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NERSC Technical Report no. 300

MERSEA TOP2 ASSESSMENT REPORT

ARCTIC THEMATIC PORTAL

by

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Bergen, January 15, 2009

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REPORT

TITLE MERSEA TOP2 Assessment report Arctic Thematic Portal	**REPORT No.** Technical report no. 300
CLIENT **EU FP6**	**CONTRACT** **MERSEA IP**
CONTACT PERSONS **Fabrice Hernandez, Mercator** **Yves Desaubies, Ifremer**	**AVAILABILITY** Public
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SUMMARY *optional*	
APPROVAL *Author*	 Ola M. Johannessen, Director

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Acronyms

ARGO	global array of profiling floats
BOOS	Baltic Operational Oceanographic System (http://www.boos.org/)
CLIVAR	CLImate VARiability and predictability
DMI	Danish Meteorological Institute
ECMWF	European Center for Medium Range Weather Forecast
EOF	Empirical Orthogonal Functions
ESEOO	Establecimiento de un Sistema Español de Oceanografía Operacional
ESSC	Environmental Systems Science Centre
FGAT	First Guess at Appropriate Time
GLOSS	Global Sea Level Observing System
GODAE	Global Ocean Data Assimilation Experiment
HYCOM	Hybrid Coordinate Ocean Model
INGV	Istituto Nazionale di Geofisica e Vulcanologia
MEC	MERSEA Executive Committee
MDT	Mean Dynamic Topography, also called MSSH (Mean Sea Surface Height)
MERSEA	Marine EnviRonment and Security for the European Area
MICOM	Miami Isopycnal Coordinate Ocean Model
MLD	Mixed Layer Depth
MRCS	POLCOMS Medium Resolution Continental Shelf Model
NCEP	National Centers for Environmental Prediction-http://www.ncep.noaa.gov/
NCOF/UKMO	National Center for Ocean Forecasting / United Kingdom Meteorological Office
NDBC	National Data Buoy Center, NOAA, USA
NEA	North East Atlantic region (and forecasting TEP)
NERSC	Nansen Environmental and Remote Sensing Center
n.m.	Nautical miles
NOAA	National Oceanic and Atmospheric Administration
NOOS	North West Shelf Operational Oceanographic System (http://www.noos.cc/)
NSIDC	National Snow and Ice Data Center (http://nsidc.org/)
NWP	Numerical Weather Prediction
RMS	Root Mean Square
ROOI	Reduced Order Optimal Interpolation
SLA	Sea Level Anomaly
SOOP	Ship Of Opportunity Program
SST	Sea Surface Temperature
SSS	Sea Surface Salinity
Sv	Sverdrup, transport unit in 10^6 m^3/s
TBD	To Be Defined
TEP	Thematic Environmental Portal
TOP	Targeted Operational Period
VOS	Voluntaree Observing Ship
WIN	Wide Integrated Network
WOCE	World Ocean Circulation Experiment
WP	Work Package

Reference documents

[REF1]	Overall Specification of the MERSEA Integrated System WP5.1., 24 March 2005". MERSEA-WP05-MERCA-STR-0005.01A"
[REF2]	Description of MERSEA Core System version v.1. Project Deliverables D9.3.2. 6 April 2006. M. J. Bell. MERSEA-WP09-METUK-STR004.01A.doc.
[REF3]	Meeting report. TOP 1 meeting. Issy les Moulineaux. May 24-25, 2005. P. Bahurel, M. Bell, Y. Desaubies. 31 May 2005. MERSEA-WP01-IFR-ECMR-006-01.doc
[REF4]	Summary of WP9 Meeting, Exeter, 1-3 February 2006. Mike Bell (NCOF/UKMO)
[REF5]	Draft Agreement and actions minutes from MERSEA WP9 TOP2 Meeting at Exeter 2-4 October 2006. Mike Bell (NCOF/UKMO)
[REF6]	Assessment during TOP1: guideline for metrics implementation. Delivery D5.4.4. MERSEA-WP05-MERCA-STR-0014.01C"
[REF7]	List of internal Metrics, specification for implementation. WP 5. Authors: L Crosnier, F. Hernandez et al. 24 March 2005. MERSEA-WP05-MERCA-STR0007_01A.doc
[REF8]	Definition of Class 1-4 metrics for the Arctic. Authors: L. Bertino, K. Lisaeter, G. Garric et al. May 2006. Project deliverable D5.4.5. MERSEA-WP05-NERSC-TECN-0017.02A.doc
[REF9]	List of internal metrics for the MERSEA-GODAE Global Ocean: Specification for implementation. L. Crosnier et al.. D5.4.5. MERSEA-WP05-MERCA-STR0015.01A.doc.
[REF10]	Guideline for the GODAE providers: Convention for the GODAE files, OpenDap and Live Access Server. L. Crosnier. D5.4.5 .MERSEA-WP05-MERCA-STR0016.01A.doc.
[REF11]	Guideline for Class 4 implementation. Project deliverable D5.4.5. MERSEA-WP05-MERCA-STR-0018.02A
[REF12]	Executive Committee Meeting Report: MEC-5. Paris, December 8-9, 2005. January 25, 2006. Y. Desaubies. MERSEA-WP01-IFR-ECMR-009.1c.doc.
[REF13]	Atlantic and Mediterranean metrics for TOP2. Project deliverable D5.4.5. MERSEA-WP05-MERCA-STR-0026.00A

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Introduction

Project context

WP5 central team	WP5	Fabrice Hernandez, Laurence Crosnier
Global	MERCATOR	Laurence Crosnier, Fabrice Hernandez
Arctic	NERSC	Knut Lisæter, Laurent Bertino
Baltic	DMI	Per Berg,Vibeke Huess
Mediterranean	INGV	Srdjan Dobricic,Paolo Oddo
North-E Atlantic	NCOF/UKMO	John Siddorn

Table 1: Forecasting TEP areas and team responsible for the validation

Purpose of the document

The goal of this document is to present the validation results from TOP2 focusing on the scientific validation (i.e., physical oceanography considerations) of five systems operated routinely.

As described in [REF6], the validation methodology follows three main steps:

1. Consistency: verifying that the system outputs are consistent with the current knowledge of the ocean circulation and climatologies.
2. Quality (or accuracy of the hindcast/nowcast): quantifying the differences between the systems "best results" (analysis) and the sea truth, as estimated from observations, preferably using independent observations (not assimilated).
3. Performance (or accuracy of the forecast): quantifying the short term forecast capacity of each system, i.e. answering the questions: do we perform better than persistency? Better than climatology?

This document is under the responsibility of the WP5 "central team", in charge of the end-to-end assessment of the MERSEA IP Integrated System. However, each forecasting TEP team (see Table 1) is contributing for its system and the corresponding area.

Description of the TOP2 v2 systems are done in another WP09 report (reference?).

Assessment documents overview

This document is associated with the following actions and documents (documents in bold/blue might evolve in the future):

A first document has been written to describe the metrics from MERSEA Strand 1: D8.1	[REF7]
General assessment methodology and implementation guideline for TOP1: D5.4	[REF6]

Class 1 to Class 4 metrics for the arctic are defined in a specific document:D5.4	[REF8]
Class 1 to Class 3 metrics for the global ocean, and GODAE are defined: D5.4	[REF9]
A guideline for GODAE metrics technical implementation has been written:D5	[REF10]
The guideline for Class 4 metrics implementation has been written: D5.4	[REF11]
This document: the TOP1 assessment results, and TOP2 assessment definition:D5.4	-

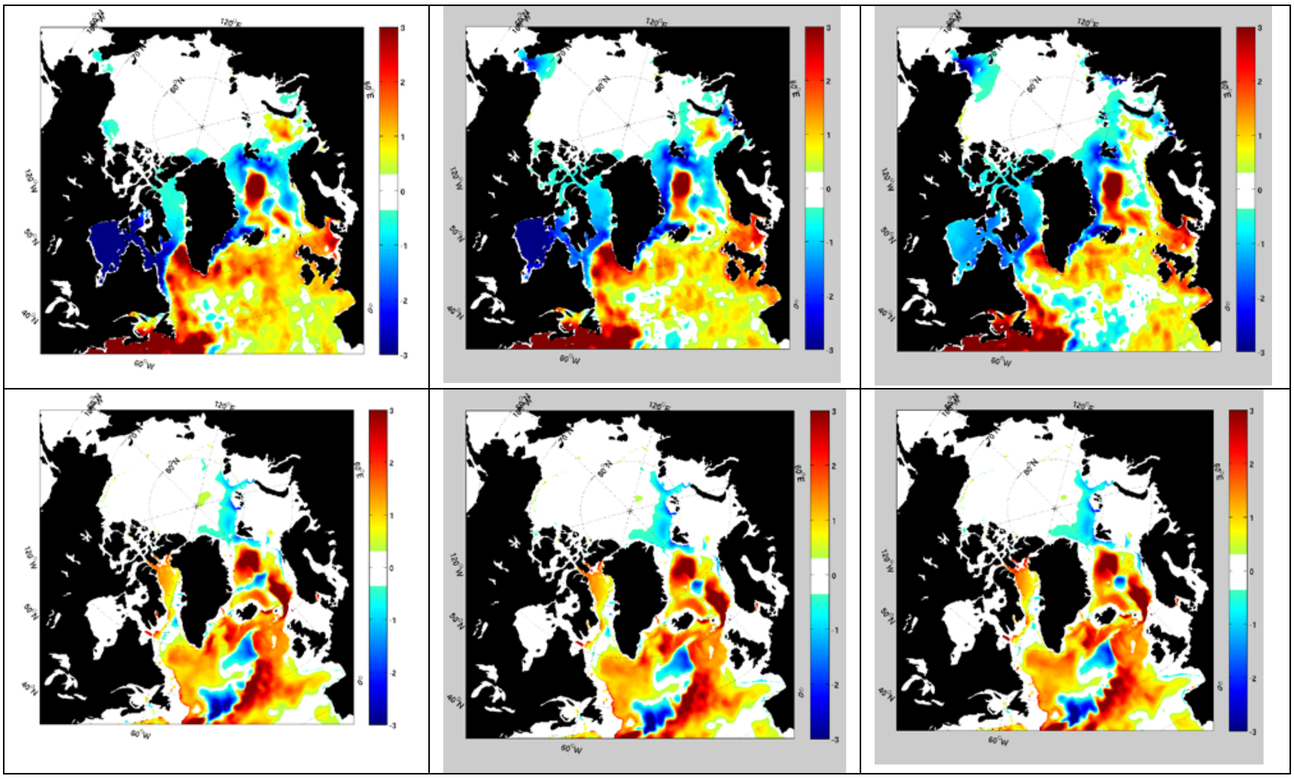
Table 2: list of validation documents in MERSEA IP

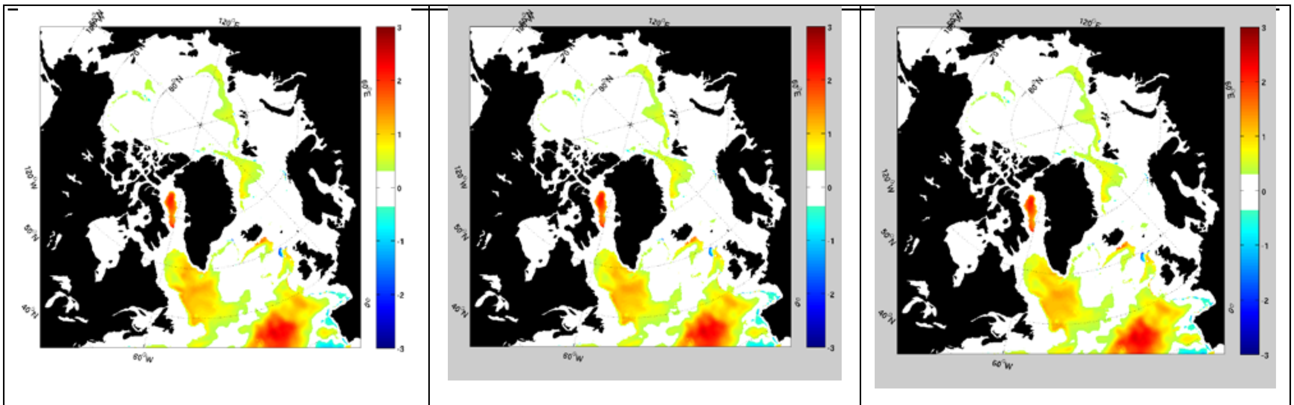
Consistency and quality: Class1, 2, and 3

Arctic TEP

Class1: Monthly mean Potential Temperature differences at 30, 400 and 1500 meters with respect to Levitus 2005.

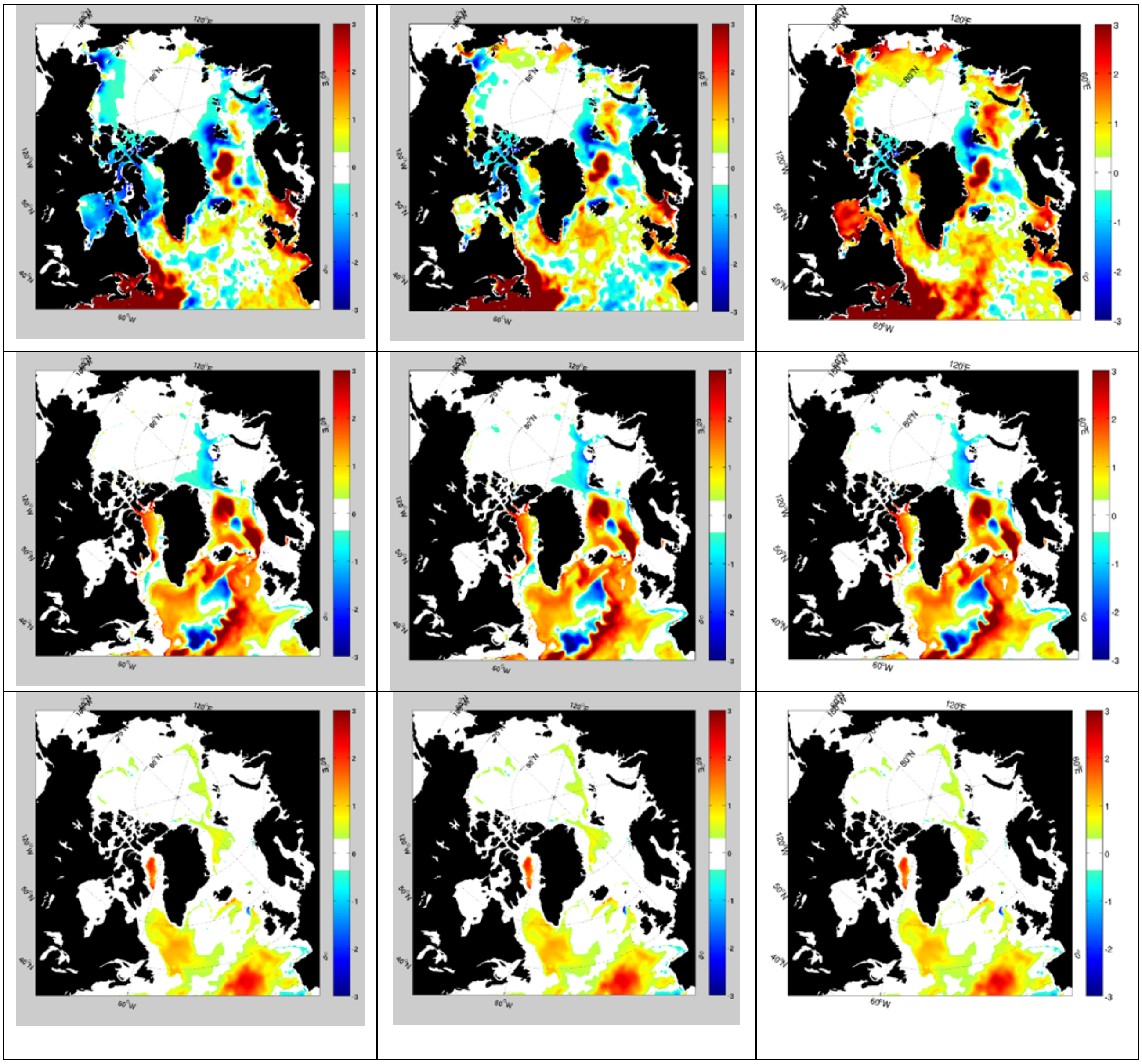
We have chosen to present the results close to the surface (30 m depths), deep (400 m) and at greater depths (1500 m) in order to highlight the main differences between the successive Arctic systems. Neither the surface properties nor the differences 3000m depths showed anything to comment on.





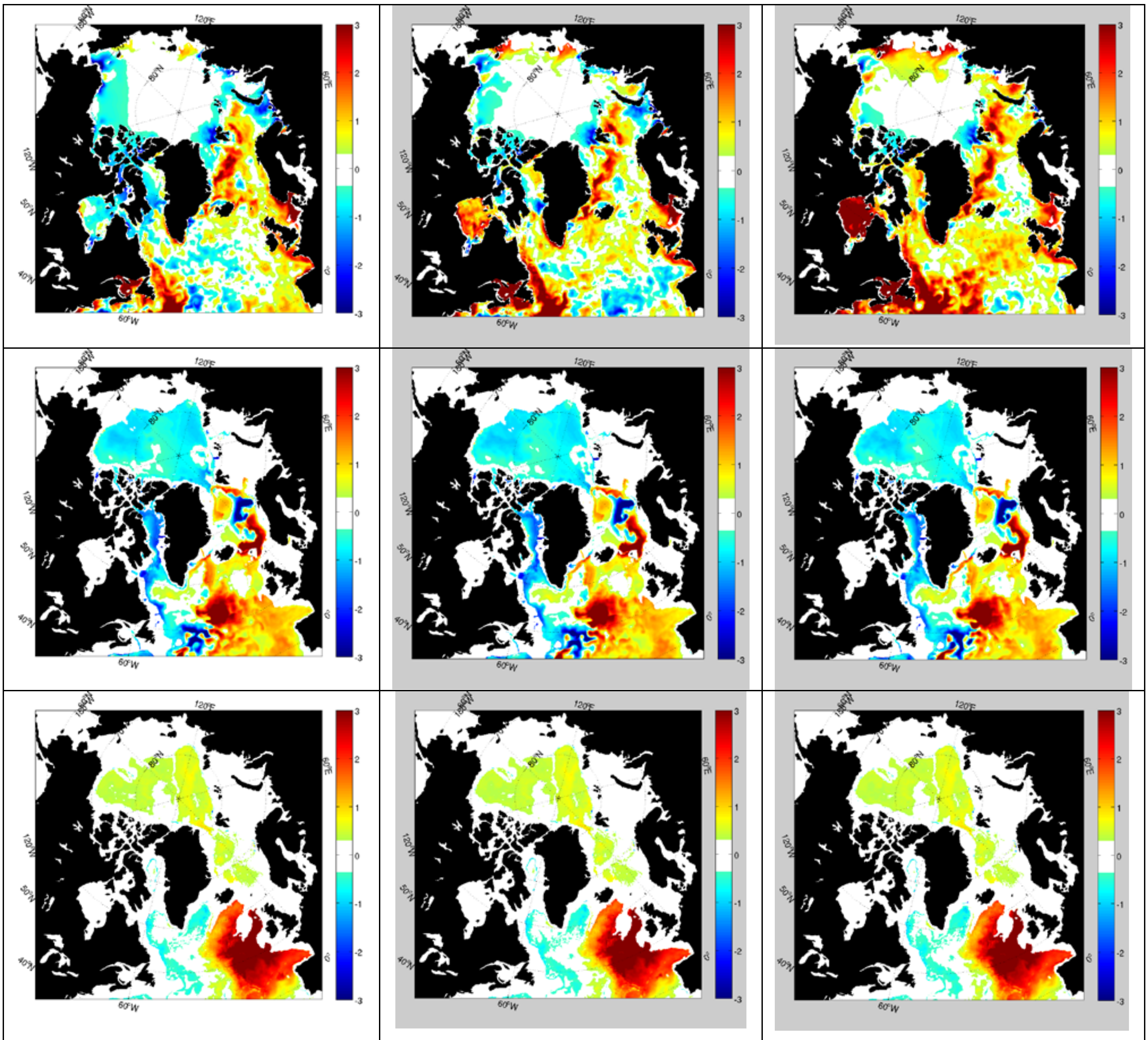
April 2007	May 2007	June 2007

Figure 0-1: TOPAZ2 Temperature anomalies at 30m (top), 400m (middle), 1500m (bottom) for the first 3 months of the TOP2 period.



July 2007	August 2007	September 2007

Figure 0-2: TOPAZ2 Temperature anomalies at 30m (top), 400m (middle), 1500m (bottom) for the last 3 months of the TOP2 period.



July 2007	***August 2007***	***September 2007***

Figure 0-3: TOPAZ3 Temperature anomalies at 30m (top), 400m (middle), 1500m (bottom) for the last 3 months of the TOP2 period.

In Figure 0-1 to Figure 0-3 the temperature anomaly at 30 m is low in the central Arctic for both systems because the surface temperature is close to the freezing point. The 30 m depth temperature error has lower values in the summer (from June to August) and then increases again in September, this is a common feature of TOPAZ2 and TOPAZ3. The differences in the Nordic Seas show a general improvement from V1 to V2 at 30 m depths and in particular the reduction of (1) the warm bias North of the Færoe Islands and (2) the cold bias West of Spitzbergen. Still, the recirculation south of the Fram Strait seems excessive – the water seems too warm South of the Fram Strait - and may require even higher horizontal resolution in order to be resolved.

The impact of the model upgrade (compare Figure 0-2 against Figure 0-3) is much larger than the temporal variability of the errors. The anomalies vary slowly from month to month.

At 1500 meters depths, the anomalies cannot be attributed to temporal variability but to model drift.

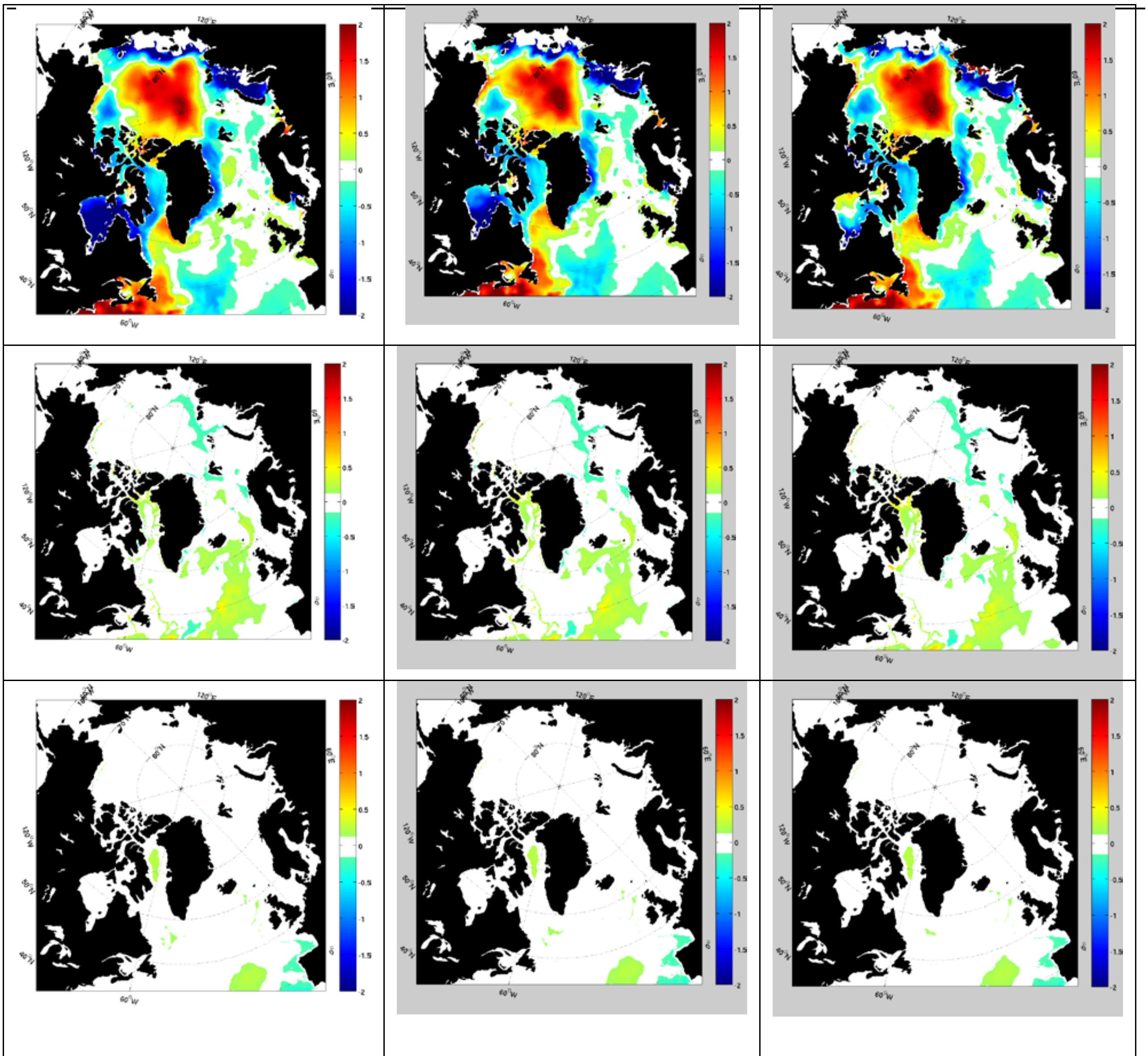
The temperature and salinity anomalies at 1500m depths show that the V2 system has drifted more than V1 below the Central Arctic and to the East of the Mid-Atlantic ridge. The deep warm and saline bias on the Eastern side of the Mid-Atlantic Ridge is probably caused by the inclusion of the Mediterranean Sea in the TOPAZ domain, as the representation of the deep Mediterranean outflow in the Atlantic is a well-known difficulty for ocean models.

On the other hand, the deep bias is reduced in the Sub-Arctic Gyre. The difference between V1 and V2 at depths is most likely caused by different spin-up integration times. The system V2 has been spun-up for 15 years instead of 7 years for V1.

Class1: Monthly mean Salinity differences at 30, 400 and 1500 meters with respect to Levitus 2005.

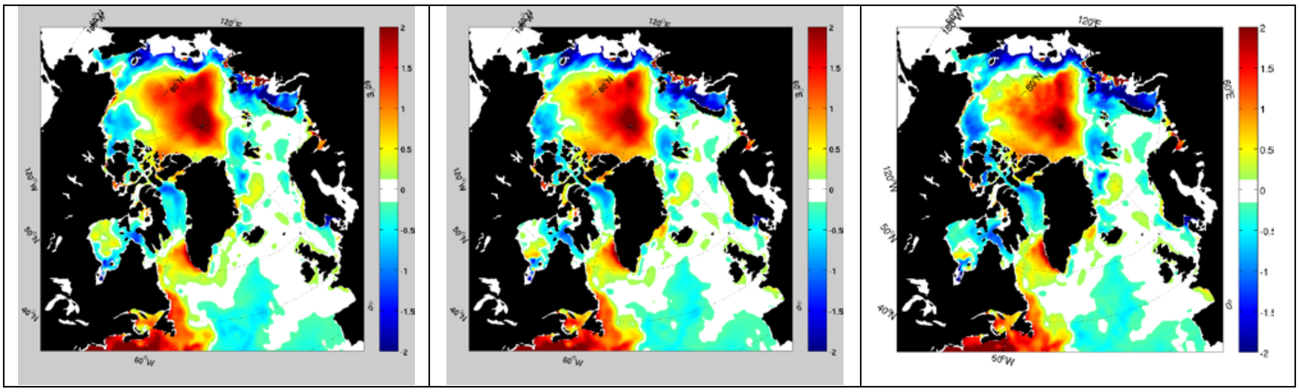
Figure 0-4 to ???? show on the contrary to temperature large salinity deviations at 30m in the Central Arctic. The anomaly has increased during the transition from TOPAZ2 to TOPAZ3 and extends through the Canadian Archipelago until the Labrador Sea. The reason is most likely a less realistic representation of the Bering Strait in V2 than in V1 (the barotropic flux of Pacific water through Bering Strait caused numerical instability of the code and was abandoned). To correct this saline bias, the system should be spun-up a dozen of years with realistic freshwater fluxes into the Bering Straits.

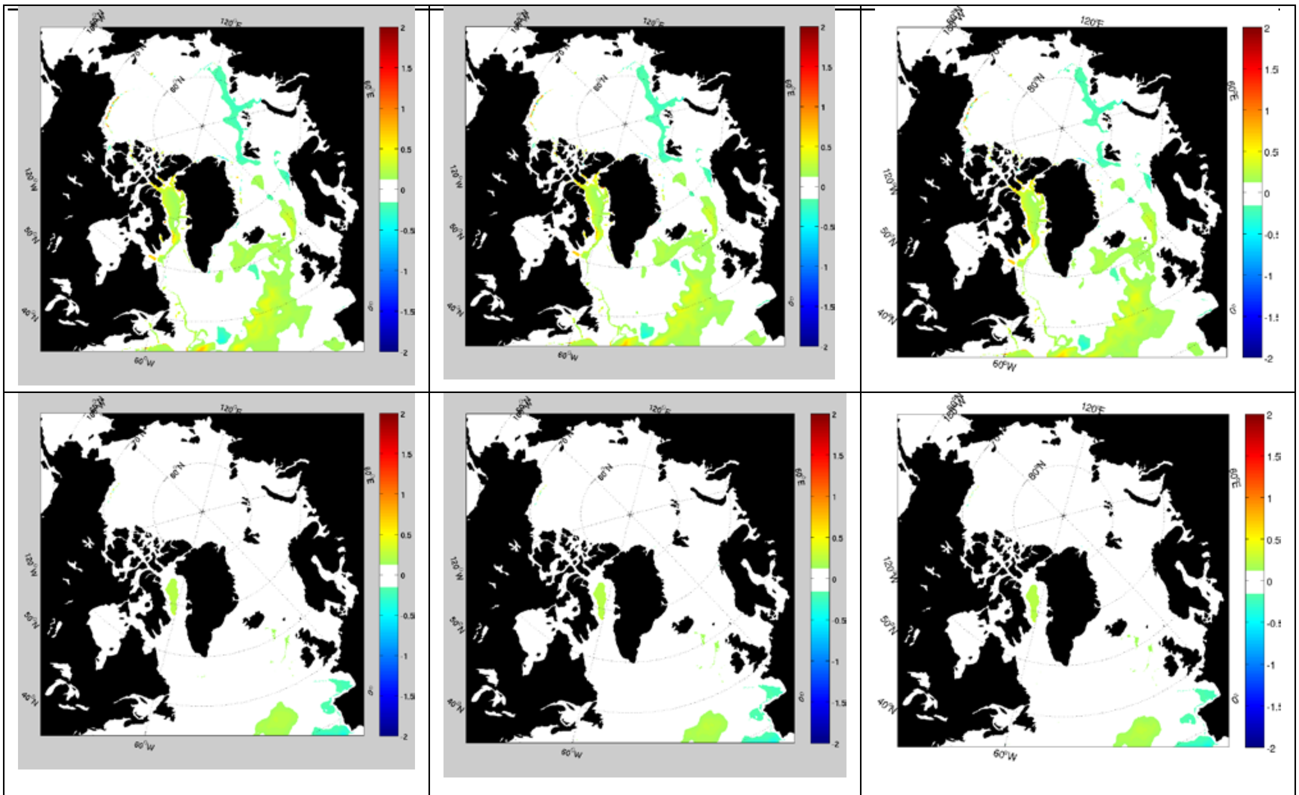
On the other hand, the surface salinity is extremely variable under the sea ice both spatially (between the fresh North Pacific waters from Bering Strait and the saline North Atlantic water) and temporally and the anomalies also reflect the errors in the Arctic climatology. The CTD casts in the vicinity of the North Pole (NPEO data) show surface salinities varying from 30 to 34 psu in a relatively small area. Elsewhere the anomalies to climatology at 30m depths have generally reduced in the upgrade of the Arctic system; in particular, the fresh bias in the northern branch of the Gulf Stream is removed, indicating an improved transport of North Atlantic Water.



April 2007	May 2007	June 2007

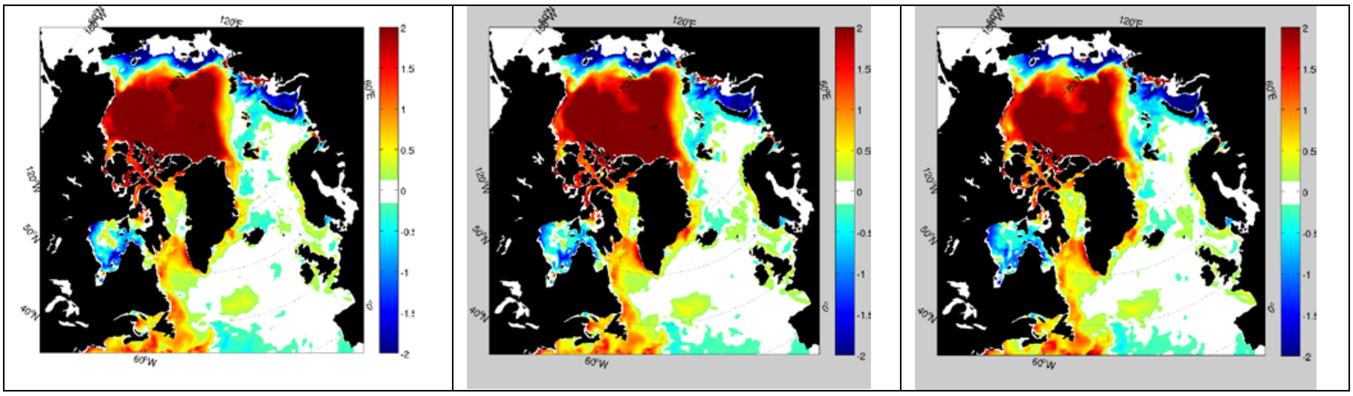
Figure 0-4 Salinity anomalies in the TOPAZ2 system at 30m (top), 400m (middle) and 1500m depth (bottom) for the first 3 months of the TOP2 period.

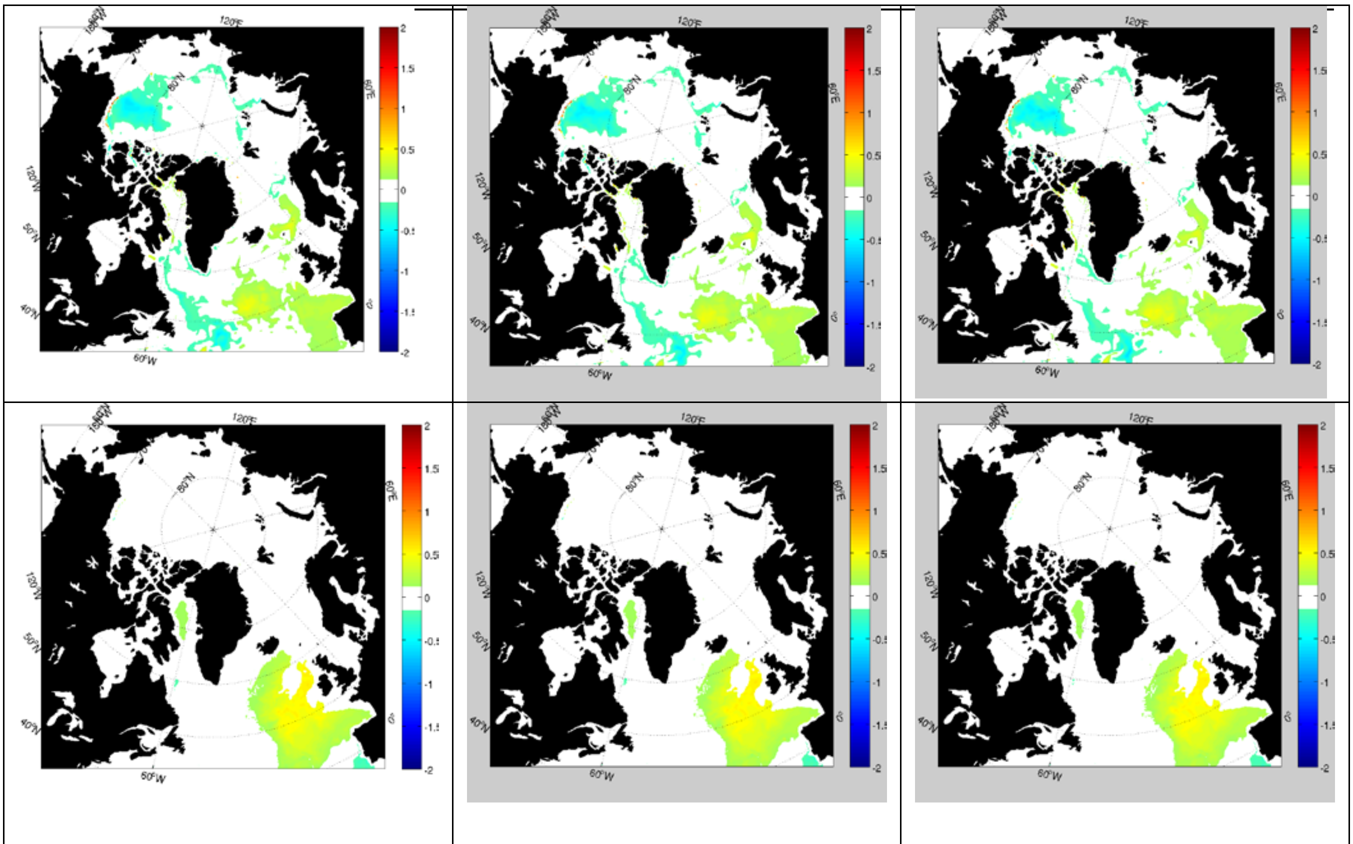




July 2007 ***August 2007*** ***September 2007***

Figure 0-5 Salinity anomalies in the TOPAZ2 system at 30m (top), 400m (middle) and 1500m depth (bottom) during the second half of the TOP2 period.



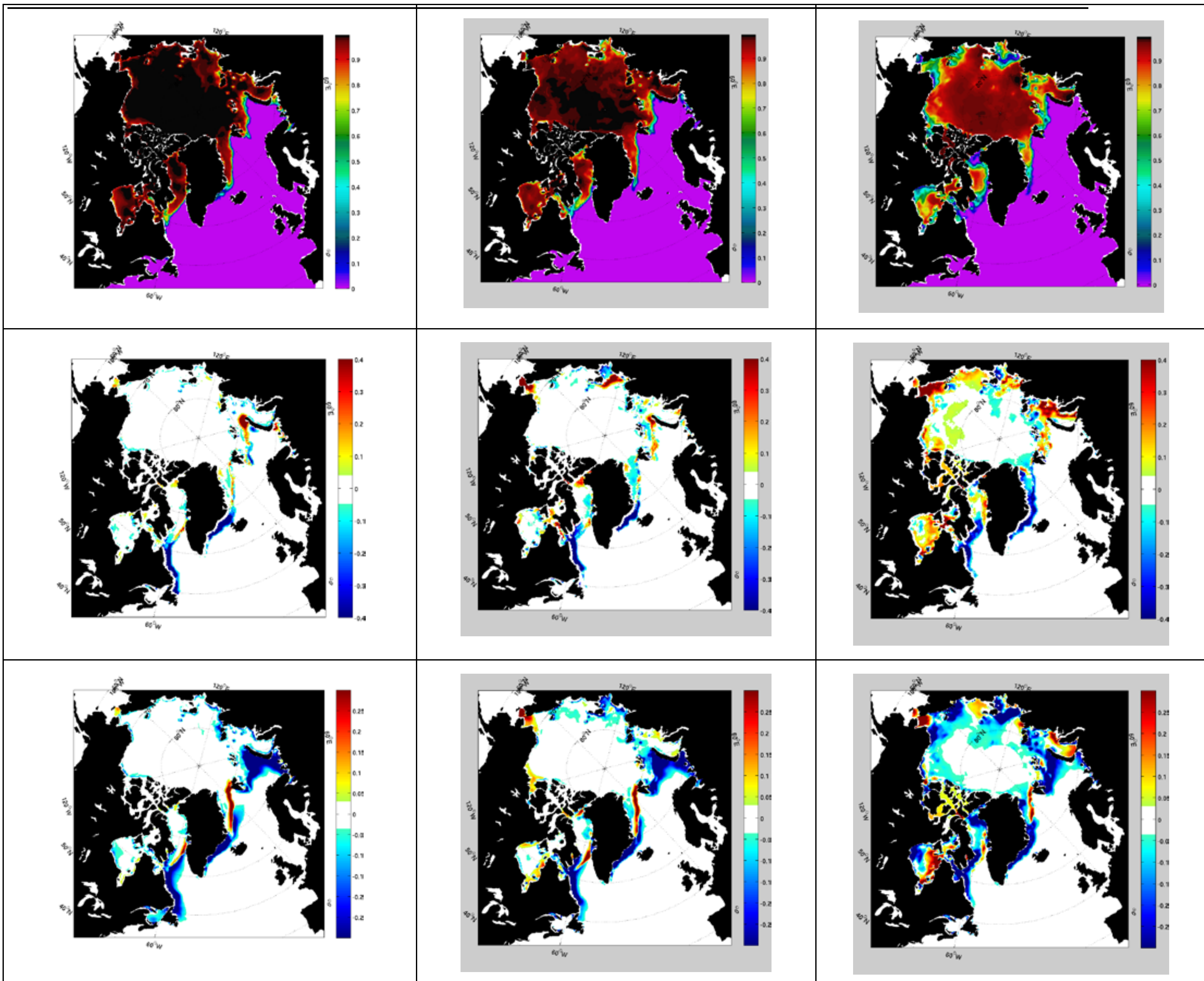


July 2007	August 2007	September 2007

Figure 0-6 Salinity anomalies in the TOPAZ3 system at 30m (top), 400m (middle) and 1500m depth (bottom) during the second half of the TOP2 period.

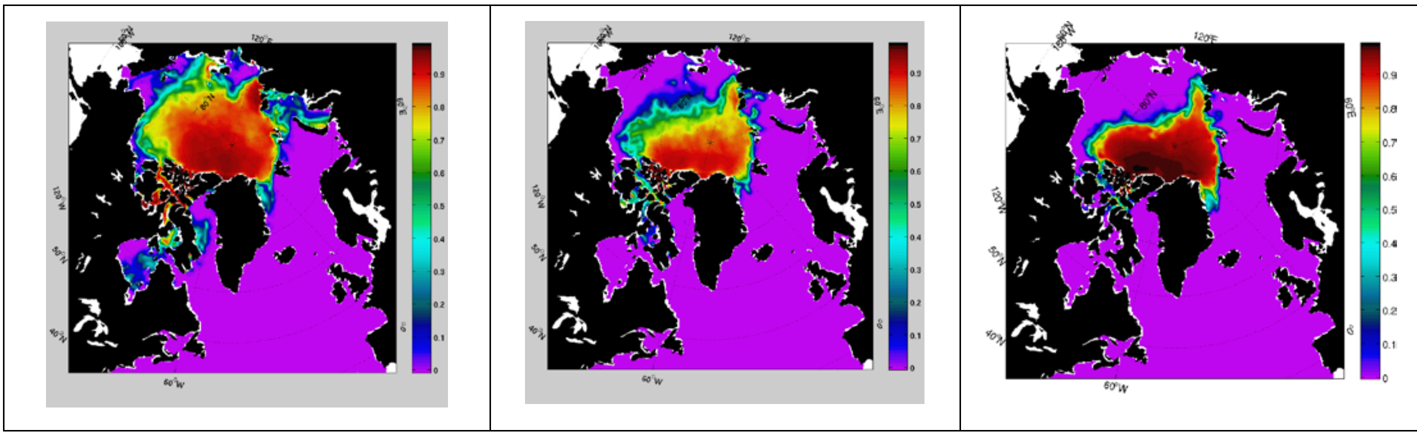
Class1: Monthly mean ice concentration differences with respect to satellite observations.

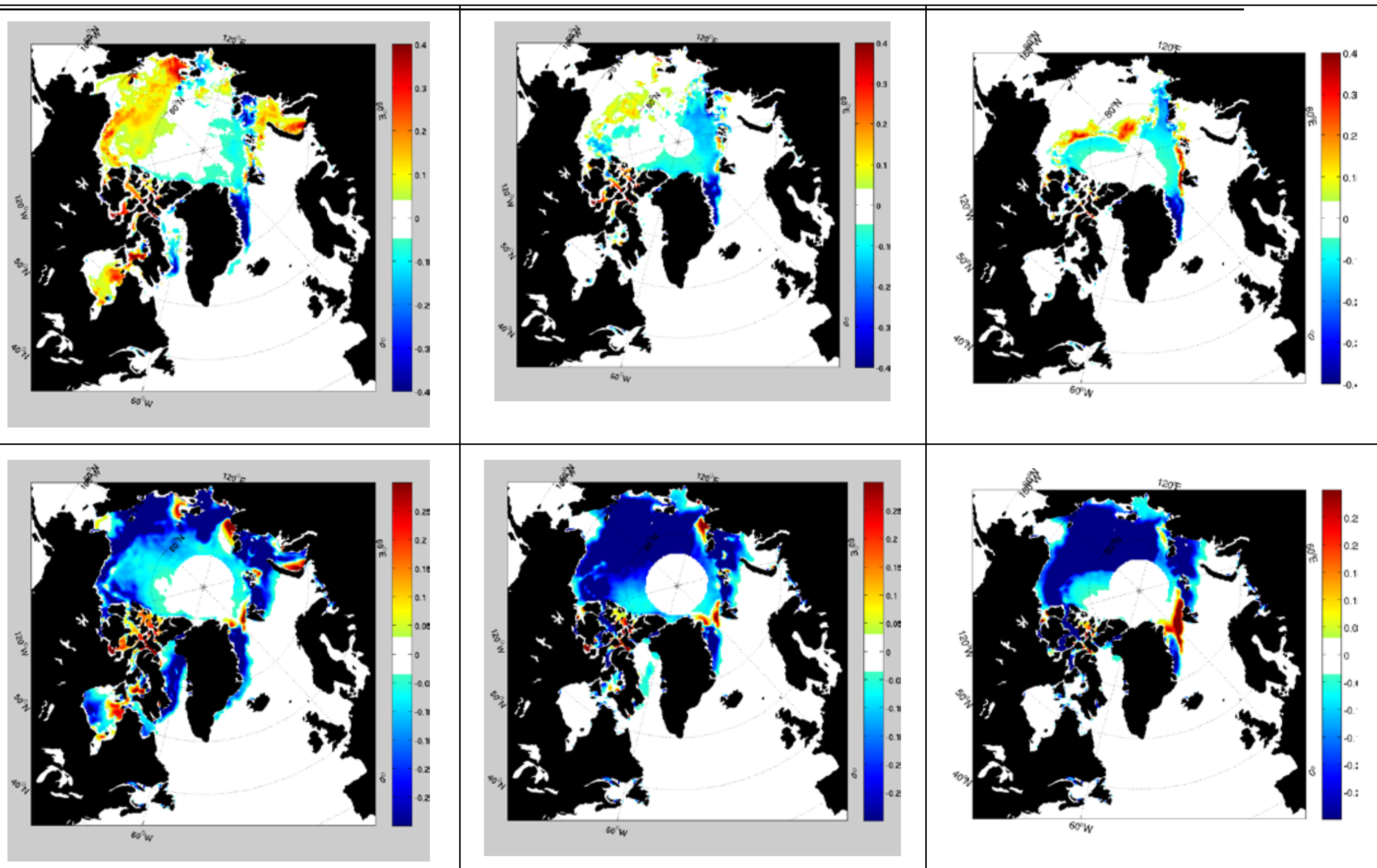
The sea-ice has reached an historical low in September 2007, in the end of TOP2. Never has the sea ice cover been so little in the Arctic since satellite observations of sea-ice became available 30 years ago, and likely since the turn of the 20eth century. For more information, see http://nsidc.org/noaa/iicwg/ or http://www.esa.int/esaCP/SEMVLJVH48F_index_0.html. The distribution of sea-ice is presented for both TOPAZ systems. The TOP2 period is a particularly interesting time to verify the model results since the ice parameters are more sensitive in summer conditions than in winter conditions. Ice models usually compare better to observations in the winter as the atmospheric forcing imposes the freezing of the surface waters. By evaluating the model performance in extremely mild conditions, we therefore test the system in difficult conditions.



April 2007 | May 2007 | June 2007

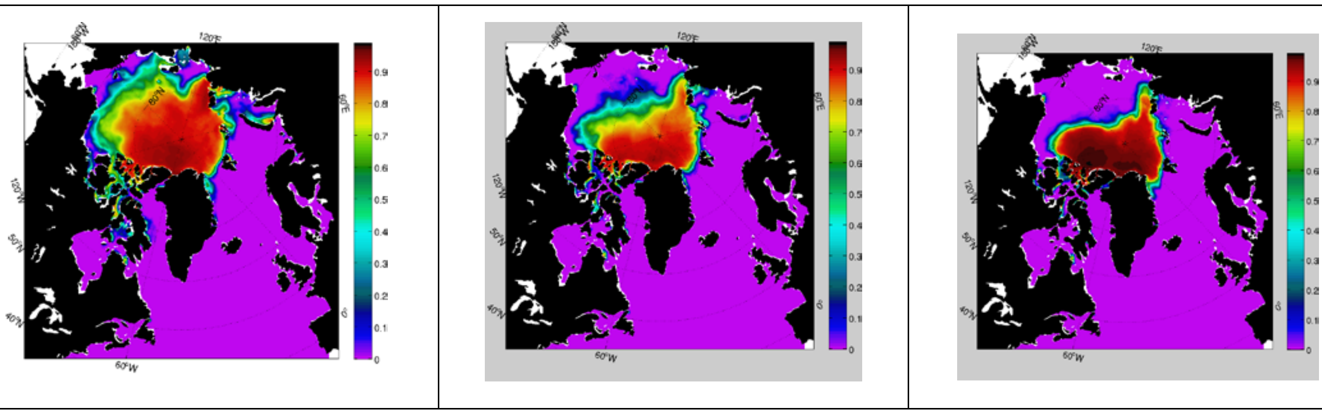
Figure 0-7 Ice concentration from TOPAZ2 (top) model minus SSM/I observations (middle) model minus climatology (bottom) during the first 3 months of the TOP2 period.





July	August	September

Figure 0-8 Ice concentration from TOPAZ2 (top) model minus SSM/I observations (middle), model minus climatology (bottom) during the last 3 months of the TOP2 period.



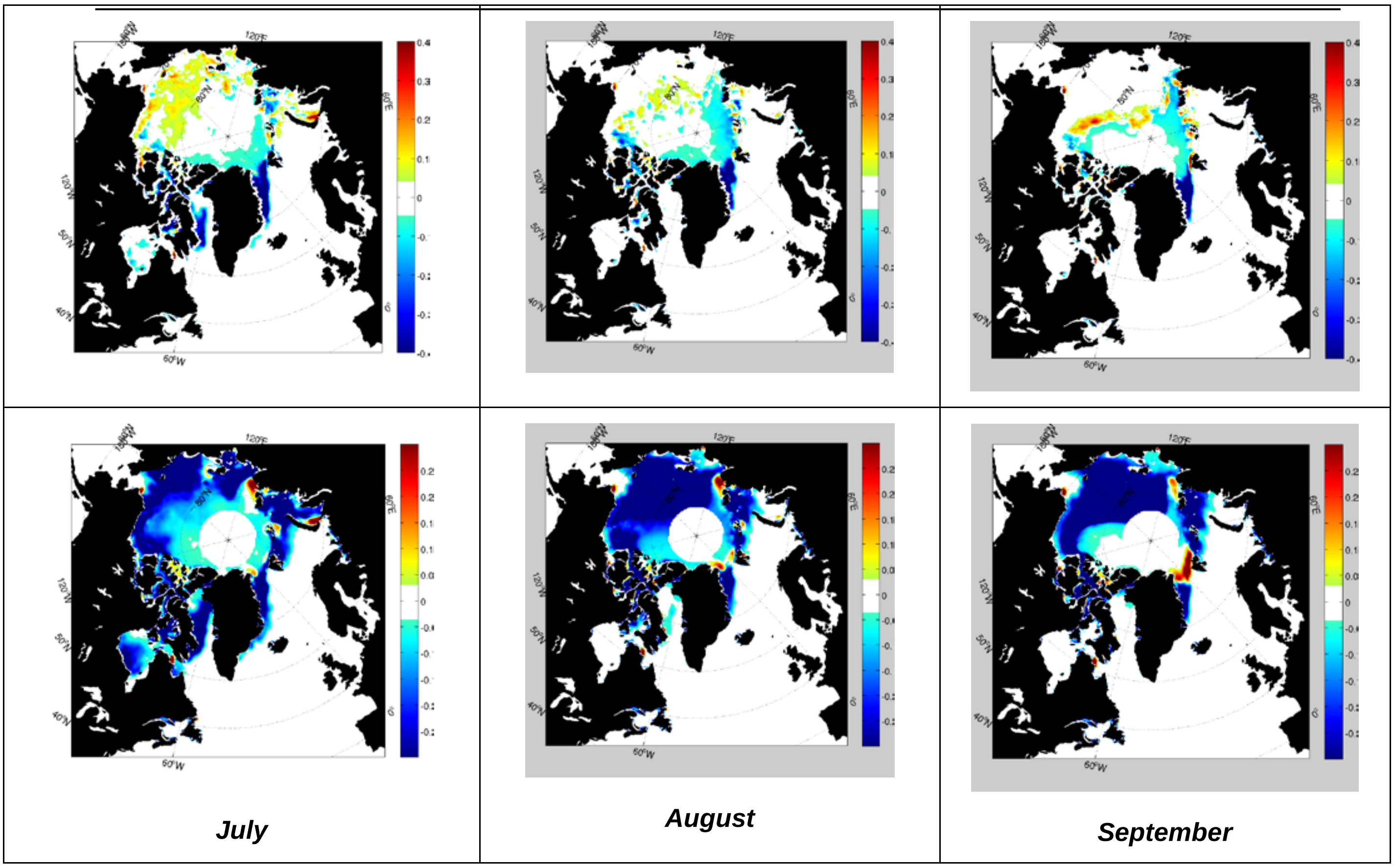


Figure 0-9 Ice concentration from TOPAZ3 (top) model minus SSM/I observations (middle), model minus climatology (bottom) during the last 3 months of the TOP2 period.

Figure 0-7 to Figure 0-9 indicate that both models agree well with the observations, as expected since they both assimilate SSM/I observations. The Northwest sea route is open in the TOPAZ3 system while some scattered ice remains in TOPAZ2. Only a thin tongue of ice remains between Severnaya Zemlya and Siberia on the Northeast sea route for both systems. The ice cover in the Greenland Sea is too low in both TOPAZ2 and TOPAZ3. The excess of surface salinity discussed above may cause the lack of sea-ice in the Greenland Sea.

The residual errors between the model and SSM/I observations are much lower than the deviations to climatology, which proves that the model sea-ice is realistic.

In the transition from TOPAZ2 to TOPAZ3, the improvement of the sea-ice is visible on along the slope North of the Barents Sea. While TOPAZ2 tends to overestimate the sea-ice cover from the North of Spitzbergen to Franz Joseph Land, the tendency has disappeared in TOPAZ3. This is mostly due to the improved representation of the warm inflow from the WSC (see below). Both systems have slightly excessive sea-ice in the Beaufort Sea but this has been reduced in the transition from TOPAZ2 to TOPAZ3.

Class1: Monthly mean ice drift differences with respect to satellite observations.

The Ice Drift service is interrupted every year from April to October, thus not available for TOP2.

Class1: Monthly mean Sea Surface Height (m). Comparison with satellite observations.

SSH data are available in the ice free areas, but the signals are not as clear in the high latitudes as in other regions. Section to be completed in the next version.

Class2: (T,S) cross sections.

Fram Strait

The DAMOCLES IP observations in the Fram Strait are so far incomplete and cannot be presented. We show below the comparison with the Levitus 2005 climatology. Other CTD, XBT and XCTD data in the Arctic have been collected by AARI from July to September 2007 onboard Akademik Fedorov and recently provided to us, unfortunately these did not follow the expected sections and the model data needs to be reprocessed from archived products for the comparison.

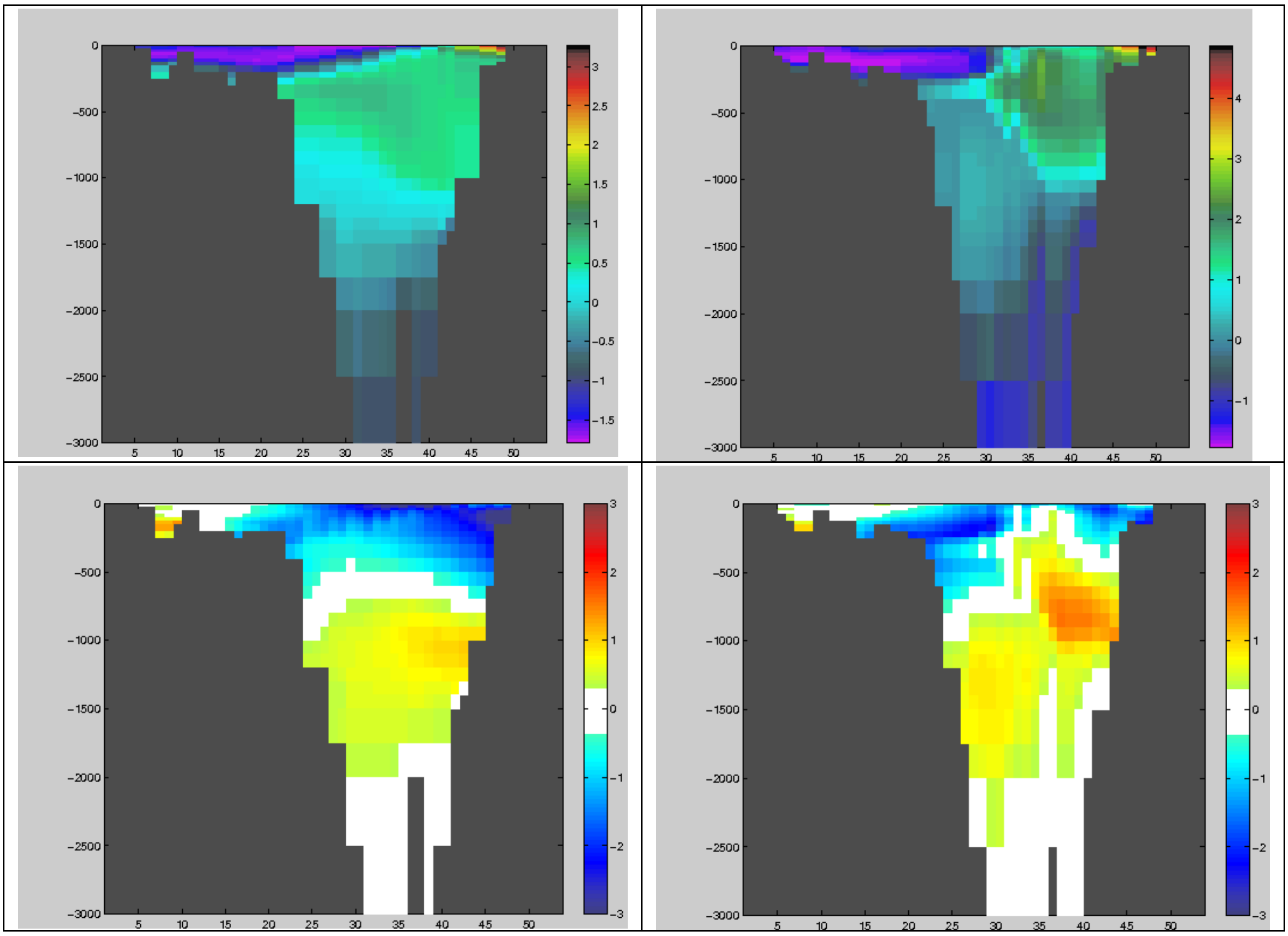


Figure 0-10 Temperature section in the Fram Strait, average from June to September 2007. Left: TOPAZ2, right: TOPAZ3.Top: model values, bottom: model-minus-climatology

The temperature section in the Fram Strait (Figure 0-10) shows the warm inflow of the West Spitzberg Current (WSC) to the East (right) and the cold outflow of the East Greenland Current to the West of the section (left). The zero degree isoline is well located around the 800 meters depths and the temperature gradient is tighter in TOPAZ3 than TOPAZ2, although the vertical resolution of the system is the same. This shows how horizontal model resolution can also favour the simulations of tight vertical gradients. The WSC was colder than observed in TOPAZ2. The cold bias is corrected in the TOPAZ3 version of the Arctic system v2. When comparing to climatology, the WSC seems to extend deeper in TOPAZ3 than in the climatology. This could be a realistic feature of the observed warming of the inflow into the Arctic, to be confirmed by observations. These figures will be updated as soon as more recent data are made available from the DAMOCLES project.

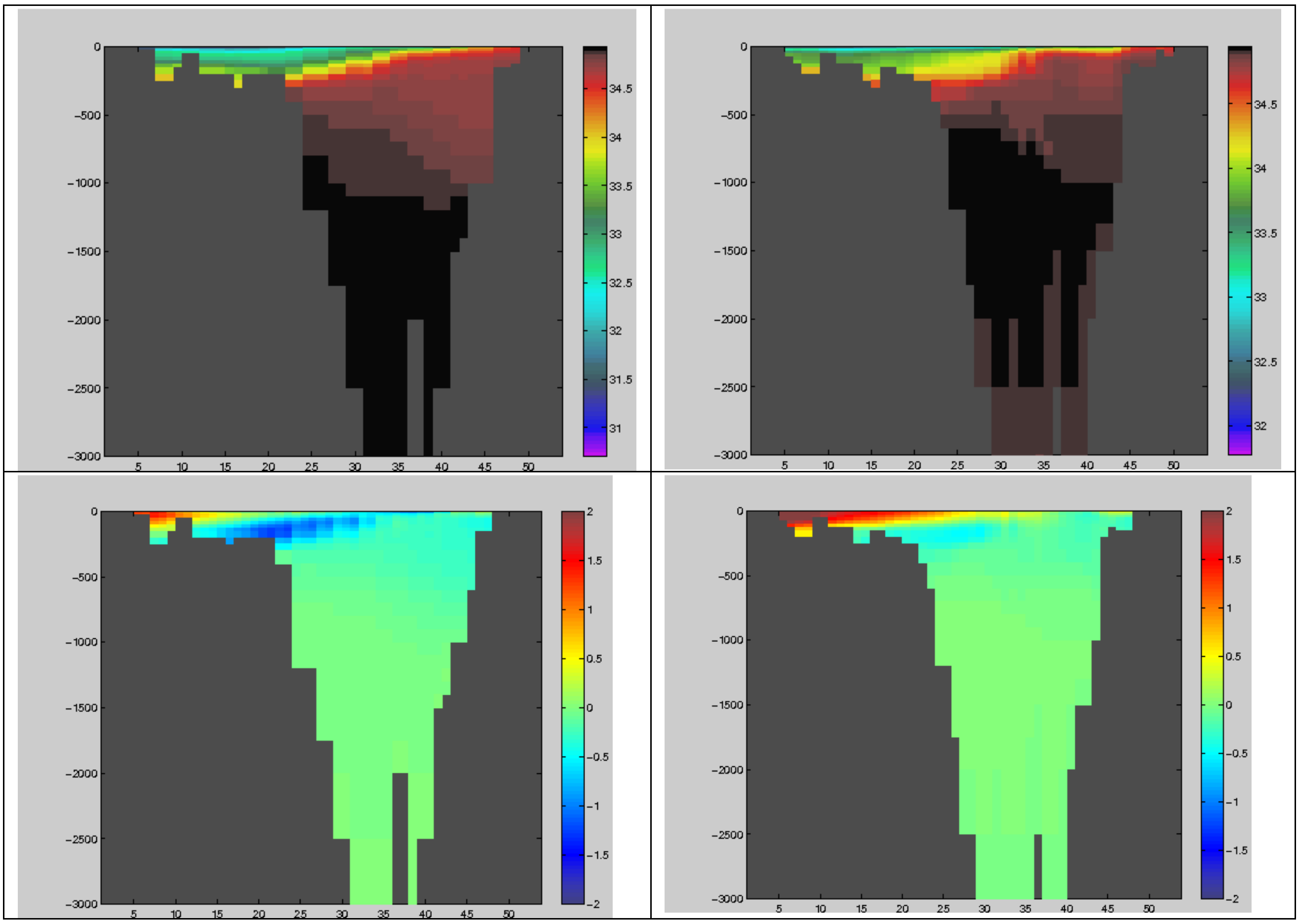


Figure 0-11 Salinity section in the Fram Strait, average from June to September 2007. Left: TOPAZ2, right: TOPAZ3.Top: model values, bottom: model-minus-climatology

The salinity of the East Greenland Current (EGC) showed a fresh bias at 100m depths, which is mostly removed in TOPAZ3. On the other hand the surface of the EGC is too saline as has been mentioned above, which corresponds to the absence of Pacific water from the Bering Strait during the model spin-up.

Bear Island (Barents Sea opening)

Some data from the standard hydrographic section from Norway to Spitzberg via Bear Island should be soon available from the IMR. The section is repeated at least once every summer we should expect them available before January 2008. In the meantime the sections are compared against the climatology.

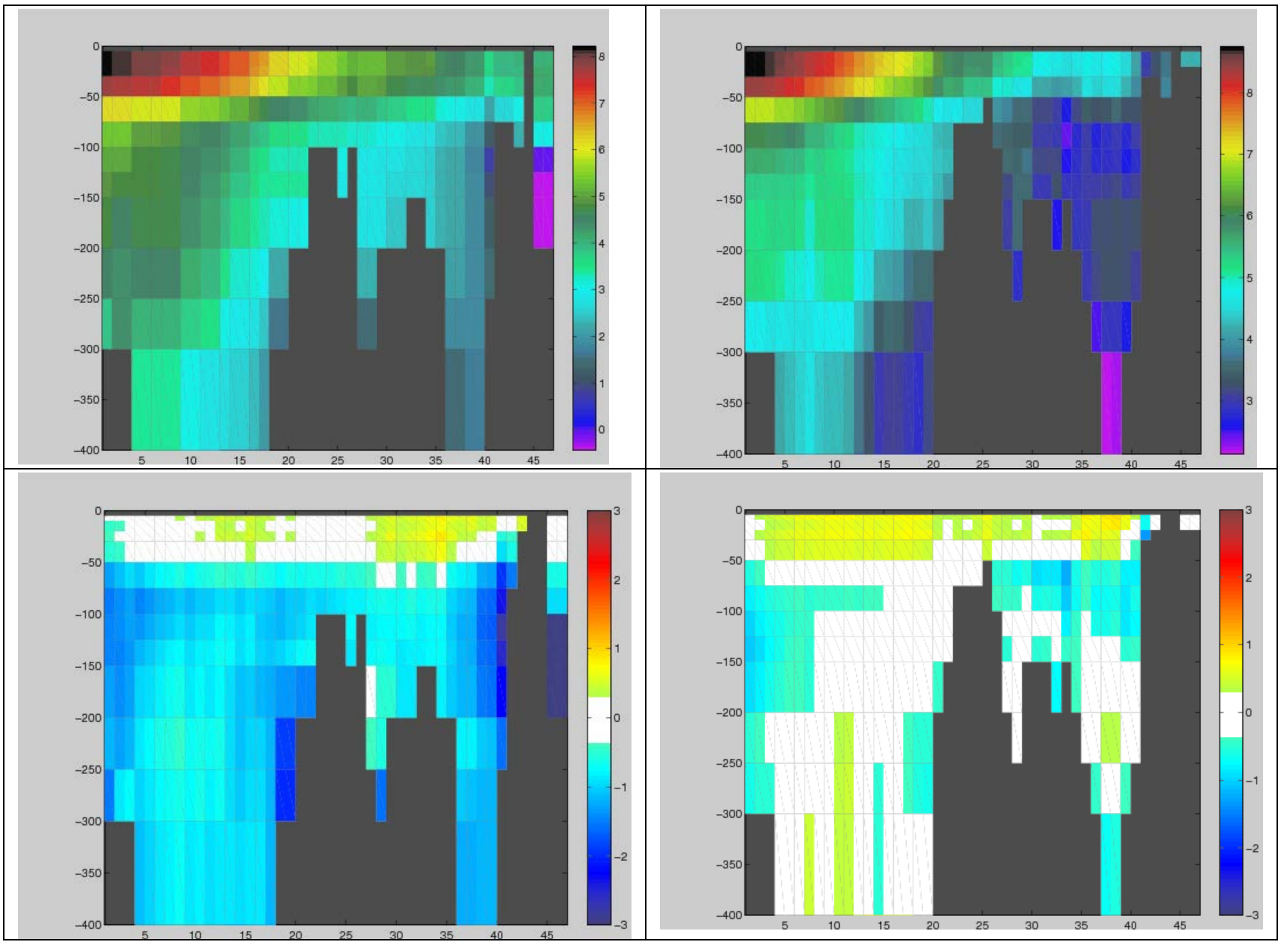


Figure 0-12 Temperature section in the Barents Sea opening (Norway to the left, Spitzberg to the right, Bear Island is at index 25), average for September 2007. Left: TOPAZ2, right: TOPAZ3.Top: model values, bottom: model-minus-climatology

The temperature section in the Barents Sea opening are displayed in Figure 0-12, the cold bias of both the incoming water (South of Bear Island) and of the outgoing water (North of Bear Island) have apparently disappeared while switching from TOPAZ2 to TOPAZ3. This illustrates the improved inflow of warm waters in the Arctic in the upgrade from V1 to V2.

Class2: Moorings. Comparison with observations

The North Pole Environment Observatory has been performing ten aerial CTD casts in the end of April 2007 (from the 21st to the 29th).

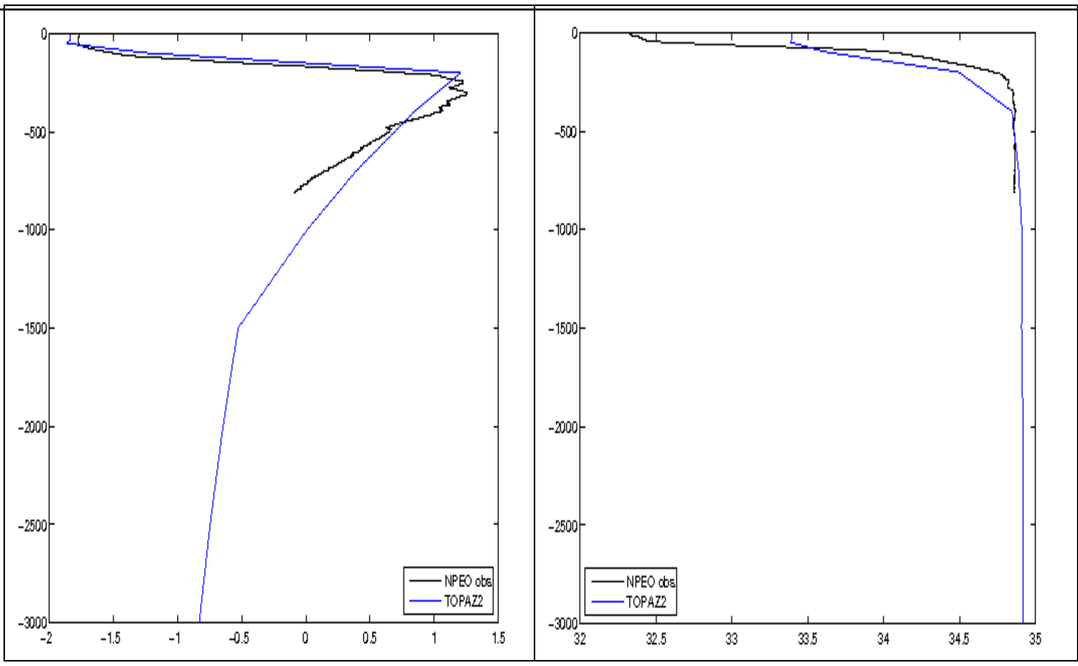


Figure 0-13 North Pole temperature (left) and salinity (right) profile on the 25th April 2007. The black line is the observed CTD profile and the blue line is the TOPAZ2 model profile.

The profiles show a good general agreement between the model and the observations: in particular the maximum of temperatures at 300 m depths is well respected. Between 100 m and 300 m depths, the model is too fresh and too warm thus indicating a model drift in the upper 300m. The comparison is thus in consistent with that of the TOP1 period [REF6] and we can deduce that there has been little model drift in the data assimilative TOPAZ2 system during the one and a half years from TOP1 to TOP2. The NPEO profiles taken during 2006 did not take measurements all the way to the surface whereas they do in 2007. They reveal that the model has an excessive surface salinity as was suggested above by the comparison to climatology.

Class3: Volume transport (m3) across various straits.

Water Transports

The transports through the Fram Strait are monitored by the DAMOCLES EU FP7 project. The data collected during the IPY cruises coinciding with TOP2 are incomplete due to unfavourable weather conditions but will be completed by AWI and made available to the MERSEA project participants. Note the very large temporal variability of the modelled transports. The observed net transport estimates of 0.46 Sv for July 2005 (Beszczynska and Fahrbach, AWI, personal communication, see [REF6]) is within reasonable range from the modelled variability in the summer 2007 (0 to 1 Sv, see Figure 0-14). Note that TOPAZ3 has overall lower Southwards transport than TOPAZ2, which is more realistic.

The transport through Denmark Strait is only partially observed but can be estimated around 3.5 Sv towards the South (Nielsen et al. 2003). The modelled transports (2 Sv) seem too low in that respect, but TOP2 covered only the summer and the winter values should increase the average to a more realistic level. The absence of fluxes in Bering Strait (about 0.8 Sv, a part of which flows through the Canadian Archipelago and the other part across the Arctic) also incurs a lack of Southward flow.

Overall the TOPAZ2 and TOPAZ3 estimates are in agreement with each other, one should note that the TOPAZ3 times series has higher variability than TOPAZ2, which is also expected more realistic. The TOPAZ2 time series are at times incomplete due to missing data.

The inflow of Atlantic water is characterized by higher salinity than 35 psu. This flux was expected to increase to a realistic level with the upgrade of TOPAZ2 to TOPAZ3. This is indeed the case in Figure 0-14 panel c) where TOPAZ3 visibly transports more Atlantic water into the Barents Sea than TOPAZ2 does.

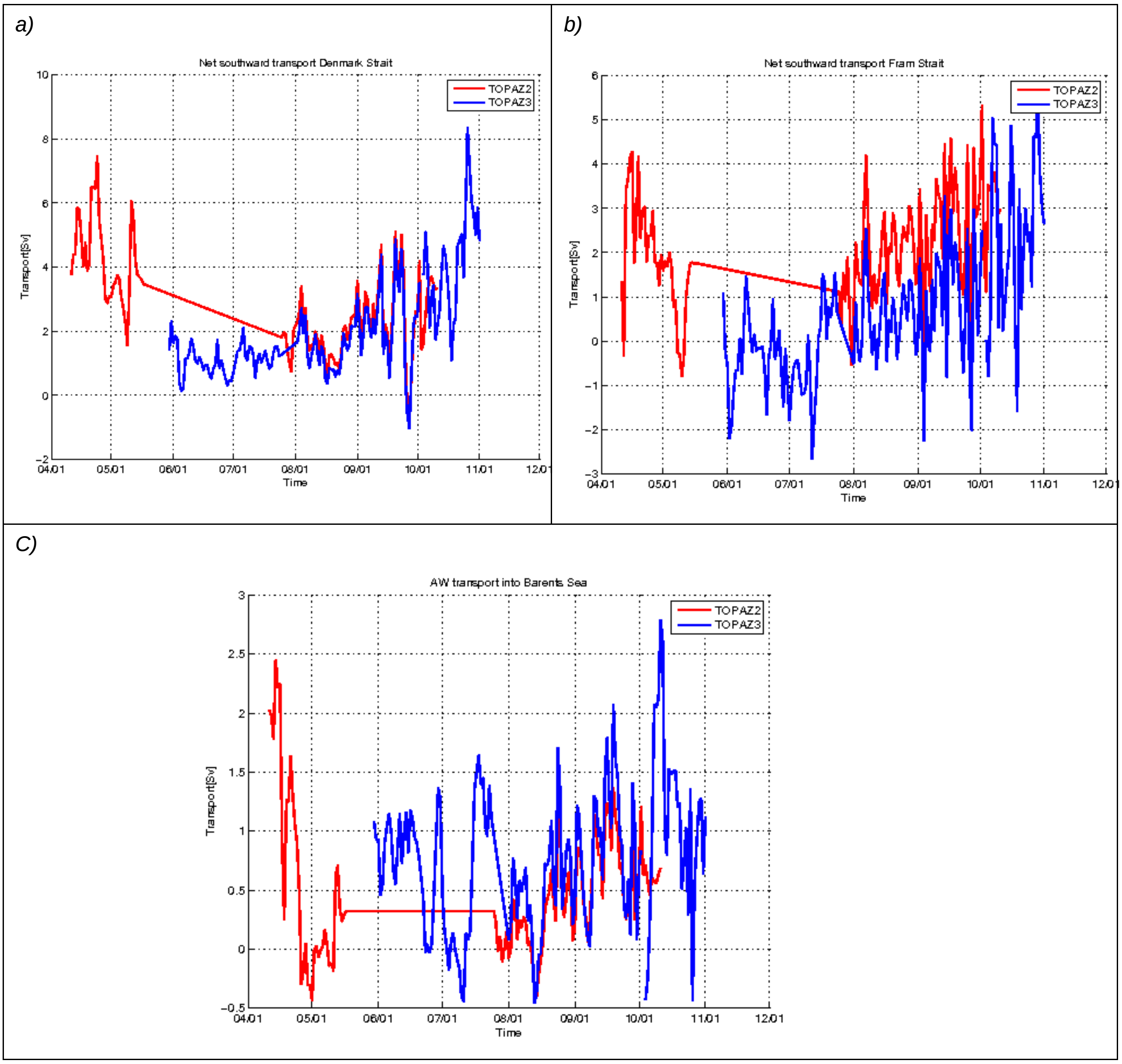


Figure 0-14 Volume transports in TOPAZ2 and TOPAZ3 a) Net volume transport through Denmark Strait, b) Net volume transport through the Fram Strait c) Net transport of Atlantic – 35+psu - water into the Barents Sea. Positive sign is Southwards (a and b) or Eastwards into *the Barents Sea (c).*

Figure 3-6 c) presents the model transports coming into the Barents Sea between Norway and Bear Island. The North Atlantic Water inflow into the Barents Sea has been estimated to 1.5 Sv by Ingvaldsen et al. (2004), 1.7 Sv in winter and 1.3 Sv in the summer. The modeled transports presented here are somewhat lower during TOP2 but still reasonable with respect to the large interannual variability.

Sea ice transport

The sea-ice area fluxes through the Fram Strait are being monitored and compared to model values as a part of MERSEA WP2. We examine here the volume fluxes for which observations are not yet available. Potential observations can be provided by the ASOF project

The export of sea-ice through the Fram Strait follows seasonal variations as expected. It has been high in September 2007 as stated by the International Ice Charting Working Group (IICWG), causing near-normal sea-ice conditions in the Greenland Sea in spite of the extremely low sea-ice cover in the Central Arctic. Figure 0-15 shows the increase of sea-ice transport from the Central Arctic to the Greenland Sea in September 2007 to very high ice volume transports, up to those of the extreme winter 1995. The estimates from measurements (Widdel et al. 2003) indicate an average of 2400 km³ per year (+/- 20%) over the 90's with a peak at 5000 in winter 1995. The export into the Barents Sea between Spitzbergen and Franz Joseph Land is lower than through the Fram Strait but reaches high value in the Fall of 2007.

As for the water fluxes, the sea-ice fluxes show the two versions of the Arctic system are in agreement and the variability is higher in the new high resolution system.

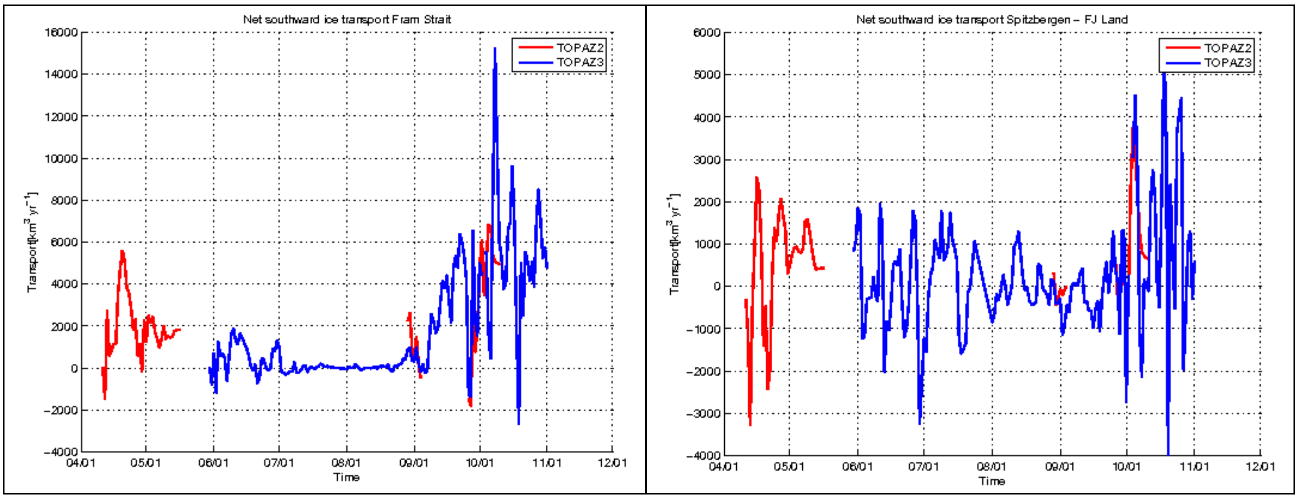


Figure 0-15 Net transport of sea ice volume estimated from TOPAZ2 (red) and TOPAZ3 (blue) during TOP2. Positive is southwards (out of the Arctic). Left: Fram Strait, right: Spitzbergen to Franz Joseph Land.

PERFORMANCE: Class4 with T/S coriolis proFiles (action: Laurence Crosnier)

Arctic TEP

Performance against ice concentrations

Integrated Sea-Ice quantities

The ice area, ice extent and ice volume are extremely important climatic quantities, especially if the MERSEA system analyses are intended to be used as initial fields for initializing decadal forecasts. In this part we include the central forecast running from bulletin day –7 to bulletin day +10 (+14 in the case of TOPAZ2). The EnKF ensemble spread is not represented for clarity of the graphics.
The total Arctic sea-ice area and sea-ice volumes are shown in Figure 0-1, the total Arctic sea-ice area observations from SSM/I are added for comparison, but no observation is available for ice volume. Note that the estimates from SSM/I also include some non-QC data over the open ocean and are at times overestimated.

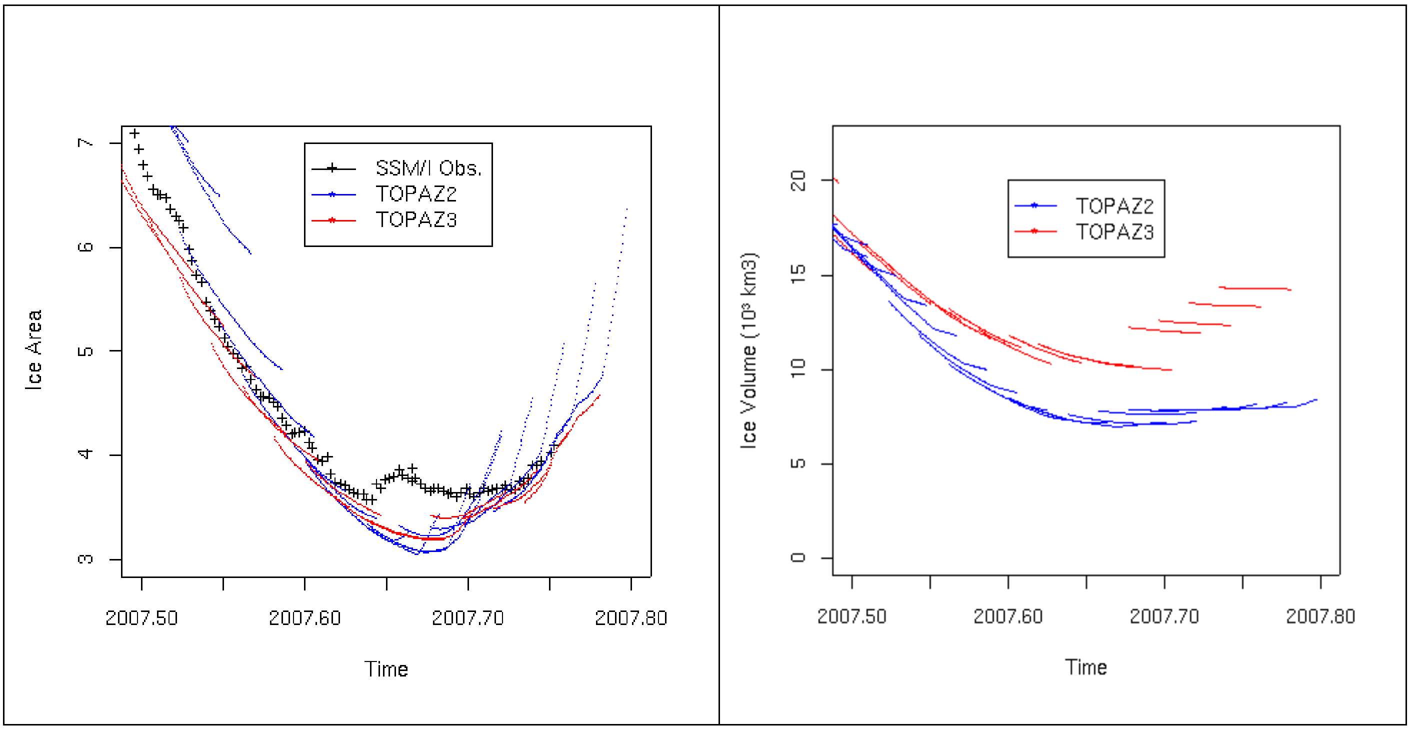


Figure 0-1 Ice Area and Volume (resp left and right) variations in the V1 and V2 Arctic Systems. The blues dots indicate the consecutive TOPAZ2 (V1) 14-days forecasts and analyses. The red dots indicate the consecutive TOPAZ3 (V2) 10-days forecasts and analyses. The black crosses indicate ice area directly computed from SSM/I (may include spurious data in open ocean).

The TOPAZ2 system overestimates the ice area in the melting period, possibly due to a too cold inflow through the Fram Strait. The TOPAZ3 estimate is much closer to observations and seems to underestimate them slightly. Later on during the freeze-up, both systems follow very closely the observations.

At the time of the sea-ice minimum, both the TOPAZ2 and TOPAZ3 forecast tend to forecast the freeze-up slightly too late. They are pulled back towards higher values by data assimilation. The tendency during the TOP1 period was actually the opposite, although the model parameterization has remained the same. It is therefore difficult to identify a model parameter to be adjusted. It appears instead that the forecast tendency is related to the atmospheric forcing and that the parameter estimation studies should aim at bias estimation in the atmospheric fields.

The ice area in TOPAZ2 increases linearly at the end of every forecast run, when the ECMWF fields are completed by climatologic atmospheric data (see the blue tails in Figure 0-1, left panel). The atmospheric climatology has most likely been computed over years colder than the present conditions in the Arctic and presents a cold bias and forces a tendency to overestimate the sea-ice area. This proves that the prolongation of the ocean forecast beyond the atmospheric forecast horizon is not efficient in the Arctic.

There are no observations of ice thickness, but the total ice volume in the Arctic system is much lower than previous model estimates over the period 1960-1995 (Hilmer and Lemke, 2000). This is expected after a succession of warmer conditions in the past decade. The seasonal variation is therefore impressive: the ice volume changes by a factor of 4 in 2007 (it was about 2 in 2006) indicating a drastic retreat of the multi-year ice. The minimum ice volume in both versions of TOPAZ is thus quite alarming (7 and 10 thousands of cubic km of ice) by comparison to the yearly averages from Hilmer and Lemke (2000) that oscillate between 26 and 34 thousands of cubic km, but still plausible. However, more careful validation is needed before ringing the bell for the ice volume since it is very strongly dependent on the procedure used for initialization.

The ice volume time series indicates that the increase starts much later than the turn of the ice area. This is expected since the new ice is generally thin and contributes little to the total ice volume. In the case of TOPAZ3, the ice volume increases mostly due to the addition of ice by data assimilation, but the tendency is slightly decreasing, indicating that some the sea-ice is still melting in some regions.

The ensemble spread is not represented for clarity of the graphic. For the total ice volume, the ensemble uncertainty is about three thousand cubic km of sea-ice in both systems (not shown).

Average ice forecast performance by sub-region.

The performance of the Arctic forecasts is assessed using the assimilated SSM/I ice concentrations in different sub-regions. Arbitrary regions have been set up for gathering the error statistics against SSM/I ice concentration data. The regions used in the present report are the same as in the TOP1 assessment period (See Figure 0-2). They will be updated to include other regions and avoid overlap following recent discussions with Mercator Océan (G. Garric, personal communication). In the graphics below, we compare the “best guess” analysis (green line) with the forecast (blue line) and the persistence of the nowcast, i.e. the best estimate at bulletin time (red line). The green line is therefore discontinuous due to the assimilation update at days 0, +7 and +14. Both the blue and red lines start from the analysis. The

TOPAZ2 system has been used to assess the performance since the TOPAZ3 system results were lost for the first months of TOP2.
The atmospheric forecast used in TOPAZ2 has been extended from the ECMWF numerical forecast horizon days + 10 to +14 by smoothly relaxing the last ECMWF forecast field to climatology. All RMS errors for all regions and all weekly bulletins are available on the Arctic TEP, we present here the 6-months averages over the TOP2 period.
The TOP2 period runs from April to September 2007 and corresponds to an unusual melting season from the maximum to the - historical - minimum of sea ice cover.

Figure 0-2 Definition of boxes for validation against SSM/I observations

Alaska

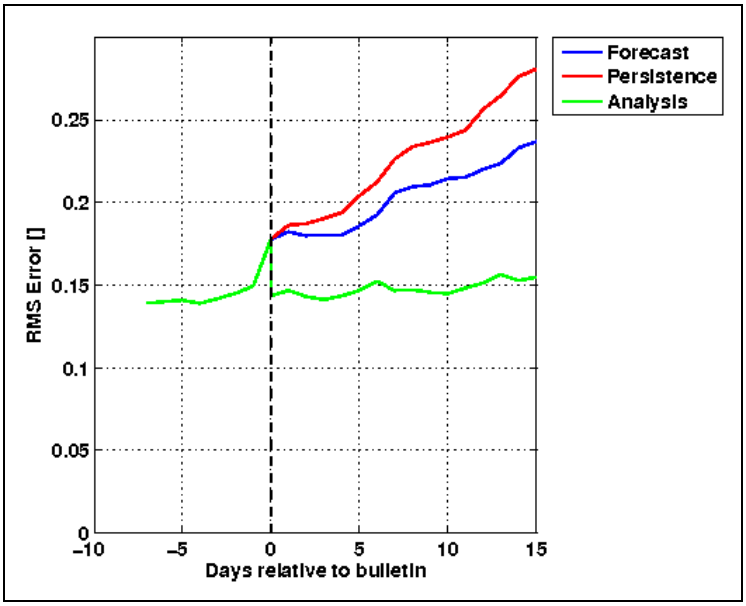


Figure 0-3 Performance of the ice concentrations forecasts in the Alaska region

The forecast and analysis do better than persistence. The assimilation does reduce the error by 25% at each step. The errors of the forecast increase gradually while the error on the analysis run seems to remain stable until the last day of the run.

Barents Sea

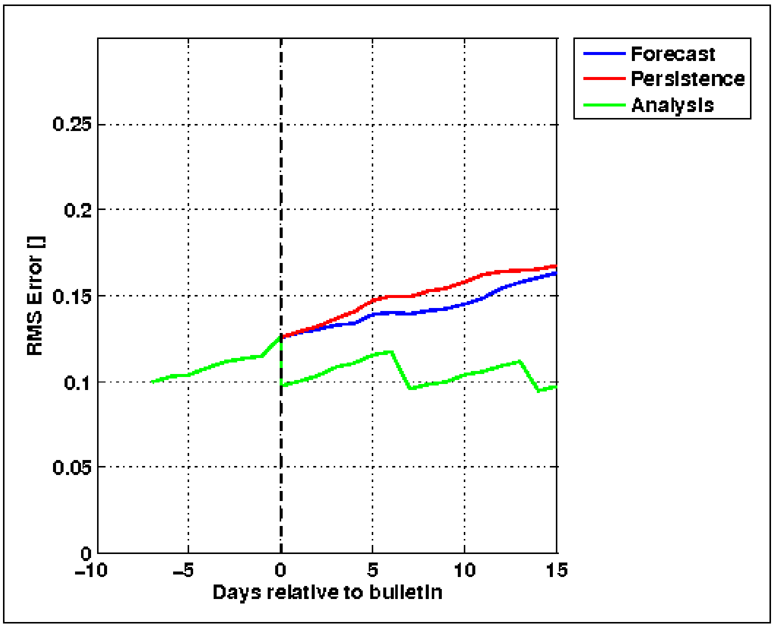


Figure 0-4 Performance of the ice concentrations forecasts in the Barents Sea

During the first months of TOP2 the Barents Sea was partially ice covered, although marginally, and the ice quickly retreated. The forecast performs better than persistence and the analysis better than the forecast. The reduction of error by the assimilation is about 20%.

Bering Strait

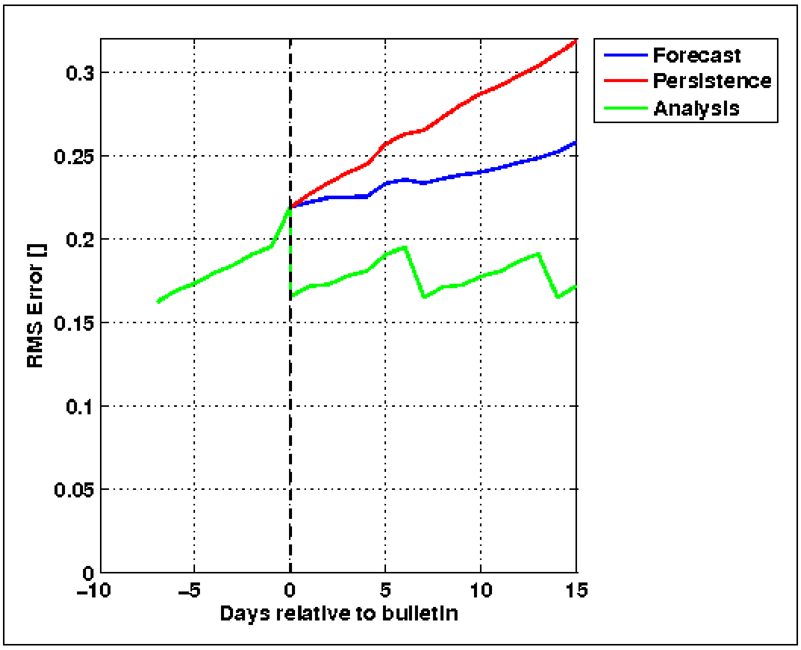


Figure 0-5 Performance of the ice concentrations forecasts in the Bering Strait

Similar to the Barents Sea, the Bering Strait was ice free during most of the TOP2 period. The assimilation proves efficient and the forecast has clear skills with respect to persistence in spite of the proximity to the closed model boundary.

Central Arctic Basin

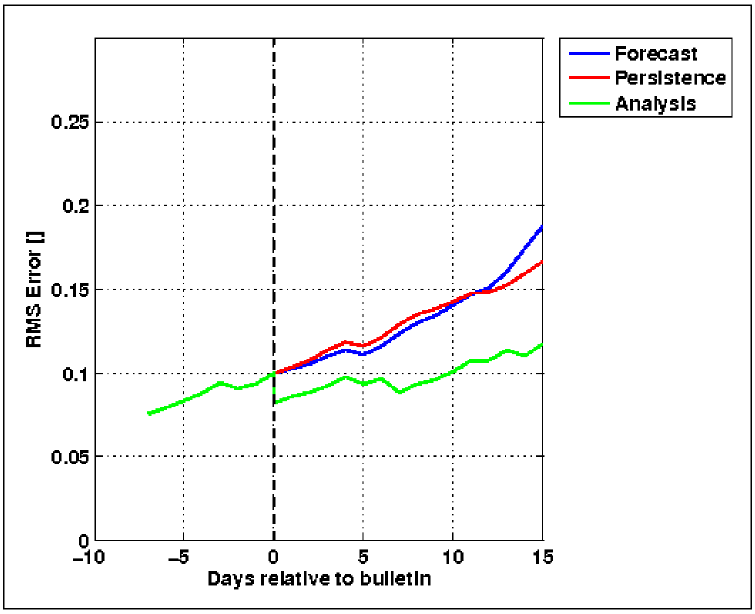


Figure 0-6 Performance of the ice concentrations forecasts in the Central Arctic

The Central Arctic is the only area that remained ice covered during the whole TOP2 period. The analysis does significantly better than the forecast, but the forecast is tightly close to the persistence. This deficiency is easily explained by the poor quality of atmospheric forecast models close to the North Pole. In the days +10 to +15, the persistence beats the forecast, which is probably caused by the prolongation of the ECMWF 10 days forecast with climatology forcing.

Greenland Sea

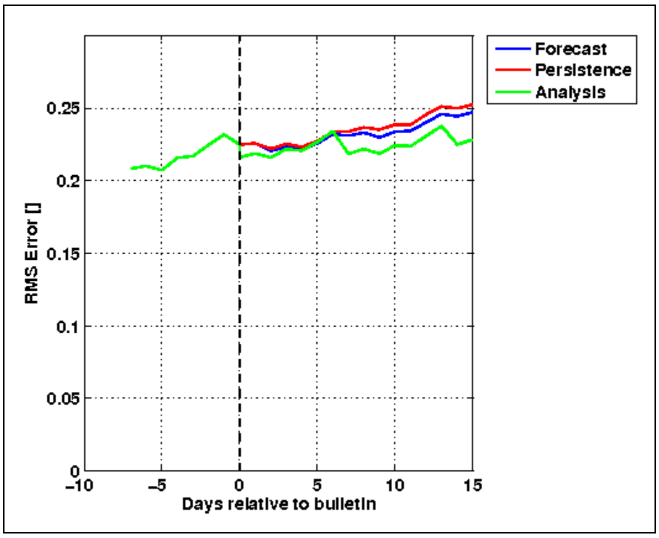


Figure 0-7 Performance of the ice concentrations forecasts in the Greenland Sea

The Greenland Sea remains at least partly ice covered all through the TOP2 period. The statistics show only a slight improvement of the analysis over the forecast and only little forecast skills with respect to persistence. The slope of the error with is also very small although the area is dynamic all year long. This indicates that the Greenland Sea is more subject to assimilation biases than the previous areas and indicates that the improvement of the forecast skills should start with the improvement of the ocean surface properties.

Kara Sea

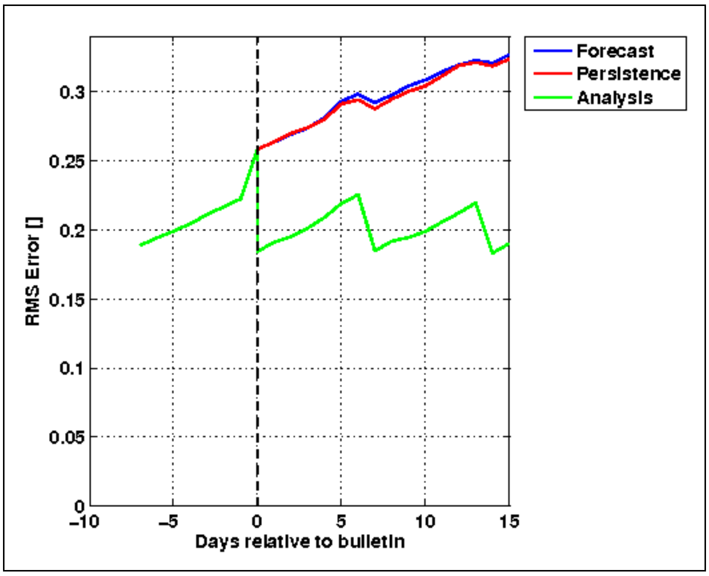


Figure 0-8 Performance of the ice concentrations forecasts in the Kara Sea

The Kara Sea is melting all through the season and the errors are increasing with time. The analysis does much better than the forecast thanks to the assimilation of sea-ice concentrations, but the forecast shows the same skills as the persistence. This is mostly caused by a tendency of the coupled ocean-sea-ice model to accumulate thick ice against the Southern coast of Novaya Zemlya. By lack of appropriate in-situ data it is still unclear whether that tendency is caused by a bias in the ocean-ice system or by a bias in the forcing fields, for example a mis-representation of the orography of Novaya Zemlya in the numerical weather products.

Siberia, Laptev Sea

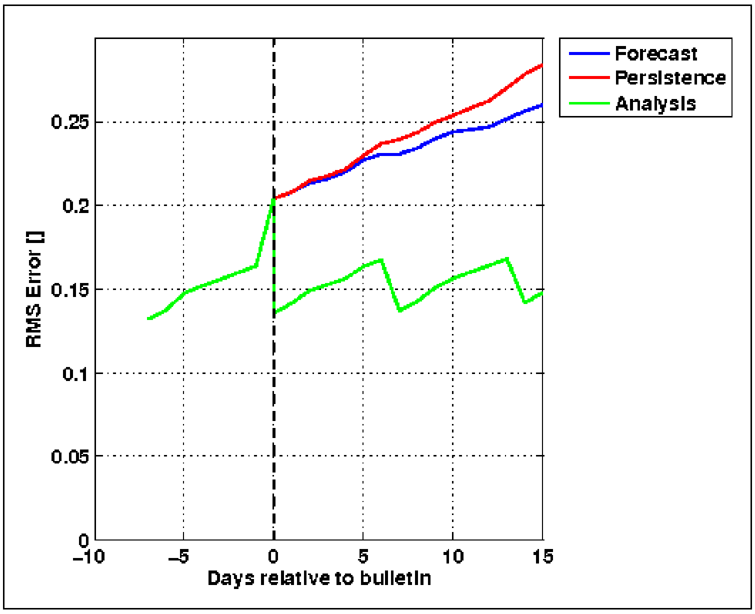


Figure 0-9 Performance of the ice concentrations forecasts in the Laptev Sea and Siberia region

Large parts of the Laptev Sea melt in the course of TOP2. The assimilation proves efficient with a fairly large reduction of the error and the forecast does better than persistence.

COnclusion

Synthesis for the Arctic system

The results of the Arctic system show in terms of **consistency**

- The climatology is relatively well respected in the Arctic Basin, with respect to the difficulties of modelling this area, at the exception of an excess surface salinity likely caused by a poor representation of the water fluxes through Bering Strait. The next prototype of the Arctic system should use an upgraded HYCOM code in which the influx of fresh Pacific water can be included early during the preparation phase of the prototype.
- The volume fluxes through the main openings: the Fram Strait, the Denmark Strait and through the Barents Sea are consistent with the literature and improved by the upgrade of the Arctic system from V1 to V2.
- The main currents systems are respected in the TOPAZ system. The West Spitzberg Current and the North Atlantic current inflow into the Nordic Seas has been improved during the upgrade from V1 to V2, as expected from the preparation of the V2 prototype.
- The ice coverage and thickness distribution is realistic in the two systems, which is usually challenging in summer conditions.

* The modelled export of ice volume from the Arctic to the Greenland Sea is high by comparison to the average in the period 1990-1999, but the IICWG has also reported that the export of ice was qualitatively high in 2007.

In terms of **accuracy**

* There is little independent in-situ data in the Arctic at the time of writing, although the International Polar Year has many activities ongoing in the Arctic. Only CTD casts at the NPEO in April 2007 have been available so far. The V1 system results have been validated against these measurements, showing an overall good agreement but confirming the lack of Pacific fresh water at the surface.
* The location of the ice edge is rather accurate due to assimilation of ice concentrations, the two consecutive systems are overall in good agreement with each other.

In terms of **performance**

* The V1 and V2 systems both tend to forecast a too late freeze-up of the Arctic at the historical minimum of September 2007. The tendency of the same V1 was the opposite in September 2006, which is somewhat puzzling. The reason could be systematic trends in the ECMWF fields.
* The analysis performs better than the forecast, the forecast performs better than persistence in all regions except in the Central Arctic, where the quality of the atmospheric fields could be limiting.
* The Kara Sea and Greenland Sea show lower forecast skills than other regions. This may be linked to biases in the ice-ocean system.