Sea Ice Development at NCEP/EMC

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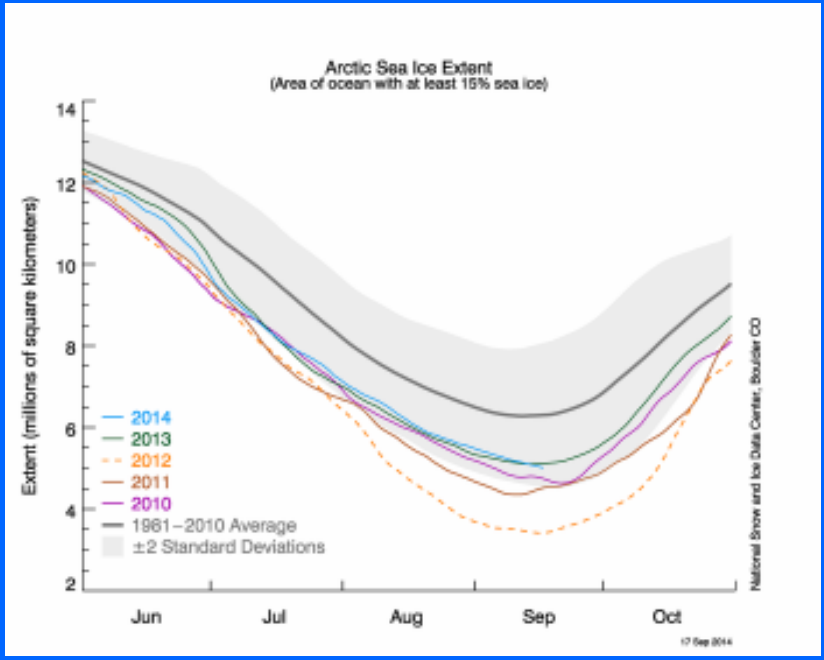
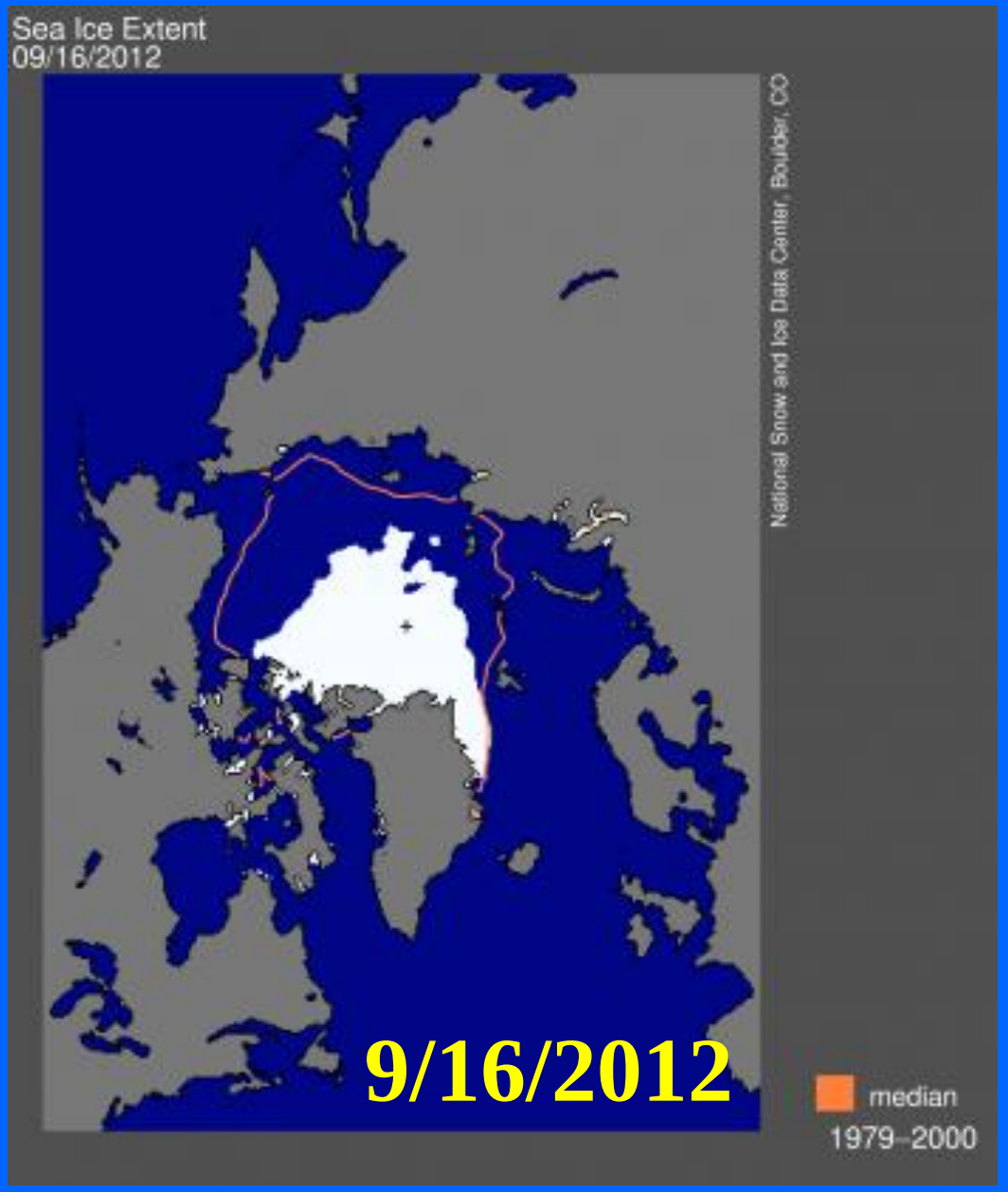
Arctic sea ice hits record low in 2012



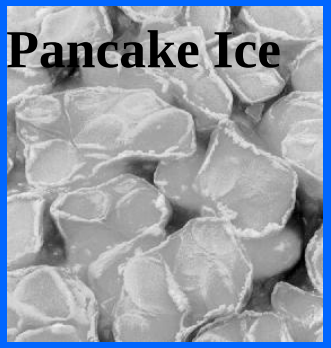


Outline

- Sea Ice
- Sea Ice Model
- Sea Ice in the NCEP Mesoscale Forecast System
- Sea Ice in the Real-Time Ocean Forecast System
- Sea Ice Drift Model at NCEP
- Sea Ice in the NCEP Global Forecast System
- Sea Ice in the NCEP Climate Forecast System (CFS)
- Sea Ice in the CFS Reanalysis (CFSR) & CFSv2
- Future Development

Sea Ice

Sea ice is a thin skin of frozen water covering the polar oceans. It is a highly variable feature of the earth's surface.



Sea ice affects climate and weather related processes

- **Sea ice amplifies any change of climate due to its "positive feedback" (coupled climate model concern):**

  Sea ice is white and reflects solar radiation back to space. More sea ice cools the Earth, less of it warms the Earth. A cooler Earth means more sea ice and vice versa.

- **Sea ice restricts the exchange of heat/water between the air and ocean (NWP concern)**

- **Sea ice modifies air/sea momentum transfer, ocean fresh water balance and ocean circulation:**

  The formation of sea ice injects salt into the ocean which makes the water heavier and causes it to flow downwards to the deep waters and drive a massive ocean circulation

Issues related to sea ice reanalysis and forecast

- Sea ice models and coupling
- Initial conditions
- Data assimilation

Sea ice model and coupling issues

- Ice thermodynamics
- Ice dynamics
- Ice model coupling to the atmosphere
- Ice model coupling to the ocean

Ice Model: Thermodynamics

Based on the principle of the conservation of energy, determine:

- Ice formation
- Ice growth
- Ice melting
- Ice temperature structure

Ice Model: Dynamics

Based on the principle of the conservation of momentum, determine:

- Ice motions
- Ice deformation
- Leads (open water)

Current Operational Sea Ice at NCEP

Model	Dynamics	Thermodynamics	Range
NAM	None	3m ~land (NOAH)	84 hr
GFS	None	3-layer	384 hr
CFS	EVP	GFDL SIS	9 months
RTOFS	None	Energy Loan	120 hr
Drift	Free Drift	None	384 hr

Sea Ice in the NCEP Mesoscale Forecast System (North American Model - NAM)

Sea Ice is treated very simply:

- ✓ Does not move
- ✓ No leads – 100% coverage
- ✓ Fixed thickness (3m) – treated similar to land
- ✓ Basal temperature is fixed at 271.13K
- ✓ ICs are from IMS (Interactive Multisensor Snow and Ice Mapping System)

Sea Ice in the NCEP Real-Time Ocean Forecast System

Energy Loan Model:

- ✓ Does not move
- ✓ No concentration or thickness
- ✓ Albedo effect
- ✓ Affect on air-sea heat exchange

Sea Ice Drift Model at NCEP

Virtual Floe Model:

- ✓ Assume sea ice floe at each point
- ✓ Sea ice drifts at a fraction of the wind speed with an turning angle
- ✓ Geostrophic winds for 1978-2007
- ✓ 10 m winds 2007-present
- ✓ To provide guidance to the forecasters up to 16 days

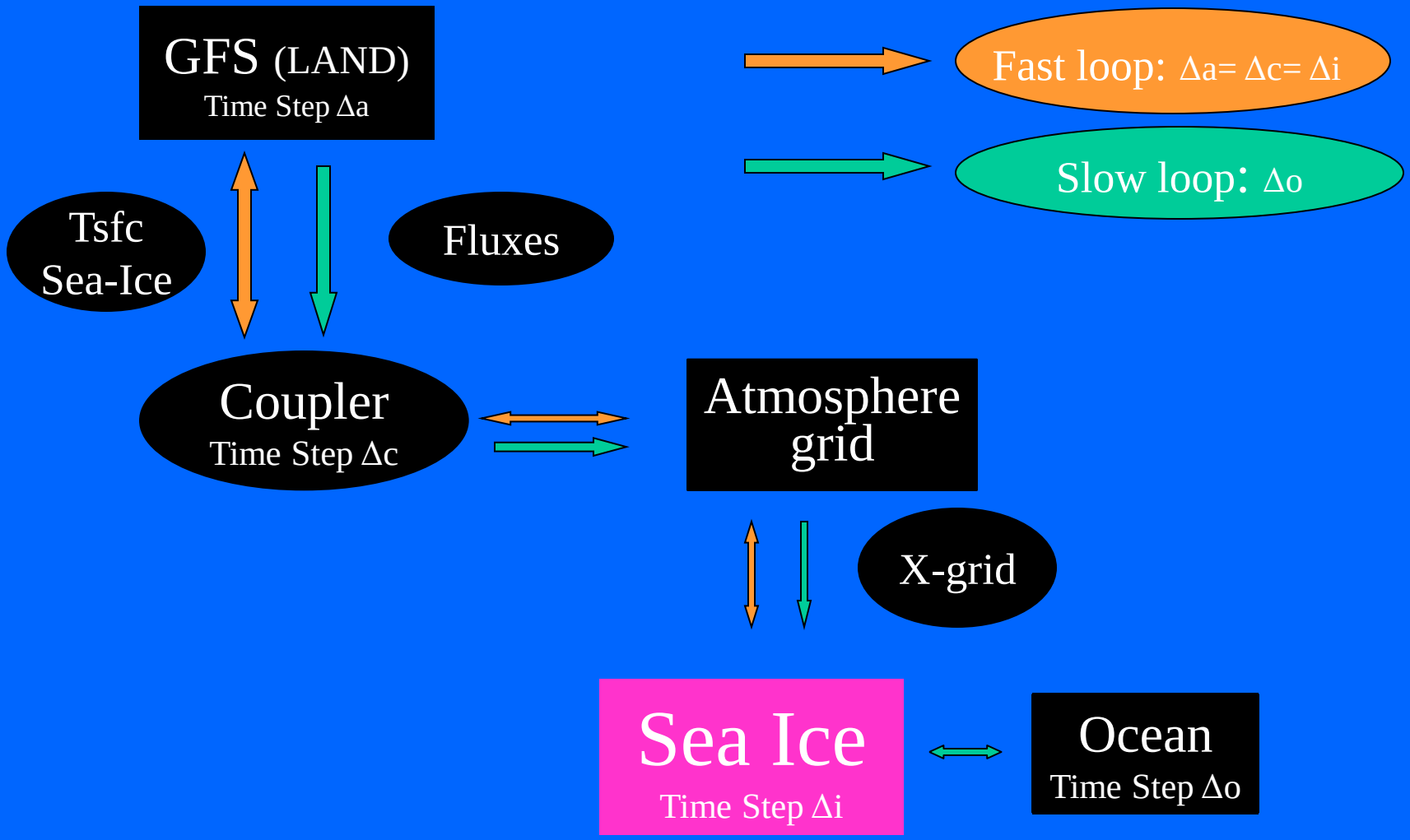
Sea Ice in the NCEP Global Forecast System

Three-layer thermodynamics:

- ✓ Winton (2000) – 2-layer of ice and 1-layer of snow
- ✓ Sea ice concentration from analysis
- ✓ Predict sea ice thickness and temperature
- ✓ Reduced cold bias in the GFS
- ✓ Implemented in May 2005

Winton M. (2000). A reformulated three-layer sea ice model, *J. of Atmospheric and Oceanic Technology*, 17, 525-531.

Sea-ice is one component of CFSv2



Sea Ice Model in NCEP CFSv2

GFDL Sea Ice Simulator:

- **Hunke and Dukowicz (1997) elastic-viscous-plastic (EVP) ice dynamics model**
  - Improved numerical method for Hibler's viscous-plastic (VP) model
  - Computionally more efficient than Hibler's VP model
- **Winton (2000) 3-layer thermodynamic model plus ice thickness distribution**
  - 2-layer of sea ice and 1-layer of snow
  - Fully implicit time-stepping scheme, allowing longer time steps
  - 5 categories of sea ice

Hunke E.C., Dukowicz J.K. (1997). An elastic-viscous-plastic model for sea ice dynamics. *Journal of Physical Oceanography,* 27, 1849-1867.

Initial condition issues

- ✓ Sea ice concentration data are available but velocity data lack to real time
- Sea ice and snow thickness data are based on model spinup values or climatology

Data assimilation issues

- ✓ Sea ice concentration data are available but velocity data lack to real time
- Lack of sea ice and snow thickness data

Sea Ice in CFSR/CFSv2

- ✓ **Sea ice fraction from sea ice concentration analysis, similar to that in GFS**
- ✓ **Melt pond in the Arctic Ocean from June to September**
- ✓ **Prediction of sea ice in CFSv2 up to 9-month**
- ✓ **CFSv2: Implemented in March 2011**

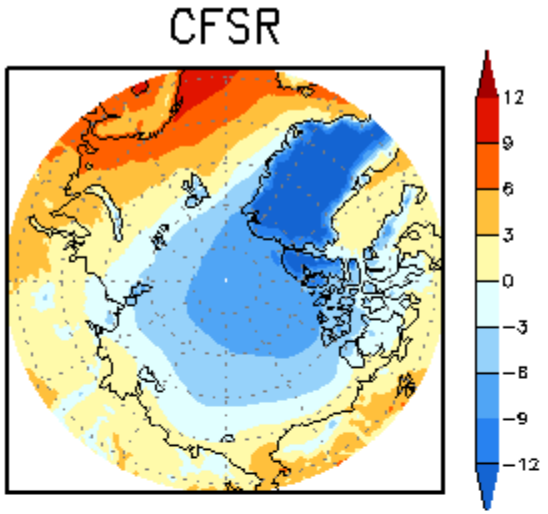
Saha, S. and Coauthors, 2014: The NCEP Climate Forecast System Version 2. Journal of Climate J. Climate, 27, 2185–2208. doi: http://dx.doi.org/10.1175/JCLI-D-12-00823.1

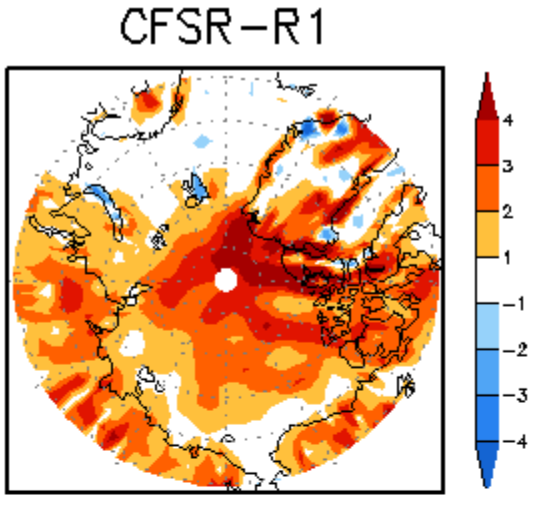
Sea ice data used for CFSR

- From 1979 to 1996, the sea ice concentrations for most of the globe are regridded from Cavalieri et al. (1996, updated 2007) (GSFC Ice).
- From Jan 1997-Feb 2000, the global ice concentration analysis was the NCEP operational ice analysis (Grumbine, 1996) (outside the Great Lakes and Canadian Lakes).
- From 1 March 2000 to 29 October 2007, the sea ice analysis is the newer NCEP sea ice analysis system (Grumbine, 2010) applied to archived passive microwave data for DMSP F-13, F-14, and F-15.
- From October 30, 2007 onwards, the concentrations are the operational NCEP passive microwave sea ice concentration analyses.

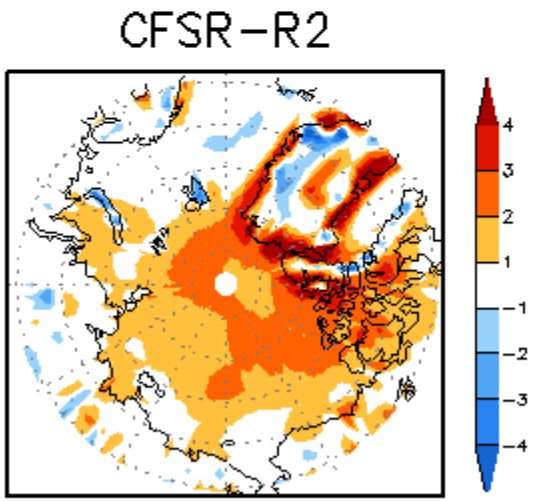
Surface air temperature from CFSR (Sept) and the difference amongst CFSR, R1, R2 and ERA40

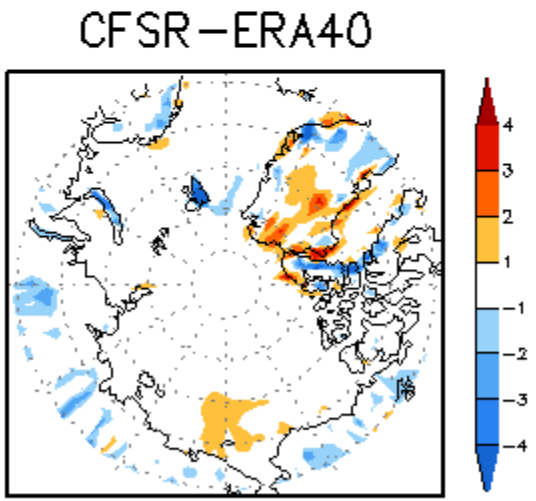
Cold bias in R1: 1.7K than obs





CFSR is: 1.8K Warmer than R1





Future Direction

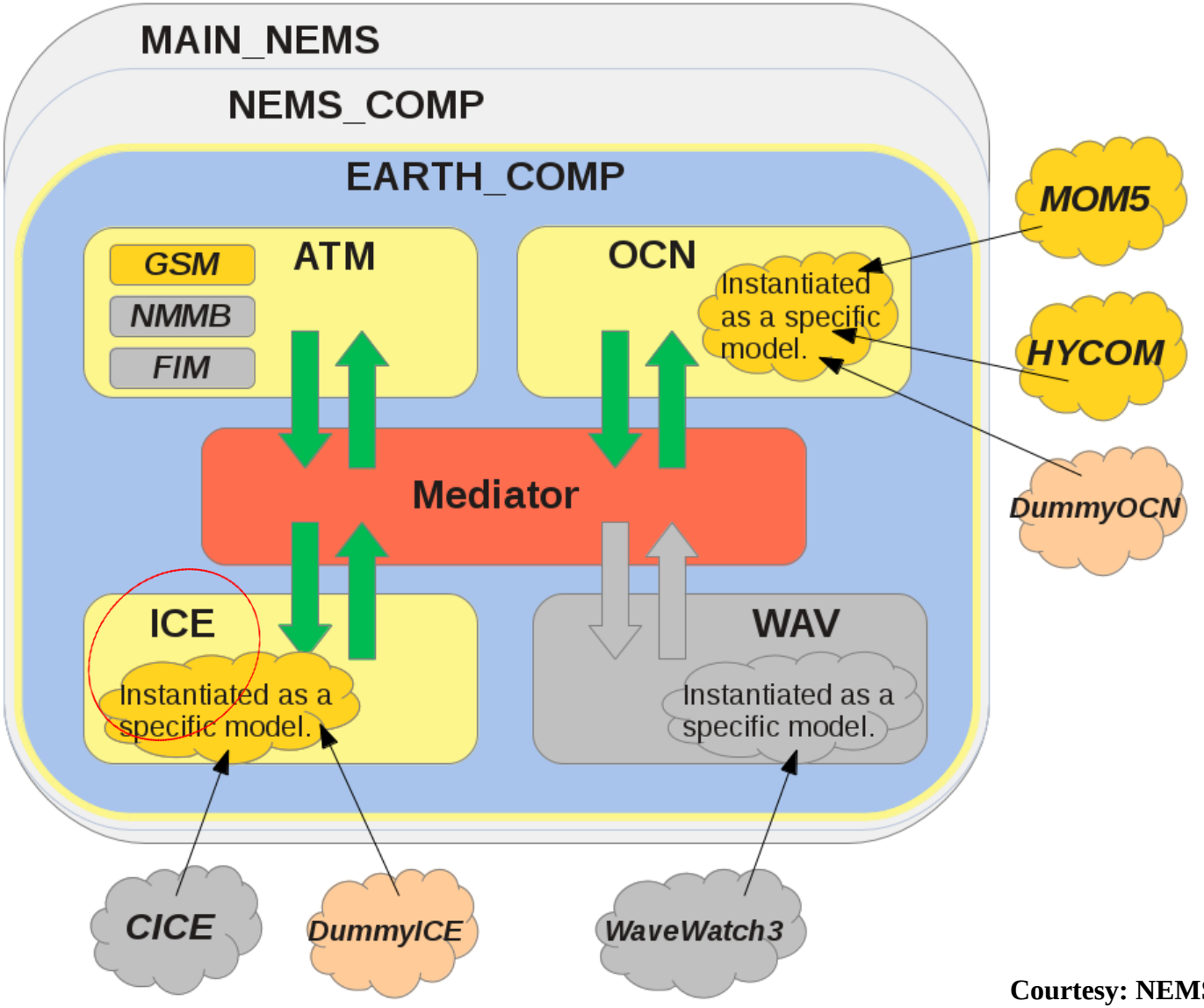
NOAA Environmental Modeling System

http://www.emc.ncep.noaa.gov/index.php?branch=NEMS

- **NEMS is a shared, portable, high performance software superstructure and infrastructure for use in operational prediction models at the NCEP.**

- **It is also part of the National Unified Operational Predication Capability (NUOPC) with Navy and the Air Force, and will eventually provide support to the community through the Developmental Test Center (DTC).**

NEMS coupled version (under development)



Courtesy: NEMS Team

Sea Ice Model (in NEMS)

- EMC/NCEP KISS (Under development - Grumbine)
- Los Alamos sea ice model (CICE version 5.0 or version 5.1)
- GFDL SIS (Sea Ice Simulator in CFSv2)
- GFDL SIS2
- …
- any other NEMS-compatible ice model which becomes available

Sea Ice Data Assimilation

- **In CFSR/CFSv2 we assimilated sea ice concentration by nudging the sea ice concentration towards the observed value:**

$$fi\_A = fi\_F + k*(fi\_O - fi\_F)$$

- **The nudging coefficient *k* was set to 1. Therefore, the CFSR/CFSv2 final product was in fact the observed sea ice concentration.**
- **Nudging of sea ice concentration in CFSR/CFSv2 has been successful; a continuation using the same technique may be acceptable; we can derive the coefficient *k* based on Lindsay and Zhang (2006) and/or Wang et al. (2013).**

Wang K., Debernard J., Sperrevik A.K., Isachsen P.R., and Lavergne T. (2013) A combined optimal interpolation and nudging scheme to assimilate OSISAF sea-ice concentration into ROMS. *Annals of Glaciology*, 54(62), 8-12.

Zhang, J., and Rothrock D.A. (2003). Modeling global sea ice with a thickness and enthalpy distribution model in generalized curvilinear coordinate. *Monthly Weather Review,* 131(5), 681-697.

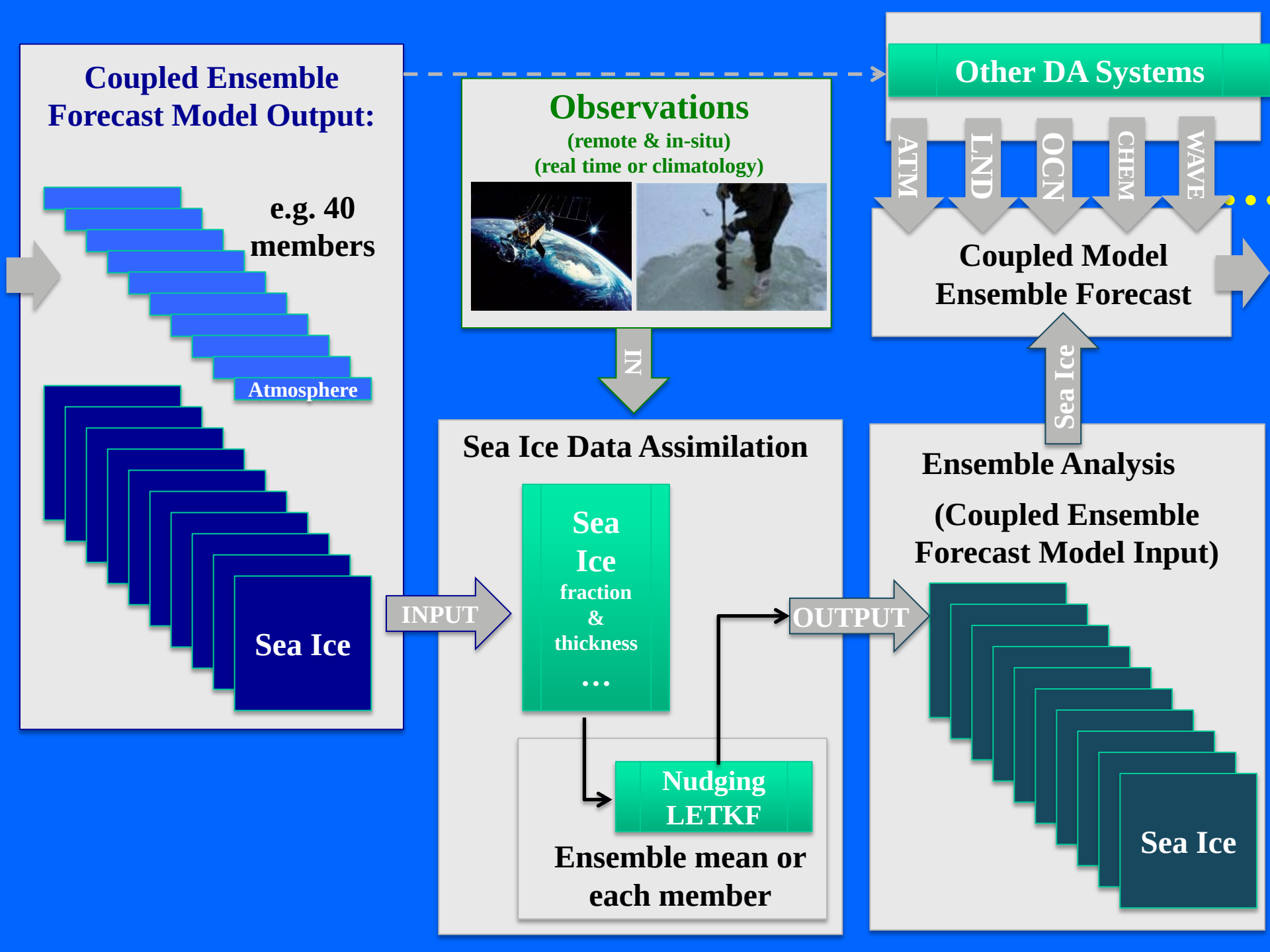
Sea Ice Data Assimilation (cont.)

- **The inclusion of sea ice thickness assimilation may be a minimum requirement for the next CFS.**
- **We can add a similar nudging approach for sea ice thickness (using a different coefficient).**
- **However, the lack of observational data needs to be resolved, since there is no global data set of real time sea ice thickness, we will carry out some tests by using sea ice thickness from:**

1. **Climatology**
2. **GIOMAS (Global Ice-Ocean Modeling and Assimilation System from Jinlun Zhang at University of Washington (Zhang and Rothrock 2003)**
3. **Tietche's approach (2013) to derive mean sea ice thickness from sea ice concentration**
4. **Available real time thickness data (not global coverage)**

Sea Ice Data Assimilation (cont.)

- A fully coupled ocean-seaice or atmosphere-sea ice data assimilation may not be feasible at the present time, but the application of the ensemble information from the fully coupled model forecast guess fields should be very useful, because ensemble forecasts will be used from the coupled model, sea ice assimilation can also be ensemble based.
- We can also try Local Ensemble Transform Kalman Filter (LETKF), similar to that of the ocean component, offered by Steve Penny.


Coupled Ensemble Forecast Model Output:
e.g. 40 members
Atmosphere
Sea Ice
Observations
(remote & in-situ)
(real time or climatology)
Other DA Systems
ATM
LND
OCN
CHEM
WAVE
Coupled Model Ensemble Forecast
IN
Sea Ice
Sea Ice Data Assimilation
INPUT
Sea Ice
fraction
&
thickness
…
Nudging
LETKF
Ensemble mean or each member
OUTPUT
Ensemble Analysis
(Coupled Ensemble Forecast Model Input)
Sea Ice


Thank you!