

Arctic Sea-Ice Prediction: Challenges and Opportunities

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Sea Ice Prediction Network



Photo by Matt Kennedy, 2012
Extreme Ice Project

Our goals are to

Improve sea ice forecasts

Advance the Sea Ice Outlook

Improve sea ice models

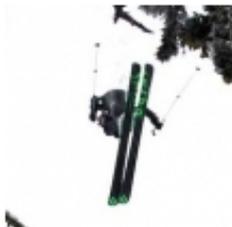
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Laboratory*

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*National Science
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*National Oceanic and
Atmospheric
Administration
(NOAA)*



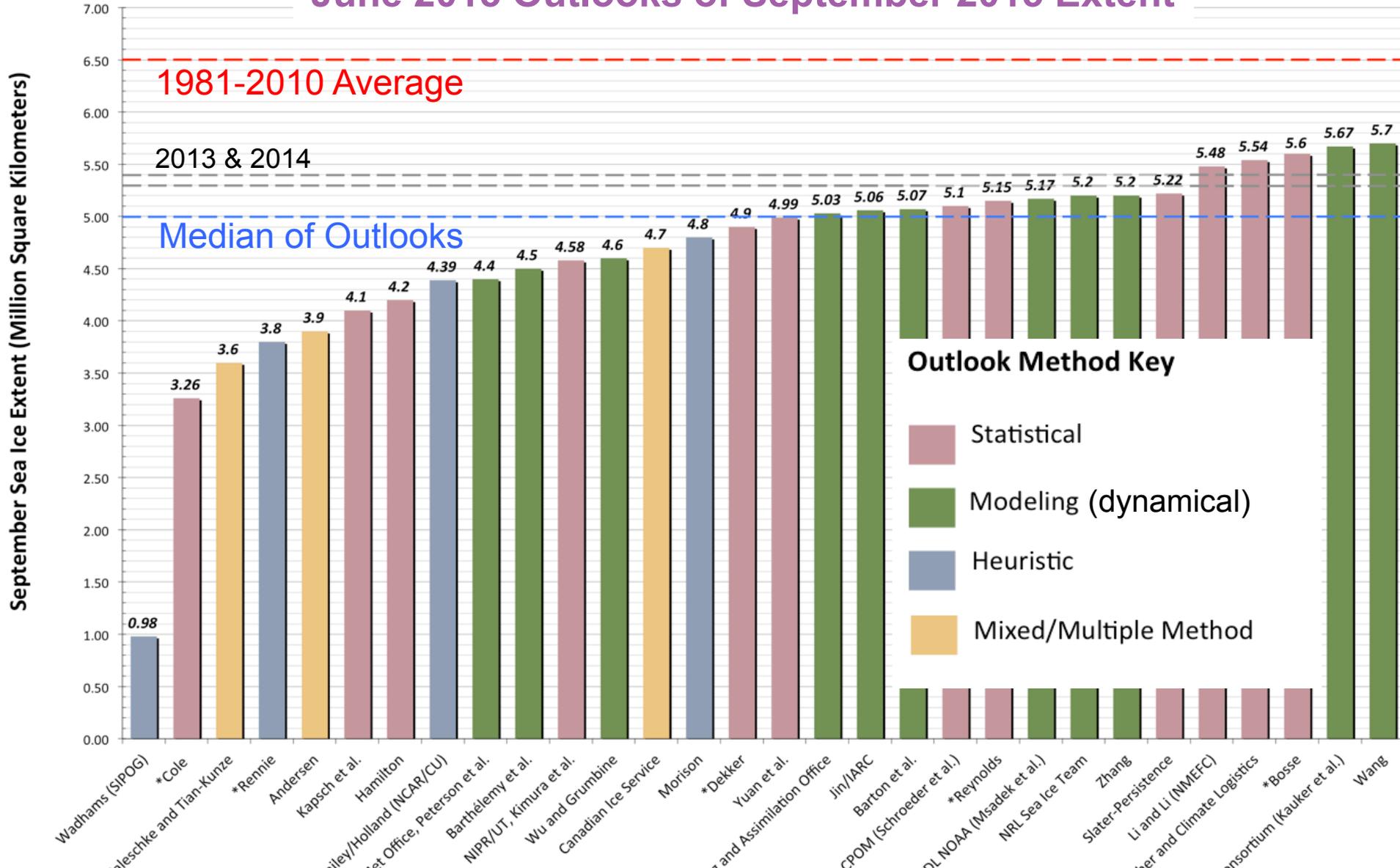
*National Aeronautics
and Space
Administration
(NASA)*



*Department of Energy
(DOE)*

Sea Ice Outlook and the Prediction Network

June 2015 Outlooks of September 2015 Extent



Sea Ice Outlook and the Prediction Network

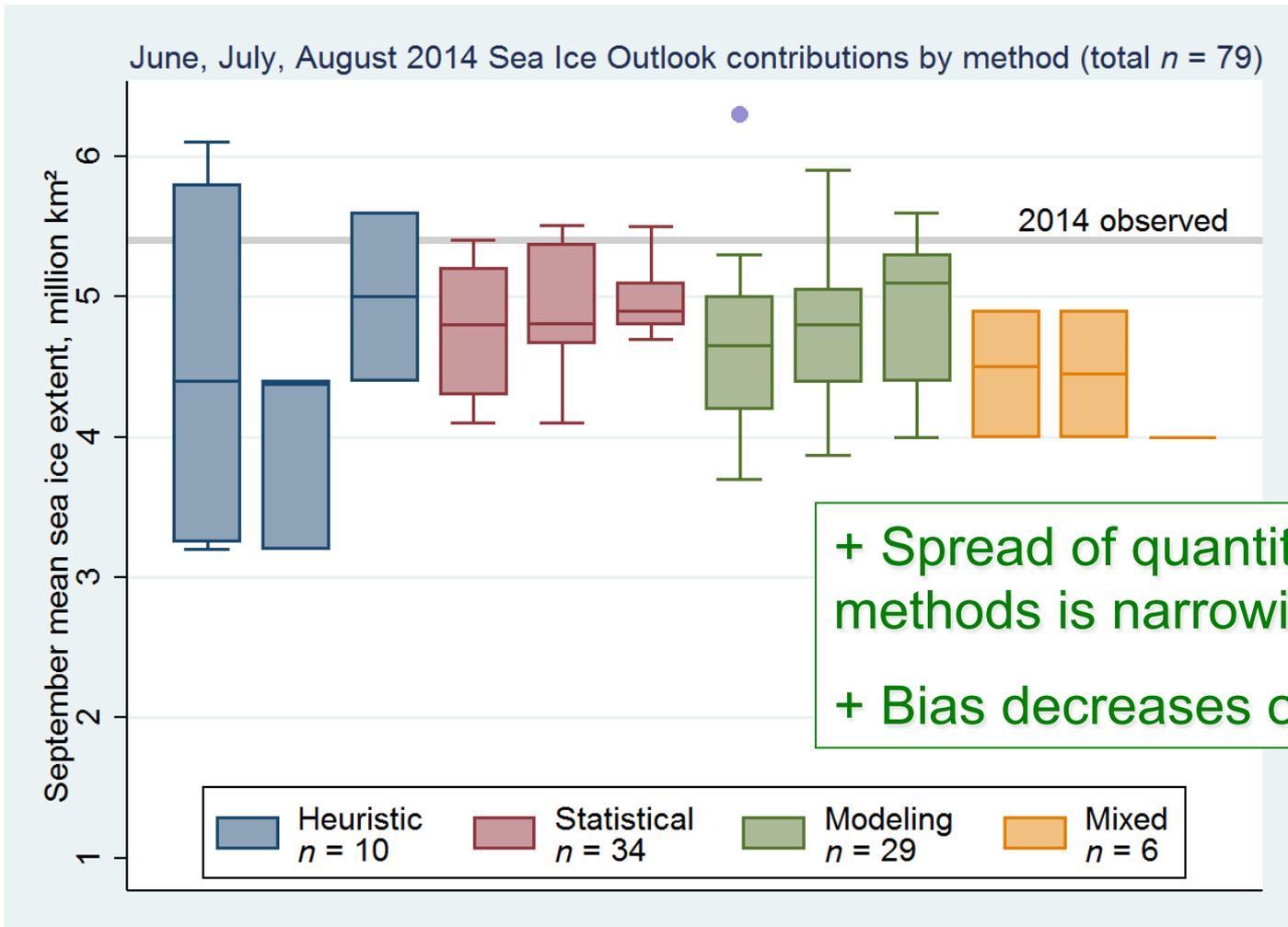


Figure by
Larry Hamilton

Sea Ice Outlook and the Prediction Network

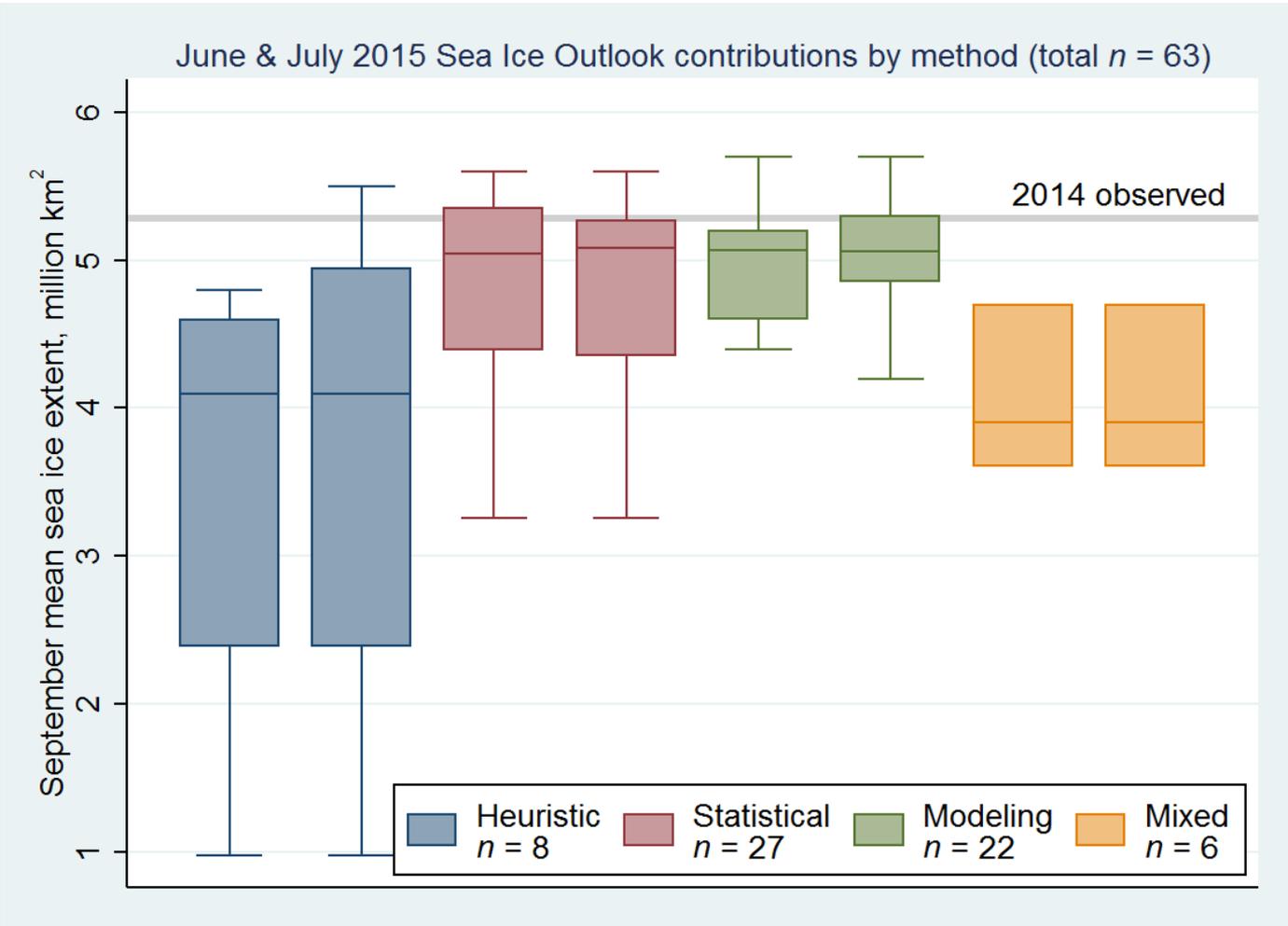
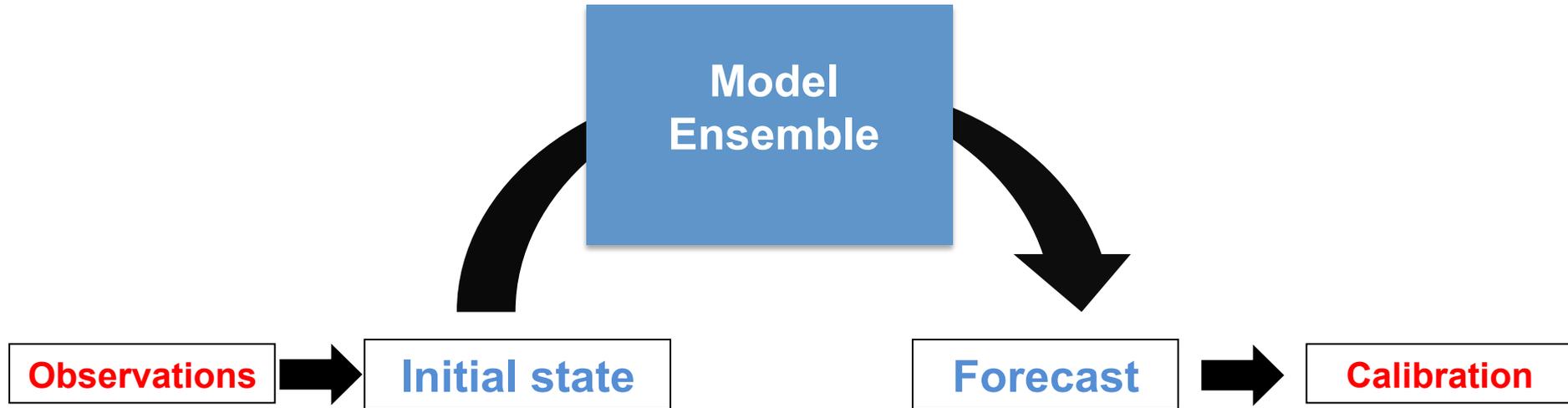


Figure by
Larry Hamilton

Sea Ice Forecast Systems



Challenges:

Initialize non-observable quantities (e.g., ice thickness)

Need to know observation uncertainty for ensemble generation

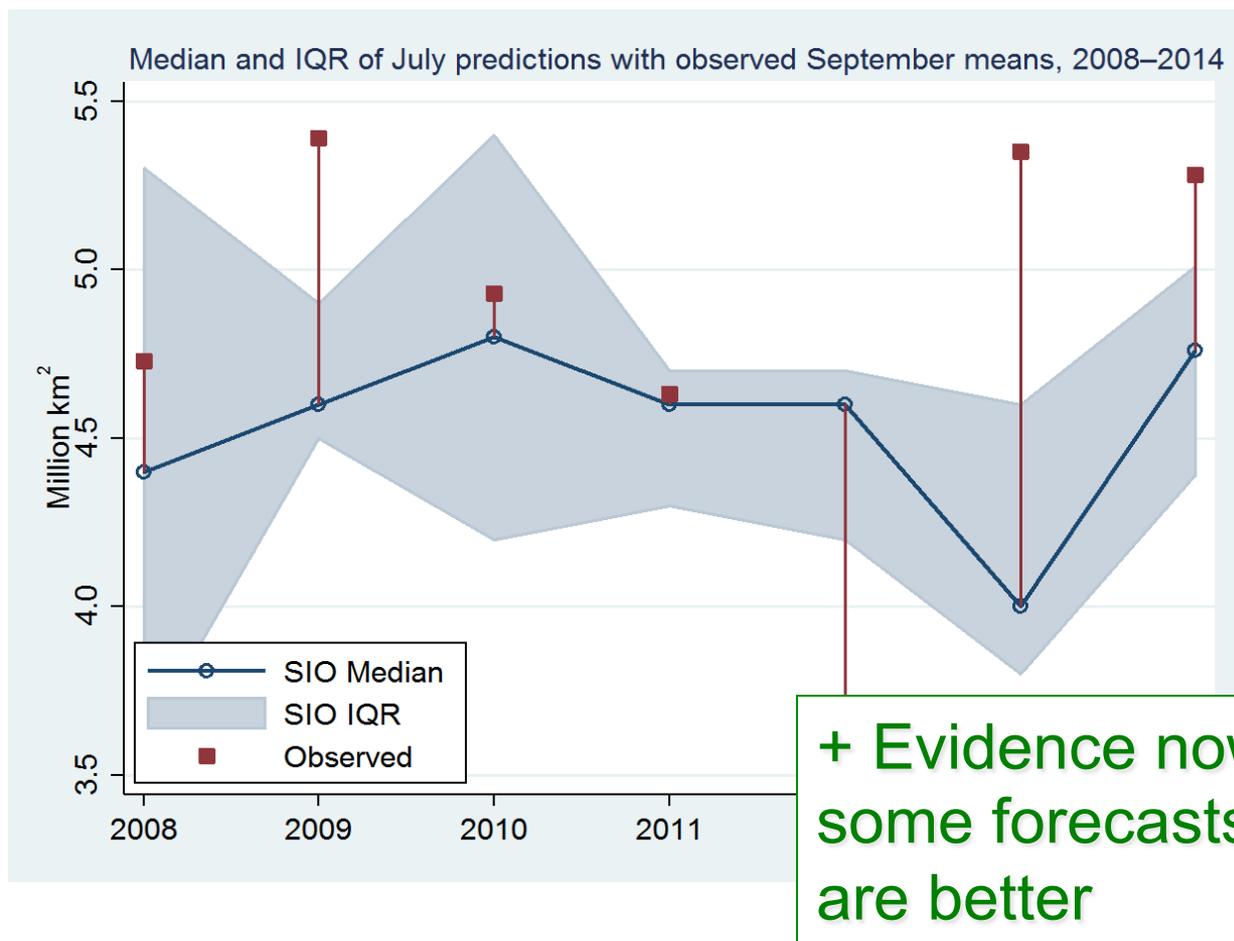
Sea ice ensemble methods and coupled data assimilation not well developed

Model error

Metrics for calibration not well developed

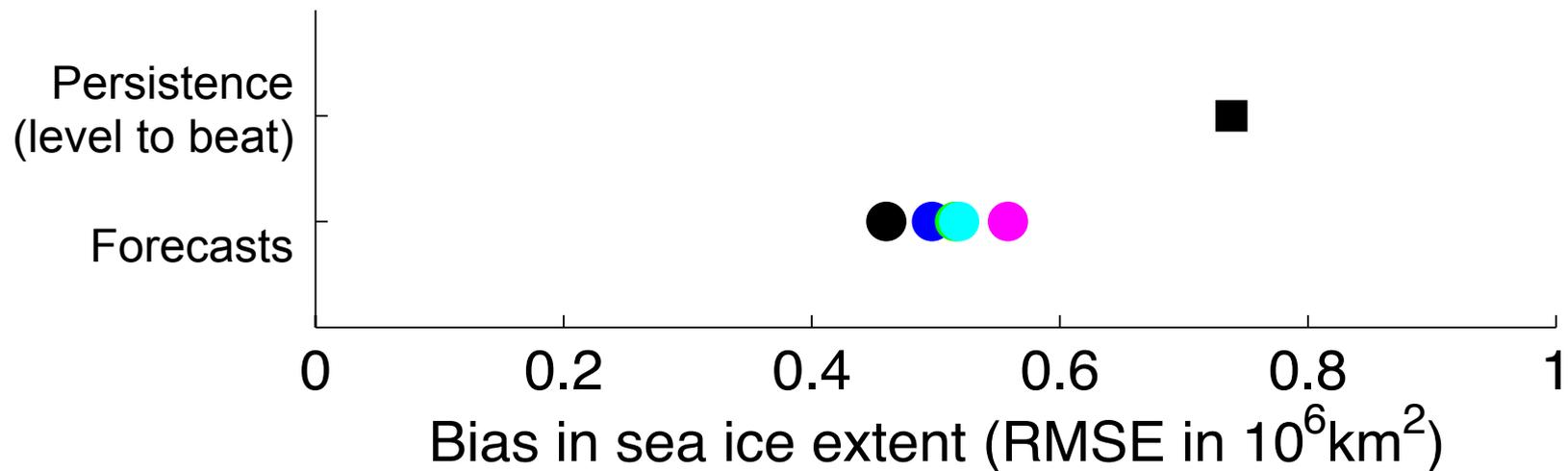
Requires massive computing effort

Synthesis of Sea Ice Outlook through 2014



Stroeve, Hamilton, Bitz, & Blanchard-Wrigglesworth (2014)

Forecast of September Sea Ice Extent at 4 Month Lead Time

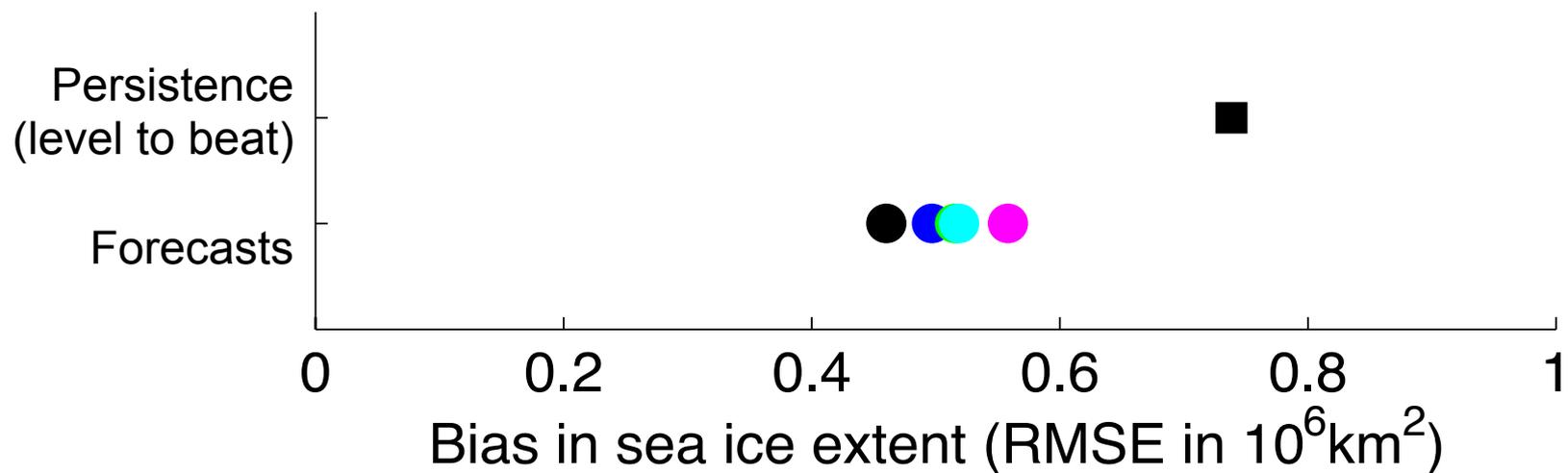


+ Retrospective forecasts in these 5 models are skillful

+ Shows importance of retrospective forecast

Figure by E. Blanchard-Wigglesworth

Forecast of September Sea Ice Extent at 4 Month Lead Time

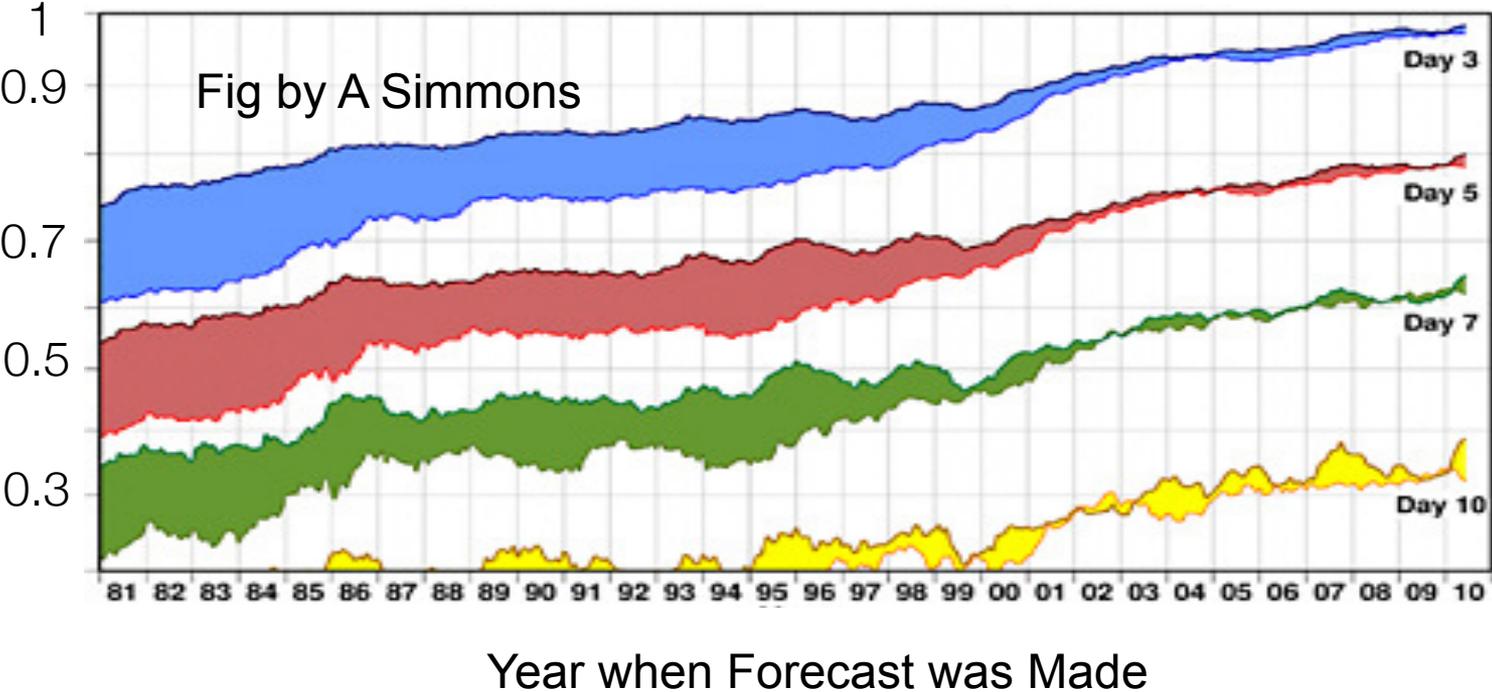


Not known why some retrospective forecasts are more skillful than Outlooks

Figure by E. Blanchard-Wigglesworth

Forecast of September Sea Ice Extent at 4 Month Lead Time

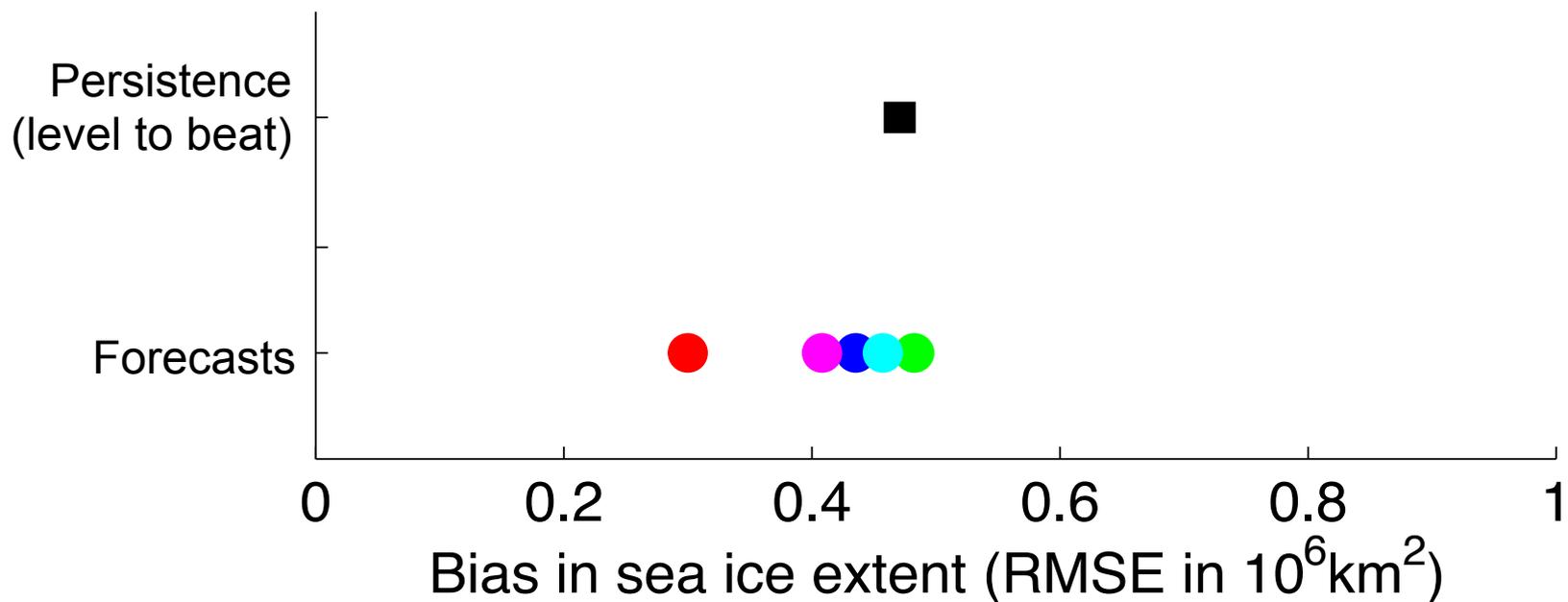
Skill of Atmospheric Circulation Forecasts from ECMWF



about as good as weather forecast at ~10 day lead time



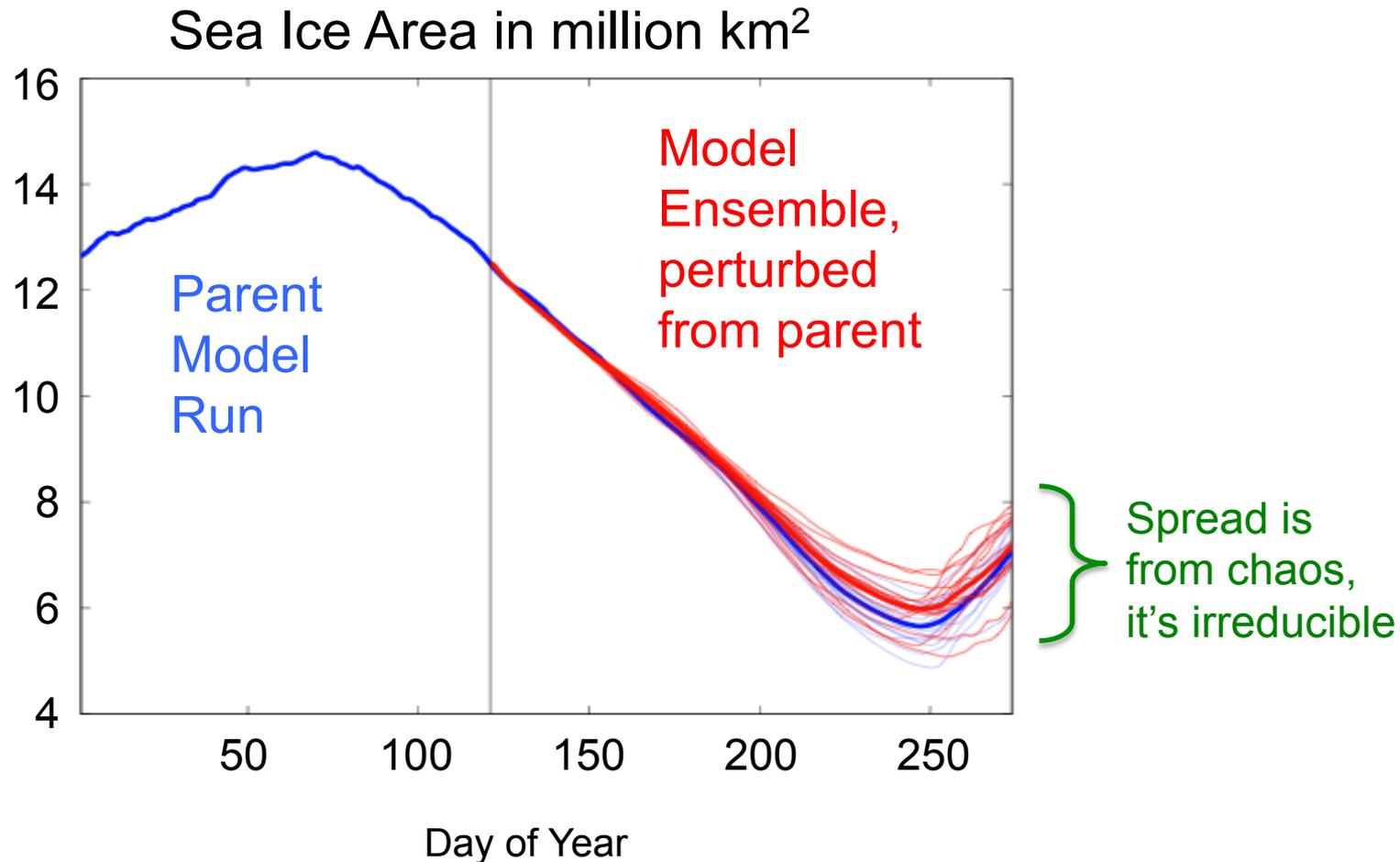
Forecast of September Sea Ice Extent at 2 Month Lead Time



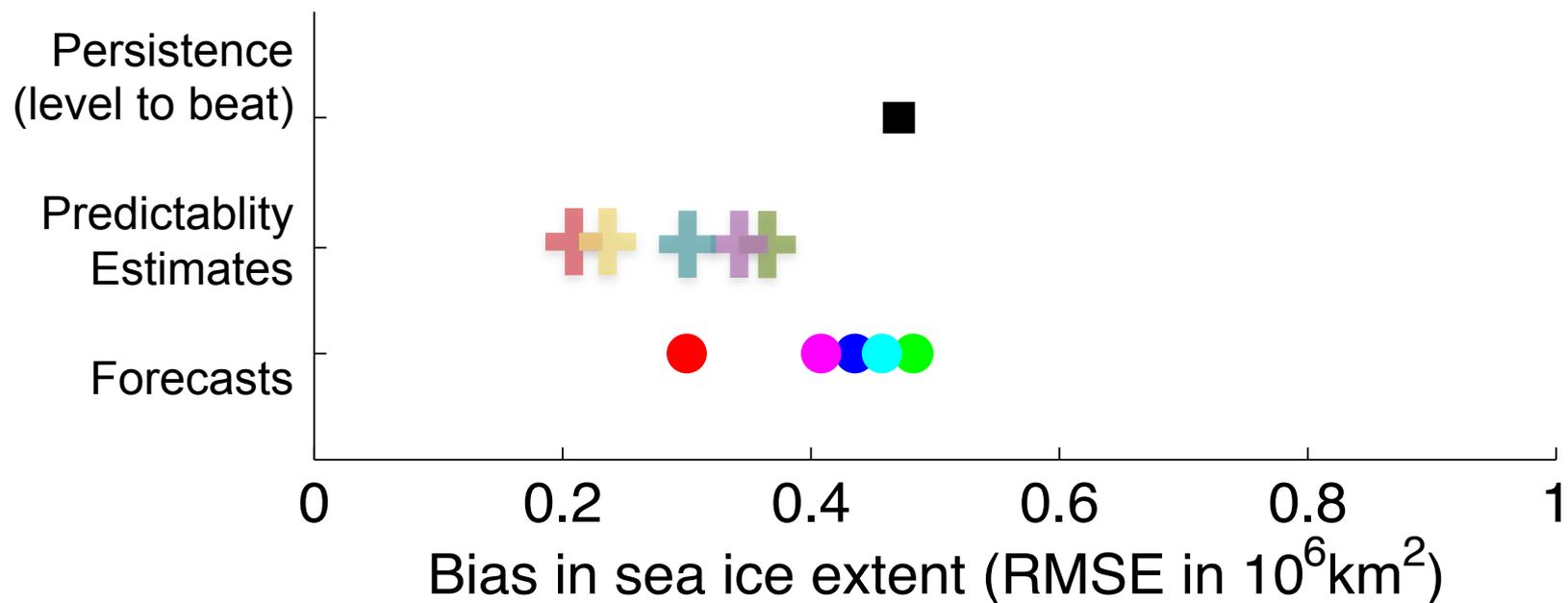
Not known why less skillful at shorter lead time

Method for Estimating Predictability

Compare ensemble forecasts to another ensemble member



Forecast of September Sea Ice Extent at 2 Month Lead Time



+ Predictability indicates room for improved forecasts

What Gives Us Sea Ice Predictability?

Initial state: concentration, thickness, SST, melt ponds, snow depths

Transport with currents and winds

Climate forcing: CO₂, aerosols, etc

What inhibits Predictability?

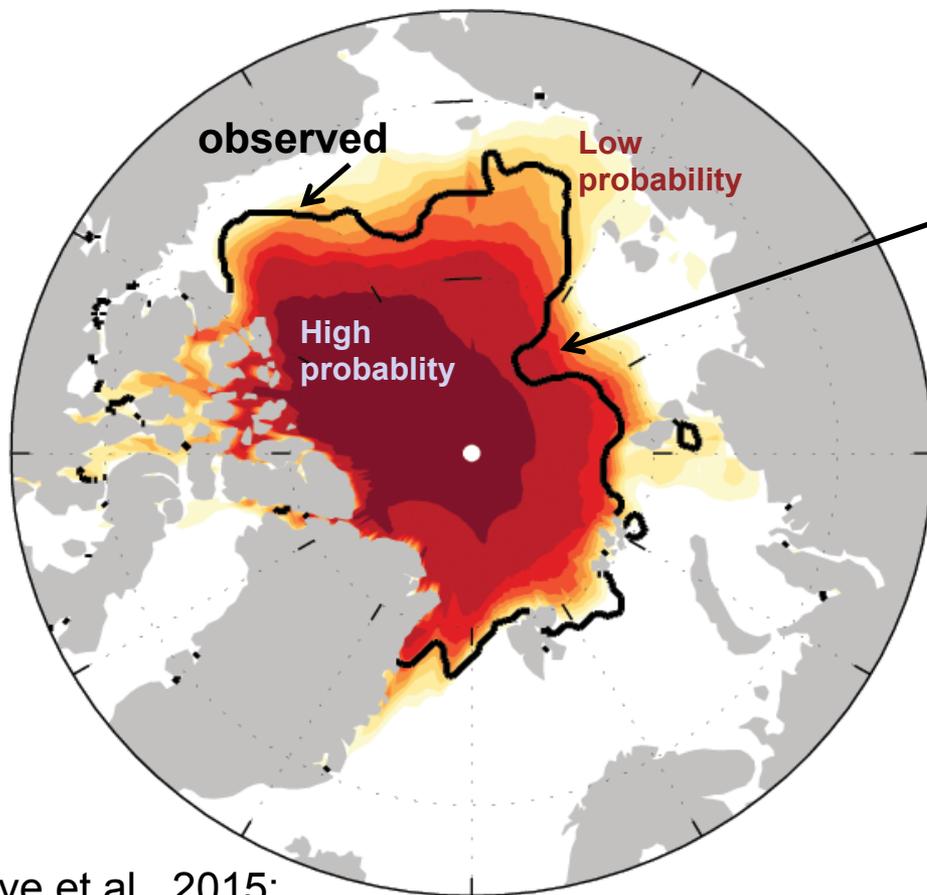
Atmospheric weather/chaos is irreducible

Why don't we achieve predictability?

Model errors, Initialization errors, climate forcing uncertainty

Sea Ice Outlook Spatial Distributions

Probability of Sea Ice Presence (SIP) September 2014



5 model mean captures reduced Laptev ice, but not as much as observed

Stroeve et al., 2015;
Fig by Ed Blanchard-
Wrigglesworth

Sea Ice Outlook Spatial Distributions

Probability of Sea Ice Presence by Model

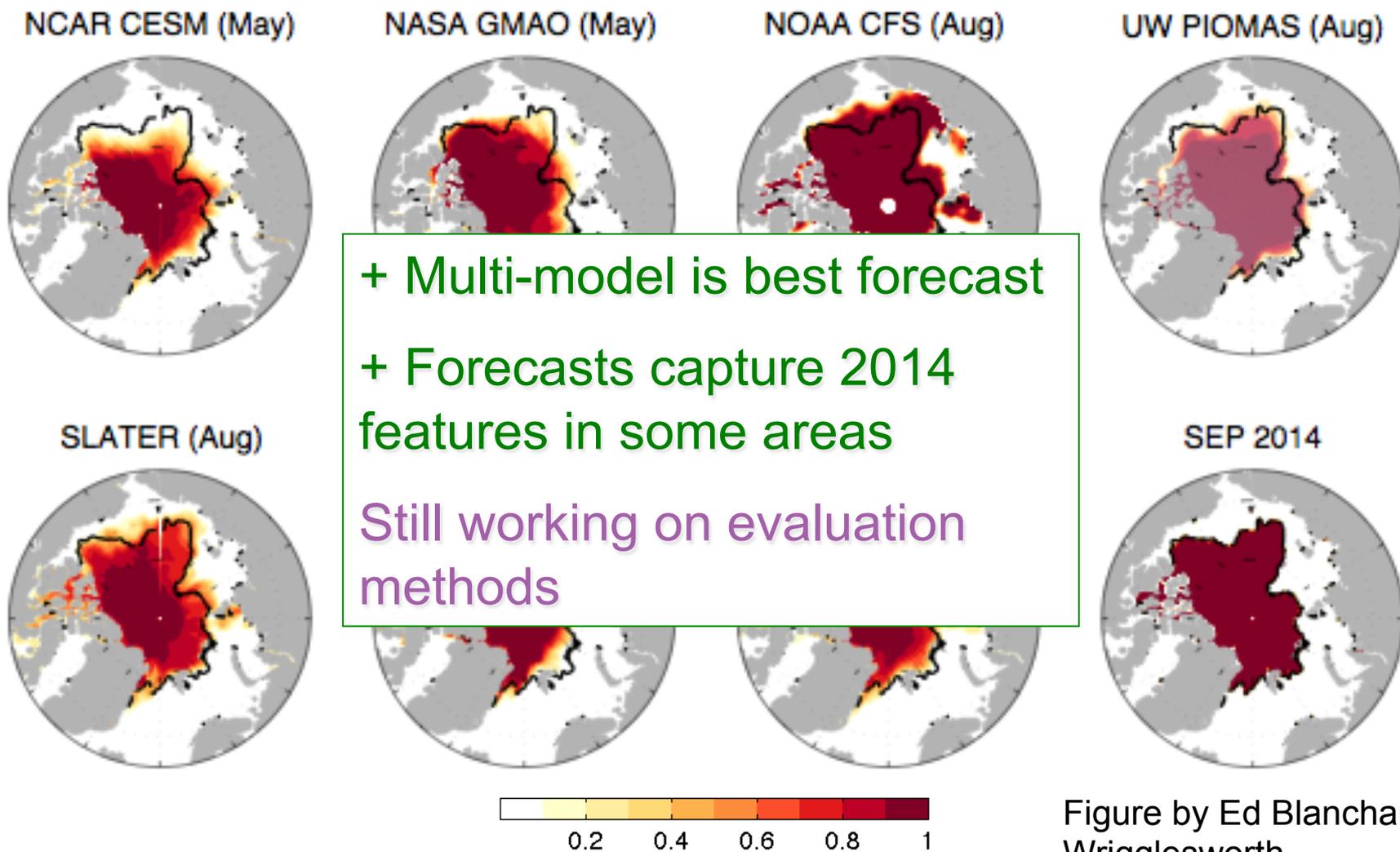
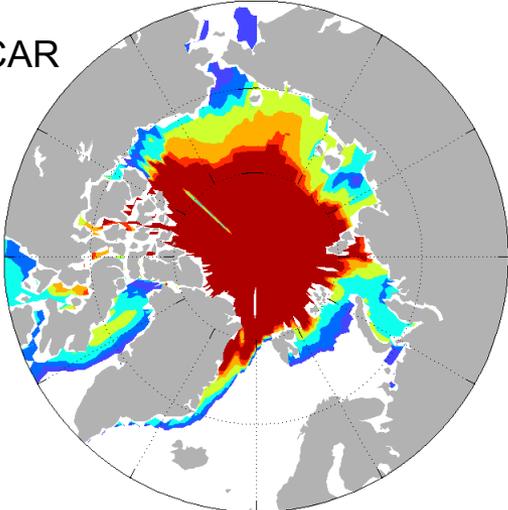


Figure by Ed Blanchard-Wrigglesworth

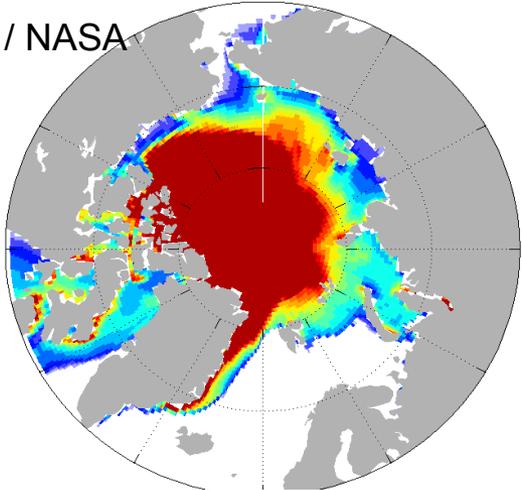
Sea Ice Outlook Spatial Distributions

First Ice-Free Day (IFD)

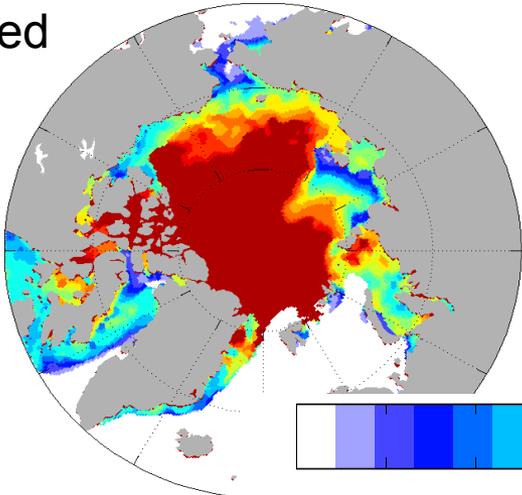
B-W / NCAR
CESM1



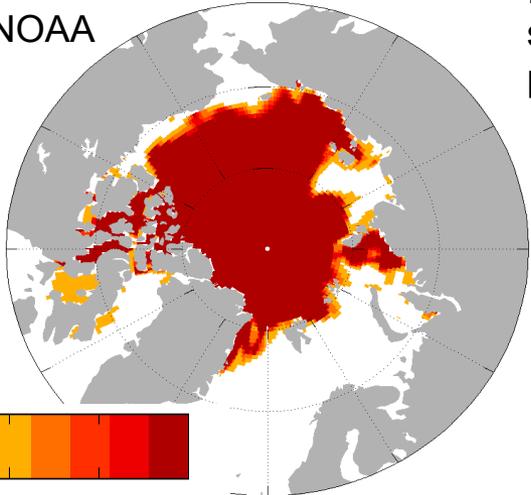
Cullather / NASA
GMAO



Observed

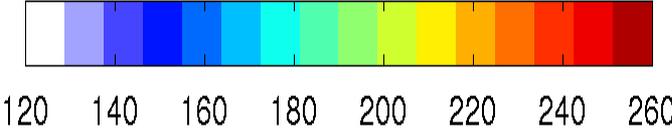


Wang / NOAA
CFSv2



Initialized 7 Aug,
so can't predict
prior to day 220

May 1= 121
June 1=152
July 1=182
Aug 1=213
Sep 1=244

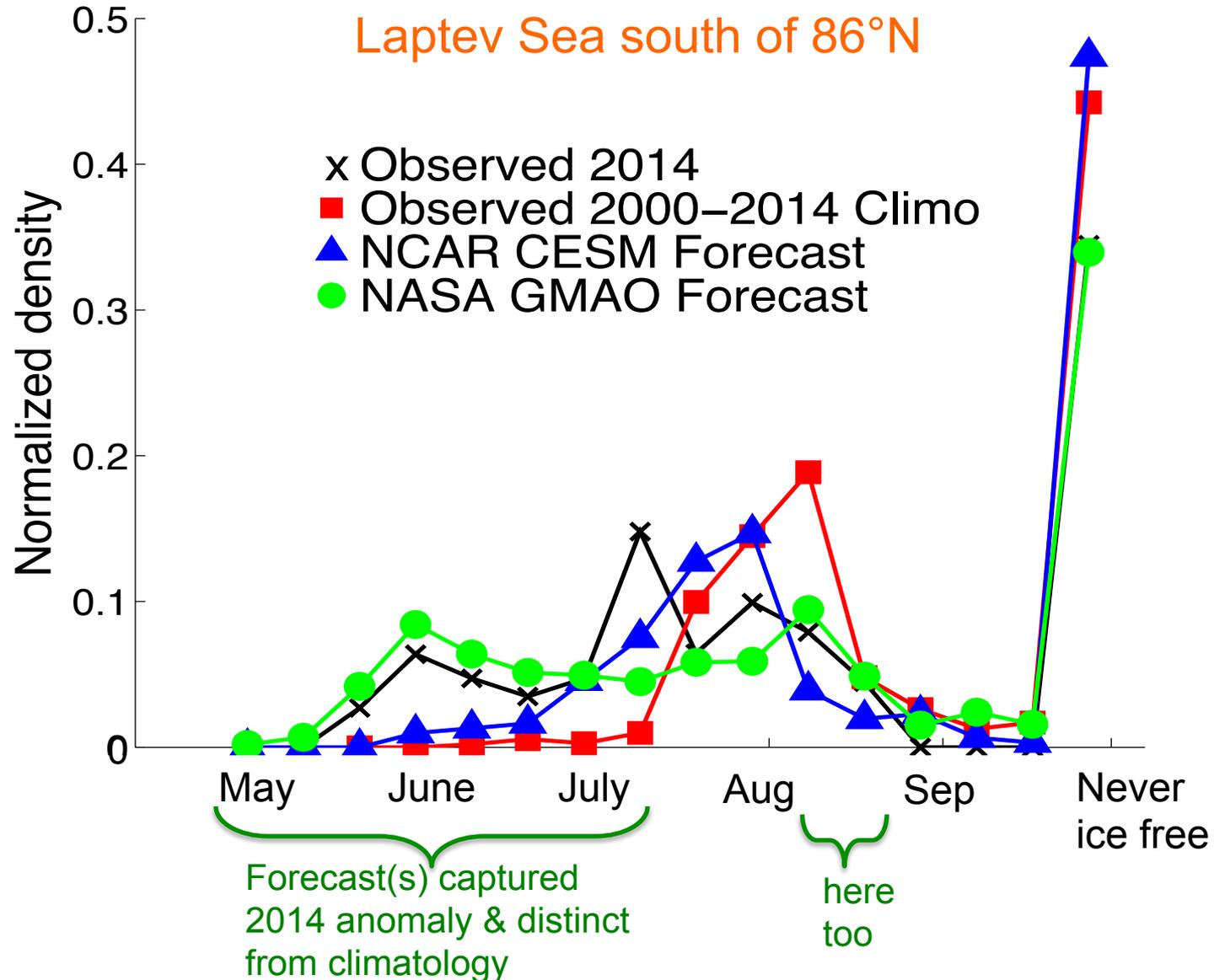


Julian Day

Figure by Ed Blanchard-
Wrigglesworth

Sea Ice Outlook Spatial Distributions

Distribution of Ice Free Day (IFD) Observed and in 2 Contributions



High Resolution and Global Coverage

Refined mesh grids, here showing an unstructured Veronoi mesh
Best qualities of regional and global models

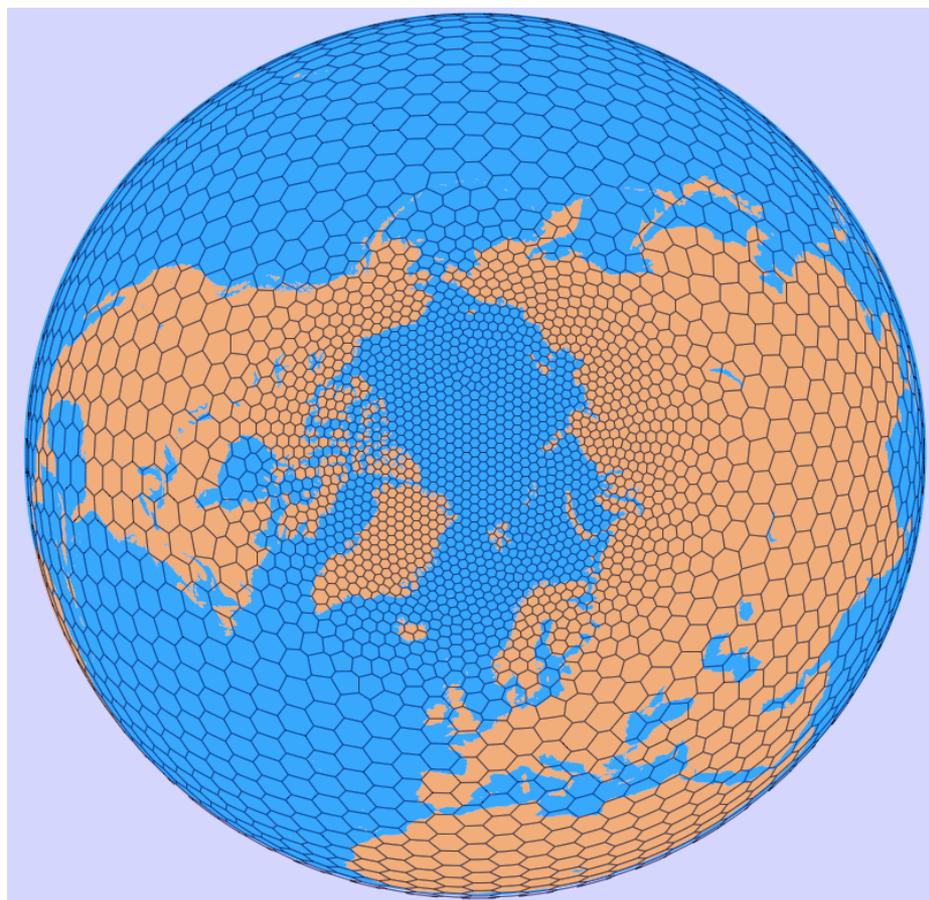
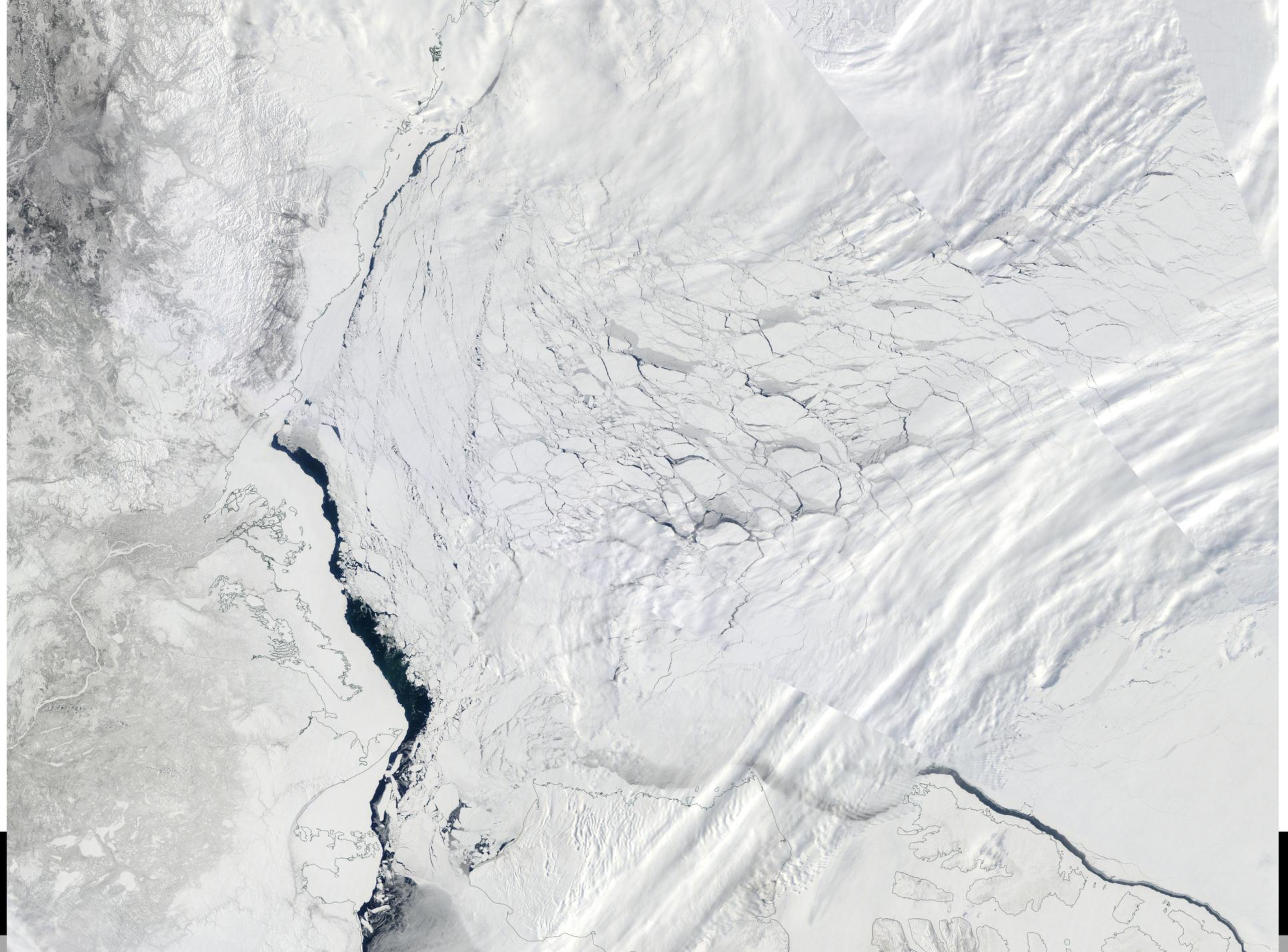
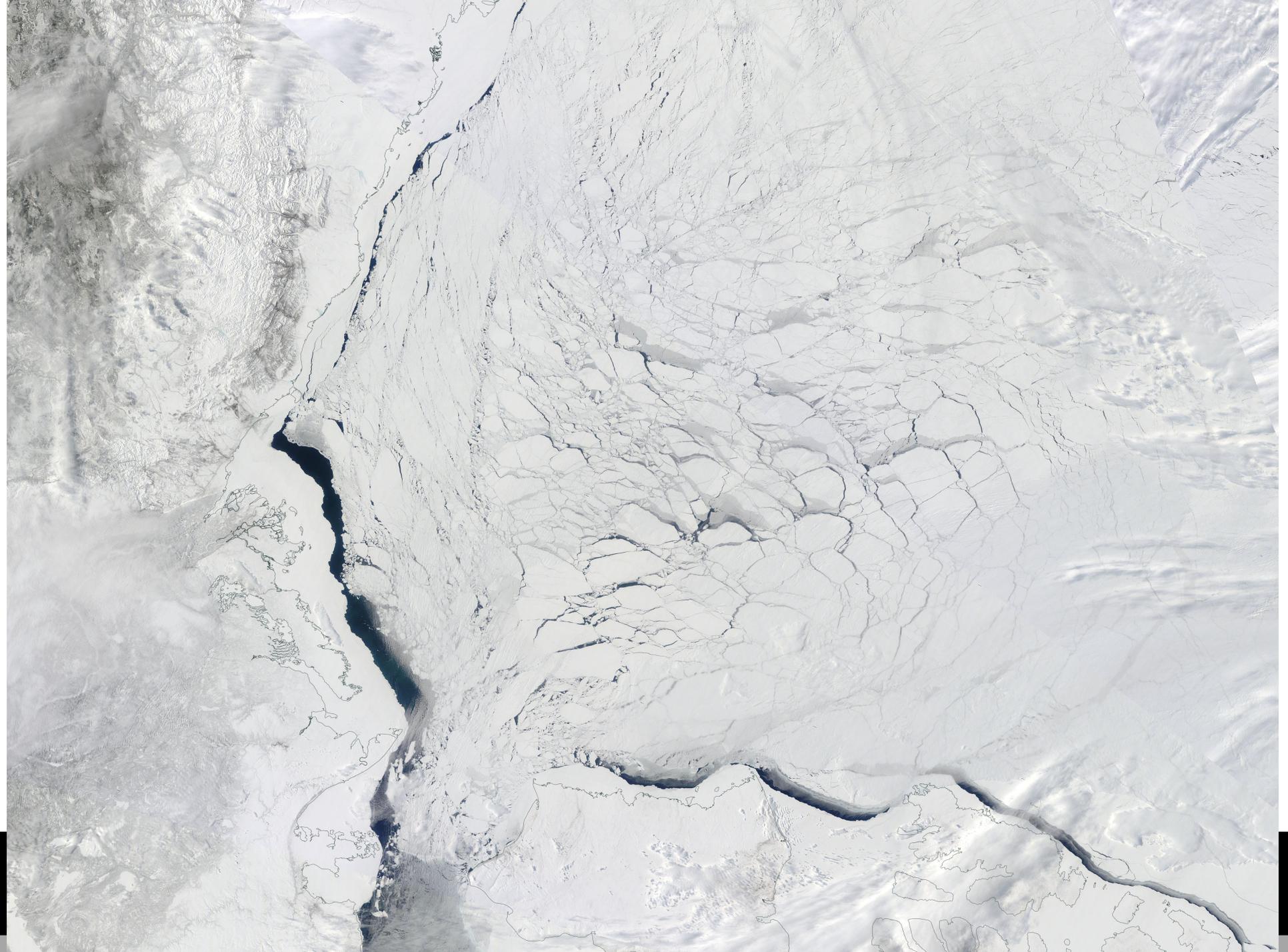


Figure by W. Skamarock







+ Even now we could provide thickness, snow depths, ridged-ice fraction, ice age

Soon we could provide lead orientation, floe size

Summary

Sea ice forecasts are currently skillful at least 4 months in advance of September. Predictability is even longer.

Challenges:

- Initialize variables that aren't well-observed

- Improve models

- Coupled, multivariate data assimilation for ensemble initialization

- Improve evaluation and calibration methods

Opportunities:

- Beyond September, Beyond extent, Beyond monthly

- Refined mesh grids, new rheologies and model physics

- Acquire observations that we know will help

We are collecting and tabulating details about forecast systems

	<i>Kauker et al.</i>	<i>NRL-ACNFS</i>	<i>Blanchard-W. et al.</i>	<i>NRL-GOFS</i>	<i>Zhang and Lindsay</i>	<i>Barthélemy et al.</i>	<i>GFDL-NOAA</i>	<i>Wang</i>	<i>Peterson et al.</i>	<i>NASA-GMAO</i>
Model characteristics										
Coupled/Forced	Forced	Forced	Coupled	Forced	Forced	Forced	Coupled	Coupled	Coupled	Coupled
Regional/Global	Regional	Regional	Global	Global	Regional	Global	Global	Global	Global	Global
Sea ice model	NAOSIM	CICE	CICE	CICE + heat flux offset	TED	LIM3	GFDL Sea ice model	GFDL Sea ice model	CICE	CICE
Ocean model	NAOSIM	HYCOM	Slab + Oce. Heat. Flux. Convergence	HYCOM	Based on Bryan&Cox	NEMO	GFDL MOM	GFDL MOM	NEMO	GFDL MOM
Oce grid resol	1/2°	1/12 °	1°	1/12°	1°	1°	1° (?)	1°	1° (?)	?
Atmosphere model	N/A	N/A	CAM	N/A	N/A	N/A	GFDL AM	NCEP GFS	MetOffice UM	GEOS
Initialization										
Atmosphere	N/A	N/A	CMIP5 historical simulation	N/A	N/A	N/A	Yes. EnKF (coupled data assimilation)	Yes	Yes	Yes (MERRA)
Ocean	NCEP/NCAR forced hindcast 1948-2014. No explicit assimilation	NOGAPS forced hindcast, assim. Sea ice concentration along ice edge	CMIP5 historical simulation	NOGAPS forced hindcast, assim. Sea ice concentration	Forced hindcast, SST + sea ice conc. Assimilation	NCEP/NCAR forced hindcast 1948-2014	EnKF (coupled data assimilation)	Yes	SST, subsurface temperature, Salinity profiles, sea level anomalies	Yes (GEOS-iodas)
Sea ice	NCEP/NCAR forced hindcast 1948-2014. No explicit assimilation	NOGAPS forced hindcast, assim. Sea ice concentration along ice edge	CMIP5 historical simulation + PIOMAS thickness anomalies	NOGAPS forced hindcast, assim. Sea ice concentration	Forced hindcast, SST + sea ice conc. Assimilation; Optimal interpolation sea ice thickness correction	NCEP/NCAR forced hindcast 1948-2014	NO assimilation	Yes. Ice concentration	Yes. Ice concentration	NO (sensitivity test: thickness)
Evaluation of uncertainty										
related to initial state	NO	NO	Compared initialized and non-initialized sea ice	NO	NO	NO	Members have different ICs	NO	NO	NO
related to atmospheric forcing	NCEP/NCAR 1994-2013	NOGAPS 2004-2013	Yes (initial state from consecutive days)	NOGAPS 2004-2013	NCEP/NCAR 2007-2013	NCEP/NCAR 2004-2013	Yes	Yes (consecutive days)	Yes (consecutive dates)	Yes (consecutive dates)
Nb members	20	10	15	10	7	10	10	40	42	10
Diagnostics										
Extent	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Concentration	No	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes
Thickness	No	No	No	No	Yes	No	No	No	No	No
Ice-free date	No	No	Yes	No	No	Yes	No	No	No	Yes
Post-processing										
Correction for model bias	Correction for model bias	Correction for model bias	Convert area to extent Correction for model bias	Correction for model bias	No bias correction (?)	Correction for model bias	Correction for model bias	Correction for model bias	Correction for model bias	Correction for model bias

Network Function, since September 2013

Sea Ice Outlook Calls (3 times each summer)
Each followed by Report

Co-authored papers & CLIVAR newsletter

Research highlights and informational webinars

AGU meetings

Annual workshop

Periodic telecons with action teams

Excellent website, updated nearly daily

Email lists

And more

Lessons learned from the 2014 SIO modeling contributions

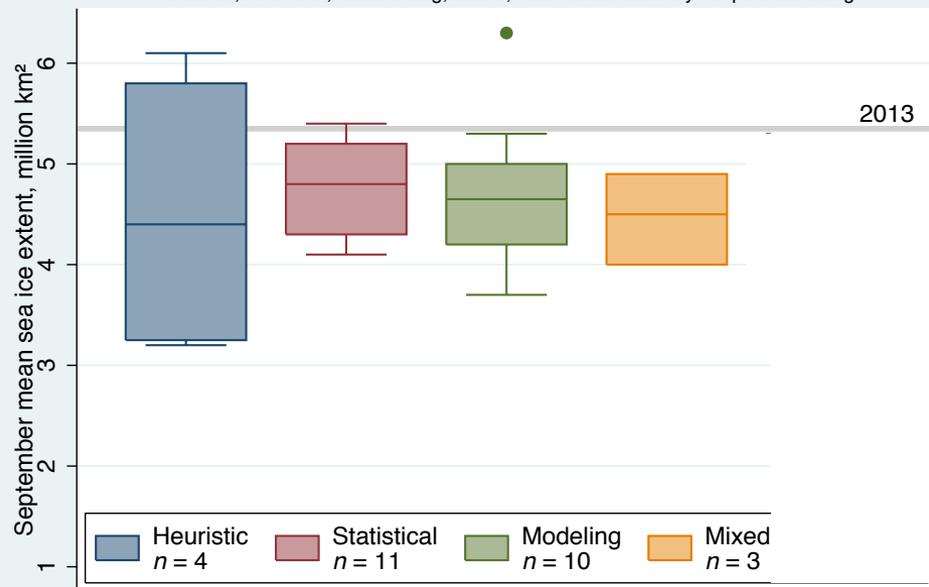
- + All groups run ensembles of simulations, most with more than 10 members
- + Uncertainty associated with stochastic atmospheric forcing is well evaluated
- + Some groups have started providing user-relevant diagnostics
- Uncertainty associated with initial conditions is not systematically evaluated
- Uncertainty associated with model parameters/physics is not evaluated
- + Predictions become more confident (individually and as a group) over time

Slide from F Massonnet

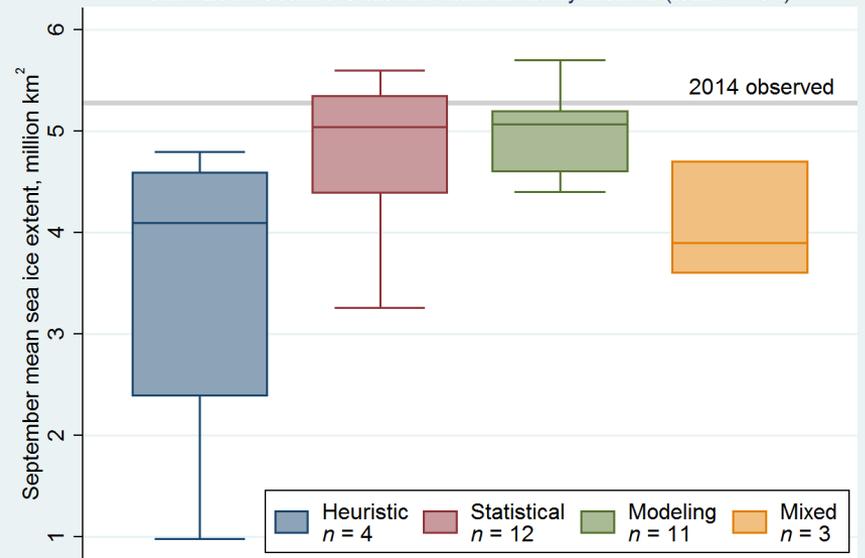
Advanced Analysis of SIO Contributions

Example for the “Pan-Arctic September” contributions

June 2014 Sea Ice Outlook contributions by method (total $n = 28$)
Heuristic, statistical, all modeling, mixed, and assimilation+fully coupled modeling



June 2015 Sea Ice Outlook contributions by method (total $n = 30$)



This style of figure appears in the SIO report for June 2014