Ocean Data Assimilation for Numerical Weather Prediction

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[1] ECMWF Earth System Assimilation Section, Coupled Assimilation Team

13 Sept 2018

ECMWF

Outline

The importance of the ocean analysis on NWP

The current observing system used at ECMWF

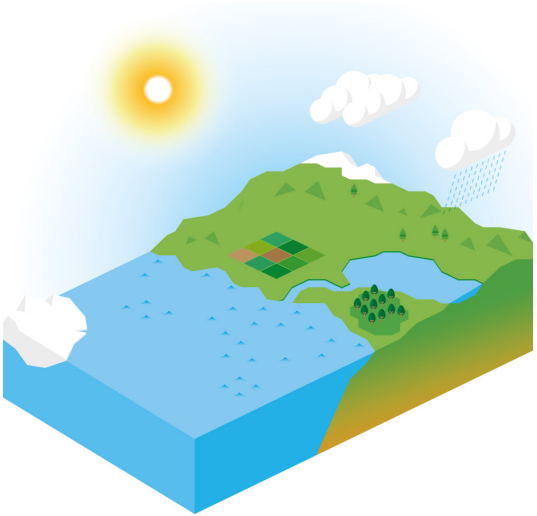
The OCEAN5 analysis at ECMWF

The future observations for the ocean

Coupled ocean–atmosphere assimilation

Outlook for future ocean analyses

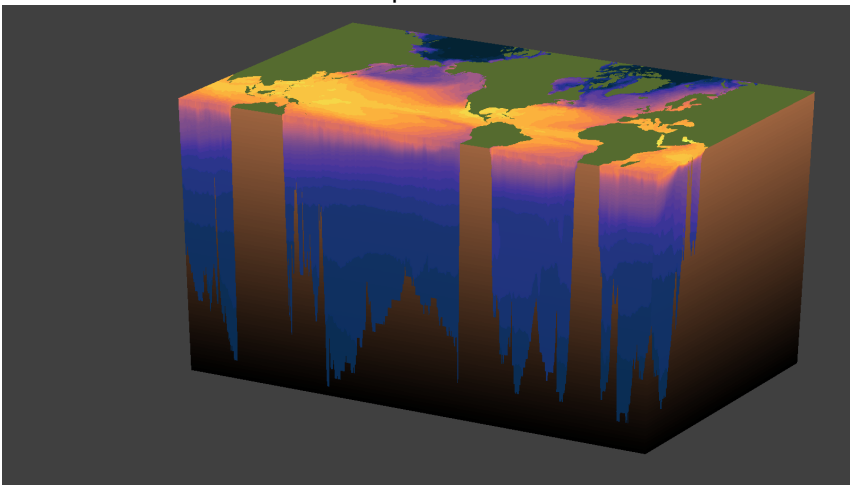
The ECMWF Earth System



Components of ECMWF's IFS Earth System. Along with the atmosphere, there are the ocean, wave, sea ice, land surface, snow, and lake models.

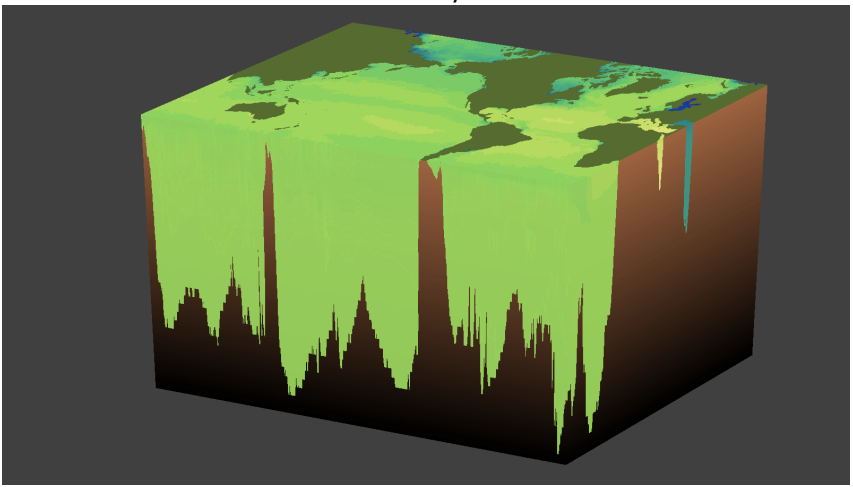
The ocean model state

Temperature



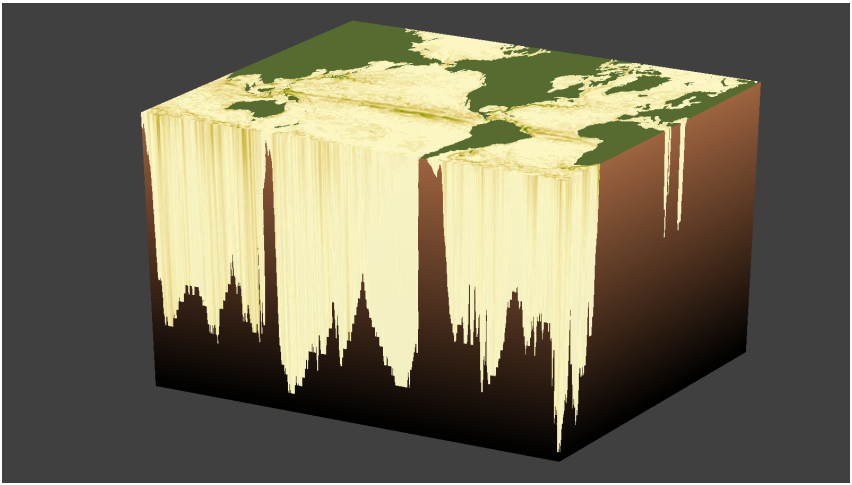
The ocean model state

Salinity



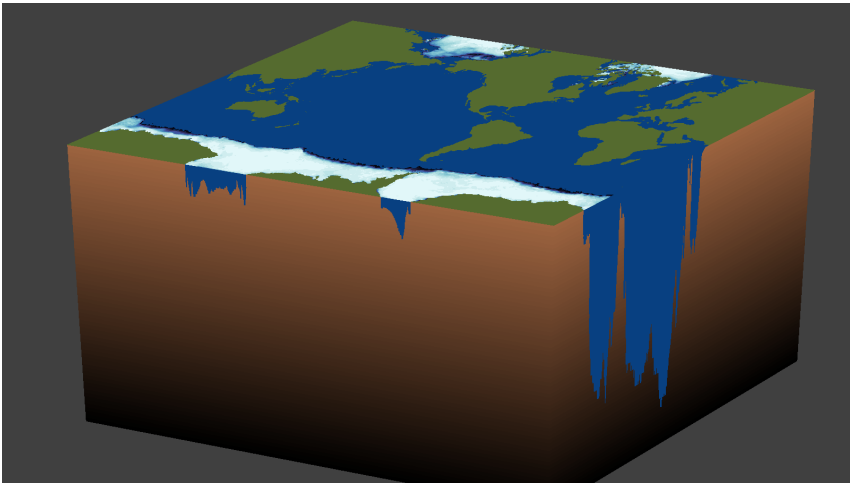
The ocean model state

Currents



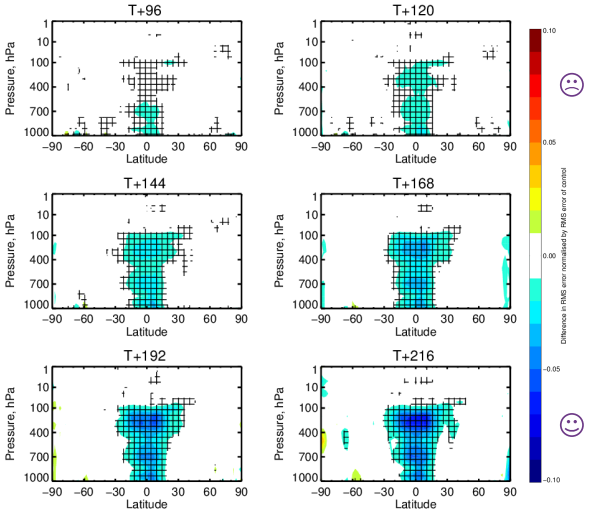
The ocean model state

Sea ice

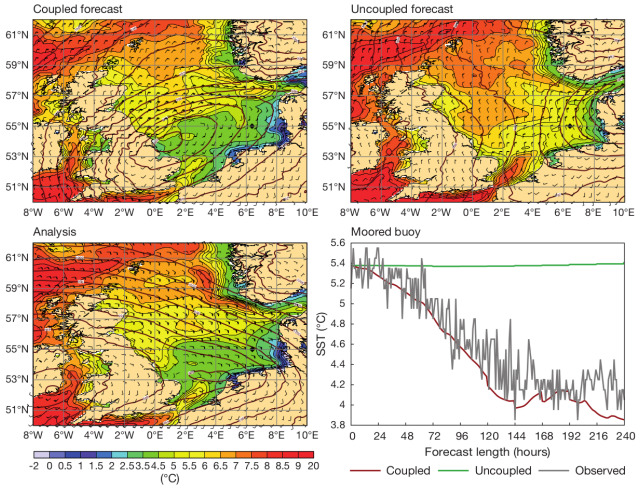


Allowing use of the coupled model

Normalised RMSE of temperature forecast errors
comparing coupled forecasts to uncoupled forecasts



Benefits of coupled ocean–atmosphere forecasts



[Mogensen et al. 2018]

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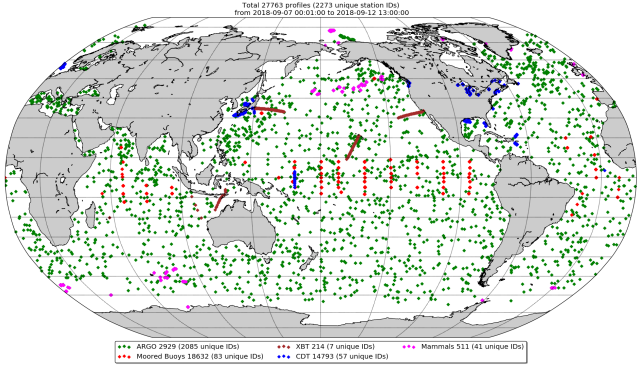
In situ ocean observations



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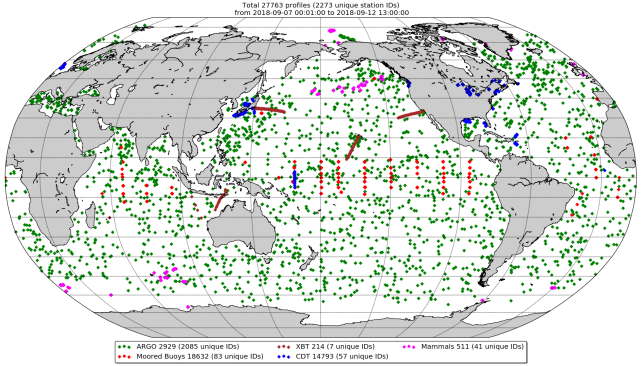
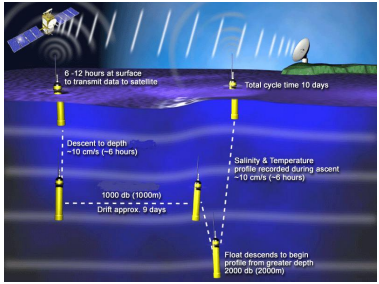
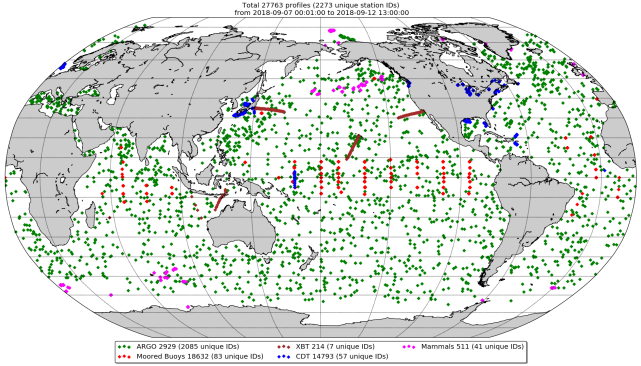


Argo floats

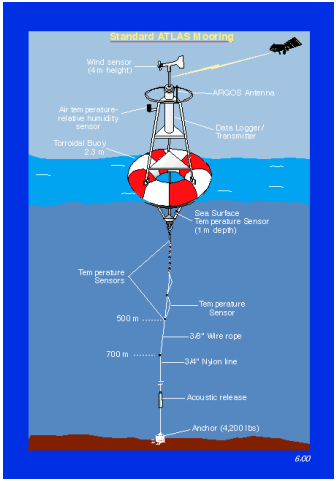


Argo operational cycle.
[Argo 2018]

In situ ocean observations

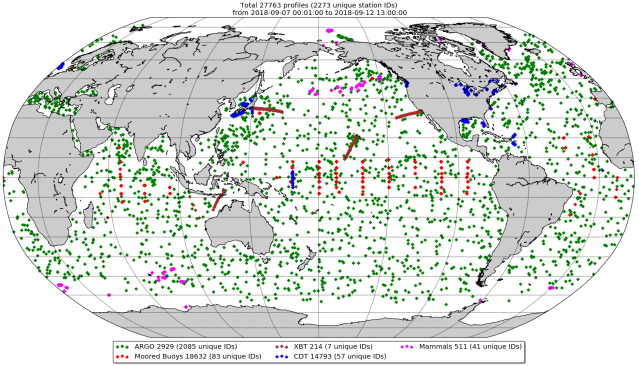


Moored buoys

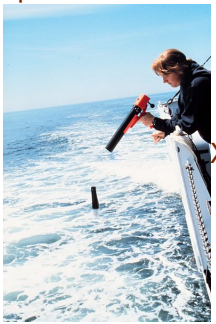


[PMEL 2018]

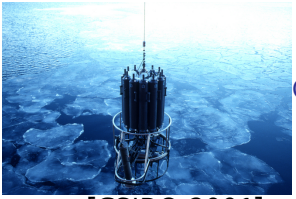
In situ ocean observations



Ship based observations



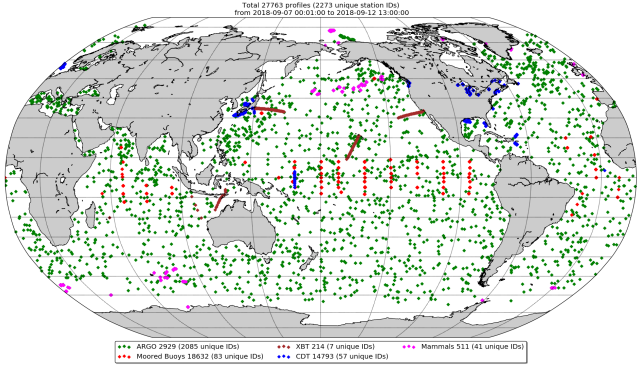
XBT



CDT

[CSIRO 2001]

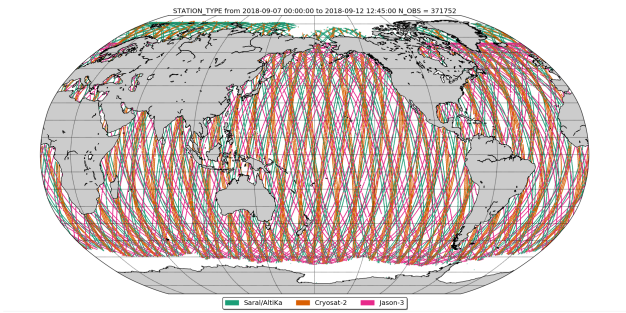
In situ ocean observations

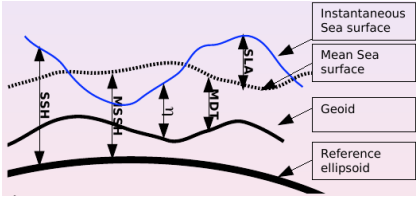


Mammals!

[MEOP et al. 2015]

Sea level anomaly observations





Altimeter measures SSH.
Model represents η.
The Geoid changes with time.

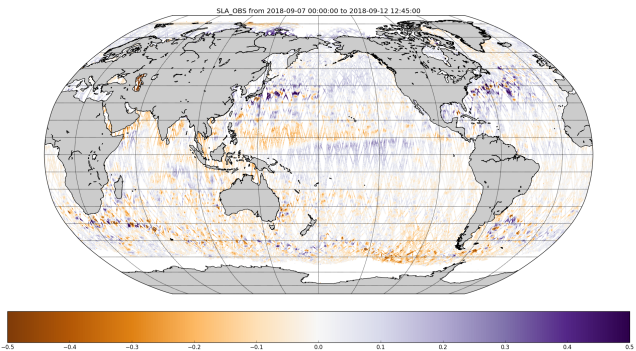
We convert to assimilating anomalies:

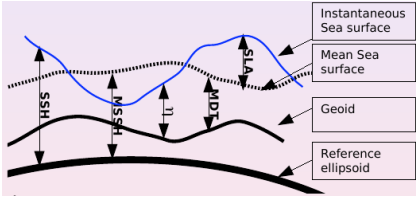
y = SSH anomalies = SSH - MSSH

$H(x)$ = η anomalies = η - MDT

MDT, or Mean Dynamic Topography, is the mean sea surface height above geoid and comes from an external dataset.

Sea level anomaly observations





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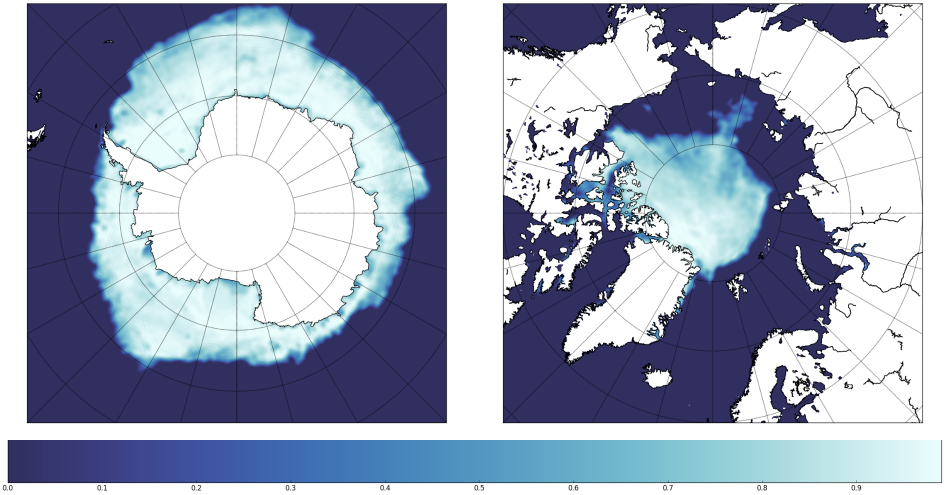
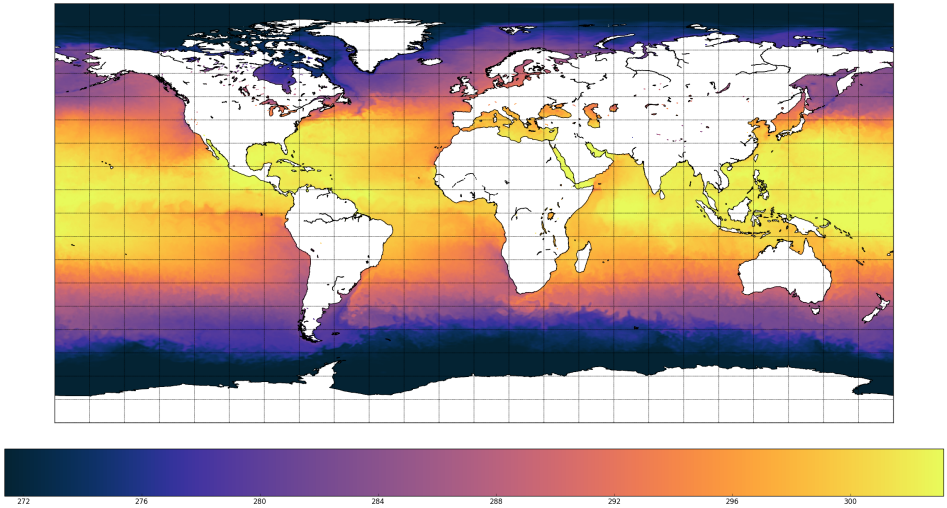
Sea ice concentration observations

Latest L4 sea ice concentration observations from OSTIA (20180912)



Sea-surface temperature

Latest L4 sea-surface temperature observations from OSTIA (20180912)



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The OCEAN5 model

The ocean model

- NEMO model v3.4.1
- ORCA_025 resolution: $0.25°$ horizontal resolution, 75 vertical levels
- Tripolar grid - poles in Canada, Russia and Antarctica
- High vertical resolution in the uppermost ocean
- Turbulent Kinetic Energy mixing

The sea ice model

- LIM2
- Viscous-plastic rheology

The OCEAN5 assimilation configuration

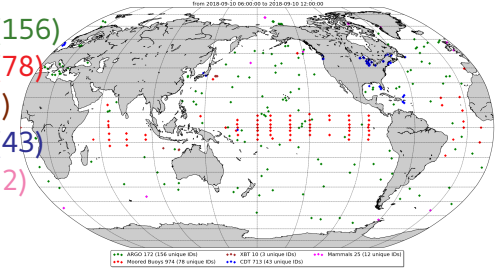
- The assimilation system is NEMOVAR
- Methodology is 3D-Var–FGAT
- Assimilation of in situ profiles, SLA, SIC
- Relaxation of SST towards OSTIA
- OCEAN5 is a reanalysis-analysis system with 2 streams - behind real-time and real-time
- Assimilation window varies from 8 days to 12 days and split into two chunks
- Minimisations performed separately for sea ice and ocean components
- Atmospheric forcing comes from the HRES system
  - Weakly coupled ocean–atmosphere assimilation
- 5 member EDA with perturbed observations and observation locations

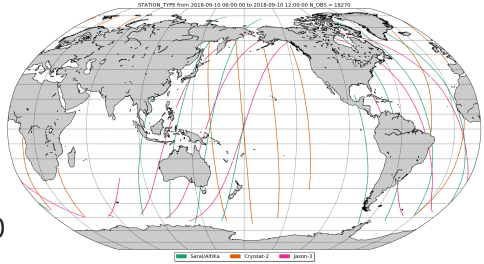
`https://www.ecmwf.int/en/research/climate-reanalysis/ocean-reanalysis`

Ocean observation latency

49 hour cut-off **Early Delivery** 1 hour cut-off

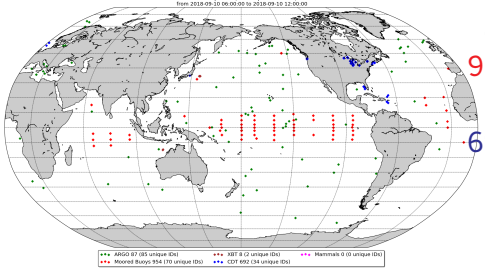
172 (156)
974 (78)
10 (3)
713 (43)
25 (12)

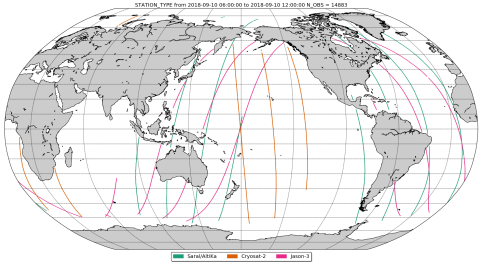




18270

87 (85)
954 (70)
8 (2)
692 (34)
0 (0)



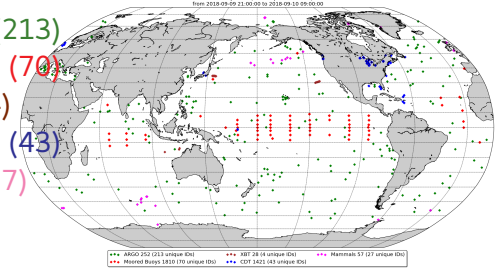


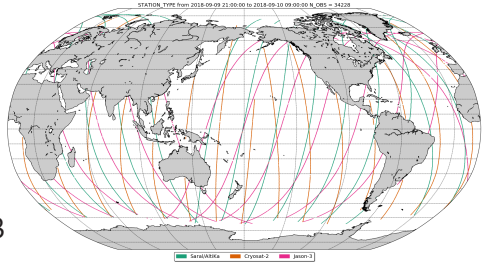
14883

Ocean observation latency

52 hour cut-off **Long Window DA** 4 hour cut-off

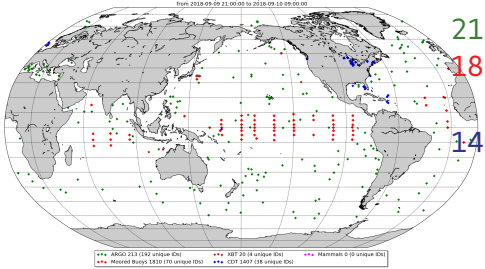
252 (213)
1810 (70)
28 (4)
1421 (43)
57 (27)

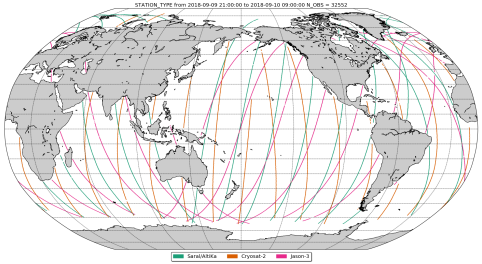




34228

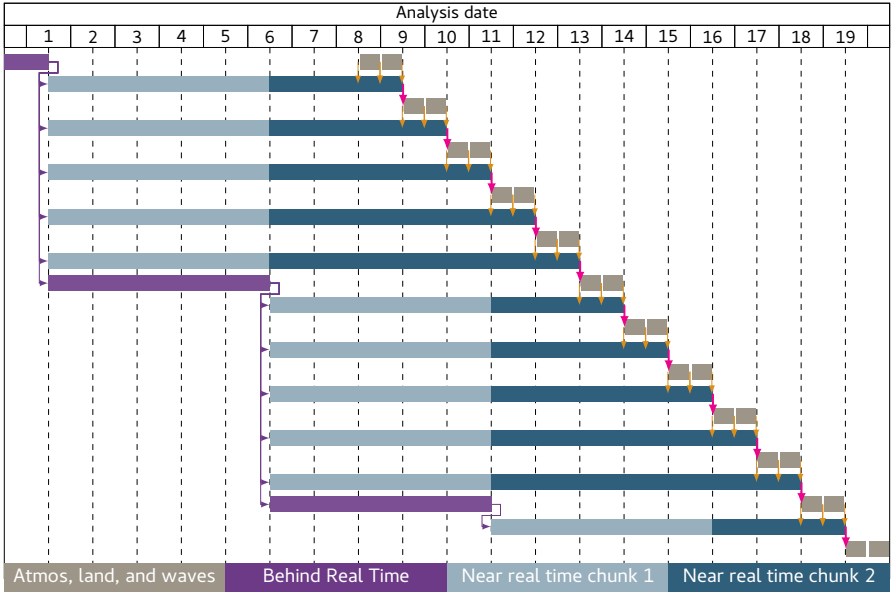
213 (192)
1810 (70)
20 (4)
1407 (38)
0 (0)



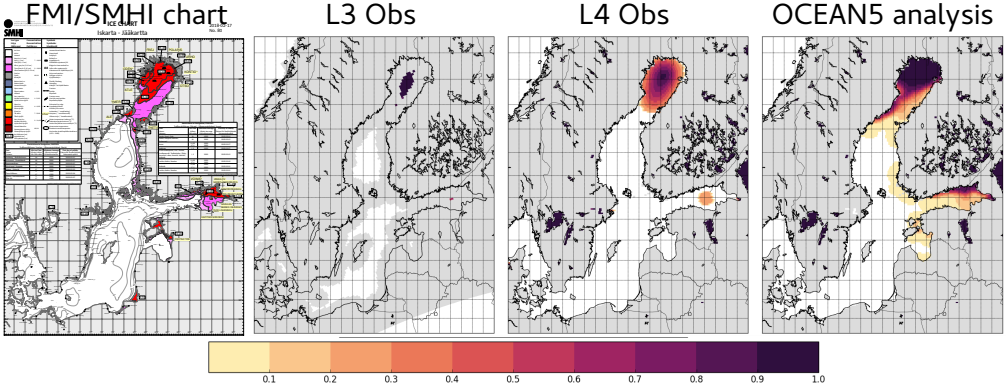


32552

Ocean analysis suite



Sea ice in the Baltic Sea



[FMI et al. 2018]

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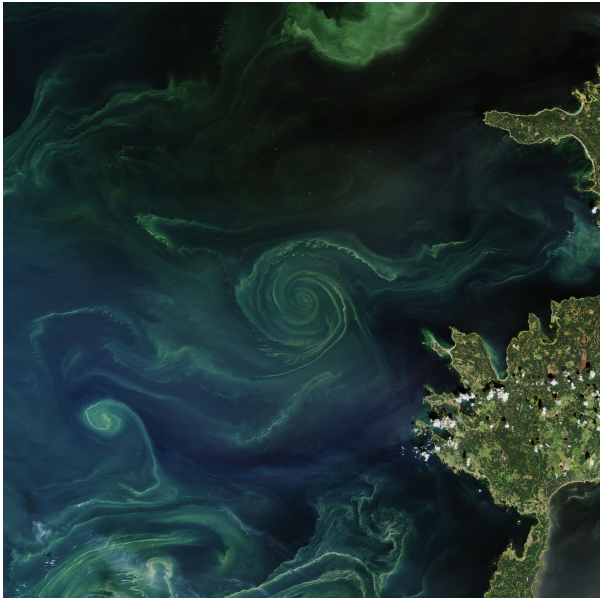
Future observing systems



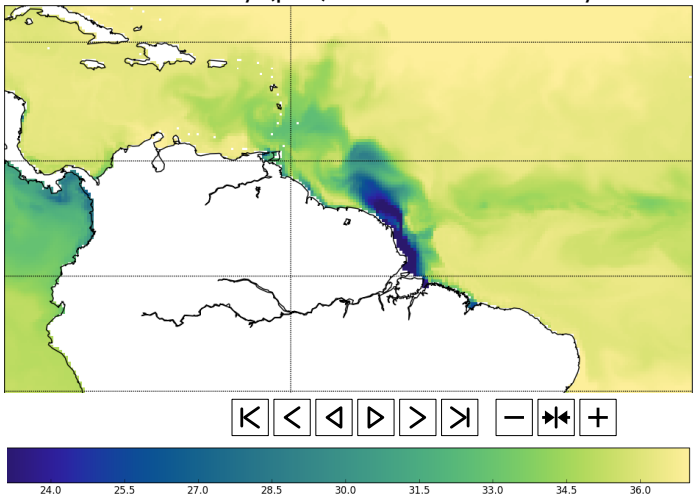
Landsat 8 - OLI (Operational Land Imager) image on 18 July 2018. [Carlowicz 2018]

Can we use images like this of blooms of phytoplankton to track eddies?

Do we need higher resolution to do so?

Use of GloFAS river runoff data

Sea Surface Salinity (psu) from OCEAN5 analysis on 20180701

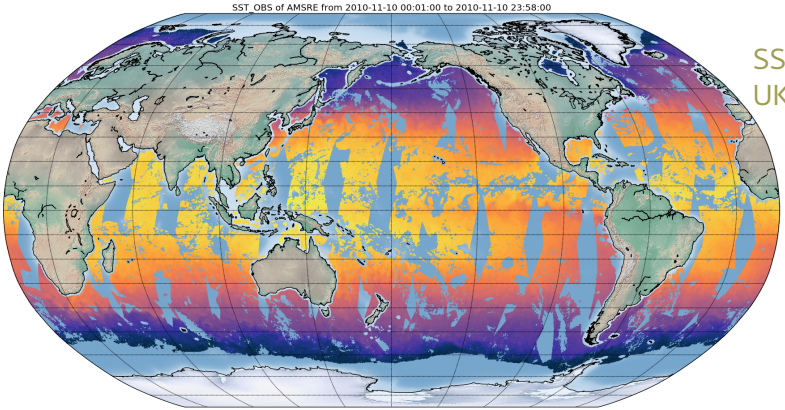


Use of GloFAS river runoff data

Instead of river runoff climatology, can we use NRT river runoff estimates from GloFAS?

Image courtesy E. Zsoter (GloFAS team). http://www.globalfloods.eu/

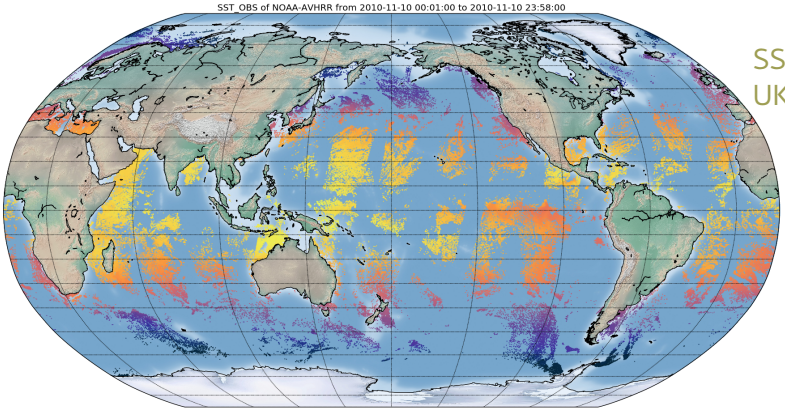
SST assimilation



SST Data courtesy of the UK Met Office.

Challenges include observation screening, bias correction, and modification of the background error covariance model to properly propagate the information to the subsurface layers of the ocean.

SST assimilation



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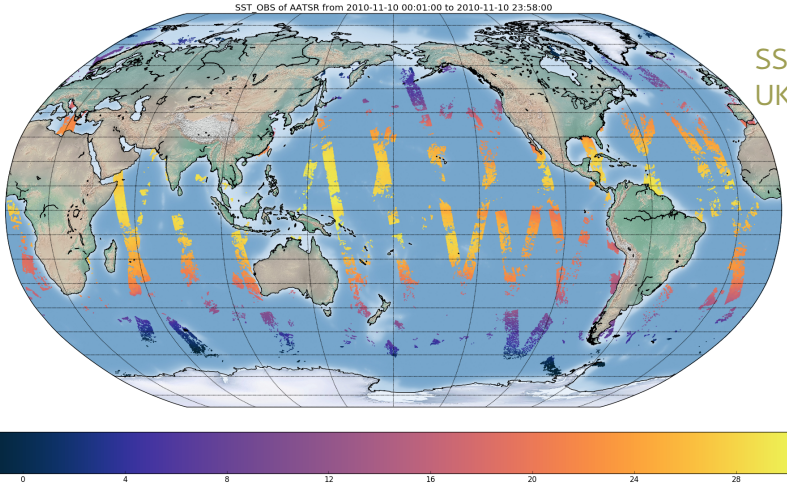

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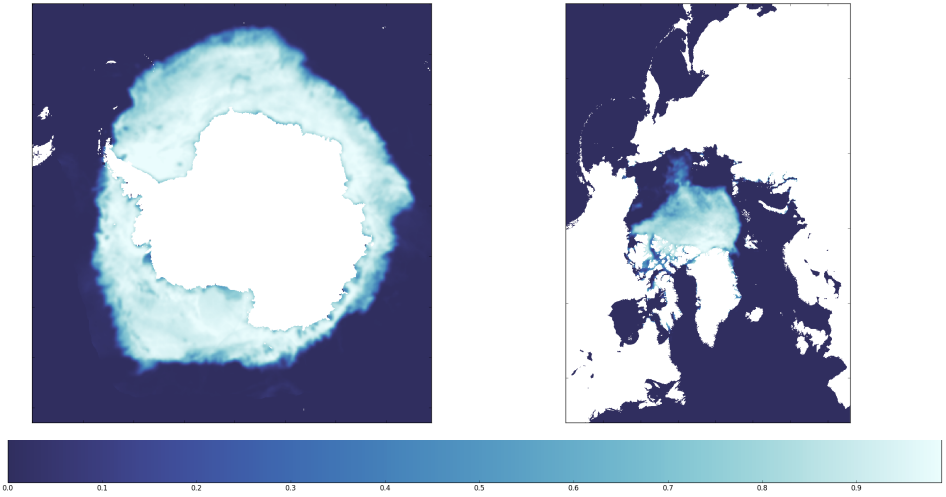
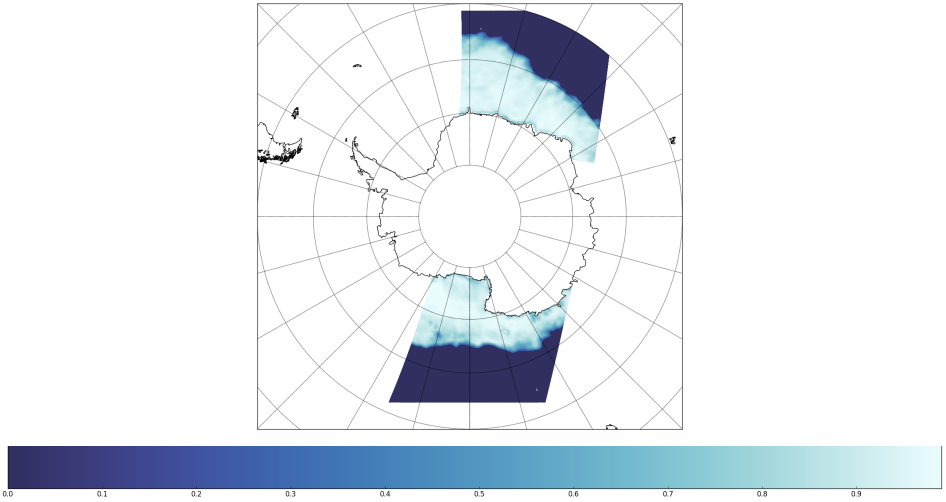
Sea ice concentration assimilation

L3 Sea Ice Concentration observations (OSI SAF OSI-401b) on 20180912



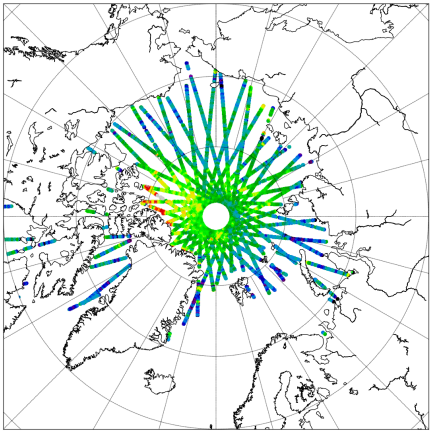
Sea ice concentration assimilation

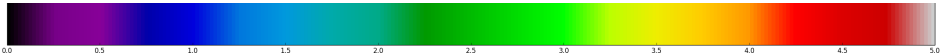
L2P Sea Ice Concentration observations (OSI SAF OSI-205) on 20180902 from 20:22 to 20:49 by AVHRR on Metop-A



Sea ice thickness

L2 Sea Ice Thickness observations (m) from 20180429 to 20180430 by Cryosat





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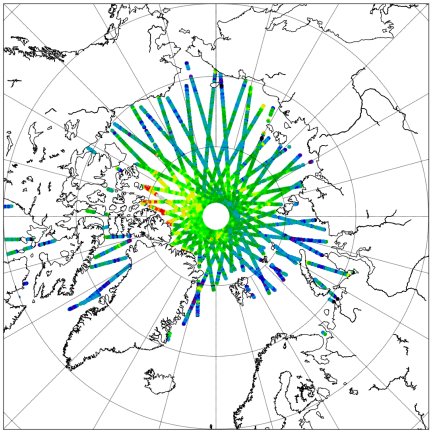

These observations are not available when melt ponds are present.

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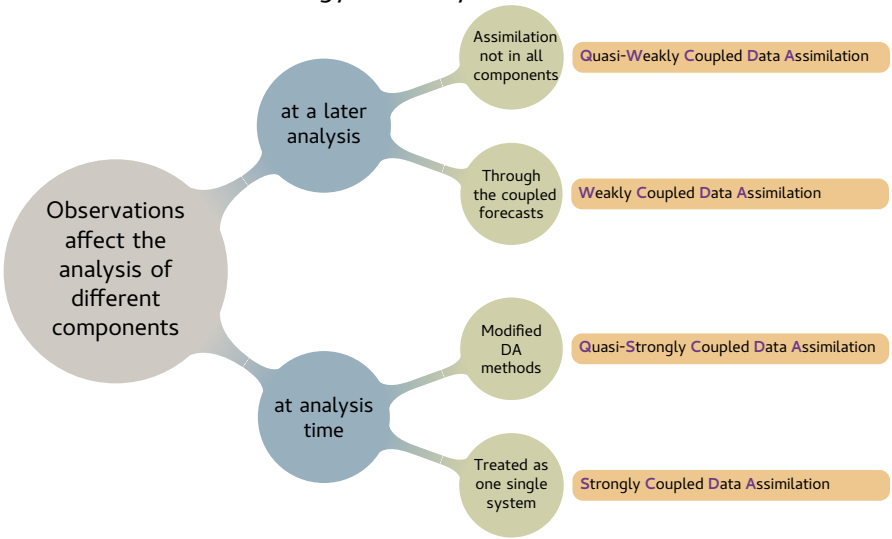
Coupled DA nomenclature

We follow the terminology of Penny et al. 2017:



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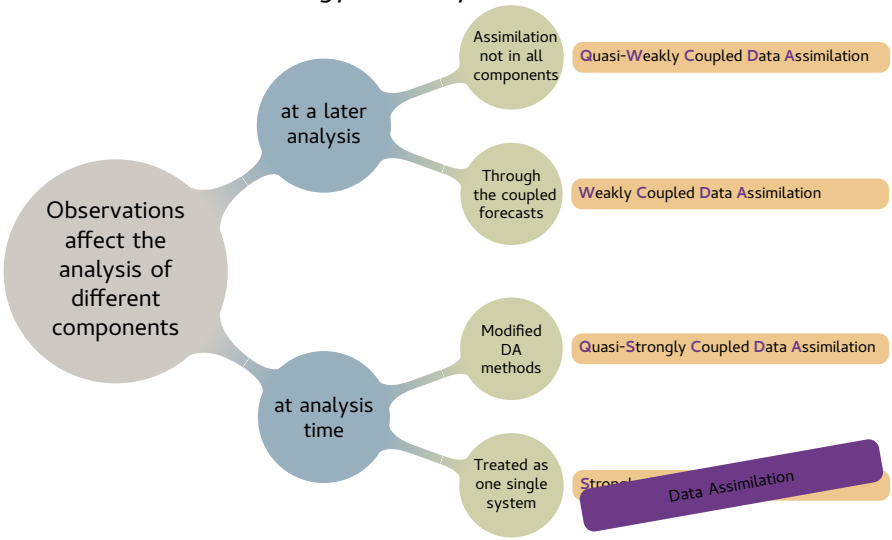
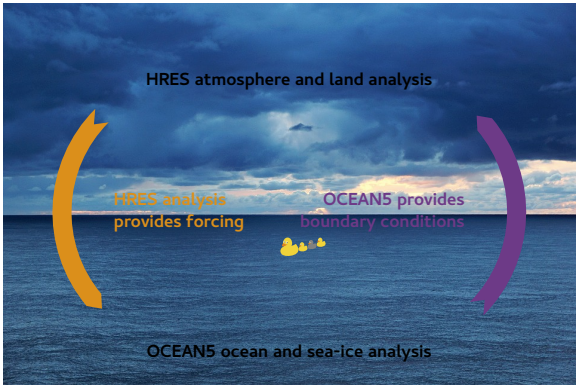
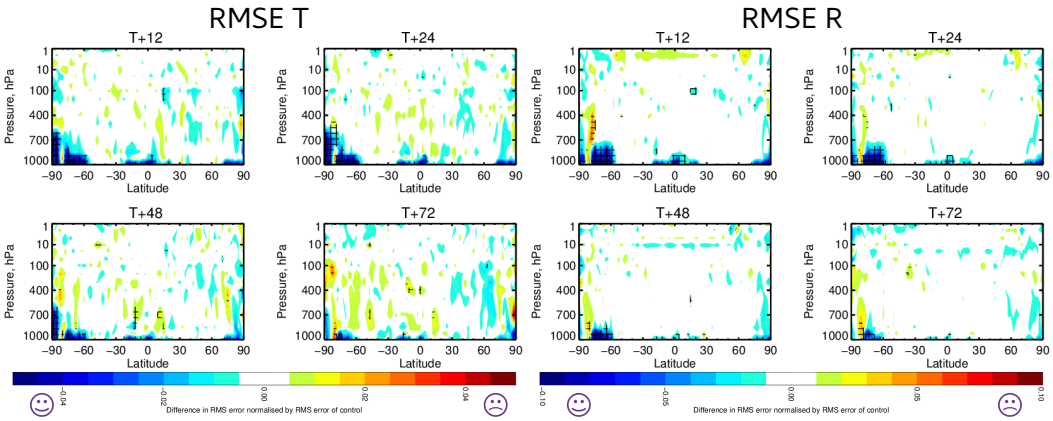


Weakly coupled ocean–atmosphere assimilation



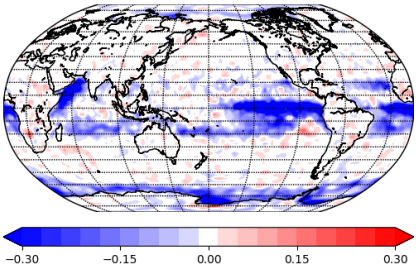
- Operational - WCDA through sea ice concentration
- Future upgrade - WCDA through sea-surface temperature $\pm 20^\circ$ to 25°

Weakly coupled assimilation results

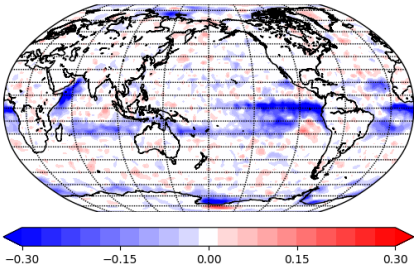


WCDA maps of surface temperatures

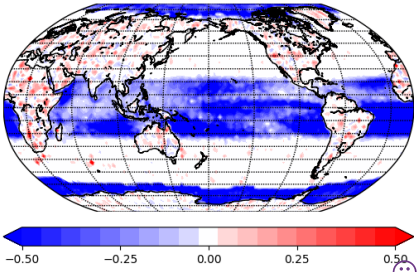
Normalised difference in rms error of T at 1000hPa T+12hrs



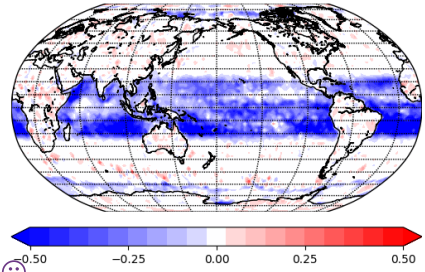
Normalised difference in rms error of T at 1000hPa T+48hrs



Normalised difference in rms error of SKT T+12hrs

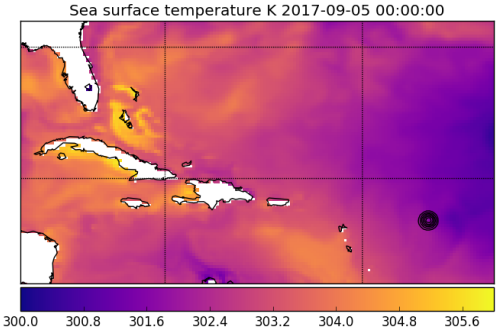


Normalised difference in rms error of SKT T+120hrs

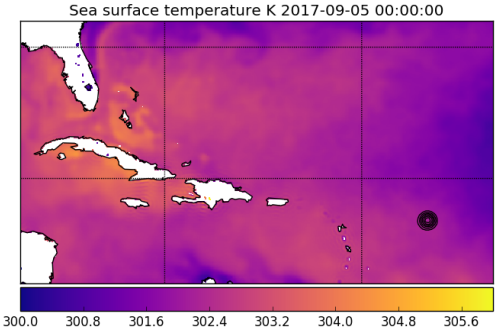


Potential of QSCDA - outer loop coupling ocean–atmosphere DA

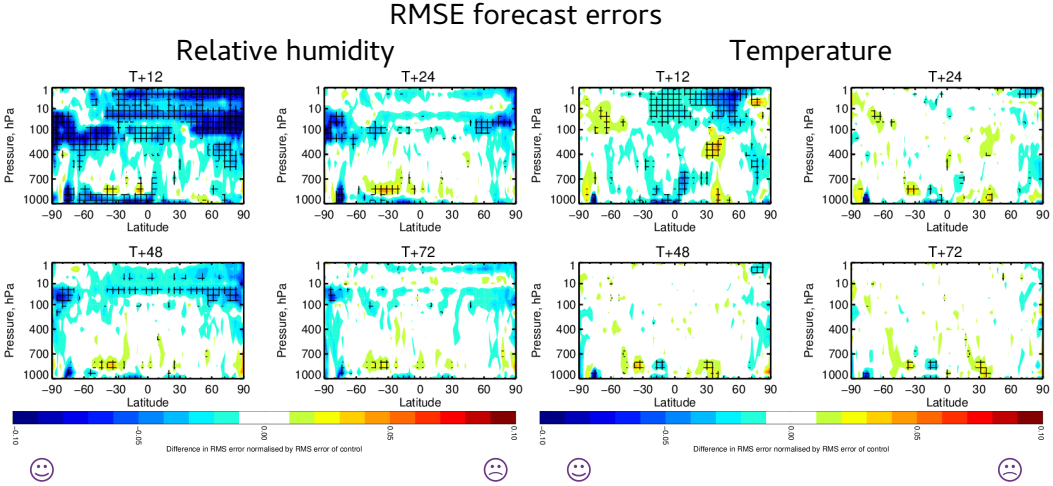
Coupled assimilation



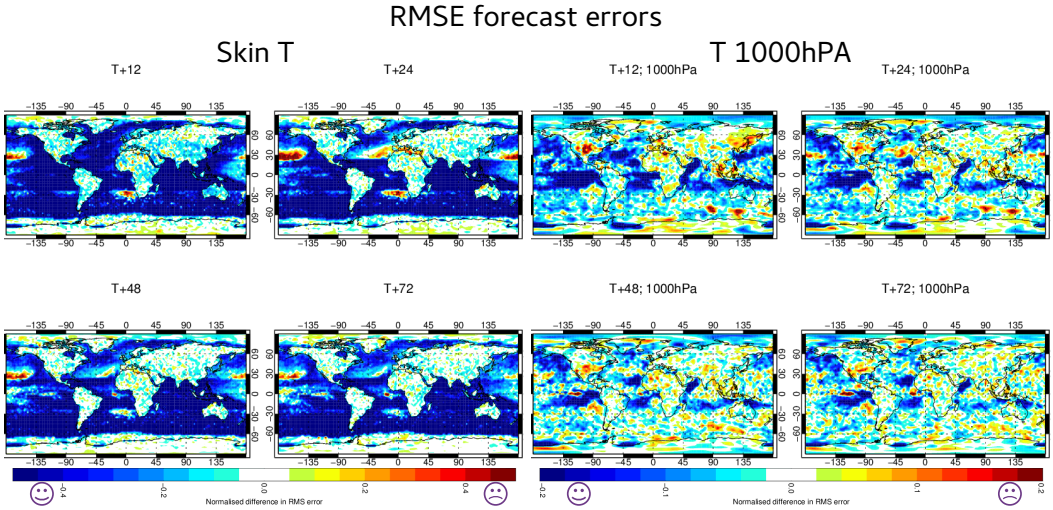
Uncoupled analysis (OSTIA)



QSCDA - outer loop coupling ocean–atmosphere DA



QSCDA - outer loop coupling ocean–atmosphere DA



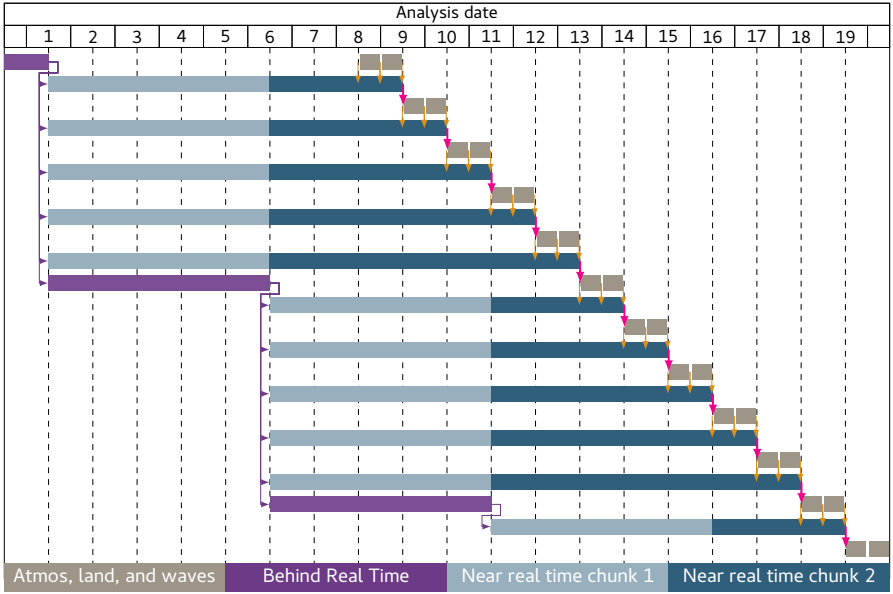
Reconciling timescales in the ocean and atmosphere

- NWP forecasts have to be produced in a timely fashion
- Not all ocean observations are available for current atmospheric cut-off times
- Would like coupled assimilation for:
  - Coupled observation operators
  - Atmospheric bias correction of ocean sensitive satellite observations
  - More balanced initial conditions

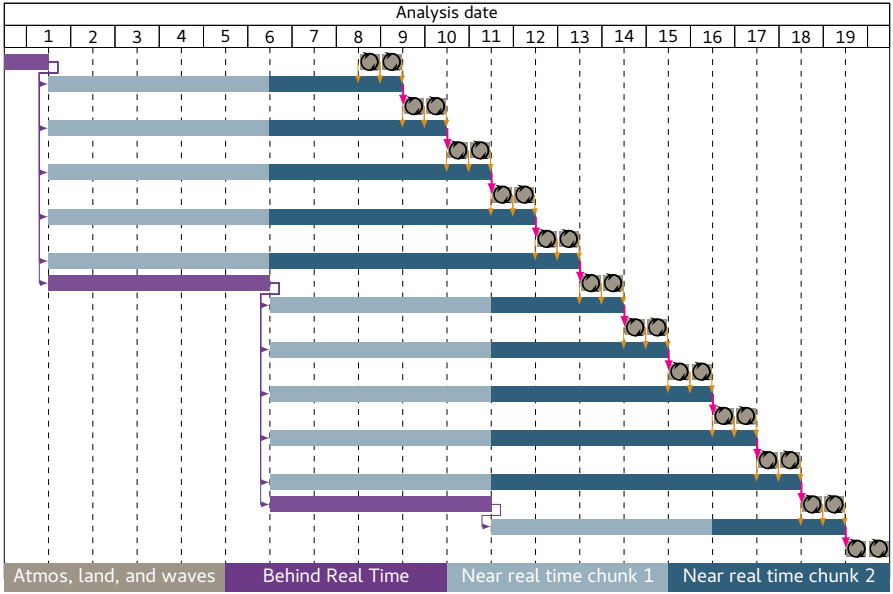
Combining WCDA and QSCDA for NWP

- Do both WCDA and QSCDA!
- For QSCDA, use the initial conditions from the latest available WCDA analysis

Combining WCDA and QSCDA for NWP

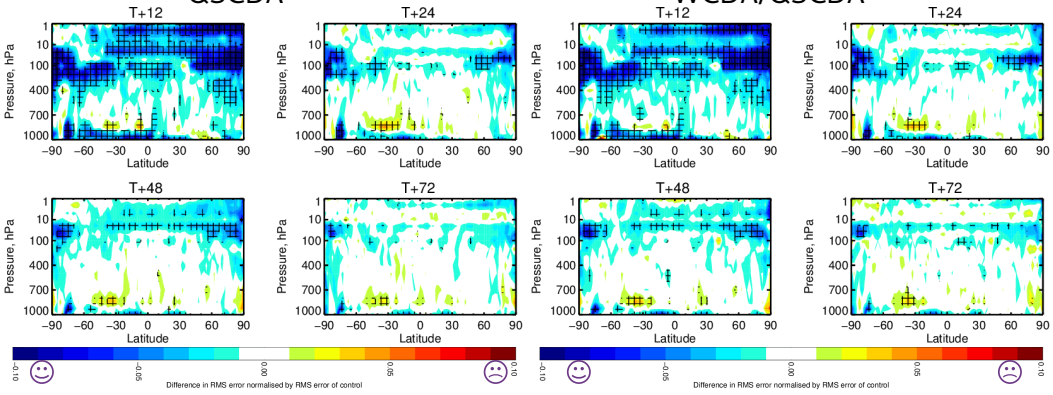


Combining WCDA and QSCDA for NWP



QSCDA compared to Composite WCDA/QSCDA

RMSE forecast errors in relative humidity



Reconciling timescales in the ocean and atmosphere

- ✓ NWP forecasts have to be produced in a timely fashion
- ✓ Not all ocean observations are available for current atmospheric cut-off times
- ▸ Would like coupled assimilation for:
  - ☺ Coupled observation operators
  - ☺ Atmospheric bias correction of ocean sensitive satellite observations
  - ☺ More balanced initial conditions
- Works with observations available in NRT
- Improves forecasts

Outline

The importance of the ocean analysis on NWP

The current observing system used at ECMWF

The OCEAN5 analysis at ECMWF

The future observations for the ocean

Coupled ocean–atmosphere assimilation

Outlook for future ocean analyses

Future developments in the ocean analysis

- Move away from L4 observations to progressively lower level observations
- More coupling to the atmosphere – driving the atmospheric analysis with more ocean analysis fields
- Use of ensemble information in the B matrix – moving towards Hybrid-3D-Var.
- Outer loop coupling with the atmosphere – lots of potential to help with bias correction and screening of ocean sensitive satellite observations
  - Aligning the ocean analysis window to the current atmospheric window would mean missing lots of vital in situ observations
  - Care needs to be taken not to inherit ocean model biases into the atmospheric analysis

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