CERA: The Coupled ECMWF ReAnalysis System – Coupled data assimilation

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Coupled reanalysis: introduction

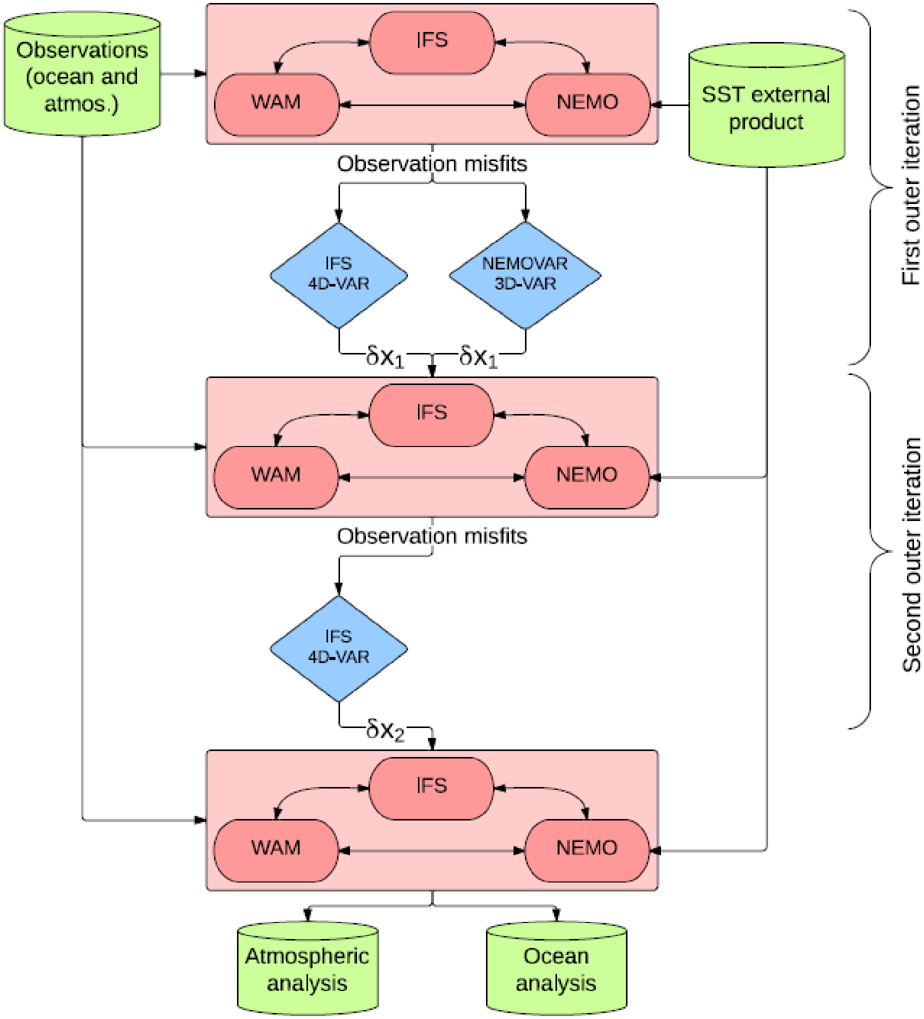
- **Context**: ECMWF monthly to seasonal predictions use coupled model with IC produced in separate DA system for ocean and atmosphere

- **Issue**: uncoupled IC unbalanced and far from the natural state of coupled model. Initialization shocks and drift

- **Purpose**: building a coupled atmosphere-ocean data assimilation framework to generate consistent climate system state for climate studies and forecasts

- **Method**: “weakly” coupled data assimilation, coupled outer loops and separate inner loops. No cross-model covariance used.

Coupled reanalysis: system design



- Principle

Coupled model to compute observation misfits
Increments computed **separately** and in parallel
Two outer loops allow O-A communication
SST nudging to control the model drift

- Coupled model

Atmosphere: IFS 40R1 T159L91
Ocean: NEMO V3.4 ORCA1 with 42 levels
1-hour coupling in a single executable environment

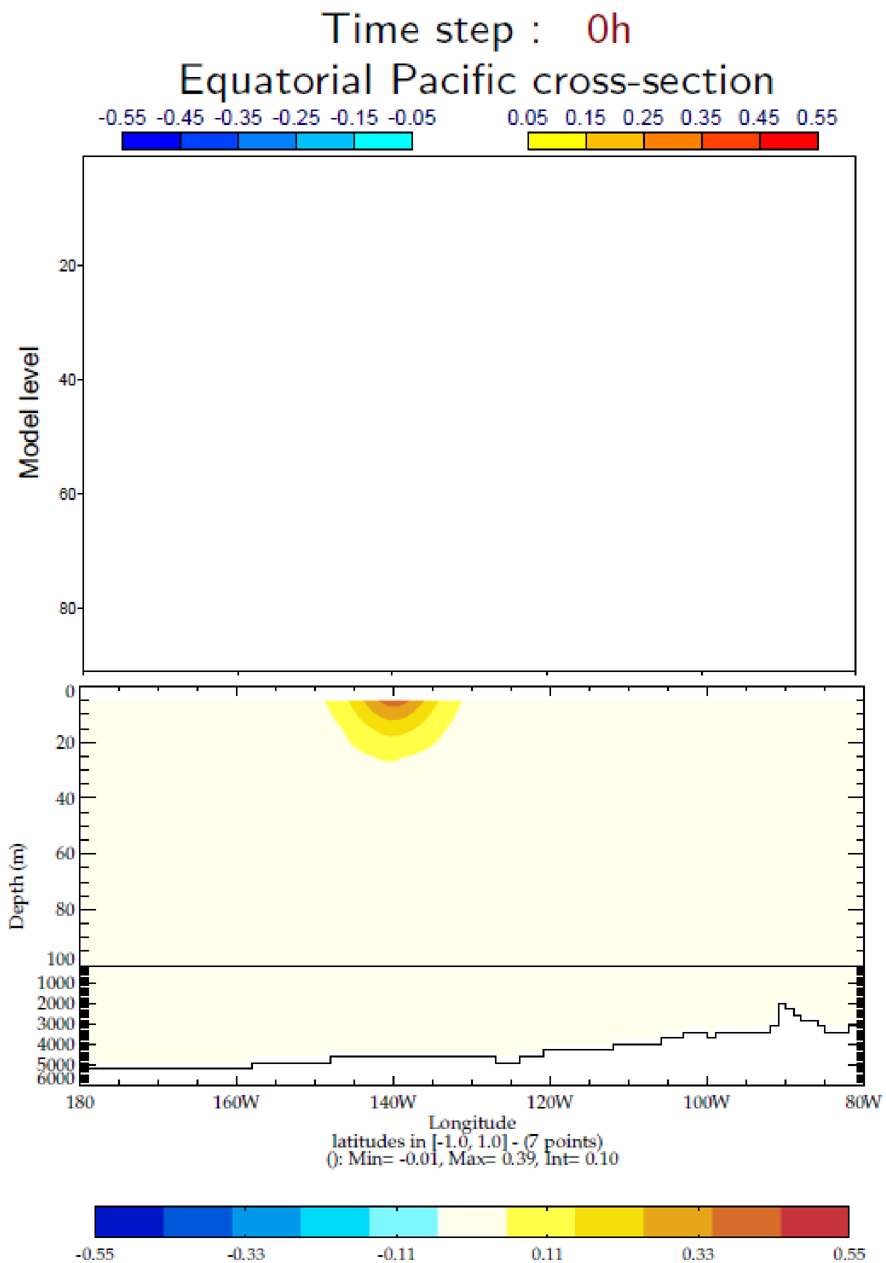
- Observations

Atmosphere: conventional and satellite obs.
Ocean: in-situ T/S profiles
24-hour data assimilation **window**

- Forecasts

Short and long coupled forecasts

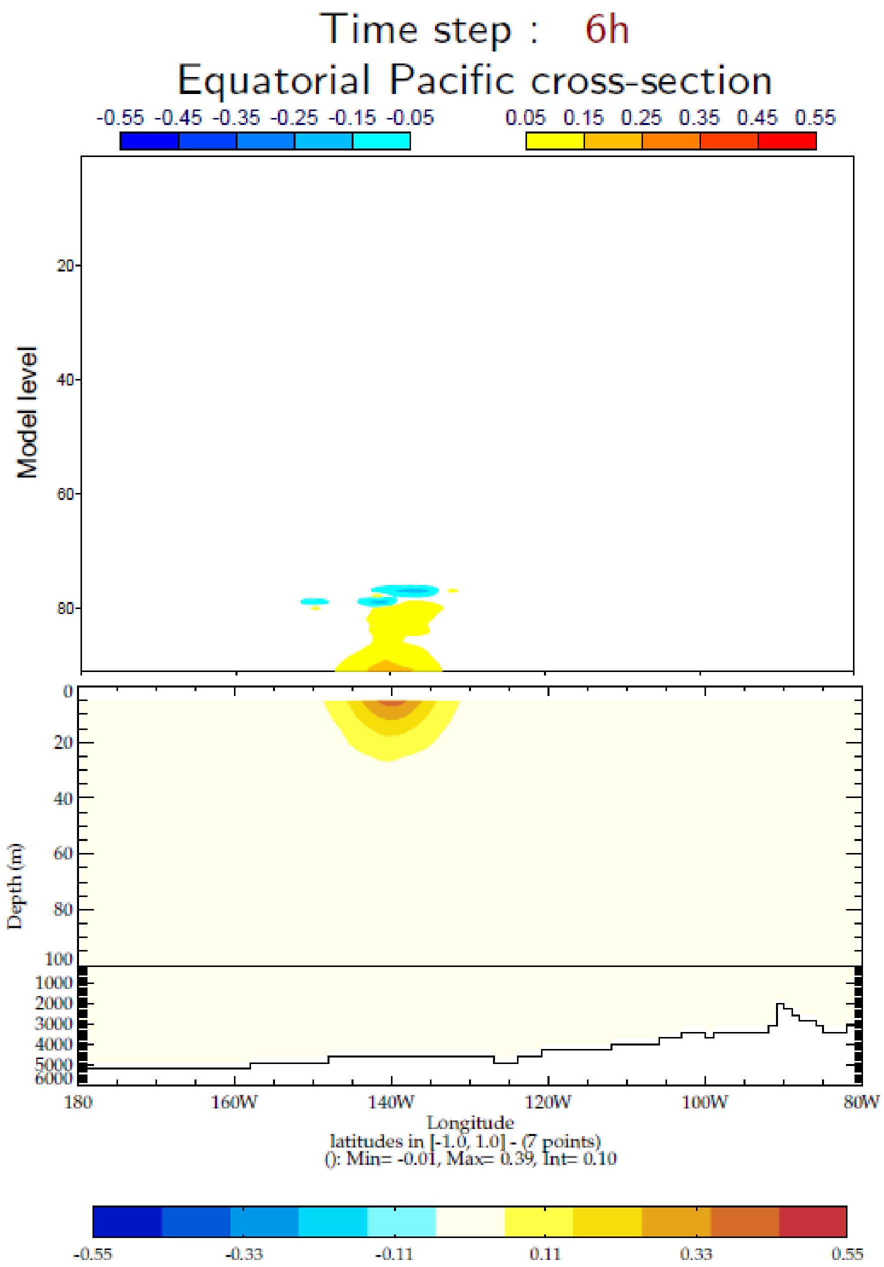
Coupled reanalysis: illustration



- Ocean single observation experiment

- No atmospheric assimilation
- No SST nudging
- One temperature observation at 5-meter depth (0°N,140°W) with an innovation of 3°C

Coupled reanalysis: illustration



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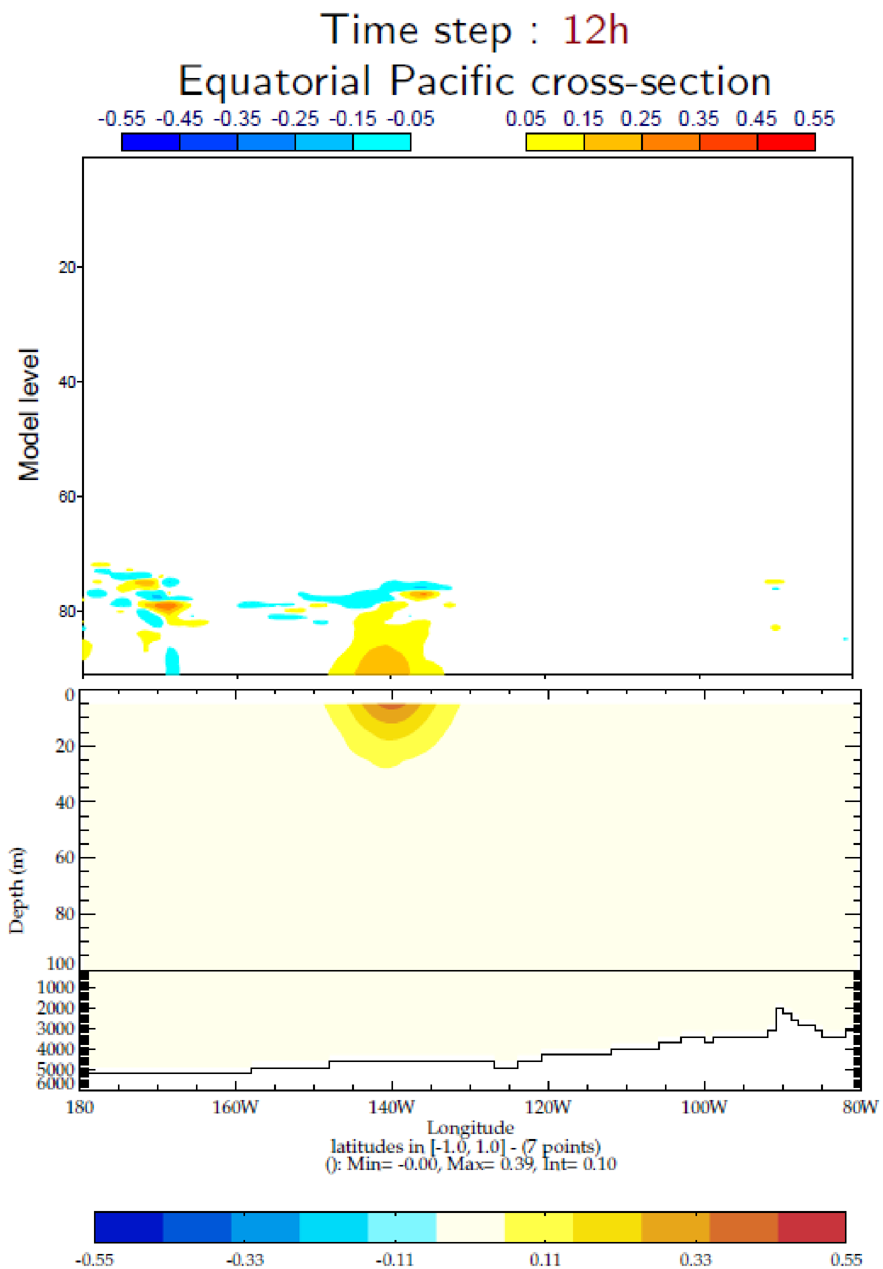

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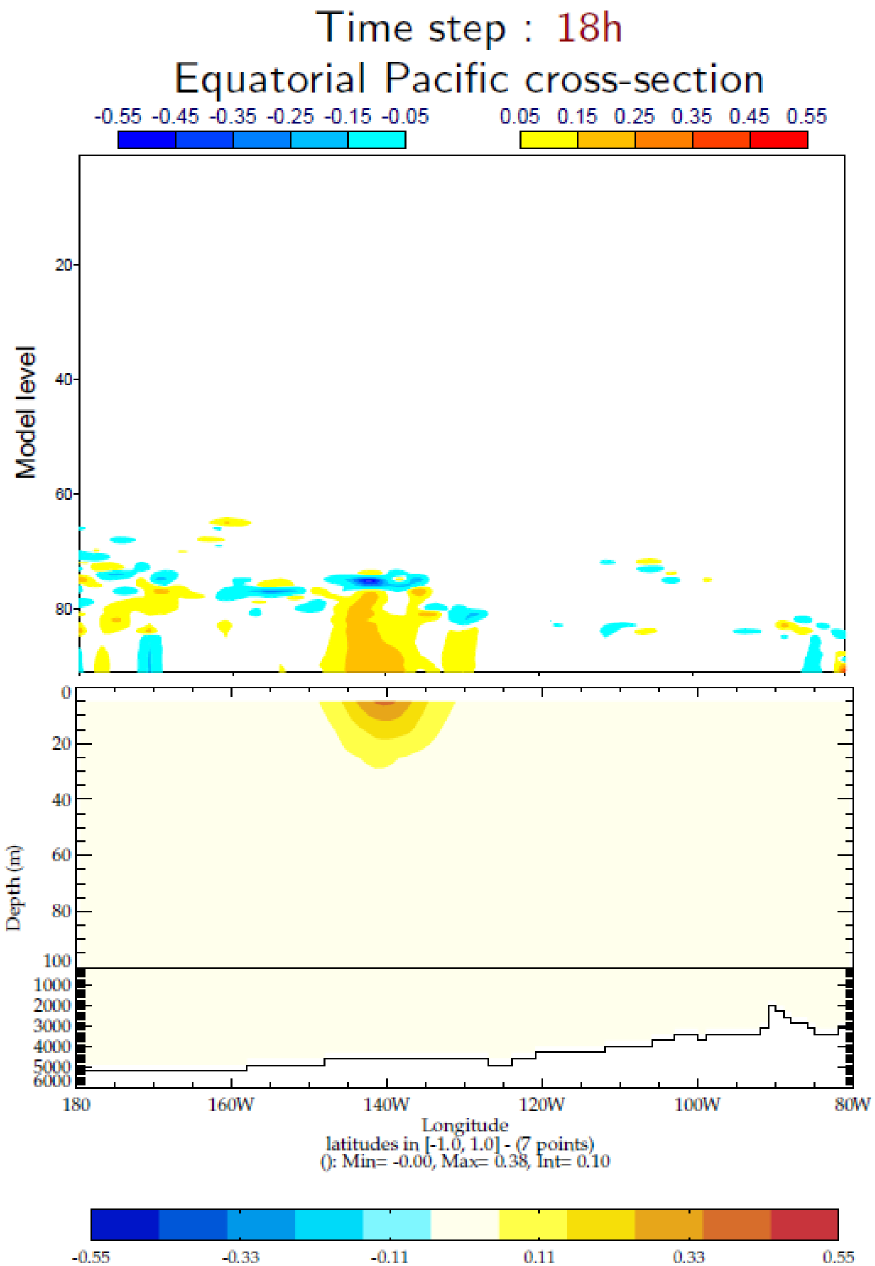

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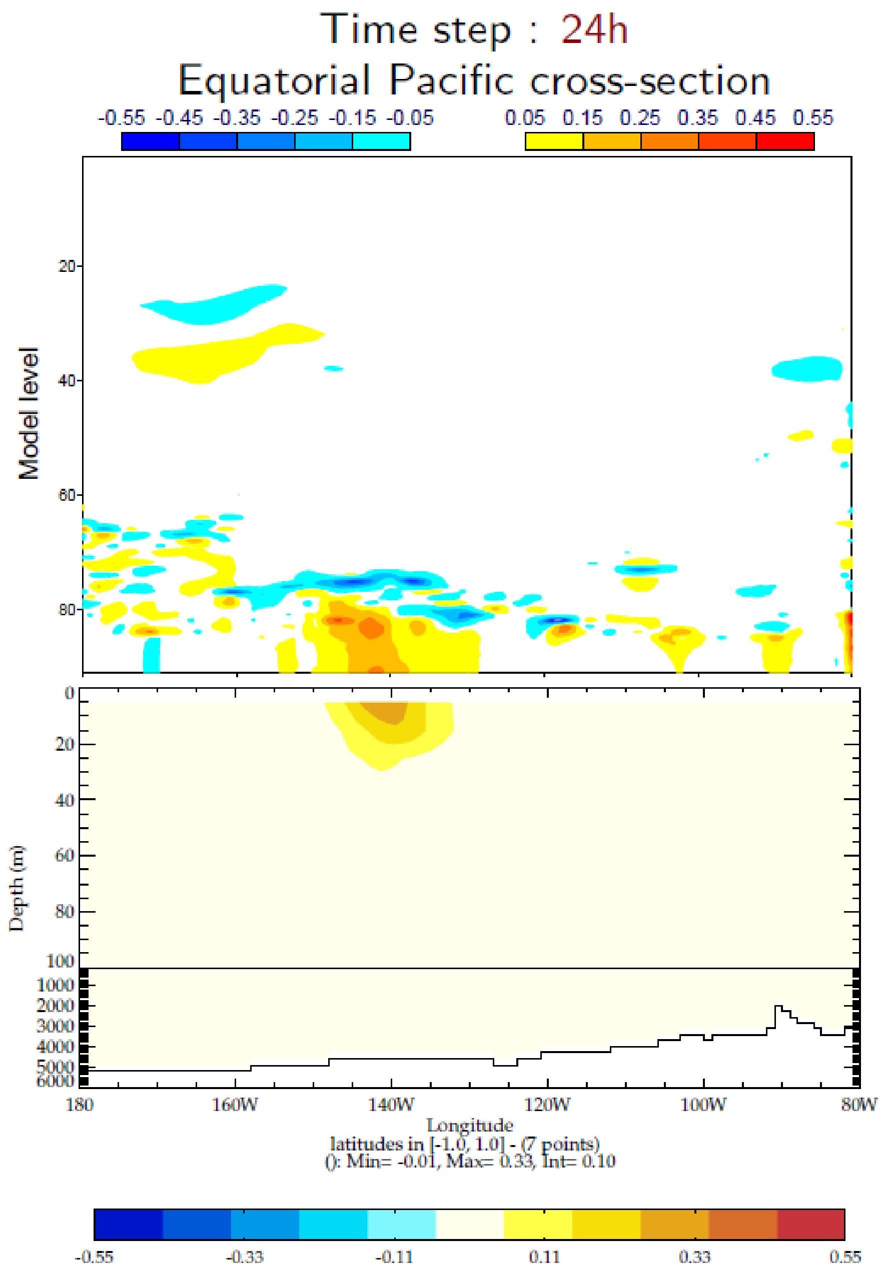

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➢ Ocean observations affect the second atmospheric trajectory

➢ Ocean observations affect the second atmospheric increment

➢ Ocean observations affect the atmospheric analysis

Constraining the SST

- In CERA, no variational assimilation of SST

    - The infrastructure is not implemented in the ECMWF system to assimilate along-track SST obs: no obs operator. Will come in the future

    - Assimilation of SST analysis maps does not give good results

    - CERA will be used in ERA-CLIM2 for a coupled reanalysis of the 20th century assimilating conventional surface obs only: need a consistent SST data set over time

        - For all these reasons, we use nudging towards SST analysis

        - For the 20th century run, HadISST analysis will be used

Constraining the SST

- Classical relaxation consists in an **additional** heat flux term:

$$\boxed{\begin{gathered} X_t = SST_t - SST_{obs} \\ \color{blue}{constraint_t = -\lambda X_t} \end{gathered}}$$

at every timestep

- Coupled model needs a **strong constraint**: inhibit coupling.

- In poorly-observed period, only **monthly SST** available. This scheme will **damp the high frequency** variability (MJO, TIWs …)

- **Alternative** = 2 constraints: strong on low freq. (monthly) and weak on high freq.

$$\boxed{\begin{gathered} \bar{X} = \overline{SST} - \overline{SST_{obs}} \\ \color{blue}{new\ constraint = -\lambda_1 (X - \bar{X}) - \lambda_2 \bar{X}} \end{gathered}}$$

2 timescales:
λ_1 fast - λ_2 slow

Should give **more weight** to the coupled model for high-frequency variability

Constraining the SST: tests

- **20-year coupled runs 1990-2010**:

  Atmosphere: IFS cycle 38R1 and resolution T159L91

  Ocean: NEMO version 3.4, resolution ORCA1 and 42 levels (10m first layer)

- **3 experiments**:

  Control run: free coupled model

  1TS run: classical relaxation at every time step (single timescale: 3-day)

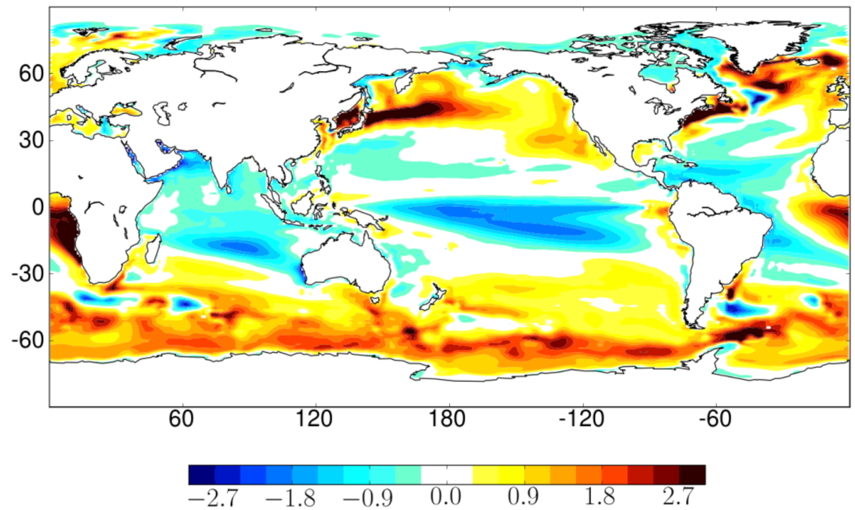
  2TS run: new relaxation scheme (2 timescales: 30-day/3-day)

- Relaxation towards NOAA OIv2

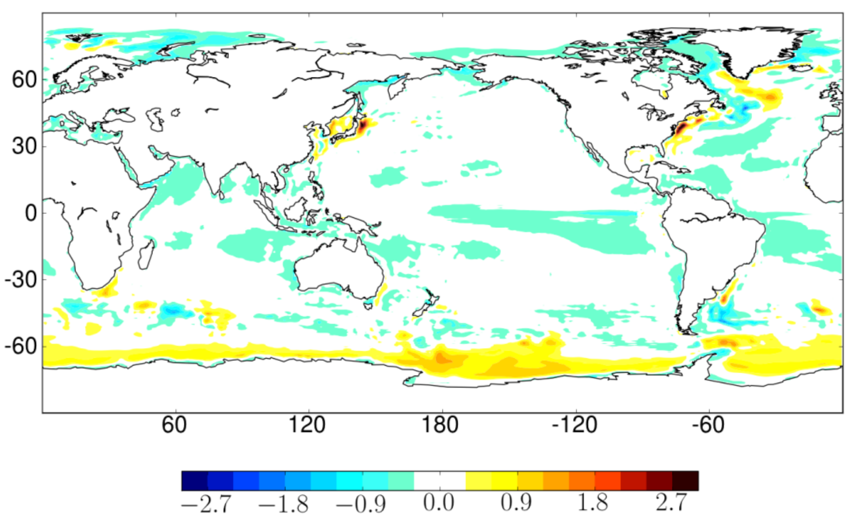
Constraining the SST: tests

Mean SST bias (resp. OIv2d1)

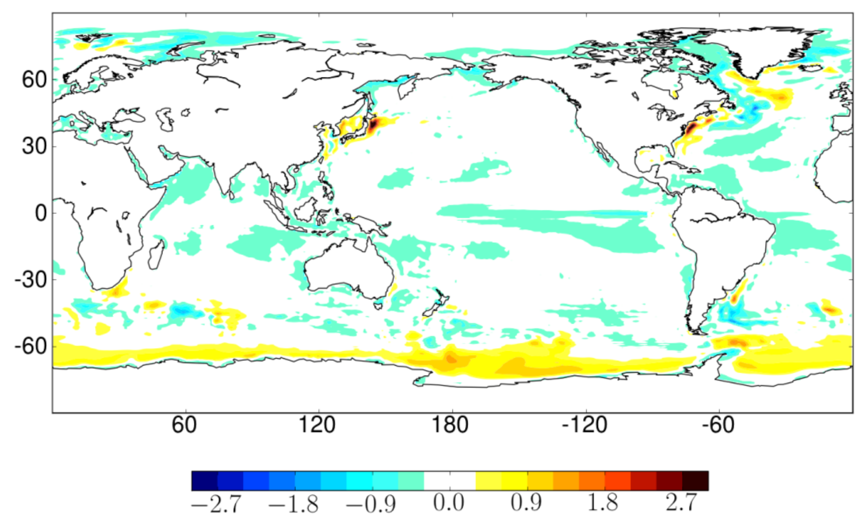
Free coupled model



1TS (3-day)



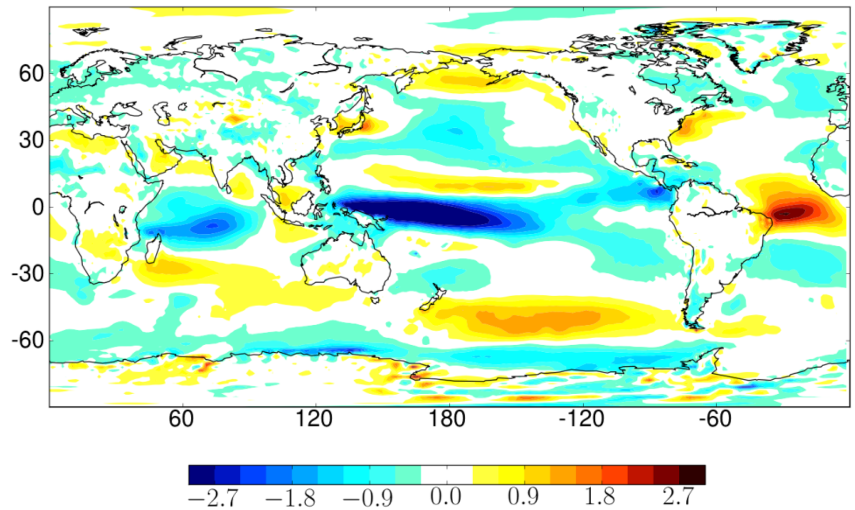
2 TS (30-day/3-day)



Constraining the SST: tests

Mean 10u CPL - ERAi

Free coupled model



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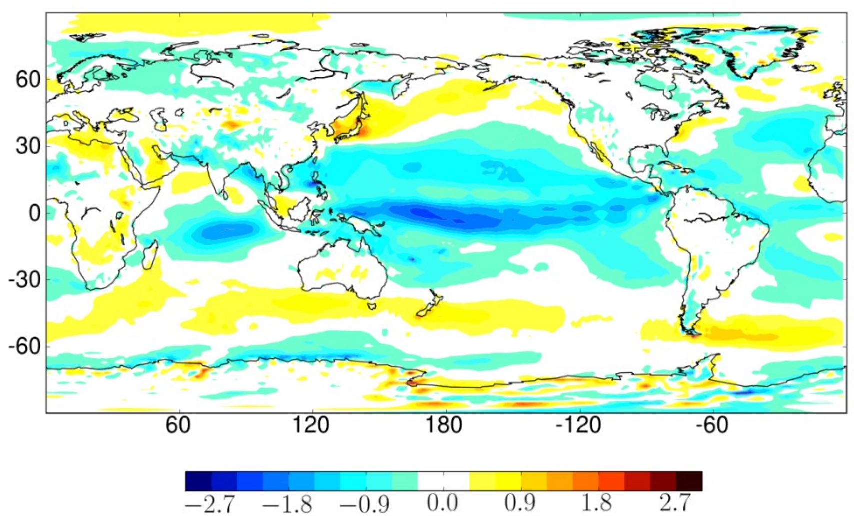

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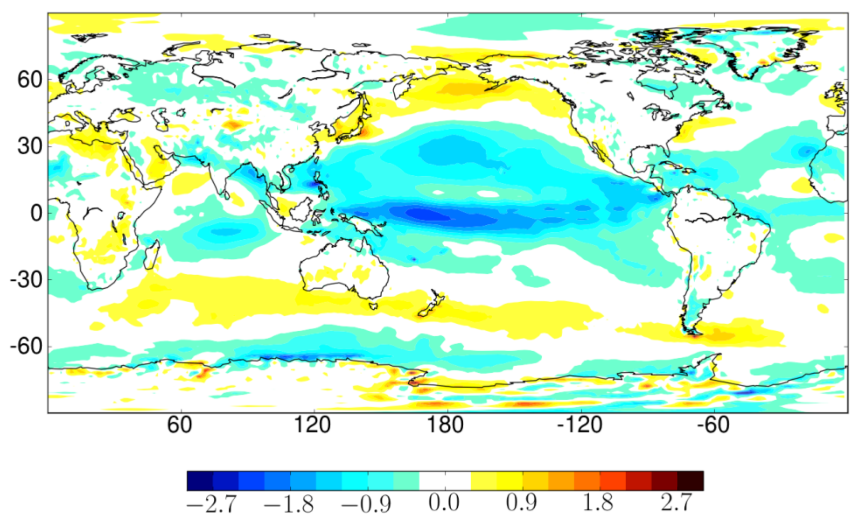
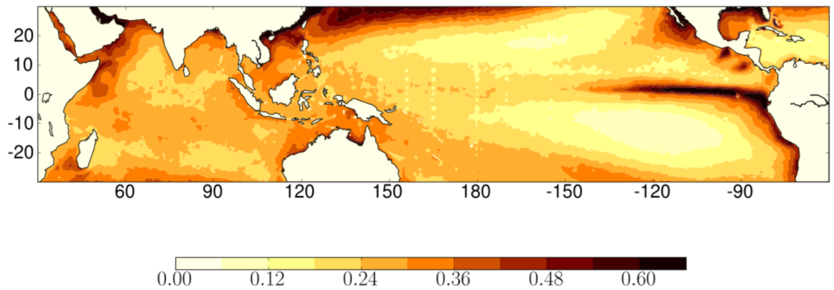


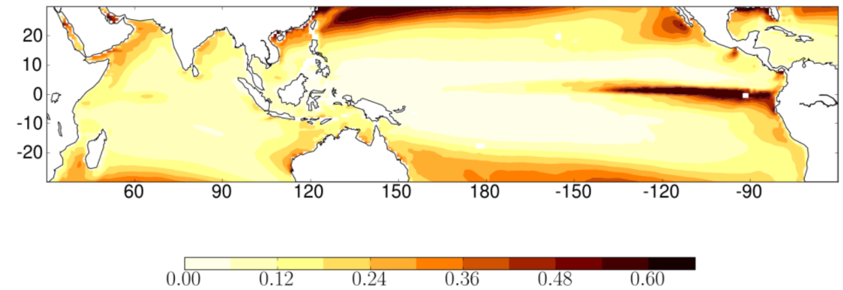
Constraining the SST: tests

SST intraseasonal variability

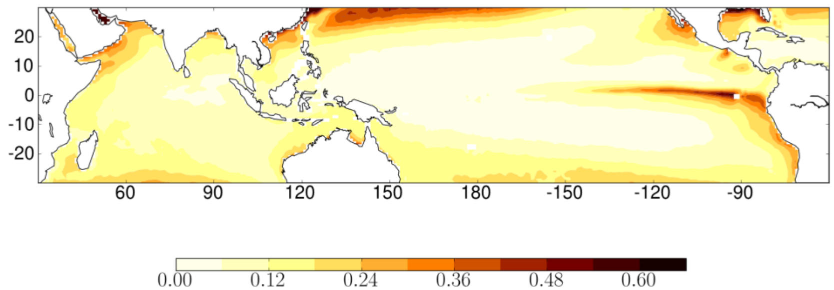
Observations: OIV2d1



Free coupled model



1TS (3-day)



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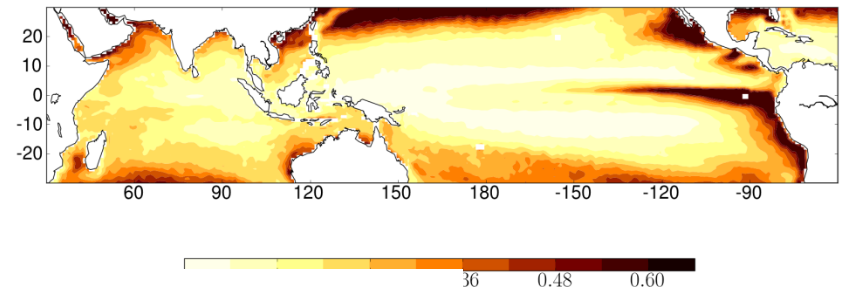
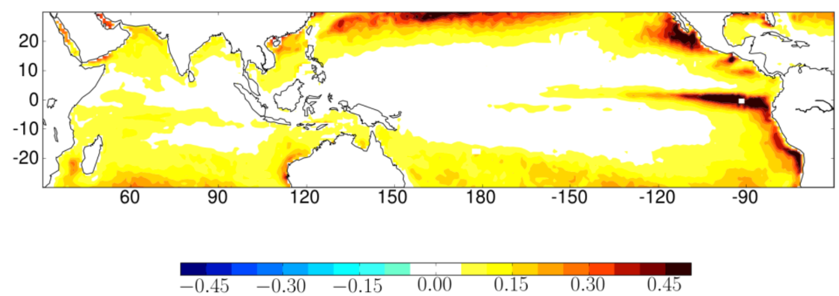


2 TS – 1 TS

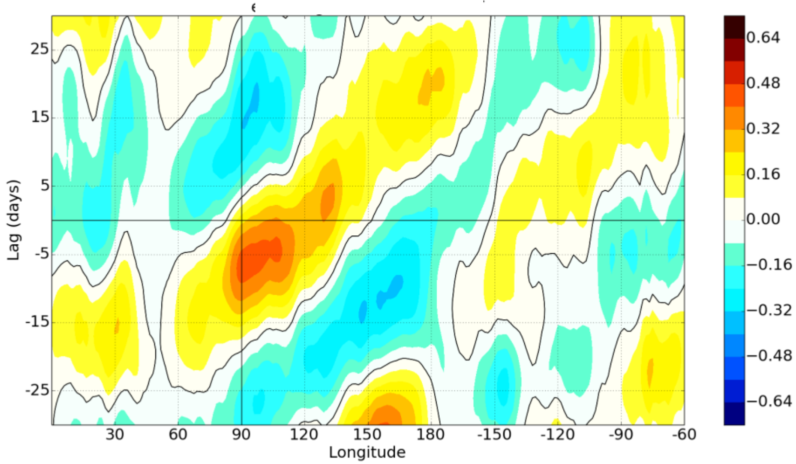


Constraining the SST: tests

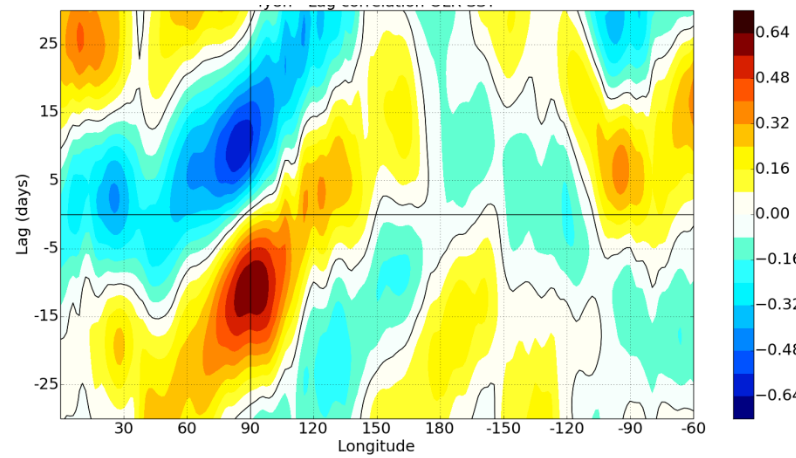
MJO propagation 1990-2010

Winter lag correlation OLR 10S-10N and SST Indian 10S-10N

ERA-Interim



Free coupled model



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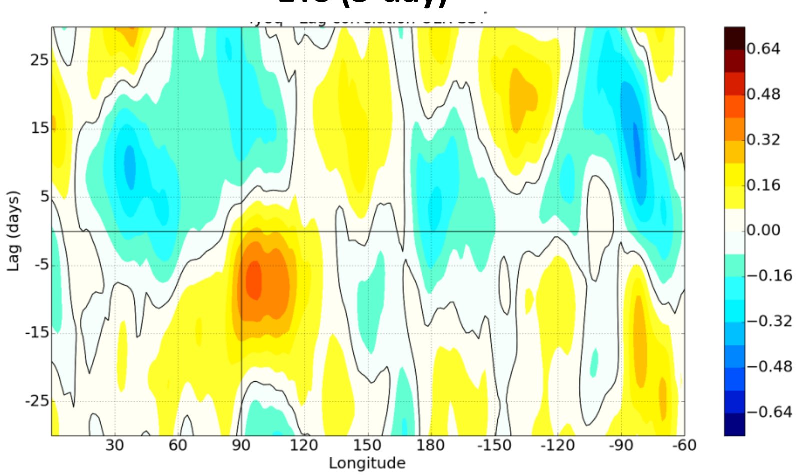

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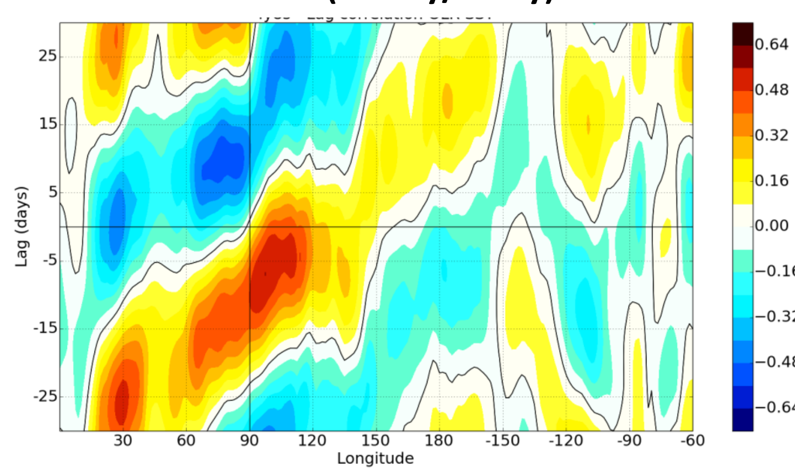


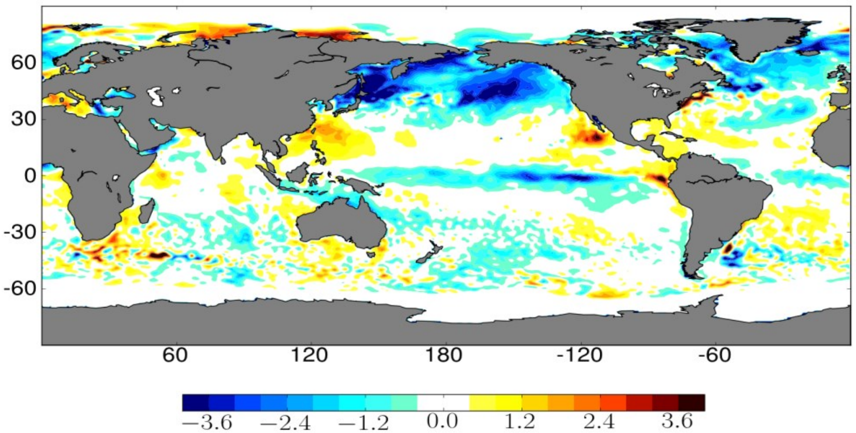
More propagation of convection when using 2TS scheme

Coupled reanalysis: first test

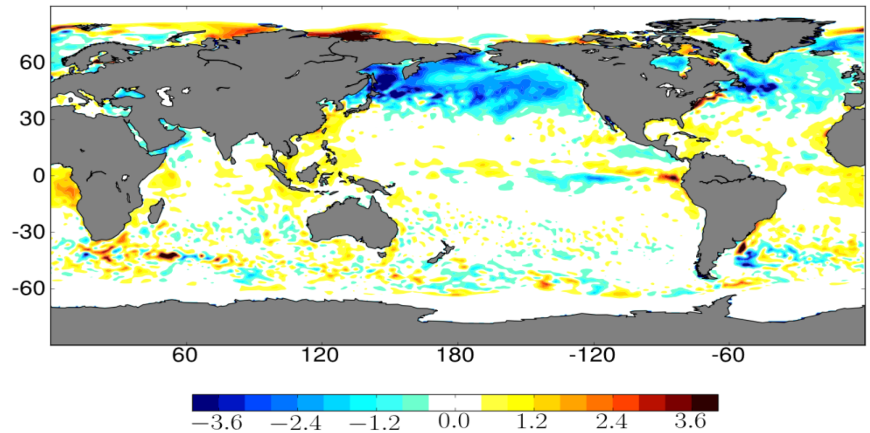
- **First test**: 2-month CERA run from 01/08/10 to 30/09/10:

Impact of the components of the CERA system on **the SST bias** (resp. OSTIA) for Sept. 2010

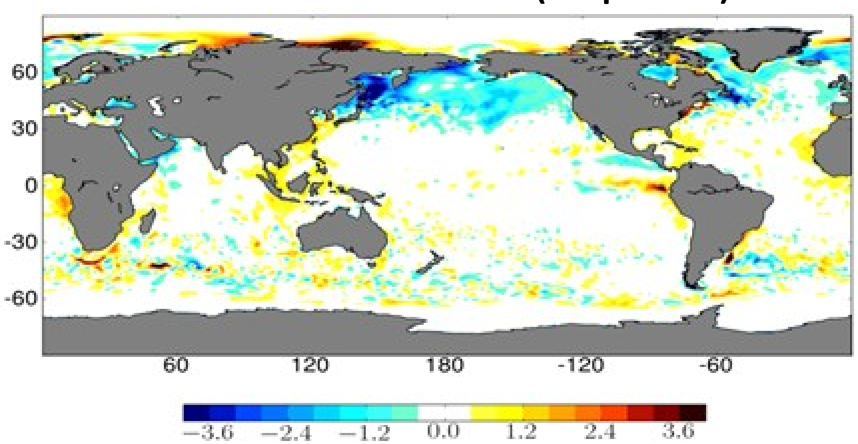
SST bias – free coupled model



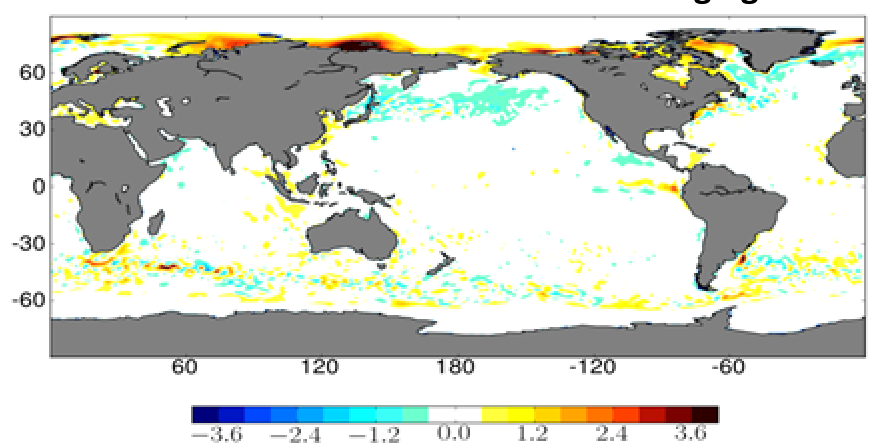
Atmos. assim. (coupled FG)



Atmos. + Ocean assim. (coupled FG)



Final CERA: O-A assim + SST nudging



Coupled reanalysis: first test

- Comparison CERA system with operational-like system in terms of medium-range FC:

CERA system

Assimilation:
All ocean and atmospheric observations
SST nudging (OSTIA)

10-day forecast:
Coupled model
SST evolves freely within the coupled model

Operational-like IFS system (same IFS cycle and resolution)

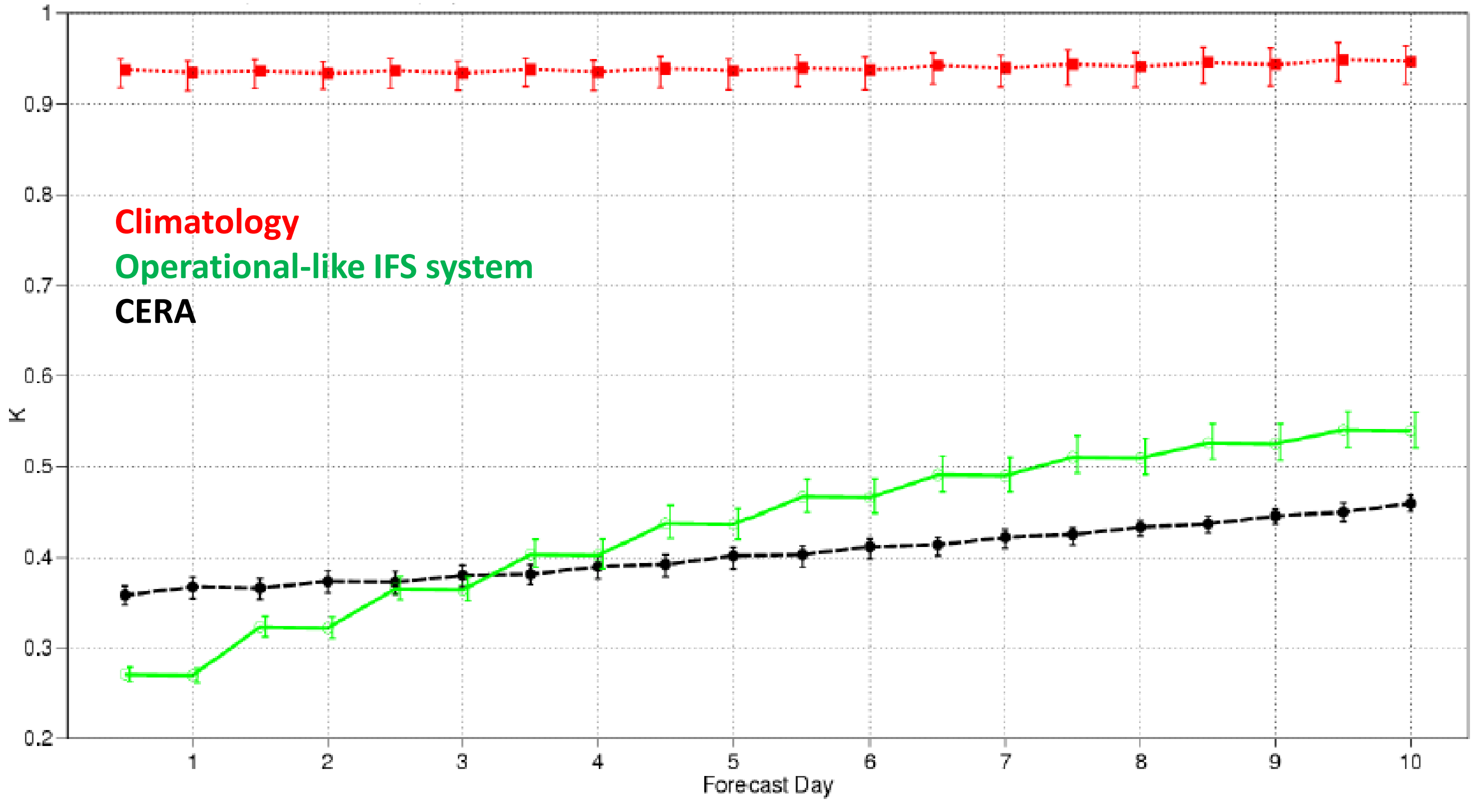
Assimilation:
All atmospheric observations
Prescribed SST (OSTIA)

10-day forecast:
Atmospheric model
Persisted SST anomaly along a climatology

Comparison for the 10-day FC of September 2010

Coupled reanalysis: first test

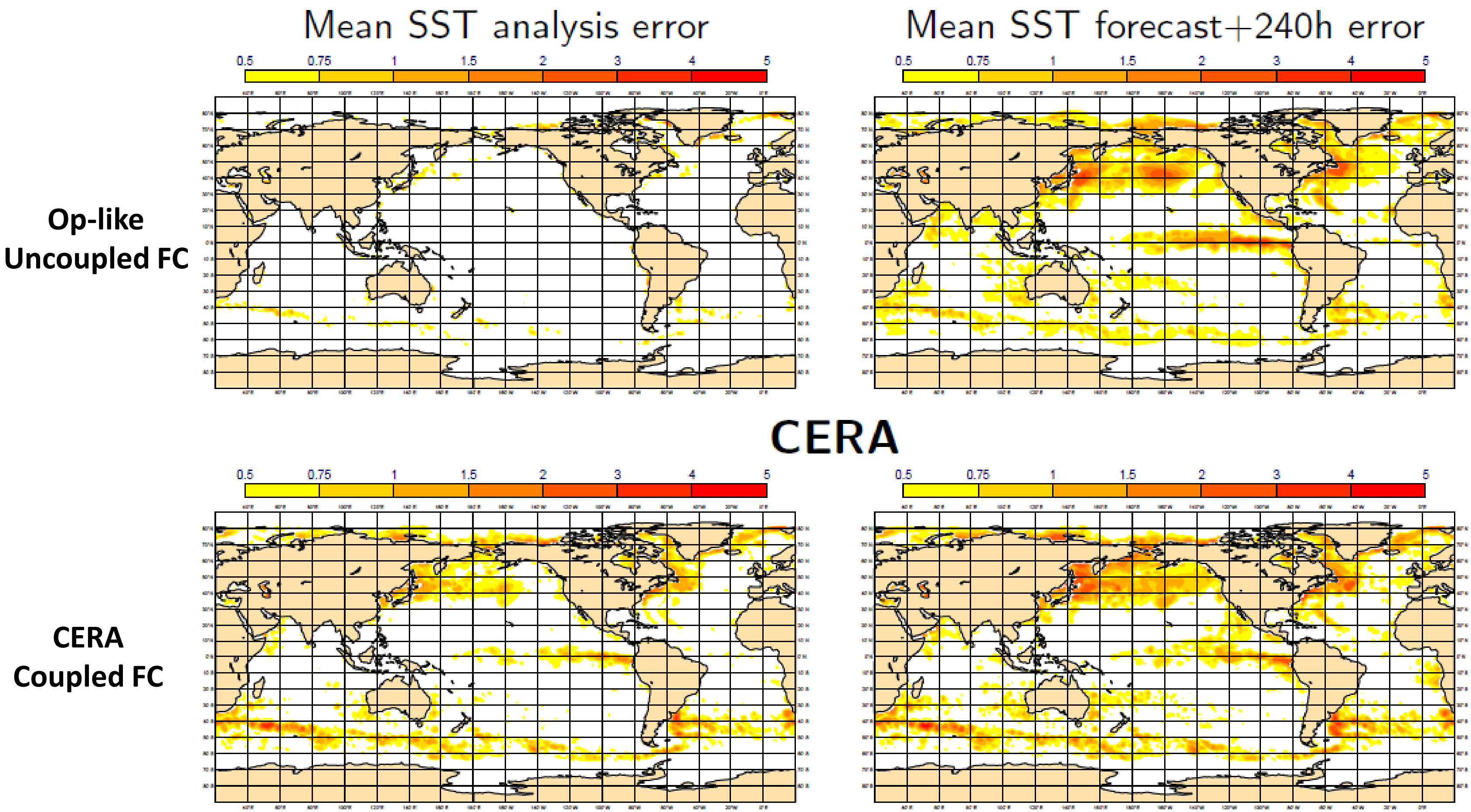
RMSE of the SST forecast in the **Tropics** for September 2010
with respect to ECMWF operational analysis (OSTIA SST)



➢ The **coupled FC** starting from **CERA** IC show slower error growth for SST than the **uncoupled FC** starting from **Op-like** system: gain of skill from day 3 in the Tropics

Coupled reanalysis: first test

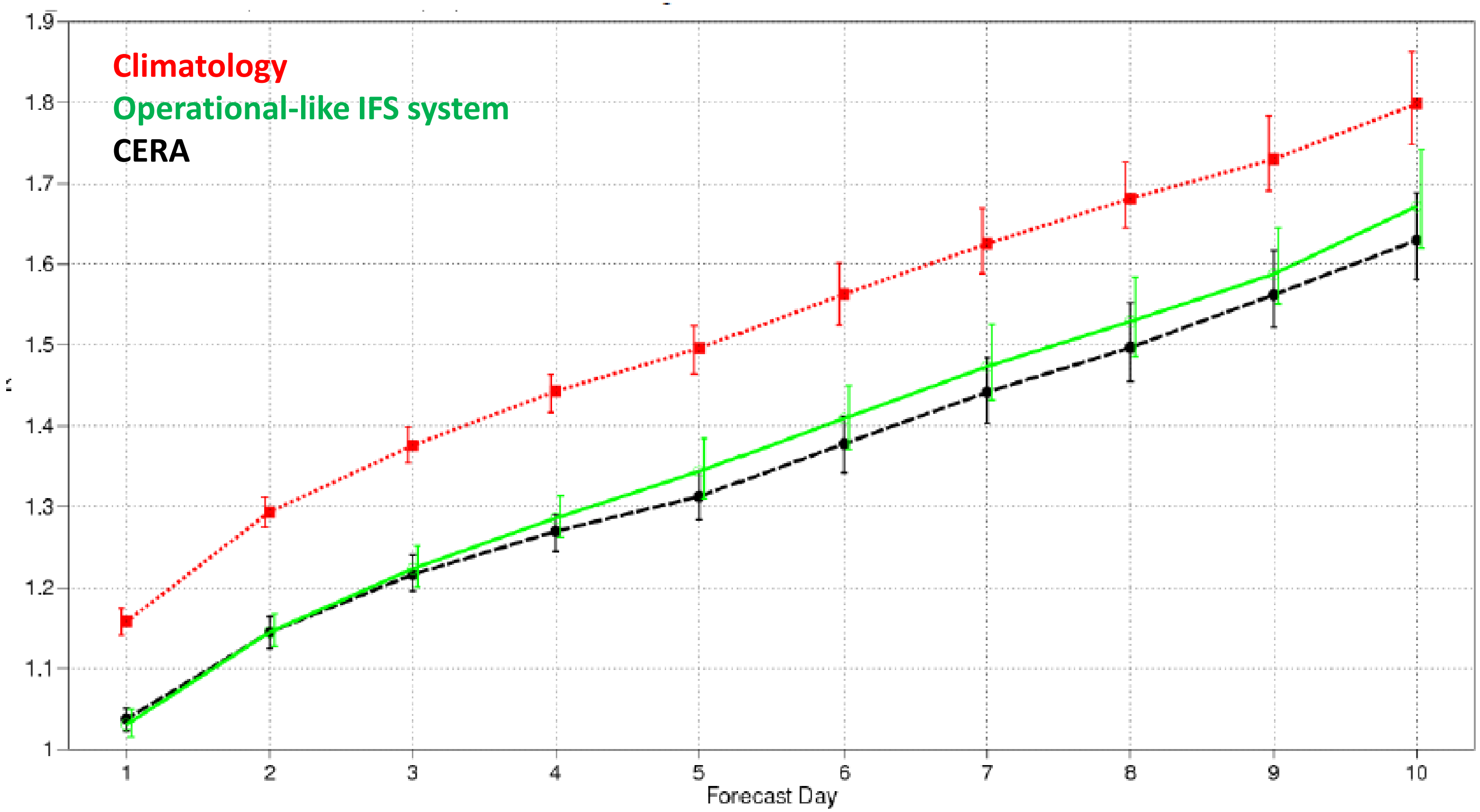
RMSE of the SST forecast for September 2010 with respect to ECMWF operational analysis (OSTIA SST)



➢ Slower error growth in the Tropics, the N. Pacific and WBC

Coupled reanalysis: first test

RMSE of the 1000hPa Temperature forecast in the **Tropics** for September 2010 with respect to ECMWF operational analysis



- Gain of skill in the SST transferred to the atmosphere

Coupled reanalysis: conclusions

- **CERA** is the ECMWF coupled data assimilation system

- **Method** allows communication between atmosphere and ocean components during the production of the analysis

- **Forecasts** starting from CERA-IC show slower SST error growth than an operational-like system. The SST improvement is transferred to the atmosphere

- **Next evaluation**: how a coupled FC starting from CERA-IC would compare to a coupled FC starting from uncoupled IC?

- **Future**: CERA will be used in the context of the ERA-CLIM2 project for the production of a 20th century coupled reanalysis