The CMCC contribution to ERA-CLIM2

Experiments with coupled covariances and other activities

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Centro Euro-Mediterraneo sui Cambiamenti Climatici

Outline

- **Strongly Coupled DA experiments**
  - Configuration: intermediate complexity experiments
  - Idealized results (single-obs tests)
  - Real-world results

- **Other activities relevant to ERA-CLIM2**
  - Constraining the global ocean heat budget through CERES data
  - Sampling-aware verification methods for reanalyses
  - Sensitivity of GOHC in reanalyses to atmospheric forcing and other datasets
  - Comparing advanced DA methods

Deliverable already sent in Jan 2017
Manuscript on “Strongly Coupled DA experiments” in review for MWR

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

A simplified air-sea balance operator

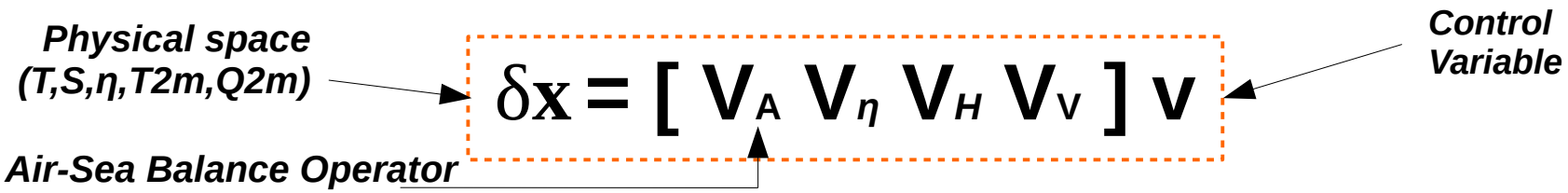
To couple the sea-surface variables with 2m atmospheric variables, balances might be thought either purely statistical, or purely analytical, or mixed (balanced + unbalanced components)
We introduce a balance operator that maps the increments of SST onto those of ($\mathbf{T_{2m}}$, $\mathbf{Q_{2m}}$)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

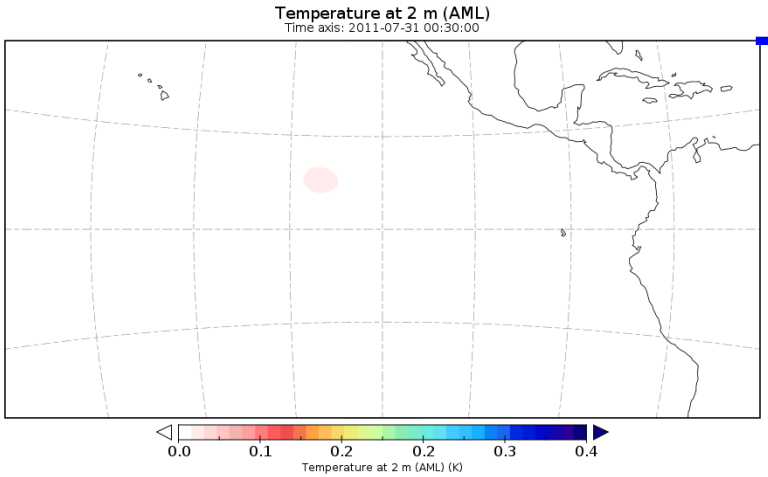
Where the transfer coefficients (**Ce, Ch** for Evaporation and Sensible heat, respectively) are assumed not to depend on **SST** and taken from the fully non-linear model. *(Might be relaxed with simple parametric formulations)*

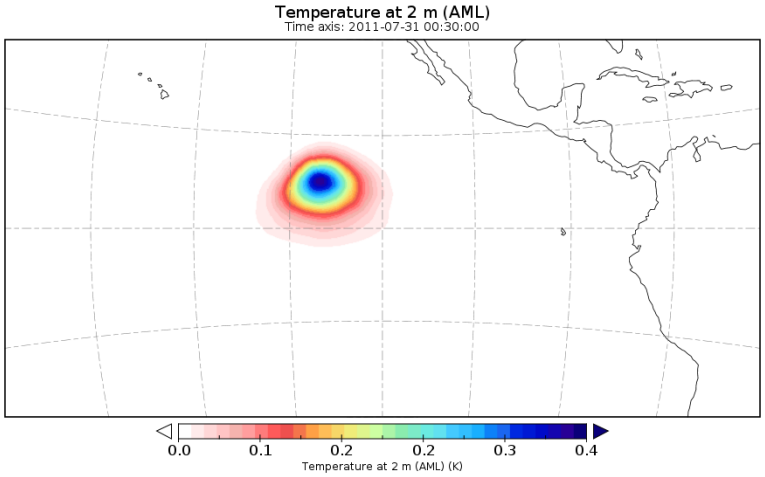


Motivation: initialization shocks

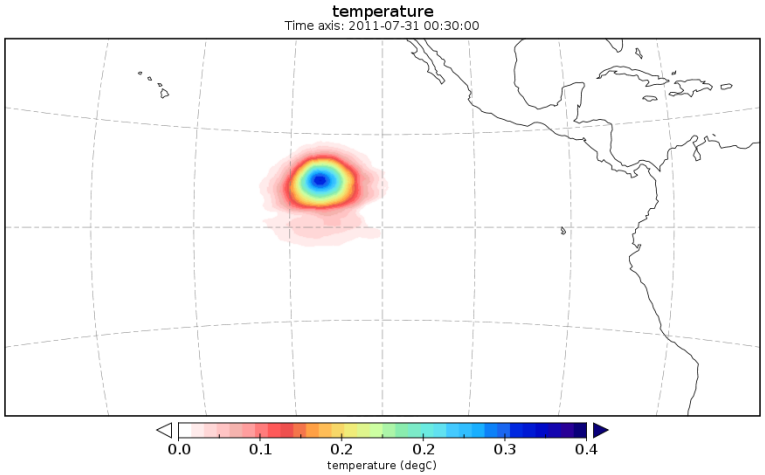
WEAKLY **STRONGLY** **+01h**

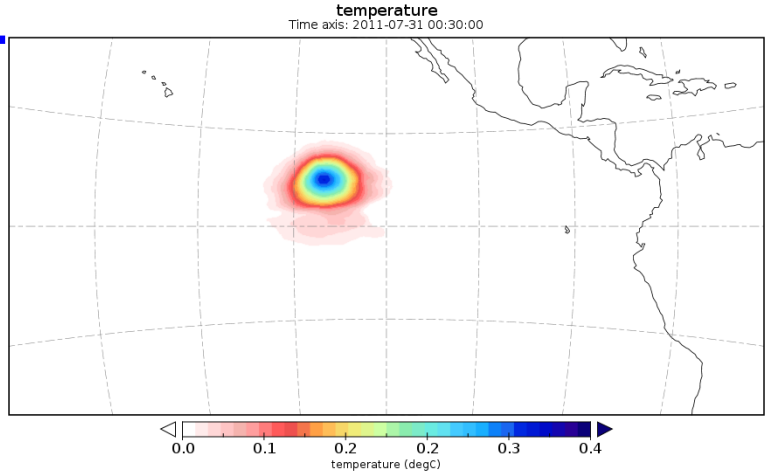
T2m





SST

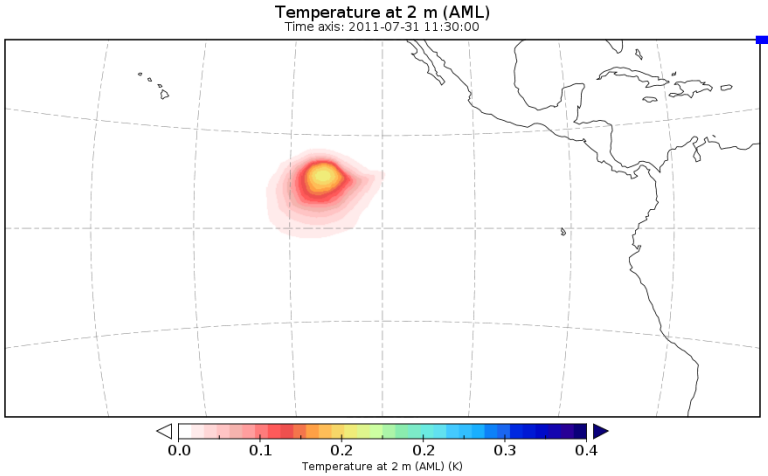


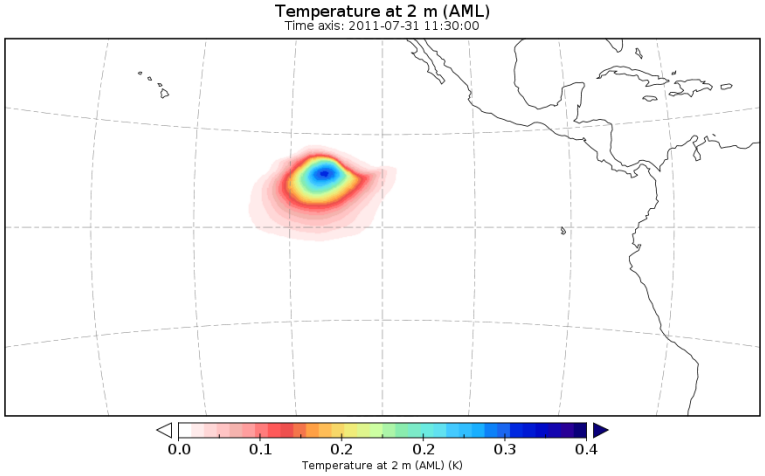


Motivation: initialization shocks

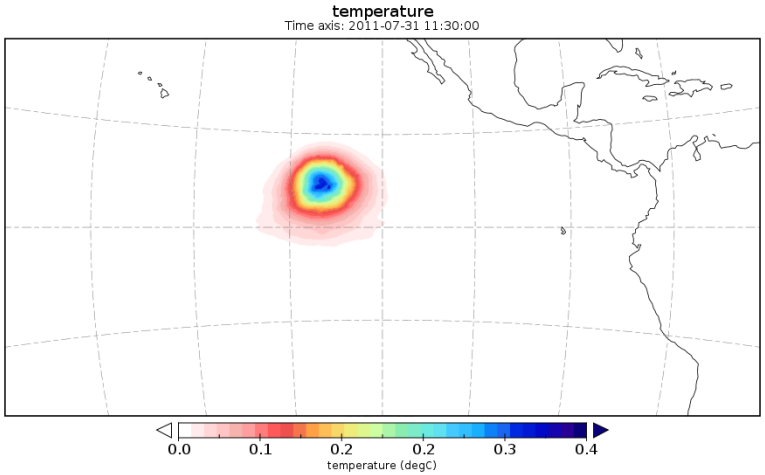
WEAKLY **STRONGLY** **+12h**

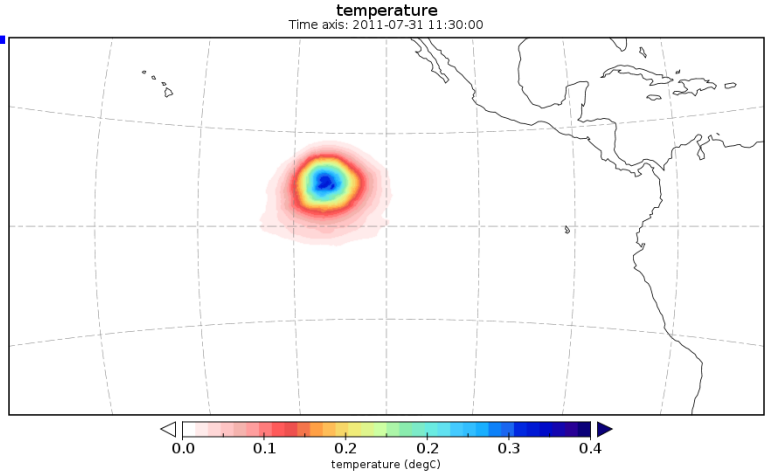
T2m





SST

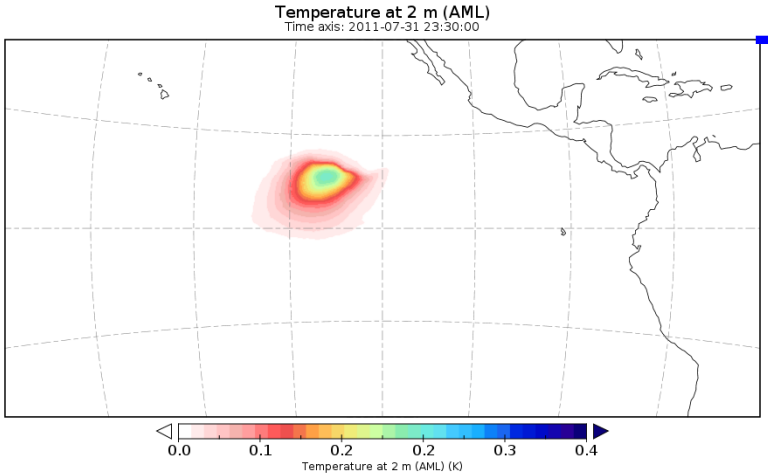


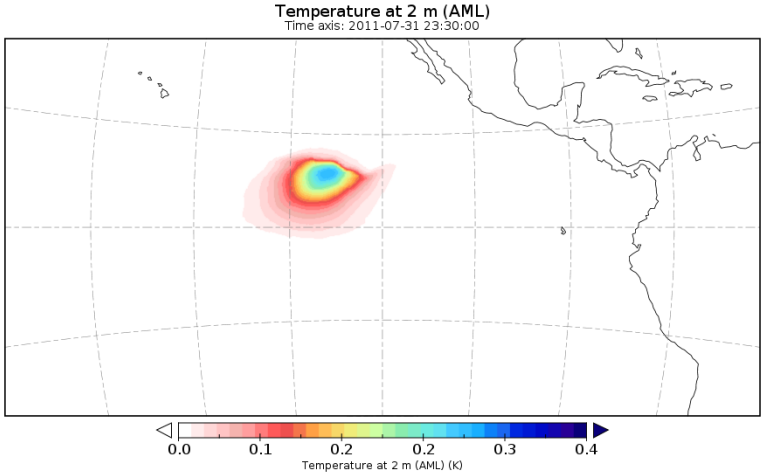


Motivation: initialization shocks

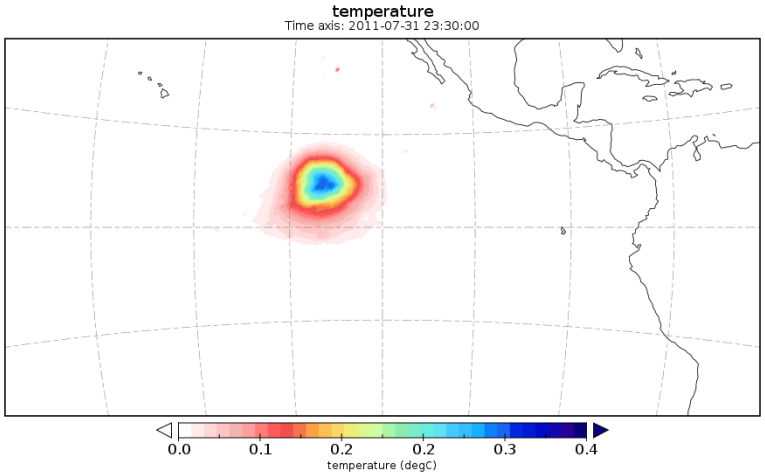
WEAKLY **STRONGLY** **+24h**

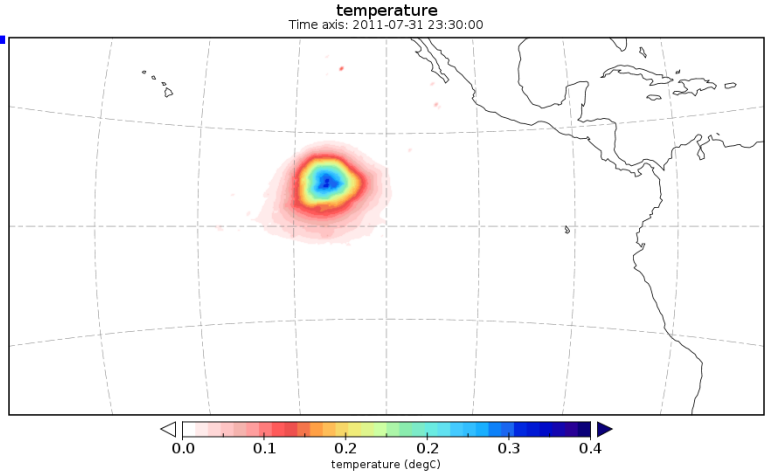
T2m





SST

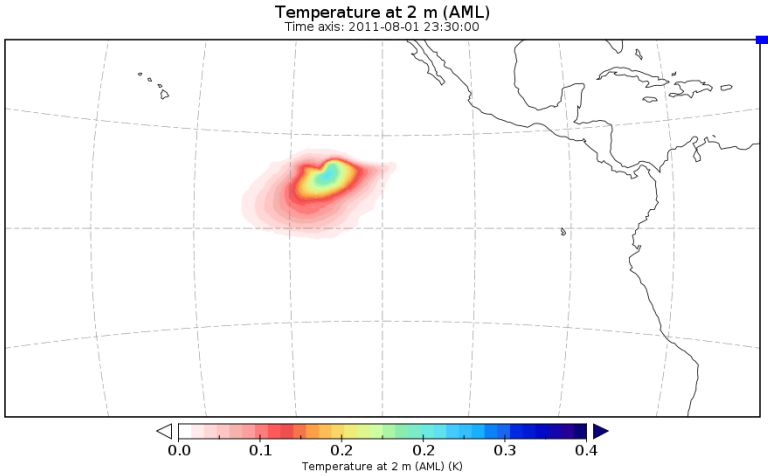


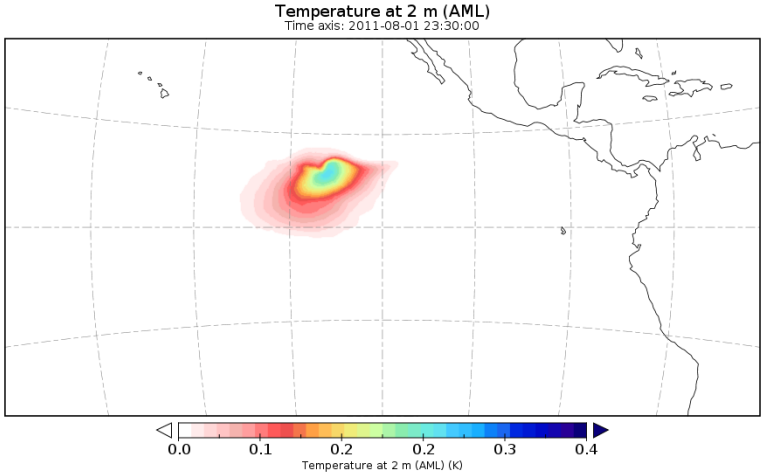


Motivation: initialization shocks

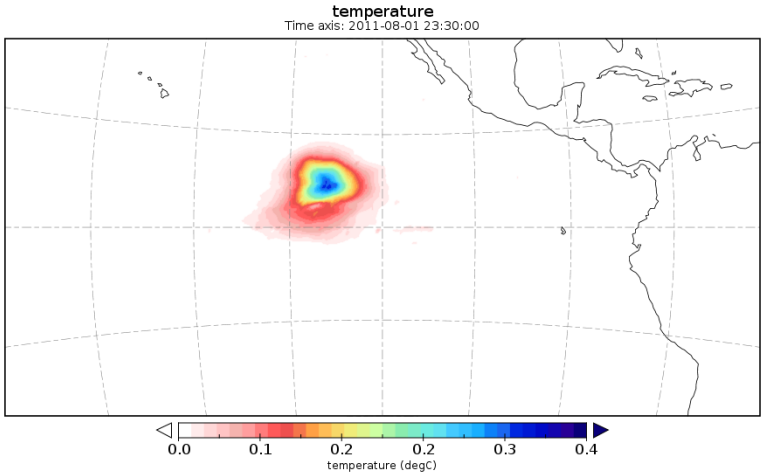
WEAKLY **STRONGLY** **+48h**

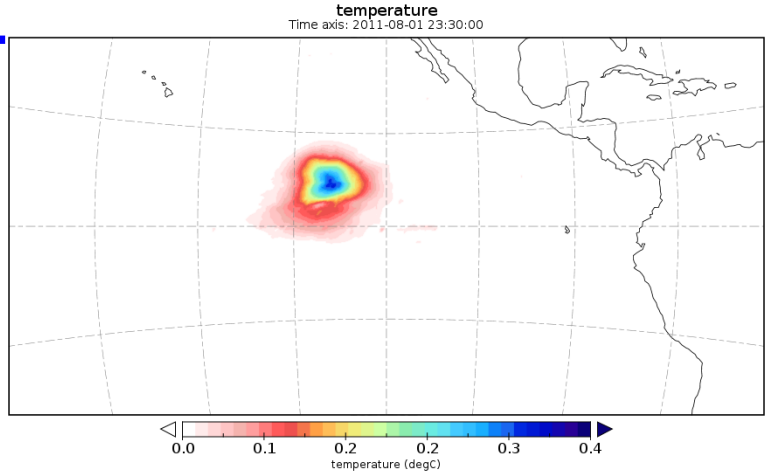
T2m





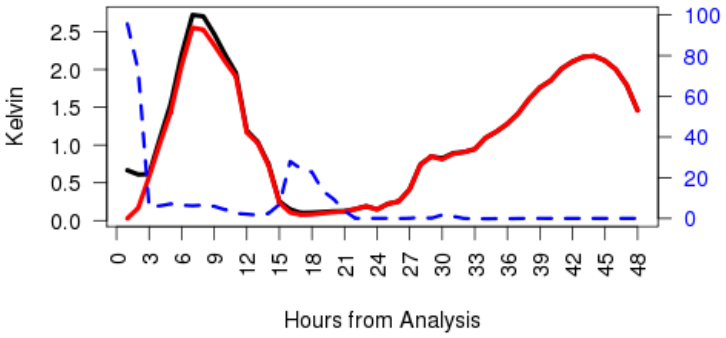
SST



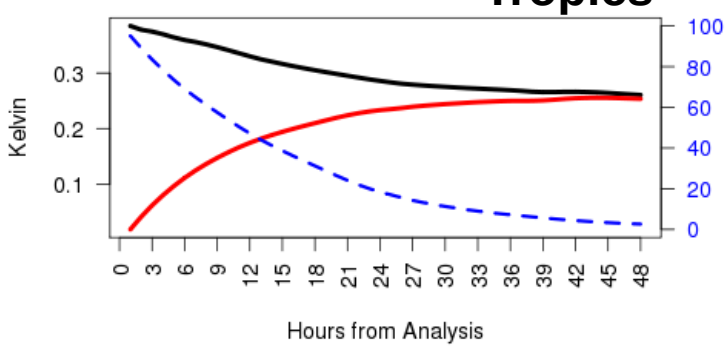


Motivation: initialization shocks

ACC

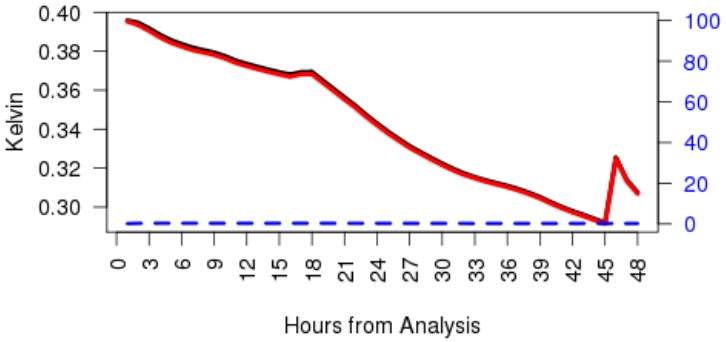


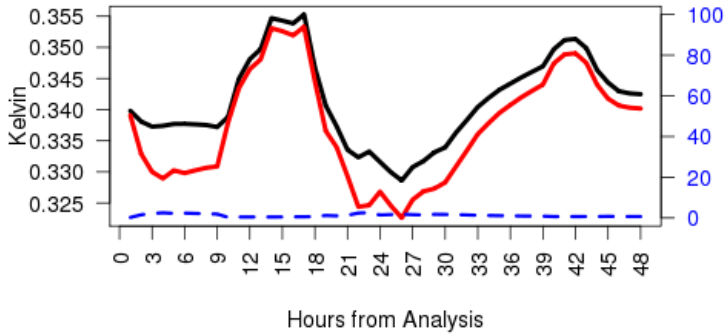
Tropics



T2m

SST





Weakly Coupled DA Analysis Increments

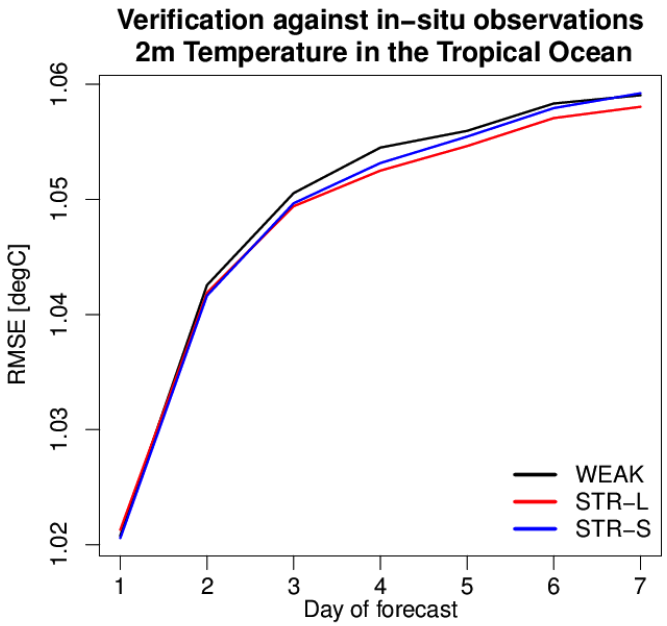
Strongly Coupled DA Analysis Increments

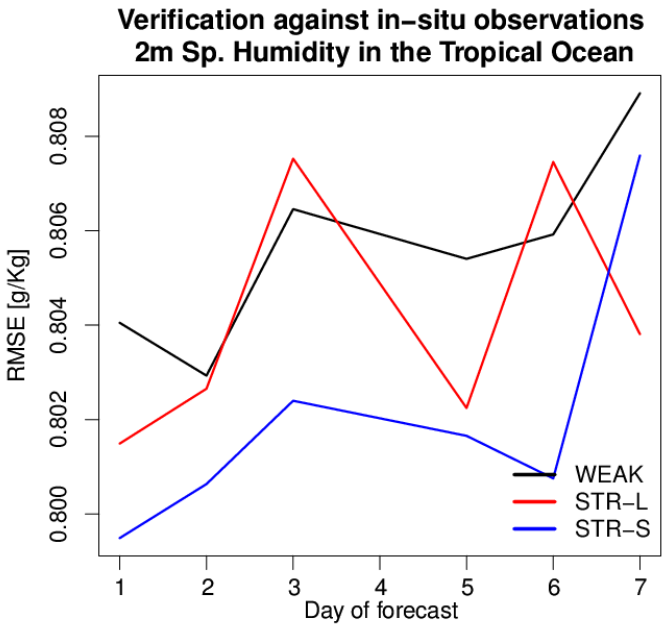
Percentage difference (right axis)

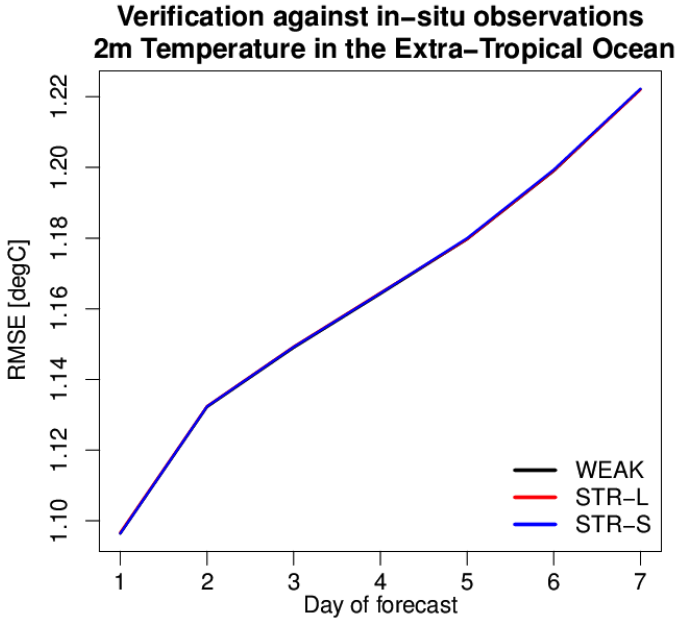
Persisting perturbation in the Tropics → ***Potential impact of strongly coupled DA on long-range predictability***

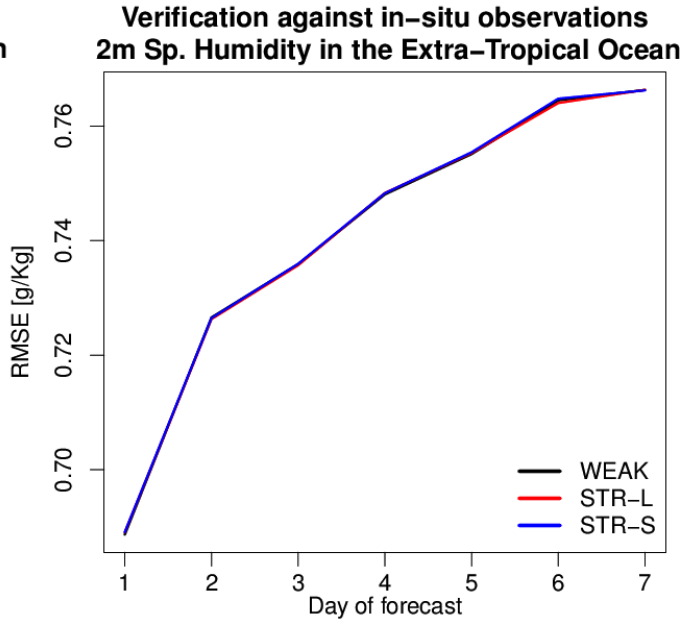
Summer

Results: assimilation of marine, impact on air









Weakly Coupled

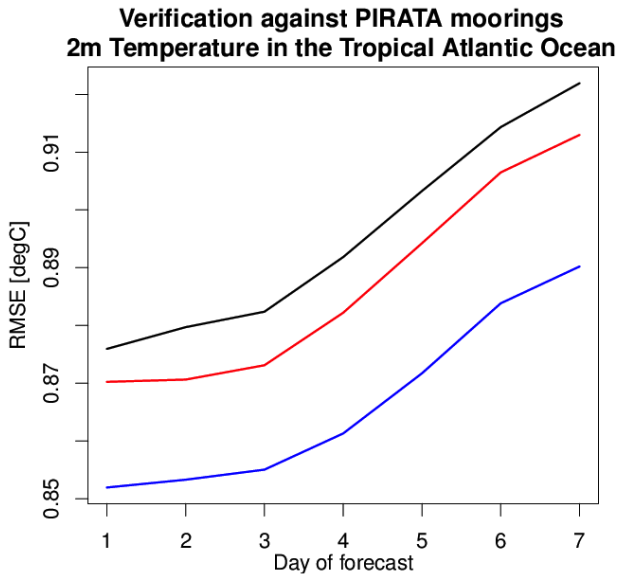
Strongly Coupled (air-sea balance)

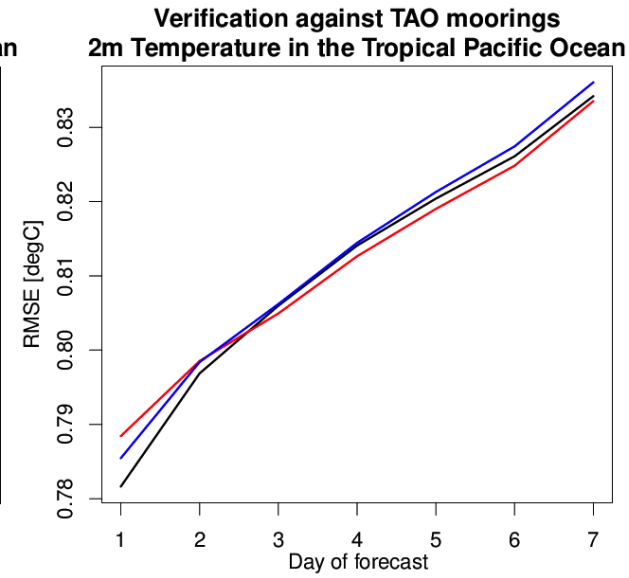
Strongly coupled (statistics)

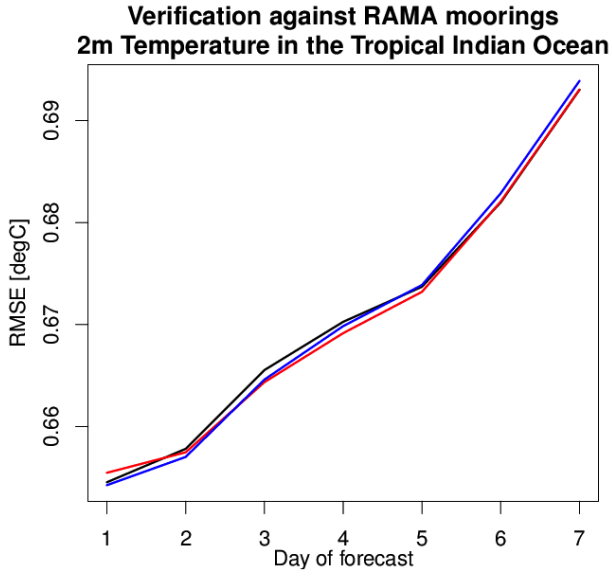
Impact Increases With Forecast length

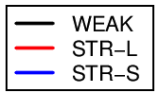
Positive impact in the Tropics

Results: assimilation of marine, impact on air









Weakly Coupled

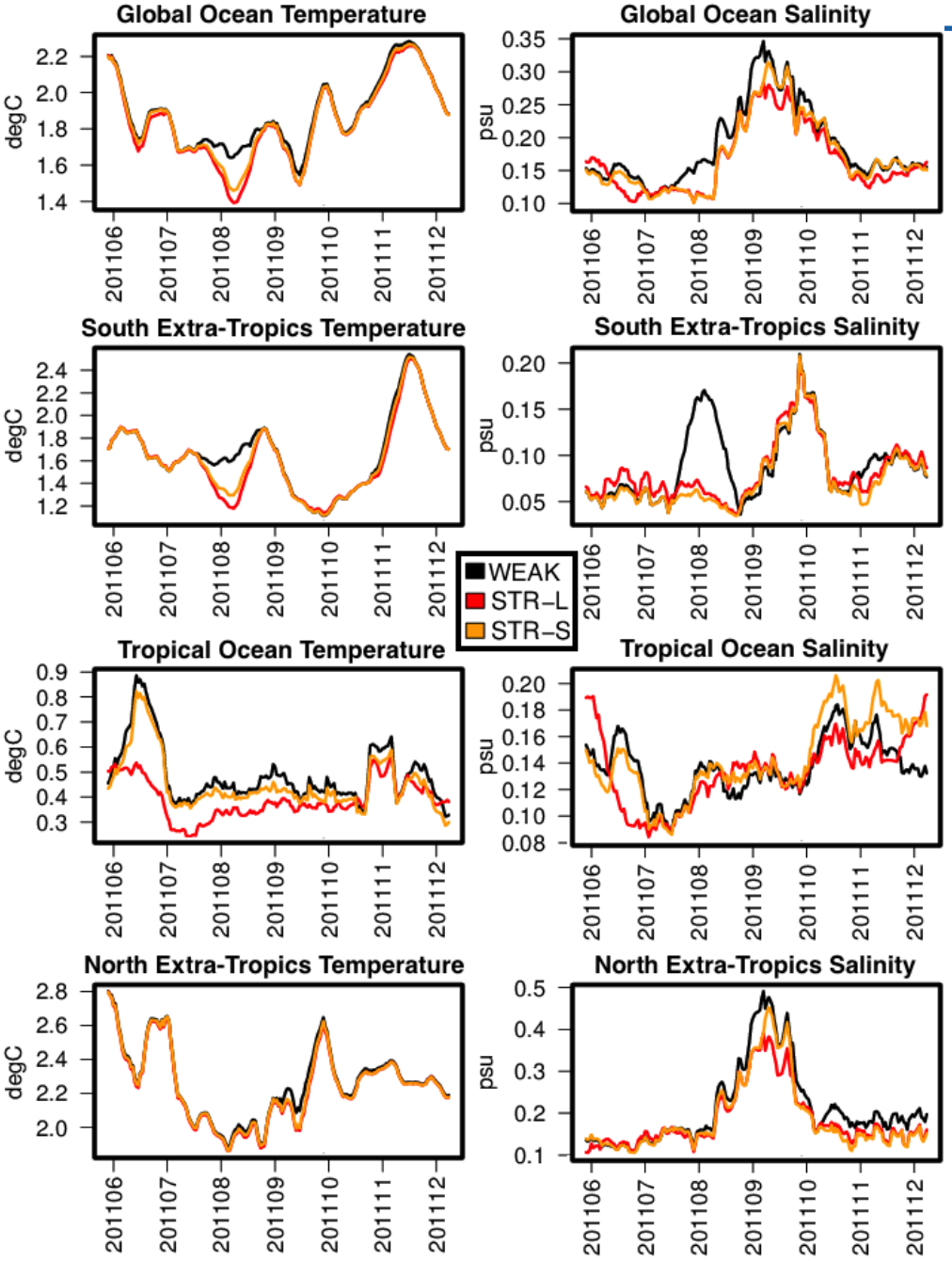
Strongly Coupled (air-sea balance)

Strongly coupled (statistics)

Persistent impact through the Forecast length in the Atlantic. In other basins emerges later

Positive everywhere, Although significant improvements only in the Atlantic Ocean

Results: assimilation of marine, impact on air



Weakly Coupled

Strongly Coupled (air-sea balance)

Strongly coupled (statistics)

Improvements for Ocean temperature in the Tropics, Negligible elsewhere

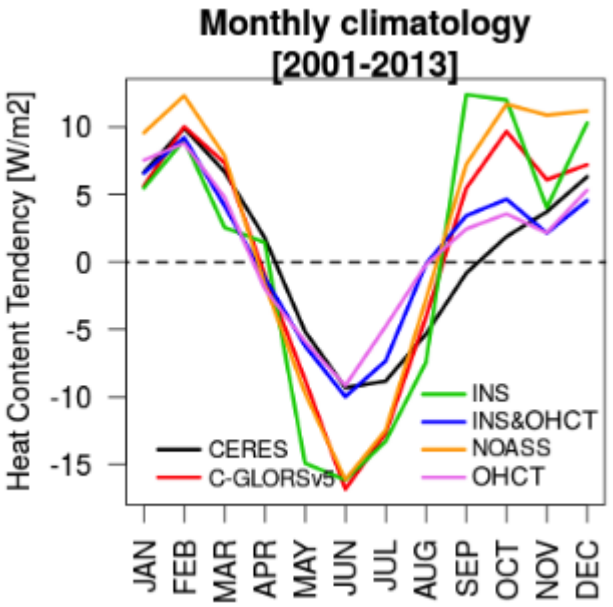
Assimilating EBAF-TOA Earth's Energy Imbalance

Introducing Constraint on Monthly Global Ocean Heat Content Tendencies (OHCT) for use in global ocean reanalyses

$$J(d\mathbf{x}) = d\mathbf{x}^T \mathbf{B}^{-1} d\mathbf{x} + (\mathbf{H}d\mathbf{x} - \mathbf{d})^T \mathbf{R}^{-1} (\mathbf{H}d\mathbf{x} - \mathbf{d}) + (dEEI - d^{CERES})^T R_{EEI}^{-1} (dEEI - d^{CERES})$$

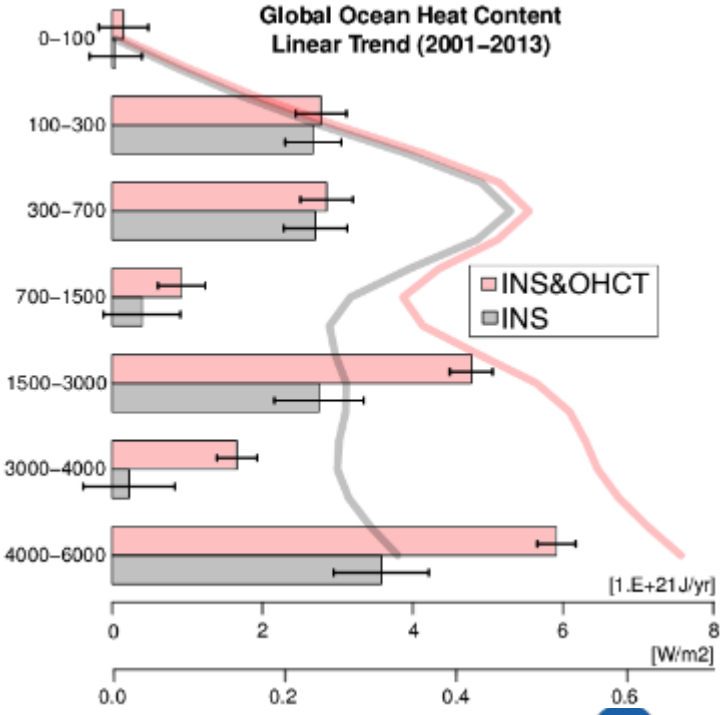
Variational Cost function augmented with OHCT penalty term

Use of CERES (EBAF-TOA Ed4) Earth Energy Imbalance's data to constrain slowly-varying Ocean Heat Content through assimilation



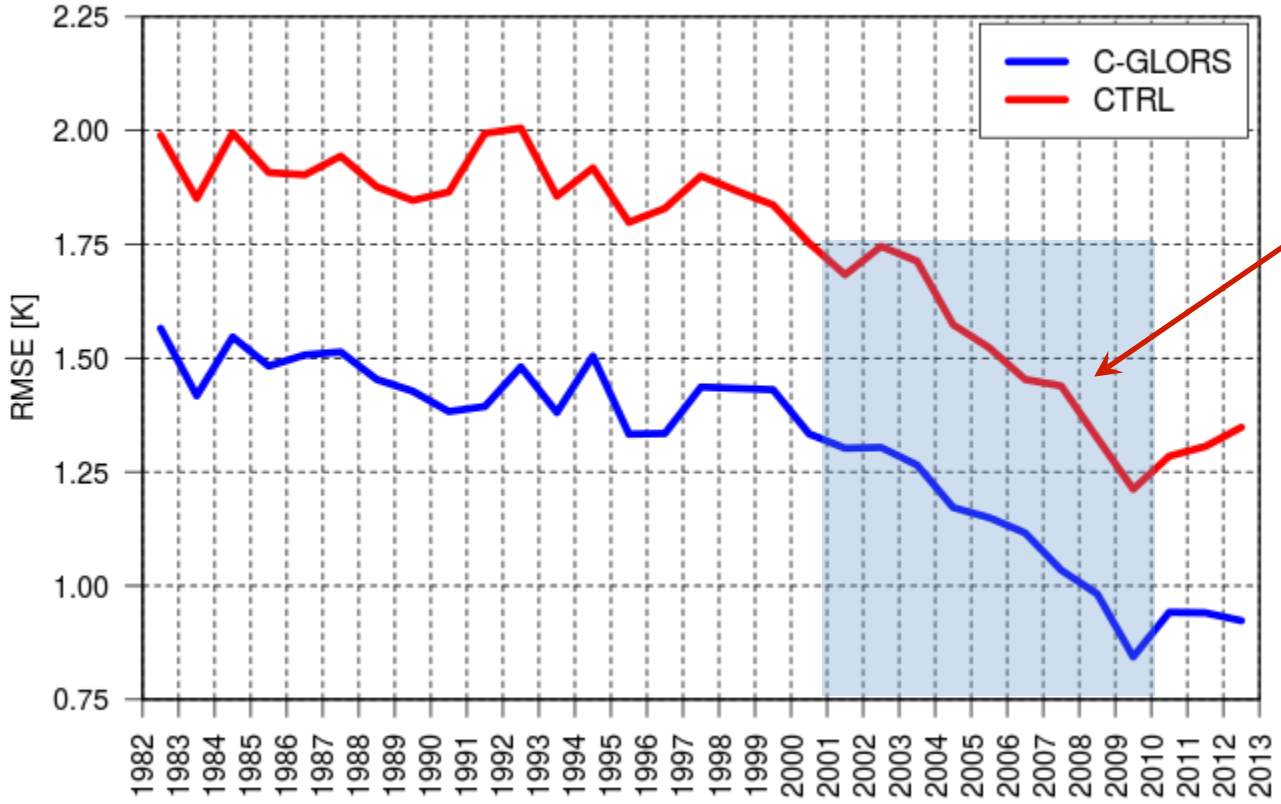
Improved Seasonal Cycle and Monthly variability

Hidden energy Issue resolved: Increase of heat Below 1500m



Sampling-aware validation of reanalyses

Temperature (top 100m) Global RMSE as a function of time
C-GLORS ocean reanalyses

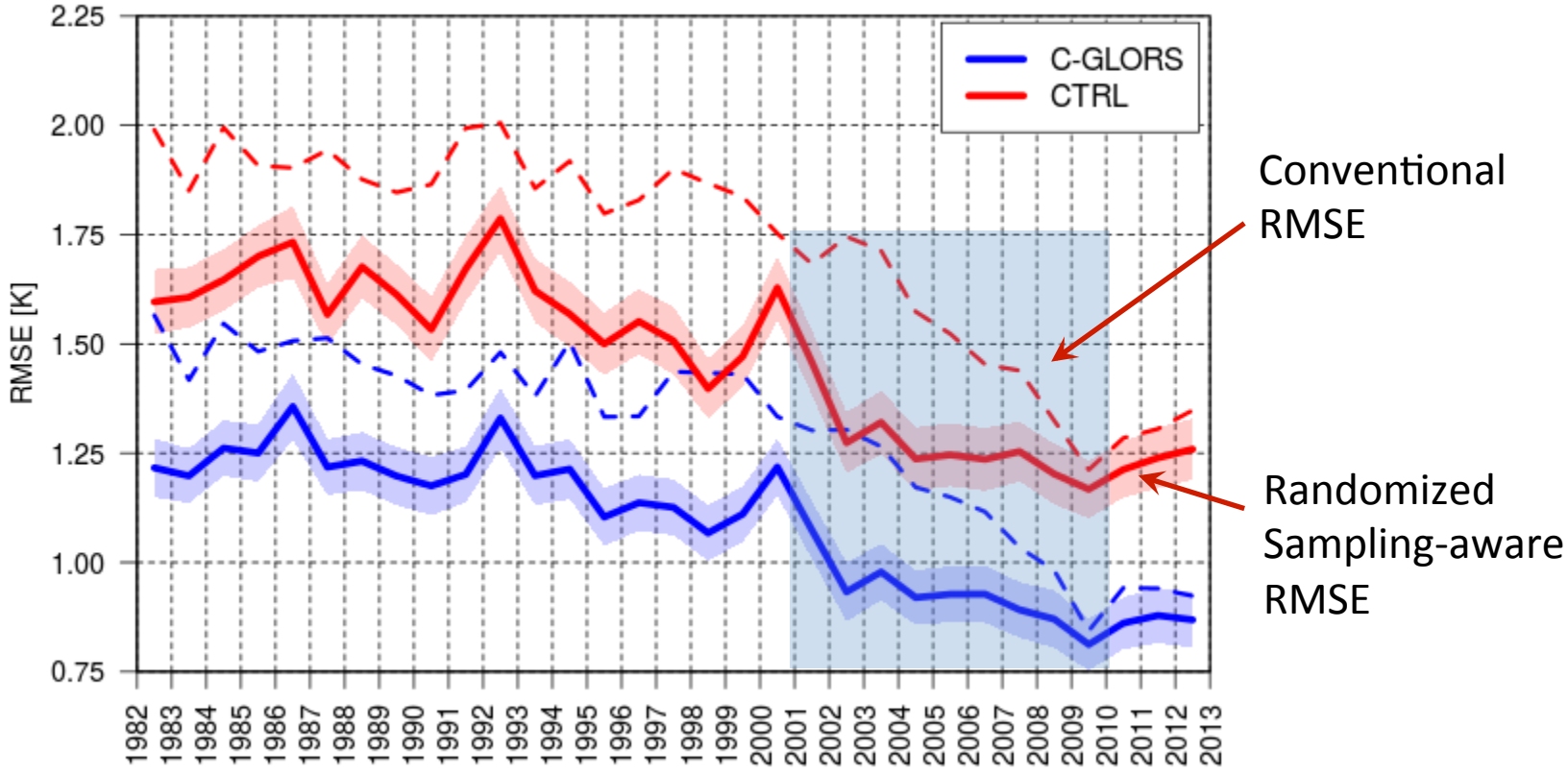


Conventional RMSE

Abrupt RMSE decrease corresponding to Argo deployment period questions the reliability of common verification methods, given the limited sampling of verifying observations in early periods

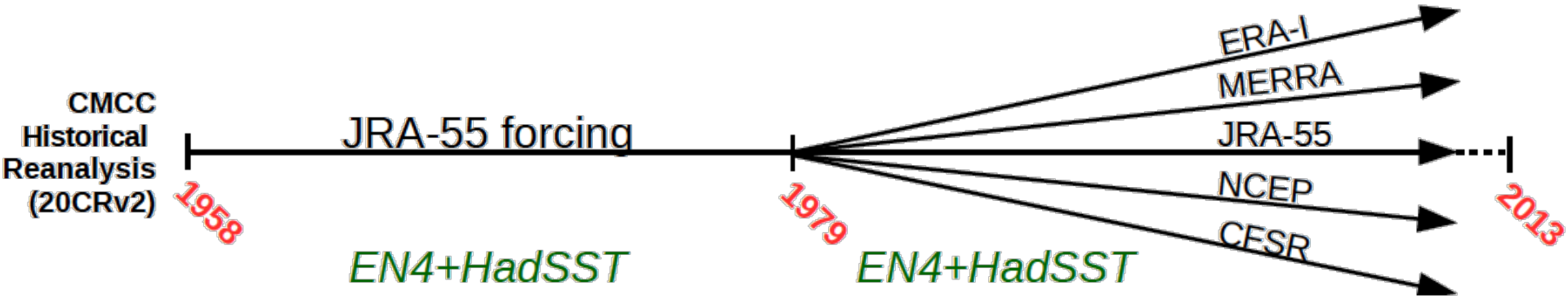
Sampling-aware validation of reanalyses

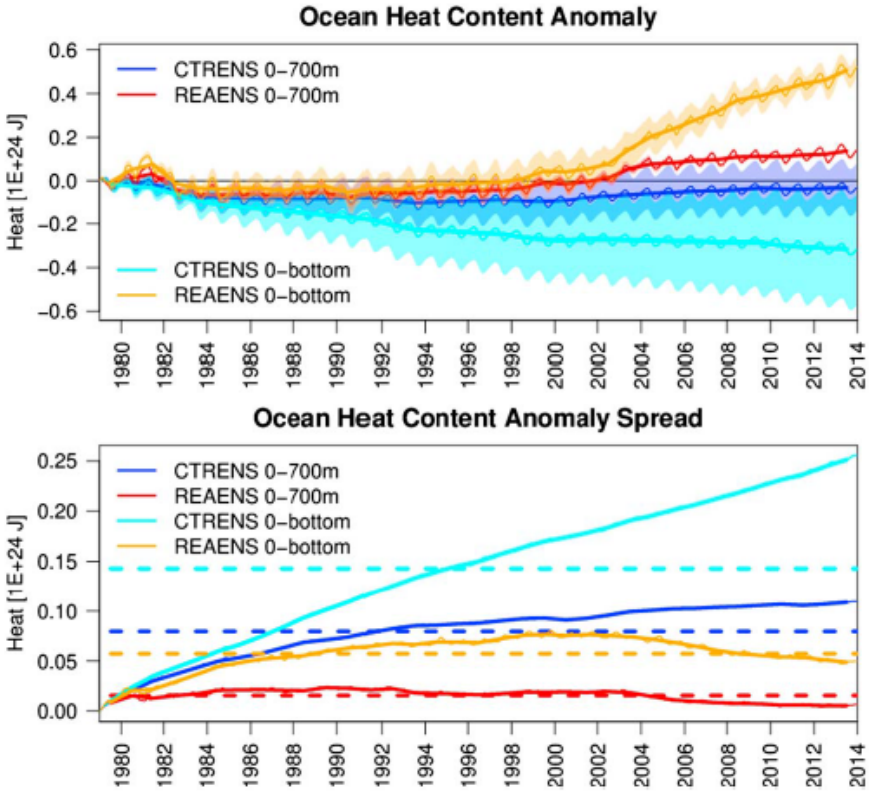
Temperature (top 100m) Global RMSE as a function of time
C-GLORS ocean reanalyses



More sophisticated approaches should be considered for accuracy assessment during observation poor periods: here, a randomization of the choice of verifying observations to preserve homogeneous sampling with time shows a rather constant rate of accuracy increase

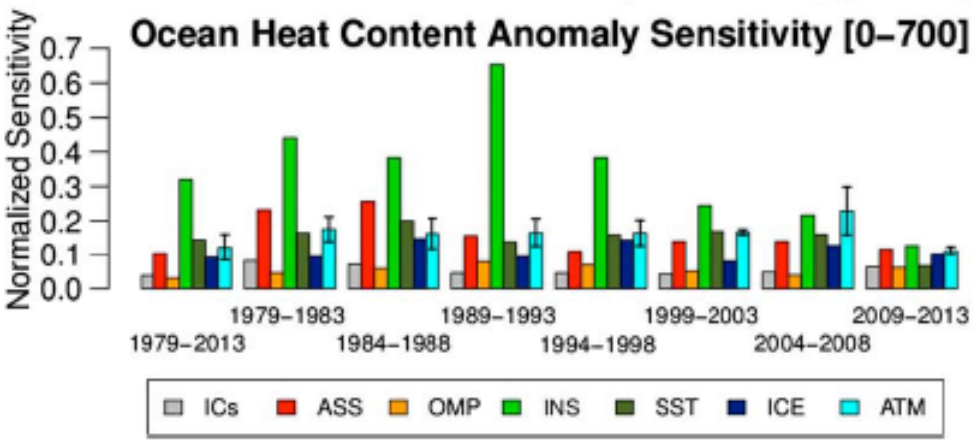
Sensitivity of GOHC to atmospheric forcing





OHC mean and spread from multi-forcing system (CTRs and REAs)

Sensitivity compared to other sources of errors



Storto et al., 2016, GRL, Sensitivity of global ocean heat content from reanalyses to the atmospheric reanalysis forcing

Comparing advanced DA methods in the ocean

OceanVar has been extended to allow hybrid ensemble-variational four-dimensional variational data assimilation through the implementation of a light TL/AD model and the use of augmented control vector to mix climatological (static) and ensemble-derived (flow-dependent covariances).
The hybrid can be conceived in a more general way, i.e. to mix two or more sets of background-error covariances (e.g. different scales, etc.)

For potential use in both reanalyses and operational oceanography

Simplified TL/AD Model That Evolves only T/S (advection, diffusion, air-sea fluxes considered). SL and currents through static balances at every TL timestep

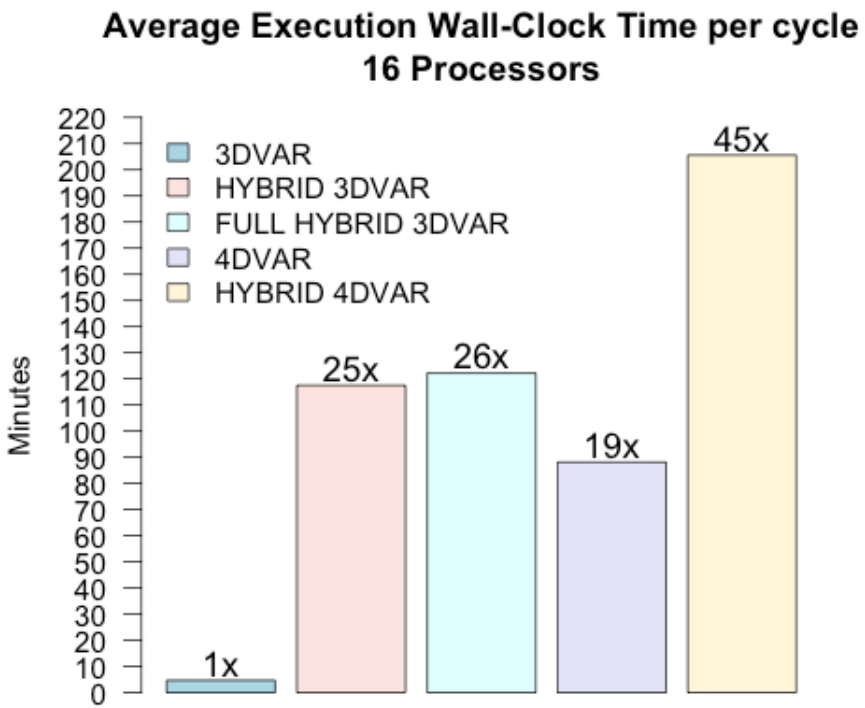
$$J(\mathbf{v_c}, \mathbf{v_e}) = \frac{1}{2} \sum_{t=1}^{t=K} \left(\mathbf{H}\mathbf{M}_{0\rightarrow t}(\beta_c \mathbf{V_c}\mathbf{v_c} + \beta_e \mathbf{V_e}\mathbf{v_e}) - \mathbf{d_t}\right)^{\mathrm{T}} \mathbf{R_t}^{-1} \left(\mathbf{H}\mathbf{M}_{0\rightarrow t}(\beta_c \mathbf{V_c}\mathbf{v_c} + \beta_e \mathbf{V_e}\mathbf{v_e}) - \mathbf{d_t}\right) + \frac{1}{2}\mathbf{v_c}^{\mathrm{T}}\mathbf{v_c} + \frac{1}{2}\mathbf{v_e}^{\mathrm{T}}\mathbf{v_e}.$$

Hybrid weight that determines the relative importance of flow-dependent BECs

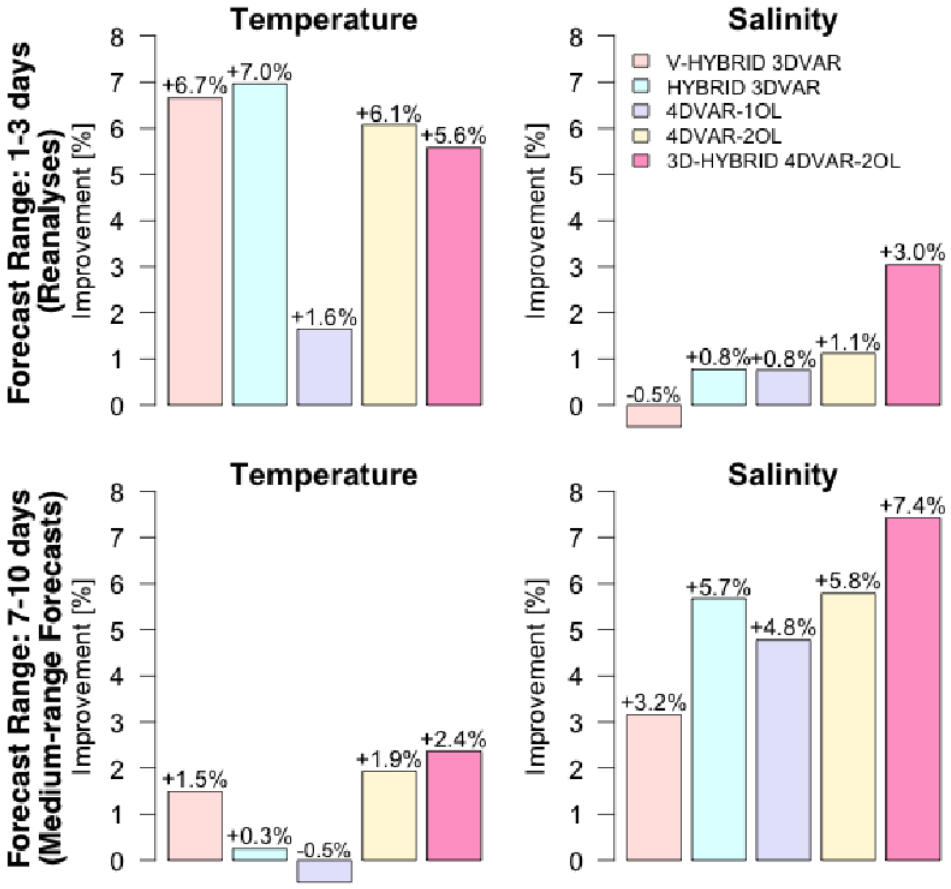
Hybrid scheme through augmented control vector, formed by two parts, Corresponding respectively to climatological and ensemble covariances

Comparing advanced DA methods in the ocean

4-year Experiments (2010-2013)
Coarse resolution configuration
(NEMO 3.6/ORCA2L31)



Comparison of computational time increase



Comparison of forecast skill score metrics (RMSE)

Thank you