Validation of the U.S. Navy Arctic Cap Nowcast/Forecast System (ACNFS)

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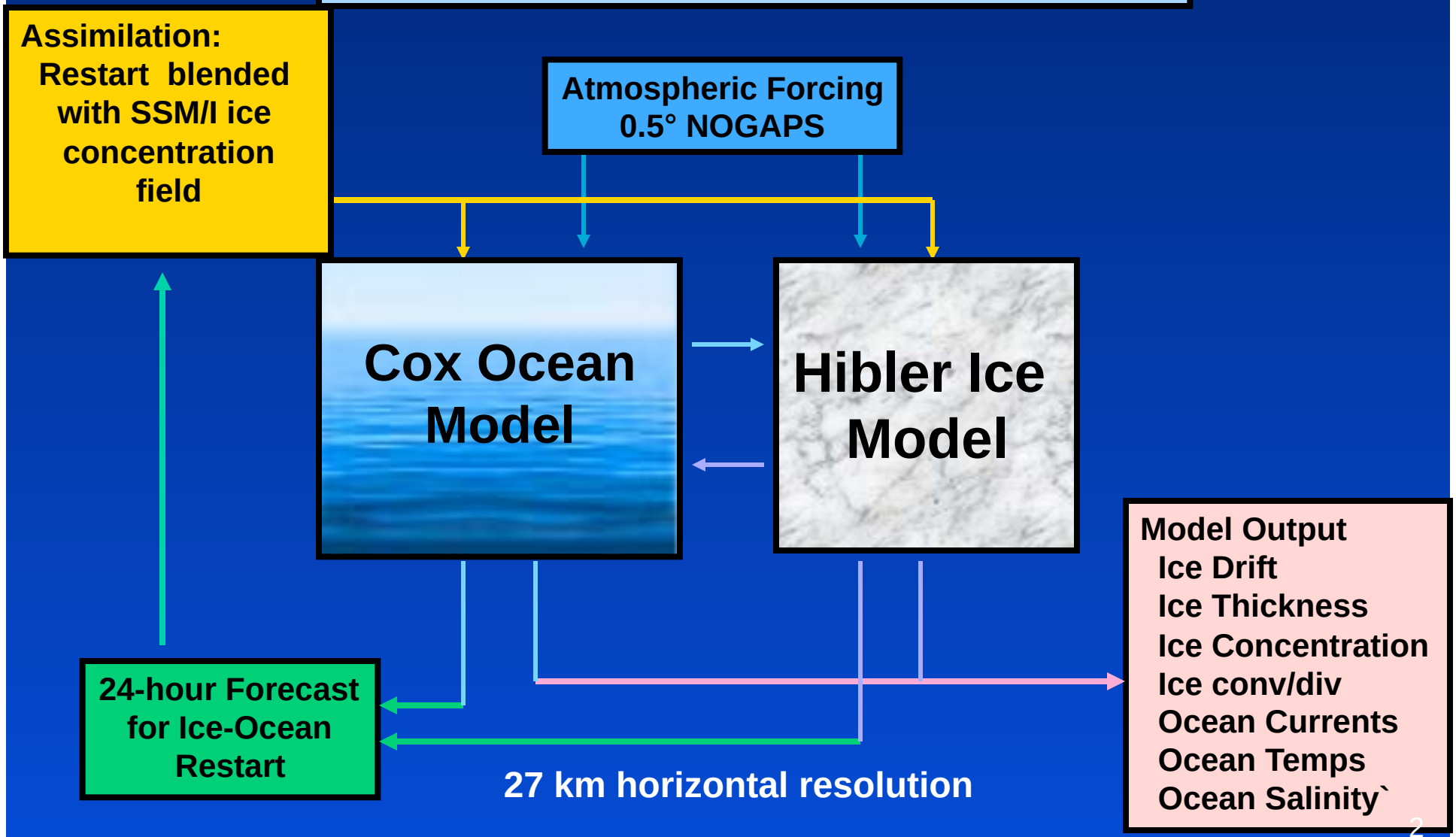
Layered Ocean Model Workshop
7-9 February 2011

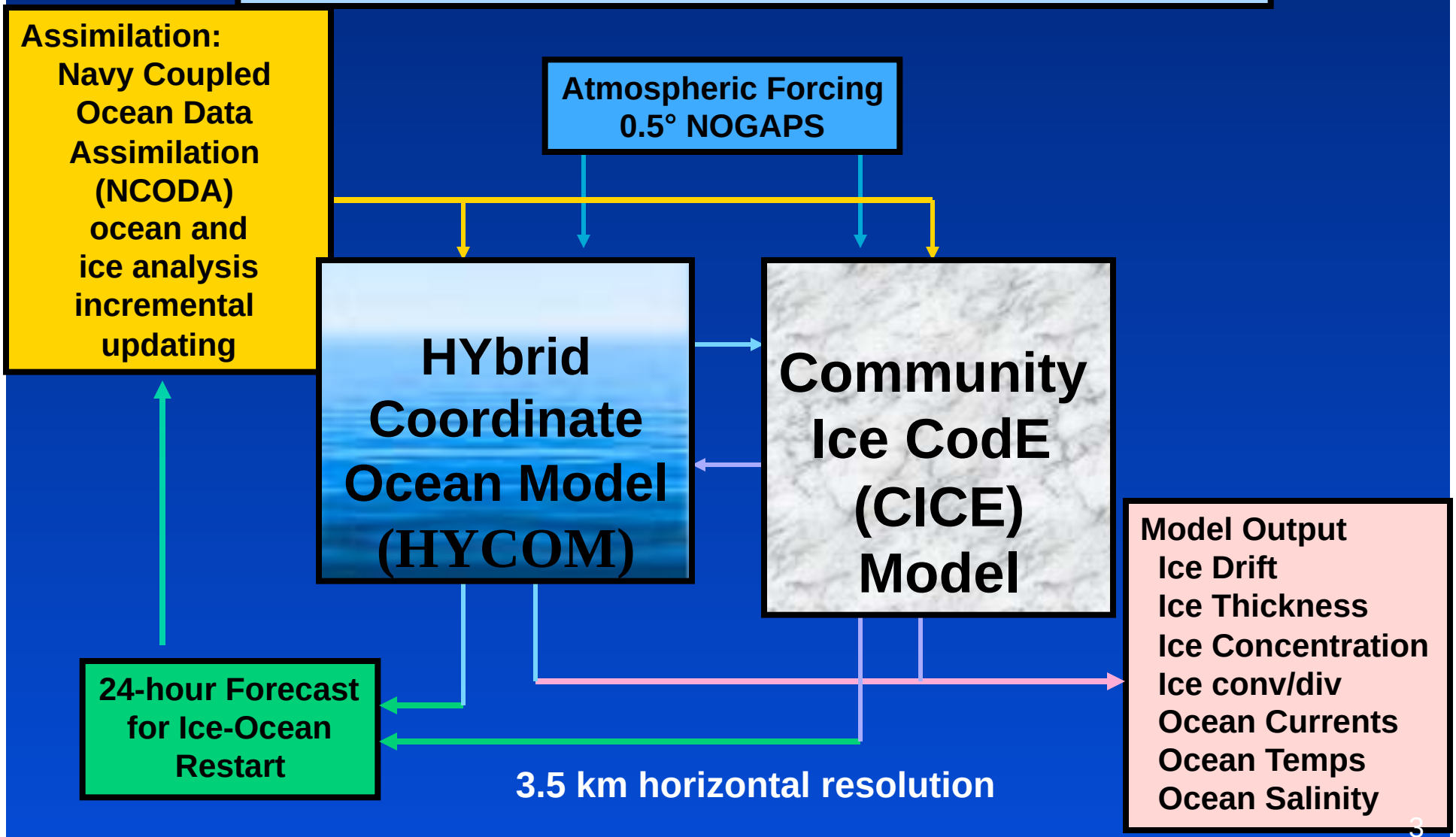
NRL Ice Forecasting Systems

Polar Ice Prediction System 2.0



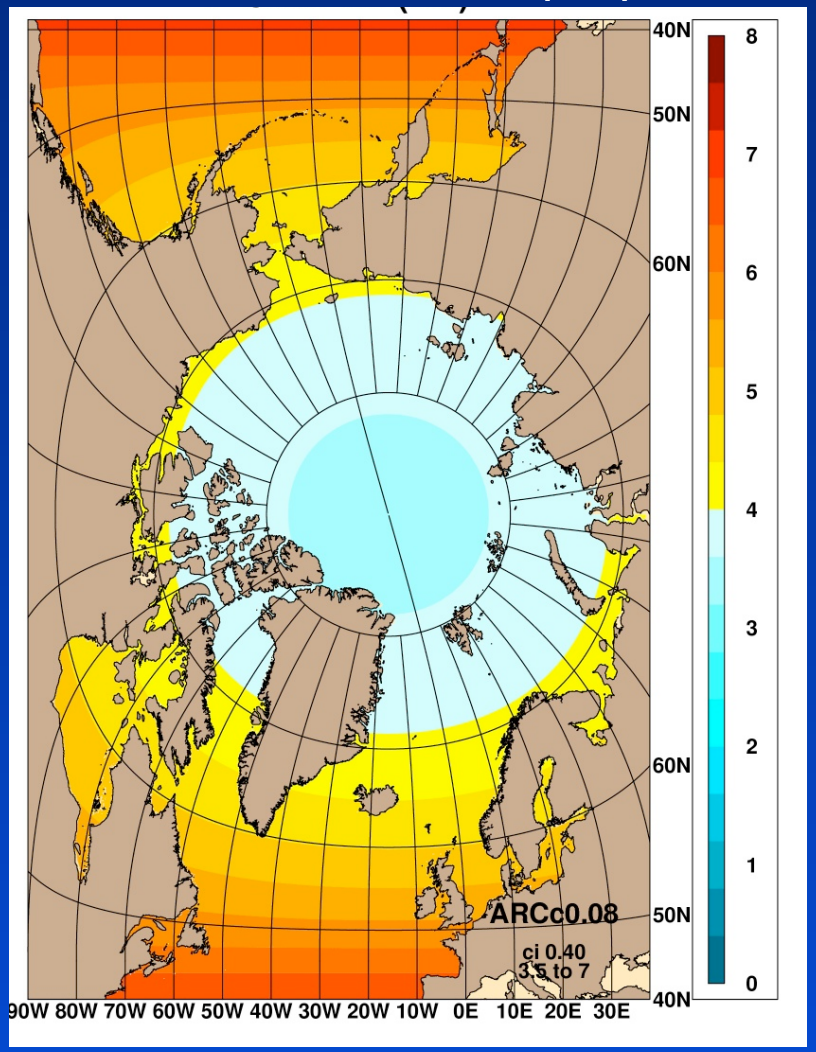
NRL Ice Forecasting Systems

Arctic Cap Nowcast/Forecast System



Arctic Cap Nowcast/Forecast System

Grid resolution (km)



- Improved ice and ocean models
- Improved data assimilation in ice and ocean models
- Increased horizontal resolution ~3.5 km at the pole
- 3-hrly forcing from NOGAPS
- Validation period: July 2007 – June 2009
- Running in real-time at NAVOCEANO since 13 June 2010 on IBM Power 6
- 3-day hindcast/analysis/5-day forecast
- Boundary conditions from 1/12°global assimilative HYCOM system running in real-time at NAVOCEANO

Community Ice CodE (CICE)

- CICE v4.0 developed by Los Alamos National Laboratory
  - Next generation, advanced system
  - Additional ice physics
    - Energy-based ice ridging scheme
    - Energy-conserving thermodynamics
    - Multi-category, linearly remapped ice thickness
  - New capability to predict areas of lower ice concentration possibly associated with lead openings
- HYCOM and CICE are coupled via the Earth System Modeling Framework (ESMF)

Navy Coupled Ocean Data Assimilation (NCODA)

SST: GAC/LAC
MCSST, GOES,
Ship, Buoy Profile:
XBT, CTD, PALACE
Float, Fixed Buoy,
Drifting Buoy
Altimeter SSHA SSM/
I Sea Ice

Ocean QC

Innovations

3D Var

Increments

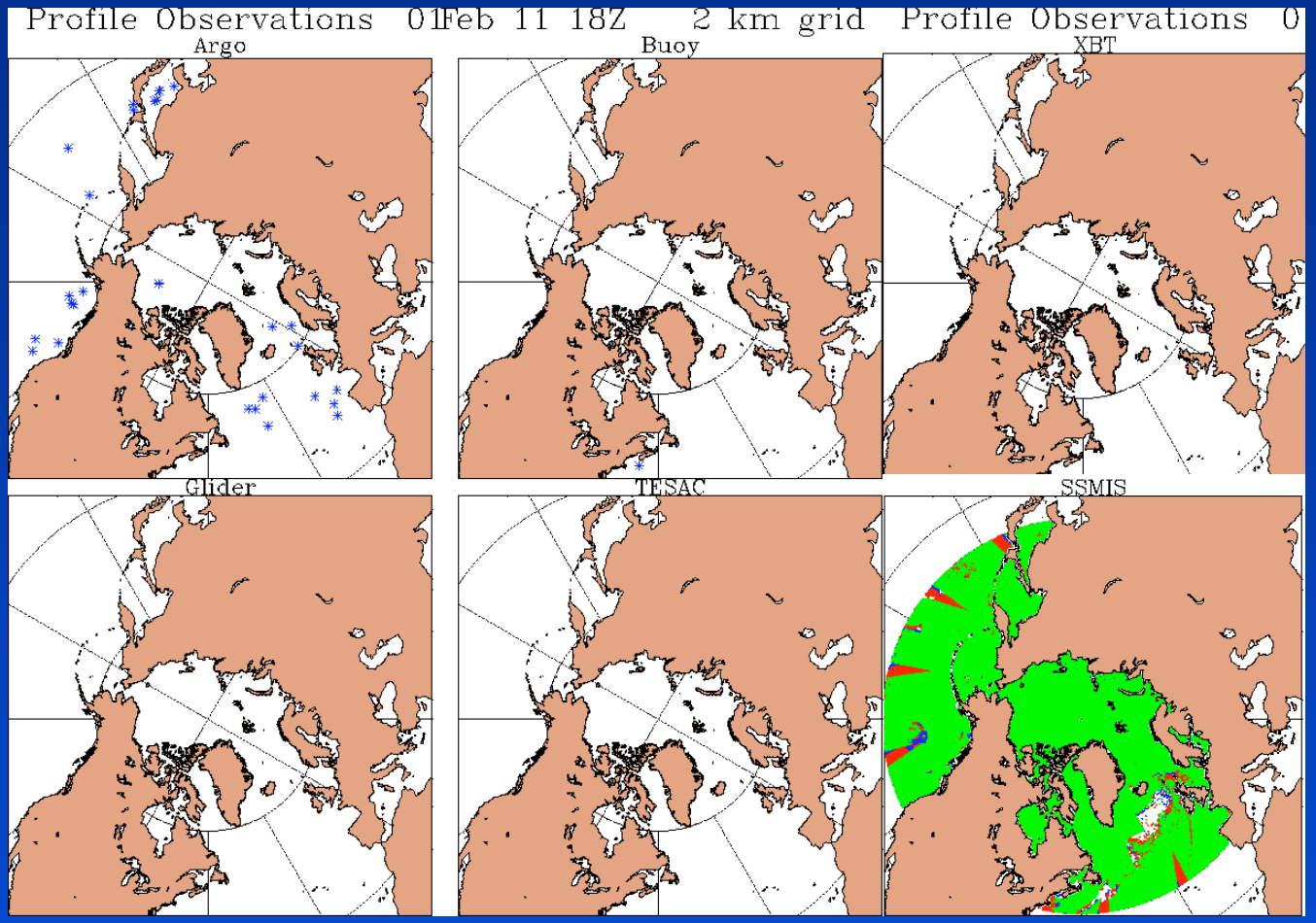
HYCOM/CICE

Sequential Incremental Update Cycle
Analysis-Forecast-Analysis

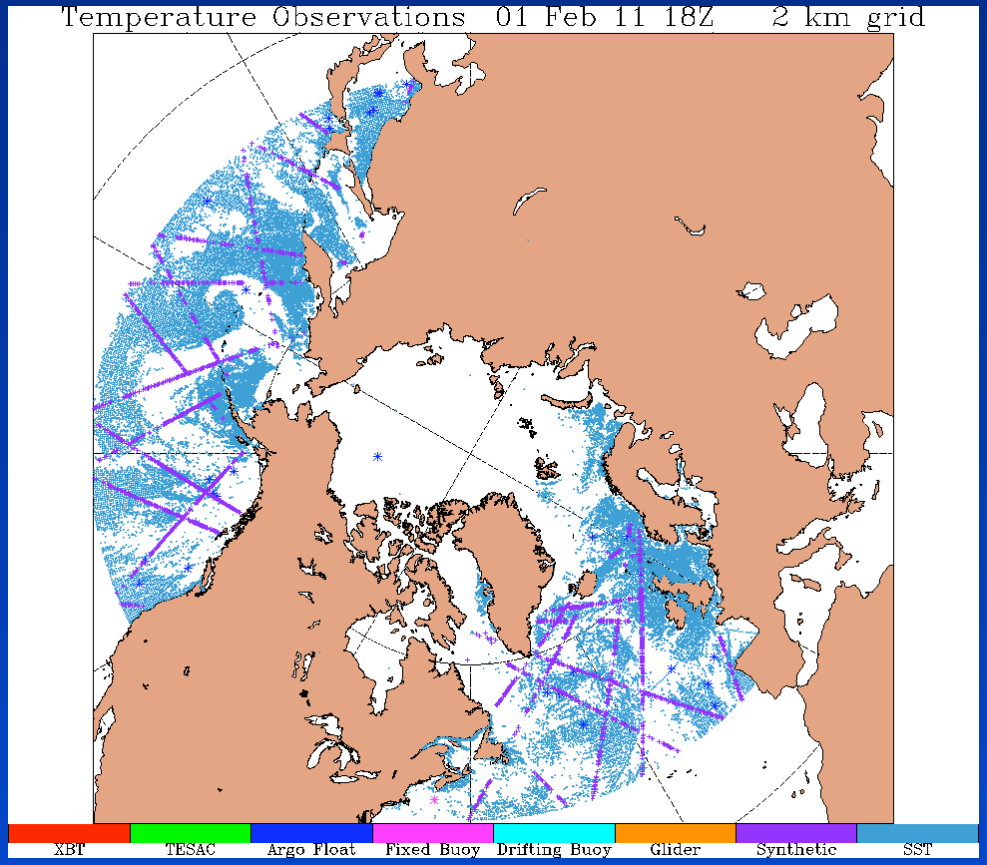
3DVar - simultaneous analysis ice concentration and 5 ocean variables: temperature, salinity, geopotential, layer pressure, velocity (u,v)
Vertical projection of SSH and SST observations using MODAS synthetic temperature and salinity profiles

HYCOM/CICE 24 hour forecast used as first guess for analysis

HYbrid Coordinate Ocean Model (HYCOM)
NCODA Profile Observations
1 February 2011



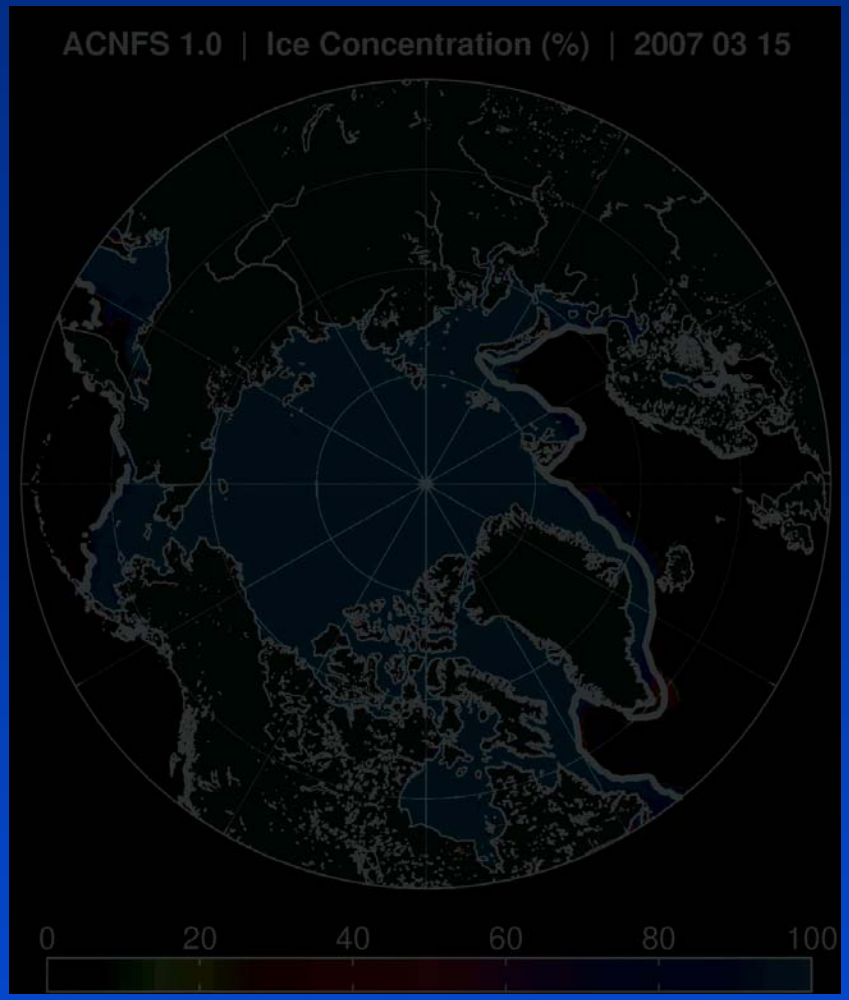
HYbrid Coordinate Ocean Model (HYCOM)
NCODA Temperature Observations
1 February 2011



MODAS synthetic temperature and salinity profiles along satellite altimeter tracks

ACNFS Development
Non-assimilative HYCOM/CICE

Winter – 15 March 2007



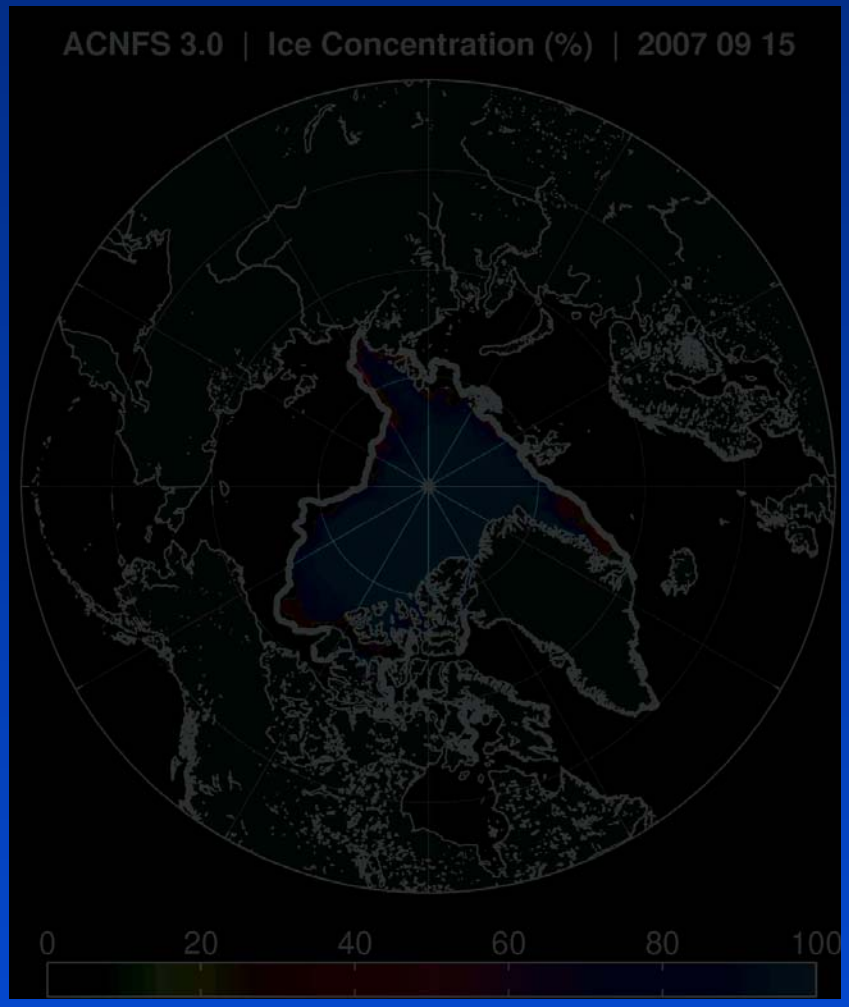
Summer – 15 September 2007

Non-assimilative ACNFS (initialized from a CICE only simulation) integration from 2005-2008.
Black line is independent National Ice Center (NIC) ice edge.

ACNFS Development

Assimilative vs. non-assimilative

HYCOM/NCODA/CICE– 15 Sept. 2007

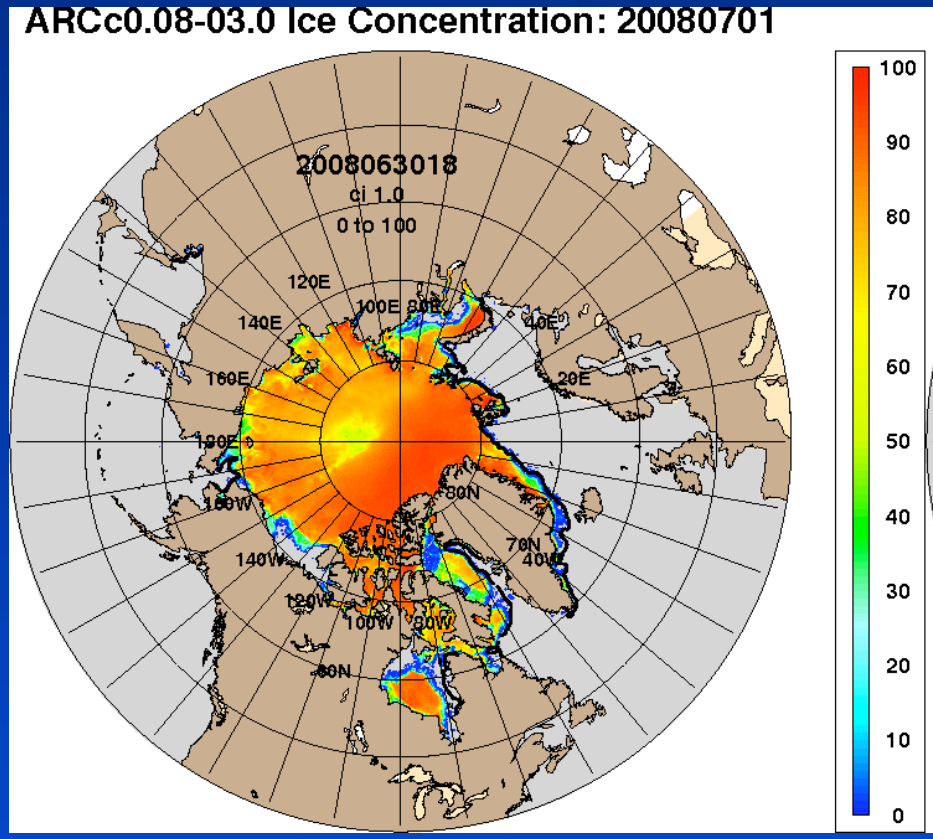


HYCOM/CICE – 15 Sept. 2007

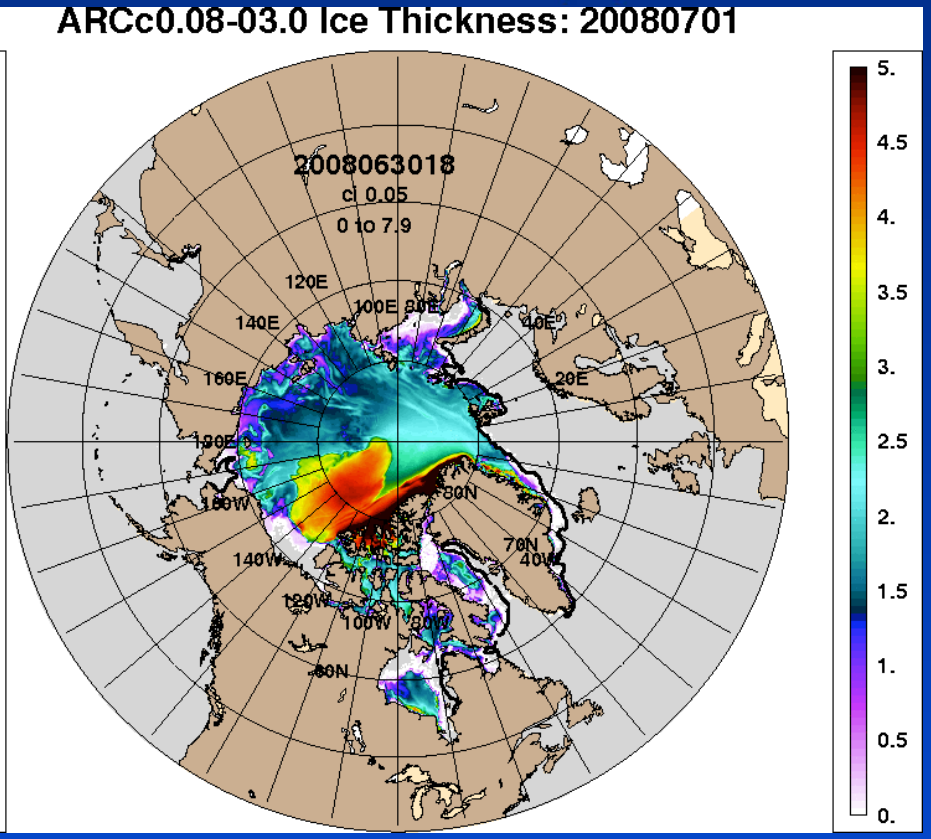
Assimilative ACNFS was initialized from non-assimilative ACNFS.
Validation period: July 2007 – June 2009.

1/12° Arctic Cap HYCOM/NCODA/CICE

Ice Concentration (%)



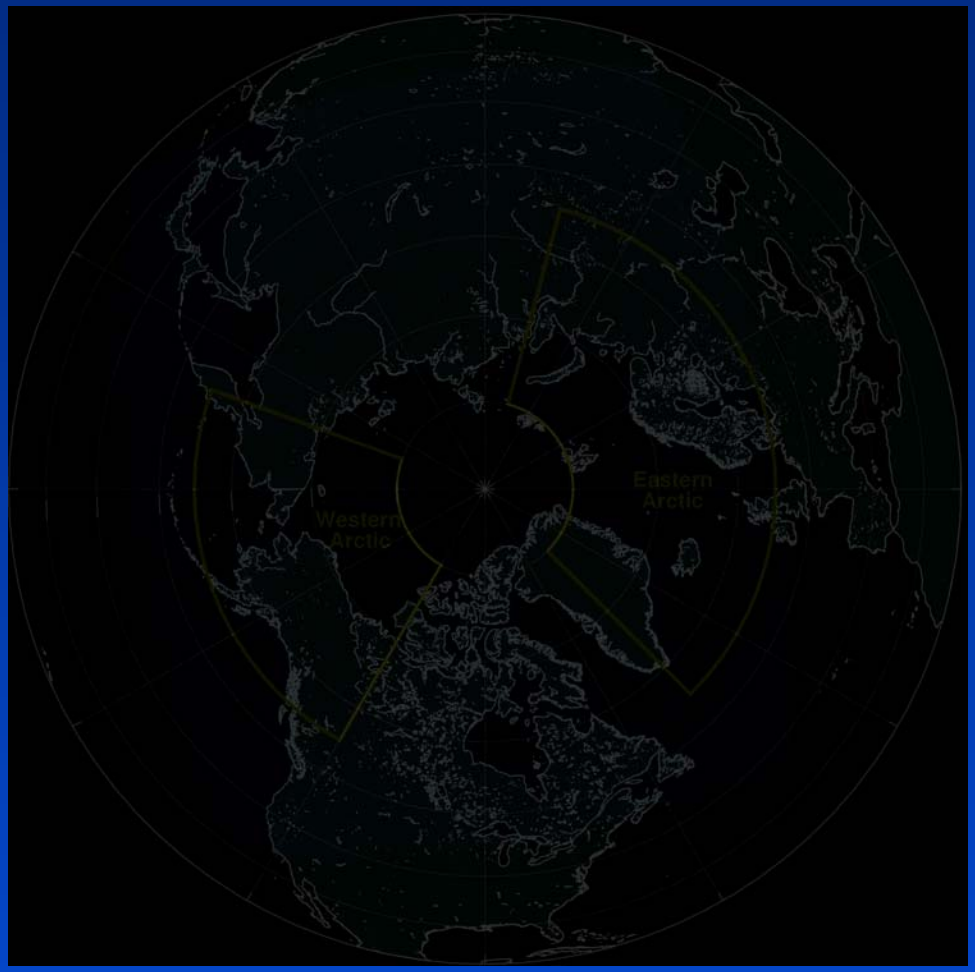
Ice Thickness (m)



Animation spans July 2008 - August 2009, every 7 days

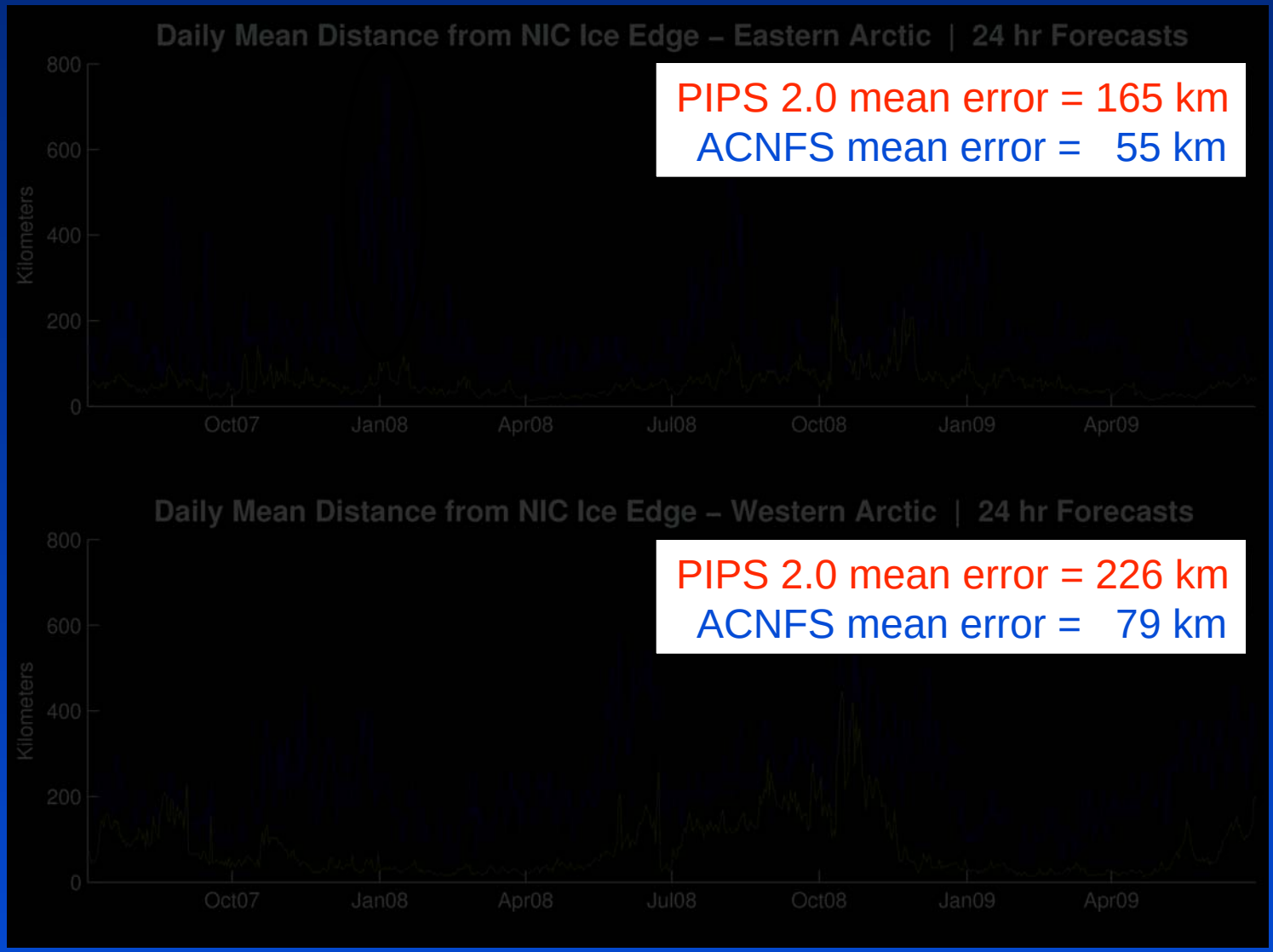
Black line is independent NIC ice edge.

Validation Results: Ice Edge Error



- Compared ice edge location from both systems to the independent NIC daily ice edge analysis
- Validated for the entire Arctic domain and regional areas (Western and Eastern Arctic)
- Validation period: July 2007 – June 2009

Validation Results: Ice Edge Error

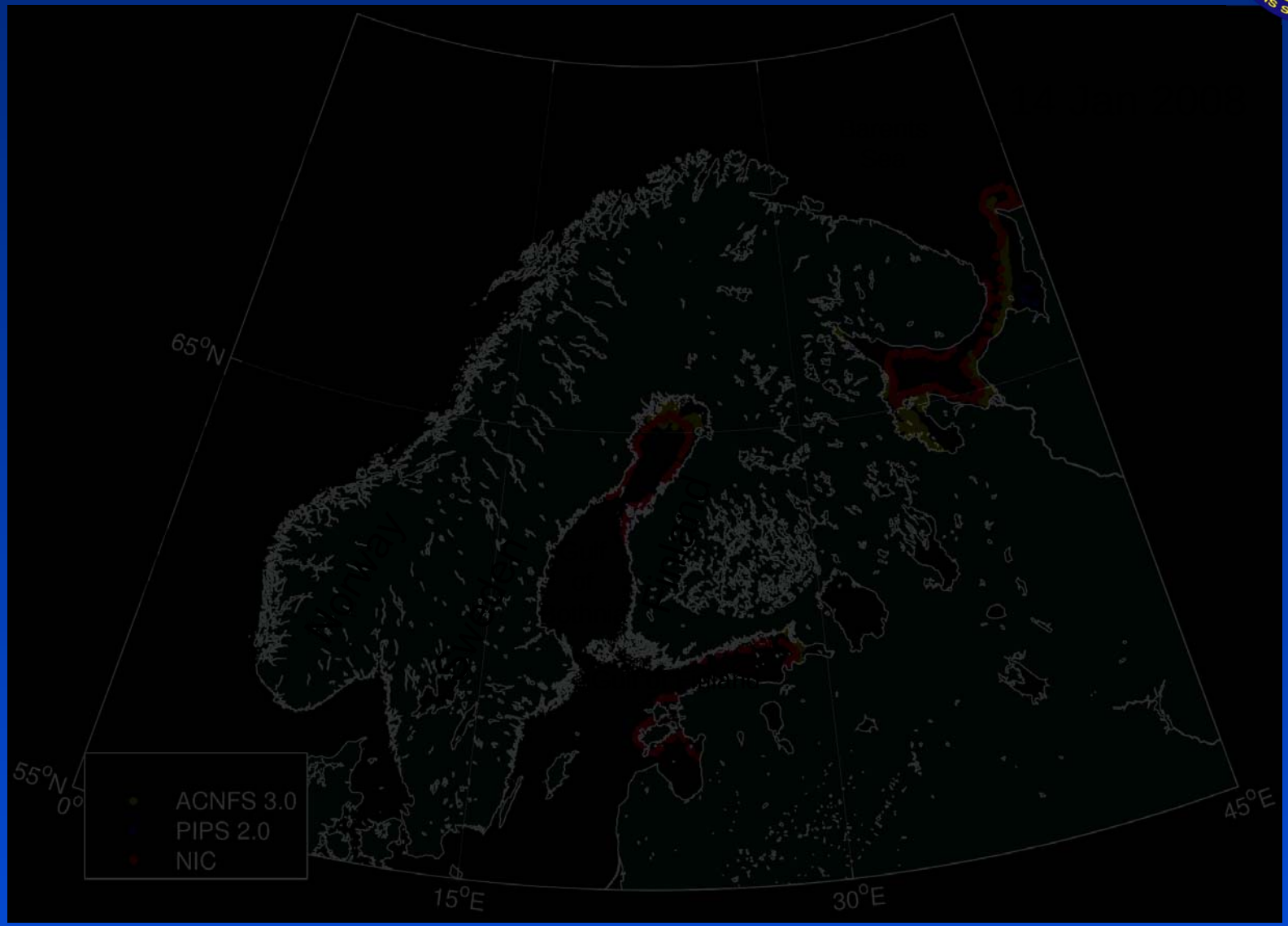


Eastern Arctic: ACNFS shows 67% improvement over PIPS 2.0

Western Arctic: ACNFS shows 65% improvement over PIPS 2.0

Using the 20% cutoff criterion

Ice Edge in Baltic Sea



Validation Results: Ice Thickness

Ice Mass Balance (IMB) Buoys (11)

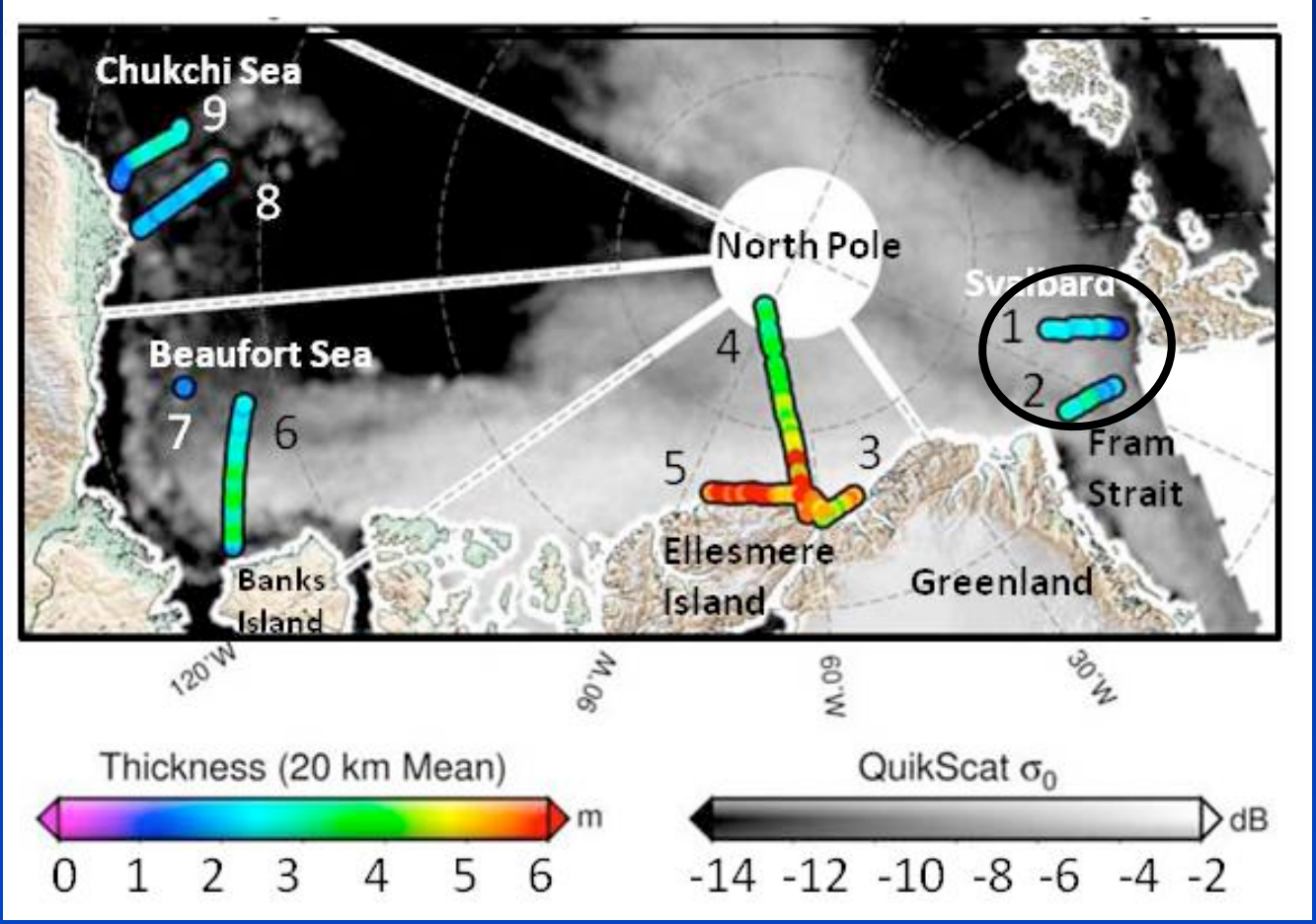
- IMB buoys deployed by the Cold Regions Research Engineering Laboratory (CRREL)
- Drift paths marked in blue – ACNFS had lower thickness bias (central and eastern Arctic)
- Drift paths marked in red – PIPS 2.0 had lower thickness bias (western Arctic and Canadian Archipelago)
- July 2007 – May 2009

Validation Results: Ice Thickness

Mean thickness error (m) (bold lower error)

Buoy name	ACNFS	PIPS 2
2006C	2.07	**2.02**
2007D	**1.50**	1.51
2006E	**1.26**	1.55
2007B	1.70	**1.07**
2007C	**0.92**	0.95
2007D	**1.40**	1.68
2007F	1.18	**0.63**
2007G	0.89	**0.53**
2007H	0.97	**-0.61**
2008D	**0.11**	-0.36
2009D	1.12	**-0.33**
Mean of absolute value of difference	1.19	**1.02**

Validation Results: Airborne Ice Thickness Survey – April 2009

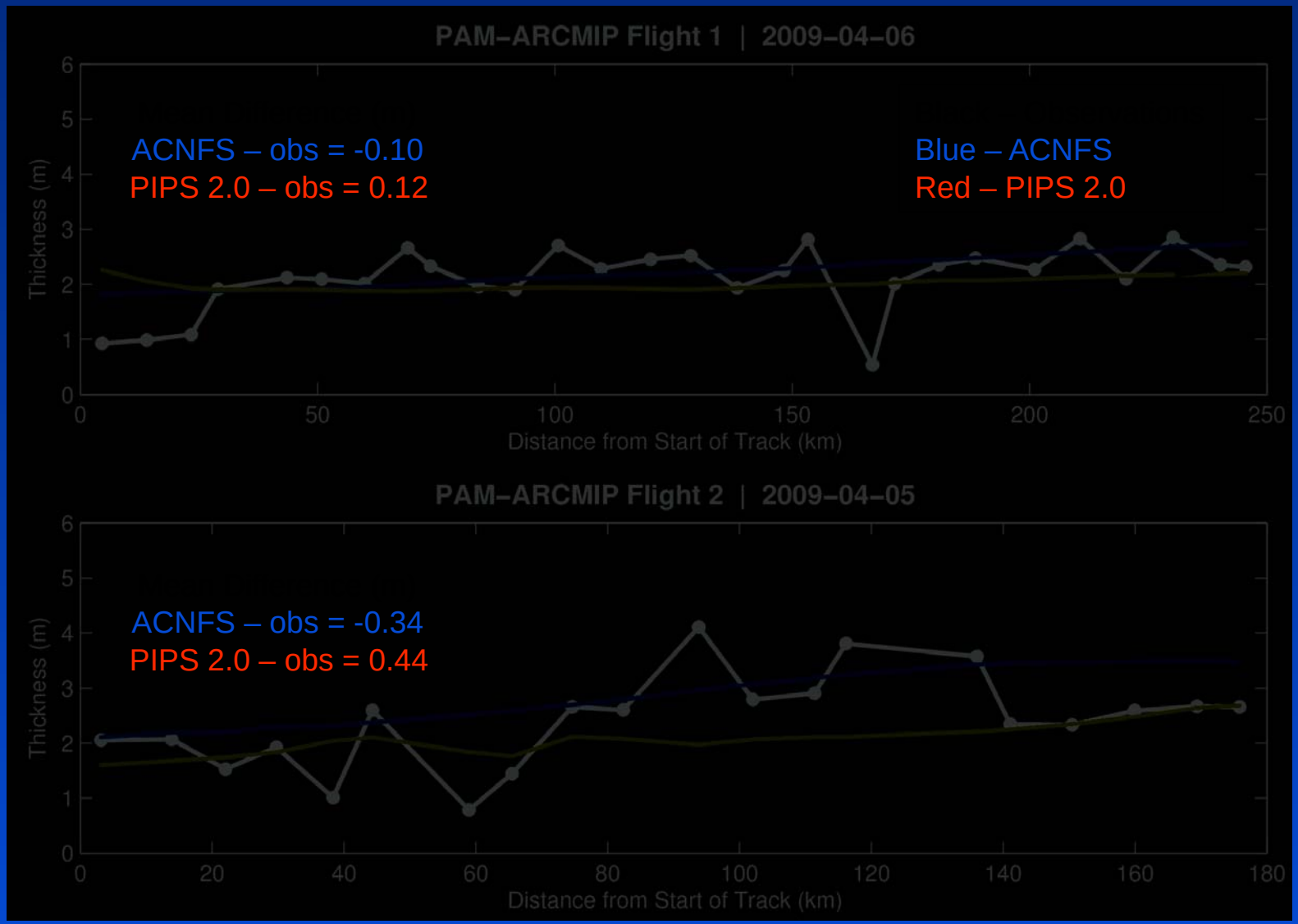


Survey reported: Total thickness (ice + snow)

Hindcast ice thickness was interpolated to the airborne survey locations

Haas et. al., 2010: Airborne electromagnetic (EM) ice thickness survey collected April 2009 as part of the Pan-Arctic Measurements and Arctic Regional Climate Model Simulations (PAM-ARCMIP) project.

Validation Results: Ice Thickness



Svalbard

Fram Strait

Validation Results: Ice Thickness

	Mean thickness (m)			Difference (m)		Difference with snow[1] (m)	
	Obs[2] AC/PIP	ACNFS	PIPS2	ACNFS – obs.	PIPS2 – obs.	ACNFS – obs.	PIPS2 – obs.
Flight 1	2.11/2.11	**2.01**	2.23	**-0.10**	0.12	**0.10**	0.32
Flight 2	2.42/2.43	**2.08**	2.87	**-0.34**	0.44	**-0.14**	0.64
Flight 4	4.48/3.83	**3.94**	3.27	**-0.54**	-0.56	**-0.34**	-0.36
Flight 6	2.97/2.98	3.52	**2.46**	0.55	**-0.52**	0.75	**-0.32**
Flight 8	1.99/1.99	**1.95**	2.21	**-0.04**	0.22	**0.16**	0.42
Flight 9	2.23/2.23	1.69	**1.95**	-0.54	**-0.53**	-0.34	**-0.33**
Absolute value of mean difference				**0.35**	0.40	**0.31**	0.40

Bold values are closest to observations.

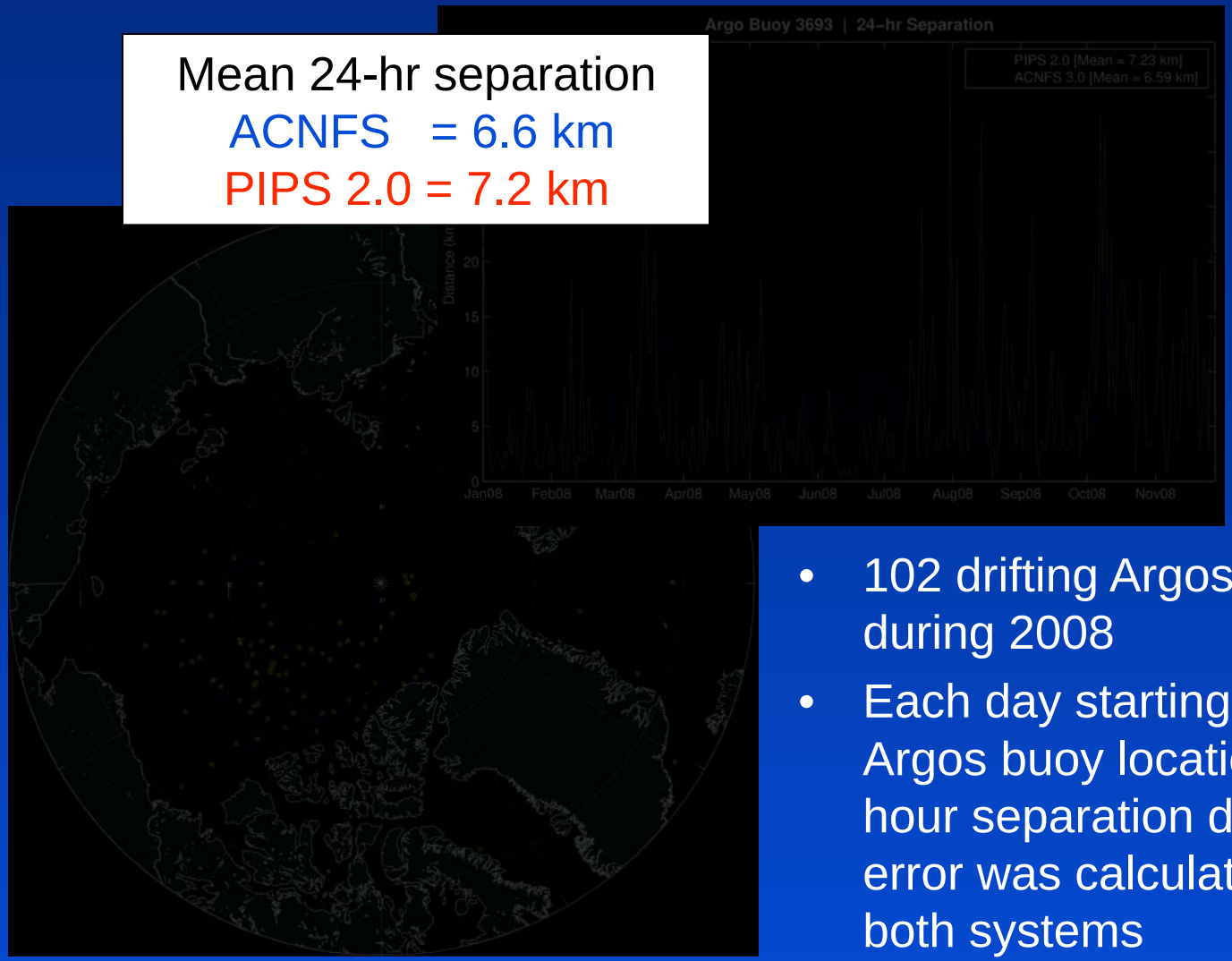
[1] Assuming a constant 20 cm snow depth for all flights.

[2] Observational mean computed only at those locations where each system also output ice.

Validation Results: Ice Drift

International Arctic Buoy Program (IABP)

Mean 24-hr separation
ACNFS = 6.6 km
PIPS 2.0 = 7.2 km



- 102 drifting Argos buoys during 2008
- Each day starting from an Argos buoy location, a 24-hour separation distance error was calculated for both systems

Validation Results: Ice Drift

Separation Distance (km)

ACNFS

Average separation error: 11 km

PIPS 2.0

Average separation error: 10 km

Isolines are annual 2008 ice thickness (m)

Validation Results: Ice Drift

Hindcast vs. observed drift velocities

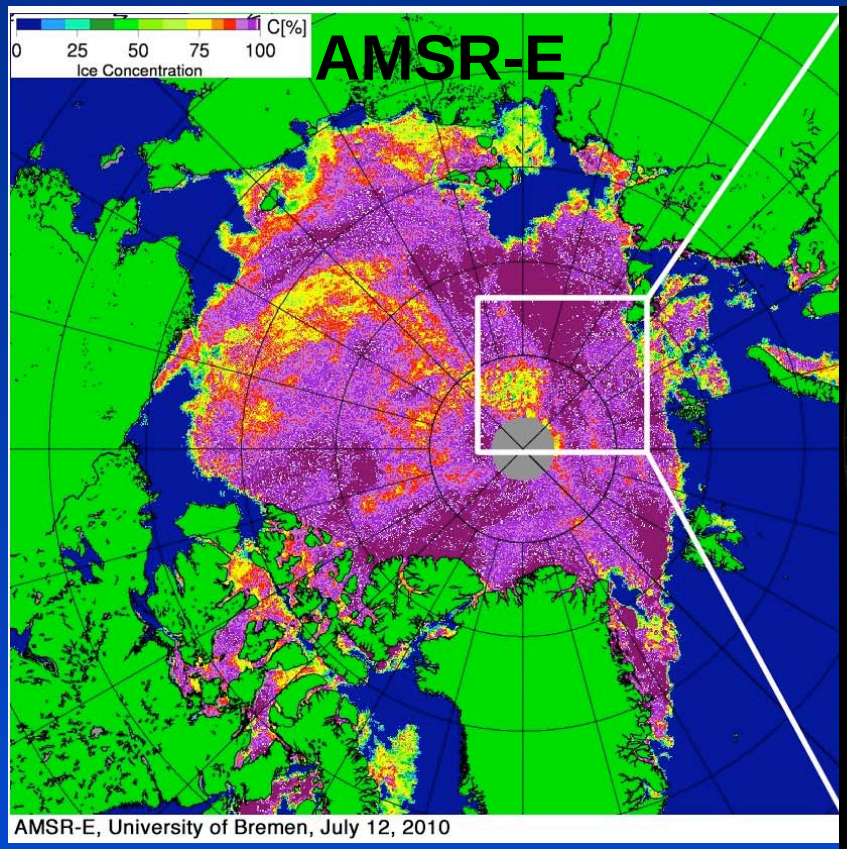
	Mean (cm/s)			Mean difference (cm/s)	
	Obs.	ACNFS	PIPS 2	ACNFS – obs.	PIPS 2 – obs.
U-vel.	5.4	6.5	5.0	1.1	-0.4
V-vel.	6.2	7.3	5.6	1.1	-0.6
Speed	9.1	10.8	8.3	1.7	-0.8

- Small differences for both systems
- ACNFS overestimates velocities and PIPS 2 underestimates velocities

ACNFS New Capability

Areas of low concentration may be indicative of leads

Ice Concentration valid 12 July 2010



Validation Testing Summary

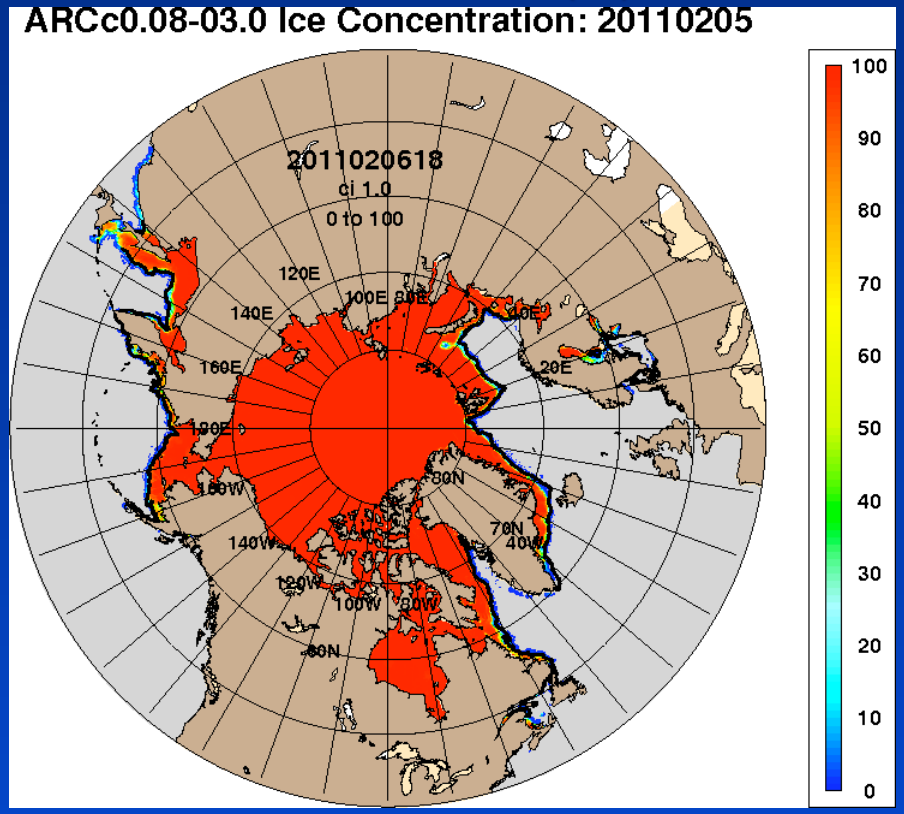
- ACNFS equal to or better than PIPS 2 and it has the capability to output products not available in PIPS 2
- NAVOCEANO is in the process of starting the operational testing

Global Real Time System

- Implement CICE in the 1/12° global model
- Change to the 3dvar version of NCODA
- Replace MODAS with ISOP (Improved Synthetic Ocean Properties)

1/12° Arctic Cap HYCOM/NCODA/CICE 5 February 2011

Ice Concentration (%)



Ice Thickness (m)