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TRACKING MOTIONS FROM SATELLITE WATER VAPOR IMAGERY: QUANTITATIVE APPLICATIONS TO HURRICANE TRACK FORECASTING

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1. INTRODUCTION

Water vapor imagery from GOES satellites has been available for over a decade. These data are used extensively, mainly in a qualitative mode, by forecasters in the United States (Weldon and Holmes 1991). Some attempts have been made at quantifying the data by tracking features in time sequences of the imagery (Stewart et al. 1985; Hayden and Stewart 1987). For a variety of reasons, applications of this approach have produced marginal results (Velden 1990). Recently, METEOSAT-3 (M-3) was repositioned at 50W by the European Space Agency, in order to provide complete coverage of the Atlantic Ocean. Data from this satellite are being transmitted to the U.S. for operational use. Compared with the GOES satellite, the M-3 has a superior resolution and signal-to-noise ratio in its water vapor channel, which translates into improved automated tracking capabilities.

During a period in 1992 which included the Atlantic hurricane season, water vapor tracking algorithms were applied to the M-3 data in order to evaluate the coverage, accuracy and model impact of the derived vectors. Data sets were produced during several tropical cyclone cases, including Hurricane Andrew. In this paper, the M-3 water vapor wind sets are assessed, and their impact on a hurricane track forecast model is examined.

2. STATISTICAL EVALUATION OF THE M-3 WINDS

During the spring of 1992, M-3 wind sets were routinely produced on a daily basis (around 12 UTC) at CIMSS. The domain of the wind sets covered the eastern U.S. and the western North Atlantic ocean basin (Fig. 1). The purpose of this exercise was to assess the horizontal and vertical coverage of the winds, and evaluate their accuracy. M-3 water vapor targets were selectively chosen to be constrained to cloud-free areas in the imagery. This was accomplished by activating an empirically-determined brightness temperature threshold value which was not to be exceeded in the target selection step of the wind-tracking algorithm.

The data set presented in Fig. 1 is typical of the data sets produced during the exercise. From a purely qualitative point of view, the horizontal coverage of the wind vectors shown in Fig. 1 is quite good in comparison to conventional observations routinely available over the western North Atlantic basin. It was found that the vertical distribution of the assigned vector pressure-heights was typically in the range of 200-500mb, with a maximum near 350mb. It was also clearly demonstrated for future considerations that the wind sets could be created on McIDAS (or VDUC at NMC) in a time scale commensurate with real time operations.

Fig. 1. Typical water vapor wind set coverage.

Comparisons between the M-3 wind vectors and collocated rawinsondes (within 1.0 degree) were compiled and are presented in Table 1. The winds are also evaluated against the collocated first guess forecast (in this case the Aviation model 12h forecast). Both vector speed bias and RMS were computed and compared. The data sets are also stratified to reflect comparisons with selected rawinsondes in relatively remote areas.

Table 1.Statistical evaluation of M-3 water vapor motion winds

1) Versus eastern US/western Atlantic rawinsondes (N=981)

	H2O Winds	NMC Forecast
Speed Bias (m/s)	-0.9	-1.8
Vector RMS (m/s)	6.5	5.5

2) Versus Bermuda rawinsonde (N=31)

	H2O Winds	NMC Forecast
Speed Bias (m/s)	-0.8	-2.1
Vector RMS (m/s)	6.2	6.4

3) Versus Guadeloupe rawinsonde (N=50)

	H2O Winds	NMC Forecast
Speed Bias (m/s)	-0.7	-1.9
Vector RMS (m/s)	5.6	5.9

Overall, the M-3 vector speed bias (wind vector minus rawinsonde) is -0.9 m/sec, which is about 1 m/sec better than the first guess forecast. The RMS error, however, is 1 m/sec higher than the first guess. The superior performance of the first guess RMS error can be explained by the fact that most of the comparisons were over the eastern United States, an area where the model has been properly initialized with abundant rawinsonde data. Examination of the relatively remote Bermuda and Guadeloupe rawinsonde comparisons, however, show the RMS error of the M-3 winds slightly below that of the first guess. The speed bias is also much improved over that of the first guess.

3. IMPACT ON NUMERICAL HURRICANE TRACK FORECASTS

Another way of quantitatively evaluating new data types is through model impact studies. In our investigation, a hurricane track forecast model (VICBAR, DeMaria et al. 1992) is used to test the sensitivity of the water vapor wind data on numerical hurricane track forecasts. VICBAR is a nested, spectral barotropic model that has been run in near-real time at the NOAA/Atlantic Oceanographic and Meteorological Laboratory Hurricane Research Division (AOML-HRD) for the past few years. The initial condition for the forecast model is a vertically averaged (mass weighted) deep-layer mean wind over the 850-200mb depth of the troposphere, with an added tropical cyclone bogus. The barotropic forecast model uses the shallow-water equations, with the forecast storm track determined from the location of the relative vorticity maximum on the innermost model mesh. This forecasting system has been used to evaluate impacts of other data types (Franklin and DeMaria 1992; Velden et al. 1992)

Wind sets were produced daily at 12UTC during several Atlantic tropical cyclones in 1992. For the model impact evaluation, forecasts were included based on the following criteria: 1) storm within the domain of generated wind set, and 2) storm intensity of tropical storm strength or better. There were 19 forecast cases, from 4 different storms (including Hurricane Andrew) that met these criteria (Fig. 2).

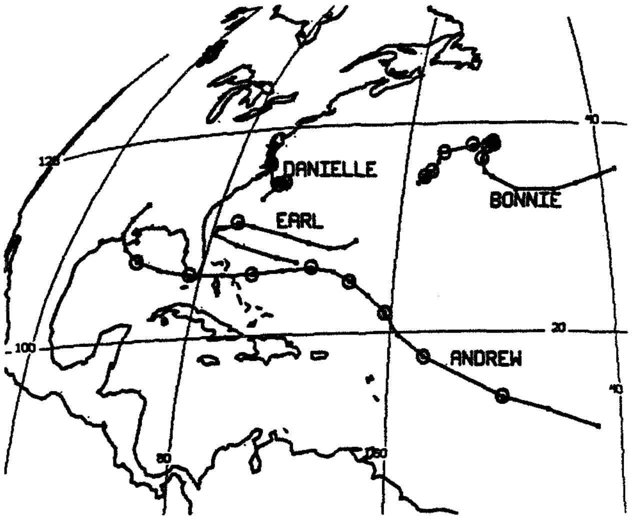

Fig. 2. Storm tracks, and center positions when forecasts were made (circles) in this study.

Table 2 shows the results of forecasts which were initialized with operationally available data plus the water vapor wind data, compared to control runs which were initialized on operationally available data only. Considering all of the cases together, the results show modest improvements to the forecasts with the inclusion of the water vapor wind data. The improvement in mean forecast error (MFI in Table 2) ranges from 1.8% at 24h to 8.2% at 72h, however, after an adjustment is made for the serial correlation between forecast cases (Franklin and DeMaria 1992), none of the improvements were found to be significant at the 95% confidence level. Another measure of forecast impact is the frequency of improved forecasts (FIF), which simply shows the percentage of forecasts which resulted in some improvement when the water vapor data were included. The FIF at 72h indicates that 79% (11 out of 14) of the forecasts were improved.

Table 2. Impact of METEOSAT water vapor winds on VICBAR tropical cyclone track forecasts. The following verification statistics are valid for forecasts which included the water vapor winds: number of forecasts (N), effective number of independent forecasts (N^*), and the mean forecast error (MFE) relative to best track verification. Also given are comparisons with the control forecasts: the mean forecast improvement (MFI), expressed in both kilometers and as a percent relative to the control forecast error, the standard deviation of the improvements (SDI), the number of improved forecasts (IF), the frequency of improved forecasts (FIF) expressed as a percent, and whether the forecast improvements are statistically significant at the 95% confidence level (SIG).

Forecast Interval (h)	N	N^*	MFE (km)	MFI (km)	MFI %	SDI (km)	IF #	FIF %	SIG (y/n)
24	19	16	139.9	2.6	1.8	22.9	10	53	n
48	17	14.4	354.1	6.8	1.9	49.1	11	65	n
72	14	11.6	381.2	34.2	8.2	94.5	11	79	n

From an examination of Fig. 2, it is evident that several of the selected cases are relatively close to the U.S. mainland. It is reasonable to assume that in these cases, the VICBAR model was relatively well initialized by the nearby conventional (operational) data base, limiting the potential for the satellite data to have a positive impact. On the other hand, storms well out to sea should make better candidates for forecast improvement. To test this hypothesis, the sample was stratified to include only those cases east of 70W. The results of these 13 cases are shown in Table 3. While still not significant, the MFI percentages are a notable improvement at 24 and 48h over the sample presented in Table 2. The FIF are also improved. The values at 72h are nearly unchanged since only one case was deleted from the original sample.

Table 3. Same as Table 2, except only cases east of 70W.

Forecast Interval (h)	N	N^*	MFE (km)	MFI (km)	MFI %	SDI (km)	IF #	FIF %	SIG (y/n)
24	13	10.8	104.5	8.9	7.8	18.8	9	69	n
48	13	10.8	221.6	10.7	4.6	53.2	10	77	n
72	13	10.8	389.0	35.9	8.5	107.2	10	77	n

It is of interest to examine the distribution of forecast differences in the stratified sample, in order to fully appreciate the FIF results. Table 4 shows the distribution of the 72h forecast differences. Of the 13 cases, two forecasts were notably degraded by the inclusion of the water vapor winds. One of these poor forecasts was a Hurricane Bonnie case, which seemed to result at least in part because Bonnie's track did not follow the deep layer flow used in the model forecast. Rather, it followed a shallow-layer flow, in a direction quite different from the deep-layer flow. The water vapor winds provide measurements in the 200-500mb layer, thus affecting the upper part of the deep layer mean wind flow field. In this case, the control analysis approximated the shallow-layer flow more closely, and as a consequence, the VICBAR model control forecast without the winds was closer to the observed storm track. The reason for the other poor forecast has not yet been identified.

Table 4. Distribution of 72-h forecasts relative to control forecasts for cases east of 70W.

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                  Forecast differences (km)

 *   *    **      * ** ***  *             *         *
|------------|------------|------------|------------|
200         100           0           100         200
         BETTER                     WORSE
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On a more positive note, Table 4 shows that 10 of the 13 72h forecasts were improvements over the control forecasts, with 4 of them being notable improvements (defined here as greater than 100km). Three of the notably improved forecasts occurred during Hurricane Andrew's interaction with an upper-level cyclonic circulation. An example is shown in Fig. 3, from 12 UT 19 August 1992. At this time the upper-level circulation was situated to the north of Andrew and quite evident in the water vapor imagery. The derived water vapor winds captured the circulation, as shown in Fig. 1. During the next 72h, Fig. 3 shows that Andrew's track was only slightly affected by the upper-level low, shifting it NNW for a short time before Andrew escaped its influence and turned more to the west. The VICBAR control forecast from this time recurved Andrew to the north and eventually to the northeast in response to the influence of the upper low on the deep layer mean steering flow. Although the turn to the west was not predicted, the VICBAR forecast made with water vapor wind data responded with much less curvature, and an improved longer-range forecast.

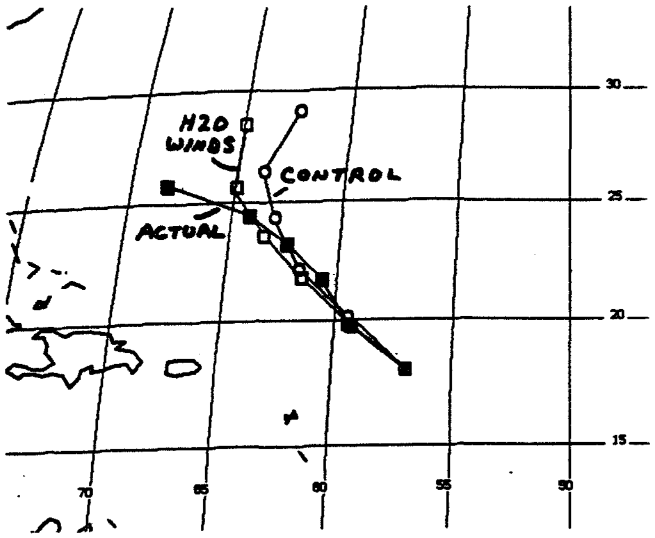

Fig. 3. Example showing impact of water vapor winds on a VICBAR forecast of Andrew's track

4. SUMMARY

The recent availability of METEOSAT data over the western Atlantic Ocean has led to an effort to extract quantitative information from the water vapor channel. Data sets containing vectors derived from animated water vapor imagery were produced during 1992 using the CIMSS automated wind derivation algorithm. A statistical evaluation of the vectors reveals that the water vapor winds (relative to collocated rawinsondes) show a reduced speed bias compared to the collocated first guess forecast values. The vector RMS errors are larger (by about 1 m/sec) than the first guess over the eastern U.S., but become slightly lower than the first guess at remote locations (e.g., Bermuda and Guadeloupe).

The wind sets were also demonstrated to have a slightly positive impact on barotropic numerical hurricane track forecasts (VICBAR model), although the results were not statistically significant at the 95% level. Except for a couple of examples, the preliminary results seem to suggest that the positive impact is maximized on cases well offshore and away from data-rich regions, as would be expected from intuitive reasoning. Most of the cases near the U.S. coast showed negligible or slightly negative impact. The most notable forecast improvements occurred during Hurricane Andrew's interaction with an upper-level low, which was well-captured by the water vapor winds. Overall, 72h track forecasts were improved by an average of around 8%, while nearly 80% of the VICBAR forecasts showed some improvement with the inclusion of the water vapor winds into the initial analysis.

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