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SUMMARY
Monarch-A provides a pilot system of fast track service (MFTS) in which the satellite observations, in-situ measurements are assimilated to provide a dynamically consistent global un-interrupted estimate of ocean parameters of high relevant to i.e. climate prediction. The MFTS pilot system has two main components. (1) A MFTS web site within the Monarch-A website and a data portal with possible access to data via e.g., html, ftp. The MFTS pilot system will in a future implementation also include access via THREDDS & OPeNDAP. (2) An internal data server which store the data and which is linked to via the MFTS web site and accessible from the group responsible for delivering and updating the data available via the MFTS. Decadal monthly model outputs, such as sea surface height, sea ice concentration, ocean circulation, temperature and salinity are available for serving as the basis to provide and expand fast track services over the Arctic. Based on the satellite observations, in-situ measurements and model outputs, an assessment was established to the MFTS to provide or expand the fast track services with climate relevance over the Arctic. The assimilated satellite observations and in-situ measurements are significant to improve the Arctic climate predictions.

MONARCH-A CONSORTIUM

Participant no.	Participant organisation name	Short name	Country
1 (Coordinator)	Nansen Environmental and Remote Sensing Center	NERSC	NO
2	The University of Sheffield	USFD	UK
3	Universität Hamburg	UHAM	NO
4	Centre National de la Recherche Scientifique	CNRS	FR
5	Scientific foundation Nansen International Environmental and Remote Sensing Center	NIERSC	RU
6	Universitetet i Bergen	UiB	NO
7	Danmarks Tekniske Universitet	DTU	DK
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1 Introduction

In order to progress our understanding of the role that the high latitudes and particularly the Arctic Ocean plays in 1) water mass formation, 2) in contributing to the global circulation and in 3) changing sea level on regional and global scale - reliable satellite observations and reanalysis of the Arctic Ocean over the last 50 years must be made available to users like climate scientists. Consequently, the overall goal of the pilot system of Monarch-A Fast track service (MFTS) will be the provision of climate relevant ocean information in form of satellite observations and re-analyses of ocean state variables with emphasis on the Arctic Ocean North of 65°N.

The last decade has seen substantial progress and developments in both refined and focused observations in the Arctic Ocean through expanded satellite capabilities and detailed surveys. Those ocean observations belongs to the list of Essential climate variables (ECVs) and includes ocean observations state parameters like sea level, currents, surface forcing fields and sea ice coverage and drift. Those observations again belong to the list of ECVs provide in the introduction and they are being used as basis for several fast track services.

The observations are the key to understand Arctic Ocean variability with specific focus on changes in Arctic Ocean circulation, sea level and sea ice cover. Without a detailed picture of the Arctic Ocean circulation, it will be very difficult to understand the role of the high latitude and Arctic Ocean in shaping the global ocean circulation and sea level changes due to mass loss from the Greenland ice sheet, which play an important role in Atlantic and global sea level change.

Most of the data available over Arctic region do not have the same quality as in most other part of the World Ocean. As an example, the quality and availability of satellite altimetry is hampered by sea ice, and not available at all above 82°N for radar altimetry. It has consequently been the focus of Monarch-A WP2.5 to provide a best possible description of the circulation of the Arctic, of sea level, of ocean and ice transports and of surface forcing fields over the last 60 years, as well as run-off required to bring the model into consistency with all available data sets as prepared in various other parts of WP2.

The way to perform the best representation of the Arctic Ocean for the Monarch-A fast track pilot project has been through the using of data assimilation techniques. Data assimilation is based on the belief that dynamically consistent “interpolation” of oceanographic observations can lead to a better understanding of the mechanisms responsible for observed changes and reliable decadal predictions will only be possible with good initial conditions, and this is what data assimilation can provide.

The Monarch-A Fast track Pilot service builds on existing data services incl. fast track GMES services like MyOcean, GlobColor, GlobeIce, NOAA, NCEP, CSIRO etc. and syntheses the available datasets and casting them into forms suitable for exploitation by Climate models with particular focus within this work-package for ocean related parameters in the Arctic Ocean.

2 The Monarch-A fast track pilot data concept.

The overall goal of the pilot system of MFTS will be the provision of climate relevant ocean information in form of satellite observations and/or re-analyses of ocean state variables for the climate system with emphasis on the Arctic Ocean North of 65°N.

The MFTS will provide:

- Model relevant climate ocean data sets for the Arctic Ocean with information about uncertainties
- Dynamically consistent interpolated supportive oceanographic observations including information about uncertainties
- Provision of Arctic ocean data sets and related data products for the further analysis of climate variability and for initialization of climate models through assimilation
- Recommendation and interpretation/evaluation by experts about the available MFTS Arctic data sets and support in using them
- Information about Arctic ocean data sets for climate and climate variability to users and the public through the MFTS web page
- Information and assessment of Arctic model relevant climate data and possible error in the ocean
- User online feedback system in order to enhance the Monarch-A Fast Track Pilot service in the future

The long-term goal of the MFTS is to increase the user uptake of the data and based on the user feedback to enhance and mature the pilot system into an Arctic Fast track service with an increasing number of relevant ocean model parameters for Arctic climate research.

2.1 The Monarch-A fast track Technical implementation

The MFTS pilot system has two main components:

1. A MFTS web site within the Monarch-A website and a data portal with possible access to data via e.g., html, ftp. The MFTS pilot system will in a future implementation also include access via THREDDS & OPeNDAP. Searching and extraction of the data should be supported by including plots for visual inspection of the available Arctic ECV’s.

2. An internal data server which store the data and which is linked to via the MFTS web site and accessible from the group responsible for delivering and updating the data available via the MFTS. Meta data information should be provided to every dataset and the datasets being available in common formats like netCDF or ASCII.

2.2 Monarch-A Fast Track data domain and grid

In order to establish a set of dynamically consistent interpolated oceanographic observations, model domain covering the region north of the North Atlantic and the Arctic Ocean was established. The bathymetry is obtained by interpolation of ETOPO2 (two-minute gridded global relief for both ocean and land areas) to the model grid. There is no artificial deepening of or widening of the Nordic Seas passages was applied, so they maintain their true depths and their cross-section areas.

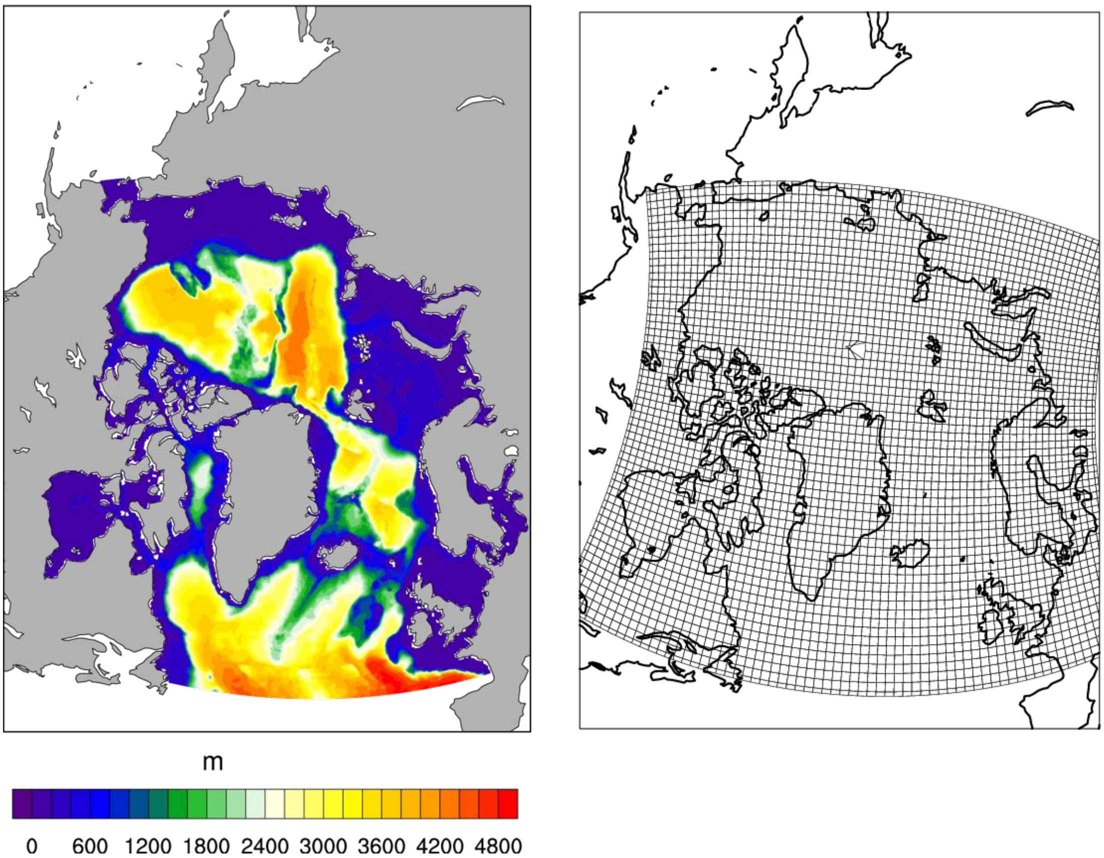


Figure 1. Model domain and bathymetry (left) and grid(right)- only every 7th grid point is shown for visual convenience.

The model grid is curvilinear and is a subset of the ATL06 model grid (50 layers). It has about 1/6° spatial resolution that translates in the Arctic Ocean to 15 km horizontal resolution. The original grid is bipolar (one pole over North America and another over the Europe). This solves the problem of the North Pole singularity in the traditional geographical latitude-longitude coordinate system, when meridians converge at the North Pole. Consequently, in this configuration there are no severe restrictions on the length of the time step allowed for computational stability of finite difference schemes.

The coordinates for all the data in the MFTS data portal through a grid in the file [ftp.space.dtu.dk\pub\MONARCH-A\MFTS\grid_coordinates.cdf](ftp.space.dtu.dk\pub\MONARCH-A\MFTS\grid_coordinates.cdf). In the file, the coordinates of the 2-D variables are provided. The depths of the 50 layers within the model are available for 3-D variables (e.g., temperature and salinity). For these files missing value and land is filled with -9.99999977819631e+22.

2.3 Model settings and assimilated data

This summary of the model setting for the derivation of the Monarch-A Fast track pilot system is condensed from the Monarch-A deliverable D5.2.1 and D5.2.2 and the details on the model derivation can be found in this document.

The model was run by the based on the Massachusetts Institute of Technology General Circulation Mode (MITgcm). The adjoint assimilation technique allows derivation of a dynamically consistent model solution that was brought into consistency with observations while obeying model dynamics. The following sets of oceanographic observations were interpolated using adjoint data assimilation technique. Part of the input datasets used for the derivation of the MFTS is taken from the existing data and fast track services like (e.g., PHC 3.0 and Monthly SST datasets).

Table 1. Data used for assimilation.

Variable	Data Source
Monthly PHC climatology	PHC 3.0, Steele et al (2001) http://psc.apl.washington.edu/nonwp_projects/PHC/Climatology.html
Mean Dynamic Topography	Produced in the framework of the MONARCH-A project by DTU.
Monthly SST	Remote Sensing Systems http://www.remss.com/
Sea Level Anomalies: TOPEX/Poseidon, ERS-1,2 and Envisat	AVISO http://www.aviso.oceanobs.com/index.php?id=1270
EN3 hydrographic data	Curry (2001) http://www.metoffice.gov.uk/hadobs/en3/
NISE hydrographic data	Nilsen et al (2008)
Sea ice concentration	Cavalieri et al (1996) (NASA Team algorithm) http://nsidc.org/data/nsidc-0051.html

The atmospheric forcing the system using 6 hourly NCEP R1 reanalysis (Kalnay et al., 1996). The sea ice component is based on the Hibler type (Hibler 1979, Hibler 1980) viscous-plastic dynamic-thermodynamic sea ice model, which implies that the seasonal variability of sea ice is exaggerated (Semtner 1984). To reduce this effect, the sub-grid scale heat flux parameterization was used (Hibler, 1984). Moreover, the viscous-plastic rheology scheme of Hibler (1979) with an extended line successive over-relaxation method (Zhang et al, 1997) was used.

The ocean component of the MITgcm model consists of conservation equations for horizontal and vertical momentum, volume, heat, and salt as well as an equation of state. The MITgcm offer wide variety of modules that can assimilate different aspects of ocean physics. For the vertical mixing parameterization, the K-Profile Parameterization (KPP) scheme of Large et al. (1994) was applied. Harmonic diffusion along neutral surfaces according to Redi (1982) in association with the parameterization of Gent and Mc Williams (1990) for eddy-induced tracer advection represents unresolved eddy processes. The model is operated in the hydrostatic configuration with an implicit free surface.

3 MFTS Arctic Ocean Variables

The Monarch-A assimilation model was developed for the Arctic Ocean by the institute for Marine Research at the University of Hamburg. The model was run for the period between 2000 and 2009 to create dynamically consistent ocean parameters for Arctic climate prediction like:

- potential temperature
- salinity
- zonal velocity
- meridional velocity
- vertical velocity
- sea surface height
- bottom dynamical height anomaly
- effective sea ice thickness
- sea ice concentration
- zonal sea ice velocity
- meridional sea ice velocity.

The Monarch-A model use z-coordinates and has 50 levels with resolution vary from 10 meters in the top layers of the water column to 550 meters in the deeper parts of the ocean. Consequently, a number of the output ocean parameters will be available for each layer.

The Monarch-A system is among the first to use adjoint data assimilation to improve estimation of the sea ice extend. Assimilation of sea ice edges is an important parameter in the Arctic as most of the Arctic Ocean is covered by sea ice throughout large parts of the year. It's the aim to provide these parameters in a later version of the MFTS.

For the MFTS pilot system only a selection of output variables were selected. These are:

Sea surface height (SSH),
Surface zonal velocity (at the surface),
Surface meridional velocity (at the surface)

The sea surface height is chosen due to its importance in climate research and the ability for us to evaluate this using existing altimetric datasets and new altimetric data from Cryosat-2 available in the Arctic Ocean since 2009 for the first time.

Due to sparseness and limited availability of direct current measurements in the Arctic Ocean, there is still very limited understanding of Arctic Ocean circulation at intermediate depths and at the deep layers. Ocean surface currents are therefore known better. Furthermore ice can be used to some extent as their proxy in an assessment of the quantity.

3.1 Sea Surface height

For the MFTS system model assimilated SSH over the 2000-2009 time span as well as the figures of the monthly SSH are available via the MFTS web page linked to the data server at ftp.space.dtu.dk\pub\MONARCH-A\MFTS\SSH\.

The data coverage is referred to Figure 1. The monthly 2-D SSH data was stored as NetCDF files labelled '2000_2009_SSH.nc' and the dimension of the monthly SSH data is 416*480*120 in latitude*longitude* time. The missing value and land is filled with -9.99999977819631e+22.

Figure 2 illustrate the standard deviation (STD) of the SSH over the 2000-2009 period. Very high dynamic consistent is seen over the Arctic Ocean. The STD of around 7cm is observed along the Russian coast. Similarly, high STD is also seen in the Nordic Seas from satellite measurements. Further assessment of the MFTS model is given in section 4.

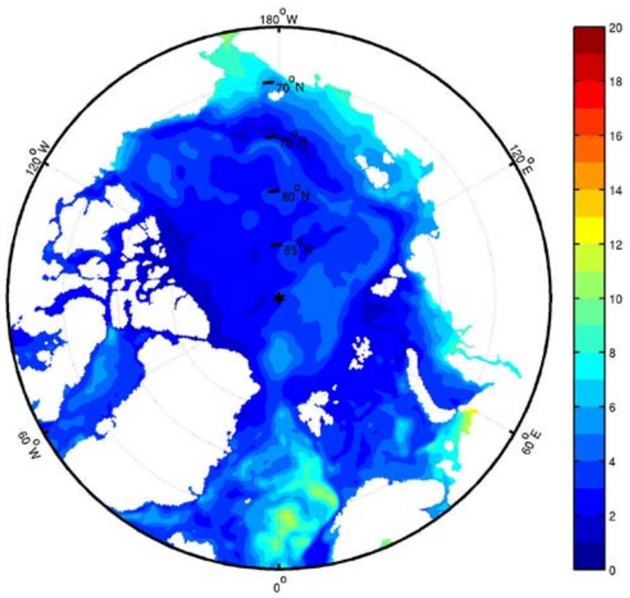


Figure 2. The distribution of standard deviation (in cm) of SSH.

3.2 Sea surface currents.

The monthly zonal (U) and meridional (V) ocean surface velocity are available at via the MFTS web service through links to data sources at ftp.space.dtu.dk\pub\MONARCH-A\MFTS\Ocean_currents\. Similarly, figures of monthly mean ocean currents of surface layers (5 m) are also distributed via the MFTS web.

The monthly ocean surface currents (U and V) data was stored as NetCDF files labelled '2000_2009_uv_5m.nc' and the dimension of the U and V data is 416*480*120 in latitude*longitude* time. The missing value and land is filled with -9.99999977819631e+22.

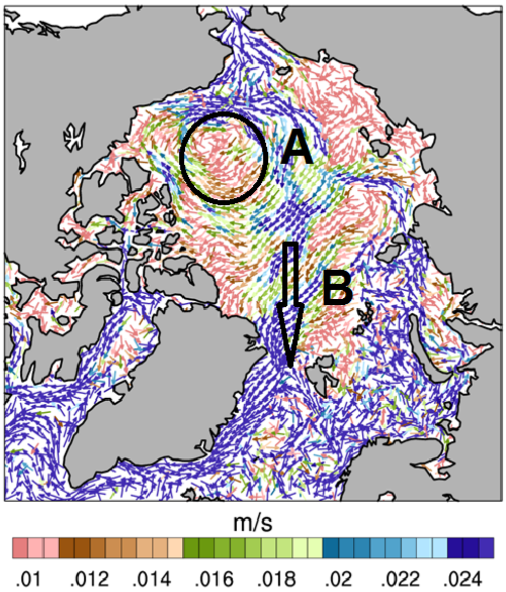


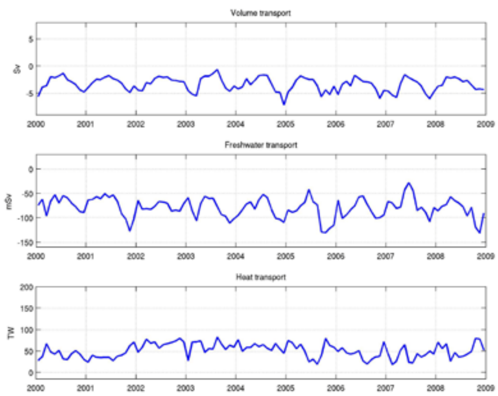
Figure 3. The distribution of mean surface ocean currents for the period 2000-2009.

Figure 3 presents the mean surface ocean currents for the period 2000-2009. The large scale wind-driven ocean surface current - Beaufort gyre (A in Figure 3) is well reproduced (e.g., Giles, 2012). Moreover, the Transpolar Drift Stream (B in Figure 3) is also well reproduced from model assimilation. It is transports water and ice from East Siberian and Laptev seas, across the Arctic through the North Pole towards the Fram Strait.

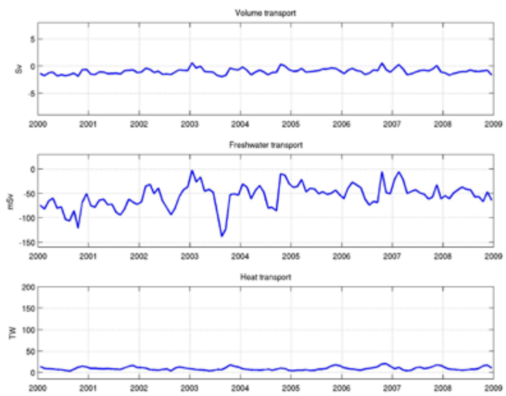
3.3 Ocean Transports

Arctic Ocean exchange heat and salt with Northern North Atlantic Ocean and Northern Pacific through few passages. The ocean transports at the Fram Strait, the Davis Strait, the Barents Sea Opening and the St. Anna straits were investigated and distributed within the MFTS pilot system. The data is available via the MFTS linking to data-sources located at [ftp.space.dtu.dk\pub\MONARCH-A\MFTS\transport\](ftp.space.dtu.dk\pub\MONARCH-A\MFTS\transport\).

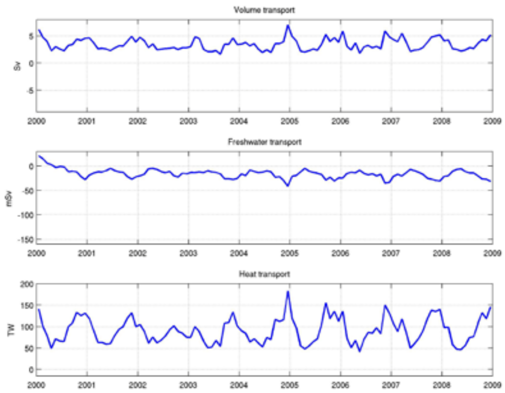
Figure 4. The positions of the Fram Strait, the Davis Strait west of Greenland, the Barents Sea Opening (BSO) and the St. Anna Trough (SAT).



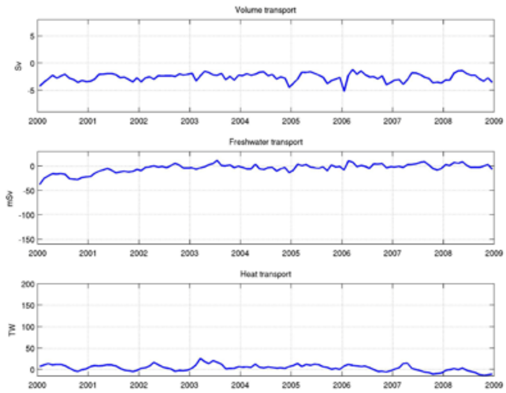
Fram Strait



Davis Strait



Barents Sea Opening



St. Anna Trough

Figure 5. The Volume, Heat and Freshwater transports through the Fram Strait (upper left), the Davis Strait (upper right), the Barents Sea Opening (lower left) and the St. Anna straits (lower right).

Figure 5 exhibit the time series of the volume, heat and freshwater transports through the Fram Strait, the Davis Strait, the Barents Sea Opening and the St. Anna straits. Comparing the volume transport at the selected sectors, it is seen that volume transport is always positive at the Barents Sea Opening for the 2000-2008 time period, which means the import of volume from the Nordic Seas through the Barents Sea Opening with a mean volume transport of 3.44 Sv. The negative volume transport is observed from the other three sectors. At the sector Fram Strait, the mean volume transport of -3.35 Sv is obtained.

Significant seasonality in fresh water transport is seen at the Fram Strait and the Davis Strait. The maximum of -138 mSv is found at the Davis Strait on August 2003, which relates to melting processing and which should be compared with the mean fresh water transport of -55.38 mSv through the sector. At the Fram Strait, the mean fresh water transport of -79.16 mSv is obtained for the 2000-2008 time period, which is the highest fresh water export at the selected sectors. The mean fresh water transport of -15.60 mSv and -4.27 mSv through the Barents Sea Opening and the St. Anna Trough, respectively.

The positive heat transport is observed in Figure 5 at the selected sectors for all the months except at the St. Anna Trough. The Barents Sea Opening shows the most significant seasonality in heat transport with mean heat transport of 95.17 TW. The Fram Strait contributes of 52.97 TW in mean heat transport to the Arctic interior. The heat transport through the St. Anna Trough is 3.94 TW, which is the lowest in the selected sectors.

In Figure 6, the mean values of volume, heat and freshwater is summarized. The red arrows denote the negative transports (out of the interior of the Arctic Ocean) and the yellow denote the positive transports (into the interior of the Arctic Ocean) through the sectors. One can see the positive heat transport at all the sectors. The positive volume transport is only observed at the Barents Sea Opening. It should be noted that the values for the Bering Strait opening has not yet been installed within the MFTS pilot system.

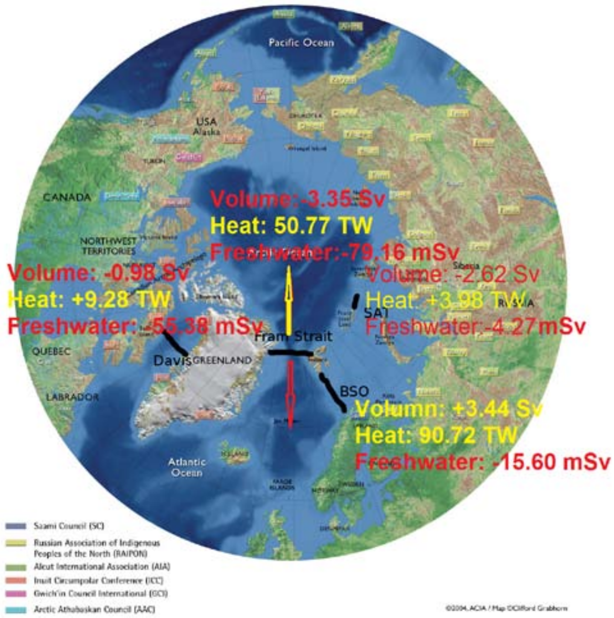


Figure 6. Mean values of volume, heat and fresh water transport.

3.4 Uncertain on MFTS ocean parameters

To access the uncertainty on the MFTS ocean parameters Figure 7 shows percentage of decrease in model-data difference with and without data assimilation. In this way the uncertainty of the assimilated parameters can be related to the uncertainty of the input parameters. The red color indicates reduction in total model-data difference, and other show reduction for individual variables. Negative values mean that there is an increase in model-data difference. Figure 7 illustrate that the average reduction for all years is around 15% with the largest overall reduction of 19% found for the year 2004 while the smallest of 10% is obtained for the year 2001. The biggest reduction in the individual variables is clearly found for the sea ice area, with overall mean of about 31% and maximum of about 45% reached in 2000. In the summer of 2003 and 2007, the model-data difference of SSH increased slightly with the data assimilation, which may be a function of implies that the error in the assimilated data during the period.

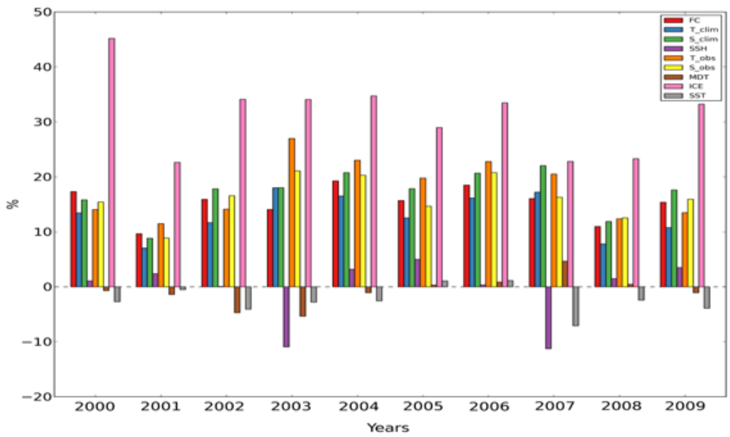


Figure 7. Percentage of decrease in model-data difference.

4 Assessment of Monarch-A Fast track service data.

The Monarch-A provide the best possible description of several ocean parameters in the Arctic Ocean. However, when assimilating several parameters into a model errors in the data might cause small in-accuracies because it might simply be impossible to make all the parameters dynamically consistent. Consequently, an assessment of Arctic model relevant climate data was established to and possible error in the ocean and provide this to users of the MFTS so they can account for this when they as an example assimilate the ocean state parameters into climate models.

The sea surface height and the ocean currents within the MFTS are quantities that can be assessed in the Arctic Ocean using i.e information from tide gauges and information from existing altimetric datasets. However, the sea surface height observations can also be evaluated with new SAR altimetric data from the ESA Cryosat-2 mission successfully launched in 2009 with the prime objective to provide new data for the Cryosphere. In parallel with the Monarch-A project, it had recently been proven, that the satellite also provide valuable information about the Arctic Ocean (i.e., Laxon et al., 2013)

4.1 Assessing the Monarch-A Fast track sea surface heights

Figure 8 presents the temporal standard deviation of the input data for the Monarch-A assimilation model used to derive the ocean variable. The standard deviation (STD) of the input DUACS gridded products from satellite altimetry is clearly significant differences to the dynamically consistent estimates in Figure 2. However, the general pattern is similar with highest STD in the same location except for the Foxe basin in Canada where the altimetric data have questionable quality. Generally the altimetric data have very sparser spatial coverage in the Arctic Ocean and equally sparse temporal coverage, which most likely explain why i.e. the temporal standard deviation is significantly higher if only sparse data exists for the computation.

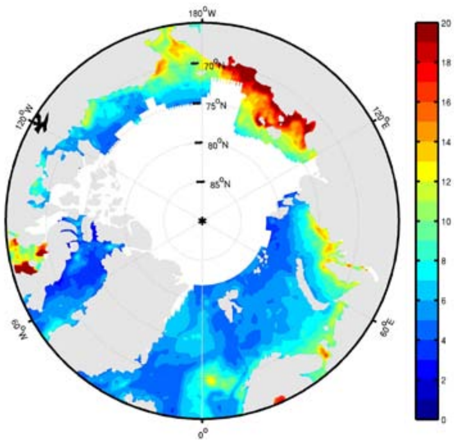


Figure 8. The standard deviation (cm) of the input interpolated DUACS altimetric data used for the assimilation into the MFTS.

By introducing data from the new ESA Cryosat-2 mission the output of MFTS pilot system can be assessed with an enhanced 20 year time series for the Arctic Ocean. This time series is shown in Figure 9, in which all altimetry data between 60°N and 81.5°N have been monthly averaged over the Arctic Ocean for the 1993-2012 time period. The colors denote the data from the various ESA missions. The dashed line in Figure 9 denotes the low passed sea level anomaly using 1-year running mean. It shows a slope of 1.1±0.1 mm/yr over the 1993-2012 time span. The data are available as supportive data from the MFTS web.

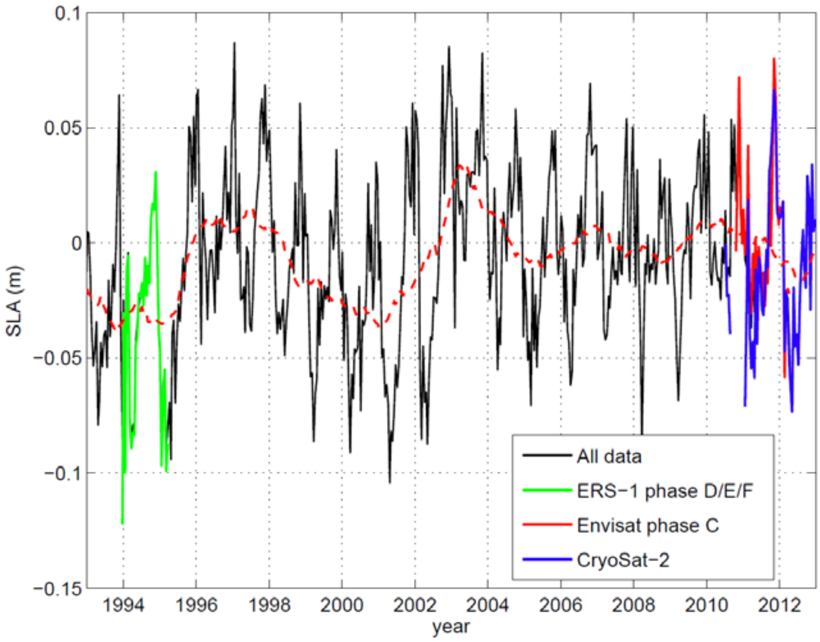


Figure 9. The new Cryosat-2 enhanced timeseries of averaged altimetry SLA time series (in meters) over the Arctic Ocean (60°N-81.5°N) over 1993-2012 time span. The 1-year running mean is shown by the dashed red line. On average this result shows a sea level rise of 1.1±0.1 mm/yr over the 1993-2012 time period

One of the central parameter for climate research is the sea level change and particularly its spatial distribution, as this is an integrated value for the ocean. The spatial distribution of linear Arctic sea level trend over the 2000 and 2009 period is shown in Figure 10. Figure 10 left present the distribution of linear sea level trend from the MFTS model outputs and Figure 10 (right) the linear sea level trend from the input DUACS satellite altimetry measurements.

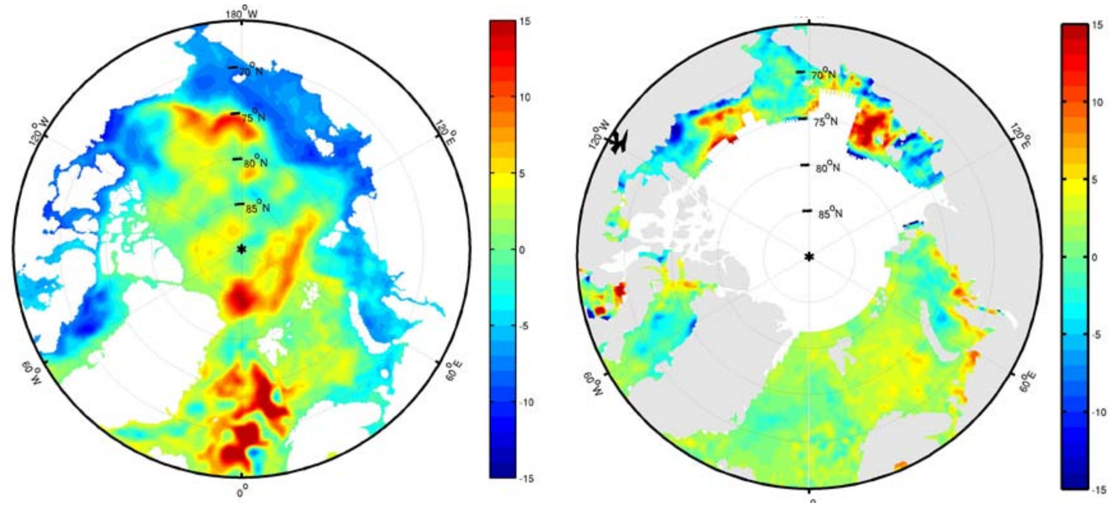


Figure 10.The distribution of linear sea level trend estimated from Monarch-A assimilation model (left) and from DUACS altimetric data (right). The values on the scale are in mm/year.

The assessment of the results in Figure 10 illustrates the importance of assimilating the sea surface height observations to obtain estimates for the entire Arctic Ocean. A few key spots of differences in the linear sea level trend are readily found in Figure 10. These are i.e. for the Eastern Laptev sea where the DUACS altimetric data shows unrealistically high sea level trend values which can most likely be subscribed to erroneous altimetric observations in the region. However the Monarch-A assimilated model exhibit also relatively large values in large parts of the Greenland-Iceland-Norwegian sea which requires further examination. Here the altimetric linear sea level trend is much more uniform which intuitively is what must be expected.

Table 2. Regional sea level trends (mm/yr) in the Arctic Ocean (65°N -81°N) for the 2000-2009 decadal period.

	40W-55E (Nordic Seas+Barents Sea)	55E-100E (Kara Sea)	100E-140E (Laptev Sea)	140E-180E (East Siberian Sea)	120W-180W (Beaufort Sea)	40W-120W (Canada)	Arctic Ocean
DUACS	1.38	1.55	-2.75	2.81	1.06	2.49	1.68±1.3
MFTS (60-81°N)	2.18	-3.90	-5.55	-5.50	-3.31	-3.43	-1.30±1.3
MFTS (60-90°N)	2.30	-2.95	-4.21	-4.82	-2.94	-3.15	-1.03±1.3

A careful inspection of the percentage of improvement in the fit to data with the assimilation as presented in Figure 5 reveals an interesting feature that the sea surface height as one of the only parameters is not improved for two years. This is naturally related to annual to intra annual signal in the Arctic Ocean. An assessment was performed to illustrate this in which the difference between the annual signal estimated by the model by fitting an annual variation to the data in a least squares sense.

The amplitude of the annual signal in sea level caused by the seasonal heating is shown in Figure 11 left and the annual signal of the input altimetric dataset for the assimilation is shown in the middle figure. To the right the annual signal derived as an altimetric adjustment of the GECCO model derived at DTU for the Monarch-A project. In figure 12 the associated phase of the annual signal is shown where the phase in degrees roughly correspond to the day number of the year that the annual signal is expected to peak.

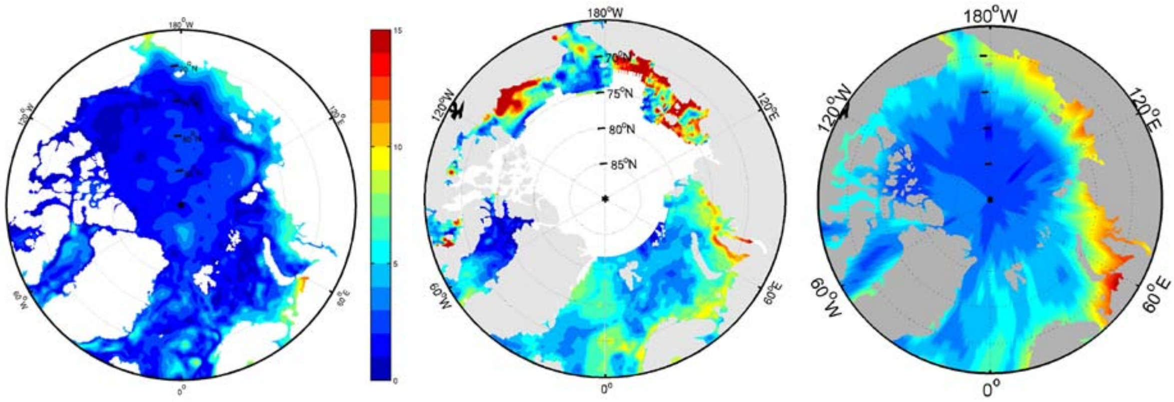


Figure 11.The amplitude of the annual signal from (left) MFTS model, (middle) DUACS input, (right) DTU10ANN model derived as part of the Monarch-A project.

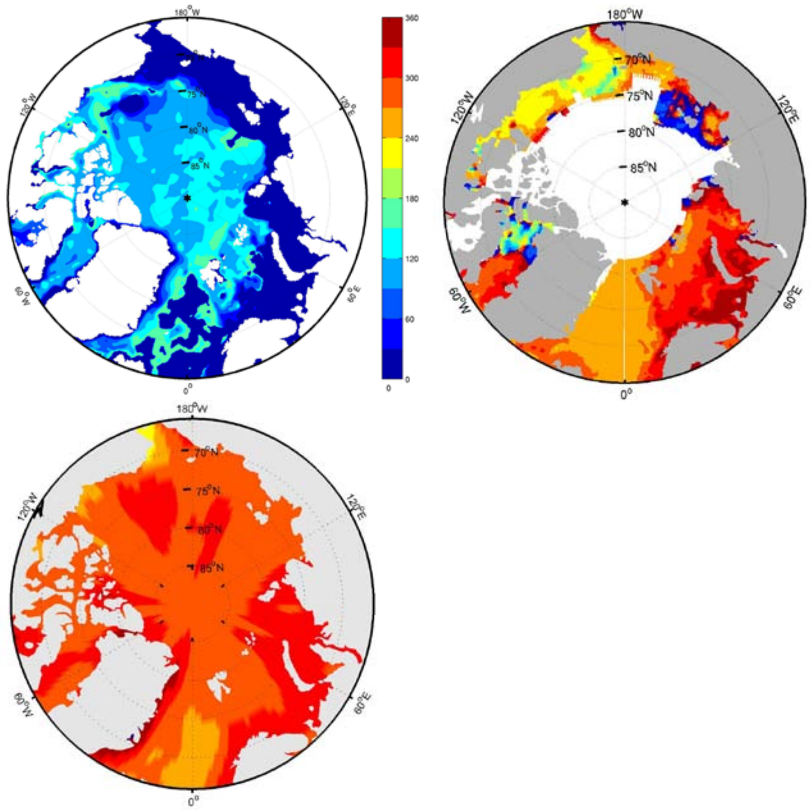


Figure 12.The phase of the annual signal from (left) MFTS model, (middle) DUACS input, (right) DTU10ANN model derived as part of the Monarch-A project.

The results in Figure 11 and Figure 12, shows that the amplitude of the dynamic consistent MFTS model available for the entire Arctic Ocean is considerable lower than the input altimetric data from DUACS. Particularly, the unrealistic high annual signal in the altimetric observations in parts of the Arctic interior is not observed from with the assimilated model. The unrealistic DUACS sea surface height values is most likely a consequence of the seasonal coverage.

In Figure 12, the phase of the annual signal is shown. It should be noted that as the amplitude of the annual signal is generally very low the phase will be relatively noisy in the way it is estimated in this analysis. Again for most of the interior of the Arctic ocean, the MFTS model is clearly more consistent than the phase estimated from satellite measurements. However, the model peaks about 2-3 month later than the input data. Comparing with the phase of the annual signal from the DTU10 annual sea surface model derived from an altimetric adjustment of the GECCO model is obvious that the annual signal in the MFTS model peaks too late. The DTU10Annual model confirms the intuitively correct phase of the annual signal to peak between October and December on the Northern Hemisphere.

4.2 Assessment of Monarch-A Fast track ocean surface currents.

The mean dynamic topography (MDT) developed at DTU based on the new ESA GOCE geoid model within the framework of Monarch-A project was assimilated into the MFTS assimilation model. The mean dynamic topography is a fundamental quantity as it governs the geostrophic currents in the worlds Ocean which can be computed from the slope of the mean dynamic topography. The estimated mean value of the Monarch-A Fast track service SSH anomalies for the 2000-2009 decadal period is shown in Figure 13 to the left. The mean SSH from satellite measurements is shown as the right panel in Figure 13.

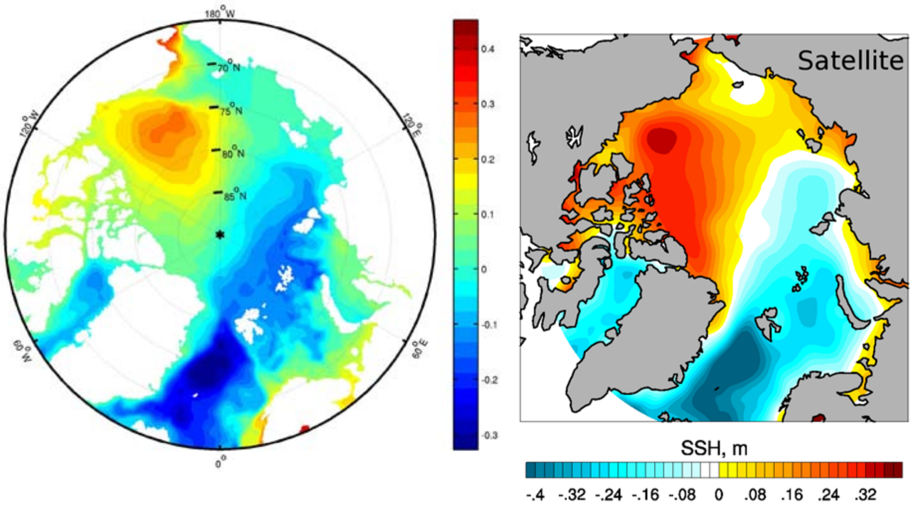


Figure 13. The 2000-2009 decadal mean SSH (in meters) from the MFTS (left) and from satellite altimetry and the GOCE geoid observations (left).

In Figure 13, similar patterns of MDT are presented from MFTS model and satellite measurements. In MFTS model, the gradient between positive mean sea surface height in Amerasian basin and negative mean sea surface height in Eurasian Basin is becoming less sharp, which make it closer to the spatial distribution of satellite mean sea surface height. Moreover, stronger negative SSH values in the northern north Atlantic are observed in MFTS model.

Sparse in-situ current measurement in the Arctic Ocean limits the understanding of Arctic Ocean circulation at intermediate depths and at the deep layers. We compared the model outputs with a new available fast track service.

The Monthly Means for HYCOM (Hybrid Coordinate Ocean Model) + NCODA (the Navy Coupled Ocean Data Assimilation) Global 1/12° Analysis (http://hycom.org/dataserver/glb-analysis/mean-std). The datasets are available on 30 m level for Jan-2004 to Dec-2008. The MFTS model outputs on third level (i.e., 25 m) are selected for the comparison.

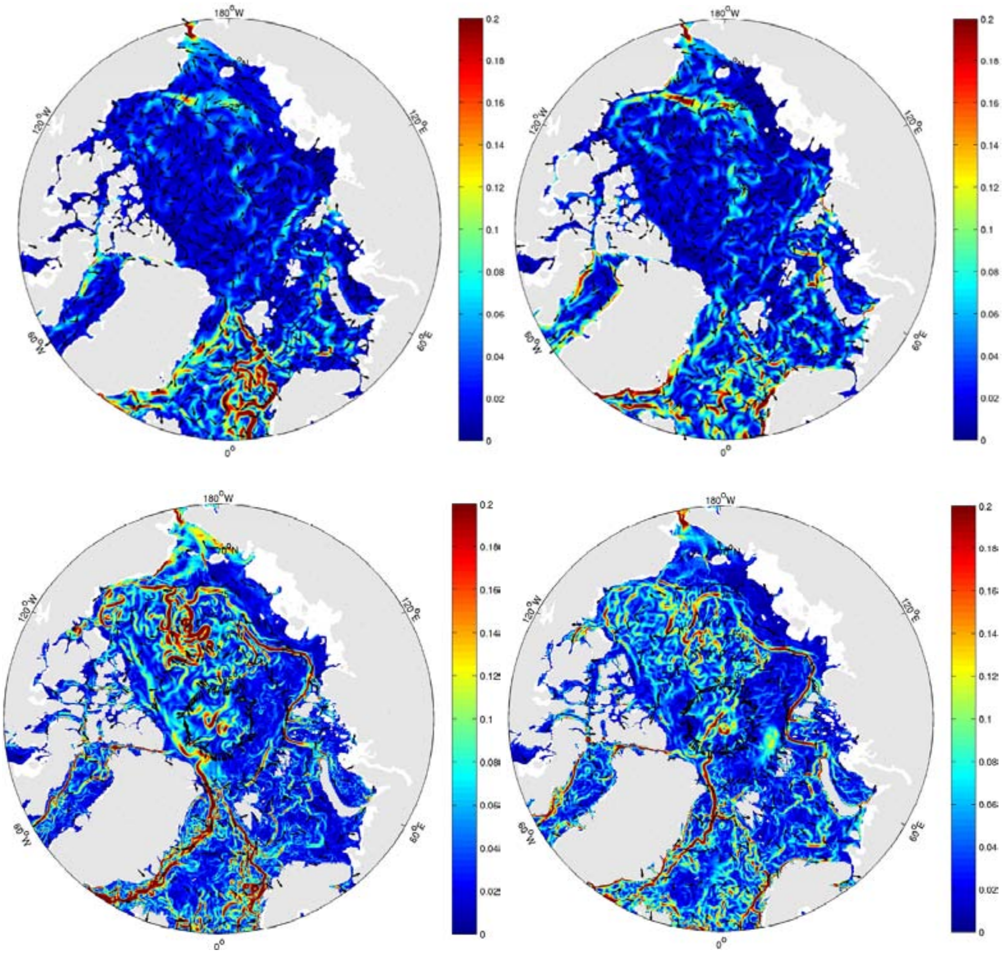


Figure 14. Model assimilated monthly averaged ocean currents for March and September of 2008. Upper row is March(left) and September (right) from MFTS assimilation model. And lower row is from HYCOM and NCODA at 30 meters for March 2008 (left) and September (right).

Figure 14 show the ocean currents in March and Septermber 2008 from the two datasets. The HYCOM and NCODA currents show more detailed currents structure due to higher spatial resolution, which call for increasing spatial resolution the MFTS models in future. Compared Figure 14(upper left) with 14(upper right) shows that in March, the ocean currents in the Nordic Seas stronger than that in September. In the Beaufort Gyre, compared with that in March, stronger ocean currents is found in September. As for the HYCOM+NCODA ocean currents, the ocean currents in March is stronger than that in September in the Nordic Seas. In the Beaufort Gyge, stronger ocean currents is found in March. Although our model have lower spatial resolution than HYCOM+NCODA, the ocean currents structure at the east Greenland, north of novaya zemlya and Bering Strait is similar to the HYCOM derived currents.

5 Summary

Monarch-A provides a fast track pilot service in which the satellite observations, in-situ measurements are assimilated to provide a dynamically consistent global un-interrupted estimate of ocean parameters of high relevant to i.e. climate prediction. Existing fast track and existing data in the frame of Monarch-A, e.g., sea level and sea ice information, is limited both spatially and temporally due to the presence of severe weather conditions and the presence of ice in the Arctic Ocean. As a consequence, most data are given sparsely and many quantities only during summer when seasonal ice coverage is at a minimum.

Through data assimilation the observations is ingested into a hydrodynamic model which is vital for fast track the climate changes in the Arctic Ocean providing i.e. monthly field of ocean quantities important to climate prediction. In addition, such Arctic wide products are practical important for people living and working activities in the Arctic regions, e.g., fishing, oil detection, shipping industry. It can provide several variables simultaneously to respond to the needs of policy, decision makes, business and public services to address the climate relevance over the Arctic. The assessment of the results in illustrates the importance of assimilating the sea surface height observations to obtain estimates for the entire Arctic Ocean.

Up to now, decadal monthly model outputs, such as sea surface height, sea ice concentration, ocean circulation, temperature and salinity are available for serving as the basis to provide and expand fast track services over the Arctic. The assimilated satellite observations and in-situ measurements are significant to improve the Arctic climate predictions. The model outputs fill the spatial and temporal gaps in the observations. The data and results in the frame of Monarch-A project is the basis for providing the integrated climate knowledge and decision support services for societal, political and business innovation etc.

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