Climate reanalysis and reforecast needs: An Ocean Perspective

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Summary

• Why needs SST/SIC and How to treat the information

• Uncertainty in SST/SIC analysis products

• SST and SIC in Ocean ReAnalysis

• Impact on reforecasts: medium-range to seasonal

• Recent development works at ECMWF
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Important of satellite SST and sea-ice observations

In-situ obs

- ~1e3 /day

Altimeter obs

- ~1e5 /day

Sea ice concentration

- ~1e6 /day

Daily available oceanic obs (24 Nov 2010)

SST

- ~1e6 /day
Model SST bias

Bias in Gulf Stream regions:
- Not enough resolution
- Inaccurate bathymetry
- Lack of A-O interactions
- Very weak constrain from in-situ observations (at continental shelf and near coast)
Ice thickness:

SST:
OSTIA
CNTL
+SST DA

Oct-Nov 2007

Tietsche et al., 2015
Use of SST/SIC obs in Ocean ReAnalysis

- Model: NEMOv3.4 + LIM2 (0.25 deg + L75)
- DA: 3DVAR-FGAT
- 5 ensemble members
- BRT+RT streams

OCEAN5 is used for initialising ocean and sea-ice components for

- ECMWF coupled forecasting systems
- Seasonal Forecasting System 5
- Atmospheric analysis: sea-ice

ORAS5

BRT stream

Zuo et al., 2018, in prep

Sea-ice conc. SST SSS Sea-Level T/S profiles

FORCING fluxes
Bulk formula

Forcing pert.

Bias corr.

BRT stream

3DVar-FGAT

Observations

Obs. pert.

Bias corr.

NEMO

LIM2

Innovations Background

Increment

BRT+RT streams

Daily Initial condition valid at 00 UTC for the next day

ORAS5

RT stream

14:00 UTC

Restart to RT stream

ReAnalysis

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ReAnalysis
SST and sea-ice analysis products used in ORAS5

Haney 1917

\[ Q_{ns} = Q_{ns}^0 + \frac{dQ}{dT}(SST_{MODEL} - SST_{TARGET}) \]

non-solar total heat flux

Fixed negative feedback coefficient

SIC ensemble sampling

Zuo et al., 2017
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Uncertainty in SST and SIC analysis products

SST and SIC L4 analysis products are commonly used in climate modelling, ocean (ECMWF ORAs) and atmosphere (ERAs) reanalysis, for the following reasons

- **Gridded product without gap**, make it very easy to use, e.g. for prescribing sea surface conditions for ERAs and surface nudging for ORAs (ORAS4, ORAS5).

- Normally consider to be more stable (no-gap, combined multiple sensors with homogeneity, bias corrected) than L2/L3 products, and less susceptible to instrumental failure due to the analysis procedure.

There are many SST and SIC analysis products available (OSTIA, ESA CCI, OIv2, HadISST2 ...). However different SST/SIC analysis products are not always consistent, with large uncertainties (magnitudes varies from global/climate to regional/daily scales) in both SST and SIC among them.

- Different SST definitions
- Different data sources
- Difference bias correction strategies
- Different analysis procedures
# Summary of some L4 SST/SIC analysis products

Only products utilized satellite observations and with a global coverage

<table>
<thead>
<tr>
<th>products</th>
<th>Data sources</th>
<th>SST definition</th>
<th>Bias correction</th>
<th>member</th>
<th>resolution</th>
<th>period</th>
</tr>
</thead>
<tbody>
<tr>
<td>OIv2d (NOAA)</td>
<td>AVHRR, AMSR, in-situ</td>
<td>bulk SST (~0.5 m depth)</td>
<td>Bias corr. against in-situ (ship-based and buyo)</td>
<td>OI 1 member</td>
<td>Daily, 0.25 deg</td>
<td>1981-NRT</td>
</tr>
<tr>
<td>OSTIA (UKMO)</td>
<td>(A)ATSR, AVHRR, in-situ Oper. only: TMI, AMSR-E, NAR, SEVIRI</td>
<td>Foundation temperature (night time only), at ~ 4-10 m depth</td>
<td>Bias corr. against AATSR and in-situ (drifting buyo)</td>
<td>OI 1 member</td>
<td>Daily, 0.05 deg</td>
<td>1985-NRT</td>
</tr>
<tr>
<td>HadISST2 (Hadley Centre)</td>
<td>ATSR, AVHRR, in-situ</td>
<td>Night time only for AVHRR and ATSR</td>
<td></td>
<td>OI 10 ens</td>
<td>Pentad, 0.25 deg</td>
<td>1961-2010</td>
</tr>
<tr>
<td>CCI-SST (ESA)</td>
<td>ATSR (ref), AVHRR</td>
<td>Daily mean SST at 0.2 m</td>
<td>No BC against in-situ</td>
<td>OI 1 + uncert.</td>
<td>Daily, 0.05 deg</td>
<td>1991-2010</td>
</tr>
</tbody>
</table>

ATSR: the Along-Track Scanning Radiometers  
AATSR: Advanced Along Track Scanning Radiometer  
AVHRRs: Advanced Very High Resolution Radiometers  
AMSR-E: Advanced Microwave Scanning Radiometer-EOS  
TMI: Tropical Rainfall Measuring Mission Microwave Imager  
SEVIRI: Spinning Enhanced Visible and Infra-Red Imager
Relative to OSTIA climatology, for different SST analysis products (OIv2, HadISST, OSTIA … in grey) and the ESA-CCI SST (green)
Uncertainty in SST analysis

CCI-SST

Olv2

OSTIA

HadISST1

SST trend

CCI climate assessment report 2014
Uncertainty in sea-ice concentration analysis

Arctic sea ice extent (10%) SIC≥10%

Movement of sea ice concentration (%; shade) in July 2007

(a) OSI–SAF repr. (b) OSI–SAF &OSTIA (c) TR14 &HadISST2.1

Hirahara et al, 2016
Uncertainty in sea-ice concentration analysis

HadISST.2.1 SIC was adjusted against NIC ice charts. As a result, it contains more ice than OSI-SAF.

Titchner et al., 2014
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## Sensitivity to SST and SIC products

### Global Ocean Heat Content ($1.0 \times 10^9$ J/m$^2$)

### DA experiments with different products

<table>
<thead>
<tr>
<th>Name</th>
<th>SST</th>
<th>SIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASM-OST</td>
<td>OSTIA</td>
<td>OSTIA</td>
</tr>
<tr>
<td>ASM-HadI</td>
<td>HadISST2.1</td>
<td>HadISST2.1</td>
</tr>
<tr>
<td>ASM-HadI-OST</td>
<td>HadISST2.1</td>
<td>OSTIA</td>
</tr>
</tbody>
</table>

### Global mean SST

![Global mean SST graph](image)

### Global Ocean Heat Content ($1.0 \times 10^9$ J/m$^2$)

![Global Ocean Heat Content graph](image)
Sensitivity to SST and SIC products

ASM-HadISST SIC overestimated Arctic sea-ice thickness in general, and particularly at the north of Greenland and in the Beaufort Sea.
Sensitivity to SST and SIC products

High sea-ice concentration in the HadISST2 analysis

• Too much fresh water export $\rightarrow$ Insulates the ocean from cooling in winter
• Increased OHC
• Weakening deep water formation in the Labrador Sea
• Produces a reduction of AMOC

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**OHC: ASM HadSIC – OSTIA SIC**

- Latitude
- Longitude

- $10^4 \times 10^3$ (J/m$^2$): Min = -0.09, Max = 0.03, Int = 0.05

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**AMOC at 26N (Sv)**

- ASM-OST
- ASM-Hadl
- ASM-Hadl-OST

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European Centre for Medium-Range Weather Forecasts
Consistency in analysis product

Filling the temporal gap in SIC analysis

OSTIA SIC: March to April 1986

Antarctic sea-ice concentration showed a historical low in 1986 March-April, which was contaminated by missing observations in this period.
Consistency in analysis product

OSTIA SST: new – old

Global: 0.05K

New (from Nov 2016): ACSPO VIIRS for bias correction
Old: MetOp-A AVHRR for bias correction

Arctic sea ice extent

Tietsche et al., 2014
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• **Impact on reforecasts: medium-range to seasonal**

• Recent development works at ECMWF
Impact of sea-ice condition in coupled forecasts - medium range

Normalised differences in T errors: OCEAN5 CI - OSTIA CI at T+12 and T+24 hours

- OSTIA CI used is with 1-day delay
- OCEAN5 CI is more realistic due to additional constrains from atmospheric forcing and other obs types (in-situ, SST)
- OCEAN5 provided CI is more consistent with coupled forecasting model, which share the same ocean model configuration as OCEAN5
Impact of sea-ice condition in coupled forecasts - medium range

Normalised differences in SKT RMS: OCEAN5-OSTIA at T+12 and T+24 hours

WINTER (DJF)

SUMMER (JJA)

Figure by Phil. Browne
Impact of SST nudging in Seasonal Reforecasts

SST reforecast bias (month=3): 1981-1995

from CTRL with SST nudging

from CTRL without SST nudging

Conclusion: SST restoration may be too strong for the early period (pre-2000)
Impact of SST nudging in Seasonal Reforecasts

Skill of seasonal forecasts is very sensitive to SST nudging and ocean data assimilation
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Development of L3 SIC assimilation

Daily assimilated SIC on 20130118

L4 analysis: with **filtering, masking**, **extrapolation** to produce a gap-free product

with 10km resolution there is ~1 milion obs per day from L3 OSI-SAF, obs reduced to ~10,000 per day with a thinning boxes of ~0.5X0.5 degree
Impact on ORA: L3 OSI-SAF VS L4 OSTIA

ORA SIC differences (2005-2015)
OSI-SAF (L3) – OSTIA (L4)

March

September

Reduced the biases of SIC in Canadian Archipelago

Figure by Beena B. Sarojini
Impact on reforecasts: L3 OSI-SAF VS L4 OSTIA

Reforecasts differences: September (May start)
OSI-SAF (L3) – OSTIA (L4)

Figure by Beena B. Sarojini
Development of SST assimilation

- Assimilation of bias corrected L2P swath SST (Kindly provided by UKMO)
- SST treated as the single first layer Temperature in model
- Mixed layer dependent vertical correlation and rossby radius dependent horizontal correlation

- In total ~8e5 observations per day
- Only ~3e4 for the profiles
SST assimilation VS nudging

**T increments**

- **Nudging L4**
  - SST relaxation - std vert. lengthscales
  - SST relaxation - MLD param

- **DA L2P**
  - SST assim - std vert. lengthscales
  - SST assim - MLD param

- **MLD param allows the propagation of the T incr. down to the thermocline**
- **Further thinning and increased SST OE reduce the weight given to SST obs. wrt to profiles**

Figure from Eric de Boisseson
SST assimilation VS nudging

First results encouraging. Work still ongoing to find the best configuration: convergence, MLD param, OE, bias correction...

- SST relaxation: fit to profiles greatly improved with MLD param. But much more expensive.

- SST assim with MLD param: assimilating all the data improves the bkg in the first levels but degrades the fit in the thermocline and at depth. Thinning and increasing the OE sdv for SST help reducing the degradation at depth but first levels still worse.
Summary

- SST and sea-ice observation is essential for climate monitoring and reanalysis/reforecasts application
  - Much more (1e3 times) SST/SIC observation available than ocean in-situ observations
  - Ensure accurate reproduction of various Essential Climate Variables (ECVs): OHC, sea-level, Transports, Overturning circulations, et al
- There is large uncertainty (0.1-0.15K) in SST analysis products due to different data sources, SST definitions, bias correction and analysis strategies.
- Ocean reanalysis is sensitive to the assimilated SST/SIC products. At the same, consistency in SST/SIC product is crucial for ORA and climate application.
- Both SST and SIC assimilations have an impact on (re)forecasts, which is not always positive.
- ECMWF is developing assimilating L2P SST and L3 SIC data.