Sea-Ice Prediction in the GFDL model framework

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Current GFDL Seasonal Forecasting Models

Model	Atmosphere	Ocean	Sea Ice	Land	Initialization
CM2.1	AM2.1 (2°; 24L)	MOM4 (1°; 50L)	SIS1 (1°; 5 cat)	LM2	ECDAv3.1
FLOR	AM2.5 (0.5°; 32L)	MOM4 (1°; 50L)	SIS1 (1°; 5 cat)	LM3	ECDAv3.1
FLOR-FA	AM2.5 (0.5°; 32L)	MOM4 (1°; 50L)	SIS1 (1°; 5 cat)	LM3	ECDAv3.1
Hi-FLOR	AM2.6 (0.25°; 32L)	MOM4 (1°; 50L)	SIS1 (1°; 5 cat)	LM3	ECDAv3.1

CM2.1: Delworth et al 2006, *J. Climate*.
FLOR: Delworth et al 2012, *J. Climate*; Vecchi et al 2014, *J. Climate*.
Hi-FLOR: Murakami et al 2015, *J. Climate*.
ECDA: Zhang et al. 2007, *Mon. Wea. Rev*.

GFDL Sea Ice Model Development Timeline

Sea Ice Simulator[1]: (SIS)

SIS1

Current seasonal forecast models

SIS2
(Interim Version)

GFDL CMIP6 model

SIS2

Future Development. Completion goal: 2018.

1: Winton 2000, *J. Atmos. Oceanic Technol.*; Delworth et al 2006, *J. Climate*

SIS2 Model Physics Improvements

Common aspects with SIS1

- Elastic Viscous Plastic (EVP) rheology[1]
- Ice-thickness distribution with multiple ice thickness categories[2]
- Fast coupling timestep (atmospheric timestep)

New Features

- C-grid differencing (consistent with ocean model). Allows for better representation of ice transport through channels; forward compatibility with MOM6 ocean model
- Revised thermodynamic algorithms (CICE4-like thermodynamics[3]) provide near-exact conservation (1 part in 10^{18}) of enthalpy, salt, mass
- Delta-Eddington radiation scheme[4]
- Tracer transport capability (e.g. ice age)
- GIT version control/GitHub allows shared development

1: Hunke and Dukowicz, 1997, *J. Phys. Oceanogr*.
2: Bitz et al, 2001, *J. Geophys. Res.*
3: Bitz and Lipscomb, 1999, *J. Geophys. Res*.
4: Briegleb and Light, 2007, *NCAR Tech. Note*

Future SIS2 Model Physics Improvements

- Melt ponds[1]
- Mushy layer physics with prognostic ice salinity[1,2]
- Ridging parameterization[1]
- Embedding sea ice dynamics into MOM6 ocean model with tightly coupled ice-ocean dynamics (avoid coupled ice-ocean instabilities[3]).
- Unified, physically-based approach to ice-ocean interactions (sea ice, icebergs, ice shelves).

Take home point: SIS2 is moving towards CICE5-like model physics, in a framework consistent with GFDL coupled modeling approach.

1: Hunke, Lipscomb, Turner, Jeffery, and Elliot, 2015, *CICEv5.1 User Manual*

2: Turner, Hunke, and Bitz, 2013, *JGR*

3: Hallberg, 2014, *CLIVAR Exchanges*

Current GFDL Seasonal Sea-Ice Forecasting

Initialization

Forecasts initialized using Ensemble Kalman Filter coupled data assimilation (ECDA)[1]

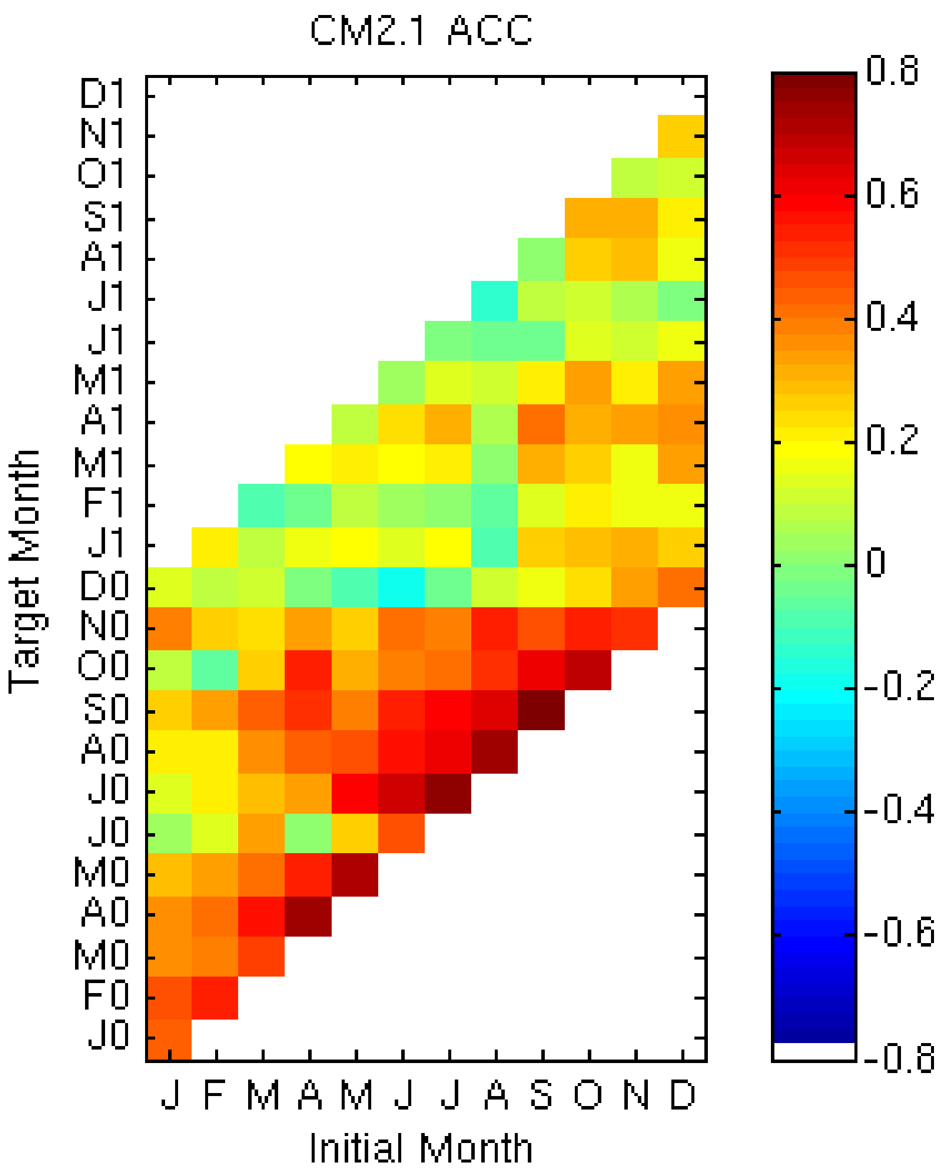
- Ocean assimilates ARGO, CTD, XBT, and satellite temperature
- Atmosphere assimilates NCEP reanalysis
- No assimilation of sea ice concentration/thickness

Forecast Ensembles

- Forecasts run for 1982-present[2]
- Initialized on the first of each month
- 10-12 ensemble members per start date
- 4 forecast models with same ocean and sea ice, differing atmospheric resolution

1: Zhang et al. 2007, *Mon. Wea. Rev*.
2: Msadek et al., 2014, *GRL*

Arctic Sea-Ice Extent Forecast Skill

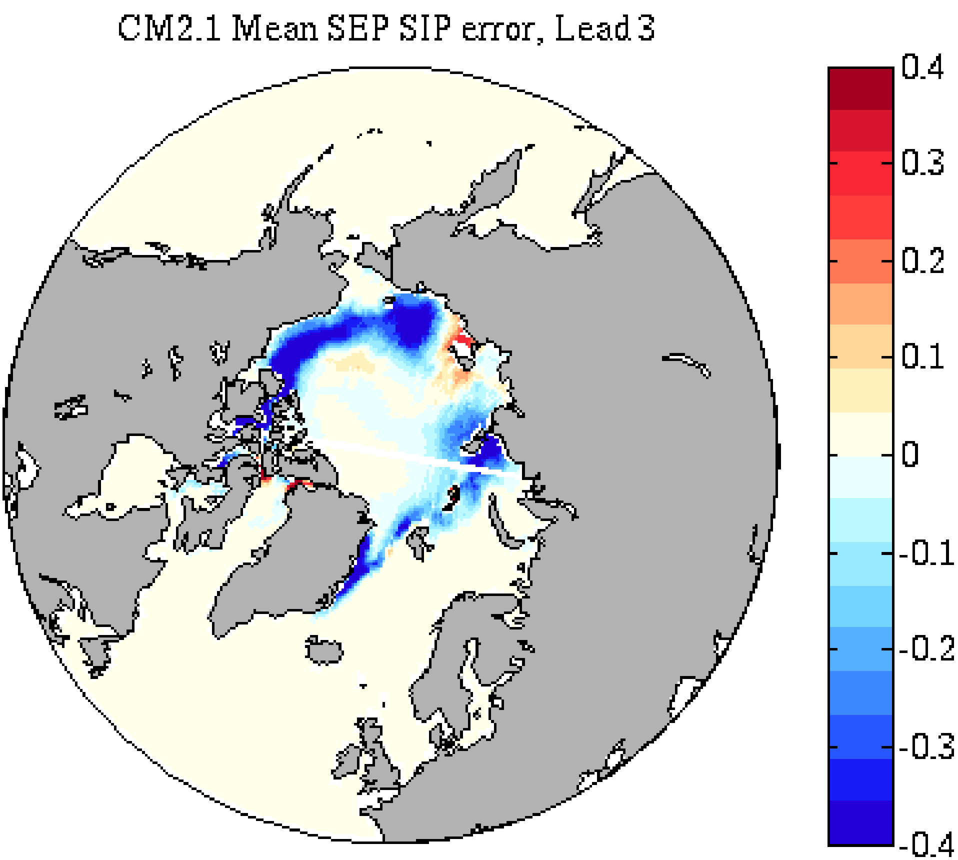


- Anomaly correlation coefficients for **linearly detrended** pan-Arctic sea ice extent predictions
- Skill for 2-6 months, depending on start date
- Skill barrier in December
- CM2.1 is model used for Sea ice outlook predictions

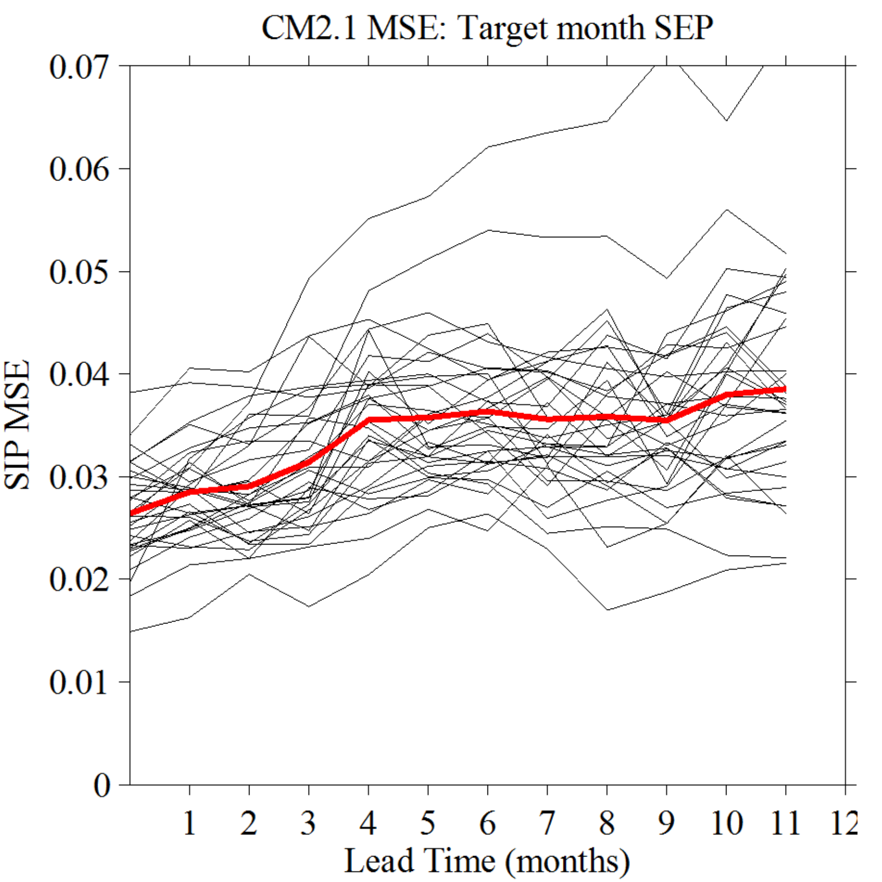
Calculation reproduced from Msadek et al 2014, *GRL*

Regional Forecast Skill: Importance of Initial Conditions

- Sea ice probability (SIP): probability that a given gridpoint is ice covered
- SIP error: Model SIP minus observed extent



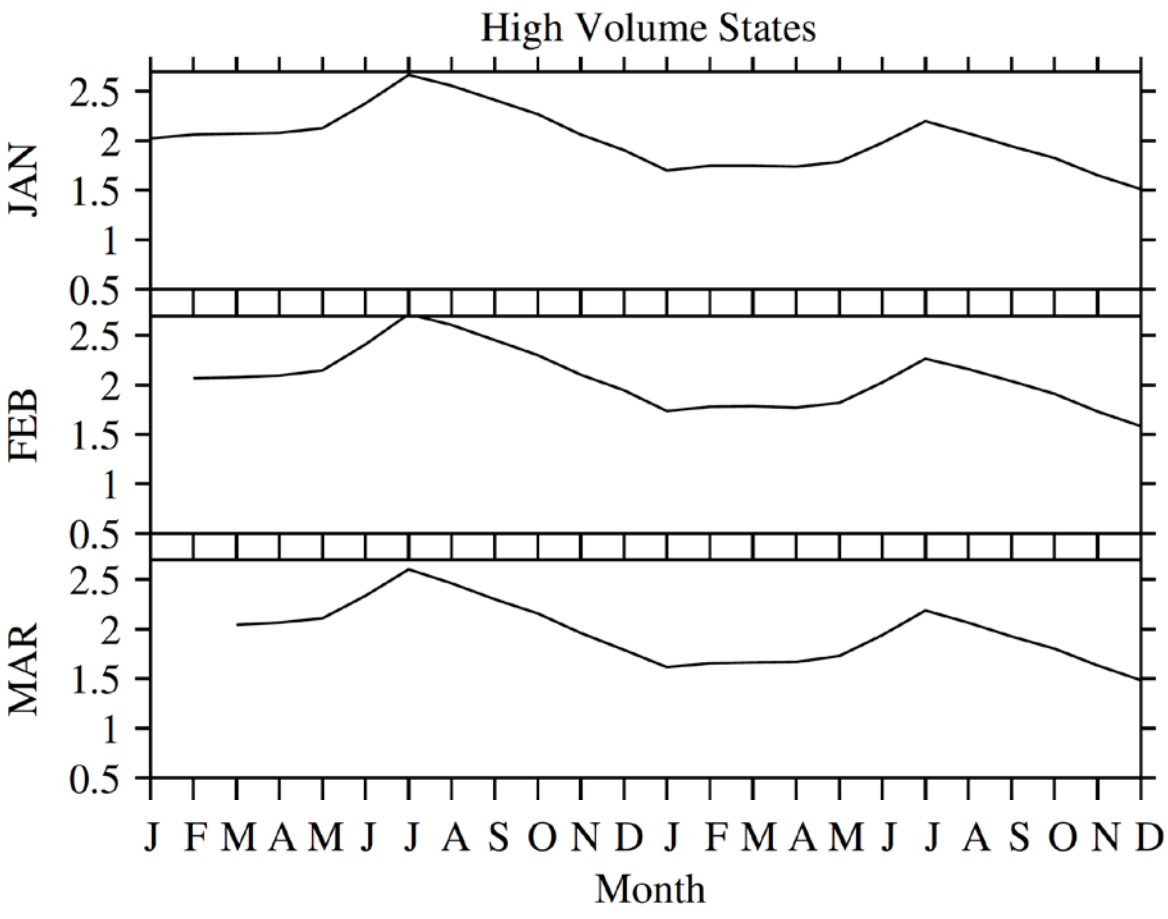
Systematic SIP Errors



Black curves: SIP MSE for each year, 1982-2014
Red curve: Time mean MSE

Volume Anomaly Growth in September Sea Ice Zone

- Spring volume anomalies in September sea ice zone tend to grow over summer months
- Effect is more pronounced for positive volume anomalies than negative volume anomalies
- Volume anomaly growth appears to be due to thickness—albedo feedback
- Potential improvements in September predictions with improved thickness initialization



Similar behavior for all initial months

Current Research Directions

- Effect of improved sea ice concentration/thickness initialization on prediction skill
- Initialization/assimiliation using Cryosat-2 thickness data
- Perfect model predictability experiments

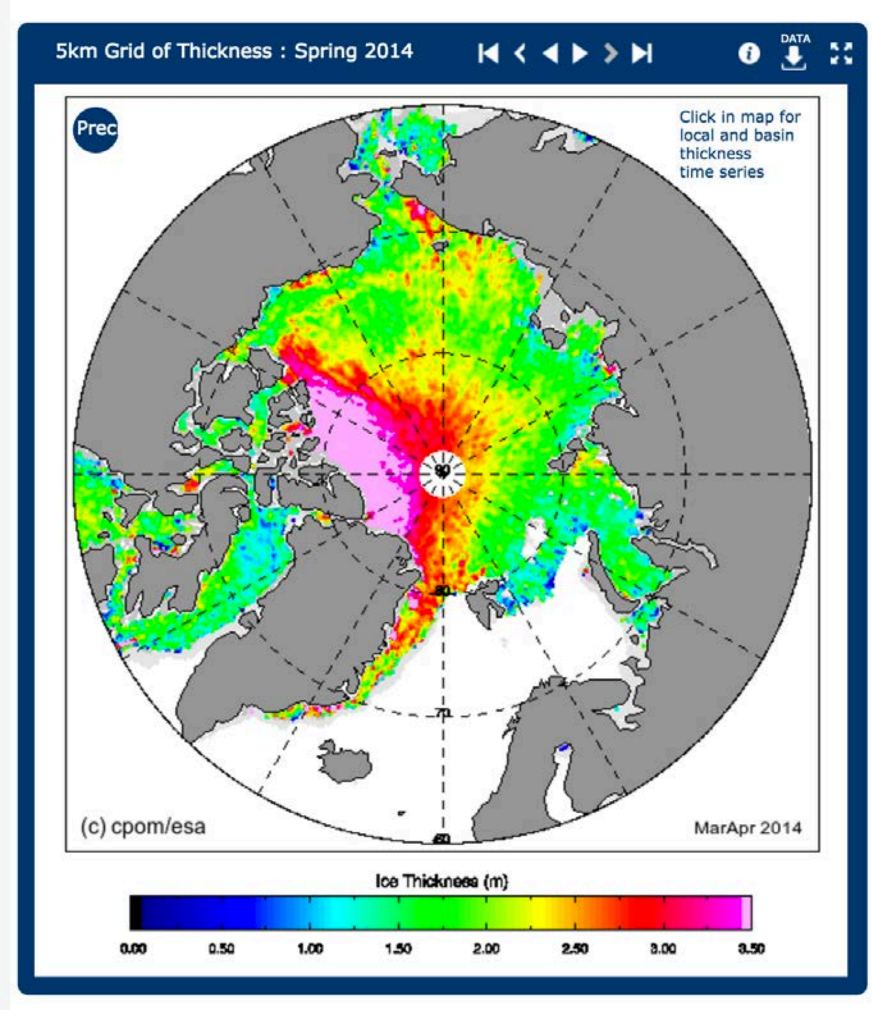
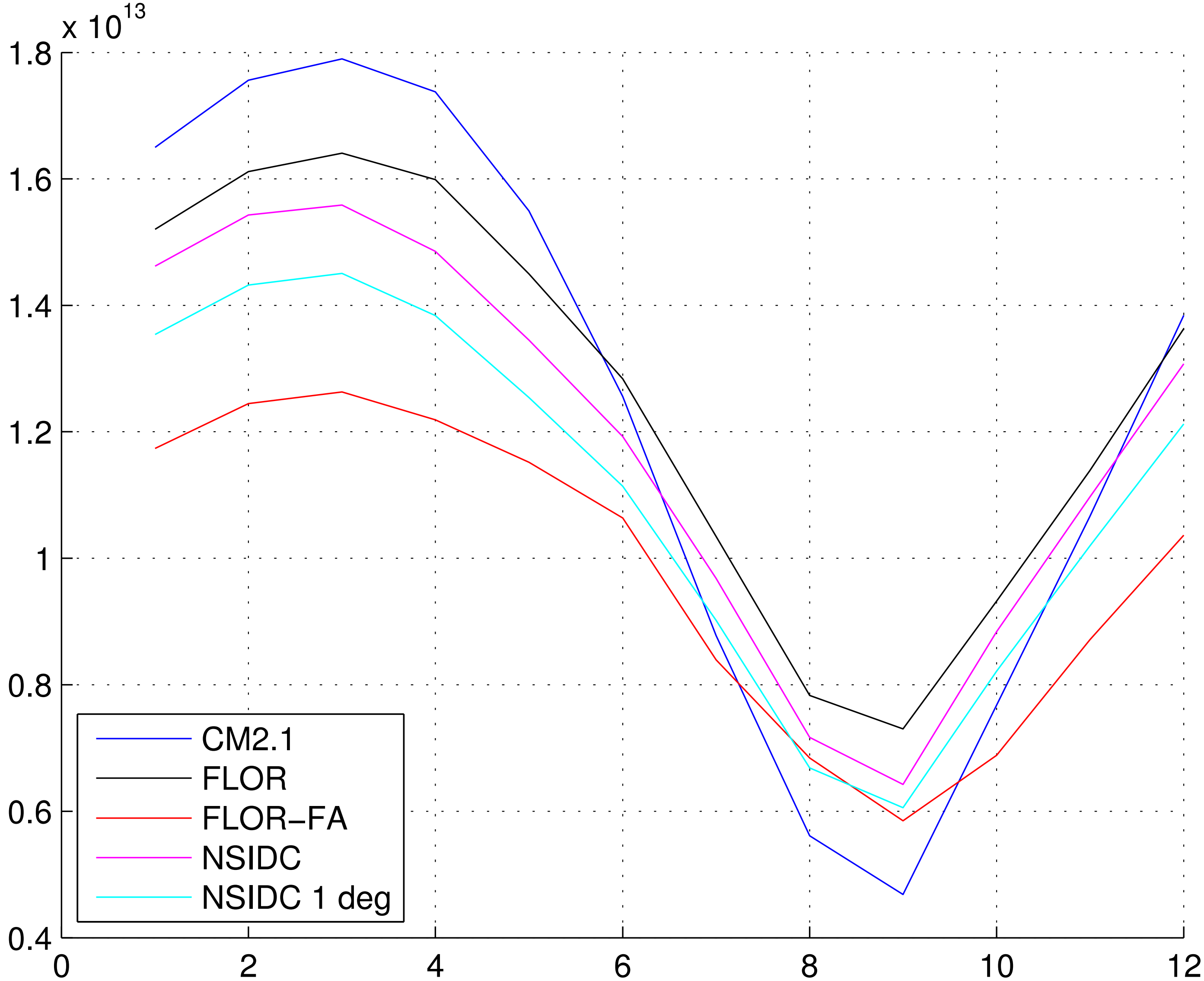


Image from CPOM

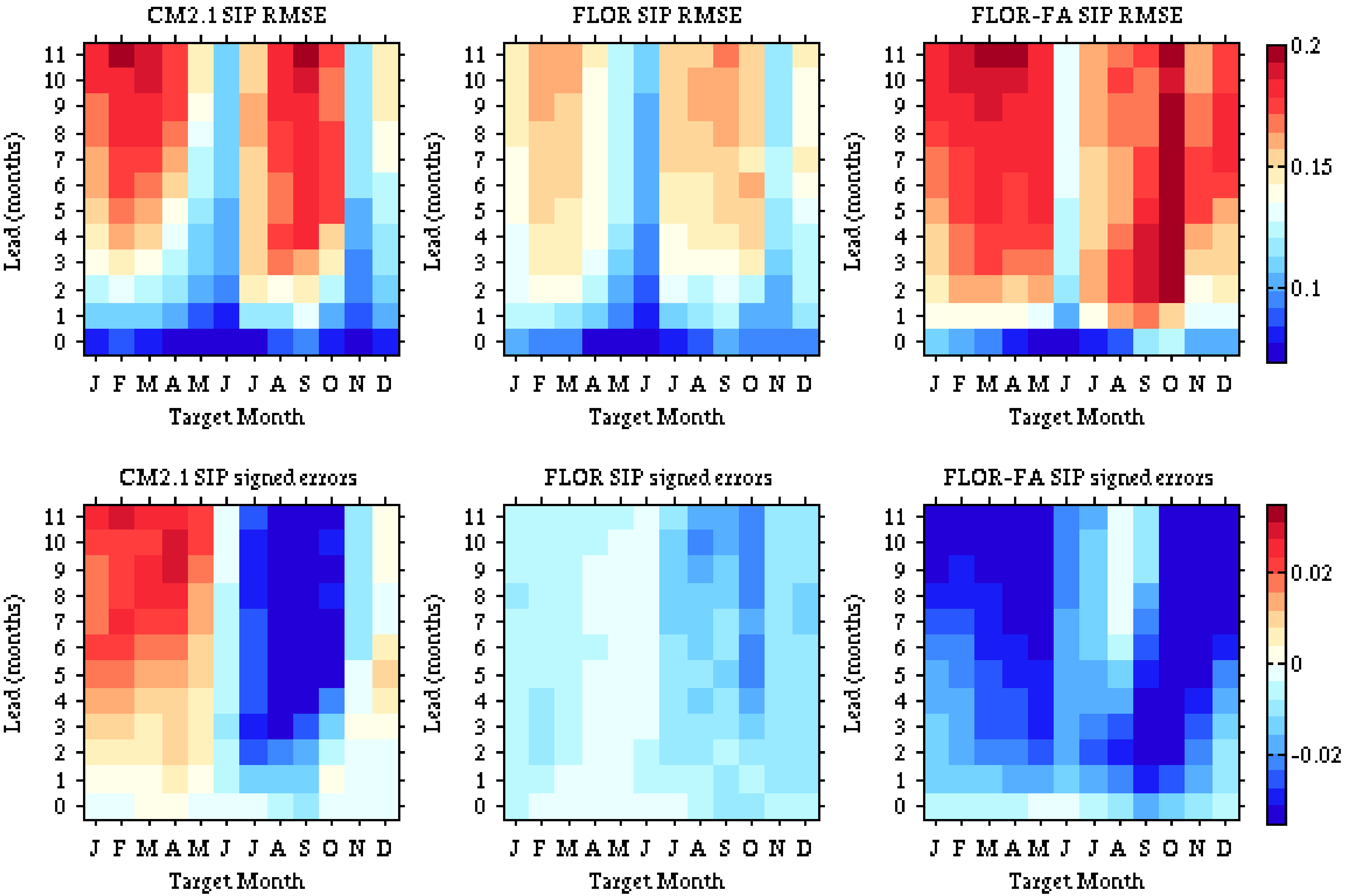
Thank you for listening!

Questions?

Sea-Ice Extent Climatologies

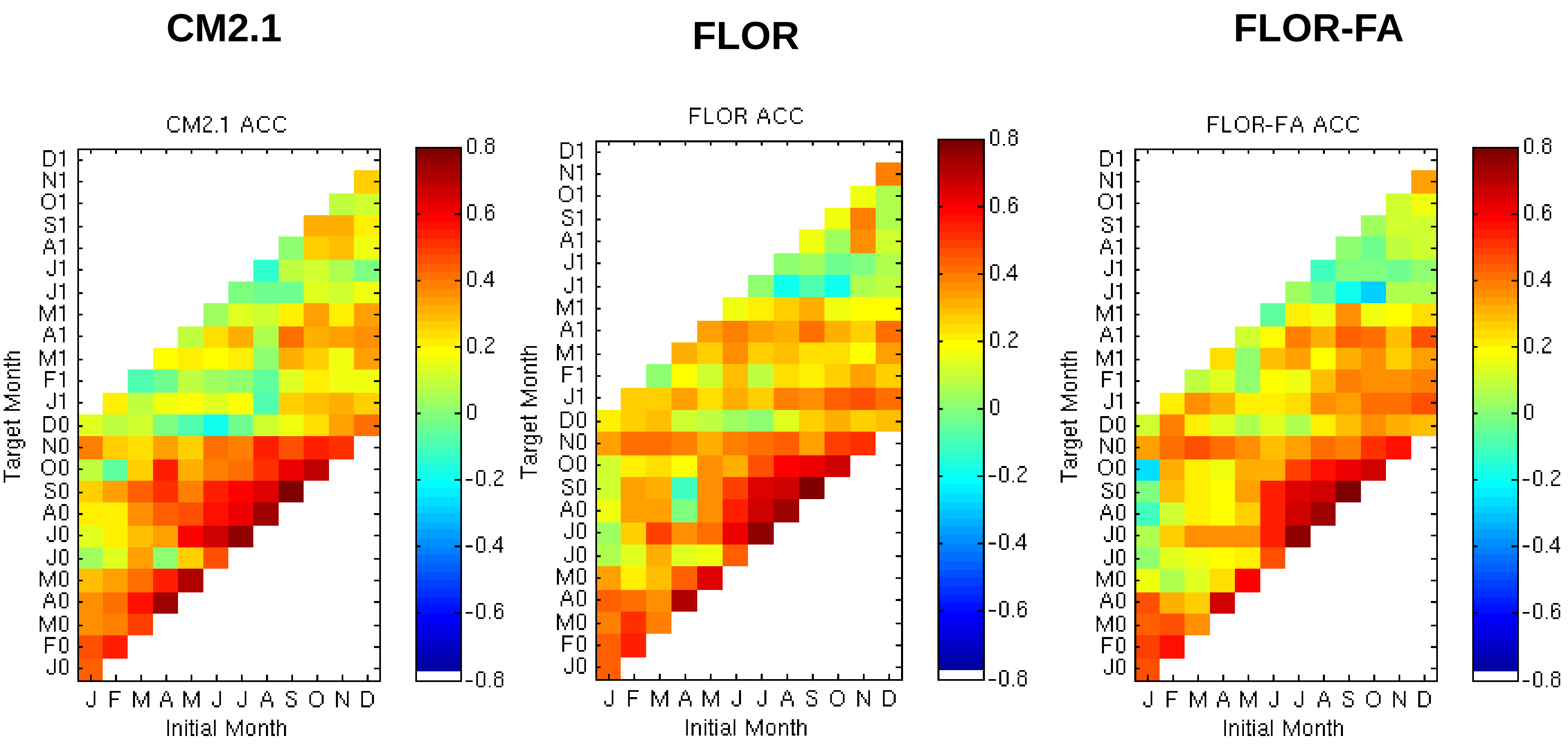


SIP RMSE: all months and leads



Arctic Sea-Ice Extent Forecast Skill

Anomaly correlation coefficients for detrended pan-Arctic sea ice extent predictions

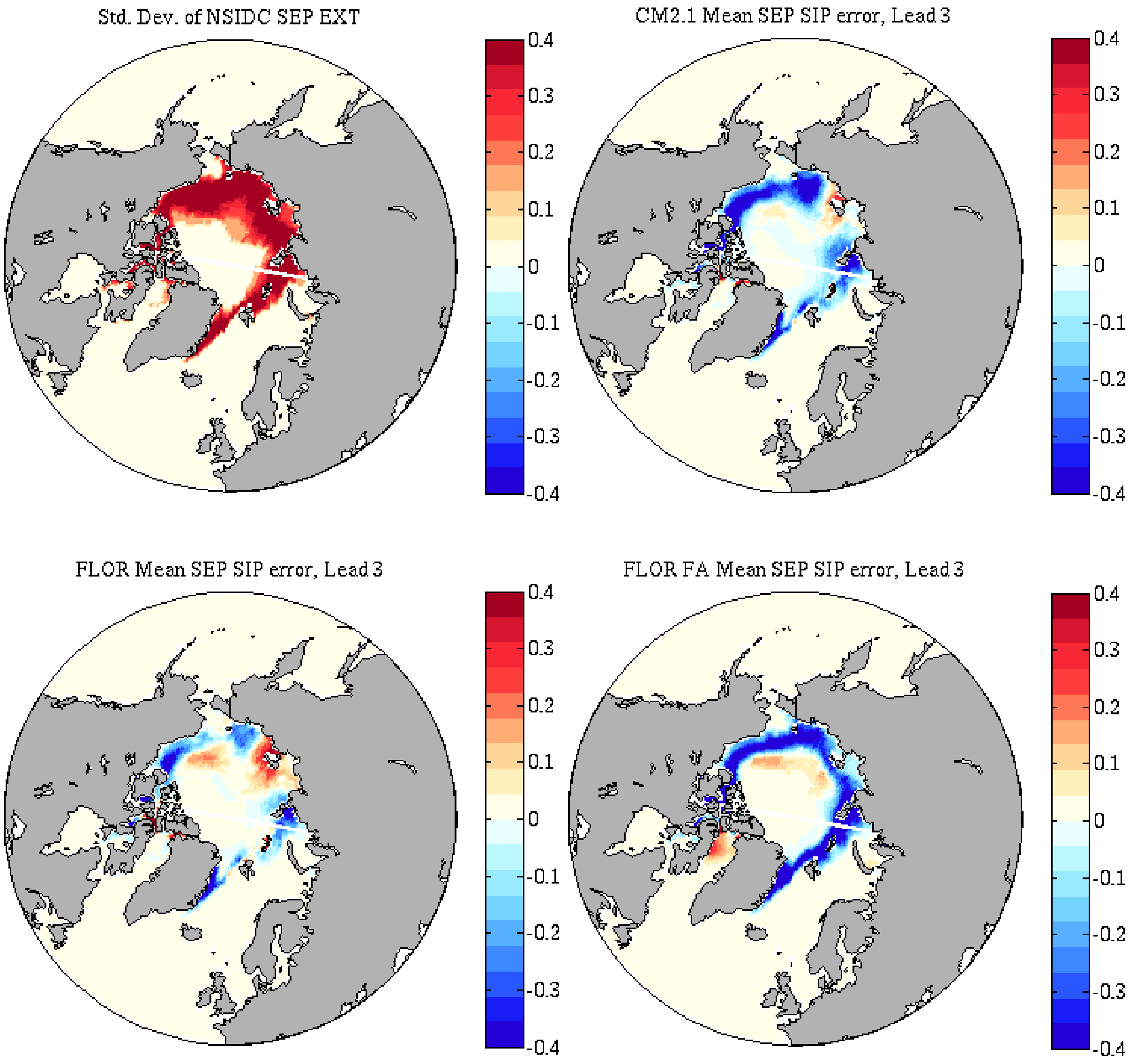


Calculation reproduced from Msadek et al 2014, *GRL*

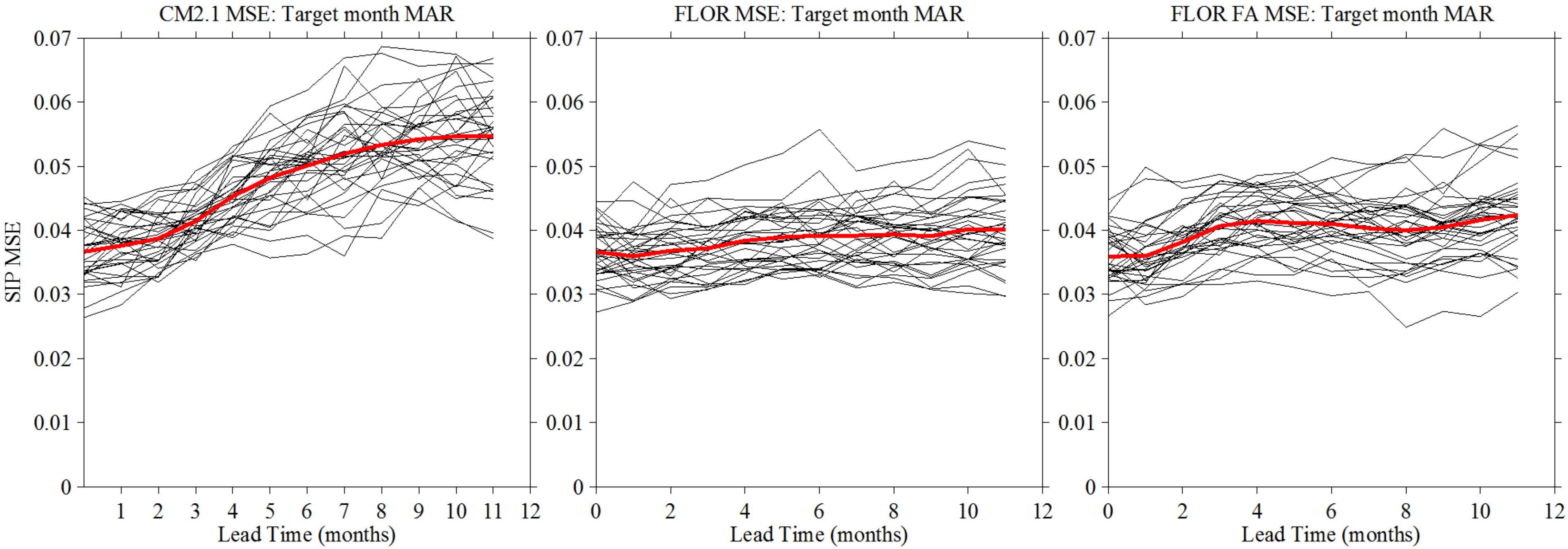
Regional Forecast Skill: Time Mean Sea Ice Probability Errors

Sea ice probability (SIP): probability that a given gridpoint is covered with September sea ice

SIP error: Model SIP minus observed extent



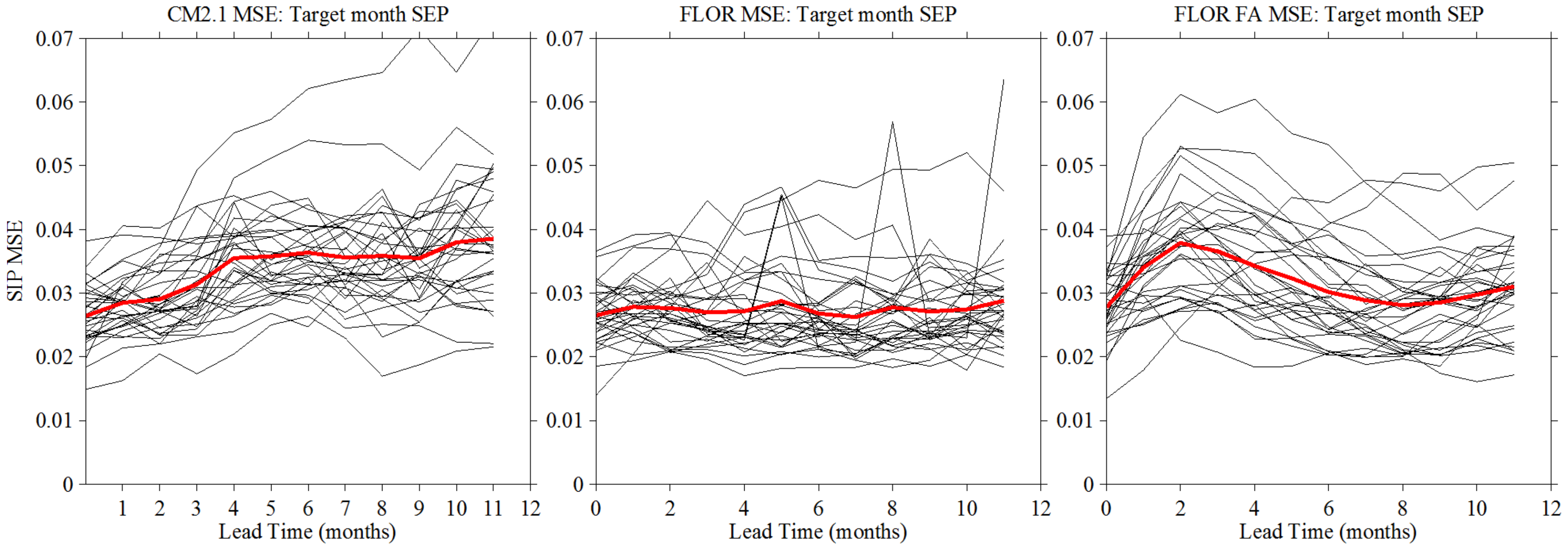
Importance of Initial Conditions: SIP Error Growth for March Predictions



Black curves: Mean square SIP errors for each year, 1982-2014
Red curve: Time mean mean square SIP errors

Lead 0 corresponds to March mean prediction initialized on Mar 1

Importance of Initial Conditions: SIP Error Growth for September Predictions



Black curves: Mean square SIP errors for each year, 1982-2014
Red curve: Time mean mean square SIP errors

Lead 0 corresponds to September mean prediction initialized on Sept 1.

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