OPERATIONAL CONSIDERATIONS AND USES FOR GEOSTATIONARY SATELLITE DERIVED WIND VECTORS

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ABSTRACT

Since 1999 the Air Force Weather Agency (AFWA) and the Fleet Numerical Meteorology and Oceanography Center (FNMOC) have cooperated with the University of Wisconsin-Cooperative Institute for Meteorological Satellite Studies (UW-CIMSS) in an effort to use geostationary satellite derived winds in an operational environment for forecasting and flight planning operations. We summarize the operational considerations relevant to other organizations using geostationary satellite derived winds in their operations, hardware needed to run effectively in a time critical environment, and software used to manage the data automatically. We discuss hardware and software issues that arose during implementation as well as errors, along with their solutions. We present statistics showing how much geostationary satellite data we are able to utilize in the production of wind vectors as well as the spatial and temporal coverage we are able to achieve. We conclude with operational uses for the data, and new capabilities it introduces.

1. Introduction

Since 1999 the Air Force Weather Agency (AFWA) and the Fleet Numerical Meteorology and Oceanography Center (FNMOC) have cooperated with the University of Wisconsin – Cooperative Institute for Meteorological Satellite Studies (UW-CIMSS) in an effort to use geostationary satellite derived winds in an operational environment for forecasting and flight planning operations. Thanks to the efforts of all involved, we are now using Feature Tracking Winds (FTW) derived wind vectors for a variety of operational purposes.

2. History

A. Early FTW Support Agreement

The FTW system as it now exists is the result of a collaborative effort between AFWA, FNMOC and UW-CIMSS. UW-CIMSS provided the Windco wind vector derivation algorithms, FNMOC provided the processing configuration, and AFWA provided the hardware and implementation support.

The FTW system is a collection of software, with Windco as its core, used to derive wind vectors from geostationary satellite images. To do this it first collects images into “triplets” or groups of three consecutive images with needed sensor types (Visual, IR, or Water Vapor). Windco identifies features in those images and tracks them between images to determine wind speed and direction. It then uses IR temperatures and numerical model data to determine vector heights (Olander 2001).

B. Windco 1.0

The original version of Windco was implemented in October of 2000. The installation and implementation of this software was the result of considerable effort and required the coordination of several different groups. This setup generated wind vectors from GMS-5 imagery. Because AFWA receives GMS-5 data on a regular schedule, we decided to run the FTW software using a time-driven setup. This worked fine as long as the input data arrived when expected. However, when problems did arise, recovering a lost run or restarting normal processing proved to be difficult.

C. Windco 2.0

In July of 2001 AFWA received a new copy of the software from UW-CIMSS. After thorough testing of the new software it was declared operational in Aug of 2001. The benefits of the new software were immediately obvious as we saw a 375% increase in global wind vectors with the addition of Meteosat processing capability. We now had coverage of Europe and Western Asia. Because of the framework we laid out for Windco 1.0, adding new functionality went smoothly. The bulk of the time was spent developing the wrappers needed to change the system from its original time-driven configuration to an event-driven one. Even though the Meteosat imagery is generated on a regular schedule, there are variable lags in processing as the data moves through AFWA. The event-driven architecture allowed processing to begin when the data arrived instead of an arbitrary wall-clock time.

D. Future

In any complex software system there is always room for improvement, and FTW is no exception. The most significant improvement on the horizon is the addition of GOES data processing capability. In addition, future versions will ingest raw data from satellites, reducing software requirements and increasing flexibility (Olander 2001).

3. Concept of Operations

A simplified version of our current architecture can be seen in Figure 1. The following sections will describe the data path in more detail.

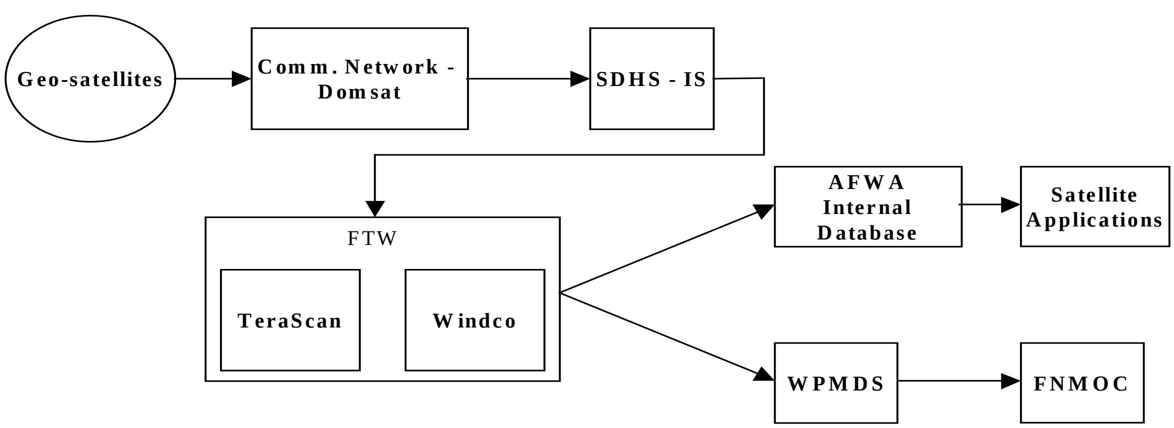

Figure 1. FTW System Architecture

A. Geostationary Satellites

AFWA generates wind vectors from GMS-5, Meteosat-5 and Meteosat-7 satellite imagery with the latter two being rather recent additions. GMS-5 provides coverage of the Eastern Pacific region from about 80E to 180E. Meteosat-5 and -7 provide coverage for the Atlantic, Europe, and most of Asia. Their coverage overlaps over Africa and Eastern Europe and stretches from about 50W to 135E.

B. Communications Network – DOMSAT

Meteosat-7 and GMS-5 data are transmitted to us by the DOMSAT network. Meteosat-7 data is beamed down to Wallops Island in Virginia then to the DOMSAT. GMS-5 data is sent to a download station in Honolulu HI and then transmitted on to the DOMSAT. Because of the small number of relays, we get data from these satellites with very little delay. Meteosat-5 data comes to us mostly through land based transmission methods. The data is downloaded to a satellite dish in Lannion France maintained by Eumetsat. From there it is transmitted by landline to NOAA/NESDIS who then sends the data to us and FNMOC via the Shared Processing Network (SPP). There is approximately a 15-minute delay in the transmission of Meteosat-5 data to AFWA.

C. SDHS IS

Our **S**atellite **D**ata **H**andling **S**ystem – **I**ngest **S**ubsystem handles all incoming satellite data traffic for AFWA. This is where the data is converted into the SIMPLE format that FTW is currently capable of processing. The SIMPLE format files retain all of the calibration, navigation, and radiance data of the original satellite transmission. The most significant changes to the data are the addition of a transmission header, documentation data at the beginning of each scan line, and the separation of the navigation, calibration, or interpretation data into separate files, depending on satellite type (Sterling 2000). The format was developed for satellite data shared among the operational processing centers in the US (AFWA, FNMOC, and NESDIS), but the format is not widely used outside of these centers.

D. Feature Track Winds System

This is where all the hard work is done. It is comprised of three primary sections. The most important section is Windco, the heart of the entire system. The next section is a program called Terascan, which handles some image preprocessing. Finally there are the processing scripts that handle most of the file management and execution details.

- Terascan

Terascan software developed by SeaSpace is used to accomplish minor image correction prior to running Windco. We use it to extract the most accurate image time from the data. We also use it to determine the number of scan lines so we can check for bad images.

- Windco

Developed to run in a UNIX environment (Olander 2001), Windco has been used by both FNMOC and AFWA for the primary purpose of incorporating the wind data into the Navy's Operational Global Atmospheric Prediction System (NOGAPS). The algorithms developed by UW-CIMSS development team represent the only method currently available for extracting high-density wind vectors from geostationary satellite imagery using computer analysis. Thanks to its ability to analyze water vapor and IR imagery, we are now able to generate wind vectors in three dimensions and in otherwise cloudless regions.

- Processing Scripts

These scripts are used to accomplish all the tasks needed to stage the wind vector derivation process. This includes grouping the images, gathering the numerical model data set, and building the context files needed by Windco to keep track of all the operating parameters. The first step in the process is the formatting of the input data. Not much work needs to be done outside the simple file corrections that are done by Terascan. Second, the images need to be gathered into groups of three to five images with height assignment files and checked for the correct time resolutions. Even though Windco can be configured to process up to five images in a single run (Olander 2001), we use the recommended grouping of three images. The next step is to ensure the availability of the numerical model data. Now that all the needed data sets are configured the context files can be built and execution can proceed.

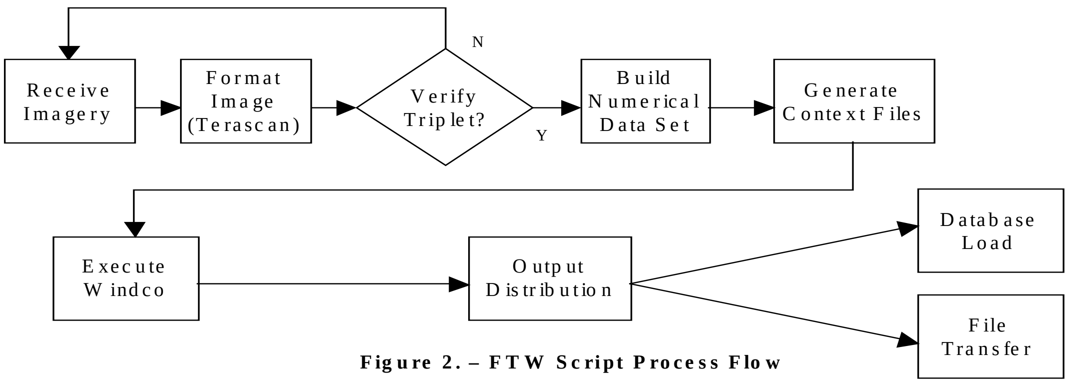

Figure 2. – FTW Script Process Flow

E. Output Distribution

AFWA has two primary customers for FTW data: FNMOC and AFWA itself. FNMOC receives all output that AFWA generates in both ASCII text and WMO BUFR format. They receive all FTW data generated by AFWA through our Weather Product Distribution Network also known as WPMDS using a simple FTP transfer. Internal AFWA customers access the data using an NCR Teradata database. This eases distribution since the data is available to anyone who needs it without the need to set up a specific transfer path. We find that the ASCII text output is the easiest to load into our database.

4. Hardware Recommendations

FTW at AFWA runs on a Sun Enterprise 450 with 512Mb of RAM, 3 Sun SPARC 333MHz processors, and an 8Gb hard drive. In this environment Windco takes 5-7 minutes to generate an output set. This time is an average and is affected by processor load and user-defined parameters for Windco. An important hardware consideration is to provide as much hard drive space as possible. Our 8Gb prevents us from storing more that 24 hours worth of image and model data. Our recommendation is to provide the system with at least 20Gb of drive space.

5. Operational Errors and Considerations

A. Time vs. Event Driven Configuration

As discussed earlier, when Meteosat-5 and -7 functionality was added we were no longer able to run in a time driven architecture. By switching to an event driven architecture, the system was better able to handle data availability irregularities.

B. Lack of Sufficient Hardware

Insufficient resources have caused a number of problems in our processing stream. As stated earlier we are unable to maintain any usable backup of data. In contrast to this, we cannot receive data in large quantity either. The increase in data flow overtaxes both the processor and the available disk space. In most cases manual intervention is required to remove any unnecessary files to free up needed disk space.

C. System Monitoring

Monitoring FTW activities entails more than just traditional software error checking. We must recognize a variety of system impacts such as the non-availability of input data. We are currently developing a method to track trends in data rates to determine the best schedule for FTW processing. We are also considering adding a quality control (QC) post-process to compare the results with rawindsonde observations.

6. Coverage and Frequency of Wind Vectors

AFWA ingests 155 images daily from the GMS-5, Meteosat-5, and Meteosat-7 satellites. From this we are able to generate a combined total of over 120,000 wind vectors spanning 225° of longitude. This area ranges from just west of Sao Paulo, Brazil (50W) to slightly east of New Zealand (180E) and from 60N to 60S. These boundaries were established to avoid creating poorer-quality wind vectors from the limb of satellite imagery.

For GMS-5, FTW vectors are computed four times per day using image triplets that contain images at 30-minute intervals. Two of the runs are IR and WV only, while the other two contain wind vectors from the VIS, IR, and WV channels. For Meteosat-5 and -7, more frequent image triplets are available and thus more frequent FTW runs are generated.

7. Operational Uses for the data and New Capabilities

A. FNMOC Uses

Data assimilation experiments using the CIMSS operational wind algorithms have shown to improve the Naval Operational Global Atmospheric Prediction System (NOGAPS) model accuracy at FNMOC (Goerss et al., 1997). In particular, the use of water vapor winds in the tropics has increased the accuracy of tropical cyclone track forecasting.

A motivating factor for the AFWA-FNMOC FTW collaboration was the choice of the model background fields used in the algorithms. The Goerss et al. (1997) data assimilation experiments used NOGAPS background fields, and therefore the project requirements specify the use of NOGAPS background whenever possible.

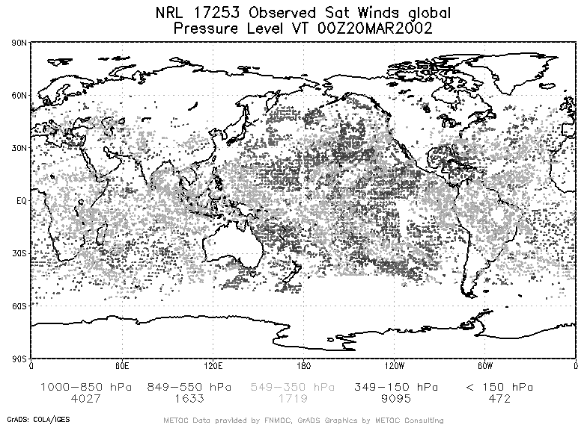

Figure 3 – Global Observed Sat Winds

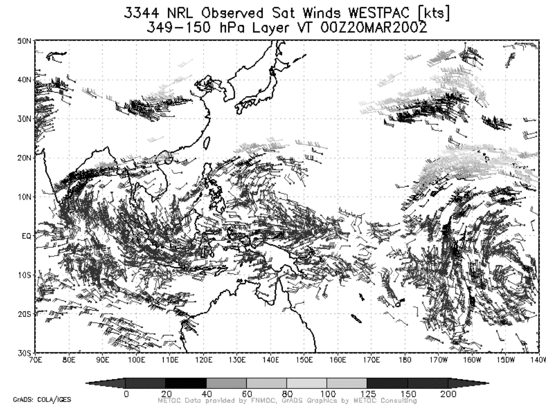

Figure 4 – Observed Sat Winds for Western Hemisphere

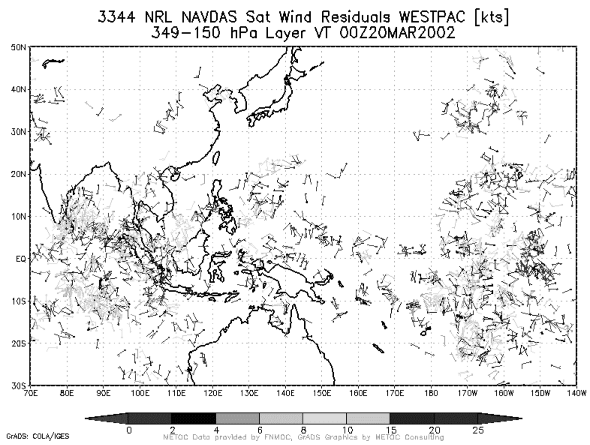

Figure 5 – Residual Sat Winds Observations

Satellite Winds Statistics – Area: WESTPAC Units:[m/sec]									
Model: NOGAPS				DTG: 00Z20MAR2002					
		Innovation				Residual			
Layer hPa	#obs	U Bias	V Bias	U Bias	V Bias	U Bias	V Bias	U Bias	V Bias
1000-850	1880	0.116	0.175	1.621	1.704	0.072	0.036	0.388	0.895
849-550	779	-0.41	-0.21	1.733	2.124	-0.27	-0.11	0.909	1.063
549-350	355	0.147	0.274	4.144	3.556	0.080	0.027	2.207	2.024
349-150	3344	-0.02	0.473	3.473	4.159	0.003	0.095	1.665	1.825
150	230	0.811	-0.40	3.701	4.816	0.489	0.010	1.558	1.728

Figure 6 – Comparison Between Innovations and Residuals

Prior to assimilation, wind vectors undergo QC checks at several processing stages. As part of the processing, winds are screened for a wide variety of known speed or height biases. See Olander (2001) for more detail. Additionally, the background enters the QC process through "QI" thresholding (50%), and the 3-dimensional recursive filter, termed "autoeditor". The autoeditor adjusts measurement heights to minimize departures from the background, and rejects outliers.

Feature tracking winds are treated as conventional observations in the NRL Atmospheric Variational Data Assimilation System (NAVDAS), where further QC is performed. Observations in layers above 100 hPa, 400 to 800 hPa, and below 1025 hPa are rejected. Thinning is performed prior to assimilation. Innovations (observation minus background) within latitude-dependent volumes are screened against height dependent thresholds, and then spatially averaged. The data assimilation uses a 3 dimensional variational (3DVAR) method in observation space. As with most 3DVAR methods, observations are removed during the iteration process, based on their background/observation error scaled departures from the solution.

Figure 3 shows the global distribution of wind observations after the QC portion of the NAVDAS. AFWA data represent about 70% of the wind vector observations for this 6-hour time window. The observations from AFWA are not shown, but the preprocessing has reduced the observations by roughly a factor of four through averaging observations into super observations and QC. Figure 4 shows a layer of analyzed vectors for the Western Pacific region. Vectors missing from Figure 3 were removed by 3DVAR. Figure 5 shows the residual, the difference between the observations and the analysis. Figure 6 lists statistics for both innovations and residuals for this case. The significant reduction in the innovation-residual RMS indicates the rather large influence of FTW wind vectors on the analysis for this region.

FTW products are also assimilated into FNMOC's Coupled Ocean/Atmosphere Mesoscale Predictions System (COAMPS) for regional forecasting. FTW supports near-real-time forecasts for Navy operations. Wind vector / imagery composites are produced for routine and special areas of interest, and made available to DOD METOC users on the FNMOC secure Internet Web site. FTW products are also distributed to remote databases and client applications, for on-site display, modeling and analysis.

B. AFWA Uses

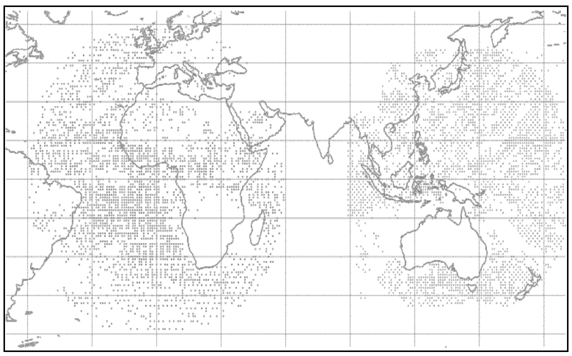

Figure 7. FTW data coverage at AFWA before implementation.

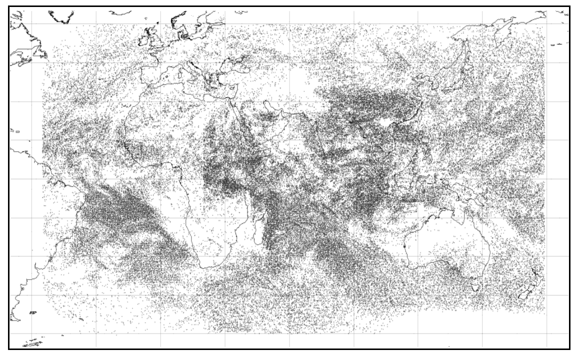

Figure 8. FTW data coverage at AFWA after implementation.

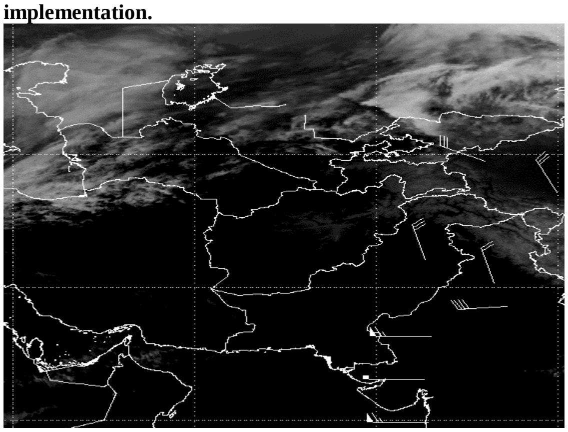

Figure 9. 300 hPa wind data from conventional observations at 1200 UTC 05 March 2002 overlay on Meteosat-5 infrared image at same time.

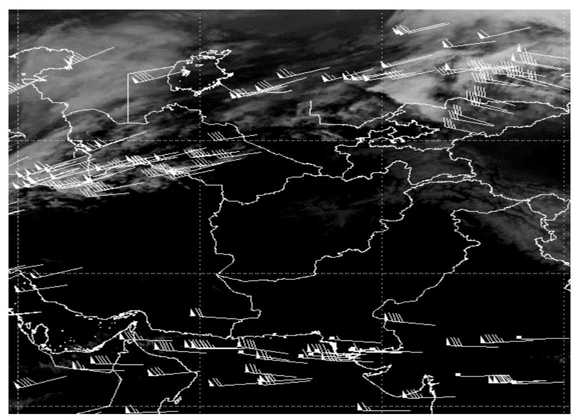

Figure 10. Similar to Figure 10, but 300 hPa FTW vectors instead.

The implementation of FTW at AFWA has resulted in a ten-fold increase in the number of wind vectors available daily for the Meteosat-7, Meteosat-5, and GMS-5 coverage areas. Before the implementation of FTW, AFWA received low-density wind vectors from Eumetsat for Meteosat-7 and from the Japan Meteorological Agency (JMA) for GMS-5. Meteosat-5 wind vectors were unavailable to AFWA. Previous data coverage and density are shown in Figure 7, and the corresponding new coverage is shown in Figure 8.

At present, one of the main uses of the FTW data is to supplement conventional observations for military weather forecasting. Figure 9 shows the 300 hPa wind data available from upper-air stations over the Arabian Sea region for 1200 UTC 05 March 2002. Figure 10 shows the equivalent wind data available from the feature-track wind vectors. Note that the feature-track wind vectors show more definition to the jet streams coming across the lower Arabian Peninsula into South Asia and from northern Iran through southern Kazakhstan. This additional wind information can be an important aid when preparing an enroute weather forecast for aviation. While feature-track winds will not completely replace conventional upper-air observations, they can be an important supplement. This is especially true in areas of the world where the upper-air network is sparse or non-existent, as is often the case when Air Force Weather is called upon to provide weather forecasts.

These wind vectors are also being provided to the Joint Typhoon Warning Center at Pearl Harbor, Hawaii. There, forecasters use the wind vectors to help diagnose potential areas of low-level convergence and upper-level divergence that aid the formation of tropical systems. As the data distribution portion of the system matures, the wind vectors will be provided to more field units for their local analysis and forecast programs.

In the future, AFWA plans to incorporate feature-track wind vectors into its mesoscale numerical weather prediction models. These wind vectors will be an important source of data to initialize these models when they are run for areas of the world with few or no conventional observations.

8. Summary

The addition of the UW-CIMSS wind derivation algorithm has had a profound impact on the operations of AFWA and its customers. There have been problems along the way, but these problems have been easily outweighed by the benefits. There remains much work to be done in improving the process to maximize output and usefulness of the derived wind vectors. These initial steps have shown that Feature Tracking Winds will remain an important tool in utilizing geostationary satellite imagery for the purpose of forecasting.

9. Acknowledgments

I would like to thank my co-authors: Capt Troy Johnson, Chuck Skupniewicz, and Mark Conner as well as Gail Dengel from UW-CIMSS for keeping me afloat during my long and tedious FTW learning curve, and for answering an unending string of questions. We would like to thank UW-CIMSS and FNMOC for providing the FTW software and its support.

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