Kessinger, C., Donovan, M., Bankert, R, Williams, E., Hawkins, J., Cai, H., Rehak, N., Megenhardt, D., Steiner, M., “Convection Diagnosis and Nowcasting for Oceanic Aviation Applications”, Wayne F. Feltz; John J. Murray, Editors, Proc. SPIE, Vol. 7088, 708808 (2008); doi:10.1117/12.795495

Convection diagnosis and nowcasting for oceanic aviation applications

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ABSTRACT

An oceanic convection diagnosis and nowcasting system is described whose domain of interest is the region between the southern continental United States and the northern extent of South America. In this system, geostationary satellite imagery are used to define the locations of deep convective clouds through the weighted combination of three independent algorithms. The resultant output, called the Convective Diagnosis Oceanic (CDO) product, is independently validated against space-borne radar and lighting products from the Tropical Rainfall Measuring Mission (TRMM) satellite to ascertain the ability of the CDO to discriminate hazardous convection. The CDO performed well in this preliminary investigation with some limitations noted. Short-term, 1-hr and 2-hr nowcasts of convection location are performed within the Convective Nowcasting Oceanic (CNO) system using a storm tracker. The CNO was found to have good statistical performance at extrapolating existing storm positions. Current work includes the development and implementation of additional atmospheric features for nowcasting convection initiation and to improve mature convection evolution.

Keywords: Oceanic convection, nowcasting, TRMM, TITAN, aviation

1. INTRODUCTION

Predicting the intensity, location and timing of convection initiation and extrapolation of existing storms is a difficult endeavor even over the continental United States (CONUS), where observing networks are dense and measurements plentiful. Over oceanic regions far-removed from land, few surface-based observations are available. Remote sensing from geostationary and polar-orbiting satellites can be the primary and sometimes exclusive source of observations. A limitation of traditional satellite imagery from visible and infrared sensors is that only the tops of clouds can be measured. Instruments capable of seeing through non-raining clouds have become available over the past decade or so and include sensors such as microwave radiometers (both imagers and sounders), and radars. For oceanic regions, observations from these instruments are invaluable for understanding the environmental characteristics in which convection initiates, matures and dissipates, as well as the convection characteristics. In this study, we show how such observations, in conjunction with a global numerical weather prediction (NWP) model, are used to devise an oceanic convection diagnosis and nowcasting system for use by the oceanic aviation community.

Oceanic regions have few convective products that have sufficient temporal and spatial resolution to adequately resolve and predict convective occurrence for use by the oceanic aviation community. The National Weather Service (NWS) Aviation Weather Center (AWC) is the designated source of weather information for transoceanic flights via their International Flight Folder web pages (http://aviationweather.gov). Within the International Flight Folder, international Significant Meteorological (SIGMET) statements are issued every four hours for convective activity that meets or exceeds spatial extent guidelines. Significant Weather (SigWx) prognostic charts and hurricane/tropical storm SIGMETs are updated at six hour intervals. Full disk, infrared satellite imagery from geostationary satellites is provided at 3 hourly intervals.

To serve the aviation community, an oceanic convection diagnosis and nowcasting system described here provides frequent updates of high resolution convective products and provides a 1-hr and 2-hr nowcast of convection location. The region enclosing the Gulf of Mexico, Caribbean and northern South America comprises the primary domain of

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interest (Fig. 1) for the suite of convective products. These products can be seen on the project web pages at http://www.rap.ucar.edu/projects/ocn. One component product, the cloud top height (described in Section 4), is available now over locations within the Pacific and provides information on storms there.

The oceanic convection diagnosis and nowcasting system consists of two parts. The first accomplishes the diagnosis of convection and is called the Convective Diagnosis Oceanic (CDO). A preliminary comparison of the CDO to data sets from the National Aeronautical and Space Administration (NASA) Tropical Rainfall Measuring Mission (TRMM) Precipitation Radar (PR) and the Lightning Imaging Sensor (LIS) is done as a precursor to a rigorous validation study. The second part of the oceanic convection diagnosis and nowcasting system gives short term predictions of the future location of the convective cells and is called the Convective Nowcasting Oceanic (CNO). Hurricane Dean (August 2007) is selected for analysis and preliminary evaluation of the CNO.

The data sets used for the CDO, the TRMM comparison and the CNO are described in Section 2. The selected case study is described in Section 3. The CDO methodology and TRMM preliminary validation are described in Sections 4 and 5, respectively, with the same discussion for the CNO described in Section 6.

2. DATA

National Oceanic and Atmospheric Administration (NOAA) Geostationary Operational Environmental Satellite (GOES) East infrared (IR) and visible (vis) imagery is used as input into three convection detection algorithms, described in Section 4. The domain of interest (Fig. 1) uses a latitude/longitude map projection with a grid resolution of ~0.04 degrees. Imagery data are updated on the grid at a nominal rate of 20 min, regardless of whether new data are available. This is done to facilitate the differing scan strategies of the GOES-East, GOES-West and the Japanese MTSAT geostationary satellites (used for the Pacific domain) and to ensure the most current data are utilized.

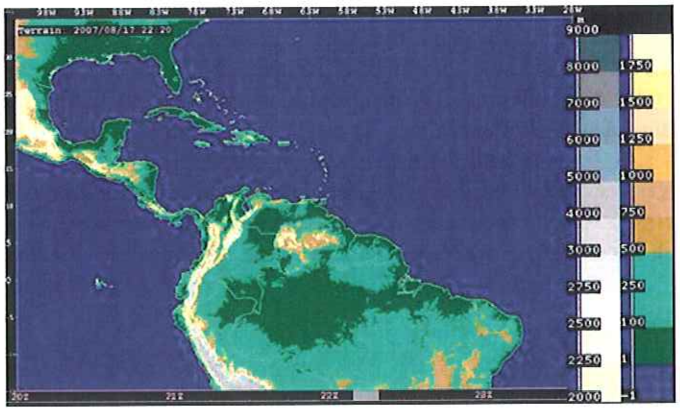

Fig. 1. The domain covered by the Oceanic Convection Diagnosis and Nowcasting effort is shown. Terrain heights (m) are plotted and color coded via the scale to the right.

The TRMM satellite in low earth orbit carries two key instruments that serve to probe the interior of deep convection, where aviation hazards originate. For example, the TRMM PR detects the internal vertical development of radar reflectivity set up in turn by the convective updraft. The TRMM LIS detects the lightning activity that results from a vigorous updraft and an active mixed phase region of convection, where supercooled water and icing conditions co-exist. These data are used for the purpose of validation of the oceanic convective diagnosis product, as described in Section 4 and provide an independent measure of convective activity. Because of its low earth orbit, a given location is scanned by TRMM only a few times per day.

The National Center for Environmental Prediction (NCEP) global NWP model, the Global Forecasting System (GFS), is available 4 times per day (i.e., 6 hr cycling), providing global coverage on a 0.5 degree latitude/longitude grid. Forecasts are generated at 3-hrly intervals. The GFS is used within the cloud top height (CTOP) product described in Section 4.

3. CASE STUDY SELECTION

Hurricane Dean was the first land-falling category 5 hurricane in the Atlantic basin since Hurricane Andrew in 1992 and was responsible for 32 fatalities. Dean occurred over the period from 12-23 August 2007 and traversed the domain of interest (Fig. 2). The National Hurricane Center Tropical Cyclone Report[1] states that Dean formed from a tropical wave off the west coast of Africa on 11 August, became a tropical depression around 06 UTC on 13 August, and reached hurricane status early on 16 August about 480 n mi east of Barbados. By 19 August, Hurricane Dean was a category 4 hurricane with a well-defined eyewall as seen by microwave and visible imagery (Fig. 3). When Hurricane Dean made

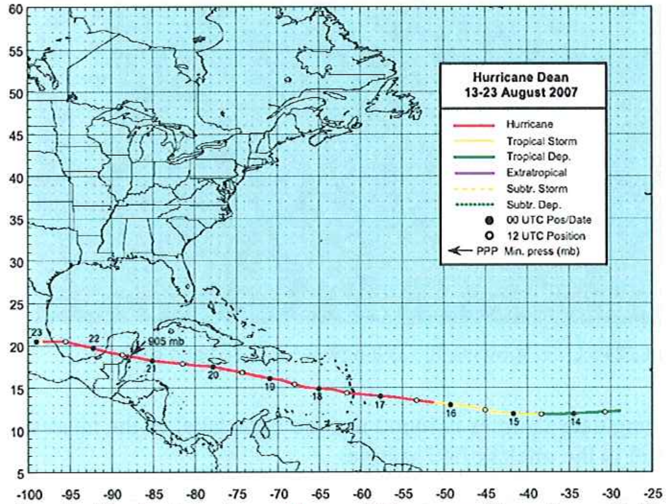

Fig. 2. The best track positions of Hurricane Dean from 13-23 August 2007. Figure courtesy of Franklin[1].

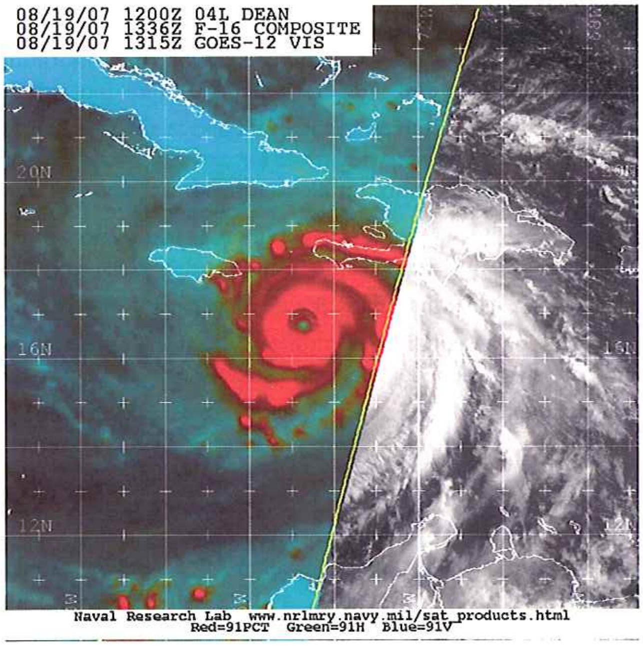

Fig. 3. Microwave imagery of Hurricane Dean (1336 UTC) superimposed over GOES-E visible imagery (1315 UTC) on 19 August 2007. Image from NRL Tropical Cyclone webpage at http://www.nrlmry.navy.mil/tc_pages/tc_home.html.

landfall on 21 August near the town of Majahual in the Yucatan Peninsula, Mexico, its central pressure was estimated at 905 mb with maximum sustained winds of 150 kt.

GOES-East infrared imagery on 17 August 2007 at 2245 UTC (Fig. 4a) shows the position of Hurricane Dean as well as significant amounts of convection over the CONUS, Cuba, Central America and northern South America. Purple-shaded regions define cloud top BT of -35°C or less. As seen in Fig. 4b, evening hours are entering the domain from the east with the terminator located across the domain. Therefore, Hurricane Dean cannot be seen in the visible channel. Results from the CDO, the TRMM validation and the CNO validation will be discussed in the following sections for this time period.

4. METHODOLOGY FOR DIAGNOSIS

4.1 Component algorithms of the CDO product

Through the CDO procedure, convective clouds are identified via a fuzzy logic combination of three satellite-based algorithms (Cloud Top Height, Cloud Classification, Global Convective Diagnosis) and are briefly described here. Additional details can be found in Donovan[2].

Cloud Classification (CClass) product: Using a supervised learning methodology that was first applied to AVHRR data[3], a cloud classifier has been developed and further refined for application to GOES data[4, 5]. A training data set is established through independent expert agreement of thousands of labeled 16*x*16 pixel samples. The classes used by the experts (and of relevance to this research) include cumulonimbus (Cb) and cirrostratus anvil (CsAn) for daytime classifications and a deep convection (DC) class at night. CsAn represents relatively deep cirrostratus (Cs) near turrets in thunderstorms and is more closely related to deep convection than "garden variety" Cs. These four categories are inputs into the CDO product.

Each training set sample is represented by a vector of characteristic features computed or extracted from each spectral channel in the GOES imager. Various training sets were established, differentiated by satellite (GOES-East or GOES-West), sea or land, and day or night. A 1-nearest neighbor algorithm is used within the classifier. The minimum distance in feature space between

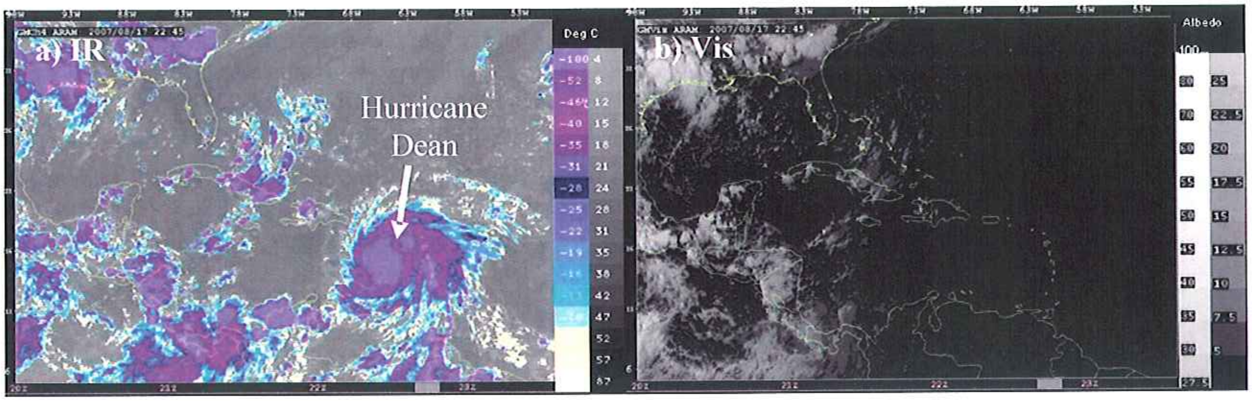

Fig. 4. Satellite imagery from GOES-East on 17 August 2007 at 2245 UTC showing the a) longwave infrared and b) the visible channels. Hurricane Dean is indicated.

an unclassified sample presented to the classifier and the training data samples is found and the class label of the nearest-neighbor training sample is subsequently assigned to each pixel in the unclassified sample.

Classifications of overlapping boxes (moving $16x16$ pixel window) within each image are performed such that each image pixel is classified four times with the majority class assigned (ties broken randomly). Since each box is assigned a specific class, no "multiple", "overlapping", or "unknown" class is used.

Cloud Top Height (CTOP) product: The CTOP algorithm, developed at the NRL[6], combines geostationary longwave infrared (IR) channel data with the temperature profile data from the GFS model to estimate the heights of convective cloud tops over ocean and land surfaces during day- and night-time hours. For a given pixel location, the algorithm converts the satellite 11-μm IR brightness temperature (approximate cloud top temperature) to a cloud top height (pressure level) using the GFS vertical profile. The estimated pressure level is converted to height above sea level using the pressure vs. height relationship given by the standard atmosphere convention, which has been widely adopted for aviation use. Note that this algorithm is intended for use over deep cloud systems, not for cloud tops lower than 15K ft.

Global Convective Diagnosis (GCD) product: The GCD algorithm[7] was developed at the AWC and, for a given pixel location, computes the brightness temperature (BT) difference between the water vapor channel (6.7-μm) and the longwave IR channel (11-μm). Deep, convective (i.e., optically thick) clouds that reach the tropopause are overlaid by dry, stratospheric air such that the BT of these two channels will be nearly equal at storm top. Within the GCD, near-zero differences (6.7-μm BT minus 11-μm BT) are associated with deep convection. The GCD[7], as originally devised, used the GFS 4-layer lifted index to remove thermodynamically stable regions. This step is not utilized as undesirable discontinuities are created within the CDO due to the large grid spacing (0.5 degrees) of the GFS model.

4.2 Methodology of the CDO product

The CDO product is computed using a fuzzy logic, data fusion procedure that ingests output from three algorithms (Fig. 5a) and is described further in Kessinger[8]. Output from each of the three algorithms is scaled by a stepwise linear "membership function" such that values that positively indicate the desired feature (i.e., convective clouds) are scaled to unity while values that do not indicate the desired feature are scaled to zero (see Figs. 5b-5d). The output from the membership function scaling is termed an "interest (or likelihood) field". The interest outputs are weighted (GCD and CTOP use a weight of 1 while CClass has a weight of 2) and summed to form the initial CDO product with a maximum value of four. The final CDO product is formed after the application of a threshold of 2.5 thus creating a binary indicator for the presence (=1) or absence (=0) of convection. The threshold value ensures positive contributions from at least two algorithms.

The target audience for the CDO/CNO product suite is transoceanic, commercial aircraft that are flying at altitudes between 30-40 kft. Membership functions for the CDO component algorithms reflect this emphasis by the selection of categories for CClass (Fig. 5d), the scaling of higher cloud top levels in CTOP (Fig. 5b) and the emphasis on deep convection by the GCD (Fig. 5c). As the TRMM validation shows in the next section, warm rain clouds are typically not detected by the CDO due to their lower cloud top heights and warmer brightness temperatures as compared to deep convective clouds.

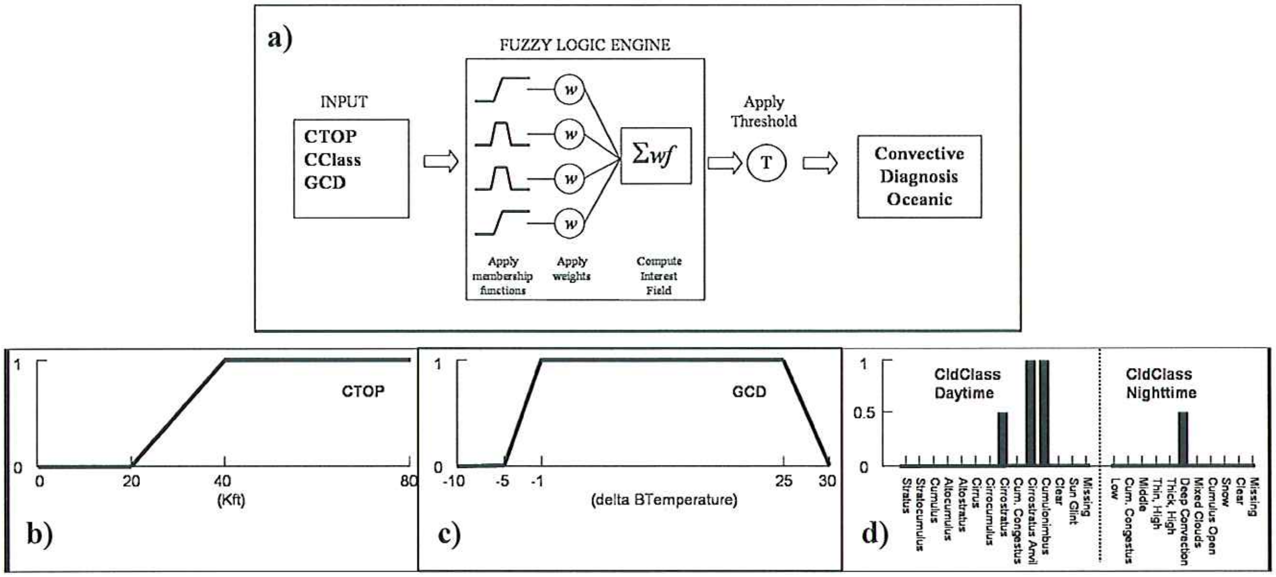

Fig. 5. In a), a schematic shows the fuzzy logic, data fusion process used to calculate the Convective Diagnosis Oceanic (CDO) product. The membership functions for b) CTOP, for c) GCD and for d) CClass are shown.

Figure 6 shows an example of the three component algorithms that are input into the CDO for the Hurricane Dean case study, taken from 17 August 2007 at 2245 UTC (Fig. 4). In the top row, Figs. 6a-6b shows the cloud top height algorithm output with its associated interest field after application of the membership function (Fig. 5b). Notice in Fig. 6b, how the highest cloud tops approach an interest value of unity. Likewise, Figs. 6c-6d show the CClass algorithm and its interest field where the sloped, vertical gray bar indicates the location of the terminator. Showing CClass output with both the daytime and nighttime categories illustrates the difference in performance realized with the inclusion of the high resolution visible imagery for daytime classifications. Considerably more daytime, small-scale structure is realized when compared to the nighttime, as expected. Because extrapolation of convective cell positions is done for all hours, consistent storm cell area is needed between the day and the night to ensure good tracking performance is attained. For this reason, the area enclosed by the daytime categories of Cb, CsAn and Cs are balanced against the area of the nighttime DC category. Because the CClass produces a cloud type rather than a range of values, the interest values are constant within a given category. The GCD algorithm output and interest field are shown in Fig. 6e-6f. Regions of deep convection, particularly the eyewall portion of Hurricane Dean, that have GCD values near zero, have interest values near unity and indicate mature updrafts. The CDO product (Fig. 7) indicates the convective regions that are present with Hurricane Dean being clearly resolved.

5. TRMM VALIDATION OF THE CDO

The strategy for validating the presence of oceanic convection that is hazardous to aviation builds on earlier published methods[2]. The GOES satellite observations that are the mainstay of the CDO and CNO algorithms are sensitive primarily to the veneer of clouds, owing to the pronounced visible and infrared opacity of a wide variety of clouds. In contrast, the TRMM satellite in low earth orbit carries two key instruments that serve to probe the interior of deep convection, where the aviation hazards originate. For example, the TRMM PR detects the internal vertical development of radar reflectivity set up in turn by the convective updraft. The TRMM LIS detects the lightning activity that results from a vigorous updraft and an active mixed phase region of convection, where supercooled water and icing conditions co-exist.

Three thresholds are established with these TRMM satellite observations to judge the presence of hazardous conditions:

1) The radar reflectivity at 5 km altitude (MSL), and the lower portion of the mixed phase region of convection, exceeds 30 dBZ.

2) At least one lightning flash is detected in the cell of interest.

3) The NASA TRMM precipitation algorithm classified the rainfall as 'convective'.

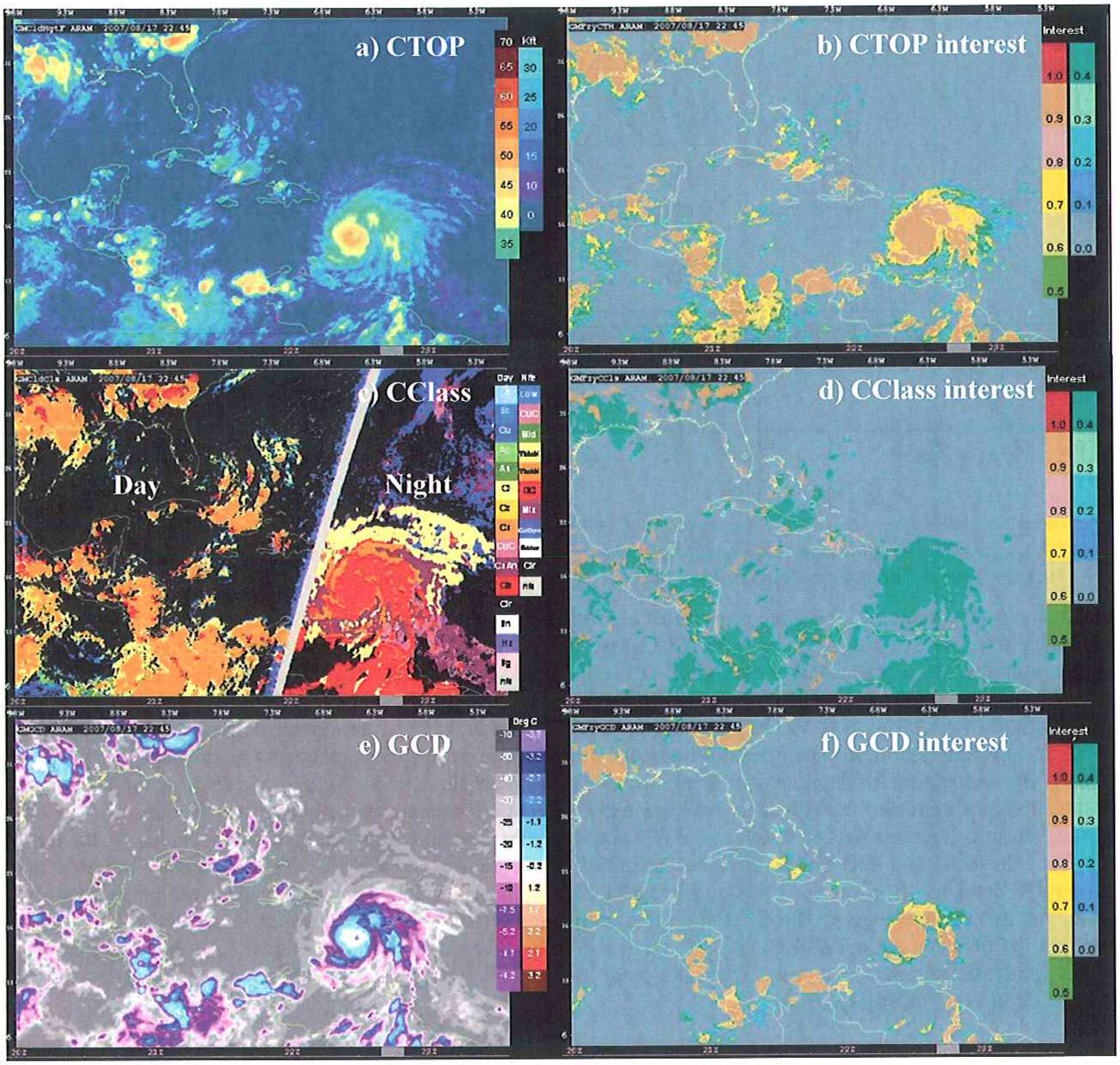

Fig. 6. For the same data shown in Fig. 4, the output from the CTOP algorithm and its interest field are shown in a) and b). Likewise the CClass algorithm output and interest field are shown in c) and d) and the GCD algorithm output and the interest field are shown in e) and f). The terminator (gray bar) can be seen in c).

If any combination of these three thresholds is exceeded, the hazard flag is raised for purposes of validation. If threshold (1) or (2) is exceeded the cell is considered hazardous; but if threshold (3) is the lone indicator of hazard, the cell is flagged as hazardous only if 5 or more grid bins of convective rain (180 km^2 area) are observed. This condition signifies the presence of warm rain clouds whose cloud tops generally do not exceed 5 km. Further study is needed to determine whether convective rain alone should be used as a hazard threshold.

Cases were selected for analysis if the visual inspection of the TRMM and GOES-East IR observations both revealed large cloudy regions ≥ 300 km^2 with cloud top temperatures $\leq$ -40° C and were time coincident within 15 min. Special consideration was given to the temporal matching between the data sets, given the large size of the primary domain of interest. Each time registered scan line of the TRMM orbital swath was compared to the estimated time of the GOES Northern Hemisphere extended sector scan line at the latitudinal location being observed. All regions within the domain that were not time coincident were excluded from the analysis.

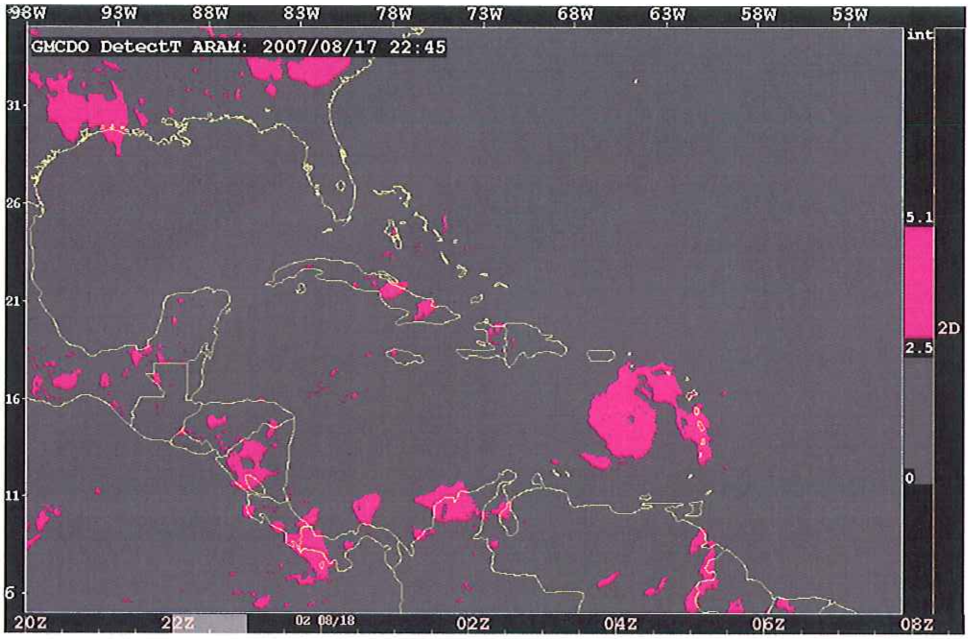

Fig. 7. The CDO output for the data shown in Figs. 4 and 6. A threshold of 2.5 is applied.

An example of the validation methodology used to evaluate the performance of the CDO product is illustrated in Fig. 8. The illustration contains a four-panel analysis display of convective cells observed over Haiti and the Dominican Republic and of Hurricane Dean south of Puerto Rico on 17 August 2007 at 22:54 UTC. Only the cells within the TRMM PR swath (region inside the two diagonal white parallel lines) are analyzed to determine the validity of the CDO interest field in Fig. 8d. The cells over land are all flagged as hazardous in Fig. 8c because one or a combination of hazard criteria was observed by TRMM. However, only the cells labeled with red arrows were considered during the evaluation. The two smaller cells over land were excluded because they did not pass the spatial criterion used during the case selection process. The CDO correctly identified the two cells to be convective (and potentially hazardous), because the maximum interest value within each cell exceeded the 2.5 interest threshold.

The radar reflectivity structure within Hurricane Dean at the 5 km altitude is represented well in Fig. 8b and the corresponding regions of hazard associated with the elevated reflectivity are shown in Fig. 8c. The CDO correctly detects a large portion of the storm to be convective, but because the IR-based product is spatially smoother than the finer resolution of the TRMM PR, the algorithm has difficulty resolving the convective bands within the storm core. It is interesting to note that TRMM observed lightning (maroon ovals) only in a small portion of the outer-most rain band and not within the main body of the storm.

A second example of the CDO performance (Fig. 9) illustrates a convective complex east of the Bahamas Islands. The large cloudy area in the center of Fig. 9a shows several regions of substantial elevated reflectivity and lightning (Fig. 9b and 9c, respectively) indicative of localized vigorous updrafts. The CDO product (Fig. 9d) captures these regions well with high interest values. Further west and southwest of this large complex, small hazardous cells containing lightning are observed by TRMM and are designated by the warm colors (yellow-red) in Fig. 9c. The CDO classifies these cells as convective, but missed the detection of the small cell marked with a red arrow. The maximum interest value for this cell is 0.6. The time skew between the TRMM and GOES data is ~10 min in this region, suggesting that the small storm developed rapidly prior to the time GOES scanned this latitude.

Figure 10 demonstrates a third example of the TRMM-CDO product comparison. The southern portion of a large storm complex is captured by the TRMM PR orbital swath. The storm contains regions of lightning and high reflectivity at the 5 km altitude and is encapsulated properly by high interest values (> 3.5) in the CDO product (Fig. 10d). The evaluation of the CDO product for this event is correct, but the large region of high interest above 2.5 is a gross overestimation of hazard not supported by the TRMM derived hazard product (Fig. 10c).

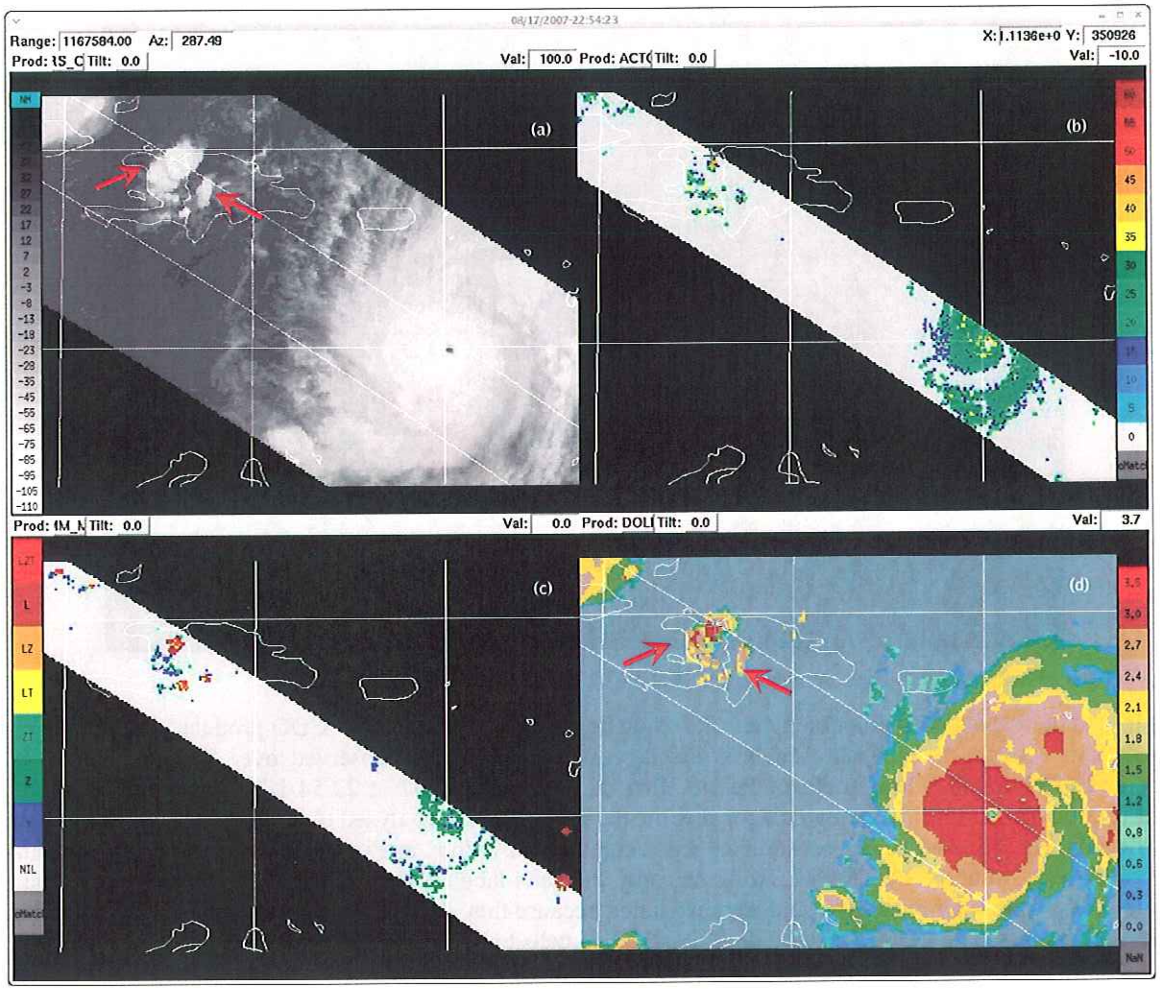

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Fig. 8. Four-panel analysis display showing (a) TRMM IR (degrees C), (b) TRMM radar reflectivity (dBZ) at 5 km altitude, (c) TRMM derived hazard product, and (d) CDO interest field of convective clouds observed over the Caribbean Sea on 17 August 2007 at 22:54 UTC. The TRMM derived product denotes regions where our criteria for hazard was observed based on the following designations: T – convective rain, Z – reflectivity ≥ 30 dBZ at 5 km altitude, L – lightning, or ZT, LT, LZ, and LZT – combination of the hazard classes. An interest threshold of 2.5 is applied to the CDO binary field to indicate the presence of convective clouds.

Further east of this complex, four small cloudy regions are observed within the TRMM swath. Three of the cells are considered hazardous by the TRMM derived product in Fig. 10c and are correctly detected by the CDO algorithm (interest > 3.0). It's also encouraging to note the agreement between the TRMM and CDO products in regard to the fourth cell, indicated by the red arrow, to be of little importance.

6. METHODOLOGY AND VALIDATION OF THE CNO

With the goal of providing high resolution, tactical decision aids to oceanic pilots and dispatchers, short-term nowcasts of the location of convection, as identified by the CDO product, are produced for 1-hr and 2-hr intervals. The extrapolation is accomplished via a cell-tracking technique, called the Thunderstorm Identification, Tracking and Nowcasting or TITAN[9]. The TITAN was developed for tracking 2- or 3-dimensional storms as identified by radar reflectivity, but for our purposes, the software performs similarly when used to track the 2-dimensional CDO product. Instead of using a typical storm reflectivity value as the storm threshold, the threshold is reduced to 2.5 interest as discussed in Section 4.2. The TITAN extrapolates the storm cell position and anticipates its growth and dissipation from past trends. A minimum storm size of 300 km^2 is a criterion that must be met before a storm is tracked.

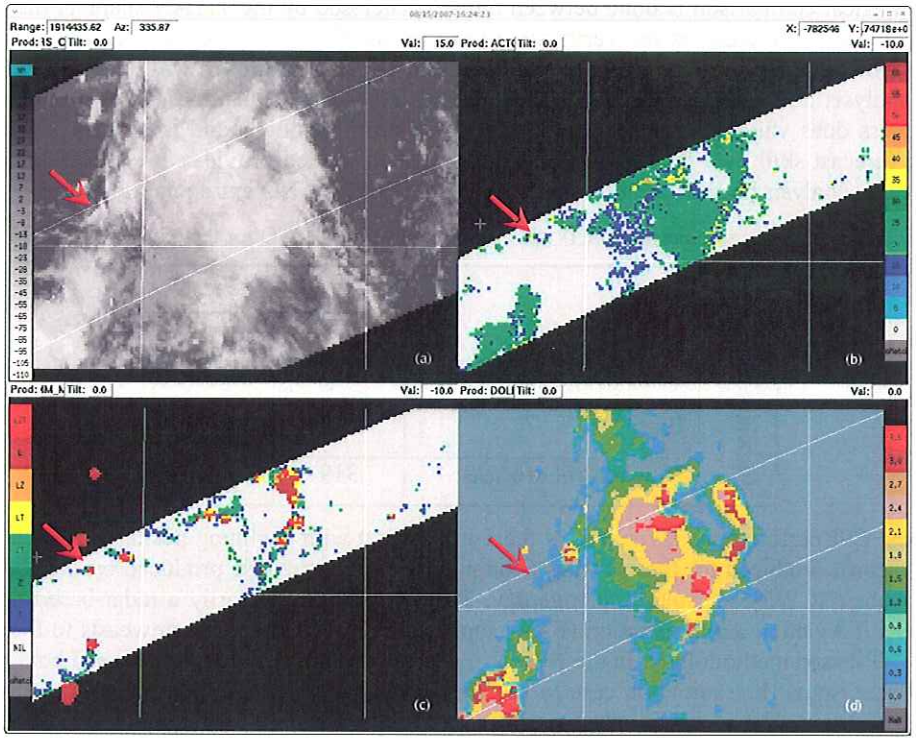

Fig. 9. Second example of the same four-panel analysis display of products shown in Fig. 8 for a convective complex located several hundred miles east of the Bahamas Islands on 15 August 2007 at 16:24 UTC.

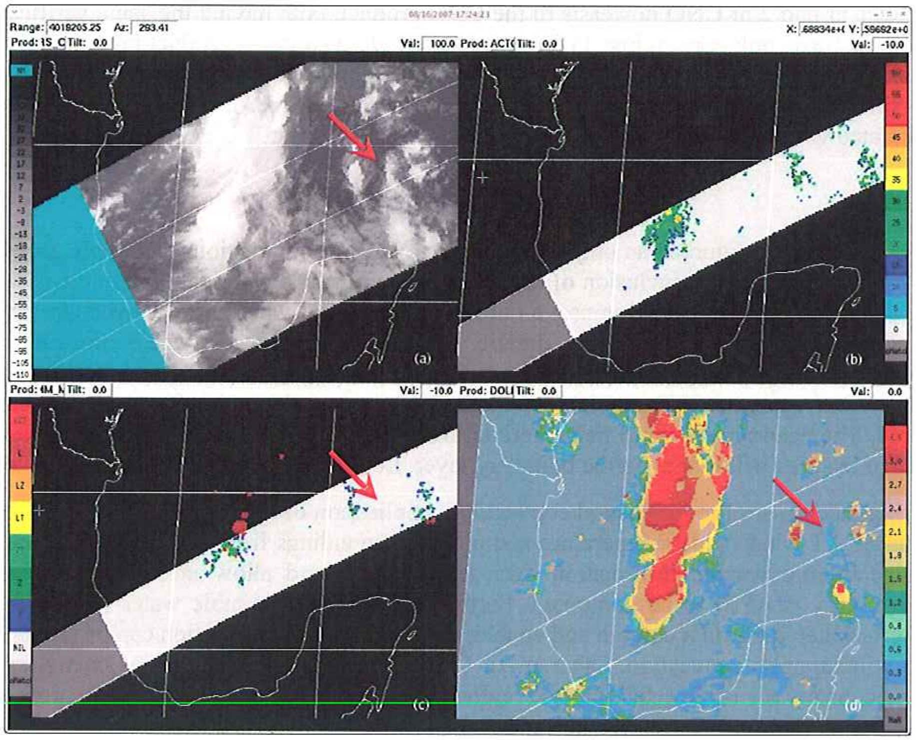

Fig. 10. Third example of the same four-panel display of products shown in Fig. 8 for convection observed in the Gulf of Mexico on 16 August 2007 at 17:24 UTC. The cyan and dark gray regions in the lower left portion of the TRMM products (a)-(c), represent time skew differences greater than 15 minutes between TRMM and GOES where the CDO product is not evaluated.

For validation, a statistical comparison is done between the area enclosed by the TITAN shape at the forecast time and the CDO product (above 2.5 interest) at the verification time for all forecasts produced between 12-22 August 2007. Standard statistical indicators are computed with results shown in Table 1 for the Critical Success Index (CSI)[10] and the bias[11]. While this analysis does not provide a fully independent comparison such as is possible for the TRMM-CDO validation, this process does validate the extrapolation of CDO storm positions and is consistent with methodologies used for validating forecast skill over the CONUS[12]. The TRMM validation provides an estimate of the quality of the CDO product while this analysis provides an estimate of the quality of the CNO extrapolation process.

Table. 1. Statistical indicators are summarized for 1- and 2-hr intervals for the CNO for the period from 12-22 August 2007.

		Nowcast Period	
		1-hr	2-hr
Indicators	Critical Success Index	0.45	0.39
	Bias	1.23	0.76
	Number of Forecasts	319	315

As expected, the best CSI performance is realized at the 1-hr nowcast with declining performance at the next hour. The CNO CSI and bias scores produced for these 11 days compare favorably to those produced by the National Convective Weather Forecast - 6hr (NCWF-6) system[12] for one day. The NCWF-6 is primarily a radar-based nowcasting system developed with Federal Aviation Administration (FAA) support to extend convective nowcasts to 6-hr using a blended observation- and NWP-based methodology. In the NCWF-6 analysis[12], the CSI scores are plotted hourly over the diurnal cycle for a Great Plains squall line initiation case to illustrate performance differences related to convection initiation, extrapolation and dissipation. CSI scores for the 1 hr nowcast varied over the diurnal cycle from 0.2-0.4 and from 0.05-0.35 for the 2 hr nowcast with maximum scores realized several hours after the squall line formed. Further evaluation in the same vein is planned for the CNO.

Figure 11 compares a 1 hr and 2 hr CNO nowcasts to the CDO product, both having the same verification time of 2315 UTC. The 1 hr nowcasts (cyan polygons in Fig. 11A) enclose the CDO validation product fairly well. The polygons tend to be generous in size compared to the area of the CDO with occasional location displacements. In Fig. 11b, the 2 hr nowcast polygons show similar results with some reduction in performance. For both, the position predictions for Hurricane Dean validated very well.

7. WORK IN PROGRESS

The CNO system as currently configured can only extrapolate existing storm positions and apply growth and dissipation adjustments based on past CDO trends. Inclusion of oceanic environment characterization into the CNO system will add greater complexity to the system and should improve our understanding of where new convection may form, given the presence of a triggering mechanism, or where mature convection should dissipate[13]. For instance, sea surface temperature (SST) is an important variable for inclusion within the CNO system, since convection is favored over areas of higher SST values. An accurate SST monitoring capability can assist in our efforts to delineate regions where convection is favored. The near-surface wind fields derived from the QuikSCAT scatterometer provide an indication of low-level convergence features within the marine boundary layer. Low-level convergence features have been shown[14, 15] to provide a triggering mechanism for continental convection. Application of this concept to oceanic convection is being tested using the QuikSCAT wind field. Temperature and moisture soundings from low earth orbit satellites such as the NASA Aqua provide thermodynamic information over remote areas and allow indicators such as the Convective Available Potential Energy (CAPE) to be computed. Further, the total precipitable water (TPW) field quantifies the amount of atmospheric water vapor in a column and enables us to ascertain if convection can be sustained or whether the presence of dry air will suppress convection. Saharan Air Layer (SAL) events with origins over Africa can impact the Gulf of Mexico region, as dry air is advected into the region. Each of these data sets will be incorporated into the CNO and tested for its ability to improve convective nowcasts. Additional GFS-derived fields[16] are also under investigation. Kessinger[17] provides an illustration and description of these data sets.

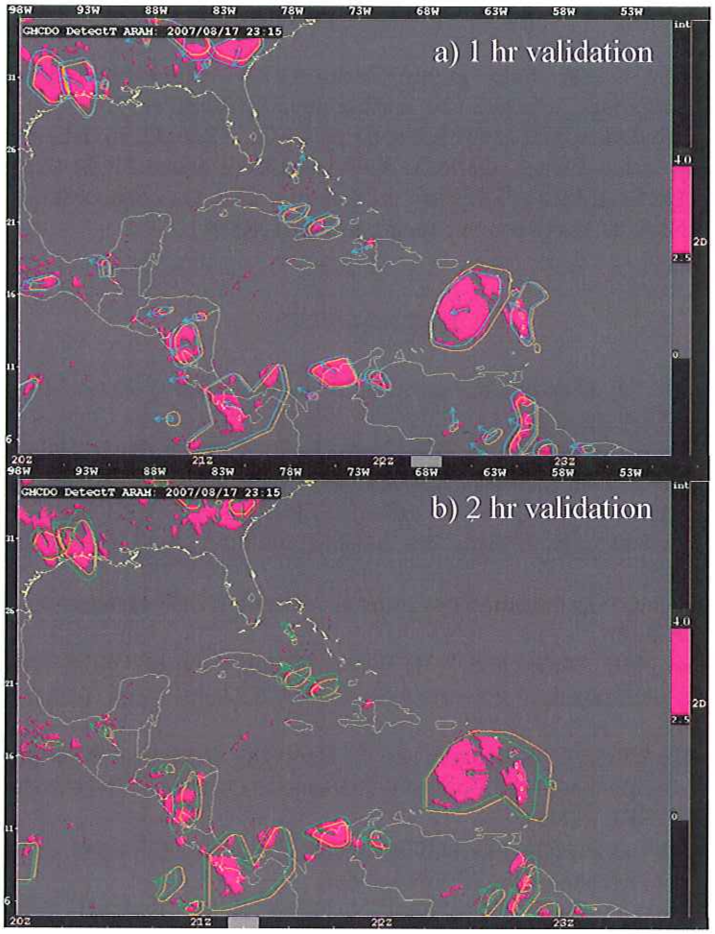

Fig. 11. For 17 August 2007, the CDO (magenta shapes) is shown at the validation time of 2315 UTC for the a) 1 hr nowcast made at 2215 UTC and for the b) 2 hr nowcast made at 2115 UTC. The position of the CDO at the respective forecast times is indicated in both panels by orange polygons. The 1 hr CDO nowcast is indicated in a) with the cyan polygons and the 2 hr nowcast is in b) with green polygons. Vectors (arrows) indicate storm motion but not speed.

To accomplish the inclusion of these additional data sets into the CNO, a methodology called "random forest" is being tested. Random forest is a powerful, non-linear statistical analysis technique that consists of a collection of independent decision trees. These decision trees are produced from a "training set" of predictor variables (i.e., SST, convergence, etc.) that are paired with their corresponding set of "truth" values (the CDO). Each decision tree's forecast logic is based on a random subset of data and predictor variables, making it independent from all others. A trained random forest functions as an "ensemble of experts" and uses a consensus vote to classify each new data point. Preliminary experiments over the CONUS suggest that the random forest technique may be quite useful[18].

8. CONCLUSIONS

In this paper, we have shown that geostationary visible and infrared imagery can be used to detect hazardous convection via the CDO product over remote, oceanic regions. The TRMM PR and LIS data to the CDO provides an independent validation source for the CDO. Preliminary results show that the CDO does detect hazardous deep convection, but can miss warm rain clouds and can be overly generous in the detected area compared to the location of convective precipitation, updrafts and lightning. The CNO product provides 1-hr and 2-hr nowcasts of convection location and is shown to have good performance at extrapolating existing storm positions. The addition of additional oceanic environmental data sets should expand its capabilities to give better indication of convection initiation and evolution.

ACKNOWLEDGEMENTS

This research is funded by the NASA under grants NNS06AA22G Cooperative Agreement Notice (CAN) and NNA07CN14A Research Opportunities in Space and Earth Sciences (ROSES). The TRMM vis, IR, and PR data are provided by the Goddard Distributed Active Archive Center (DAAC). TRMM LIS data are provided in near real-time from the Global Hydrology Research Center (GHRC), NASA Marshall Space Flight Center (MSFC). Near real-time digital data sets for AMSU, AIRS, AMSR-E SSTs are provided to NRL via collaborations with NOAA, NASA Near Real Time Processing Effort (NRTPE) and Remote Sensing Systems (RSS).

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