# Ensemble experiments for global ocean reanalyses and air-sea coupled covariances

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# CMCC Contribution to ERA-CLIM2 WP2

- Global ocean ensemble generation for different applications (flow-dependent background-error covariances, initial conditions for seasonal predictions, probabilistic ocean reanalyses)

*Sensitivity of global ocean heat content to atmospheric forcing and other uncertainties*

- Ensemble-derived coupled covariances for use in strongly coupled data assimilation

*Towards idealized strongly coupled data assimilation*

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# Sensitivity of GOHC to atmospheric forcing

## Goals

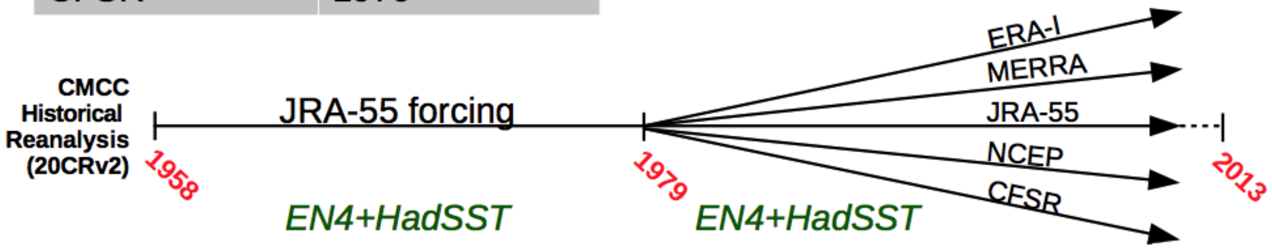
- Evaluate global ocean heat content changes associated with different atmospheric forcing (from reanalyses) in ensemble systems with (REAENS) and without (CTRENS) ocean data assimilation
- Evaluate sensitivity to the atmospheric forcing in comparison with other sources of uncertainty in ocean reanalyses
- Provide indications for optimal ensemble generation

## Strategy

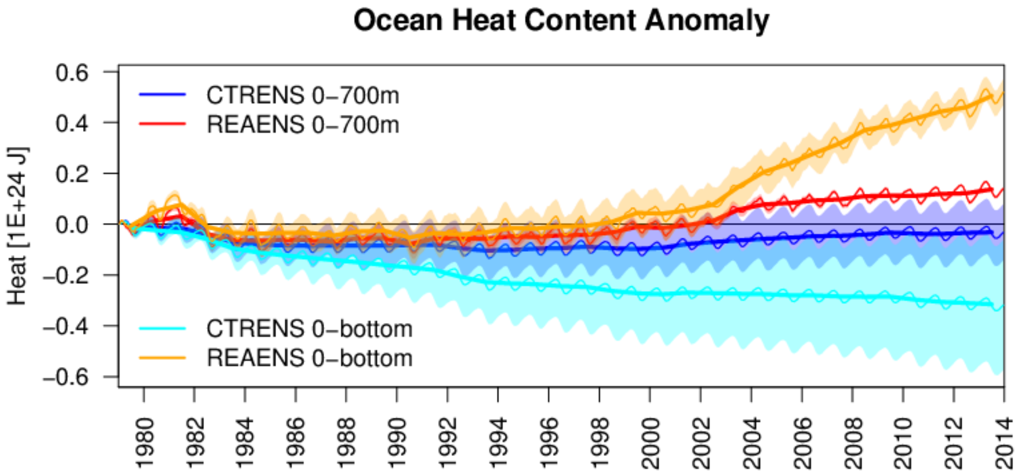
| *Forcing* | *Starting Year* |
|---|---|
| ERA-Interim | 1979 |
| MERRA | 1979 |
| JRA-55 | 1958 |
| NCEP-R2 | 1979 |
| CFSR | 1979 |

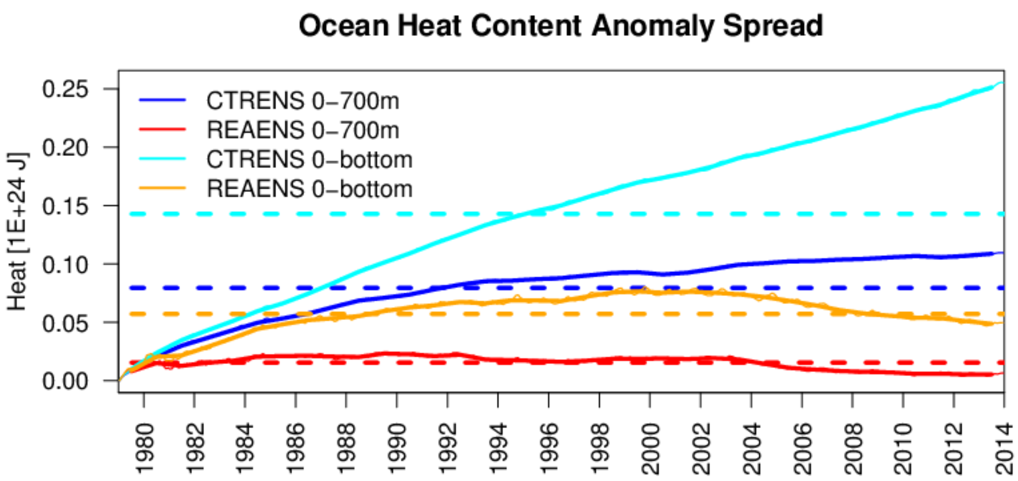
**Pros:**
- Straightforward generation
- Implied assessment of atmospheric reanalysis accuracy from the ocean point of view

**Cons:**
- The ensemble is under-dispersive, ie only the uncertainty in the atmospheric forcing is spanned



# Sensitivity of GOHC to atmospheric forcing




## Contributions to total heat content tendency (1979-2013, W m$^{-2}$)

| | Surface Heat Flux | Assimilation Contribution | Total heat content tendency |
|---|---|---|---|
| CTRENS | -0.50 ± 0.64 | – | -0.50 ± 0.64 |
| REAENS | -3.05 ± 0.71 | 4.53 ± 3.62 | 1.48 ± 0.18 |

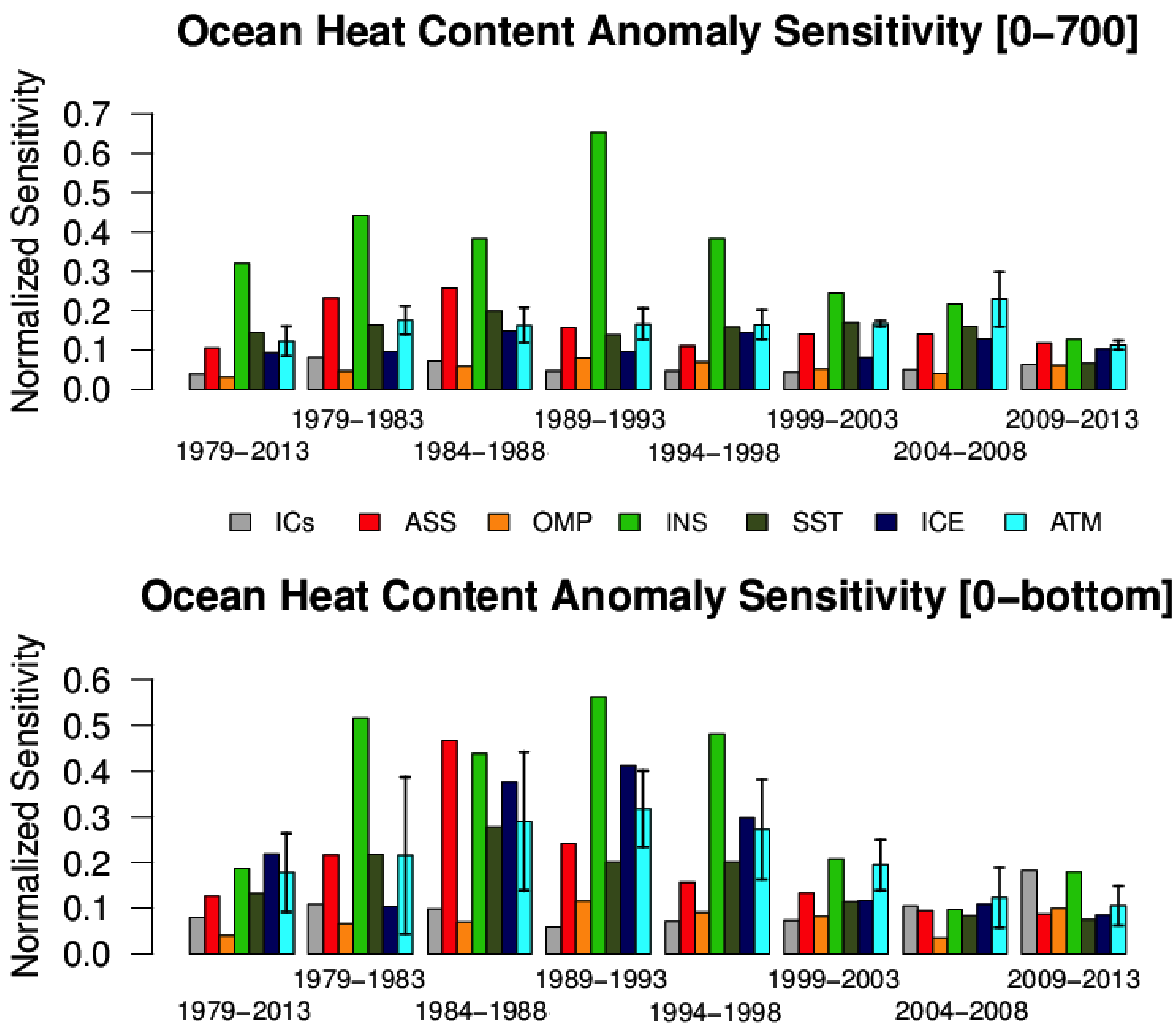
*When Ocean data assimilation is switched on, the impact of atmospheric forcing is marginal (about 10% of the mean signal)*

*Without Ocean data assimilation, the atmospheric forcing is wrong (cooling) and the spread exceeds the mean signal*

# Sensitivity of GOHC to uncertainty sources

*Comparing sensitivities from perturbed experiments using GOHC norm metrics*

**ICs**: Initial conditions
**ASS**: Assimilation configuration (background and observation errors)
**OMP**: Ocean model physics (small scale physics)
**INS**: In-situ observations (XBT correction, quality check, sampling)
**SST**: Sea-surface temperature the reanalysis is nudged to
**ICE**: Sea-ice concentration the reanalysis is nudged to
**ATM**: Atmospheric forcing



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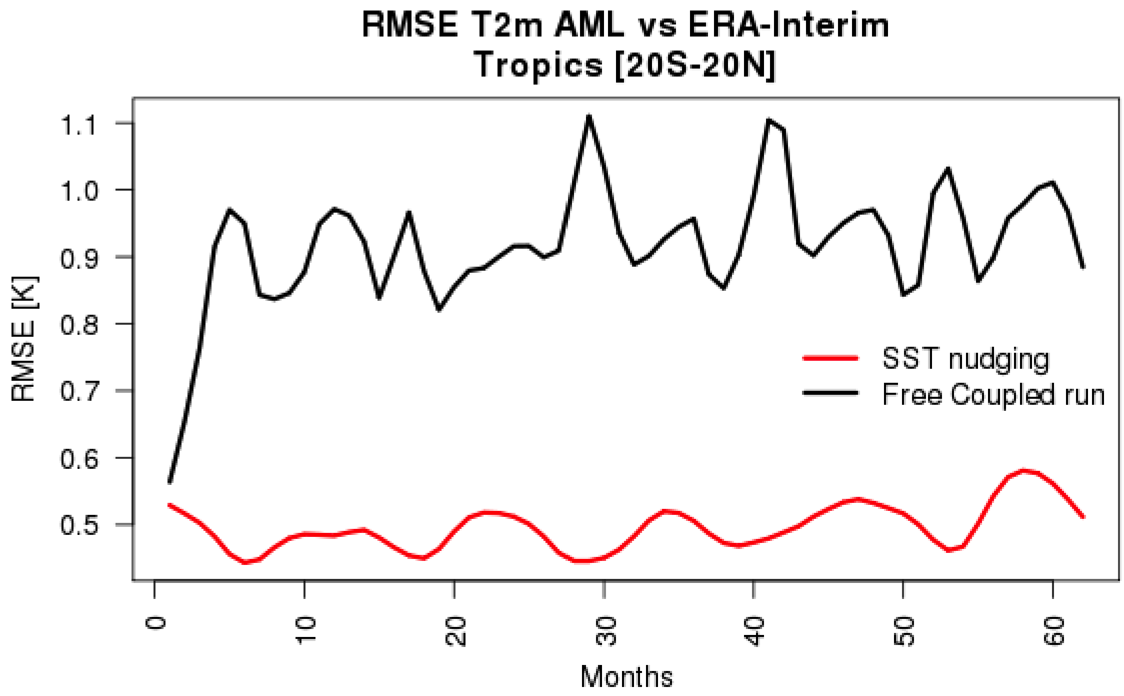
# Coupled covariances and strongly coupled DA

**Motivation**: Weekly coupled DA proves successful in improving near-surface atmospheric parameters in simple configurations (especially in the Tropics). Example: Tropical T2m skill scores with/without SST nudging. ***Does strongly coupled DA lead to further improvements?***

**Strategy**: Use simplified ABL model coupled to NEMO to test the impact of strongly coupled (via ensemble-derived inter-medium covariances and balances)



# Coupled covariances and strongly coupled DA

## Modeling framework

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

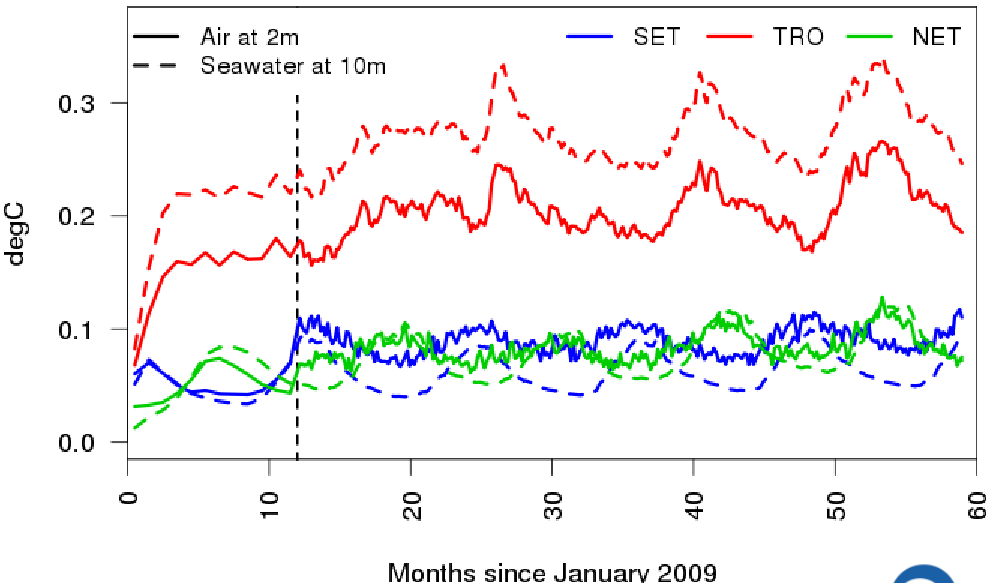
$\partial\,(\mathbf{T_{2m}},\mathbf{q_{2m}})\,/\partial t = ADV[\mathbf{u},(\mathbf{T_{2m}},\mathbf{q_{2m}})] + DIFF\,[(\mathbf{T_{2m}},\mathbf{q_{2m}})] + THDY\,[\mathbf{SST},\mathbf{u},(\mathbf{T_{2m}},\mathbf{q_{2m}}),\mathbf{H_{ABL}}]$

- It allows augmenting the ocean state control parameters to include $T_{2M}$ and $Q_{2M}$, now prognostic, in both model and 3DVAR
- Wind is not prognostic and imposed externally (ERA-Interim)

## Ensemble System

- Used to derive ensemble air-sea cross-covariances
- Ensemble system:
  Period 2009-2013, 12 members with perturbation of wind (20CRv2d ensemble anomalies) and model physics (EOS, Brankart et al., 2013)

Horizontal average of temperature ensemble spread



# A simplified air-sea balance operator

In order 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)

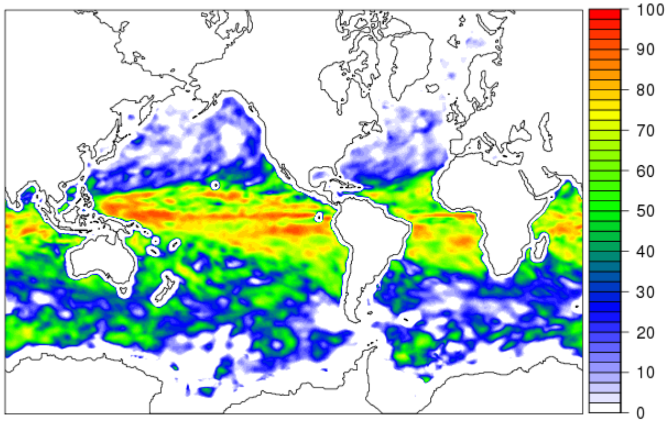
- $\delta \mathbf{T_{2m}} = \Delta t \; [\delta\, \mathbf{Q_{LW}}\, (\delta \mathbf{SST}) + \delta\, \mathbf{Q_{SEN}}\, (\delta \mathbf{SST})] \, / \, [\rho_A\, cp_A\, \mathbf{H_{ABL}}]$
  *(no condensation in ABL)*

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

Where the exchange coefficients (**Ce, Ch** for Evaporation and Sensible heat, respectively) are assumed not to depend on **SST** and taken from the fully non-linear model.

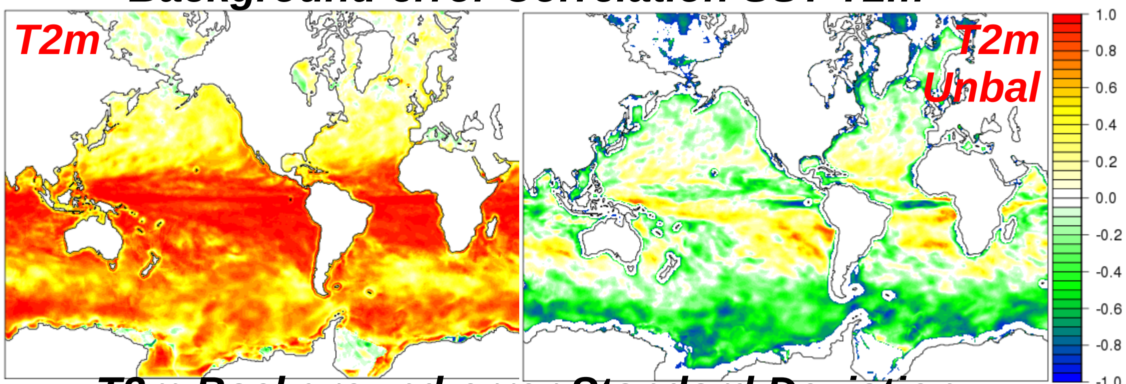
This allows to compare purely statistical balances – cross-covariances of (**T,S**) and ($\mathbf{T_{2m}}$, $\mathbf{Q_{2m}}$) – and mixed – cross-covariances of (**T,S**) with the unbalanced components ($\mathbf{T_{2m}}$, $\mathbf{Q_{2m}}$).

# Coupled covariances

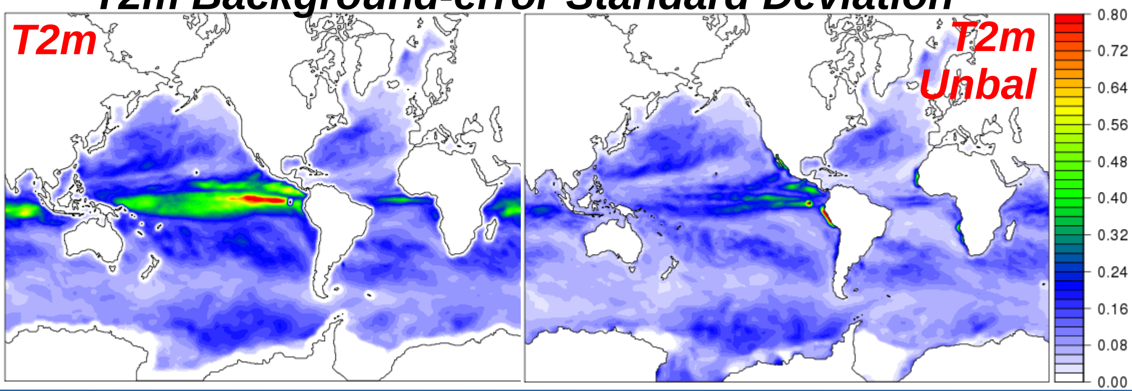


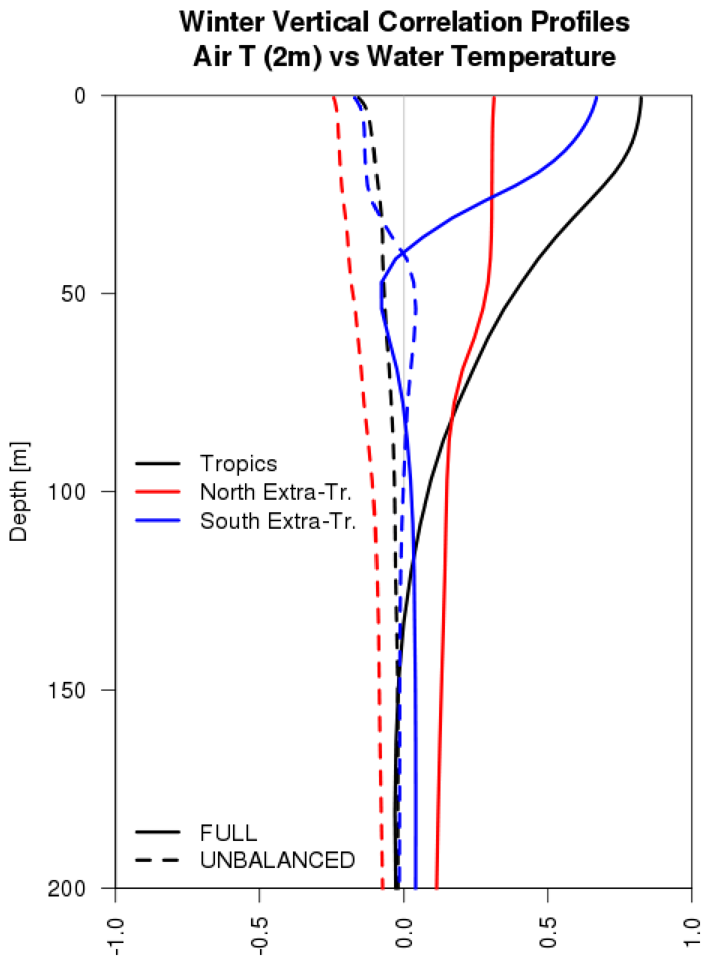

***Explained Variance***
***T2m vs T2m balanced***

***Background-error Correlation SST-T2m***




***T2m Background-error Standard Deviation***



# Summary and next steps

## MAIN RESULTS

- Sensitivity of atmospheric forcing in ocean reanalyses is assessed through multi-forcing ensemble reanalysis and compared to other sources of uncertainty: the impact of atmospheric forcing is generally marginal when ocean data assimilation is used; importance of in-situ observation pre-processing and surface nudging
- An ABL model coupled to NEMO is used to derive (full or unbalanced) coupled cross-covariances for use in idealized strongly coupled DA experiments

## NEXT STEPS

- *Ongoing*: extension of 3DVAR control vector to include T2m, Q2m
- *Planned*: Impact of 3DVAR assimilation of ocean observations on T2m, Q2m skill scores with difference configuration of coupled covariances and introduction of flow-dependence of covariances

# Thank you

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