Coupled Ocean-Atmosphere Assimilation for NWP at ECMWF

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ECMWF Earth System Assimilation Section, Coupled Assimilation Team

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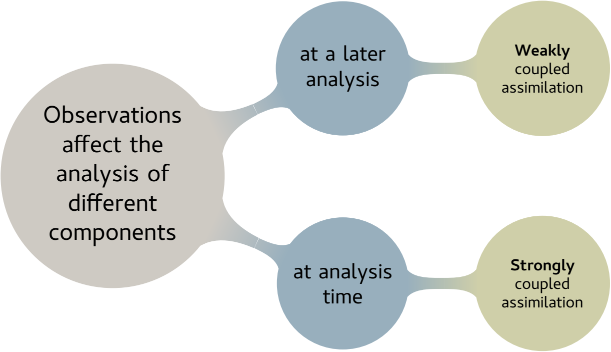
ECMWF

Coupled DA nomenclature

We follow the categorisations of Penny et al. 2017:



Outline

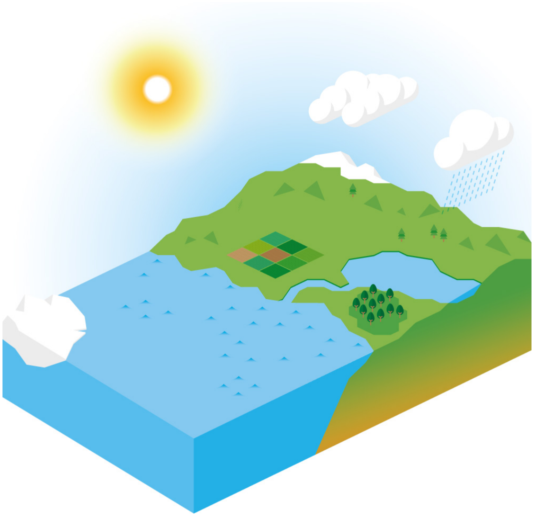
ECMWF Earth system and ocean observations

Weakly coupled ocean-atmosphere assimilation

Outer loop coupling (QSCDA)

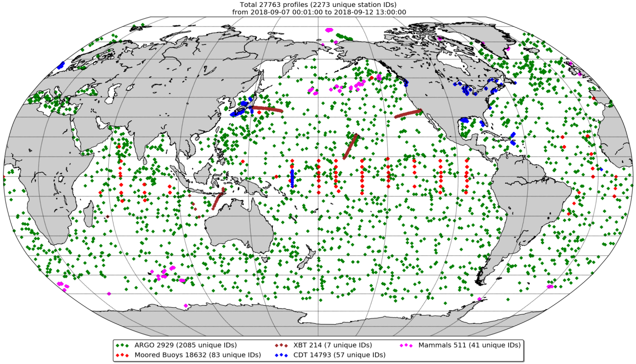
Reconciling timescales in the ocean and atmosphere analyses and observation networks

The ECMWF Earth System

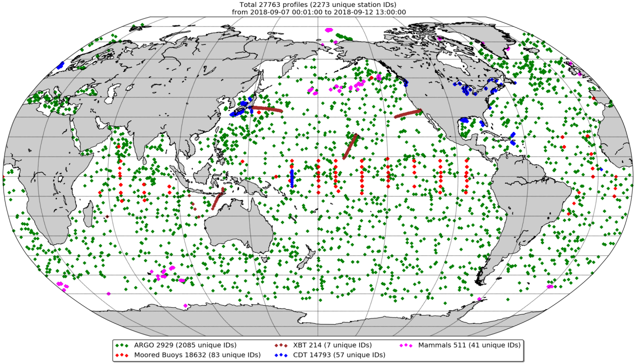


Components of ECMWF's IFS Earth System. Along with the atmosphere, there are the ocean, wave, sea ice, land surface, snow, and lake models.

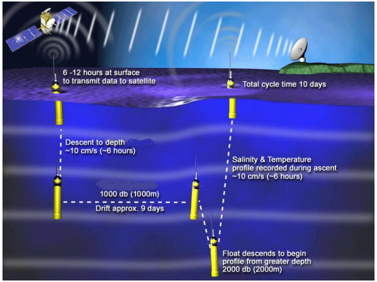
In situ ocean observations



In situ ocean observations

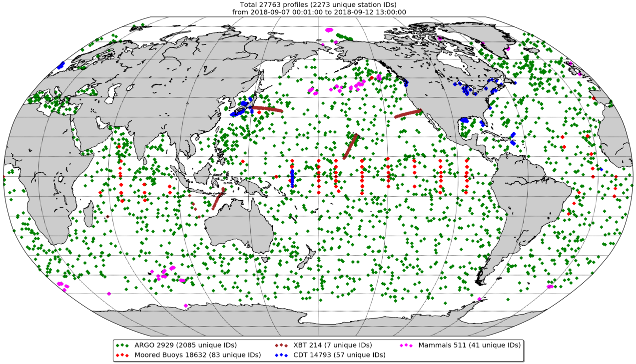


Argo floats

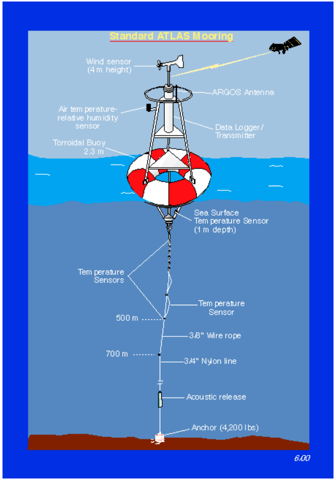


Argo operational cycle.
[Argo 2018]

In situ ocean observations

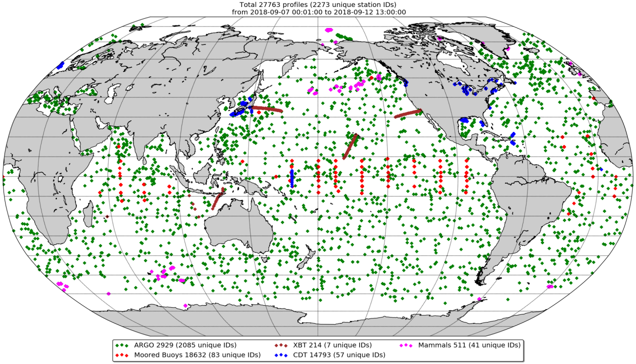


Moored buoys



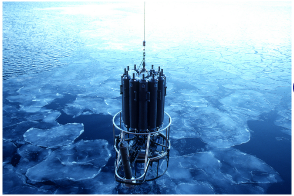
[PMEL 2018]

In situ ocean observations



Ship based observations

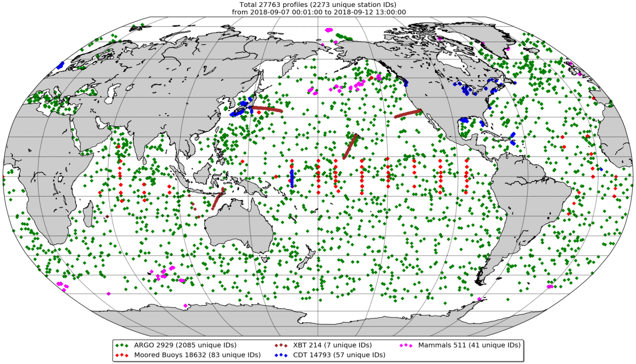
XBT



CDT

[CSIRO 2001]

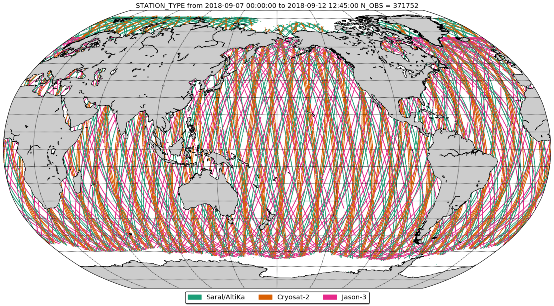
In situ ocean observations

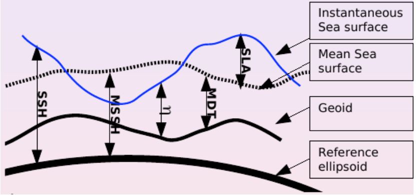


Mammals!

[MEOP et al. 2015]

Sea level anomaly observations





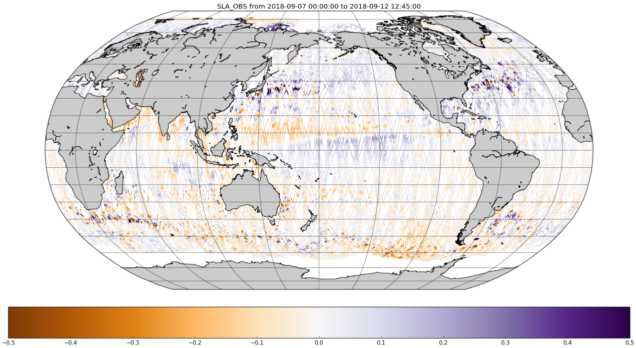
Altimeter measures SSH.
Model represents η.
The Geoid changes with time.

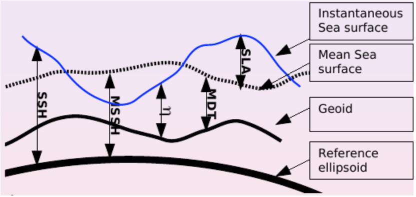
We convert to assimilating anomalies:

y = SSH anomalies = SSH - MSSH $\quad$ $H(x)$ = 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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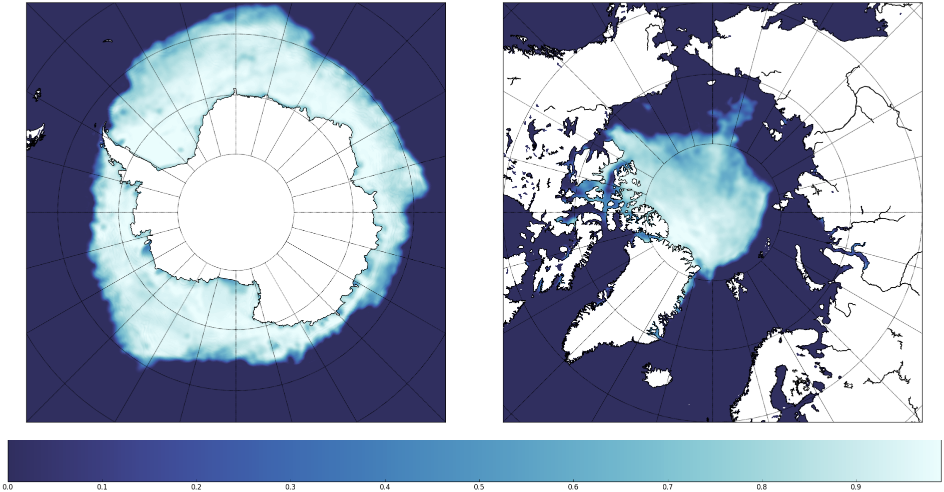
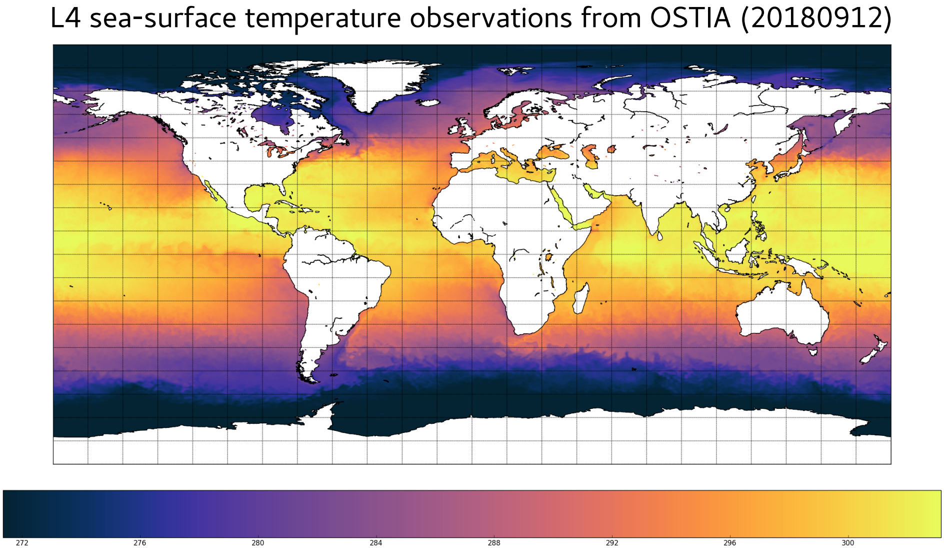
Sea ice concentration observations

L4 sea ice concentration observations from OSTIA (20180912)



Sea-surface temperature



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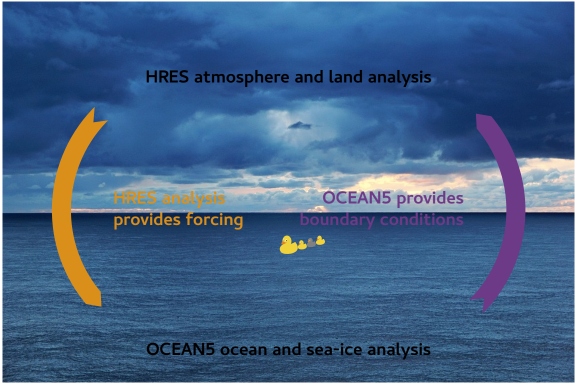
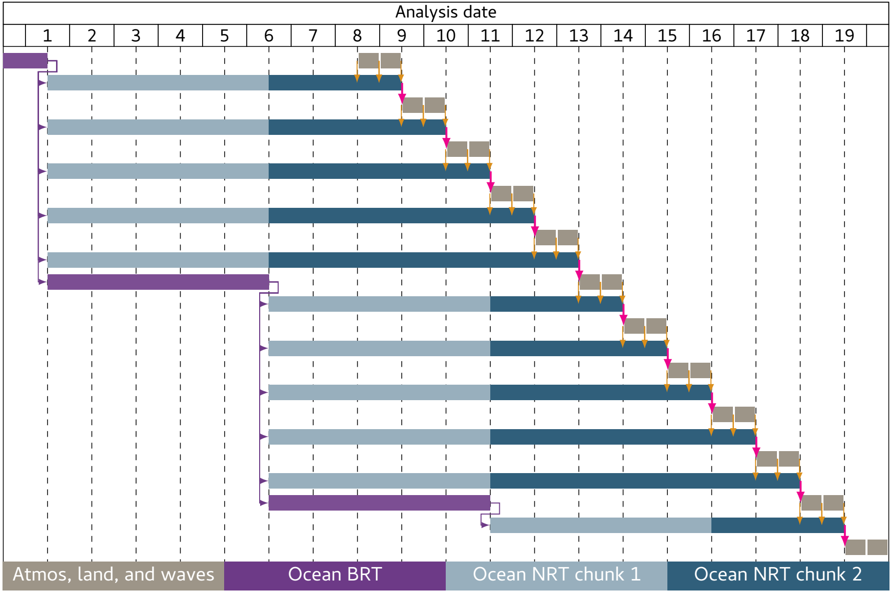
Weakly coupled ocean-atmosphere assimilation

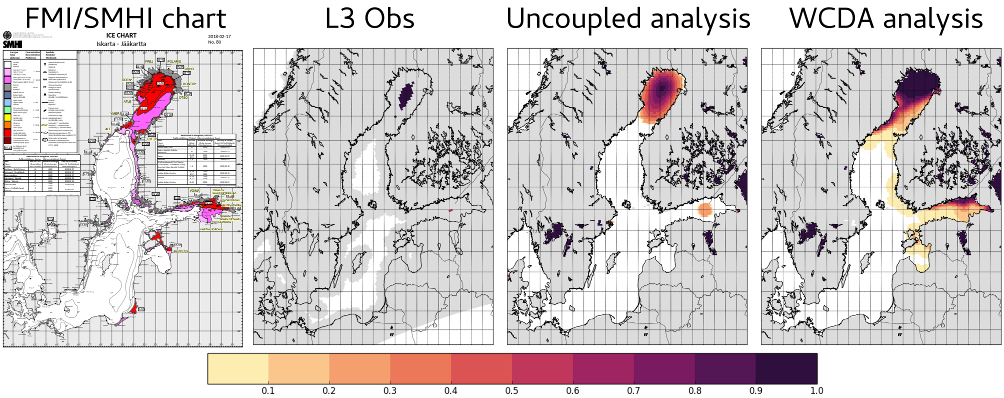


- Operational - WCDA through sea ice concentration
- Next upgrade - WCDA through sea-surface temperature $\pm 20^\circ$ to 25°

Ocean analysis suite

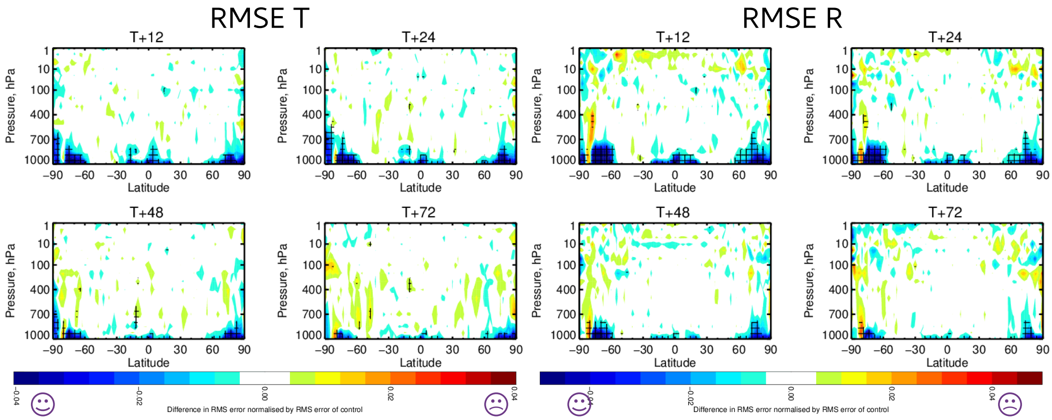


WCDA Sea ice in the Baltic Sea

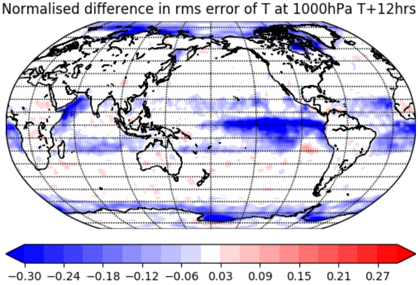


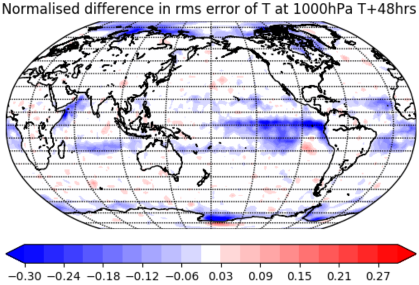
Sea ice concentrations in the Baltic sea on 20180217. [FMI et al. 2018]

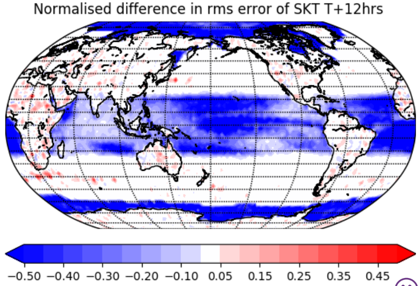
Weakly coupled assimilation results

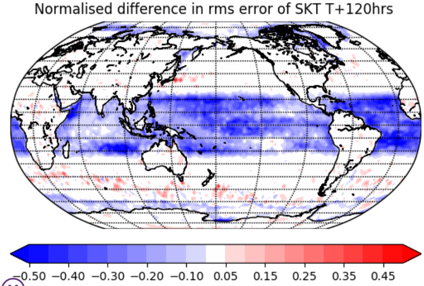


WCDA maps of surface temperatures









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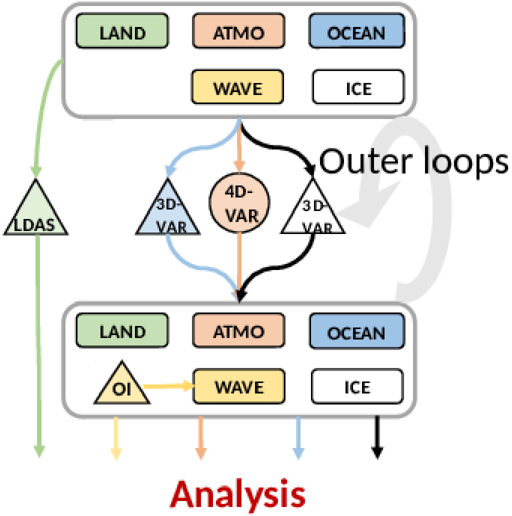
Outer loop coupling within 4D-Var

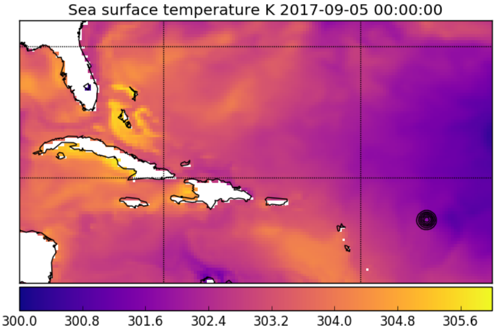
Developed for CERA: coupled reanalyses. See CERA-20C [Laloyaux et al. 2016] and CERA-SAT [Schepers et al. 2018].

- For each outer loop, the nonlinear trajectories are coupled and used to compute observation departures $(y - \mathcal{H}\mathcal{M}[x])$.
- Separate minimisations for atmosphere, ocean, and sea ice are performed.
- Increments in those components are applied at start of next outer loop.

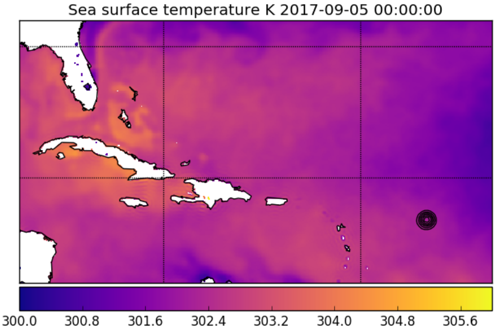


Potential of QSCDA - outer loop coupling ocean–atmosphere DA

Coupled assimilation



Uncoupled analysis (OSTIA)

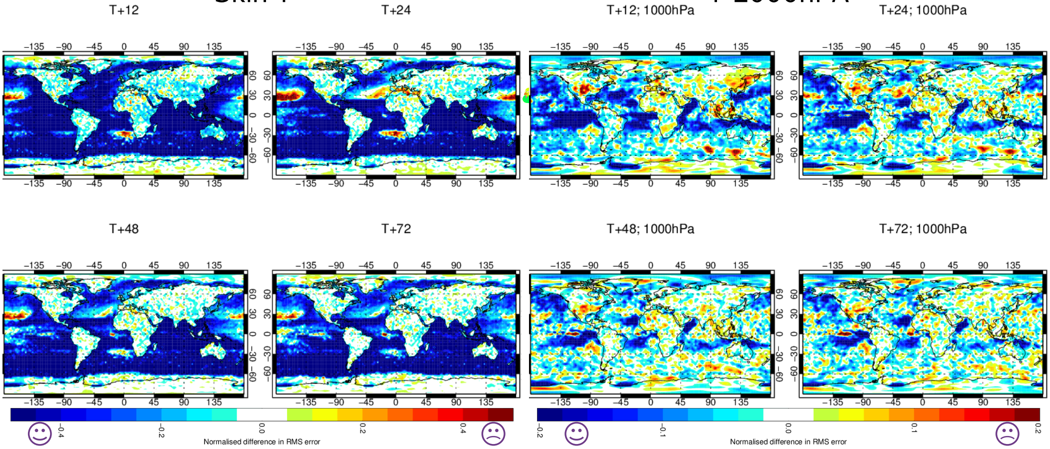


QSCDA - outer loop coupling ocean–atmosphere DA

RMSE forecast errors

Skin T

T 1000hPA



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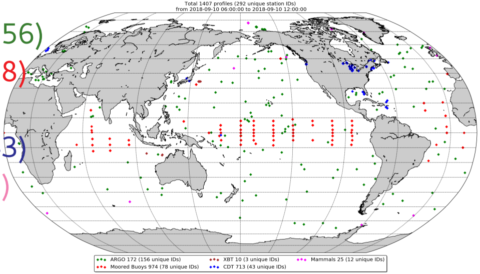
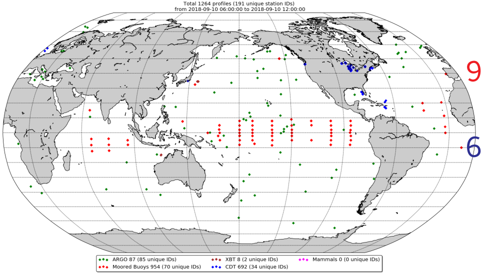
Ocean observation latency

49 hour cut-off

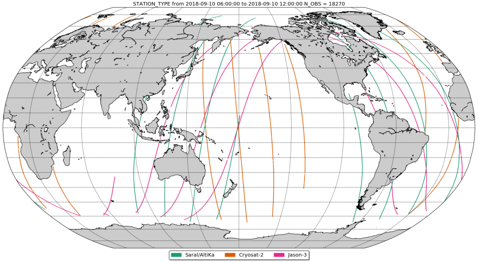
1 hour cut-off

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





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



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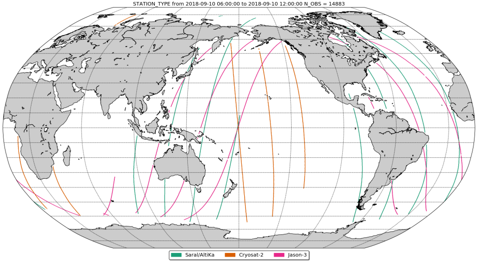

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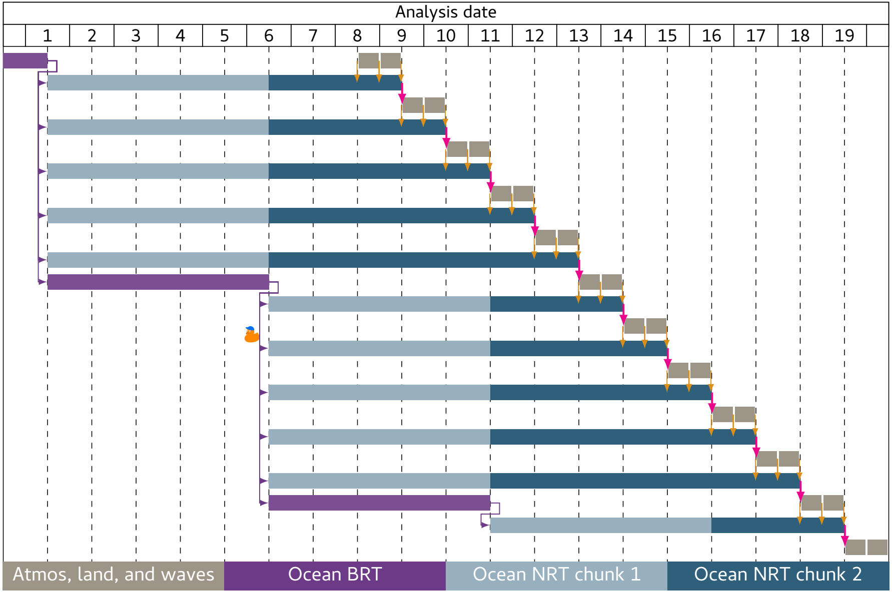
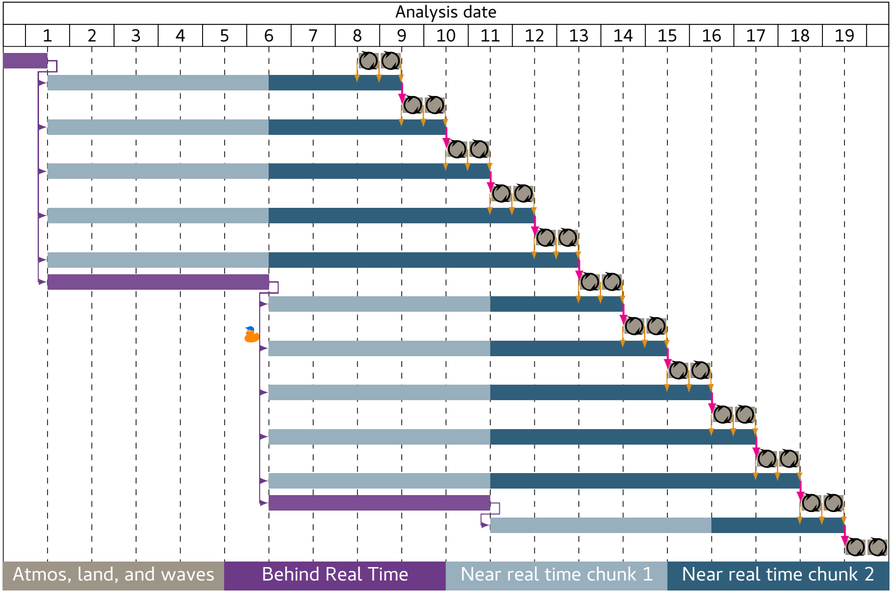
Combining WCDA and QSCDA for NWP

- Do both WCDA and outer loop coupling!
- For outer loop coupling, use the initial conditions from the latest available WCDA analysis
- Effectively we just apply outer loop coupling on top of the weakly coupled system to “spin up” the analysis

Combining WCDA and outer loop coupling for NWP



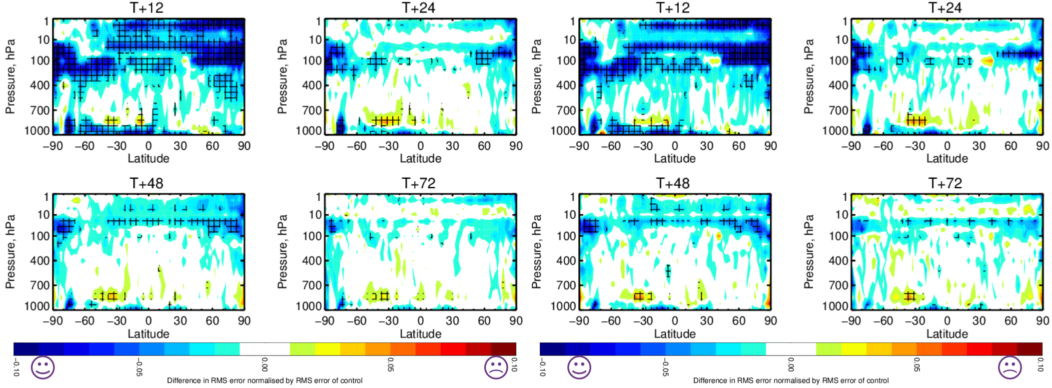
Combining WCDA and outer loop coupling for NWP



QSCDA compared to Composite WCDA/QSCDA

RMSE forecast errors in relative humidity

QSCDA WCDA/QSCDA



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

References

Argo (2018). *How Argo floats work*. URL: http://www.argo.ucsd.edu/How{_}Argo{_}floats.html (visited on 08/06/2018).

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PMEL, NOAA (2018). *Moorings | Global Tropical Moored Buoy Array*. URL: https://www.pmel.noaa.gov/gtmba/moorings (visited on 08/14/2018).

Schepers, Dinand et al. (2018). "CERA-SAT: A coupled satellite-era reanalysis". In: *ECMWF Newsletter* 155, pp. 32–37. DOI: 10.21957/sp619ds74g.

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Extra slides

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

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