OceanPredict
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National Report – TOPAZ

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a. Norway – TOPAZ

Background

TOPAZ has been running near real time forecasts since 2003. In 2020 TOPAZ runs a regional Arctic + North Atlantic physical ice-ocean near-real-time forecast system (2011 to present) and reanalysis (1992-2019 included) with similar settings. Both are based on the HYCOM ocean model, a modified version of the CICEv3 sea ice model and the Deterministic EnKF for assimilation. In addition to the TOPAZ systems, these Arctic models are also part of the service:

- In March 2020, a tidal and storm surge forecast has been added based on HYCOM,
- A stand-alone sea ice model using neXtSIM has also come to operations in July 2020.
- In 2017, a wave forecast from MET Norway's WAM model has been added to the service and a wave hindcast (1998-2019) included in 2020.

1. Input data

- In-situ observation input data: All the CMEMS IN-SITU TAC reprocessed data all platforms.
    - Argo T&S profiles from CMEMS IS TAC / Ifremer (real-time and reanalysis)
    - Ice Tethered Profilers from CMEMS IS TAC (real-time and reanalysis).
    - T&S data from research cruises and moorings (reanalysis)
- Satellite observation input data
    - SSH: Along-Track SLA from CMEMS SL TAC / CLS (Sentinel-3ab, Jason 3, CryoSAT2 and Saral/AltiKa in real-time, all satellites in reanalysis)
    - SST: OSTIA from CMEMS SST TAC / UK Metoffice (real-time) and ESA CCI in reanalysis
    - Ice concentrations: SSM/I from CMEMS SI TAC (OSI-SAF), in real-time and OSI-SAF / ESA CCI in reanalysis. neXtSIM assimilates a combination of SSM/I and AMSR-2.
    - Ice drift: 2-days Lagrangian drift from CMEMS SI TAC (OSI-SAF) also in Summer since 2017, merged from ASCAT and SSM/I (3-days drift from CERSAT in reanalysis)
    - Ice thickness: Weekly merged CryoSAT2-SMOS (CS2SMOS) from the CMEMS SI TAC both in NRT and reanalysis.
    - Ocean colour: Surface Chlorophyll-a is projected downwards using the Uitz et al. (2006) relationship.

- Forcings
    - ECMWF (0.1 deg x 6 hours, real-time)
    - ERA5 (0.5 deg x 6 hours, reanalysis)
- Auxiliary data
    - Bathymetry: GEBCO
    - T/S Climatology: Blended WOA05 – PHC
    - Mean SSH: TOPAZ4 free run (NRT) and CNES/CLS Rio2018 (reanalysis)
    - Rivers monthly climatology from ERA-Interim run-offs, channelled through the TRIP hydrological model (Oki & Sud, 1998), Greenland mass loss from GRACE (in reanalysis)
    - Estimated Pacific Water fluxes and temperatures through Bering Strait from Woodgate et al. GRL 2011 (reanalysis only, constant +0.8 Sv in real-time).
- Processing procedures
    - Data arriving on the same grid cell are averaged arithmetically (super-obing).
    - No "background check" is applied, but observation errors are inflated if obs and forecast uncertainties do not overlap (until there is an overlap).

2. Data serving

Please provide information about

- System products
    - NRT physical ocean forecast and analyses (TOPAZ4)
    - NRT biogeochemical ocean forecast and analyses (TOPAZ5-ECOSMO)
    - NRT physical tidal and storm surge forecast and analysis (TOPAZ6)
    - NRT stand-alone sea ice forecast and analysis (neXtSIM-F)
    - NRT wave forecast and analyses (WAM-Arctic)
    - Physical ocean reanalysis (TOPAZ4)
    - Biogeochemical ocean reanalysis (ECOSMO)

For all products, NetCDF4 files are provided (TOPAZ4 in NetCDF3), CF-compliant in two datasets: daily averages (NRT and surface-only reanalysis), monthly averages (reanalysis) hourly data (waves, neXtSIM and NRT ocean surface data) and 15-minutes averages (tides and storm surges)

- Dissemination systems
    - The CMEMS data portal on http://marine.copernicus.eu
    - As a backup dissemination, the THREDDS server at MET Norway http://thredds.met.no/thredds/myocean/arc_mfc.html
- Delivery mechanisms
    - Secured FTP
    - Subsetter
    - THREDDS
    - WMS
- Services
    - Visualisation
    - Discovery
    - Download
    - Invoke

3. Models

Please provide information about

- Model name(s)
- Model type(s) / versions
- Model specifications (e.g. domain, resolution, vertical coordinates, forcings, etc.)

The TOPAZ4 NRT system uses the version 2.2.37 (2.2.18 for reanalysis) of the Hybrid Coordinate Ocean Model (HYCOM, Bleck 2002), used with the Canuto (GISS) turbulent mixing scheme, it uses a 4^{th} order scheme for advection of momentum (Winther et al. 2007, Backeberg et al. 2010). Since 2007, the TOPAZ4 grid has horizontal resolution varying from 11 to 16 km, covering the Arctic and North Atlantic basins. The hybrid coordinate is isopycnal and z-level and uses 28 layers (50 in reanalysis).

A dynamic - thermodynamic ice model is coupled to HYCOM with the EVP rheology from CICE v3 (Hunke and Dukowicz, 1997) and thermodynamics from Drange and Simonsen (1996). A stand-alone sea ice model called neXtSIM-F, based on the Brittle Bingham Maxwell rheology, is using TOPAZ4 as initial and bottom (ocean) forcing (Rampal et al. 2016) runs for the whole Arctic on a ~10km Lagrangian triangular mesh.

The ECOSMO-II ecosystem model (Dæwel & Schrum 2013) has run in near-real-time TOPAZ4 runs at MET Norway since April 2016 with online coupling (same resolution), it has been upgraded in May 2021 to run at 6 km horizontal resolution (TOPAZ5). Reanalysis ecosystem runs have been carried out with a 50km HYCOM prototype coupled to ECOSMO-II in the period 2007-2010.

The TOPAZ system is running in near real time on the Alvin cluster on the Swedish National Supercomputing Center. Versioning is managed through a Subversion repository (transitioning to GitHub for TOPAZ5).

The Arctic Ocean Wave Analysis and Forecast system uses the WAM model at 3 km resolution forced with surface winds and boundary wave spectra from the ECMWF (European Centre for Medium-Range Weather Forecasts) together with currents and ice from the ARC MFC analysis (Sea Ice concentration and thickness). A WAM hindcast covers the years 1998-2019

4. Assimilation method

Please provide information about

- DA systems
- Methods

For NRT and reanalysis, TOPAZ4 uses the DEnKF with 100 members (Deterministic EnKF, Sakov et al. Tellus, 2008), fully multivariate, dynamical error propagation. The assimilation is asynchronous (= “ensemble-FGAT” or 4D-assimilation) for assimilation of sea-ice drift and track SLA data (see Sakov et al. Tellus, 2010), other observations are taken on the day of the analysis. Bias estimation is performed online for Mean SSH and SST, only in reanalysis mode.

The assimilation scheme is local with an observation search radius of 300 km and a smooth localization window (Gaspari & Cohn, 1997). The effective radius is thus about 90 km. When outliers are encountered, their observation error is increased instead of being removed by background check (“moderation of observation errors”). The assimilation step is hybrid MPI –OpenMP parallel and uses no more than 50 mins to assimilate about 400.000 observations – once superobed – on 20 CPUs. The memory usage is below 4Gb.

Diagnostics for assimilation sensitivity to observations are produced locally by the assimilation system routine: Degrees of Freedom of Signal (DFS) and Spread Reduction Factor (SRF) for each data type assimilated and jointly.
Version control between NERSC and MET Norway is using a similar Subversion repository as for the HYCOM code (transitioning to GitHub).
The standalone neXtsIM-F sea ice forecasts use a daily nudging to observed sea ice concentrations. TOPAZ6 and WAM run without assimilation for the time being.

5. Systems (operational)

The operational TOPAZ4 system runs a weekly assimilation cycle, ensemble forecasts (10 members) are run daily with updated weather forcing. Only the ensemble mean is provided in daily average forecasts. TOPAZ6 runs daily providing 10-days forecasts. WAM runs twice daily providing one hourly 10 days forecast and one hourly 5 days forecast. neXtSIM-F runs daily providing 7-days forecasts.

6. Link to observations (e.g. Argo, GHRSST, etc.)

Observations are assimilated (as mentioned above) and used for validation. Observing System Experiments have been conducted for

- Sea ice thickness data from ESA's SMOS satellite (thin ice Xie et al. 2016 and merged CryoSAT+SMOS, Xie et al. 2018)
- Altimeter data from reflectometry (GNSS-R), Xie et al. 2017.
- Sea Surface Multiscale Kinematics Mission (SKIM), Ardhuin et al. 2018.
- Surface salinity from SMOS (CSIC product)

7. Internal metrics and intercomparison plans

- Internal metrics are published on http://cmems.met.no/ARC-MFC/V2Validation/index.html
- GODAE metrics are provided regularly on the US GODAE server since December 2017.
- Contribution to the Sea Ice Drift Experiment (SIDFEx) a contribution to YOPP. https://www.polarprediction.net/yopp-activities/sidfex/

8. Targeted users and envisioned external metrics

a. Wave modelling (ECMWF, Ifremer).
b. Downstream coastal services at MET Norway and IMR (ROMS 800m model).
c. Downstream sea ice charting and nowcasting service at MET Norway.
d. Arctic research community (ice stations drift forecast, ordering of SAR images)
e. E-Navigation with Navtor AS.
f. Ice navigation with Drift+Noise, Germany.
g. Norwegian fishing fleet, through ecosystem modelling.

h. French Navy (SHOM)
i. Norwegian Navy (FFI).
j. Design criteria for Oil and gas industry in the Arctic (TOTAL E&P Norge, Statoil, …).

9. Reanalysis and Hindcasting activities

- A 28-years reanalysis" has been completed with TOPAZ4 for the period 1991-2019. It has mostly the same characteristics as the V1 real-time system, but additional in-situ T/S profiles in the Nordic Seas and Arctic. It is being upgraded by a 50-layers model TOPAZ4b.
- This reanalysis is being updated twice a year until Yr-1.
- A biogeochemical reanalysis has been completed with joint assimilation of satellite ocean colour data from the ESA CCI and in situ nutrient profiles in a coarse resolution model (50km, period 2007-2010). It uses the one-lag smoother version of the EnKF (Gharamti et al. 2017).

10. Computing resources

- (For NRT forecasts) Stratus: Intel HNS2600BPB with Intel H2204XXLRE 2U/4-node chassis. The Stratus cluster uses 520 nodes / 16,640 compute cores. Stratus is operated by NSC at Linköping University. *Stratus* was installed in the end of 2018 to support the official duties of SMHI in Sweden, MET in Norway, and FMI in Finland within MetCoOp (the meteorological co-operation on operational numerical weather prediction in the Nordic countries).
- (for reanalysis) SurfSARA is provided by Cartesius, Nl, via a PRACE/DECI Tier-1 grant.

11. Consolidation phase and transition to operational systems (activities)

The Real-time system is fully operational at MET Norway (monitored 24/7), redundancy is partly implemented on SMHI supercomputing facilities.

The new TOPAZ5 prototype is setup jointly by NERSC and MET Norway and will be made pre-operational by MET Norway on the operational facilities. Transition to operations is scheduled for 2022.

12. GODAE OceanView related achievements and measures of success

a. Multivariate assimilation of all data types jointly (satellite and in-situ).
b. Demonstration of the stability of the dynamical ensemble assimilation method over a period of 28 years with all types of observations assimilated and inhomogeneous data coverage (Xie et al. 2017).
c. Renewed confidence from users such as TOTAL E&P Norge, ECMWF, SHOM, Joint Industry Projects from the Oil and Gas Producers association (OGP).

System Information overview

System name	TOPAZ
Ocean Models	
OGCM	HYCOM
Domain	North Atlantic (from 10S) – Arctic (until Bering Strait)
Horizontal resolution	12 km (between 1/8th – 1/6th)
Vertical sampling	28 Hybrid z-isopycnal layers
Atmospheric Forcing	ECMWF 0.1 deg resolution.
Assimilation characteristics	
Assimilation Scheme	DEnKF (Sakov and Oke 2008), 100 dynamical members
SST	L4 data from CMEMS SST TAC (OSTIA)
SSH	Along track SLA from CMEMS SL TAC
Ice concentrations	SSM/I from CMEMS SI TAC (OSI-SAF)
In-situ	Temp and Salinity profiles from CMEMS Arctic in-situ TAC (including Argo floats, CTD sections, ITPs)
Other	Sea ice drift from CMEMS SI TAC (OSI SAF product).
System Set-ups	
Forecast range	Out to 10 days
Update frequency	Weekly assimilation (with daily update of atmospheric forcing)
Hindcast length	1 week
Ensemble forecast	10 members (only ensemble mean distributed)
System website links	
General information	http://marine.copernicus.eu/
Technical description	http://marine.copernicus.eu/ CMEMS quality document (QuID) and user manuals (PUM)
Viewing service	http://marine.copernicus.eu/