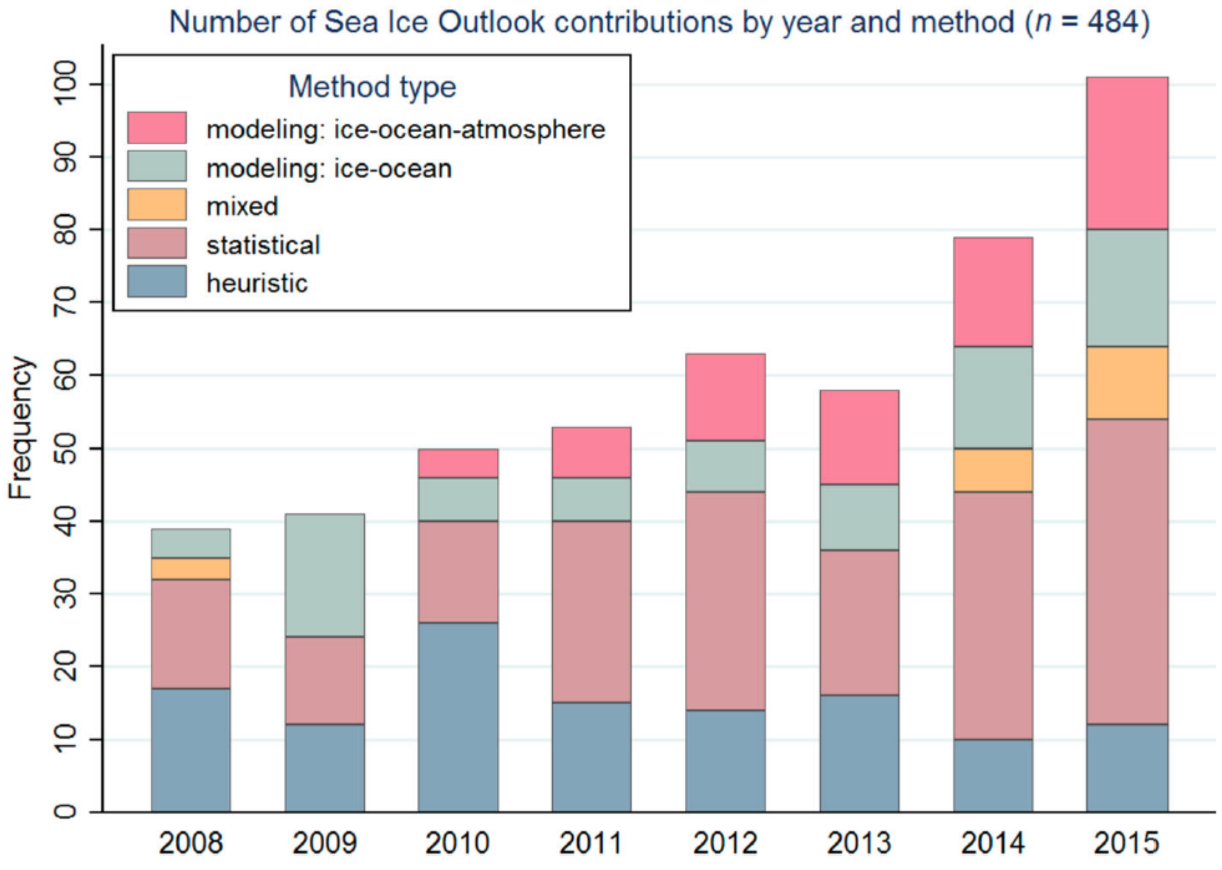
"Data Assimilation" as it Relates to the Sea Ice Outlook (SIO) and Prospects for Improvement

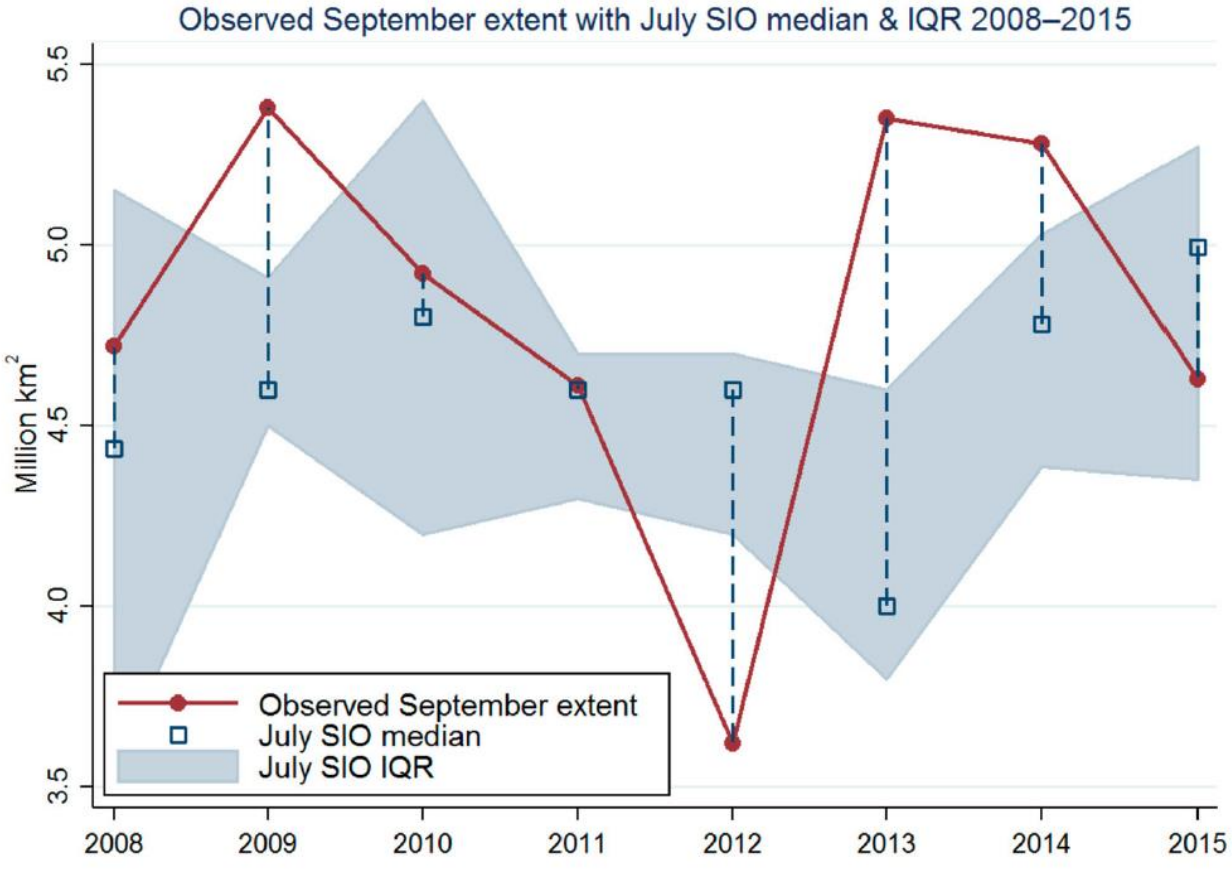
Richard Cullather

Earth System Science Interdisciplinary Center (ESSIC), Univ. Maryland at College Park &
NASA Global Modeling and Assimilation Office (GMAO)

Sea Ice Outlook (SIO)

- Proof-of-concept seasonal forecasting contest since 2008, sponsored by SEARCH.
- Forecast September monthly NH ice extent from 1- (“June”), 2- (“July”) and 3- (“August”) months lead time.
- There is considerable interest in the SIO among modelers and stakeholders.
- Since 2014, the SIO has been administered under a funded project, the “Sea Ice Prediction Network” (SIPN). Analysis was conducted on dynamical model forecasts, including offline experiments.



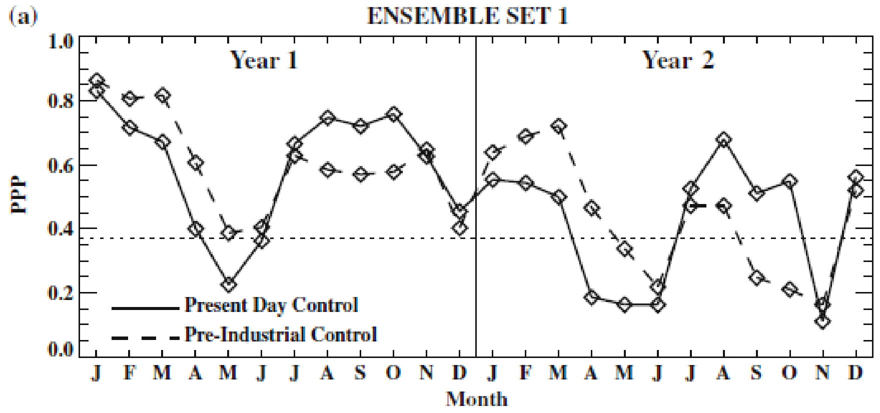


Hamilton and Stroeve, 2016

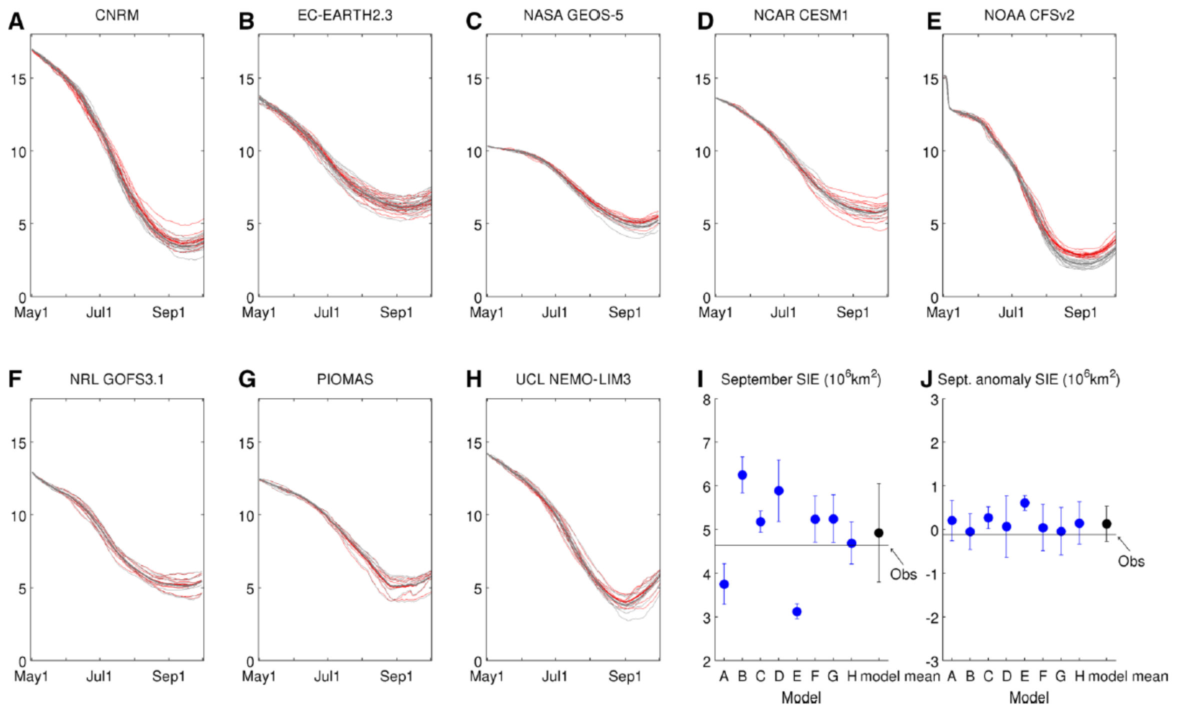
Rationale for Sea Ice Predictability on Seasonal Time Scales

- Arctic sea ice extent has a decorrelation time scale of 2-5 months.
- Experiments have shown signal "re-emergence", suggesting predictability on potentially longer time scales.
- Experiments have shown the *importance of initial conditions*. In particular, the initial sea ice thickness (volume) is key for predictability.

Fig. 9 The prognostic potential predictability of northern hemisphere ice area for the three Ensemble Sets. In panel a, the prognostic potential predictability is assessed relative to both the present day (*solid*) and pre-industrial (*dash*) control integrations. The *dotted line* indicates the 95% statistical significance threshold



Holland et al., 2011



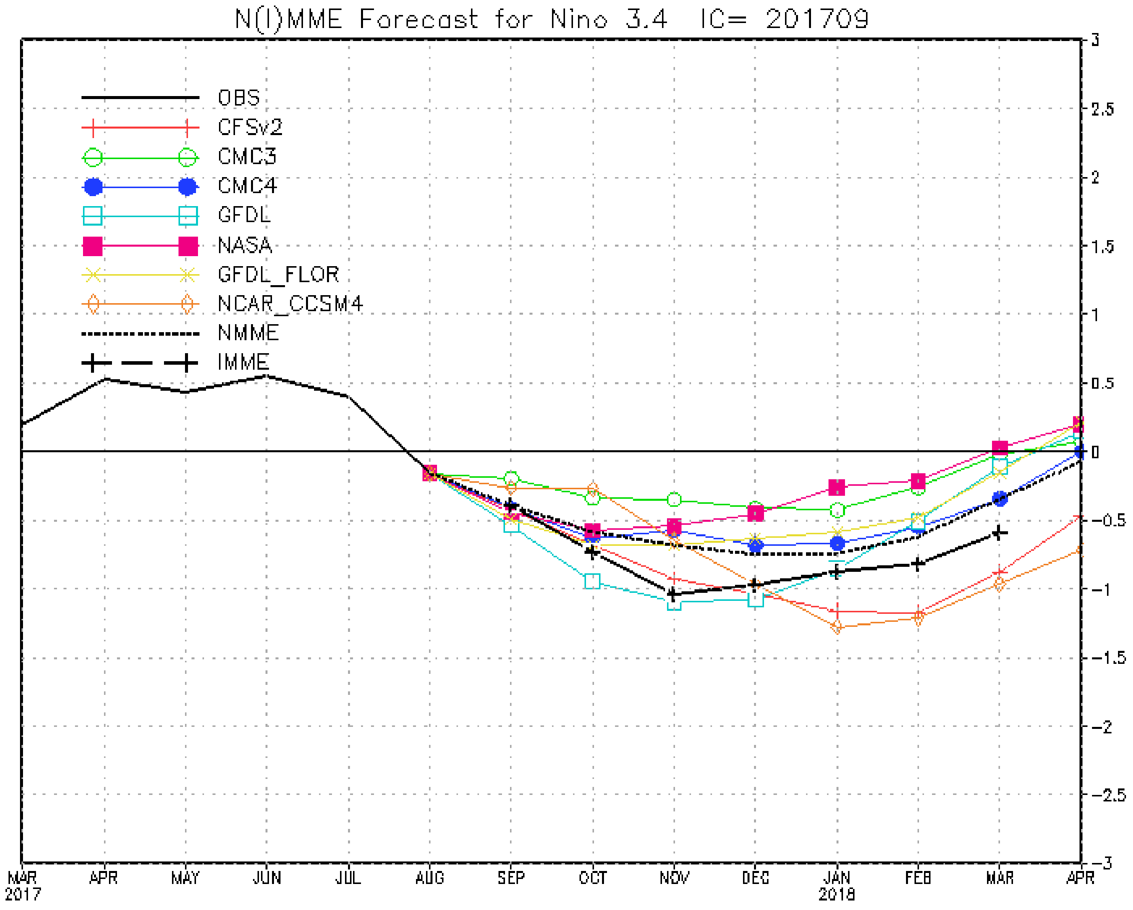
Blanchard-Wrigglesworth et al., 2017

Coupled Atmosphere/Ocean Forecast Models in the SIO

- There is considerable interest in the SIO. The 2017 SIO participants included **15** dynamical model predictions including **10** global atmosphere/ocean model forecasts from **9** groups.
- Many groups take their sea ice forecasts from a seasonal forecasting system (e.g., NMME) which is composed of a DAS and a suite of hindcasts for anomaly computation, for removing forecast drift.
- Most (all?) participating centers perform ODAS separately from ADAS.
- Nearly all systems do not incorporate observed sea ice thickness into initial conditions. *Many do not incorporate observed sea ice concentration* (??!). Differences in initial conditions among the models is large.

NOAA North American Multi-Model Ensemble (NMME)

- Several SIO participants use forecasts produced through NMME/IMME.
- Experimental multi-model seasonal forecasting system, consisting of coupled models from US and Canadian modeling centers, including NCEP, GFDL, NCAR, NASA, and Canada's CMC.
- International Multi-Model Ensemble (IMME) consists of UK MetOffice & ECMWF.
- Initial focus on El Niño and midlatitude response.
- System requires a consistent ensemble of hindcasts (1981-present) to remove model drift.
- New sub-seasonal component, call for sea ice fields.



Initial Conditions for Global Models Participating in the Sea Ice Outlook*

Model	Atmosphere	Ocean	Sea Ice Data Used	
			Concentration	Thickness
Météo-France CNRM	ECMWF Oper. Anys.	EnOI (Mercator Océan)	*<None>*	*<None>*
FIO Qingdao	Climate Model	EAKF	*<None>*	*<None>*
NOAA GFDL	NCEP CFSR	EnKF	*<None>*	*<None>*
NASA GMAO	MERRA-2	EnOI (MERRA-2 Ocean)	SSMI	*<None>* / CryoSat-2
MPAS-CESM	NCEP GEFS	Climate Model	*<None>*	*<None>*
US Navy ESM	NAVDAS	3DVar (NCODA)	SSMI/AMSR2	*<None>*
NOAA EMC	NCEP CDAS	3DVar (NCEP GODAS)	NCEP SIC	*<None>*
NOAA CPC	NCEP CDAS	3DVar (NCEP GODAS)	NCEP SIC	PIOMAS
UK MetOffice	MetOffice 4DVar	3DVar (FOAM)	OSI-SAF	*<None>*

*There could be some errors here.

Ocean Re-Analysis Intercomparison Project (ORA-IP) Arctic Assessment [Chevallier et al., 2017]

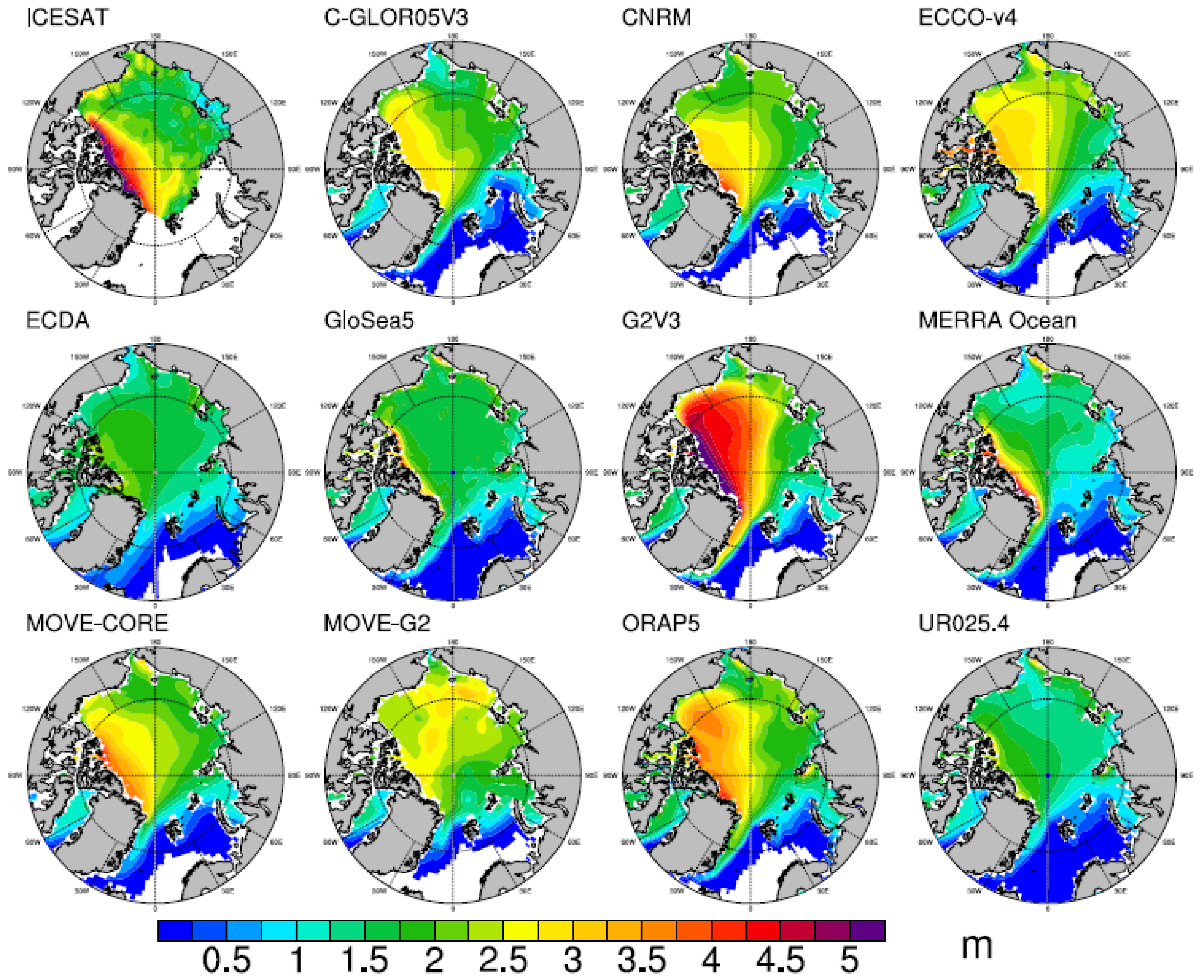


Fig. 5 March mean sea ice thickness (m), averaged over the period 2003–2007, for all the ORA-IP systems. *Top left* is the estimate from ICESat mean thickness over all February–March campaigns in the period 2003–2007

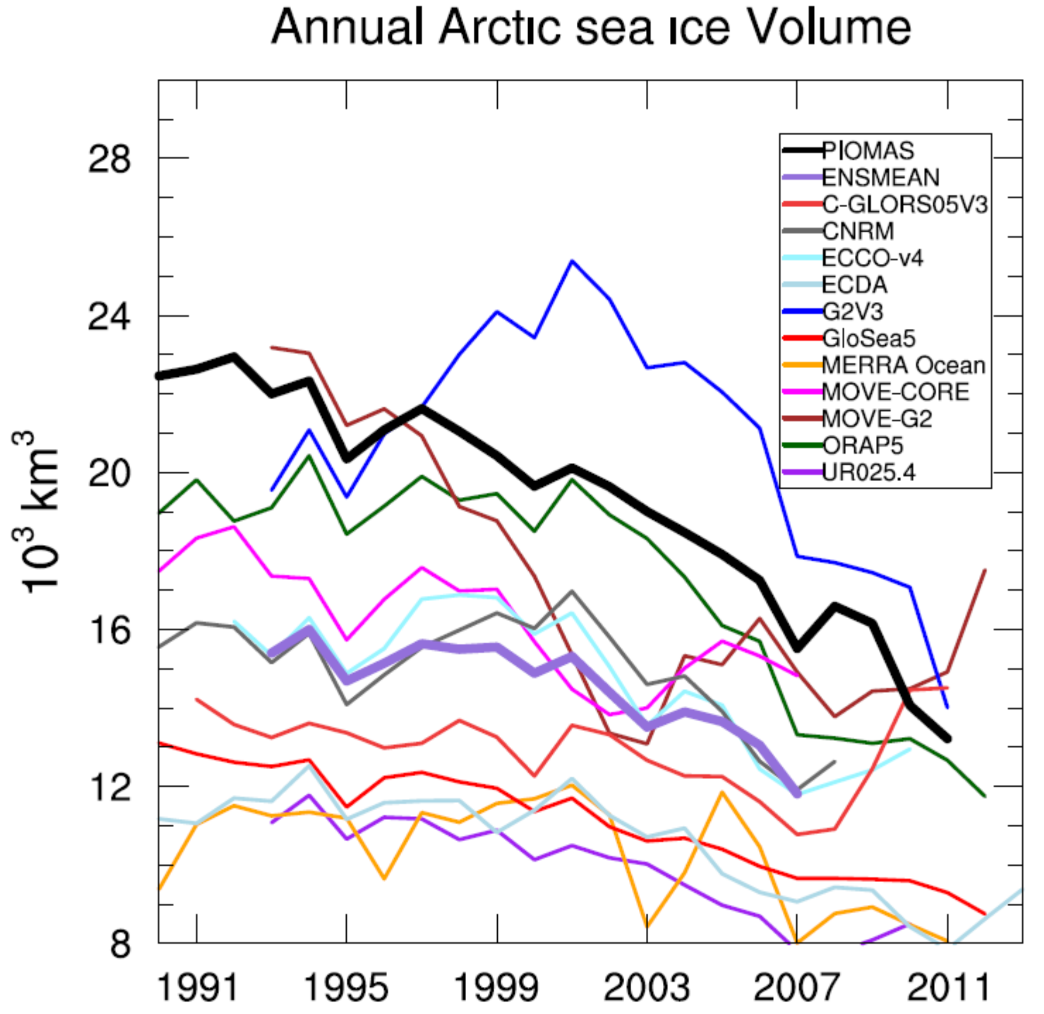
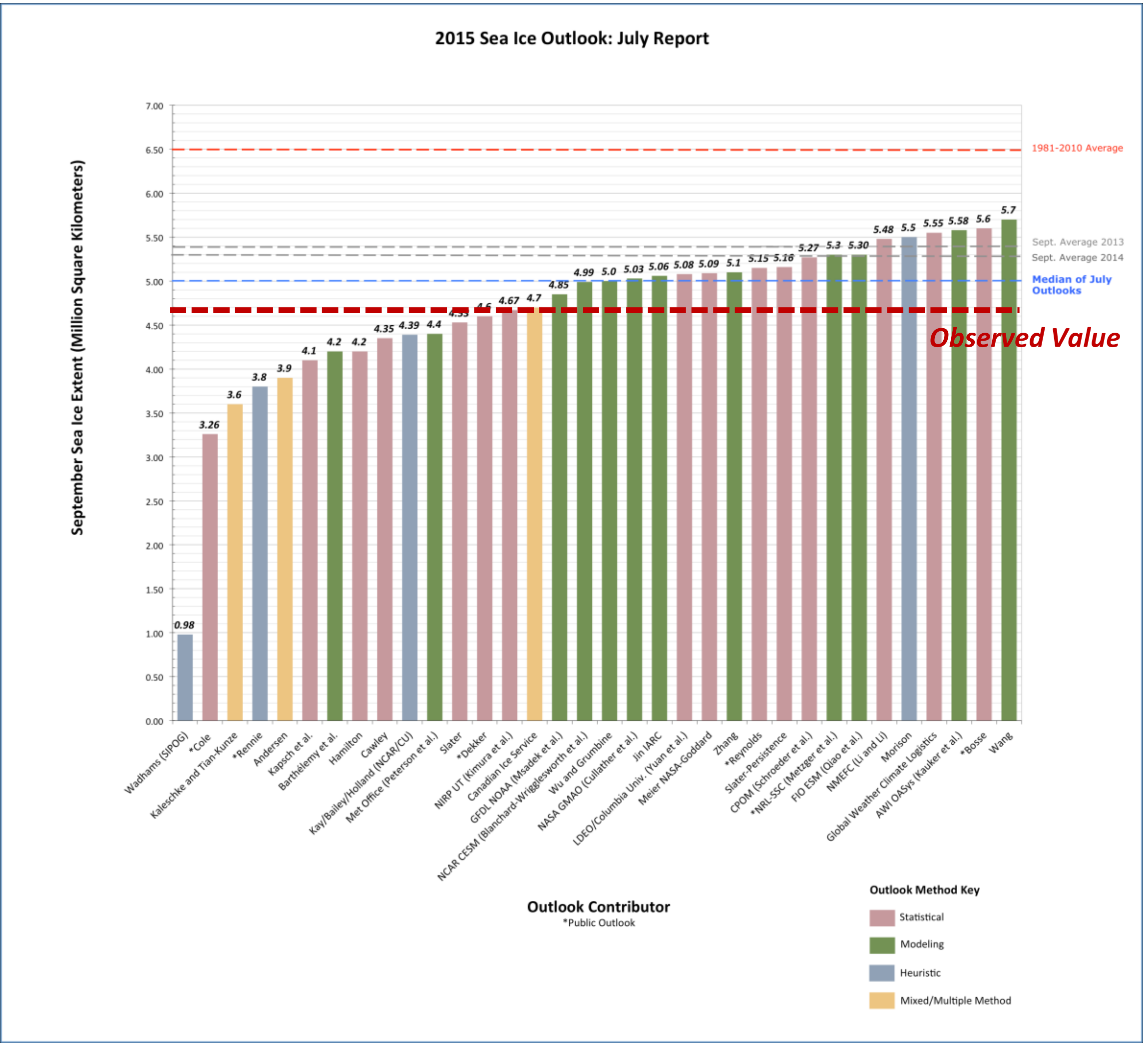
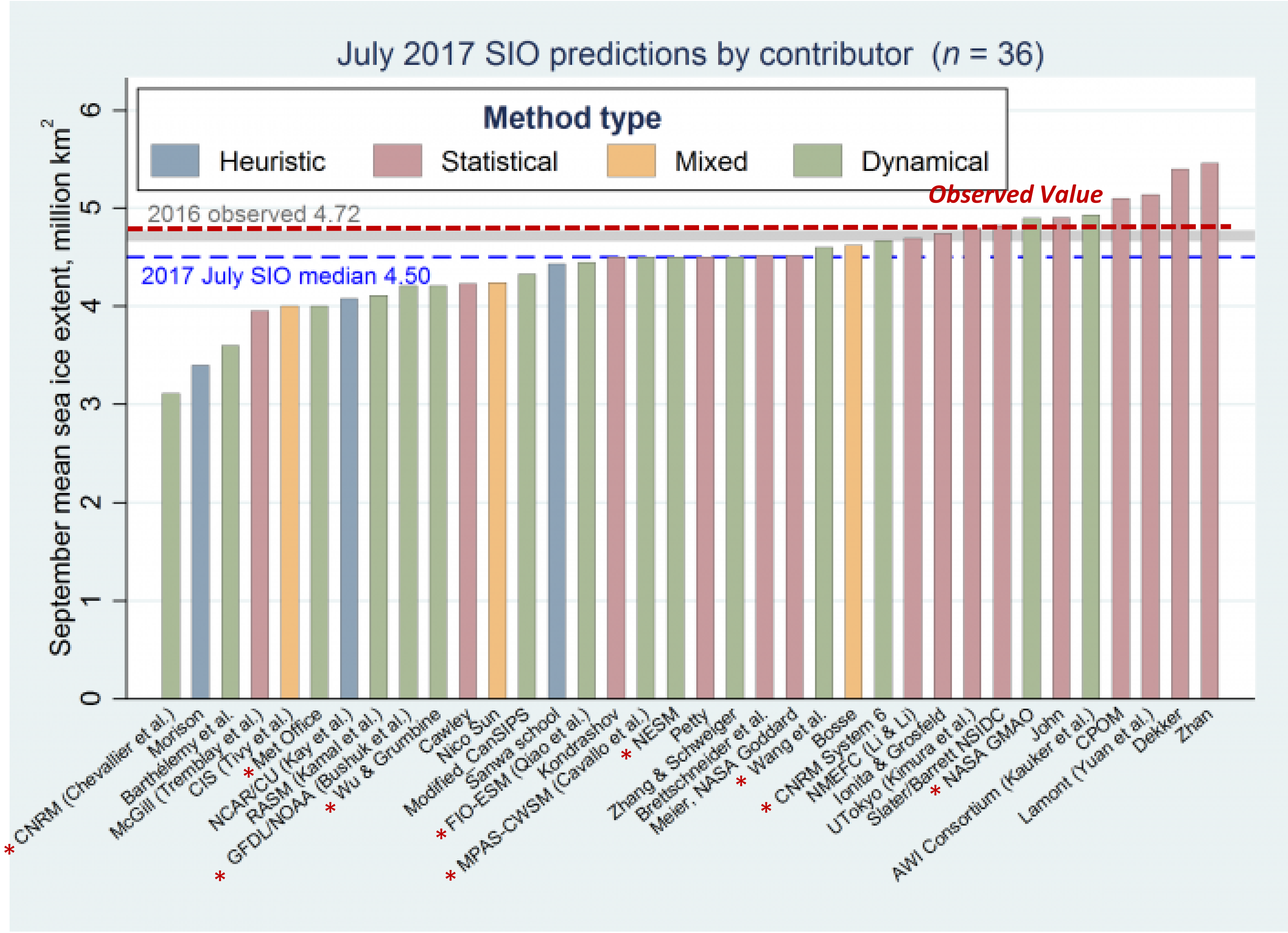


Fig. 9 Time series of annually-averaged pan-Arctic sea ice volume (10^3 km^3) in ORA-IP reanalyses and PIOMAS model. ENSMEAN is the ORA-IP ensemble mean





* Global atmosphere/ocean

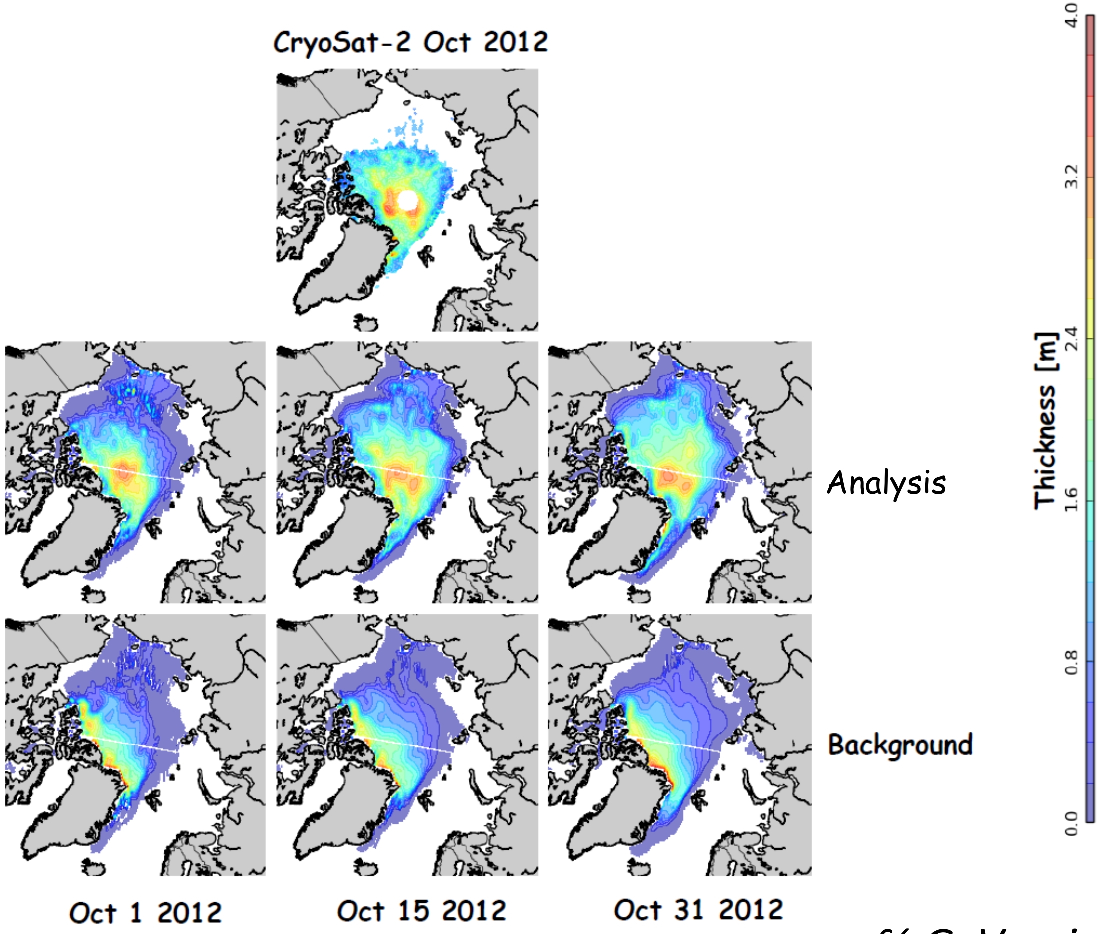
- Considerable spread for each method.
- Forecast error for statistical methods has been steadily declining.
- ***Conjecture***: Coupled models have large initial condition uncertainty & large required hindcasts; Statistical methods have seen rapid advancement. **Statistical methods in the SIO will outperform coupled models in the near term, possibly until improvement in initial conditions.**

Potential Sources of Arctic Data for Ocean Analyses

- Sea ice thickness data may be obtained from SMOS and CryoSat-2 (e.g., NSIDC, AWI, UCL). ICESat-2 to be launched in 2018.
- Other observations of ice thickness: CRREL Ice mass buoys, NASA OIB.
- Argo profiling floats: Extremely limited coverage in high latitudes.
- IABP buoy data: Air temperature, pressure, ice motion; on the GTS.
- WHOI Ice-Tethered Profilers (ITP): Continuous ocean temp & salinity profiling; Limited coverage, not on GTS.

Some Difficulties In Using/Assimilating Sea Ice Thickness

- Limited observational spatial coverage.
- Time scales: no data in the melt season or in melt conditions.
- Difficulty characterizing spatial uncertainty.
- Translating data into the model representation of ice (e.g., identifying the innovation).
- Inter-variable consistency is important.



% G. Vernieres

Coupled Atmosphere/Ocean Analysis

- Motivation:
  - Coupled forecasts require initial conditions that have some consistency.
  - Need to reduce initialization shocks in seasonal prediction.
  - Atmospheric reanalyses have very simplistic representations of the sea ice surface.
  - Inadequacy of surface fluxes from atmospheric analyses that are used in ocean reanalyses.
- Drawbacks:
  - Mismatch in time scales.
  - Component model deficiencies may be amplified.
- A spectrum of interaction:
  - **Strongly coupled**: Assimilation into a coupled model where observations in one medium are used to generate analysis increments in the other (minimization of a joint cost function with controls in both media).
  - **Quasi weakly coupled**: Assimilation is applied independently to each component separately.
  - **Everything in between**.
- Some current examples:
  - **NCEP CFSR, CFSv2**: each component initialized separately; sea ice nudging.
  - **ECMWF CERA-20C**: assimilates sfcp, marine winds, ocean temperature, salinity; relaxation to SSTs; no sea ice assimilation.

Further Discussion

- Beyond sea ice initial conditions, SIPN experiments suggest a spread in the simulation of physical processes. What are priorities for improving model representation?
- What additional measures are needed to enhance prediction capabilities (9.3)?
- How do improved Arctic sea ice forecasts affect predictions of larger scales (9.2)?