Strongly coupled data assimilation experiments with a full OGCM and an atmospheric boundary layer model: preliminary results

Andrea Storto

CMCC, Bologna, Italy

Coupled Data Assimilation Workshop

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Centro Euro-Mediterraneo sui Cambiamenti Climatici

Strongly coupled data assimilation (SCDA)

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

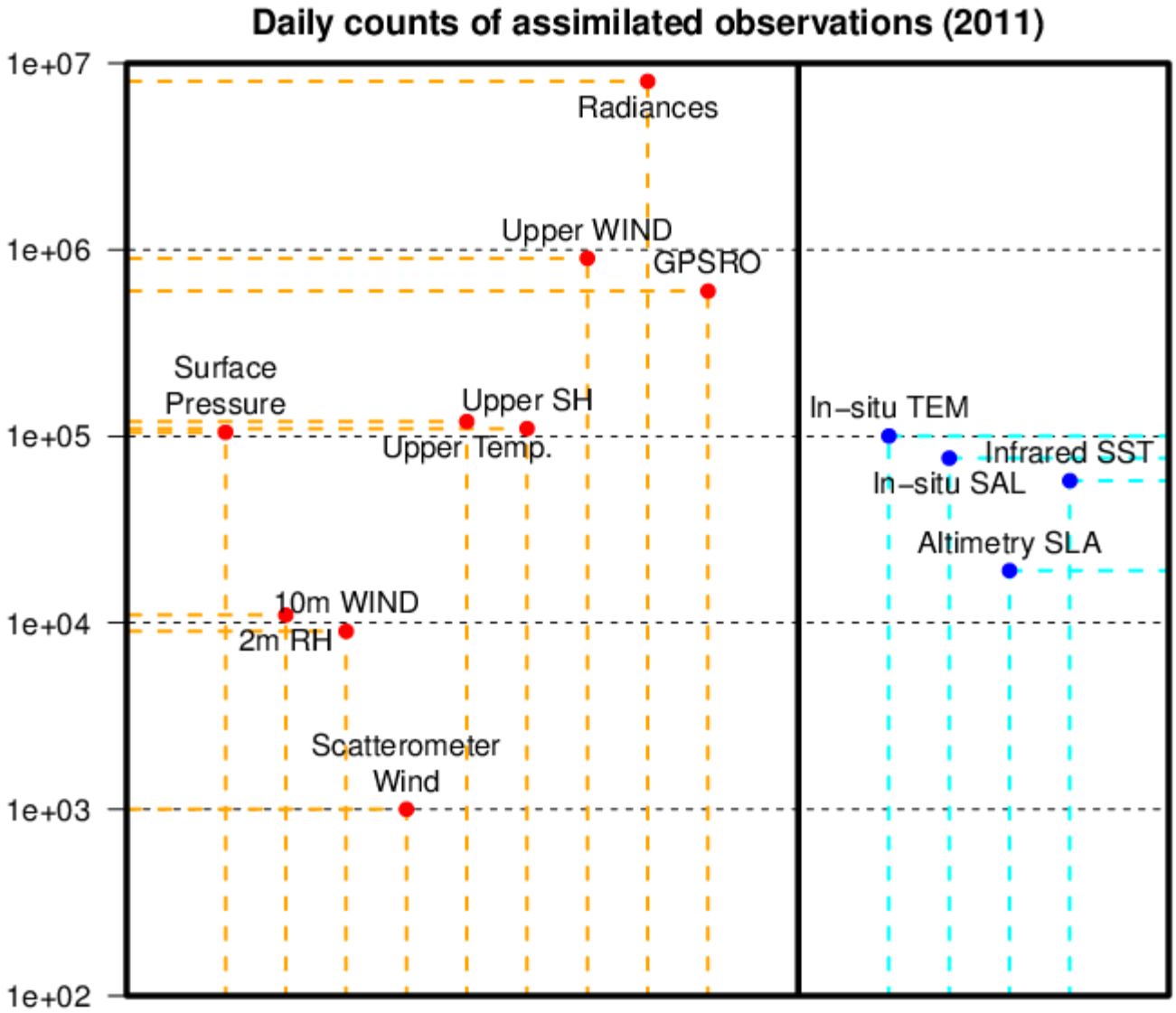
Does strongly coupled DA lead to further improvements?

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



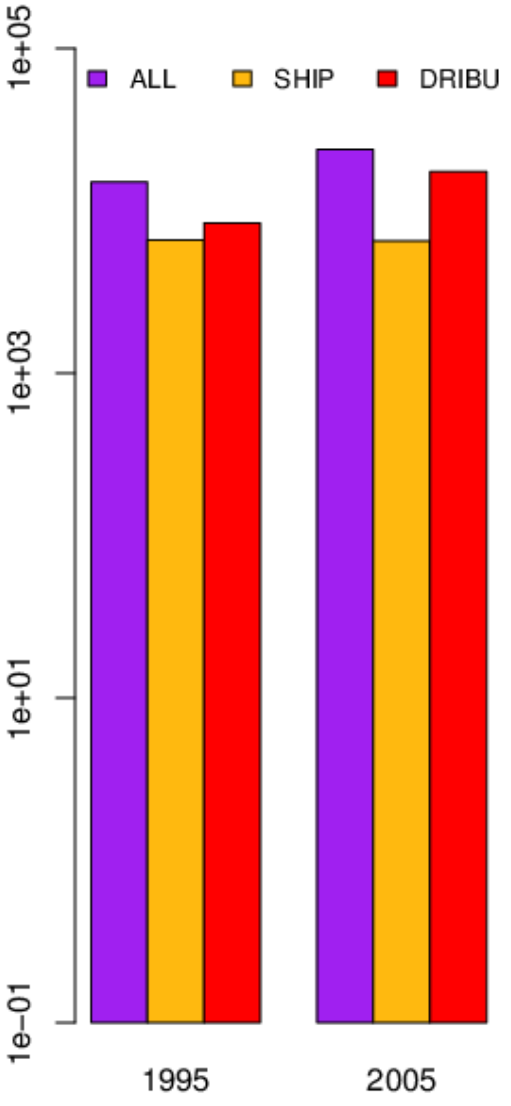
No of Single-level Observations

ECMWF ERA-Interim
(Adapted from Dee et al., 2011)

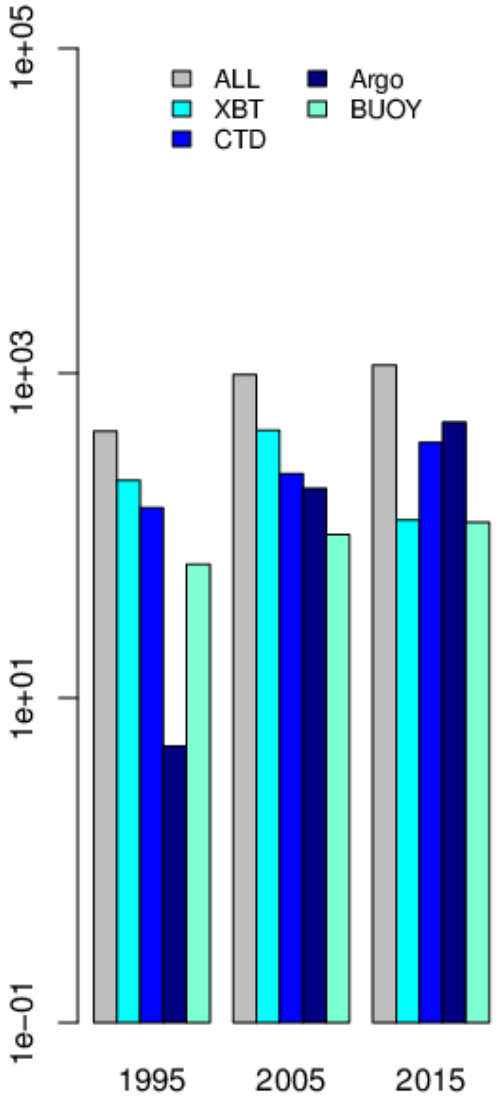
CMCC C-GLORS
www.cmcc.it/c-glors

Motivation: observation synergy

No of Platforms



ECMWF ERA-Interim
(Adapted from Tavolato & Isaksen)

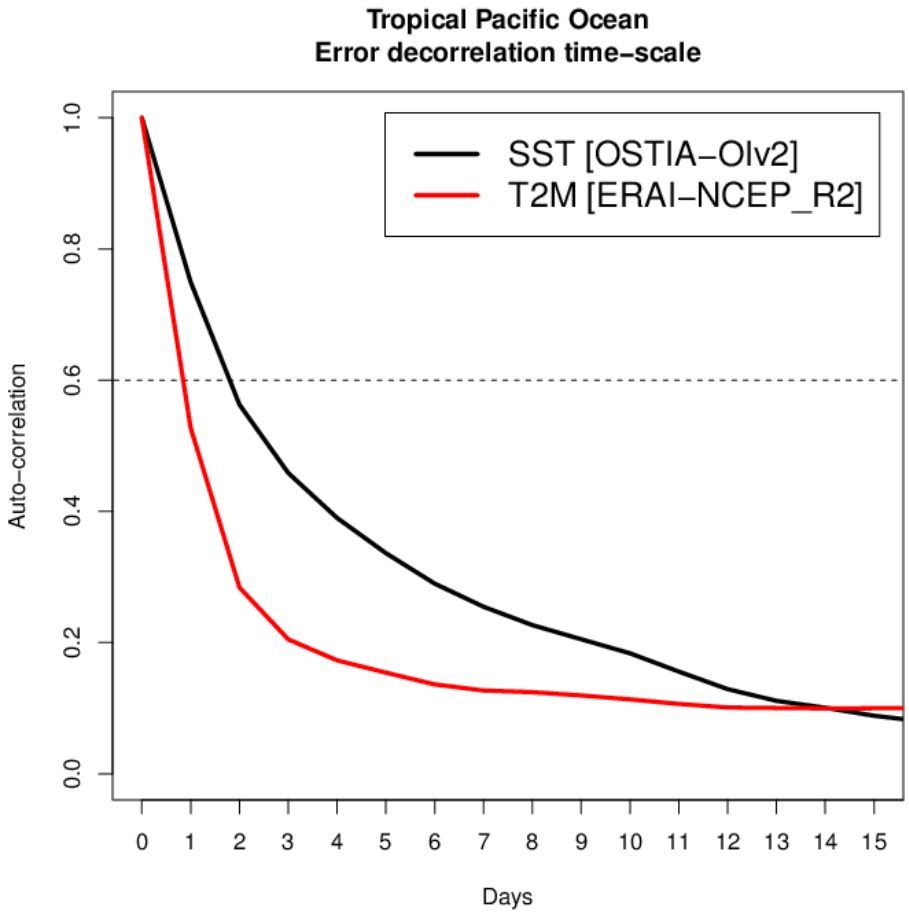


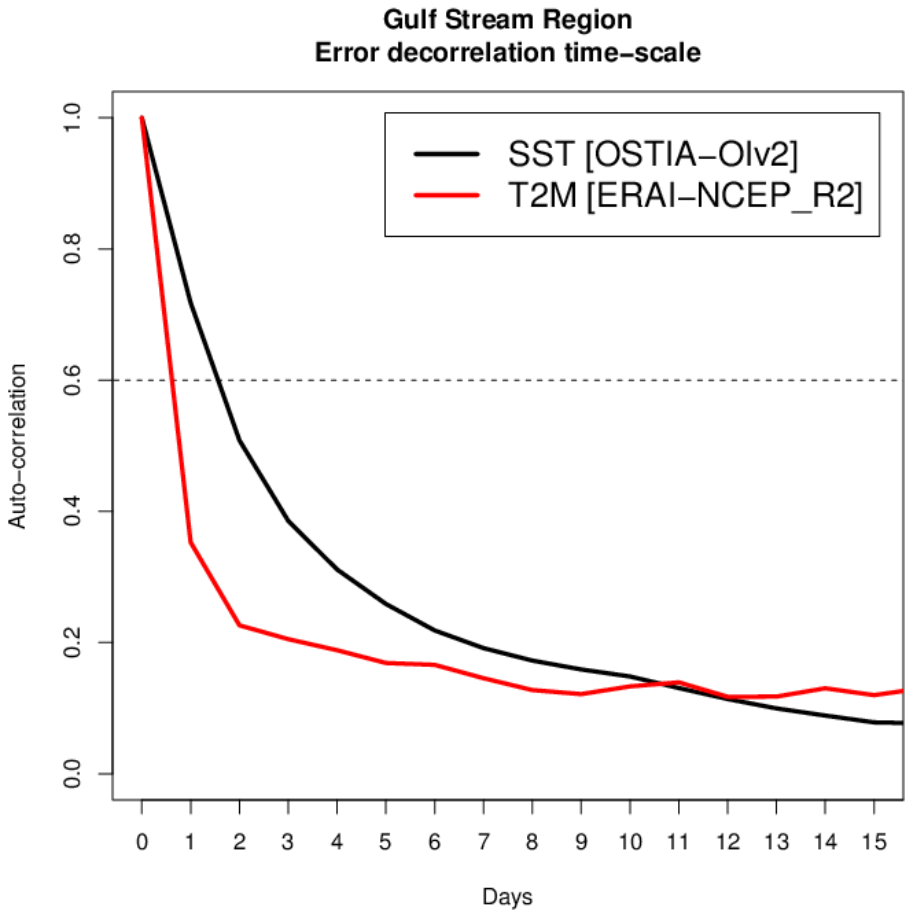
No of Profiles

CMCC C-GLORS
(UKMO EN4)

Air or Sea Temperature Stations

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:

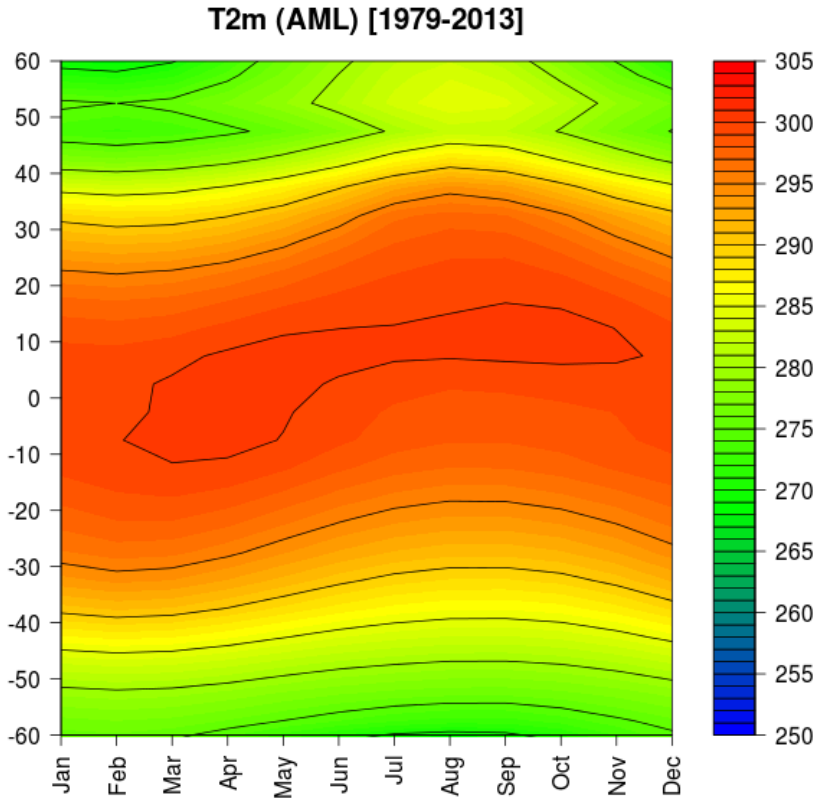
- No atmospheric DA system (not available at CMCC)
- It allows augmenting the ocean state control parameters to include T_{2M} and Q_{2M}, now prognostic, in both model and 3DVAR, i.e. allow to use 1 DA software, extended to atmospheric variables (ideal strategy)

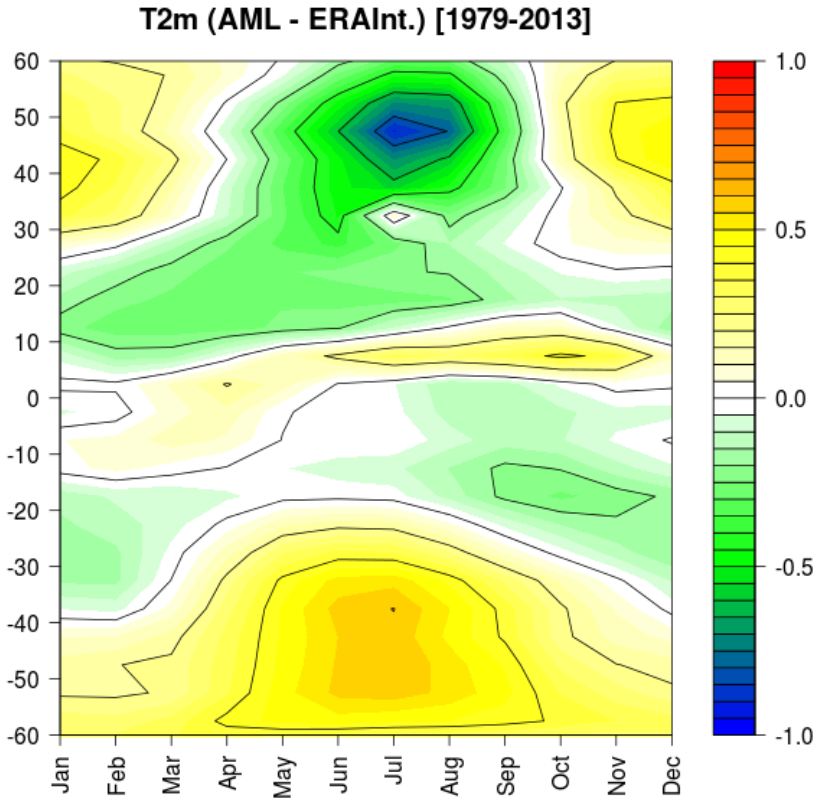
DISADVANTAGEs:

- 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

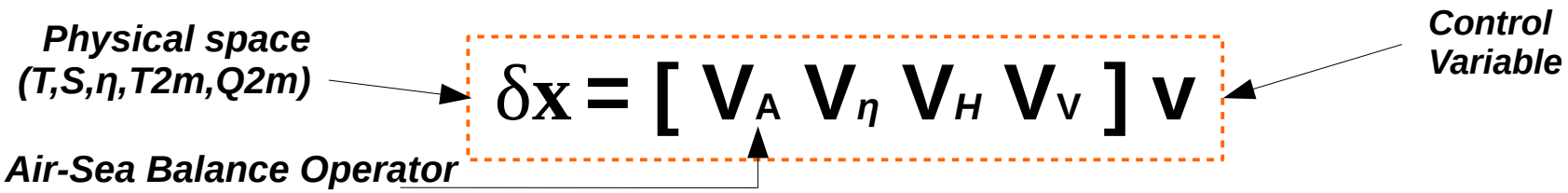
To couple the sea-surface variables with 2m atmospheric variables, balances might be thought either purely statistical, or purely analytical, or mixed (balanced + unbalanced components)
We introduce a balance operator that maps the increments of SST onto those of ($\mathbf{T_{2m}}$, $\mathbf{Q_{2m}}$) 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

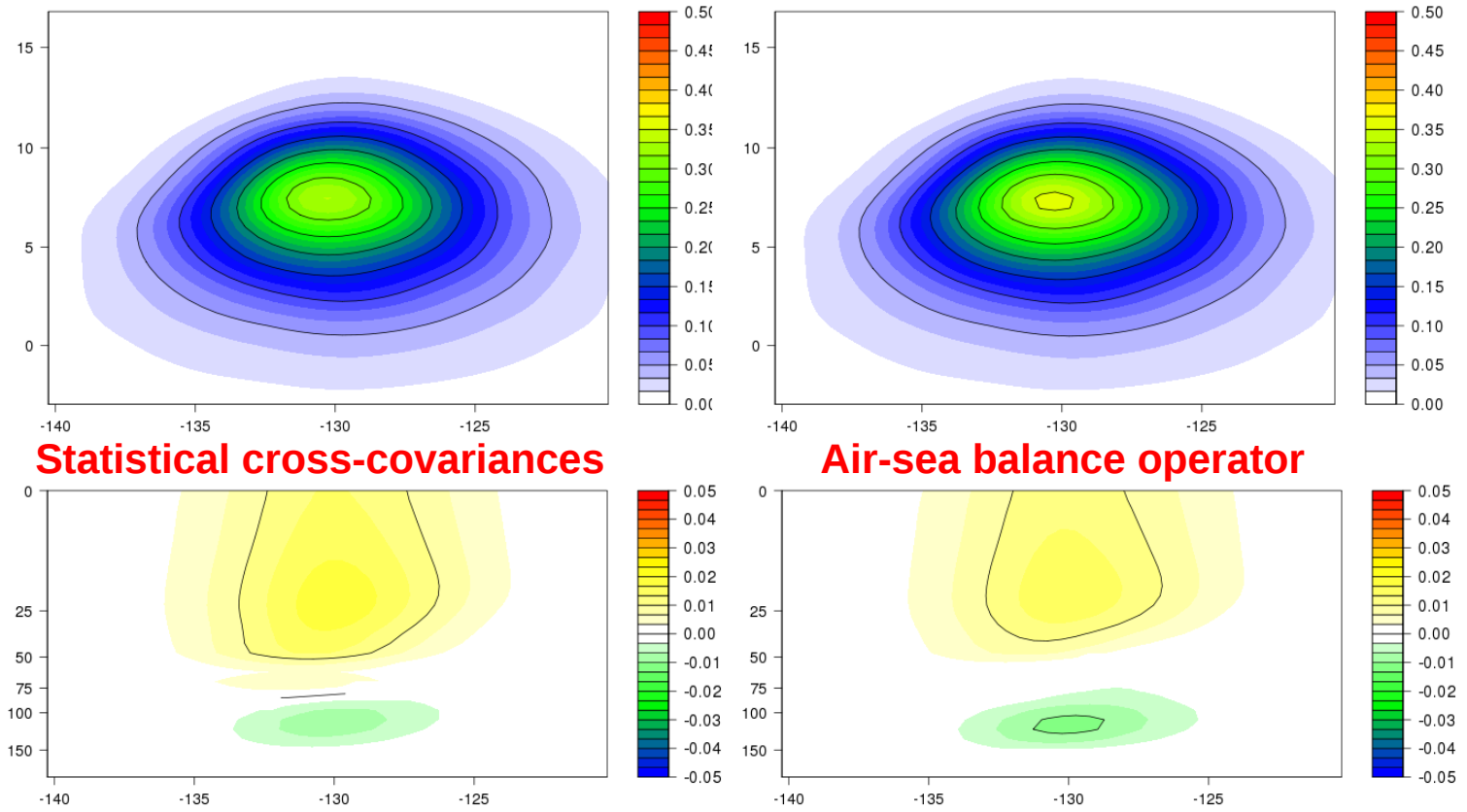
Where the transfer coefficients (**Ce, Ch** for Evaporation and Sensible heat, respectively) are assumed not to depend on **SST** and taken from the fully non-linear model. *(Might be relaxed with simple parametric formulations)*



A simplified air-sea balance operator

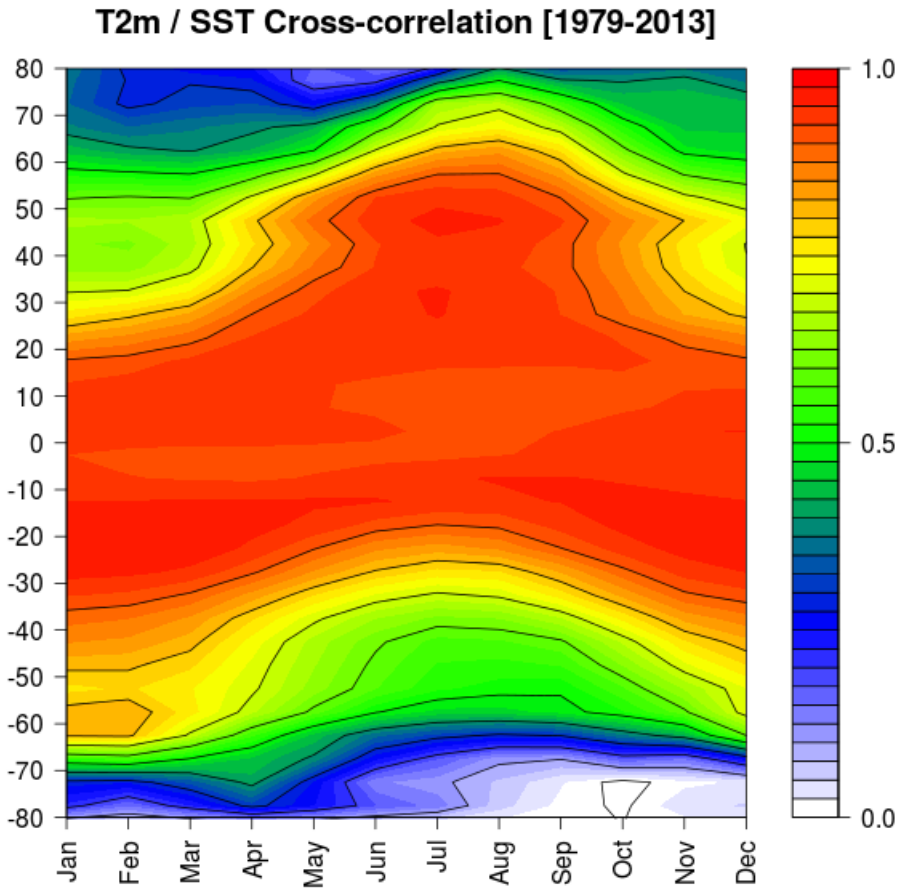
Single-observation example:

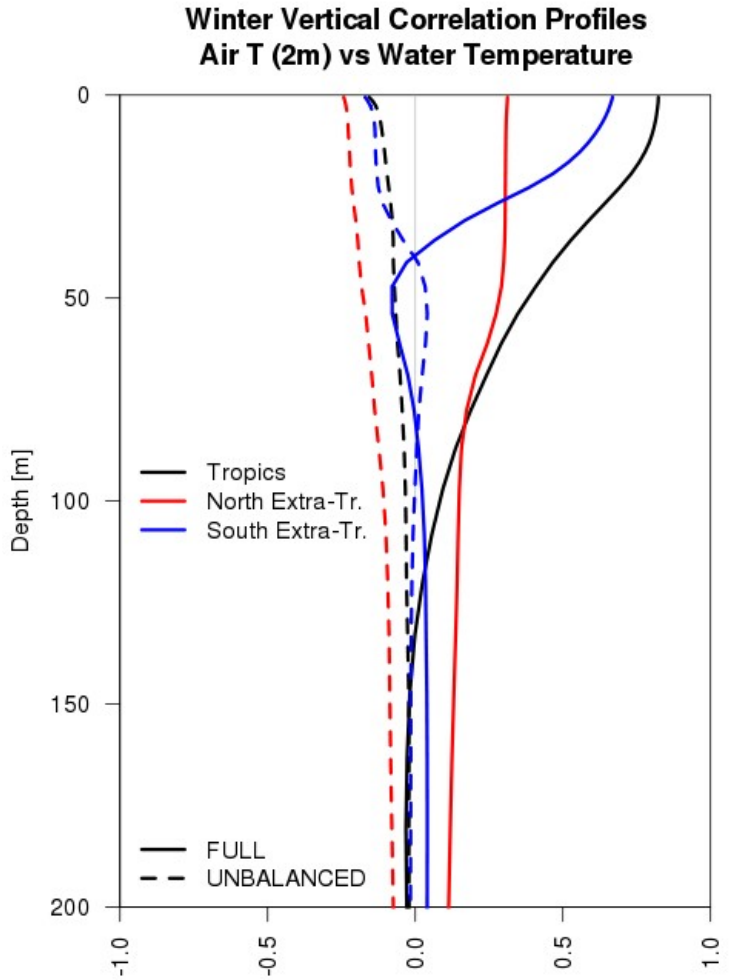
Seawater temperature (horizontal at 1m of depth) and salinity (vertical) analysis increments from an observation of temperature at 2m in the Tropical Pacific Ocean from SYNOP SHIP (+0.75 K)



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

Coupled covariances

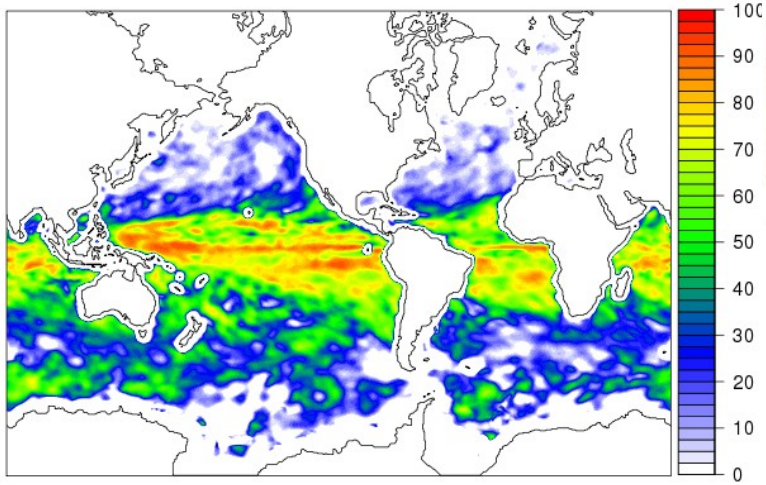




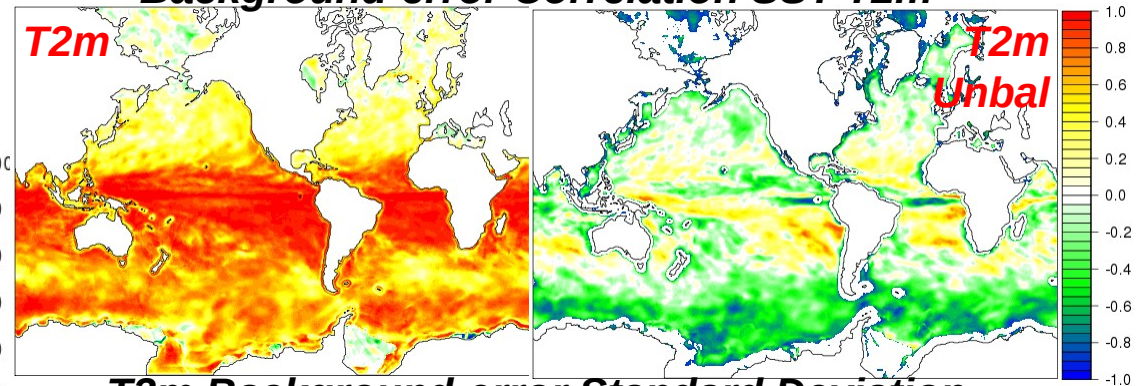
Strong thermodynamic coupling in Tropics and at mid latitudes in Summer.
In these regimes SCDA with the proposed balances
may lead to significant impact

Coupled covariances

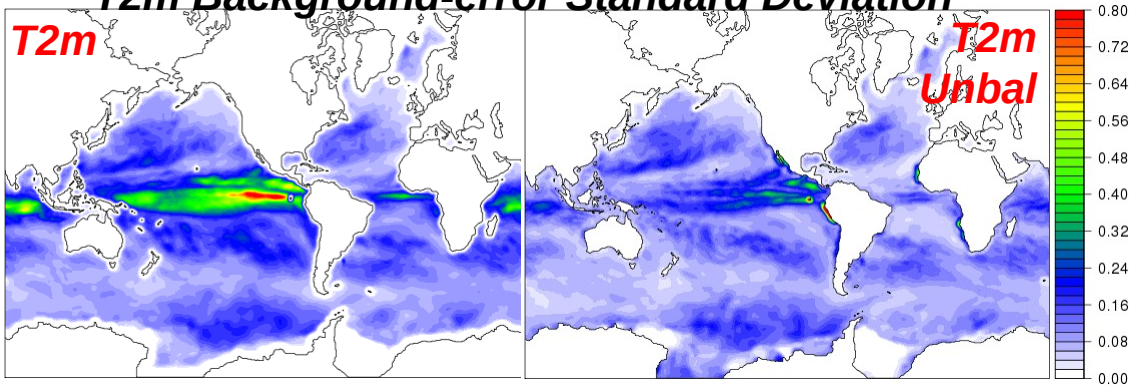
Explained Variance
T2m vs T2m balanced



Background-error Correlation SST-T2m



T2m Background-error Standard Deviation



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:*

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

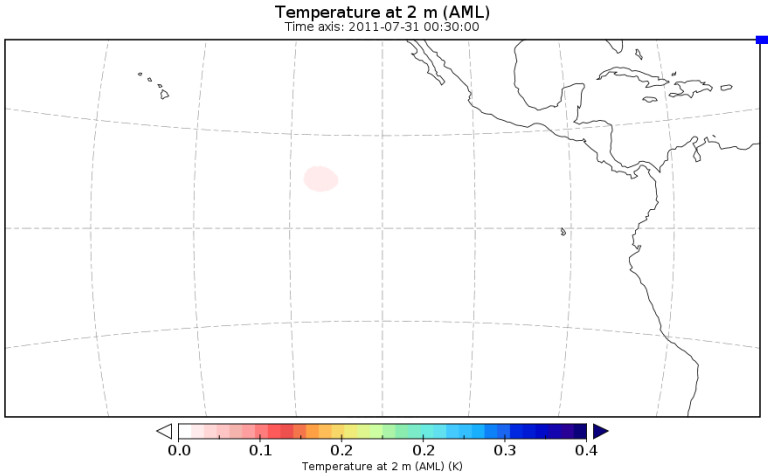
Comparison between weakly and strongly coupled Data assimilation systems

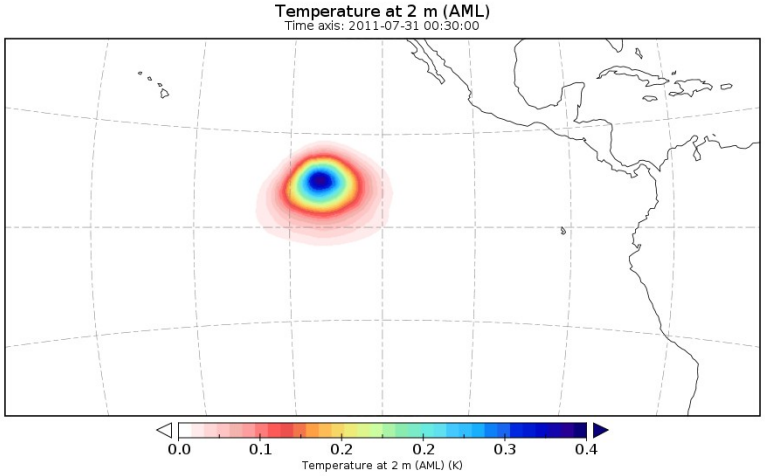
Motivation: initialization shocks

+01h

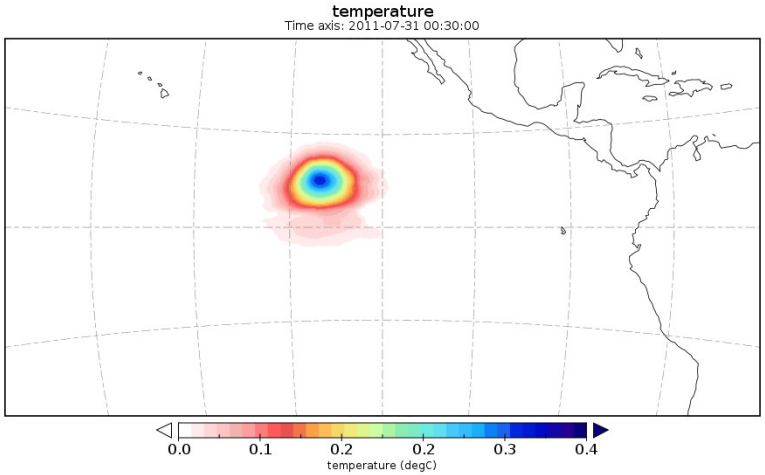
WEAKLY STRONGLY

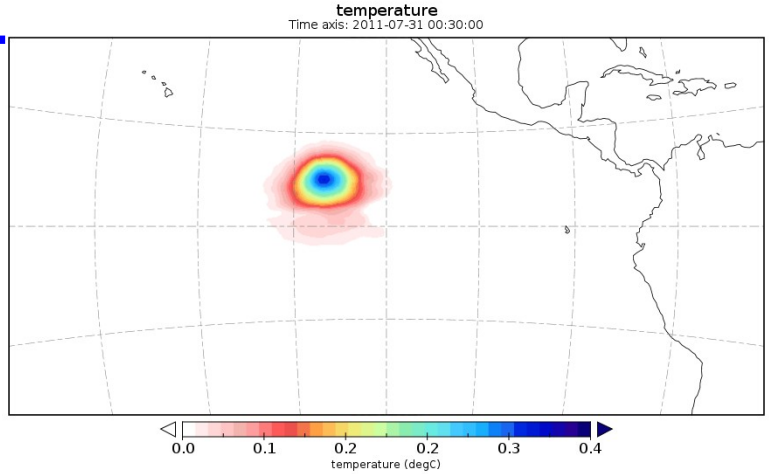
T2m





SST



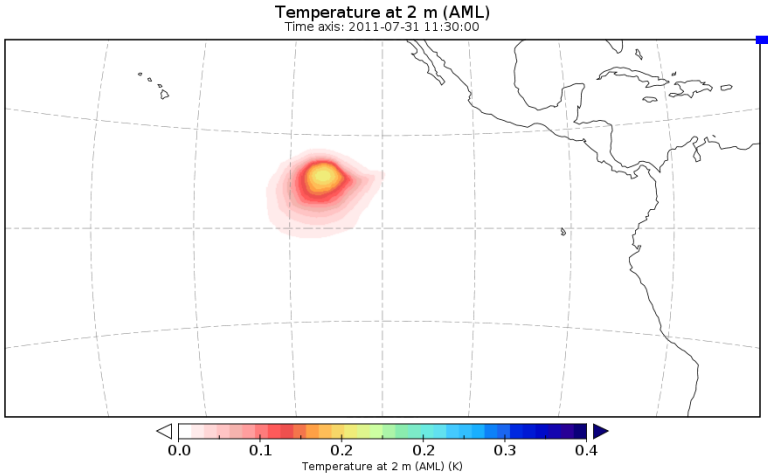


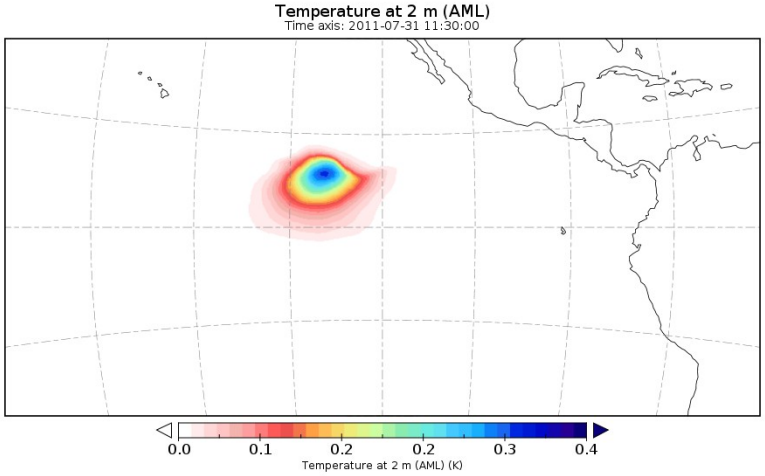
Motivation: initialization shocks

+12h

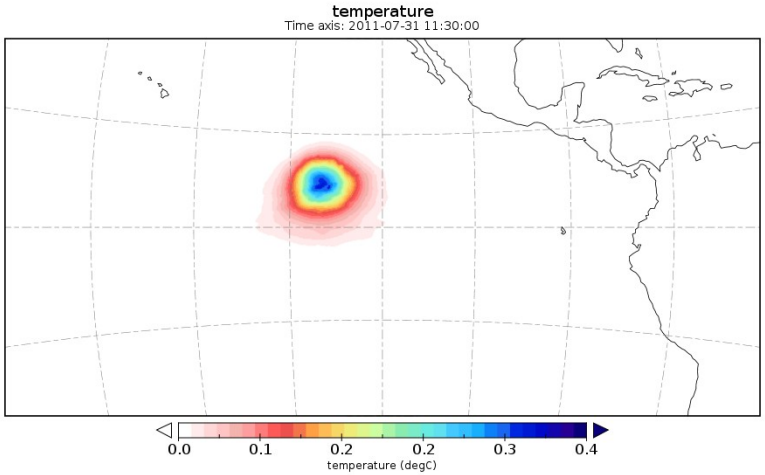
WEAKLY STRONGLY

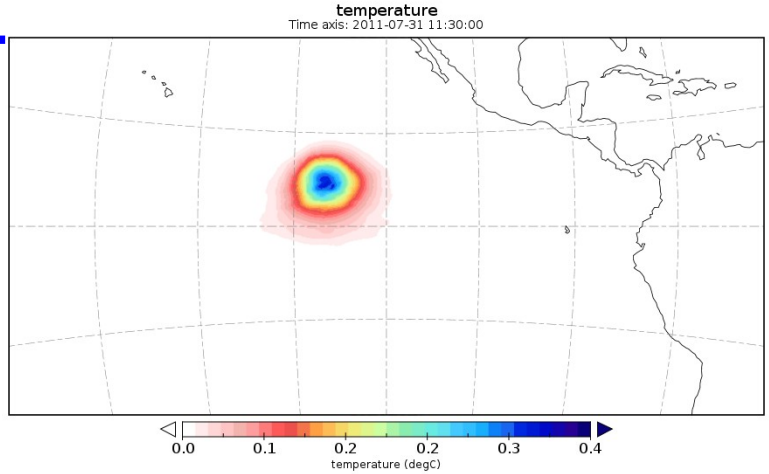
T2m





SST



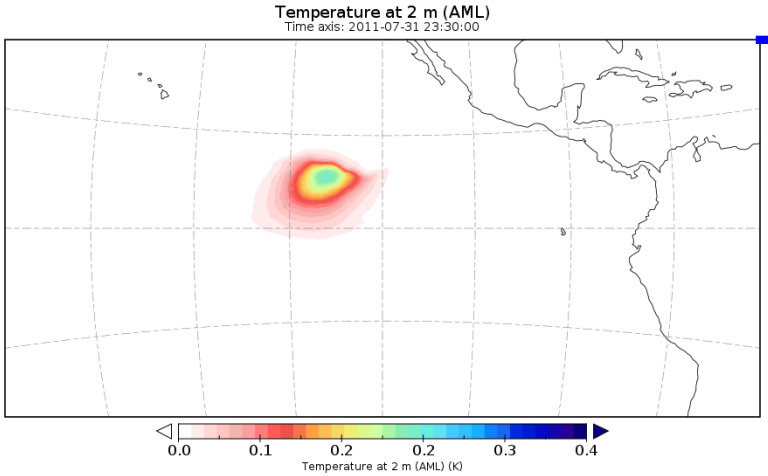


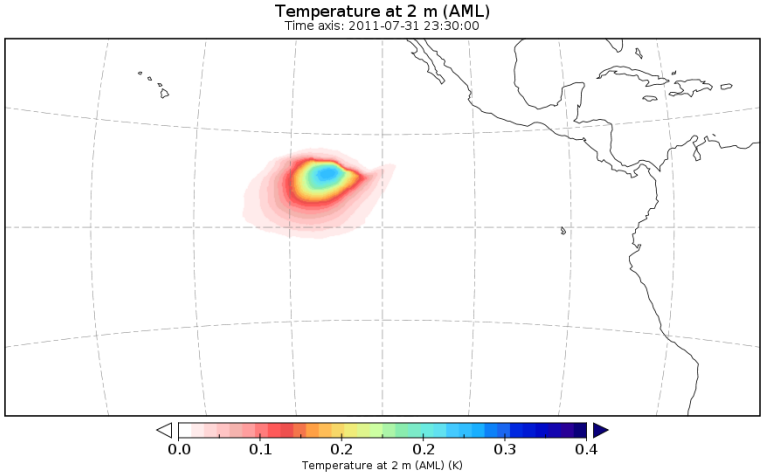
Motivation: initialization shocks

+24h

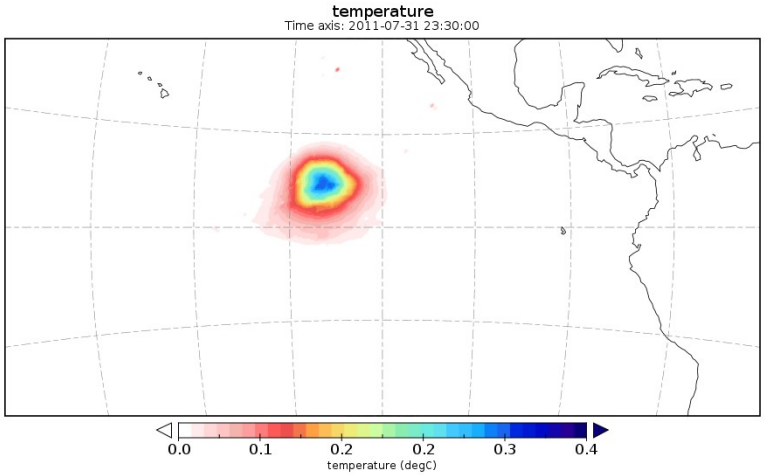
WEAKLY STRONGLY

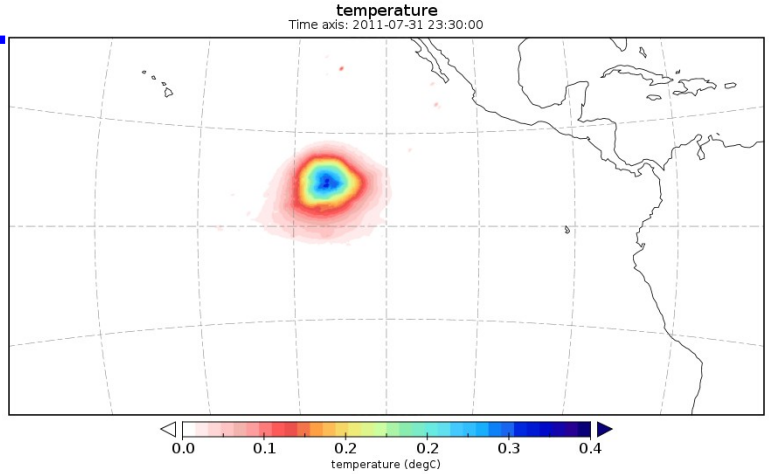
T2m





SST



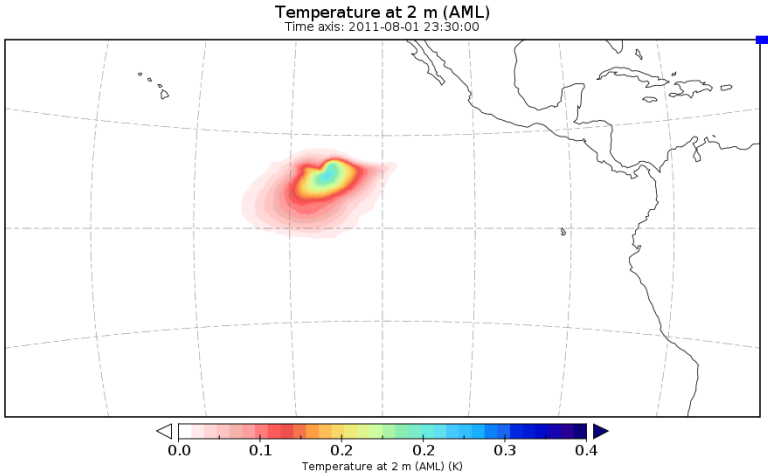


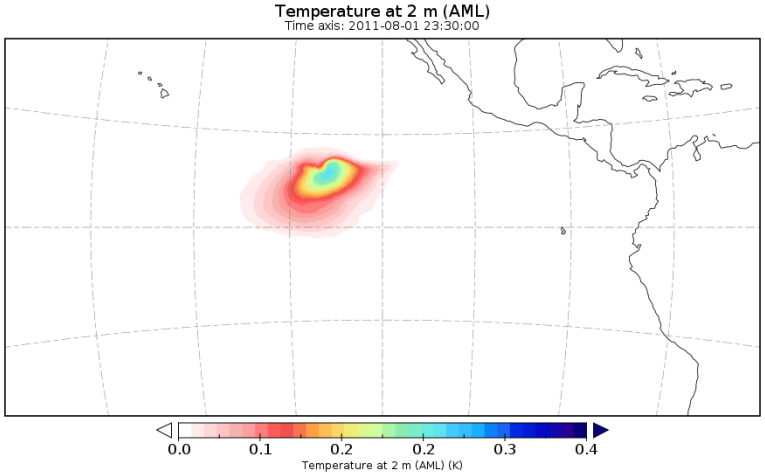
Motivation: initialization shocks

+48h

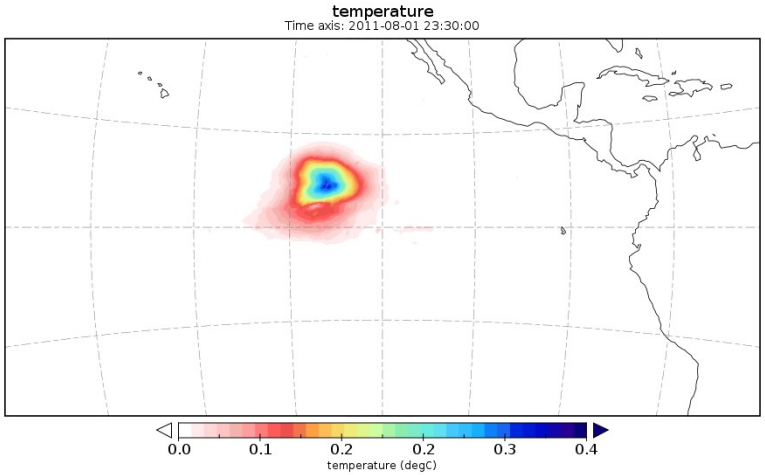
WEAKLY STRONGLY

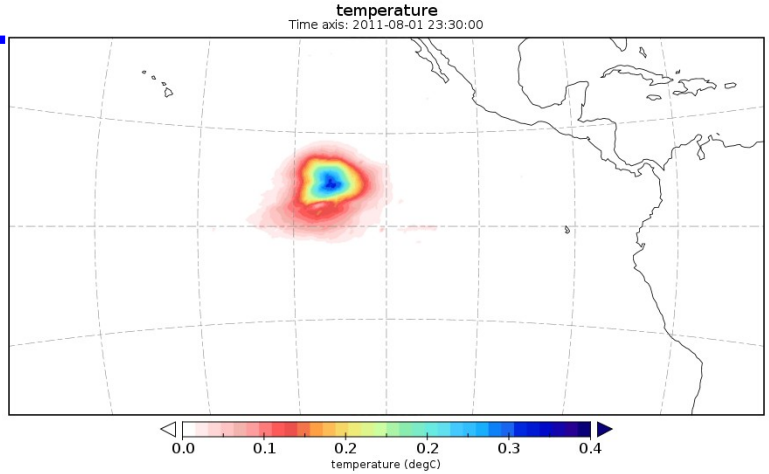
T2m





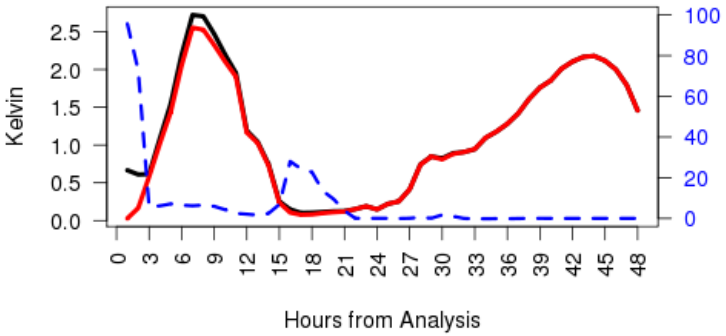
SST



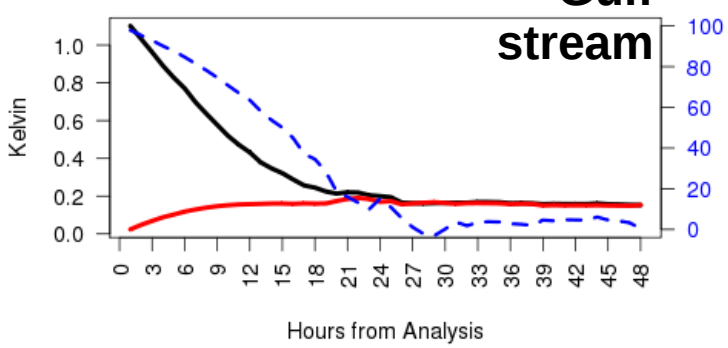


Motivation: initialization shocks

ACC

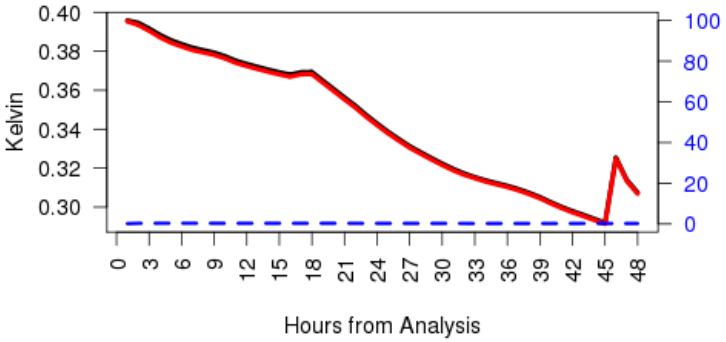


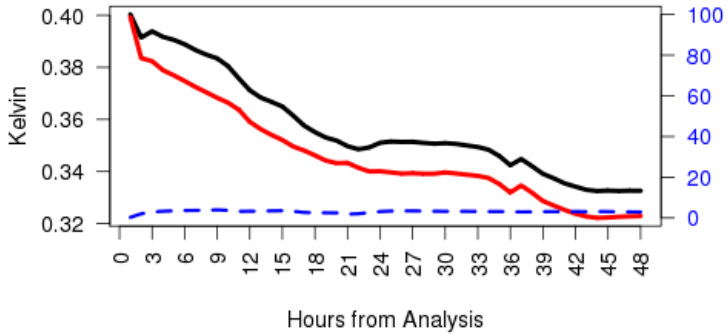
Gulf stream



T2m

SST



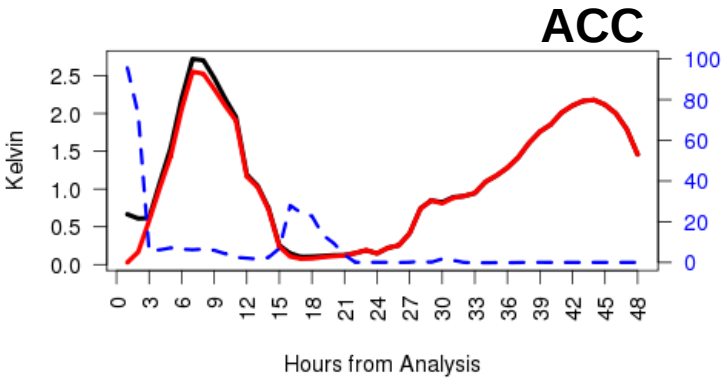


Weakly Coupled DA Analysis Increments
Strongly Coupled DA Analysis Increments
Percentage difference (right axis)

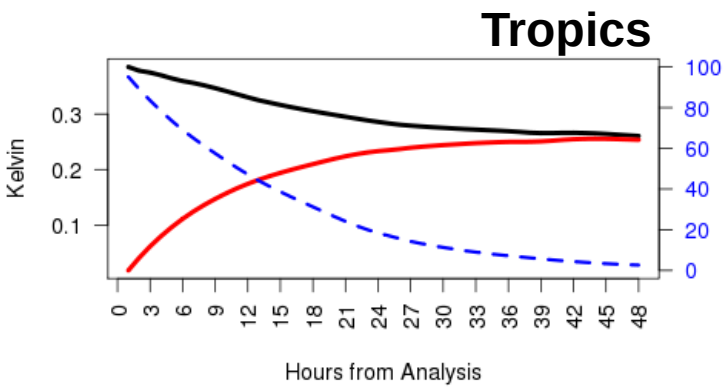
Winter time coupling is weaker → ***Expected lower impact of strongly coupled DA on the prevention of initialization shocks***

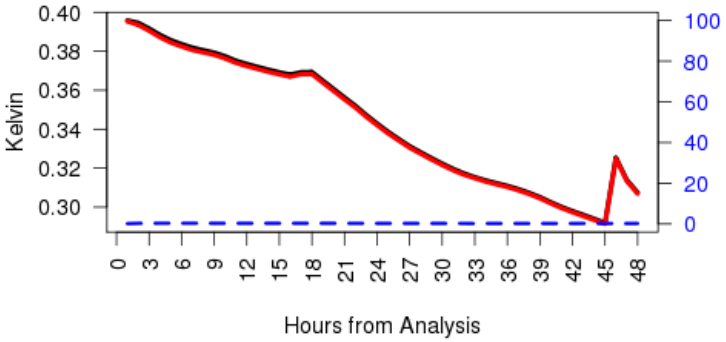
Summer

Motivation: initialization shocks

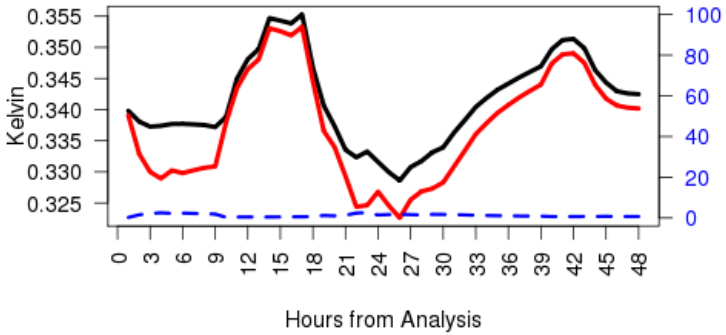


T2m





SST



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

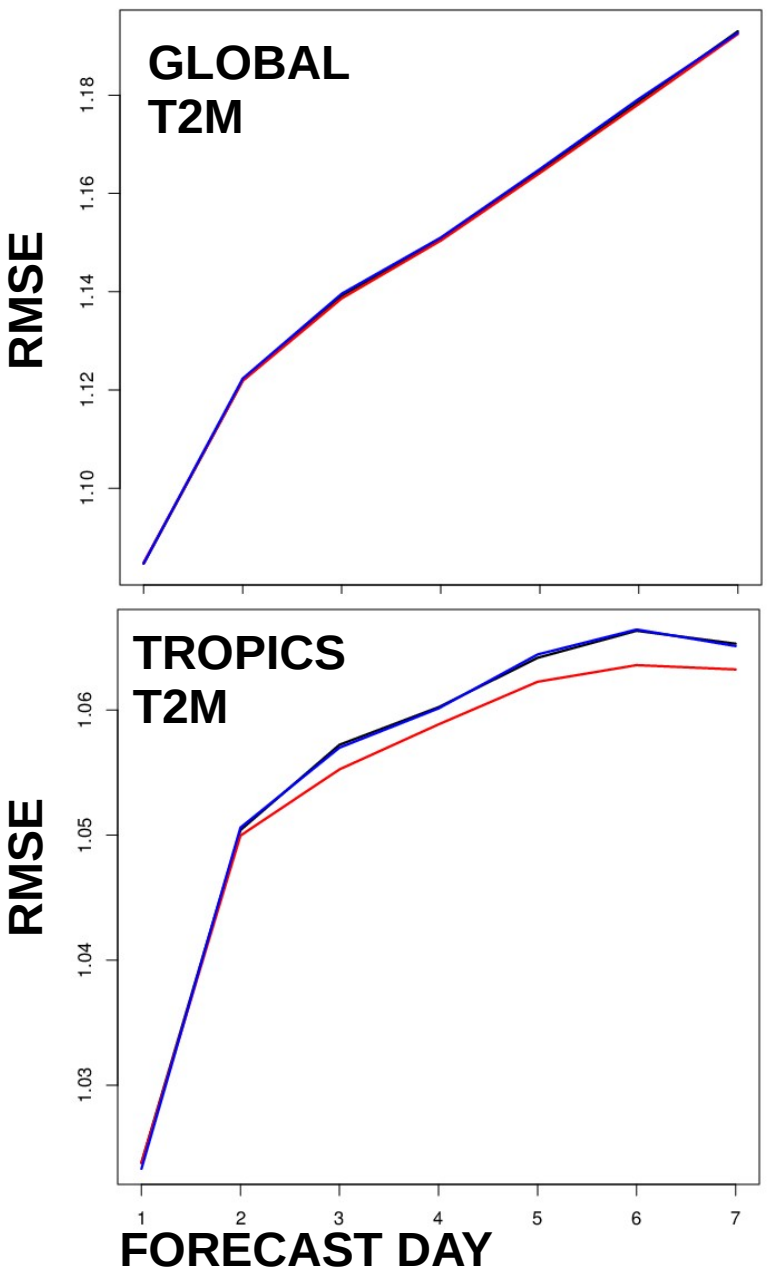
Persisting perturbation in the Tropics → ***Potential impact of strongly coupled DA on long-range predictability***

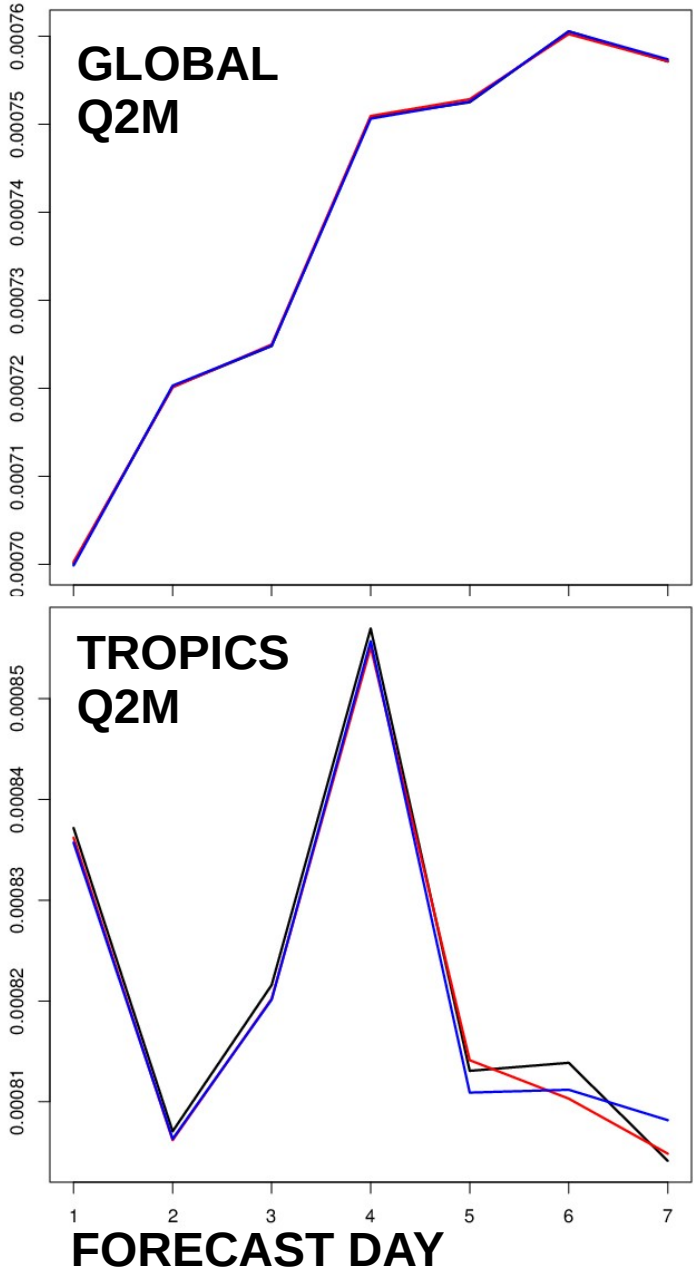
Experimental configuration

Model	NEMO(v3.4)+LIM2
Resolution	ORCA05 (55-25 Km), 75 levels
Period	May to July 2011 (3-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, 1st 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

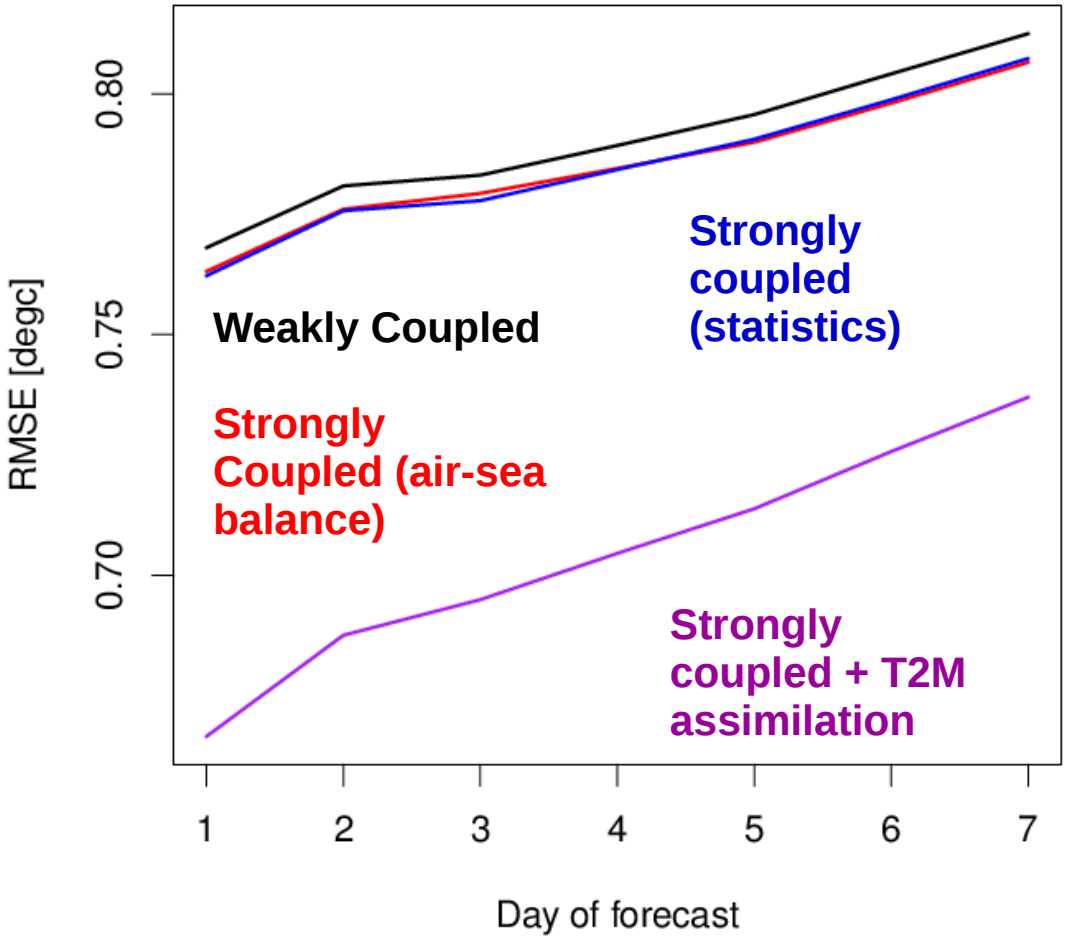
Strongly Coupled (air-sea balance)

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

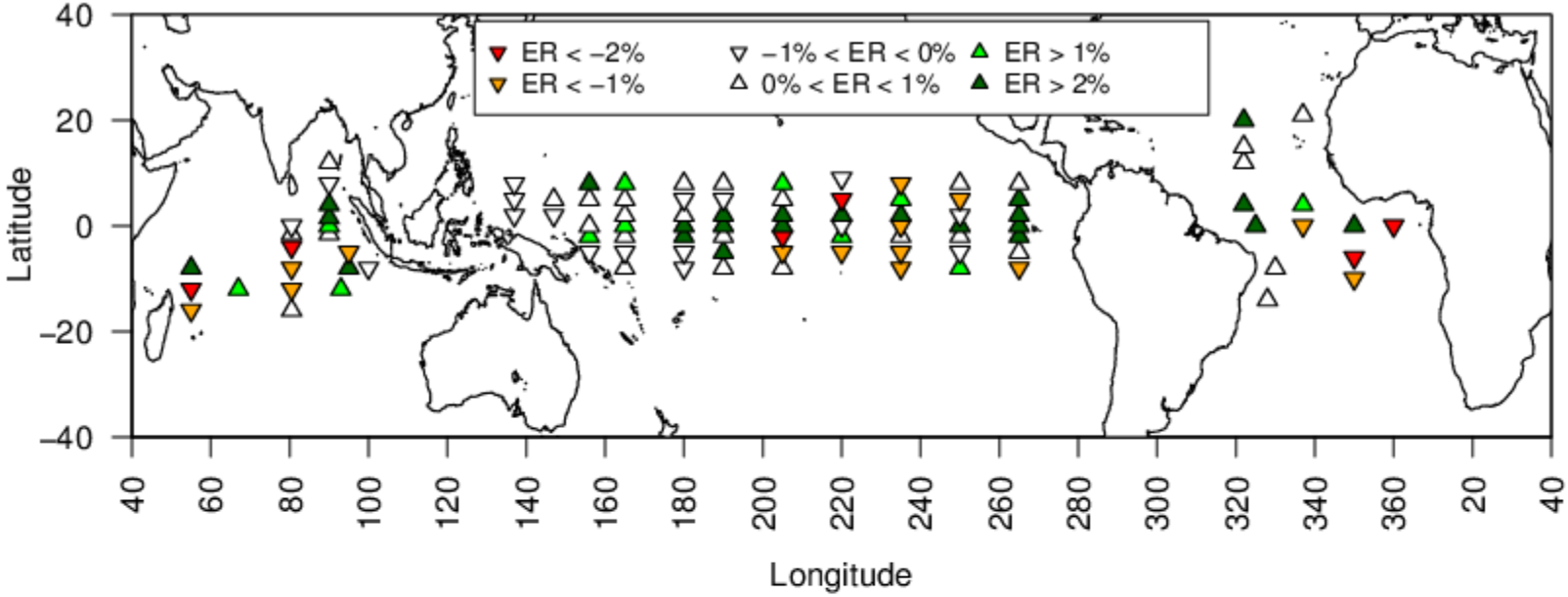
Verification vs T2M from TAO mooring array



Persistent impact through the Forecast length

Comparable results between the two kinds of balance

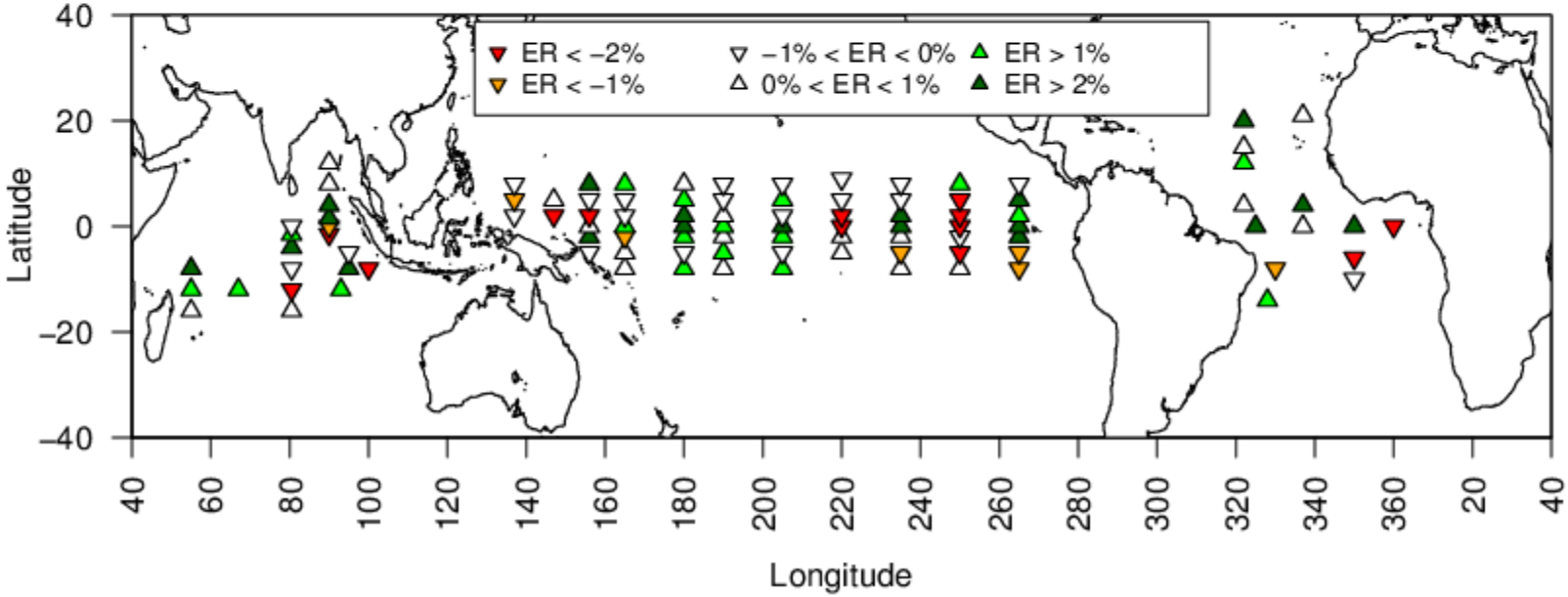
Results: assimilation of marine, impact on air



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***

Thank you

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