Arctic Prediction and Forecasting at NRL

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Outline

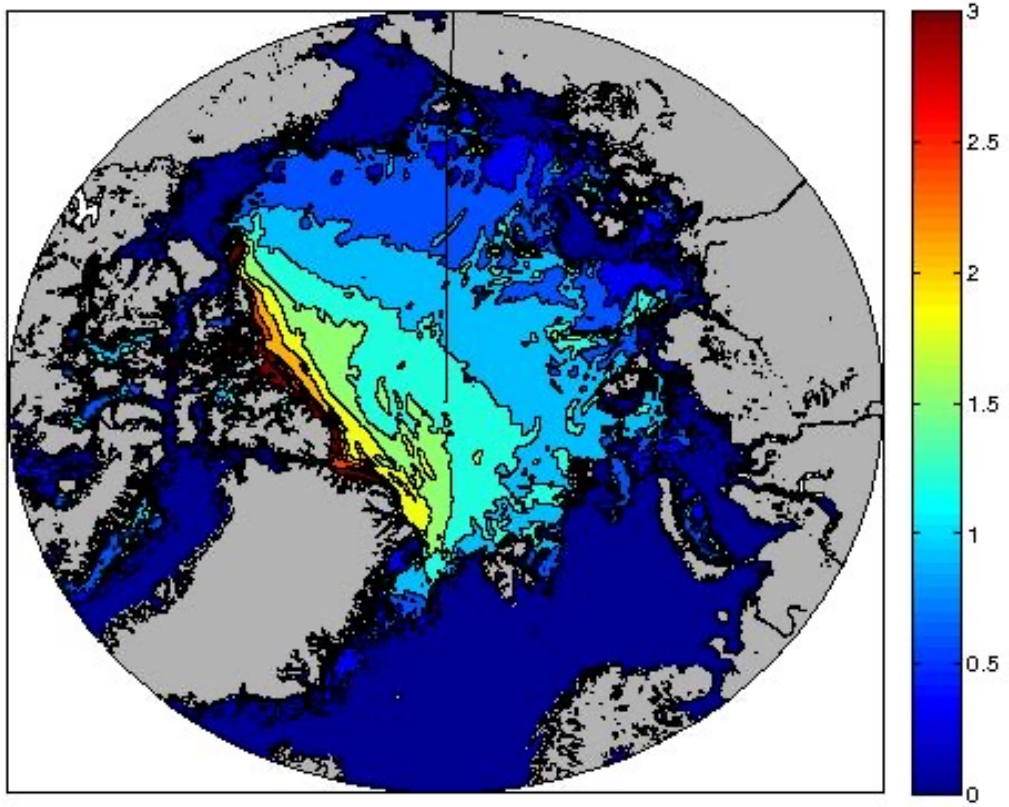
- Past system: GOFS 3.1
- Current system: GOFS 3.5
- Future system: ESPC
  - Examples of ESPC use
- Recent developments/improvements
  - Assimilation of ice thickness
  - Assimilation of high-res VIIRS ice data
  - Refinement of LFI parameterization
  - Arctic OSSE project (assessment of suitability of current Arctic climatology)

Global Ocean Forecasting System (GOFS)

- Coupled system: HYCOM ocean plus CICE sea ice
- Atmospheric forcing from NAVy Global Environmental Model (NAVGEM)
- Navy Coupled Ocean Data Assimilation (NCODA) system used to assimilate all real-time data: satellite altimetry, SST, and ice; in situ profiles; basically all available data.
- GOFS 3.1 became the Navy's operational system in November 2018
  - Global system with 1/12.5 degree resolution; provides boundary conditions for regional systems

GOFS 3.1: Current operational model

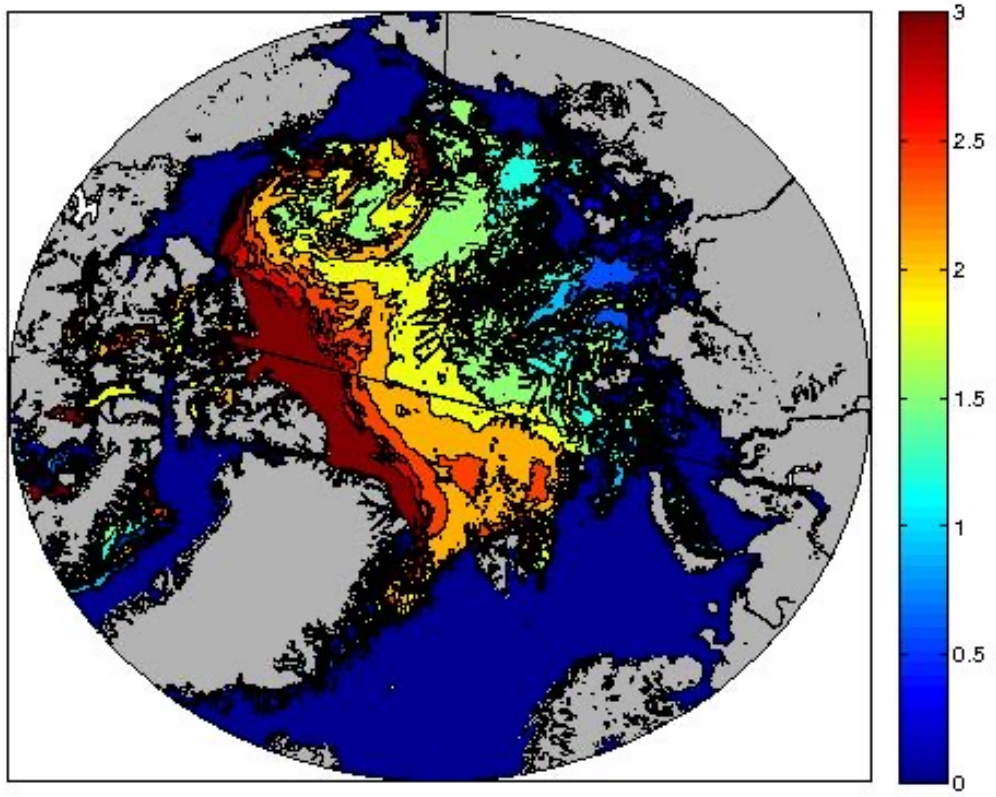
Ice thickness, July 1, 2017



- Nominal resolution of 1/12 degree
- HYCOM+CICE4
- Reasonable ice edge; thickness is less reliable

GOFS 3.5: Next operational model

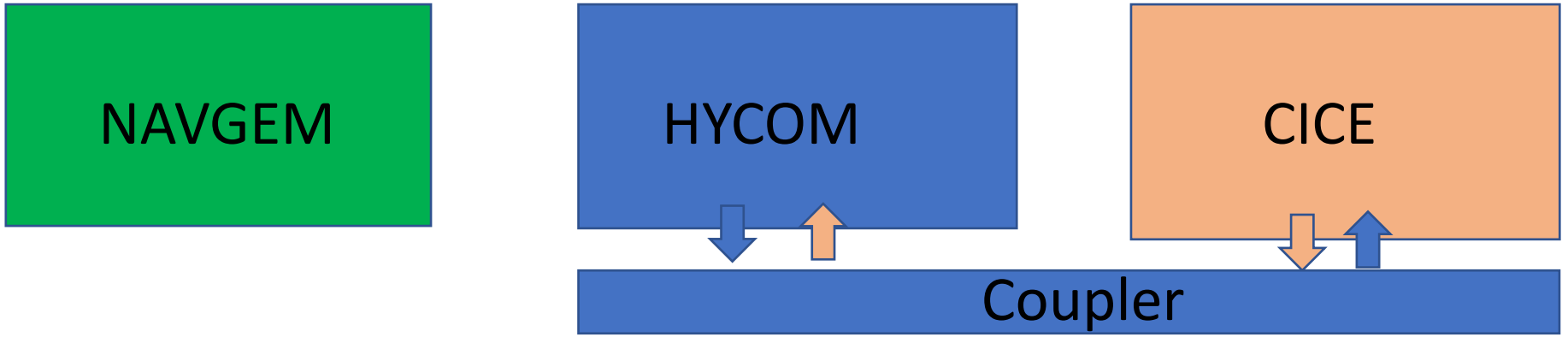
Ice thickness, July 1, 2017



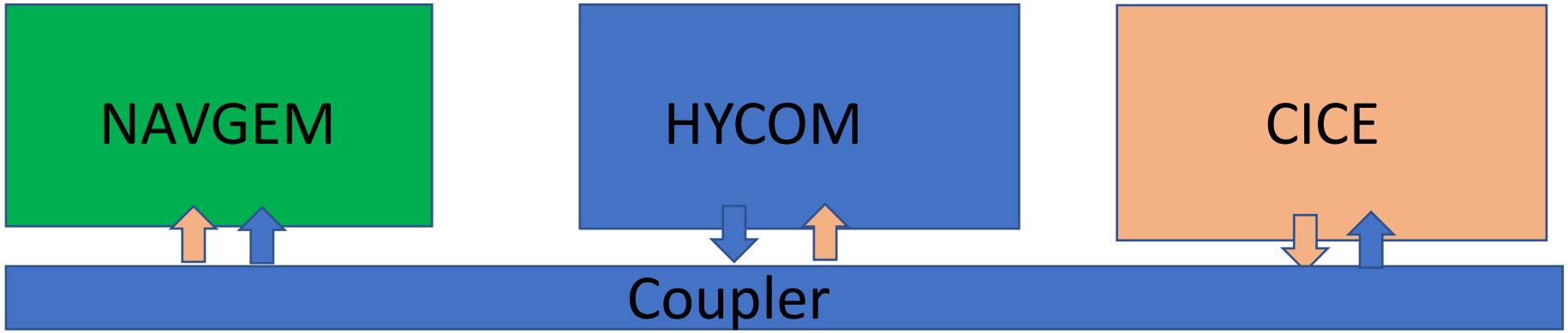
- Increased resolution (1/25 instead of 1/12.5)
- CICE v5 instead of CICE v4
- Add tides
- Will be operational any day now (in final stages of operational testing, just needs a final stamp of approval)
- Ice is much thicker

ESPC – Earth System Prediction Capability

- GOFS has: Ocean (HYCOM) and sea ice (CICE) are coupled, forced by atmosphere (NAVGEM)



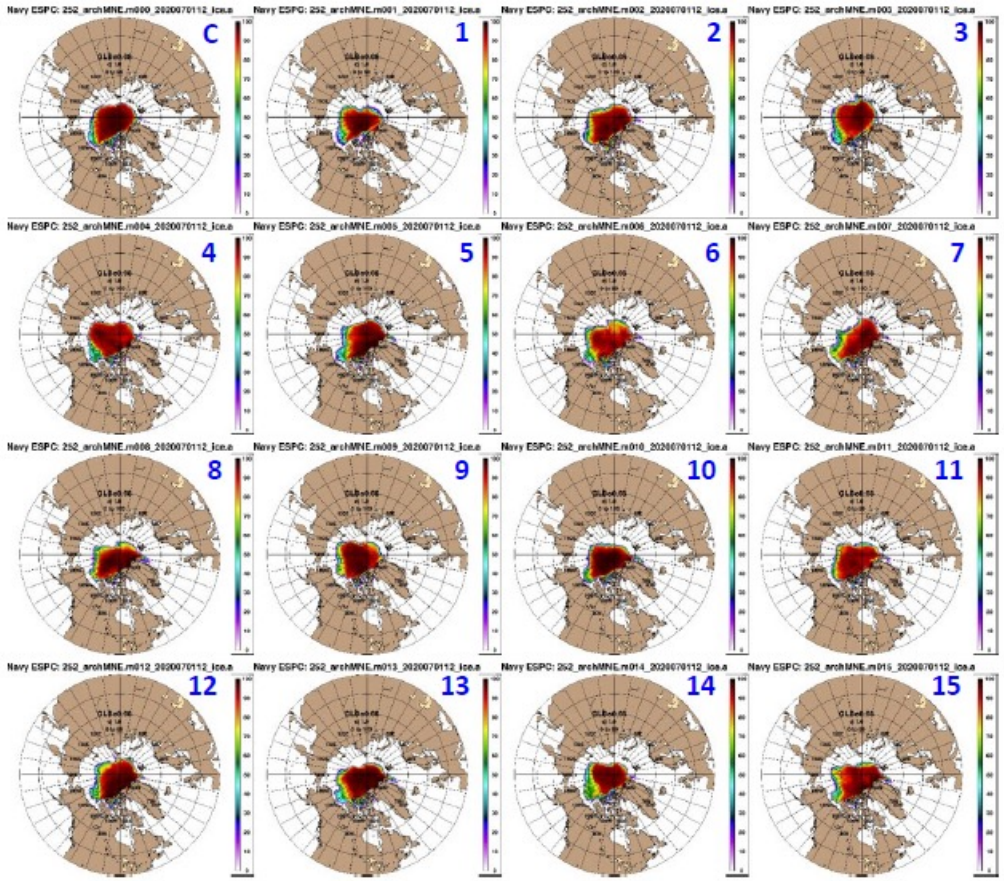
- ESPC will have fully coupled atmosphere, ocean and sea ice model



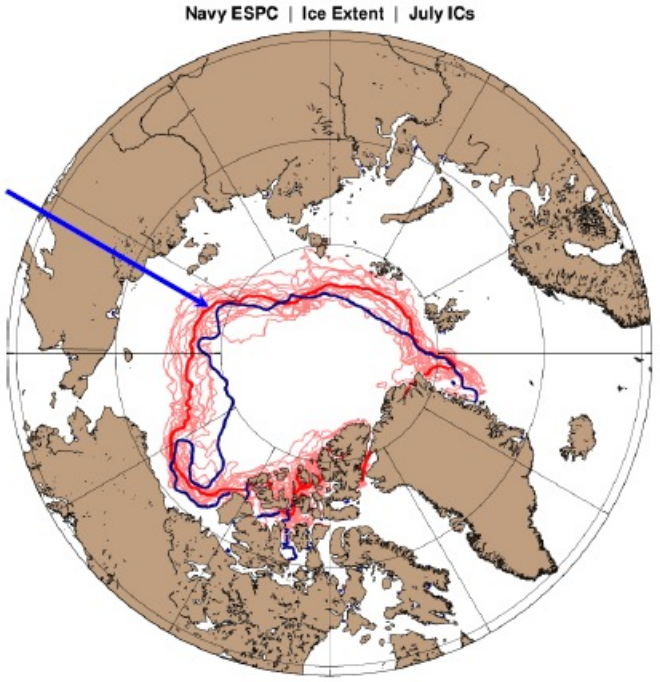
ESPC Components (and version comparison)

ESPC Version Number	Time Scale, Frequency	Atmosphere NAVGEM	Ocean HYCOM	Sea Ice CICE	Waves WW3	Land surface LSM	Aerosol
V1	0-45 days weekly 16 members	T359L60 (37 km) 60 levels	1/12 (9 km) 41 layers	1/12 (3.5 km) CICE V4		Module within NAVGEM	
V2	0-45 days (2x) weekly 16 members	T681L100 (19 km) L143 HA	1/12 (9 km) 41 layers Tides	1/12 (3.5 km) CICE V6	¼ (28 km)	Module within NAVGEM	Module within NAVGEM

ESPC example: sea ice extent prediction



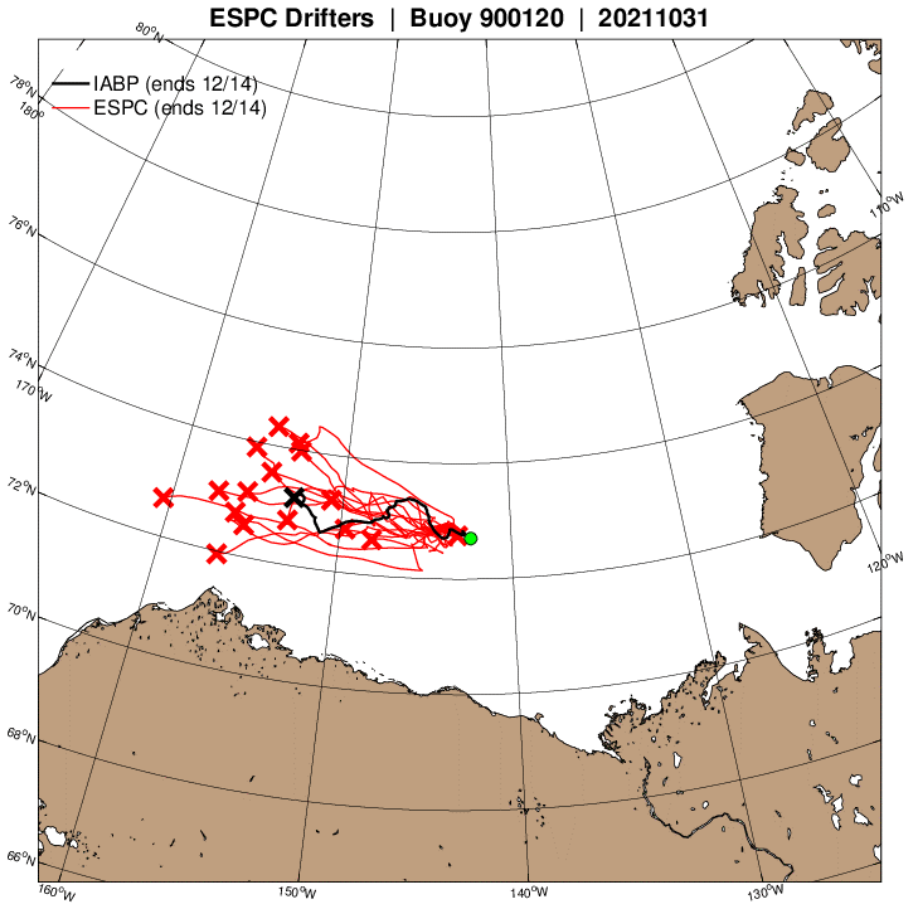
Predicted September Minimum Sea Ice Extent
Initialized 1 July 2020



NSIDC minimum extent for 13 Sep shown in blue

16 Ensemble members shown in red

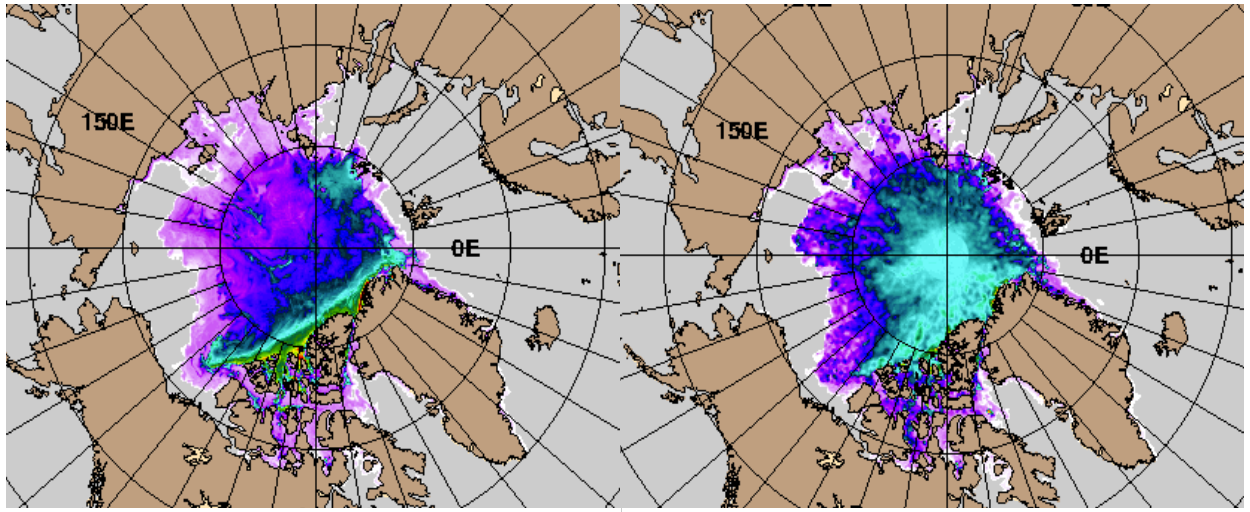
ESPC example: ice buoy location



- ESPC system was in use during ICEX
- Red lines show ESPC ensemble prediction of ice buoy location
- Black line shows observed ice buoy location

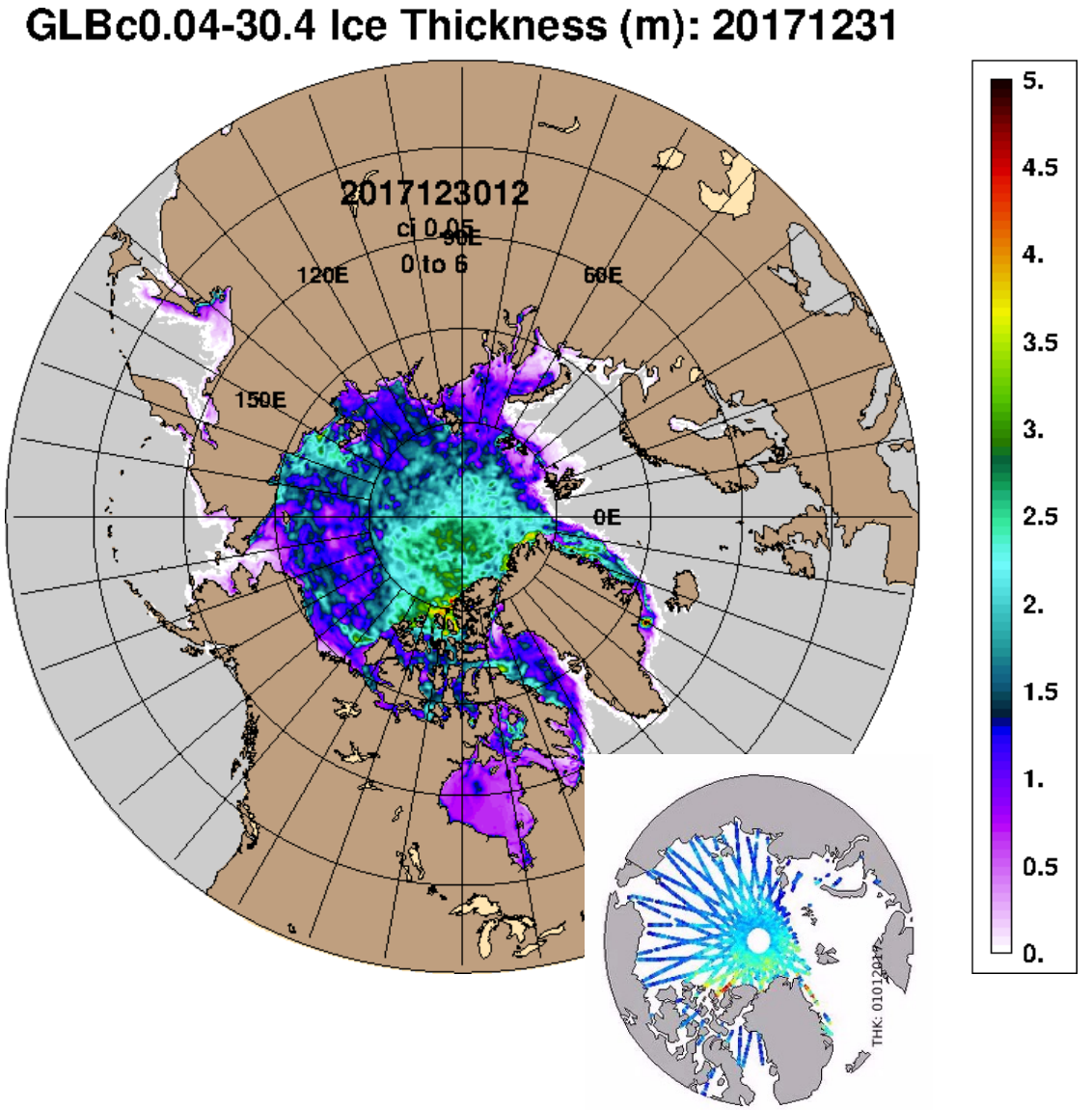
Recent Development: Assimilation of ice thickness

- Ice thickness type added to NCODA. Completed 15 month test run in GOFS 3.5
- Started from GOFS 3.5, but reinitialized with CryoSat-2 28 Day data 15 OCT 2017
  - Reduce large initial difference in ice thickness.

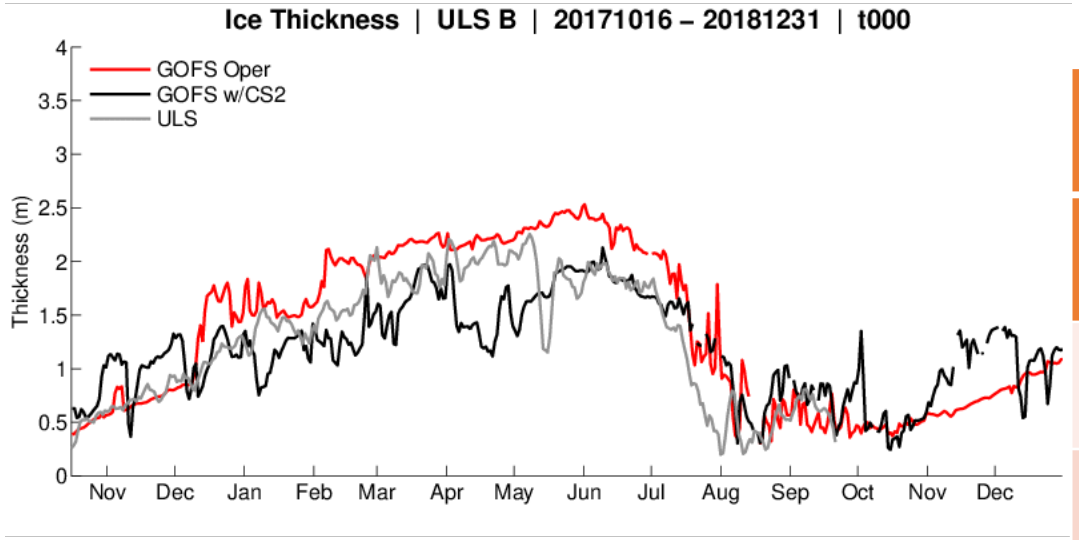


Thickness before reinitialize

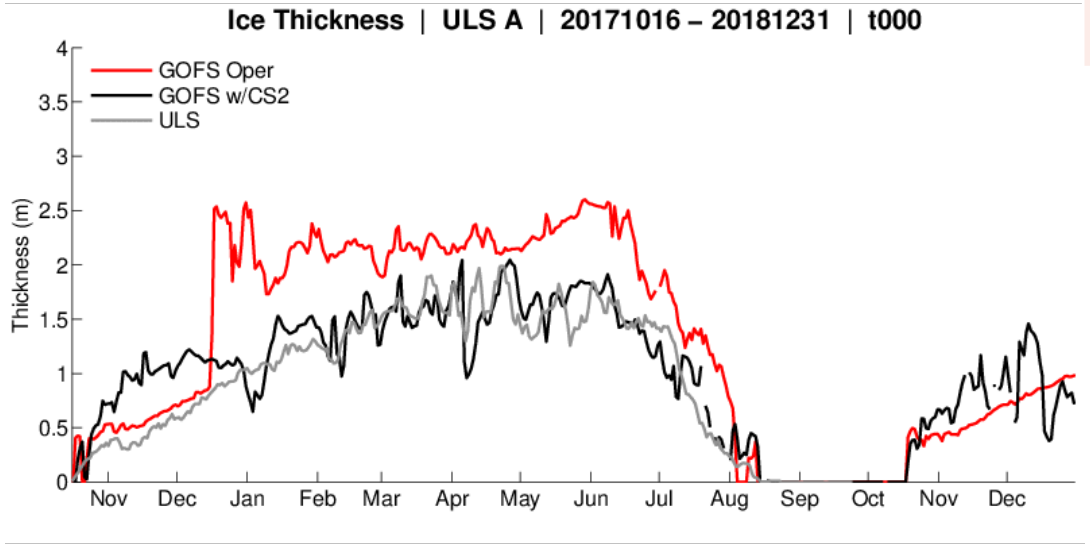
Thickness after reinitialize

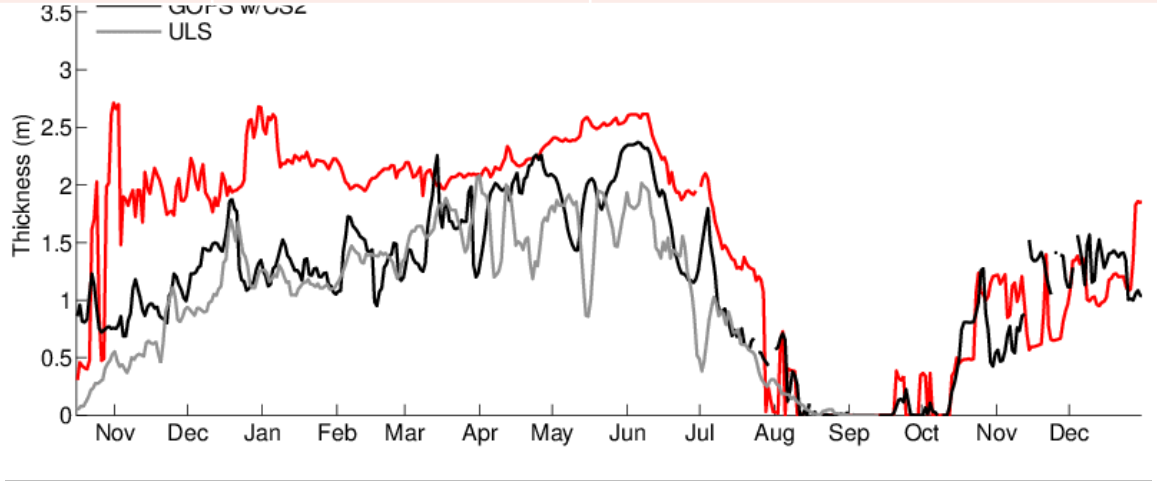


Operationally implementing satellite-derived ice products within the Navy's ice forecast systems: Assimilate CryoSat-2 2-day tracks.

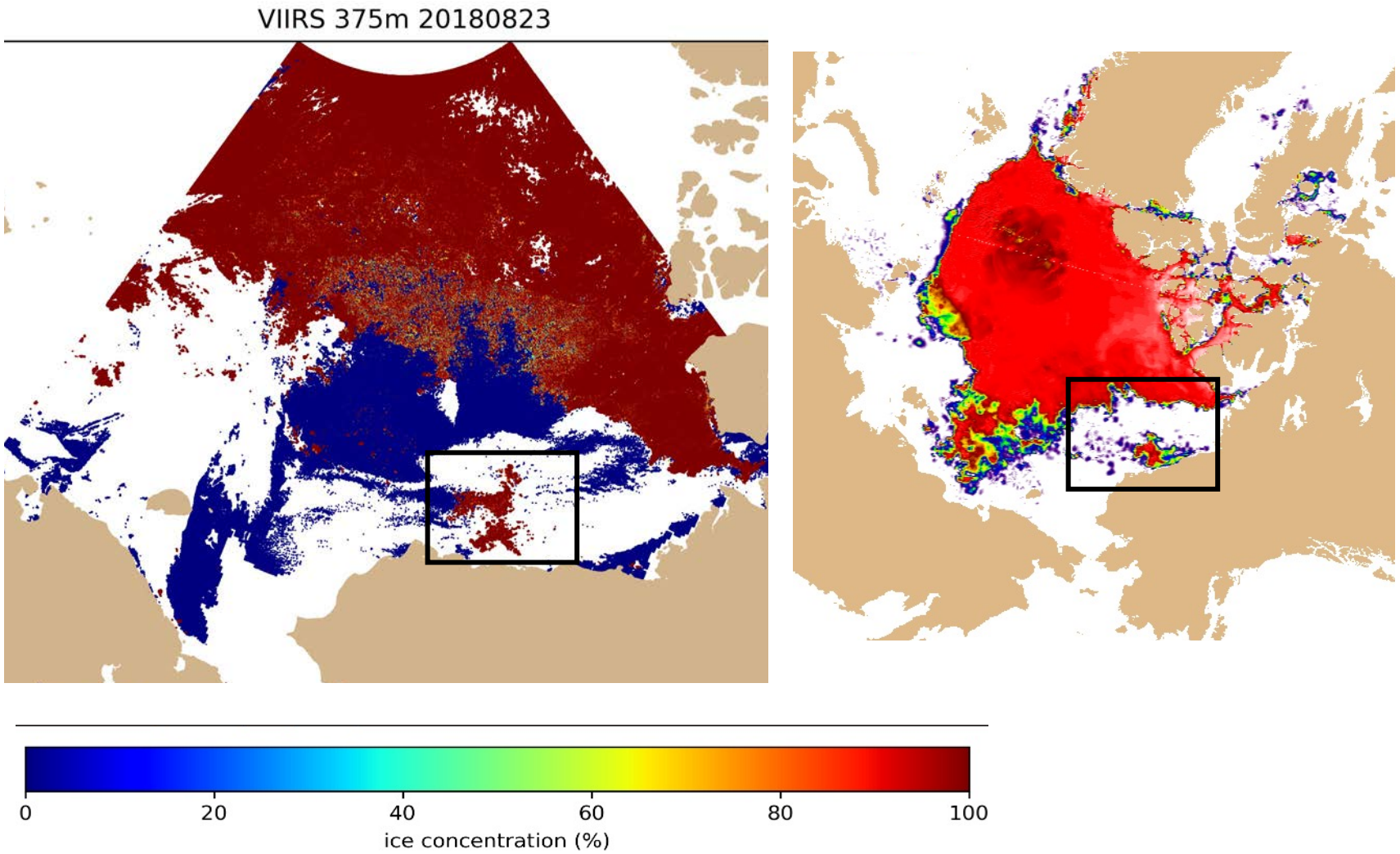


	RMSE (m) (% Improvement)	
Mooring	GOFS 3.5	GOFS 3.5 + CS2
A	0.66	0.28 (58%)
B	0.38	0.36 (5%)
D	0.86	0.39 (55%)





Recent Development: Assimilation of VIIRS



VIIRS data has a native resolution of 375 m
Recent improvements in algorithms better distinguish ice from clouds

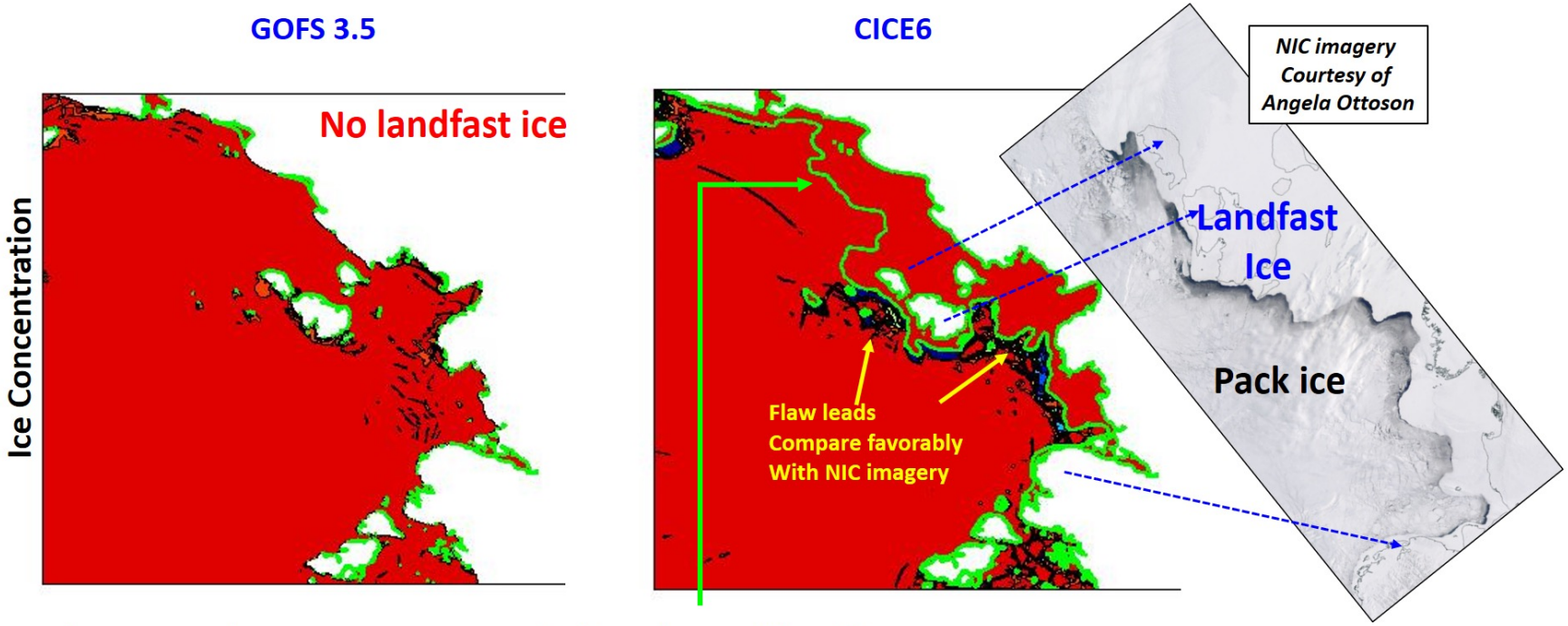
Results:
High area of concentration added north of alaska

VIIRS observations outside ice mask (created from other sources) – showing ice that was previously misidentified or missed.

Effect on model ice edge location and concentration will be further examined

Recent Development: Landfast Ice parameterization (CICE 6)

Realistic landfast ice extent and flaw leads



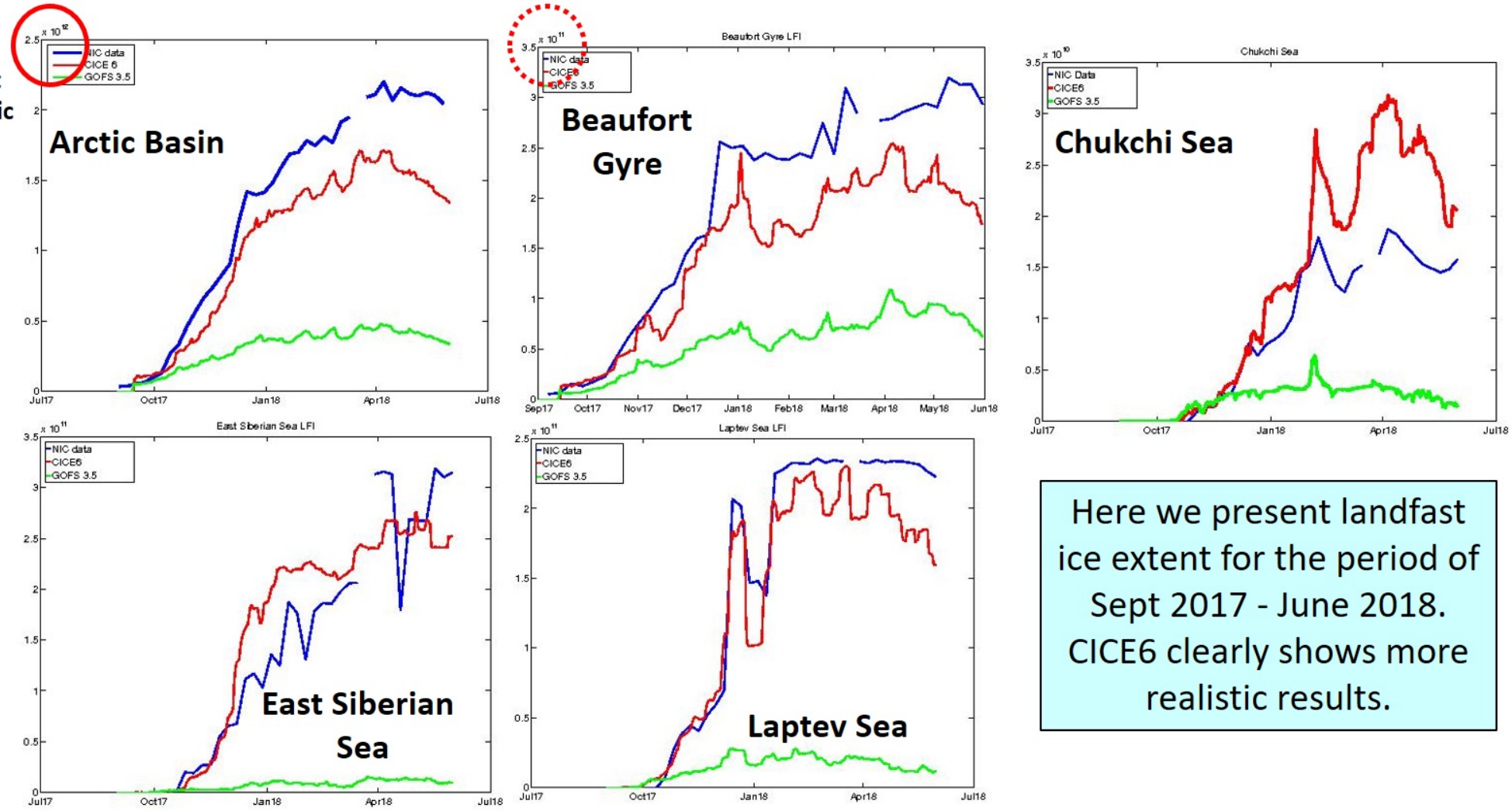
Thin green line represents model's poleward landfast ice extent

Flaw leads evident in CICE6, but not GOFS 3.5

- Landfast Ice: Ice attached to land (coast or ocean bottom) that doesn't move
- GOFS 3.5 shows no landfast ice (all ice moves with the pack)
- When the LFI parameterization is used, results compare well with imagery
- NRL has created a spatially varying LFI parameterization

Improvement from LFI parameterization

Note different scaling for Arctic



Here we present landfast ice extent for the period of Sept 2017 - June 2018. CICE6 clearly shows more realistic results.

GOFS 3.5 (without LFI), CICE6, NIC chart data

System assessment: Arctic OSSE project

- NOPP project (collaboration between NRL, FSU and SIO)
- GOAL: to examine the system and determine the best way to optimize the system
  - New observations necessary?
  - Better use of existing observations?
  - Is the system responding in the way it should to the data with which it is provided?
  - What assumptions already included in the system need to be challenged?

System assessment: Arctic OSSE project

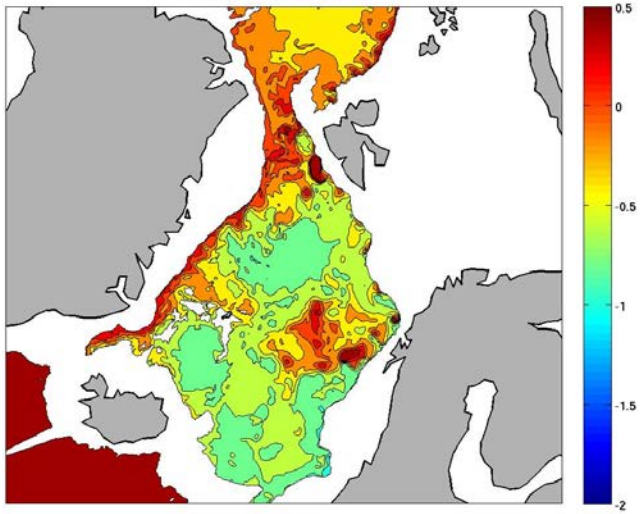
- Two “nature runs” were created
  - High-resolution, non-assimilating global runs from 2017-2020
  - One based on POP (See Elizabeth Fine’s presentation) and one on HYCOM (see Dmitry Dukhovskoy’s presentation)
- The nature runs were “sampled” in the way our observing systems would sample them, and these “obs” are assimilated into the model
- The resulting model output is compared with the nature run to see how well the model can replicate “reality”, and what changes need to be made to improve the system

Synthetic profiles

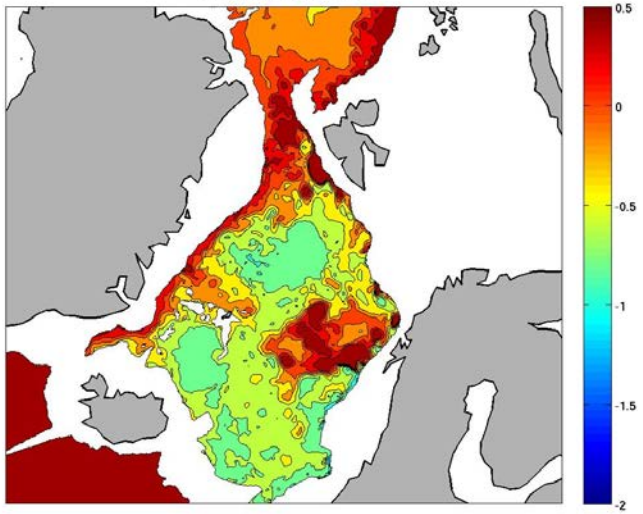
- SSH is not assimilated directly by NCODA
- Instead, “synthetic profiles” of T and S are created from each SSH anomaly
  - Uses “ISOP” (Improved Synthetic Ocean Profiles)
  - Assumes a known covariance of SSH anomaly with T/S structure
  - Based on climatology
- One question is: does the current state of the Arctic/high-latitude Atlantic still match the climatology?

Arctic OSSE project: Assimilating T/S vs using ISOP

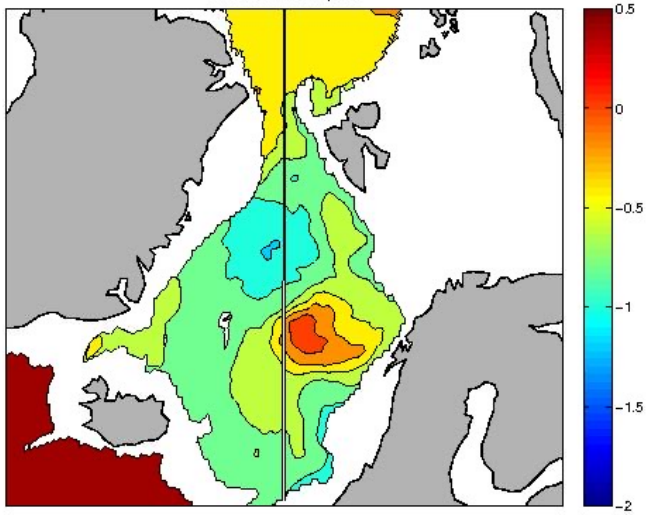
Nature Run



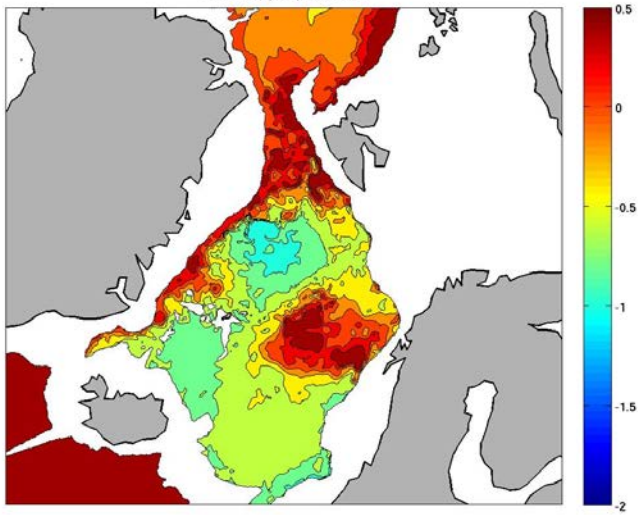
T/S assimilation OSSE



Climatology



ISOP assimilation OSSE



- One OSSE assimilates Nature Run T/S profiles at all locations, one uses ISOP to create synthetic T/S profiles at all locations
- The OSSE that uses ISOP has too-cold temperatures at 1000 m, closer to climatology than to the observations
- Does this indicate that the climatology of the region has changed, and a new climatology should be developed so that steric changes can be more accurately translated into temperature/salinity profiles?

Other issues being addressed

- Currently, ISOP is not applied in locations thought to be unstratified (T_sfc – T_1000 < 3C)
  - Stratification check determined by climatology (is it correct?)
  - Also, can we do better than this? Is there a way to make a “high-latitude ISOP” that will let us get information from these data instead of just discarding them?
- Ice edge: currently, CICE does not assimilate unless the difference between the model and the obs is greater than 10%. Should we try to “match closer”? If not, how else can we improve the ice edge?

Summary

- Arctic modeling evolved from GOFS 3.1 -> GOFS 3.5 -> ESPC
- Recent additions include assimilation of ice thickness, inclusion of VIIRS satellite data, and improved LFI parameterization
- OSSE experiments suggest new climatologies may be needed

Any Questions?