# Strongly coupled data assimilation experiments with a full OGCM and an atmospheric boundary layer model

## WP2.3 Coupled Ensemble Information

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Centro Euro-Mediterraneo sui Cambiamenti Climatici

# CMCC Task

- Implementation and sensitivity tests of hybrid formulation combining static and ensemble-derived background error covariances in the global ocean (OceanVar)

- Coupled DA with air-sea balance operator

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- Implementation and sensitivity tests of hybrid formulation combining static and ensemble-derived background error covariances in the global ocean (OceanVar)

- **Coupled DA with air-sea balance operator**

# Strongly coupled data assimilation (SCDA)

**Motivation**: Weekly coupled DA proves successful in improving near-surface atmospheric parameters in many test cases:

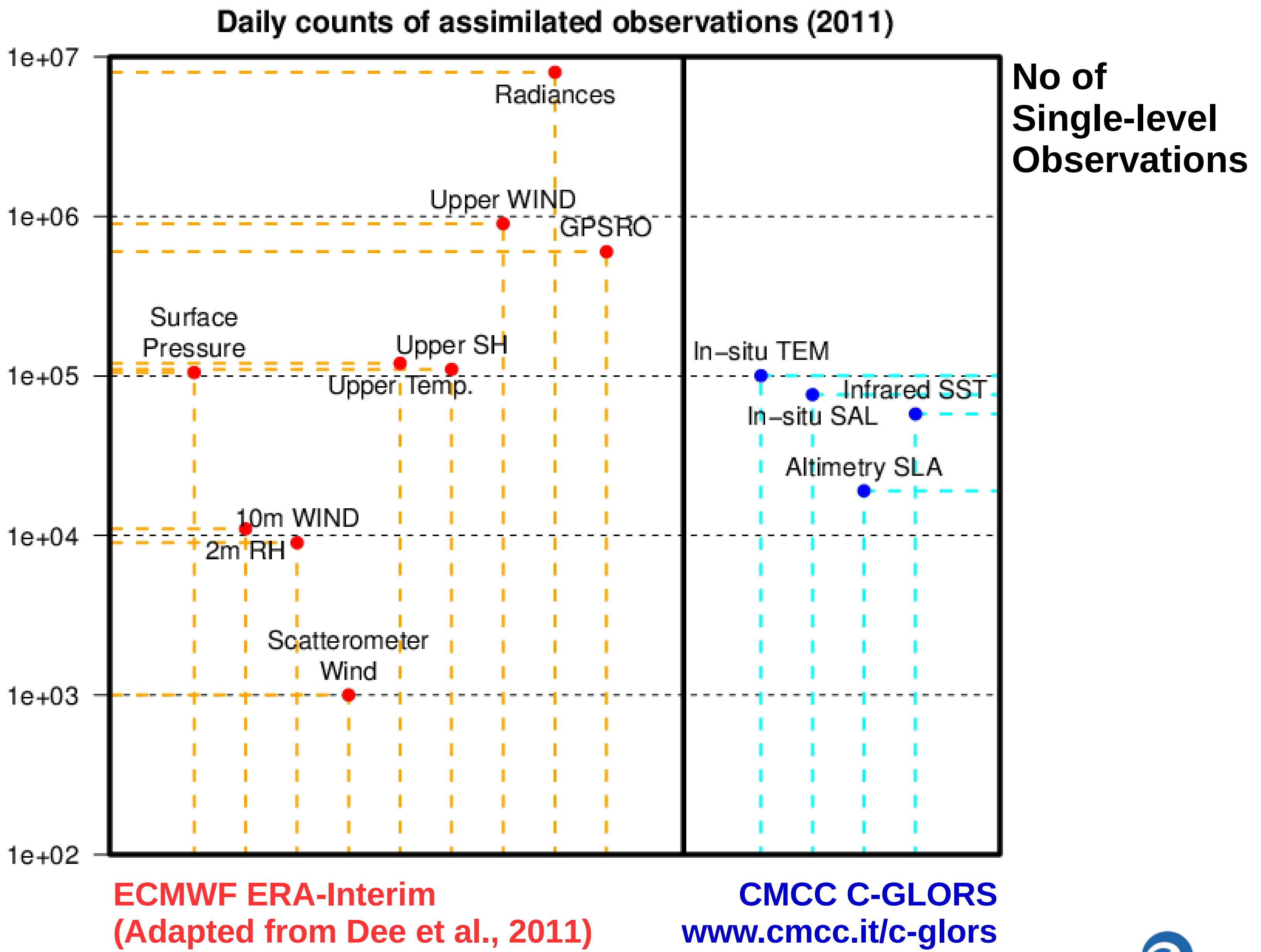
***Does strongly coupled DA lead to further improvements?***

**1] Observation synergy and inter-medium observation impact may alleviate observational deficiencies in a single medium**

**2] Strongly coupled DA may also alleviate initialization shocks typical of weakly coupled DA systems**, although different time scales of the errors in the two media are not straight-forward to treat.

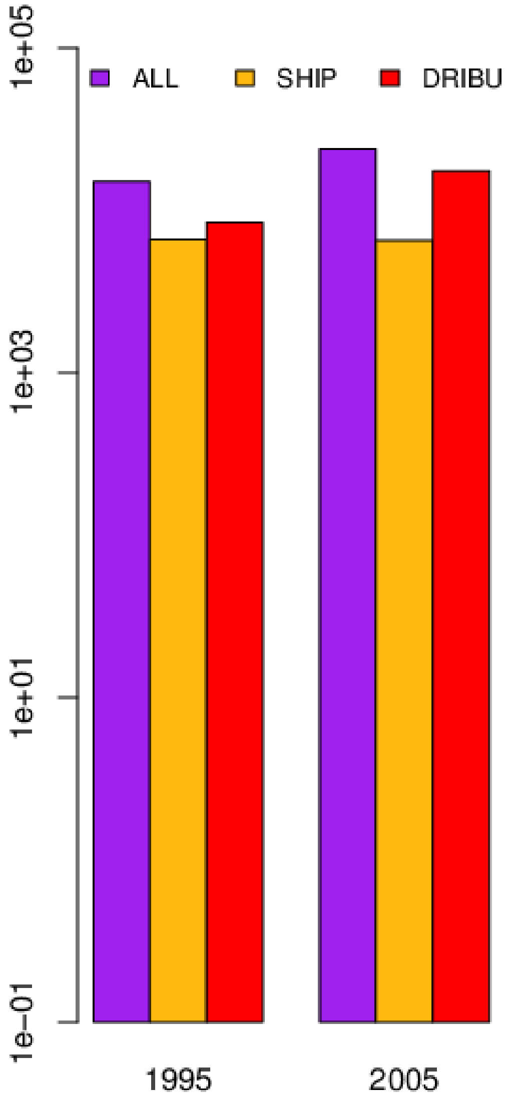
**Strategy**: Use simplified ABL model coupled to NEMO to test the impact of strongly coupled data assimilation

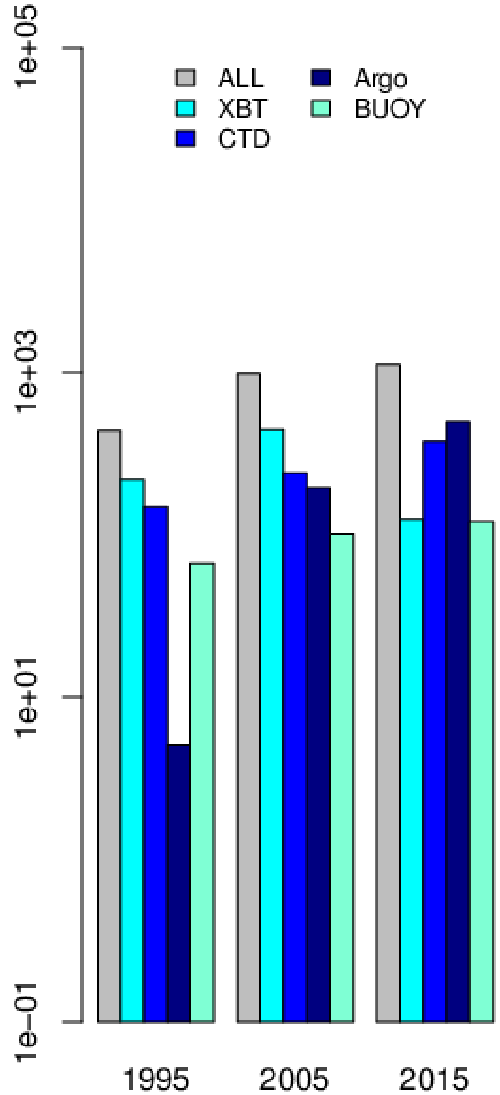
# Motivation: observation synergy



# Motivation: observation synergy

**No of Platforms**



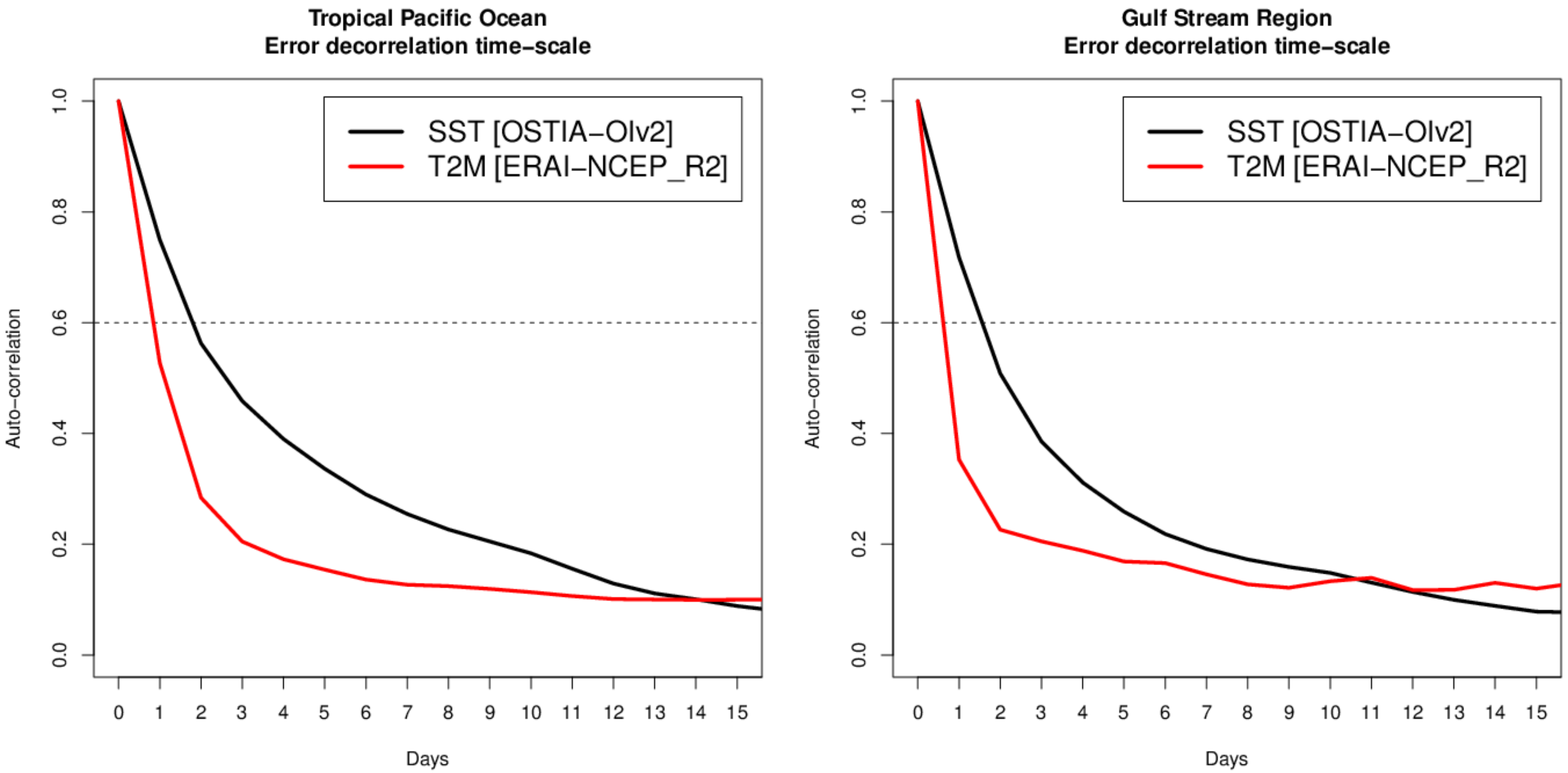

**No of Profiles**

**Air or Sea Temperature Stations**

**ECMWF ERA-Interim**
**(Adapted from Tavolato & Isaksen)**

**CMCC C-GLORS**
**(UKMO EN4)**

# Motivation: possible problems




**Decorrelation time-scale of errors is significantly different between sea-surface temperature and near-surface air temperature (shorter)**

Daily mean data from 2011

# Modeling framework

**Modeling framework**

- NEMO-ORCA05L75 global configuration +
  CheapAML atmospheric boundary layer model (Deremble et al., 2013):

$$\partial (\mathbf{T}_{2m},\mathbf{q}_{2m}) /\partial t = ADV[\mathbf{u},(\mathbf{T}_{2m},\mathbf{q}_{2m})] + DIFF\,[(\mathbf{T}_{2m},\mathbf{q}_{2m})] + THDY\,[\mathbf{SST},\mathbf{u},(\mathbf{T}_{2m},\mathbf{q}_{2m}),\mathbf{H}_{ABL}]$$

- Wind is not prognostic and imposed externally (ERA-Interim)

**ADVANTAGEs:**

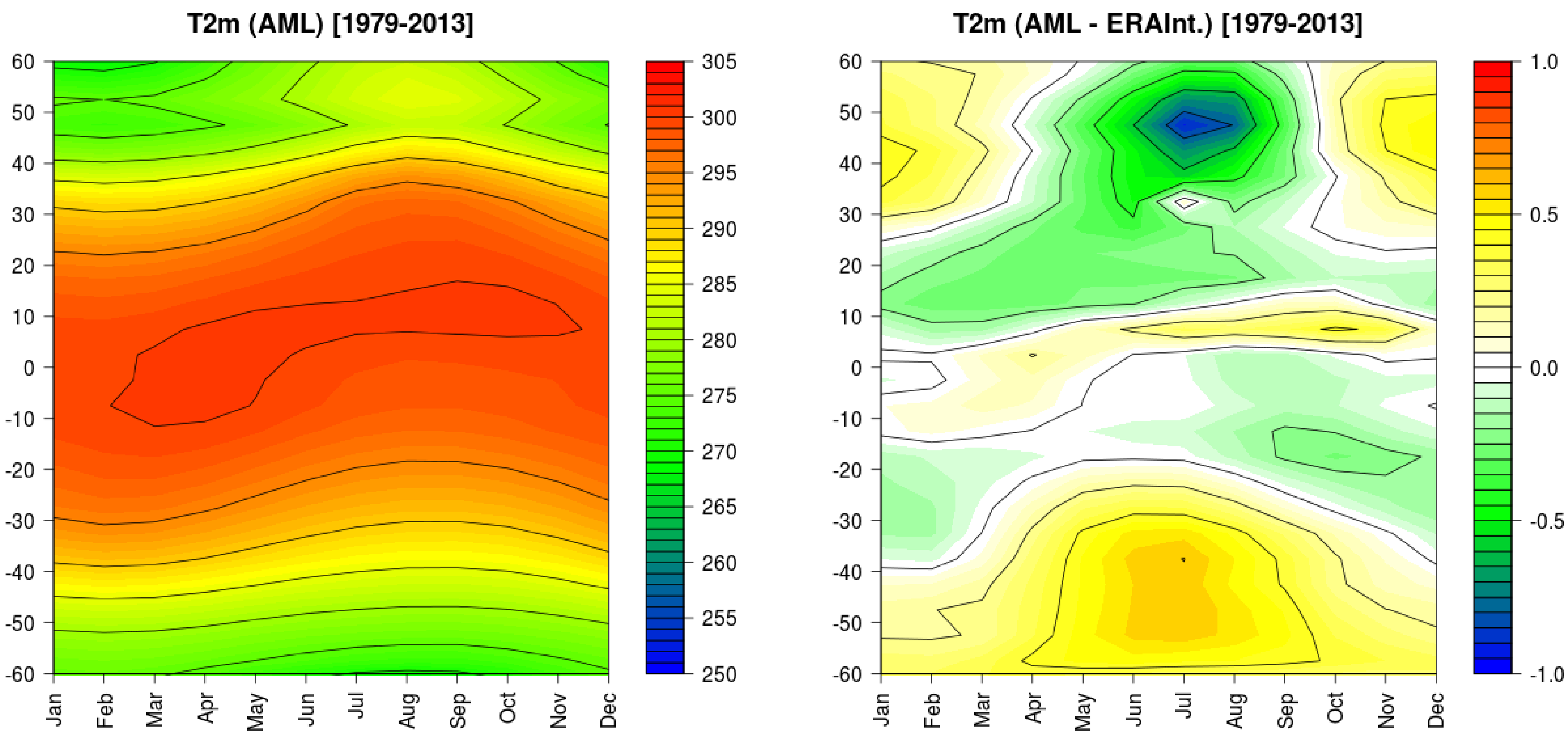
- No atmospheric DA system (not available at CMCC)
- It allows augmenting the ocean state control parameters to include $T_{2M}$ and $Q_{2M}$, now prognostic, in both model and 3DVAR, i.e. allow to use 1 DA software, extended to atmospheric variables (ideal strategy)

**DISADVANTAGEs:**

- Care must be taken to extend results to real-world NWP systems
- Rely on T2M/Q2M observing network over oceans only

# Modeling framework

*T2m Climatology from NEMO(ORCA05L75)+LIM2+CheapAML and Difference with ERA-Interim*




**Climatology shows reasonable features especially in the Tropics, largest biases occurring at high latitudes**

# A simplified air-sea balance operator

To couple the sea-surface variables with 2m atmospheric variables, balances might be thought either purely statistical, or purely analytical, or mixed (balanced + unbalanced components)
We introduce a balance operator that maps the increments of SST onto those of ($\mathbf{T}_{2m}$, $\mathbf{Q}_{2m}$) and uses tangent-linear version of CORE bulk formulas (Large & Yeager, 2007)

- $\delta \mathbf{T}_{2m} = \Delta t \; [\delta\, \mathbf{Q}_{LW}(\delta \mathbf{SST}) + \delta\, \mathbf{Q}_{SEN}(\delta \mathbf{SST})] \,/\, [\rho_A\, cp_A\, \mathbf{H}_{ABL}]$
  *(no condensation in ABL)*

- $\delta \mathbf{q}_{2m} = \Delta t \; [\delta\, \mathbf{E}(\delta \mathbf{SST})] \,/\, [\rho_A\, \mathbf{H}_{ABL}]$

***TL model of air-sea thermodynamics***

Where the transfer coefficients (**Ce, Ch** for Evaporation and Sensible heat, respectively) are assumed not to depend on **SST** and taken from the fully non-linear model. *(Might be relaxed with simple parametric formulations)*

***Physical space (T,S,η,T2m,Q2m)***

$$\delta \mathbf{x} = [\, \mathbf{V}_A\, \mathbf{V}_\eta\, \mathbf{V}_H\, \mathbf{V}_V \,]\, \mathbf{v}$$

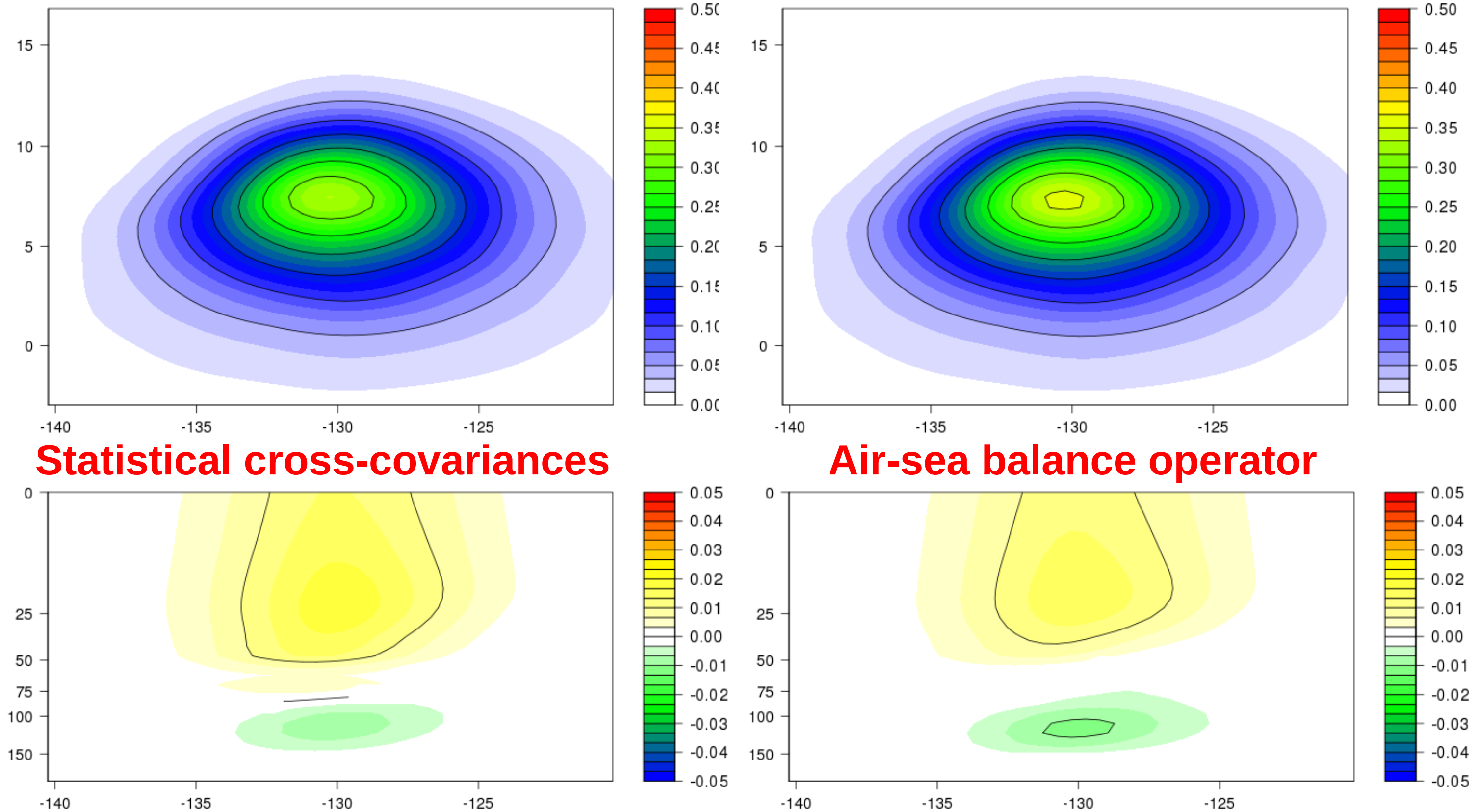
***Control Variable***

***Air-Sea Balance Operator***

# A simplified air-sea balance operator

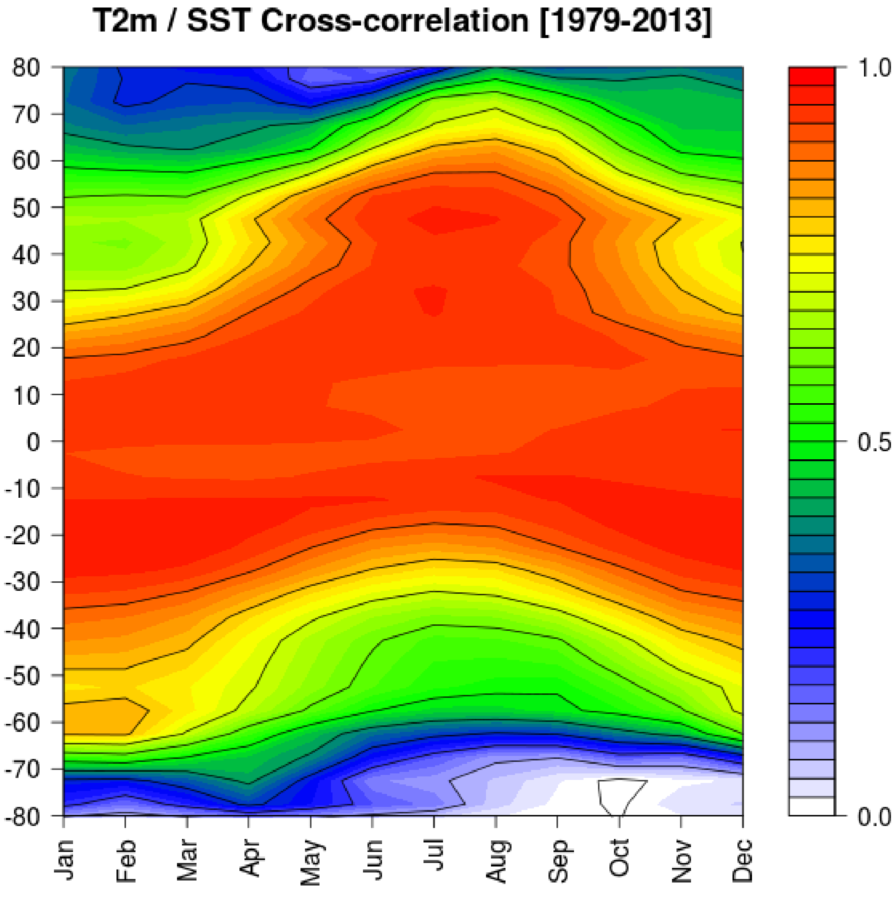
**Single-observation example:**

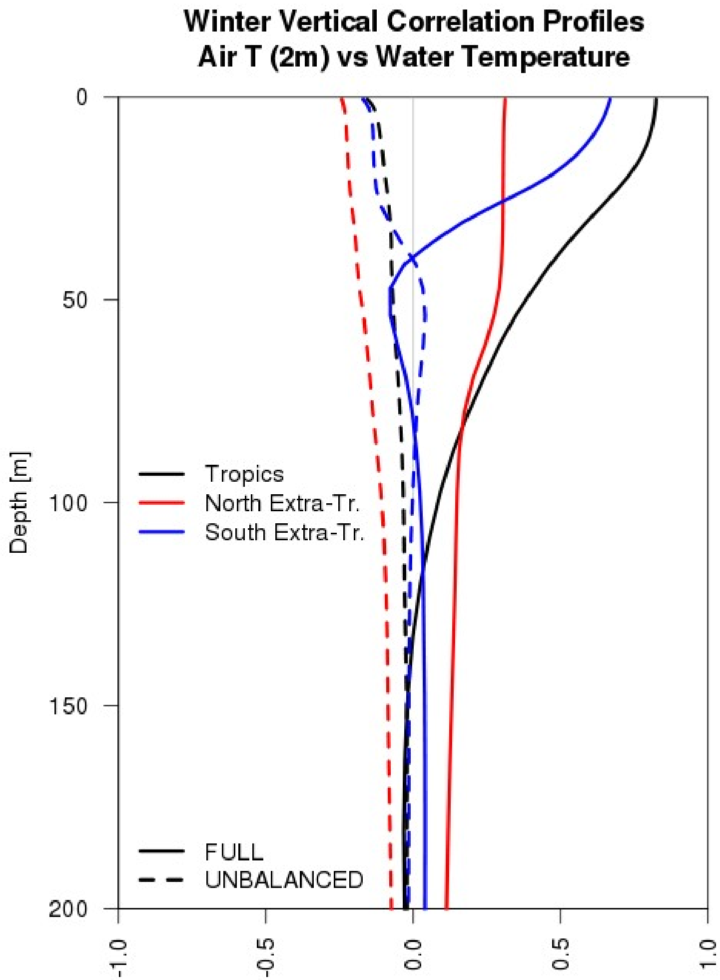
*Seawater temperature (horizontal at 1m of depth) and salinity (vertical) analysis increments from an observation of temperature at 2m in the Tropical Pacific Ocean from SYNOP SHIP (+0.75 K)*




**Air-sea balance based increments resemble those from purely statistical cross-covariances, with a slightly larger surface coupling but weaker downward penetration**

# Coupled covariances

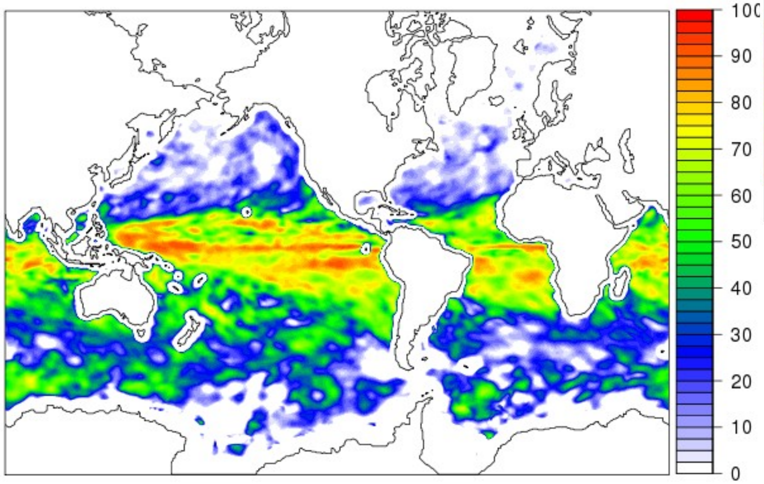


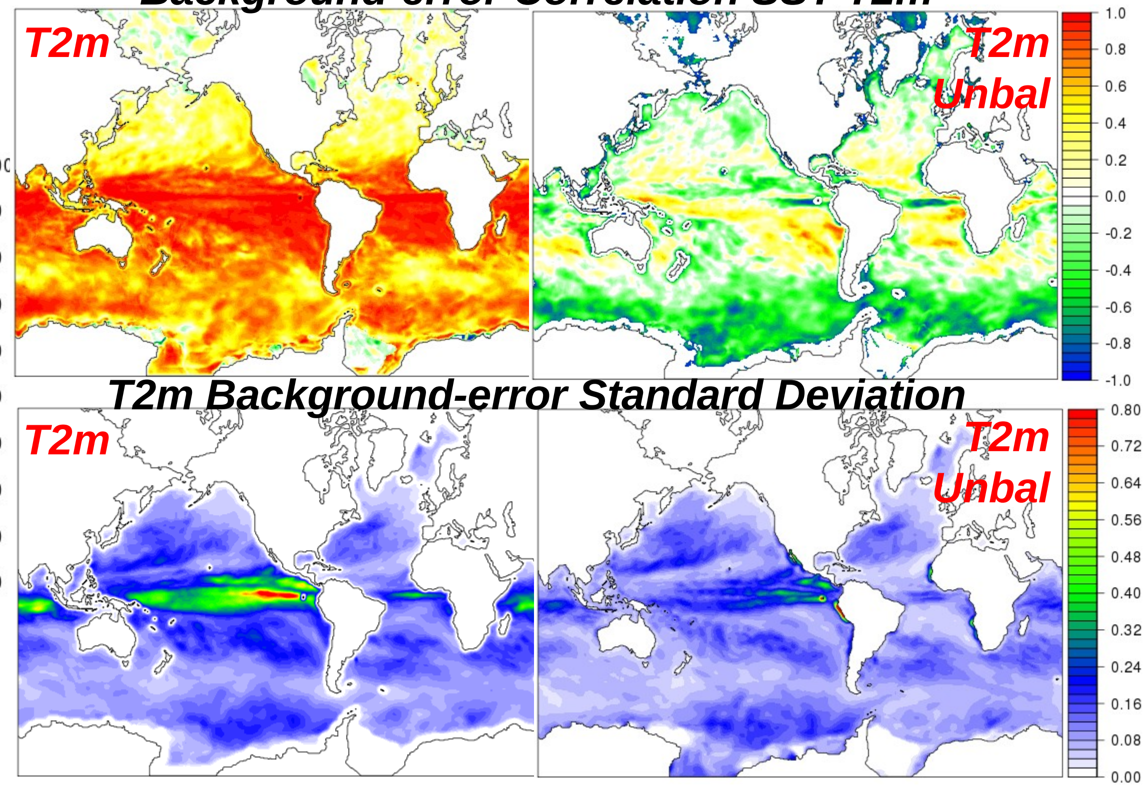

**Strong thermodynamic coupling in Tropics and at mid latitudes in Summer.**
**In these regimes SCDA with the proposed balances**
**may lead to significant impact**

# Coupled covariances

*Explained Variance*
*T2m vs T2m balanced*




*Background-error Correlation SST-T2m*




**Explained variance of the air-sea balance from 60 to 90 % in the Tropics,**
**Decreasing polewards**

# Motivation: initialization shocks

**Evaluation of the model evolution of the analysis increments in terms of perturbations at time *t*:**

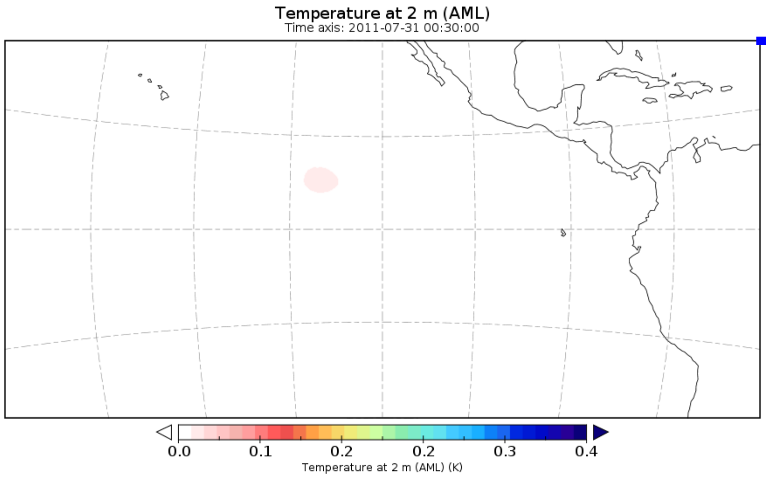
$$M_{0\to t}\left(x^{a}\right)-M_{0\to t}\left(x^{b}\right)$$

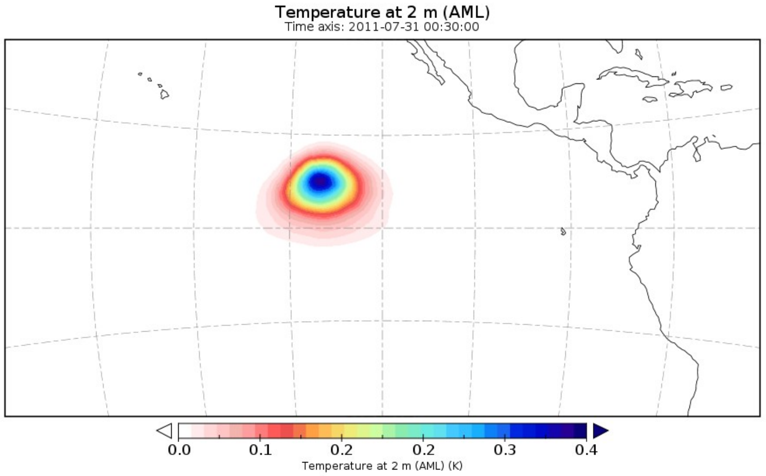
**Comparison between weakly and strongly coupled Data assimilation systems**

# Motivation: initialization shocks

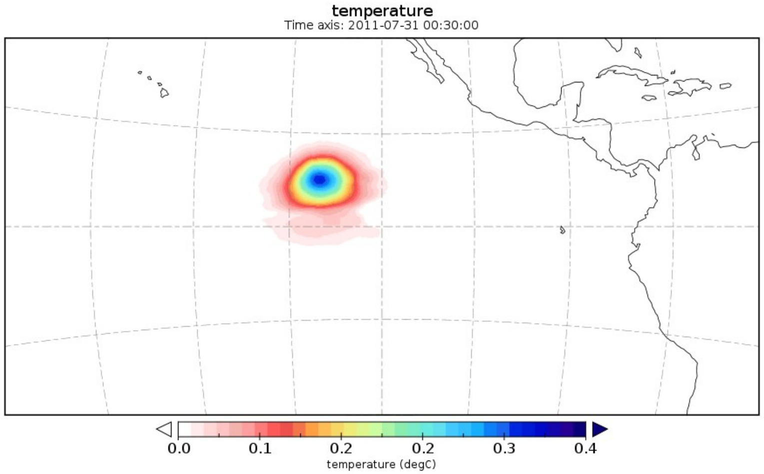
**WEAKLY** **STRONGLY** **+01h**

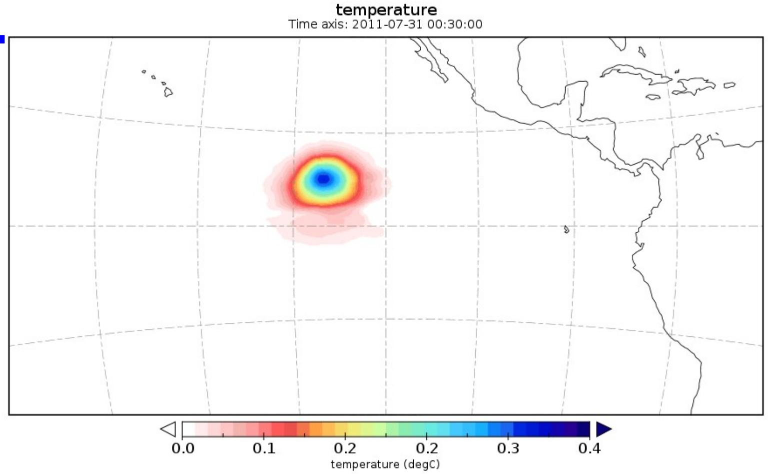
**T2m**




**SST**

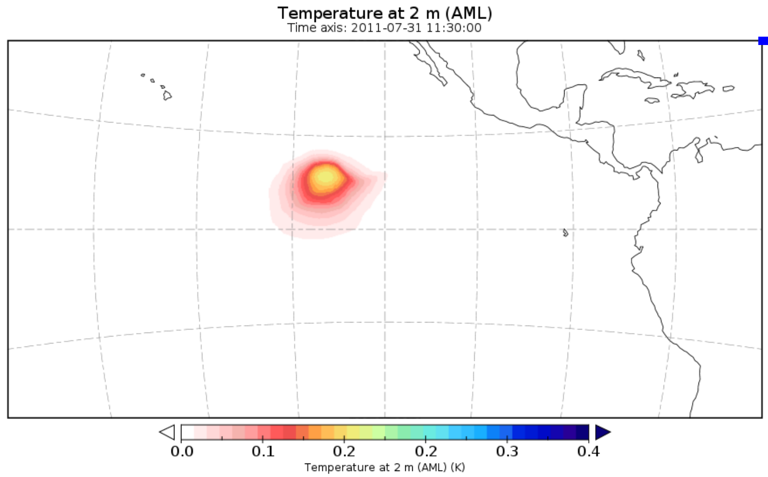


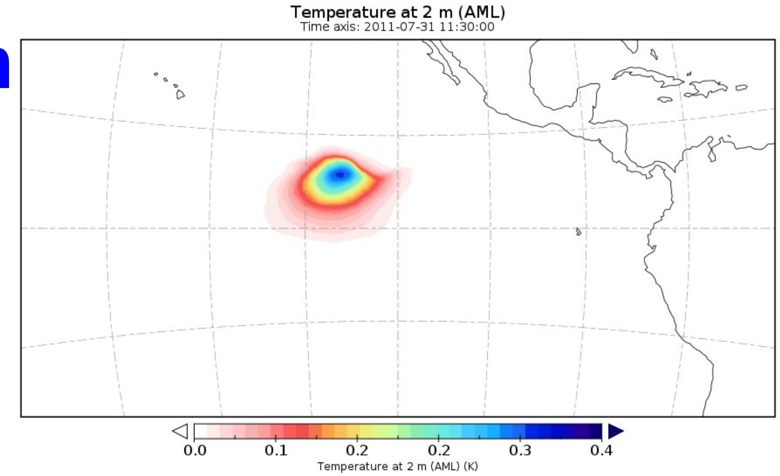



# Motivation: initialization shocks

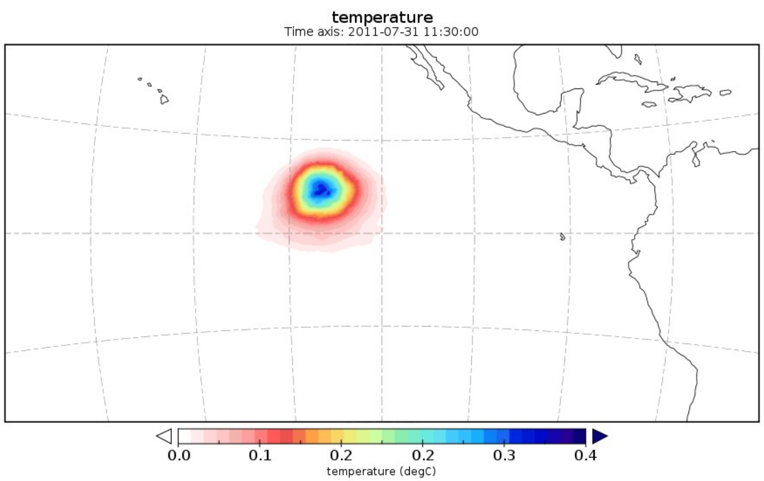
**WEAKLY** **STRONGLY** **+12h**

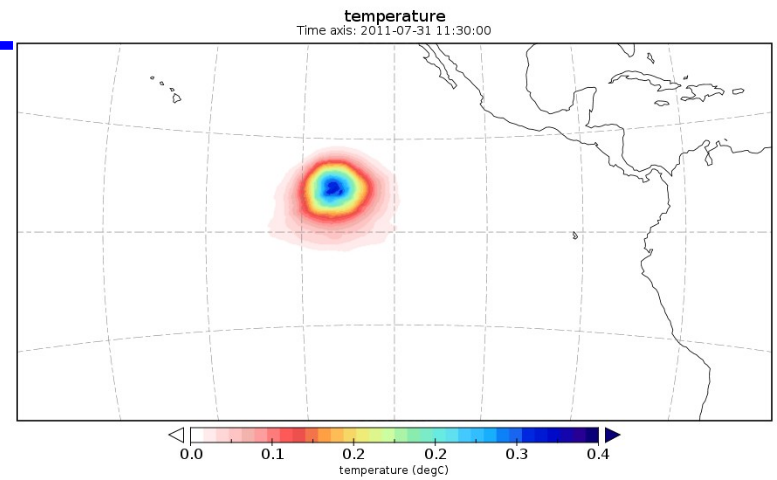
**T2m**




**SST**

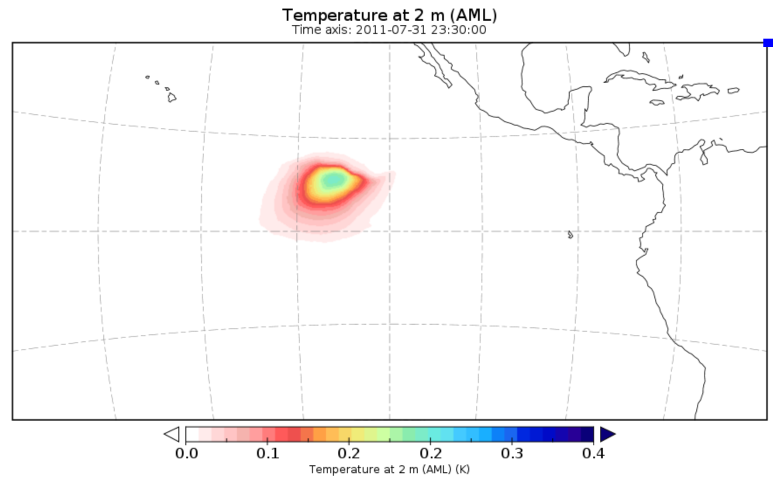


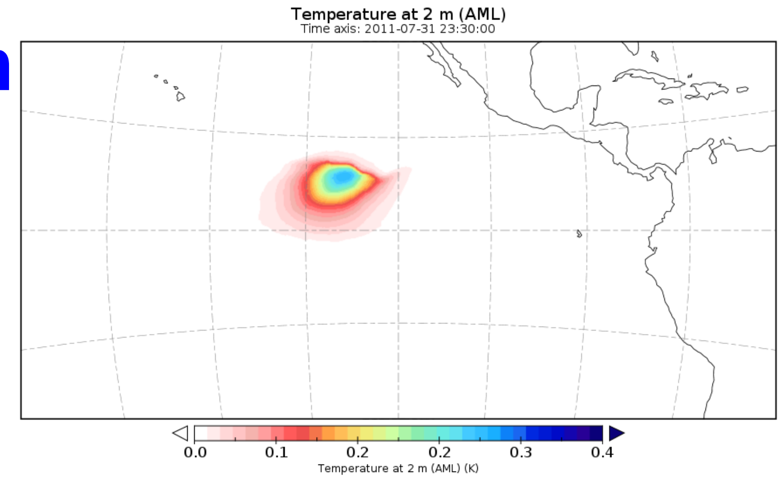



# Motivation: initialization shocks

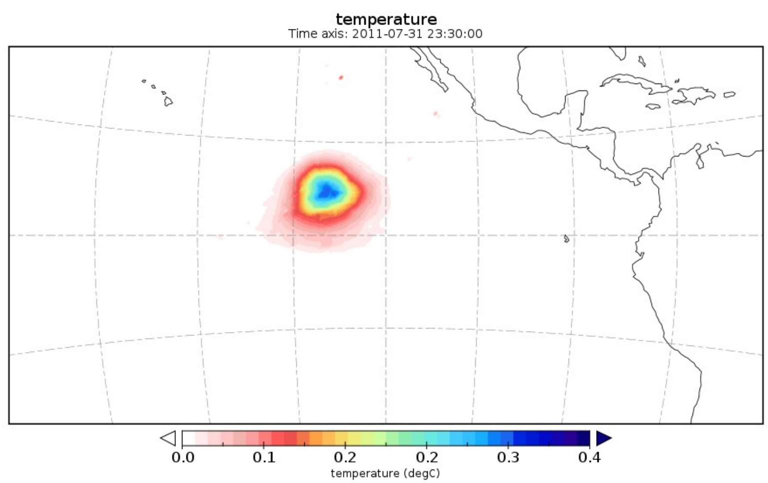
**WEAKLY** | **STRONGLY** | **+24h**

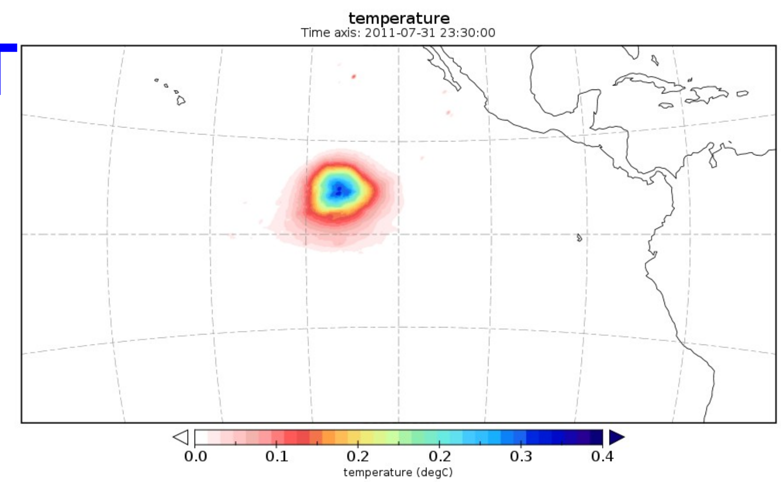
**T2m**




**SST**

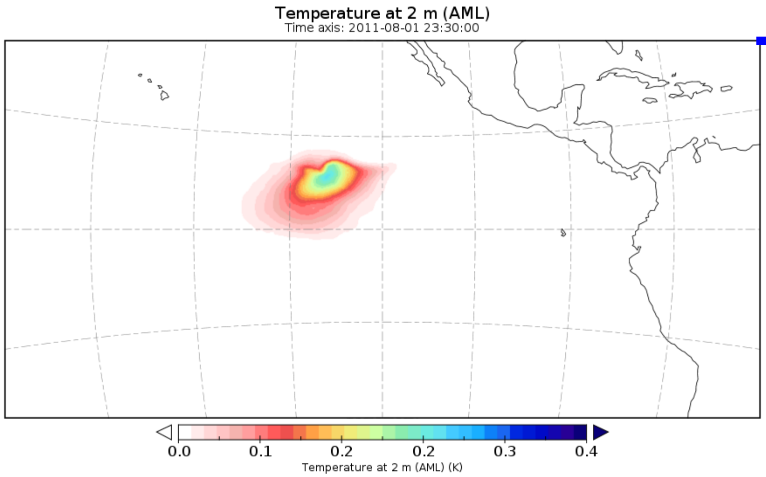


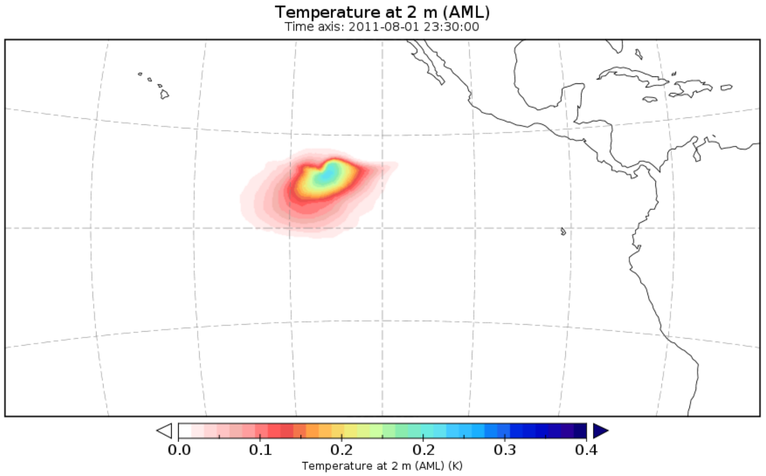



# Motivation: initialization shocks

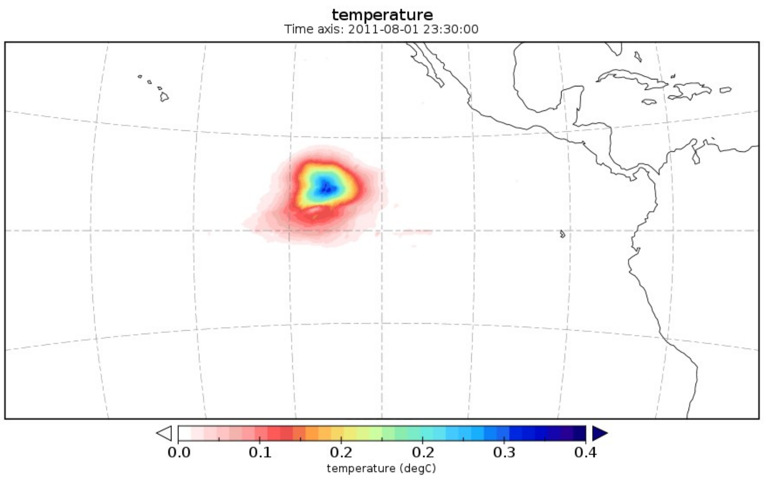
**WEAKLY** | **STRONGLY** | **+48h**

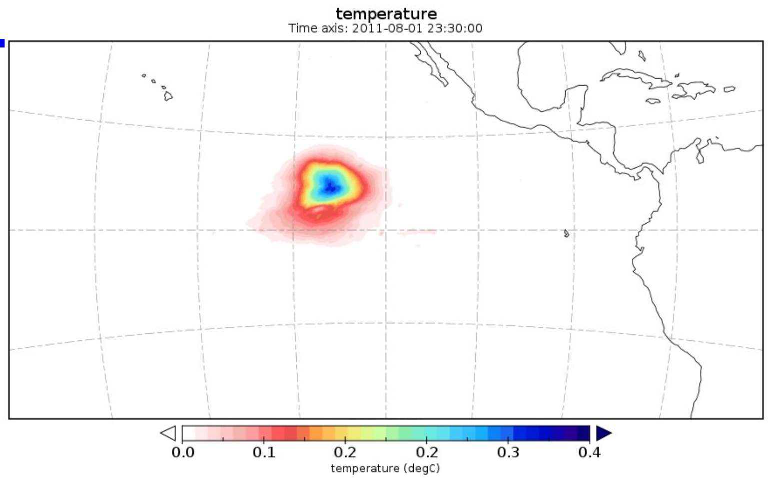
**T2m**



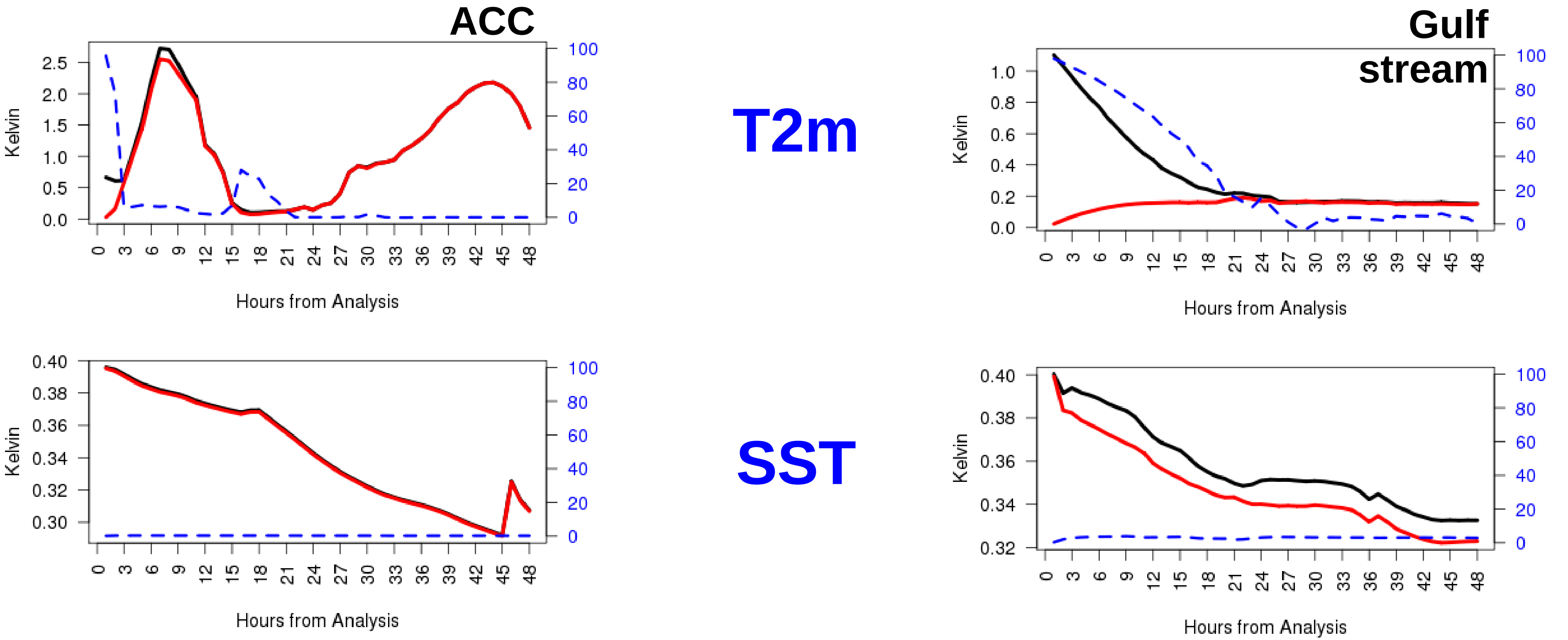




**SST**



# Motivation: initialization shocks



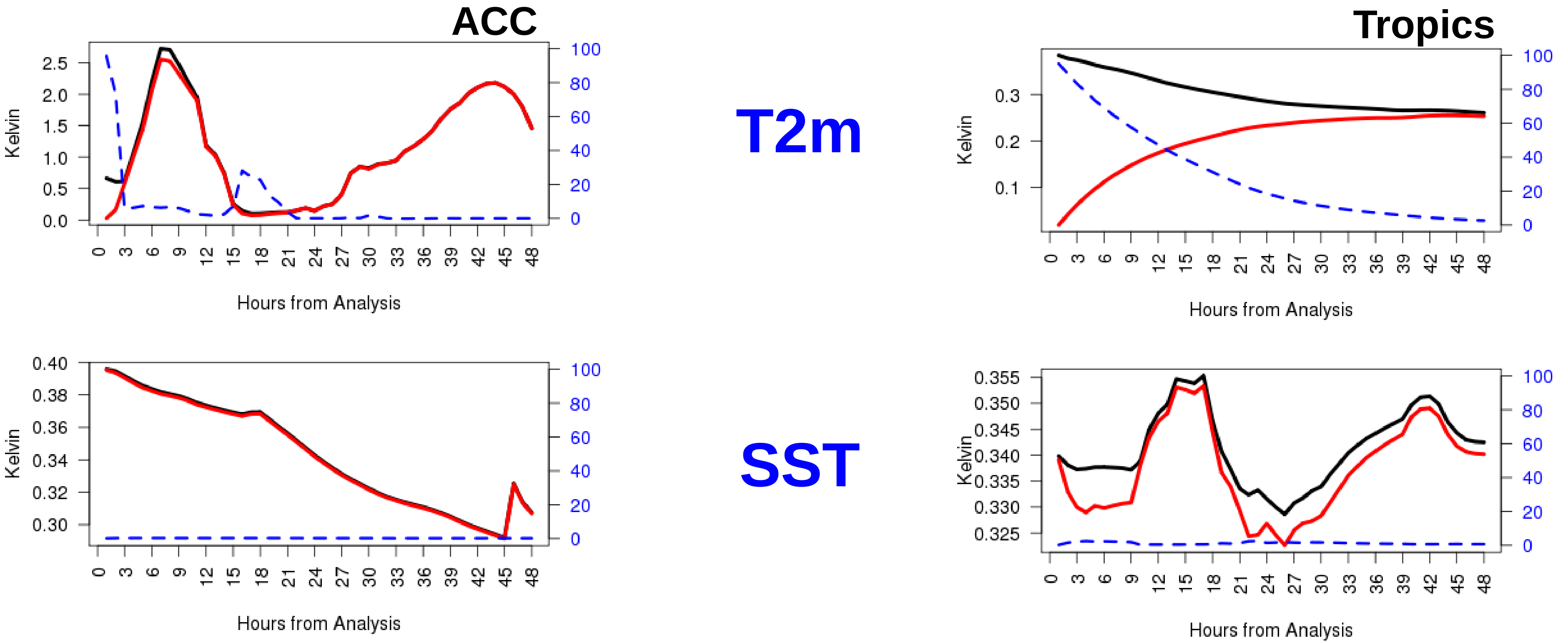

**Weakly Coupled DA Analysis Increments**

**Strongly Coupled DA Analysis Increments**

**Percentage difference (right axis)**

**Winter time coupling is weaker** → ***Expected lower impact of strongly coupled DA on the prevention of initialization shocks***

# Motivation: initialization shocks




**Weakly Coupled DA Analysis Increments**
**Strongly Coupled DA Analysis Increments**
**Percentage difference (right axis)**

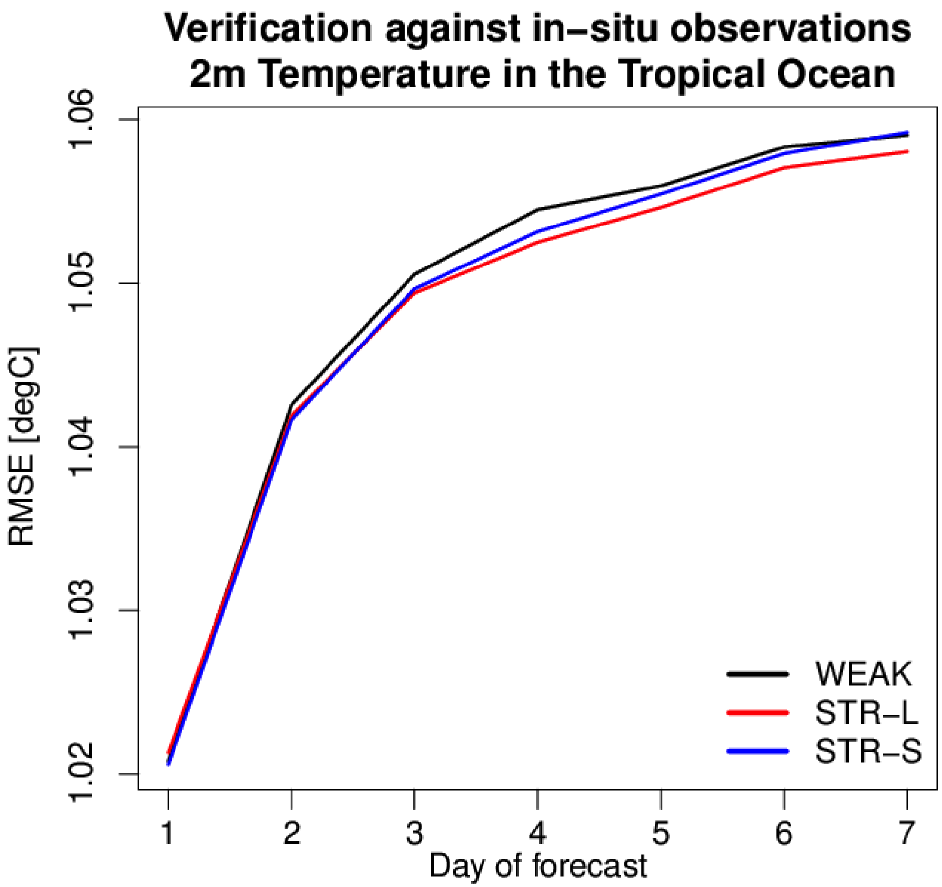
**Persisting perturbation in the Tropics** → ***Potential impact of strongly coupled DA on long-range predictability***

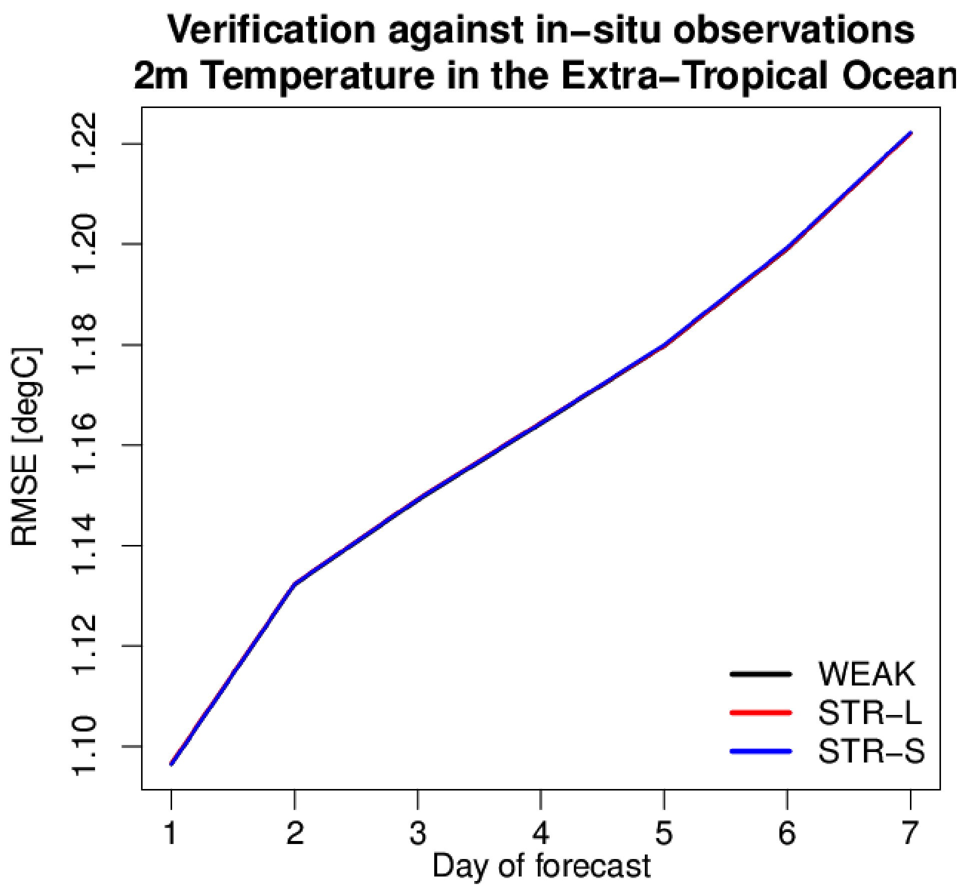
# Experimental configuration

| | |
|---|---|
| ***Model*** | NEMO(v3.4)+LIM2 |
| ***Resolution*** | ORCA05 (55-25 Km), 75 levels |
| ***Period*** | June to December 2011 (7-month period) |
| ***Wind, Radiative, Freshwater forcing*** | CORE bulk with ECMWF ERA-Interim (3-hourly for wind, daily for fluxes) |
| ***Assimilation frequency*** | Daily, 24h assim. Time-window, 7-day forecasts every day |
| ***Data Assimilation*** | 3DVAR/FGAT, Vertical Eofs, 1$^{st}$ order RF with non-homogeneous correlat. length-scales *(Storto et al., 2016, QJRMS)* |
| ***Background error covariances*** | From monthly anomalies w.r.t. climatology |
| ***Marine Observations*** | Hydrographic profiles (XBT, CTD, Argo, moorings), Along-track altimetry data |
| ***Atmospheric Observations*** | Ships, buoys |

**Scientific Question:**
*Can strongly coupled DA of hydrography profiles improve the forecasts of near-surface air parameters over the oceans?*

# Results: assimilation of marine, impact on air



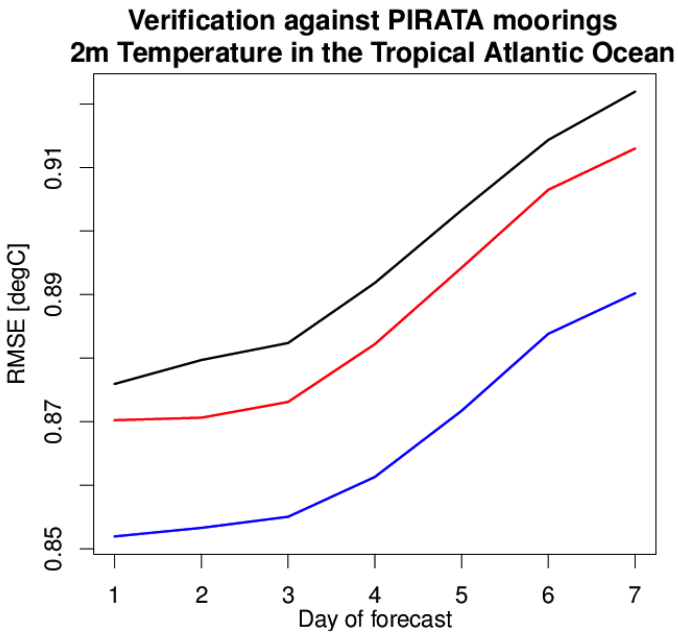

**Weakly Coupled**

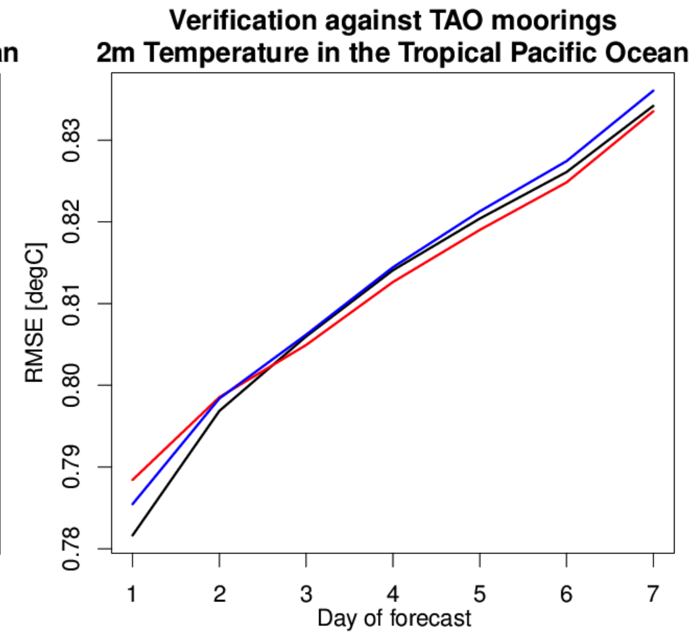
**Strongly Coupled (air-sea balance)**

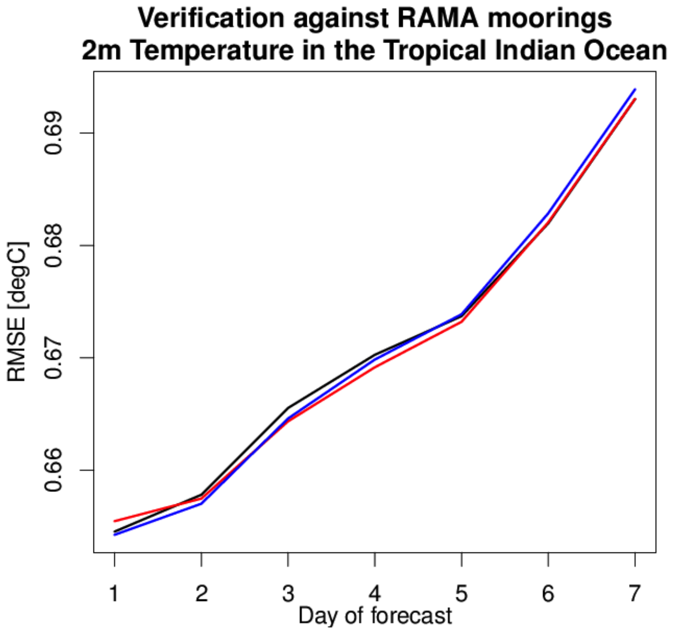
**Strongly coupled (statistics)**

**No significant impact at global scale, but positive impact in the Tropics with air-sea balance**

# Results: assimilation of marine, impact on air



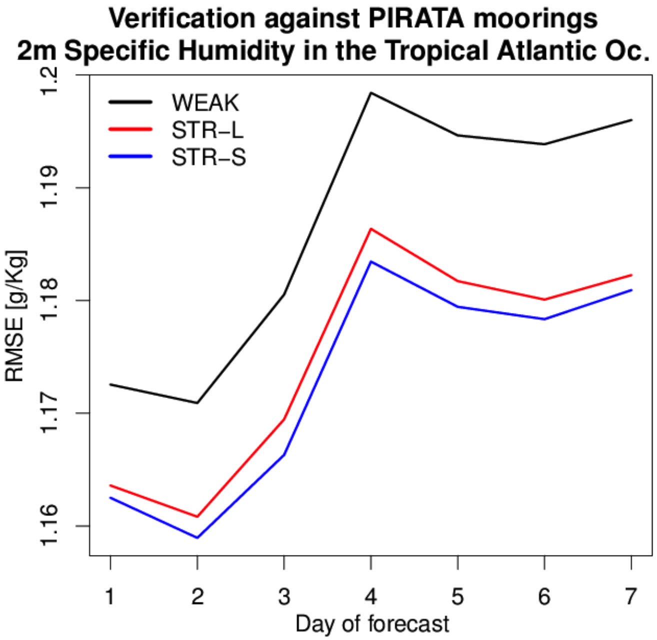

**Weakly Coupled**

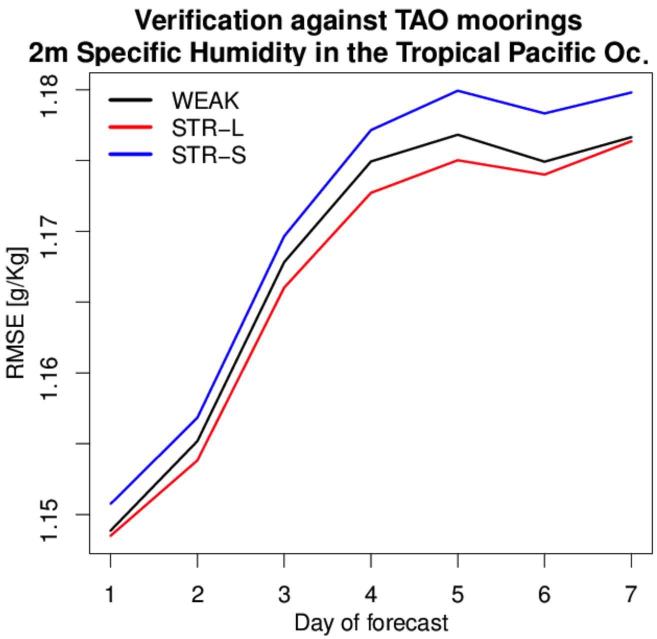
**Strongly Coupled (air-sea balance)**

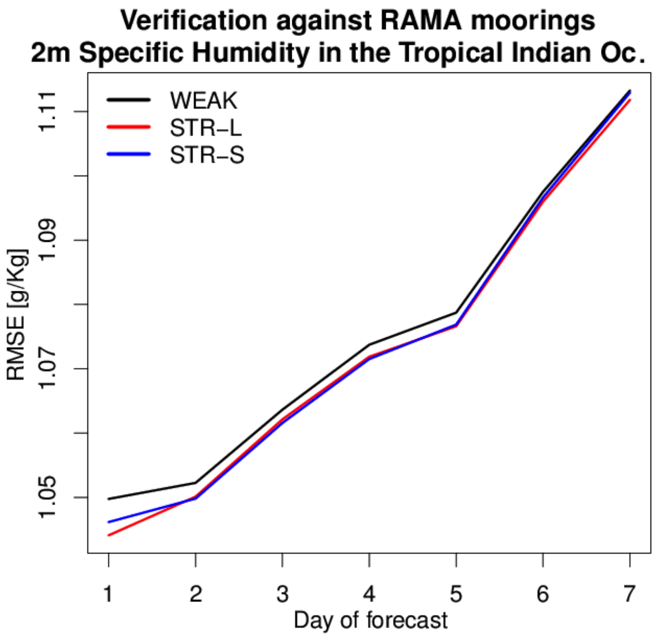
**Strongly coupled (statistics)**

**Impact is significant in the Atlantic Ocean, less obvious elsewhere**

# Results: assimilation of marine, impact on air

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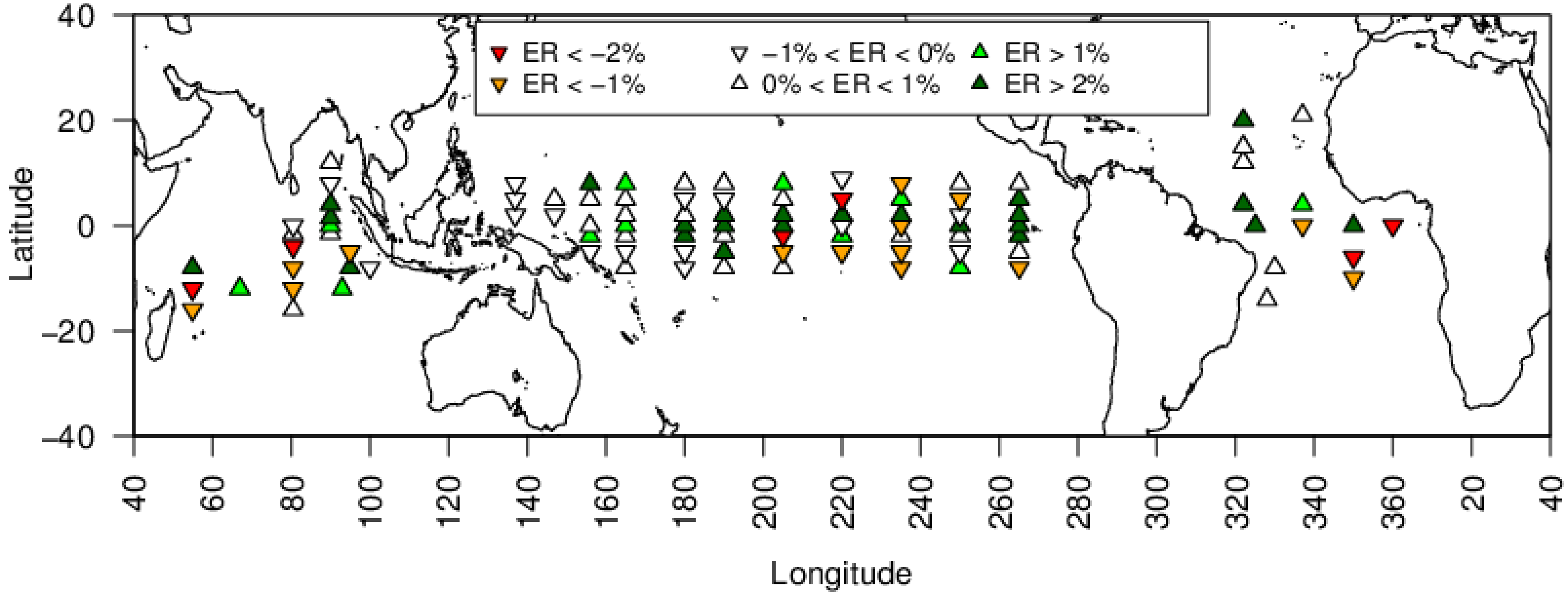
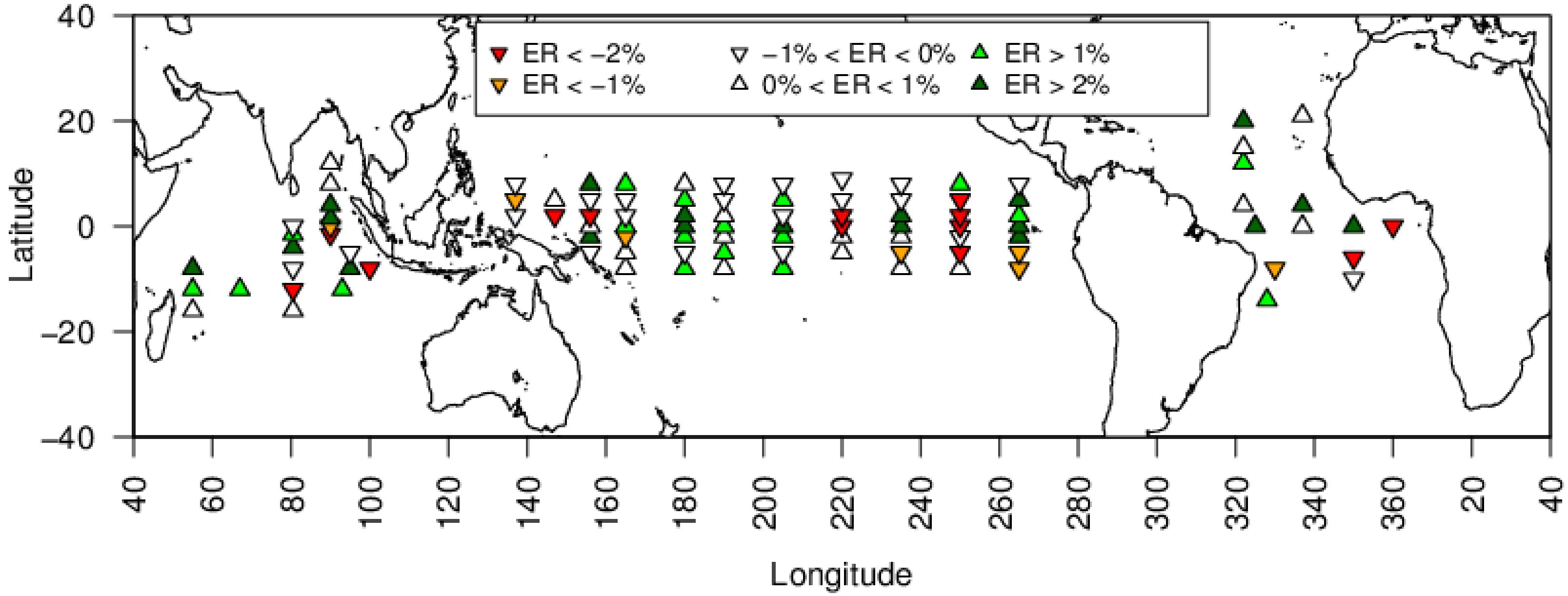
# Results: assimilation of marine, impact on air




SCDA (Air-sea bal.)

vs

WCDA




SCDA (Air-sea bal.)

vs

SCDA (Statistical)

# Summary

- ***A simplified strongly coupled variational assimilation system provides a framework to study the inter-medium observation impact and the optimal choice of the air-sea balance operator***

- ***An analytical air-sea balance operator that mimics a thermodynamical TL model of the air-sea fluxes proves adequate in the Tropical region to model inter-medium cross-covariances***

- ***The impact of marine observations on near-surface air parameters is found negligible at global scale but positive in the Tropics, especially when the air-sea balance operator is used and not the statistical operator***

# Hybrid covariances

- ***Within the project, OceanVar has been extended to include hybrid static-ensemble covariances***

$$\delta \mathbf{x} = \beta\, \mathbf{V}_c\, \mathbf{v}_c + (1-\beta)\mathbf{V}_f\, \mathbf{v}_f \quad \Leftrightarrow \quad \mathbf{B} = \alpha\, \mathbf{B}_c + (1-\alpha)\mathbf{B}_f$$

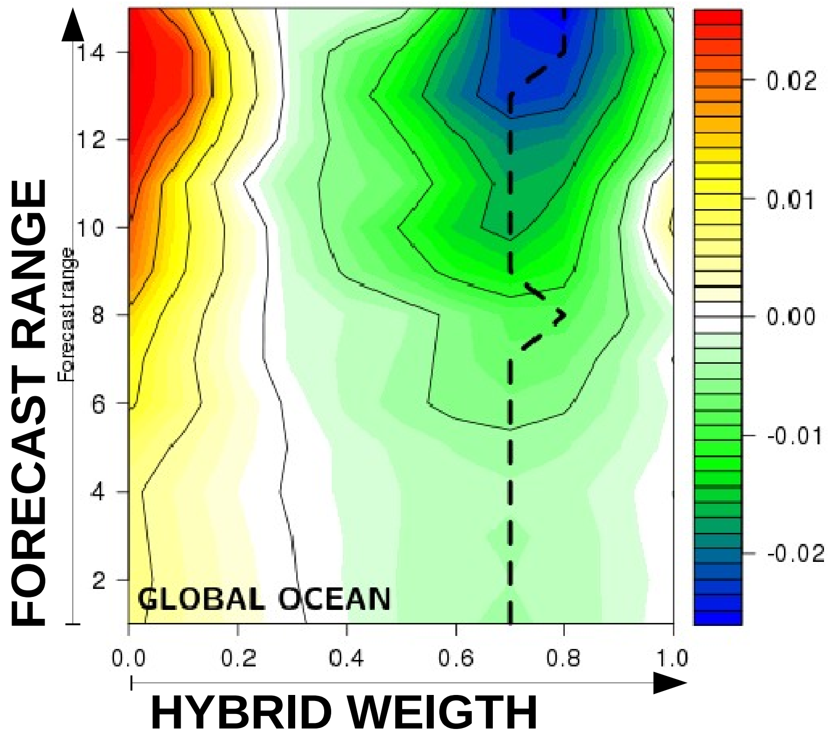
(Lorenc 2003 formulation) (Wang et al., 2007: $\alpha=\beta^2$)

- ***Simplification: only vertical covariances are "hybridized"***

$$\delta \mathbf{x} = \mathbf{V}_B \mathbf{V}_H \left[ \beta\, \mathbf{V}_{Vc}\, \mathbf{v}_c + (1-\beta)\mathbf{V}_{Vf}\, \mathbf{v}_f \right]$$

- ***Extensive experiments with coarse resolution configuration (ORCA2) and 24-member off-line ensemble system (with perturbation of observations and atmospheric forcing) prove benefits of the hybrid extension***

***ERROR METRIC (NORMALIZED BY FORECAST RANGE)***



# Project outcomes and finalization

- *The project deliverable (D2.4) has been produced and it is under internal review ("Strongly coupled data assimilation experiments with linearized ocean-atmosphere balance relationships and hybrid covariances")*
- *Paper published on GRL: Storto, Yang, Masina (2016): Sensitivity of global ocean heat content from reanalyses to the atmospheric reanalysis forcing: A comparative study*
- *A few additional experiments aiming at assessing*
  - *Impact of SST observations in the strongly coupled DA system*
  - *Impact of atmospheric observations of T2M and Q2M on upper ocean temperature*

  *will be performed in the remaining months*
- *Comparison of hybrid 3dvar vs 4dvar with OceanVar in the global ocean (in terms of CPU time and skill)*

# Thank you