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Use of the U.S. National Ice Center Marginal Ice Zone Product with Sea Ice Data Assimilation in U.S. Navy Modeling Systems

DAVID HEBERT

JACKIE MAY

TAMARA TOWNSEND

Ocean Dynamics and Prediction Branch
Ocean Sciences Division

MICHAEL PHELPS

Peraton, Inc
Herndon, VA

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14. ABSTRACT

Within the U.S. Navy, operational sea ice modeling is performed via the Earth System Prediction Capability (ESPC) and Global Ocean Forecast System (GOFS) 3.1. Both ESPC and GOFS 3.1 assimilate observations via the Navy Coupled Ocean Data Assimilation (NCODA) system. Currently the only operational sea ice products assimilated into ESPC and GOFS 3.1 are from passive microwave observations. Passive microwave observations are known to under-represent sea ice concentration near the ice edge and mis-classify melting ice and snow as water in summer melt seasons. The U.S. National Ice Center Interactive Multisensor Snow and Ice Mapping System (IMS) product is used within NCODA to help correct the identification of ice during the summer melt season. While IMS improved assimilated ice concentration in summer melt months, it does not extend to the ice edge, and thus does not update the modeled ice edge where ice concentration is typically low. The USNIC produces a daily ice edge product called the Marginal Ice Zone (MIZ) product that defines the ice edge. In this study we update NCODA to ingest and use the MIZ product with the IMS product to improve the assimilated sea ice observations and modeled ice edge.

15. SUBJECT TERMS

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Contents

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1 Introduction

In high-latitude regions where sea ice formation occurs, knowing the location of sea ice is extremely important to maritime safety of navigation and the success of U.S. Navy operations. The U.S. Navy Global Ocean Forecast System (GOFS) 3.1 is the Navy's operational system to forecast ocean and sea ice conditions [Metzger et al., 2014, 2017]. GOFS 3.1 is a two-way coupled ocean sea ice system. The ocean model is the HYbrid Coordinate Ocean Model (HYCOM) [Bleck 2002; Chassignet et al., 2003] and the sea ice model is the Los Alamos Community Ice CodE (CICE) version 4.0 [Hunke and Lipscomb, 2008]. Both models in the GOFS system are forced with atmospheric data from the NAVy Global Environment Model (NAVGEM) [Hogan et al, 2014].

GOFS is a data assimilative system, ingesting ocean and sea ice observational data via the Navy Coupled Ocean Data Assimilation (NCODA) system [Cummings and Smedstad, 2013]. Sea ice concentration observations from Special Sensor Microwave Imager / Sounder (SSMI/S) and Advanced Microwave Scanning Radiometer 2 (AMSR2) are currently assimilated into GOFS 3.1. While SSMI/S and AMSR2 provide full global ice concentration observations each day, one of their limitations is they have a difficulty detecting low ice concentrations as well as ice with water on the surface (such as melt ponds or wet snow) [Campbell, 1980; Cavalieri, 1990. Kern et al., 2020]. As a result, they often underestimate the extent of sea ice, especially in summer months when there is more water on the ice surface due to ice melting. To help correct this issue, the U.S. National Ice Center (USNIC) Interactive Multisensor Snow and Ice Mapping System (IMS) [Helfrich et al., 2007] is used within the NCODA system to verify the quality of the satellite observation (a more detailed description of IMS is provided in Section 2). Briefly, if an observation shows zero ice concentration but is within the IMS sea ice region, it is corrected by adding ice to that location. Conversely, if the observation has ice greater than zero where IMS indicates there should not be ice, the observation is corrected to be zero (details can be found in [Hebert et al, 2015]). Using IMS has been shown to improve the model ice edge prediction in the Arctic [Posey et al, 2015].

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While IMS has improved the model ice edge forecast, it has two main limitations for global operational use. First, IMS analyses are only available in the northern hemisphere. Thus, it cannot be used to improve model performance in the Antarctic. Second, IMS does not generally extend to the ice edge; the reported minimum ice concentration detected by IMS in the 4 km operational product is 40% [Meier et al., 2015] or 50% [Helfrich et al., 2007] (in this document we use 40% as minimum ice concentration detection). A complementary USNIC product, the Marginal Ice Zone (MIZ) product, has the potential to address both of these issues. It is produced daily by USNIC analysts, is available in both hemispheres, and marks the outer limit of ice seen by all imagery (further description is given in Section 2). In this study we test application of the USNIC MIZ product into GOFS via NCODA.

This report is organized as follows: Section 2 describes the USNIC MIZ product as well as differences between the MIZ and IMS products, Section 3 describes how MIZ is implemented in the NCODA system, Section 4 describes the test performed, Section 5 contains results from the test, and Section 6 is a summary and conclusion.

2 MIZ and IMS product description

A detailed explanation of the USNIC MIZ product can be found at their website [USNIC MIZ 2023]. Briefly, the MIZ product is generated daily by USNIC analysts identifying two regions of ice coverage: (1) The marginal ice zone, defined as the region between the ice edge (less than 10% ice concentration) to 80% ice concentration, and (2) pack ice, defined as the region with ice concentration greater than 80% (Figure 1). Analysis is performed for both the Northern and Southern Hemispheres making it an ideal choice to use within the Navy global modeling systems. Synthetic Aperture Radar (SAR) (e.g. from RADARSAT-2, RADARSAT Constellation Mission, Sentinel-1) and visible/infrared imagery from VIIRS, MODIS are the core imagery types used by USNIC analysts when making the MIZ product. Passive microwave observations, due to their coarse resolution, are minimally used in MIZ product generation. The MIZ product is available in multiple formats, including ASCII, ESRI Shapefile, KMZ, and PNG images. In this test we used the MIZ product in ESRI Shapefile format within NCODA.

The IMS is an operational software package for analyzing snow and ice coverage [USINC IMS, 2023]. Similar to the MIZ product, IMS is a product generated daily by an analyst. However, IMS is also used to identify snow--covered areas and uses additional data sources such as ground-based radar and station data. The analysis is performed only for the Northern Hemisphere. Also, as with the MIZ product, IMS does not provide specific ice concentration values at given points. It provides a mask that identifies if a location is ice covered (greater than 50% ice concentration) or not. The main purpose of IMS is to provide inputs for environmental models [Helfrich et al., 2007], whereas the MIZ product is intended for safety of navigation by maritime users. The main differences between the IMS and MIZ products are (1) IMS products are delivered on predefined grids of 1 km, 4 km, 24 km, whereas MIZ is produced in vector format (e.g., shapefile) with polygon locations that differ daily, (2) IMS identifies locations of ice concentration greater than 40%, while MIZ delineates locations of ice concentration at the ice edge, usually taken as greater than 10%, and (3) IMS includes lake ice, while MIZ does not [Helfrich et al., 2007; USNIC, 2008], and (4) the IMS product is only produced for the Northern Hemisphere, while the MIZ product is produced in both the Northern and Southern Hemispheres.

3 Using MIZ and IMS in NCODA

While both the IMS and MIZ products identify regions that are ice covered or open water, they do not provide specific ice concentration values at specific locations, as required to ingest into a sea ice model like CICE. Their primary application within NCODA is to quality control the ice concentration determined from passive microwave observations, specifically from SSMI/S and AMSR2. Here we will review how IMS is applied within NCODA, then provide details on the application of MIZ within NCODA.

3.1 IMS within NCODA

The main parts of NCODA are quality control (QC) and variational analysis (VAR). NCODA QC performs quality control checks on values determined from satellite retrievals (in this case ice concentration determined from passive microwave brightness temperatures) and applies flags based on the checks performed. NCODA VAR then reads in the QC data and the flags applied. Based on the flagged values, NCODA VAR will either ignore, alter, or use the observation in the variational analysis.

Within NCODA QC the satellite derived ice concentration is first checked to be between 0% and 100%; ice concentration values outside this range are ignored. The ice concentration values are then checked to see if they fall within or outside the IMS mask (that is, within or outside IMS determined ice covered areas). In this case we use the IMS 4km gridded product. A flag is applied indicating if the ice concentration values conflict with IMS. NCODA VAR then reads the QC data and flags and modifies the ice concentration values in the analysis as follows: If the QC flag indicates an ice concentration value is greater than 0% and is outside the IMS mask, the ice concentration is changed to 0%. If the QC flag indicates an ice concentration value equals 0% and is within IMS mask, the value is changed to 70%. 70% was arbitrarily chosen as the midpoint between the minimum IMS value of 40% and maximum of 100% ice concentration [Posey et al., 2015]. Otherwise the ice concentration value is left unchanged. After this QC process, it is ingested into NCODA VAR to generate an ice concentration analysis field.

3.2 MIZ and IMS within NCODA

Similar to the IMS product, the MIZ product provides information on where there is sea ice or open water. As mentioned above, MIZ product identifies two regions of ice concentration, the ice edge (between 0% and 10%) - 80% (referred to hereafter at 10%-80%) and 80% - 100%. MIZ vector shapefile formatted data are used in the same way as IMS to quality control ice concentration derived from passive microwave observations. After verifying if the satellite derived ice concentration value is within physical limits of 0%-100%, NCODA QC then checks if the ice concentration value is inside/outside IMS 4 km product. Then NCODA QC checks if the ice concentration value is outside MIZ, within the 10%-80% MIZ shapefile region, or within the 80%-100% shapefile region. A flag is applied indicating if the ice concentration values conflict with IMS and / or MIZ. NCODA VAR then reads the QC data and flags. In the Northern Hemisphere, NCODA VAR modifies the ice concentration values in the analysis as follows:

- If satellite derived ice concentration is > 0% and outside of both IMS and MIZ, it is changed to 0%.
- If satellite derived ice concentration is 0%, outside IMS, and within MIZ 10%-80%, it is changed to 20%.
- If satellite derived ice concentration is 0%, inside IMS, and within MIZ 10%-80%, it is changed to 40%.
- If satellite derived ice concentration is 0% and within MIZ 80-100%, it is ignored and not assimilated.
- If satellite derived ice concentration is > 90% and within MIZ 10-80%, it is ignored and not assimilated.
- If satellite derived ice concentration is between 1% and 70%, and also within MIZ 80-100%, it is changed to 90%.
- Otherwise, the satellite derived ice concentration is left unchanged.

IMS data is not available in the Southern Hemisphere. As a result, the application of MIZ is slightly different:

- If satellite derived ice concentration is > 0% and outsize of MIZ, is changed to 0%.
- If satellite derived ice concentration is 0% and within MIZ 10%-80%, it is changed to 20%.
- If satellite derived ice concentration is 0% and within MIZ 80-100%, it is ignored.
- If satellite derived ice concentration is > 90% and within MIZ 10-80%, it is ignored.
- If satellite derived ice concentration is between 0% and 70% and within MIZ 80-100%, it is changed to 90%.
- Otherwise, the satellite derived ice concentration is left unchanged.

4 Test Description: Standalone CICE

CICE is used operationally in Navy forecast systems. NCODA including the USNIC MIZ and IMS products to quality control the satellite-derived ice concentration values was tested in a "standalone" CICE v6.1.4 setup (hereafter referred to as "CICE+MIZ") at 1/12th degree resolution, the same resolution as GOFS 3.1. In standalone configuration CICE is not coupled to an ocean or atmosphere model as done in GOFS. Instead, when running CICE in standalone mode, it is forced by externally applying NAVGEM atmospheric data and HYCOM ocean data from GOFS 3.1. Testing in this manner saves approximately 90% of the computational cost compared to running with a GOFS 3.1 system, as only NCODA and CICE are required. Although the effect of including MIZ in a coupled run is not captured, this test fully exercises the ability of NCODA to use MIZ data in the generation of ice concentration analyses.

The testing period was from Aug 2, 2020 – Aug 31, 2021. This test covered a full year cycle of sea ice melt and freeze in each hemisphere. Results are compared to operational GOFS 3.1.

5 Results

5.1 Ice Edge Distance Error

Ice edge distance error is defined as the distance between the modeled ice edge and the USNIC ASCII ice edge product (the ASCII ice edge product is derived from the MIZ product). The model ice edge is defined as a model grid cell greater than 5% ice concentration with an adjacent model cell less than 5% ice concentration. Here 5% was used as the midpoint between 0% and 10% ice edge definition used by the USNIC. In this study we examined the ice edge distance error in each entire hemisphere as well as geographic regions as shown in Figure 2.

Figure 3 and Figure 4 contain plots of ice edge distance error vs forecast length 'tau' for GOFS 3.1 (red line) and CICE+MIZ (black line) for the Arctic and Antarctic, respectively. The top plot in each figure is the average ice edge distance error for the specific tau over the entire hemisphere (it is not an average of the regional error data). The remaining plots are the ice edge distance error for each analysis region shown in Figure 2. At the initialization time tau = 0, the ice edge distance error for the CICE+MIZ is 12 km in the Arctic and 5 km in the Antarctic (top plots in Figure 3 and Figure 4). Compared to GOFS 3.1 this is an improvement of 12 km (51%) in the Arctic and 36 km (89%) in the Antarctic. Improved modeled ice edge is demonstrated through the 72-hour forecast (against the MIZ ASCII product of that day), at which time the ice edge distance error reduction was 14% (5km) and 47% (22km) in the Arctic and Antarctic, respectively.

Each region has improvement at initial tau = 0. However, the duration of the improvement varies by region, with the longest duration in the Canadian Archipelago and Laptev/Siberian Seas and shortest improvement in Barents/Kara and Greenland/Norwegian Seas. It is unclear why the regional differences. One possibility is the dynamical differences in each region (i.e., limited ice drift in Canadian Archipelago compared to other regions). However since each region shows improvement at tau = 0 the differences are likely due to a CICE model performance and not the use of MIZ within NCODA.

5.2 Integrated Ice Edge Error

The Integrated Ice Edge Error (IIEE) is the area of modeled sea ice that does not match a reference sea ice field [Goessling et al, 2016]. In contrast to the ice edge distance error, which is a linear distance metric, IIEE takes into account the shape of the ice fields and provides a sense of the erroneous area of simulated ice. IIEE is the sum of the area of sea ice that is both over- and under-estimated by the model (Figure 5). Traditionally, the 15% ice concentration contour is used as the reference ice edge, and is also used in this study to determine the over- and under-estimates. Following equations (1) - (3) in Goessling et al. [2016], IIEE overestimate (O) and underestimate (U) are defined as:

$$O = \int_A \max(c_f - c_t, 0)\, dA$$

$$U = \int_A \max(c_t - c_f, 0)\, dA$$

$$IIEE = O + U$$

where A is area of interest (North or South Hemisphere in this case), $c = 1$ if ice concentration is above 15% and $c = 0$ if it is below 15%. The subscripts f and t refer to the forecast (or model) and truth (or reference data). Below we compute IIEE using two different 'truth' values: (1) SSMI and (2) initial model state after data assimilation. The choice of these truth values is explained in each section.

5.2.1 IIEE with SSMI as Truth

Figure 6 contains plots of IIEE for forecast tau's 0-72 in the Arctic and Antarctic. In each hemisphere GOFS 3.1 has a lower IIEE than the CICE test including MIZ. The difference is relatively small in the Arctic, 0.2 Mkm^2 at tau=0, likely because in the Northern Hemisphere GOFS assimilates IMS data (see Hebert et al., 2015 for details). In the Antarctic, where there is no IMS data available, the difference is much larger, with the CICE+MIZ test showing an IIEE 1.1 Mkm^2 larger than operational GOFS 3.1 that does not assimilate MIZ.

To look further into why assimilating MIZ increased IIEE, Figure 7 contains plots of the over- and underestimates that contributed to Arctic and Antarctic IIEE for each day of each test. In each plot, the overestimate is the main contributor to IIEE, and by far dominates the IIEE for the tests including MIZ. In addition, the IIEE increases in each hemisphere's summer months (June-August in Arctic, December-February in Antarctic). This bias towards overestimation can be explained by the nature of passive microwave observations of sea ice. As mentioned earlier, passive microwave observations such as SSMI/S and AMSR2 are known to misclassify ice that has wet snow or water on the surface (such as a melt pond) as open water [Campbell et al., 1980; Cavalieri et al, 1990]. Also, passive microwave sensors have a difficult time detecting low ice concentrations [Posey et al., 2015]. Figure 8 and Figure 9 contain plots of SSMI from a summertime day (July 15 for Arctic, December 15 for Antarctic) as well as model results. In each figure SSMI/S ice concentration observations (upper left plot) do not have ice that is shown in the GOFS or CICE model ice concentration fields (upper row, middle and left), or in the USNIC IMS and MIZ products (lower row). Recall that if the ice concentration is 0% but within IMS and / or MIZ, the observation will be changed to a large value for model assimilation purposes (as described in

Section 3). In the Arctic plot (Figure 8) there is more ice extent compared to that shown in SSMI/S, especially in Hudson Bay, Davis Strait, and off the coast of Siberia. In the Antarctic MIZ plot (Figure 9) there is clearly more ice identified by USNIC MIZ around the outer perimeter of sea ice (upper portion of plot). This result suggests that using passive microwave sensors as a reference for IIEE is problematic, especially when also using other ice data sources like IMS or MIZ in the assimilation process.

5.2.2 IIEE with Model Initial State after Data Assimilation as Truth

An alternative to calculating IIEE using SSMI as a reference state is to use the model initial state after assimilation at time tau=0 as a reference field. The model initial state is the best depiction of the true sea ice state due to assimilation of the passive microwave observations SSMI and AMSR2 as well as the USNIC IMS and MIZ products, as described in Section 3. This is sometimes termed "self-analysis" since the reference field is taken from model output and not strictly from observations. When calculating IIEE in a self-analysis, tau=0 is used as the reference field for prior forecast outputs. For example, yesterday's 24-hour forecast is compared to today's tau=0; two days ago model 48-hour forecast is compared to today's tau=0, etc. Note that with a self-analysis, there is no IIEE at tau=0, since that is the reference field.

In this study, the tau=0 field from the CICE+MIZ test is used as the reference field for both models. The reason for using the CICE+MIZ as the reference field is since the MIZ is an analyst-derived product that defines the ice edge, we take it as the most accurate ice coverage information to be used for comparison. Also, it is important to have the same reference field in order for the comparison to be meaningful. If we were to use the GOFS 3.1 tau=0 to calculate the GOFS 3.1 IIEE, and CICE+MIZ tau=0 to calculate the CICE with MIZ IIEE, the reference fields would be different (since GOFS 3.1 does not include MIZ), and an IIEE comparison does not make sense with different reference fields.

Results of the model tau's 24, 48, and 72 hour forecast IIEE comparison using the CICE+MIZ tau=0 as the reference field for the Arctic and Antarctic are shown in Figure 10 and Figure 11, respectively. Each plot contains the total IIEE (black line) as well as the area overestimate (red line) and underestimate (blue line). The left column is IIEE for GOFS 3.1, the right column is IIEE for the CICE+MIZ test; the rows from top to bottom are tau 24, 48, and 72. The IIEE derived using the more realistic sea ice state as the reference field is larger in GOFS 3.1 than the CICE+MIZ test through tau=72 hours. At tau=24, the difference is 0.29 Mkm^2 (47%) in the Arctic and 0.76 Mkm^2 (49%) in the Antarctic (Table 1). The vast majority of the GOFS 3.1 IIEE is due to underestimation of the ice area, particularly in the Antarctic. This is expected because the MIZ extent is greater than the IMS extent. Since GOFS 3.1 only includes IMS, which is Northern Hemisphere only, and not MIZ, the model output is not updated to update the ice edge at tau=0.

In Figure 10 and Figure 11, each model has an increase in total IIEE in the summer months in each hemisphere (June-September for Arctic, December-February in Antarctic), with a corresponding increase in area underestimate. This indicates that each model melts ice too fast in the summer months, and is not related to the assimilation method. Although it is worth noting that there is less ice melt in the CICE+MIZ test compared to GOFS 3.1, particularly in the Antarctic. This rapid ice melt is actively being investigated at this time.

6 Summary

In this study we added the capability to include the USNIC defined ice edge via their MIZ product within NCODA. The MIZ product is used to verify, or quality control, and update SSMI/S and AMSR2 ice concentration observations. These updates were performed in addition to updates using the USNIC IMS product, since IMS and MIZ detect different ice concentration ranges; IMS detects ice concentration greater than 40%, while MIZ detects two regions (a) ice edge - 80% and (b) 80%-100%.

The results showed that the CICE test using the USNIC MIZ product improved the forecast ice edge distance error by 51% in the Arctic and 89% in the Antarctic (Figure 3 -Figure 4). The IIEE comparison using SSMI/S as a reference showed that the CICE+MIZ was worse than GOFS 3.1 which does not include MIZ. The reason for the higher error in the CICE+MIZ test is due to the fact that passive microwave sensors like SSMI/S and AMSR2 misclassifies ice with melt ponds or wet snow as no-ice

[Campbell 1980, Cavalieri 1990], and also has difficulty detecting low concentrations of sea ice [Posey et al, 2015]. Including MIZ is intended to correct this low bias in SSMI/S and AMSR2; thus using SSMI/S as the IIEE reference field is not appropriate in this study. Instead, taking the position that the ice extent defined by the MIZ product is the most accurate sea ice extent, using the CICE+MIZ initial tau=0 field as a reference for IIEE showed the CICE+MIZ IIEE was reduced by 47% (0.29 Mkm^2) in the Arctic and 49% (0.76 Mkm^2) in the Antarctic compared to GOFS 3.1 (Table 1). Figure 10 and Figure 11 also show IIEE increases in each model during the summer months in both hemispheres (June-September in Arctic, December-February in Antarctic). This is due to model performance where each model melts ice too quickly in the summer, and is not a consequence of the assimilation method, and is an active area of research.

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8 Tables

Table 1: Mean IIEE values for each forecast tau using CICE with MIZ as the reference field. Total IIEE = Over + Under. Units are million km²

Arctic							
	GOFS 3.1			CICE + MIZ			Total IIEE diff GOFS 3.1–CICE+MIZ
Tau	Over	Under	Total IIEE	Over	Under	Total IIEE	
24	0.07	0.55	0.62	0.09	0.24	0.33	0.29
48	0.07	0.66	0.73	0.11	0.38	0.49	0.24
72	0.07	0.75	0.82	0.11	0.47	0.59	0.23
Antarctic							
	GOFS 3.1			CICE + MIZ			
Tau	Over	Under	Total IIEE	Over	Under	Total IIEE	
24	0.03	1.28	1.31	0.19	0.35	0.55	0.76
48	0.03	1.31	1.34	0.23	0.53	0.53	0.81
72	0.04	1.34	1.38	0.24	0.60	0.75	0.63

9 Figures

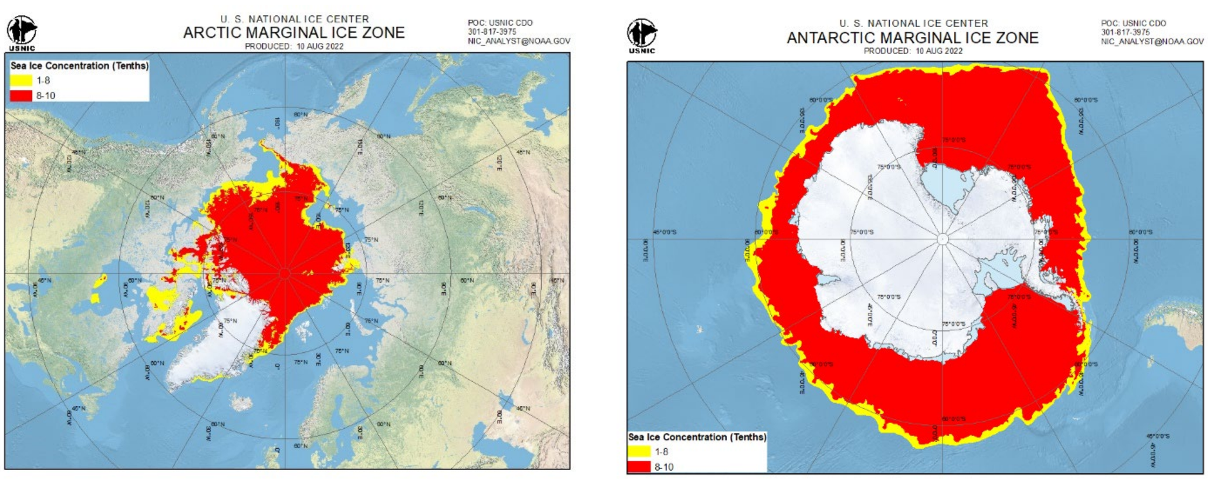

Figure 1: Sample USNIC MIZ product for (left) Arctic and (right) Antarctic from 10 AUG 2022. In each plot the yellow area indicates ice between ice edge and 80% concentration, while the red indicates area with ice concentration greater than 80%.

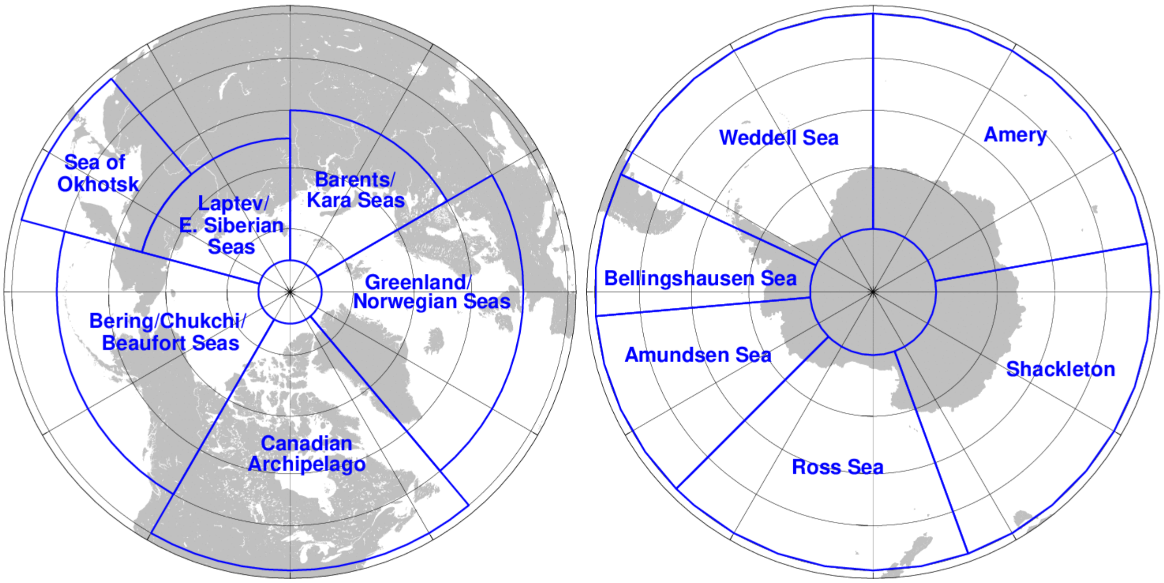

Figure 2: Analysis regions for the Arctic (left) and Antarctic(right).

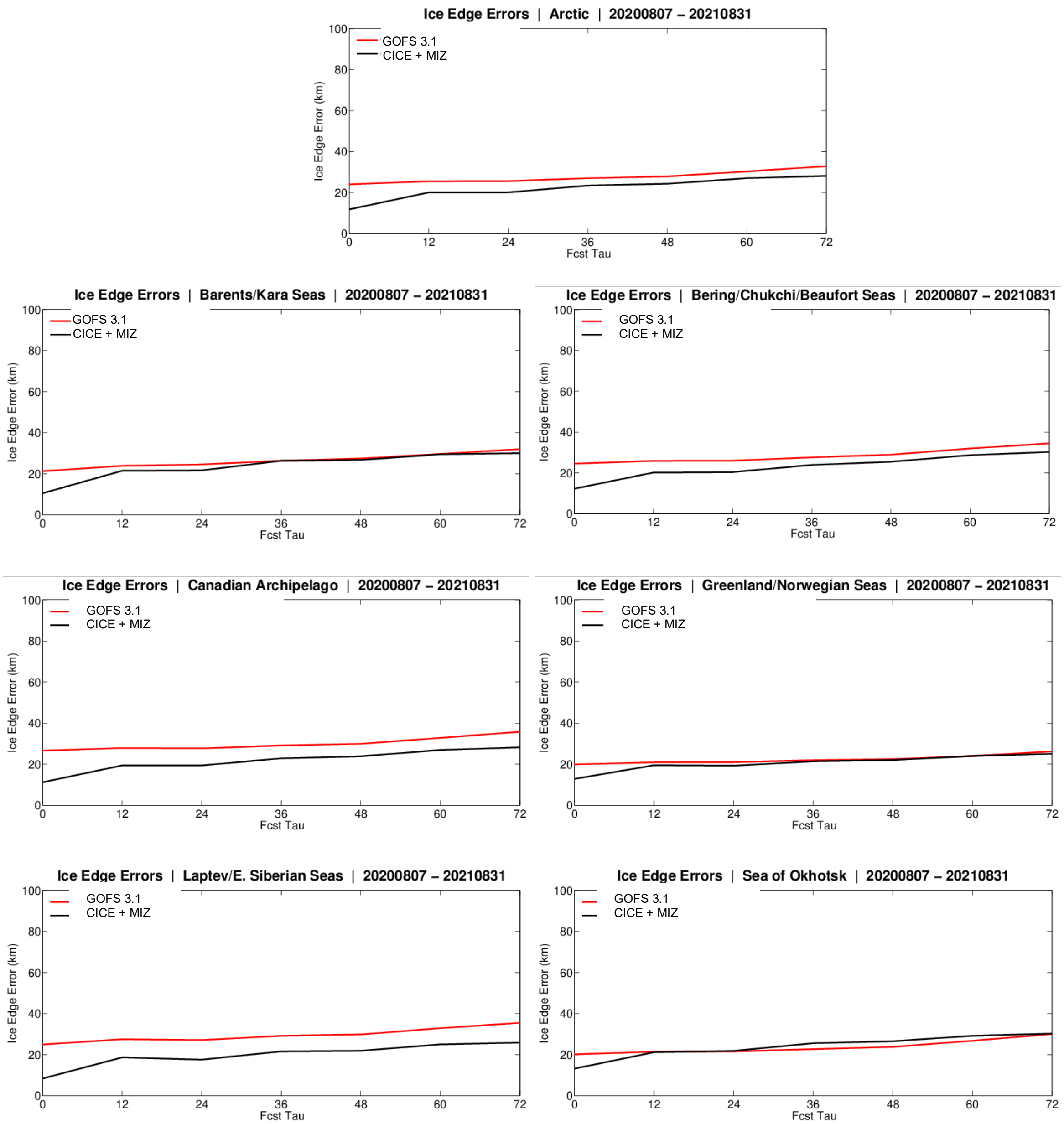

Figure 3: Ice edge distance error vs each forecast tau for Arctic regions shown in Figure 2. Each plot is the average error from each daily run from Aug 7, 2020 through Aug 31, 2021. The top plot is the average over the entire arctic. The remaining plots are the ice edge error for their respective region.

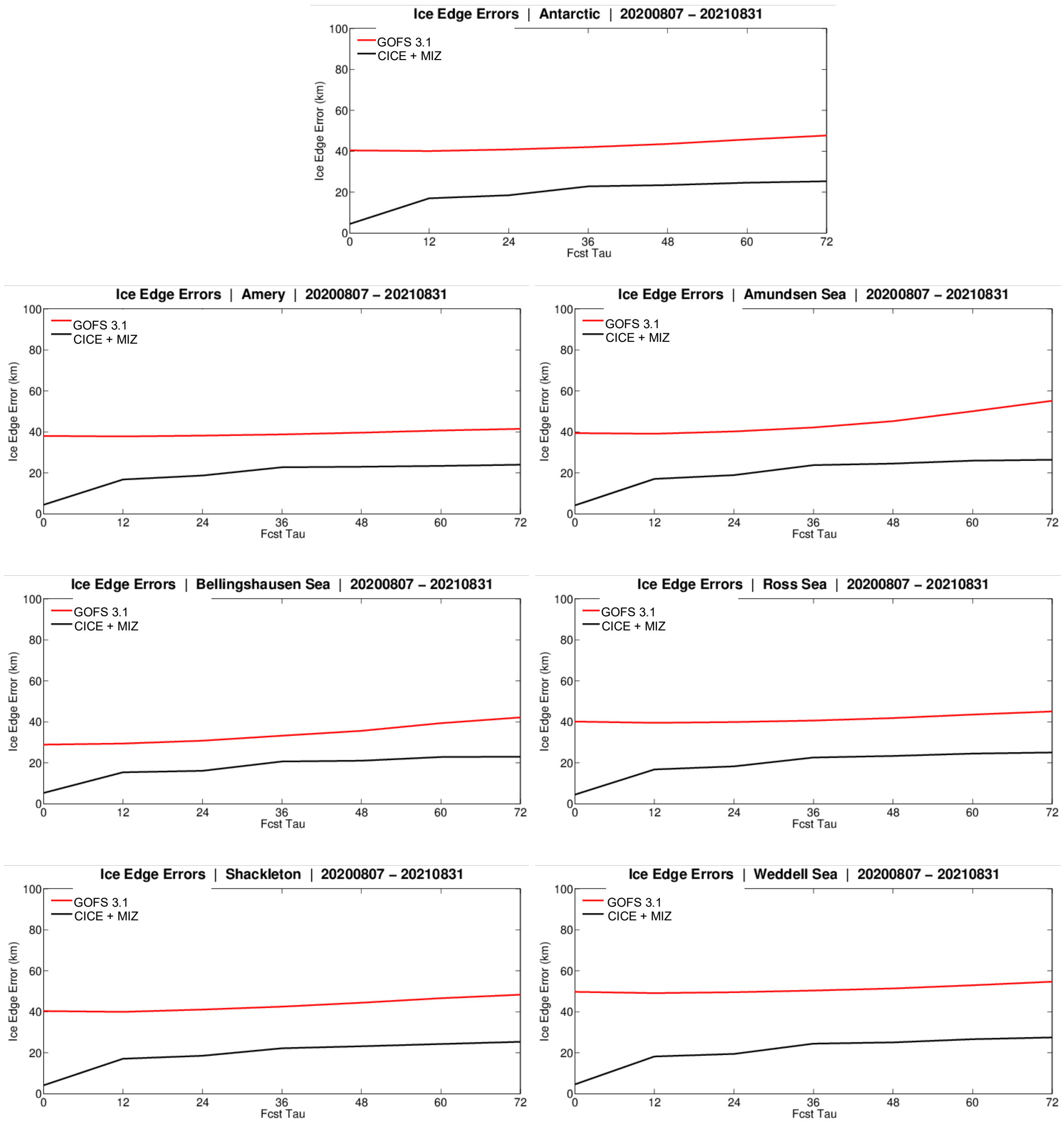

Figure 4: Ice edge distance error vs each forecast tau for Antarctic regions shown in Figure 2. Each plot is the average error from each daily run from Aug 7, 2020 through Aug 31, 2021. The top plot is the average over the entire arctic. The remaining plots are the ice edge error for their respective region.

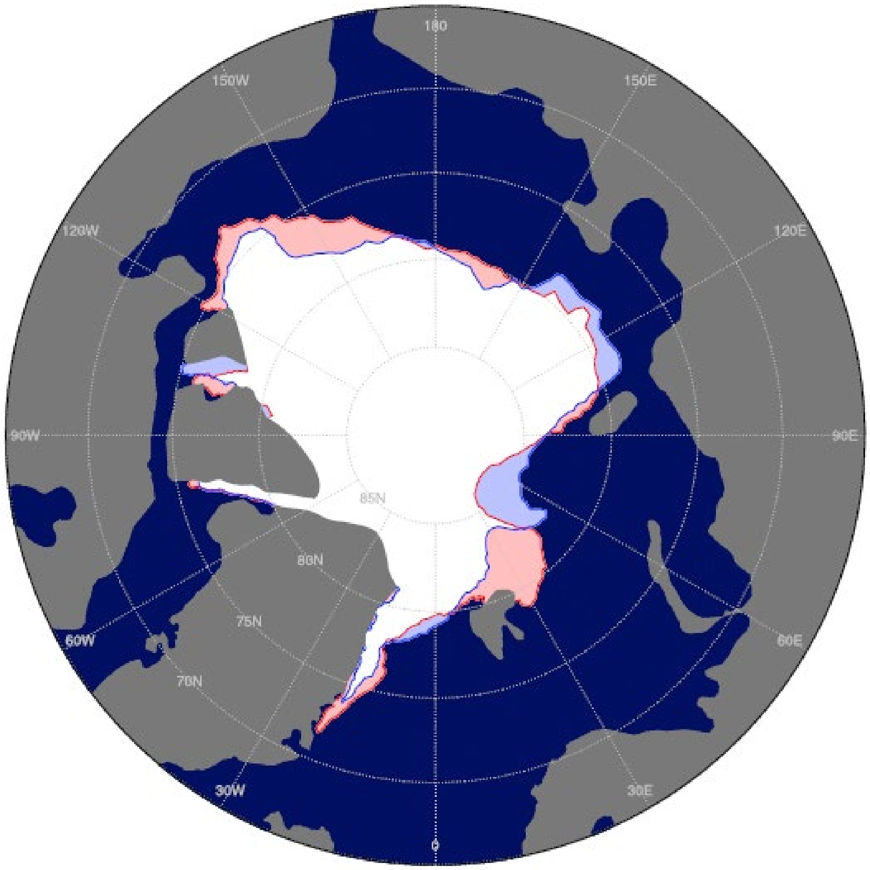

Figure 5: Example of IIEE. Blue line = model ice extent. Red line = reference ice extent. The light blue area is where the model overestimated the reference ice extent. The light red area is where the model under-estimated the ice extent. The white area is the overlap between the two. (Adapted from Figure 1, Goessling et al., 2016).

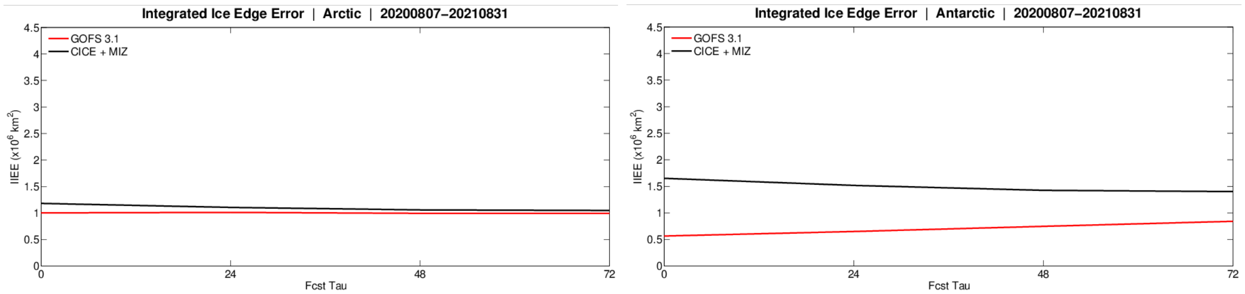

Figure 6: IIEE vs forecast length (tau) for the Arctic (left) and Antarctic (right). In each plot the black line is IIEE for GOFS 3.1, the red line is IIEE for CICE assimilating MIZ.

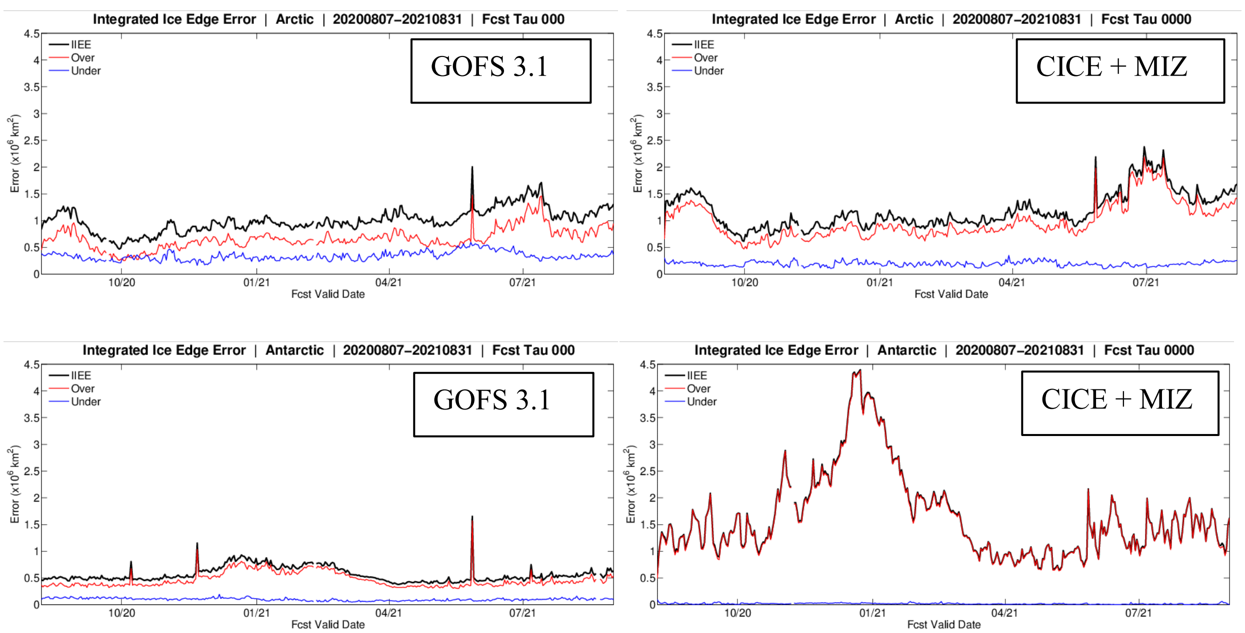

Figure 7: IIEE using SSMI/S as a reference field for GOFS 3.1 (Left column) and CICE + MIZ test (Right column) at forecast tau=0. Top row is IIEE for Arctic, bottom row is IIEE for Antarctic. The red line is the sea ice area overestimated by the model. The blue line is sea ice area underestimated. The black line is the total IIEE = Over + Under.

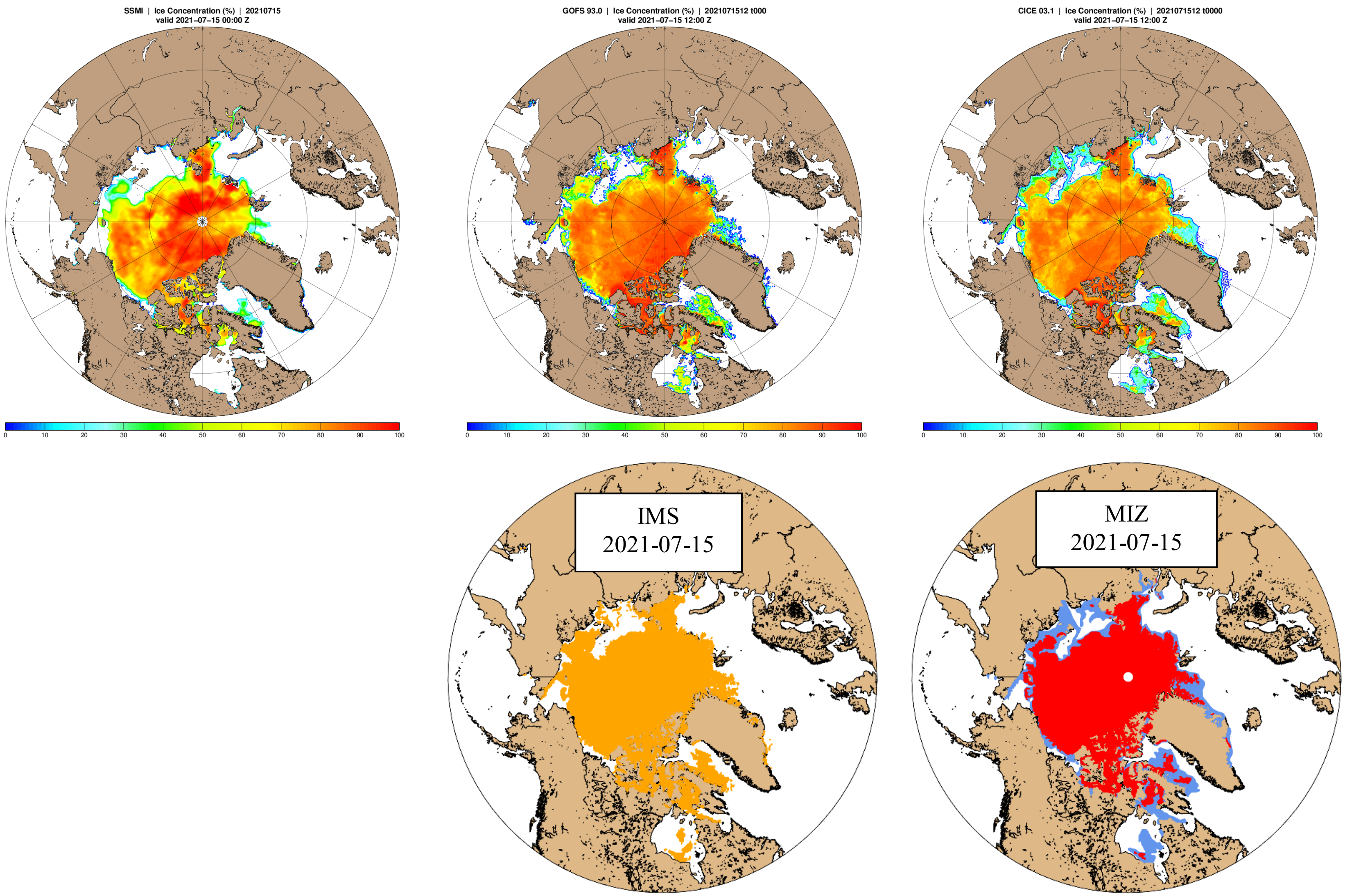

Figure 8: Observed and modeled ice concentration on July 15, 2021. Top row: SSMI observations (left).GOFS 3.1 (center), CICE assimilating MIZ (right). Bottom row: IMS (center) and MIZ (right) data on the same day. In the MIZ plot, the blue area is 10-80% ice concentration, the red area is 80%-100% ice concentration.

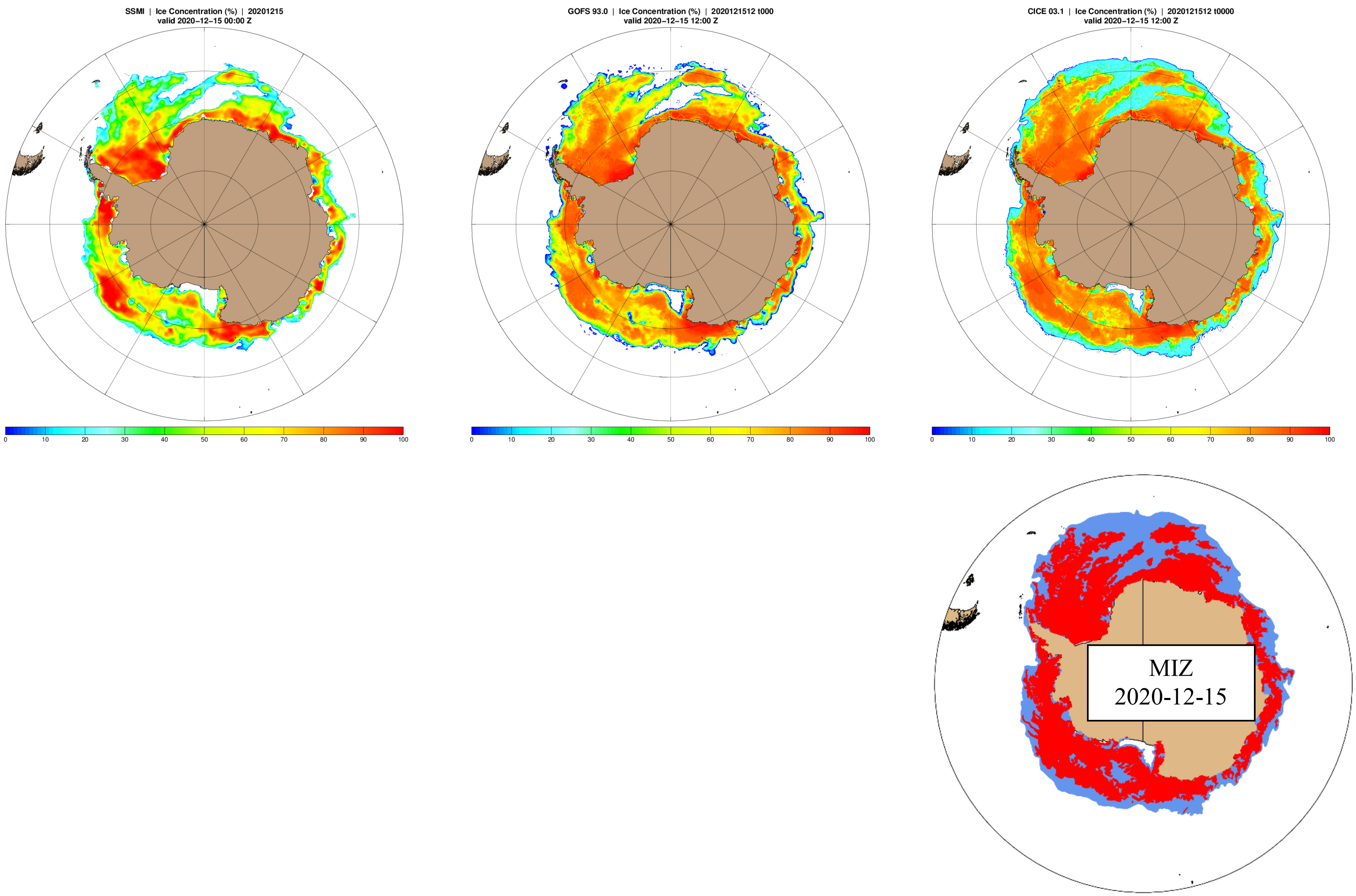

Figure 9: Same as Figure 9, but for Antarctic on Dec 15, 2020. CICE assimilating MIZ demonstrates much more ice area that is not seen in SSMI. Note IMS data is not available in the Antarctic.

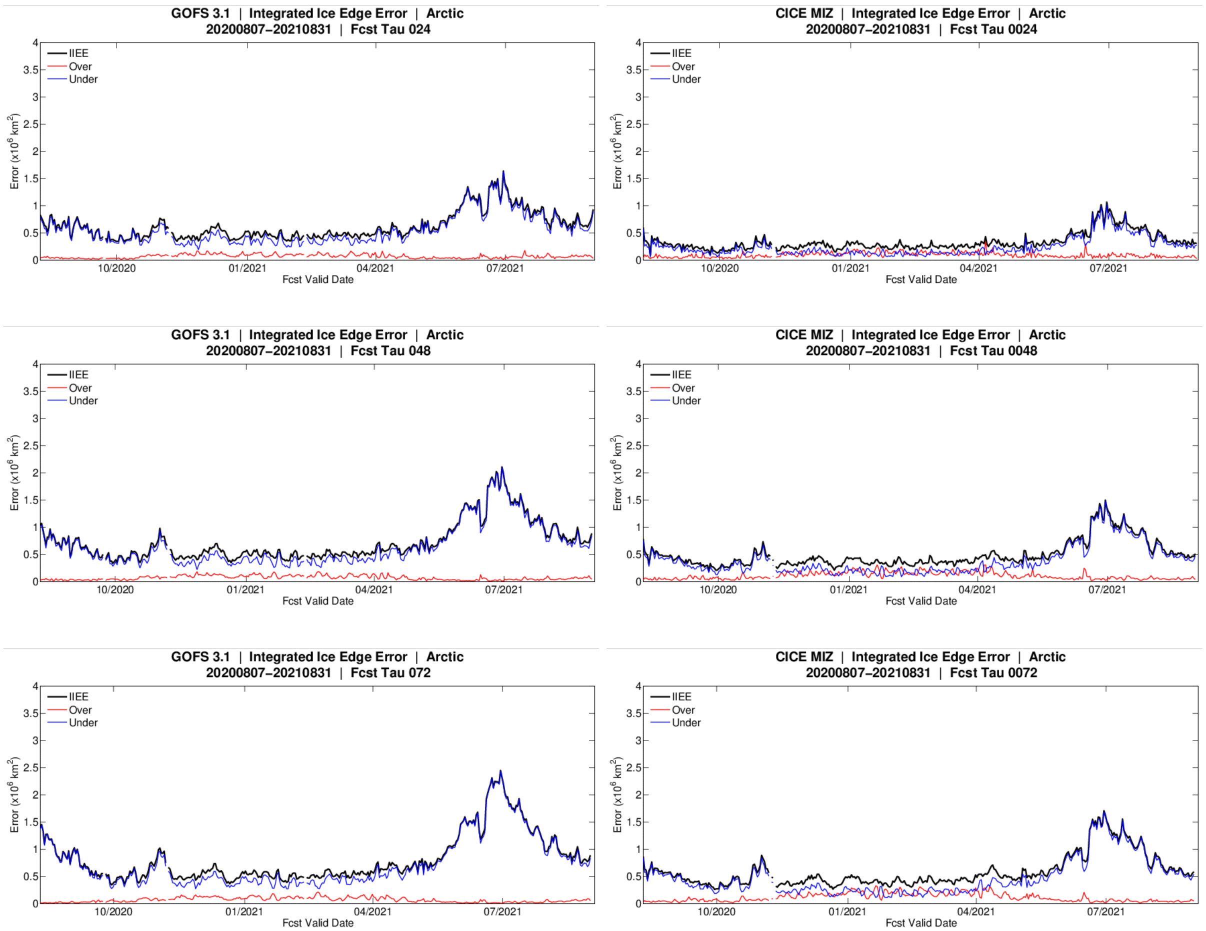

Figure 10: Integrated Ice Edge Error using self-analysis in the Arctic for GOFS 3.1 (left column) and CICE assimilating MIZ (right column). Top row is forecast tau 24, middle row is forecast tau 48, bottom row is forecast tau 72. In each plot the black line is the total IIEE, the blue line is area overestimate, and the blue line is the area underestimate.

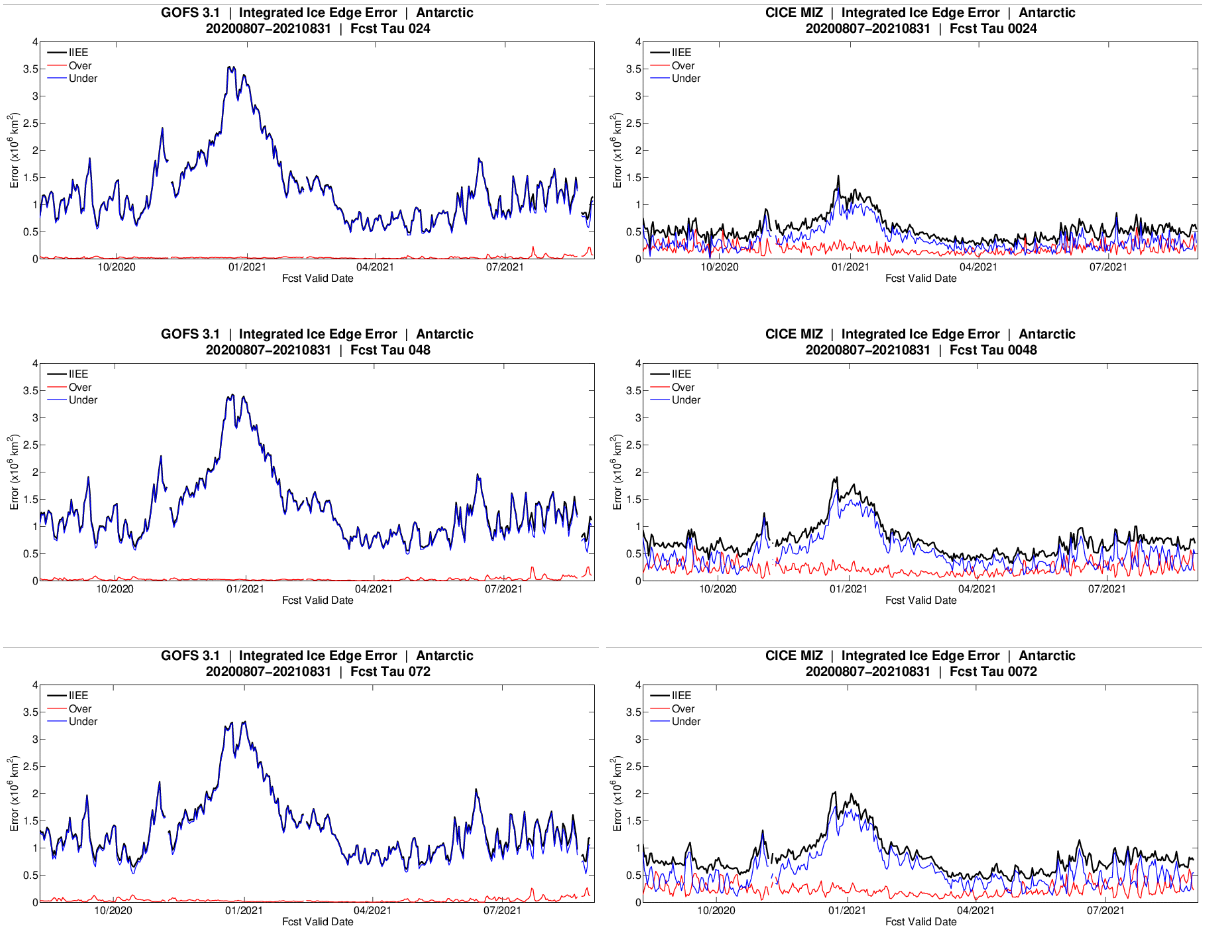

Figure 11: Integrated Ice Edge Error using self-analysis in the Antarctic for GOFS 3.1 (left column) and CICE assimilating MIZ (right column). Top row is forecast tau 24, middle row is forecast tau 48, bottom row is forecast tau 72. In each plot the black line is the total IIEE, the blue line is area overestimate, and the blue line is the area underestimate.