Improving Arctic sea ice edge forecasts by assimilating high resolution VIIRS sea ice concentration data into the U.S. Navy's ice forecast systems

O.M. Smedstad[1] P.G. Posey[2], D. A. Hebert[2], W. Johnston[3], L. Li[2], J. May[2] and M. W. Phelps[4]
[1]Vencore Services and Solutions, Inc., [2]Naval Research Laboratory, [3]Computational Physics, Inc., [4]Jacobs Technology Inc.

Abstract

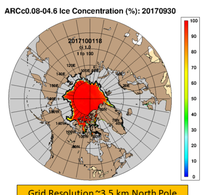
This study presents the improvement in ice edge error within the U.S. Navy's sea ice forecast systems gained by assimilating the high horizontal resolution visible/infrared satellite-derived VIIRS ice concentration products. A series of hindcast studies are performed for the period of 1 November 2016 - 31 October 2017 using the Global Ocean Forecast System (GOFS 3.1), a 1/12° HYbrid Coordinate Ocean Model (HYCOM) that is two-way coupled to the Community Ice CodE (CICE) in a daily update cycle with the Navy Coupled Ocean Data Assimilation (NCODA). Comparisons using the VIIRS ice concentration products (< 1km resolution) show lower ice edge location errors than the current system, which assimilates near real-time passive microwave data from the Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave/Imager (SSMIS) and the Advanced Microwave Scanning Radiometer (AMSR2) ice concentration products (25 and 12.5 km resolution respectively). The daily ice edge locations from the model simulations are compared against independent observed ice edge locations. Results from the Arctic and Antarctic regional areas will be presented. A previous study using the Arctic Cap Nowcast/Forecast System (ACNFS), a 1/12° coupled HYCOM/CICE/NCODA for the Northern Hemisphere only, has shown that by assimilating the VIIRS (along with SSMIS and AMSR2) ice concentration products reduced the ice edge location errors by 25% in the pan-Arctic region for a year-long time period from 1 January – 31 December 2016.

The U.S. Navy's Sea Ice Forecasting Systems

Arctic Cap Nowcast/Forecast System (ACNFS)

www7320.nrlssc.navy.mil/hycomARC

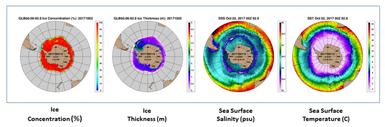
- ACNFS consists of 3 components:
  - **Ice Model:** Community Ice CodE (CICE)
  - **Ocean Model:** HYbrid Coordinate Ocean Model (HYCOM)
  - **Data assimilation:** Navy Coupled Ocean Data Assimilation (NCODA)
- Declared operational Sept 2013
- Runs daily at the Naval Oceanographic Office (NAVO)
- ACNFS produces nowcast/7-day forecasts of ice concentration, ice thickness, ice drift, lead opening rate (FLAPs), sst, sss and ocean currents for the Northern Hemisphere
- Products pushed daily to the U.S. National Ice Center (NIC) and NOAA



Grid Resolution ~3.5 km North Pole
Dark line is the independent ice edge location from NIC

Global Ocean Forecast System (GOFS 3.1)

- 1/12°global two-way coupled HYCOM-CICE modeling system with data assimilation
  - Uses HYCOM/CICE/NCODA like ACNFS but with improved HYCOM and NCODA
  - Currently undergoing operational testing by NAVO/NIC (**NIC completed the ice EVAL – June 30, 2017** and waiting for ocean EVAL from NAVO)
  - **GOFS 3.1 replaced ACNFS on 1 Oct 2017.**
  - Added capability of forecasting ice conditions in the southern hemisphere



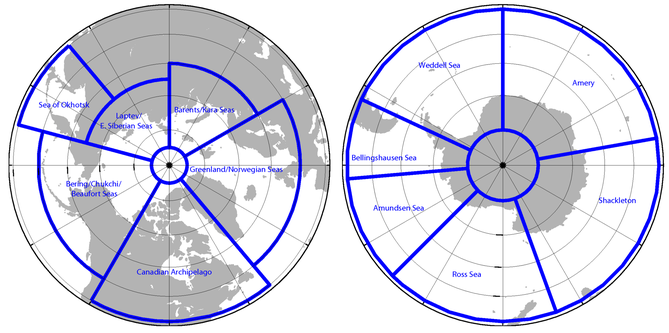
Daily GOFS 3.1 products:
www7320.nrlssc.navy.mil/GLBhycomcice1-12

ACNFS Hindcast Study

In operational mode, ACNFS assimilated satellite derived ice concentration products from SSMIS and AMSR2. More recently, high resolution visible/infrared VIIRS ice concentration (< 1 km resolution) has become available in real time.

A year-long ACNFS hindcast study from 1 January - 31 December 2016 was run to quantify the improvement of the ice edge location by assimilating VIIRS ice concentration products. Ice edge error distance (km) between the National Ice Center's (NIC) observed ice edge and ACNFS forecasts were calculated for several regional seas.

Analysis regions used for the NIC ice edge comparison are shown below. For the ACNFS comparison only the Northern Hemisphere areas were used. For the GOFS 3.1 comparison (shown in the next column) both the Northern and Southern Hemispheres were used.



The table below shows the regional mean distance differences (km) between the NIC ice edge and 6 hour ACNFS forecast for the time period of 1 January – 31 December 2016. The highlighted green columns denote the smallest mean distance error.

U.S. NAVAL RESEARCH LABORATORY ACNFS ice edge error statistics

Mean ice edge errors (km) between the observed ice edge and 6 hr ACNFS forecast for the time period of Jan – Dec 2016

Region	Op ACNFS SSMI/AMSR2 IMS post-processed	ACNFS SSMI/AMSR2/VIIRS* IMS inside NCODA	Total improvement over operational ACNFS
Pan-Arctic	45.8	33.4	27%
Greenland	43.8	34.6	21%
Barents	37.7	25.3	33%
Laptev	64.8	51.6	25%
Sea of O	40.1	35.8	11%
Bering/Beaufort	43.0	35.6	17%
Can Arch	57.6	33.3	42%
Average overall improvement over operational ACNFS			25%

Improvement of 25% over current operational capability adding in VIIRS data.

GOFS 3.1 Hindcast Study

Like ACNFS, GOFS 3.1, in pre-operational mode, also assimilates satellite derived ice concentration products from SSMIS and AMSR2.

A year-long GOFS 3.1 hindcast study is currently underway from 1 November 2016 – 31 October 2017 to quantify the improvement of the ice edge location by assimilating VIIRS ice concentration products. Ice edge error distance (km) between the NIC's observed ice edge and GOFS 3.1 forecasts were calculated for several regional seas. Analysis regions used for the NIC ice edge comparison are shown in the middle column.

The tables below shows the regional mean distance differences (km) between the NIC ice edge and the 12 hour GOFS 3.1 forecast for time period of 1 November 2016 – 31 May 2017 for the Arctic and Antarctic regions.

U.S. NAVAL RESEARCH LABORATORY GOFS 3.1 Arctic ice edge error statistics

Mean ice edge errors (km) between the observed ice edge and 12 hr GOFS 3.1 forecast for the time period of Nov 2016 – May 2017

Region	GOFS 3.1 SSMI/AMSR2 IMS post-processed	GOFS 3.1 SSMI/AMSR2/VIIRS* IMS inside NCODA	Total improvement over pre-operational GOFS 3.1
Greenland	32.6	20.9	36%
Barents	23.5	22.4	5%
Laptev	36.3	33.6	8%
Sea of O	19.8	18.1	9%
Bering/Beaufort	22.2	20.9	6%
Can Arch	33.3	25.2	24%
Average overall improvement over pre-operational GOFS 3.1			22%

Improvement of 22% over current pre-operational capability adding in VIIRS data.

U.S. NAVAL RESEARCH LABORATORY GOFS 3.1 Antarctic ice edge error statistics

Mean ice edge errors (km) between the observed ice edge and 12 hr GOFS 3.1 forecast for the time period of Nov 2016 – May 2017

Region	GOFS 3.1 SSMI/AMSR2 IMS post-processed	GOFS 3.1 SSMI/AMSR2/VIIRS* IMS inside NCODA	T11.3otal improvement over9.3 pre-operational 15.9GOFS 3.1
Amery	39.5	31.5	20%
Shackleton	28.3	26.6	6%
Ross Sea	44.7	39.6	11%
Amundsen	41.4	37.6	9%
Bellingshausen	26.0	21.9	16%
Weddell	57.8	48.8	16%
Average overall improvement over pre-operational GOFS 3.1			20%

Improvement of 20% over current pre-operational capability adding in VIIRS data.

Conclusion: This study demonstrates the improvement in the ice edge location for both the Arctic and Antarctic regional seas by assimilating the high resolution VIIRS ice concentration products. This new data source is scheduled to be implemented into the pre-operational GOFS 3.1 job stream by early January 2018.