Coupled Forecasting With Navy Models

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Outline

- GOFS 3.1
- GOFS 3.5
- Ongoing research with VIIRS sea ice concentration
- Navy Earth System Prediction Capability (Navy ESPC)
- CryoSat-2 Study
- Examples of Navy models used in support of polar operations
- Summary

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Global Ocean Forecast System (GOFS 3.1)

- Global Ocean Forecast System (GOFS) 3.1 was declared operational on 7 November 2018
- Navy's global ocean prediction system to provide first look information "anywhere, anytime"
- Provides boundary conditions to regional (ice and ocean) models
- 1/12° HYCOM two-way coupled to Community Ice CodE (CICEv4)
- Uses the Navy Coupled Ocean Data Assimilation (NCODA) to assimilate available real-time observations: satellite altimeter, SST and sea ice concentration data, in-situ SST, profile data (Argo profiles, XBTs, CTDs, gliders, marine mammals)
- Atmospheric forcing from NAVy Global Environmental Model (NAVGEM)
- Runs daily at Navy DSRC under FNMOC control: 7-day forecasts

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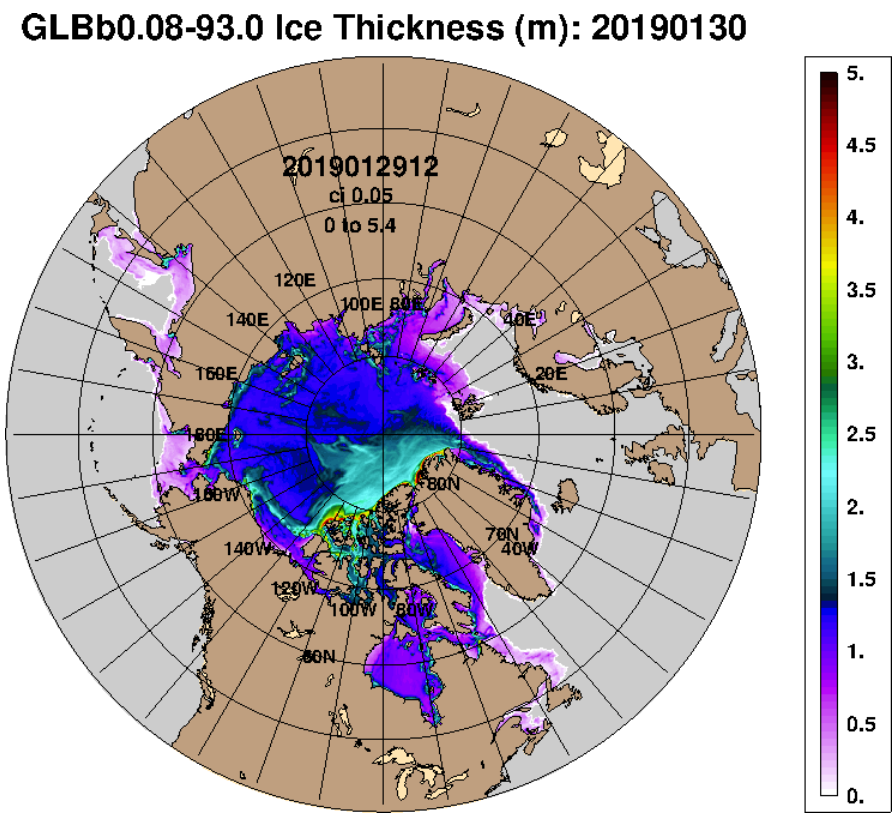
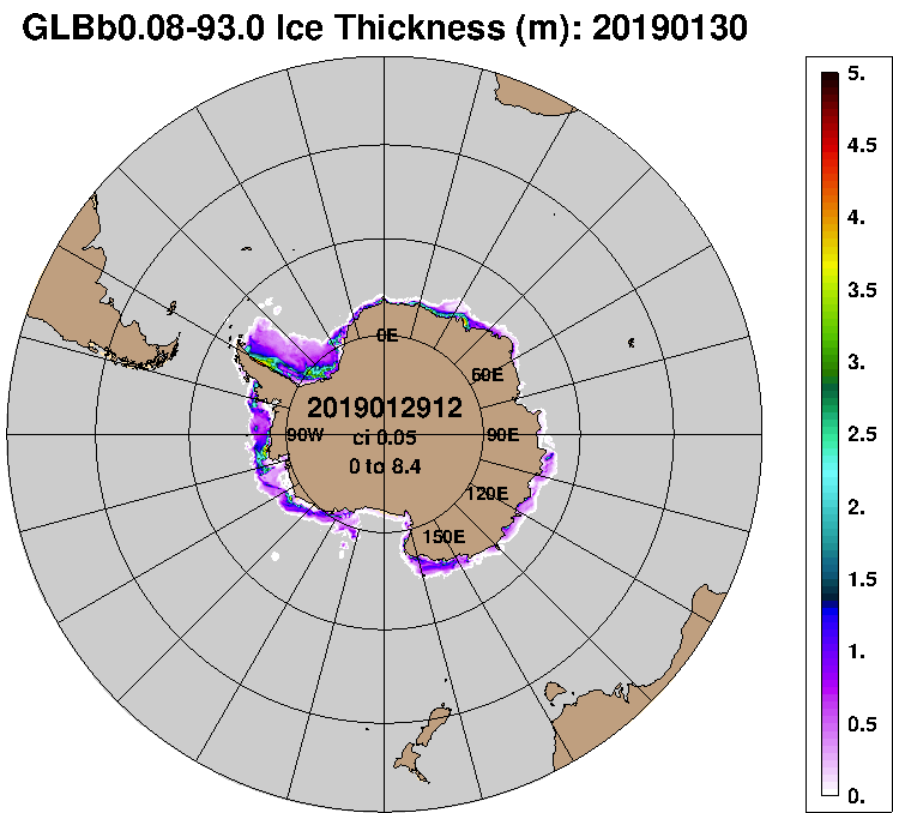
Global Ocean Forecast System (GOFS 3.1)

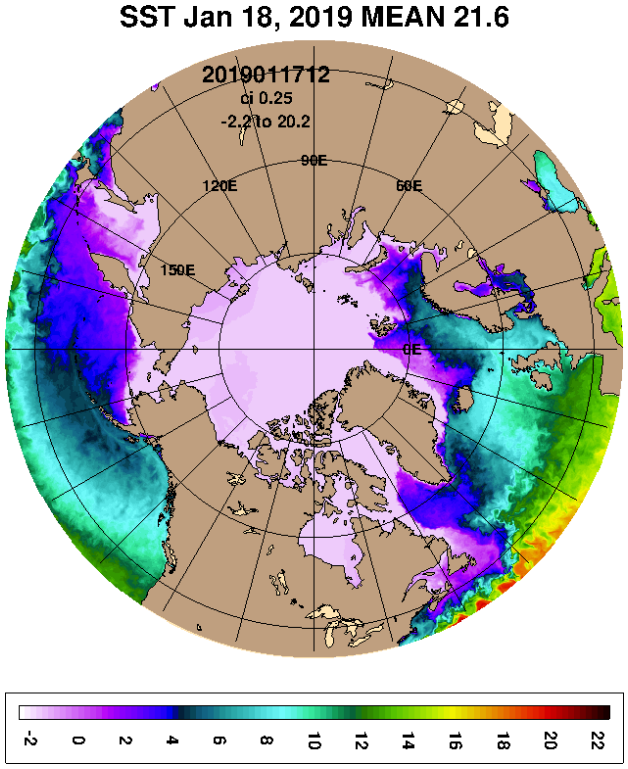




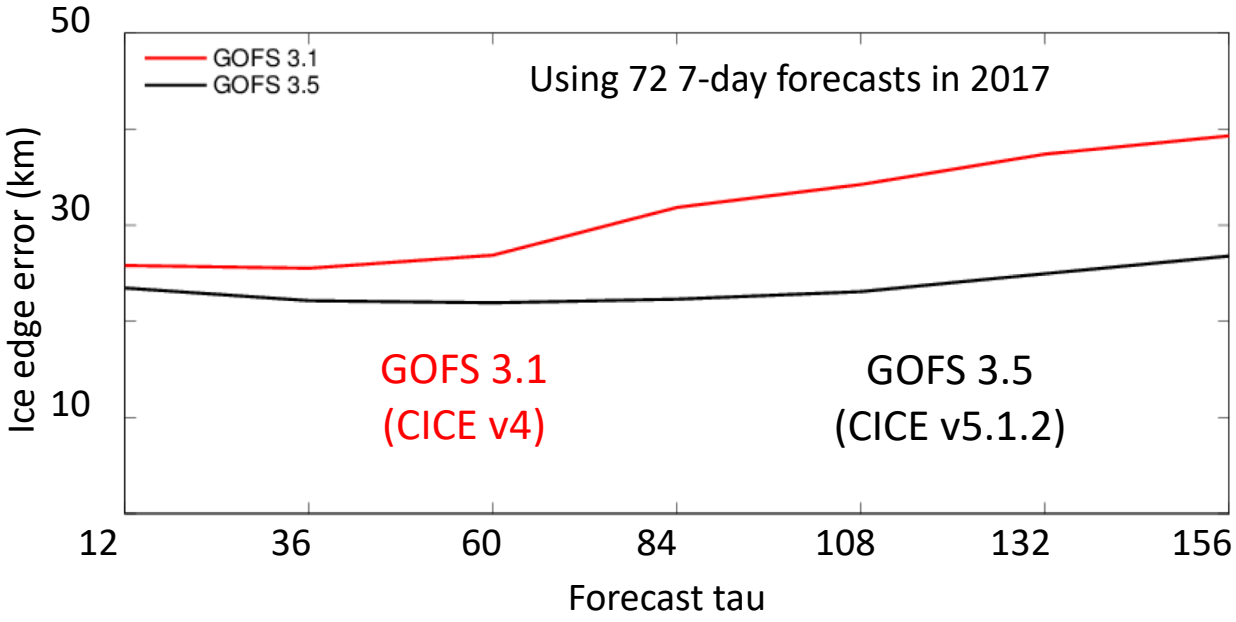
https://www7320.nrlssc.navy.mil/GLBhycomcice1-12/skill.html

Global Ocean Forecast System (GOFS 3.5)

- Global Ocean Forecast System (GOFS) 3.5 is scheduled for transition later this year.
- Resolution increase from 1/12° to 1/25° (1.75 km at North Pole)
- Inclusion of tides in HYCOM → internal waves at tidal frequencies
- Coupled HYCOM – CICE (v5.1.2)

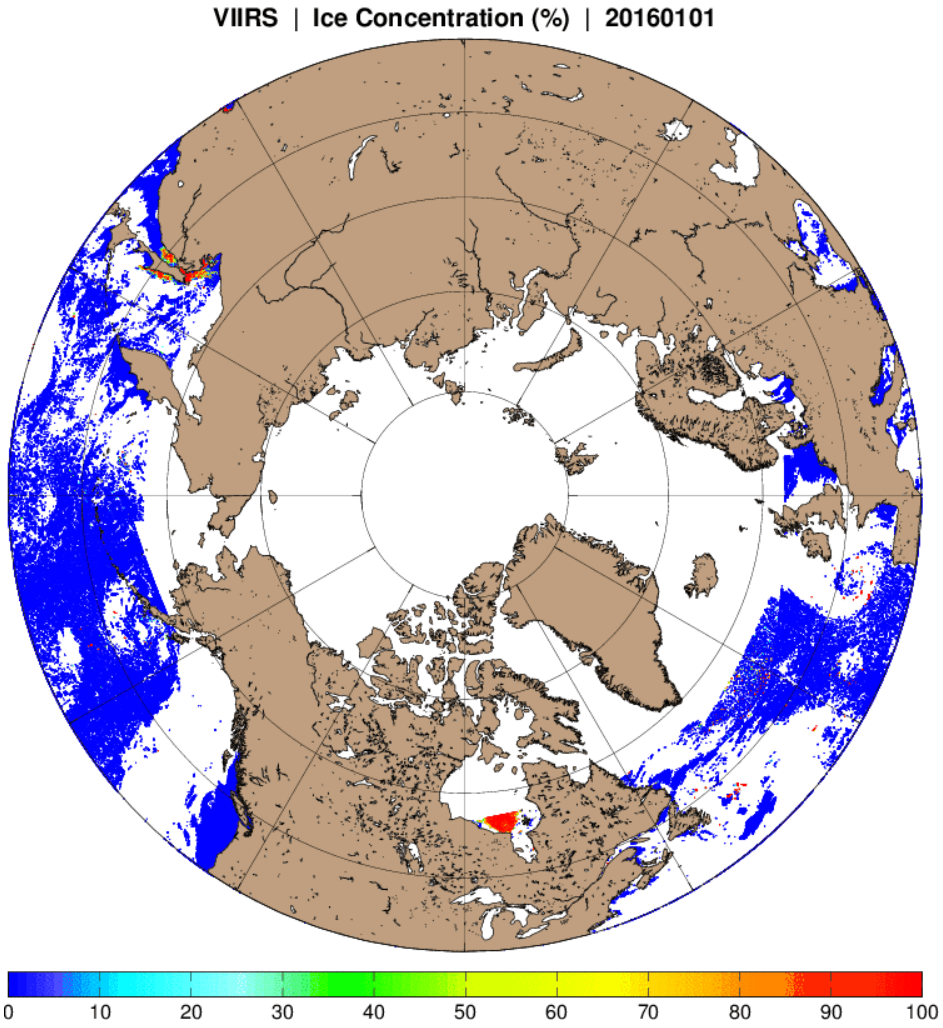


Sea ice edge error (km) as a function of forecast length vs. the independent NIC ice edge: Pan-Arctic domain



Visible Infrared Imaging Radiometer Suite (VIIRS)

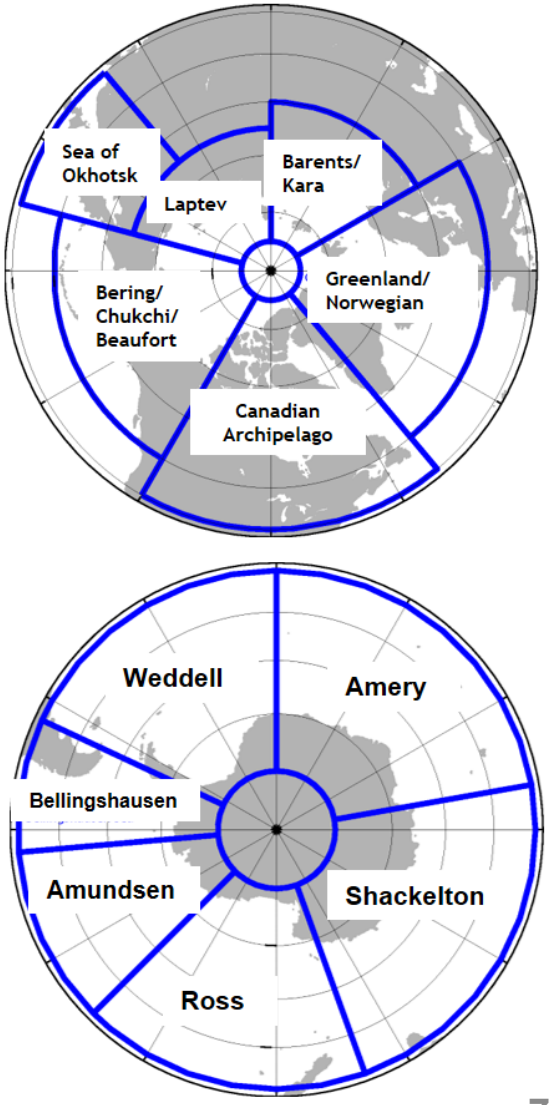
- High resolution (375-750m) vs AMSR2 (10km), SSMI (25km)
- Does not see through clouds
- Ice concentration data available during visible light periods (spring, summer, autumn)
- Does not misclassify melt ponds as open water (passive microwave issue, most problematic in melt season in spring/summer)
- VIIRS provides observations during melt seasons to help overcome this passive microwave issue
- NOAA-20 VIIRS also available as of FEB 2018. This test was performed on data we had before NOAA-20 VIIRS
- NRL algorithm currently provides VIIRS on 4km grid. Working on native resolution (375m)



VIIRS NCODA Updates, Ice Edge Error Regional Analysis

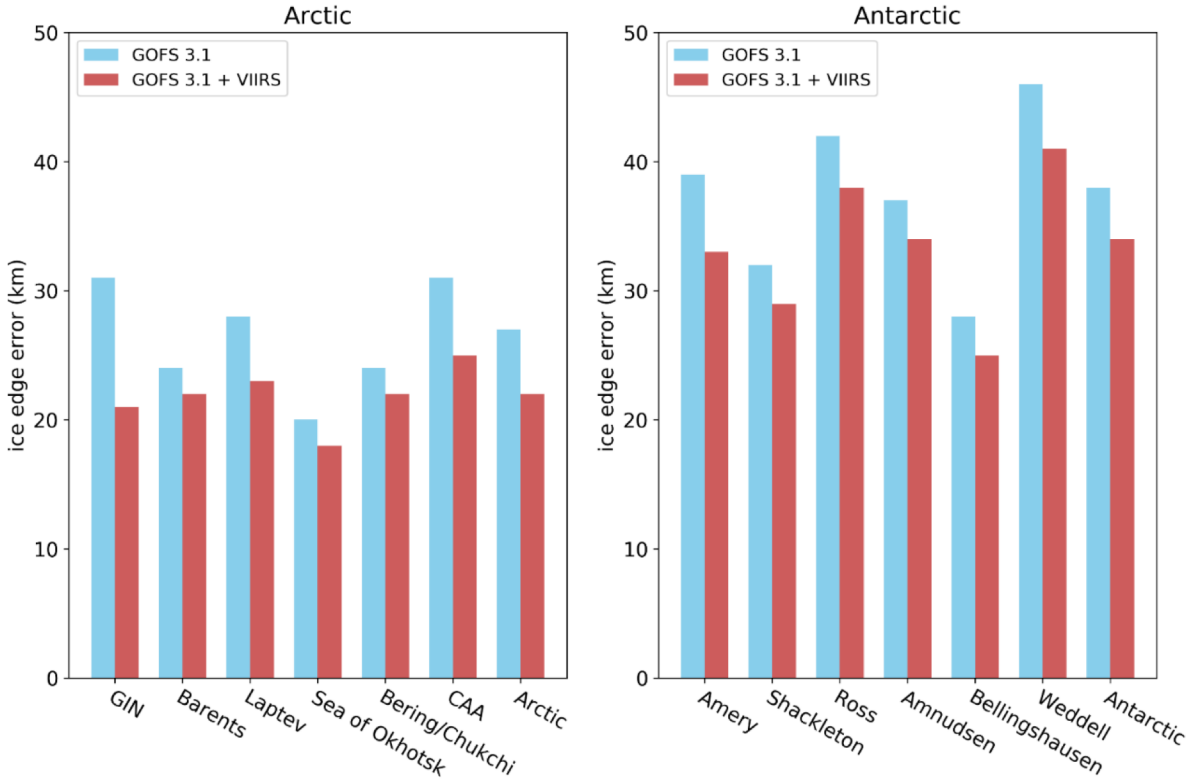
- Updated NCODA to ingest VIIRS ice concentration products
- Updated NCODA to use the USNIC Interactive Multi-Sensor Snow and Ice Mapping System (IMS) product as a quality control flag
  - Previously used as 'post-process' after NCODA.
  - Bringing IMS inside NCODA allows us to not apply IMS to VIIRS (Next slide)
- Ran GOFS 3.1 for one year (Nov 2016 – Oct 2017) assimilating NPP-VIIRS ice concentration products
- Performed ice edge analysis validation for both the Northern and Southern Hemispheres
- Ice edge analysis = distance from model ice edge to nearest USNIC Ice edge location (next slide)

Ice validation analysis regions (Top: Arctic, Bottom: Antarctic)



Ice Edge Error Results

- Ice edge errors in each region averaged over entire year
- Blue: Operational GOFS 3.1
- Red: GOFS 3.1 + VIIRS
- Addition of VIIRS reduced ice edge error in all regions
  - Arctic: Error reduction 8-32% (Average 19%)
  - Antarctic: Error reduction 8-15% (Average 11%)



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Growing Importance of Seasonal Ice Prediction

- Increasing interest by operational U.S. Navy to provide seasonal forecasts of ice conditions in polar regions to support navigation.
- Pre-operational Navy ESPC has been providing 45-day ice forecasts (e.g., ice thickness, ice concentration, ice drift) to the U.S. National Ice Center since November 2017 to support:
  - ICEX 2018 (and ICEX 2020)
  - McMurdo Resupply 2018/2019
- New techniques and additional satellite-derived ice freeboard data present opportunities for improving predictive skill with coupled modeling.

McMurdo Resupply

ICEX 2018

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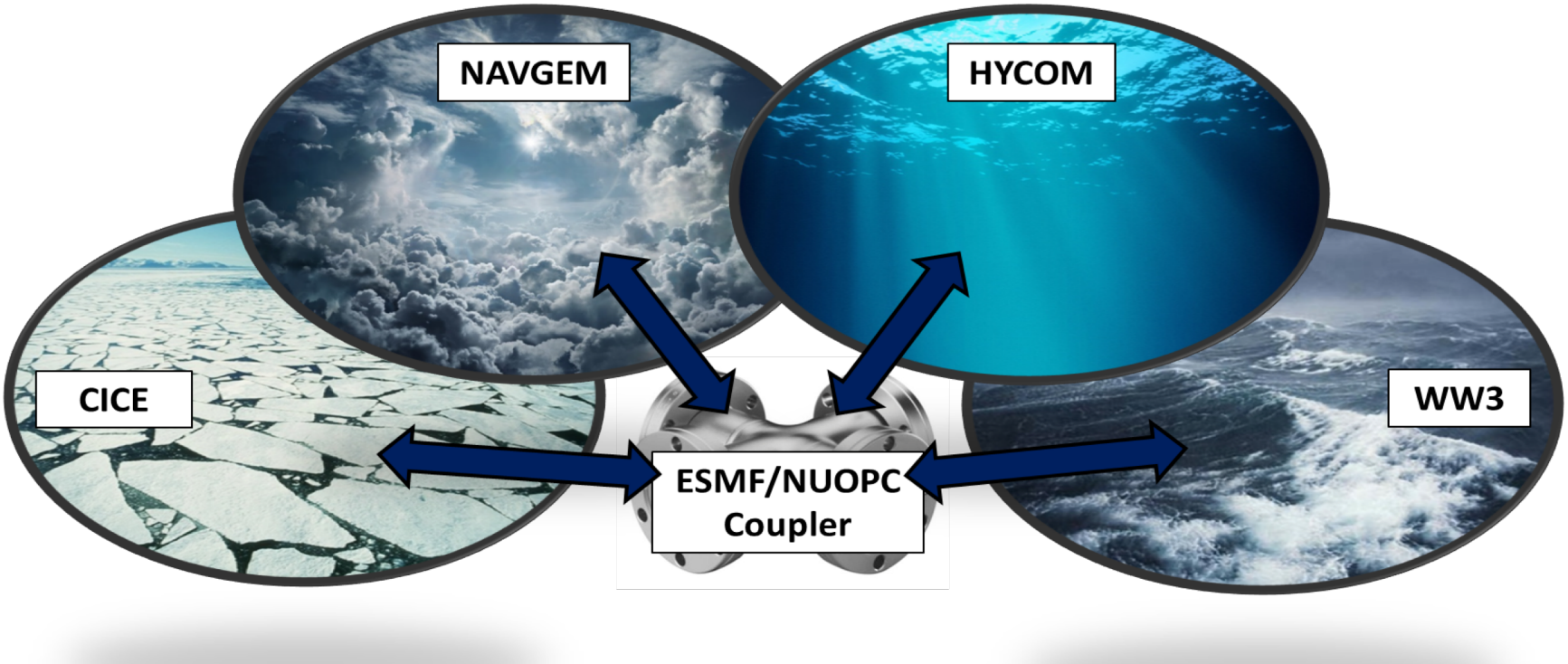
Toward Next-Gen Earth System Prediction

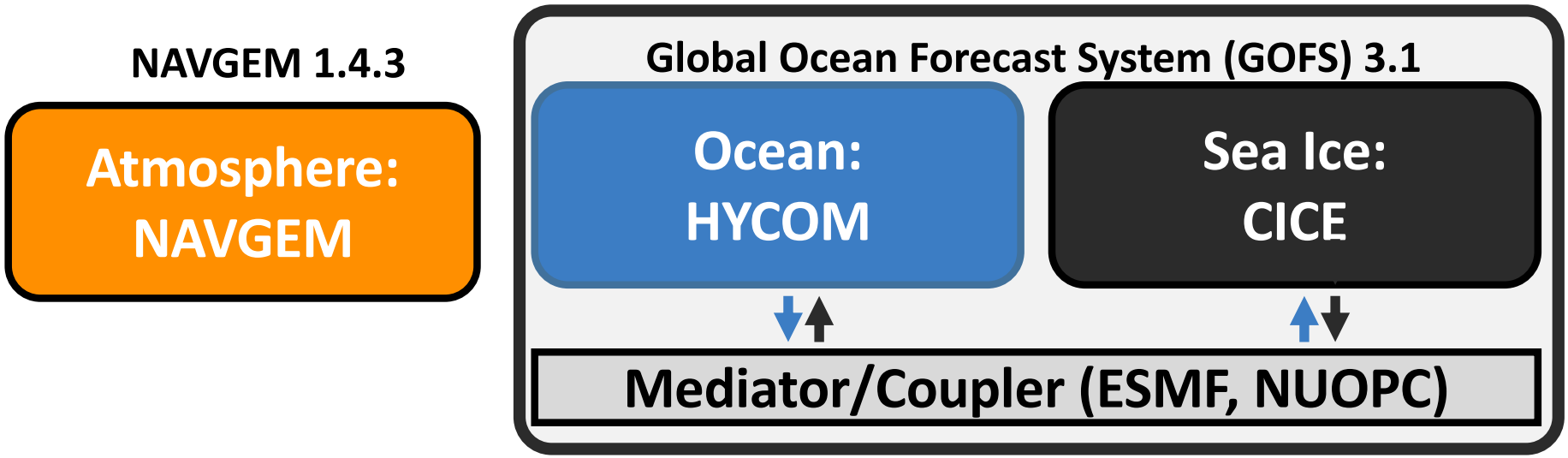


- Developed to meet Navy needs for global earth system forecasts on timescales from days to months: Initial Operational Capability (IOC) FY20
- Navy ESPC team: NRL Monterey CA, NRL Stennis MS, NRL DC, NOAA ESMF
- Earth System Modeling Framework (ESMF) used to facilitate upgrades

Toward Next-Gen Earth System Prediction ESPC

Current Operational Global Atmosphere Model

Current Operational Global Ocean/Sea Ice Models

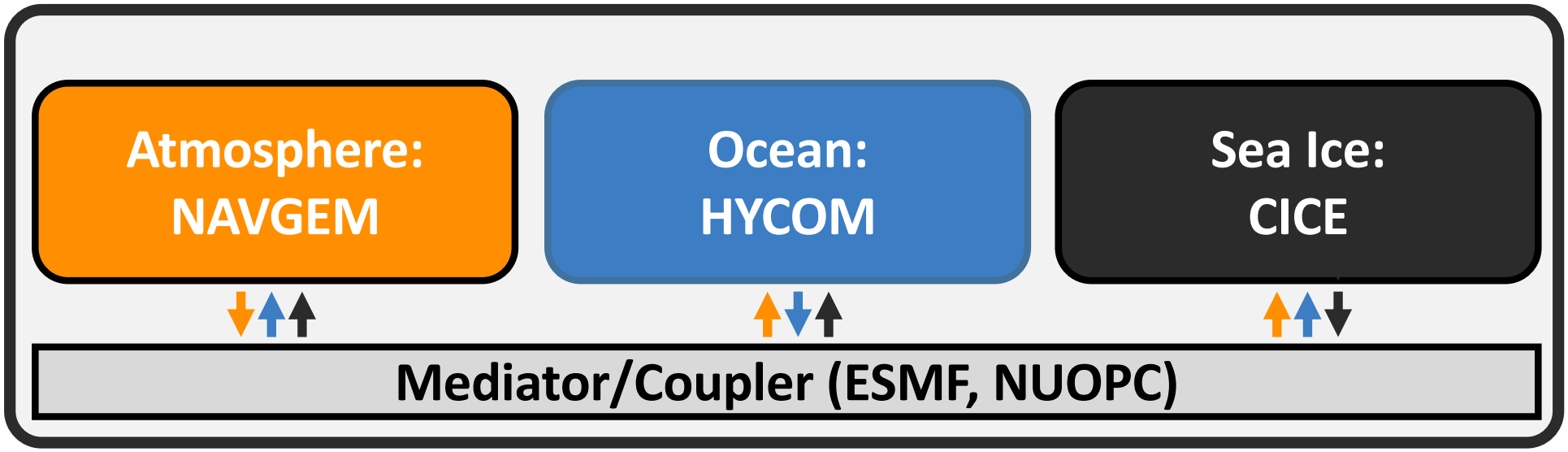


NAVGEM = NAVy Global Environmental Model
HYCOM = HYbrid Coordinate Ocean Model
CICE = Community Ice CodE

Toward Next-Gen Earth System Prediction ESPC

The Navy's Global Coupled System Based on Current Operational Systems

Navy ESPC



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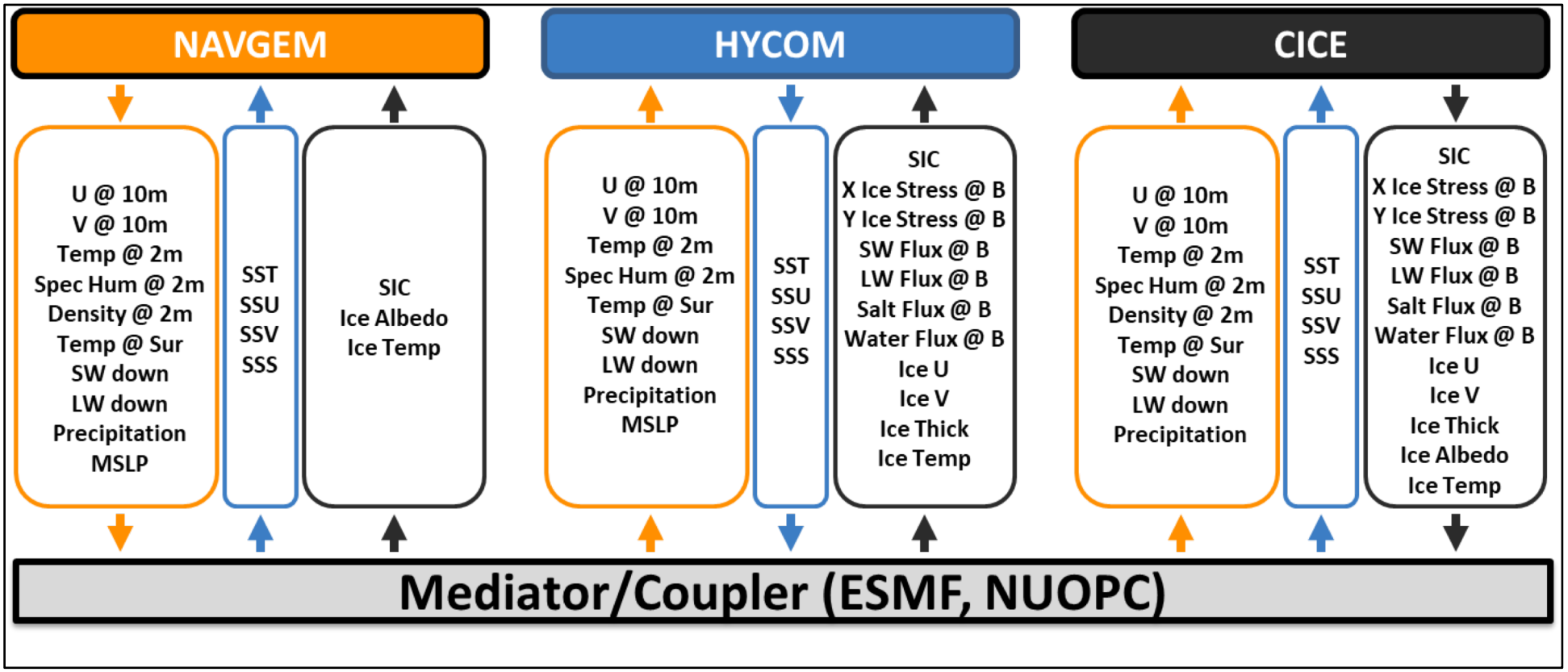
ESPC Overview



Model fields exchanged hourly

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Navy ESPC Initial Operational Capability (IOC) Transition to Operations Plans

Forecast	Time Range, Frequency	Atmosphere NAVGEM	Ocean HYCOM	Ice CICE4	Waves WW3 FY22
Deterministic short term	0-16 days, Daily	T681L80 (19 km) 60 levels	1/25° (4.5 km) 41 layers	1/25° (4.5 km)	1/8° (14 km)
Probabilistic long term	0-45 days Weekly 15 members	T359L60 (37 km) 60 levels	1/12° (9 km) 41 layers	1/12° (9 km)	1/4° (28 km)

- **IOC Probabilistic Forecasts scheduled to be operational in May 2020**
- **GOFS 3.5 (with CICE 5.1.2) to be transitioned afterwards**
- **IOC deterministic forecasts to be transitioned after GOFS 3.5**
- **Final Operational Capability: FY22**
  - **Seasonal (90-day ?) ensemble forecasts**
  - **Coupled data assimilation**
  - **Interactive ocean surface waves**

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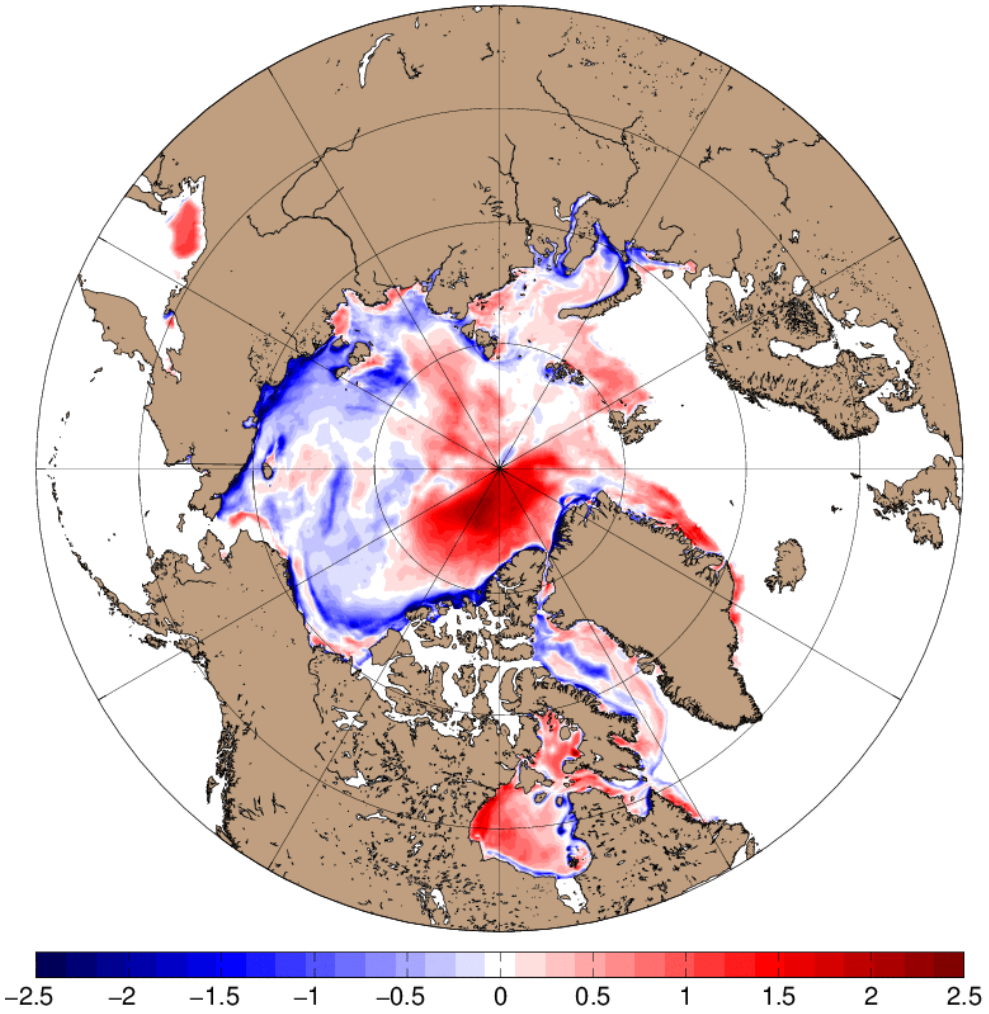
Seasonal ESPC Studies With CryoSat-2

Twin time-lagged ensemble forecasts performed for the period of 1-10 May, 2018 – 30 September, 2018

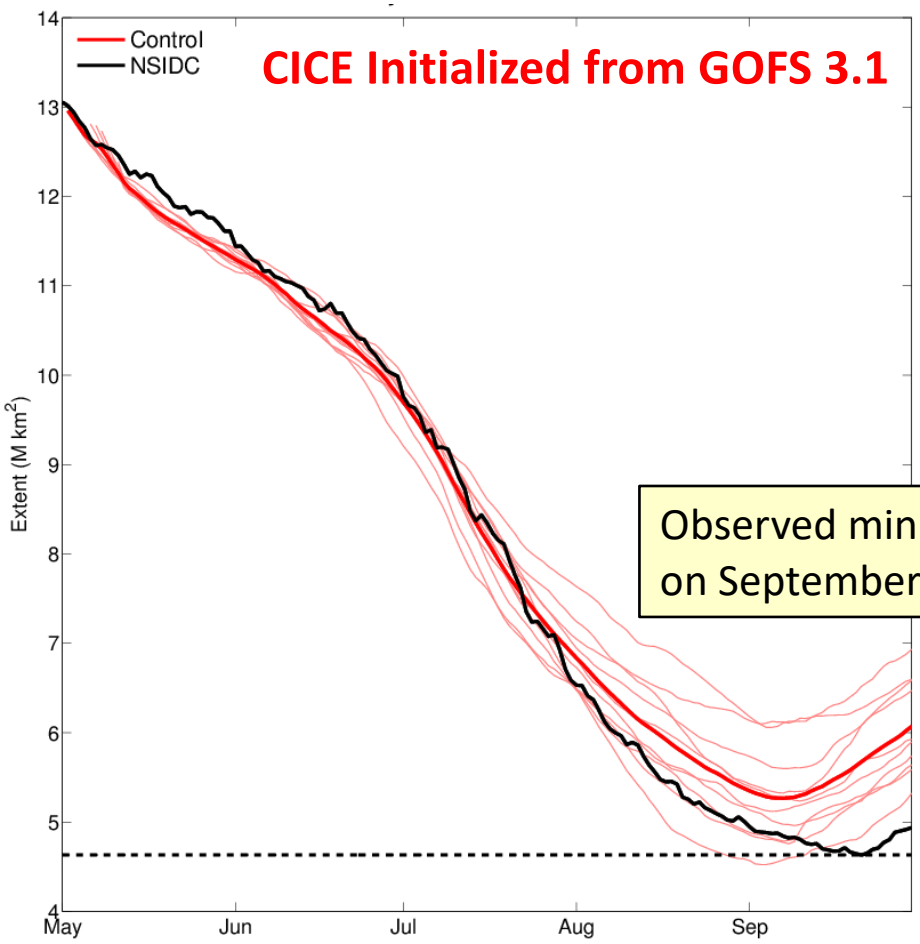
- Reference ensemble forecasts conducted as part of Sea Ice Prediction Network (SIPN2) where CICE model initialized with ice concentration from SSMIS and AMSR2. GOFS 3.1 ice and ocean, and NAVGEM atmosphere initialization fields used for the period of 1-10 May, 2018.
- Second set of ensemble forecasts performed in same manner but using CryoSat-2 ice thickness fields for May 1-10, 2018.

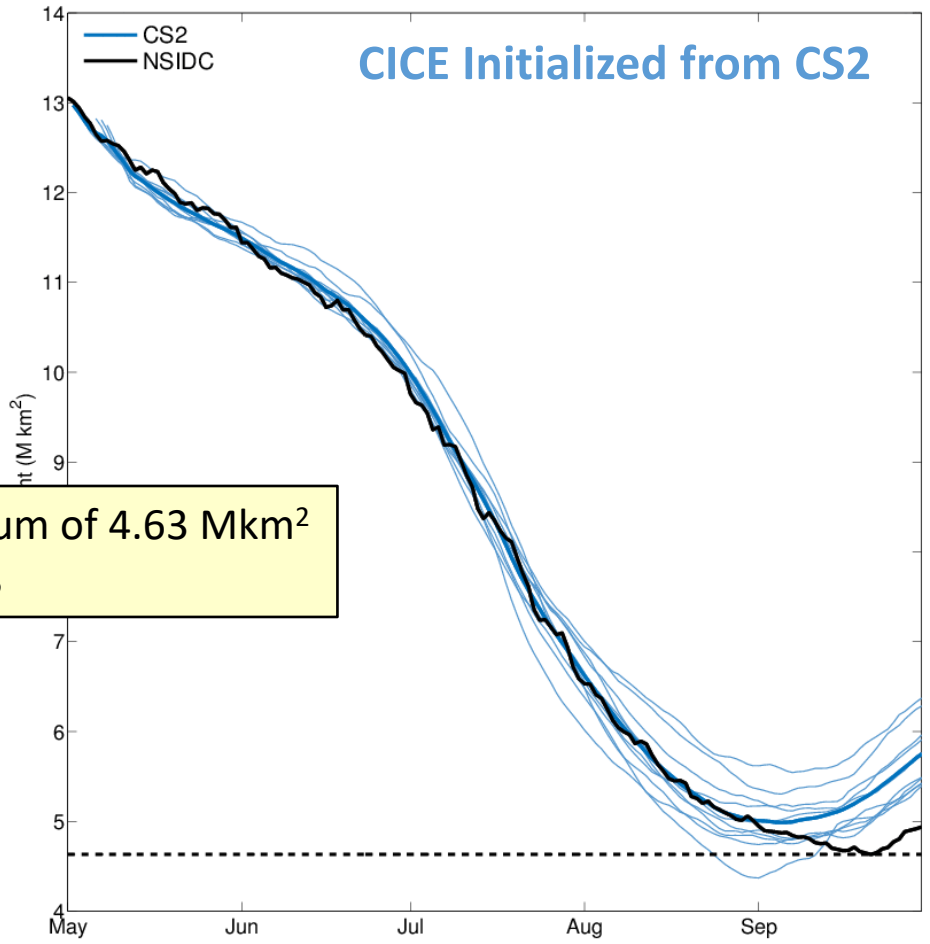
Ice Thickness Difference (m) for May 1, 2018



- Blue regions indicate CS2 initialization results in thinner ice than GOFS 3.1-based initialization.
- Red regions indicate thicker ice with CS2 initialization.

Ice Thickness Difference (m) for May 1, 2018

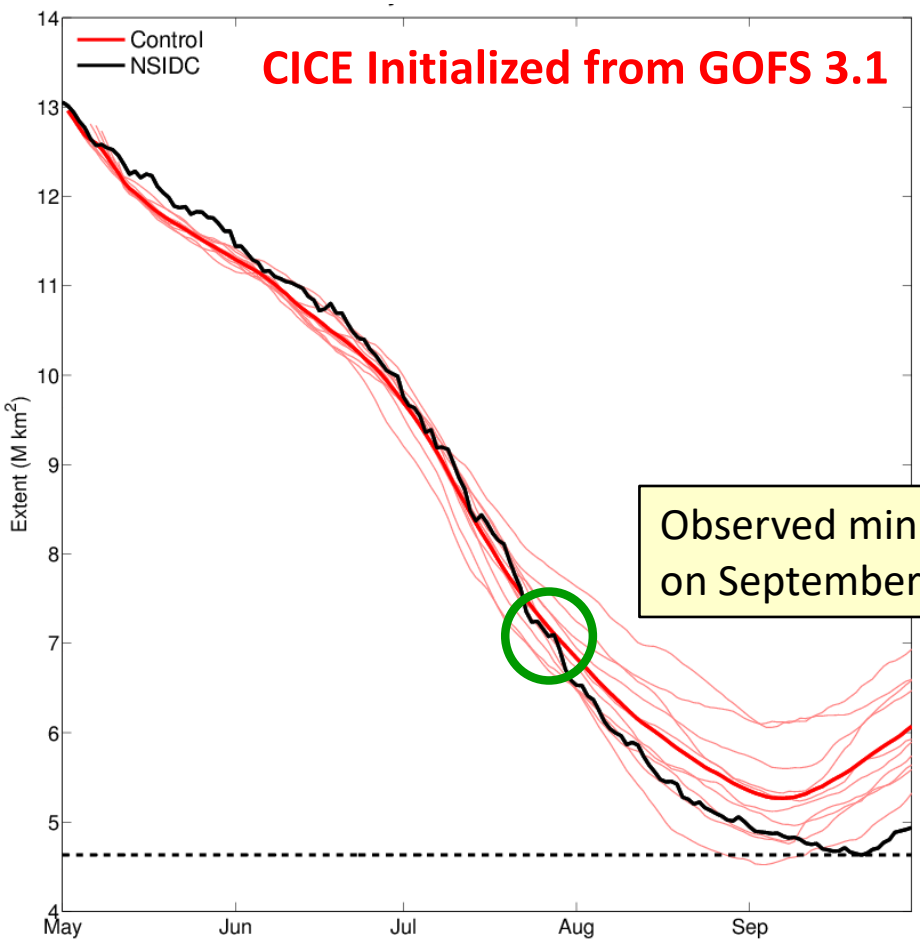


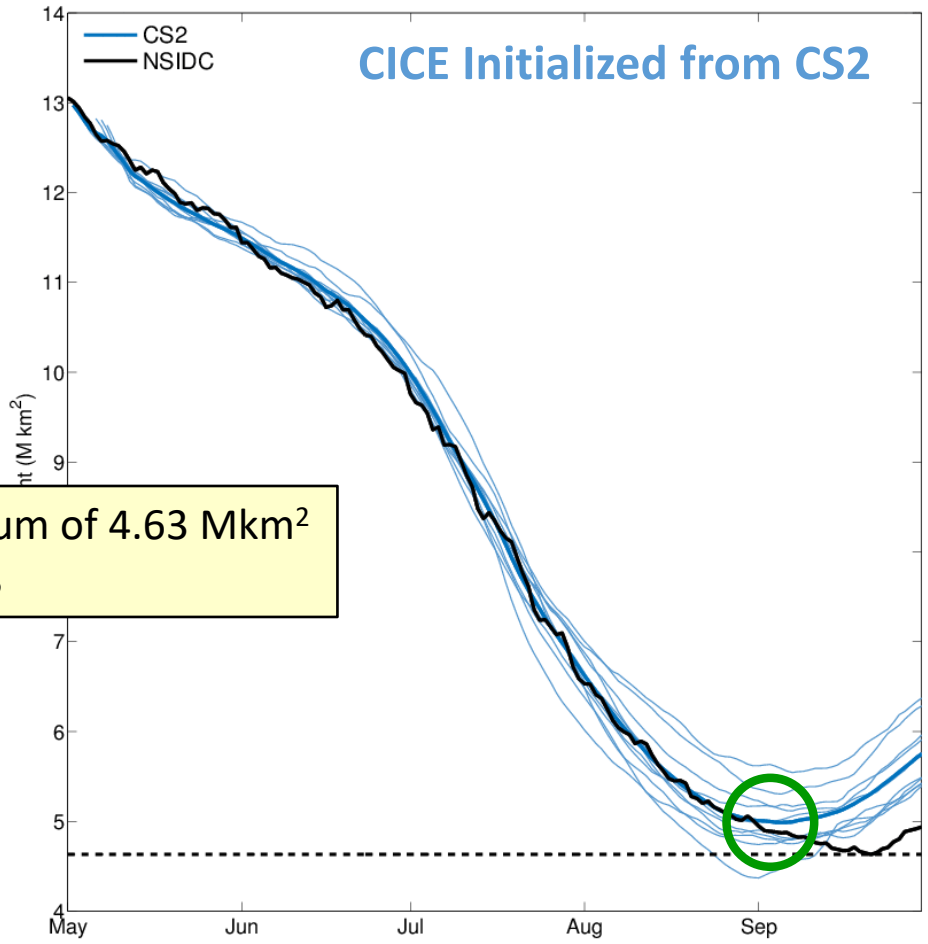


Observed minimum of 4.63 Mkm² on September 23

Navy ESPC ensemble mean September 2018 minimum sea ice extent initialized with GOFS 3.1 ice thickness was over-predicted by 0.64 M km² (5.27 M km²) versus the ensemble set of runs initialized with CS2 ice thickness which had an error of 0.36 M km² (4.99 M km²), a 43% reduction in error.

Ice Thickness Difference (m) for May 1, 2018





Observed minimum of 4.63 Mkm^2 on September 23

In control forecasts, ensemble mean separates from NSIDC extent on July 29; in CS2 forecasts, separation occurs on Aug 31, an improvement of 33 days.

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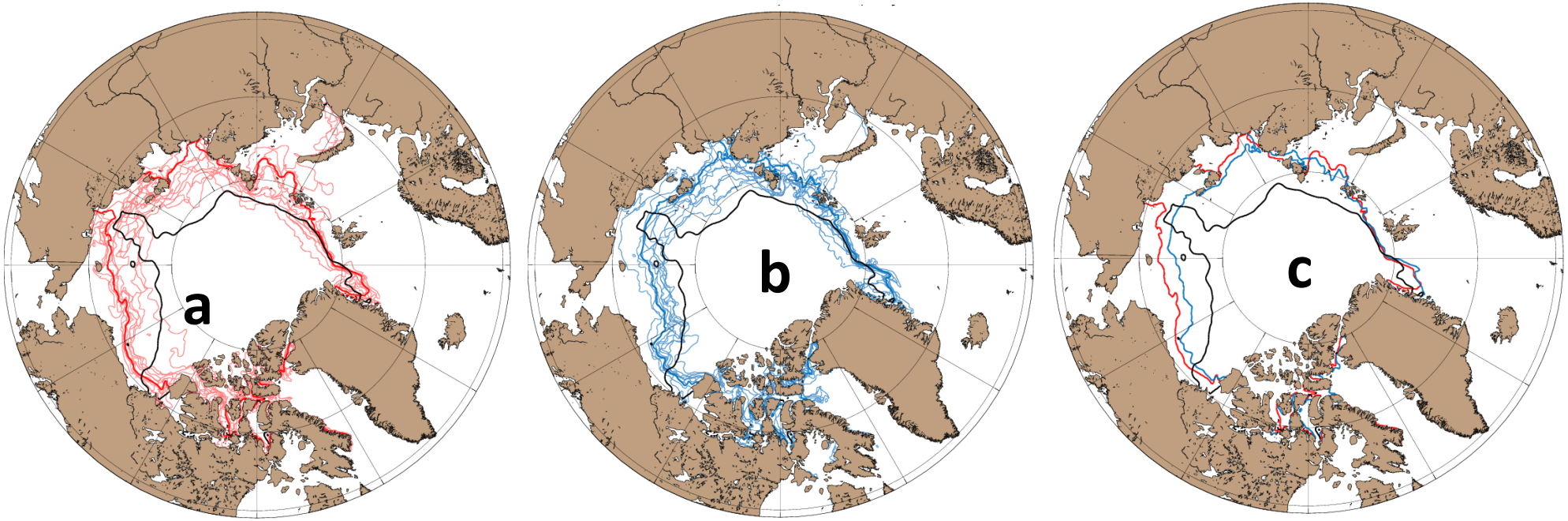
September, 2018 Sea Ice Extent



(a) September mean sea ice extent prediction for 10 ensemble members from control run; **dark red line** denotes ensemble mean. (b) Same as (a) but based on CS2 initialization; **dark blue line** represents ensemble mean. (c) Ensemble mean for control (red) and CS2 (blue). **Black lines** denote NSIDC observed mean September extent.

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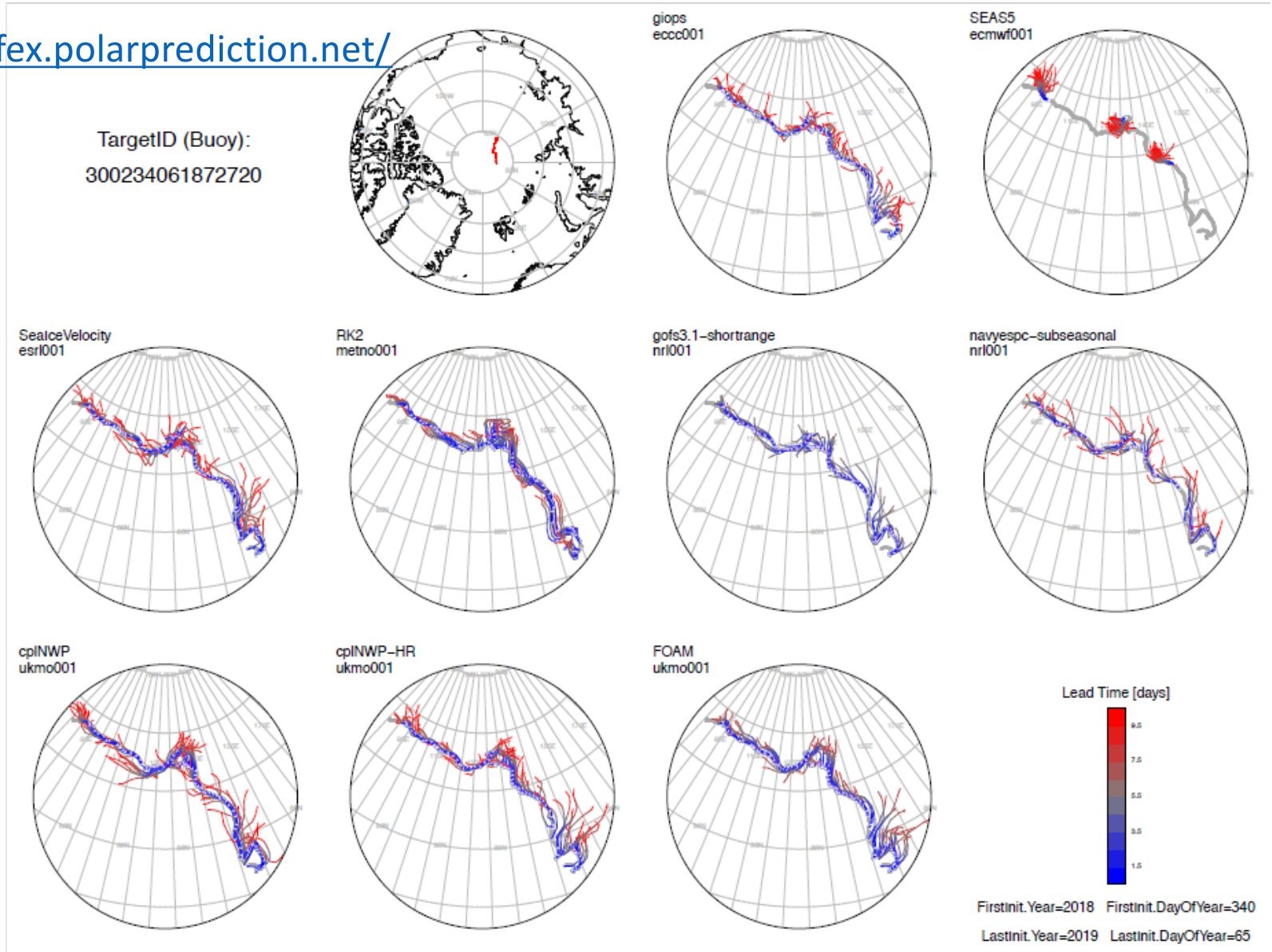
Sea Ice Support to the Sea Ice Drift Forecast Experiment (SIDFEx)

- SIDFEx is a community effort to collect and analyze Arctic sea ice drift forecasts at lead times from days to a year, based on various methods, for a number of sea ice buoys and, ultimately, the trans-Arctic MOSAiC drift campaign, on a regular basis.
- NRL participates in SIDFEx by automatically providing sea ice drift fields from Navy ESPC and GOFS 3.1 to the data portal
- Model sea ice drift forecasts are compared against ice-bound drifting buoys in the Arctic
- Other participants include: European Centre for Medium-Range Weather Forecasts, Environment Canada, Norwegian Met Office, UK Met Office, NOAA Earth System Research Laboratory

Sea Ice Support to the Sea Ice Drift Forecast Experiment (SIDFEx)

https://sidfex.polarprediction.net/



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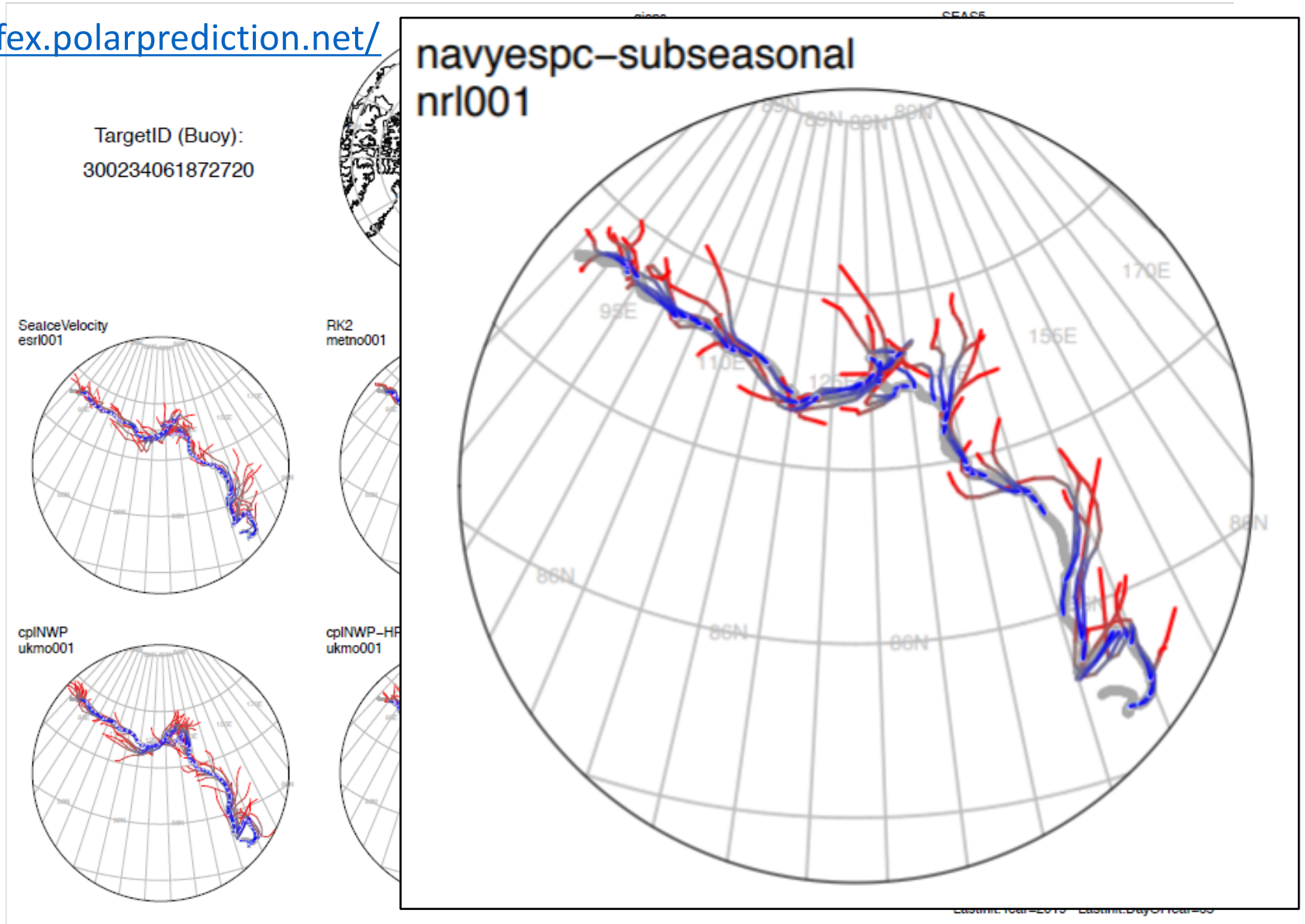

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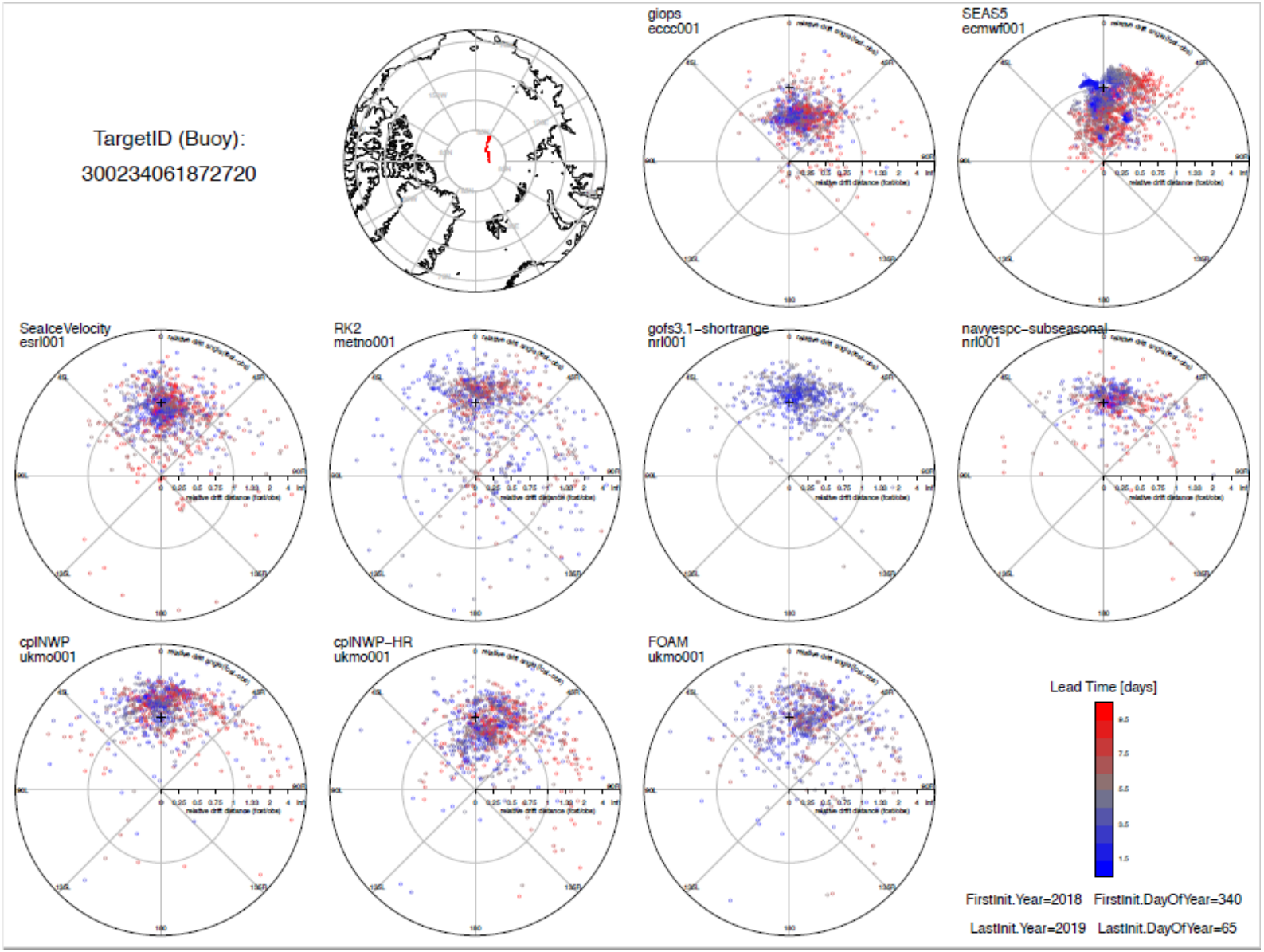
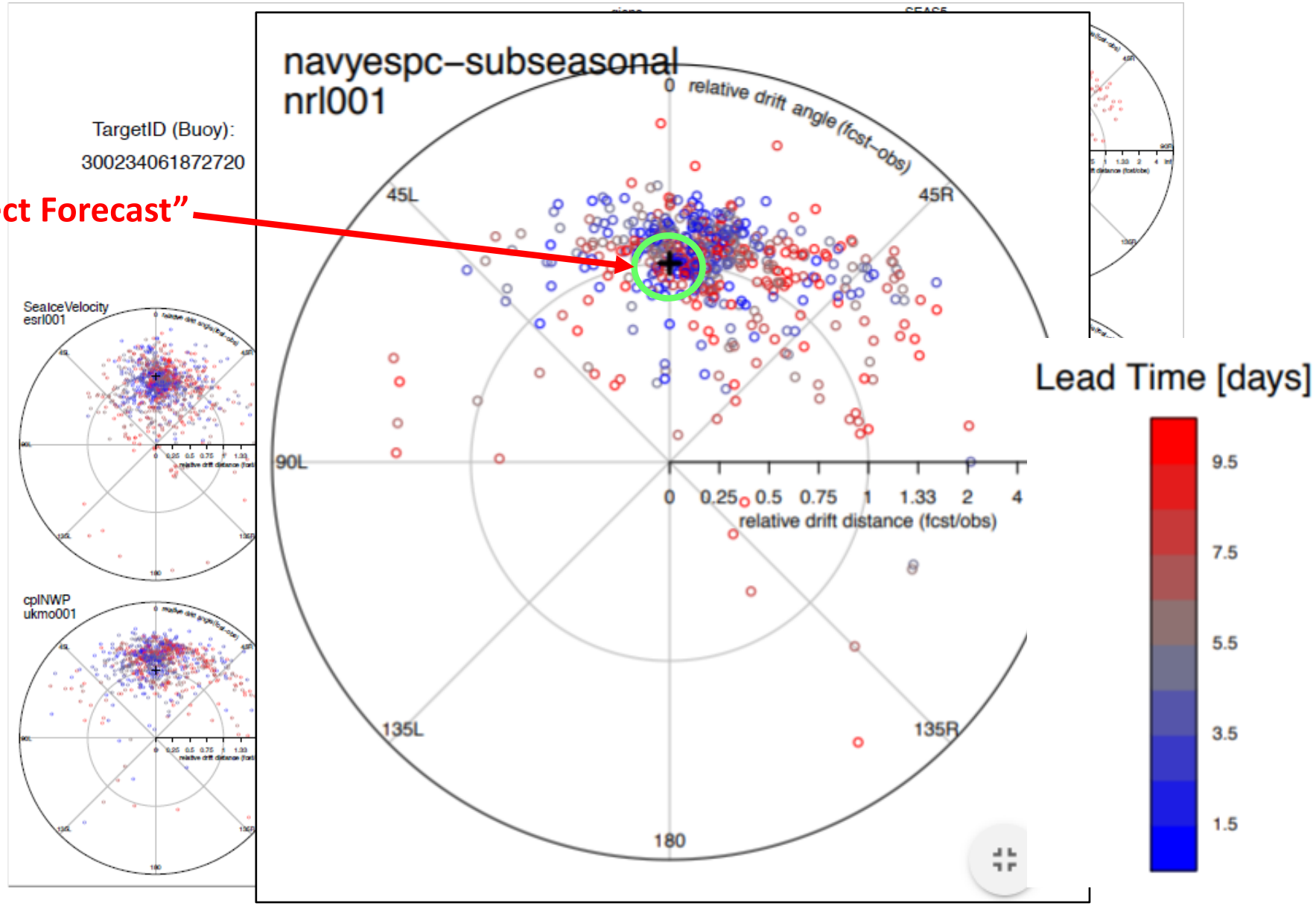
Sea Ice Support to the Sea Ice Drift Forecast Experiment (SIDFEx)



Sea Ice Support to the Sea Ice Drift Forecast Experiment (SIDFEx)



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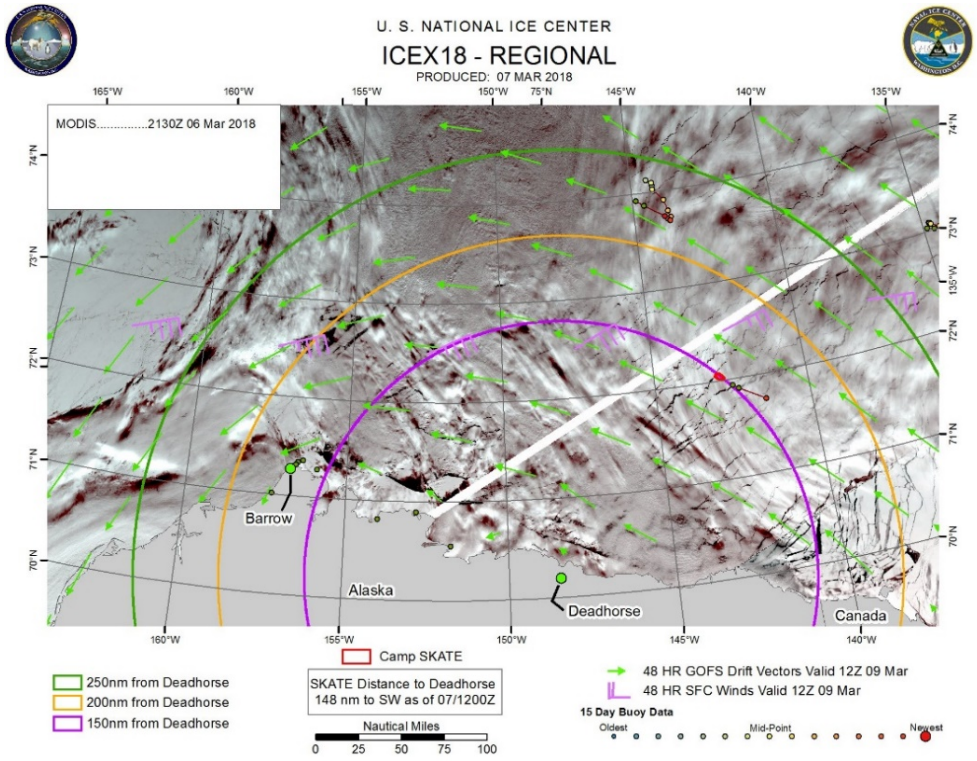
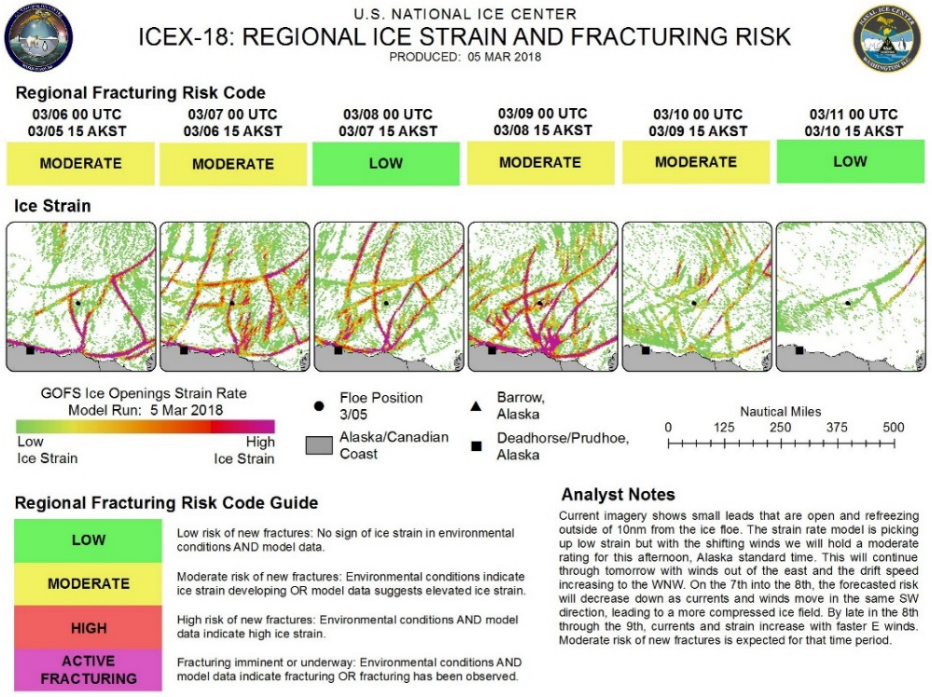
GOFS 3.1 Support for ICEX 2018

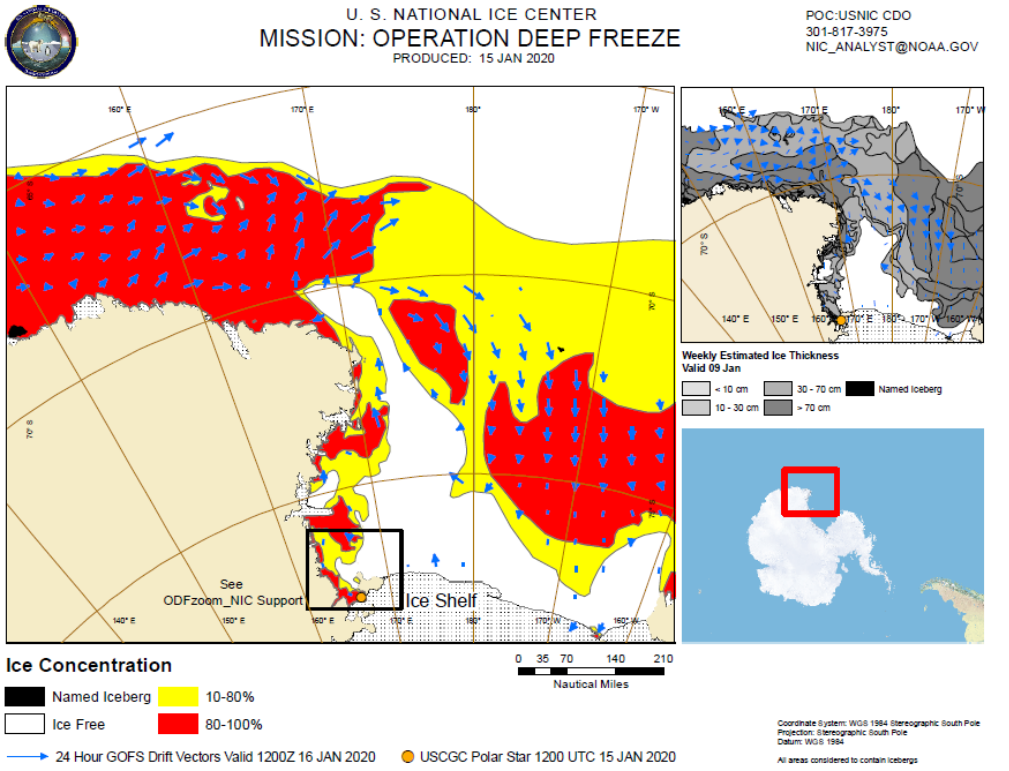


GOFS 3.1 (green arrows) used to forecast ice camp (red polygon) drift

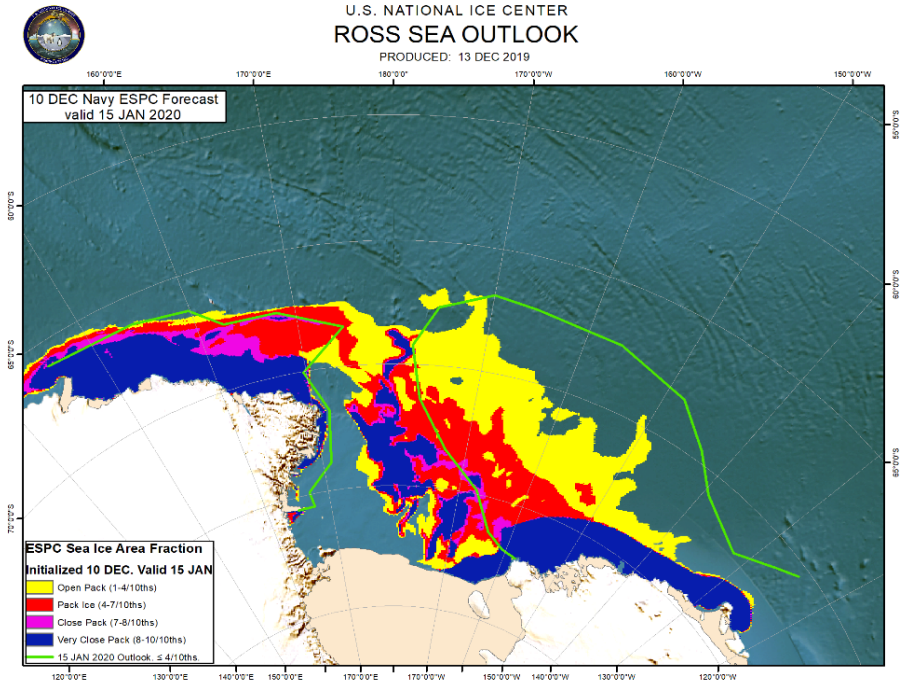


GOFS 3.1 forecasts used in the ice fracturing analysis produced at NIC

National Ice Center's Use of GOFS 3.1 and ESPC in Support of McMurdo Resupply



GOFS 3.1 forecast ice drift vectors shown in blue



ESPC predicted ice edge for 15 JAN 2020 produced on 13 DEC 2019 versus NIC outlook (**green line**).

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Summary & Plans

- GOFS 3.1 will be replaced by GOFS 3.5 later this year
  - —Coupled ice-ocean modeling system (1.75 km res at North Pole) uses CICE 5.1.2
- ESPC 15-member ensemble based system is scheduled for operational transition in May 2020 providing 45-day forecasts (fully coupled atmosphere-ocean-ice) using CICE v4
- Next version of ESPC (FY22) is scheduled to use CICEv6 with landfast ice; coupled to WaveWatch-III