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Review Article

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Application of Remote Sensing to Study Tropical Cyclones/ Hurricane Energetic to Develop Tropical Cyclone/Hurricane Forecasting Models (TCFM/HFM) Through Morphological and Dynamical Properties of Meso-Scale Convective Systems

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ABSTRACT

The present Tropical Cyclones/Hurricane Weather Research and Forecast (TCFM/HWRF) system is capable to forecast the inner core structure of the Tropical Cyclones/Hurricanes out to 5 days. Hence, efforts are to be made to test, evaluate, and improve predictions of Hurricane's track(motion), intensity, speed, and inner core Structure, beyond 5 days ,through the study of Hurricane energetic in correlation with dynamical fluid motions and physical features (e.g. radiative transfer, chemistry, cloud processes), of meso-scale NH-SH Convective systems in order to develop a unique Tropical Cyclone/Hurricane Forecast Models (TCFM/HFM), acting as an Operational real-time forecast guidance for all global tropical cyclones/hurricanes across the Atlantic, Asia Pacific, North Indian Ocean and Southern Hemisphere ocean basins.

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The key to this new prediction system (TCFM/HFM) would be the development of a very fine (1deg–1deg) grid nests moving with individual storms within the global model, having a coupling capability for these nests in space & time mode. (TCFM/HFM) would be coupled to Atlantic, and North Indian Ocean basins Storms, so that its grid filter gets updated whenever, there are active cyclonic storms in these basins.

Next, the high-resolution Satellite imageries of the two Super Cyclonic Storms (SCS) over the Atlantic& North Indian Oceanic basins occurred during May- October 2020 would be examined with emphasis on the large scale kinematic and thermodynamic behavior of these two SCS named Laura'(Atlantic,26Aug'20,240 Kmph,937hPa) Amphan'(BOB,17May'20,240Kmph,920hPa) & other selected mesoscale Convective Systems, e.g. intense Cloud Clusters Thunderstorms, Depression, by making use of Aircraft, Doppler Weather Radar and conventional data over the selected domain in order to study mathematical and computational aspects of weather and climate through spatial structure of Cloud field incorporating the Tropical Cyclones/Hurricane Weather Research Forecast Models (HWRF).

Based on Cloud Cluster studies, and of wherein, the two plausible Models of Monsoon Depression have been postulated in terms of Cluster Coalescence Theory and Giant Cluster Theory along with technique described for inferring vertical mass circulations within and around the monsoon depression in tropical regions by making use of satellite imageries, be employed to study the said two SCS over Atlantic & North Indian oceanic basins during the Storm-Cycle (May-Oct)'20 to develop (TCFM/HFM) [1,2].

Next, the Thermodynamic structure of these Hurricanes be studied by computation of deep convective mass transport inside the Cloud Cluster by means of Cloud Tracer Analysis (WINDCO measurements) using McIDAS. The Tele-connection of SH features e.g. Depressions, Cyclonic Storms, Equatorial Trough & movement of ITCZ with the identical features of NH, governing the storms activity over the region would also be studied.

Short Description of Project

The present Tropical/ Hurricane Weather Research and Forecast (TC/HWRF) system is capable to forecast the inner core structure of the Tropical Cyclones/Hurricanes out to 5 days. Hence, efforts are to be made to test, evaluate, and improve predictions of Hurricane's track(motion), intensity, speed, and inner core Structure, beyond 5 days, through the study of Hurricane energetic in correlation with dynamical fluid motions and physical features (e.g. radiative transfer, chemistry, cloud processes), of meso- scale NH-SH Convective systems in order to develop a unique Tropical Cyclone/Hurricane Forecast Models (TCFM/HFM), acting as an Operational real-time forecast guidance for all global tropical cyclones/hurricanes across the Atlantic, Asia Pacific, North Indian Ocean and Southern Hemisphere ocean basins.

Next, the high-resolution Satellite imageries of the two Super Cyclonic Storms (SCS) over the Atlantic& North Indian Oceanic basins occurred during May-October 2020 would be examined with emphasis on the large scale kinematic and thermodynamic behavior of these two SCS named 'Laura'(Atlantic,26Aug'20,240Kmph,937hPa) Amphan'(BOB,17May'20,240Kmph,920hPa) & other selected mesoscale Convective Systems, e.g. intense Cloud Clusters Thunderstorms, Depression, by making use of Aircraft, Doppler Weather Radar and conventional data over the selected domain in order to study mathematical and computational aspects of weather and climate through spatial structure of Cloud field incorporating the Tropical Cyclones/Hurricane Weather Research Forecast Models (TCFM/HFM).

Based on Cloud Cluster studies, and of wherein, the two plausible Models of Monsoon Depression have been postulated in terms of Cluster Coalescence Theory (CCT) and Giant Cluster Theory (GCT) along with technique described for inferring vertical mass circulations within and around the monsoon depression in tropical regions by making use of high resolution satellite imageries, would be employed to study the said two SCS over the selected Atlantic & North Indian oceanic basins during the Storm-Cycle(May-Oct)'20; in order to develop Tropical Cyclones/Hurricane Forecast Models (TCFM/HFM) [1,2].

Based on study on the Inter-Hemispheric Confluence Zones findings that Northern Hemispheric Confluence Zones (NHCZ) were greater in size, intensity and life time than that of Southern Hemispheric Confluence Zone (SHCZ) and the higher SSTs favored their formation; these Hurricanes energetic would be correlated with the Time Series plot of 0300 UTC Surface Pressure Gradient between a few selected station falling at almost the same latitude and longitude would be plotted in order to correlate with the Disturbed Phases vis-a-vis evolution features of the Hurricanes [3]. Later, the kinematic features of the Disturbed Phases are to be correlated with the extracted Sea Surface Temperature (SSTs) over the grid box to bring out a few optimum values of these to develop (TCFM/HFM).

In order to study mathematical and computational aspects of weather and climate modeling, this Research Proposal also, examines the spatial structure of Cloud field in the domain of the Hurricanes. The possibility is being considered to identify the Tele- connection of SH features e.g. Depressions, Cyclonic Storms, Equatorial Trough & movement of ITCZ with the identical features of NH, governing the storms activity over the region. Consideration is given to the internal structure of these Weather Systems in relation to change in Pressure, Vorticity, Divergence, Vertical Velocities with time.

Next, the Thermodynamic structure of these Hurricanes would be studied by computation of deep convective mass transport inside the Cloud Cluster by means of Cloud Tracer Analysis (i.e. WINDCO measurements); with the help of Mc IDAS (Man -Computer -Interactive –Data-Access System).

The TC/HWRF is the current mesoscale numerical weather prediction system designed for atmospheric research and operational forecasting applications. Operational tropical cyclone/hurricane forecasting consists of multiple movable two-way interactive nested grids following the projected path of a tropical system/hurricanes. There are two dynamical cores, a data assimilation system and a software architecture supporting parallel computation and system extensibility. The model serves a wide range of meteorological applications across scales from tens of meters to thousands of kilometers.

The key to this new prediction system (TCFM/HFM) would be the development of a very fine (1deg–1deg) grid nests moving with individual storms within the global model, having a coupling capability for these nests in space & time mode. (TCFM/HFM) would be coupled to Atlantic, and North Indian Ocean basins Storms, so that its grid filter gets updated whenever, there are active cyclonic storms in these basins.

Description of The Project/ (Statement of Problem, Background and Relevance to Previous Work & General Methodology)

Introduction

As the intensity and timely onset of Monsoon rains have a great influence on the agriculture and aviation of many populous nations of South-East Asia.; so, the case is of Hurricanes causing devastation over the Se-Atlantic & Caribbean Oceanic regions comprising American & Caribbean nations. The predicted global average annual loss associated with Hurricanes / tropical cyclones (wind and storm surge), earthquakes, tsunamis and floods are US $314 billion.

Although, any specific event in any given area dependent only partially on the local structure of the atmosphere inside the region but, the major central comes from the broad scale situations existing over very long areas. The broad scale situation is most clearly understood most readily by the current aloft as well as when viewed in their hemispheric setting. With this end in view, the remote sensing has been used to study the (Hurricane)Energetic over SE-Atlantic and Indian oceanic regions.

Tropical cyclone (Hurricane) forecasting relies on data provided by numerical weather models viz. Statistical & Dynamical Models. Statistical Models are Climatology based, Dynamical are Atmospheric Physics based. NWP include special computational techniques of spatial domains that move along with the cyclone. Models that use elements of both approaches are called Statistical -Dynamical models. TC/HWRF is a very useful product in terms of track, intensity, rainfall and landfall forecast guidance. The qualitative and quantitative estimation of the precipitation, devastation arising out of severe weather systems e.g. Cyclones/ Hurricanes, Thunderstorms, Tornado etc., involving time and space variation constitute an important aspect of long, medium and shortrange forecasting on different scales viz. Global, macro, synoptic, meso and micro. With this end in view; the remote sensing would be used to study Hurricane Energetic of the said latest SCS over Atlantic, North Indian Ocean (NIO) regions by studying the Cloud clusters & mesoscale convective systems during (May-Oct)'20, using high resolution Satellite imageries, and incorporating the optimum values of dynamical and morphological characteristics of severe weather systems, SCS in particular, to improve existing operational HWRF and develop new TCFM/ HFM.

Earlier Studies

Morphological & Dynamical Properties of mesoscale convective systems viz. cloud clusters, thunderstorm, Depressions, cyclone, NHET, SHET, NHCZ, SHCZ etc. were done in the past at Univ. of Wisconsin, USA by Goswami VK, Sikdar DN, Martin, and Suomi, and found that Northern Hemispheric Confluence Zones (NHCZ) were greater in size, intensity and lifetime than that of Southern Hemispheric Confluence Zone (SHCZ) and the higher SSTs favored their formation. A good number of publications are available in literature on the characteristics of Cloud Cluster s over the Atlantic # pacific and other parts of tropics [4,5].

At University of Wisconsin, USA, made the pioneer studies of the summer MONEX Cloud Cluster s characteristics, viz, the distribution, size, intensity, lifetime and trajectories over the summer MONEX domain (0 – 30o N & 70 – 120o E) and related their distribution to the synoptic scale weather disturbances [2]. Further, Goswami VK (1986) studied the Satellite observed cloudiness and Inter-Hemispheric Confluence Zones during Summer Monsoon and came out with the plausible Monsoon Model over the Indian region.

There are hardly alike correlative studies on Tropical Cyclone/ Hurricane, North Indian Ocean,Atlantic,e.g.'Laura' (Atlantic,26Aug'20,240Kmph,937hPa)&'Amphan'(BOB,17 May'20,240Kmph,920hPa) as regards NWP-Models by making use of Geostationary Satellite studies of Dynamical & Physical characteristics of Meso-Scale Convective Systems. It's imperative to know how and why these Storms form, intensify and what are the morphological and thermodynamic properties responsible for the energetic and movement.

As regards, Northern Hemisphere, though the dense network of stations is available in mid-latitude but, the tropics still face the paucity of data, specially over the Oceans and high mountain terrain. Though, the scarcity has been alleviated by Satellite imagery and by several regional scale observational programs but, very little has been done with the Percentage Cloud Coverage, observed Cloud Peaks, tropical Cloud Clusters and their relation with Pressure perturbations in the main Southwesterly flow in relation with tropical cyclones (Hurricanes).The qualitative and quantitative estimation of the precipitation involving time and space variation constitute an important aspect of long, medium and short-range forecasting on different scales viz. Global, macro, synoptic, meso and micro.

Evolution of HWRF & Objective

HWRF got evolved in 2008 from Vortex initialization, upgraded to Python in 2014 with tornado probability forecasts and advanced as a unique and one of the best tropical cyclone models, catering to both operations and research for all oceanic basins of the world. Though the HWRF is high- resolution hurricane model operating at cloud-permitting 3 km resolution; is useful to track, intensity, rainfall and landfall forecast guidance but, very little has been addressed as regards the Percentage Cloud Coverage, observed Cloud Peaks, tropical Cloud Clusters, internal structure of these weather systems in relation to change in Pressure, Vorticity, Divergence, Vertical Velocities with time, the Tele-connection of NH& SH features e.g.(NHET&SHET),(NHCZ&SHCZ),IT CZ & their Inter -Hemispheric movements to correlate with the Hurricane Dynamics.

Therefore, efforts are to be made to evolve an improved Hurricane Forecasting Model (HFM) with a very fine (1 deg– 1deg) grid nests moving with individual storms within the global model, having a coupling capability for these nests in a space & time mode incorporating the aforesaid Kinematic features of Mesoscale Convective Systems e.g. Cyclones (Hurricanes). Also, the high-resolution Satellite imageries of the these storms would be examined with emphasis on the large scale kinematic and thermodynamic behavior of these Hurricanes & other selected mesoscale Convective Systems, e.g. intense Cloud Clusters Thunderstorms, Depression, by making use of Aircraft, Doppler Weather Radar and conventional data over the selected domain in order to study mathematical and computational aspects of weather and climate through spatial the structure of Cloud field incorporating the (TC/HFM) Model.

Further, the studies may be extended to study the Morphological and Dynamical properties of Cyclonic Storms, Tornadoes & other Severe Weather Systems over the other regions of the Globe by making use of Geostationary Satellite Imageries to develop Numerical Weather Forecasting Models (NWFM) subsequently .Also, the project aims at testing and evaluating new NWP technologies, e.g. uncovering problems related to physics, initialization, model uncertainty, spread, etc.& evolve potential solutions, in order to improve one or more UFS applications through numerical weather model components.

Data & Computational Resource Requirements

High Resolution Geostationary, Polar (DMSP), Satellite imageries, in two spectral bands, Visible, Infrared regions for Laura'(Atla ntic,26Aug'20,240Kmph,937hPa)&'Amphan'(BOB,17May'20 ,240Kmph,9 20hPa) SCS along with Aircraft data, Radar, Laser (LIDAR) data and the international data sets of Conventional data, NCEP's EMC-HWRF-Data Initialization/Assimilation) & Processing, Diskspace and Storage. The project aims at testing and evaluating new NWP technologies, e.g. uncovering problems related to physics, initialization, model uncertainty, spread, etc. to evolve potential solutions, in order to improve one or more UFS applications though numerical weather model components, and by advancing software codes and tools, workflow systems. Also, HWRF would be improved through vortex initialization, increased vertical resolution, nested domain sizes and three-way Atmosphere-Ocean-Wave coupling by making use of vortex tracker, CCPP, SCM, UPP, GSI, MET plus & EnKF-DA System. The proposed model would be run four times a day: 00Z, 06Z, 12Z, and 18Z. Each run producing forecasts of every 3 hours from the initial time out 126 hours for a maximum number of 8 storms per cycle and extending later to 144 hours.

Research Methodology

High resolution Satellite imageries (Geostationary & DMSP) would be examined with emphasis to improve high-resolution HWRF model, operating at cloud-permitting 3 km resolution to address, intensity, track, rainfall, Percentage Cloud Coverage, observed Cloud Peaks, tropical Cloud Clusters, the selected Super Cyclonic Storms,(Laura &Amphan), internal structure of these severe weather systems in relation to change in Pressure, Vorticity, Divergence, Vertical Velocities with time, as well as Tele-connection of NH & SH features (NHET&SHET),(NHCZ&SHCZ),ITCZ,SH-Cyclonic Storms & their Inter-Hemispheric movements to correlate with the Hurricane Dynamics.

Therefore, efforts are to be made to evolve an improved Hurricane Forecasting Model (HFM) with a very fine (1 deg.– 1deg) grid nests moving with individual storms within the global model, having a coupling capability for these nests in a space & time mode incorporating the Kinematic features of Mesoscale Convective Systems (Tropical Cyclones/Hurricanes).Next, the digital images from the Satellite would be analyzed as a "Movie Loop" sequence on a computer-controlled image storage display and processing device called Mc IDAS(Man-Computer- Interaction-Data Access-System).Next, to identify the evolutionary features associated with the TC/Hurricanes, the mean divergence (D)and mean vorticity (f) will be computed by making use of mean values of wind velocities (u & v – components) in a LaGrange an frame by using Drop -Wind-Sonder data & WINDCO measurements. Also, three to six hours Sounding (Surface) and Drop- Sounding, would be analyzed in time section of temperature anomaly, relative humidity and equivalent potential temperature. The integration of Satellite and Surface Sounding data would be accomplished through plausible model in which the section strips are treated as space sections.

Later, the kinematic features of the Disturbed Phases be correlated with the extracted (SSTs) over the grid box to bring out the few optimum values of these parameters to develop TCFM/HFM. Next, the predictions of Cyclone(Hurricanes) track, intensity, in the HWRF/HAFS models would be improved through Numerical Weather Prediction (NWP) technology using mathematical models of the atmosphere and oceans to predict the weather based on current weather conditions by producing realistic results through the initialization, Computation, Parameterization in the selected Domains of horizontal /vertical coordination system by making use of above derived results of morphological and dynamical properties of meso-scale convective systems viz. Cyclones/ Hurricanes energetic.

Planned Steps for TC/Hurricane Forecast Modelling at NASA-GSFC

The derived optimum values of Kinematic features (Pressure, Vorticity, Divergence, Vertical Velocities) of Mesoscale Convective Systems (cloud clusters, thunderstorm, Depressions, cyclone, NHET, SHET, NHCZ, SHCZ etc.) & the two selected SCS (Laura & Amphan) in correlation with the physical characteristics (lifetime, intensity, rainfall, percentage cloud coverage, Sea Surface Temp.) would be assimilated with the current and future steps to improve HWRF in order to develop new (TCFM/HFM).

Improvements to Hurricane Physics

Additional Bug fix for the Kinetic features viz. the 700 mb vergence, vorticity and vertical velocities, studied in LaGrange an frame, as regards of the few meso-scale convective systems within the (1 x 1) deg. grid-box .Additional Bug fix for the data profiles u and v to compute the mean divergence (D) and mean vorticity (f) to identify the evolutionary features associated with the two selected SCS (Laura & Amphan), Hurricanes, convection, cloudiness, inclusive Bug fix for 10 meter wind (already in HWRFV3.8a) .Also, add Microphysics Changes by computing the wind in the inflow and on flow layers of a Cloud Cluster from motions of trade cumulus and cirrus Clouds for the computation of thermodynamic structure of Hurricanes.

Improvements to Vortex Initialization and Data Assimilation

Improve new composite storm vortex, with new derived optimum values of kinematic features and morphological parameters of mesoscale convective systems (intense cloud clusters and their lifetime, distribution, trajectories, size and vertical extent), NHET, SHET, NHCZ, SHCZ, ITCZ, and the two selected SCS (Laura & Amphan); along with the calculated day to day Pressure Gradient at mean sea level between the two stations falling on the same longitudes , and SSTs over the(1 x 1)deg. grid- box; for the month of (May-Oct)'2020.Next, imply Three-way Atmosphere-Ocean- Wave coupling& replace operational HWRF system with (TCFM/HFM).

Scope & Significance of Research

This study of Meso-scale Convective Systems ,Hurricanes; over the region, where the conventional data cannot be made available due to unforeseen reasons, may enable one to make use of Satellite imageries to depict the instability areas and predict precipitation, the evolution and advance information of Tropical Cyclonic Storm ,Hurricanes, particularly, over the American & Caribbean cities leading to the development of Numerical Prediction Models. As the consideration is given to the internal structure of these Disturbances in space and time variations, the results of these investigations would help to understand better the regional aspect of precipitation, flash floods through an insight into the revolutionary feature of SH vis-à-vis their Tele-connection with NH features.

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