## Optimal initial perturbations for ensemble prediction of Madden-Julian Oscillation during boreal winter season using GEOS-5 coupled model

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To investigate the impact of the optimal initial perturbations on ensemble prediction of Madden-Julian oscillation (MJO), the Empirical Singular Vector (ESV) is applied to the ensemble MJO prediction system using the Goddard Earth Observing System Model, Version 5 Coupled General Circulation Model (GEOS-5 CGCM) during boreal winter season. The initial ESV, extracted using 10-year hindcast data from 1990 to 1999, shows the robust zonal wind anomalies over the western Indian ocean, while the final ESV at 10-day lead forecast shows that the zonal wind anomalies propagates to the east over the maritime continent. With the ESV, the ensemble MJO prediction is performed for boreal winter season from 1990 to 1999, and the forecast skill is compared to that with 1-day Lagged Averaged Forecast (LAF). It is shown that the prediction with the ESV has a systematically higher bivariate correlation skill compared to that with the LAF. Especially, the improvement of the correlation skill with the ESV is robust during the MJO phase 4-8. For example, the improvement of bivariate correlation skill with the ESV during 20-25 day lead forecast is about 0.25 for MJO phase 4. Because the correlation skill with the LAF method during these MJO phases are relatively lower than the other MJO phases, it implies that optimal perturbation works more effectively during the unpredictable period. Similarly, the improvement of bivariate correlation skill with the ESV is robust for weak MJO cases, which is relatively hard to predict than the strong MJO cases.