POSITIVE IMPACT OF SATELLITE-DERIVED WINDS DURING THE 1995 HURRICANE SEASON: EXAMPLE OF OPTIMIZING DATA APPLICATION AND PROCESSING STRATEGY

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ABSTRACT

With the recent advances in numerical weather prediction, it is becoming increasingly important to provide satellite-derived data in such a way as to maximize the impact on the initialization process in order to positively affect the subsequent forecasts. Therefore, data processing strategies must take into account the increased resolution and accuracy of today's models. The 1995 Atlantic hurricane season provided many opportunities to show how tropospheric wind information derived from GOES can be both qualitatively and quantitatively useful to analyses and forecasts. Utilizing a multispectral approach with optimized processing and QC strategies, high-density wind sets were produced by CIMSS during hurricane events. The datasets were disseminated to modelling centers for data impact studies. Numerical hurricane track forecasts were shown to be improved considerably with incorporation of the satellite-derived wind information. Generally, track forecast errors were reduced by 8-21%, with several cases upwards of 30%. As a result of these initial studies, the National Hurricane Center and several model centers will employ the data sets in real time during the 1996 Atlantic hurricane season.

1. INTRODUCTION

GOES-8 was successfully launched in 1994, and has performed up to expectations and in some cases has actually exceeded pre-launch specifications. A similar geostationary satellite, GOES-9, was launched in May of 1995. This new generation of NOAA's geostationary satellites carry a superior design and instrumentation package that allow for greater detection of meteorological features and parameters. The new GOES imager has a 5 band multispectral capability with high spatial resolution, while the sounder contains 18 thermal infrared (IR) bands plus a low-resolution visible band. The imager carries a visible channel with 10-bit quantization and increased sampling frequency, a short-wave and long-wave window channel, and a water vapor band with a twofold increase in spatial resolution and a factor of 3 improvement in signal-to-noise over that obtained from previous GOES sensors.

The advances in observing the earth's atmospheric system anticipated from these improvements are outlined in Menzel and Purdom (1994). The specific impact of this improved remote sensing capability on the analysis of hurricanes is discussed here, using cases from the prolific 1995 Atlantic season. In addition to the instrument precision improvements, an optimized processing and quality control strategy is employed. Together, multi-spectral wind datasets at very high spatial resolution are possible. The elements of these datasets and the processing strategy are discussed and shown to lead to a superior analysis of the hurricane environment, and improved numerical hurricane track forecasts.

2. DATASET DESCRIPTION

Quantitative wind information derived from sequences of GOES-8 imagery has the potential to impact hurricane analysis by improving the depiction of the upper-level environmental flow fields. The detector improvements with GOES-8 are resulting in superior qualitative image presentations of hurricane structure and development. In the visible spectrum, sharper images are resulting in improved cloud top and cloud edge feature detection. This helps in the subjective interpretation of the imagery in regards to eye and eyewall characteristics, but also enhances the ability of automated cloud tracking algorithms. In particular, low level cumulus in the storm region can be tracked to define the vortex wind structure and extent of the vortex circulation (i.e. radius of gale-force winds). In the cases examined in 1995, 15 minute interval GOES-8 images at full resolution (1 km) were employed for this purpose.

In the IR spectrum, the improved spatial resolution and signal-to-noise again benefits the ability to detect trackable cloud features, and is resulting in higher quantity and quality wind vectors. Velden et al. (1992) have shown that high-density satellite-derived wind information in the hurricane near-environment can lead to important forecast improvements. The IR winds are especially important in defining the outflow circulation which is often characterized by cirrus cloud.

Water vapor observations from geostationary satellites have been shown to be useful in delineating features in the hurricane environment that can affect intensity and motion (Dvorak 1984; Weldon and Holmes 1991, Velden et al., 1993). The water vapor observations from the GOES-8 6.7 micron channel are of unprecedented quality, and are providing substantially improved wind vectors in cloud-free regimes (Velden et al., 1996). High-density water vapor winds were produced over a region covering the large-scale hurricane environment during 1995 cases. An example of this product is shown in Fig. 1.

The importance of the GOES sounder information is to utilize the 7.0 and 7.4 micron water vapor absorption channels as surrogate imagers in order to track moisture features and provide vertical wind profile observations in cloud-free regions in the hurricane environment. This is possible since energy sensed from these two channels peaks in lower portions of the troposphere with respect to the 6.7 micron channel. An example of the vector fields resulting from these two bands is shown in Fig. 2. The spatial coverage of vectors from the sounder channels was somewhat limited in 1995 due to scanning limitations and operational requirements.

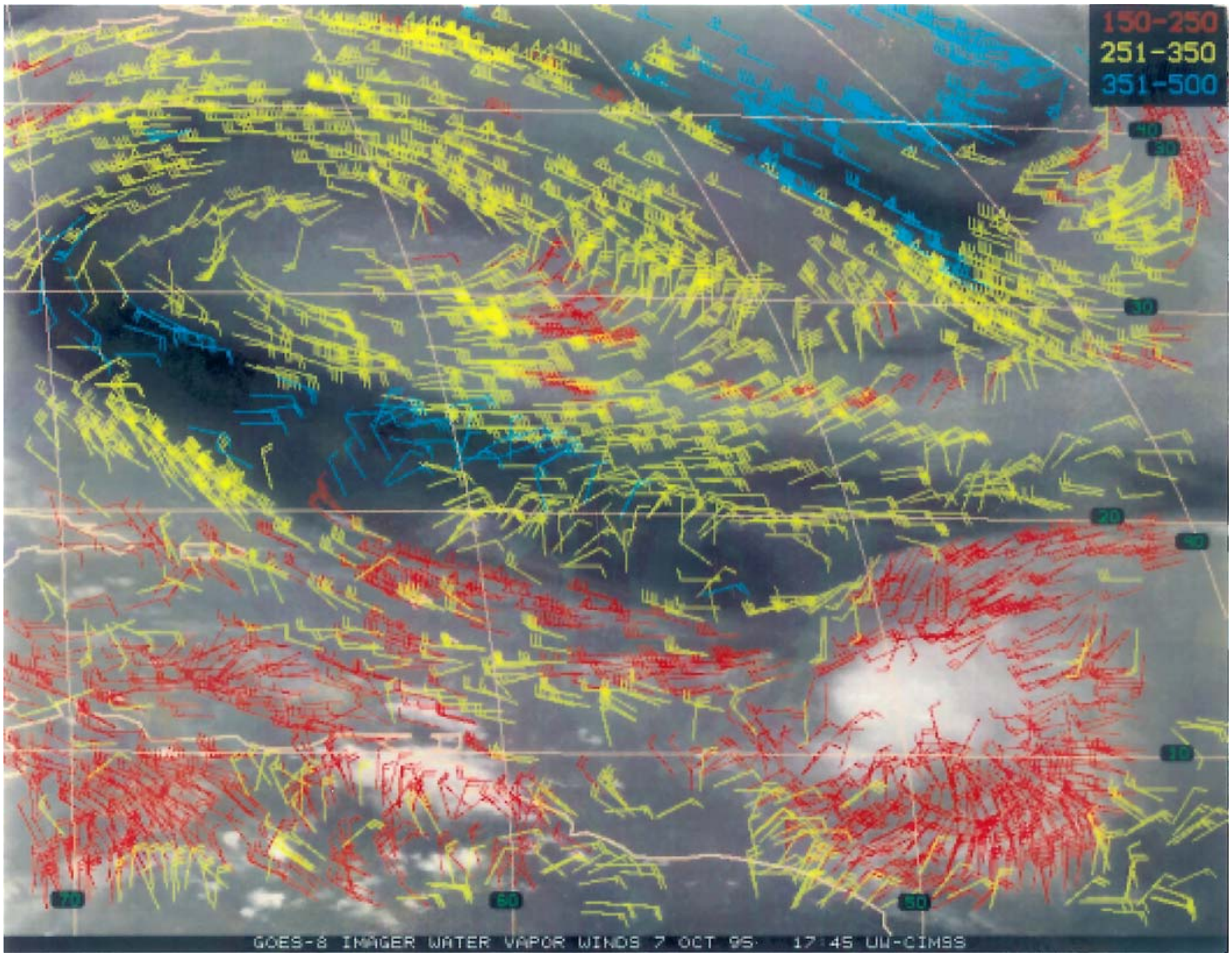

Figure 1. High-density GOES-8 water vapor winds (6.7 micron channel) during Tropical Storm Pablo (lower right) on October 7,1995. Vectors are in knots, and the colors refer to assigned heights (mb) with the legend in the upper right hand corner.

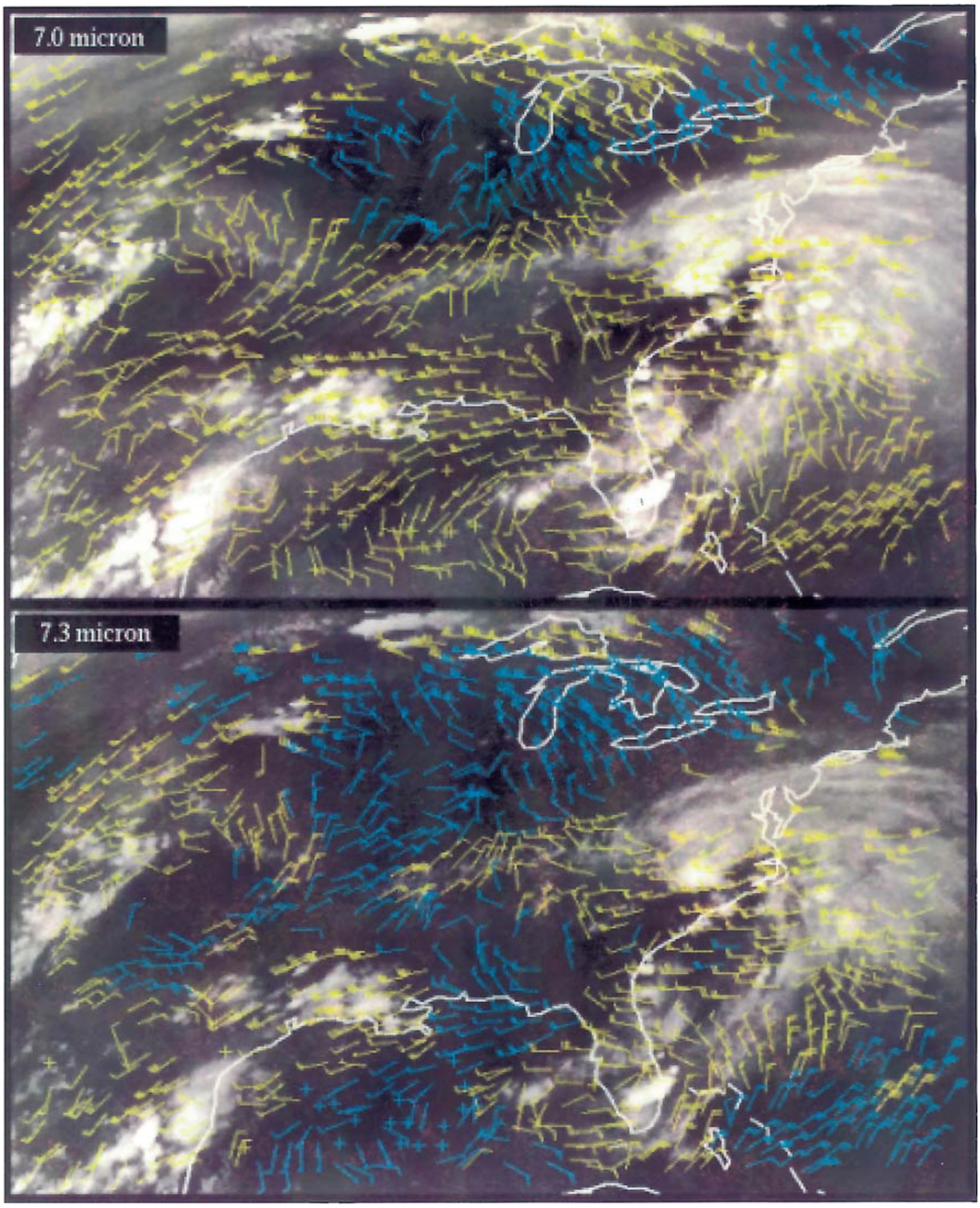

Figure 2. Example of wind vector coverage that can be achieved from tracking features in the 7.0 and 7.3 micron channels from the GOES-8 sounder. Yellow (blue) vectors (kts) indicate winds with assigned heights above (below) 400 mb.

3. 1995 HURRICANE CASES

Multispectral GOES-8 datasets were produced at 12-hour intervals and delivered to the National Hurricane Center in near real time during the 1995 season for their subjective evaluation. In addition, several cases were identified for post analysis: Tropical Storm Chantal, and Hurricanes Humberto and Iris. Datasets were post-processed at 6 hour intervals and delivered to numerical modeling centers for their evaluation on track forecast impacts.

The dataset impact was evaluated by two independent sophisticated hurricane track assimilation and forecast systems which employ physical initialization schemes and use the full primitive equations. The GFDL model is a limited area, multi-nested system that has achieved top status in numerical prediction of Atlantic hurricane tracks over the past several years. The US Navy NOGAPS model is a global assimilation system which was competitive with the GFDL model in the 1995 season.

The results from the numerical prediction trials are shown in Table 1. Taken collectively, the mean track forecast errors are reduced by 8-21% over the 24-72 hr forecast periods. Up to a 30% reduction is found in some cases. Nearly 70% of the forecasts were improved at 48 and 72 hrs. Further cases are being examined.

It is insightful to determine the impact of the various elements of the data set. To examine this, a component analysis was conducted with the Tropical Storm Chantal case. The overall impact on the track forecasts with the NOGAPS model is shown graphically in Fig. 3. The experimental (with the satellite winds) forecasts are much improved over the control in terms of curving the storm to the north and northeast. The actual forecast errors are compared in Table 2. The assimilation of the satellite-derived winds resulted in a 20-31% improvement over the control runs in the 24-72hr forecast period. All forecasts were improved at 48 and 72 hrs. The impact of individual GOES-8 wind components on the reduction of forecast errors were assessed and are shown in Table 3. Each component was left out of the data set, and the assimilation and forecast cycles were rerun. The resulting forecast error analysis in Table 3 shows the water vapor winds are a key contributor to the error reduction. The sounder winds impact the shorter time scales while the imager winds are important in the medium and longer range forecasts. The IR winds are an important contributor to the 24 hr forecast error reduction. It is important to note the best results are achieved when the multispectral wind data are combined and employed collectively.

4. SUMMARY

GOES-8 has performed up to expectations, and in some cases is exceeding pre-launch specifications. Applications of this new and improved satellite data to the analysis of hurricanes commenced in 1994 during the spacecraft and instrumentation check-out, and continued during the active 1995 Atlantic hurricane season. Findings are revealing that the data being provided by GOES-8 are superior to observations from previous geostationary satellites, and have the potential to positively impact both the subjective and objective analysis of hurricane situations. Development of algorithms and processing strategies designed to optimally extract the information from these higher-precision observations is an important consideration in order to achieve the desired positive impact on objective analyses and numerical weather prediction.

Table 1. Numerical weather prediction data impact results for selected 1995 Atlantic tropical cyclones. The effects of high-density multispectral GOES-8 winds on mean track forecast errors are evaluated, and the results expressed as a % improvement over the control (without the GOES-8 winds). GFDL is the Geophysical Fluids Dynamics Laboratory hurricane model, and NOGAPS is the Navy Operational Global Atmospheric Prediction System. TS = Tropical Storm and Hurr = Hurricane

Mean Forecast Error Improvement (%)

Forecast Interval (hr)	24	48	72
1) TS Chantal			
GFDL	-9	12	12
# of cases (# improved)	10 (4)	8 (6)	6 (5)
2) TS Chantal			
NOGAPS	20	31	20
# of cases (# improved)	10 (8)	8 (8)	6 (6)
3) Hurr. Humberto			
NOGAPS	16	5	-1
# of cases (# improved)	14(11)	11 (6)	10 (5)
4) Hurr. Humberto			
GFDL	1	12	25
# of cases (# improved)	13 (7)	11 (7)	9 (5)
5) Hurr. Iris			
NOGAPS	16	22	29
# of cases (# improved)	21 (14)	19 (14)	17 (12)
6) Hurr. Iris			
GFDL	-3	8	24
# of cases (# improved)	12 (5)	12 (6)	12 (8)
7) TS Karen			
GFDL	4	41	46
# of cases (# improved)	7 (4)	4 (3)	3 (3)
Overall MFE improvement (%)	8	15	21
# of cases (# improved)	87 (53)	73 (50)	63 (44)

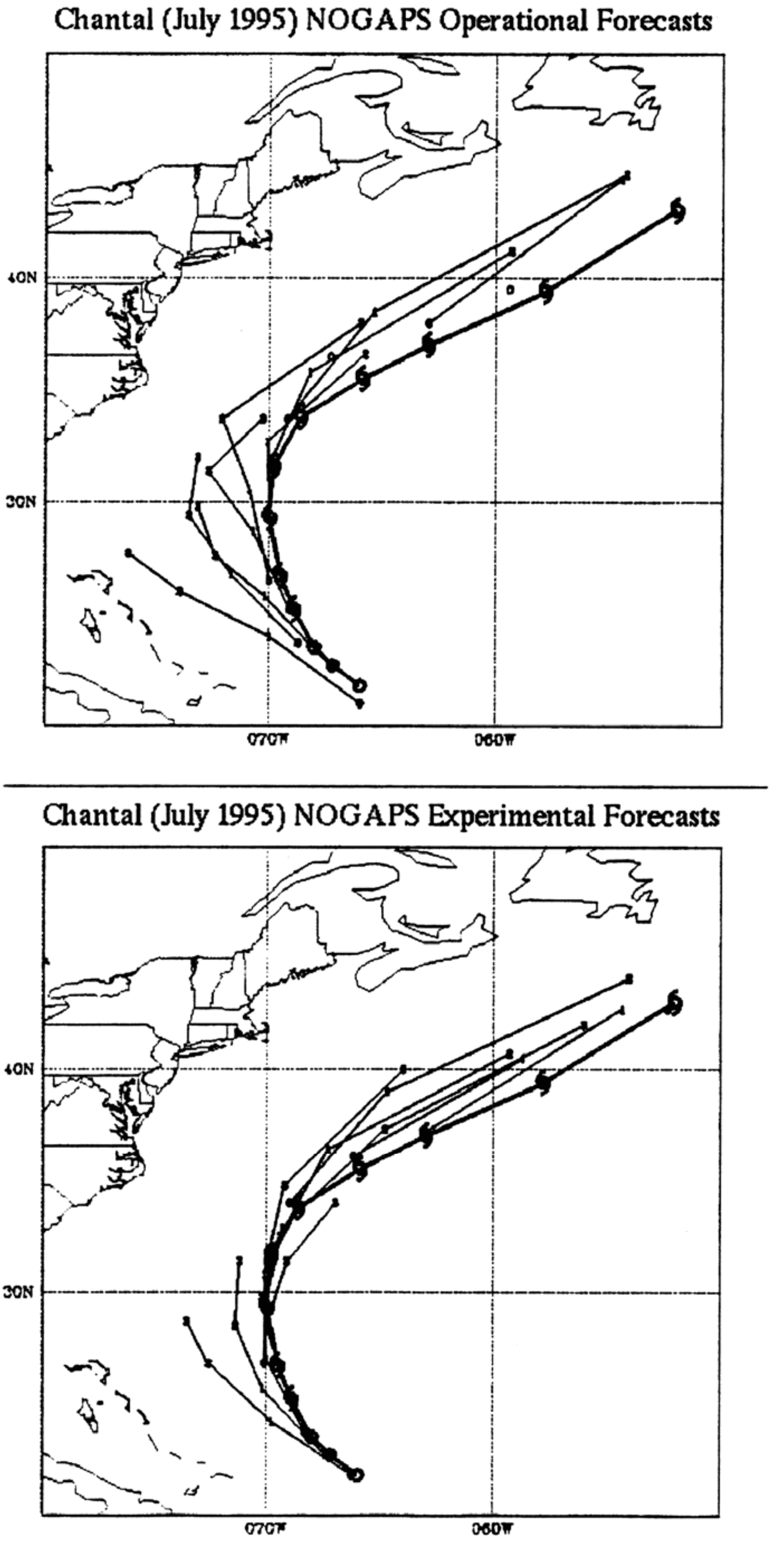

Figure 3. Track of Tropical Storm Chantal (bold) in July of 1995. Numerical track forecasts (out to 72 hr) are also indicated from the NOGAPS model; top) operational, bottom) experimental with GOES-8 high-density multispectral winds

Table 2. NOGAPS forecast impact results for Tropical Storm Chantal (1995). CLIPER is the climate/persistence model, a standard for assessing skill.

Mean Forecast Errors (nm)

Forecast Interval (hrs)	24	48	72
CONTROL (CON)	100	179	301
CONTROL+SATWINDS (CON+SAT)	80	124	242
CLIPER	112	210	358
% Improvement (CON+SAT over CON)	20	31	20
% Improvement (CON+SAT over CLIPER)	29	41	33
# Forecasts	10	8	6
# Improved Forecasts (CON+SAT over CON)	8	8	6
T -test Significance (%) (CON+SAT over CON)	92	97	93

Table 3. NOGAPS sensitivity study of the impact of individual GOES-8 wind components for the Tropical Storm Chantal case. SNDRH2O is the combined sounder WVWV, IMGRH2O is the 6.7 micron WVWV, ALLH2O is the combined imager and sounder WVWV, VIS is visible cloud tracked winds and IR is infrared cloud tracked winds. Each component is subtracted from the collective dataset and the subsequent NOGAPS forecast results are shown.

Mean Forecast Errors (nm)

Forecast Interval (hrs)	24	48	72
CONTROL	100	179	301
CONTROL+SATWINDS	80	124	242
CONTROL+SATWINDS-SNDRH2O	94	148	246
CONTROL+SATWINDS-IMGRH2O	82	151	280
CONTROL+SATWINDS-ALLH2O	97	156	281
CONTROL+SATWINDS-VIS	82	133	239
CONTROL+SATWINDS-IR	90	126	236

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