Coupled Ocean–Atmosphere Assimilation for NWP at ECMWF

Philip Browne, Patricia de Rosnay

ECMWF Earth System Assimilation Section, Coupled Assimilation Team

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We follow the categorisations of Penny et al. 2017:

Observations affect the analysis of different components.

- At a later analysis time:
  - Weakly coupled assimilation

- At analysis time:
  - Strongly coupled assimilation
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
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

Arp go floats

Argo operational cycle.
[Argo 2018]
In situ ocean observations

Moored buoys

[PMEL 2018]
In situ ocean observations

Ship based observations

[CSIRO 2001]
In situ ocean observations

[MEOP et al. 2015]
Sea level anomaly observations

Altimeter measures SSH. Model represents $\eta$. The Geoid changes with time.

We convert to assimilating anomalies:

$$ y = \text{SSH anomalies} = \text{SSH} - \text{MSSH} \quad \quad H(x) = \eta \text{ anomalies} = \eta - \text{MDT} $$

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

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

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Reconciling timescales in the ocean and atmosphere analyses and observation networks
Weakly coupled ocean–atmosphere assimilation

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

Analysis date

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

RMSE T

RMSE R

Difference in RMS error normalised by RMS error of control
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

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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
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 \((y - \mathcal{H}M[x])\).

- 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)
RMSE forecast errors

T+12
Skin T

T+24

T+12; 1000hPa

T+24; 1000hPa

T+48

T+72

T+48; 1000hPa

T+72; 1000hPa

QSCDA - outer loop coupling ocean–atmosphere DA
Outline

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Reconciling timescales in the ocean and atmosphere analyses and observation networks
Ocean observation latency

49 hour cut-off

Total 499 profiles (397 unique stations)
from 2018-09-28 00:00:00 UTC to 2018-09-30 12:00:00 UTC

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

18270

1 hour cut-off

Total 124 profiles (193 unique stations)
from 2018-09-28 00:00:00 UTC to 2018-09-29 12:00:00 UTC

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

14883

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CDA for NWP at ECMWF
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

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- Atmos, land, and waves
- Behind Real Time
- Near real time chunk 1
- Near real time chunk 2

ECMWF
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CDA for NWP at ECMWF 22
QSCDA compared to Composite WCDA/QSCDA

RMSE forecast errors in relative humidity

QSCDA

WCDA/QSCDA

T+12

T+24

T+12

T+24

T+48

T+72

T+48

T+72

Pressure, hPa

Latitude

1000

0

1000

0

1000

0

1000

0

1000

0

1000

0

1000

0

1000

0

1000

0

1000

0

Difference in RMS error normalised by RMS error of control

CDA for NWP at ECMWF 23
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

çe Works with observations available in NRT
.Mailbox Improves forecasts


Extra slides
### The ocean model

- **NEMO model v3.4.1**
- ORCA\(_{025}\) resolution: 0.25\(^\circ\) 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