

기후예측시스템 모델의 MJO 원격상관 진단연구

문자연¹, 김기영¹, 조정아¹, 양영민², 현유경³, 김백조³

¹(주)포디솔루션 기업부설연구소,

²난징정보과학기술대학교 대기과학과

³국립기상과학원 기후연구부

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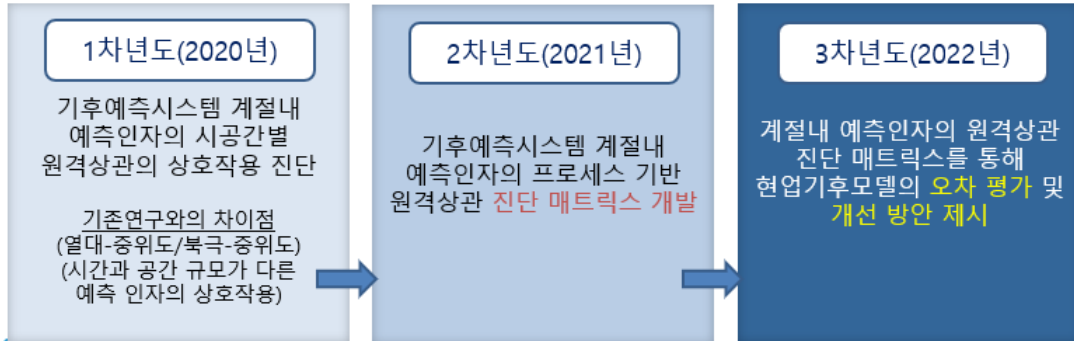
1. 연구배경

최종목표

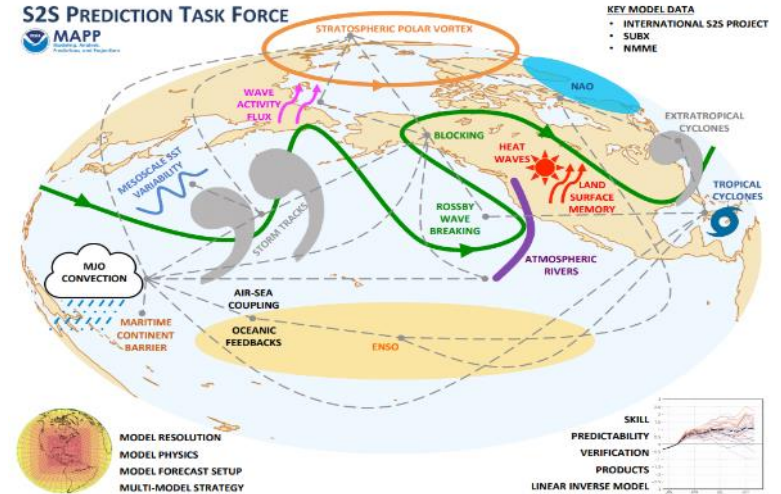
과제명: 계절내 규모 예측인자의 원격상관 진단분석

- 1 계절내 예측인자의 시공간별 원격상관 상호작용 분석 및 원격상관 진단 매트릭스 개발을 통해 **현업기후모델의 계절내 예측 오차 및 한계 진단**
- 2 계절내 예측인자의 원격상관 과정의 문제점과 개선방안 제시를 통해 기후예측시스템의 **계절내 예측성 향상**

세부목표



구분	진단 매트릭스
원격상관	열대 ↔ 중위도 ↔ 북극
대상지역	동아시아, 아시아-북태평양, 북반구 중위도, 북극
예측인자	MJO, BSISO, PNA, NAO, AO, SIC, PCH, WACE, Blocking, ART1, ART2
진단기준	강도, 패턴, 빈도, 지속기간
예측선행시간	일(daily), 주(week), 월(monthly)



2-1. 연구자료

▲ 모델 자료 및 재분석 자료 정보

- 현업기후모델(GloSea5)의 예측성 및 구조적 오차를 재분석/관측 자료와 비교하여 평가
- 현업기후모델의 기후변화실험(CMIP control) 결과를 분석하여 모델의 구조적 오차 평가

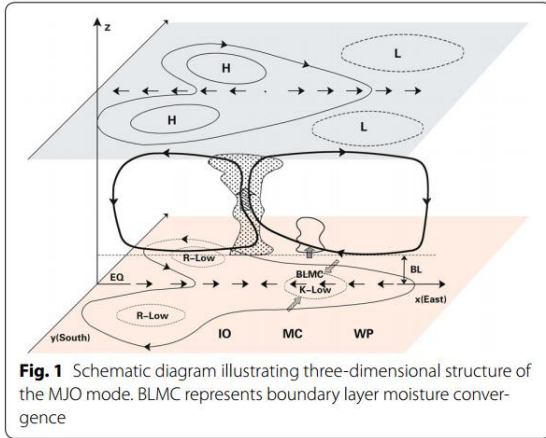


분석 자료 및 모델 정보

2-2. 연구방법

계절내진동 모의성능 진단

Wang et al. (2018) Dynamics-Oriented Diagnostics for the MJO



- 1) the horizontal structure of boundary layer moisture convergence
- 2) the horizontal structure of 850-hPa zonal wind and its equatorial asymmetry (Kelvin easterly versus Rossby westerly intensity)
- 3) the equatorial vertical-longitudinal structure of the equivalent potential temperature and convective instability index
- 4) the MJO available potential energy generation that reflects the amplification and propagation of an MJO

계절내진동 및 원격상관 모의성능진단

Wang et al. (2020) Teleconnections over the PNA region in climate models +

MJO_Period
MJO_Pattern
MJO_Amplitude

Teleconnection_Pattern

Teleconnection_Amplitude

Teleconnection_IPC

Teleconnection_E-W Position

Teleconnection_Persistence

Performance_Jet location

RWS_Pattern

RWS_Amplitude

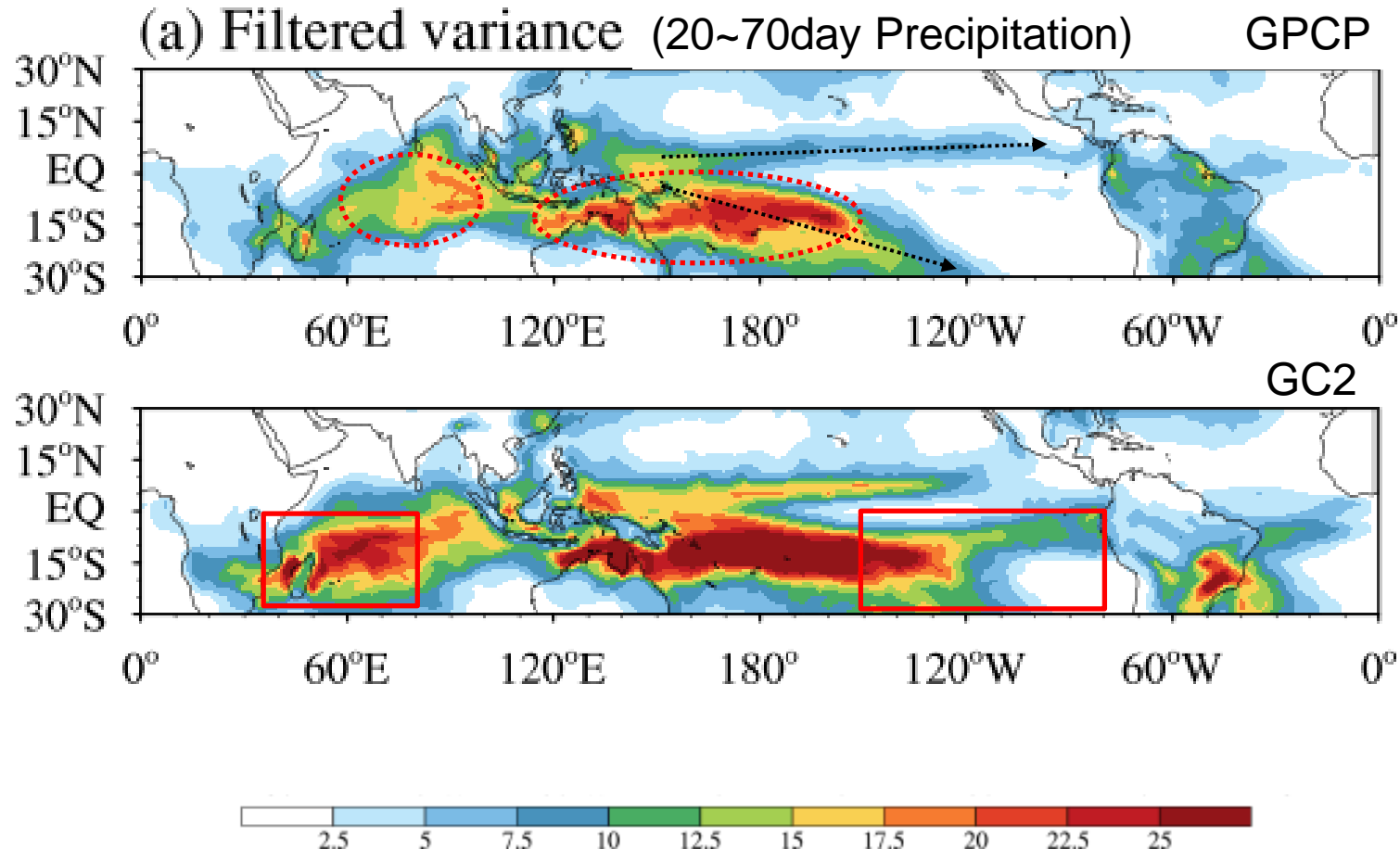
3. MJO 모의성능 진단

Basic diagnostics in MJO properties

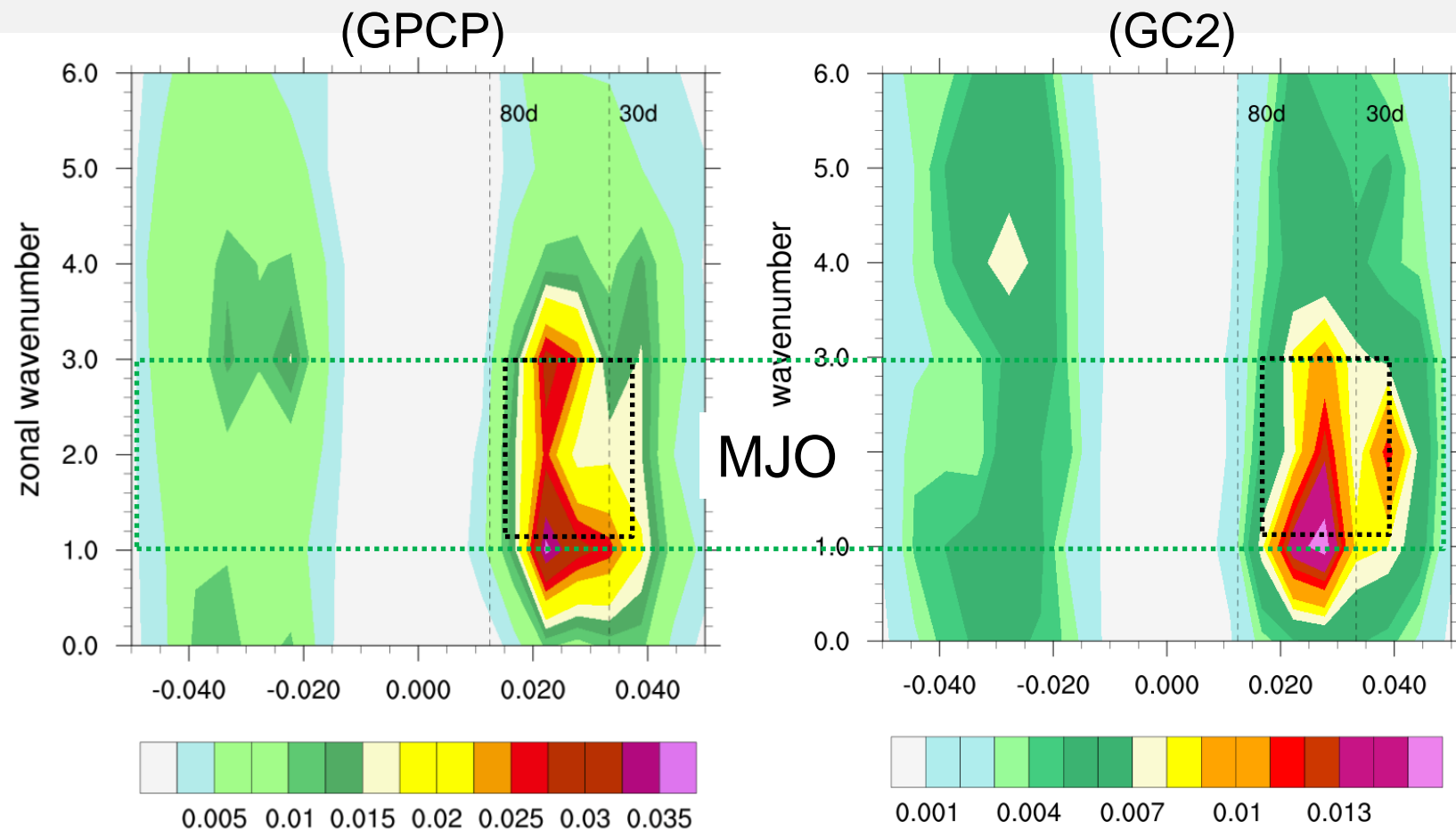
- Key Features:

- Variance Peak at IO and WP
- ITCZ/SPCZ band

-Stronger variability over western IO over ITCZ&SPCZ



Basic diagnostics in MJO properties



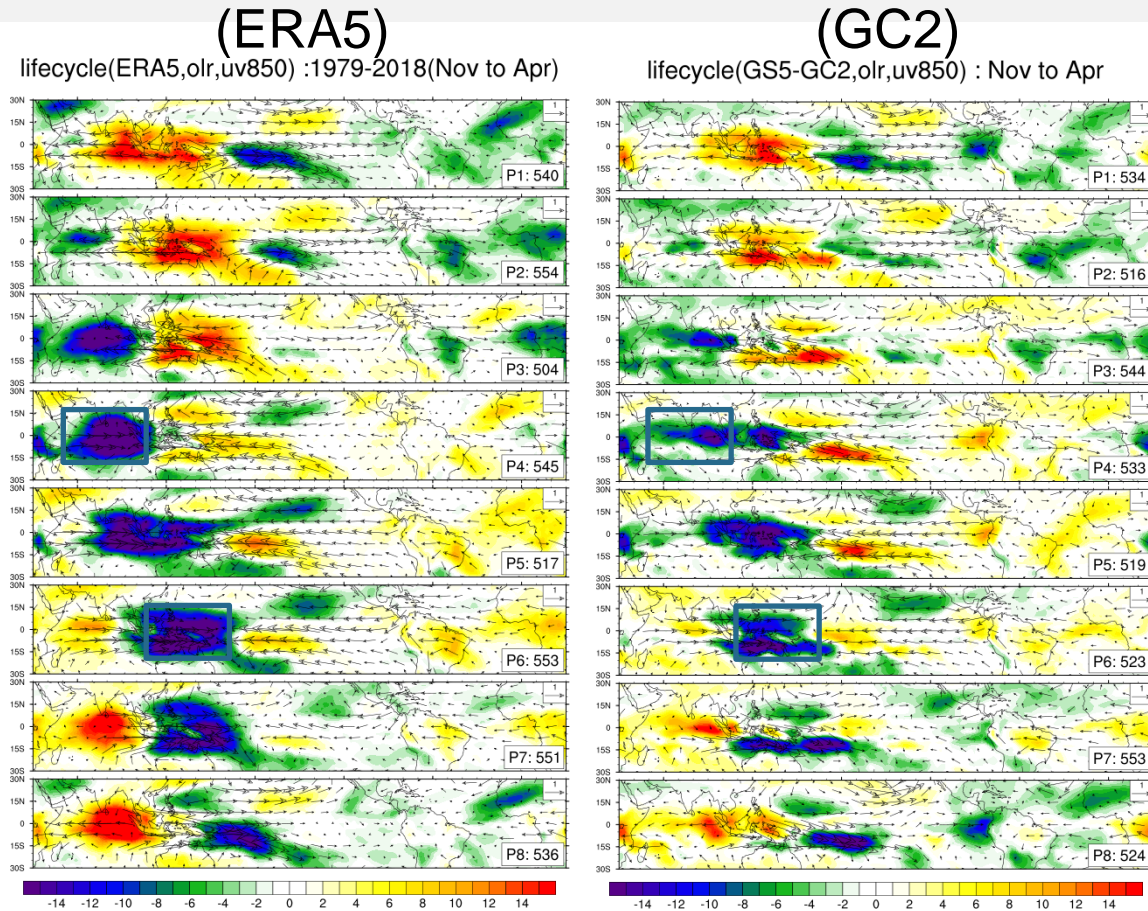
- Key Features of frequency-wavenumber spectrum of the precipitation

- Maximum power occurs at 40-50-day periods and zonal wavenumber one
- The power for westward propagation is much weaker than eastward movement

- GC2 simulation successfully capture the planetary scale of precipitation anomalies(zonal wavenumber one)

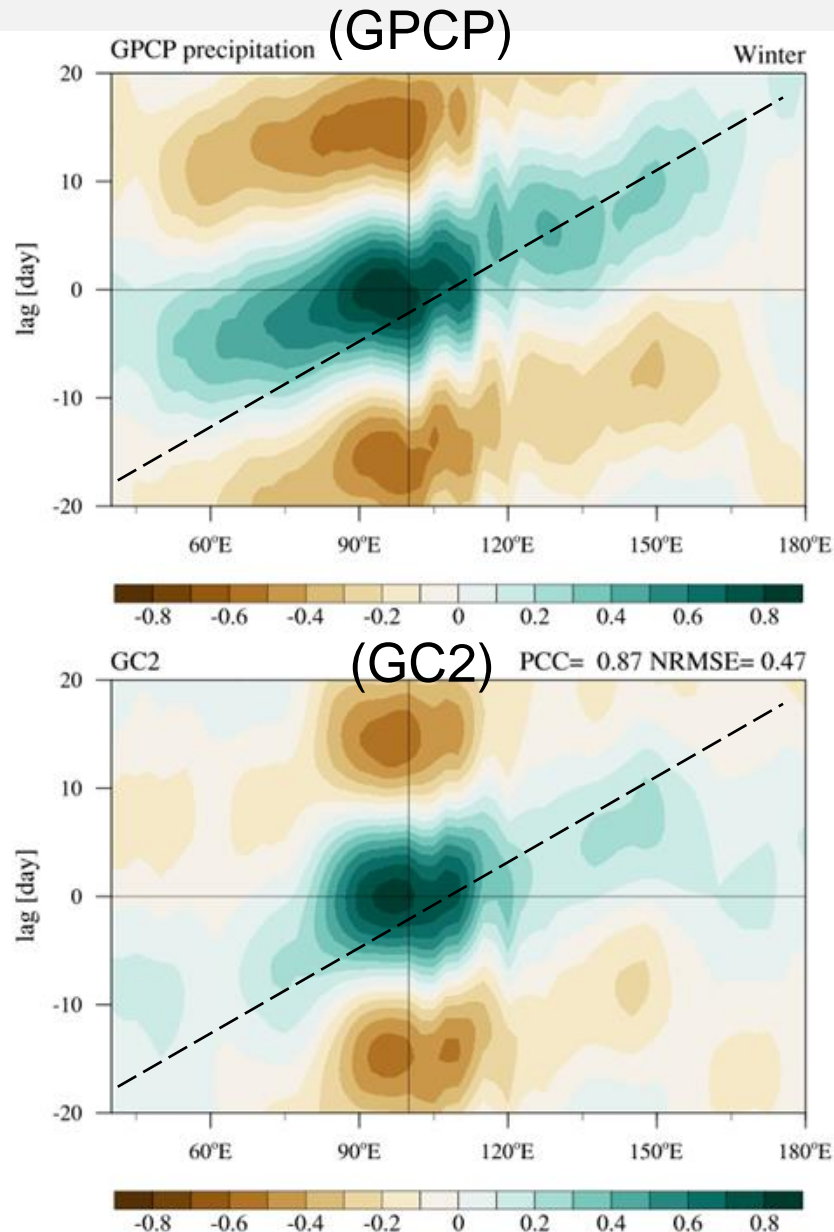
- Shorter time scale at wavenumber 2 is stronger and westward propagation in stronger than the observation

MJO eastward propagation



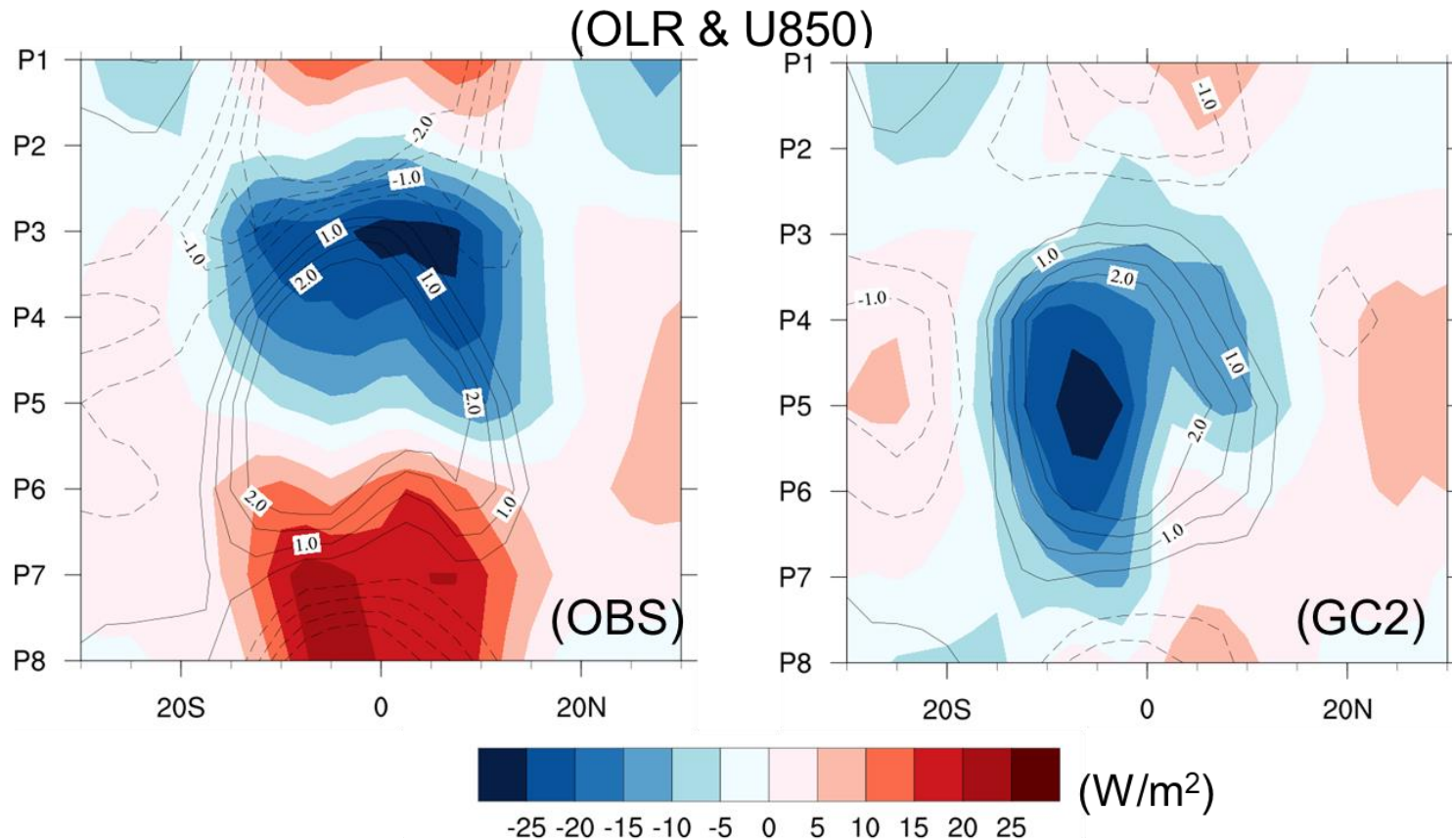
- Composite anomalies of OLR and low-level(850hPa) wind from MJO phase 1 to 8
- Systematic eastward propagation from IO to the dateline
- Largest convection center over the IO(P4) and WP(P6)
- **GC2** produces MJO eastward propagation successfully but weaker intensity and fast decay over WP(northern edge) from phase 7

Basic diagnostics in MJO properties



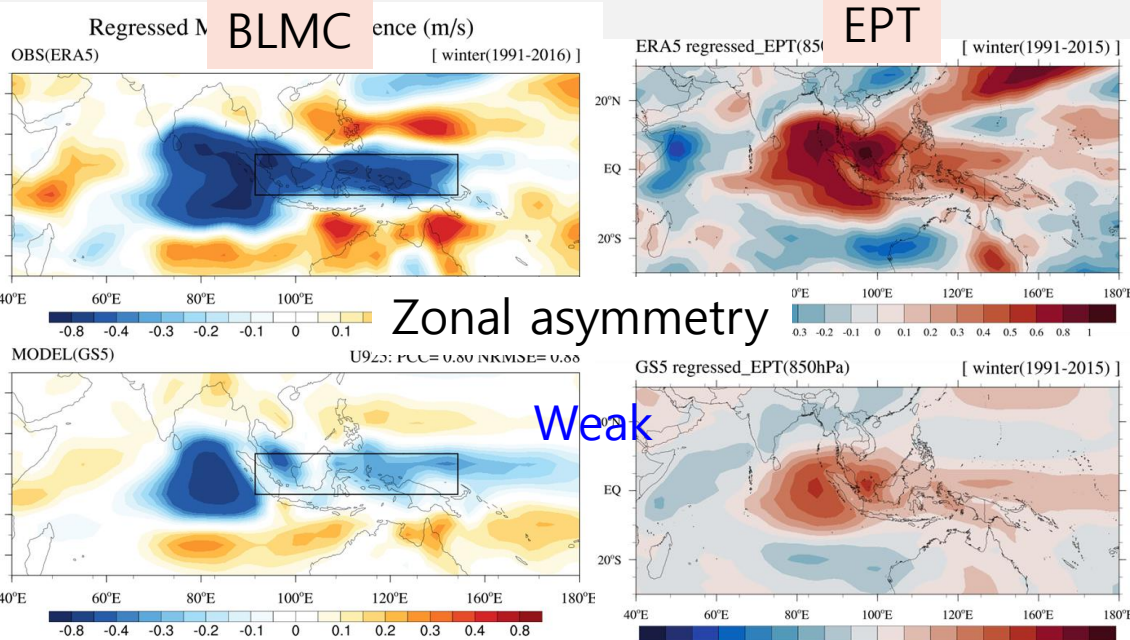
- Lead-lag correlation of 20-70 day filtered precipitation averaged over 5°S-5°N with reference to the precipitation at the equator eastern Indian Ocean(5°S-5°N, 90°-110°E) from GPCP and the model(GC2)
- **GC2** produces MJO eastward propagation quite successfully compared with the models in the previous slide(wet and dry anomalies with the center at IO and WP)

Basic diagnostics in MJO properties



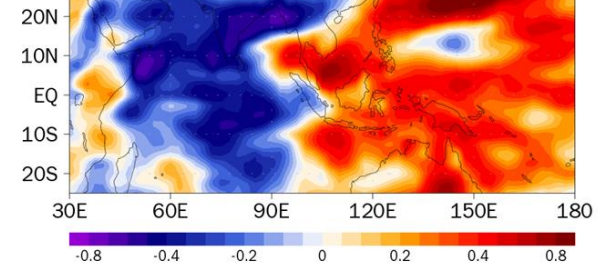
- OLR and U850 averaged over the Indian Ocean from MJO phase 1 to 8
- Maximum convection centered at the equator, easterly leading the convection
 - **GC2** has fast propagation, U850 and OLR has simultaneous evolution

Evaluation of MJO using dynamic-oriented diagnostics

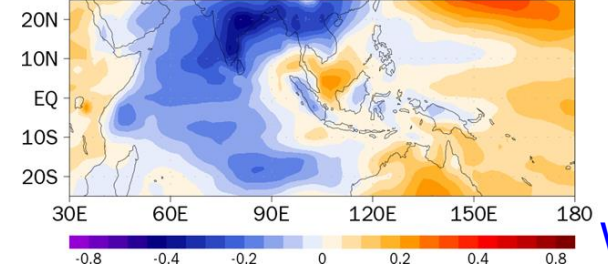


Convective instability

Regressed EPT 850 - 400 (ERA5)

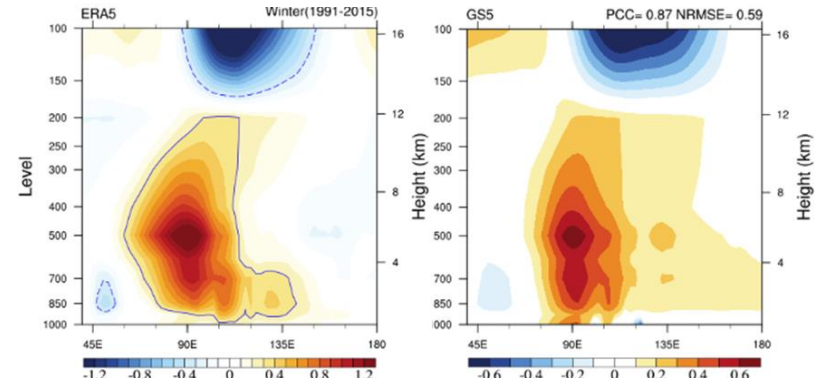


Regressed EPT 850 - 400 (GS5)

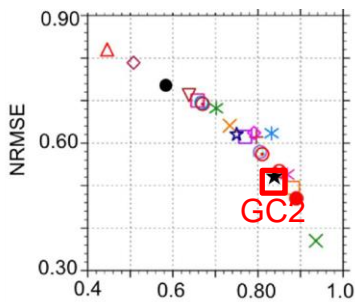


Weak

Destabilization to the east



Premoistening and rearward tilting



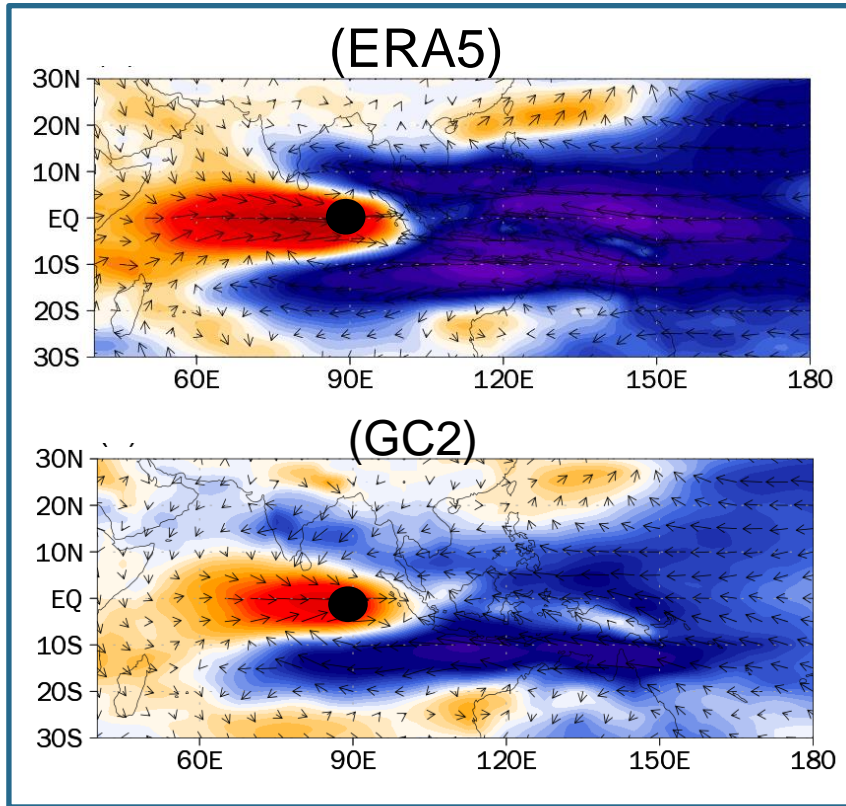
Pattern Correlation

- ★ CanESM2
- CCSM4
- ★ ACCESS1-0
- ✦ bcc-csm1-1
- FGOALS-g2
- GFDL-ESM2M
- ✦ CNRM-CM5
- ✦ CSIRO-Mk3-6
- △ HadGEM2-ES
- △ inmcm4
- GISS-E2-R
- △ HadGEM2-CC
- △ MIROC5
- △ GFDL-ESM2G
- ✦ IPSL-CM5A-LR
- ✦ IPSL-CM5A-MR
- MRI-CGCM3
- ✦ NorESM1-M
- MIROC-ESM
- MPI-ESM-LR
- NESM3.0_CTL
- NESM3.0_MOD

★ GloSea5-GC2

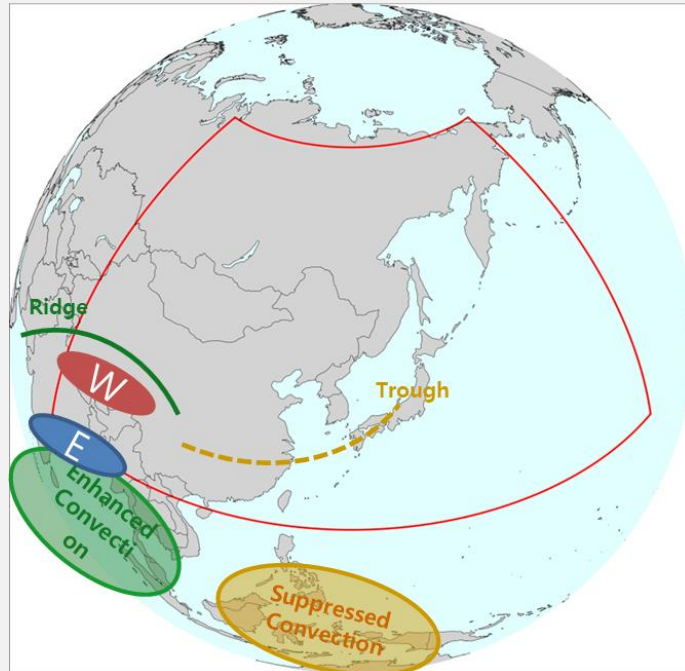
Evaluation of MJO using dynamic-oriented diagnostics

Horizontal structure of 850-hPa zonal wind



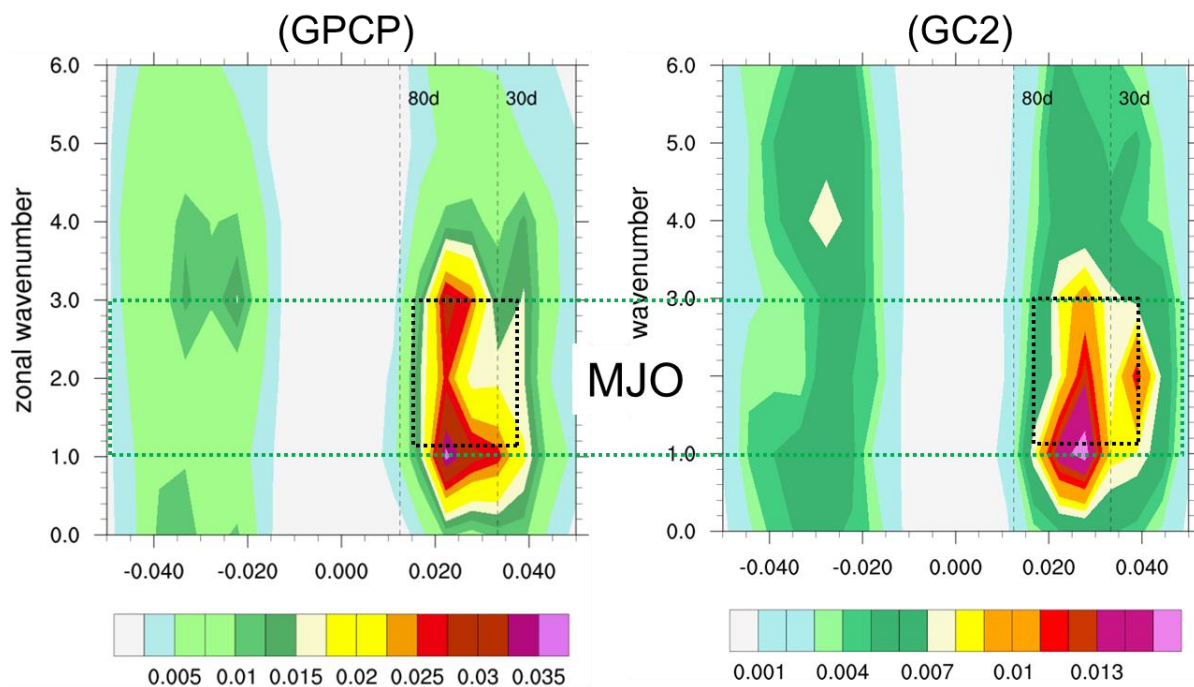
- the Kelvin wave is closely coupled with the Rossby wave around the convective center in the eastern Indian Ocean
- The peak of easterly at the EQ is comparable to the peak of westerly + asymmetry between Rossby and Kelvin Wave
- Key feature(R:K zonal extent, intensity) is well captured

4. MJO 원격상관 모의성능 진단

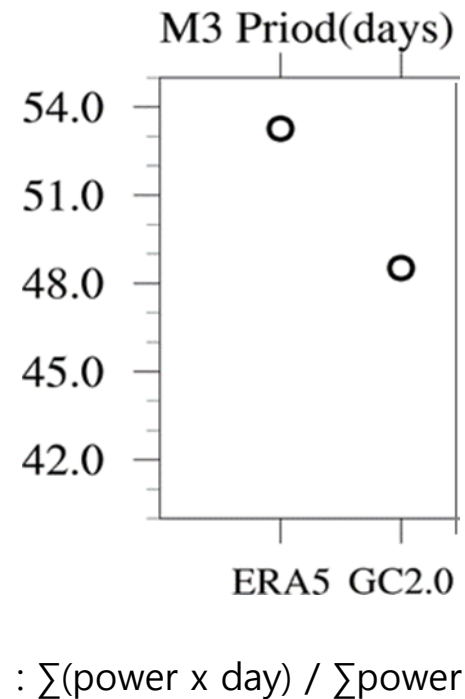


MJO Period

Diagnostic 1



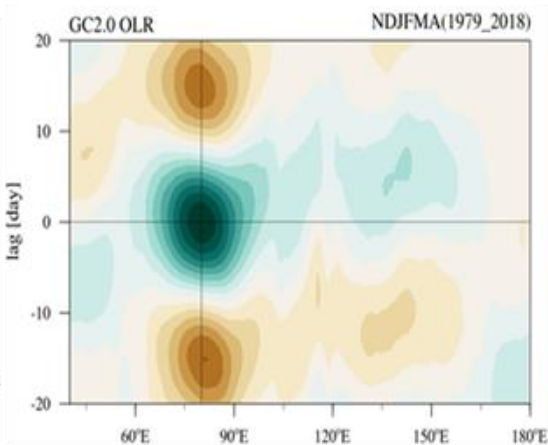
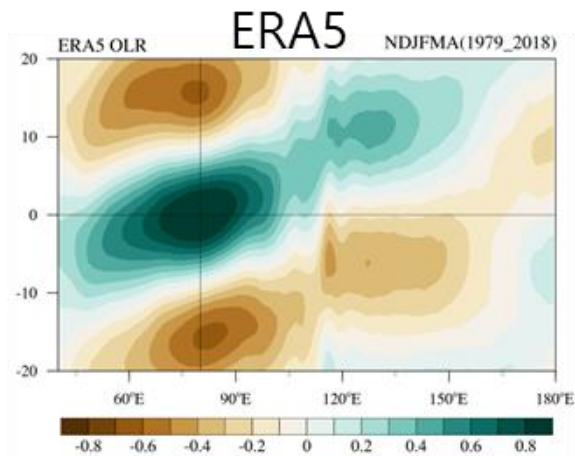
Diagnostic 2



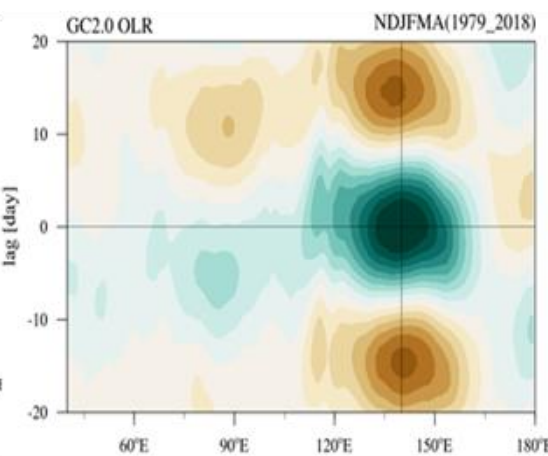
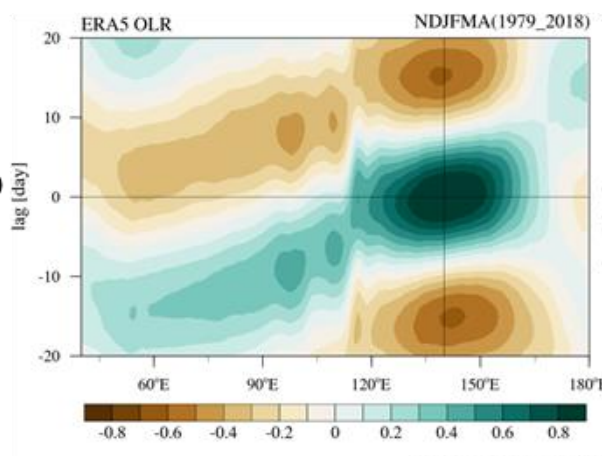
MJO Pattern

Diagnostic 1

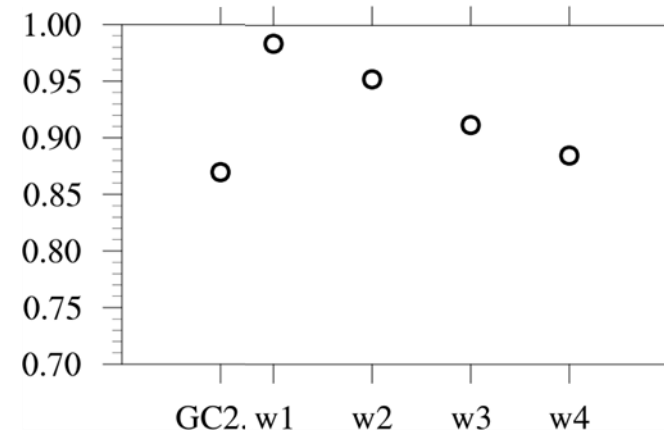
EIO



WP

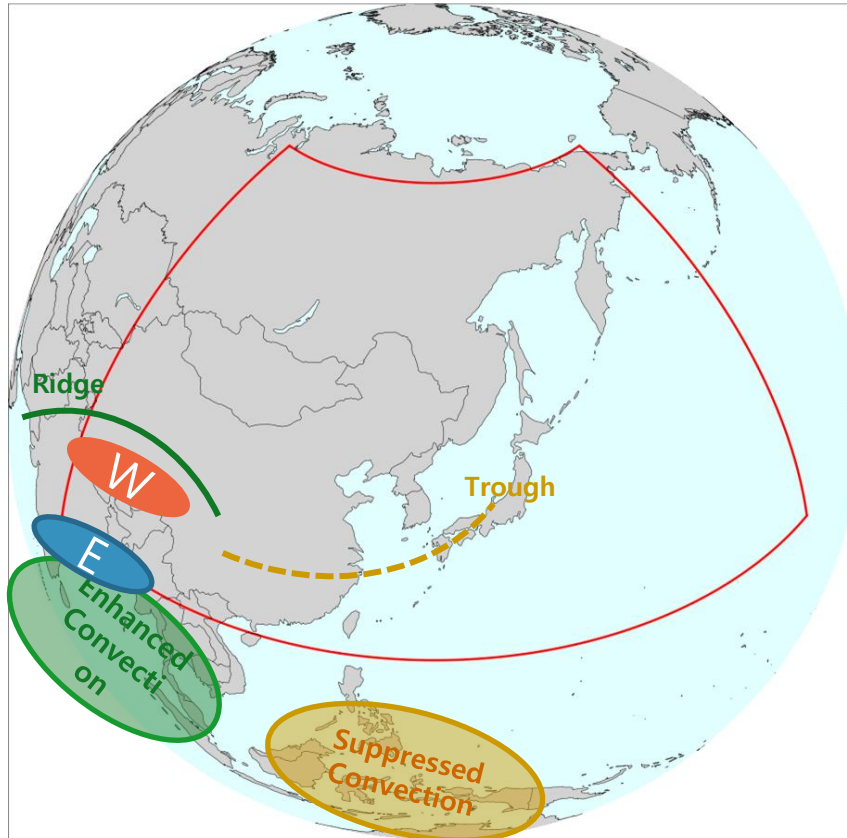


Diagnostic 2



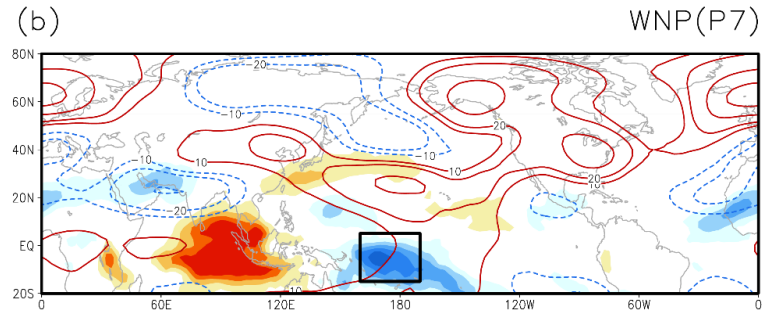
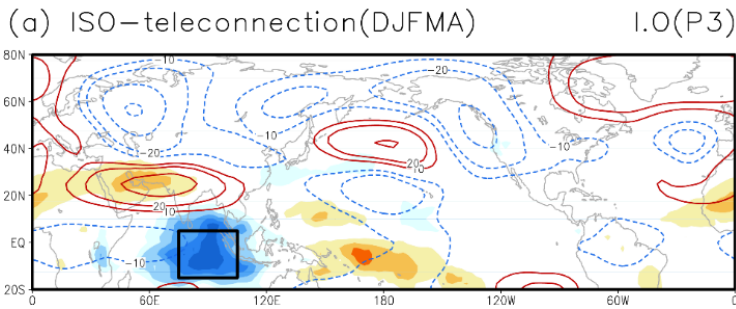
Pattern CC

열대-중위도 원격상관 진단 범위



- (1) 전구규모
- (2) 열대지역 forcing에 따른 동진구조
- (3) Coupled Kelvin-Rossby wave 반응에 의한 상층 고기압성 순환
- (4) 상층 제트(평균류)
- (5) 원격상관 과정에 의해 발생하는 상층 로스비파 이동
- (6) 대상지역:
 - 북반구 중위도(N. Extratropics): 20° – 80° N, 0° E– 360
 - 아시아-북태평양(Asia-Pacific): 20° – 70° N, 80° E– 120° W
 - 동아시아(East Asia): 20° – 50° N, 100° E– 150° E

MJO Teleconnection Pattern



진단: 열대-중위도 원격상관 패턴 모의 성능(PCC)

아시아-태평양지역(20°-70°N, 60°E-120°W)에서 재분석자료와 모델사이의 MJO 위상(P)별 상층지위고도(Z200)의 패턴 상관관계(DJFMA)

0.5 이상

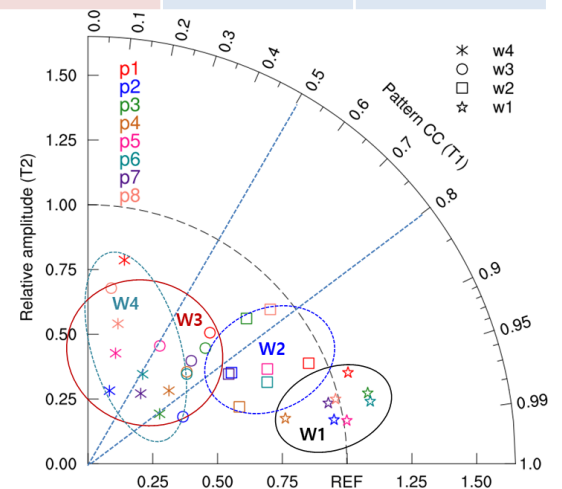
	P1	P2	P3	P4	P5	P6	P7	P8
W1	0.96	0.88	0.91	0.91	0.96	0.89	0.95	0.97
W2	0.92	0.66	0.89	0.79	0.84	0.65	0.84	0.92
W3	0.76	0.54	0.76	0.85	0.77	0.59	0.36	0.81
W4	0.32	-0.01	0.72	0.46	0.39	0.4	0.34	0.58
GC2.0	0.69	0.33	0.42	0.45	0.64	0.27	0.23	0.77

MJO Teleconnection Amplitude

재분석자료 대비 모델의 MJO 위상(P)별 아시아-태평양지역(20°-70°N, 60°E-120W°)에서 상층지위고도(Z200) STD 비율

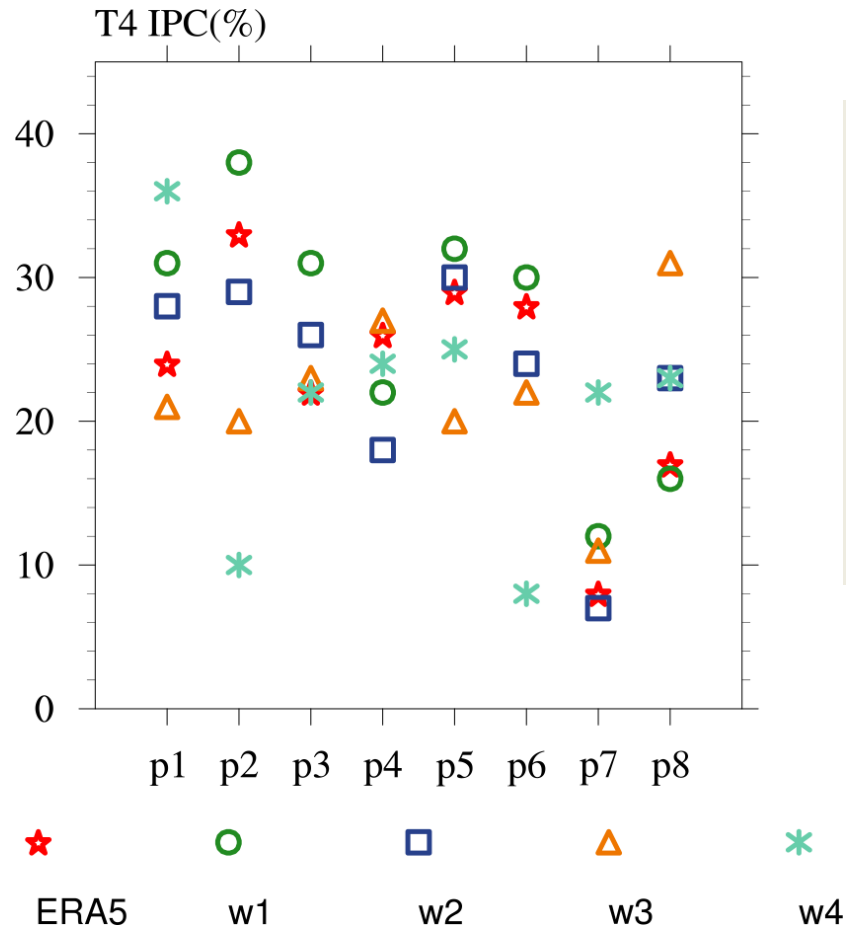
						1.0 미만	1.0 초과	
	P1	P2	P3	P4	P5	P6	P7	P8
W1	0.98	0.96	0.99	0.93	0.99	1	0.98	0.96
W2	0.8	0.88	0.87	0.76	0.91	0.81	0.93	0.86
W3	0.56	0.83	0.51	0.61	0.66	0.73	0.52	0.56
W4	0.41	0.49	0.35	0.55	0.45	0.56	0.38	0.37
GC2.0	0.64	1.37	0.81	0.95	0.94	1.15	0.91	0.7

- 모델의 전반적인 **중위도 약한 반응**
- Lead time 에 따라 강도의 약화(1.0->0.8->0.6->0.4)



MJO teleconnection (Intra Phase Consistency)

MJO 위상(P)별 원격상관 패턴 상관계수가 0.5 이상 발생하는 빈도를 계산 (PCC > 0.5, %) : CMIP5 모델평균(5~20%, Tseng et al. 2018)



Each Phase 에서 sampling 된 event간의 일치도 즉 얼마나 consistent한 패턴을 모의하는 지에 대한 정보

- ERA5 결과, Phase 2가 가장 높고 Phase 7(Maritime continent)에서 가장 낮음
- 모델에서도 유사한 결과가 나타남

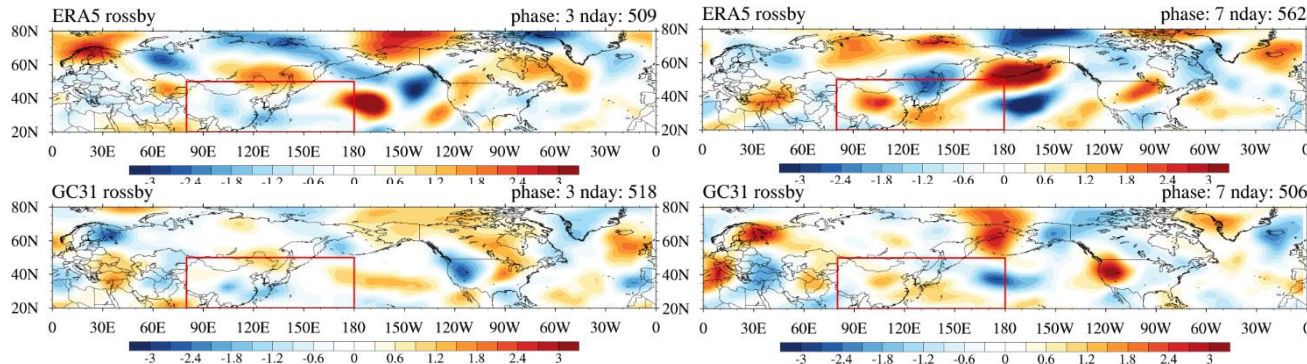
Rossby Wave Source Pattern

$$RWS = (-\bar{\xi} \nabla \cdot \mathbf{V}'_x - \xi' \nabla \cdot \bar{\mathbf{V}}_x) + (-\mathbf{V}'_x \cdot \nabla \bar{\xi} - \bar{\mathbf{V}}_x \cdot \nabla \xi')$$

열대지역의 강제력에 의해 발생하는 중위도 순환 아노말리는 로스비파의 전파로 설명되며 linear, stationary Rossby wave theory에 따라 로스비파의 발생 원인을 설명할 때 로스비 근원항(RWS)을 적용하여 진단함. 아시아-태평양지역(20°-70°N, 60°E-120°W)에서 재분석자료와 모델사이의 MJO 위상(P)별 RWS의 패턴 상관관계는 다음과 같음.

	P1	P2	P3	P4	P5	P6	P7	P8
GC2.0	0.51	0.58	0.59	0.44	0.33	0.35	0.49	0.5
W1	0.77	0.79	0.79	0.79	0.82	0.8	0.81	0.81
W2	0.65	0.67	0.62	0.52	0.62	0.57	0.61	0.6
W3	0.5	0.67	0.58	0.54	0.53	0.45	0.51	0.45
W4	0.41	0.58	0.48	0.52	0.55	0.53	0.52	0.49

0.5 이상

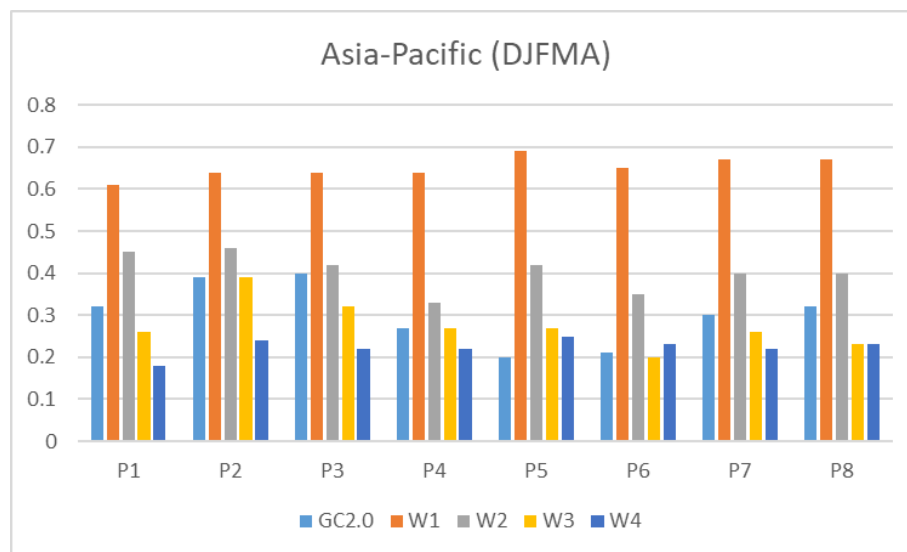


Rossby Wave Source Amplitude

재분석자료 대비 모델의 MJO 위상(P)별 중위도 지역(20°-50°N, 80°E-180°)에서 로스비근원항(RWS) STD 비율

		1.0 미만						1.0 초과	
	P1	P2	P3	P4	P5	P6	P7	P8	
GC2.0	0.96	1.04	1.04	0.97	1.06	0.88	0.77	1.06	
W1	0.99	0.96	1.01	1.06	1.02	0.94	1	1	
W2	0.8	0.74	0.85	0.8	0.84	0.67	0.74	0.85	
W3	0.54	0.5	0.51	0.47	0.5	0.44	0.49	0.55	
W4	0.44	0.35	0.45	0.38	0.41	0.39	0.38	0.44	

RWS 원격상관 패턴의 상관성 및 강도 (Taylor Skill Score)



5. 요약

The Madden Julian Oscillation (MJO) is the important prediction source for the sub-seasonal to seasonal forecast

GC2 successfully captures three-dimensional dynamics and thermodynamics structure of MJO eastward propagation. The model produces the boundary layer (BL) moisture convergence anomalies to the east of the MJO deep convection with easterly anomalies associated with the Kelvin wave.

The enhanced BL moisture convergence increases upward transport of moisture from the surface to the lower troposphere, inducing the moist lower troposphere and the positive convective instability by destabilization of the lower atmosphere and, thus, generating the next convection to the east of MJO deep convection and promoting MJO eastward propagation.

However, the signal for eastward propagation is relatively weak in the Maritime Continent (MC) and the Western Pacific (WP). To improve the MJO eastward propagation in the MC and WP, improved heating induced by shallow (or congestus) clouds interacting with enhanced BL dynamics may be required.



감사합니다