Prediction of Western Disturbances Tracks using NEPS

Arulalan.T[1,2], Krishna AchutaRao[2], Kieran M R Hunt[3], Andrew G Turner[3,4], Ashish K Mitra[1] and Abhijit Sarkar[1]

1 National Centre for Medium Range Weather Forecasting (NCMRWF), Noida, India
2 Centre for Atmospheric Sciences, Indian Institute of Technology Delhi, India
3 Department of Meteorology, University of Reading, Reading, United Kingdom
4 National Centre for Atmospheric Science, University of Reading, Reading, United Kingdom
arulalan@ncmrwf.gov.in (corresponding author)

Abstract

Western disturbances (WDs) are synoptic-scale cyclonic weather systems advected over Pakistan and northern India by the subtropical westerly jet stream. There, they are responsible formost of the winter precipitation, which is crucial for agriculture of the rabi crop as well for as more extreme precipitation events, which can lead to local flooding and avalanches. Using ERA5 reanalysis (1979-2018) found more than 3000 WDs tracks, 5% out of which caused heavy precipitations (40mm/day), which have a frequency of about per 4 year. Prediction of WDs is most essential to take necessary precautions in advance by local government during winter extreme precipitation events.

1 Introduction

Western disturbances (WDs) are formally defined by the India Meteorological Department as: "cyclonic circulation/trough in the mid and lower tropospheric levels or as a low pressure area on the surface, which occurs in middle latitude westerlies and originates over the Mediterranean Sea, Caspian Sea and Black Sea and moves eastwards across north India" [1]. WDs are, at the most fundamental level, synoptic-scale vertical perturbations embedded in the subtropical westerly jet stream (STWJ). They are often associated with extreme rainfall events in the Karakoram and Hindu Kush regions of Pakistan and north India (e.g.,[2]), and have been the subject of a number of modelling case studies (e.g., [3]). The recent study Hunt et al., (2017) defined the algorithm to track WDs and found 3090 tracks using ERA-I reanalysis [4] (1979-2016), elaborated the WD tracks by in terms of its associated precipitations (normal to heavy). In the current study, we implemented the same algorithm (Hunt et al., 2017 [5]) using NCMRWF operational global unified model (NCUM-G) analysis (near real time 4Dvar data assimilation) and global ensemble model (NEPS) 1 control + 22 members forecasts upto 240 hours, to predict the WDs tracks and its associated precipitation.

2 Methodology

Hunt et al., (2017) examined the vertical structure of vorticity in many case studies (using ERA-I from 1979-2016), found the strongest signal seen in between 450 and 300 hPa, with a spatial scale of the order of several hundred kilometres. In order to expand this case study selection into a complete catalogue of western disturbances, [5] developed a tracking algorithm to be run on any reanalysis data and forecast models. The prescription is as follows.

2. 1 Tracking algorithm

(1) Compute the mean relative vorticity in the 450–300 hPa layer, then truncate the spectral resolution at T63 (~200 km at the Equator). We shall call this quantity ξ.

(2) Locate all local maxima in ξ subject to some radius δ, such that a point is considered a local maximum if no points with a distance δ have a greater value of ξ. We shall call this set of local maxima χi.

(3) For each χi, associate local positive non-zero values of ξ and integrate to find the centroid of ξ for each. We shall call this set of points Xi.

(4) (a) To group the candidate points into tracks: for each Xi at time point j, seek and attach the nearest neighbour from time point j + 1, so long as it is within some distance Δ, using the kd-tree nearest- neighbour algorithm.

(4) (b) The efficacy of this step can be increased by introducing the concept of a background velocity, important when considering the high-frequency, high-velocity nature of WDs. Here this is done by biasing the search radius using the contemporaneous wind field: for example, in a wind field u, the central location from which the nearest neighbour is sought is not X_i but $X_i + u(X_i) \cdot (t^{j+1} - t^j)$. Simply put, rather than starting the nearest neighbour search at the location of the candidate point at the previous time point, we assume it is advected by the background winds and start the search from the location where it would have ended up after such advection.

(5) We also hold the tracks in memory for one time point, looking for a candidate in time point j + 2 within 2Δ of X_i. This prevents breaking a track into two pieces unnecessarily in the event of a candidate apparently disappearing for a single time point.

(6) These resulting tracks are then filtered three times. Firstly, 'stubs' of length shorter than 2 days are rejected. Secondly, tracks that do not pass through Pakistan or north India, here defined as 20–36.5°N, 60–80°E are rejected as not of interest to this study. Finally tracks whose geneses are east of their lyses and thus do not propagate eastwards are rejected.

(7) The values of δ and Δ are determined empirically by running the algorithm over the 19 case studies identified from previous literature and choosing the combination giving the closest match. These were chosen to be 850km and 1000km $(6\ h)^{-1}$, respectively.

2.2 WD tracks using Medium-Range Forecasts

NCMRWF is running high resolution (12km) deterministic global model (NCUM-G [6]) and ensemble global model (NEPS, 22 members [7]) for next 10 days (medium range), operationally. To implement the above WD tracking algorithm (section 2.1) on NCUM-G and NEPS, we derive relative vorticity at very high resolution (12km) from winds at pressure levels 300, 400, and 500 hPa. Then we convert the relative vorticity to T63 resolution and followed by finding mean relative vorticity in the 500–300 hPa. Finally, apply the tracking algorithm to all ensemble members (1 control + 22 members) individually.

3 Results

The NCUM and NEPS models showed the capability of prediction of western disturbances tracks (Figure 2, 3, 4).

3.1 ERA5 reanalysis Vs NCUM analysis

Both ERA5 reanalysis [8] and NCUM analysis (near real time) shows a very similar WD tracks during Nov-2019, Dec-2019 and Jan-2020 months. In Figure-1, showed the WD tracks using ERA5 dataset, there are 12 tracks during Nov, Dec 2019 and 11 tracks during Jan 2020, but where as in NCUM analysis (Figure-2) 15 tracks during Nov, Dec 2019 and 8 tracks during Jan 2020. Though most of the tracks are found to be similar in position for NCUM and ERA, but there are 2 different tracks in NCUM which geneses over north Atlantic and north poleward. This may be come from difference in reanalysis and near real time analysis data assimilations.

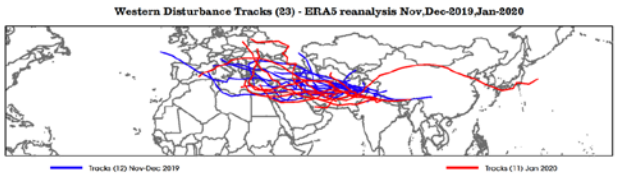

Figure 1. In ERA5 reanalysis – found 23 WD tracks during Nov,Dec-2019, Jan-2020.

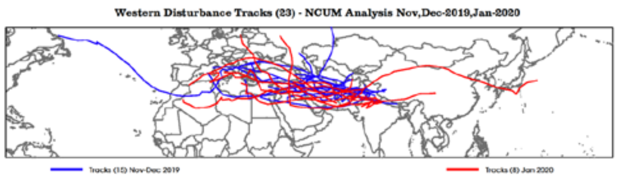

Figure 2. In NCUM analysis – found 23 WD tracks during Nov,Dec-2019, Jan-2020.

3.2 NEPS Forecast Vs NCUM analysis

In Figure-3, showed WD tracks forecast using NEPS (1 control + 22 members) based on initial condition as on 01-Feb-2020. The algorithm found 6 different tracks within 10 days period (01-Feb to 10-Feb 2020). The different color depicts different start date of the WD tracks in figure-3. The verification of this forecast can be compared with the actual NCUM analysis (showed in Figure-4). By comparing the figure 3 and 4, it is proved that NEPS model able to capture the WD tracks in its all ensemble members (few members are over predicted in location which lysis are gone beyond Russia and West Pacific regions. Other than few members tracks, most of the tracks forecast are found to be better match with the NCUM analysis. Few NEPS members forecast tracks lyses are crossing central and south Indian subcontinent which are match with NCUM analysis.

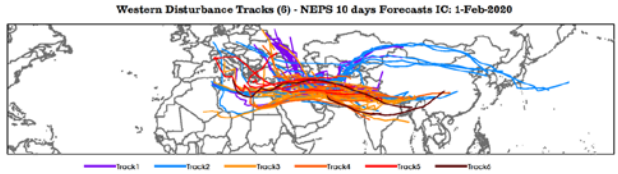

Figure 3. In NEPS (1 control + 22 members) 10 days forecast – found 6 different WD tracks initial condition as on 01-Feb-2020. Actual tracks (verification) are plotted in Figure 4.

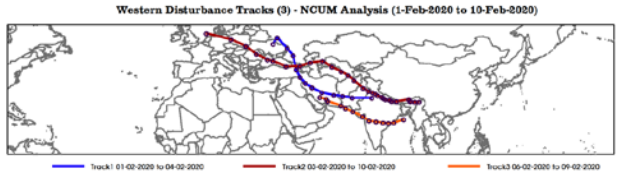

Figure 4. In NCUM analysis – found 3 WD tracks during 01-Feb-2020 to 10-Feb-2020 (10 days). Black dots in track line indicates the 6-hourly time positions of the WD tracks.

4 Scope for future work

The ensemble prediction of WD tracks can be verified against analysis by statistical significance correlation and rms methods. Also, the precipitation associated with WDs can be overlined in the figures and type of precipitation category (same as in Hunt et al., 2017) can be found empirical orthogonal functions using observational rainfall dataset and historical analysis WD tracks.

References

[1] IMD-Glossary http://imd.gov.in/section/nhac/wxfaq.pdf

[2] Dimri, A. P., et al., (2015): Western disturbances: a review. Rev. Geophys., 53 (2), 225– 246.

[3] Dimri, A. P., and A. Chevuturi, (2014): Model sensitivity analysis study for western disturbances over the Himalayas. Meteor. Atmos. Phys., 123 (3-4), 155–180.

[4] Dee, D. P., et al., (2011): The ERA-Interim reanalysis: configuration and performance of the data assimilation system. Q.J.R. Meteorol. Soc., 137: 553–597. doi:10.1002/qj.828

[5] Kieran M. R. Hunt, et al., (2017): The evolution, seasonality and impacts of western disturbances. Q.J.R. Meteorol. Soc., 144: 278-290. doi:10.1002/qj.3200

[6] Sumit Kumar, et al., (2018): Implementation of New High Resolution NCUM Analysis-Forecast System in Mihir HPCS, NMRF/TR/01/2018

[7] Mamgain Ashu, et al., (2019): Medium‐range global ensemble prediction system at 12 km horizontal resolution and its preliminary validation. Meteorological Applications, doi.org/10.1002/met.1867

[8] Copernicus Climate Change Service (C3S) (2017): ERA5: Fifth generation of ECMWF atmospheric reanalyses of the global climate . Copernicus Climate

Change Service Climate Data Store (CDS), 01-Feb-2020. https://cds.climate.copernicus.eu/cdsapp#!/home