

북극·중위도 원격상관 예측 성능 평가를 위한 진단 매트릭스의 개발과 활용

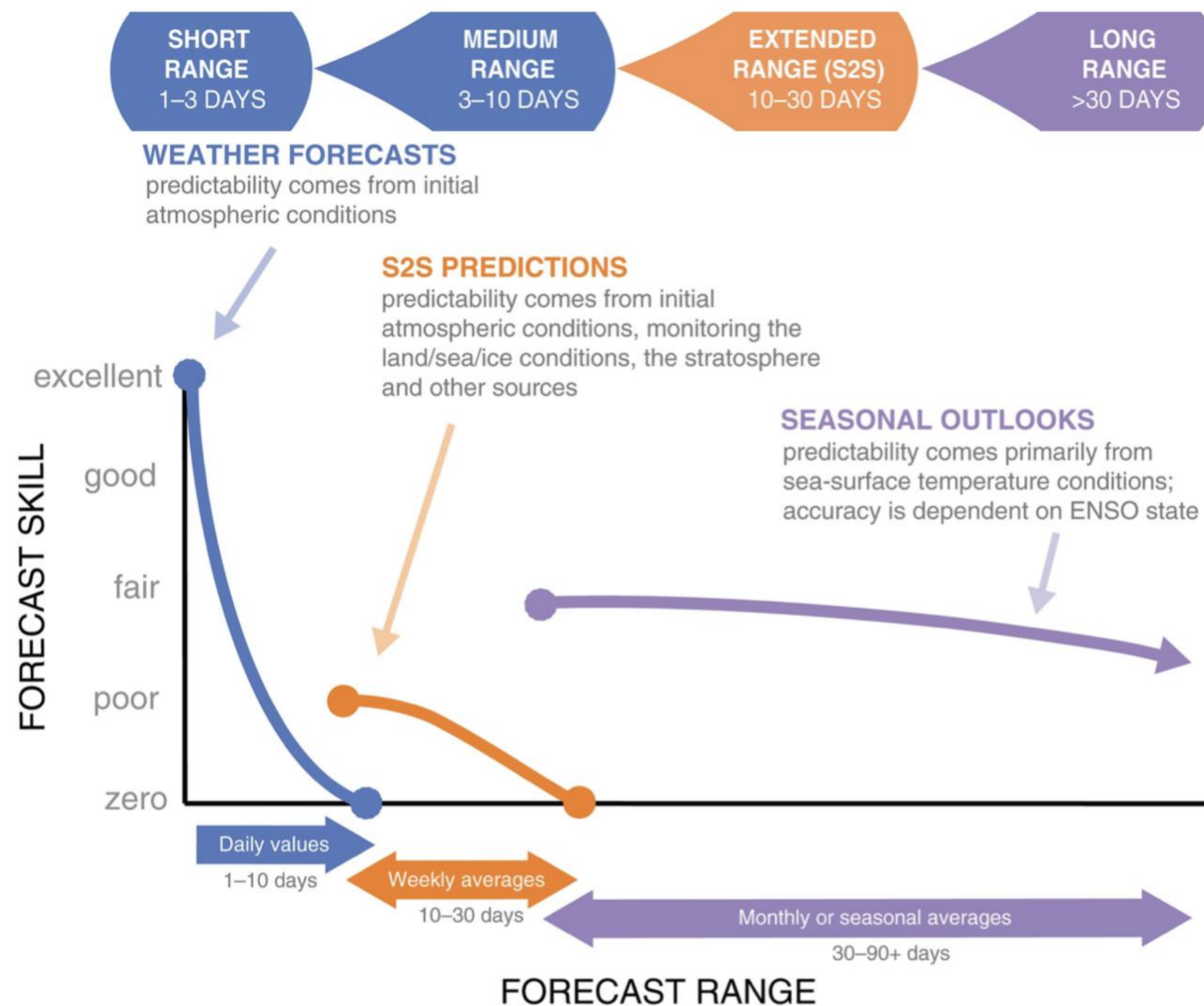
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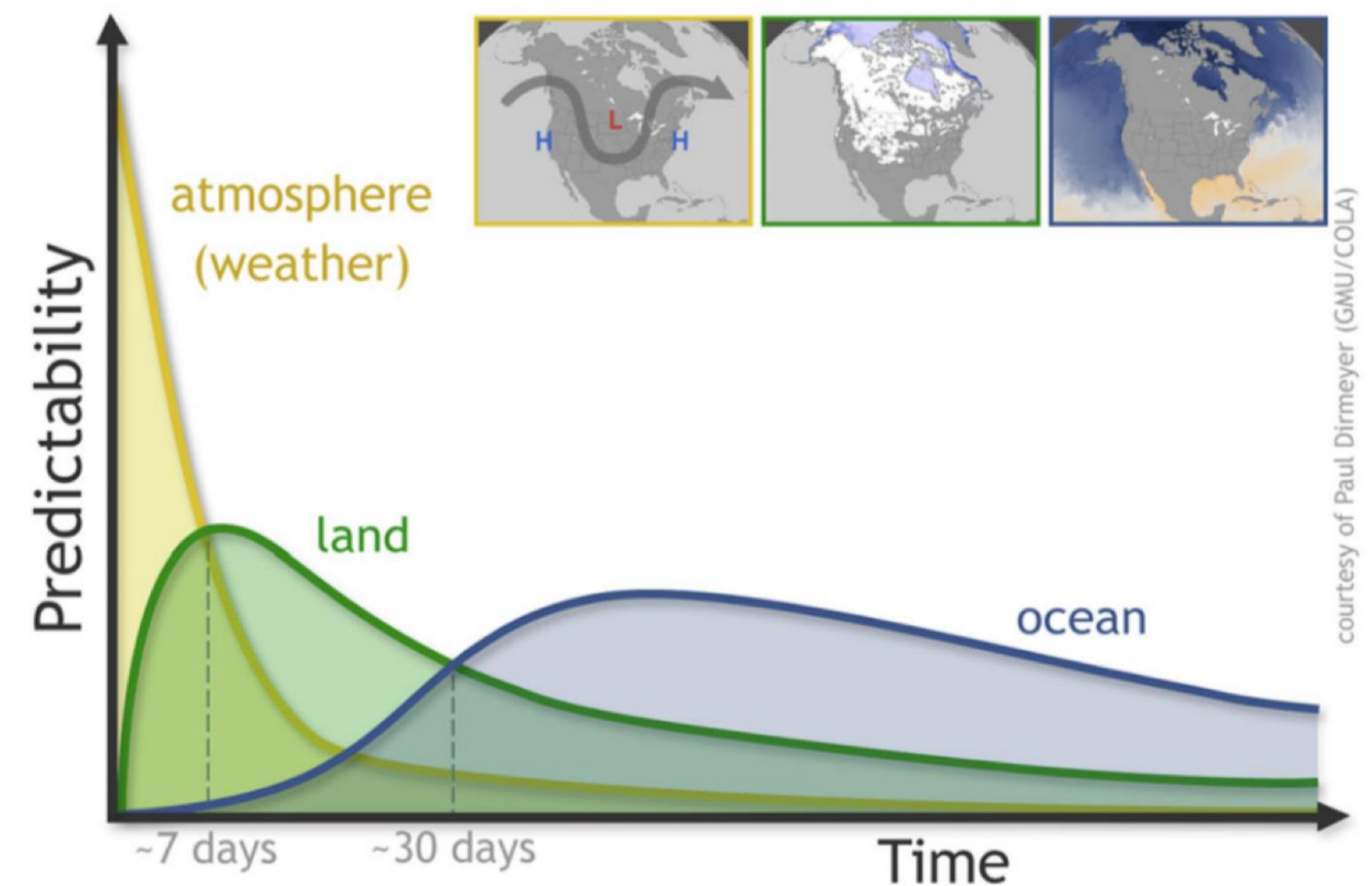
1. 서론 | 연구 배경

- 준계절-계절 시간 규모에서의 예측 및 진단 평가 연구의 필요성

시간 규모에 따른 예측 성능 차이



예측 시간 규모에 따른 불확실성 요인



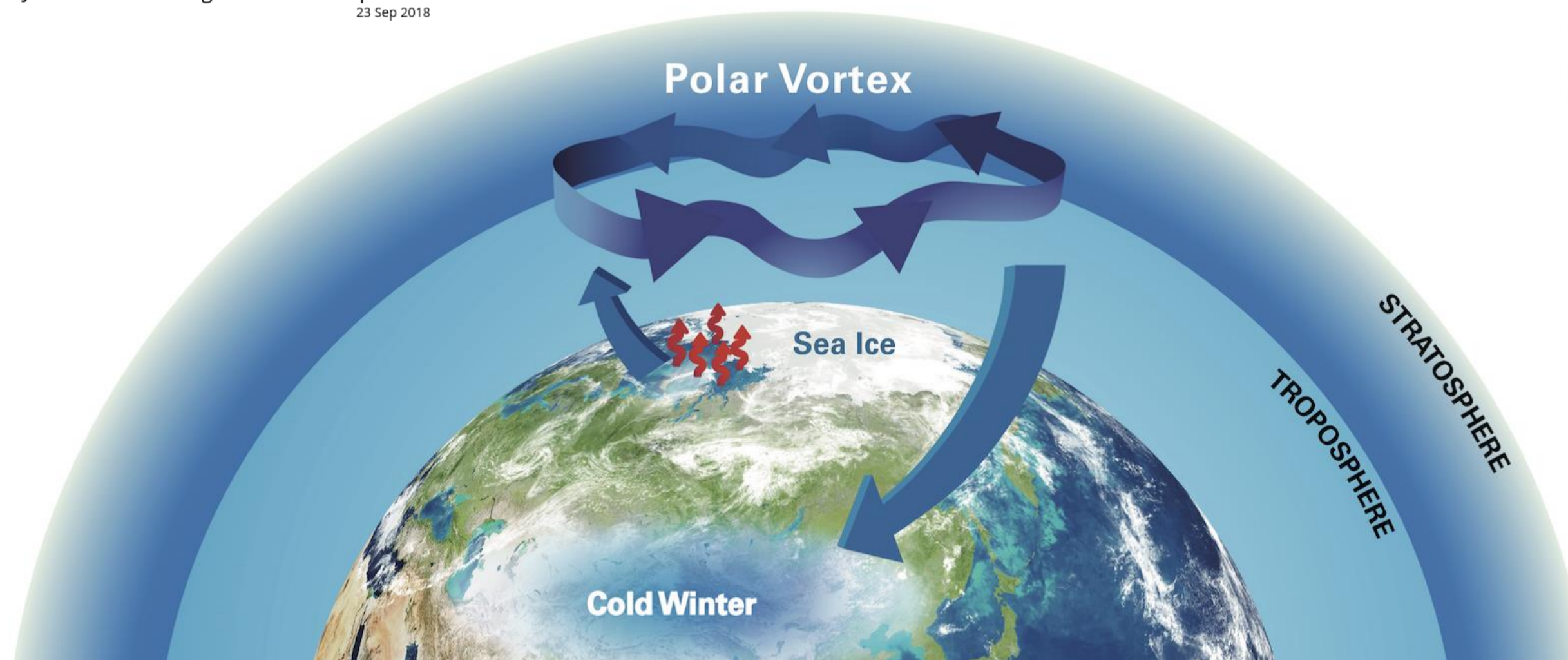
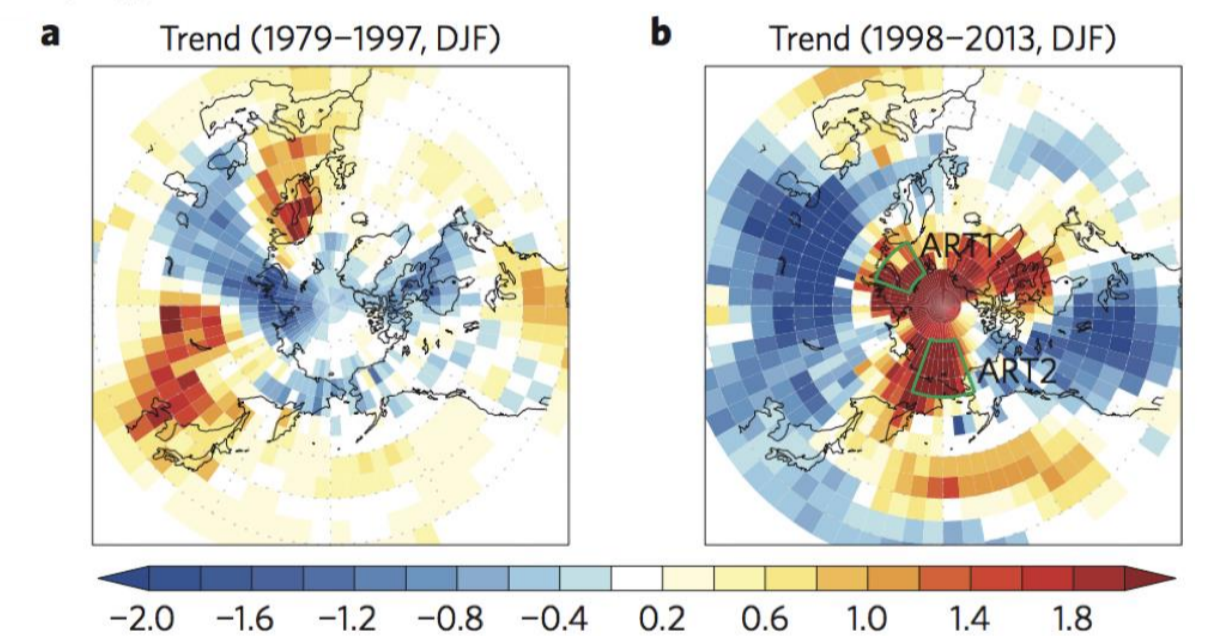
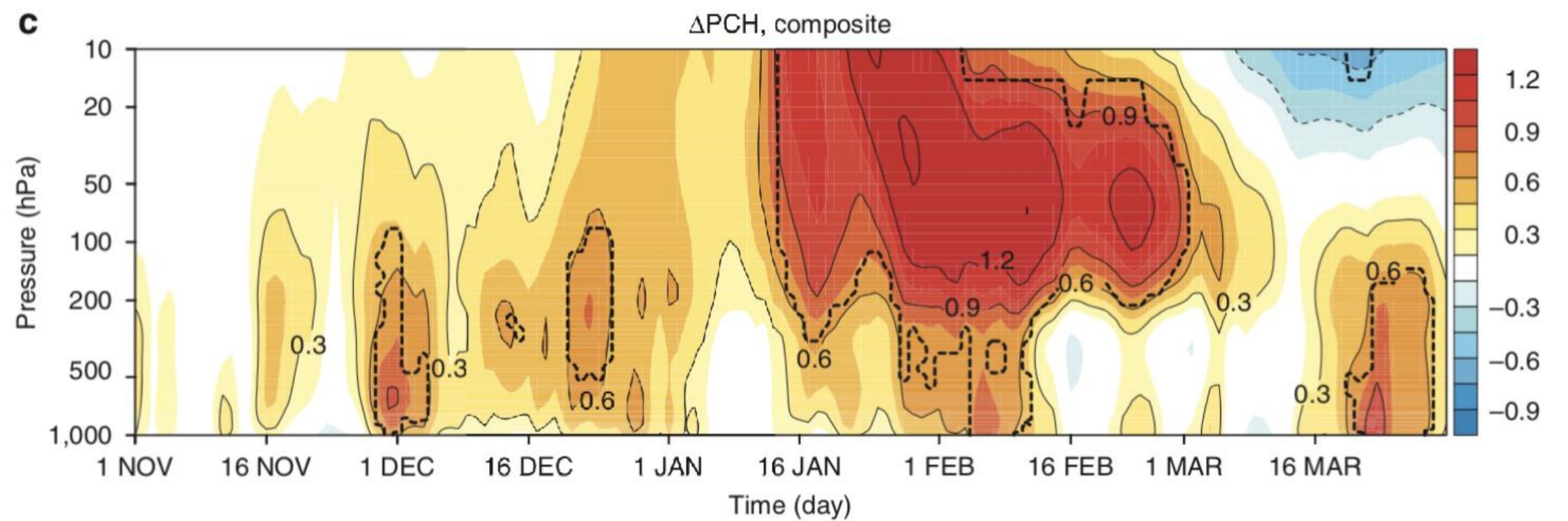
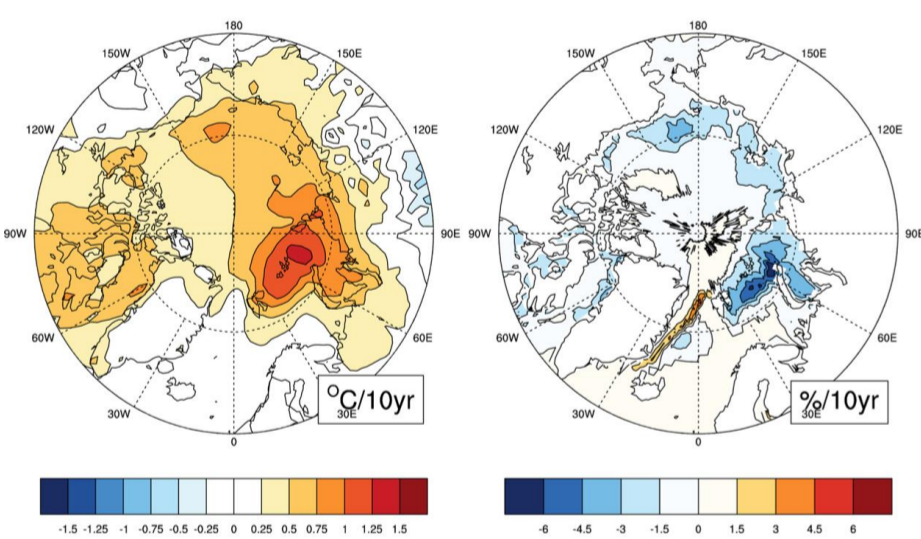
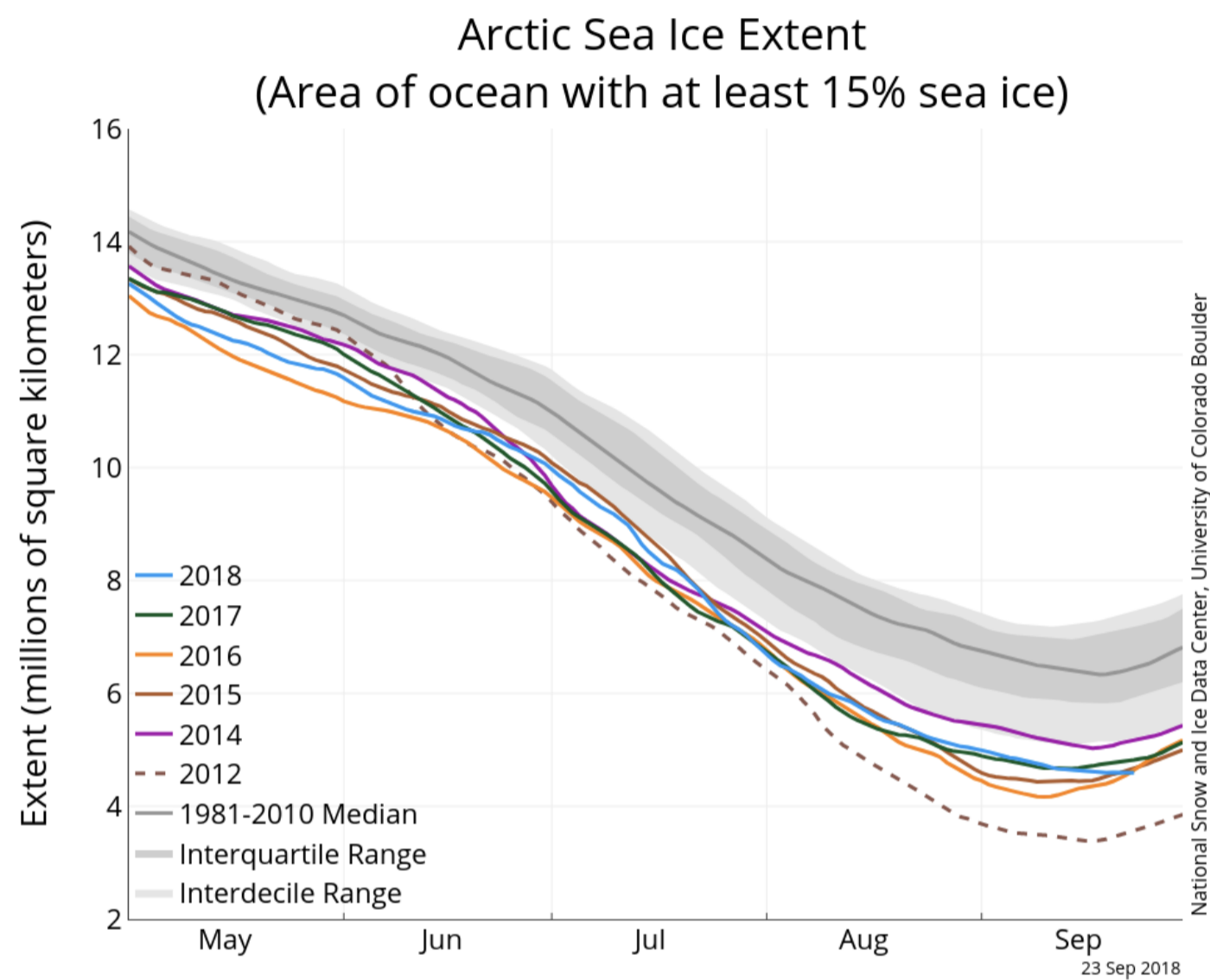
- 준계절-계절 시간 규모는 대기 초기 조건 및 경계조건이 영향을 미치는 구간 모두를 포함하여 복잡한 예측 구간으로 주요한 예측 구간임에도 불구하고 정확한 예측 및 진단 평가 연구가 적은 편임.
- 하지만, 최근 전 세계적으로 이상기상 및 기후 현상으로 인한 피해 경감을 위해 준계절-계절 예측의 연구 및 기술 향상의 필요성을 인식하고 이음새 없는 예보 체계로 전환이 진행되고 있음.

1. 서론 | 연구 배경

북극-중위도 원격상관성

겨울철 북극 지표온도/해빙의 변화 양상

겨울철 북극-중위도 원격상관성



- 여름철 보다 겨울철 북극의 경우 지표 온도의 변화 및 해빙의 변화 폭이 상대적으로 더 크게 나타나며, 이러한 겨울철 북극 기후 시스템의 변화는 원격 상관을 기반으로 중위도 기후 변화와 밀접한 연관이 있음을 시사함.
- 대표적으로, 북극 해빙의 변화에 따른 북극해 지표 온도의 변화와 중위도 대륙 지역의 지표 온도의 변화의 연관성을 기반으로 한 'Warm Arctic Cold Eurasia (WACE)' 패턴을 통해 '북극-중위도 원격상관' 메커니즘을 이해할 수 있음.

1. 서론 | 연구 배경

북극-중위도 원격상관성 및 예측성 선행 연구

북극-중위도 원격상관 기반의 겨울철 계절 예측 연구 (Jung et al., 2021)

Environmental Research Letters

LETTER

Impacts of the Arctic-midlatitude teleconnection on wintertime seasonal climate forecasts

Eulhyun Jung¹, Jee-Hoon Jeong², Sang-Ho Woo³, Baek-Min Kim¹, Jin-Ho Yoon⁴ and Gyo-Ho Lim¹

Abstract
The impact of the Arctic on midlatitude weather and climate is still in scientific debate. The observation-based analysis, however, shows frequent concurrences of Arctic warming with extreme cold in the midlatitudes, and vice versa. This teleconnection could aid in seasonal climate forecasts for the midlatitudes. This study assessed the forecast skill of Arctic temperature and the Arctic-midlatitude teleconnection patterns in operational seasonal climate forecast models based on their wintertime forecast archives. Further, the impact of the Arctic-midlatitude teleconnection on the midlatitude forecast skill is evaluated. The results revealed that most climate forecast models have the capability to simulate the overall pattern of Arctic-midlatitude teleconnection, eastern Eurasian and North American regions. However, this is little skill in midlatitude likely due to poor capabilities in forecasting Arctic analysis (assuming a perfect forecast of Arctic temperature) showed that improvements could be achieved, and further improvements are possible of the Arctic and its teleconnection patterns. These results highlighted that predictions of the Arctic conditions in seasonal forecasts that are not in region but extend to midlatitude weather and climate as well.

북극 해빙 및 눈덮임 변화에 따른 겨울철 원격상관 연구 (Handorf et al., 2015)

Geophysical Research Letters

RESEARCH LETTER

Impacts of Arctic sea ice and continental snow cover changes on atmospheric winter teleconnections

Dörthe Handorf¹, Ralf Jaiser¹, Klaus Dethloff¹, Annette Rinke¹, and Judah Cohen²

Abstract
Extreme winters in Northern Hemisphere midlatitudes in recent years have been connected to declining Arctic sea ice and continental snow cover changes in autumn following modified planetary waves in the coupled troposphere-stratosphere system. Through analyses of reanalysis data and model simulations with a state-of-the-art atmospheric general circulation model, we investigate the mechanisms between Arctic Ocean sea ice and Northern Hemisphere land snow cover changes in autumn and atmospheric teleconnections in the following winter. The observed negative Arctic Oscillation in response to sea ice cover changes is too weakly reproduced by the model. The planetary wave train structures over the Pacific and North America regions are well simulated. The strengthening and westward shift of the Siberian high-pressure system in response to sea ice and snow cover changes is underestimated compared to ERA-Interim data due to deficits in the simulated changes in planetary wave propagation characteristics.

1. Introduction

The Arctic is on the track to a new climate regime dominated by thinner first year ice (Kwok and Rothrock, 2009). The decline in Arctic summer sea ice concentration is connected with atmospheric circulation responses in the following winter months (Cohen et al., 2014; Liu et al., 2012; Mori et al., 2014; Overland and Wang, 2010; Overland et al., 2011; Vihma, 2014) and linked to anomalous cold winters over Eurasia (Honda et al., 2009; Cohen et al., 2014) and other regions of the Northern Hemisphere (Cohen et al., 2014; Francis et al., 2009). Sea ice decline leads to an enhanced absorption of solar radiation in the mixed layer of the Arctic Ocean in autumn intensifies the vertical fluxes of heat and moisture into the atmosphere. This can be seen in model results and reanalysis data (e.g., Rinke et al., 2013; Screen and Simmonds, 2010; Kim et al., 2014). As shown by Sato et al. (2014), horizontal advection of heat and moisture can reduce the strength of vertical latent and sensible heat fluxes. Since there are no in situ measurements of vertical latent and sensible heat fluxes available, reliable trends in these fluxes following sea ice decline cannot be estimated as discussed by Bovett et al. (2013). Through reduced vertical stability, baroclinic systems grow in autumn and exert a strong impact on the intensification of planetary waves in the coupled troposphere-stratosphere system in the following winter (Jaiser et al., 2012). Elissen-Palm fluxes (Jaiser et al., 2012, 2013; Trenberth, 1986) due to planetary waves are enhanced as a result of the stronger diabatic heat source associated with the larger open ocean areas where Arctic sea ice is low. The enhanced baroclinic systems and modified cloud development process impact the hydrological cycle and snowfall over the continental areas (Purk et al., 2013; Ghatak et al., 2010). Therefore, in addition to sea ice changes, associated snow cover changes affect the winter large-scale atmospheric circulation (Cohen et al., 2013). Interactions between baroclinic processes and large-scale planetary wave changes trigger a negative surface Arctic Oscillation (AO) signal that extends up to the stratosphere in winter, which is connected to reduced sea ice cover in late summer (Kim et al., 2014; Jaiser et al., 2013). Another process impacting the winter AO signal is related to Siberian snow cover anomalies in October. Though the satellite data (Robertson et al., 1993) exhibit a positive trend in October snow cover, Brown and Dierken (2013) found a negative trend using reanalysis data, in situ snow depth observations, and passive microwave data. Despite this observational uncertainty in the trend of October snow extent, positive anomalies of Siberian snow cover in October enhance planetary wave activity resulting in a negative winter AO signal (Cohen et al., 2007, 2012; Allen and Zender, 2011). The sea ice-related and snow cover-related mechanisms are connected through changed moisture budgets following the Arctic sea ice decline (Cohen et al., 2012). Low sea ice and extensive snow cover, by influencing the characteristics of baroclinic cyclones and

북극 해빙 변화에 따른 성층권 극소용돌이 변화 연구 (Kim et al., 2014)

nature COMMUNICATIONS

ARTICLE

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Weakening of the stratospheric polar vortex by Arctic sea-ice loss

Baek-Min Kim¹, Seok-Woo Son², Seung-Ki Min³, Jee-Hoon Jeong⁴, Seung-Joong Kim¹, Xiangdong Zhang⁵, Taehyoun Shim⁶ & Jin-Ho Yoon⁶

Abstract
Successful cold winters of severely low temperatures in recent years have had critical social and economic impacts on the mid-latitude continents in the Northern Hemisphere. Although these cold winters are thought to be partly driven by dramatic losses of Arctic sea-ice, the mechanism that links sea-ice loss to cold winters remains a subject of debate. Here, by conducting observational analyses and model experiments, we show how Arctic sea-ice loss in extra-polar regions are dynamically connected. We find that decreased sea-ice cover during early winter, especially over the Barents-Kara seas, enhances the poleward propagation of planetary waves with wavenumbers of 1 and 2, subsequently weakens the stratospheric polar vortex in mid-winter (January-February). The weakening of the polar vortex induces a negative phase of Arctic Oscillation at the surface in mid-latitudes.

북극 온도 변화에 따른 중위도 기후 및 날씨 변화 연구 (Vavrus 2018)

Current Climate Change Reports (2018) 4:238–249

ARCTIC CLIMATE CHANGE (MARK SERREZE, SECTION EDITOR)

The Influence of Arctic Amplification on Mid-latitude Weather and Climate

Stephen J. Vavrus¹

Abstract
Purpose of Review The rapidly warming Arctic climate may affect weather in middle latitudes, but controversies remain as to mechanisms and robustness. Here, I synthesize recent advances in this rapidly changing field and summarize recommendations on paths forward.
Recent Findings Initial “black-and-white” debates about whether Arctic amplification (AA) affects mid-latitude circulation have evolved toward a more nuanced perspective awash in gray. Recent research has demonstrated myriad ways in which AA can influence weather remotely and explored whether any Arctic-based signal is significant against the backdrop of natural variability.
Summary The popularity of and controversies surrounding this topic have spurred a multitude of approaches and often-conflicting studies that have widened the envelope of our understanding but hindered a scientific consensus. This messy but necessary exploratory phase of independent investigations is benefiting from recent efforts by the research community to self-organize through workshops, working groups, and coordinated experiments.

Introduction

For such a small region of the planet, the Arctic has recently commanded a disproportionate share of attention. Climatic and environmental changes in recent decades have been especially acute in the Arctic and have thrust the region into the spotlight of global change concerns. It is not difficult to understand why, given the area's dramatic trends in rising temperatures and declining ice and snow cover [1–3]. A logical question is whether such pronounced climate changes can remain isolated in high latitudes or whether they necessitate a remote expression in boreal middle latitudes and perhaps beyond. Concurrent with these polar changes, more frequent and costly extreme weather events have been documented in the USA and globally [4–7]. The emergence of these two trends has motivated questions about their potential relationship, especially how Arctic amplification (AA) of global warming might affect mid-latitude weather and promote extratropical weather extremes.

This possibility is generally rooted in dynamical considerations, such that a rapidly warming Arctic could alter extratropical circulation and thus mid-latitude weather patterns. A commonly hypothesized pathway for such an influence is a weaker and wavier westerly atmospheric flow that fosters prolonged extreme weather episodes [8–11]. The simplicity of this supposition, coupled with clear evidence of both AA and an overall increase in extreme weather events, has sparked considerable interest in the public sphere and debate about its validity in the scientific community [12–15].

Keeping up with the latest discoveries is challenging, due to the topic's popularity and the rapid research progress. Sharply divergent results and conclusions reported in the literature have made this task even more difficult, yet such discrepancies also make attempts at synthesis more important. The abundance of often contrasting studies on potential Arctic mid-latitude linkages has spawned a number of international workshops and working groups to facilitate

준계절 시간 규모 내에서 북극 변화에 따른 중위도 예측성 연구 (Jung et al., 2014)

AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER

Arctic influence on subseasonal midlatitude prediction

Thomas Jung¹, Marta Anna Kaspar¹, Tido Semmler¹, and Soumia Serraf¹

Abstract
Forecast experiments with the European Centre for Medium-Range Weather Forecasts model with and without relaxation of the Arctic troposphere toward reanalysis data are carried out in order to explore the influence that improved Arctic forecasts during wintertime would have on the skill of medium-range and extended-range prediction of 500 hPa geopotential height in the Northern Hemisphere midlatitudes. It turns out that the largest midlatitude improvements are found over eastern Europe, northern Asia, and North America; no discernible impact is found over the North Atlantic and North Pacific, where midlatitude and tropical dynamics appear to be more important. The strength of the linkage between the Arctic and the midlatitudes is found to be flow dependent, with anomalous northerly wind leading to a stronger Arctic influence. Finally, the results are discussed in the context of the possible impact of Arctic sea ice decline on midlatitude weather and climate.

겨울철 북극 지표 온도 변화와 북미/동아시아 지표 온도 변화 연관성 연구 (Kug et al., 2015)

nature geoscience LETTERS

Two distinct influences of Arctic warming on cold winters over North America and East Asia

Jong-Seong Kug¹, Jee-Hoon Jeong^{2*}, Yeon-Soo Jang¹, Baek-Min Kim¹, Chris K. Folland^{3,4,5}, Seung-Ki Min¹ and Seok-Woo Son⁶

Abstract
Arctic warming has sparked a growing interest because of its possible impacts on mid-latitude climate^{1,2}. A number of unusually harsh cold winters have occurred in many parts of East Asia and North America in the past few years^{3,4}, and observational and modelling studies have suggested that atmospheric variability linked to Arctic warming might have played a central role^{5,6,7,8,9}. Here we identify two distinct influences of Arctic warming which may lead to cold winters over East Asia or North America, based on observational analyses and extensive climate model results. We find that severe winters across East Asia are associated with anomalous warmth in the Barents-Kara Sea region, whereas severe winters over North America are related to anomalous warmth in the East Siberian-Chukchi Sea region. Each regional warming over the Arctic Ocean is accompanied by the local development of an anomalous anticyclone and the downstream development of a mid-latitude trough. The resulting northerly flow of cold air provides favourable conditions for severe winters in East Asia or North America. These links between Arctic and mid-latitude weather are also robustly found in idealized climate model experiments and CMIP5 multi-model simulations. We suggest that our results may help improve seasonal prediction of winter weather and extreme events in these regions.

Figure 1 | SAT trends and Arctic temperature (ART) indices. a, b The linear trend in surface air temperature during December-February for the periods 1979/1980–1992/1998 (a) and 1997/1998–2013/2014 (b) from the observed data¹⁰. Green boxes denote the region for ART indices in b. c, Time series of seasonal-mean ART1 and ART2 during December-February for the period 1979/1980–2013/2014. DT denotes the de-trended state.

- 겨울철 북극-중위도 원격상관 메커니즘 이해를 위한 다양한 연구들이 진행되어 왔으며, 비교적 최근 이러한 상호작용 및 물리 기작에 대한 이해를 기반으로 준계절-계절 시간 규모에서 예측 연구가 진행되고 있음.
- 북극-중위도 원격상관성에 대한 명확한 이해는 극지역 뿐만 아니라 중위도 예측성 향상에 큰 도움이 될 수 있으며, 이를 위해 예측성을 정확히 진단하고 평가할 수 있는 도구를 구축하는 것이 필수적임.

1. 서론 | 연구 배경

예측 성능 평가 및 진단을 위한 진단 매트릭스 구축의 필요성

기후 모델의 ENSO 예측성 진단 및 평가를 위한 진단 매트릭스 구축 연구
(Planton et al., 2021, BAMS)

BAMS
Article

Evaluating Climate Models with the CLIVAR 2020 ENSO Metrics Package

Yann Y. Planton, Eric Guilyardi, Andrew T. Wittenberg, Jiwoo Lee, Peter J. Gleckler, Tobias Bayr, Shayne McGregor, Michael J. McPhaden, Scott Power, Romain Roehrig, Jérôme Vialard, and Aurore Voldoire

ABSTRACT: El Niño–Southern Oscillation (ENSO) is the dominant mode of interannual climate variability on the planet, with far-reaching global impacts. It is therefore key to evaluate ENSO simulations in state-of-the-art numerical models used to study past, present, and future climate. Recently, the Pacific Region Panel of the International Climate and Ocean: Variability, Predictability and Change (CLIVAR) Project, as a part of the World Climate Research Programme (WCRP), led a community-wide effort to evaluate the simulation of ENSO variability, teleconnections, and processes in climate models. The new CLIVAR 2020 ENSO metrics package enables model diagnosis, comparison, and evaluation to 1) highlight aspects that need improvement; 2) monitor progress across model generations; 3) help in selecting models that are well suited for particular analyses; 4) reveal links between various model biases, illuminating the impacts of those biases on ENSO and its sensitivity to climate change; and to 5) advance ENSO literacy. By interfacing with existing model evaluation tools, the ENSO metrics package enables rapid analysis of multipetabyte databases of simulations, such as those generated by the Coupled Model Intercomparison Project phases 5 (CMIP5) and 6 (CMIP6). The CMIP6 models are found to significantly outperform those from CMIP5 for 8 out of 24 ENSO-relevant metrics, with most CMIP6 models showing improved tropical Pacific seasonality and ENSO teleconnections. Only one ENSO metric is significantly degraded in CMIP6, namely, the coupling between the ocean surface and subsurface temperature anomalies, while the majority of metrics remain unchanged.

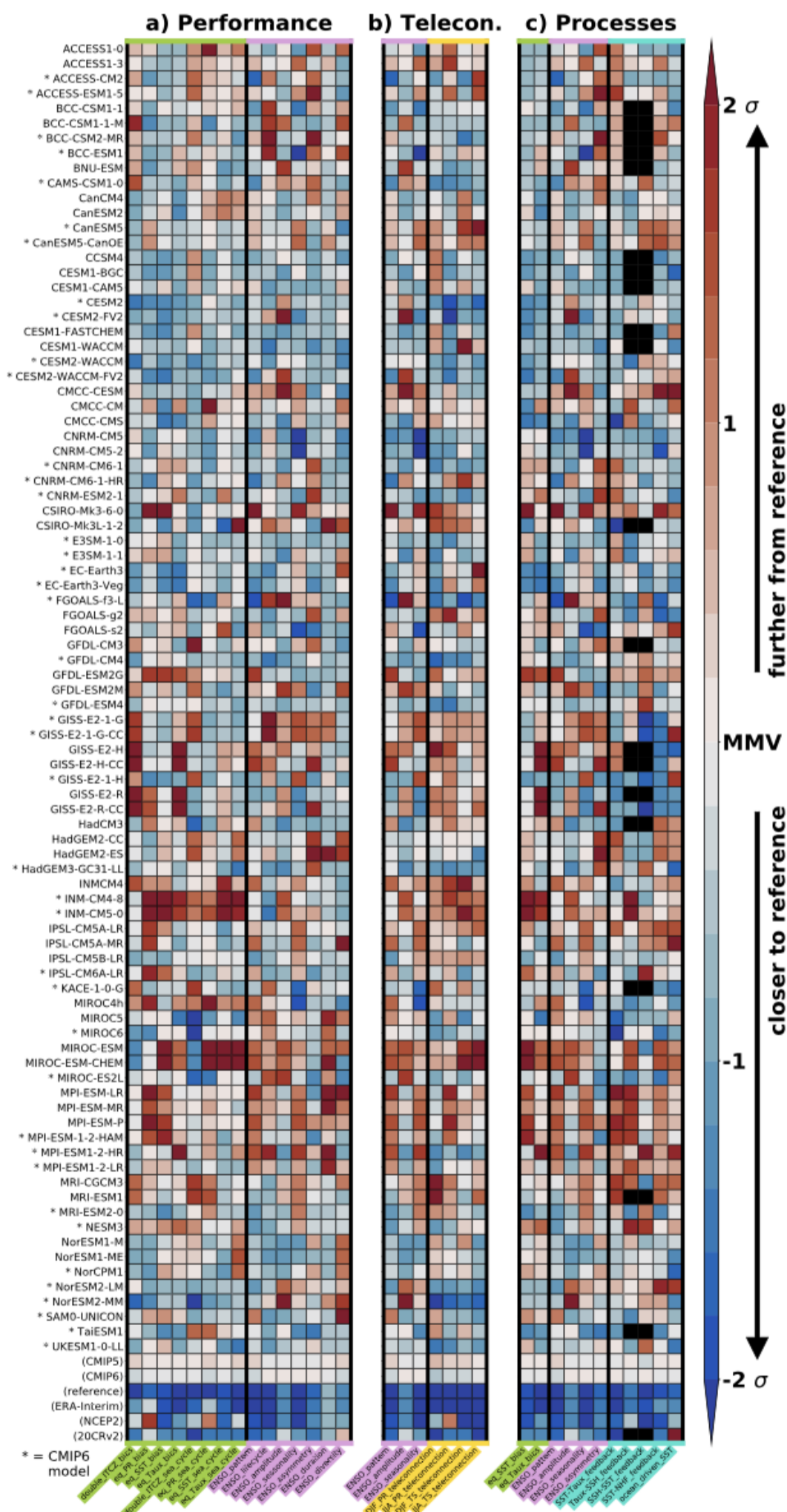
<https://doi.org/10.1175/BAMS-D-19-0337.1>
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CMIP 모델들을 활용한 ENSO의 예측성 진단 매트릭스 구축 및 표출
'Performance, Teleconnection, Process'



- 기존 연구인 Planton et al (2021) 연구에서는 CMIP 모델들을 활용하여 ENSO 예측성을 평가하였으며, 보다 정밀하고 정확한 예측성 평가를 위해 'Performance', 'Teleconnection', 'Process'로 ENSO 발생 및 기작을 세분화하여 예측성을 진단하고 평가하였음.

- 이렇게 분석한 예측 결과를 하나의 진단 매트릭스로 구축하여 ENSO와 연관된 다양한 대기장 패턴 및 원격상관성의 예측 정보를 표출하였음.

1. 서론 | 연구 목표

- 국내 현업기후모델인 GloSea5를 활용하여 겨울철 북극-중위도 원격상관성을 기반으로 모델의 예측성 및 구조적 오차를 평가하여 진단 매트릭스로 표출하고자 함.
- 모델의 예측 성능 평가는 재분석 자료 및 미국 현업에서 활용되는 국립환경예측센터 (NCEP Climate Forecast System)의 예측 자료와 비교 분석을 통해 진행하며, 진단 매트릭스는 ‘북극-중위도 원격 상관성’을 나타내는 변수 및 물리 기작의 예측 성능으로 표출하고자 함.

2. 연구 분석 방법 및 자료 | 분석 자료

▪ 모델 자료 및 재분석 자료 정보

- 현업기후모델(GloSea5)의 예측성 및 구조적 오차 평가를 위해 미국 현업에서 활용되는 **국립환경예측센터(NCEP Climate Forecast System)의 예측 자료와 비교 분석**을 통한 예측성 진단 및 오차 평가
- **늦가을(ON), 초겨울(DJ), 늦겨울(FM)**로 세분화하여 계절내 예측인자의 원격상관 분석

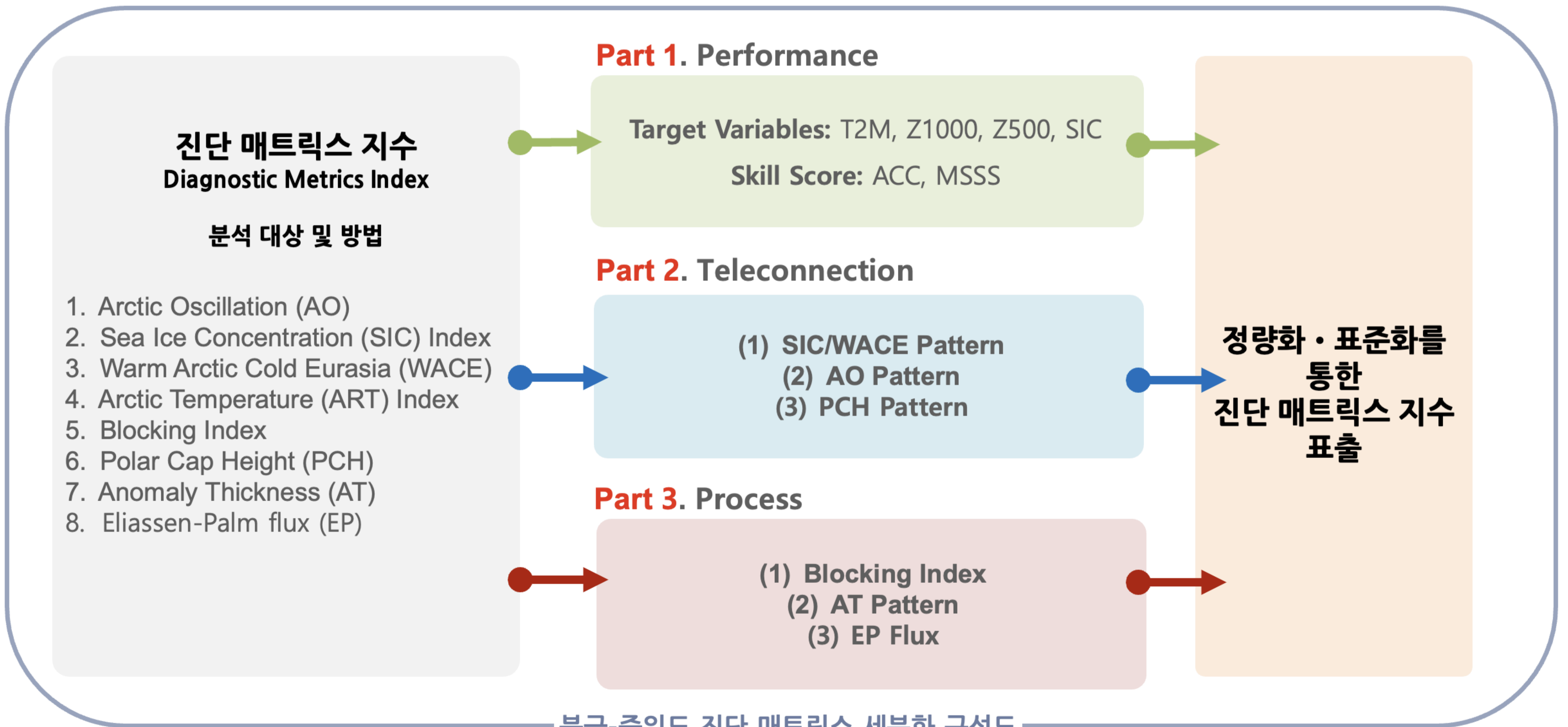


분석 자료 및 모델 정보

2. 연구 분석 방법 및 자료 | 진단 매트릭스 구성

▪ 북극-중위도 진단 매트릭스 구성

- 기존 북극-중위도 진단 매트릭스 지수(Index)를 1. Performance, 2. Teleconnection, 3. Process 로 세분화하여 평가

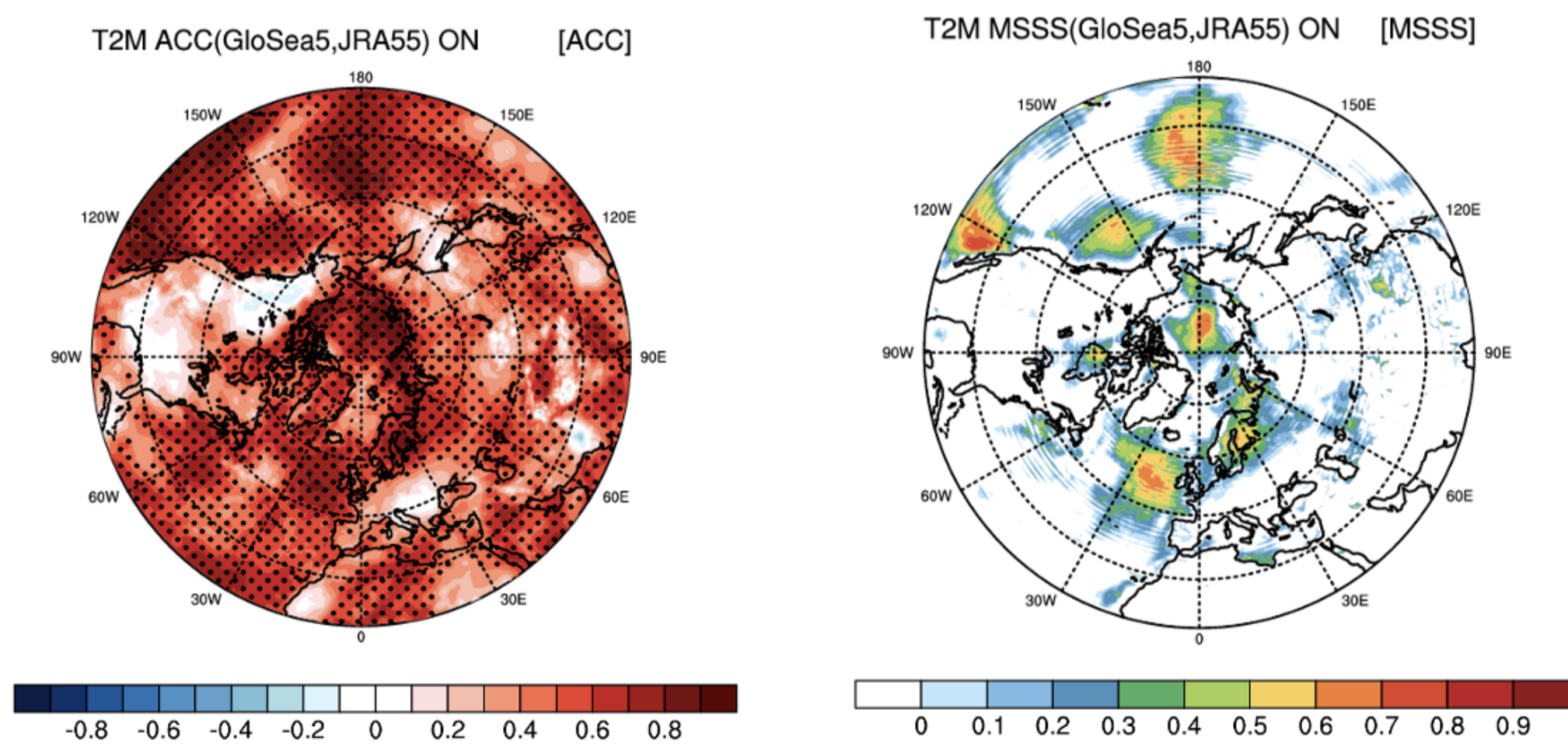


3. 연구 결과 | I. Performance

Part 1. Performance Metric 분석 목적 및 방법 (Choi et al., 2015)

- 북반구 원격 상관 평가에 활용되는 대표적인 예측 인자를 선정하여 기본적인 예측성 평가 및 모델의 구조적 오차 파악을 통해 진단 평가 지수 제공
- 예측성 평가를 위해 이상상관계수(Anomaly Correlation Coefficient; ACC), 평균제곱근예측성(Mean Squared Skill Score; MSSS)을 활용하고, 모델의 구조적 오차 파악을 위해 평균제곱근오차(Root Mean Squared Error; RMSE), 표준 오차(% of Error)를 활용하여 분석

● Performance 분석 예시: ACC, MSSS



$$(1) \text{ACC} = \frac{1}{N-1} \frac{\sum (M - \bar{M})(O - \bar{O})}{\sigma_M \sigma_O}$$

이상상관계수

$$(2) \text{MSSS} = 1 - \frac{MSE}{MSE_c}$$

평균제곱근예측성

$$(3) \text{RMSE} = \left[\sum_{i=1}^N \frac{(M - O)^2}{N} \right]^{1/2}$$

평균제곱근오차

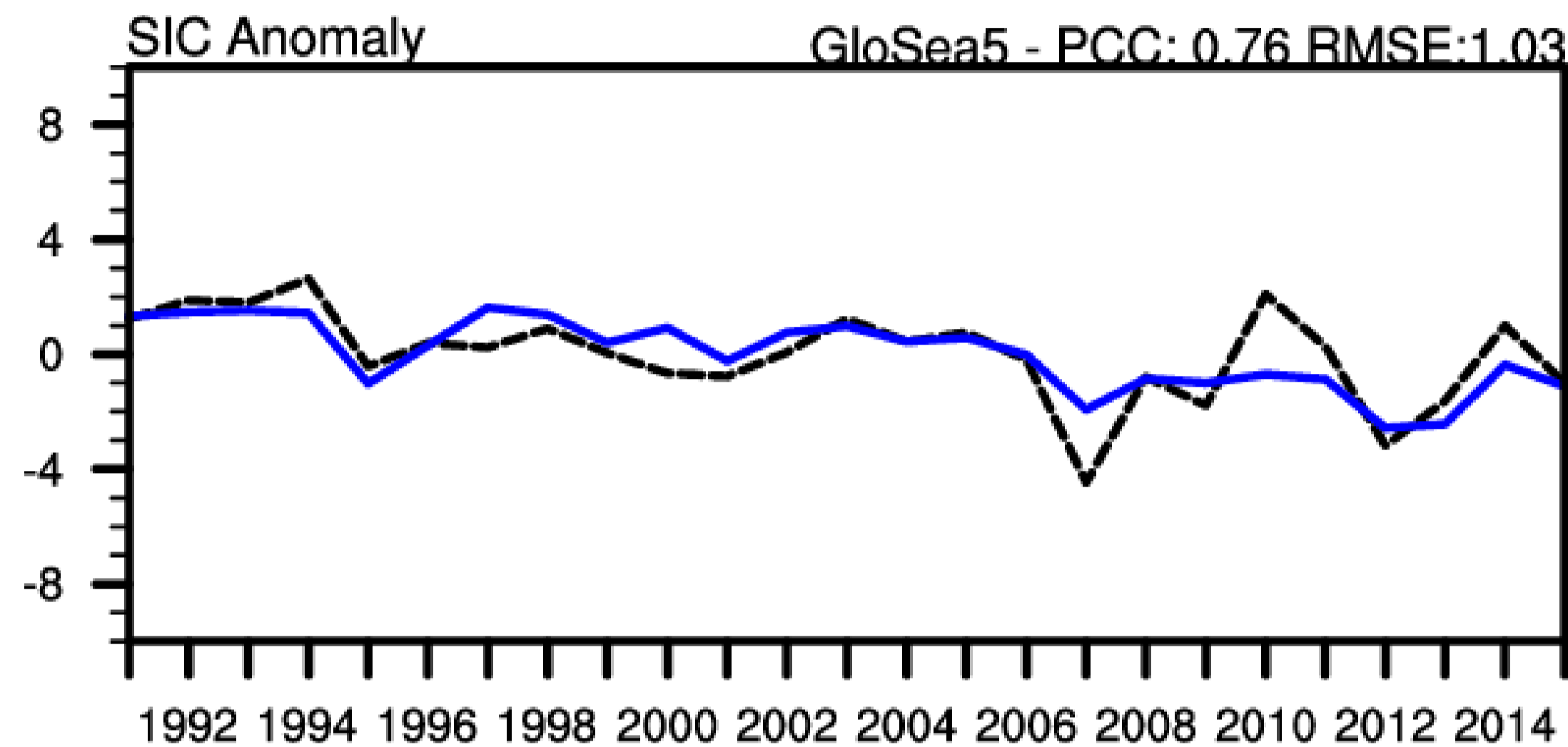
$$(4) \% \text{ of Error} = \text{abs} \left(\frac{M - O}{\text{ref}} \right) * 100$$

표준 오차

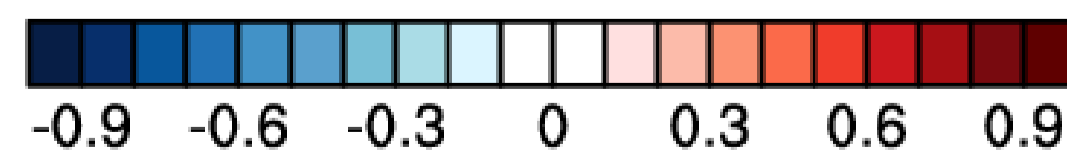
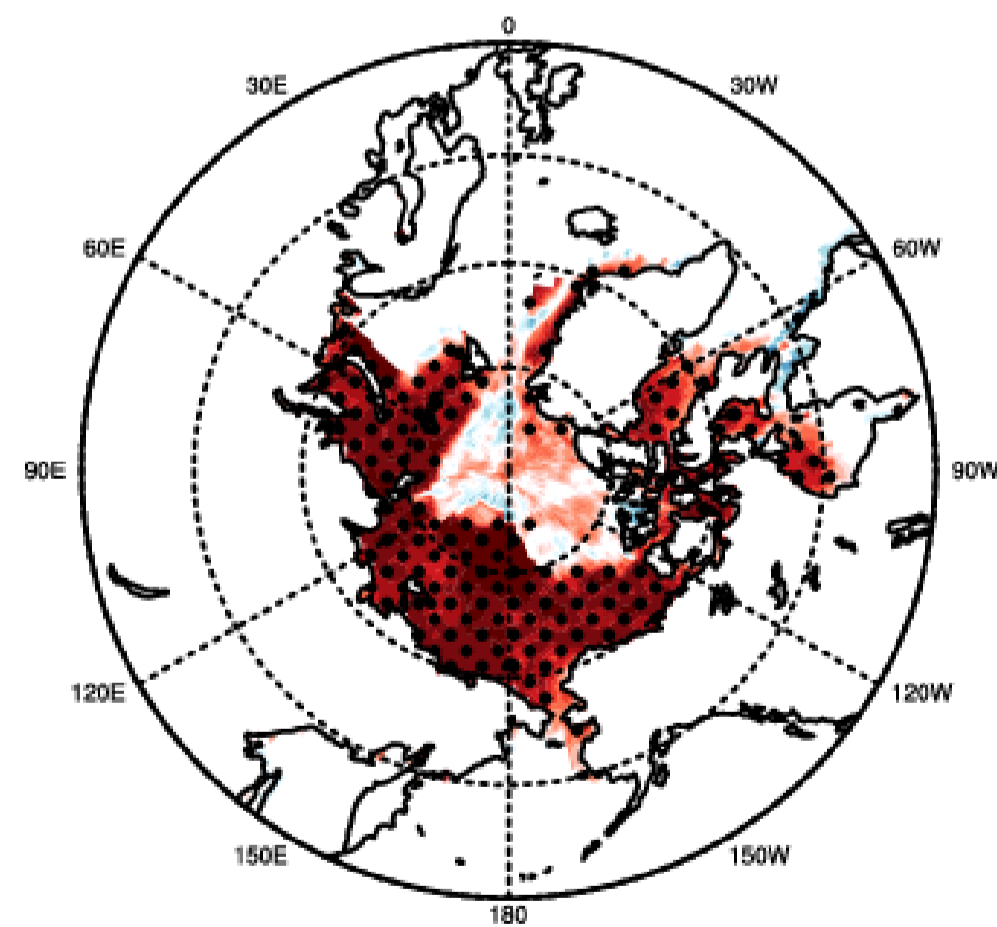
3. 연구 결과 | I. Performance

Part 1. Performance 예측성 분석 결과

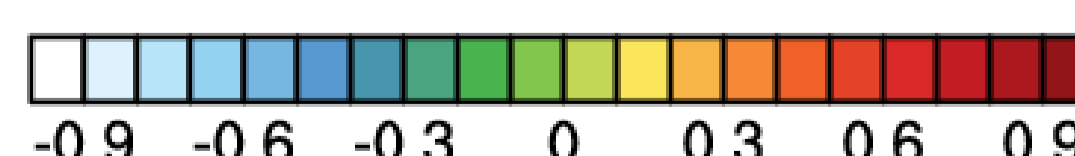
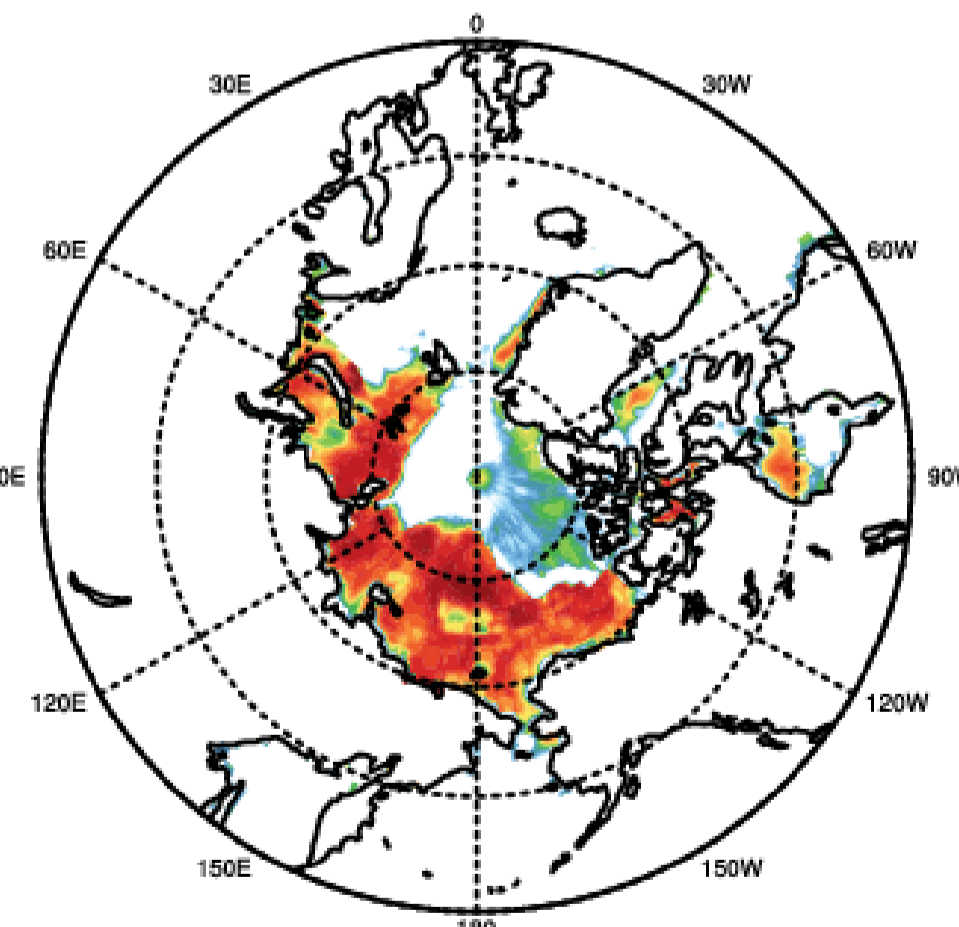
Performance | 해빙 예측성 분석 결과 (GloSea5 only, ON)



SIC ACC(HadISST,GloSea5) ON



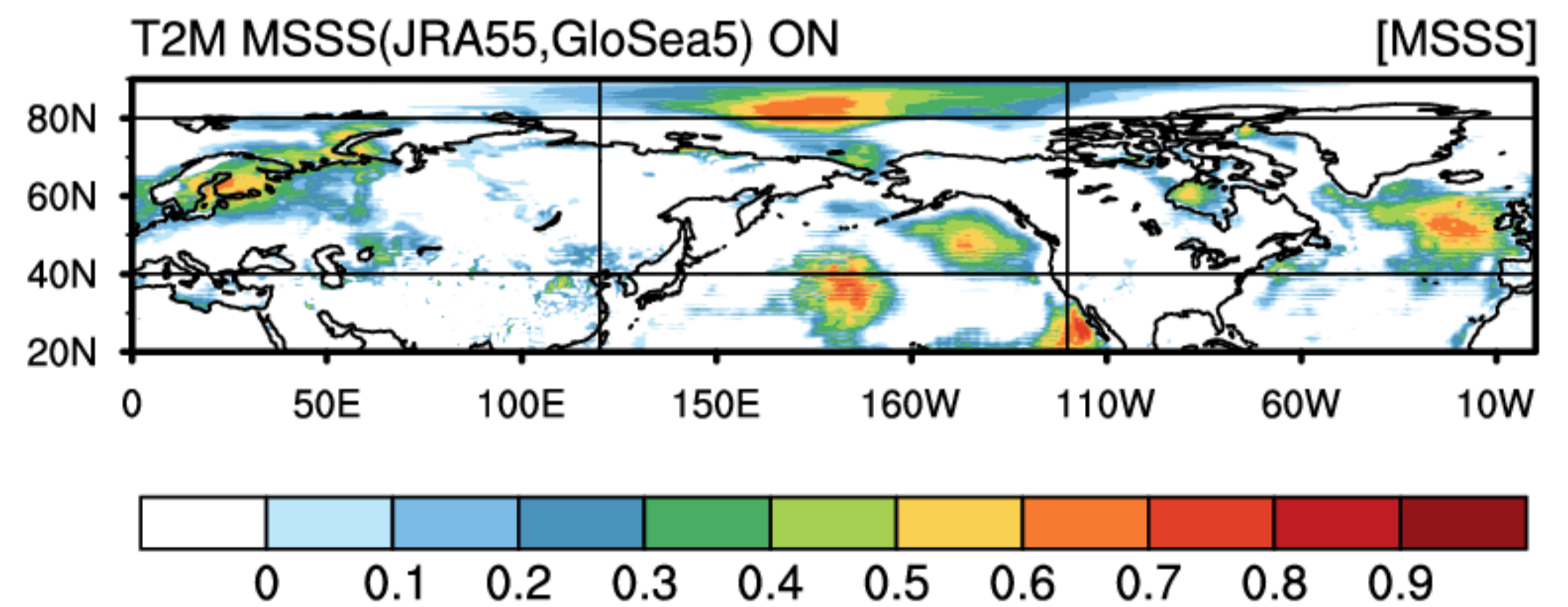
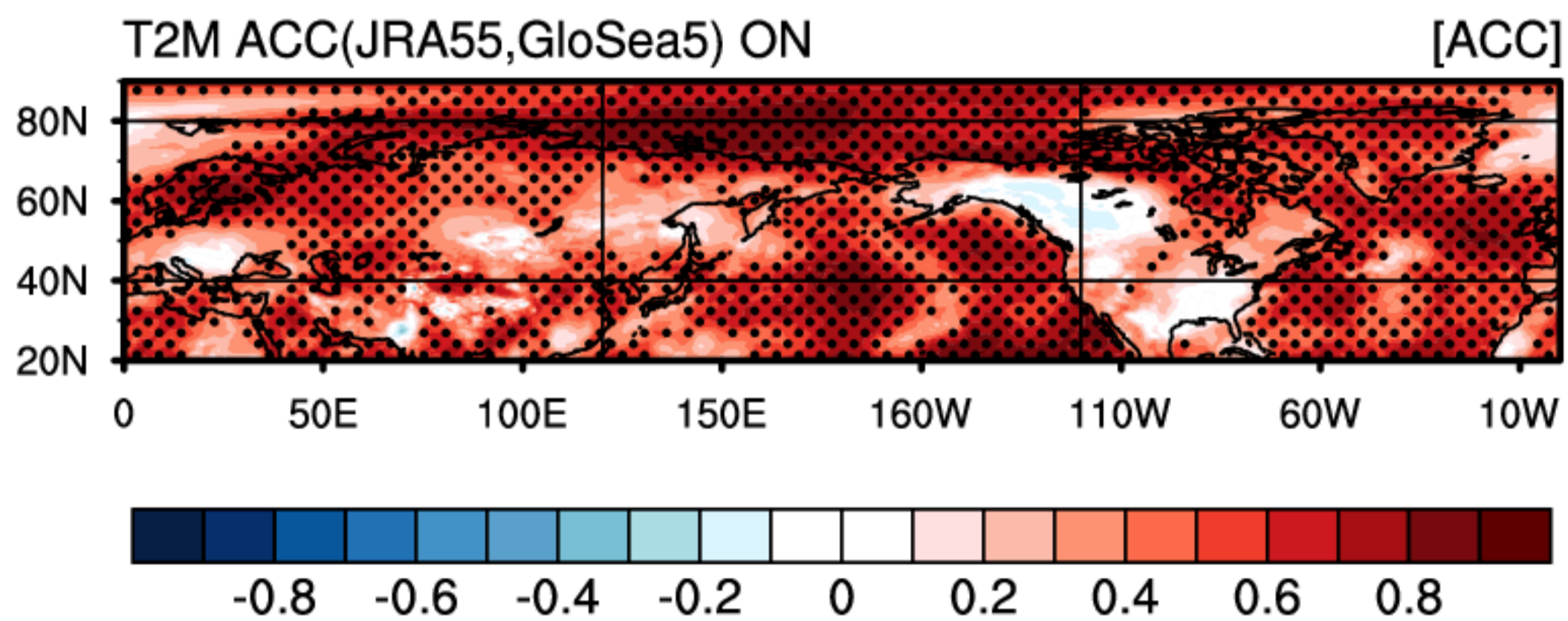
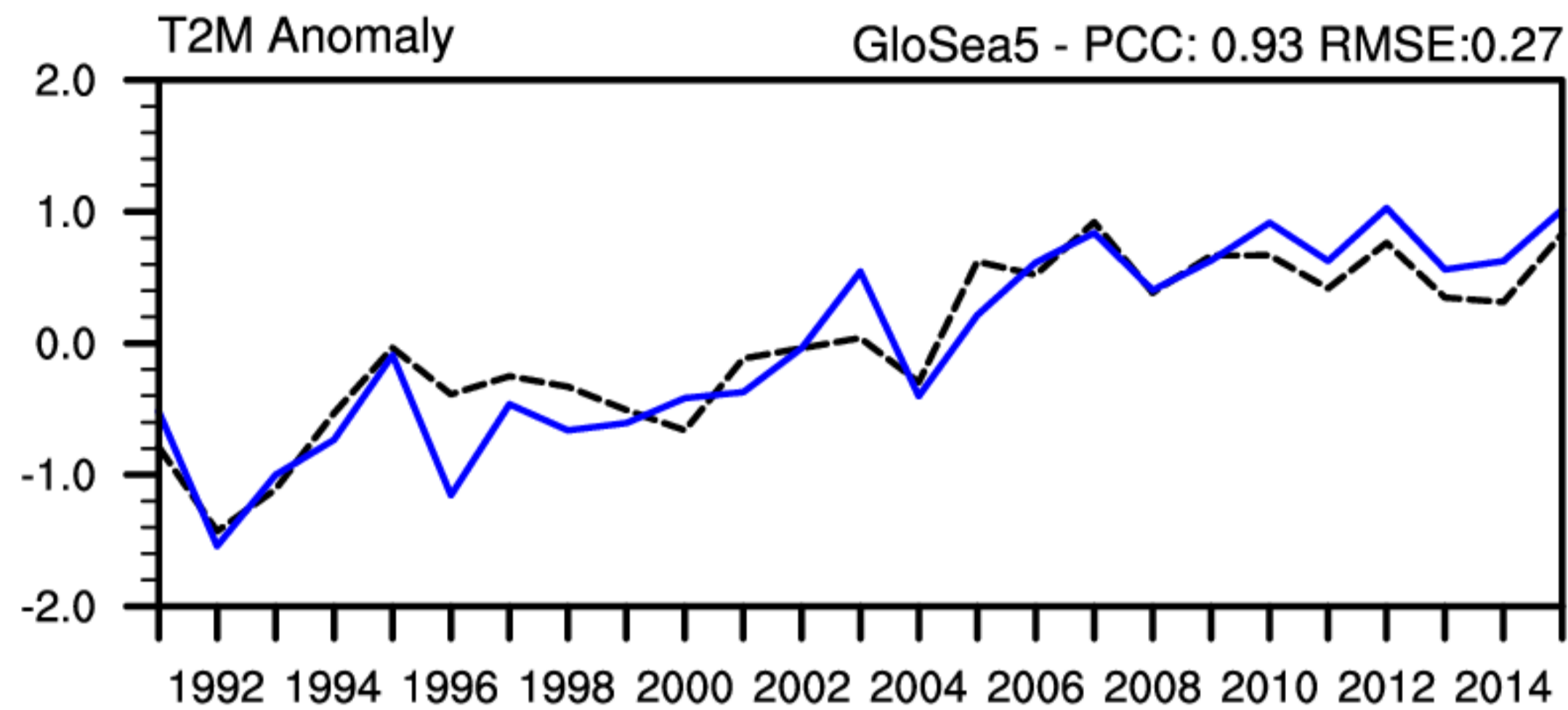
SIC MSSS(HadISST,GloSea5) ON



3. 연구 결과 | I. Performance

Part 1. Performance 예측성 분석 결과

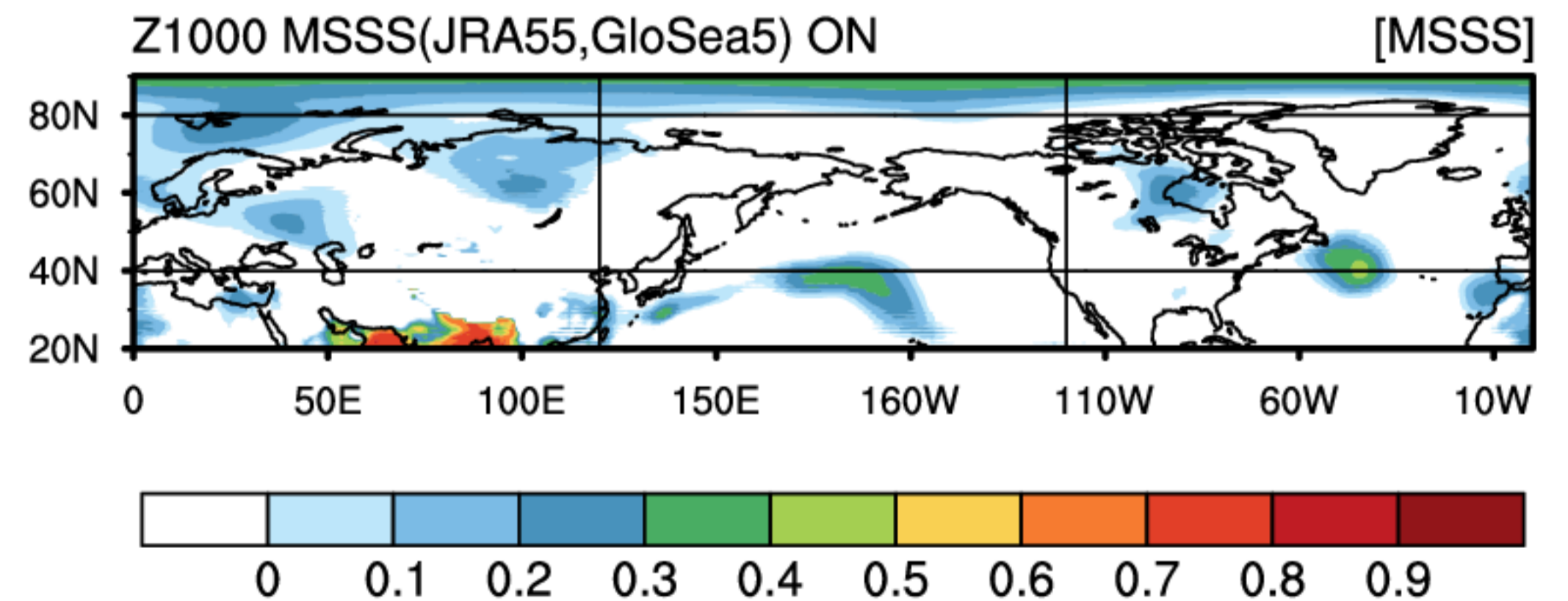
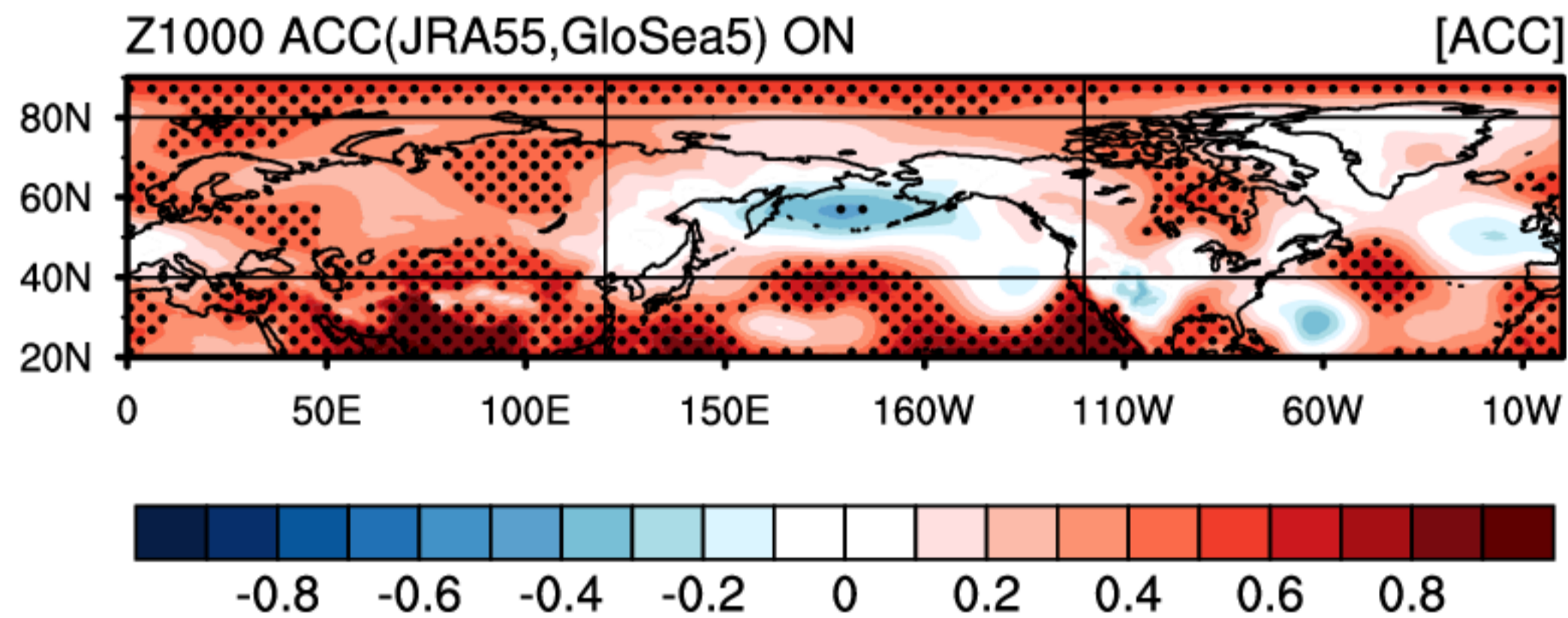
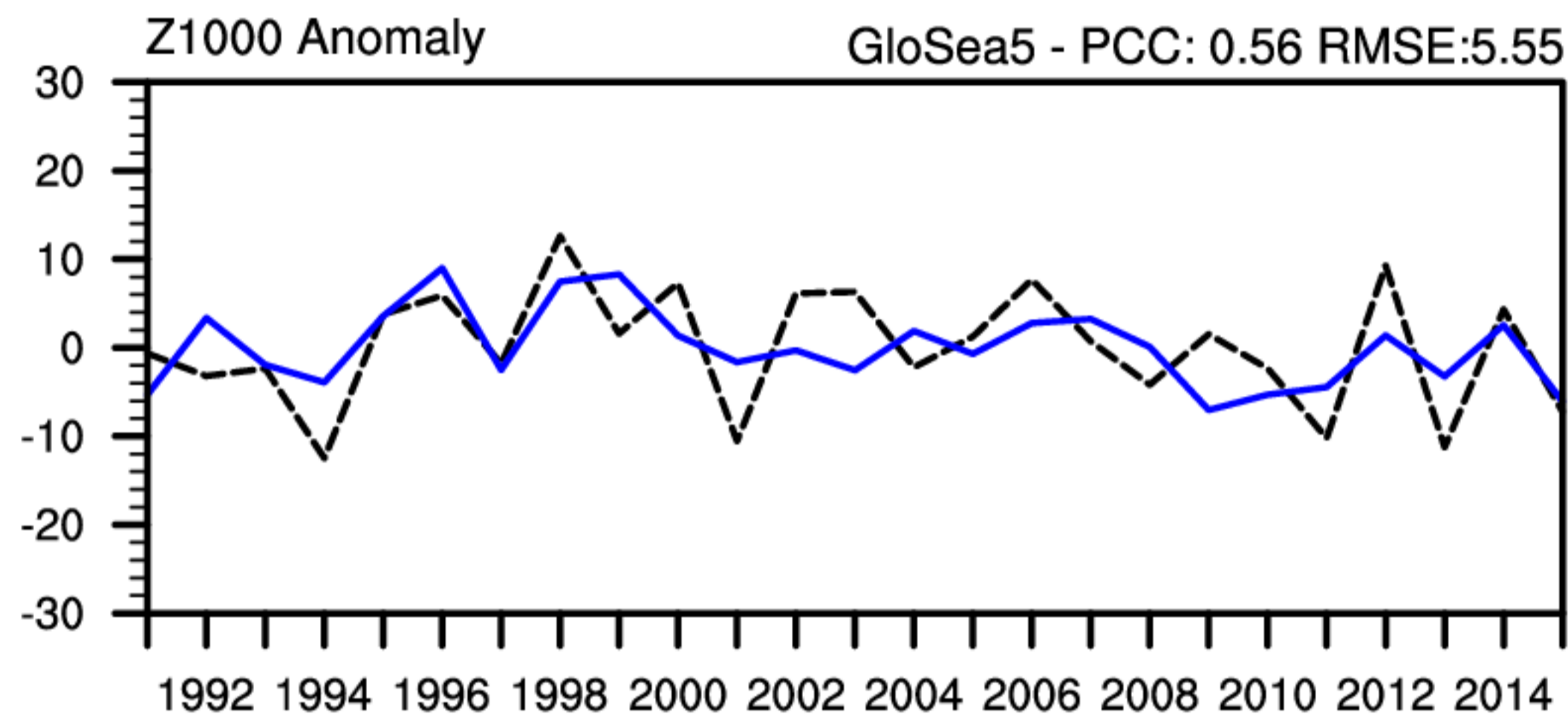
Performance | T2M 예측성 분석 결과 (GloSea5 only, ON)



3. 연구 결과 | I. Performance

Part 1. Performance 예측성 분석 결과

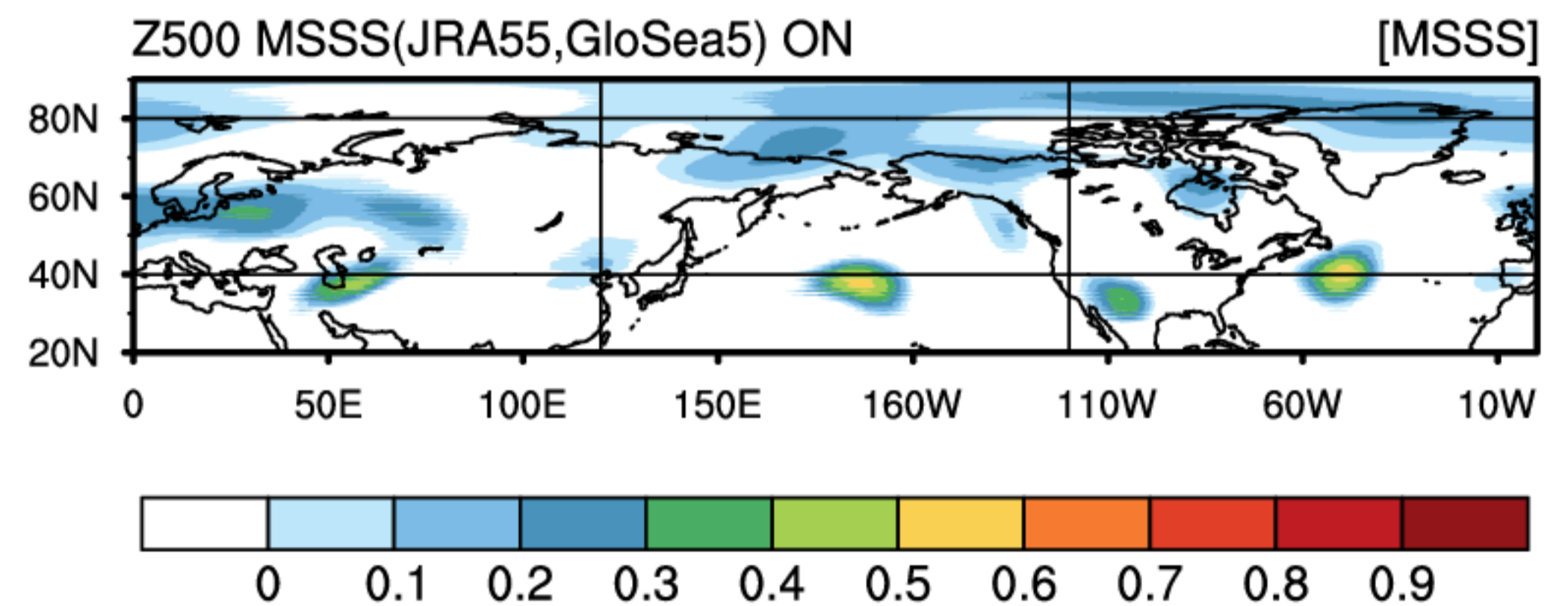
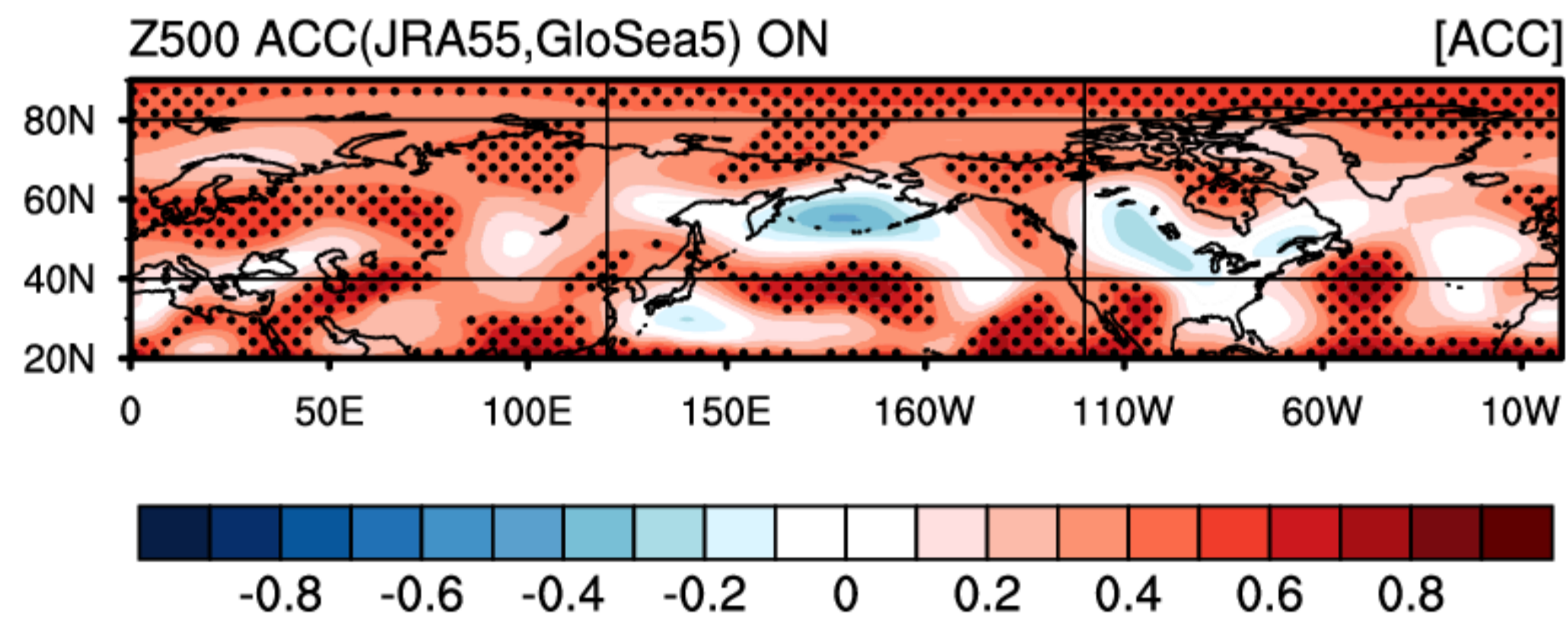
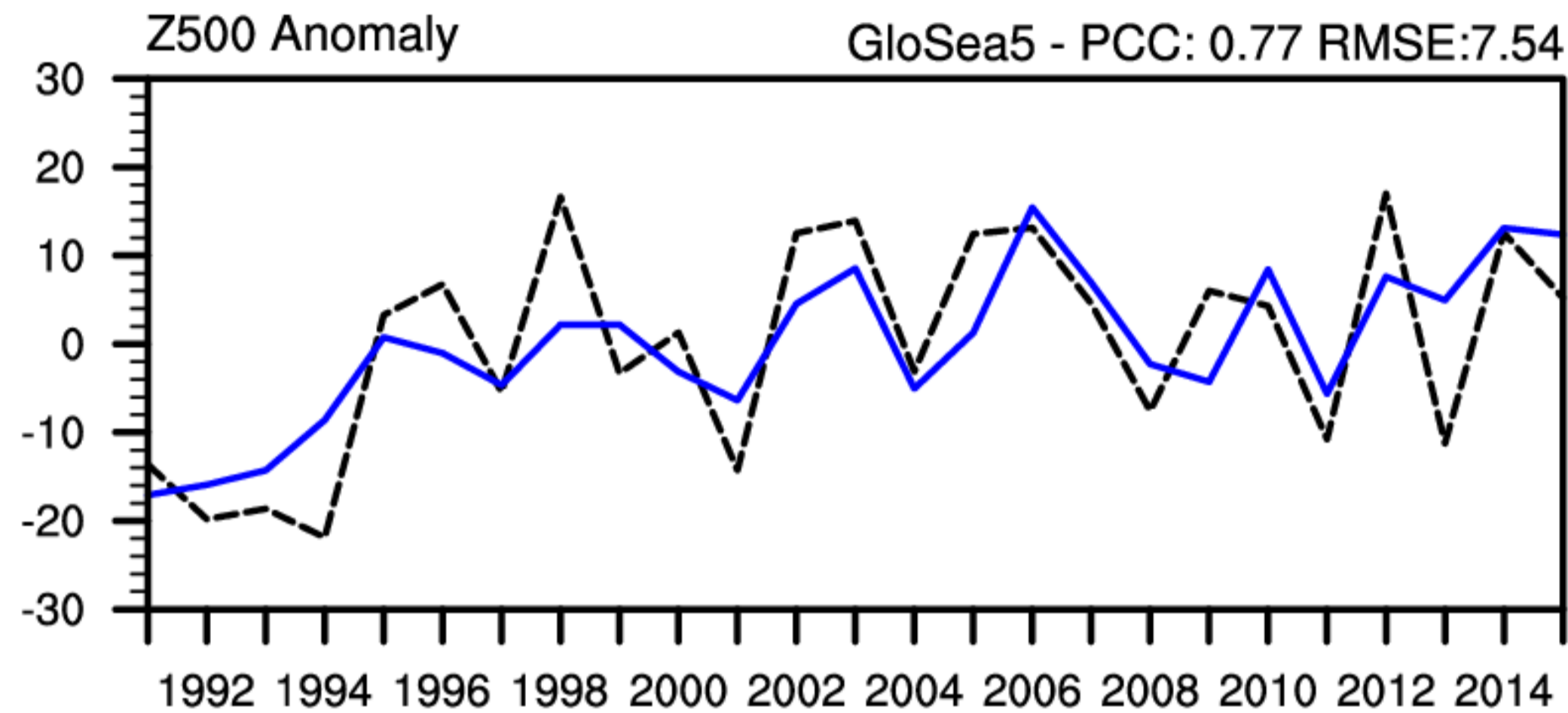
Performance | Z1000 예측성 분석 결과 (GloSea5 only, ON)



3. 연구 결과 | I. Performance

Part 1. Performance 예측성 분석 결과

Performance | Z500 예측성 분석 결과 (GloSea5 only, ON)



3. 연구 결과 | II. Teleconnection

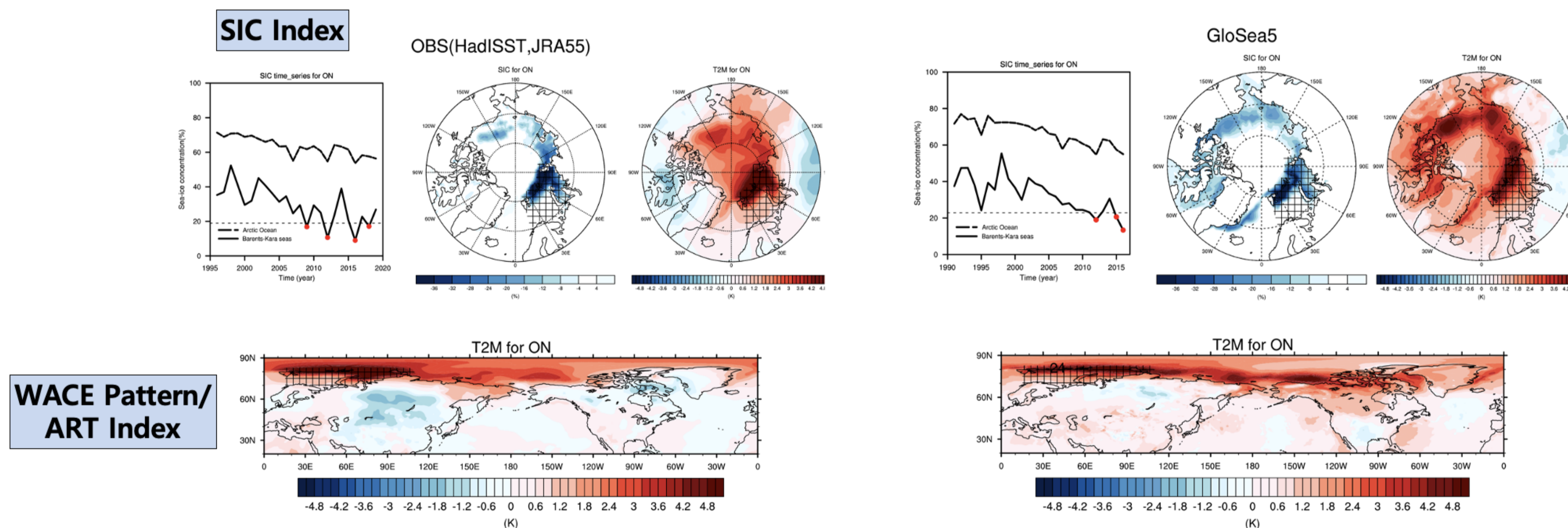
Part 2. Teleconnection: SIC/WACE 예측성 분석 목적 및 방법

(1) Sea Ice Concentration (SIC) Index/Warm Arctic Cold Eurasia (WACE) 분석

(Kim et al., 2014; Kug et al., 2015)

- 해빙 감소 기간에 따른 중위도 기온 원격 상관(북극 고온-중위도 저온) 성능 평가
- 해빙 농도 시계열 (SIC Index)을 바탕으로 해빙 감소 기간 선정 및 해당 기간 온도 합성장의 패턴 상관계수 또는 북극 기온 지수 기법 (Arctic Temperature Index; ART Index) 을 활용하여 지수화

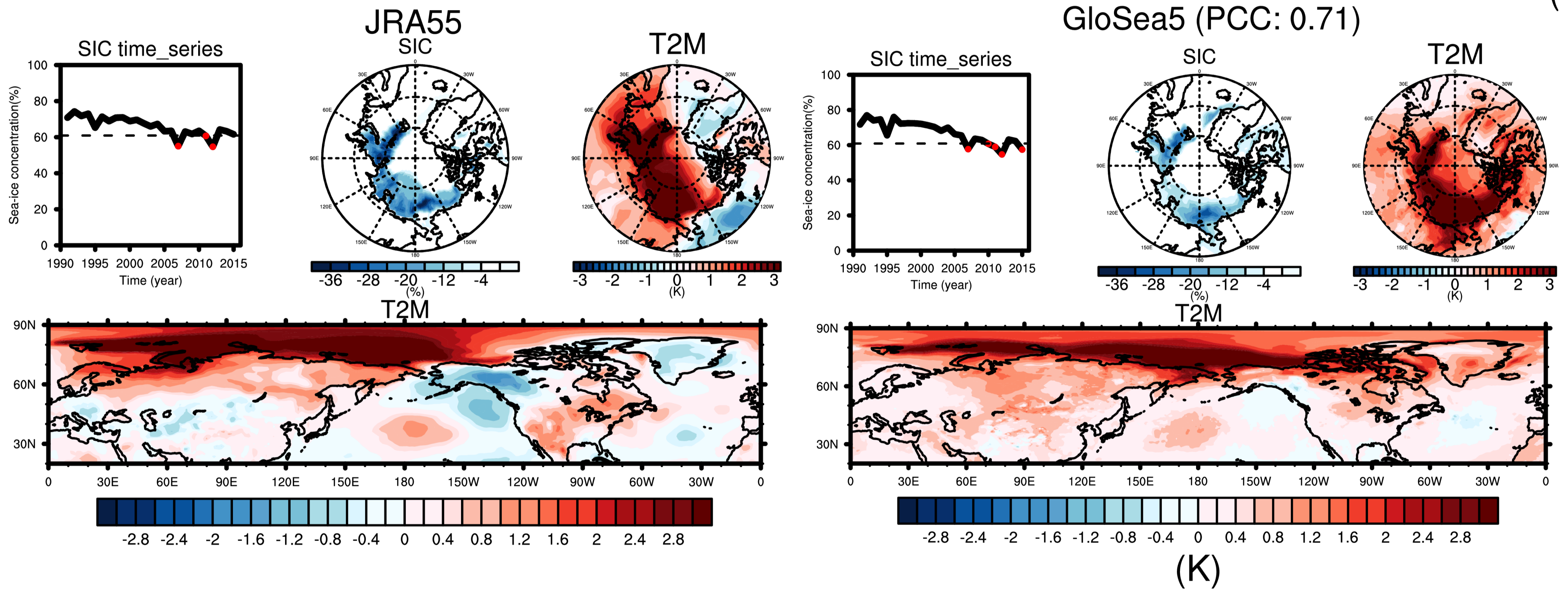
● Teleconnection 분석 예시: SIC Index & WACE/ART Index



3. 연구 결과 | II. Teleconnection

Part 2. Teleconnection: SIC/WACE 예측성 분석 결과

Teleconnection | SIC/WACE 예측성 분석 결과 (GloSea5 only, ON)



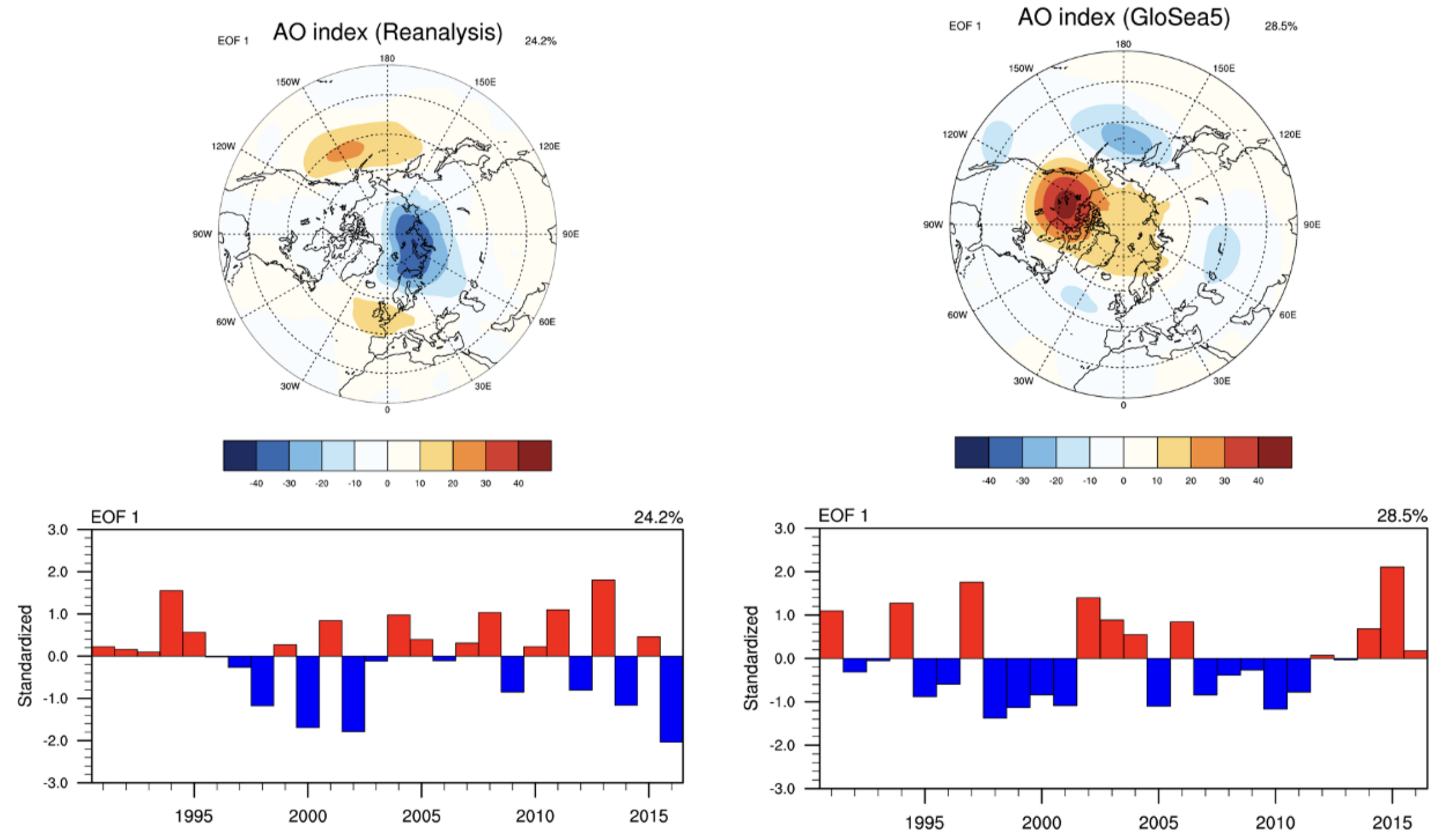
3. 연구 결과 | II. Teleconnection

Part 2. Teleconnection: AO 예측성 분석 목적 및 방법

(2) Arctic Oscillation (AO): 북극진동 분석 (Higgins et al., 2000; Wallace & Hobbs et al., 1998; 2000)

- 중위도 한파와 밀접한 연관이 있는 북극진동 모의 성능 평가
- EOF(Empirical Orthogonal Function) 기법을 이용하여 산출된 북극진동 모드의 패턴 상관계수(Pattern Correlation) 또는 주성분 시계열 상관계수(Principal Component Timeseries Correlation)를 활용하여 지수화

● Teleconnection 분석 예시: AO Pattern/Index



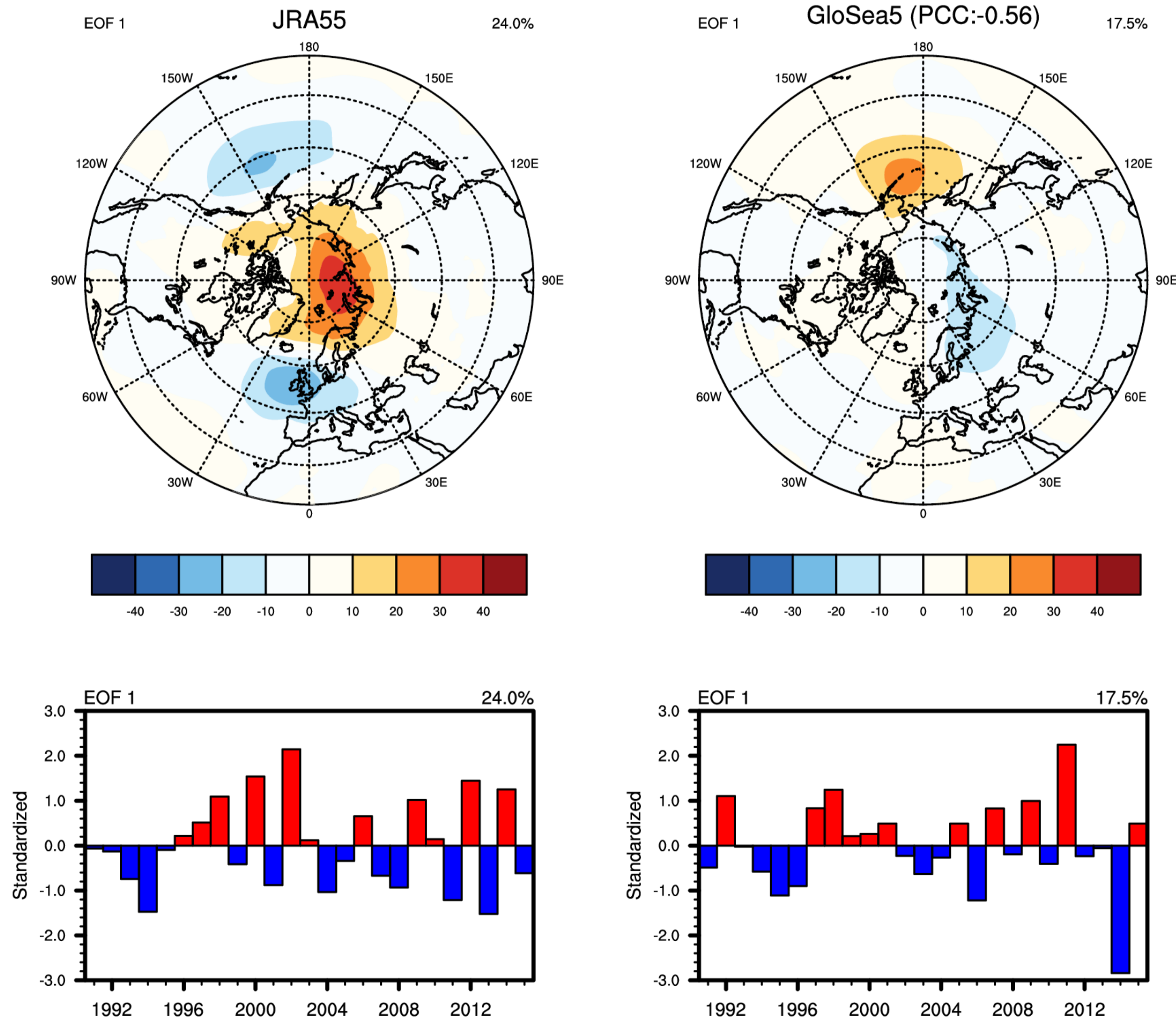
지수화 방안

- 북극진동 모드의 패턴 상관계수
- 주성분시계열 상관계수
- 북극진동지수 활용 (Wallace & Hobbs., 1998; 2020)

3. 연구 결과 | II. Teleconnection

Part 2. Teleconnection: AO 예측성 분석 결과

Teleconnection | AO 예측성 분석 결과 (GloSea5 only, ON)



JRA55 : 2007, 2011, 2012
 GloSea5 : 2007, 2010, 2011, 2012, 2015

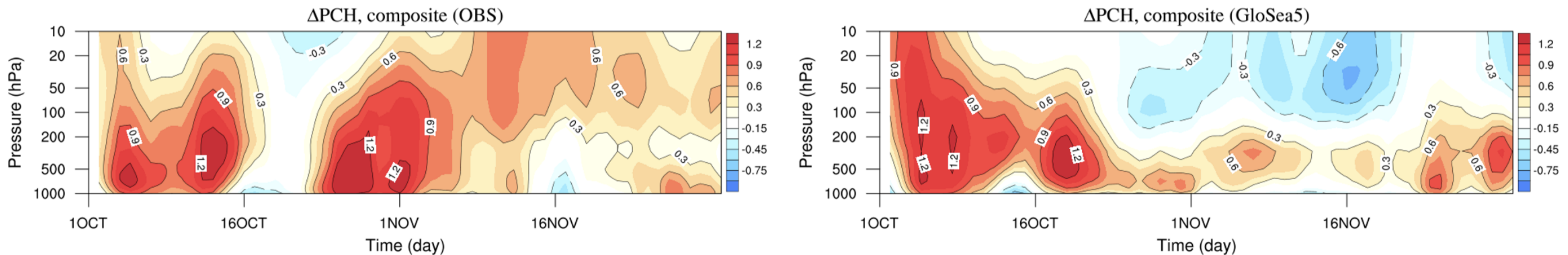
3. 연구 결과 | II. Teleconnection

Part 2. Teleconnection: PCH 예측성 분석 목적 및 방법

(3) Polar Cap Height (PCH) 분석 (Kim et al., 2014)

- 해빙 감소 기간에 따른 극소용돌이 변동성 (대류권-성층권 극소용돌이 변동성의 상호 연관성) 평가
- 해빙 감소 기간에 따른 극지역 지위고도 아노말리 합성장의 패턴 상관계수를 활용하여 지수화

● Teleconnection 분석 예시: PCH



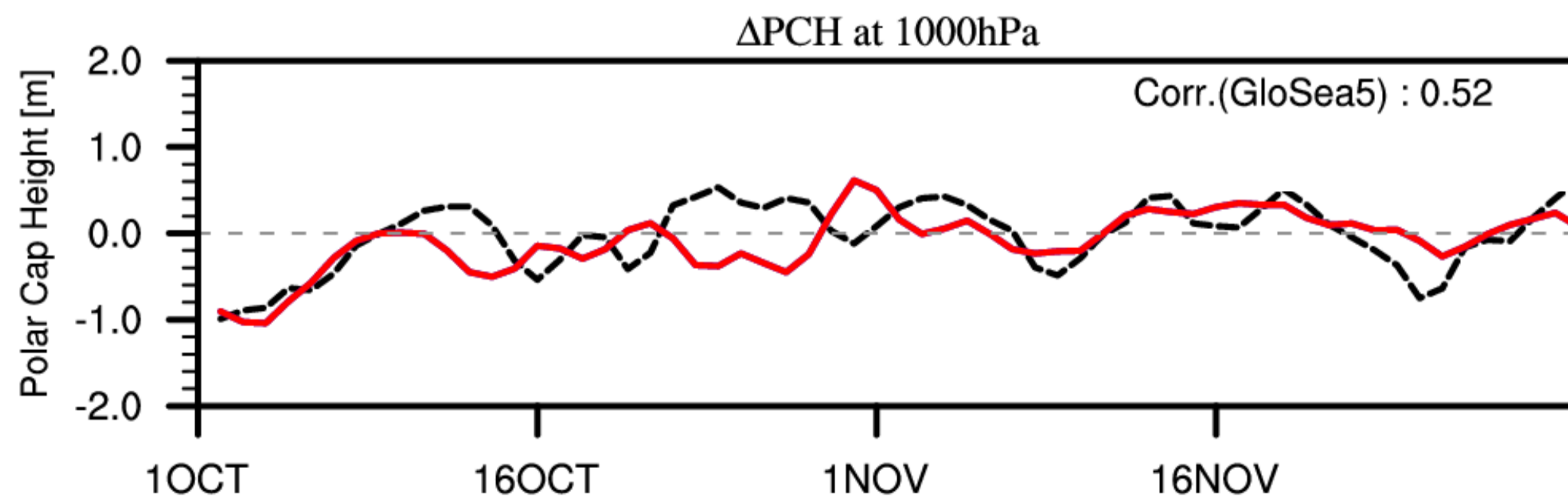
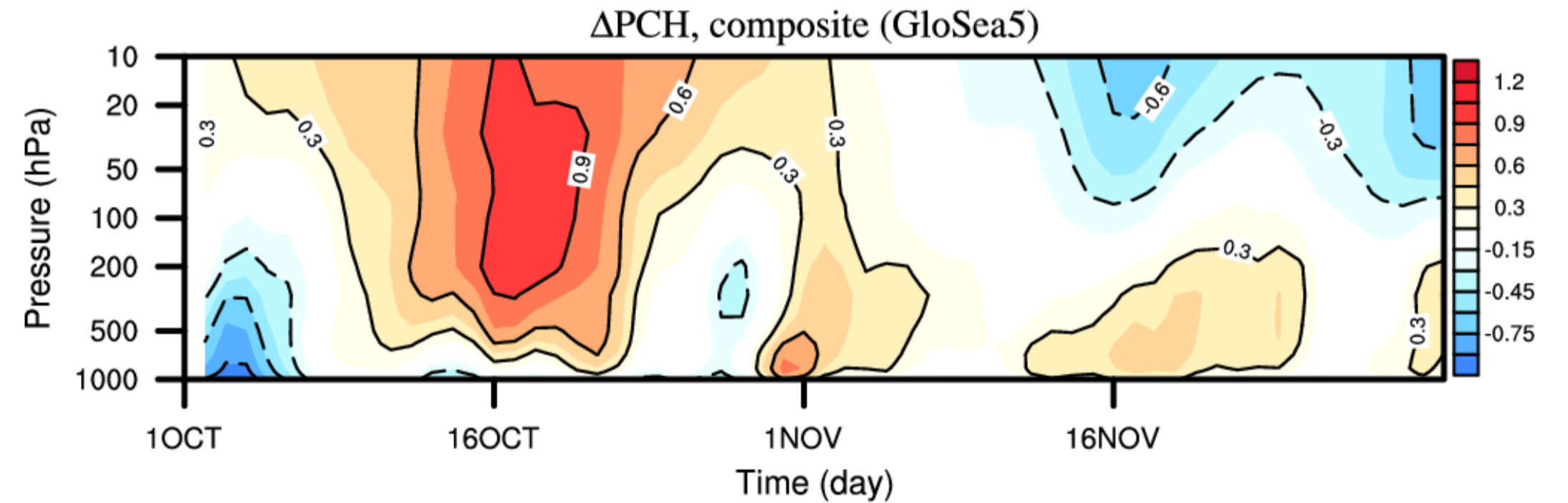
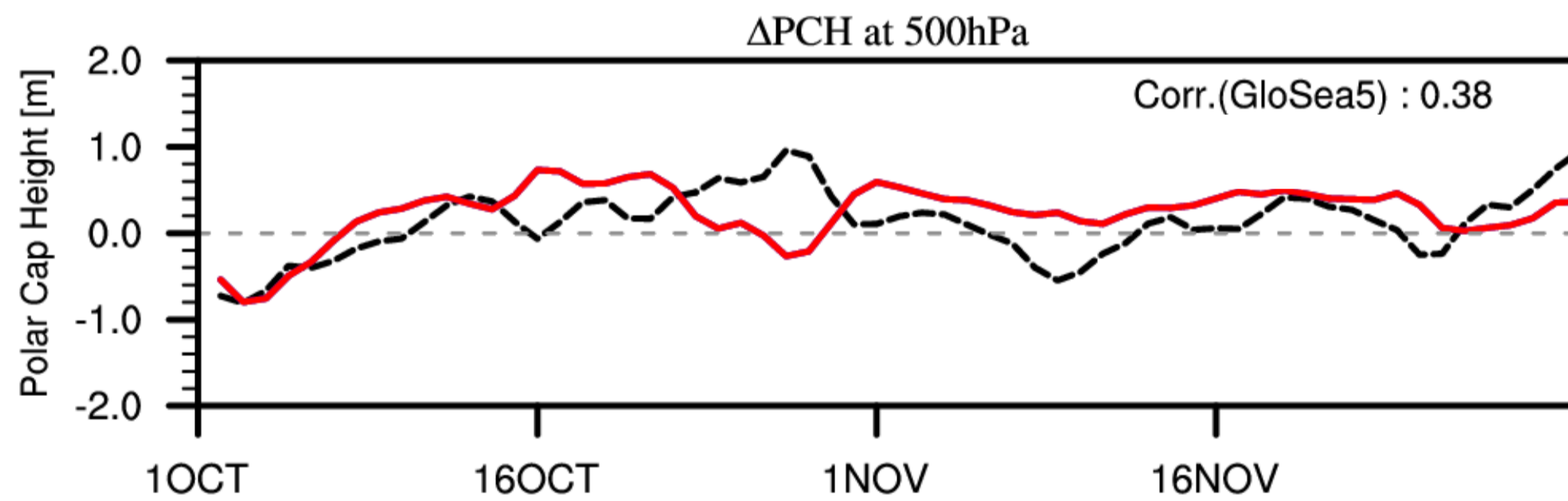
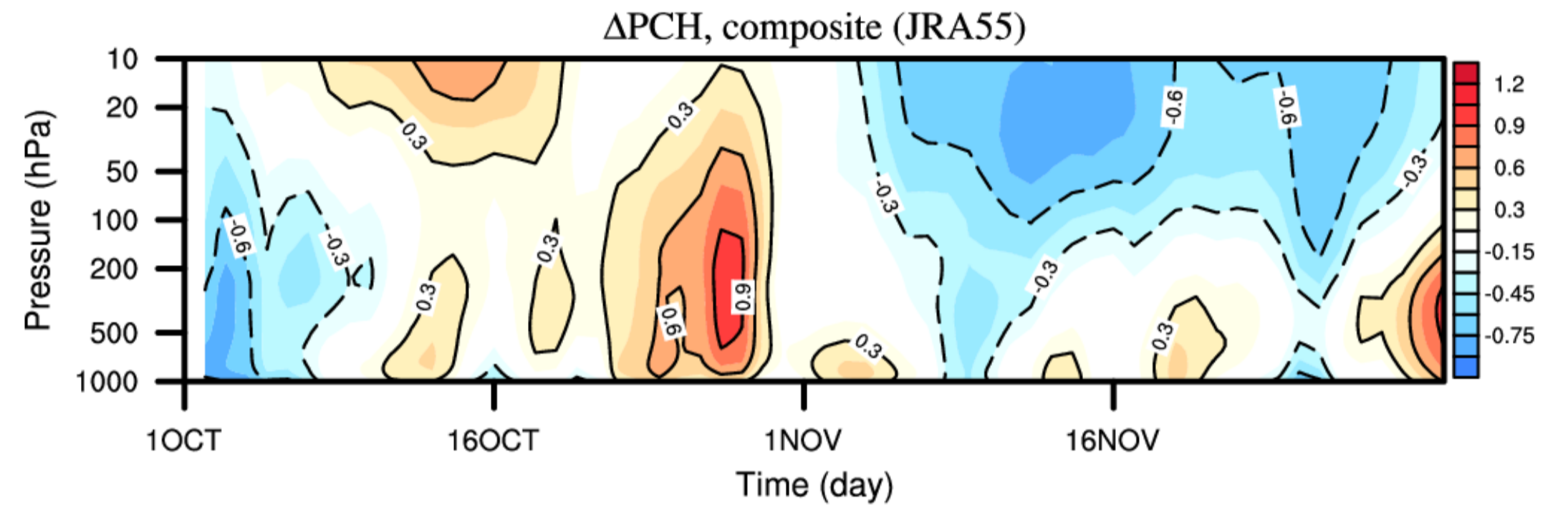
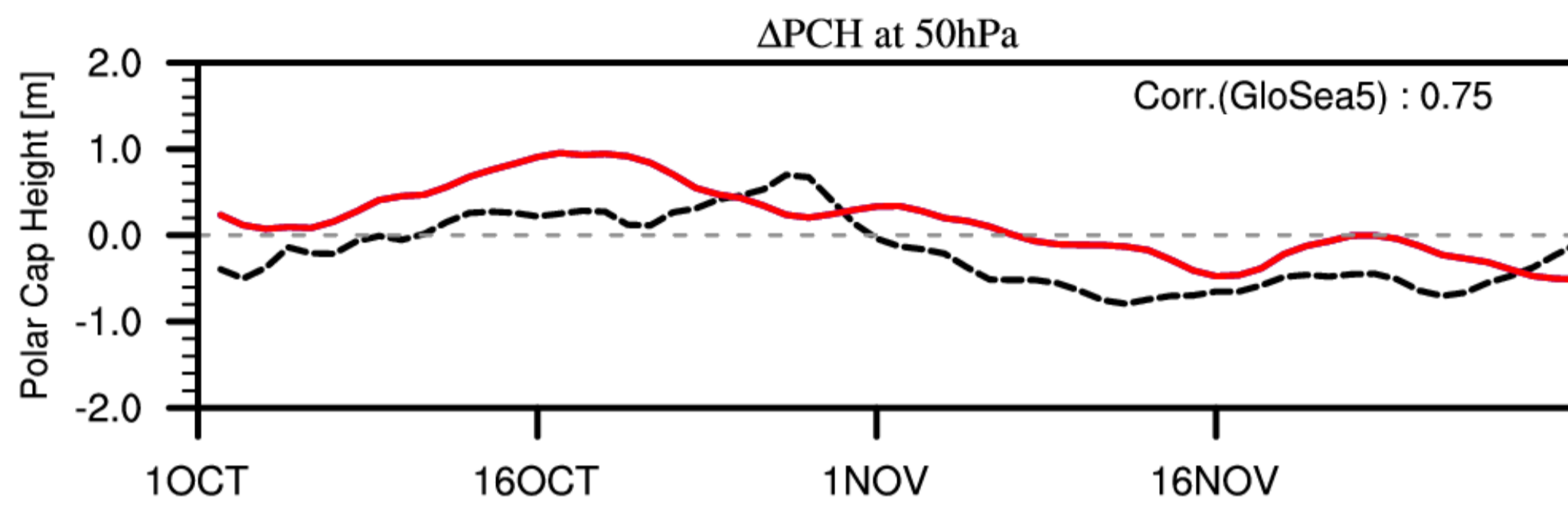
지수화 방안

- SIC Index를 기반으로 해빙 감소 기간 선정 및 극지역 지위고도 아노말리 합성장의 패턴 상관계수 또는 AO Index와의 상관계수를 활용하여 지수화 (Courtesy of NOAA CPC: https://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/hgt.shtml)

3. 연구 결과 | II. Teleconnection

Part 2. Teleconnection: PCH 예측성 결과

Teleconnection | PCH 예측성 분석 결과 (GloSea5 only, ON)



3. 연구 결과 | III. Process

Part 3. Process: Blocking Index 예측성 분석 목적 및 방법

(1) Blocking Index 분석 (Tibadli & Molteni, 1990)

- 중위도 기압계 및 기온 날씨와 밀접한 연관이 있는 대표적인 Blocking의 강도, 빈도, 지속기간 평가

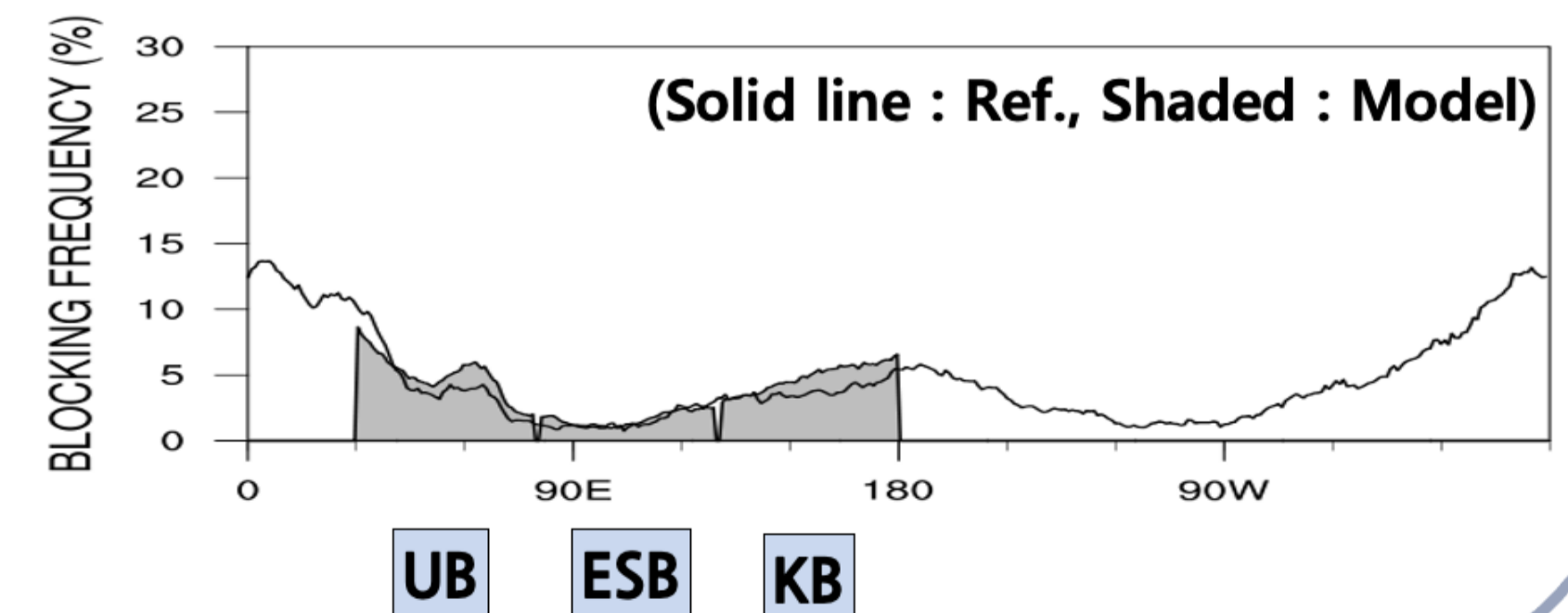
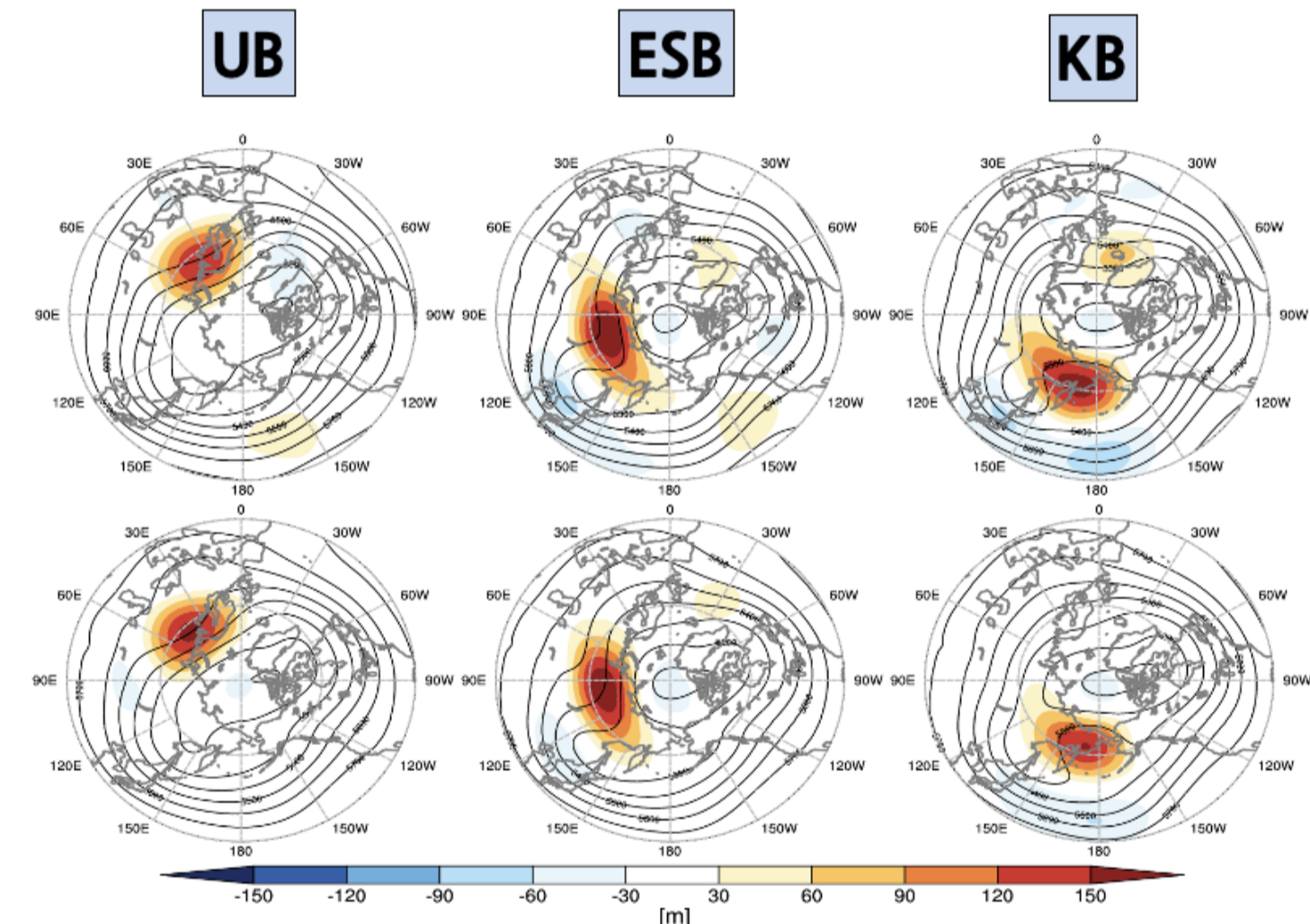
● Process 분석 예시: Blocking Index

Blocking 분석 정의 및 기법

Region	UB	Ural Blocking (30°E-80°E)
	ESB	East Siberia Blocking (80°E-130°E)
	KB	Kamchatka Blocking (130°E-180°E)
Index	Mean Amplitude	[모델-재분석 자료] (블로킹 발생 기간 내 지역별 평균 500hPa 지위고도 합성장 아노말리)
	Frequency	[모델-재분석 자료] $(\frac{\text{총 블로킹 일수}}{\text{총 분석기간}}) * 100(\%)$
	Duration	[모델-재분석 자료] $(\frac{\text{총 블로킹 일수}}{\text{총 블로킹 발생횟수}})$

재분석 자료

GloSea5

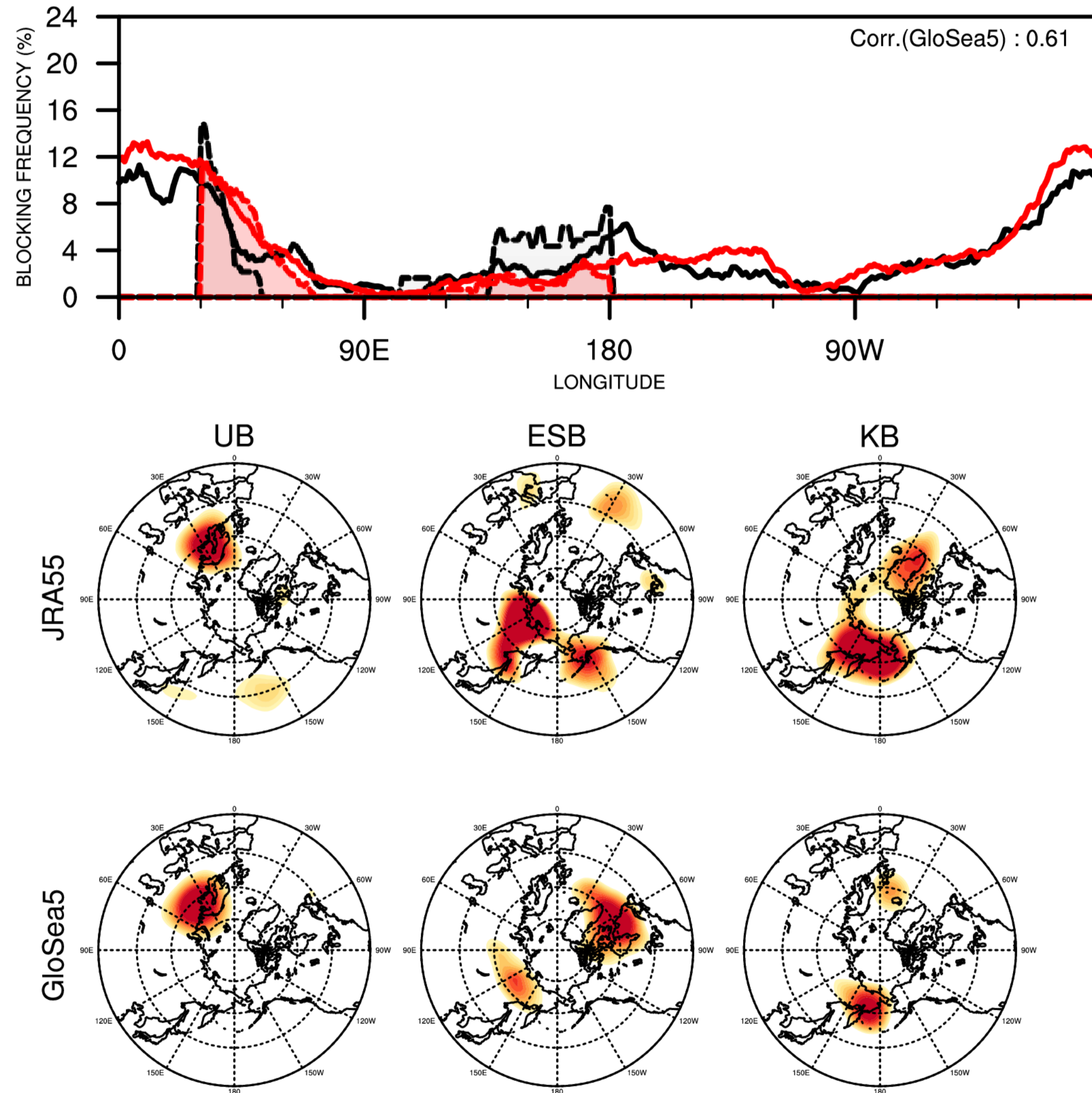


계절(OND)		Strength	Pattern Correlation	Frequency	Duration
Region	UB	18.9	0.98	0.52	-1.00
	ESB	-0.22	0.92	0.08	0.29
	KB	-26.5	0.92	1.03	0.10

3. 연구 결과 | III. Process

Part 3. Process: Blocking Index 예측성 분석 결과

Process | Blocking Index 예측성 분석 결과 (GloSea5 only, ON)



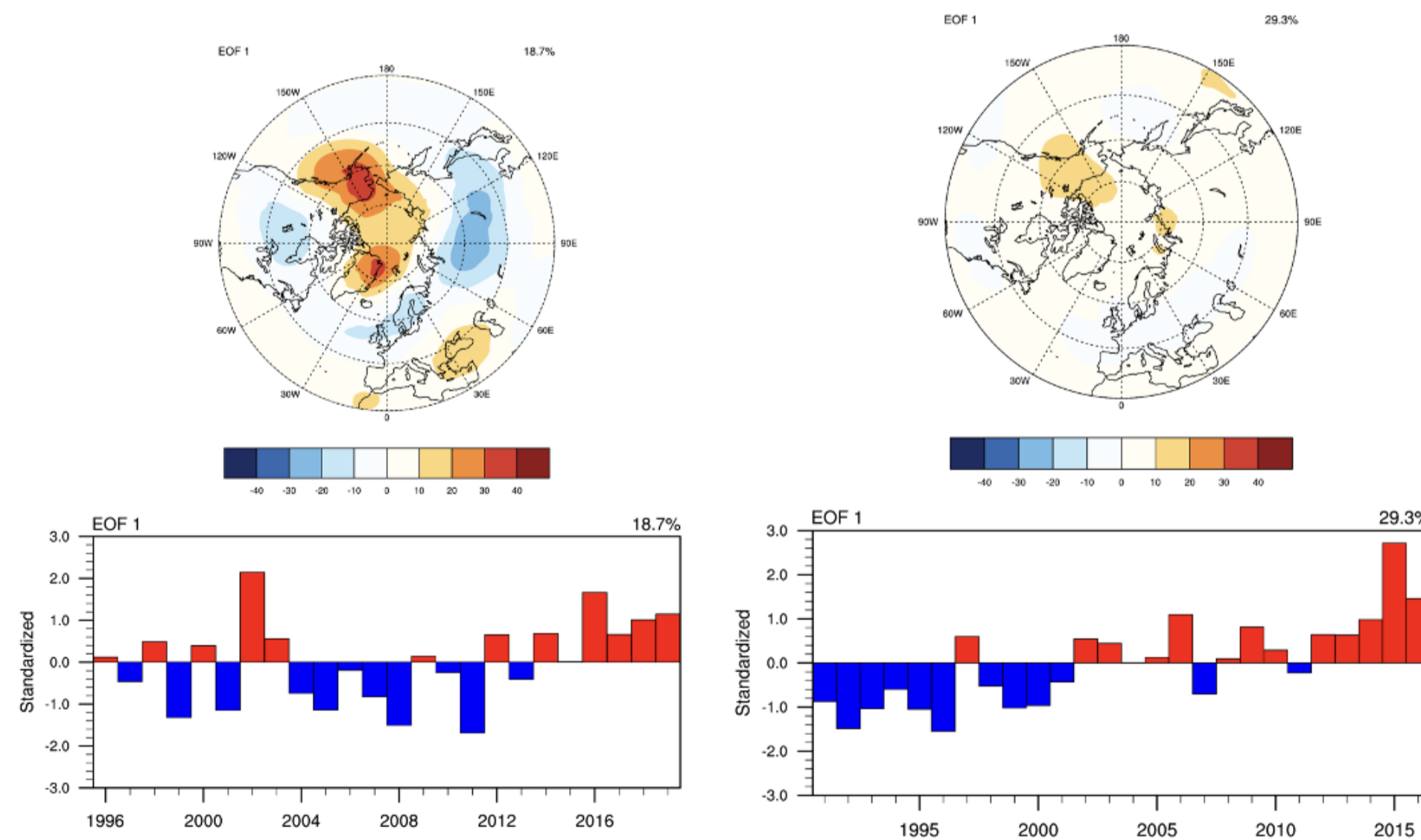
3. 연구 결과 | III. Process

Part 3. Process: Anomaly Thickness 예측성 분석 목적 및 방법

(2) Anomaly Thickness (AT) 분석 (Wu, B., & Francis, J. A., 2019)

- 대기 연직 층후 (1000-500hPa Anomaly Thickness)를 통한 중위도 열적 구조 평가
- 중위도 대기에서 하부의 열적 구조(얇은 층후: 찬 공기/두꺼운 층후: 따뜻한 공기)와 동시에 장마, 비, 눈 예보 경계 판단에 대한 정보 제공
- 지위고도장의 1000hPa과 500hPa 차이로 나타낸 층후의 EOF 분석을 통한 모드 별 패턴 상관계수 또는 주성분시계열 상관계수를 활용하여 지수화

● Process 분석 예시: AT



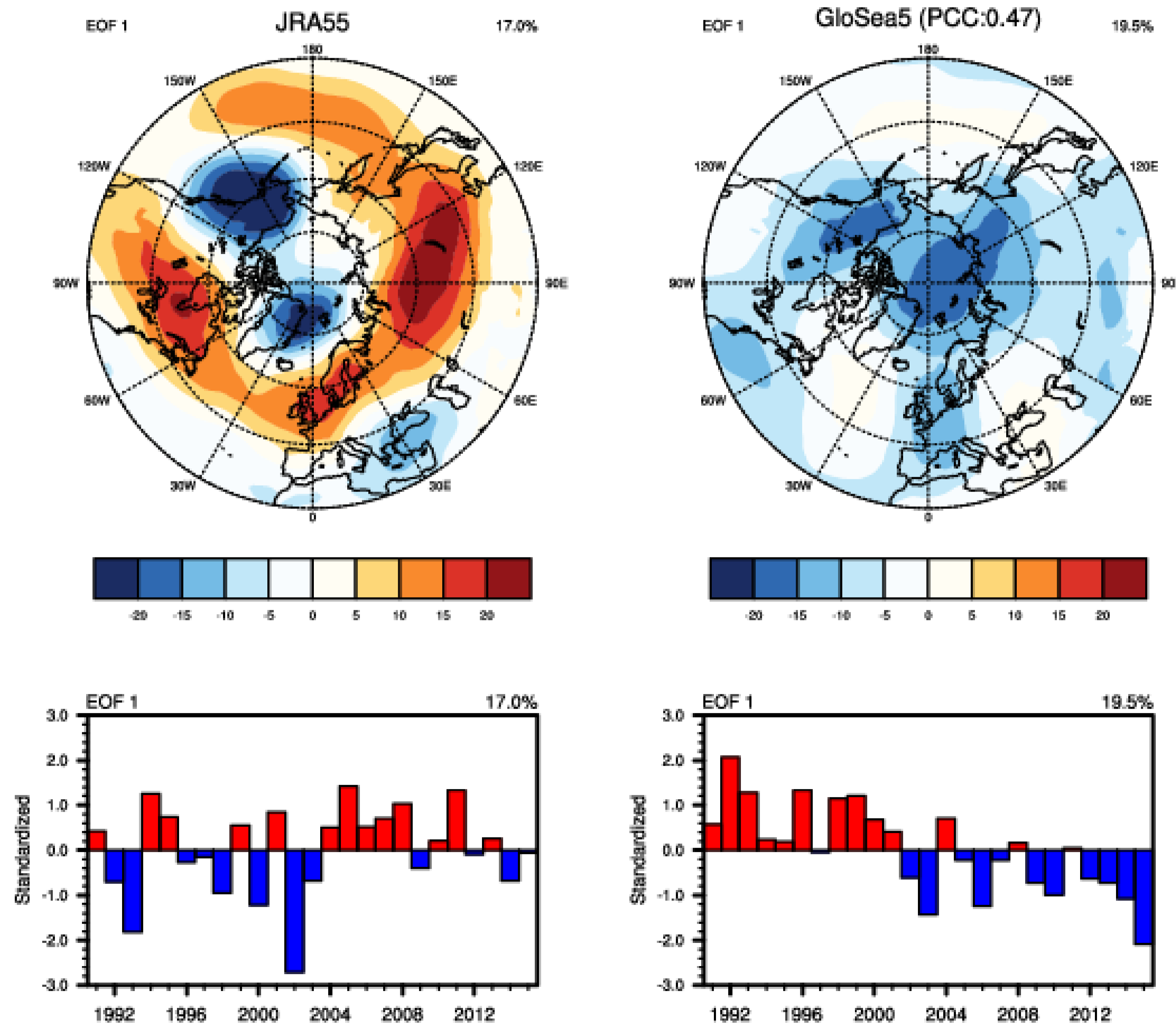
지수화 방안

- 층후 EOF 모드의 패턴 상관계수
- 주성분시계열 상관계수

3. 연구 결과 | III. Process

Part 3. Process: Anomaly Thickness 예측성 분석 결과

Process | Anomaly Thickness 예측성 분석 결과 (GloSea5 only, ON)



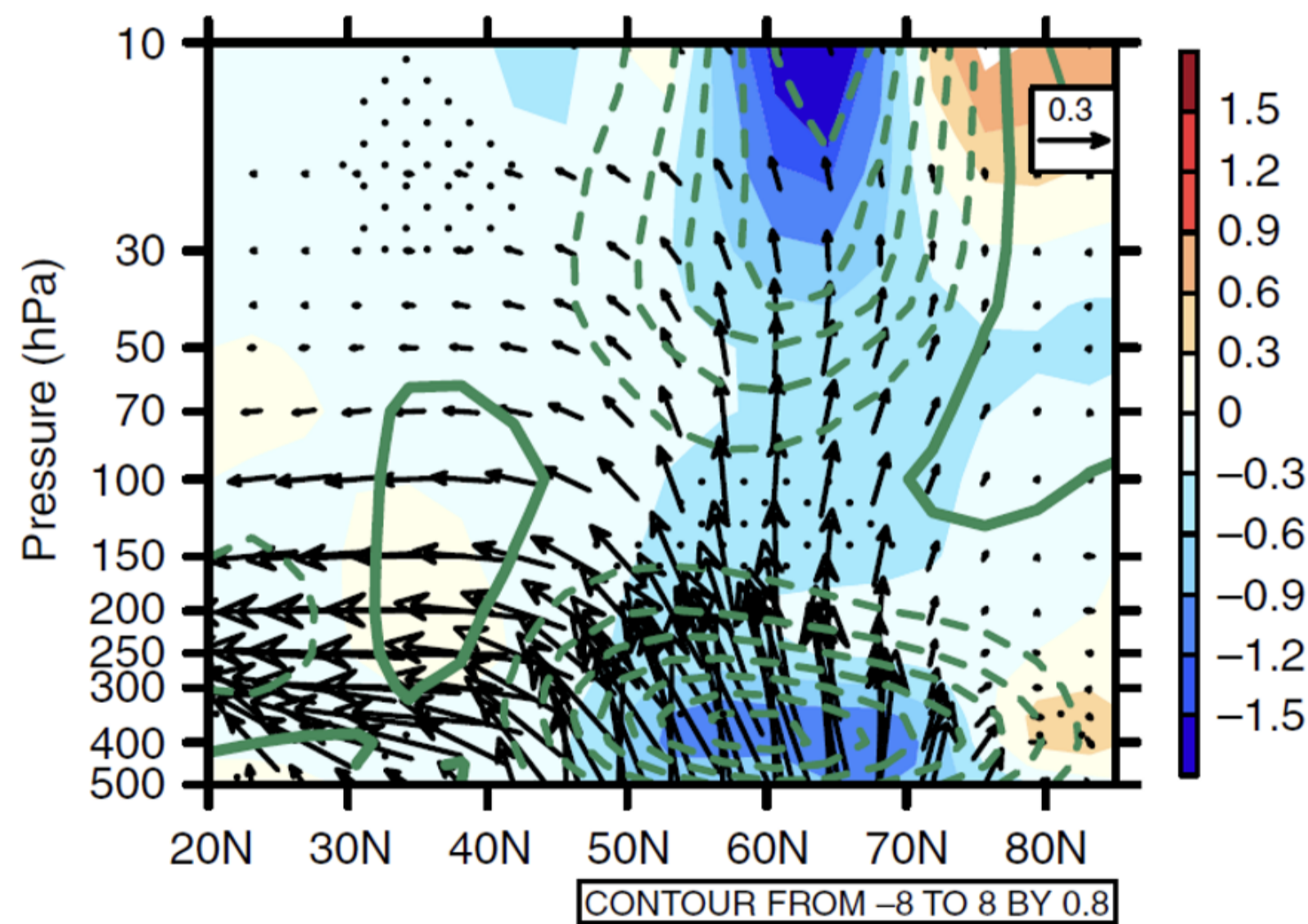
3. 연구 결과 | III. Process

Part 3. Process: E-P Flux 예측성 분석 목적 및 방법

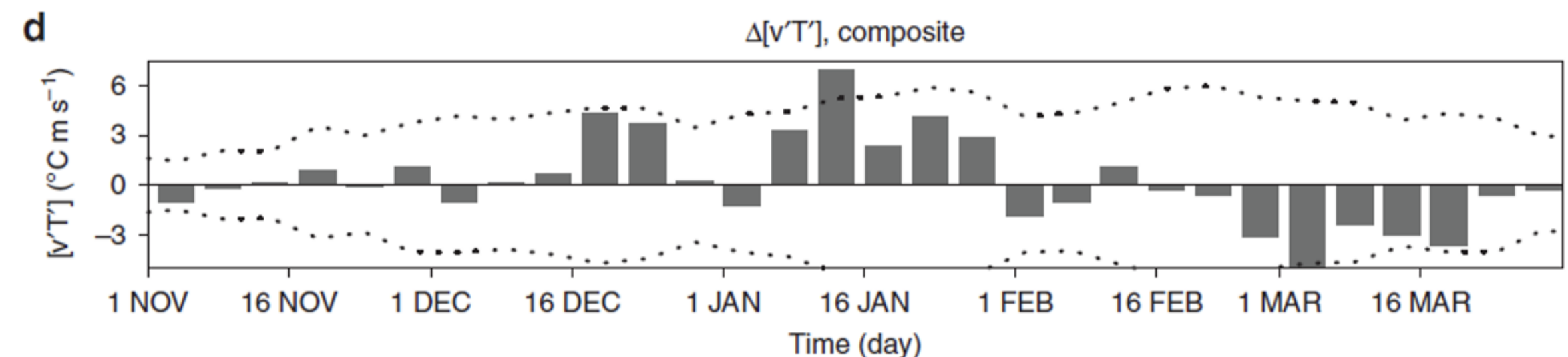
(3) Eliassen-Palm (EP) Flux 분석 (Hu, D., 2018; Kim et al., 2014)

- EP Flux 분석을 통한 대류권과 성층권 사이 Wave 전파 과정 평가
- 해빙감소 기간에 따른 EP Flux 아노말리 합성장의 시계열 분석을 통한 Wave 전파 과정 평가
- EP Flux의 Pressure/latitude 분포장의 패턴 상관계수 또는 EP Flux의 시계열 상관 계수를 활용하여 지수화

● Process 분석 예시: EP Flux



The trends in the Eliassen-Palm (EP) flux vectors (arrows with units of $10^4 \text{kg s}^{-2} \text{decade}^{-1}$ for vertical vectors, and $10^6 \text{kg s}^{-2} \text{decade}^{-1}$ for horizontal vectors) and the EP flux divergence (shading) (Hu, D., 2018)



5-day averaged composite poleward heat flux anomalies at 100 hPa from ERA-Interim data. (Kim et al., 2014)

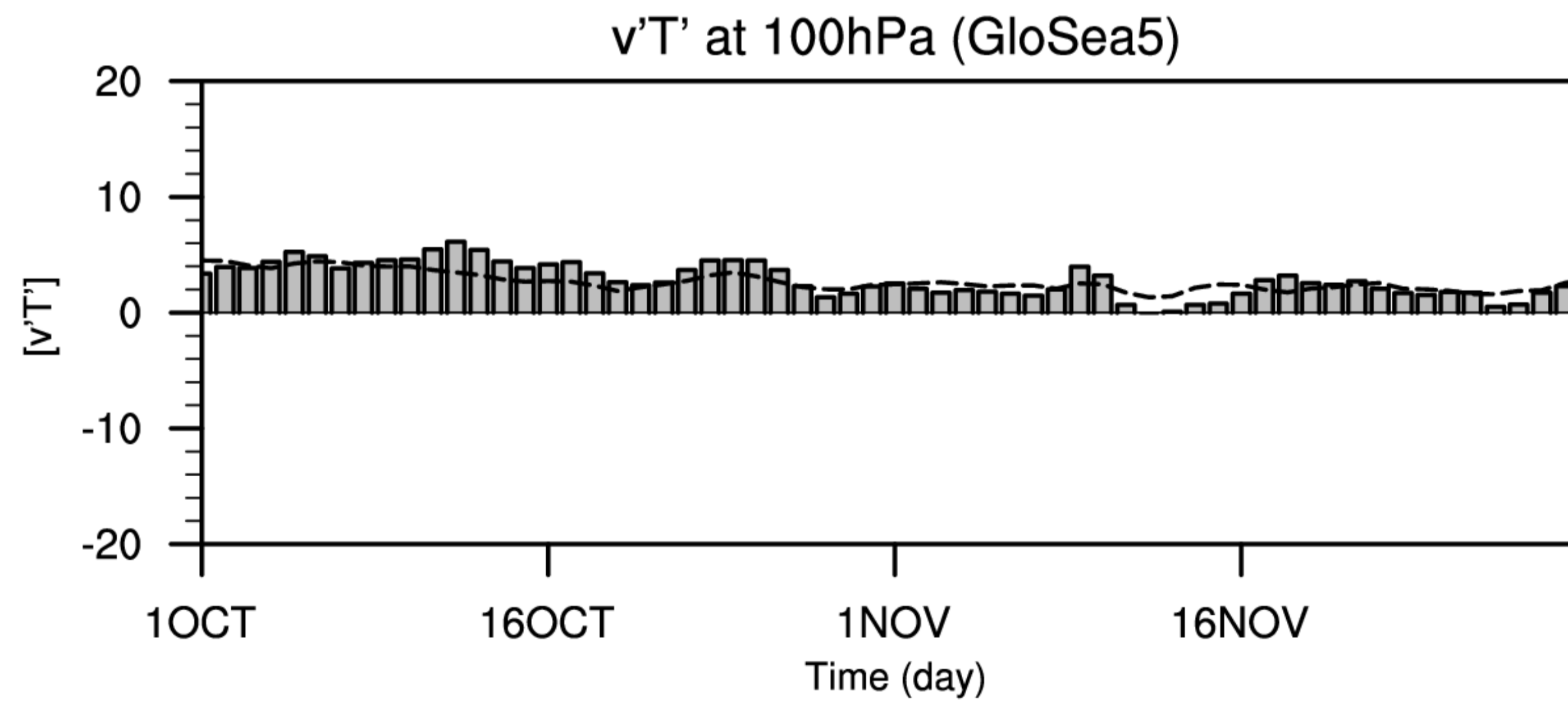
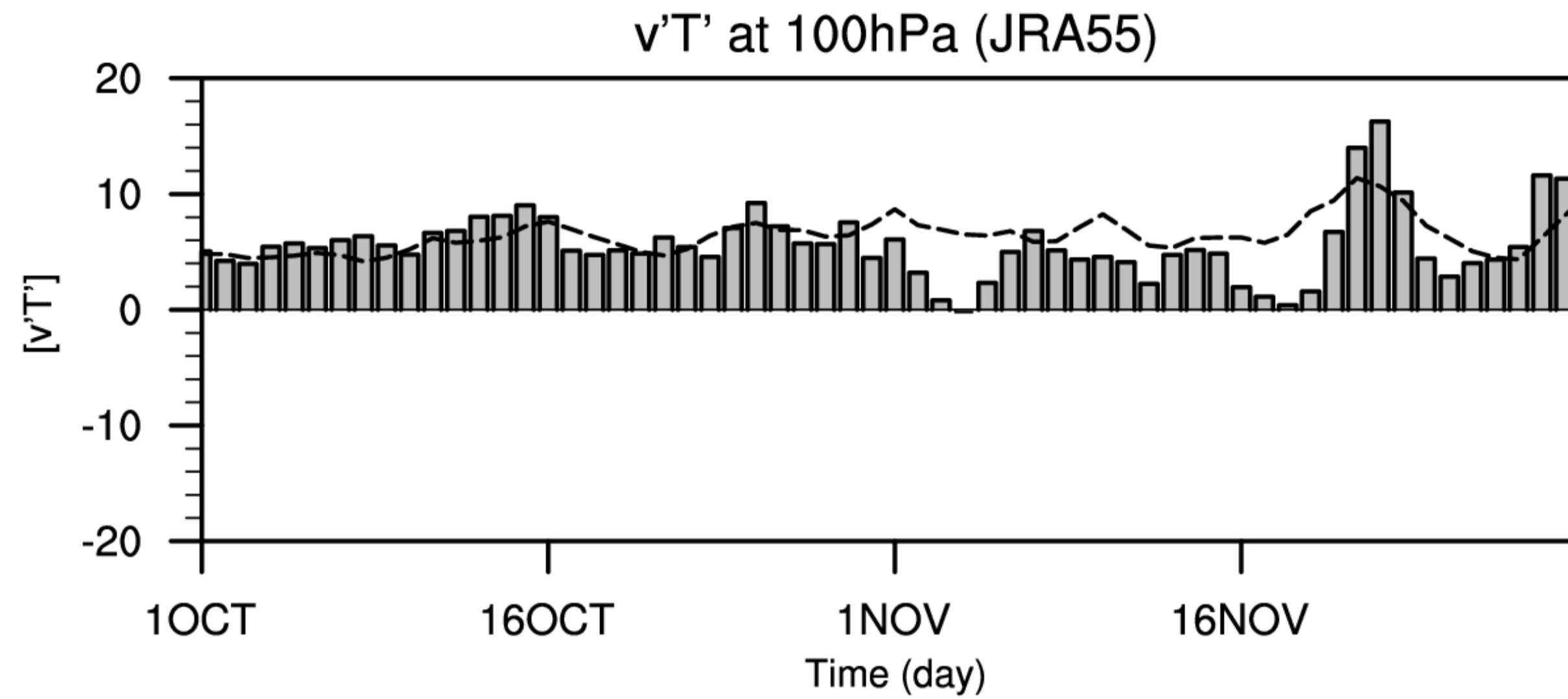
지수화 방안

- EP Flux의 Pressure/latitude 분포장의 패턴 상관계수
- EP Flux 아노말리 합성장 시계열 상관계수

3. 연구 결과 | III. Process

Part 3. Process: E-P Flux 예측성 분석 결과

Process | E-P Flux ($[v'T']$) 예측성 분석 결과 (GloSea5 only, ON)



3. 요약

- 본 연구에서는 준계절-계절 예측 모델의 '북극-중위도 원격상관' 메커니즘을 기반으로 예측 성능 평가 및 진단을 진행하여 진단 매트릭스로 표출하였음.
- 진단 매트릭스는 북극-중위도 원격상관 메커니즘과 밀접하게 연관된 변수 및 기작을 선정하여 예측성을 평가하고, 'Performance, Teleconnection, Processes'로 세분화하여 매트릭스를 구성하였음.
- Performance 예측 성능
 - GloSea5의 ON(늦가을) 기간 해빙의 예측성은 2006년까지는 높은 예측성능을 보였지만, 이후 해빙의 변동성 모의는 성능이 감소함 (해빙감소기간: '07,'11, '12).
- Teleconnection / Processes 예측 성능
 - Blocking index 예측성능: 관측자료의 해빙감소의 합성장 분석을 통한 블로킹 분석은 UB(Ural Blocking), KB(Kamchaka Blocking)의 빈도(Frequency)가 증가하는 것을 확인할 수 있었으나, GloSea5에서는 낮은 모의 능력을 보임.
 - WACE 예측성능: 관측의 WACE 패턴에서 보이는 유라시아, 알래스카 지역의 음의 아노말리 (북극 고온-중위도 저온)는 GloSea5의 모의 결과, 관측에 미치지 못하는 낮은 상관성을 확인할 수 있음.
→ 이는 WACE 패턴 발생 메커니즘과 연관된 블로킹의 모의능력이 낮기 때문에 WACE 패턴 또한 낮게 모의된 것으로 보임.
- 본 연구에서 구축한 진단 매트릭스를 통해, 북극-중위도 원격상관 패턴을 기반으로 북극 기인의 Performance, Teleconnection, Processes에 영향을 미치는 요소 및 기작을 함께 표출함으로써, 이를 통해 모델의 북극-중위도 원격상관 예측 성능 및 모델의 구조적 오차 원인을 파악할 수 있을 것으로 판단 됨



감사합니다.