MJO simulation in the extended range hindcast of Korean Integrated Model (KIM)

Hye-Jin Park (hjpark@kiaps.org), Shin-Woo Kim & Taehyoun Shim
Korea Institute of Atmospheric Prediction System (KIAPS)

1 Introduction

- The Madden-Julian Oscillation (MJO) is the dominant mode of tropical atmospheric variability on sub-seasonal time scales. It is characterized by a periodic eastward propagation of large-scale atmospheric disturbances including enhanced convection, cloudiness, and related atmospheric circulation. Understanding and accurately predicting the MJO is crucial because of its significant impact on global weather systems. Accurate MJO forecasts can improve the predictability of weather patterns weeks in advance, offering valuable insights for agriculture, disaster management and various socio-economic sectors.
- Korean Integrated Model (KIM) is currently utilized by the KMA as its operational numerical weather forecast model for medium-range forecasts. KIAPS is making various efforts to extend the forecast range from 10 days to 30 days using the KIM. In this study, we evaluated the performance of the MJO simulation in an extended-range ensemble hindcast (HCST, reforecasts) dataset of KIM to understand its characteristics within the atmospheric model.

2 Datasets

- **KIM extended-range ensemble Hindcast datasets**

Model version	KIM4.0 NE090L91 (~50km)
Initial conditions	ERA5 reanalysis data
Boundary condition	**Prescribed ERA5 SST at 24-hour intervals**
Ensemble size	1 control run (CTRL) + 5 perturbed runs = 6
Hindcast period	2001-2020 (20 years)
Initial integration date	1, 9, 17 and 25th of Nov. – next Feb, 2001/02-2020/21
Forecast length	40 days

- **Validation datasets (OBS)**
  - ERA5 reanalysis / NOAA HIRS OLR (daily mean data)

3 Methods

- **Real-time Multivariate MJO (RMM) index** (Wheeler and Hendon, 2004)
  Indices based on the combined EOF 1 & 2 structure of intraseasonal anomalies of OLR, U850 and U200 in the equatorial region (15˚S – 15˚N)
- **Verification Materials of MJO**
  - **Bivariate Correlation Coefficient (BCOR)** as a function of forecast lead time (Rashied et al., 2011)

$$\mathrm{BCOR}(\tau)=\frac{\sum_{i=1}^{N}[\mathrm{oRMM1}_i(t)\mathrm{fRMM1}_t(t,\tau)+\mathrm{oRMM2}_i(t)\mathrm{fRMM2}_i(t,\tau)]}{\sqrt{\sum_{i=1}^{N}[\mathrm{oRMM1}_i^2(t)+\mathrm{oRMM2}_i^2(t)]}\sqrt{\sum_{i=1}^{N}[\mathrm{fRMM1}_i^2(t,\tau)+\mathrm{fRMM2}_i^2(t,\tau)]}}$$

✓ **MJO amplitude & phase**

$$AMP=\sqrt{RMM1(t)^2+RMM2(t)^2}$$

$$\phi=\tan^{-1}\left[\frac{RMM2(t)}{RMM1(t)}\right]$$

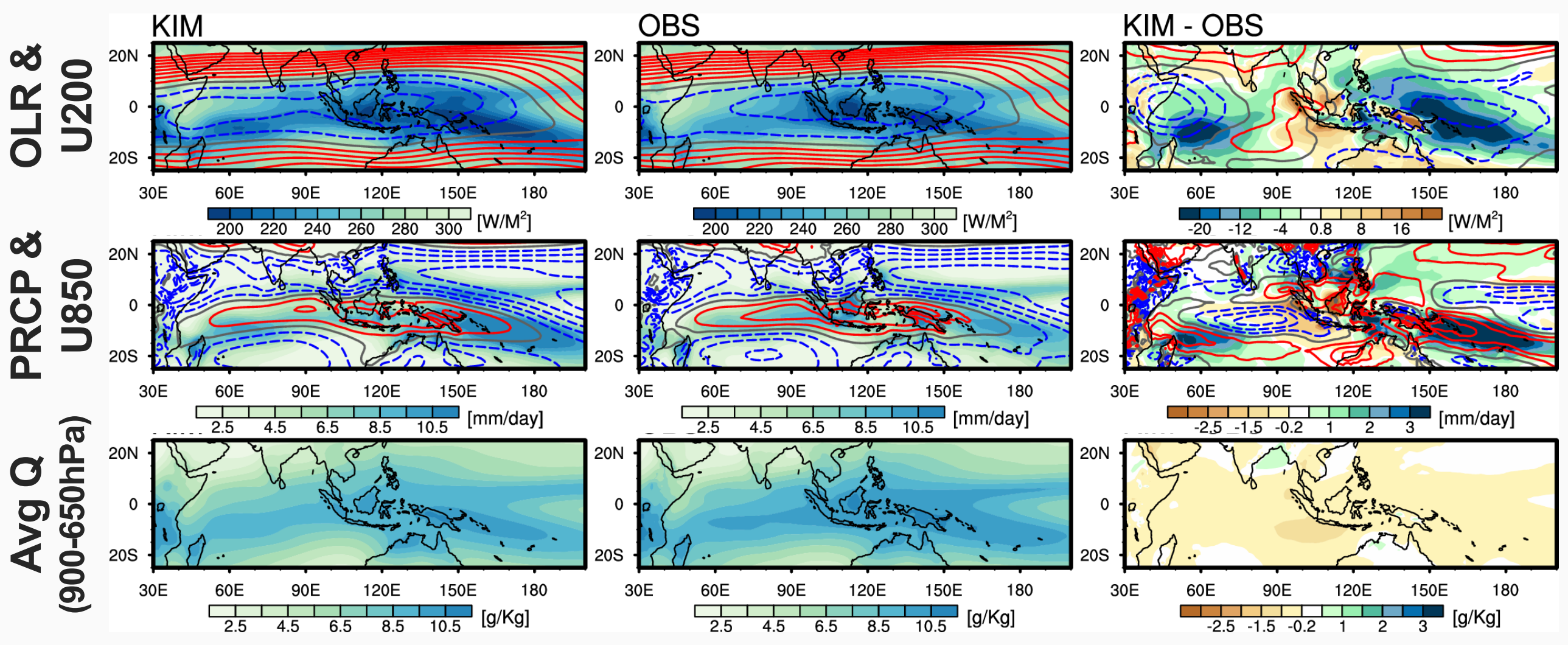
  - **Segment Prediction Skill (SPS)** for each individual initialization (H. Kim et al., 2016)

$$\mathrm{SPS}(i)=\frac{\sum_{\tau=1}^{T}[\mathrm{oRMM1}(\tau)\times\mathrm{oRMM1}(\tau)+\mathrm{oRMM1}(\tau)\mathrm{oRMM1}(\tau)]}{\sqrt{\sum_{\tau=1}^{T}[\mathrm{oRMM1}^2(\tau)+\mathrm{oRMM2}^2(\tau)]}\sqrt{\sum_{\tau=1}^{T}[\mathrm{fRMM1}^2(\tau)+\mathrm{fRMM2}^2(\tau)]}}$$

$\tau = 1$: first lead time
$\tau = T$: last lead time (30D)

4 Results

A. Mean State



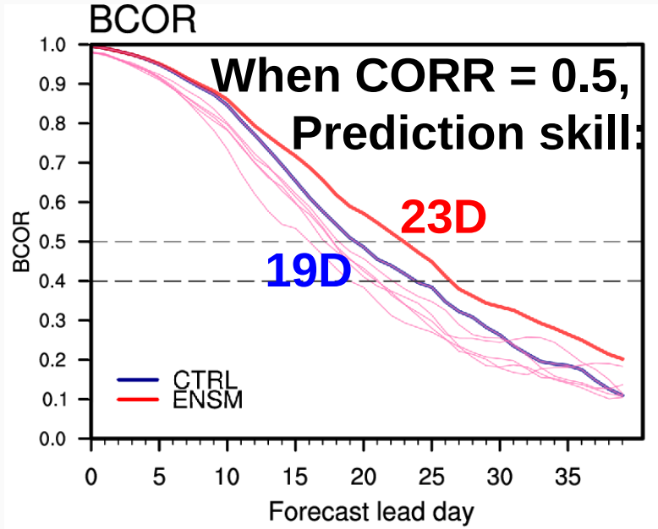
Figure> Mean state of atmospheric variables of KIM and OBS over the tropical Indo-western Pacific Ocean for the 1-30 lead time forecast, and **the mean bias of KIM** (average of 320 initiations).

- Wind contour interval (mean /diff)
  - U850: 2m/s / 0.5m/s
  - U200: 4m/s / 1m/s

B. Overall MJO Prediction Performance

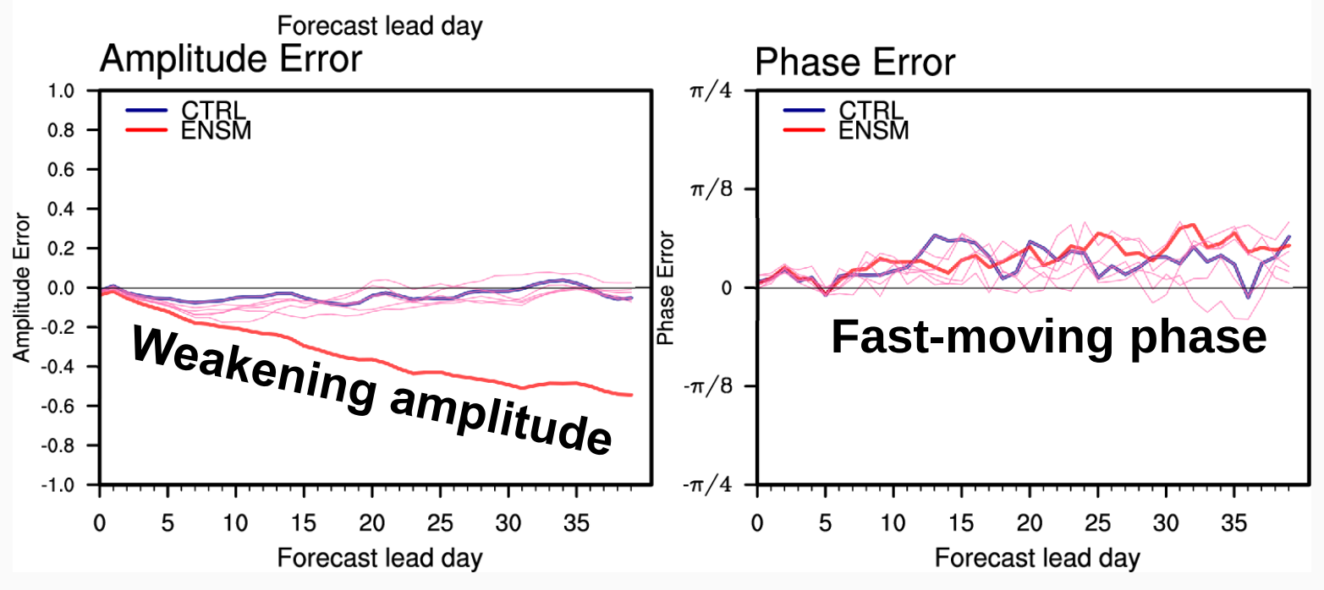
Figure> Prediction skill metrics as function of forecast lead time for the 320 initiations (20years x 4 months x 4 times).

BCOR & MJO amplitude/phase Errors

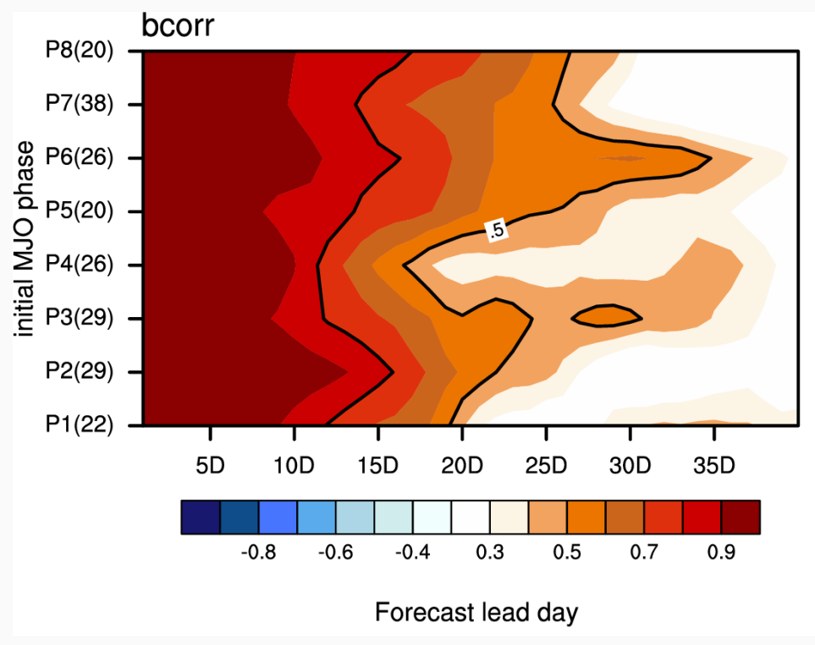


▶ Ensemble forecasting (ENSM) can improve the MJO prediction skill.

▶ **[AMP-ERROR]**: Due to the growing ensemble spread with increasing forecast lead time.



MJO skill for MJO phase in initiation date

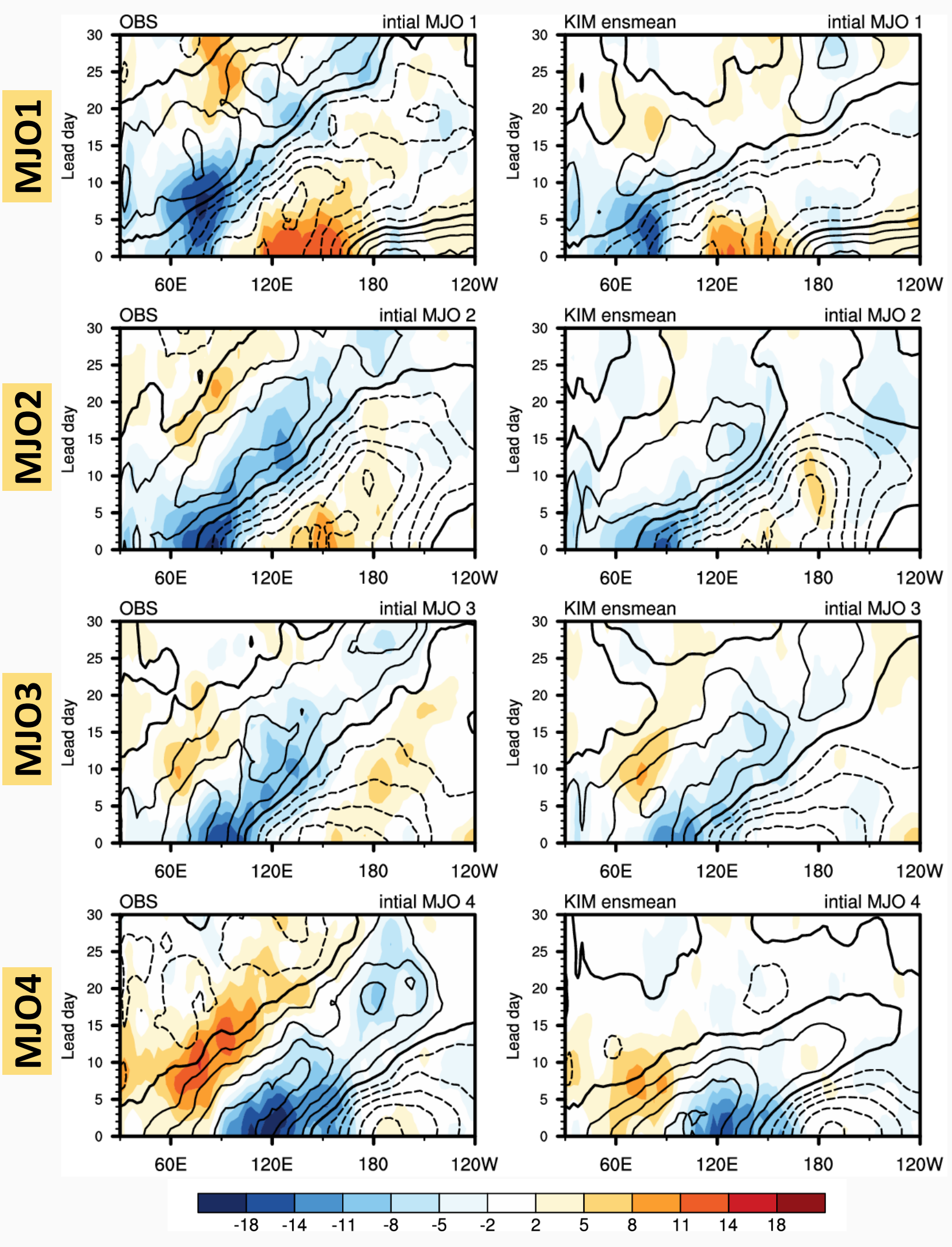


▶ MJO skill is higher for initializations starting from MJO P6. On the other hand, the skill is lowest for those starting from MJO P4 due to MC barrier effect.

Composite of OLR & U850 Anomalies

- 5-day moving average / 15˚S – 15˚N meridional average

- Shading : OLR
- Contour : U850

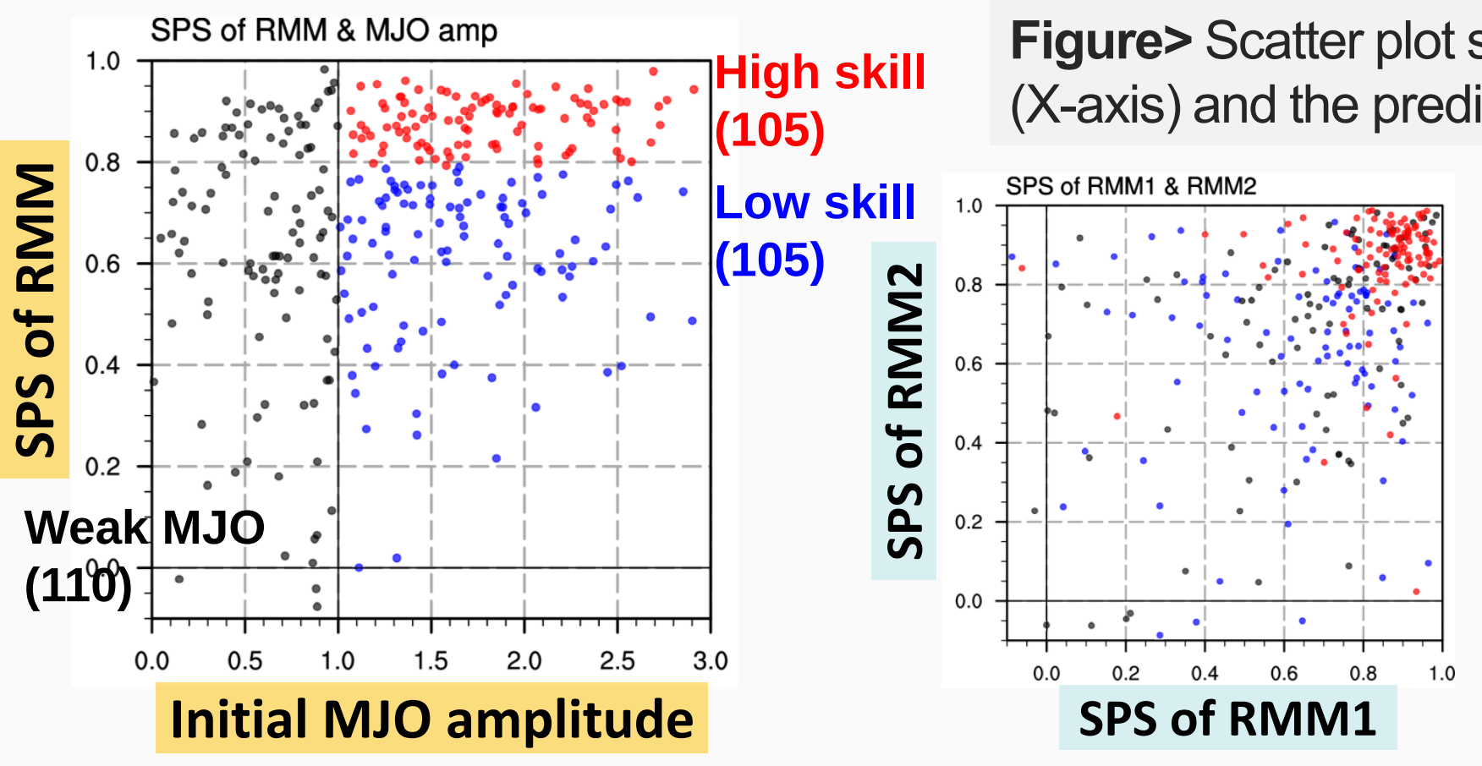


▶ OLR anomalies decrease more rapidly than OBS. Also speed of U850 anomaly increase when passing through the MC region.

Figures> Composite of tropical OLR and U850 anomalies for OBS and KIM ensemble mean starting from each MJO phase (P1 – P4).

C. MJO Prediction Skill in High (Low) SPS

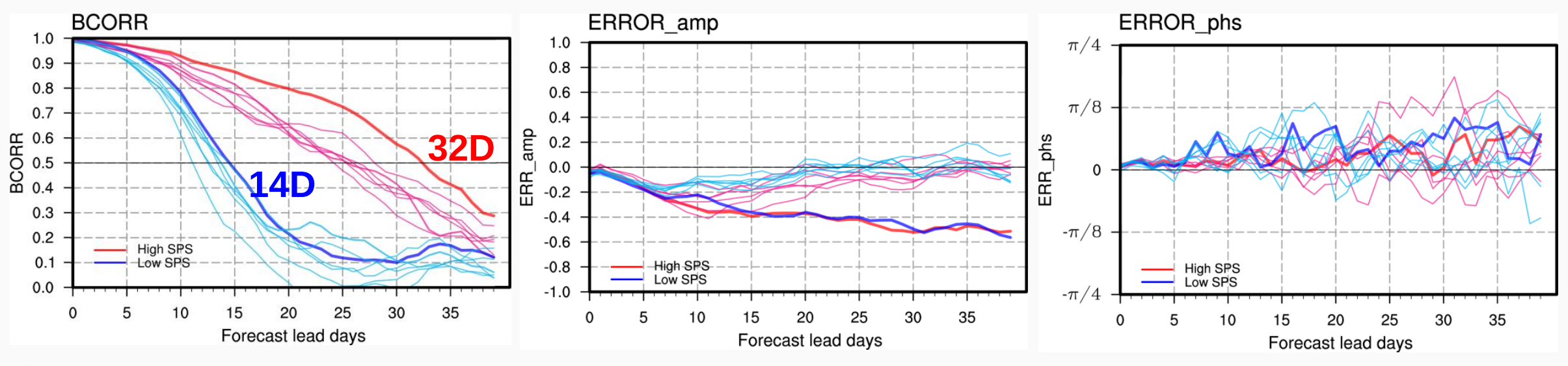
Grouping by MJO prediction skill for individual initialization



Figure> Scatter plot showing the relationship between initial MJO amplitude (X-axis) and the prediction skill of RMM for individual initializations (Y-axis).

▶ When the initial MJO amplitude is larger, the SPS values tend to cluster towards high skill. However, when the initial MJO amplitude is smaller, the SPS values are more widely distributed.
▶ As expected, when both RMM indices have high SPS prediction skill, the MJO prediction skill is also high.

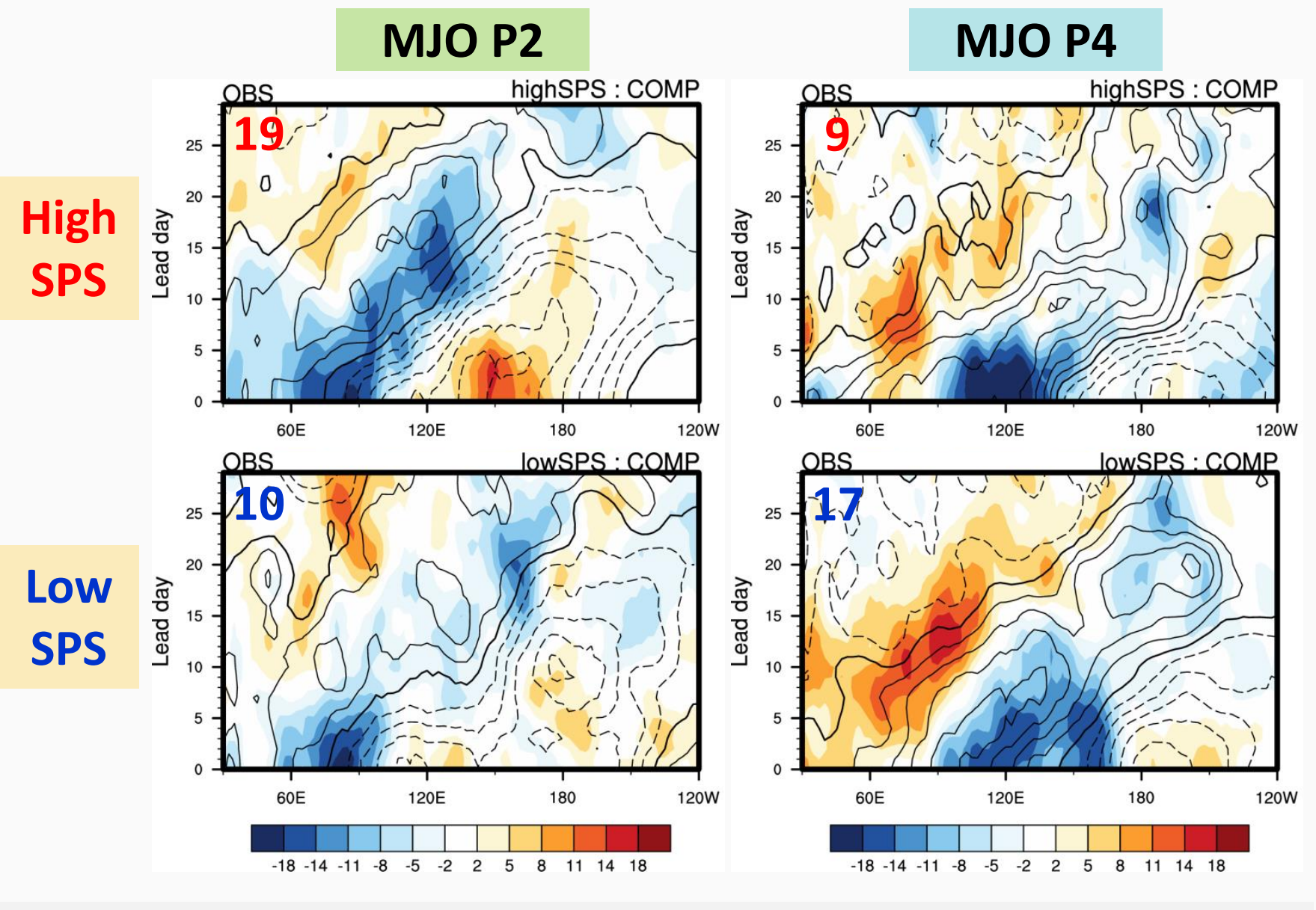
MJO prediction skill as a function of forecast lead time for High & Low SPSs



Figure> BCOR (Left), **Amplitude Error (Center)** and **Phase Error (Right)** as a function of forecast lead time for High and Low SPSs. X-axis denotes the forecast lead time. Red (blue) lines denote the prediction skills for High (Low) SPS and Thick (thin) lines denote for the ensemble mean(individual ensemble member).

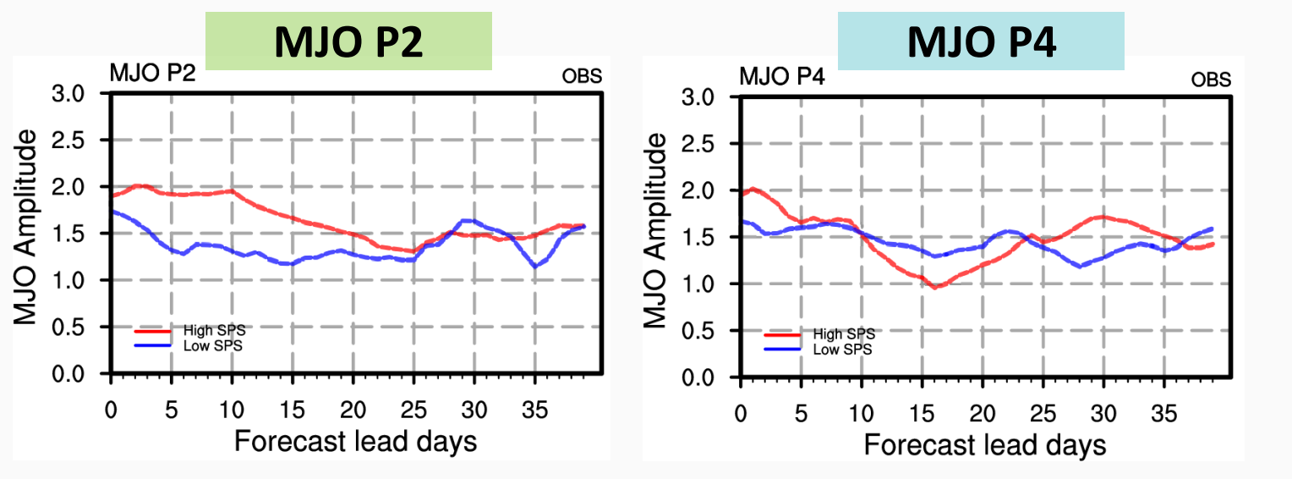
▶ **[BCOR]** As the forecast lead time increases, the BCOR for High (Low) SPS decreases gradually (sharply). Also, the BCOR difference between the ensemble mean and individual ensemble members is larger at High SPS compared to Low SPS. **[Errors]** The amplitude error both two groups are similar weakened. the low SPS group has faster phase errors at earlier forecast lead times compared to the high SPS group.

Difference in OBS between High & Low SPS in each initial MJO phase



Figure> Composite of tropical OLR and U850 anomalies for **OBS** starting from MJO P2 and P4 for High and Low SPSs. X-axis (Y-axis) denotes longitude (the forecast lead time). The number in the top left of figure represents to number of initializations

▶ **[MJO P2]** The high SPS exhibits clear eastward propagation of the MJO over a long forecast lead time, whereas the low SPS does not. Similar characteristics are observed in most phase, except for P4. **[MJO P4]** On the contrary, a relatively more distinct eastward propagation appears in the Low SPS.



▶ **[MJO P2]** For high SPS, the MJO amplitude either grows or is maintained at the beginning of the forecast. In contrast, the amplitude decrease in the low SPS. **[MJO P4]** The MJO amplitude in the high SPS decreases gradually.

5 Summary and Conclusions

- This study assessed the Madden-Julian Oscillation (MJO) prediction performance using the Korean Integrated Model (KIM) in extended-range ensemble hindcasts.
- **[Mean State]** KIM showed weaker convection in the tropical eastern Indian Ocean and stronger in the western Pacific, with reduced low-level moisture in these regions.
- **[Prediction Performance]** The ensemble mean provided better MJO predictions than individual members, but errors increased with lead time, with reduced amplitude and faster propagation compared to observations.
- **[High vs Low SPS]** MJO prediction skill was notably higher when the initial MJO amplitude was large, particularly in high SPS group. As the forecast lead time increased, the BCOR showed significantly different decrease patterns between High SPS (gradual) and Low SPS (sharp).
- Further analysis is required to identify the cause of the difference between High and Low SPS in the KIM model and to determine if similar characteristics are represented in other models. This results could help improve MJO prediction performance in the KIM model.

Workshop on Diagnostics for Global Weather Prediction, 9-12 September 2024, ECMWF