To study the long-term wind trend in Uttarakhand Himalayas using WRF simulation

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***Abstract* - 30 years of ECMWF Re-Analysis (ERA5) are dynamically downscaled from 1986 to 2015 with the Weather Research and Forecasting (WRF) model over central Himalayan region at convection permitting grid spacing (6.7 km). In winter and summer, the central Himalaya has been under the influence of an anti-cyclonic trend, which in summer the downscaling shows has reduced cloud cover, leading to significant warming and reduced snowfall in recent years. The aim of this study is to present the wind speed climate in the central Himalayan state of Uttarakhand based on ERA5 and to identify any long-term linear trends. Additionally, Inter-annual variability of wind speed has been examined in seven meteorological stations in Uttarakhand Himalaya.**

INTRODUCTION

The information of the near-surface wind speed climate and variability is essential for industries that are dependent or affected by winds such as wind energy, forestry and insurance. The near-surface winds have an important role in advection and surface fluxes to transfer heat and moisture horizontally and vertically between the atmosphere and the surface. Gregow et al. (2016) highlight the energy sector's desire for higher resolution and accurate wind datasets. In addition to global and regional wind atlases, reanalyses are a relevant source for wind assessments. Reanalysis systems provide a consistent analysis of the atmospheric state and aim to utilize observations as extensively as possible (Dee et al., 2014). Such datasets are well suited to wind assessments due to their global coverage, homogeneous data and long time periods. Previous studies (e.g., Kaiser-Weiss et al., 2015, 2019) have compared in-situ surface wind observations to reanalysis and, in general, it has been shown that the frequency distributions of mean wind speeds are well captured in reanalysis. The long-term wind speed variability and/or trends have been studied with many different reanalyses—e.g., ERA-Interim, MERRA-2, and JRA-55 (Torralba et al., 2017), NOAA-20CR (Bett et al., 2013) and ERA-40 (Kiss and Jánosi, 2008)- but not yet with the new ERA5 reanalysis (Hersbach et al., 2020). Furthermore, ERA5 has been found to outperform MERRA-2 in the wind power modelling (Olauson, 2018) and hence, ERA5 is likely to be used in many wind-related applications.

Previously, climatological studies of 10-m wind speeds (e.g., Bett et al., 2013, 2017) have mainly concentrated on long-term linear trends and the variability has been examined over the whole time period with statistical measures (e.g., the standard deviation). Variations of the wind climate between different decades has received less attention and often the decadal variability can be determined from time series using techniques such as Gaussian low-pass filters (Azorin-Molina et al., 2014; Minola et al., 2016) or piecewise linear regression models (Zeng et al., 2019). Such station-based time series studies have been examined separately in multiple European countries (e.g., Azorin-Molina et al., 2014; Minola et al., 2016; Laapas and Venäläinen, 2017, Zahradníček et al., 2019). However, a decadal analysis over a larger domain would provide new information on the largescale spatial patterns and their changes in each decade. Furthermore, the decadal analysis of 10-m wind speeds can then be compared to spatial and decadal patterns in other atmospheric variables, such as upper-level winds and mean sea level pressure, to study the reasons behind the decadal changes.

Longer range predictions of 10-m wind speeds on multiple time scales (months, years, decades) give value in long-term planning, adaptation and preparedness in societies and many sectors since extreme winds can cause diverse impacts, for example, uproot trees in forests (Gardiner et al., 2010; Usbeck et al., 2012; Gregow et al., 2017) or generate high waves which impact coastlines and offshore infrastructure (Vose et al., 2014). As long-term variations in 10-m wind speeds are influenced by changes in the atmospheric circulation, seasonal forecasts of near-surface winds are often based on indices that describe the large-scale atmospheric patterns (Scaife et al., 2014).

DATA AND METHODOLOGY

ERA5 reanalysis

ERA5 is the fifth-generation atmospheric reanalysis from the European Centre for Medium Range Weather Forecasts (Hersbach et al., 2020). ERA5 uses the Integrated Forecasting System (IFS, cycle 41r2) and includes atmosphere, land surface and ocean wave models. In addition to the improved data assimilation system compared to its predecessor ERA-Interim (Dee et al., 2011), ERA5 has a higher spatial and temporal resolution. The horizontal resolution in ERA5 is approximately 31 km (TL639 in spectral space) and it has 137 vertical levels (from surface to around 80 km). The analysis and forecast fields are available hourly. Currently ERA5 covers the time period from 1979 onwards. In this study, we used 6-hourly data from 1986 to 2015 with 0.25 (~31 km) horizontal resolution. The variables we obtained are instantaneous 10-m and 300-hPa horizontal wind components and mean sea level pressure.

Field data

Long term wind characteristics in Uttarakhand were recorded at 7 meteorological stations (Figure 1) of the India Meteorological Department (IMD). Table 1 lists the IMD stations and periods of wind measurement exercises. Since the station data was of different time periods, wind speed was obtained from the literature on wind climatology in India (Mani and Mooley, 1983). The measured data included: 1) synoptic hour values (local time 8:30 and 17:30 hrs); 2) daily averages for durations between synoptic hours and 3) monthly averages of wind speeds. Daily averages of wind speeds were obtained by averaging the mean for two 12-hour periods starting from 17:30 hrs, capturing the diurnal variations of the wind. Wind measurements were standardized to 10m using power law equation (1) as per World Meteorological Organization (WMO) norm (Ramachandra et al., 1997).

$$V/Vo = (H/Ho)^{\alpha} \quad (1)$$

where Vo is the measured wind speed, V is the standardized wind speed, Ho is the measured height, H is the desired height (10m) and α is the power law index. Here α is a measure of roughness due to frictional and impact forces on the ground surface which varies according to terrain, time and seasons. The value of α calculated for most of the regions representing the Himalayan terrain are well above 0.40 based on long term observations and calculations (Mani and Mooley, 1983). In order to minimize extrapolation errors, we considered the least value of 0.40 for Uttarakhand. The wind measurement heights in Uttarakhand were standardized using power law equation with α as 0.4.

Station	Height(m)	Lat	Long	Availability	Data frequency
Uttarkashi	1158	30.7268° N	78.4354° E	1969-1985	Daily
Mukhim	1822	30.5763° N	78.4667° E	1969-2008	Daily
Tehri new	1750	30.3739° N	78.4325° E	1969-2014	Daily
Pauri	1469	29.8688° N	78.8383° E	1974-1978	Daily
Joshimath	1821	30.5506° N	79.5660° E	1969-1986	Daily
Chamoli	1550	30.2937° N	79.5603° E	1980-1987	Daily
Munsiyari	2200	30.0715° N	80.2373° E	1970-1987	Daily

Table 1. List of meteorological stations of Uttarakhand with wind records

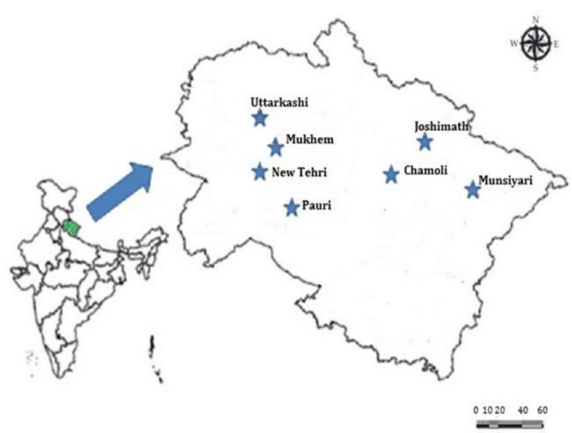

Figure 1. Area of study and distribution of meteorological stations

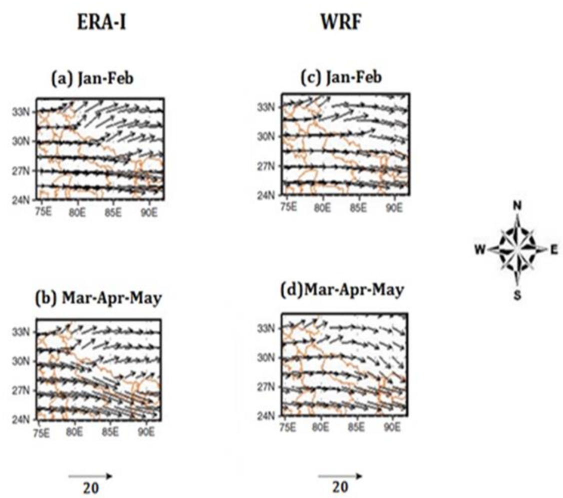

Figure 2. Mean ERA5 winds (m/s) at 500 hPa for (a) January and February (JF); (b) March, April and May (MAM) for 2015. Mean of WRF model (CNTL) winds (m/s) at 500 hPa for (c) JF; (d) MAM for the same year

The mean winds at 500 hpa for JF and MAM have been examined from reanalysis and WRF model CNTL simulation to establish the consistencies between circulation and precipitation. During winter and spring seasons (JF and MAM), westerly flow dominates the study region and a large number of cyclonic systems (western disturbances) travel across the Himalayan region from west to east. In ERA5, in JF and MAM a trough is seen in the westerlies around 75°E–80°E and 30°N to 33°N (Fig. 2 a, b). The westerly trough is oriented northwest-southeastward. In the model simulations (Fig. 2 c, d), all the essential features of the circulation are seen indicating that the model is able to simulate consistent circulation and precipitation over the domain of the present study.

INTER-ANNUAL VARIABILITY

To calculate the IAV using the ERA5 data set, firstly, for every grid point, we have calculated the mean speed at 10 m height above ground for each year in the record. Next, we have calculated the standard deviation of the annual means over the period 1986-2015 and divided the result by the overall average speed over the same period.

It is apparent that inter-annual variability is low and almost homogeneous over the mountainous part of Uttarakhand. It is slight higher in the southwestern part of the state over the foothills of the Himalaya. Overall, this region is showing a high degree of consistency in the average wind speed from year to year.

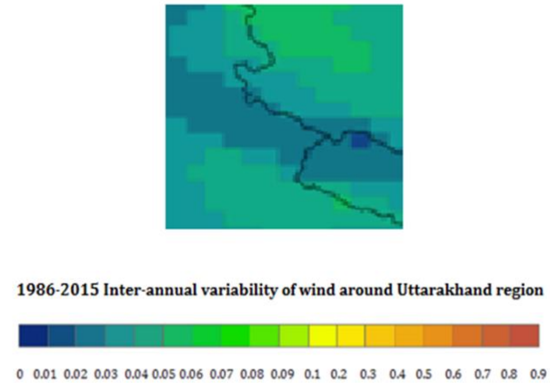

Figure 3. IAV for the period 1986-2015 based on the ERA5 data set

The final step of the analysis was to compare the predicted and observed IAV at 7 meteorological stations in Uttarakhand Himalaya with periods of record ranging from 5 to 46 years. The results are shown in Figure 4.

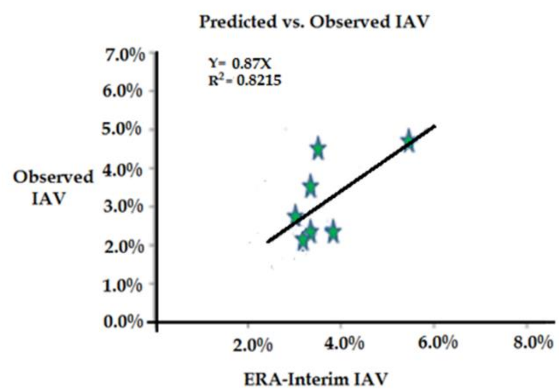

Figure 4. Comparison of predicted and observed IAV at meteorological stations in the Uttarakhand with records of at least 5 years

CONCLUSION

The 30-year period from 1986 to 2015 provides a suitable long-term baseline for studying wind anomalies and variability. Before this period, inhomogeneities in all data sets become more common, possibly reflecting changes in the observational systems driving the models. The IAV values calculated from ERA5 data for 1986-2015 compare well (r^2 ~ 0.82) with those observed at 7 meteorological stations in the Uttarakhand with periods of record of at least 5 years. The slight overestimation of observed IAV by ERA5 is consistent with its longer period of record.

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