Validation of Global Ocean Forecast System (GOFS) 3.1

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Layered Ocean Model Workshop
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Copenhagen, Denmark

GOFS Descriptions and Status

GOFS 3.0:

1/12° 32 layer HYCOM
NCODA-3DVAR
Modular Ocean Data Assimilation System (MODAS)
energy-loan ice

Operational system running on Navy DSRC IBM iDataPlex computers

GOFS 3.1:

1/12° 41 layer HYCOM (9 additional layers in the upper ocean)
NCODA-3DVAR
Improved Synthetic Ocean Profiles (**ISOP)**
Los Alamos Community Ice CodE (**CICE)**

Currently in operational testing mode (OPTEST)

GOFS 3.5:

1/25° 41 layer HYCOM **(Transition scheduled for Fall 2016)**
NCODA-3DVAR
ISOP
CICE
tides

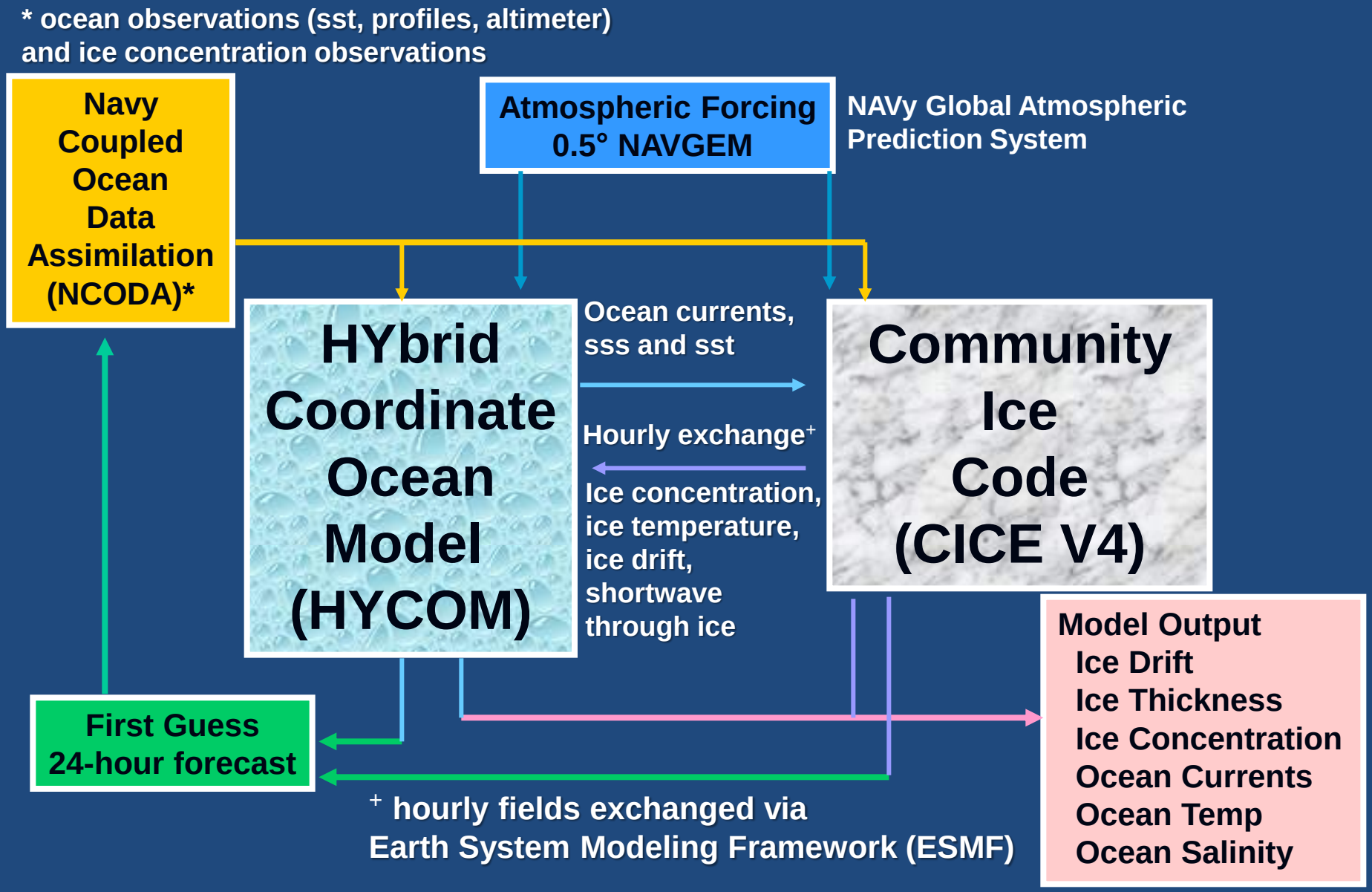
Arctic Cap:

Sub region of GOFS 3.0 north of 40°N
CICE

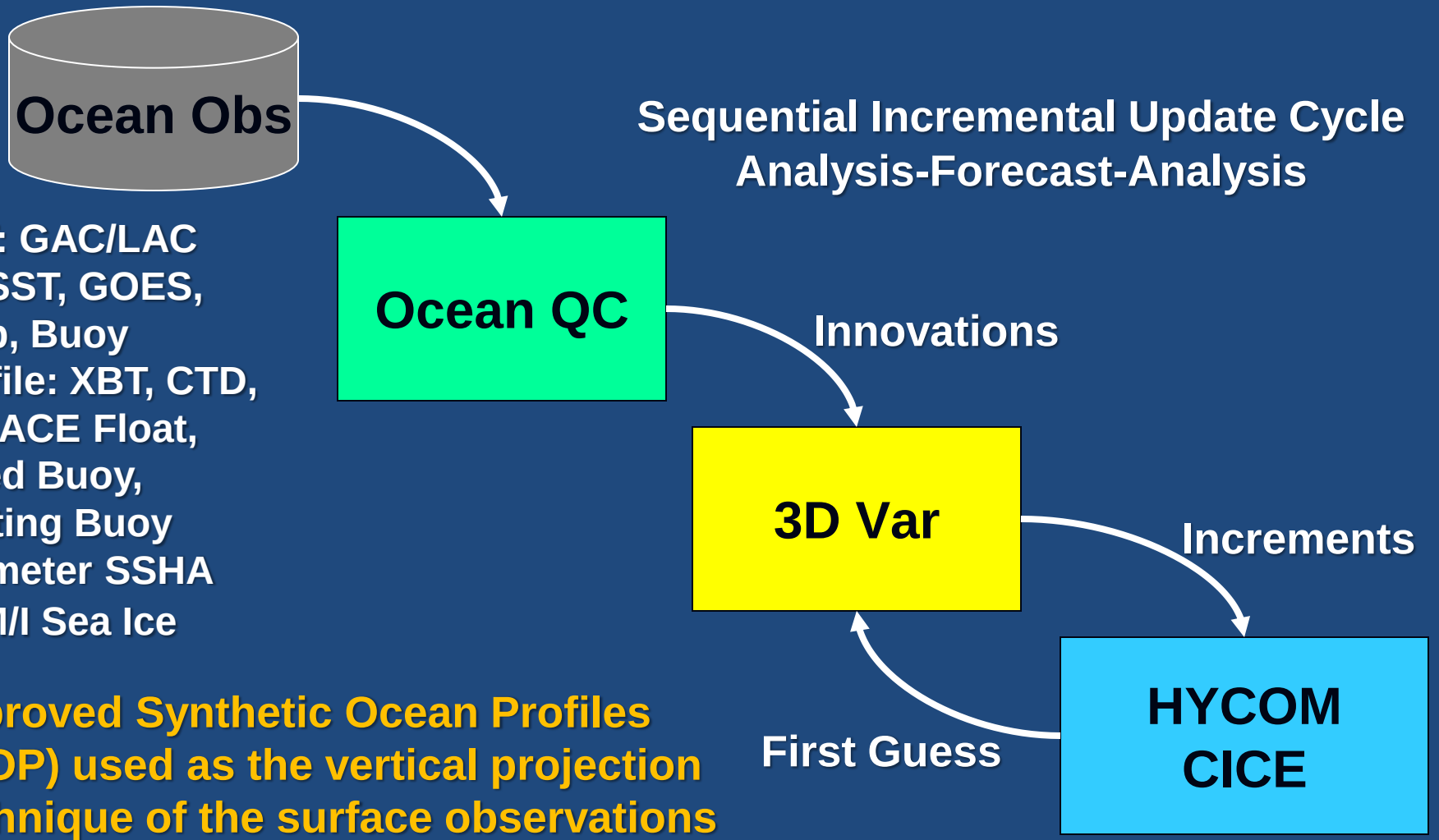
GOFS 3.1 Configuration

- **Horizontal grid: 1/12° equatorial resolution**
  - **4500 x 3298 grid points, ~6.5 km spacing on average, ~3.5 km at pole**
- **Mercator 79°S to 47°N, then Arctic dipole patch**
- **Vertical coordinate surfaces: 41 for σ_2***
- **KPP mixed layer model**
- **Community Ice CodE (CICE v4) sea-ice model**
  Coupling between ocean and ice via the Earth System Modeling Framework (ESMF)
- **Surface forcing: wind stress, wind speed, thermal forcing, precipitation, relaxation to climatological SSS**
- **Monthly river runoff (986 rivers)**
- **Initialize from January climatology (GDEM 4.2) T and S**
  - **No subsurface relaxation to climatology**

HYCOM/NCODA/CICE

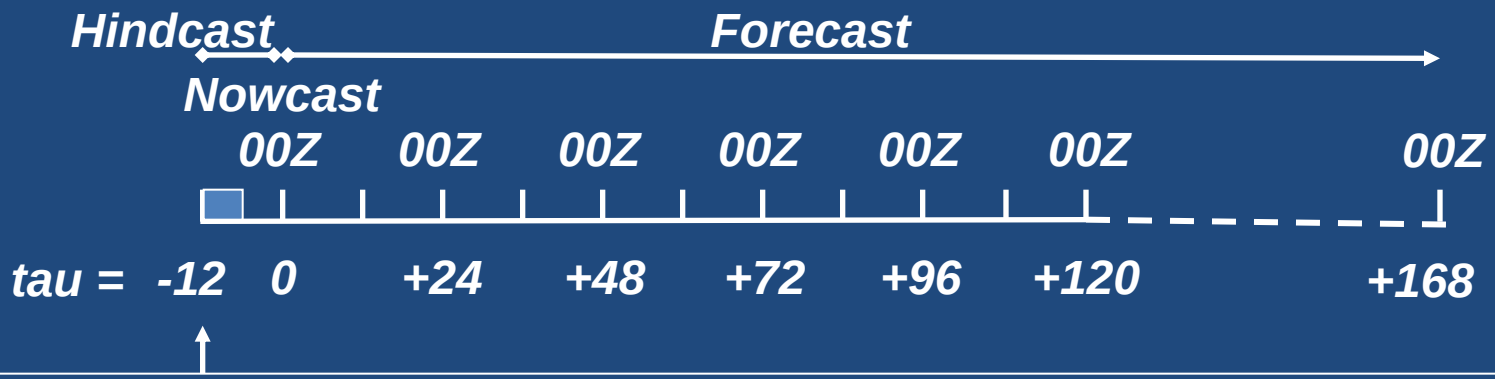


Navy Coupled Ocean Data Assimilation



3Dvar - simultaneous analysis ice concentration and 5 ocean variables: temperature, salinity, geopotential, layer pressure, velocity (u,v)

GOFS 3.1 Runstream



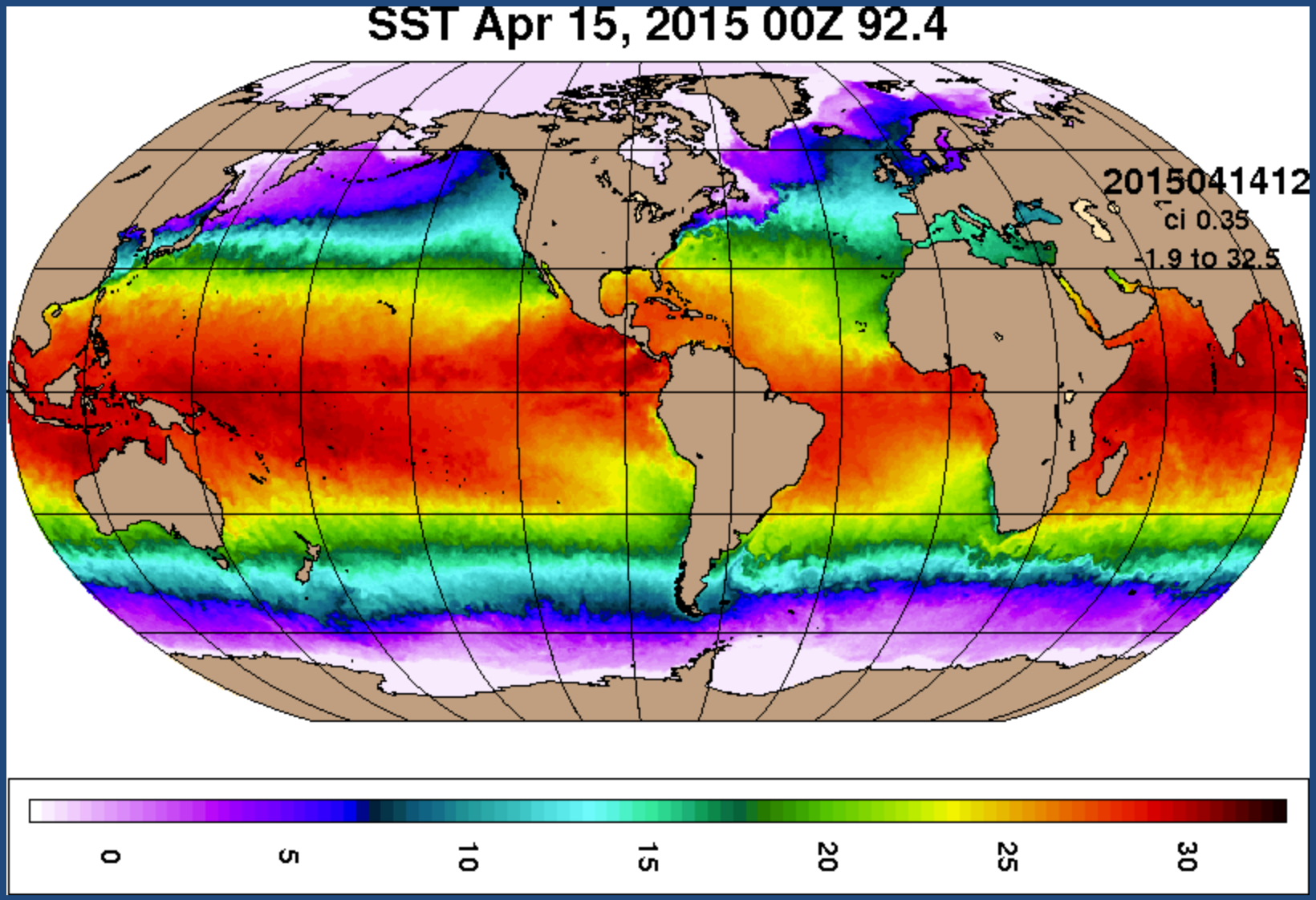
NCODA analysis windows centered at this time using receipt time and FGAT using observations received since the previous analysis and looking back:
-96 hours for profile data
-120 hours for altimeter data

1) *Perform first NCODA analysis centered on tau = -12*
2) *Run HYCOM using incremental updating (▭) over the first 6 hours*
3) *Run HYCOM in forecast mode out to tau = 168*

FGAT – First Guess at Appropriate Time

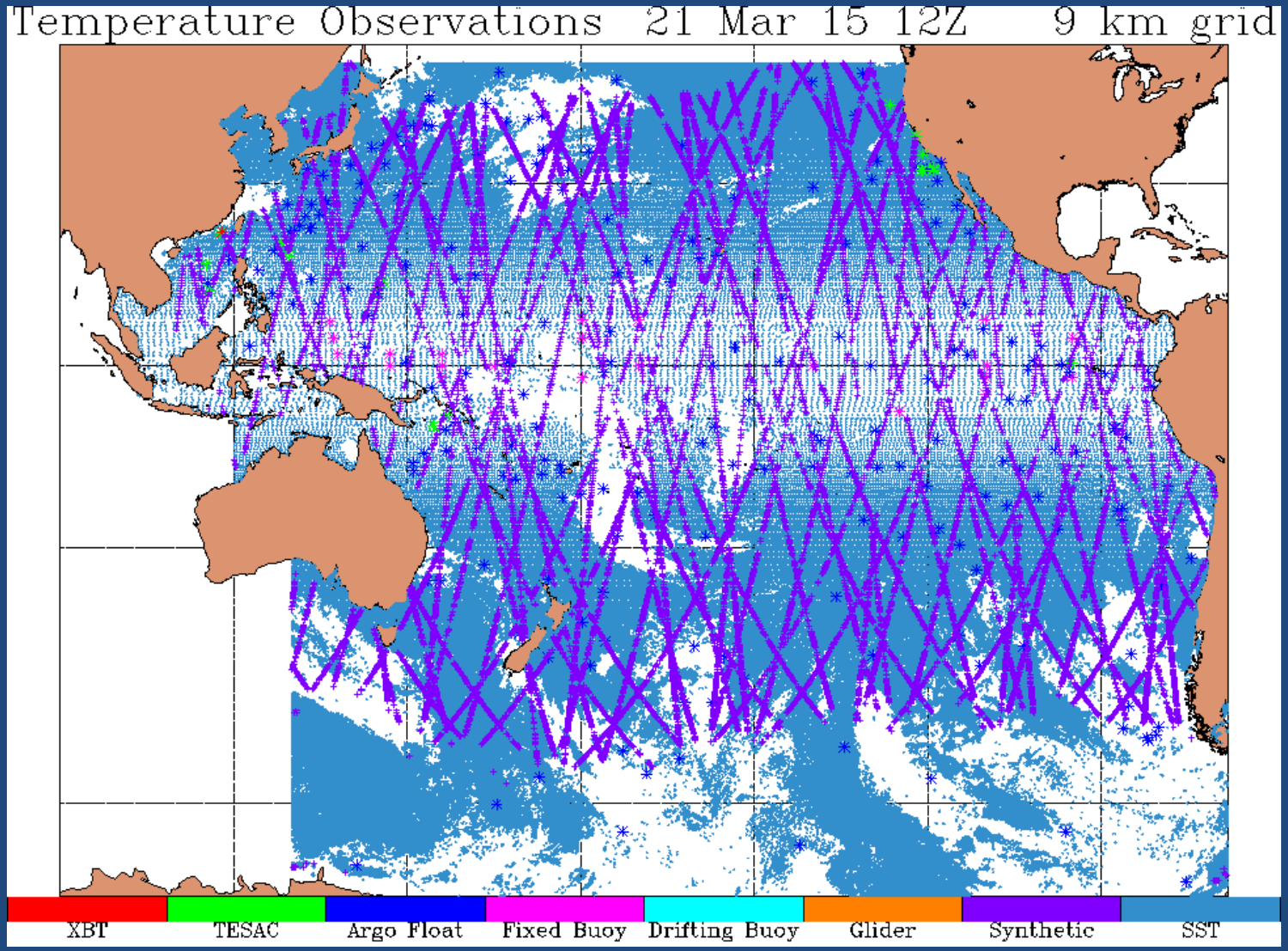
1/12° Global HYCOM/CICE

Snapshot of Sea Surface Temperature



GOFS 3.1 Temperature Observations

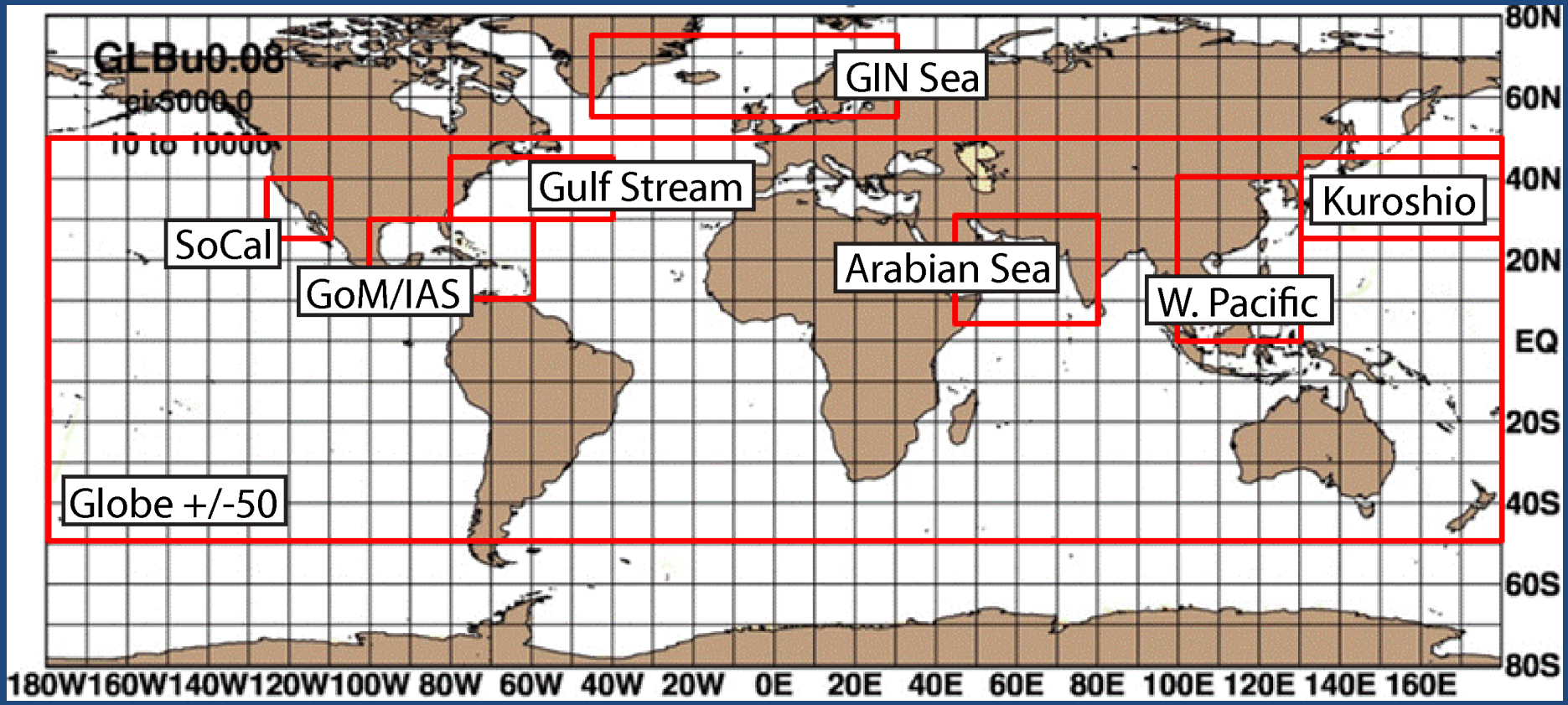
Pacific Ocean



Downward projection into the interior at all locations with SSH and SST (synthetics)

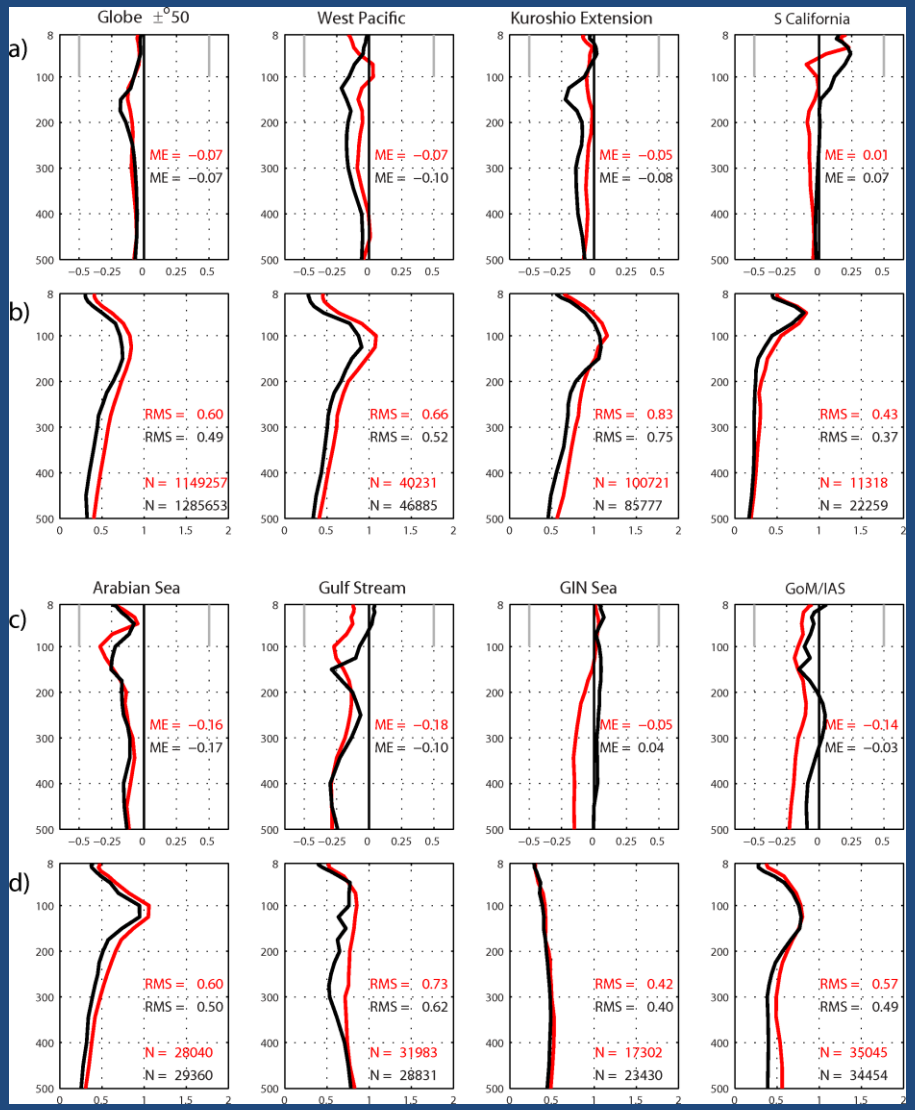
Ocean Validation Regions

Used in the Validation Test Report (VTR)



Validation regions are defined by the Naval Oceanographic Office

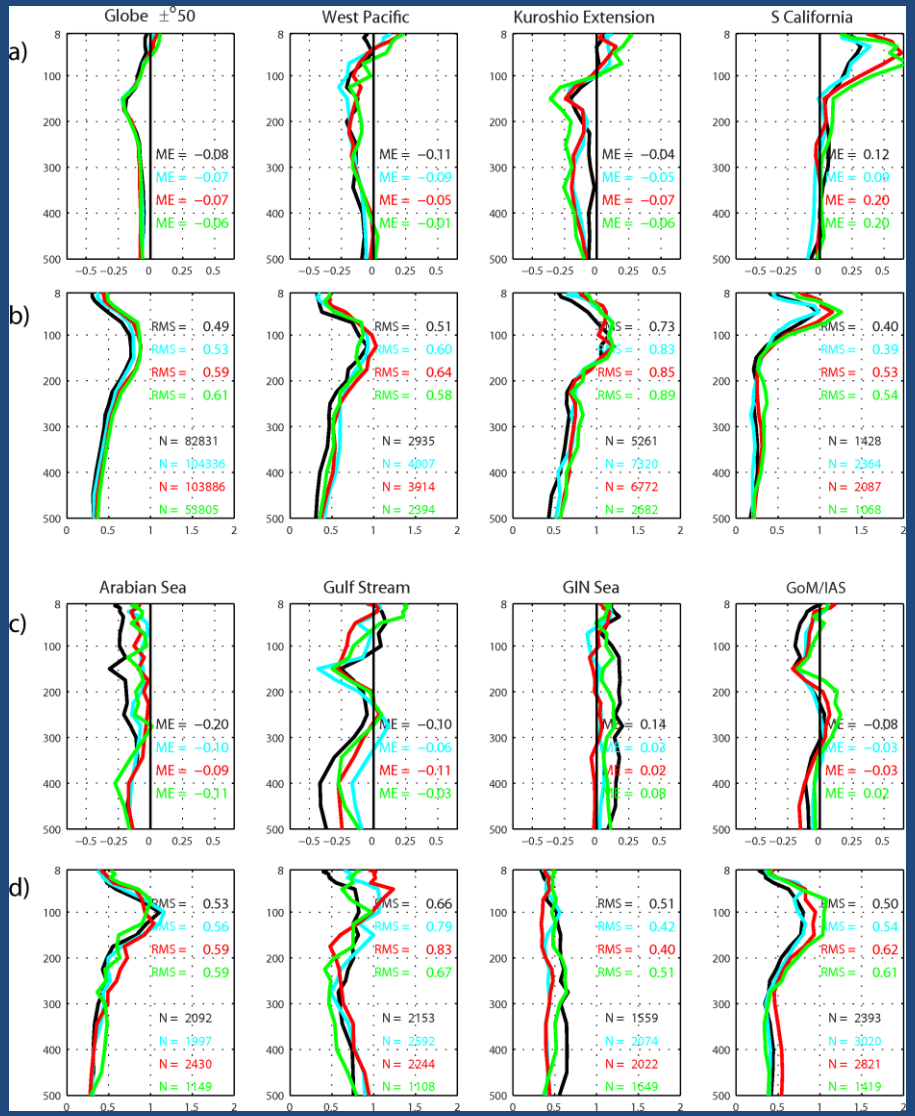
Ocean Validation – Temperature Profiles
GOFS 3.0 vs. GOFS 3.1 Nowcast Time



Red curves: **GOFS 3.0**
Black curves: **GOFS 3.1**

Temperature (°C) vs. depth error analysis in the upper 500 m against **unassimilated** profile observations at the "nowcast" time for the eight regions defined on the previous slide spanning the hindcast period August 2013 – April 2014. The gray lines in the ME plots are the tolerances set by NAVOCEANO for the temperature bias in the GOFS 3.0 OPTEST

Ocean Validation – Temperature Profiles
GOFS 3.1 Forecast Horizons (5,10,14 days)



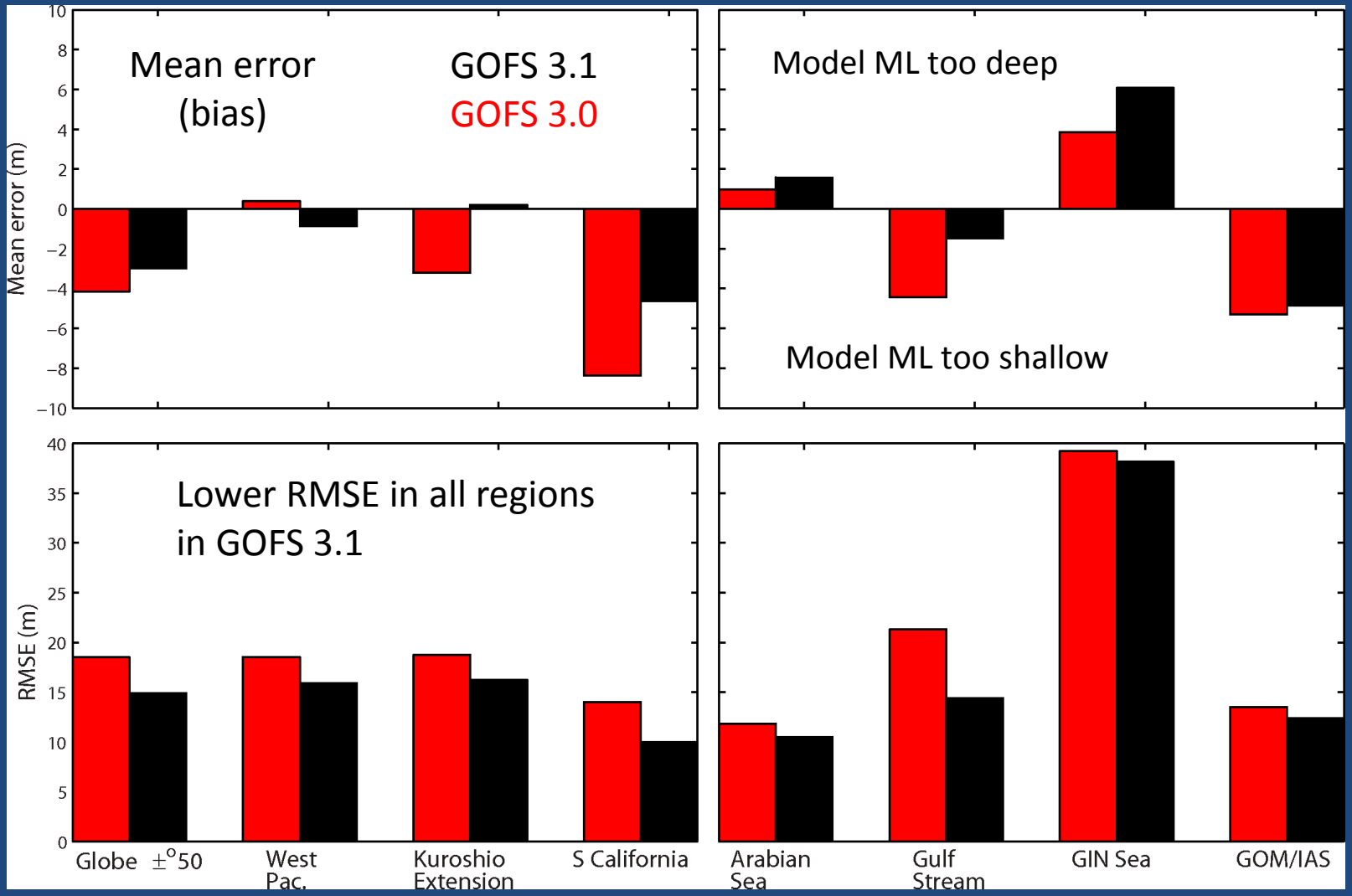
Black curves: **Nowcast**
Cyan curves: **5-day forecast**
Red curves: **10-day forecast**
Green curves: **14-day forecast**

Temperature (°C) vs. depth error analysis in the upper 500 m against **unassimilated** profile observations for the eight analysis regions for the 14-day forecasts initialized from the hindcast period August 2013 – April 2014.

Not a lot of forecast skill degradation Out to 14 day forecast horizon.

Ocean Validation – Mixed Layer Depth

GOFS 3.0 vs. GOFS 3.1Nowcast Time

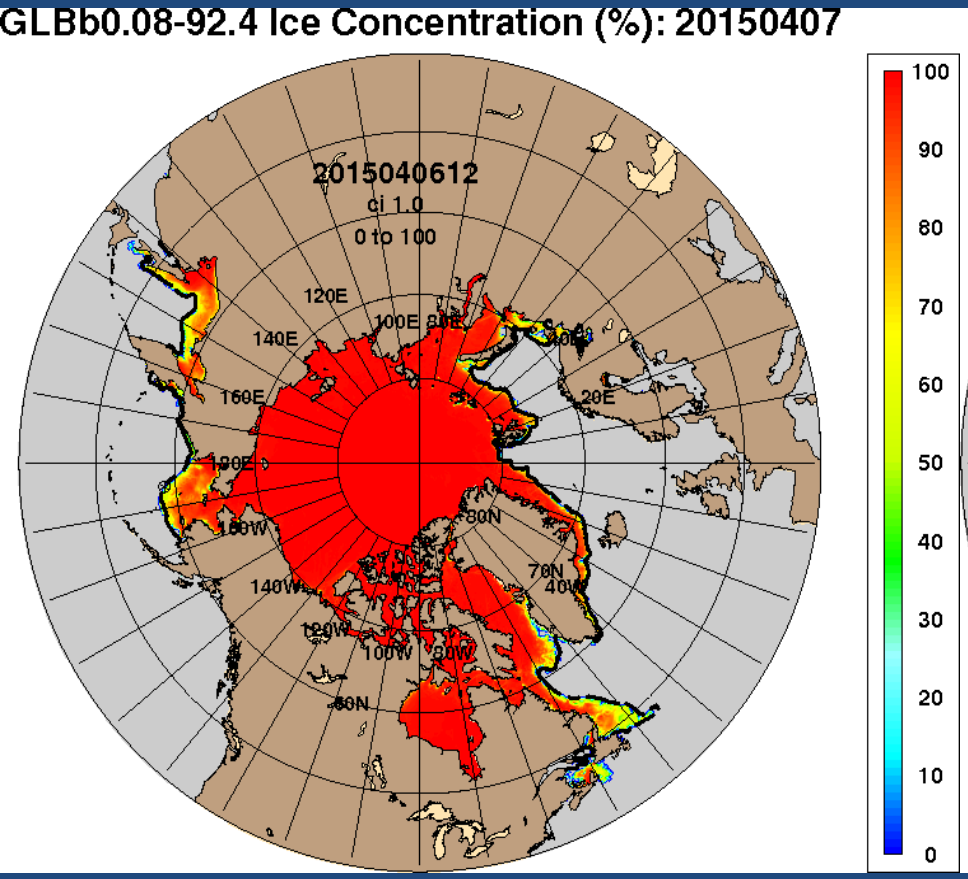


August 2013 – April 2014

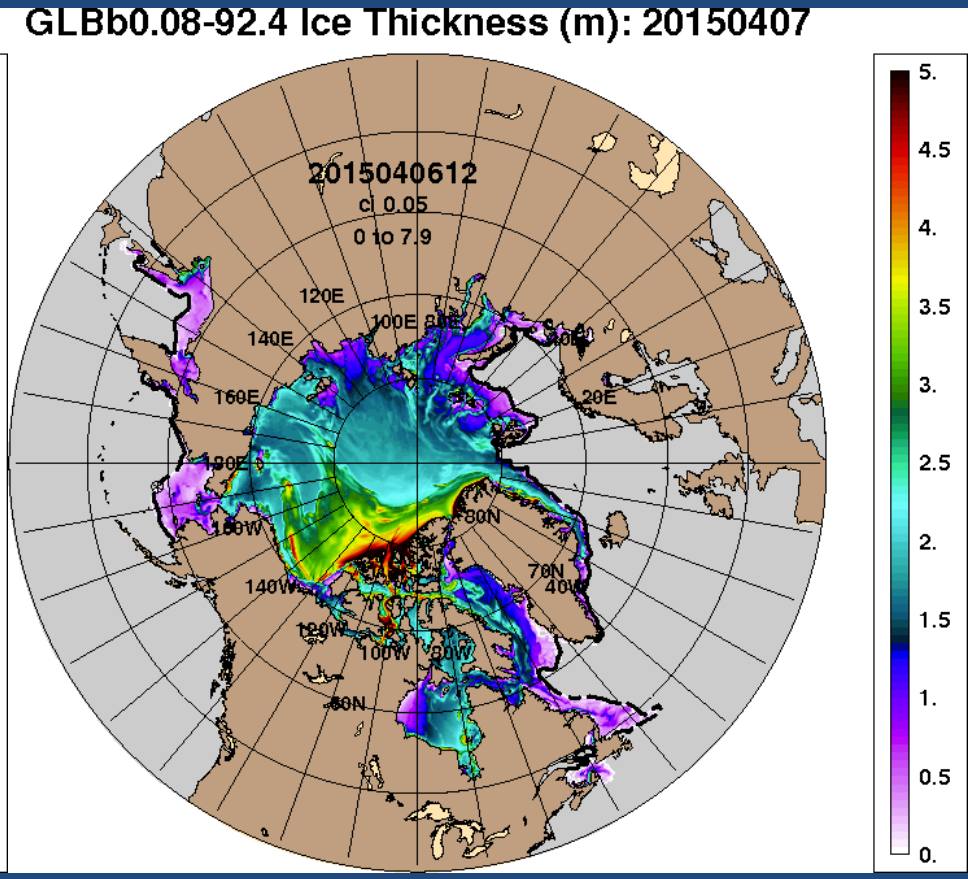
GOFS 3.1 includes 2-way nested CICE

30-day animation starting on 7 April 2015

Ice Concentration (%)

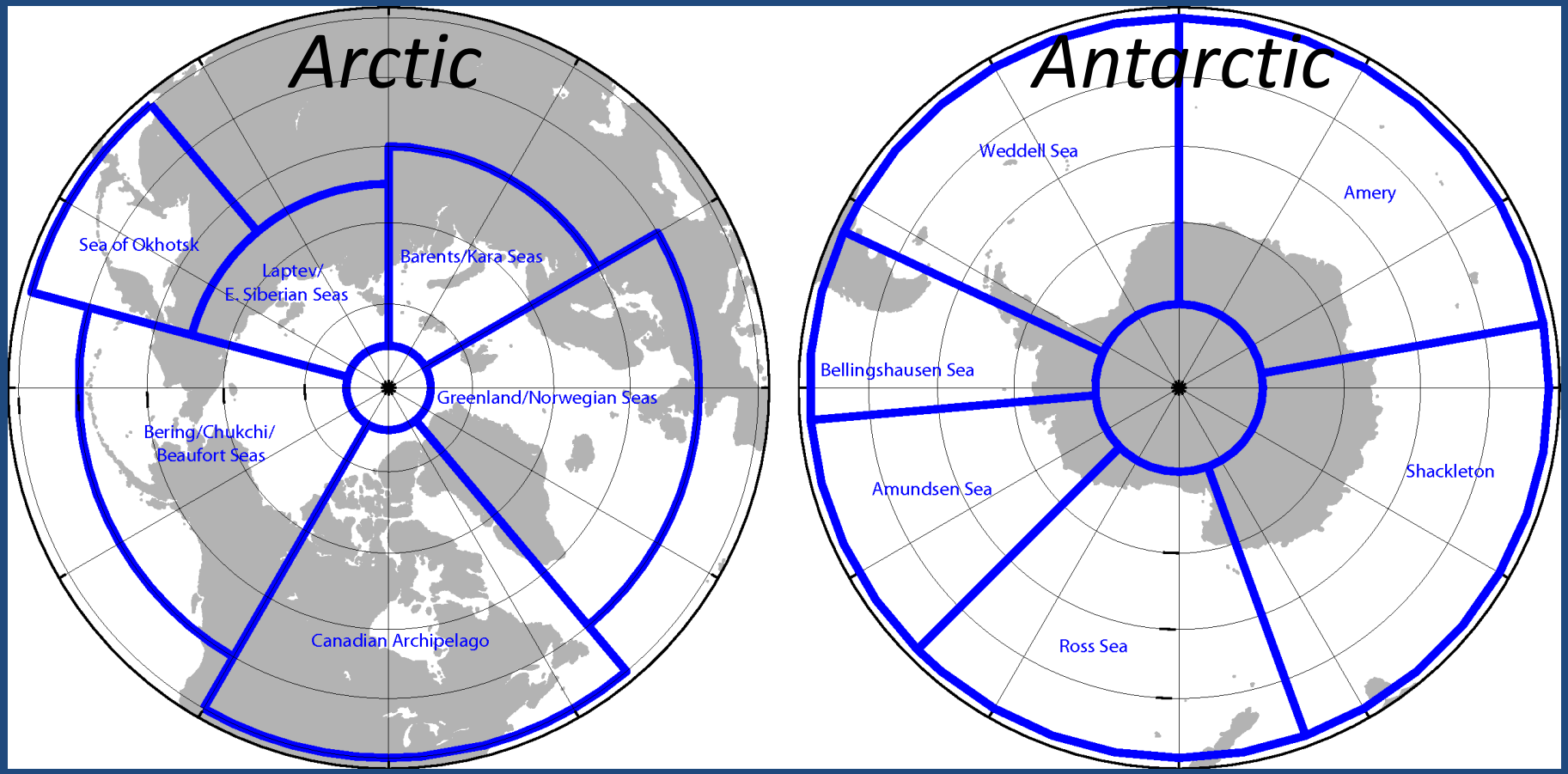


Ice Thickness (m)



Black line is the independent ice edge analysis from the National Ice Center (NIC)

Polar (Ice) Validation Regions

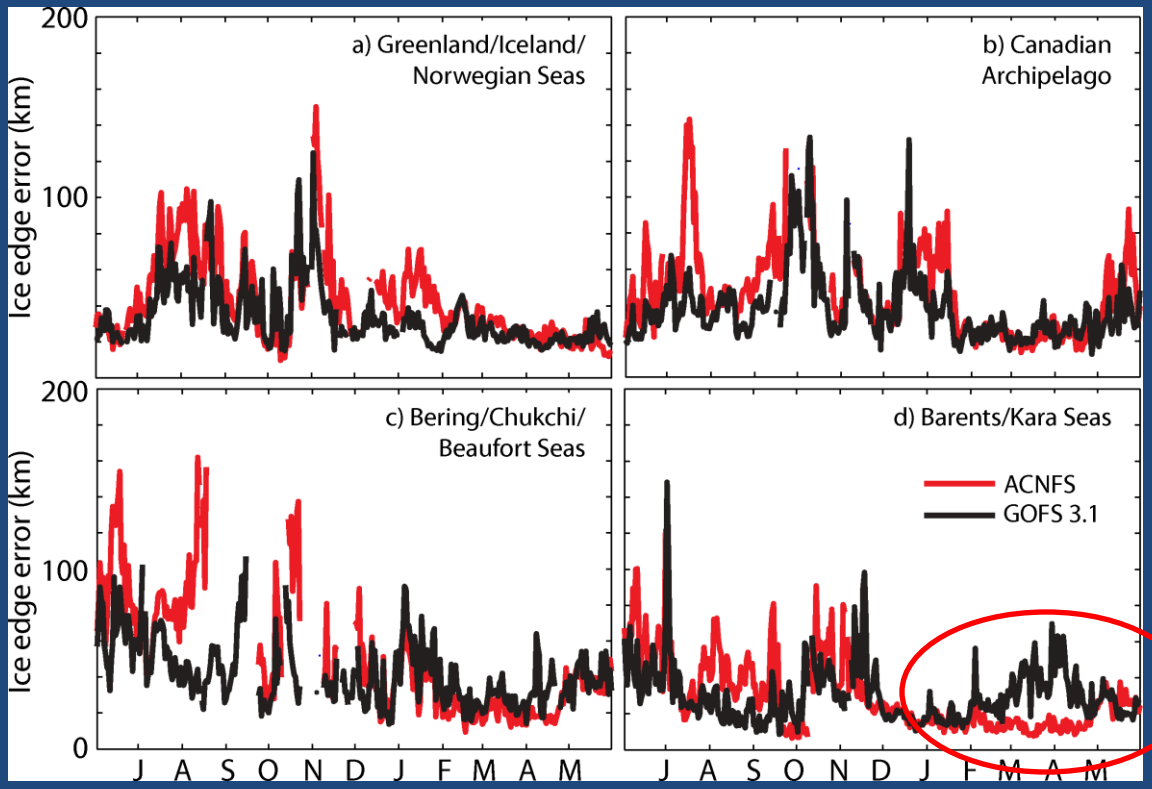


Compare independent observations against **GOFS 3.1 and ACNFS** hindcast output (1 June 2012 – 31 May 2013)

Ice Edge Error

Arctic

Ice edge error (km) at nowcast time vs. time, (1 June 2012 – 31 May 2013)



Mean Error

28.4 km 36.4 km 22%	38.4 km 43.6 km 12%
38.9 km 44.9 km 13%	28.8 km 25.6 km -13%

Due to an assimilation error that has been corrected

The GOFS 3.1 and ACNFS 5% ice concentration isolines are compared against the independent National Ice Center ice edge analysis

Mean Ice Edge Location Error (km)

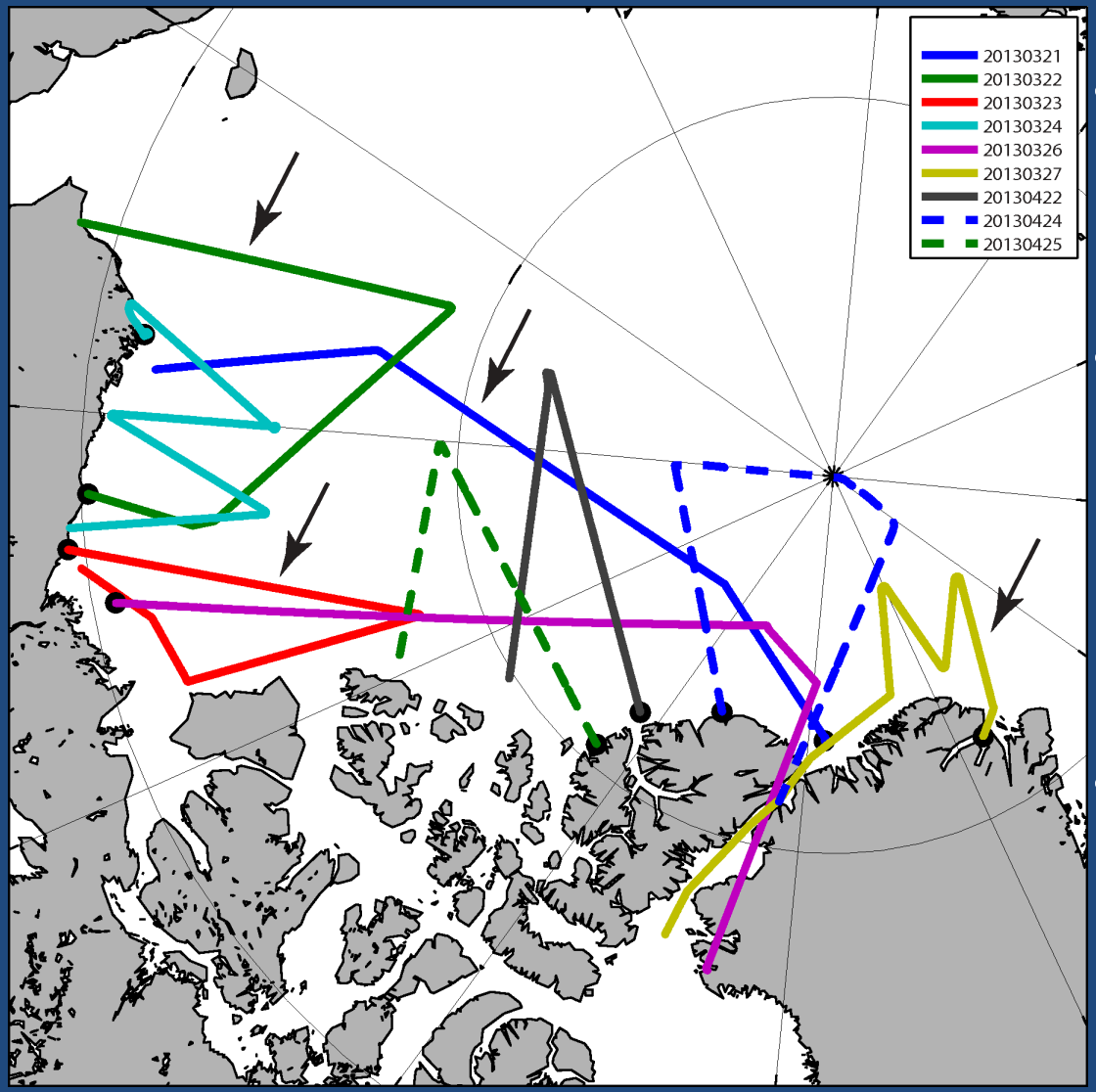
Antarctic

Region	GOFS 3.1
Amery Sea	34.2
Shackleton Sea	30.6
Ross Sea	29.2
Amundsen Sea	37.0
Bellinghausen Sea	39.9
Weddell Sea	47.3

Validation period is 1 June 2012 – 31 May 2013

Take-home message: Ice edge errors in the Southern Hemisphere have similar magnitudes as ice edge errors in the Northern Hemisphere

"IceBridge" Flights (in lieu of satellite obs)

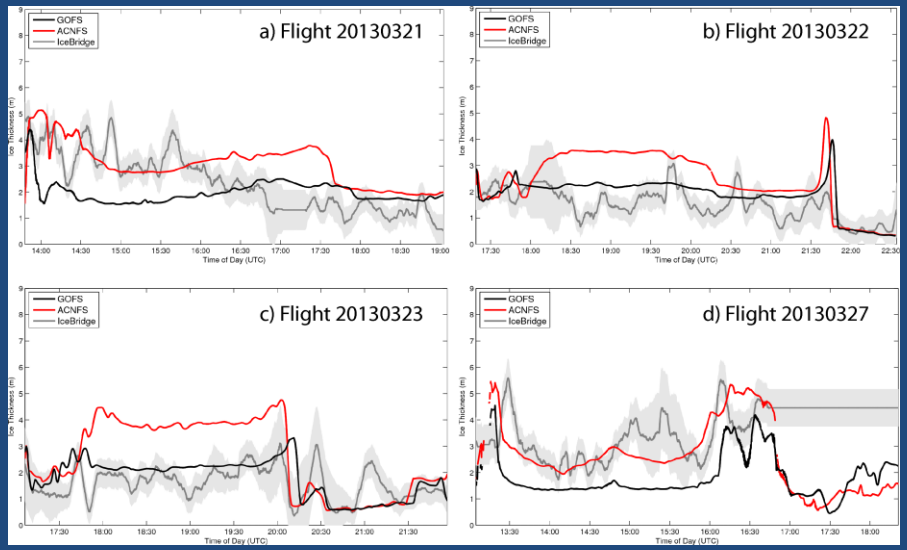


- Black arrows indicate flight data comparison shown on the next slide
- GOFS 3.1 has generally lower thickness error north of Alaska (Beaufort Sea) and the Canadian Archipelago
- ACNFS generally has lower thickness error north of Greenland

Ice Thickness vs. IceBridge

Select 2013 IceBridge Thickness Comparisons

IceBridge
GOFS 3.1
ACNFS

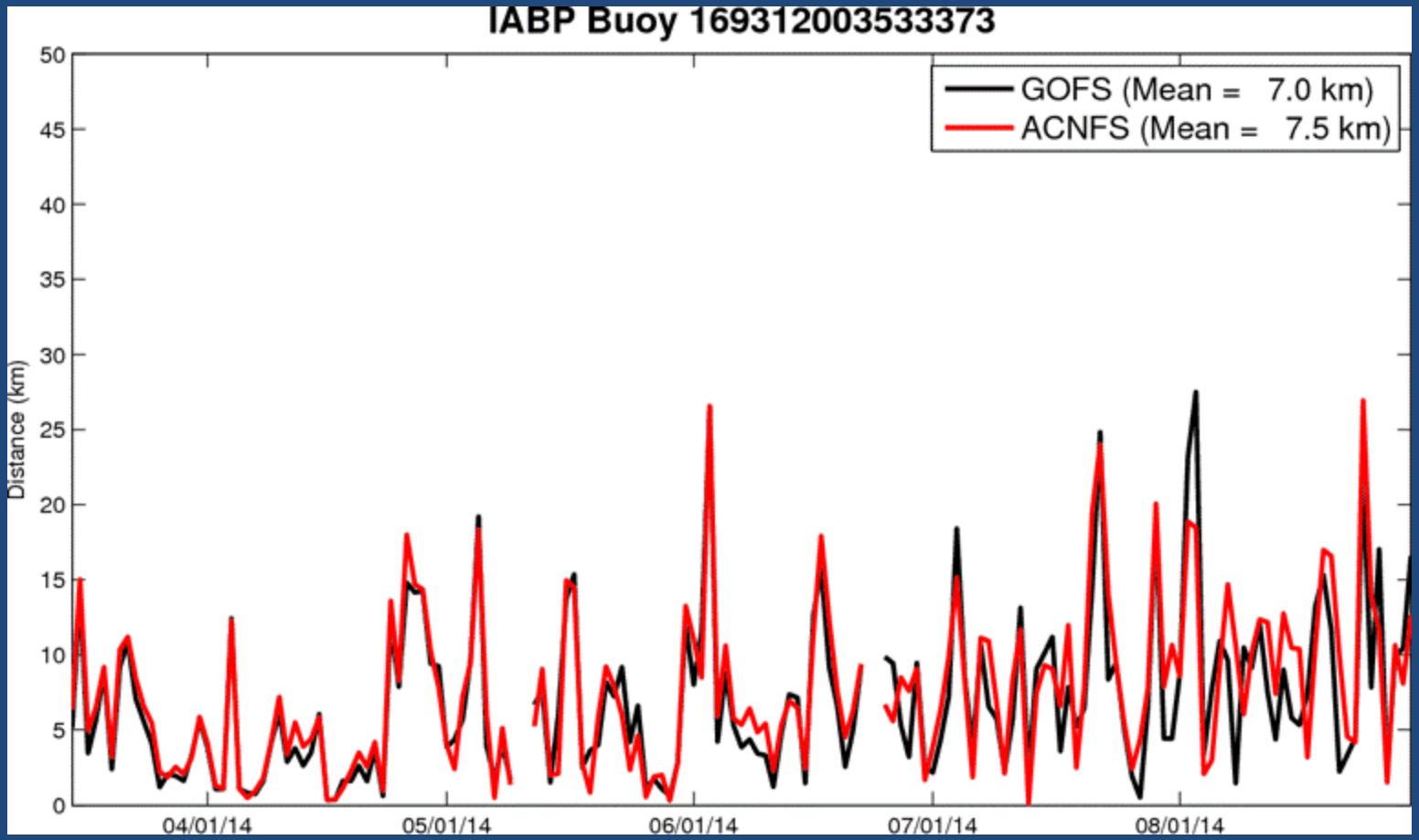


Flight	Bias		Absolute Bias		RMS Difference	
	GOFS 3.1	ACNFS	GOFS 3.1	ACNFS	GOFS 3.1	ACNFS
20130321	-0.43	0.60	0.98	0.90	1.22	1.09
20130322	0.39	0.98	0.54	1.08	0.67	1.33
20130323	0.23	1.04	0.55	1.33	0.77	1.59
20130324	0.59	0.82	0.82	1.01	1.05	1.32
20130326	-0.76	0.76	0.96	1.09	1.23	1.32
20130327	-1.89	-1.11	1.91	1.45	2.14	1.93
20130422	-0.57	0.80	0.83	0.85	1.00	0.99
20130424	-1.33	-0.11	1.40	0.62	1.87	0.94
20130425	-0.28	1.46	0.63	1.47	0.79	1.55

Ice Drift

- Compared 24-hour forecast ice drift against 129 International Arctic Buoy Program drifting buoys
- Initial results showed GOFS 3.1 was 35% too fast and ACNFS was 15% too fast
- GOFS 3.1 used ocean currents averaged over 3 m but ACNFS used currents averaged over 10 m
  - Options:
    - Use consistent depth for averaging ocean currents
    - Modify the ice-ocean drag coefficient
- Ice-ocean drag coefficient doubled and a new Jan-Aug 2014 hindcast was integrated to compute new ice drift errors

Drifting Buoy Comparison



Twenty-four hour separation distance (km) between the International Arctic Buoy Program (IABP) ice drifting buoy 169312003533373 and GOFS 3.1 (black) and ACNFS (red) over the period 15 March - 3 September 2014. The mean separation distance for GOFS is 7.0 km and 7.5 km for ACNFS.

Ice Drift

Observed and forecast ice speed (cm/s) against all IABP drifters

Variable	Observed	GOFS 3.1	ACNFS	GOFS - Observed	ACNFS - Observed
Statistics over the period January-August 2014					
Speed	8.78	9.97	9.59	1.19 (14%)	0.81 (9%)
Statistics over the period January-March 2014					
Speed	7.90	9.43	9.96	1.53 (19%)	2.06 (26%)
Statistics over the period June-August 2014					
Speed	10.41	11.20	9.87	0.79 (8%)	-0.54 (-5%)

- ACNFS has lower overall (Jan-Aug) error
- GOFS 3.1 has lower error in the winter (Jan-Mar)
- ACNFS has lower error in summer (Jun-Aug)
- Even though ACNFS slightly outperformed GOFS 3.1 in ice drift, the NIC agreed that in the net, GOFS 3.1 outperformed ACNFS (edge, concentration, thickness, etc.)

High resolution ice assimilation

- SSMIS ≈ 25 km resolution
- AMSR2 ≈ 10 km resolution
- IMS ≈ 4 km resolution
- Implemented 2 Feb 2015 in real-time GOFS 3.1 runstream
- Significant improvement in edge location error

GOFS 3.1 ice edge location error (km) using various ice assimilation data sources

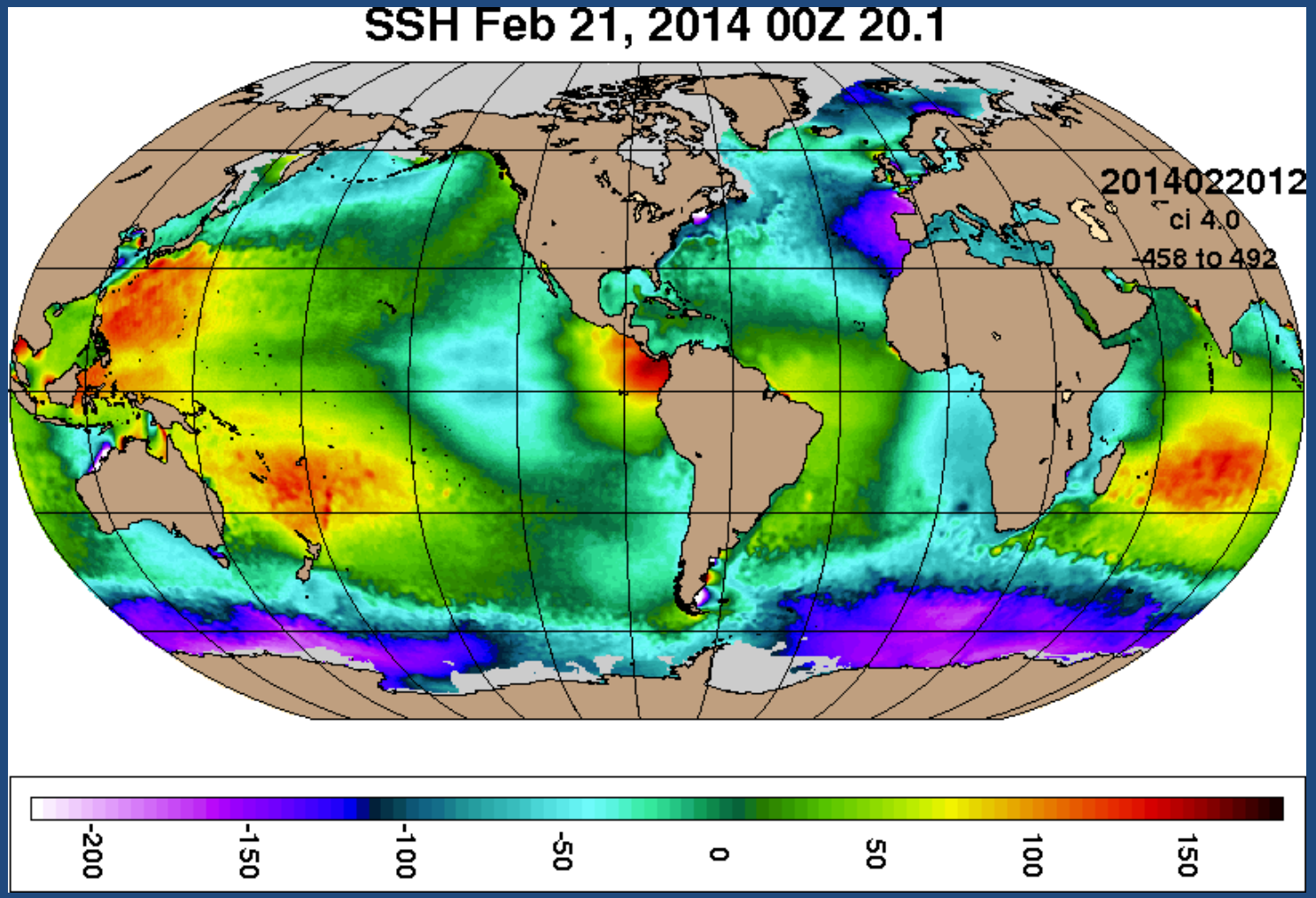
Region	GOFS 3.1		
	SSMIS	AMSR2 and IMS	AMSR2 + SSMIS and IMS
GIN Sea	72	19	19
Barents/Kara Seas	47	22	22
Laptev Sea	59	24	24
Bering/Chukchi/ Beaufort	57	22	22
Canadian Archipelago	83	31	31
Total Arctic	64	25	25
Percent improvement over SSMIS	---	62%	62%

Hindcast period: Jun-Aug 2014

GOFS 3.5 Demonstration

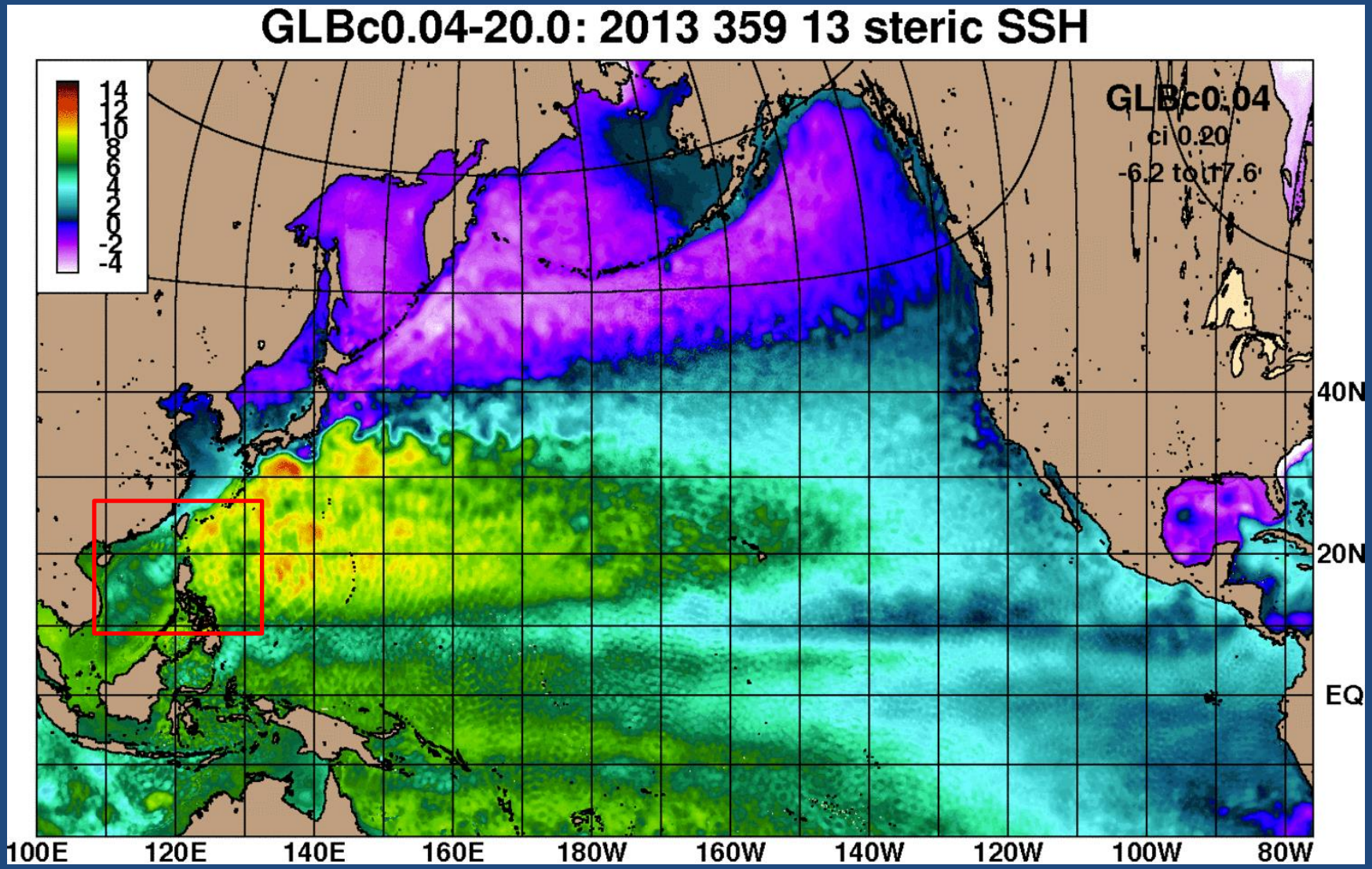
1/25° HYCOM/CICE/NCODA with tides running in demonstration mode at Navy DSRC on Cray XC30

Total SSH (including the barotropic tidal signal)



GOFS 3.5 Demonstration

Steric SSH reveals the generation locations and propagation of internal waves



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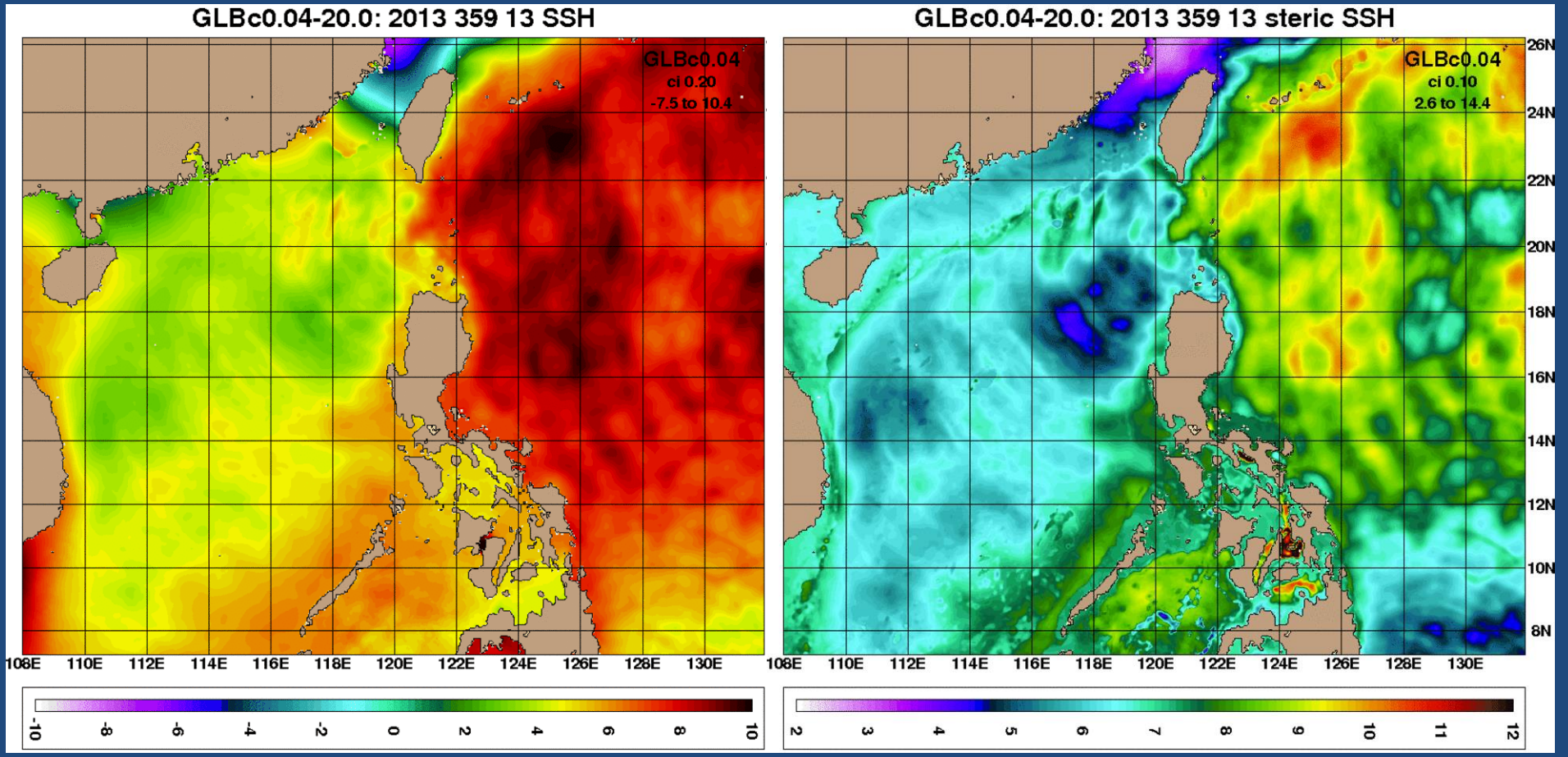
1/25° HYCOM/CICE/NCODA with tides running in demonstration mode at Navy DSRC on Cray XC30

Total SSH

Steric SSH



Barotropic tides

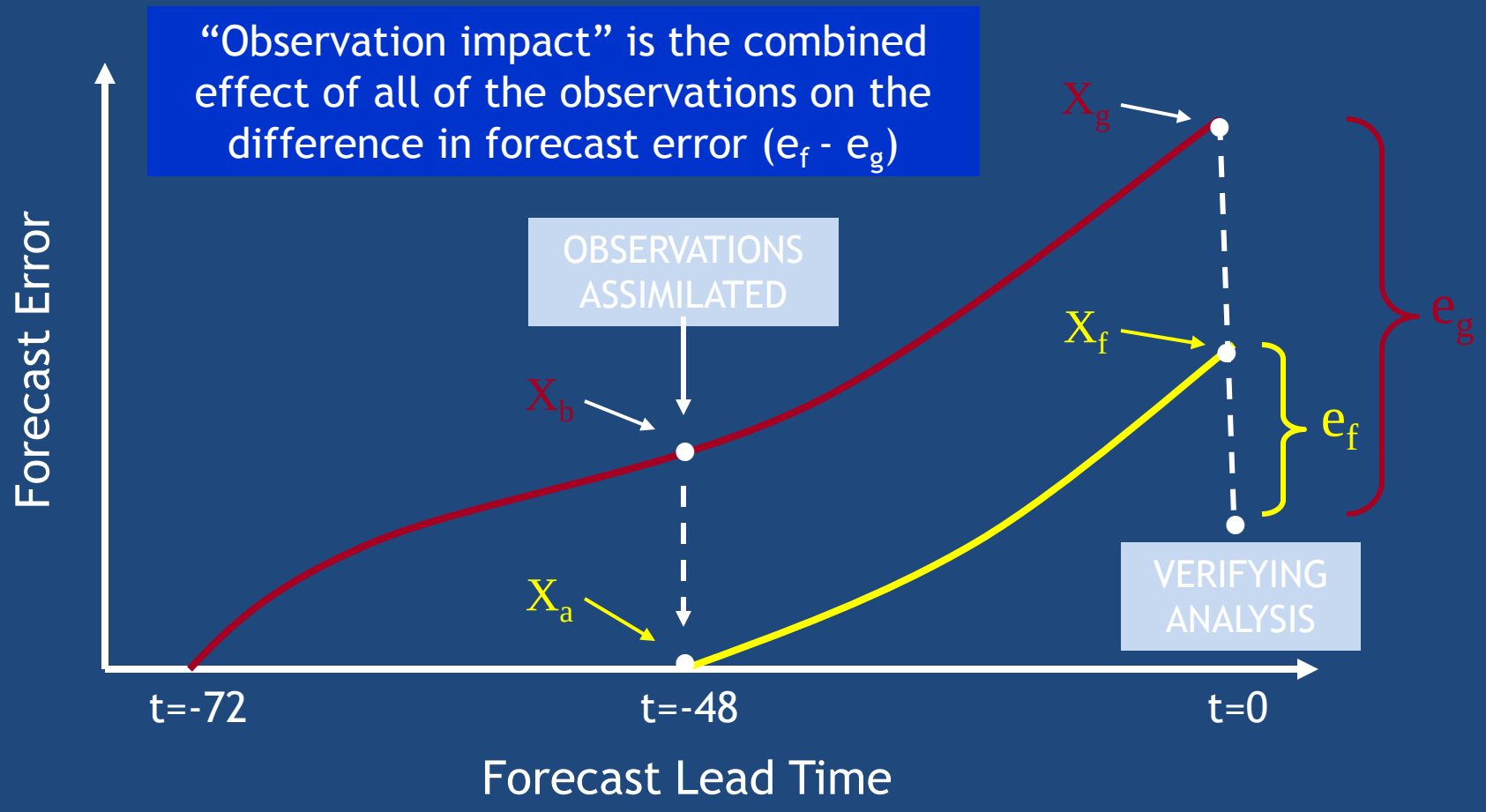
Internal waves at tidal frequencies

Thanks!

Questions?

Observation Impact: Concept

Observations move the forecast from the background trajectory (X_b) to the trajectory starting from the new analysis (X_a)



Observation Impact: Equations

$$\frac{\partial J}{\partial x_f} = e_f - e_g$$

Forecast error cost function

$e_f = (x_{48} - x_0)(x_{48} - x_0)$

$e_g = (x_{72} - x_0)(x_{72} - x_0)$

$$\frac{\partial J}{\partial x_a} = L^T \frac{\partial J}{\partial x_f}$$

Initial condition sensitivity

L^T adjoint forecast model

$$\frac{\partial J}{\partial y} = K^T \frac{\partial J}{\partial x_a}$$

Observation sensitivity

K^T adjoint assimilation system

$$\delta e_f^g = \langle (y - Hx_b), \frac{\partial J}{\partial y} \rangle$$

Impact for each observation

Observation innovation

Forecast error sensitivity in observation space

Langland and Baker (2004) *Tellus* 56A:189-201

Observation Impact: Interpretation

For any observation assimilated, if ...

δe_f^g < 0.0 the observation is **BENEFICIAL** - forecast errors decrease

δe_f^g > 0.0 the observation is **NON-BENEFICIAL** - forecast errors increase

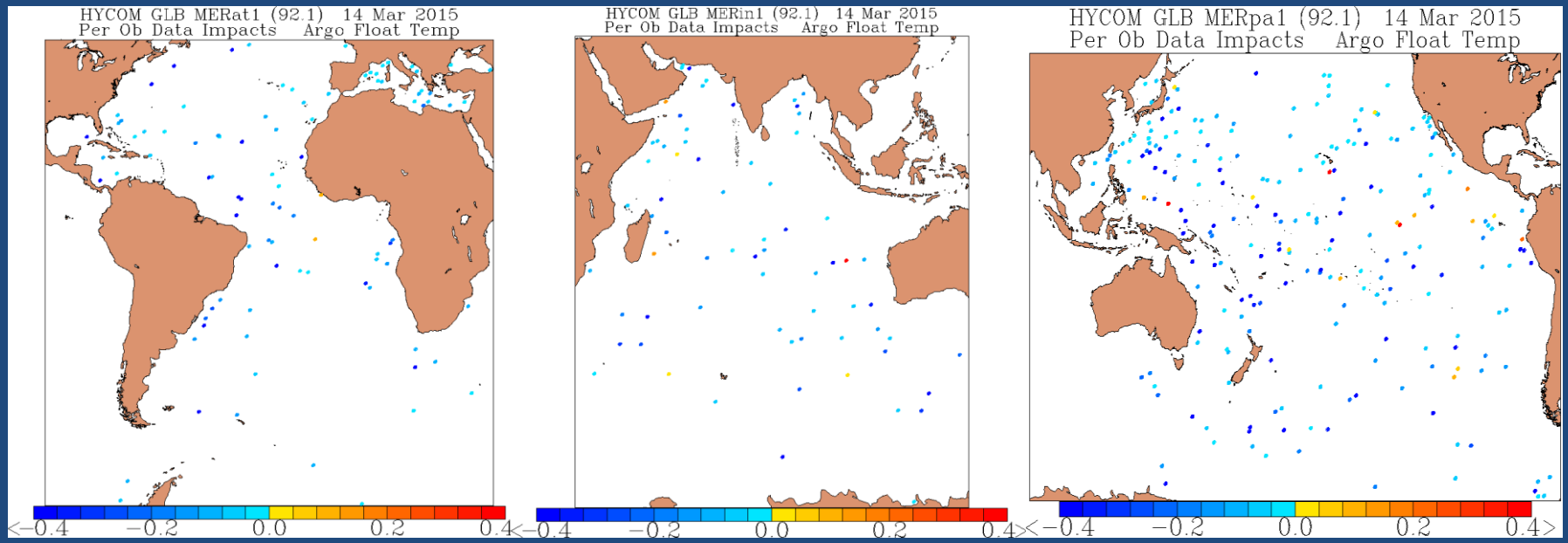
Non-beneficial impacts:

- not expected, all observations should decrease forecast error

- if occurs (and is persistent), look for problems in data QC, instrument accuracy, model error, specification of assimilation error statistics (observation error, background error)

Observation Data Impact

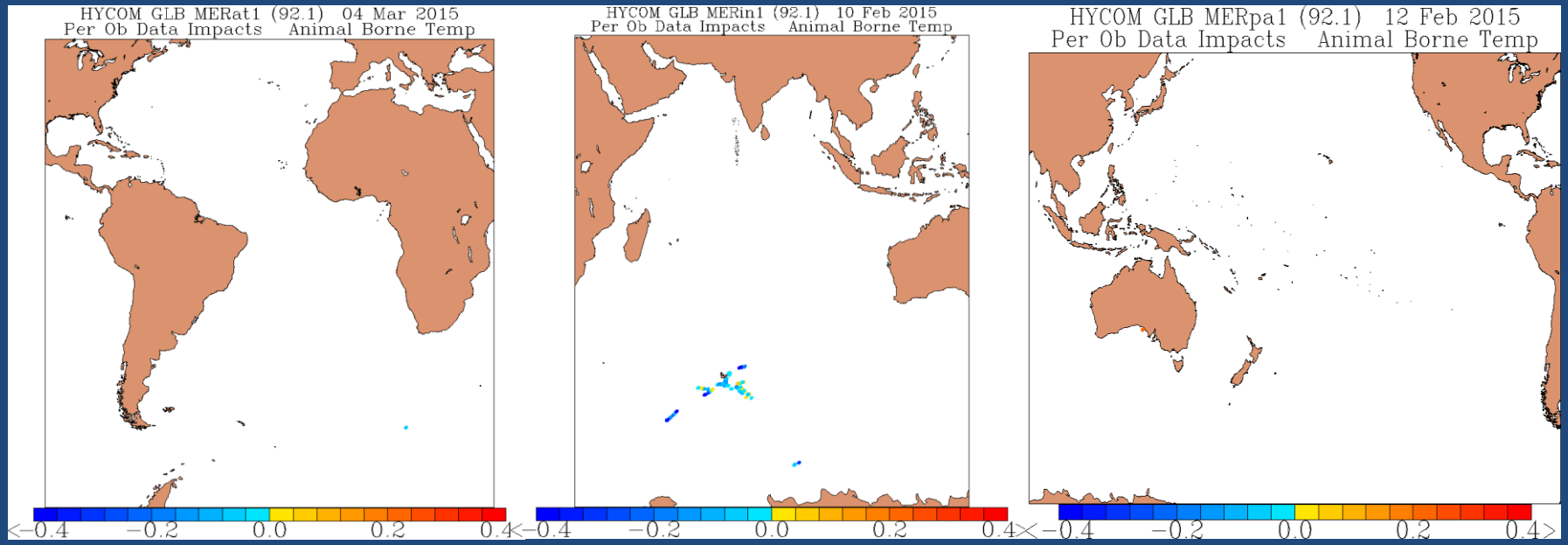
Argo Float Temperature



Blue: Positive impact on the forecast
Yellow/Red: Negative impact on the forecast

Observation Data Impact

Animal Borne Temperature



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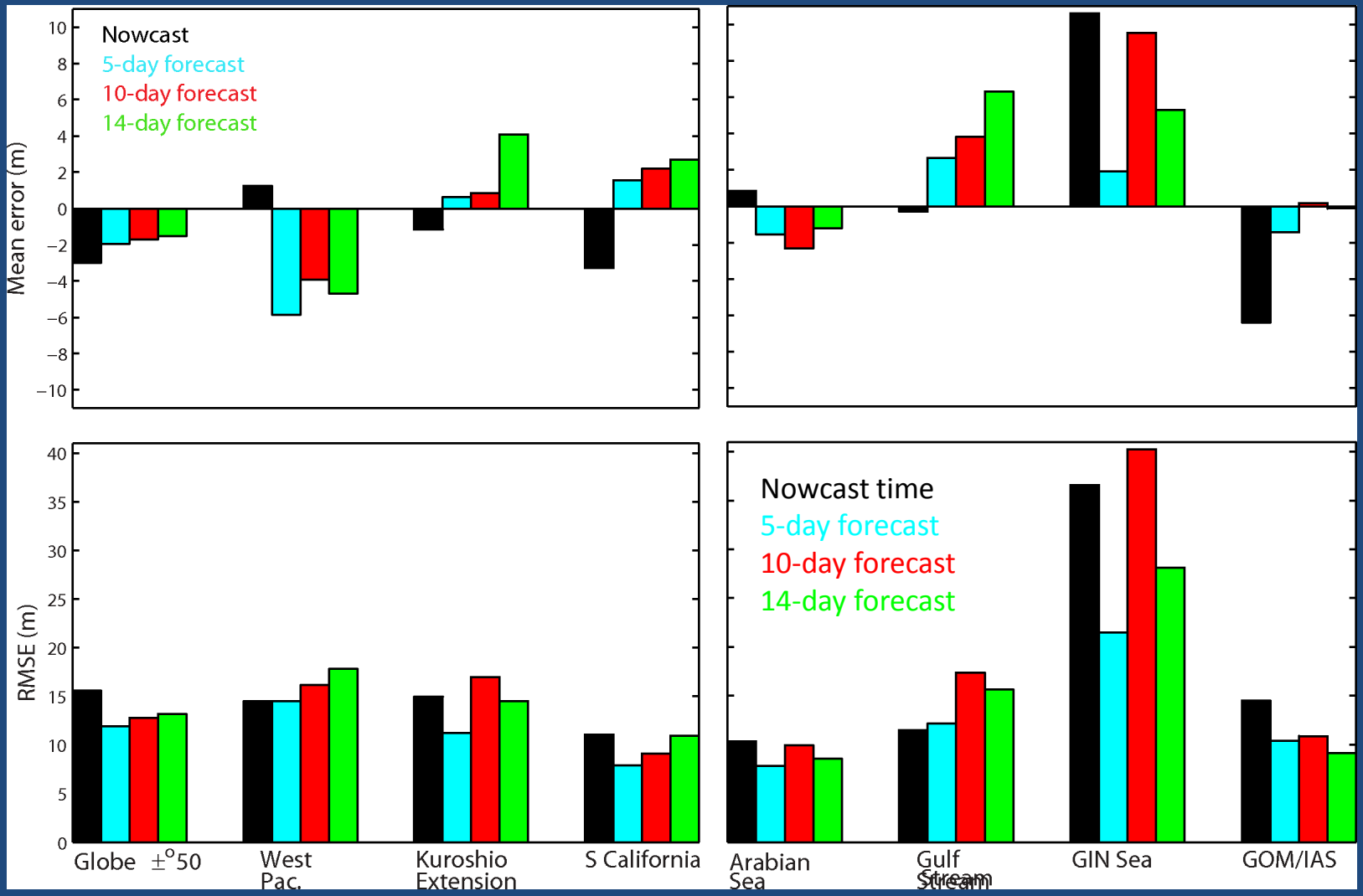
Ocean Validation – Mixed Layer Depth

Forecast



August 2013 – April 2014