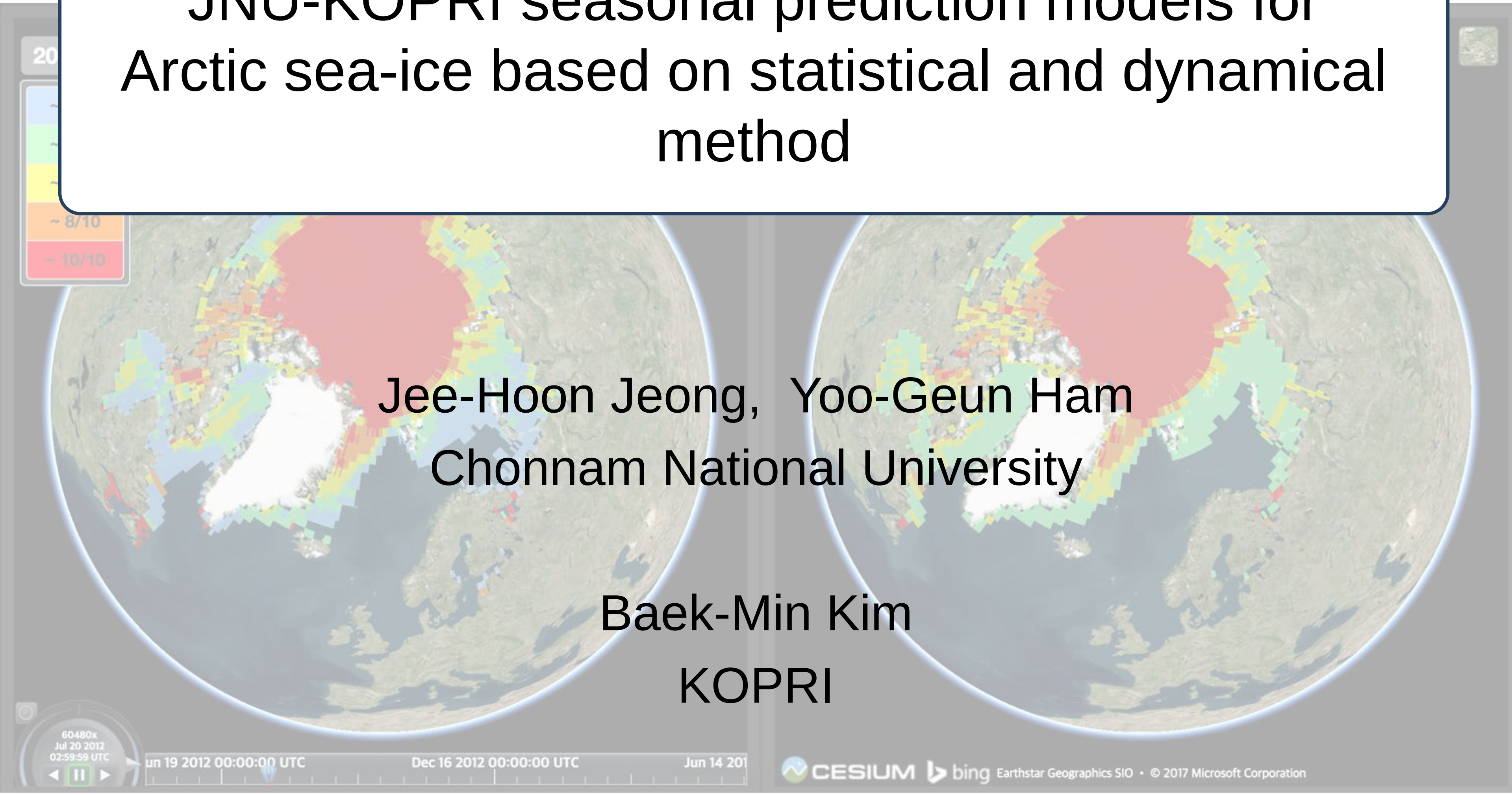
Nov 2017, PAG meeting

JNU-KOPRI seasonal prediction models for Arctic sea-ice based on statistical and dynamical method

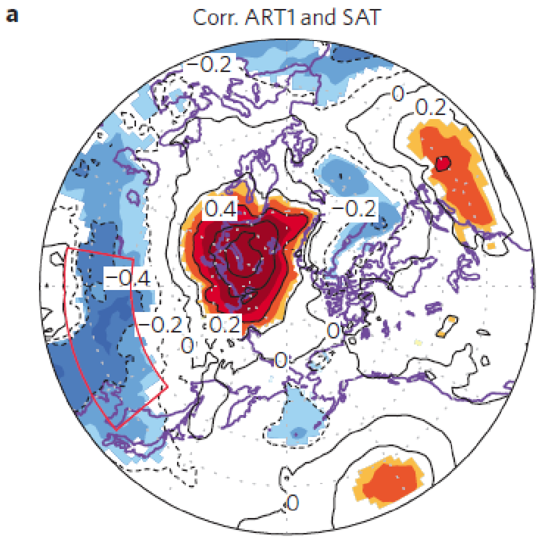


Jee-Hoon Jeong, Yoo-Geun Ham
Chonnam National University

Baek-Min Kim
KOPRI

Practical needs for the Arctic sea ice prediction in seasonal time-scale

- Seasonal climate prediction
  - Anomalous pattern of Artic sea ice concentration is a useful predictor of East Asia winter climate
  - Low September SIC over the Barents-Kara Sea is known to lead cold winters, cold waves in East Asia

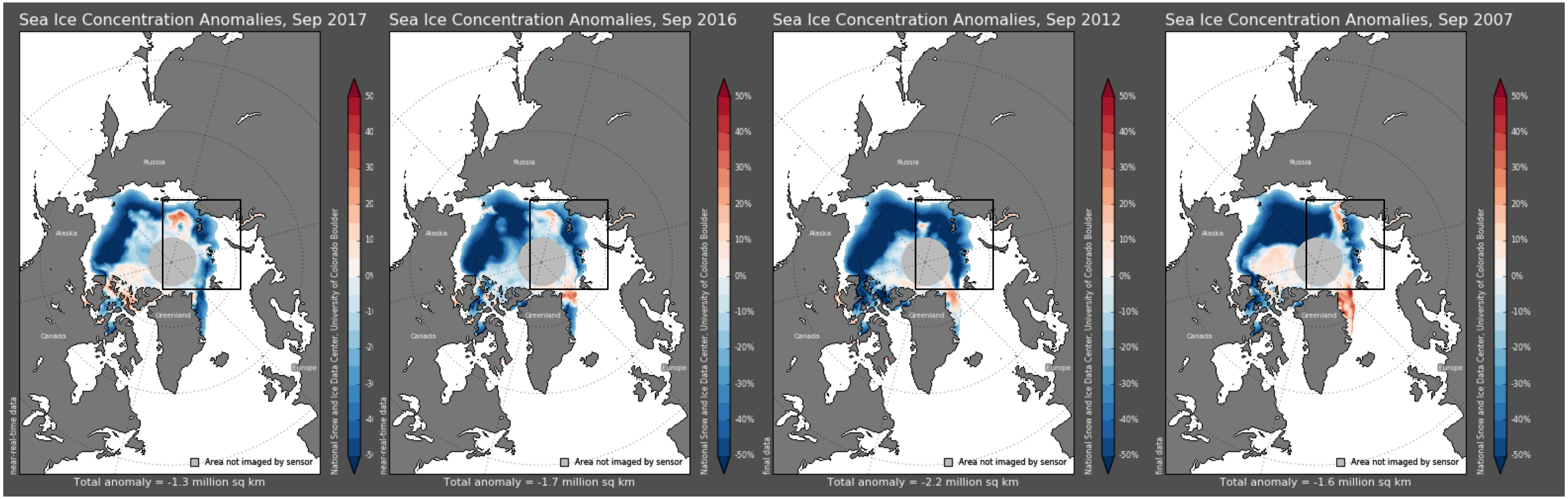


Kug et al. 2015 (Nat. Geo)

- Expectation for the Arctic route
  - Korean Government asks for seasonal prediction of Arctic sea ice
  - Needs from shipping companies

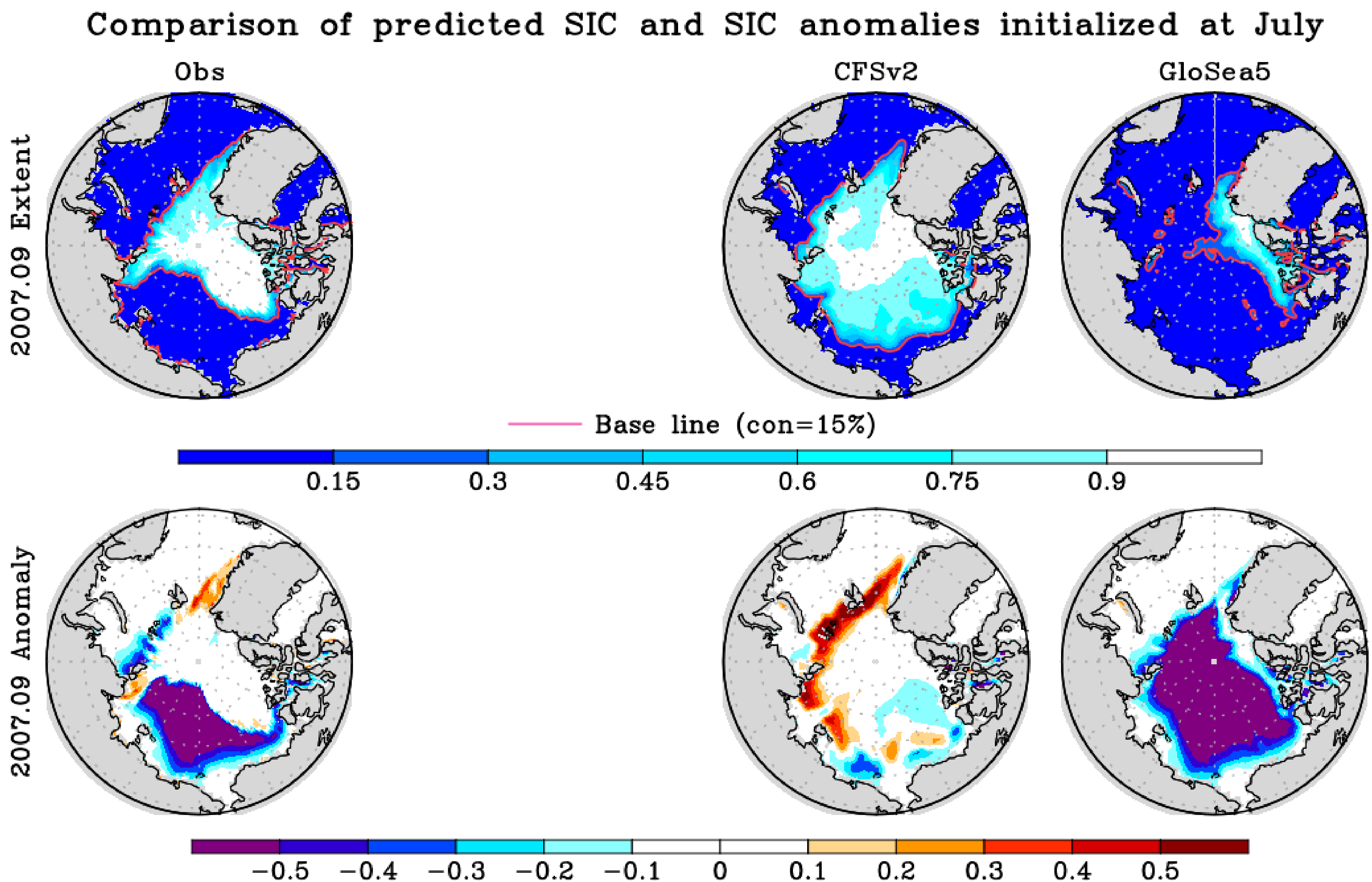
Large year-to-year variation of regional sea-ice conditions

- The Arctic sea ice extent is decreasing continuously, and relatively well predicted a season beyond. However, it is a difficult task to predict regional sea ice conditions, which varies greatly year-to-year.



- Sea ice over a different region has a different atmospheric responses

Still, dynamical models, GCMs, have large bias: forecast example Sep. 2007

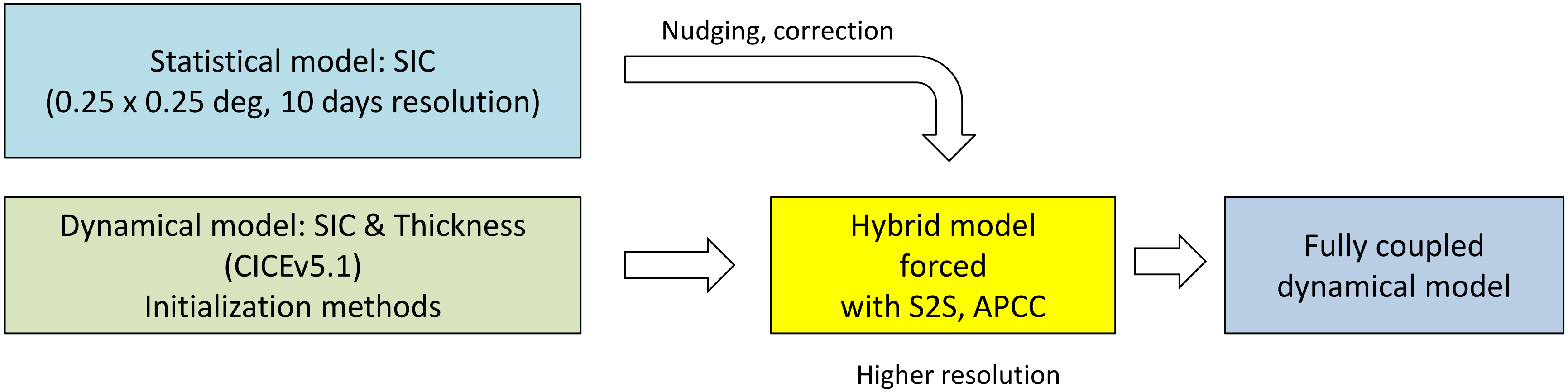


Too much

Too little

KOPRI-JNU's roadmap for Artic sea ice prediction

- At the moment, dynamical predictions have limitations for practical use, so we developed a statistical model only for forecasting sea ice concentration (SIC) (~'17), but
- are developing a dynamical prediction model as well for SIC and thickness based on offline sea ice model (~'18).
- A hybrid (dynamical model combined with statistical predictions) model will be developed (~'20).



Statistical prediction model for Arctic SIC

STEP1:
Extracting major spatio-temporal variation patterns from historical SIC observations of SIC using Season-reliant EOF (SEOF)

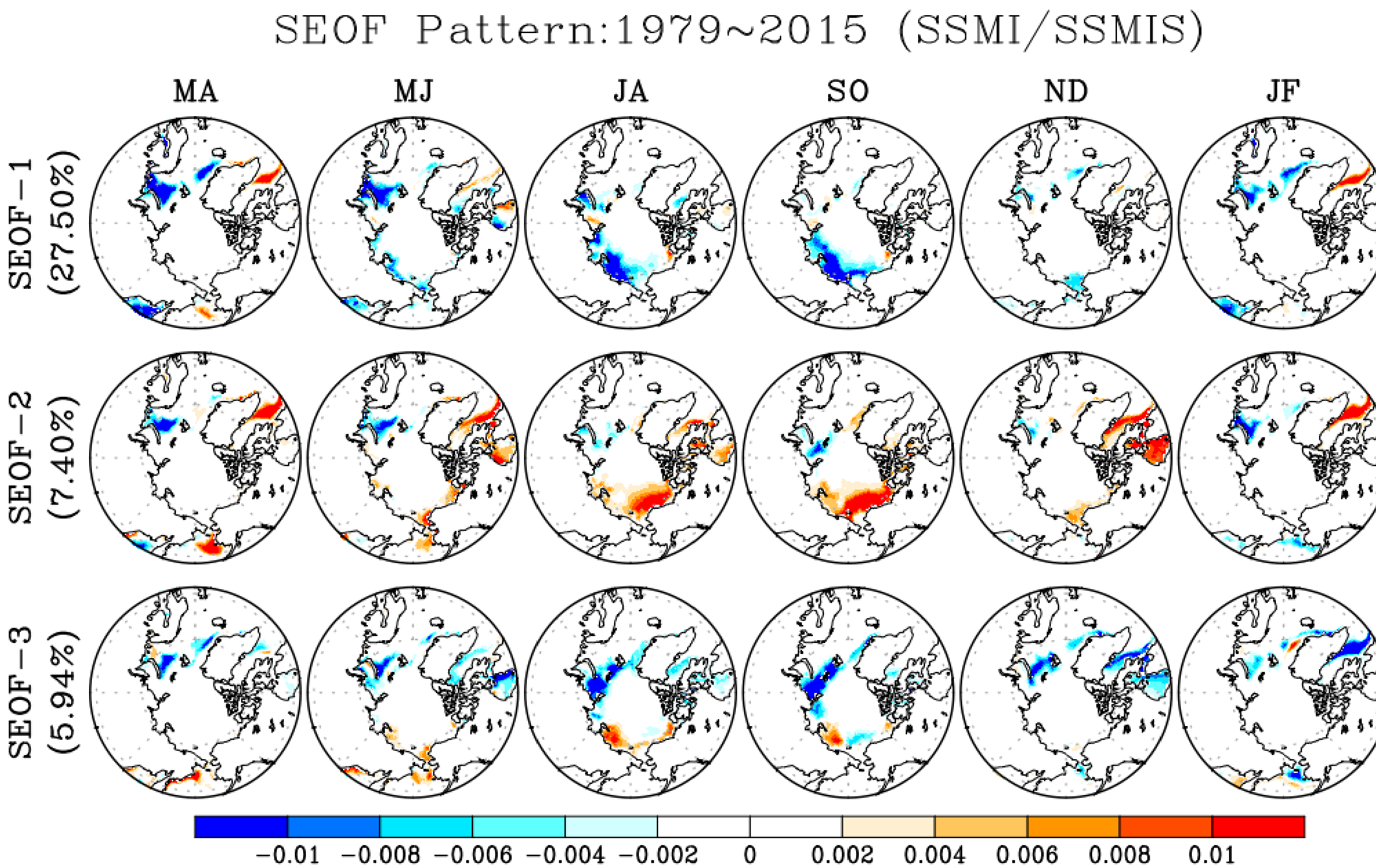
STEP2:
Estimating the current state of SIC with observed SIC anomalies for last 12 months

STEP3:
Projecting the future evolution of SIC using S-EOFS and the current state

STEP4:
Corrections with atmospheric circulation, surface radiation

Sea ice concentration anomalies over the Arctic,
Monthly average forecasts up to 12 months, half degree resolution

Extracting the spatio-temporal variation: Leading 3 Season-reliant EOFs of Arctic SIC

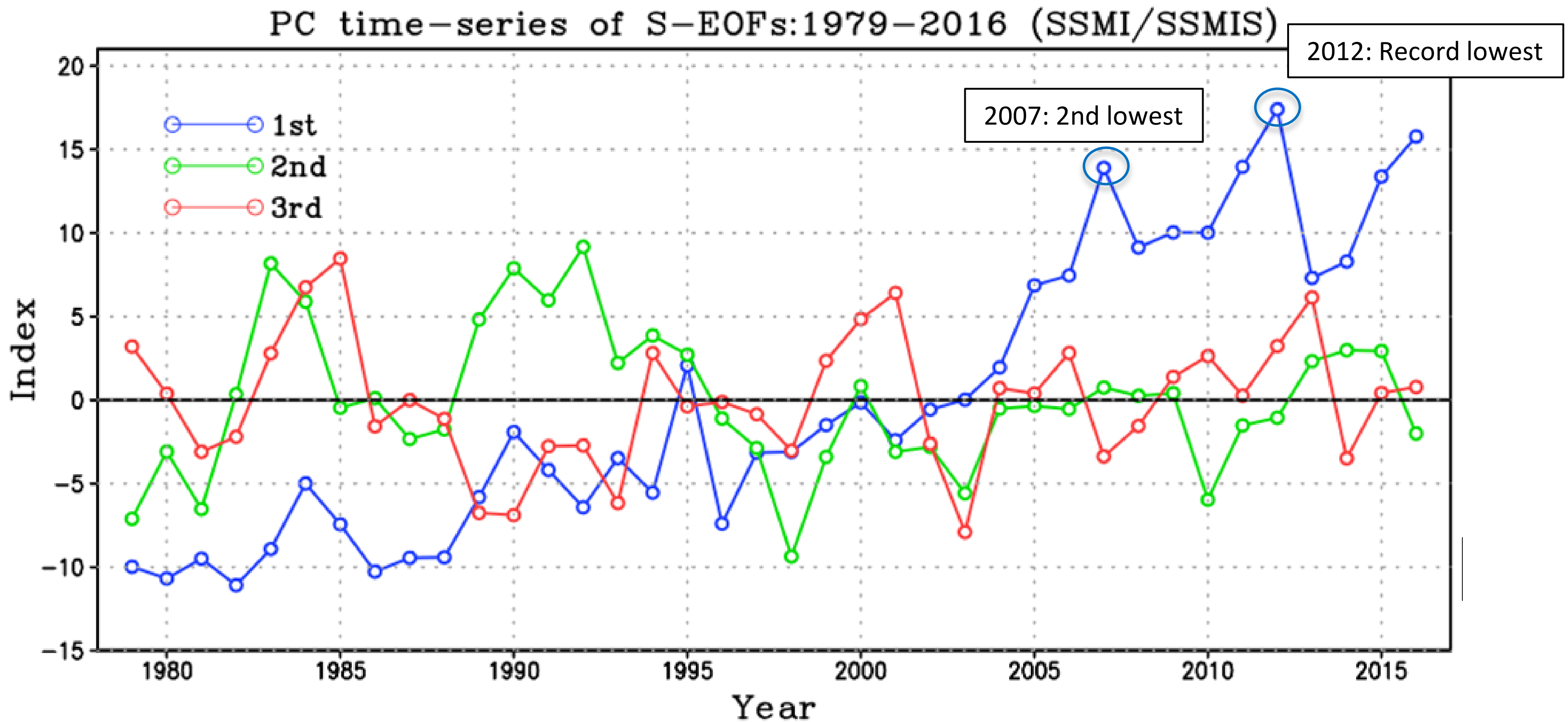


Overall melting/freezing

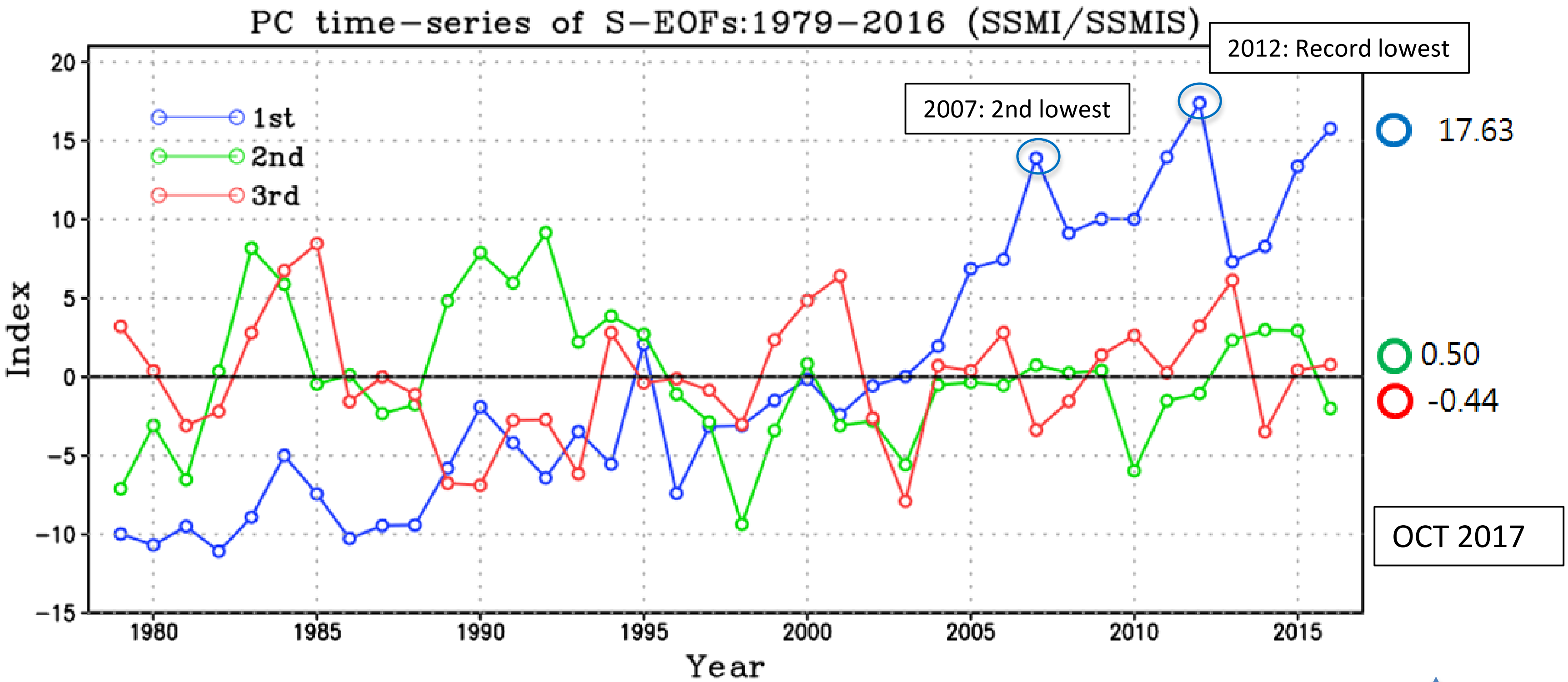
Eurasian/N Ame sector seesaw

Atlantic/Pacific Sector seesaw

PC time-series of S-EOFs

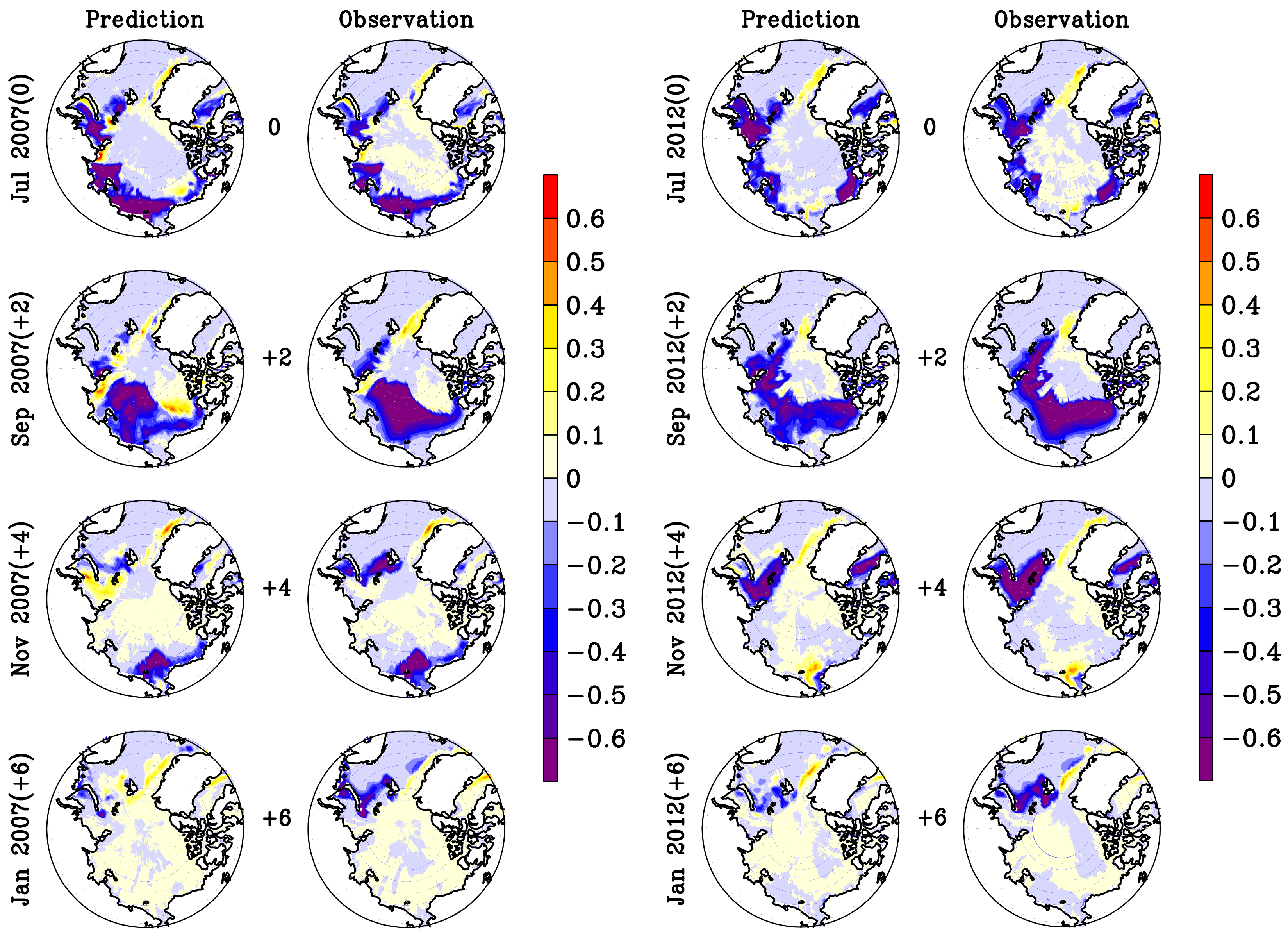


PC time-series of S-EOFs

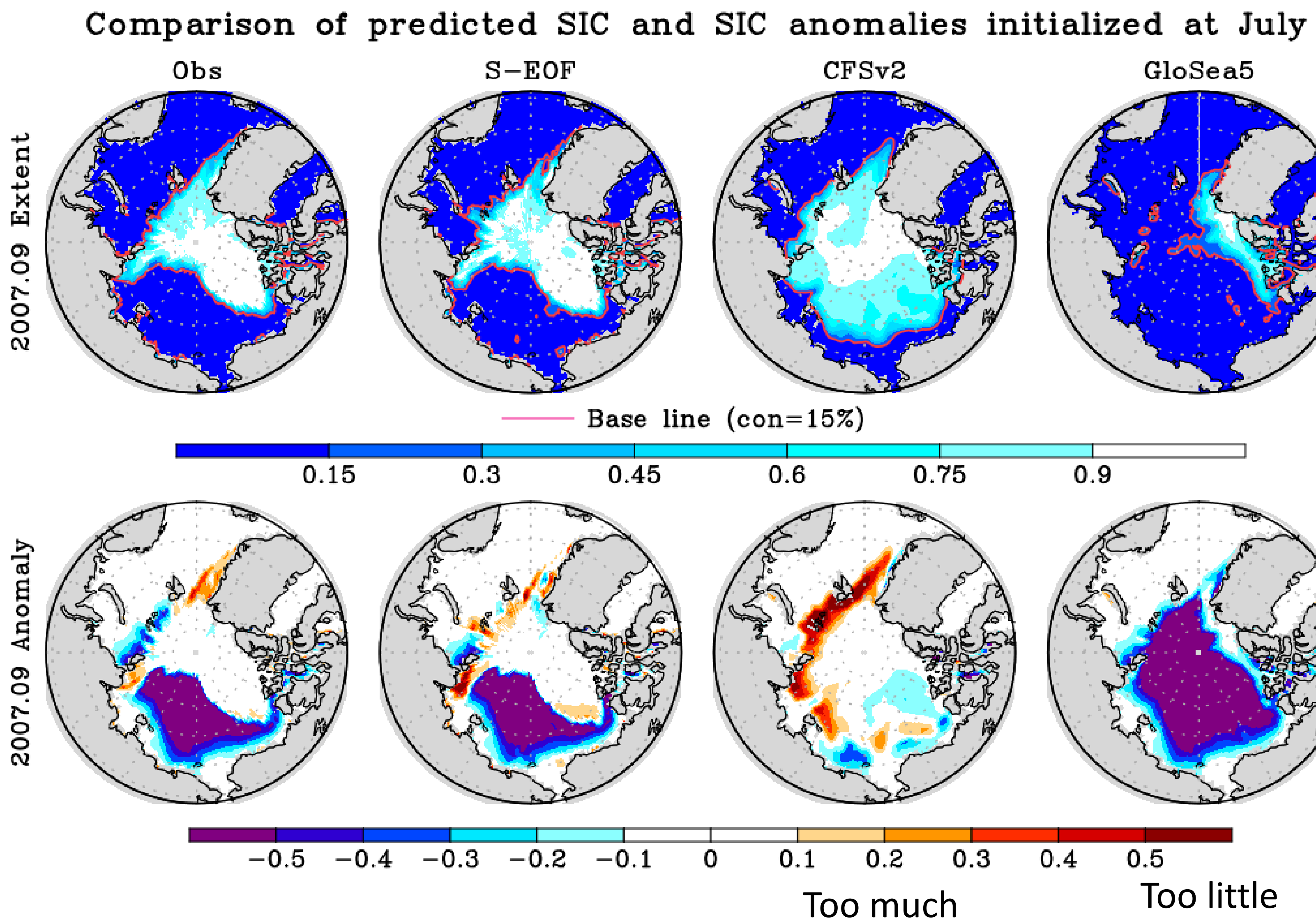


Estimating current state from the latest observations, and assuming it will persist for the next 12 months

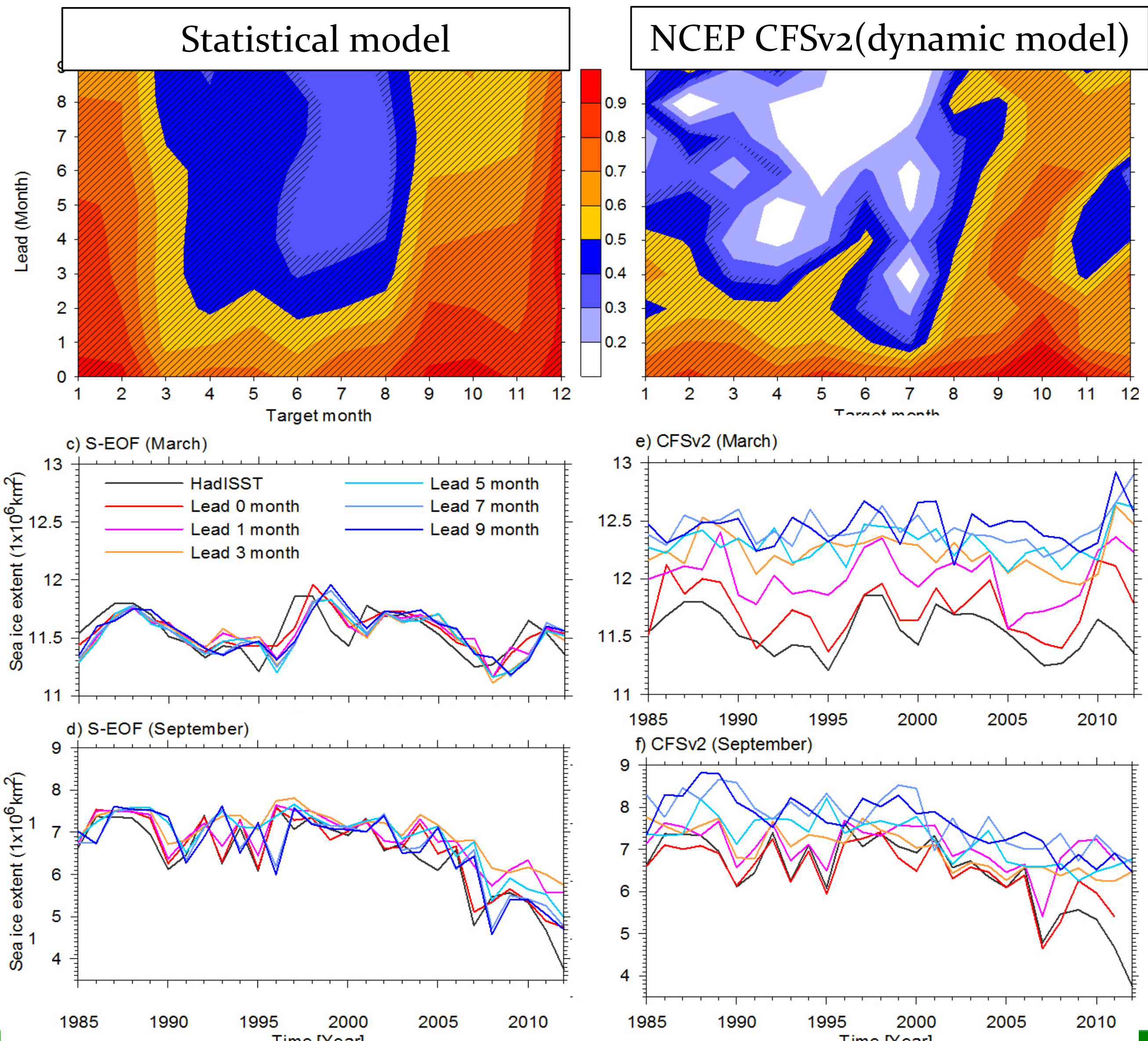
Forecast example: 2007, 2012



Still, dynamical models, GCMs, have large bias: forecast example Sep. 2007



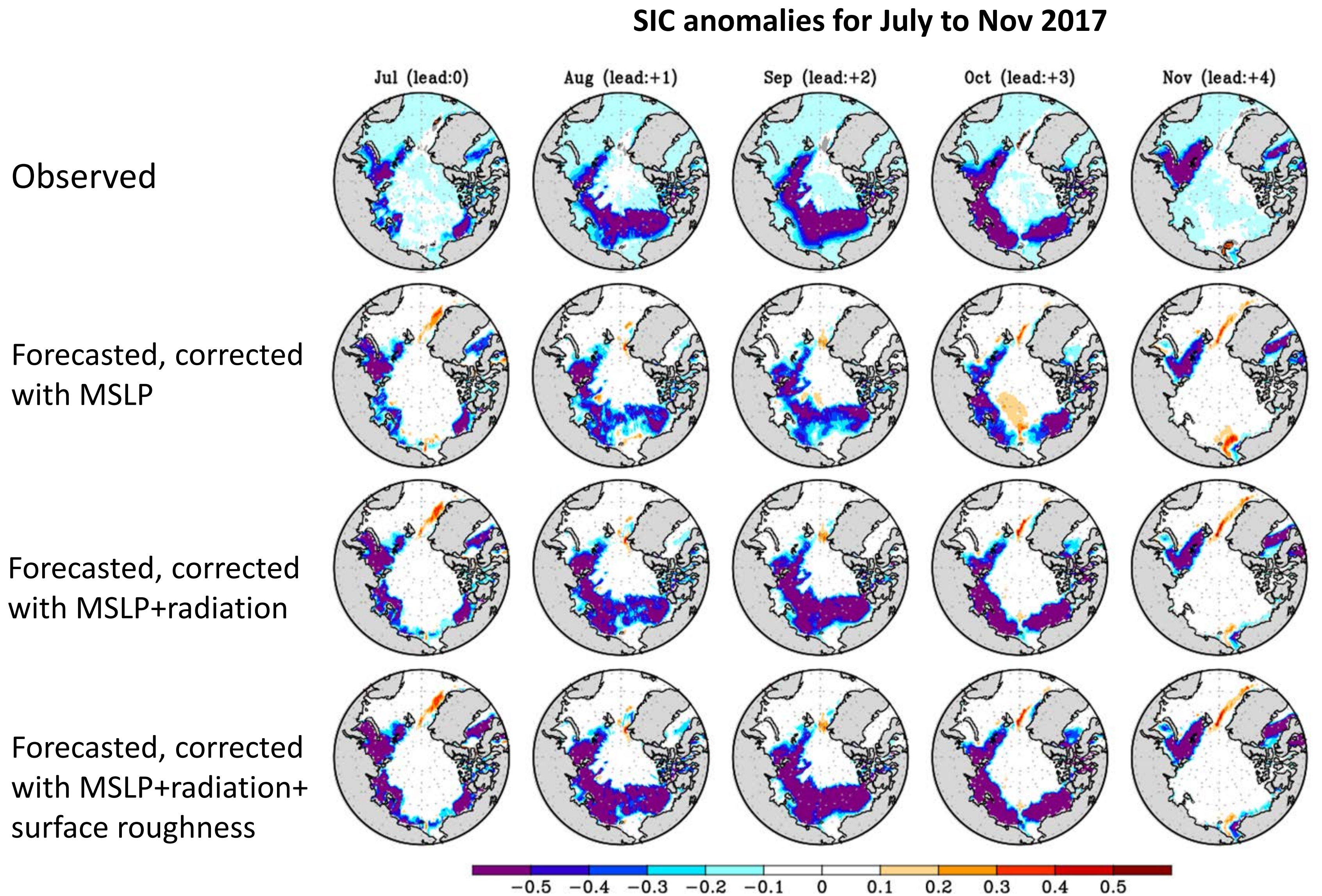
Arctic SIE prediction skill (in correlation)



Compared with NCEP CFS,

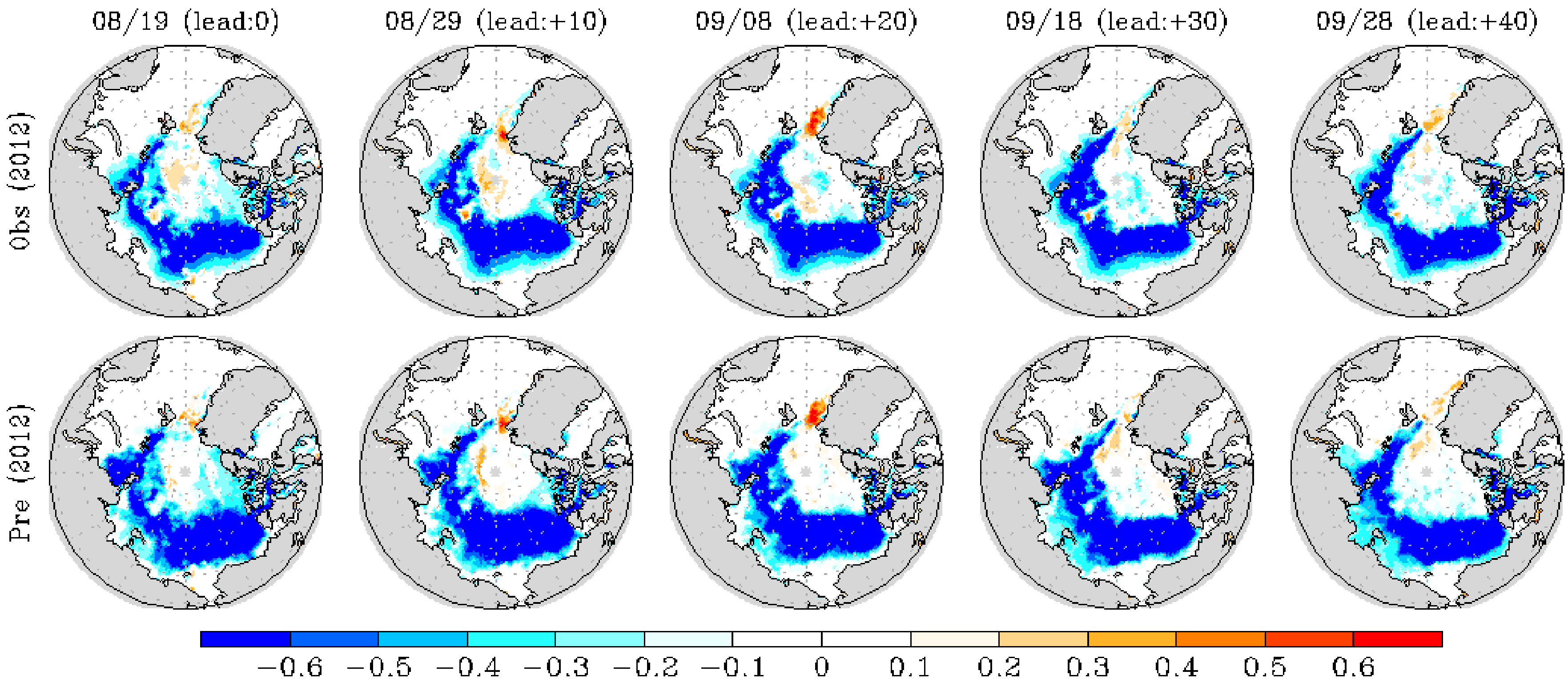
- High obs-fcst correlation
- No bias
- Spring barrier exist

Corrections using atmospheric circulation, radiations..



Higher resolution test using SSMI/SSMIS

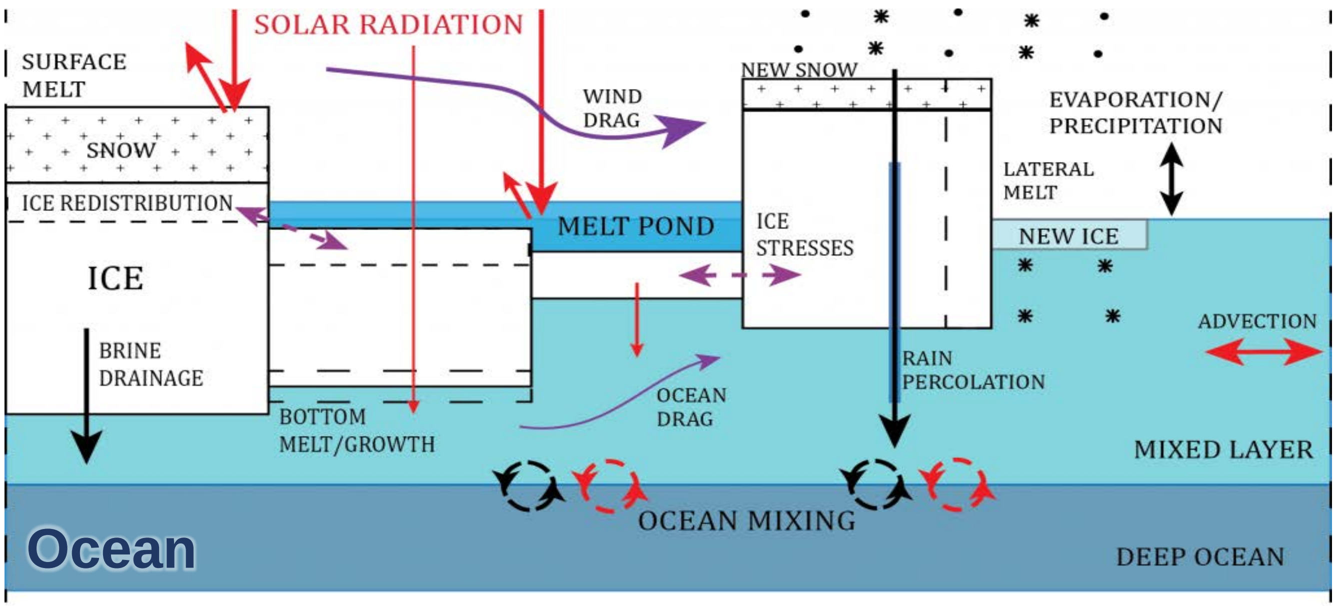
Forecasted at 19 Aug 2012: 10-day, 0.25 ° x 0.25 °



Dynamical model under development

CICE(Los Alamos Sea-Ice Model) v5.1

Atmosphere



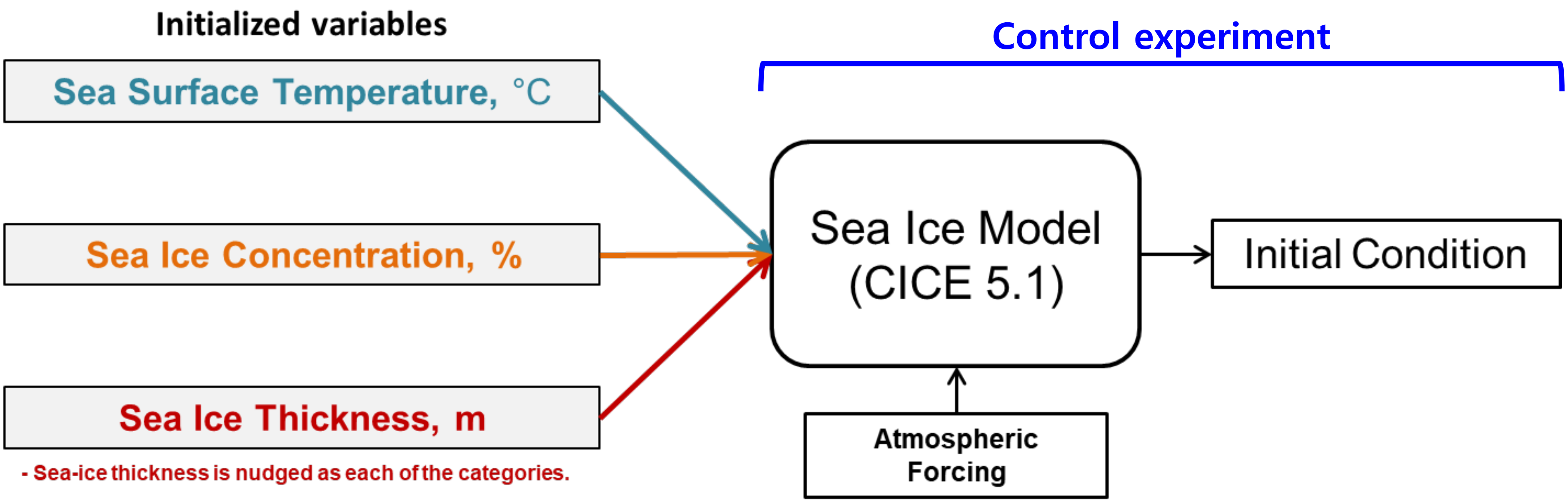
Some of the various physics now included in state-of-the-art sea ice models (e.g. CICE). Red arrows indicate heat fluxes, black arrows indicate salt/freshwater fluxes, and purple arrows indicate dynamic forces

http://www.climate-lab-book.ac.uk/2015/the-sea-ice-orchestra

- **The stand-alone ice model that predict sea ice fields by simulating the dynamic/thermodynamic processes.**
- **The CICE5 is the latest version of the Los Alamos Sea Ice Model.**
- **It can be run coupled in a global climate model(CICE4) or uncoupled as a stand-alone ice model.**

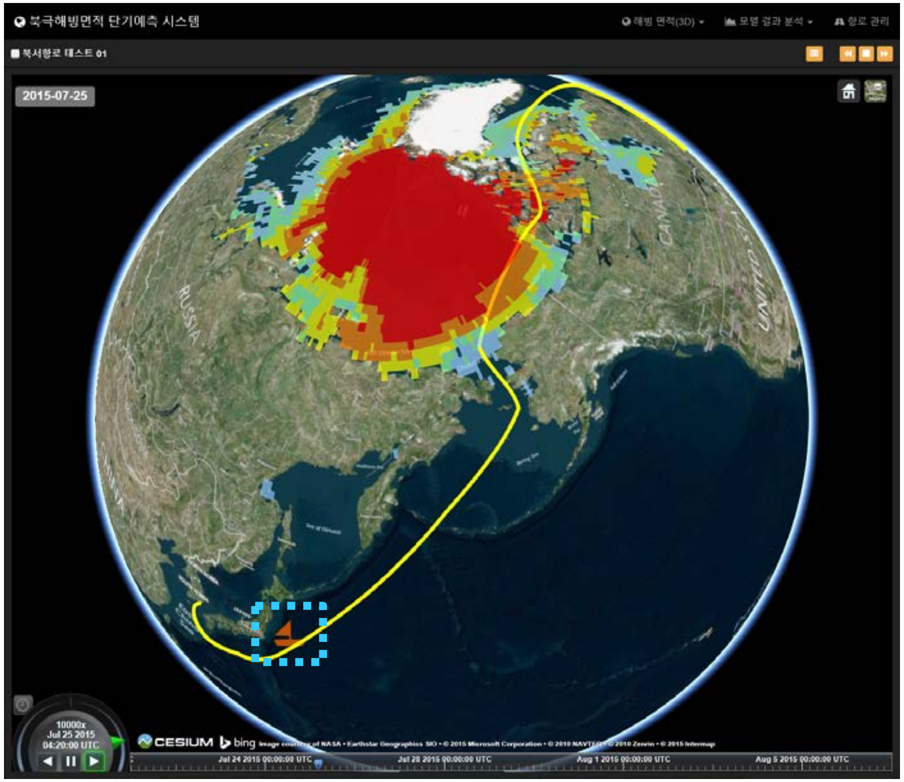
Dynamical model under development

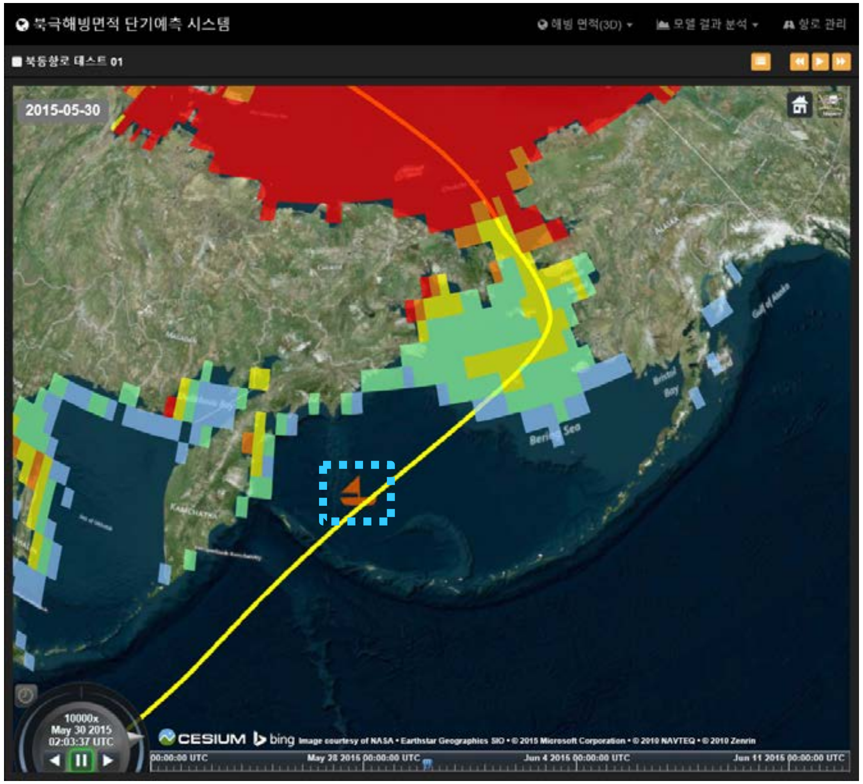
<Initialization system for SST/SIC/thickness>



- **Initialization scheme: Nudging(Newtonian relaxation)**
- **Experiment period: 1990.01.01 ~ 2008.12.31(19-years)**
- **Control experiment: Only atmospheric forcing**
- **Initialization system: Initialization + Atmospheric forcing**

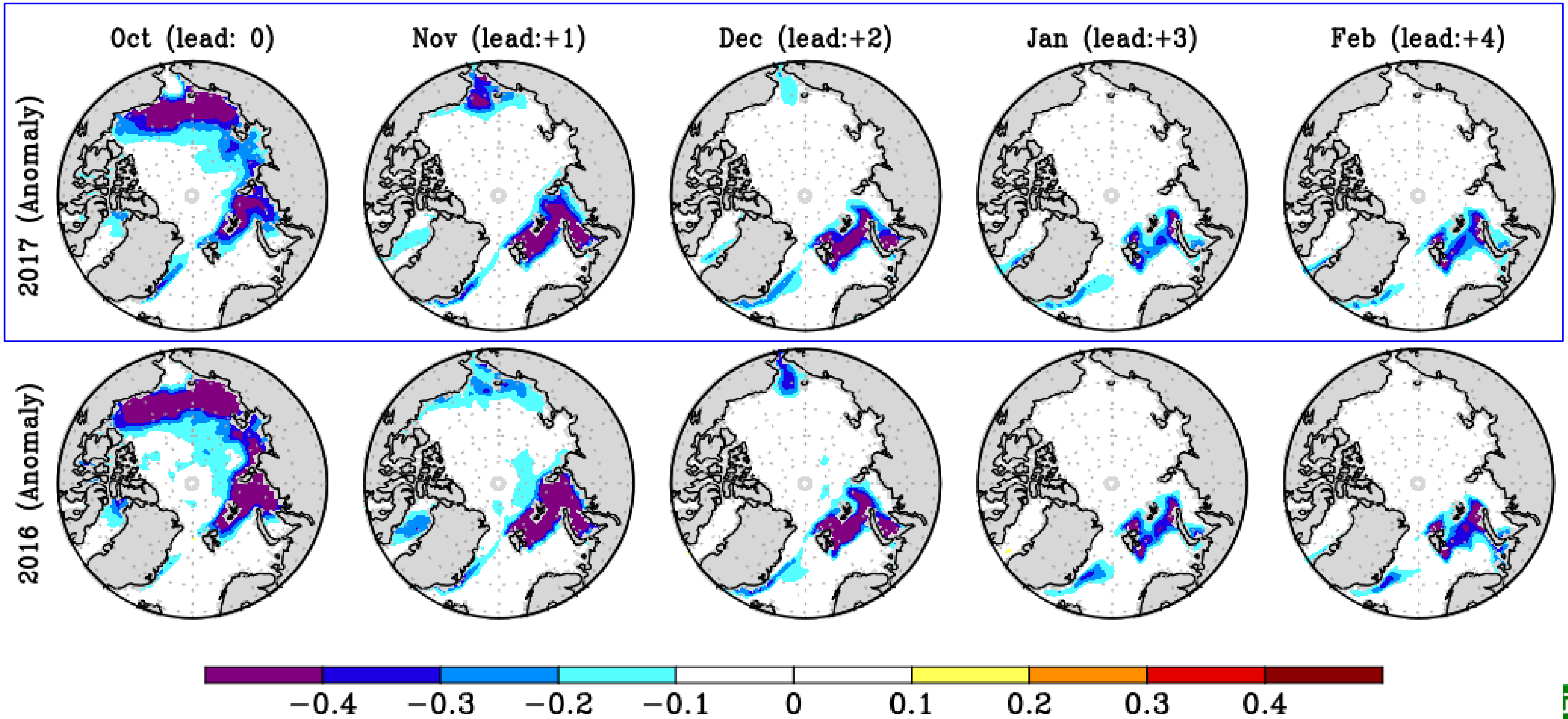
Visualization prototype





Summary

- JNU-KOPRI developed a prototype of Arctic sea ice statistical prediction model for ~12 months SIC predictions. Dynamical and hybrid model is being developed.
- Forecasted for this winter (initialized at Oct2017) as below



Thanks for your attention!

Backup slides

Possible methods for sea ice prediction

Dynamical model
by coupled GCM of interactive atmosphere, ocean, and sea ice with proper initialization

VS.

Statistical model
based on statistical relationship between the Arctic sea ice and preceding SST/OLR/circulation etc.

GCMs have large-bias of sea ice

Observation (SSM/I and SSMR)

Climate Model (CCSM4)

Difference (obs-model)

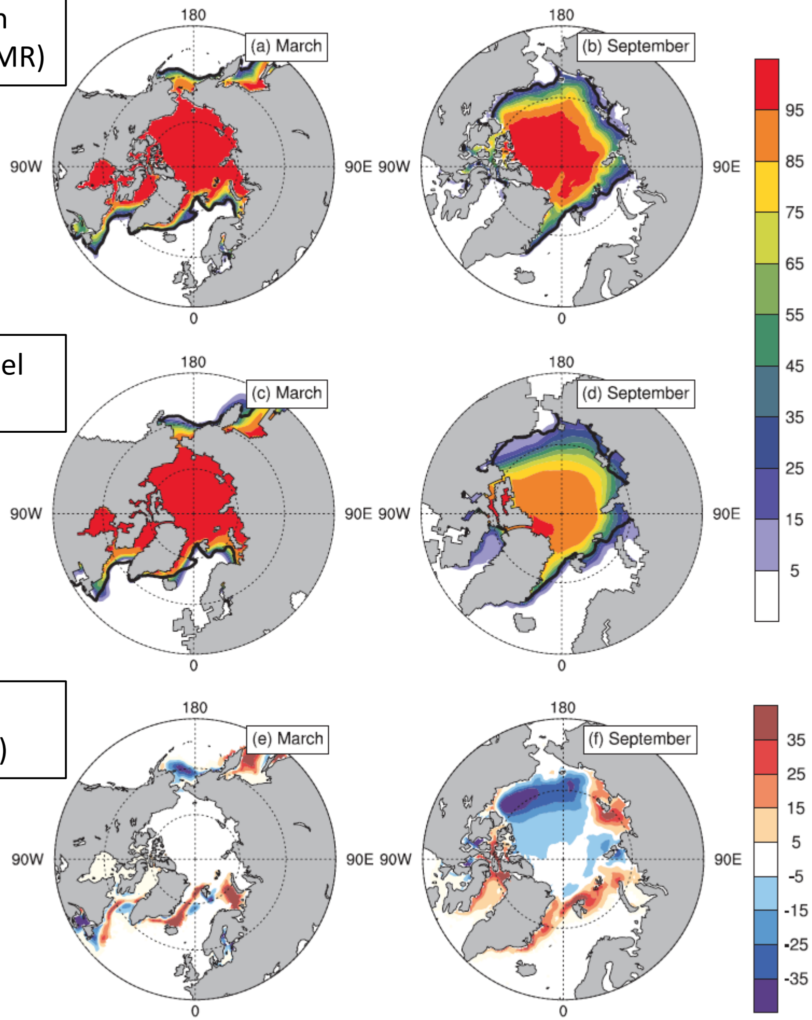


FIG. 1. SSM/I and SSMR (Comiso 1999) climatological sea ice concentration (%) compared to the six member CCSM4 ensemble average sea ice concentration for 1981–2005 for (a),(c) March and (b),(d) September. The ice edge (taken as 15% sea ice concentration contour) from the SSM/I and SSMR data are shown as black line. (e),(f) The difference between the CCSM4 and the SSM/I and SSMR ice concentration, showing regions with too much ice in the simulation (red colors) and regions with not enough ice in the simulation (blue).

(bot) SIC difference between CFS and CFRS, suggesting large of dynamical model

NCEP CFSv2: 1, 3, and 6-month prediction

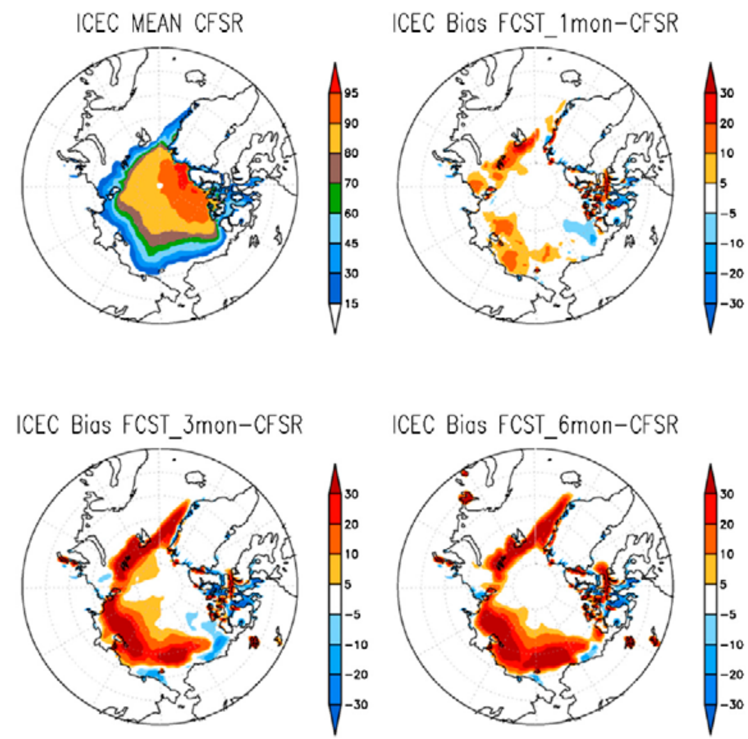


FIG. 10. (top left) The mean September sea ice concentration from 1982 to 2010 from CFSR, and the bias from the predicted mean condition for the September sea ice concentration with a lead time of (top right) 1 month (15 Aug IC), (bottom left) 3 months (15 Jun IC), and (bottom right) 6 months (15 Mar IC).

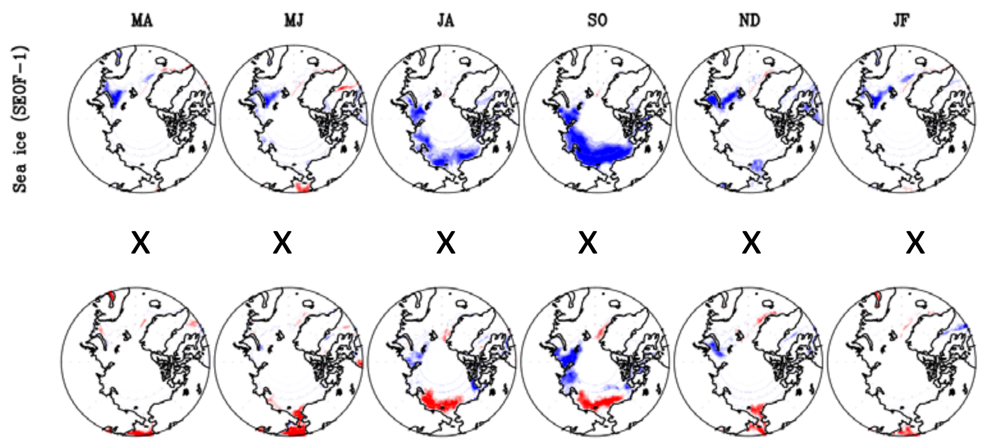
Saha et al 2014, JC

Step 2: SIC state index

1. 현재(0~ -11 month) 해빙 상태지수의 결정
   – SIC anomalies for the last 12 months
   – Projection onto the identified S-EOFs

SEOF1

Observed anomalies for last 12 months

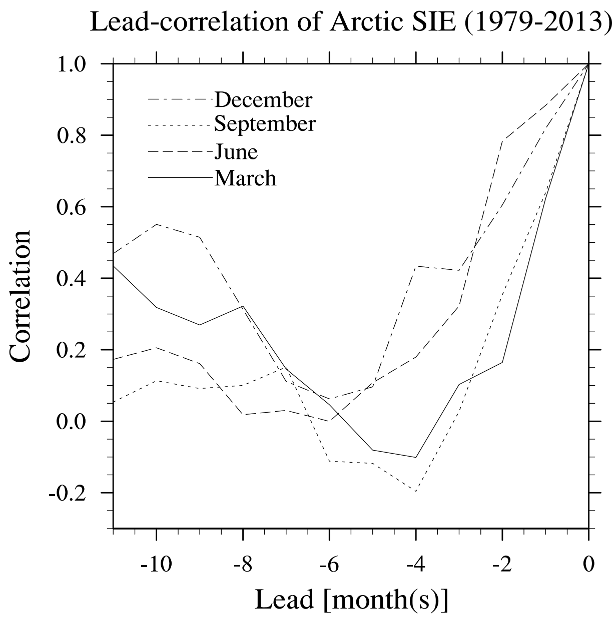


-> Prediction ->

summation → State index for SEOF1

Step 2: SIC state index – weighting

현재 해빙 상태지수 계산 기법



북극해빙 면적 지수의 lead-correlation
- 해빙 메모리의 대부분은 최근 0-3개월 사이에 존재 exponentially 감소하고 있으며
- 9-10개월전 이전해 해빙 depth와 관련된 메모리도 존재함

- 이 lead-lag correlation을 weighting function으로 사용, 테스트

$$SI_i(t) = \sum_{i=1}^{30}\sum_{y}\sum_{x} E_i(x,y,t-n) \times SIC'(x,y,t-n) \times \frac{COR(n)}{\sum_{n=0}^{-11} COR(n)}$$

해빙면적 autocorrelation을 weighting function으로 이용

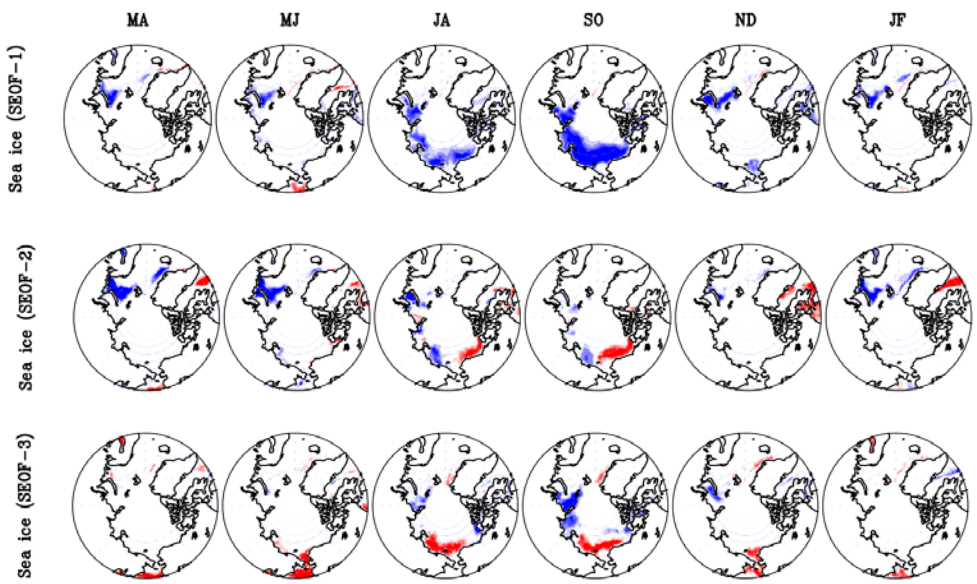
Step3: S-EOF를 이용한 해빙 통계예측 모델

2. 상태지수가 예측기간 동안에 유지(혹은 trend가 유지) 된다고 가정
3. Pre-identifie된 S-EOF 패턴과 상태지수를 곱하여 각 mode에 해당하는 미래 해빙 anomalies를 reconstruction

SEOF1

SEOF2

SEOF3

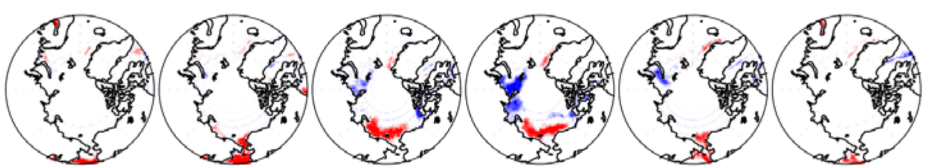


X state index for S-EOF1

X state index for S-EOF2

X state index for S-EOF3

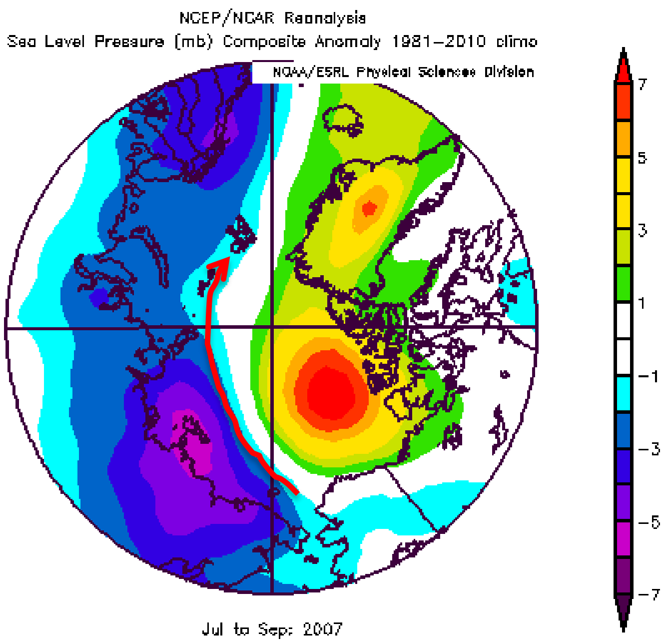
summation



Projected (forecasted) anomalies

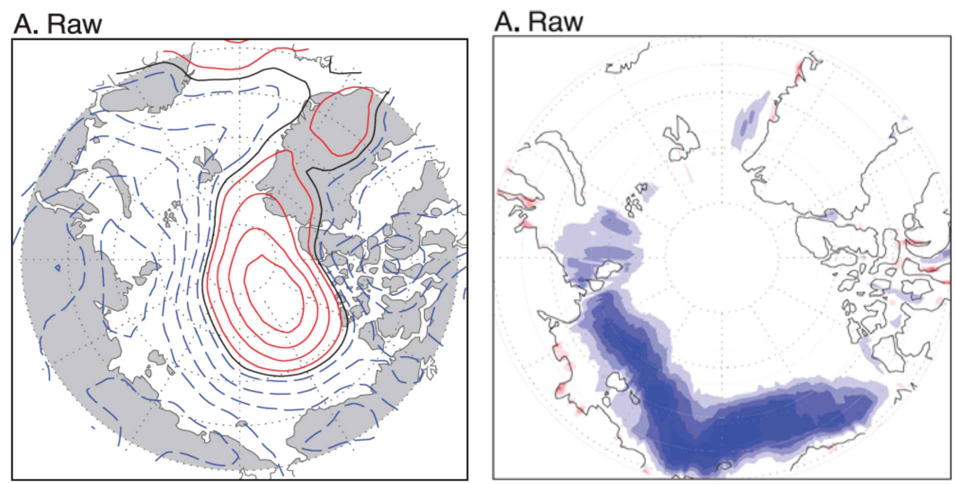
Step4: Correction with atmospheric circulation

JAS 2007 MSLP anomaly



Sea ice loss mainly
due to wind stress

북극지역 9월 해빙면적을 여름철(JAS)
(좌) 해수면 기압 (우) 해빙농도에 regression한 결과



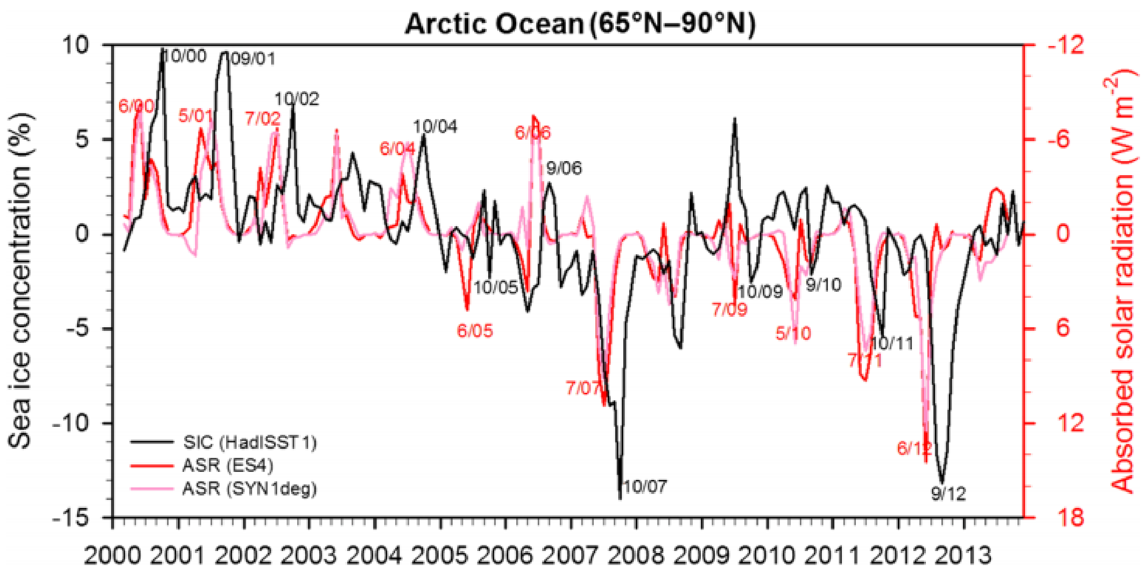
Regression of JAS SLP and SIC to September sea ice extent 1979-2006. Ogi and Wallace 2007 (GRL)

Melting phase의 대기정보-해빙농도 regression 모델 구축
통계모델에 보정 term으로 적용

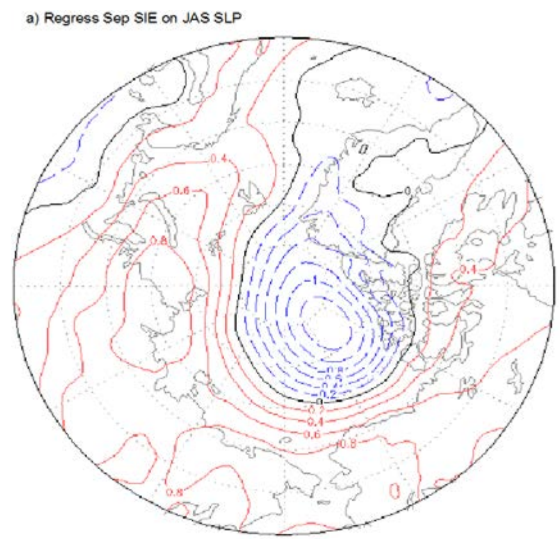
Step4: Correction with MSLP, radiation

1. 추가예측보정기법 개발

9월 해빙 면적과 여름철
단파 복사와의 관계



9월 해빙과 여름철
SLP간의 상관성 (regression)

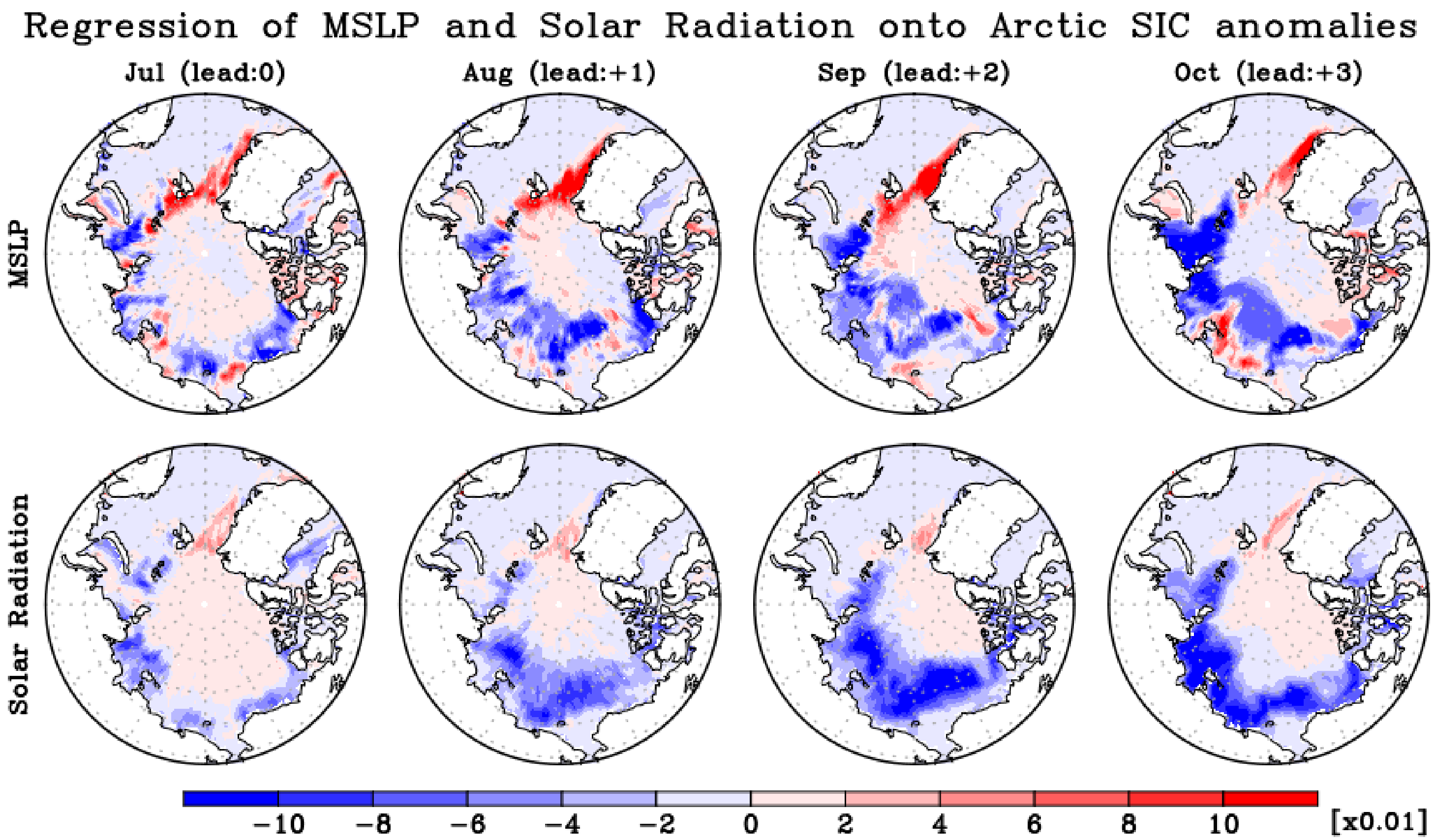


해수면기압 및 단파복사 - 해빙 간의 다중선형 회귀 기반 보정

$$SIC'(x,y,t^*) = \sum_{i=1} E_i(x,y,t^*) \times SI_i(t) + PC \times reg_1(PC, SIC(x,y,t^*))$$
$$+SW \times reg_2(SW, SIC(x,y,t^*))$$

Step4: Correction with MSLP, radiation

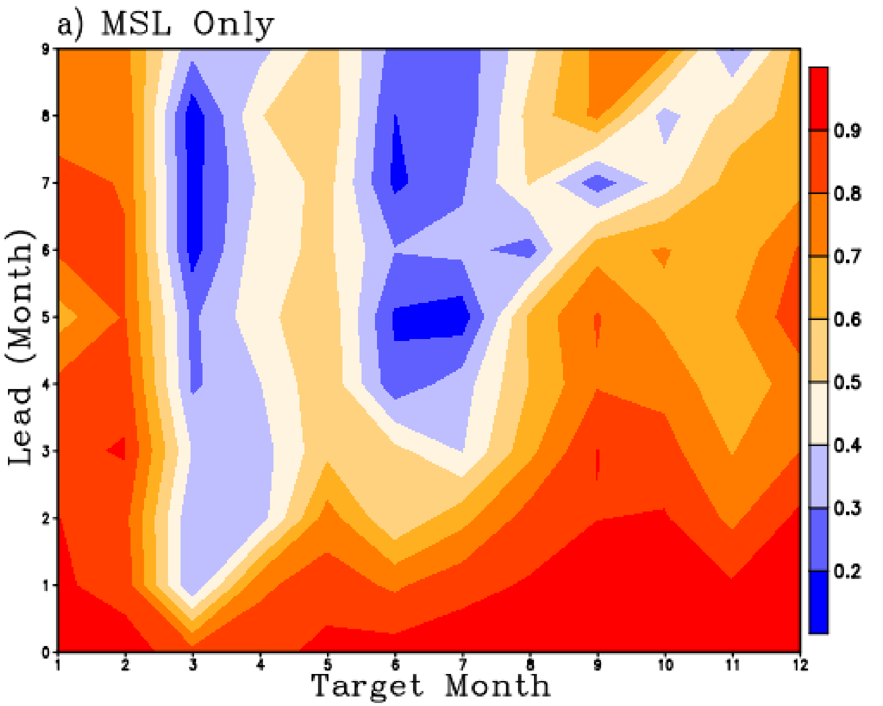
Spatial patterns of coefficient for multiple regression between MSLP and Solar Radiation onto Arctic SIC anomalies



Step4: Correction with MSLP, radiation

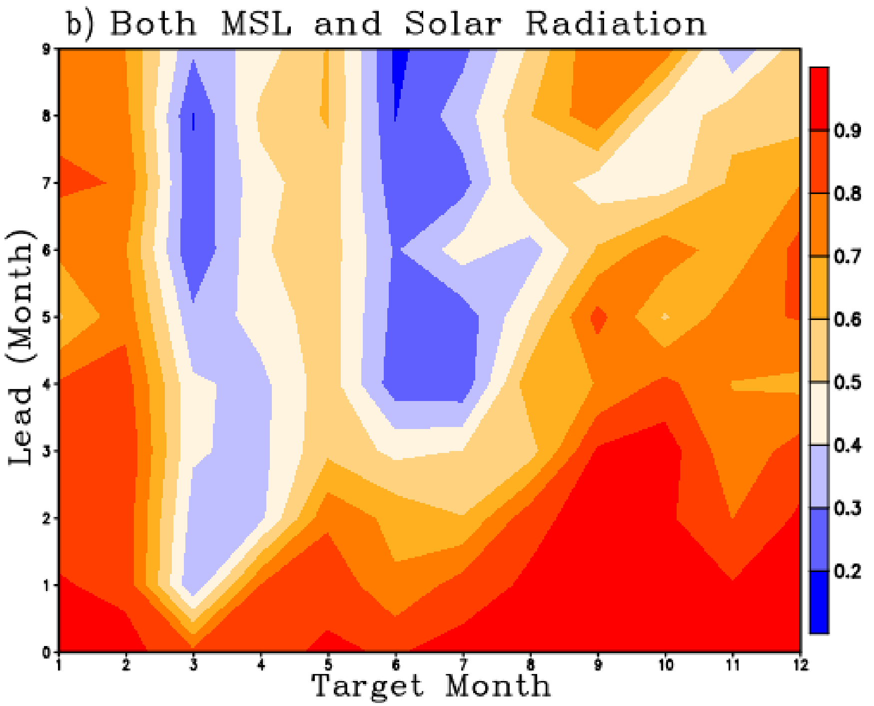
- 해수면 기압 보정과, 해수면 기압 + 단파 복사 에너지를 보정했을 때 예측성 비교

해수면 기압 보정
(1987.01 ~ 2014.12)



JRA reanalysis MSL 보정

해수면 기압 + 단파 복사 보정
(1987.01 ~ 2014.12)



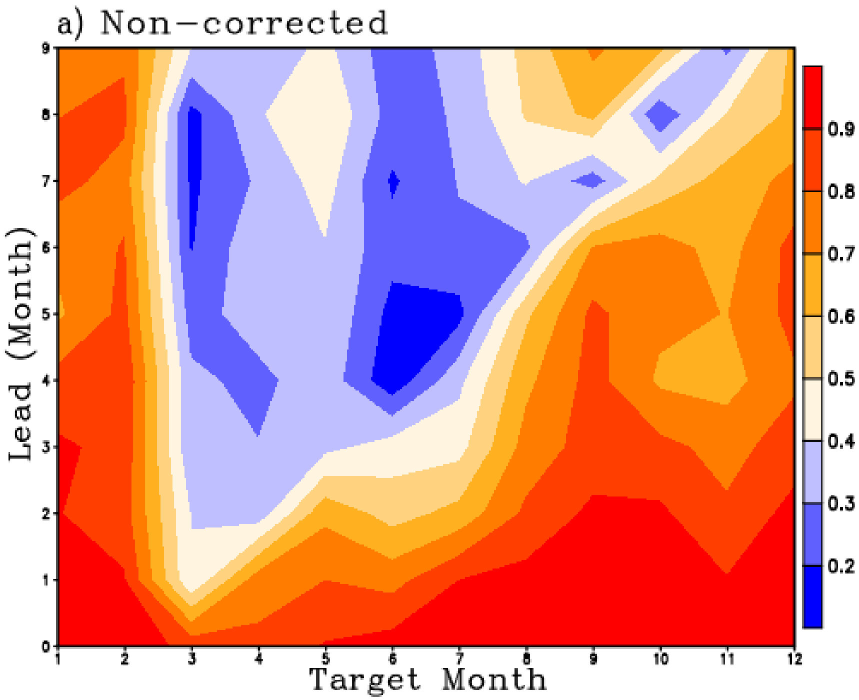
JRA reanalysis MSL and Solar Radiation 보정

여름-가을철 예측성 향상이 나타남

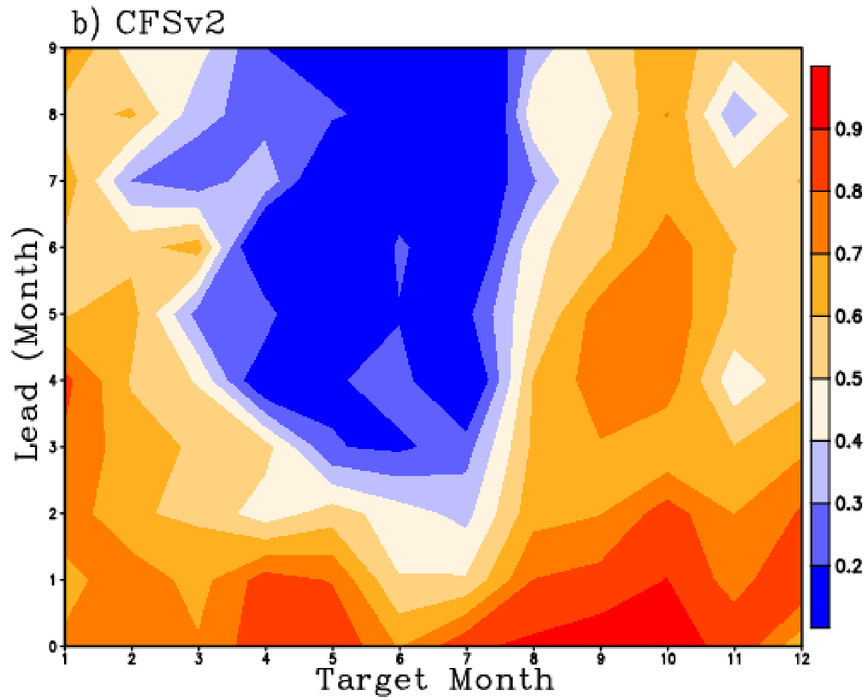
Step4: Correction with MSLP, radiation

- 통계 모델과 역학모델(CFSv2)의 예측성 비교 (관측 vs. 예측 correlation)

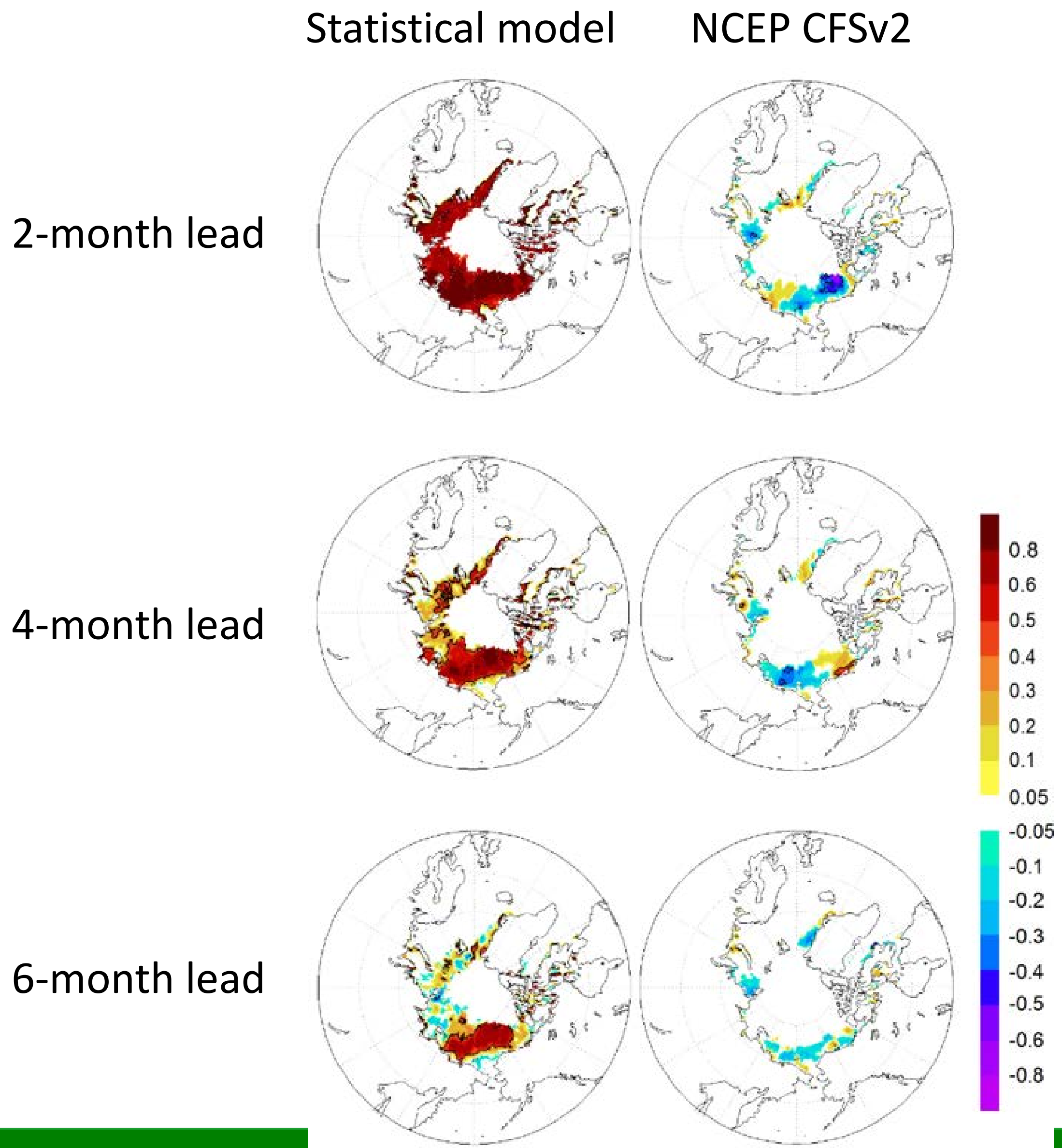
S-EOF 통계 모델
(1982.01 ~ 2010.12)



NCEP CFSv2
(1982.01 ~ 2010.12)

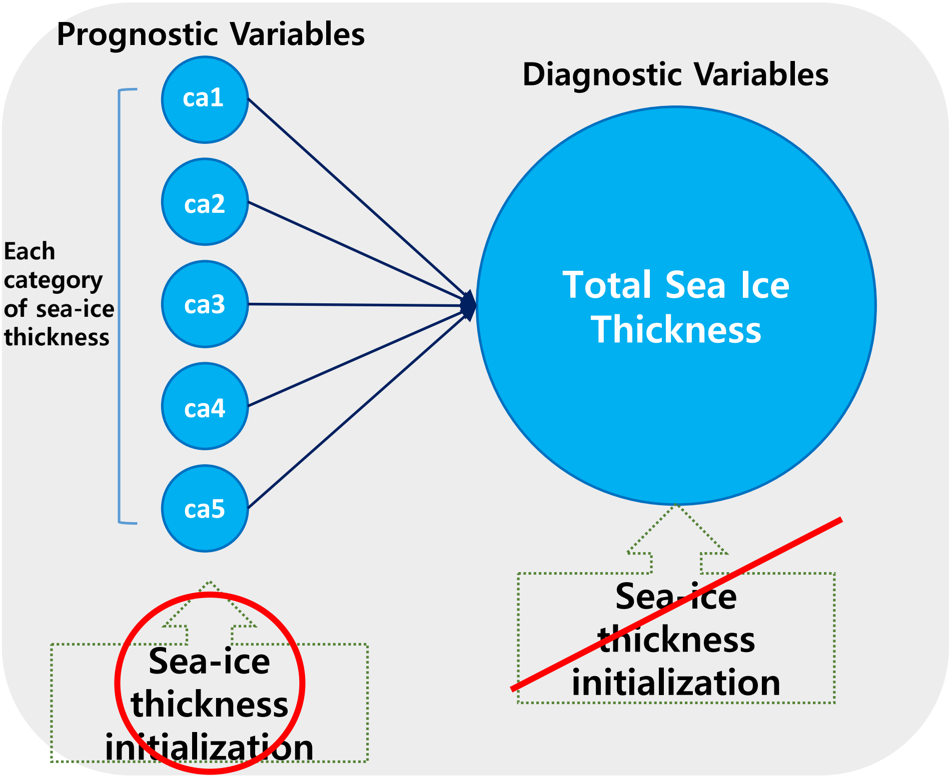


Sep. SIC observation-forecast correlation



Development of initialization scheme of sea-ice thickness

Method of initialization for each ice thickness category



There is no DATA for each ice thickness category
But, Nudging term for them is required

Control Run

$$H_{mod\_tot} = H_{mod\_ca1} + H_{mod\_ca2} + H_{mod\_ca3} + H_{mod\_ca4} + H_{mod\_ca5}$$

Nudging Run

$$H_{nu\_tot} = (H_{mod\_ca1} + \Delta H_1) + (H_{mod\_ca2} + \Delta H_2) + (H_{mod\_ca3} + \Delta H_3) + (H_{mod\_ca4} + \Delta H_4) + (H_{mod\_ca5} + \Delta H_5)$$

$$\Delta H_1 = (H_{piomas\_tot} - H_{mod\_tot}) \times \left(\frac{H_{mod\_ca1}}{H_{mod\_tot}}\right)$$

$$\Delta H_2 = (H_{piomas\_tot} - H_{mod\_tot}) \times \left(\frac{H_{mod\_ca2}}{H_{mod\_tot}}\right)$$

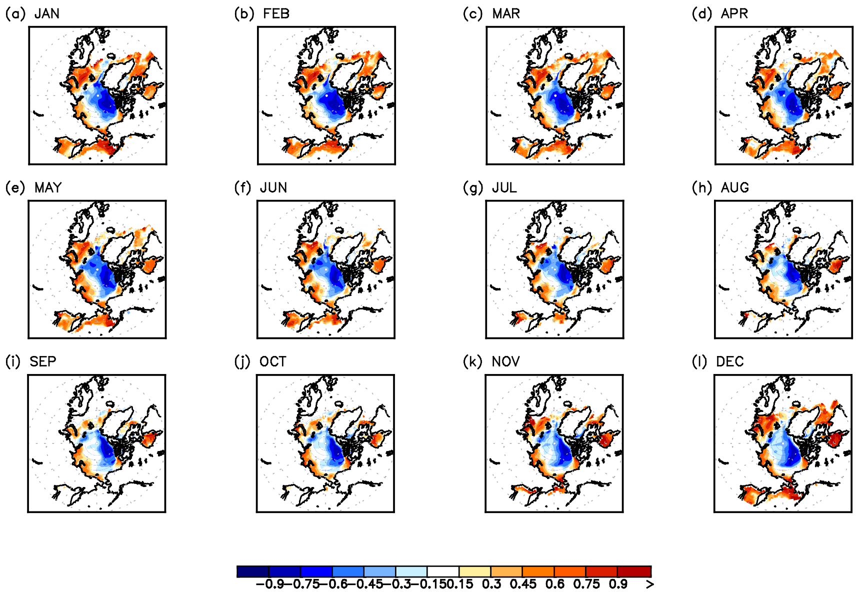
...

- The **nudging term for prognostic variable each category of sea-ice thickness** is required, because total thickness is diagnostic variable in model.
- The nudging terms for them are constructed by multiplying the ratio of each category in the model by the total sea-ice thickness difference.
- This method can directly initialize sea-ice thickness, maintaining the balance within the model.

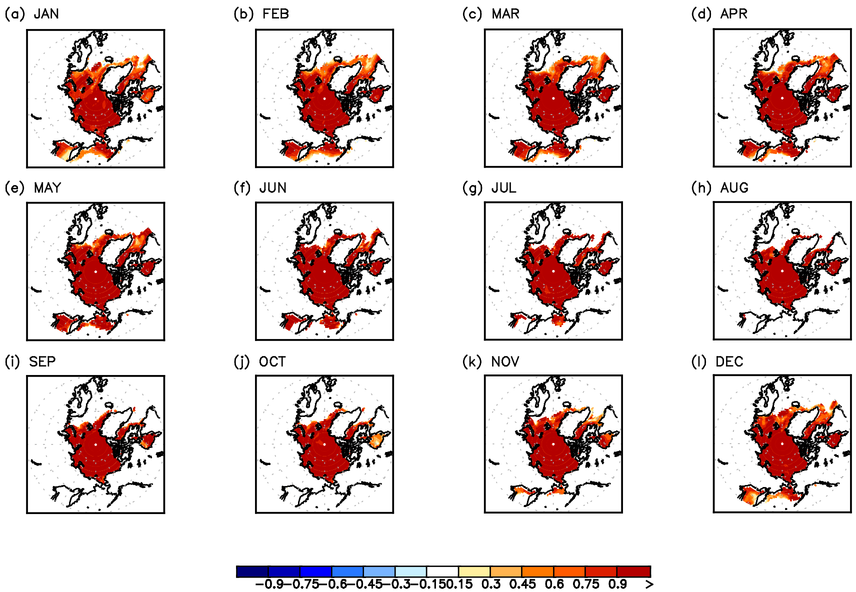
Only each category of sea-ice thickness initialization

Observation-Model correlation

Control SIT



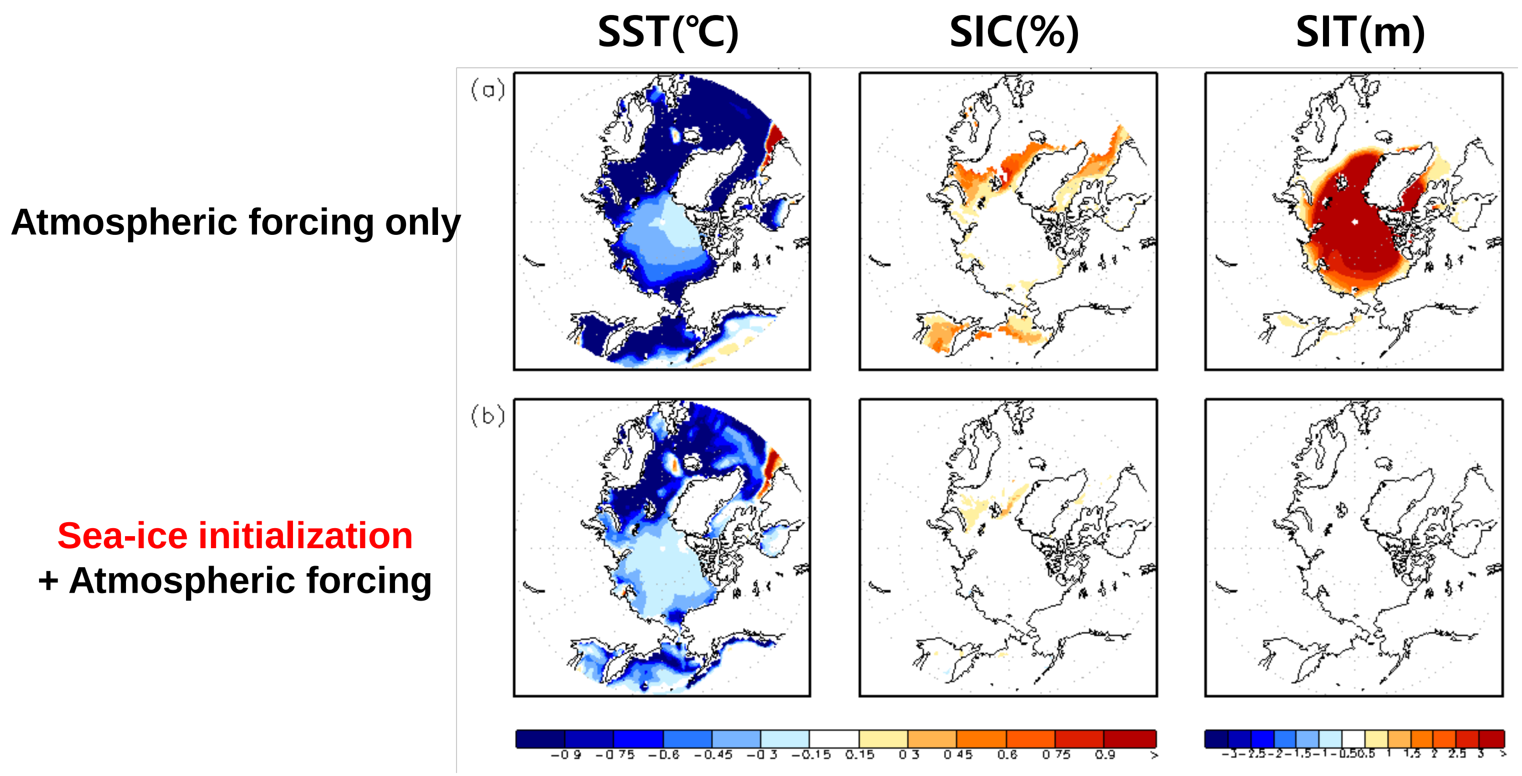
Nudging system SIT



- **SIT correlation becomes high in all seasons compared to control experiment.**

→ The each category of sea-ice thickness nudging initialization system is successfully setup and total SIT is well constrained by observation through each SIT category initialization method .

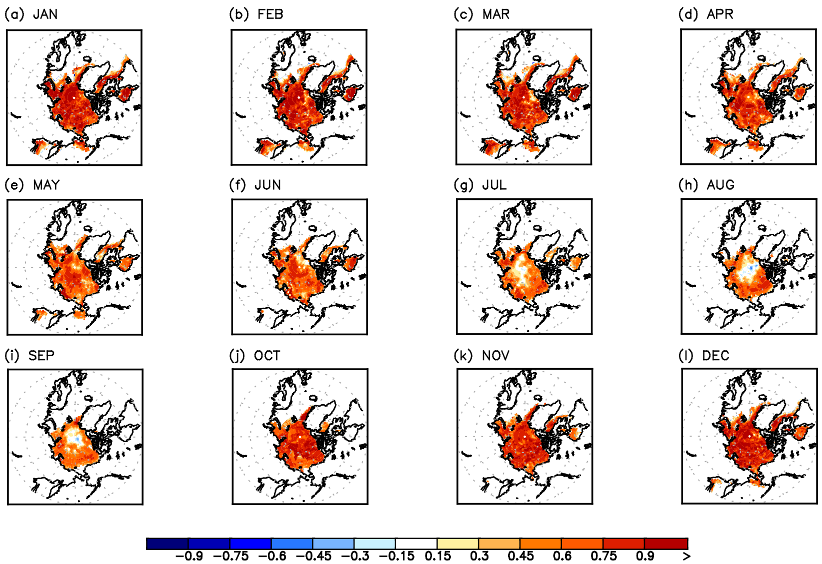
Bias (Model climatology – Observation climatology) of initial condition



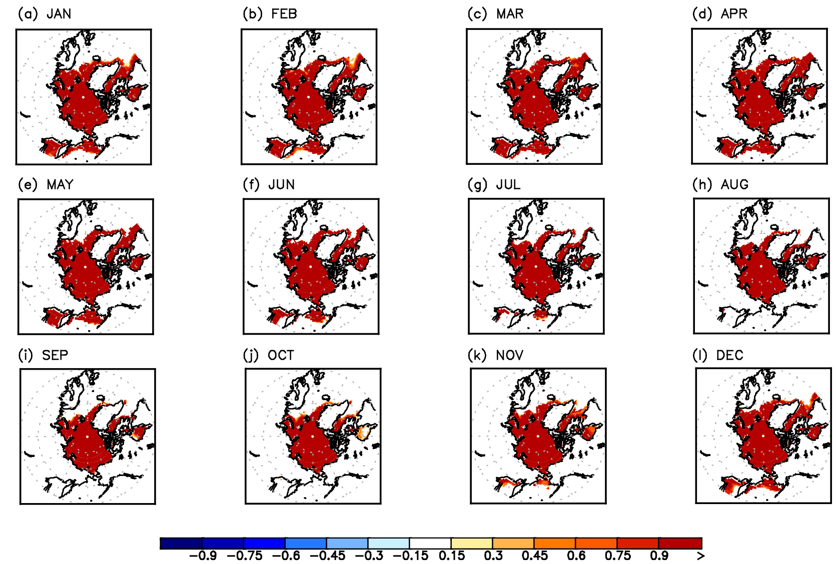
- The **combined nudging** initialization system is successfully setup.
- Bias of the sea-ice nudging experiments becomes significantly low
  → **Well constrained** by the observation.

Correlation(Model↔Observation) of initial condition

Sea-ice concentration correlation



Sea-ice thickness correlation



- **The combined nudging initialization system is successfully setup**
- **Correlation between the sea-ice nudging experiments and the observations shows significantly high value for both SIC and SIT.**

  → Well constrained by the observation, especially sea-ice thickness