Examination of Analysis and Forecast Uncertainty Generated from a Global Ocean Reanalysis

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Outline:

- HYCOM Global Ocean Reanalysis
- Ensembles/Uncertainty from the Reanalysis
- HYCOM-CICE Outlook (removed because of time)
- Earth System Prediction Capability
- Future Plans

HYCOM/NCODA Ocean Reanalysis

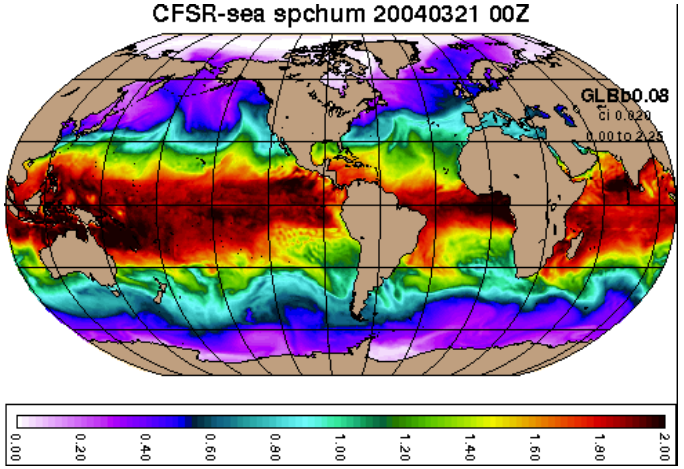
- Based on GOFS 3.0 (current operational system)
- Forced with NCEP Climate Forecast System Reanalysis (CFSR)
- Addresses the need for a long time period eddy-resolving ocean reanalysis (1993 to 2014, consistent with altimetry observations)
- Purpose is to provide physically consistent environmental scenarios for planning and scenarios to support Navy exercises and operations
- Numerous other applications and research opportunities

Atmospheric Forcing

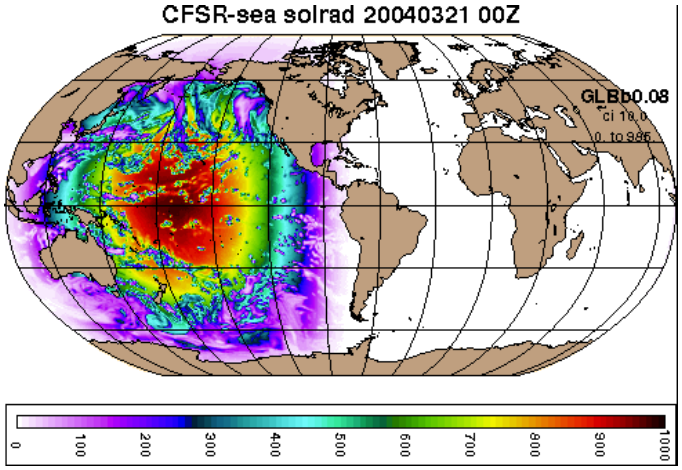
NCEP Climate Forecast System Reanalysis (CFSR)

- Time frame: 1993-2012 (altimeter period)
- Horizontal resolution: 0.3125° gaussian
- Temporal resolution: 1-hourly
- Inputs:
  - Bulk-derived wind stress
  - Wind speed
  - Radiative fluxes
  - Thermal fluxes
  - Precipitation

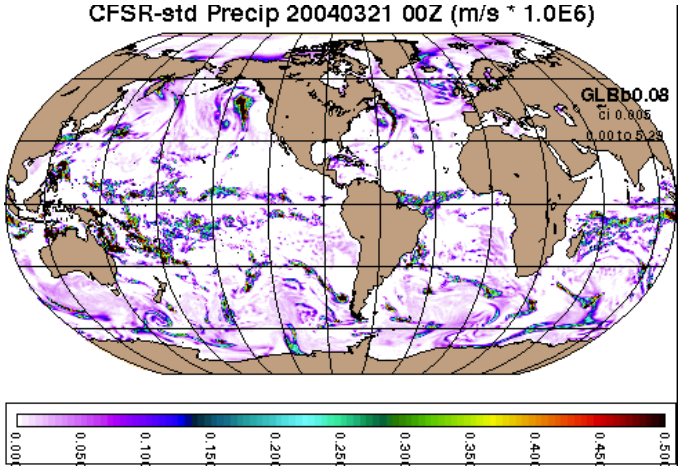
Surface Specific Humidity (kg/kg x 10^2)



Net Surface Shortwave (W/m^2)



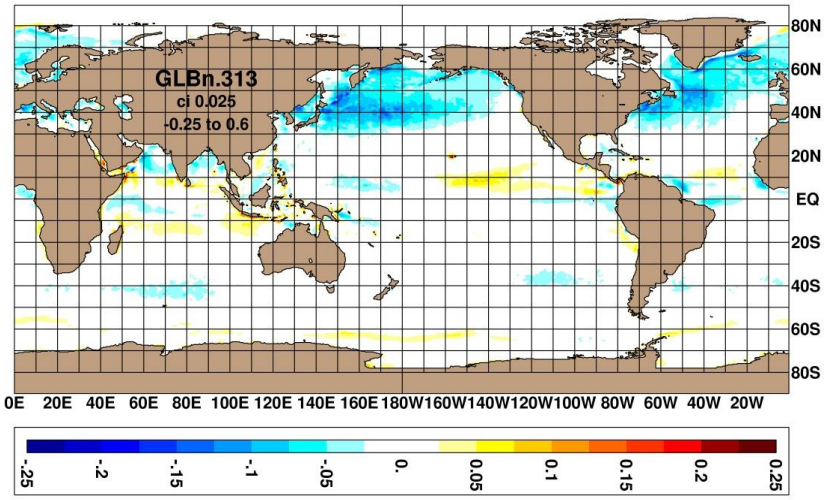
Precipitation (m/s x 10^6)



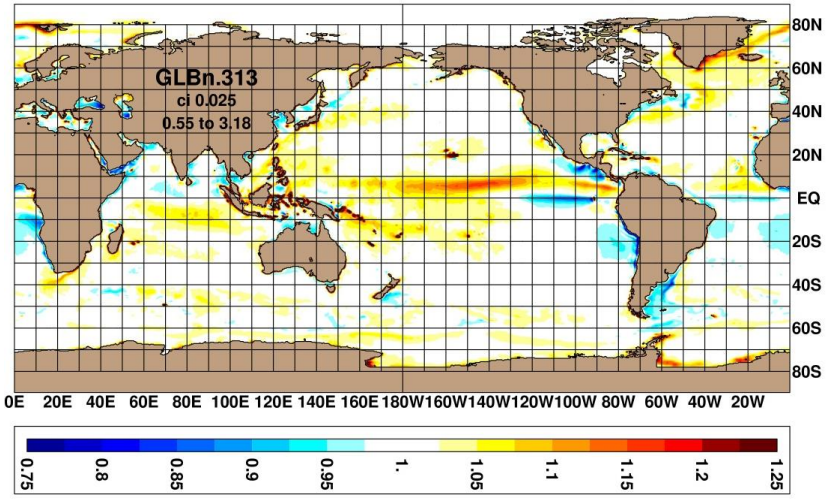
Modifications to CFSR Wind Forcing

QuikSCAT Scaling

Offset



Bias



Based on a regression analysis from 11 years (1999-2009) of monthly contemporaneous CFSR and QuikSCAT wind speed data

In addition a surface flux bias correction based on the annual mean SST error was applied (45 W/m**2 per 1°C)

Output and Storage

- HYCOM 3D native grid archive files (compressed):
  - Single hour: ~7 GB
  - Saving 3-hourly output:
    - ~20 TB / model year
    - ~340 TB for the entire reanalysis

- HYCOM 3D constant .08° grid (±80° lat) netCDF files remapped to 40 z-levels (compressed):
  - Single hour: ~1.2 GB
  - Saving 3-hourly output:
    - ~3.5 TB / model year
    - ~59 TB for the entire reanalysis

- The 20-year run consumed ~5 million CPU hours
- Output is available on the hycom.org data server

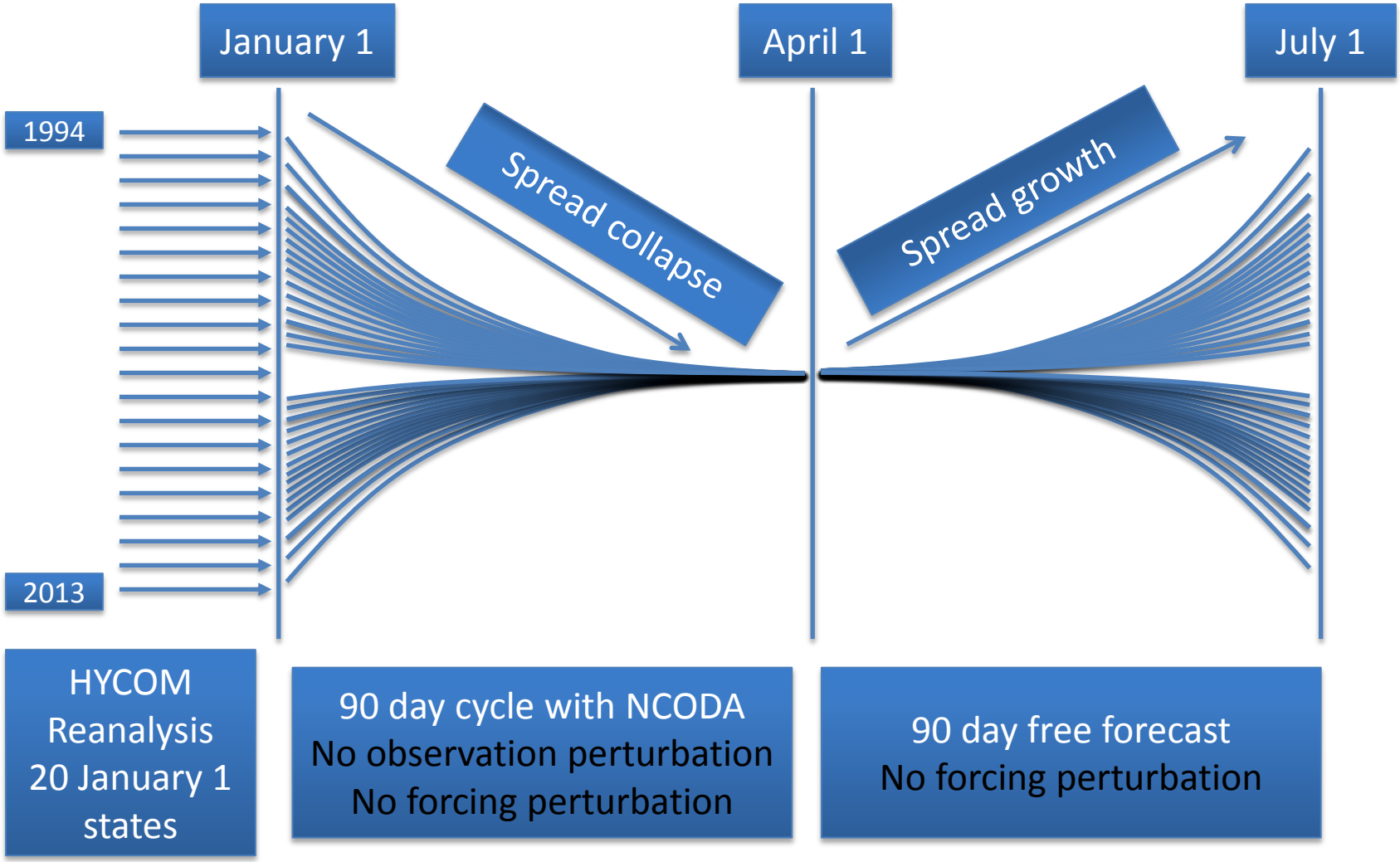
Ocean re-forcasted ensembles

Purpose: Use the 20-year reanalysis to generate perturbed initial conditions for ocean ensembles.

- Address these questions:
  - What is the timescale of spread collapse without perturbed obs, and what is the background model variability? (Exp 1)
  - What is the rate of growth of ensemble spread from the model variability? (Exp 1)
  - What is the contribution of atmospheric model uncertainty? (Exp 2)
  - What is the contribution of perturbed observations in the analysis? (Exp 3)
  - What is the relative role of internal ocean dynamics vs. atmospheric forcing on uncertainty/spread in ocean variables, including mixed layer depth?

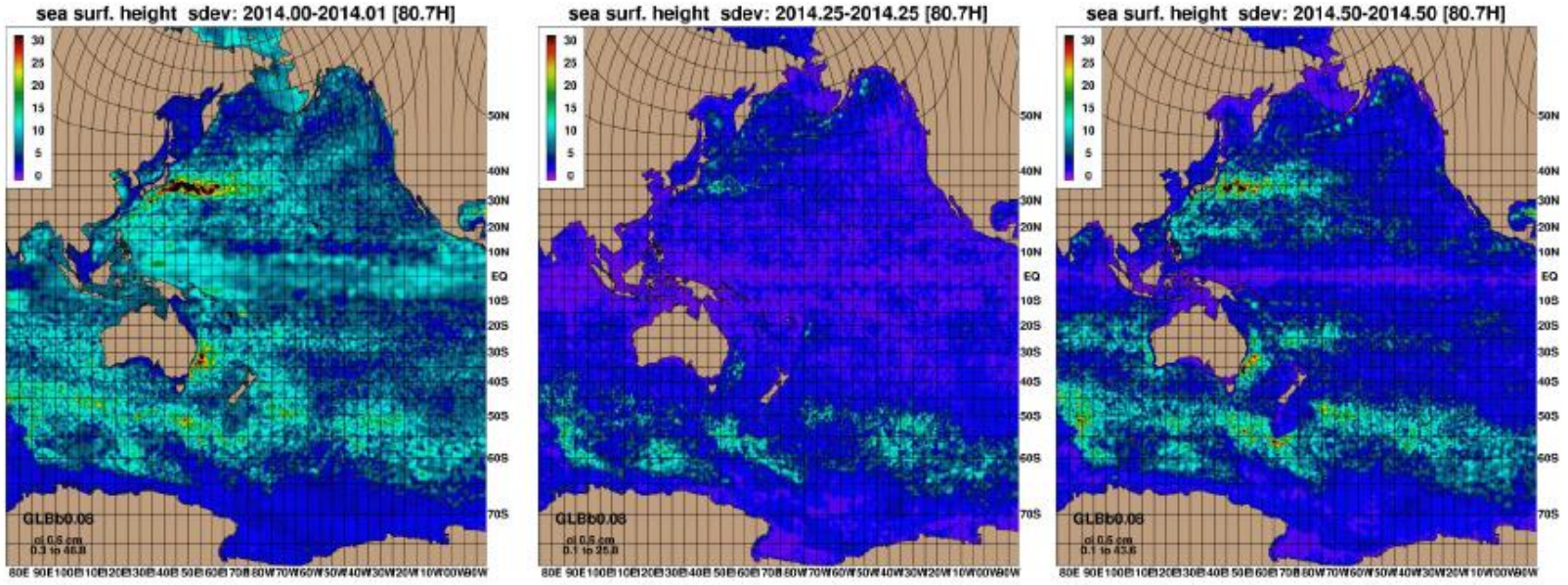
- Global HYCOM ensembles based on the 20-year HYCOM/NCODA reanalysis
- 20 different 01 Jan states from years 1994-2013 initialize 01 Jan 2014
- 10 different 01 July states from years 2003-2012 initialize 01 Jan 2014
  - Experiment 1: Initial perturbations only; 3 month reanalysis, 3 month forecast
  - Experiment 2: Add surface forcing variability
  - Experiment 3: Add perturbed observations
  - Experiment 4: Add perturbed physics (stochastic forcing)

Ensemble Generation using the Reanalysis



Schematic of the setup of Experiment 1: Initialized from 20 different 01 January states from the 20-year reanalysis; cycled for 90 days with identical observations and no other perturbation; and a 90-day forecast run from the 90-day states.

8-member 1/12°Global Ensemble



perturbed initial state

after 90 day analysis

90 day forecast

(I) Initial perturbations

a) Experiment 1: 20 members, January – June 2014

b) Experiment 1a: 10 members July-December 2014

(II) [planed] perturbations to data and forcings

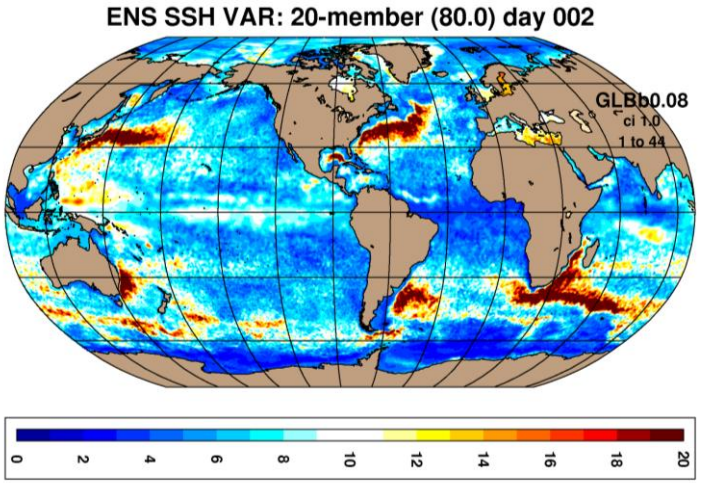
a) add perturbed ocean observations

b) add perturbed atmosphere

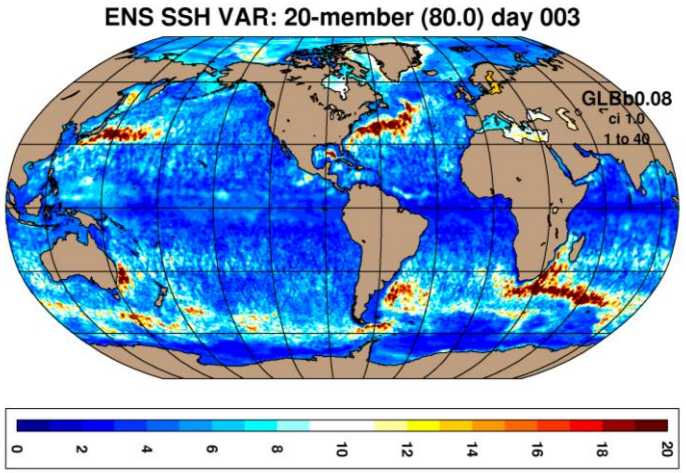
c) add perturbations to stochastic ocean physics

Surface Eddy Kinetic Energy after 30 days of DA cycling

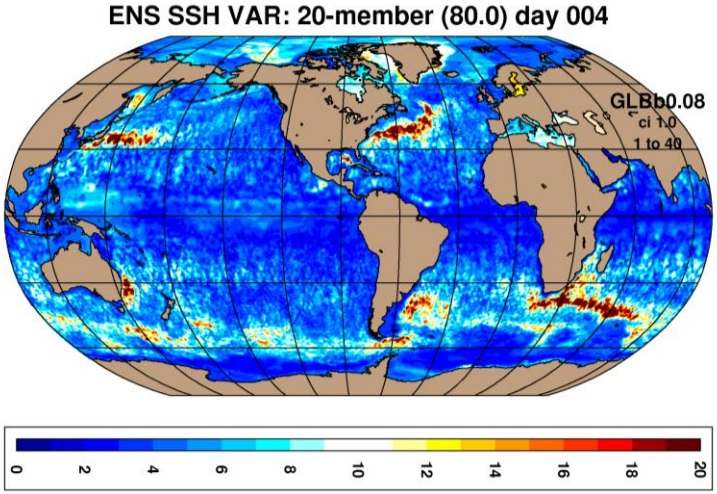
Was there too much initial spread – or too much collapse of the spread?



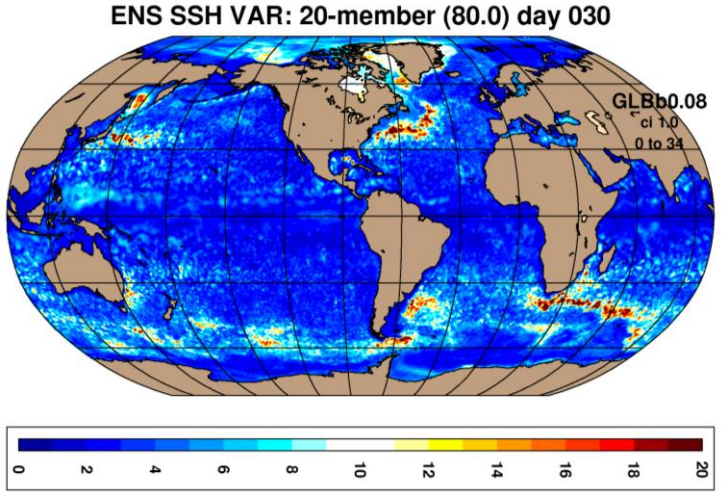
Start of the analysis



Analysis + 1 day

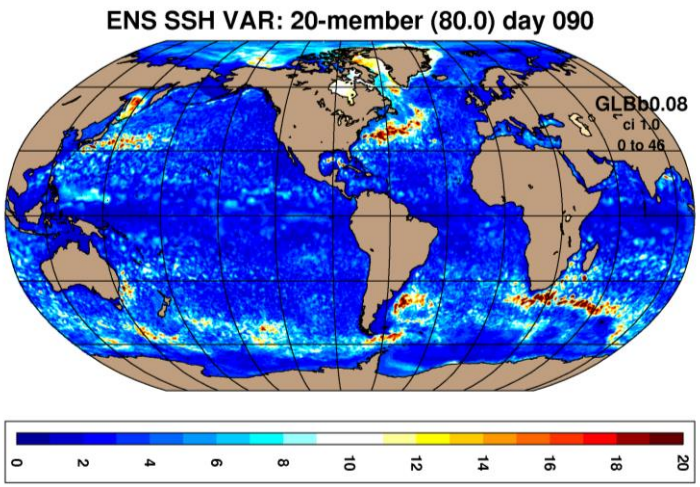


Analysis + 2 day

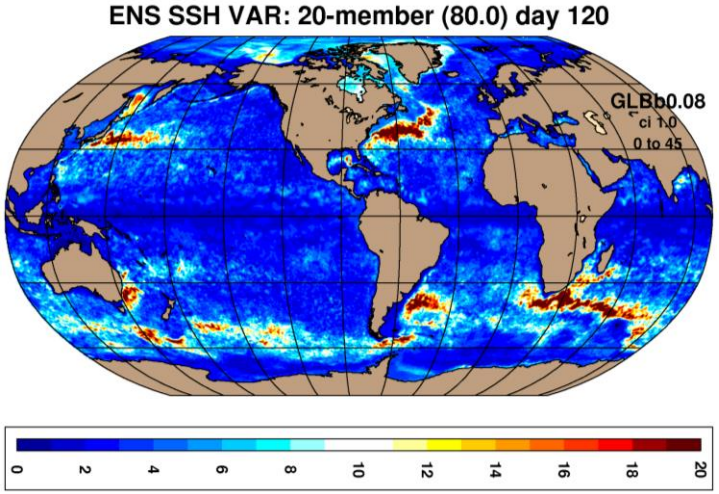


30 days after initialization

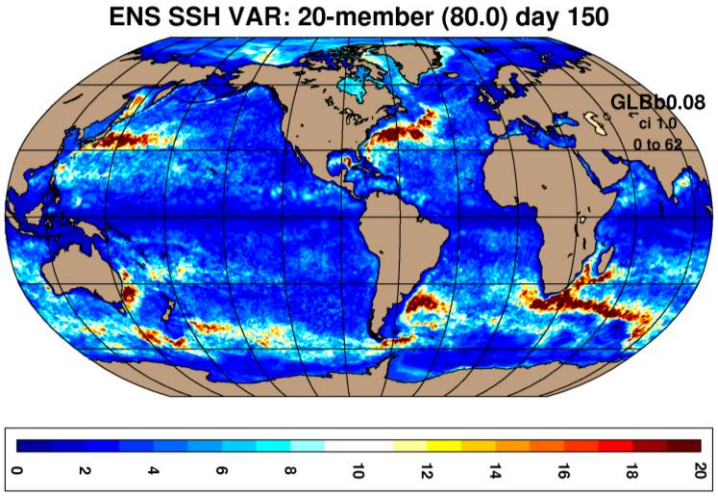
Sea Surface Height STD



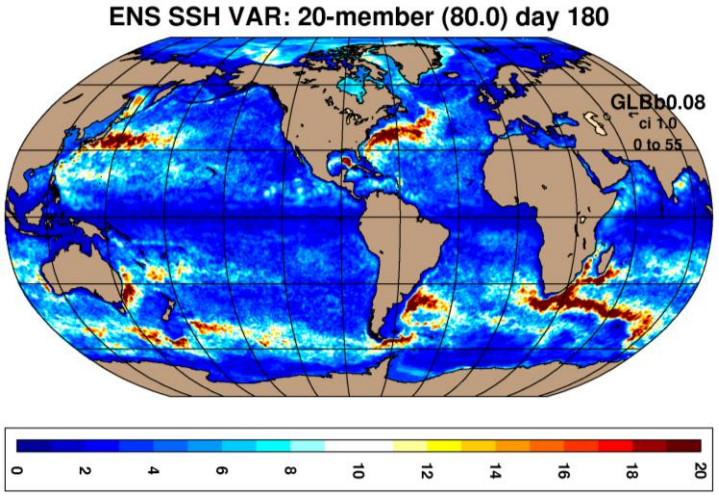
90 days after initialization



30 days into forecast

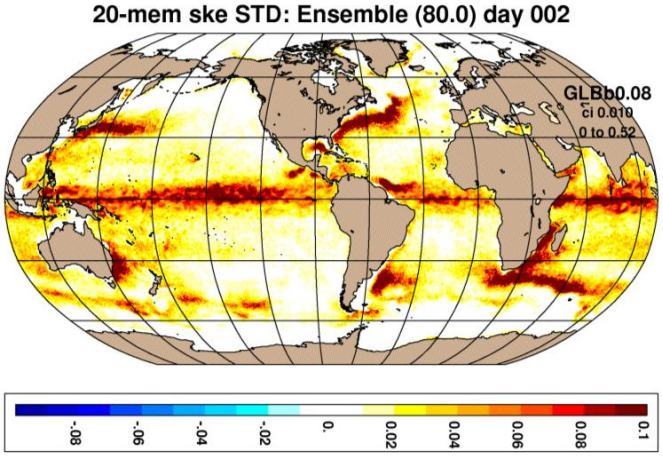


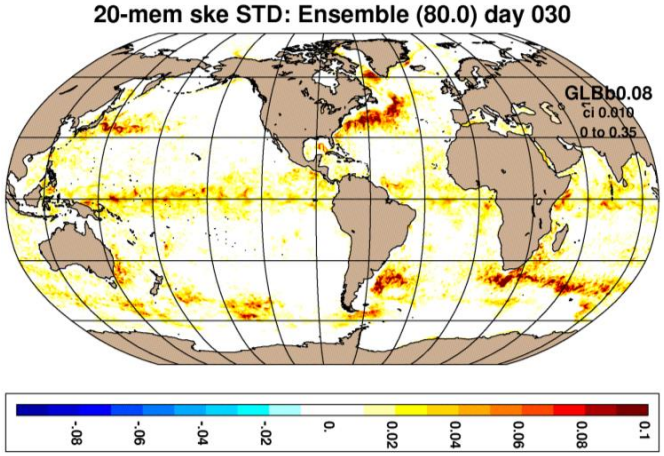
60 days into forecast



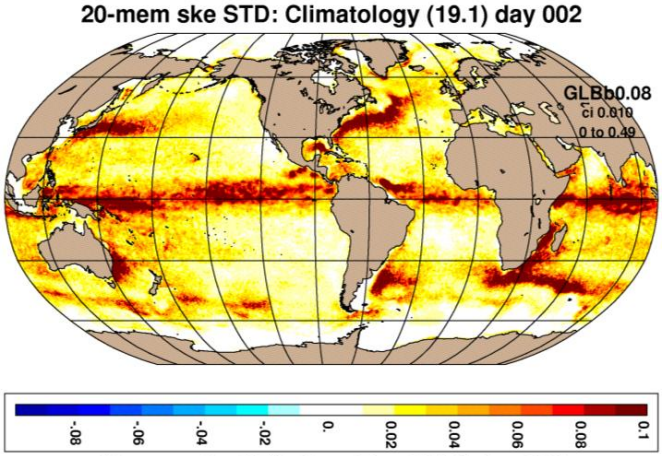
90 days into forecast

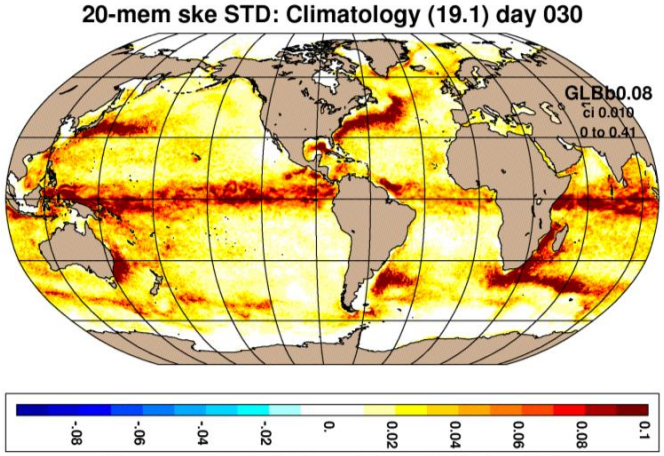
Ensemble variance



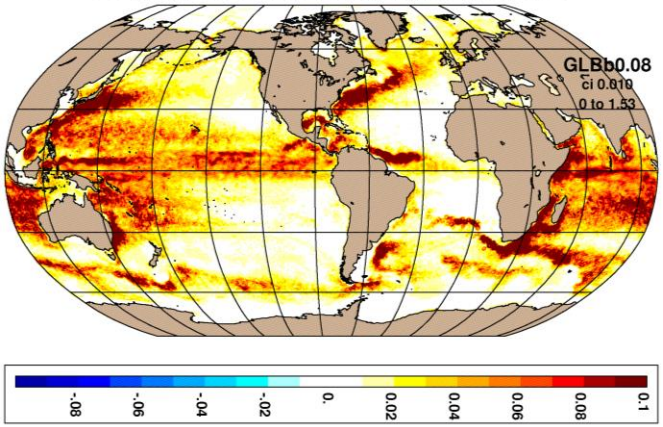


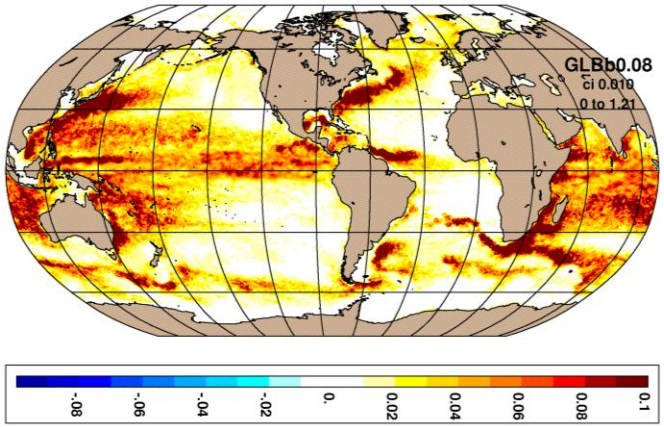
Climatological variance



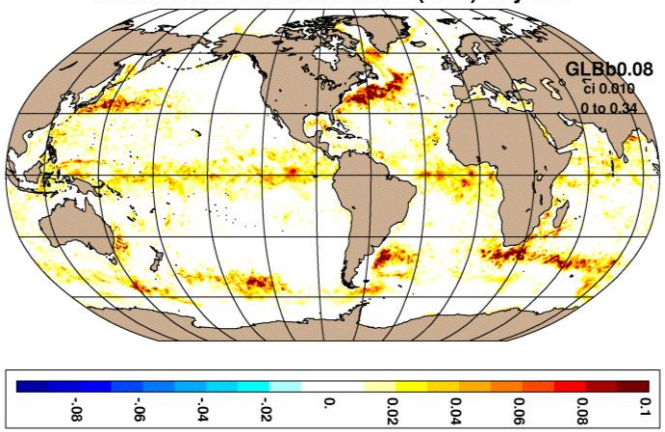


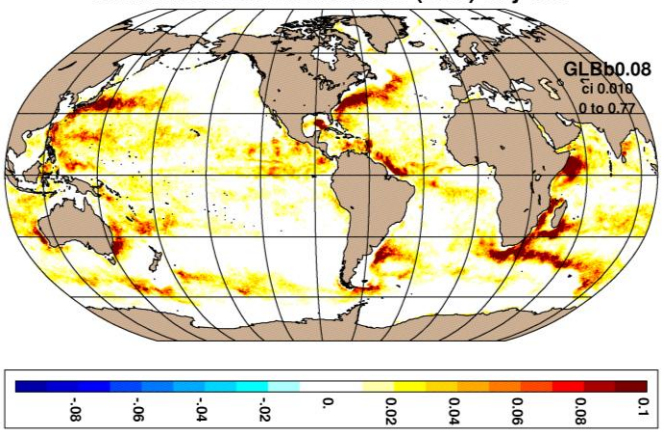
Simulation variance



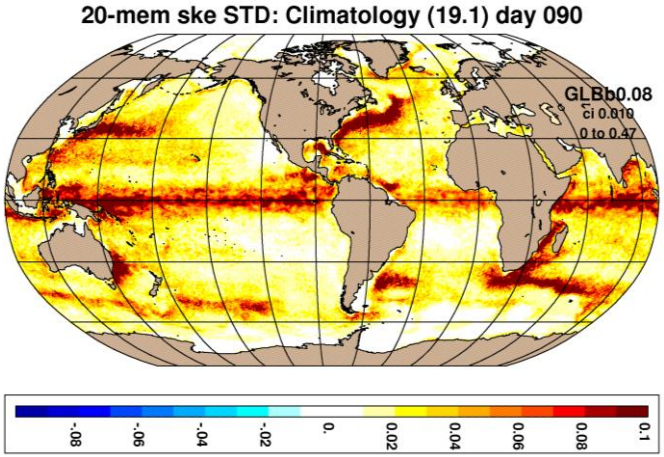


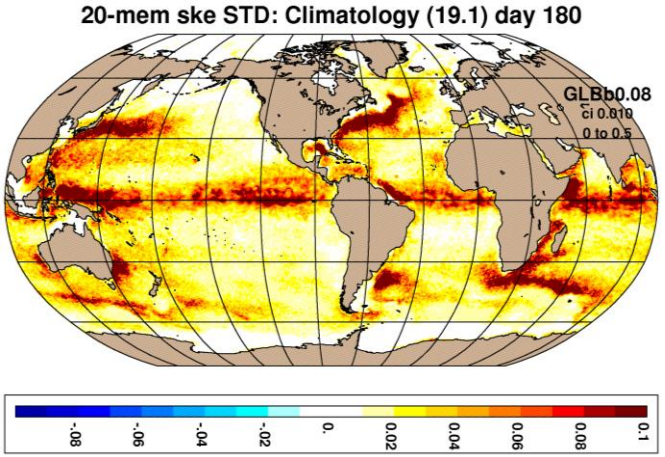
Ensemble variance



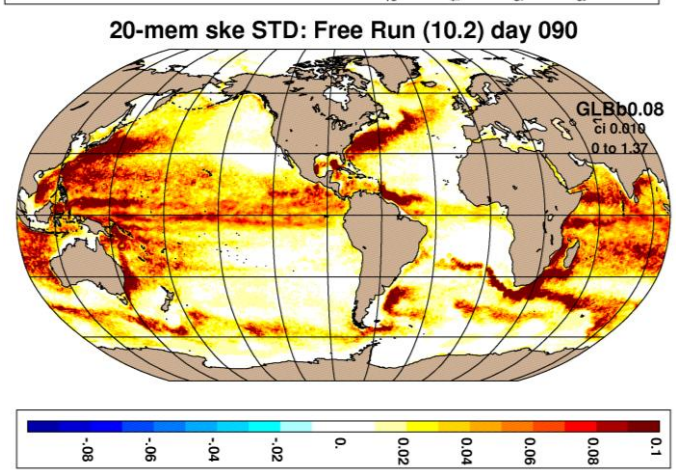


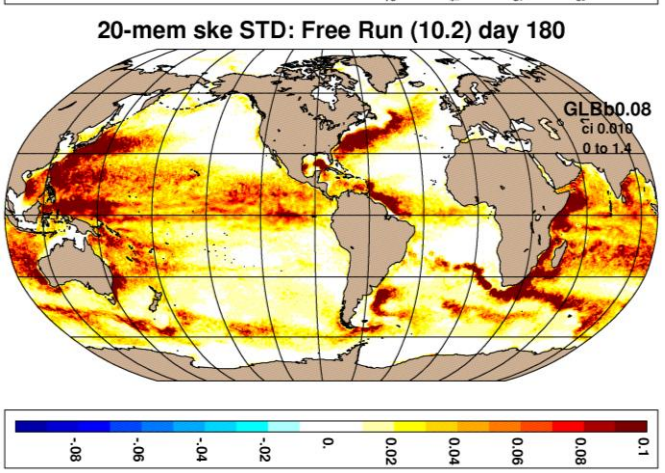
Climatological variance





Simulation variance



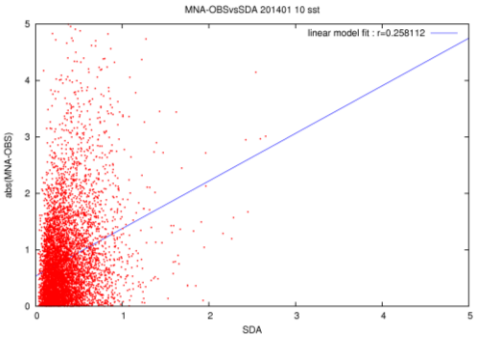


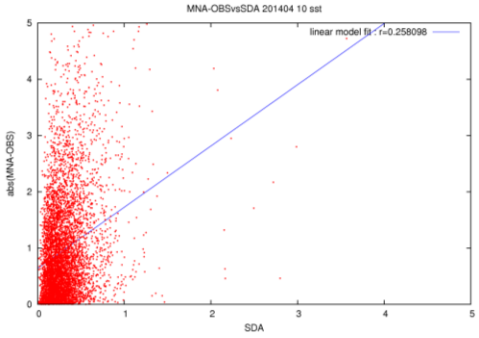
L10: Ensemble Error vs. Ensemble Spread

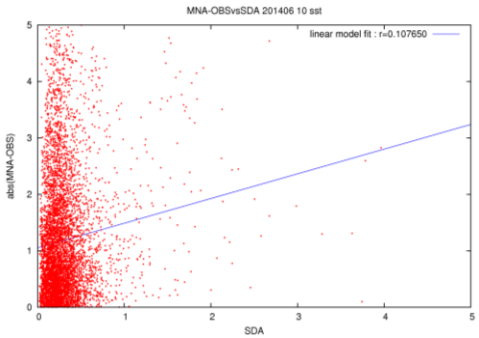
Layer 10 is ~60m global average

January **April** **July**

error

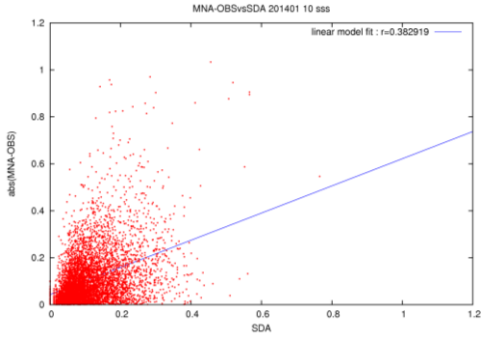


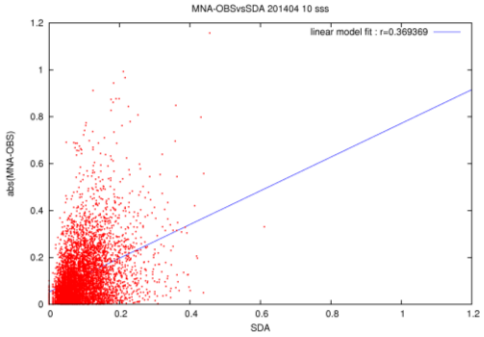


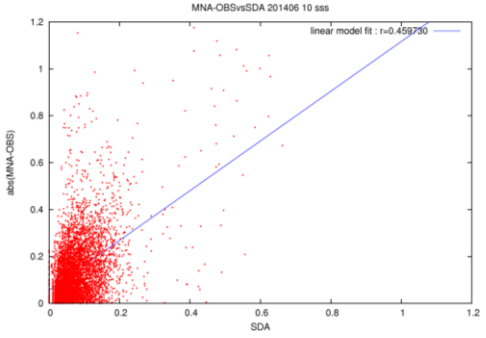


spread

Temperature







Salinity

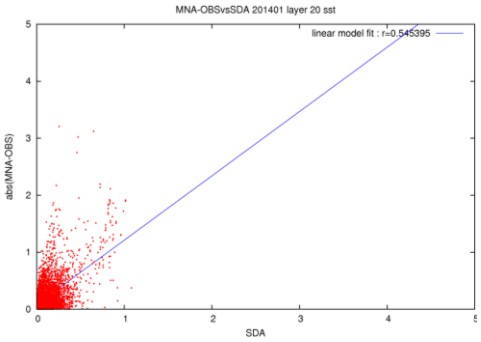
The end of the analysis is more underdispersive (less ensemble spread) than the climatological uncertainty,.
The forecast spread is improved, but still underdispersive.

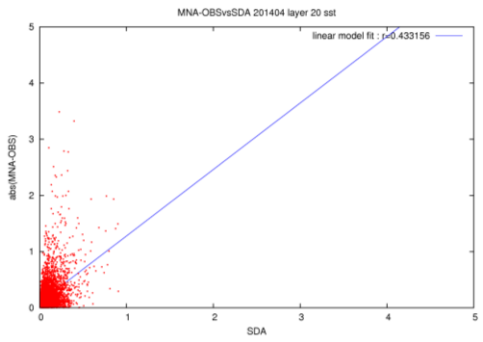
L20: Ensemble Error vs. Ensemble Spread

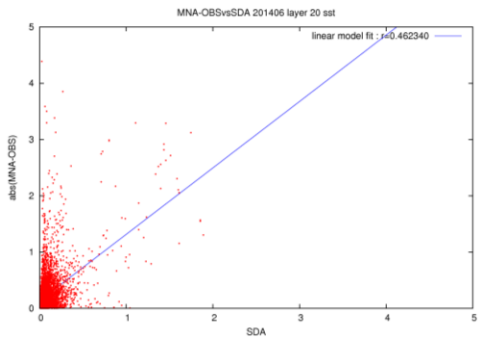
Layer 20 is ~700m global average

January **April** **July**

error

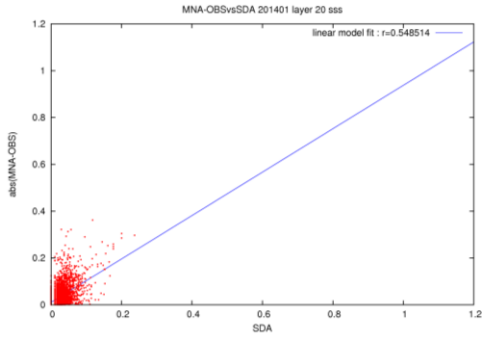


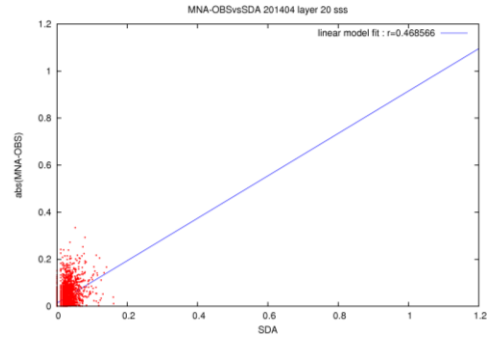


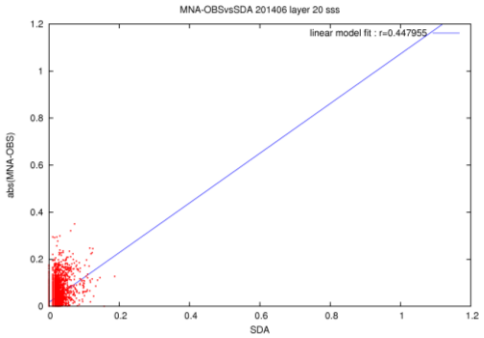


spread

Temperature



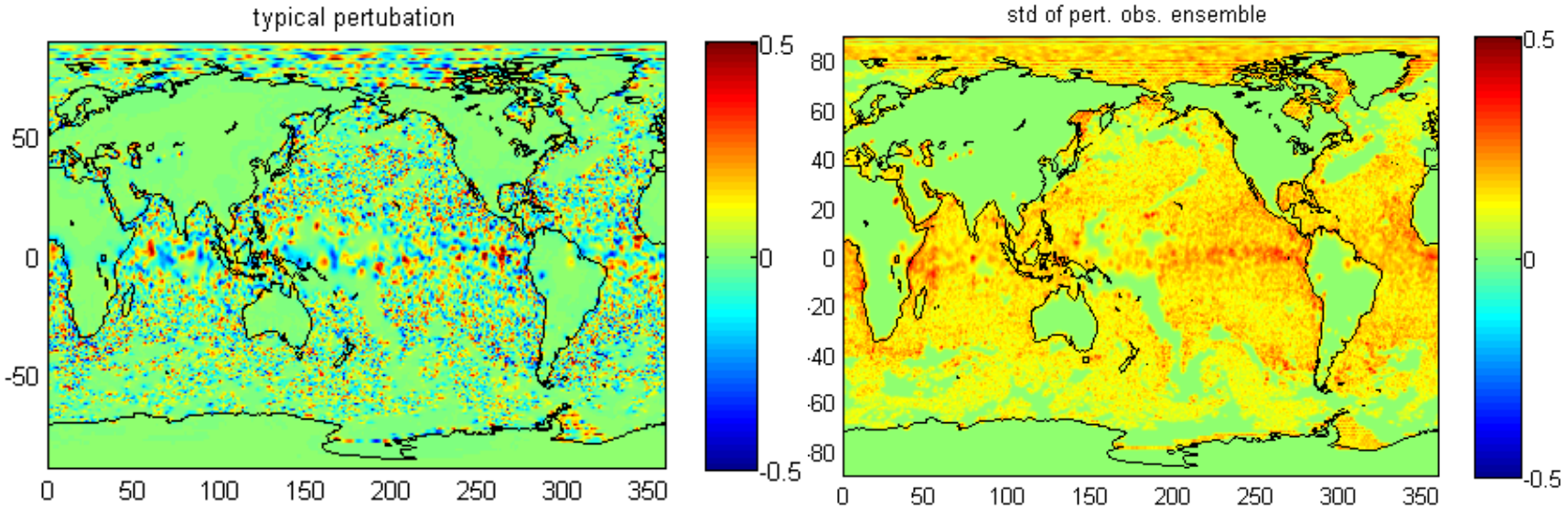




Salinity

Both show characteristics of under-dispersiveness
Especially in the long term forecast…..

Perturbed obs. SST (S. Frolov, NRLMRY)



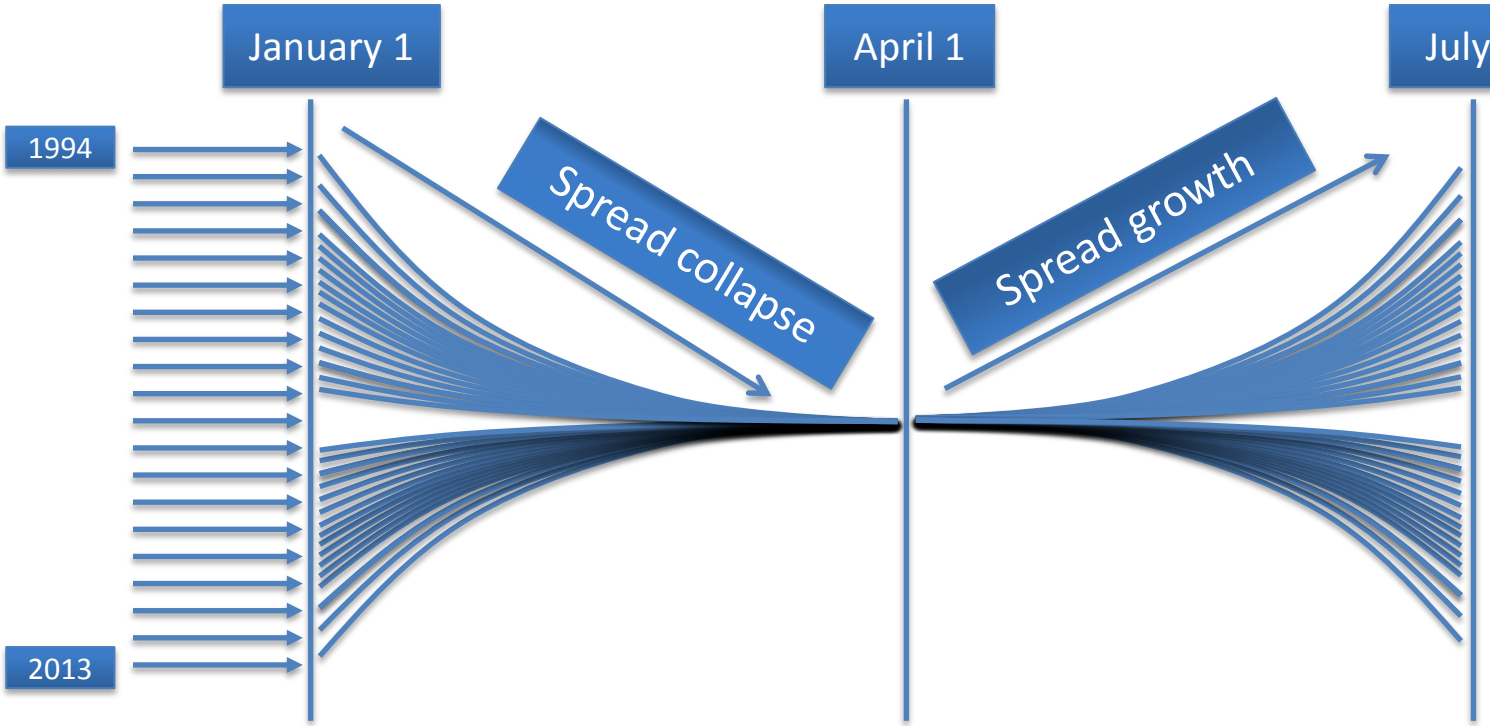
Methods

- SST obs perturbations = white noise * NCODA SST obs error; then normalized by the PDF from NCODA to get analysis perturbations
- Add climatological perturbations(?)
- Add flow dependent perturbations (historical hycom states?)

Results:

- Global std of analysis increment 0.14°C
- Global std of innovation pert is 0.6°C

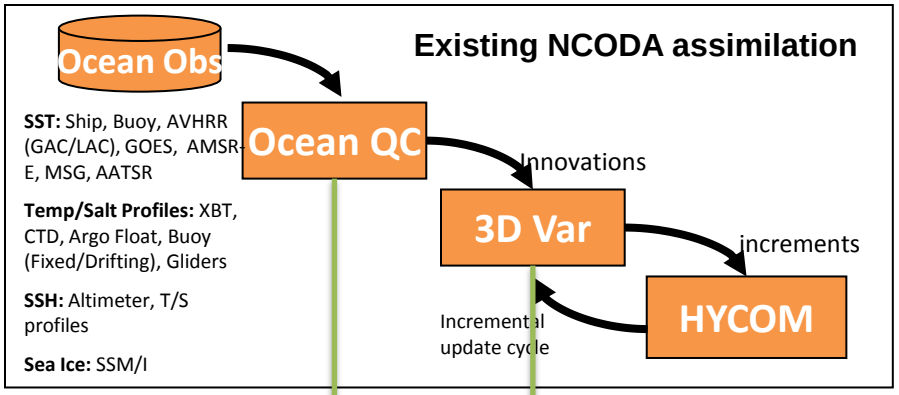
Ensemble Generation using the Reanalysis



- Error spread collapse is rapid; model spread is underdispersive at end of 3-month analysis period, but not zero
- Error growth during forecast (due only to IC perturbations) is insufficient; additional sources of uncertainty need to be included (perturbed obs, perturbed atmosphere, perturbed model physics)

EnKF Flow Chart

What's new:
- Using ensembles to generate uncertainty
- Time and flow evolving error covariances



Existing cycling system used to generate single (deterministic) global ocean forecast

For scaling to global and covariance performance

Use the deterministic system to set the mean EnKF analysis

To maintain error growth during forecast

Localization

Hybrid covariance

EnKF

X^a_N

P^a

Drift control

$X^{a'}_N$

P^a

HYCOM

Atmospheric perturbations

Stochastic perturbations

X^f, P^f

Background error covariance

Post processing/ calibration

EnKF for global uncertainty

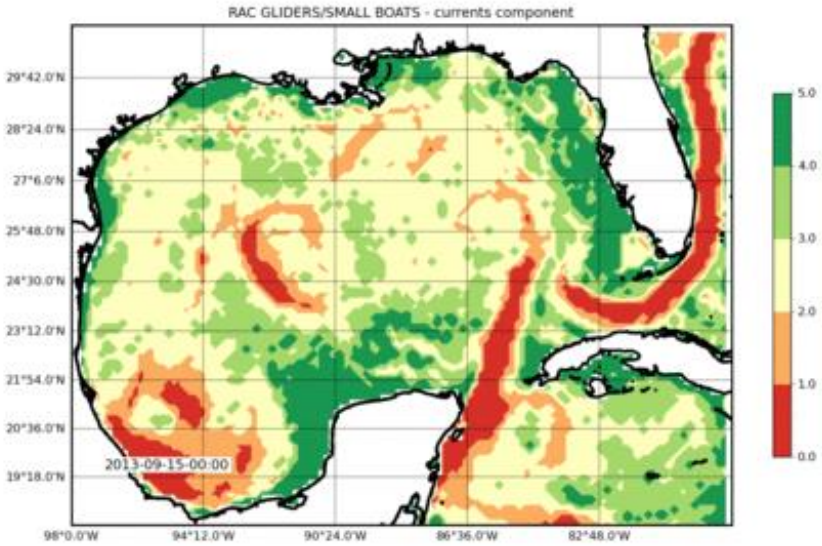
N = number of ensemble members

Risk Assessment Code/Risk of Occurrence – Surface **Velocity**

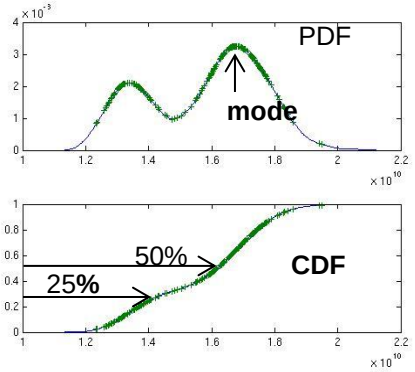
Risk of occurrence is the integrated (cumulative) PDF for any variable

Sept. 15 – Nov. 14 2013

Risk of Occurrence of Strong Currents



risk quantification, mission planning, etc.



Risk Management RAC Codes		Probability			
		A >0.75	0.75>B>0.5	0.5>C>0.25	0.25>D>0.1
Severity	Level I – Very High	1	1	2	3
	Level II – High	1	2	3	4
	Level III - Medium	2	3	4	5
	Level IV - Minimal	3	4	5	5

1 – Critical 2 – Serious 3 – Moderate 4 – Minor 5 – Negligible

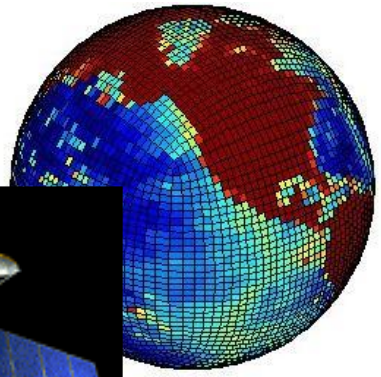
Risk Assessment Code (RAC)

- For this case, velocity thresholds: 0.7-0.5-0.25-0.15 m/s
- Can be done for any model quantity
- The user sets the thresholds
- Can also be used for plumes, trajectories, etc.

The result will be the ability to generate output that can be used to enable existing risk management tools, globally, and out to 30 days

Earth System Prediction Capability (ESPC)

National ESPC
EARTH SYSTEM PREDICTION CAPABILITY



Coupled Global Forecast System

Improve Model Physics through
- Coupled modeling
- Improved parameterizations

Improve Data Assimilation through
- Joint observational retrievals
- New hybrid DA approaches

Increase Forecast Information through
- Stochastic prediction
- National Multi-model ensembles
- Seamless prediction

Increase System Resolution affordably through
- Efficient Computational Architectures
- Efficient Numerics/ Discretization

Navy ESPC
Initial Operational Capability 2018

- Not yet fully defined: initial working definition is NavESPC should be running in pre-operational mode at Navy DSRC under EOM with FNMOC-NAVO-DSRC cycling (uncoupled) DA and producing “prototype products”.

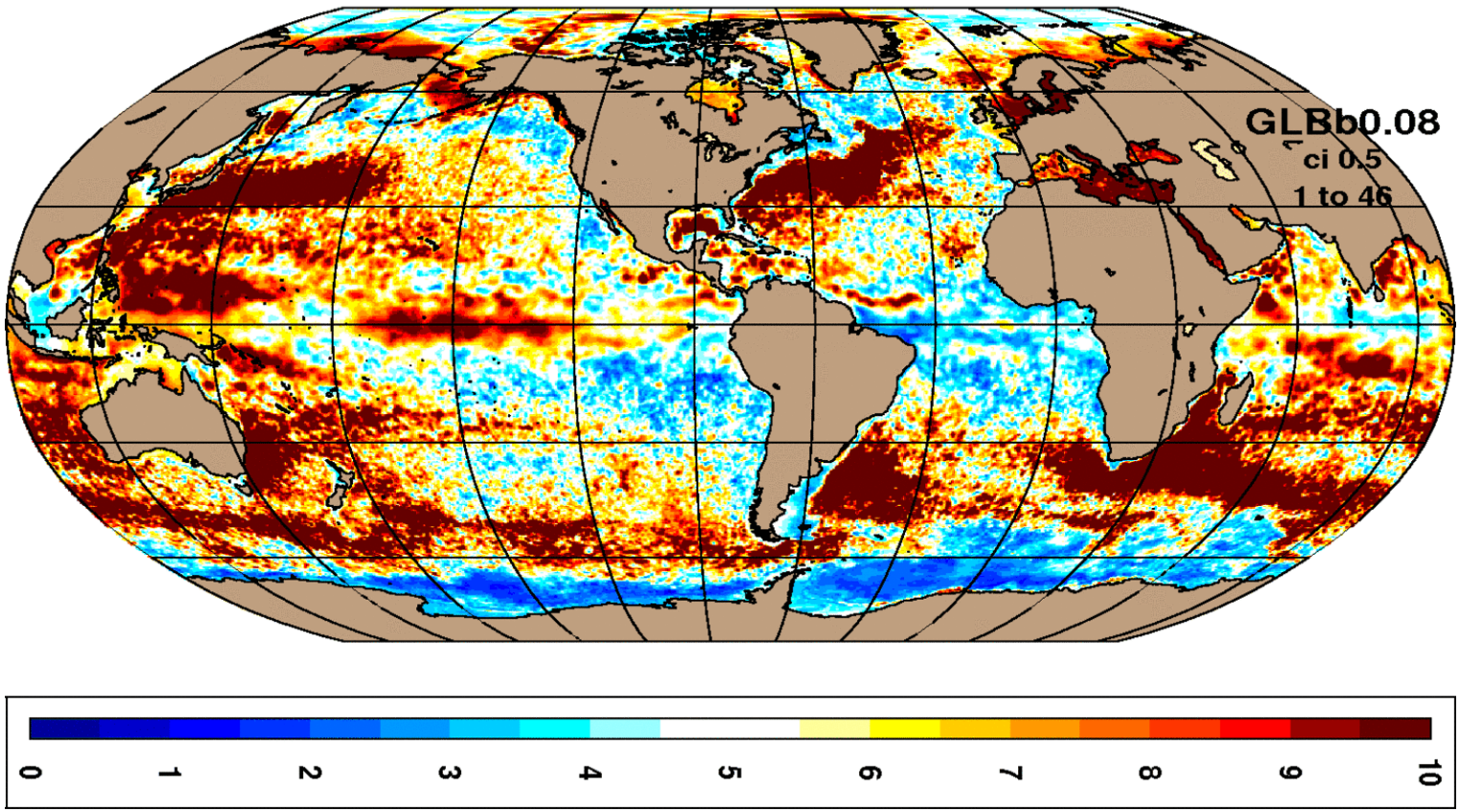
Forecast	Time Scale, Frequency	Atmosphere NAVGEM	Ocean HYCOM	Ice CICE	Waves WW3	Land-Surface NAVGEM-LSM	Aerosol NAAPS
Deterministic short term	0-16 days, Daily	T1025 (13 km) 100 levels	1/25° (4.5 km) 41+ layers[1]	1/25° (4.5 km)	1/8° (14 km)	Module within NAVGEM	Module within NAVGEM
Seasonal Ensemble	0-90 days, Weekly 28 members[2]	T681 (19 km) 80 levels	1/12° (9 km) 41 layers	1/12° (9 km)	1/4° (28 km)	Module within NAVGEM	Module within NAVGEM

[1]Vertical resolution of HYCOM still to be determined.

[2]Because the operational centers don’t get significantly more time on any one specific day of the week, the ensembles need to be broken up across the week. Run four ensemble members each day of the week.

Thanks!

Questions?


10-member sshio StnDev: (82.0) day 183
GLBb0.08
ci 0.5
1 to 46
0
1
2
3
4
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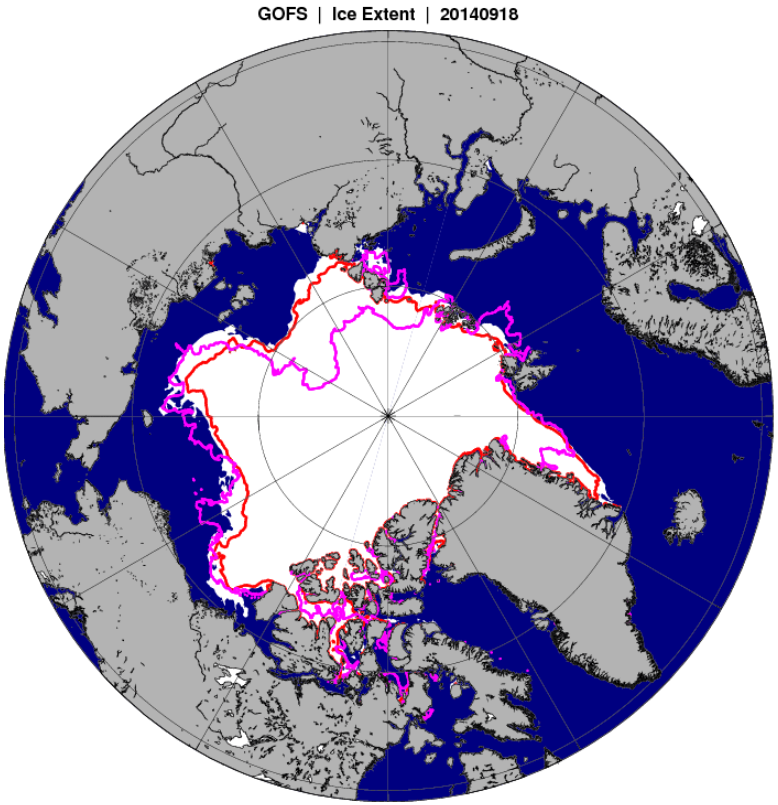
6
7
8
9
10

Sea Ice Prediction Network (SIPN)
Sea Ice Outlook 2014

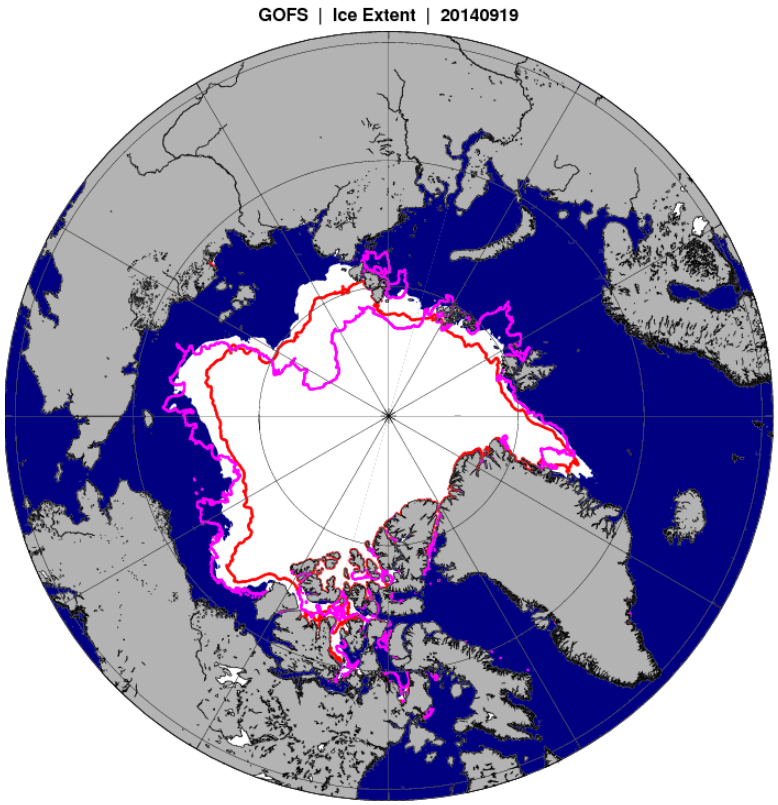
- Community wide summary of predicted September Arctic sea ice extent minimum
- ACNFS and GOFS 3.1 ensemble initialized from a single sea ice analysis: May 1, June 1 and July 1
- Forced by different years of NOGAPS atmospheric forcing (2004-2013)
- To calculate the ACNFS/GOFS 3.1 minimum September sea ice estimate:
  - Used all grid cells with at least 15% ice concentration
  - Calculated the daily mean ensemble value
  - Used minimum September value as estimate

Predicted Versus Observed Ice Extent

June 1 initialization



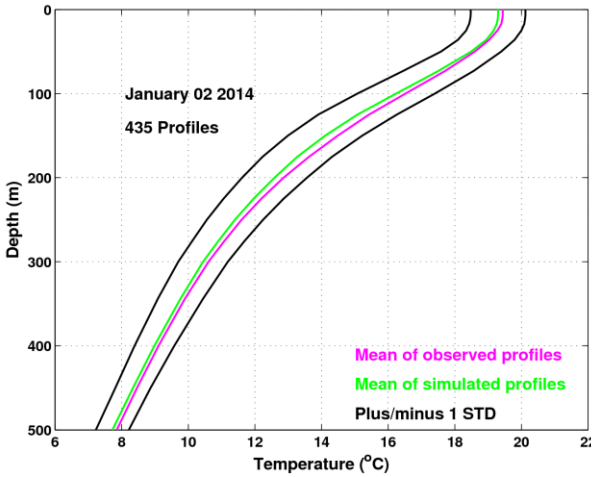
July 1 initialization

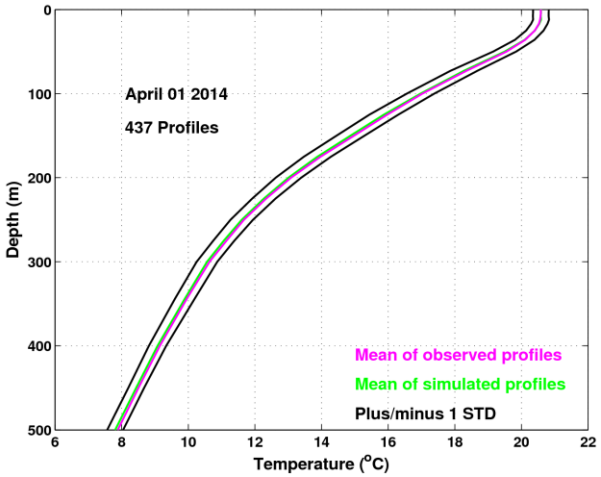


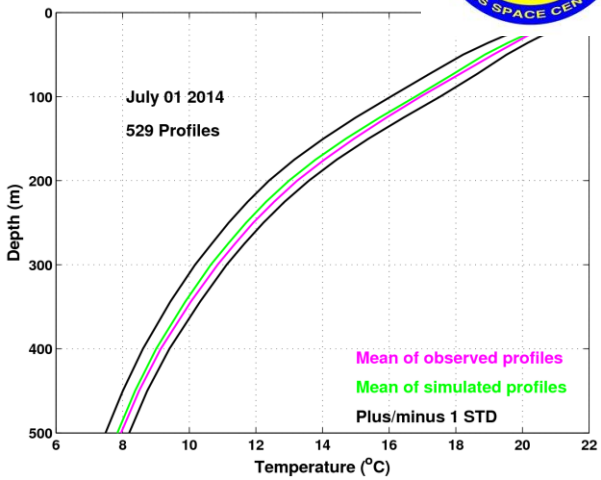
White region represents ensemble-averaged sea ice extent; red line represents adjusted sea ice extent; magenta line denotes IMS ice edge on September 18, 2014.

Mean of Obs vs. Ensemble Profile

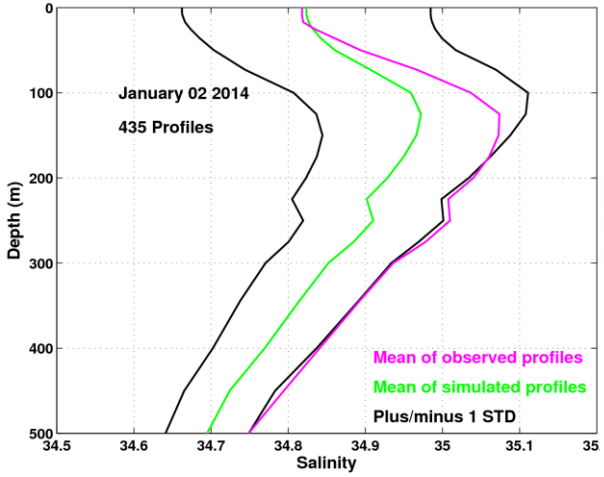
Temperature

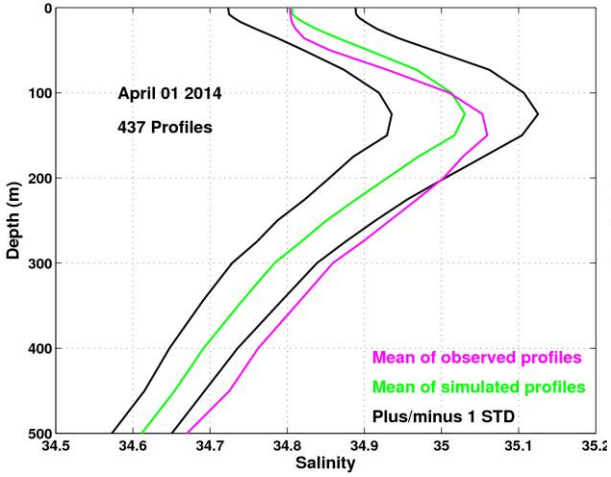


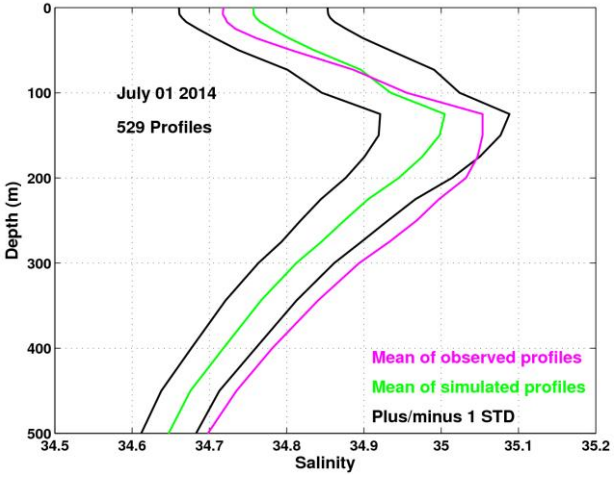




January **April** **July**







Salinity

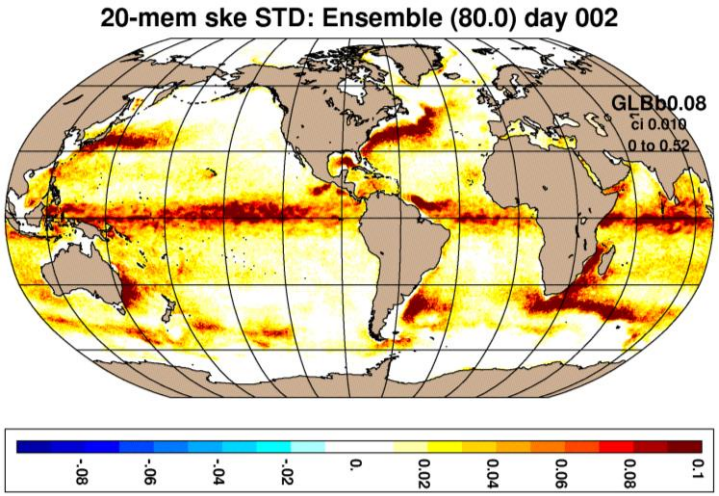
Ocean re-forcasted ensembles

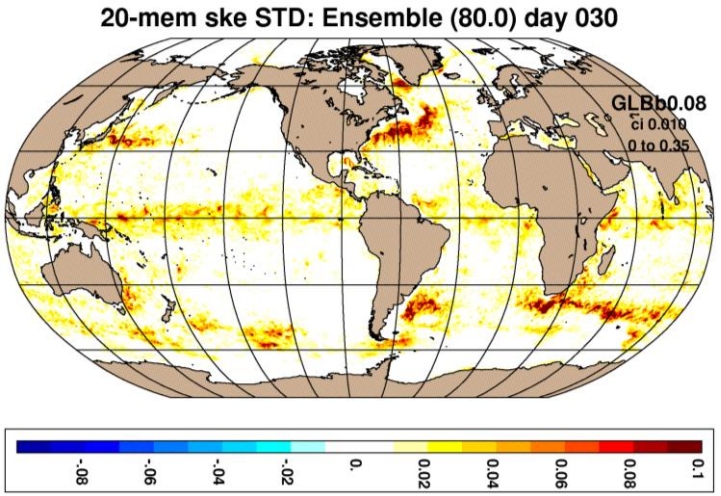
Purpose: Use the 20-year reanalysis to generate perturbed initial conditions for ocean ensembles.

- Global HYCOM ensembles based on the 20-year HYCOM/NCODA reanalysis
- 20 different 01 Jan states from years 1994-2013 initialize 01 Jan 2014
- 10 different 01 July states from years 2003-2012 initialize 01 Jan 2014
  - Experiment 1: Initial perturbations only; 3 month reanalysis, 3 month forecast
  - Experiment 2: Add surface forcing variability
  - Experiment 3: Add perturbed observations
  - Experiment 4: Add perturbed physics (stochastic forcing)
- Address these questions:
  - What is the timescale of spread collapse without perturbed obs, and what is the background model variability? (Exp 1)
  - What is the rate of growth of ensemble spread from the model variability? (Exp 1)
  - What is the contribution of atmospheric model uncertainty? (Exp 2)
  - What is the contribution of perturbed observations in the analysis? (Exp 3)

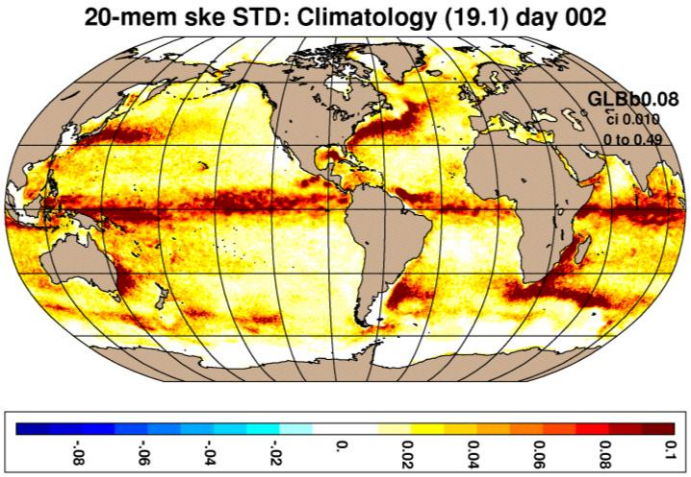
What is the relative role of internal ocean dynamics vs. atmospheric forcing on uncertainty/spread in ocean variables such as mixed layer depth?

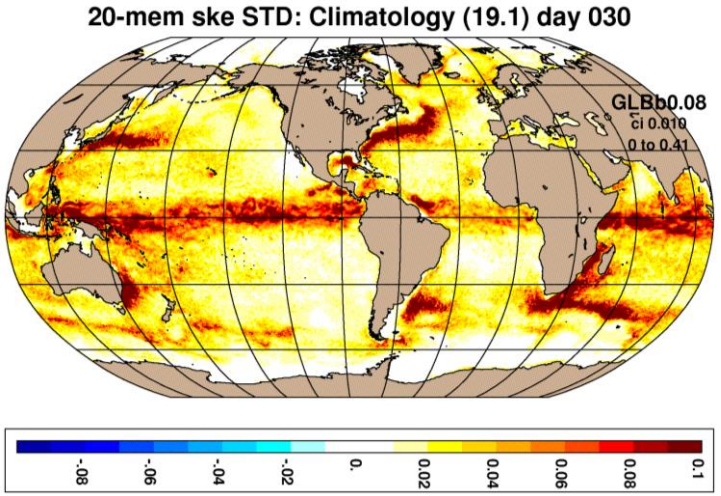
Surface Eddy Kinetic Energy after 30 days of DA cycling





Ensemble Variance (standard deviation)





Climatological Variance (standard deviation)

What is ESPC?

National ESPC
EARTH SYSTEM PREDICTION CAPABILITY

Coupled global analysis and prediction framework at accuracies and timescales beyond traditional synoptic weather forecasts.

More than just a model. An approach towards advanced understanding and systems-based prediction leveraging multiple U.S. national efforts

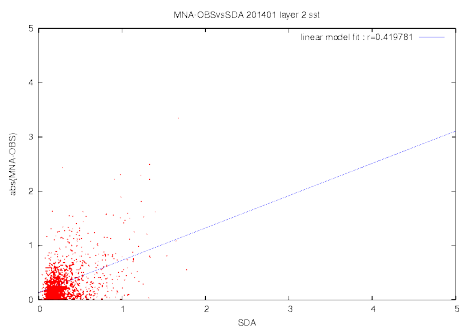

National
ESPC
EARTH SYSTEM PREDICTION CAPABILITY
NSF
NOAA
NASA

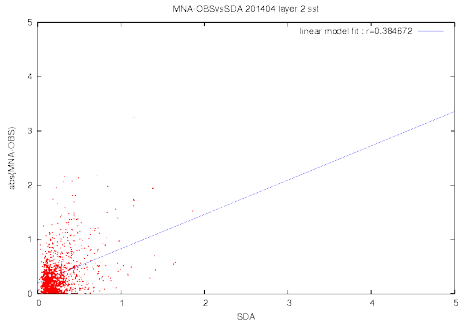
L10: Ensemble Error vs. Ensemble Spread

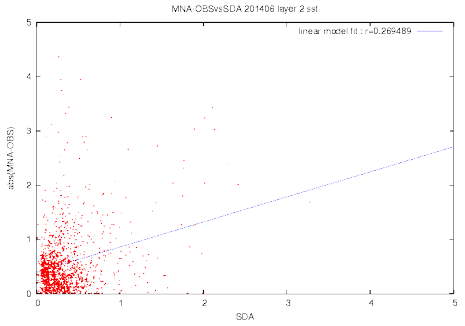
Layer 2 is ~2.5m global average

January **April** **July**

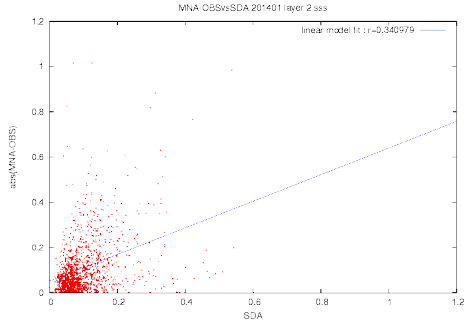
error

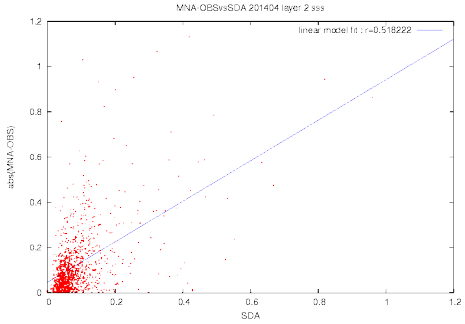


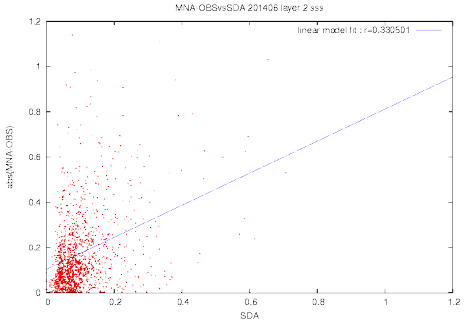




spread **Temperature**







Salinity

The end of the analysis is more underdispersive (less ensemble spread) than the climatological uncertainty,.
The forecast spread is improved, but still underdispersive.