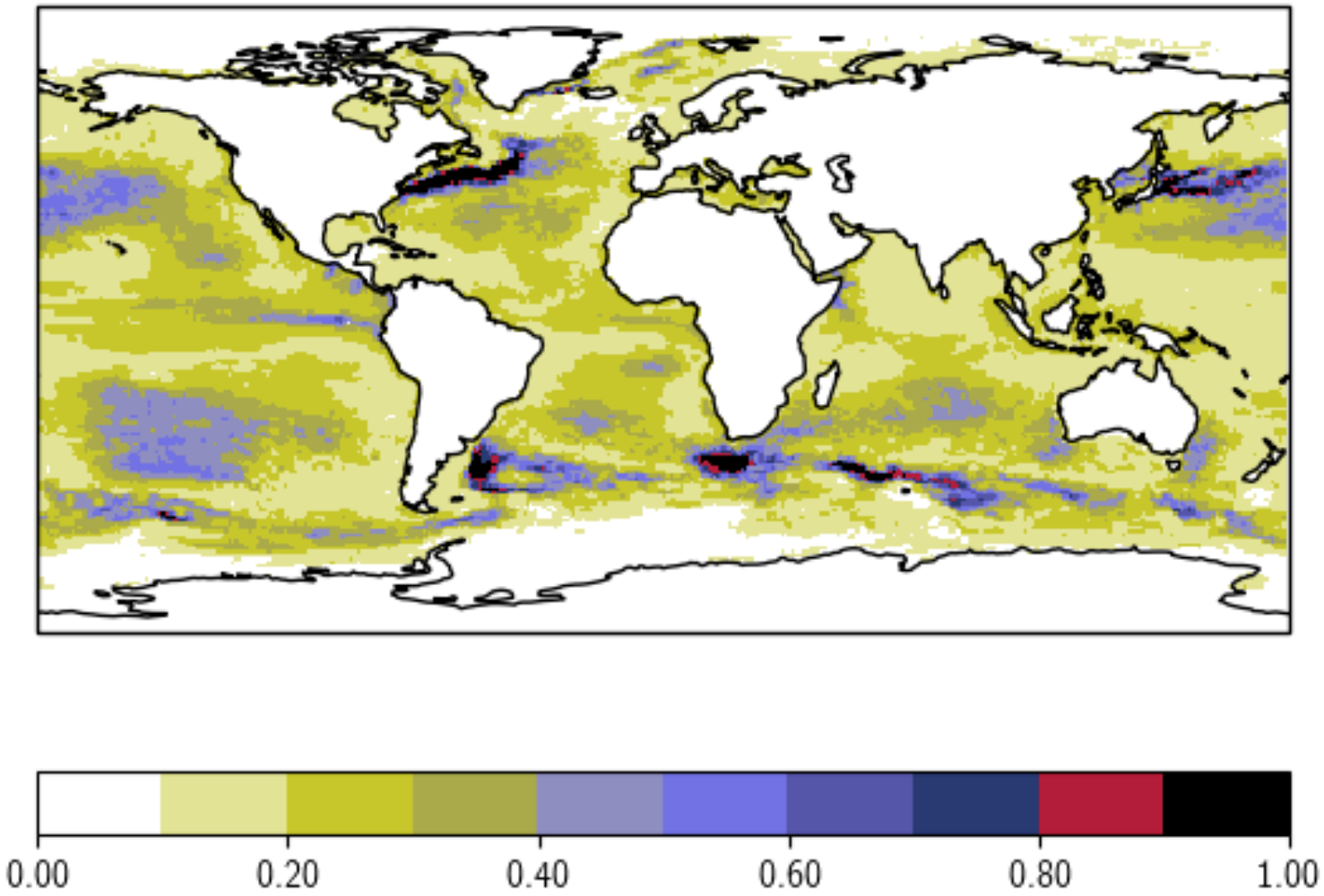

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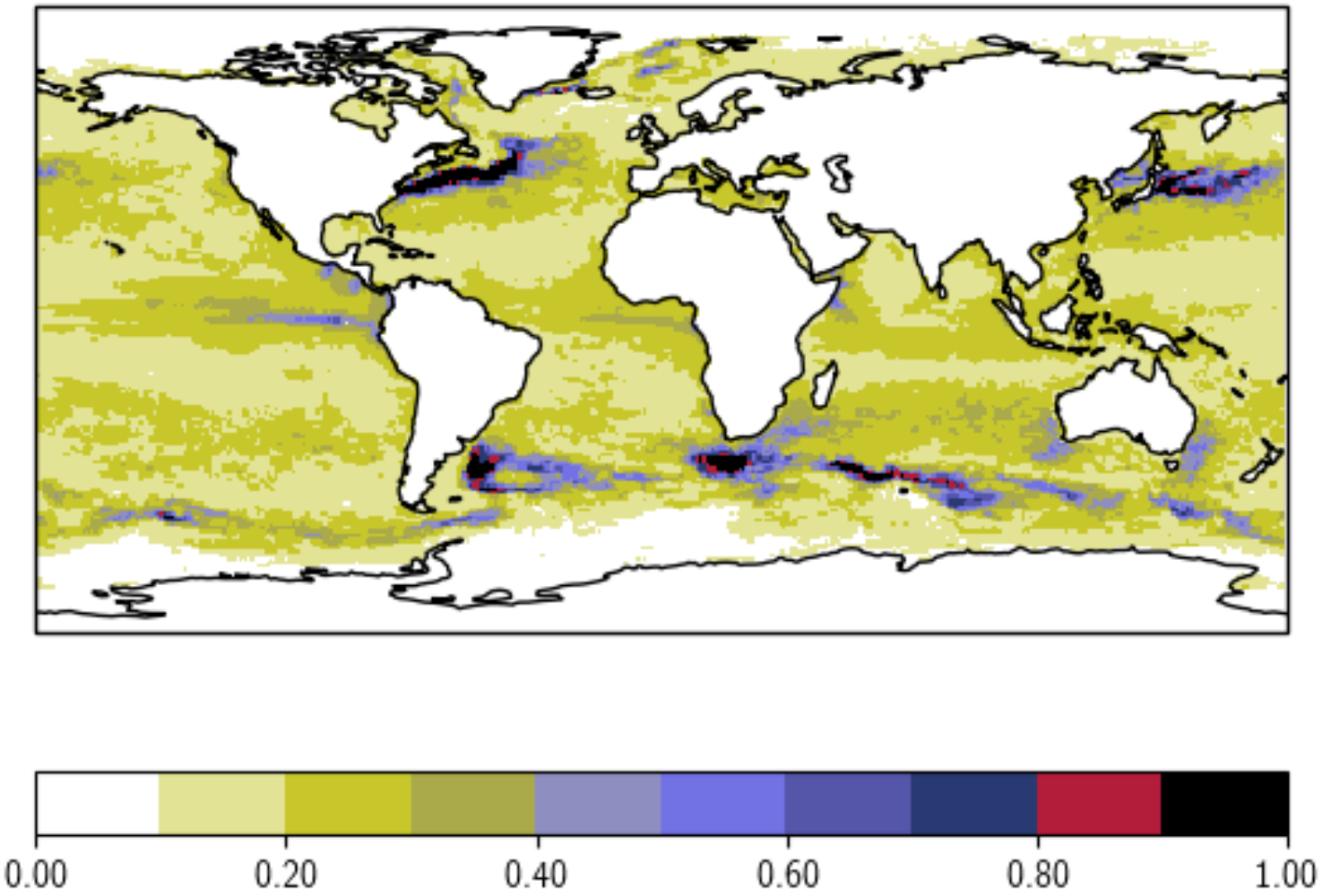
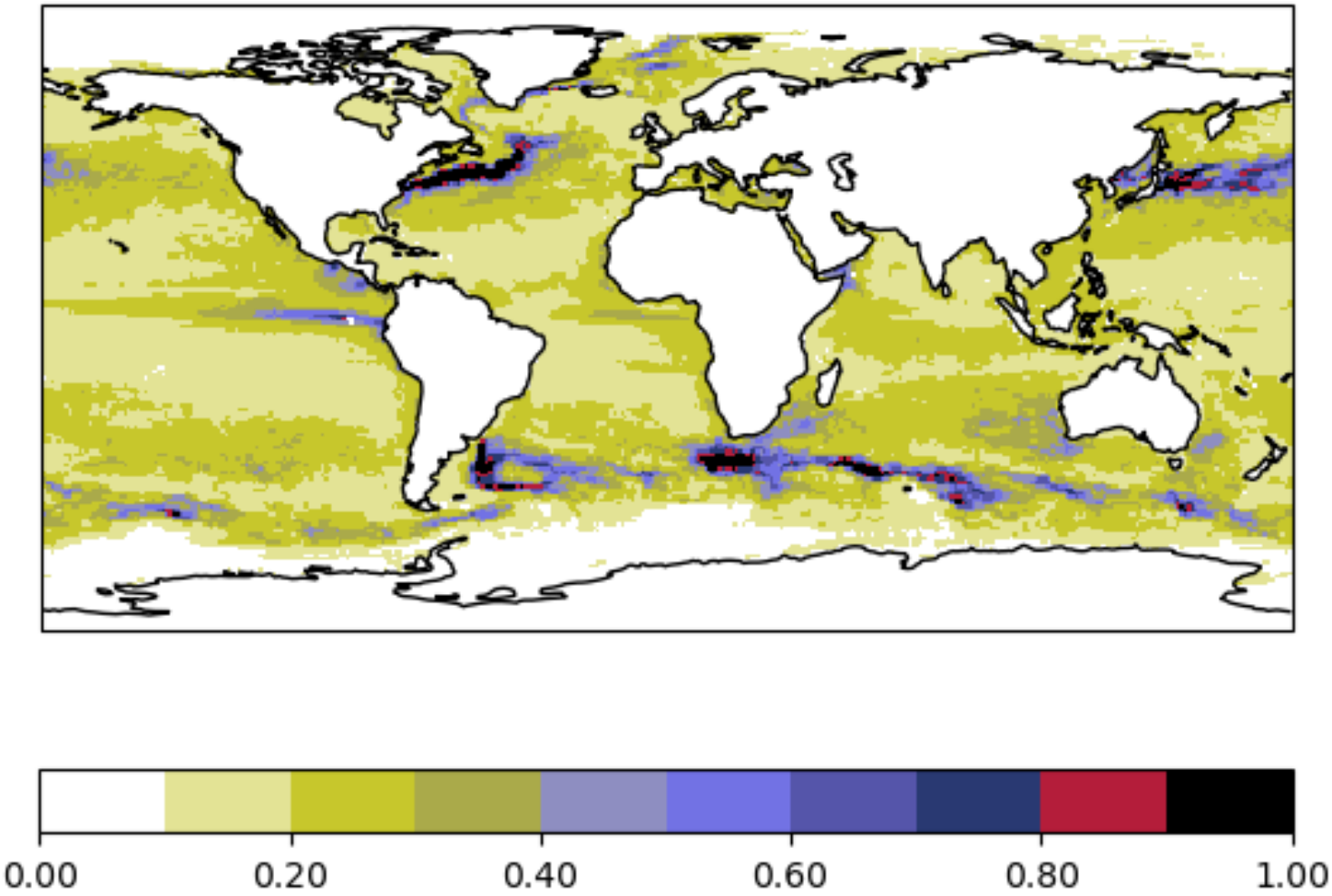


SST SPREAD / RMSE Relationship

SPREAD 2021/06/02–2022/06/01



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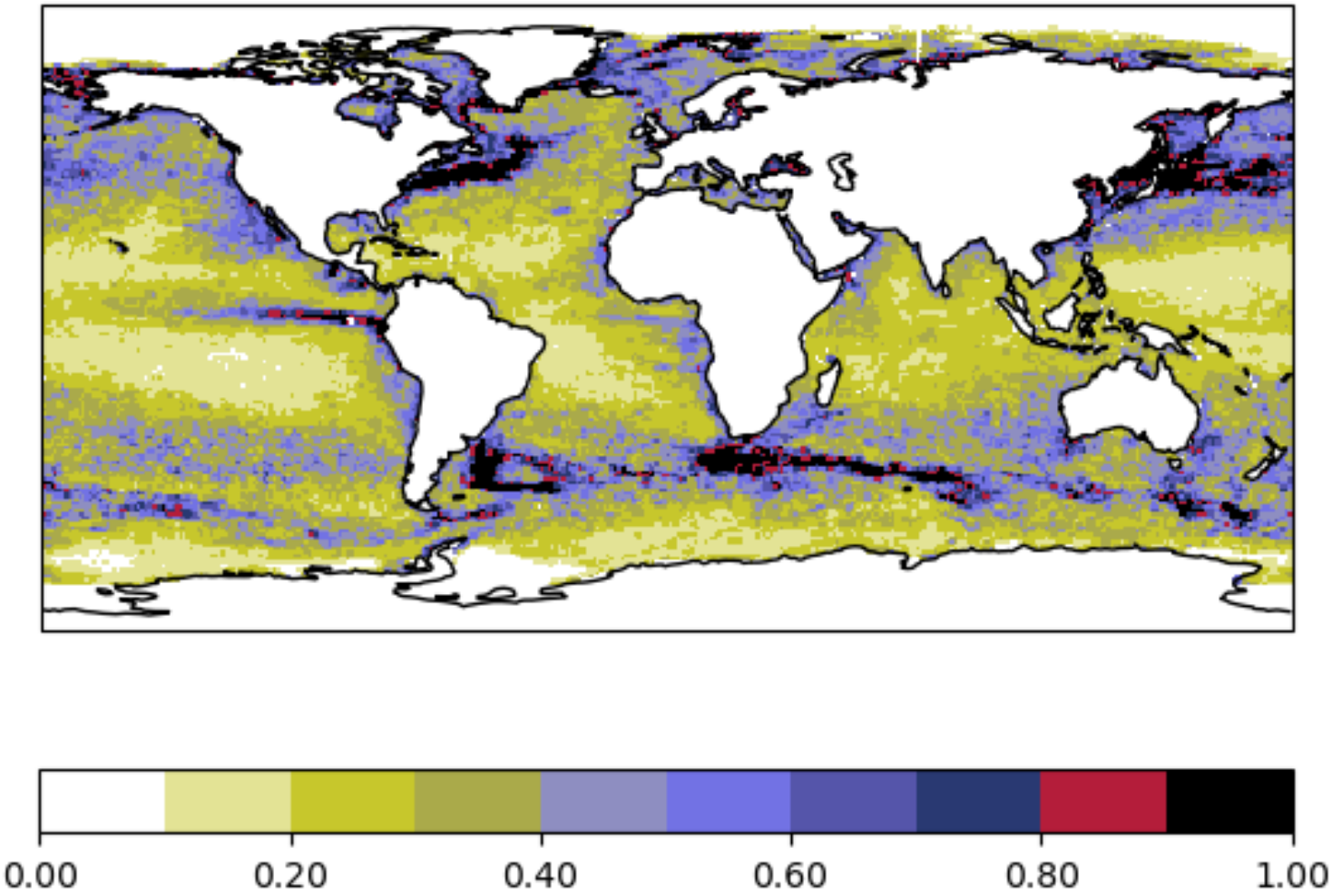
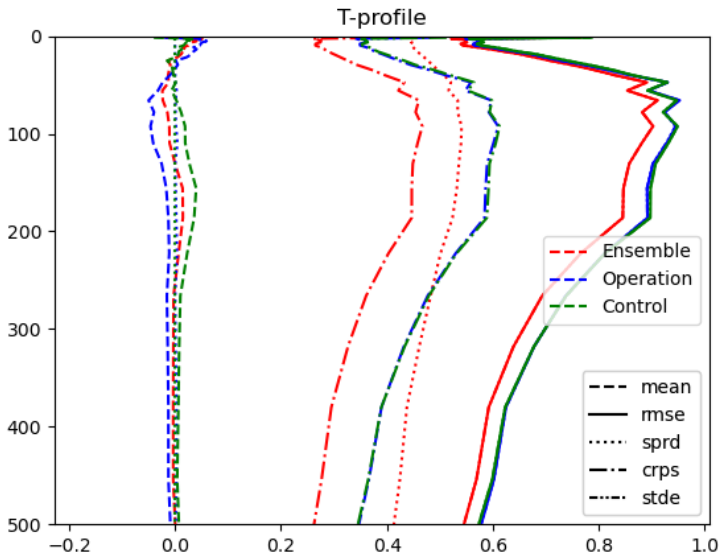


Profile Error Relations

Global 500m

Temperature



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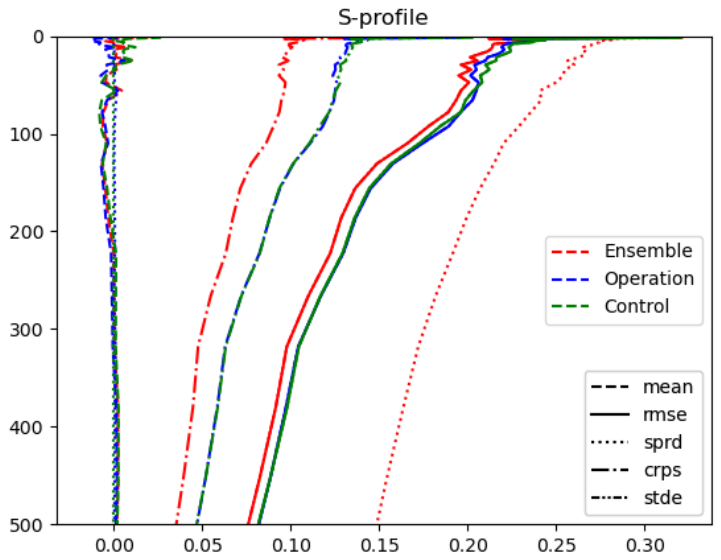

Profile Error Relations

Global 2000m

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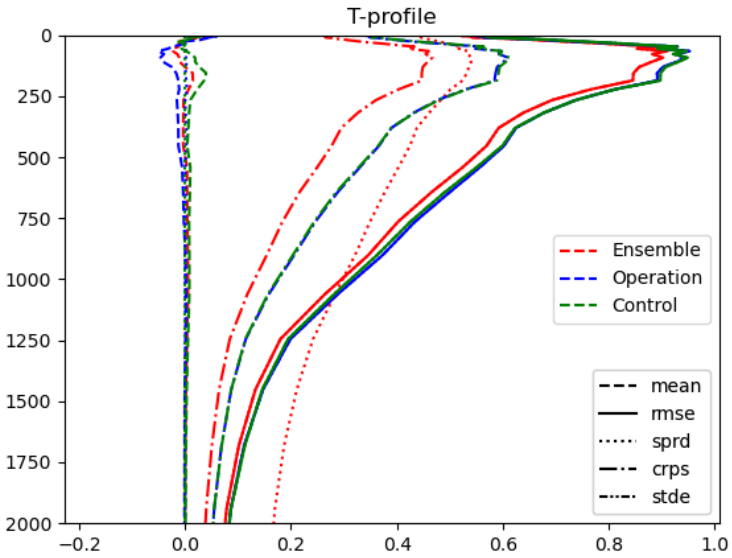

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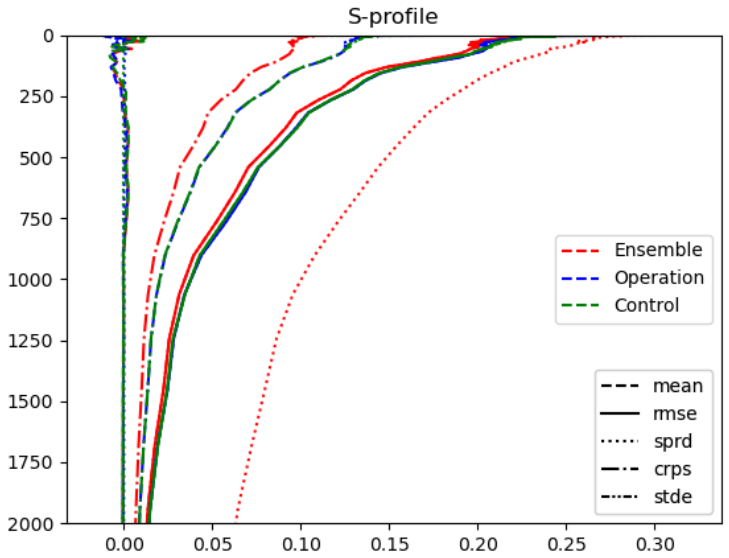
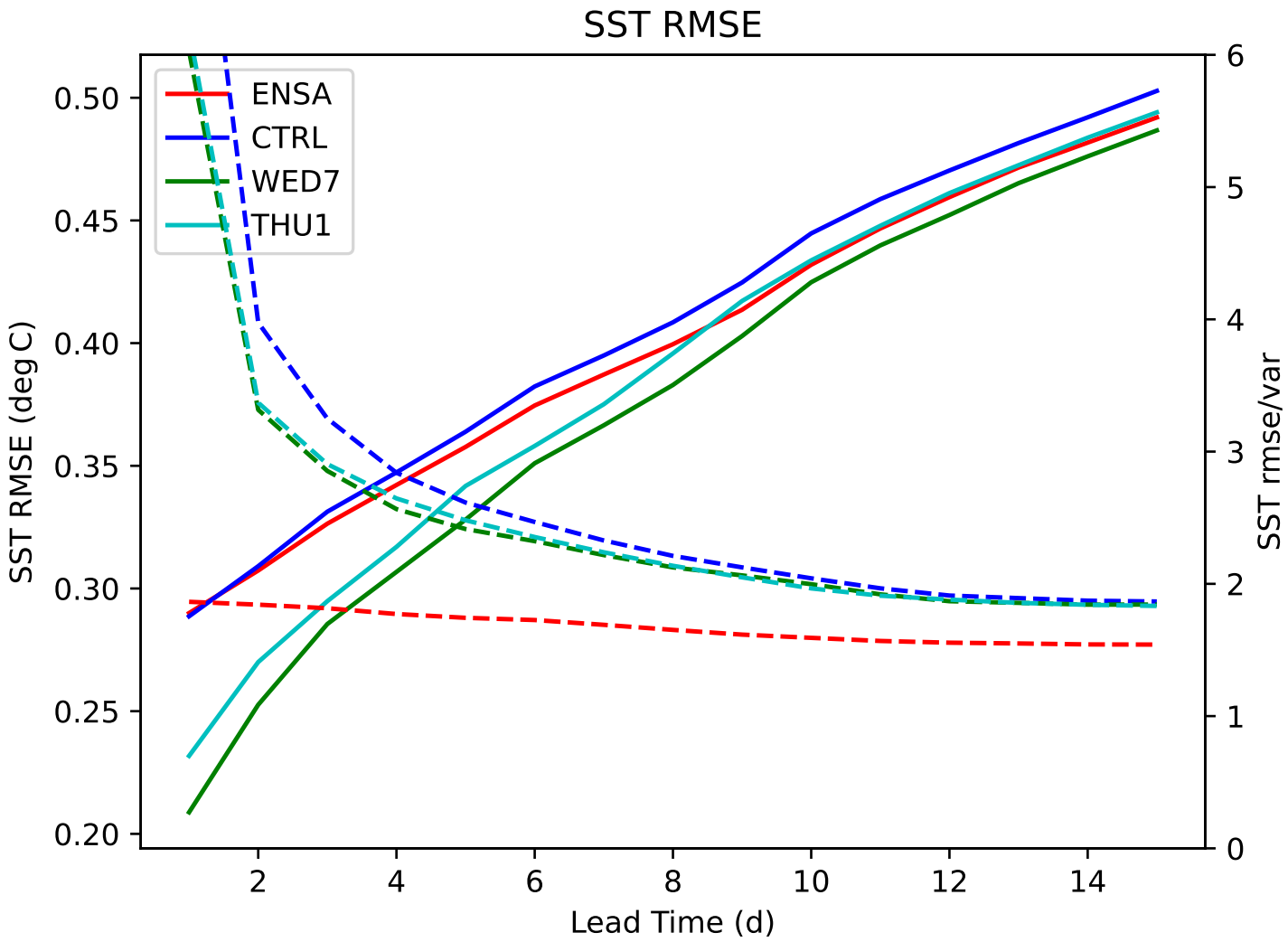


Forecasts using Ensemble Analysis

Solid Lines – RMSE **Red Dashed line – Ratio RMSE/Ens.Std.**

NINO3.4 Region



Forecasts using Ensemble Analysis

- GEPS forecasts using Ensemble Analysis (ENSA)
- GEPS forecasts using GIOPS-GD operational analysis (CTRL)
- Operational GEPS forecasts on Wednesdays (WED7)
  - *7 day removed from GD analysis*
- Operational GEPS forecasts on Thursday (THU1)
  - *1 day removed from GD analysis*

- Operational GEPS Wednesday and Thursday forecast have been updated 7 and 1 times respectively by a SST assimilation only update (GU), and therefore are likely positioned closer to the validating and assimilated SST analysis than the full assimilation GD cycle Ensemble and GIOPS-GD analysis.
- Wednesday operational GEPS forecasts will match forecast dates exactly, Thursday forecasts will be offset by one day.

Forecasts using Ensemble Analysis

Solid Lines – CRPS

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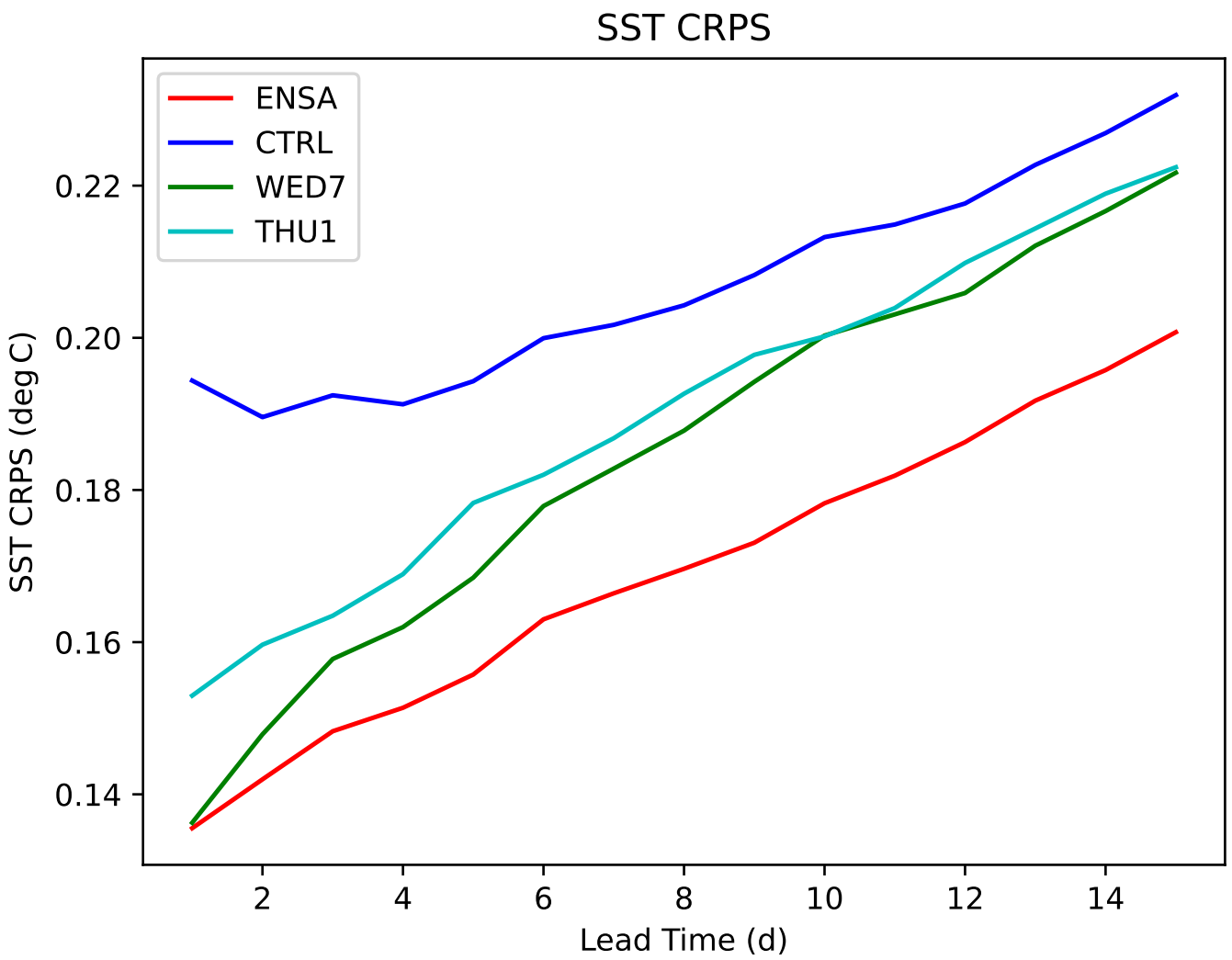

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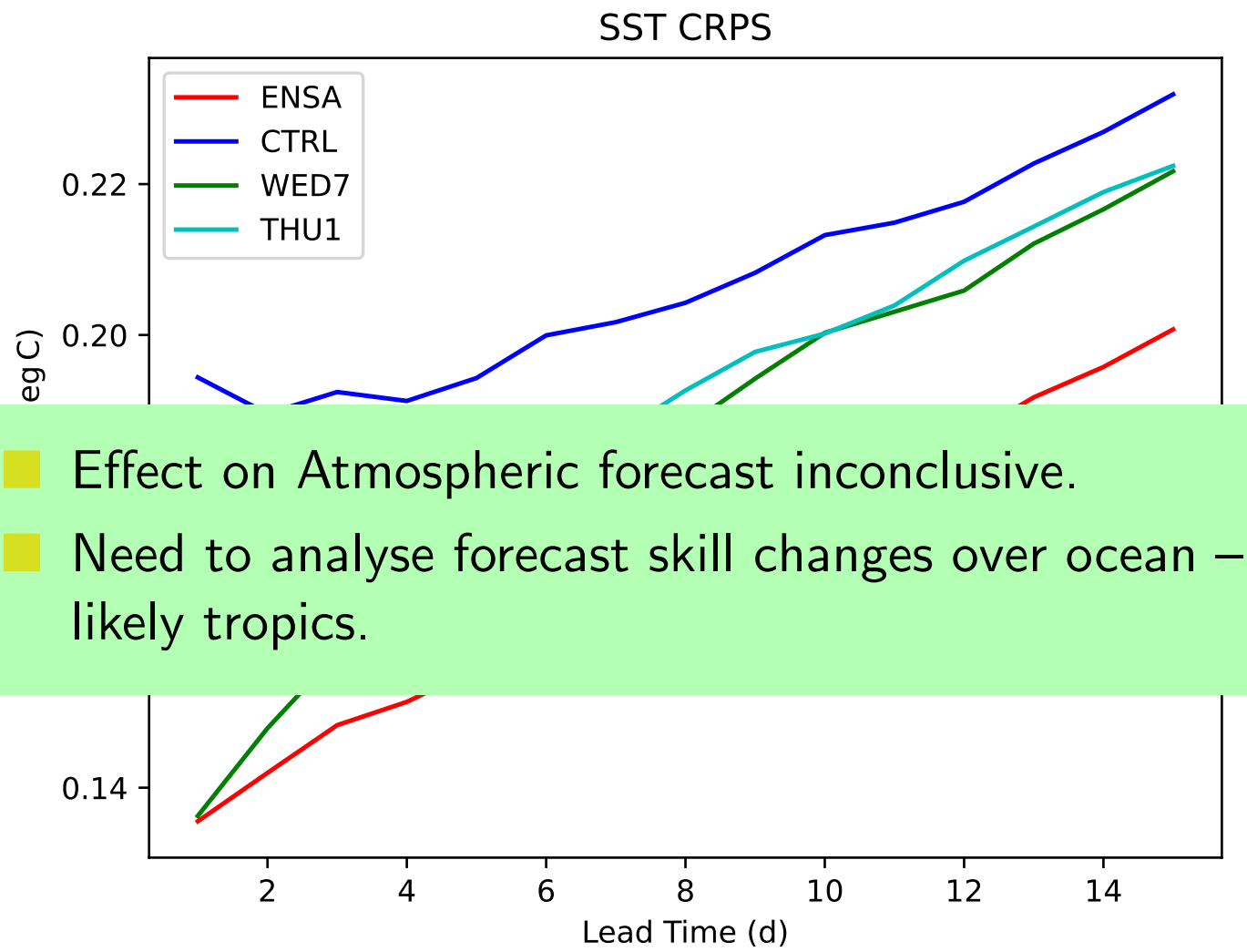
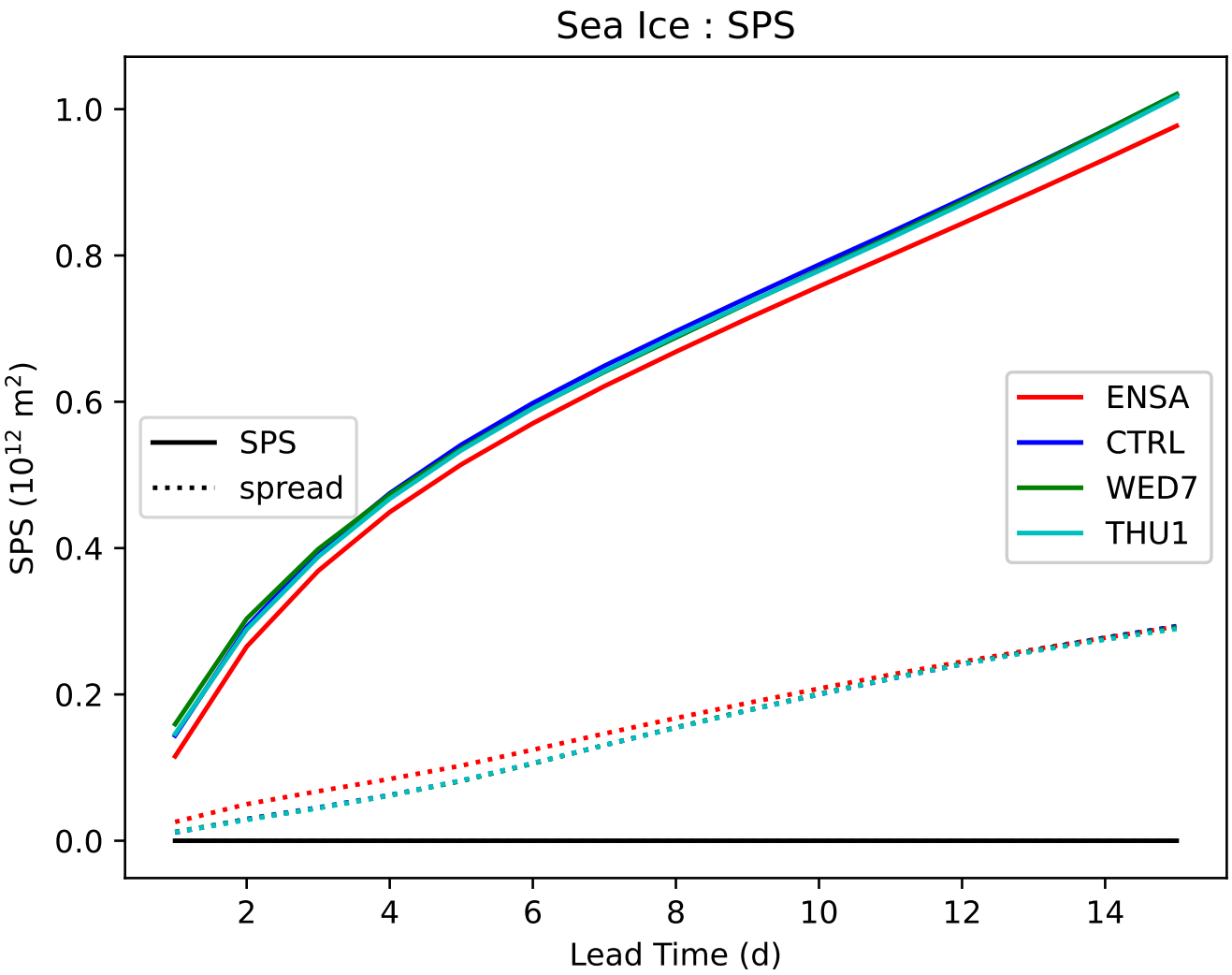


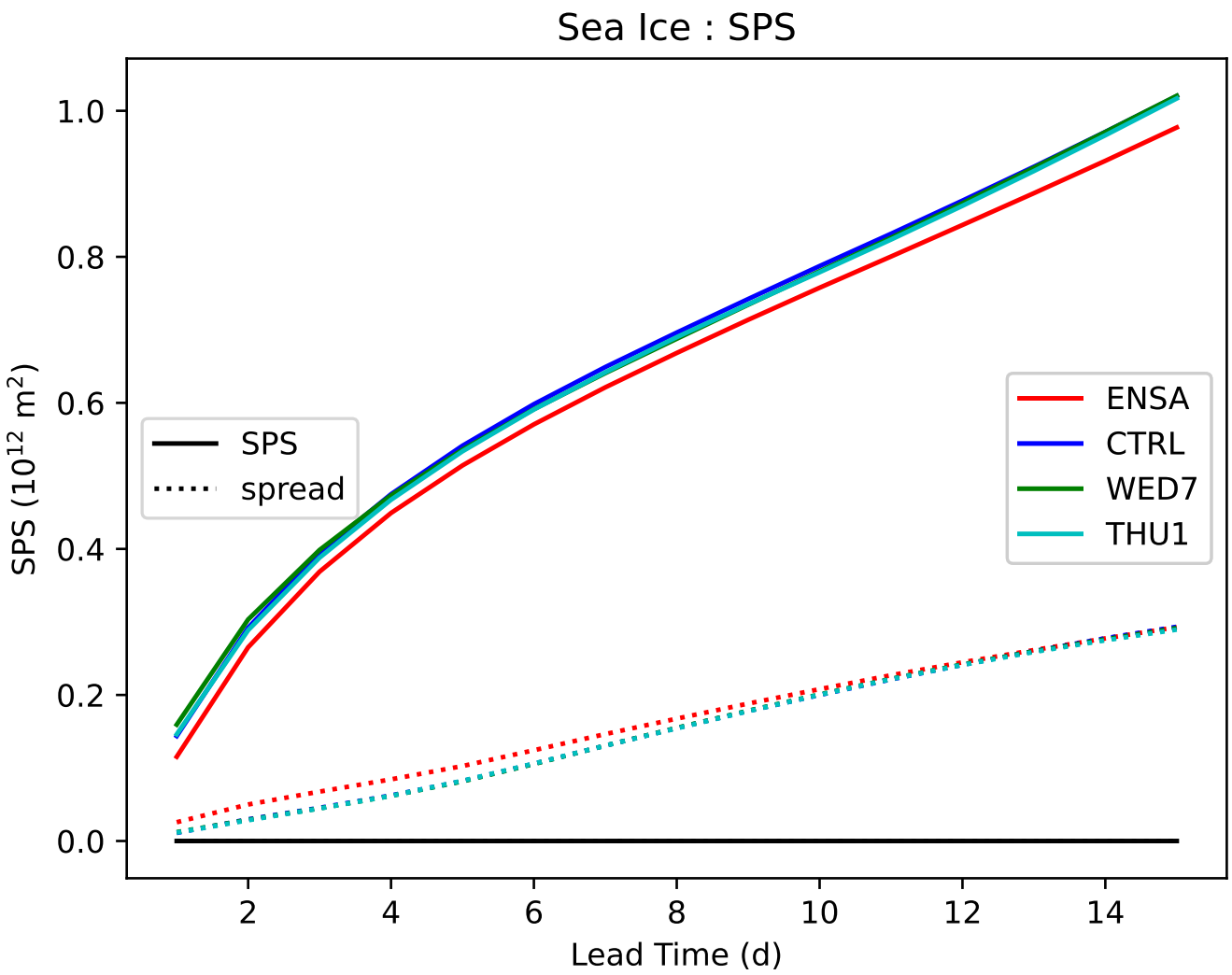
- Effect on Atmospheric forecast inconclusive.
- Need to analyse forecast skill changes over ocean – likely tropics.

N.H. SeaIce Forecasts using Ensemble Analysis



N.H. SeaIce Forecasts using Ensemble Analysis

Sea Ice Analysis is still deterministic



Errors of the Day

Question

Can we use the ensemble information to generate better background error covariances.

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Can we use the ensemble information to generate better background error covariances.

Solution

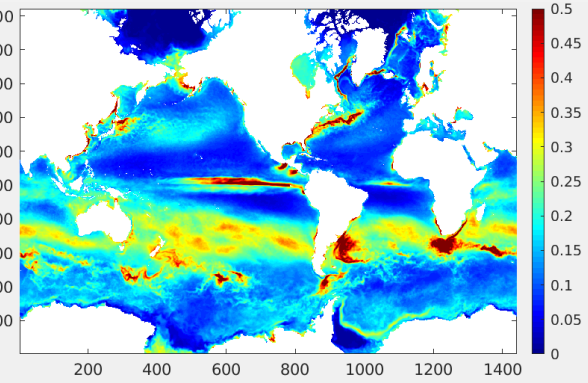
Not ready for large ensemble size yet. Early attempt using GEPS forecast at several long leads – with no initial spread!! Required lead times up to 28 days.

Errors of the Day

SST Variance of Background Error Modes

Valid for Dec. 12, 2019

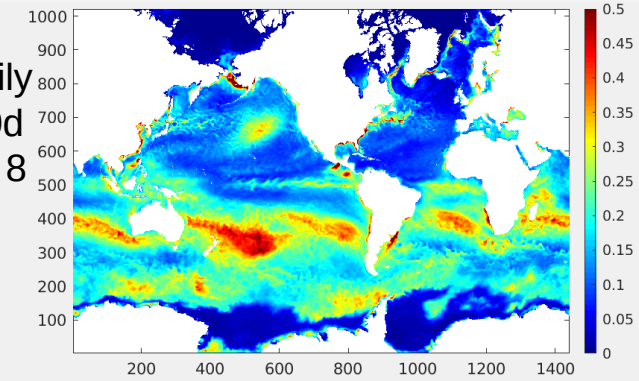
Climatological modes (249)



Climatological

- Generated from daily differences from 30d running mean over 8 year period.

Ensemble modes (252)



Ensemble

- Generated from 21 ens member differences from ens mean
- Lead 7,14,21, 28d
- Each normalized to cliim modes
- 4 x 21 x 3 (+/-3d)

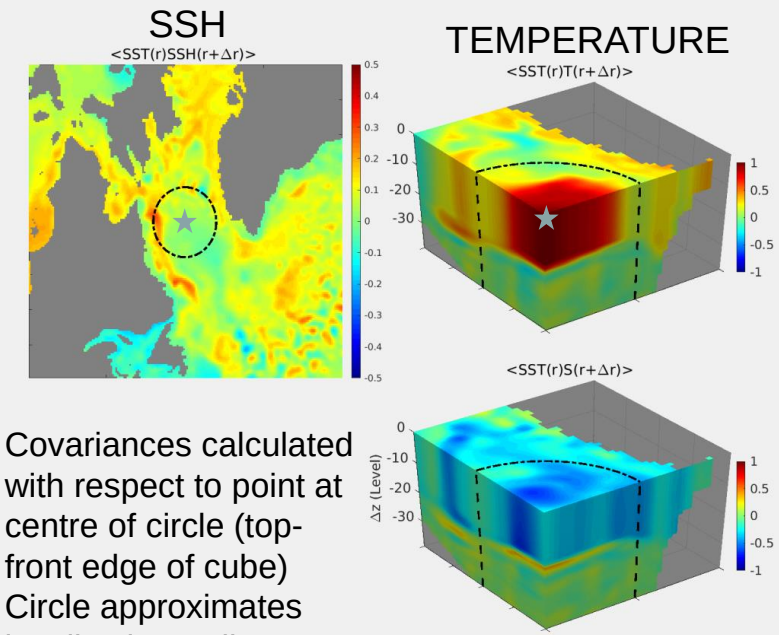
Climatological modes represent sub-monthly scale variability
- e.g. Ocean mesoscale features

Ensemble modes represent ocean response for a particular date to variations in atmospheric state
- i.e. projection of atmospheric uncertainty on ocean
- Effect is amplified due to use of large lead times (much larger error than typical forcing used for trial fields)
- Large differences in Southern Ocean (near sea ice)

Errors of the Day

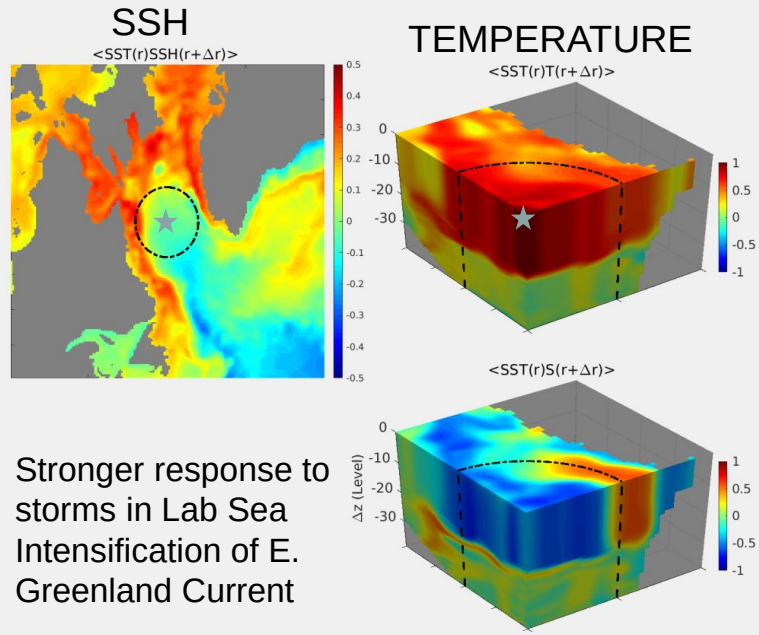
SST Covariances in Labrador Sea

Climatological background error



- Covariances calculated with respect to point at centre of circle (top-front edge of cube)
- Circle approximates localization radius

Ensemble background error



- Stronger response to storms in Lab Sea
- Intensification of E. Greenland Current

Errors of the Day

Projection of SST observations on SSH/SSS

Recall: We assimiltate an SST analysis product

Use of climate modes for SST assimilation shows impact on eddy-active regions. Ensemble modes reduce this effect, in particular for Southern Ocean.

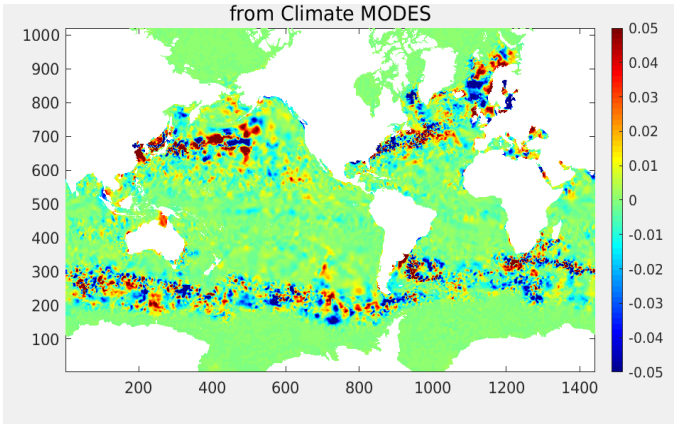
Ensemble modes show under-ice amplification of SST innovation in southern ocean. SST observations under ice set to model freezing temperature.

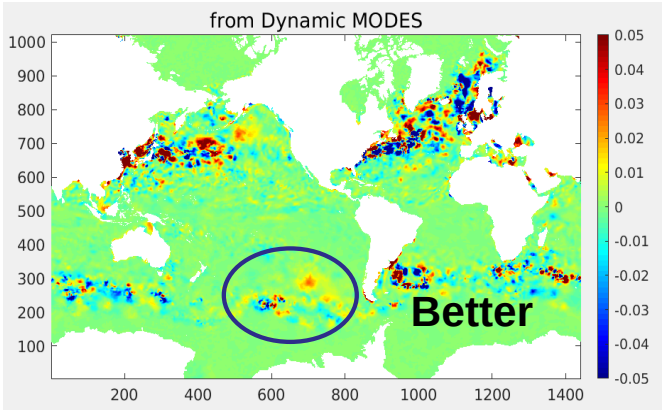
SSH

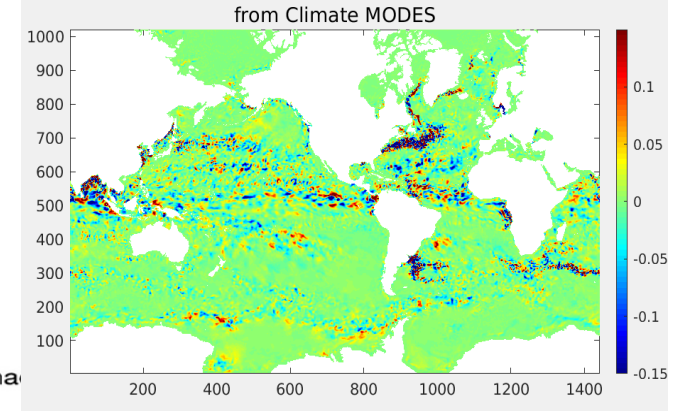
SSS

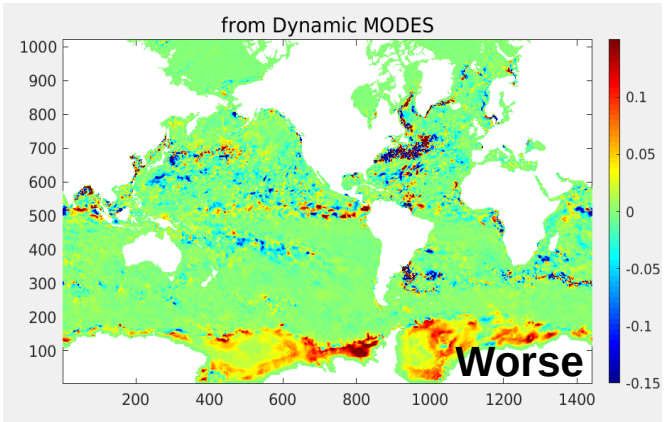
Climatological modes

Ensemble modes









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Summary and Future Plans

- Have constructed ensemble GIOPS system
  - *Really just 21 difference GIOPS systems!*
- Initial investigations have shown improvements in spread
- Profile RMS error reduced
- Require ensemble of SST analysis to represent obs error.
- Include ensemble wave effects to further perturb
- Ultimately will likely require inflating ensemble spread.
- Improvements in atmospheric forecast harder to find.
- But forecast SST does show improvements (CRPS)
- Forecast Sea Ice SPS also shows improvement.
- Incorporate *Errors of Day* using ensemble spread.
- Other improvements?
  - Global drifter statistics?
  - Sound speed wave guides?
  - El Niño and Tropical Hurricane Forecasts?

Extra Slides

STOPACK Package

- Random Perturbations

$$\zeta_t = \zeta(x, y, z, t) = \gamma(z)[c\zeta(x, y, z, t-1) + d\phi(x, y, z, t)]$$

  - AR(1) process with decorrelation time τ and $c = exp(-\Delta_t/\tau)$ and $d = \sqrt{(1-c^2)}$.
  - ϕ is random white noise generated at each grid point with a normal distribution.
  - Spatial correlation are archived via an N-pass Shapiro filter, with response at length scale L

$$R = \left(1 - \sin^2\left(\frac{\pi\Delta x}{L}\right)\right)^N$$

Stochastic Parameter Perturbations (SPP)

- Parameter p perturbed to $\hat{p}$ with lognormal distribution:

$$\hat{p} = p \exp \zeta_t$$

- with mean of lognormal 1 $\rightarrow$ mean of normal $= -\frac{1}{2}\sigma^2$
- could also be normal distribution $\hat{p} = p(1 + \zeta_t)$ (but isn't).
- $\tau = 10$ days and $N = 300$ (~ 300 km).
- σ varies 0.01 (TKE below ML) – 0.3 (diffusion/viscosity).
- Perturbations on 13 parameters activated.

SPP terms used

```
! Vertical mixing of tracers (TKE or GLS only)
nn_spp_avt          = 2
! Vertical mixing of momentum (TKE or GLS only)
nn_spp_avm          = 2
! Lateral diffusivity (working ONLY for key_traldf_c2d /
nn_spp_ahtu         = 2
! ahtu/ahtv : for laplacian/iso operator
nn_spp_ahtv         = 2
! ahtw : for iso operator
nn_spp_ahtw         = 2
! Enhanced vertical diffusion
nn_spp_aevd         = 2
```

SPP terms used (continued)

```
! TKE : Langmuir cell coefficient
 nn_spp_tkelc       = 2
 ! TKE : Kolmogoroff dissipation coeff.
 nn_spp_tkeds       = 2
 ! TKE : Fraction of srf TKE below ML
 nn_spp_tkefr       = 2
 ! Diffusive bottom boundary layer:
 nn_spp_ahubbl      = 2
 ! Recommended: same values for both
 nn_spp_ahvbbl      = 2
 ! Bottom friction
 nn_spp_bfr         = 2
 ! Solar radiation penetration
 nn_spp_qsi0        = 2
 ! Solar radiation penetration
```

Stochastically Perturbed Parameter Tendency (SPPT)

- Standard Tracer X Tendency

$$\frac{\partial X}{\partial t} = D(X) + P(X),$$

  where $D(X)$ is dynamics (advection), and $P(X)$ is other physics.

- Perturb as

$$\frac{\partial X}{\partial t} = D(X) + (1 + \zeta_t)P(X)$$

- $\tau = 1$ days and $N = 75$ (~ 75 km).
- $\sigma = 0.99$
- 4 terms are active (see next page).

SPPT settings activated

- SPPT currently in effect (4)

```
!!! Switch for lateral diffusion
ln_sppt_traldf       = .true.
!!! Switch for solar radiation
ln_sppt_traqsr       = .true.
!!! Switch for Asselin time-filter
ln_sppt_traatf       = .true.
!!! Switch for lateral diffusion
ln_sppt_dynldf       = .true.
```

Stochastic Energy Backscatter (SKEB)

- See Storto QJRMS paper for details.
  - Backscattering of energy from unresolved to resolved scales
  - inverse cascade
- $\tau = 0.5$ days and $N = 40$, with ratio of 0.4.
- Deactivated in final setup
  - Results in instabilities.
  - Increases spread in quiescent (gyre) areas with small errros.