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Diagnostical and observational analysis of clear air turbulence over the middle east and Iran

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ABSTRACT: Turbulence forecasting started in World War II when scientists and individuals in the field of aviation began attempting to correlate observed clear air turbulence events with large scale synoptic features. Encounters with significant turbulence or simply bumpiness in flight, are a major concern not only for passenger comfort but also for safe, efficient, and cost-effective aircraft operations. Clear air turbulence represents disorganized fluid motions in the form of micro scale eddies that can take place within cloud-free or limited cloud patches in the free atmosphere, which causes in-flight bumpiness of aircraft. This study aims to present two case studies and comparison of the report of clear air turbulence over center, east and south east crossings over Iran region. Regional weather predictions are carried out using an ensemble forecasting system. In addition, the initial and lateral boundary conditions are taken from the global forecast system. For each member of the ensemble system, two nested computational domains with spatial resolutions of 27000 meters and 9000 meters are used. Case study of the predicted clear air turbulence indicates the proper performance of the predicted meteorological parameters.

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1. INTRODUCTION

Turbulence or simply bumpiness in flight [1], is a major concern not only for passenger comfort but also for safe, efficient, and cost-effective aircraft operations. The magnitude of aircraft bumpiness depends on the magnitude and size of the encountered atmospheric turbulent eddies as well as the aircraft response to those eddies. Aircraft bumpiness is felt mainly for a range of eddy sizes between 100 m and 1 km. Larger eddies cause only slow variations in the flight path while the effect of very small eddies is integrated over the surface of the aircraft.

Cleat Air Turbulence (CAT) represents disorganized fluid motions in the form of micro scale eddies that can take place within cloud-free (clear air) or limited cloud patches in the free atmosphere, which causes in-flight bumpiness of aircraft. CAT forecasts are typically derived from the output of Numerical Weather Prediction (NWP) models. Almost all these algorithms diagnose turbulence by identifying large values in computed horizontal or vertical gradients of different atmospheric state variables (velocity, temperature) from the NWP model output and then threshold these gradients empirically to correspond to light, moderate, and severe turbulence (e.g., see [2]).

While most early studies related turbulence to wind shear and temperature gradients, late studies suggested that one more atmospheric feature, i.e. deformation, may play an important role in turbulence production. Mancuso and Endlich [3] used statistical methods to show that turbulence occurred in areas with large vertical wind shear and deformation values. Roach [4] also found that large scale shearing and stretching deformation may play a role in turbulence production. Several studies comparing satellite imagery and PIREPs (e.g., Schwartz [5]) supported the hypothesis that turbulence frequently occurs along deformation zones [6-8].

Considering the theory that wind shear and deformation are important factors in turbulence production, Ellrod and Knapp [8] suggested the Turbulence Index (TI), which presents turbulence by highlighting areas that have large vertical wind shear and deformation values. The TI is derived from Petterssen's frontogenesis intensity equation, which relates frontogenesis to an increase in vertical wind shear [8, 9].

This research work aims to present two case studies and comparison of the report of CAT over Middle East with emphasis on Iran region. Weather predictions are carried out using an ensemble forecasting system developed for the Weather Research and Forecasting (WRF) model.

2. METHODOLOGY

To construct the ensemble members of the ensemble forecasting system developed for the WRF model a combination of perturbed initial condition and model perturbations, using multi physical parameterization

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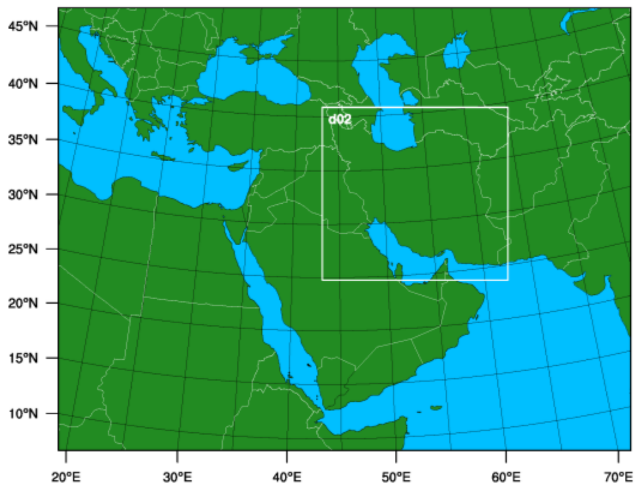

Fig. 1. Domains used for the WRF model in the present work

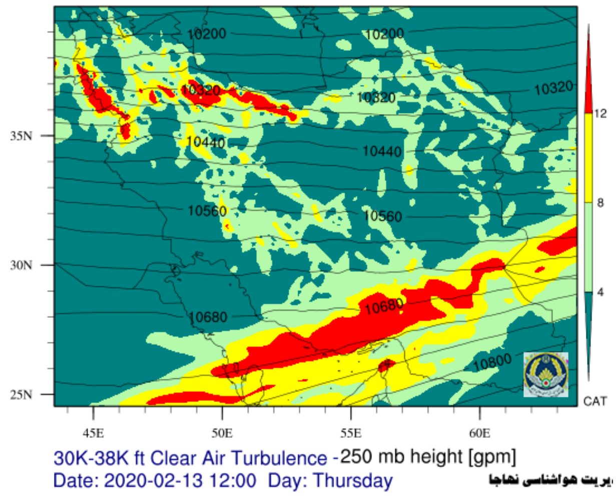

Fig. 2. Prediction of clear air turbulence for 30K-38K ft level at 12 UTC on February 13, 2020

schemes, is employed. Here, an ensemble prediction system with 25 members including five physical parameterization configurations and five initial condition perturbations for each one, is used to generate the meteorological field predictions over the study area. The Global Forecast System (GFS) data is used to provide the initial and boundary condition of the control run of the developed ensemble prediction system.

In the present work, to diagnose clear air turbulence the index suggested by Ellrod and Knapp [8] which is known as the turbulence index (TI) is employed. The formulation of the index is as bellow:

$$TI = VWS \times \left[DEF + CVG \right] \tag{1}$$

In which

$$VWS = \frac{\left(\Delta u^2 + \Delta v^2\right)^{1/2}}{\Delta z}, \quad DEF = \left(DST^2 + DSH^2\right)^{1/2}, \quad DST = \frac{\partial u}{\partial x} - \frac{\partial v}{\partial y}, \quad DSH = \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}, \quad CVG = -\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right) \tag{2}$$

where VWS is the vertical wind shear, u and v are wind component from the model forecast data, Δz is the thickness between the pressure level. DEF is the deformation term, stretching deformation is denoted by DST, DSH is shearing deformation term and CVG is the convergence.

3. RESULTS AND DISCUSSION

Fig. 1 presents the main domain of the WRF model. As an example of obtained results, Fig. 2 shows prediction of CAT for main domain at 30K-38K ft level. Similarly, Fig. 3 presents CAT at 22K-30K ft level. From results present in Fig. 2 it can be seen that CAT is occurred in south-east, south and south-west regions of Iran on February 13, 2020 (12:00UTC). Based on this prediction any flight crossing these regions needs to modify its flight path to avoid CAT.

4. CONCLUSIONS

This research work aimed to present predictions of the CAT over Middle East with emphasis on Iran region. Weather predictions were carried out using an ensemble forecasting system developed for the WRF model. To diagnose the CAT the index suggested by Ellrod and Knapp [8], namely, the turbulence index (TI) was employed. A case study of the predicted CAT indicates the proper performance of the predicted meteorological parameters.

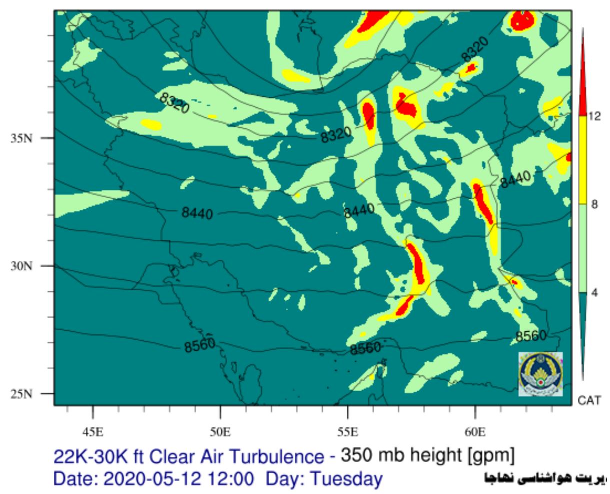

Fig. 3. Prediction of clear air turbulence for 22K-30K ft level at 12 UTC on May 12, 2020

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