

# GEFSv12 Real time multivariate MJO Indices

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## Overview

This document provides details about the Real time multivariate MJO (RMM) indices available for the GEFSv12 reanalysis and reforecast datasets.

## Methodology

The MJO indices are calculated using the methodology outlined in Wheeler and Hendon (2004).

### Reanalysis RMMs

For the GEFSv12 reanalysis, anomalies of outgoing longwave radiation (OLR), 200 hPa zonal winds (U200), and 850 hPa zonal winds (U850) are calculated by removing the mean and climatological seasonal cycle (first three harmonics) of each of these fields from their full January 1<sup>st</sup> 2000 – December 31<sup>st</sup> 2019 timeseries. Next, for one of the aforementioned fields of anomalies on a given day in January 1<sup>st</sup> 2000 – December 31<sup>st</sup> 2019 timeseries, the mean of the most recent 120 days of anomaly data for that field is subtracted to remove the influence of low frequency variability (e.g., ENSO). In order to remove the means of the most recent 120 days for the early 2000 period, year 1999 data is needed, therefore we use anomalies derived from Climate Forecast System Reanalysis (Saha et al. 2010). CFSR data is also used to extend the MJO indices beyond 2020 for comparison with reforecasts initialized in December of 2019. Next, the anomalous fields are latitudinally averaged between 15S and 15N using square root of cosine weighting. Then each of these latitudinally averaged sets of anomalies is divided by the normalization factor provided by WH04: 15.1 W/m<sup>2</sup> for OLR; 4.81 m/s for U200 1.81 m/s for U850. The anomalous fields are then projected onto the GEFSv12 reanalysis EOFs shown below in solid contours. Finally, the projection coefficients are standardized by their respective standard deviations (8.6 and 8.4).

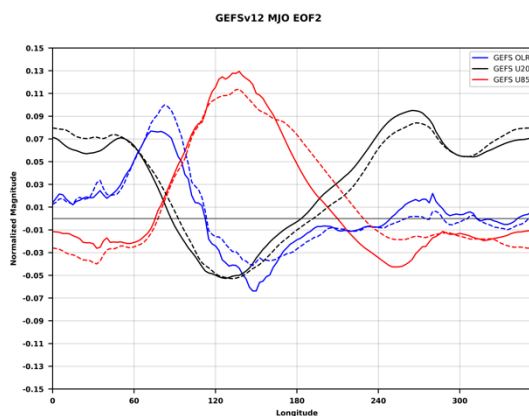
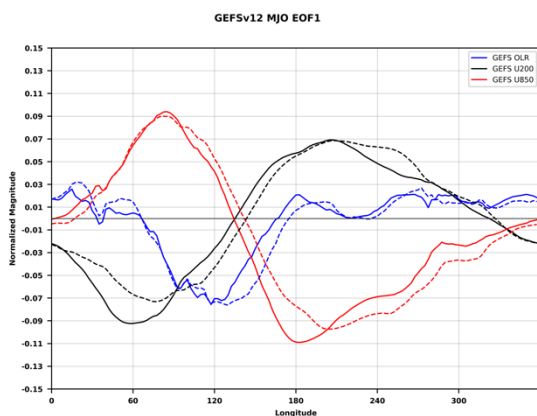


Figure 1: EOF1 (left) and EOF2 (right) derived from 2000-2019 GEFSv12 reanalysis are shown in solid contours and 1979-2002 NCEP equivalents (as in WH04) are shown dashed for comparison. OLR is shown in blue, U200 in black, and U850 in red.

### Reforecast ensemble mean RMMs

For the GEFSv12 reforecasts, each of the 11 ensemble members for a given reforecast initialization are first averaged together. The MJO indices are then calculated using the adaptations of WH04 methodology applied to forecast datasets detailed by Gottschalck et al. (2010). Different from step (i) of G2010, here, anomalies of OLR, U200, and U850 are calculated relative to lead-time dependent reforecast climatologies as described in Pegion et al. (2019), their Appendix B, which helps to remove biases in the anomalies originating from the natural drift of the reforecast towards a model's own internal mean state (Becker et al. 2014). While removing the means of the most recent 120 days of anomaly data for a given field in step (ii) from G2010, a combination of GEFSv12 reanalysis and GEFSv12 reforecast data is used. For instance, if we seek to remove the mean of the most recent 120 days of U200 anomaly data from lead 15 of the January 2<sup>nd</sup>, 2019 reforecast, noting that lead 15 will correspond to January 17<sup>th</sup>, 2019, the 120 days of anomalies will be made up of 105 days of GEFSv12 reanalysis data derived from the period preceding January 2<sup>nd</sup> and 15 days of reforecast data between January 2<sup>nd</sup> 2019 and January 17<sup>th</sup> 2019. Following this step, all steps are the same as in the reanalysis: latitudinal averaging in the tropics, dividing the fields by their normalization factors, projecting onto the GEFSv12 reanalysis EOFs, and standardizing.

Ensemble mean RMM1 values computed by projecting OLR, U200, and U850 ensemble mean anomalies of GEFSv12 reforecast data onto EOF1 derived from the GEFSv12 reanalysis and then standardizing the coefficients by dividing by 8.6. The anomalies are determined by removing the lead-time dependent reforecast climatologies and the mean of the most recent 120 days of reanalysis/reforecast data.

### Reforecast individual member RMMs

Rather than averaging together the 11 ensemble members for a given reforecast initialization as in the ensemble mean calculations, each member can be preserved and from it, the corresponding lead time dependent climatology for the relevant field is removed. This allows us to calculate anomalies for each member of each reforecast and subsequently calculate RMMs exactly the same way as described in the preceding section.

**ncdump -h GEFSv12\_RMMs\_Reforecast\_ensemble\_mean**

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dimensions:
    lead = 36 ;
    init = 1043 ;
variables:
    int64 lead(lead) ;
        lead:units = "days" ;
        lead:long_name = "Days from initialization" ;
    double rmm1(init, lead) ;
        rmm1:_FillValue = NaN ;
        rmm1:long_name = "Real-time multivariate MJO indices 1" ;
        rmm1:description = "Ensemble mean RMM1 values computed by
projecting OLR, U200, and U850 ensemble mean anomalies of GEFSv12
reforecast data onto EOF1 derived from the GEFSv12 reanalysis and then
standardizing the coefficients by dividing by 8.6. The anomalies are
determined by removing the lead-time dependent ensemble mean
reforecast climatologies and the mean of the most recent 120 days of
reanalysis/reforecast data." ;
    int64 init(init) ;
        init:long_name = "Initialization Date" ;
        init:standard_name = "forecast_reference_time" ;
        init:units = "days since 2000-01-05" ;
        init:calendar = "proleptic_gregorian" ;
    int64 valid_time(init, lead) ;
        valid_time:units = "days since 2000-01-05" ;
        valid_time:calendar = "proleptic_gregorian" ;
    double rmm2(init, lead) ;
        rmm2:_FillValue = NaN ;
        rmm2:long_name = "Real-time multivariate MJO indices 2" ;
        rmm2:description = "Ensemble mean RMM2 values computed by
projecting OLR, U200, and U850 ensemble mean anomalies of GEFSv12
reforecast data onto EOF2 derived from the GEFSv12 reanalysis and then
standardizing the coefficients by dividing by 8.4. The anomalies are
determined by removing the lead-time dependent ensemble mean
reforecast climatologies and the mean of the most recent 120 days of
reanalysis/reforecast data." ;
        rmm2:missing_value = NaN ;

// global attributes:
    :source = "GEFSv12 Reforecasts (obtained from
https://registry.opendata.aws/noaa-gefs-reforecast/)" ;
    :contact = "Dillon Elsbury (dillon.elsbury@noaa.gov), Zachary
Lawrence (zachary.lawrence@noaa.gov), Maria Gehne
(maria.gehne@noaa.gov)" ;
}
```

**ncdump -h GEFSv12\_RMMs\_Reforecast\_ensemble\_members.nc**

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netcdf GEFSv12_RMMs_Reforecast_ensemble_members {
dimensions:
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    init = 1043 ;
    member = 11 ;
variables:
    int64 lead(lead) ;
    double rmm1(init, member, lead) ;
        rmm1:_FillValue = NaN ;
        rmm1:long_name = "Real-time multivariate MJO indices 1" ;
        rmm1:description = "Single ensemble member RMM1 values
computed by projecting OLR, U200, and U850 anomalies for a given
enesmble member and given initialization of GEFSv12 reforecast data
onto EOF1 derived from the GEFSv12 reanalysis and then standardizing
the coefficients by dividing by 8.6. The anomalies are determined by
removing the lead-time dependent ensemble mean reforecast
climatologies and the mean of the most recent 120 days of
reanalysis/reforecast data." ;
        rmm1:coordinates = "init" ;
    int64 init(init) ;
        init:long_name = "Initialization Date" ;
        init:standard_name = "forecast_reference_time" ;
        init:units = "days since 2000-01-05" ;
        init:calendar = "proleptic_gregorian" ;
    int64 valid_time(init, member, lead) ;
        valid_time:coordinates = "init" ;
        valid_time:units = "days since 2000-01-05" ;
        valid_time:calendar = "proleptic_gregorian" ;
    double rmm2(init, member, lead) ;
        rmm2:_FillValue = NaN ;
        rmm2:long_name = "Real-time multivariate MJO indices 2" ;
        rmm2:description = "Single ensemble member RMM2 values
computed by projecting OLR, U200, and U850 anomalies for a given
enesmble member and given initialization of GEFSv12 reforecast data
onto EOF2 derived from the GEFSv12 reanalysis and then standardizing
the coefficients by dividing by 8.4. The anomalies are determined by
removing the lead-time dependent ensemble mean reforecast
climatologies and the mean of the most recent 120 days of
reanalysis/reforecast data." ;
        rmm2:coordinates = "init" ;

// global attributes:
    :source = "GEFSv12 Reforecasts (obtained from
https://registry.opendata.aws/noaa-gefs-reforecast/)" ;
    :contact = "Dillon Elsbury (dillon.elsbury@noaa.gov), Zachary
Lawrence (zachary.lawrence@noaa.gov), Maria Gehne
(maria.gehne@noaa.gov)" ;
}
```

**ncdump -h Reanalysis\_GEFSv12\_RMM1\_RMM2.nc**

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netcdf Reanalysis_GEFSv12_RMM1_RMM2 {
dimensions:
    time = 7396 ;
variables:
    int64 time(time) ;
        time:units = "days since 2000-01-01" ;
        time:calendar = "proleptic_gregorian" ;
    double rmm1(time) ;
        rmm1:_FillValue = NaN ;
        rmm1:long_name = "Real-time multivariate MJO indices 1" ;
        rmm1:description = "Reanalysis RMM1 values computed by
projecting OLR, U200, and U850 anomalies of GEFSv12 reanalysis data
onto EOF1 derived from the GEFSv12 reanalysis and then standardizing
the coefficients by dividing by 8.6. The anomalies are calculated by
subtracting the mean and climatological seasonal cycle (first three
harmonics), then removing the mean of the most recent 120 days of
reanalysis data." ;
    double rmm2(time) ;
        rmm2:_FillValue = NaN ;
        rmm2:long_name = "Real-time multivariate MJO indices 2" ;
        rmm2:description = "Reanalysis RMM2 values computed by
projecting OLR, U200, and U850 anomalies of GEFSv12 reanalysis data
onto EOF2 derived from the GEFSv12 reanalysis and then standardizing
the coefficients by dividing by 8.4. The anomalies are calculated by
subtracting the mean and climatological seasonal cycle (first three
harmonics), then removing the mean of the most recent 120 days of
reanalysis data." ;

// global attributes:
    :source = "GEFSv12 Reanalysis (obtained from
ftp.emc.ncep.noaa.gov/GEFSv12/reanalysis/FV3_reanalysis/)" ;
    :contact = "Dillon Elsbury (dillon.elsbury@noaa.gov), Zachary
Lawrence (zachary.lawrence@noaa.gov), Maria Gehne
(maria.gehne@noaa.gov)" ;
}
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