THE VALIDATION OF ATMOSPHERIC MOTION VECTORS PRODUCED AT FLEET NUMERICAL USING THE FMQ-17 SYSTEM BY SEASPACE CORPORATION

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ABSTRACT

For over a decade, the Fleet Numerical Meteorology and Oceanography Center (FNMOC) in Monterey, California has been using Atmospheric Motion Vectors (AMVs) derived from Geostationary satellites. These AMVs have been used as a key input to the data assimilation system employed to initialize the US Navy's atmospheric Numerical Weather Prediction (NWP) Models, specifically the **Navy Operational Global Atmospheric Prediction System** (NOGAPS), then later, the Navy Global Environmental Model (NAVGEM) and the **Coupled Ocean/Atmosphere Mesoscale Prediction System** (**COAMPS**®). The AMVs are produced using algorithms originally developed by the Cooperative Institute for Meteorological Satellite Studies (CIMSS), Space Science and Engineering Center (SSEC), at the University of Wisconsin−Madison.

Historically, these AMVs have been computed and sent to FNMOC in an operational setting by the Air Force Weather Agency (AFWA) and the National Environmental Satellite, Data, and Information Service at NOAA (NOAA/NESDIS) using modified versions of the CIMSS software. However, FNMOC acquired a pair of upgraded satellite data ingest systems (referred to as the “FMQ-17”) from Seaspace Corporation that possess the ability to perform the AMV computations independent of AFWA and NESDIS. If these AMVs possess sufficient data quality, there would be significant advantages gained in terms of timeliness, as well as providing a backup capability for these essential data sets. It is the authors' purpose to provide a report regarding the current state of affairs regarding the production of these new AMVs from the FMQ-17 at FNMOC, including up to date efforts to validate these data products. While a final verdict cannot be rendered at this time, results thus far are encouraging.

I. INTRODUCTION

Atmospheric Motion Vectors (AMV) are estimates of Wind speed and direction at various altitudes based on an algorithm that tracks conservative features in Geostationary satellite data. The original algorithm was developed at the Cooperative Institute for Meteorological Satellite Studies (CIMSS), Space Science and Engineering Center (SSEC), at the University of Wisconsin − Madison and first implemented in 1992 [Nieman, 1997] at the National Environmental Satellite, Data, and Information Service at NOAA (NOAA/NESDIS). Since that time, the use of AMVs has grown internationally, most notably to populate the data assimilation systems that are used to initialize Numerical Weather Prediction (NWP) models, which are so essential to modern weather forecasting.

The general idea is to find a cloud feature that remains extant for a sufficient period of time. Generally, a feature is found infrared (IR), Visible (VIS), and Water Vapor (WV) data. The work of Olander [2001] describes the specific process and procedures in explicit detail. It is not the intent of this paper to reproduce the details of AMV production, but to place greater focus on the assessment of the data quality associated with the end product(s).

The US Navy's Fleet Numerical Meteorology and Oceanography Center (FNMOC) in Monterey, CA has been producing NWP output for decades, and has been an early user of the AMV products in its models. FNMOC collaborates with CIMSS and the Naval Research Laboratory, Monterey, CA (NRL) to exploit these data sets to improve the performance of the Navy's NWP models. AMVs have long proven their worth, imparting highly valuable and positive impact to the Navy's NWP performance. See Baker et al, [2012] for compelling demonstrations of AMV impacts to NWP. Thus, FNMOC makes strident efforts to ensure the regular receipt of these products.

Normally, FNMOC receives operational AMV products from the Air Force Weather Agency (AFWA) and NOAA/NESDIS. FNMOC has accepted data from CIMSS itself as well, although it is not considered an operational data source. CIMSS only provides data support on a Monday through Friday, 8am to 5pm basis. However, despite all these efforts, FNMOC has experienced occasional data outages, which has forced the organization to pursue potential backup sources of the AMV data.

Beginning in 2002, FNMOC provided feedback to the Naval Research Laboratory (NRL), indicating that a home-grown AMV production capability was needed. NRL engaged in an effort with Seaspace Corporation to develop software that would enable the NRL/FNMOC team with the ability to compute in-house AMVs, using the Seaspace system known as the “FMQ-17”, a geostationary satellite receiving system for GOES data/imagery. This effort led to the development of a software suite that appears to work, but the products were never validated due to a loss of funding. Starting in 2012, FNMOC re-invigorated its efforts to obtain the in-house AMVs, at which time the author was assigned the task of developing a concept of operations to produce , validate, and distribute FMQ-17 derived AMV products.

This paper will document progress to date on this project. While all efforts are not complete, significant progress has been made.

II. THE AUTOMATED ALGORITHM

It is not the intention of this paper to explain the AMV production process. For the details of the AMV computation process, see Olander [2001], Forsythe [2007], and others. However, a short explanation is necessary to help understand this validation effort.

Referring to figure 1 below, the process begins when – in this example – a cloud feature in the IR is detected and tracked through successive satellite images. Focus in placed on features that are conservative – that is – features that exist and are traceable from satellite image to image. The algorithm from CIMSS identifies the feature using a fast fourier transform and determines where the net speed and direction based on the locations of the traced cloud feature(s) in each successive image.

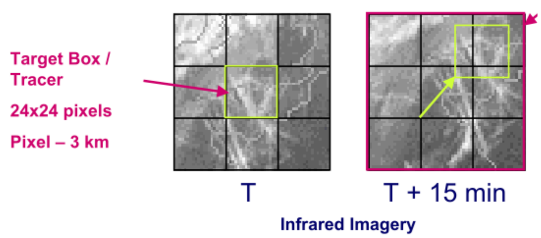


Figure 1: Graphic Taken from Forsythe [2007]

The "...new location [...in each satellite image is...] determined by best match of individual pixel counts of [the cloud] target with all possible locations of [the] target in the search area (use cross-correlation in Fourier domain)." [Forsythe, 2007].

- The SEASPACE Software: Specific details that affected this effort.

The Text below, highlighted in grey, are summarized from the SEASPACE software documentation in TERASCAN Software version 4.0.2. While much of this section directly quotes the software documentation, significant portions are modified to improve readability.

The Seaspace software, know as TERASCAN (TM), uses the ***cloudvec_script*** procedure, which is a UNIX shell procedure script facilitating cloud motion vector generation from IR brightness temperature channel data and water vapor channel data, including all necessary pre- and post-processing procedure calls for generating vector-level assignment data. Two independent sets of vectors are generated, from the input IR and the WV channels respectively, sorted according to appropriate height levels. Vectors are generated with the ***cloudvec*** function.

The ***cloudvec*** procedure, the primary function utilized by cloudvec_script, is invoked twice: First to generate motion vectors from IR_var & WV_var temperature channel data, then to generate associated average height and pressure levels using cloudprod output variables cloud_top, cloud_pressure, wv_height, and wv_pressure. Vector level assignments are performed explicitly after the vectors have been generated... , with 3 cloud-levels, low, mid, high, being available and corresponding respectively to pressure values above, between, below, the 700 and 400 mb pressure levels. These pressure-level values are currently fixed in the script, so that their modification would involve a custom adaptation.

Usage:
cloudvec_script [inputfile1 inputfile2 inputfile3 surface_temp_file] [parameters]
Parameters are: IR_var, WV_var, max_wind_speed, min_vec_space .

As an example, here are specific files to be processed.

- 2012.0208.2345.goes-13.gvar
- 2012.0209.0245.goes-13.gvar
- 2012.0209.0545.goes-13.gvar

These would be inputfile1, 2 & 3, respectively.

NOTE: Although these file extensions say ".gvar", these are actually Terascan Data Format , or 'TDF', files for TERASCAN, a proprietary data format, but containing all the data needed from the standard GVAR data stream of the GOES-8+ series of satellites. It is very important to note that the script does not select the files that are desired. A logical process had to be developed to select the files and input them into the cloudvec_script sequence. The author accomplished this using PERL routines, including basic data quality control (Examples: Does the desired file exist? Does each file contain the required data sets, etc.).

So, we need to know year, month, date (today & yesterday), and satellite id. We will know the times apriori (0245Z,0545Z,0845,1145,1445,1745,2045,2345Z). These are the times for full disk images with GOES EAST. Since we know what the filenames should be, we can build data sets in the script that have these expected filenames. Tests were made to ensure that these files exist and are nonzero size (otherwise stop the script.)

Note that the original intent was to provide global coverage every 3 hours. Thus, initially, full disk sectors were chosen from GOES EAST in order to provide the greatest spatial coverage. However, the results from this effort were disappointing: Numerous wind vectors were clearly going in a non-meteorological direction. In many cases, it was discovered that the vectors were clearly pointing 180 degrees out.

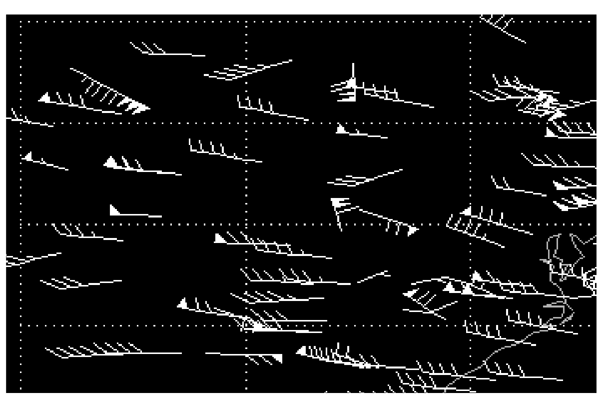


Figure 2: Examples of poor FMQ-17 derived wind vectors from full-disk imagery.

Figure 2 displays obvious examples of errant wind vectors seen in this graphic, taken from earlier in this project in 2012. Clearly, the overall flow of the jet in this case is zonal, out of the west, yet there are multiple examples of cloud vectors that are easterly, and possessing a very high wind speed in some cases – 70 knots and higher! Obvious examples can be seen in the southern/central region of this chart, as well as in the extreme northeast (upper left). This can be thought of as an aliasing problem in the cloud detection algorithm caused by the selected time step.

A careful human analysis of satellite imagery loops (of IR and WV imagery) showed that - since imagery was only being used every three hours - some of the cloud features were dissipating in the intervening time period, and new cloud feature(s) were arriving to replace the older ones. The CIMSS algorithm was falsely associating some of the new cloud features as being traceable to previous clouds that had actually dissipated in that time period. The solution was to use hourly sectors of GOES imagery, and accept that we would not achieve the spatial coverage that FNMOC was hoping to attain. Non-the-less, it was possible to achieve 60% coverage of the desired region(s), and the aforementioned aliasing problem was greatly reduced (though not fully eliminated).

III. GENERAL APPROACH TO VALIDATION

To start the validation process, we started with the following general principles, taken from the data assimilation group at the Met Office in Exeter, UK (via the ECMWF):

"How can we investigate AMV errors?
1. O-B statistics studies (e.g. NWP SAF) and comparisons to sondes and aircraft winds
2. Comparisons to rawinsonde/model best-fit
3. Comparisons with other cloud top pressure products (e.g. MODIS, Calipso …). Also consideration of other cloud properties (e.g. optical depth).
4. Analysis of AMVs overlain on imagery " ***[Forsythe, 2007]***

As a result, the author is attempting to follow these principles as general guiding set of concepts in an effort to assess the usefulness of the 'new' FMQ-17 derived AMV data products. Because this requires coordination with the FNMOC and NRL NWP modeling groups, some of the tools needed to accomplish all these investigations are not available to the author. However, some validation tools are available, and, using the above concepts from Forsythe [2007] as inspiration, the author has accomplished the following:

1. The plotting of FMQ-17 AMV data on standard maps
2. The plotting of CIMSS AMV data (same date & time as above)
   - The items from (1) and (2) are compared to each other and to satellite imagery
3. Comparing significant meteorological features on the FMQ-17 output to raob plots (on a case by case basis)
4. Histogram plots of Wind speed and direction for both FMQ-17 and CIMSS AMV data with subsequent comparisons (over the same geographic area)

The remaining efforts pertain to infusing the FMQ-17 AMV data into a beta (testing) version of the data assimilation system for FNMOCs NWP model and conducting an assessment of the impact of the AMV data on the model running at FNMOC.

Regarding the plots of AMV winds on maps, the idea is to first of all determine that the data has any kind of coherence of any sort at all. The data that is plotted is filtered by the following conditions:

- Winds over 250 knots are rejected as unlikely to be real winds.
  - The FMQ-17 algorithm produces wind vectors in the familiar wind speed and direction format. With that in mind, negative wind speed values are interpreted to be meaningless and thus that kind of observation is discarded.
- Winds are only considered between 700 and 100 mb
  - The FMQ-17 was not programmed to produce AMV winds with Visible data (it can only use IR and WV), although CIMSS/AFWA/NESDIS does use VIS, thus winds from the Surface to 700mb are not accurate enough for use in the FNMOC data assimilation system. The low level winds are thus discarded.
- Obviously, it is ensured that wind direction values only range between 0 to 360 degrees. If a direction value lies outside these limits, it was assumed that the FMQ-17 algorithm was in error, and that particular value is also discarded.

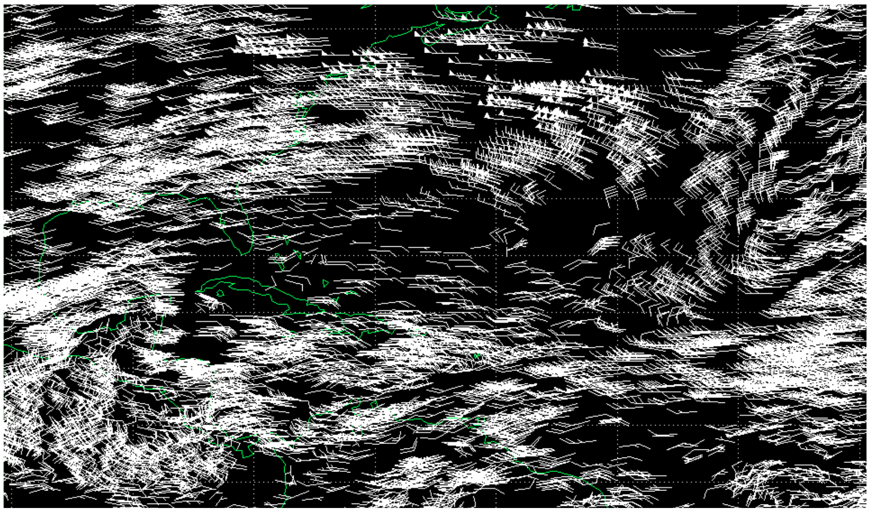


Figure 3(a): CIMMS AMV Data, 12/09/2013 00 GMT, Water Vapor

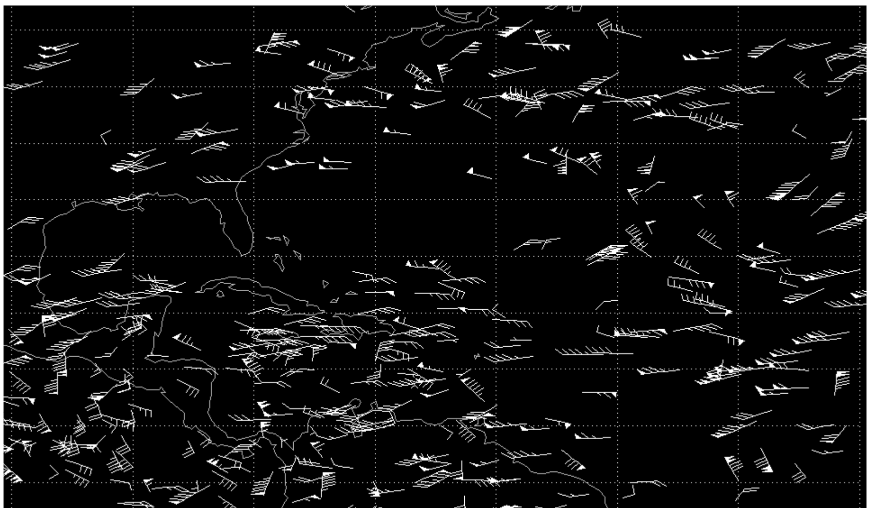


Figure 3(b): FMQ-17 Derived AMV Data, 12/09/2013 00 GMT, Water Vapor

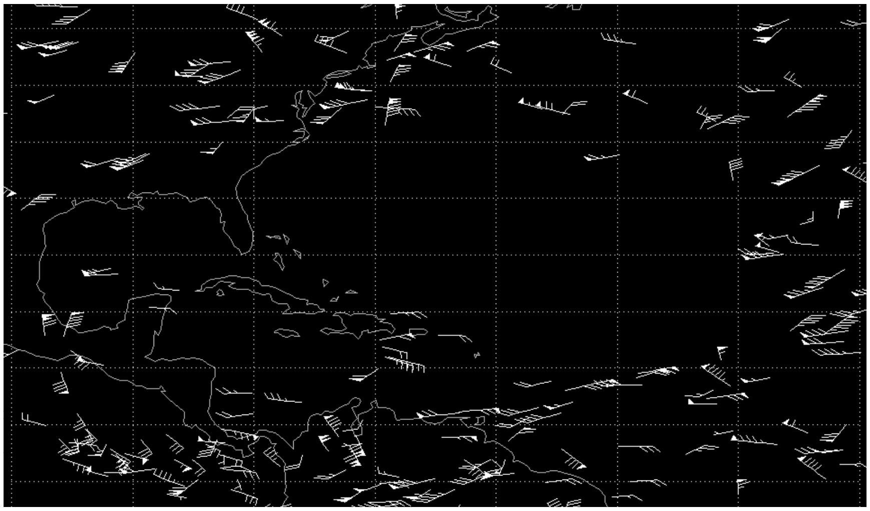


Figure 3(c): FMQ-17 Derived AMV Data, 12/09/2013 00 GMT, Infrared

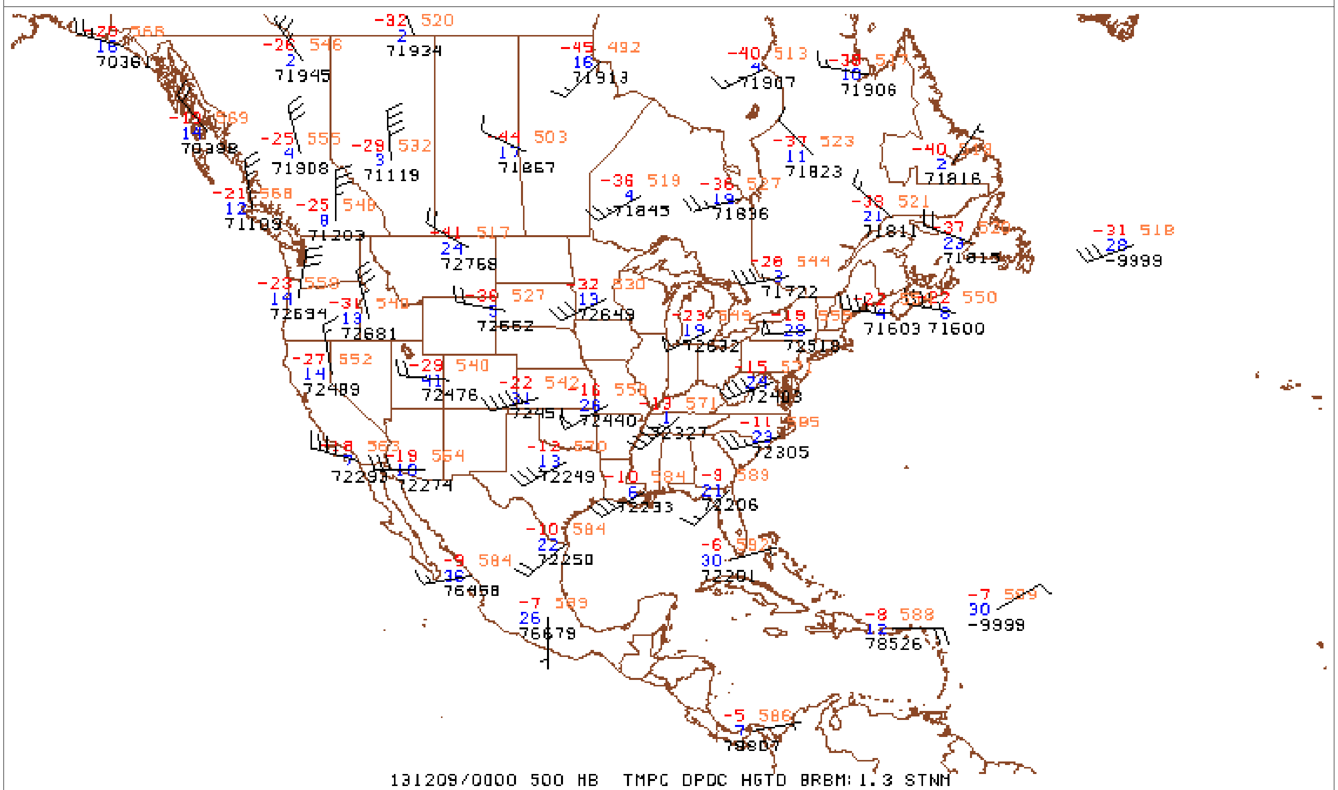


Figure 3(d): 500 mb RAOB winds, 12/09/2013 00 GMT
courtesy NOAA/ARL (www.arl.noaa.gov/ready)

IV. DATA AND DISCUSSION

The author proceeded to perform the plots of both the FMQ-17 AMV data on standard maps, along with similar mapping plots of the CIMSS derived versions of the same data for comparison. For all these, see figure 3 (a) through (c). Note that CIMSS is constantly upgrading their algorithms, thus it should be expected that there will be noticeable differences between the FMQ-17 and CIMSS versions of the data product. Figure 3(a) shows the CIMSS WV version, and fig. 3(b) shows the FMQ-17 WV version. The FMQ-17 IR data is shown in figure 3(c) for comparison. Note that this set of examples from December, 2013 is merely for demonstration purposes. Actual plots have been completed for numerous dates/times. These are meant to be representative examples to help illustrate FNMOC data inspection efforts. Also provided were plots of RAOB data from the 500 mb level (and other levels as well) to help assess the quality of the data.

When comparing Figures 3(a) and (b) (both being water vapor), some things stand out: First, there are clearly more observations being reported by the CIMSS version, an indicator of both the improvement of the newer algorithm, as well as possibly a better approach used by CIMSS to filter data. Based on conversations between the author and CIMSS personnel, significant changes have been made to the newer algorithm. This newer algorithm has already been validated by NRL [Baker et al, 2012] as adding useful, positive impact value to the FNMOC NWP models, so this still makes a good standard to evaluate the FMQ-17 against, even if the FMQ-17 does not possess all the positive attributes of the newer algorithm.

Second, we notice that, as a rule, the jet stream appears to be in the right locations, comparing CIMSS and FMQ-17. The wind directions are generally in agreement, although there are still examples of aliasing to be seen. The wind speeds appear generally acceptable, though somewhat weaker in the FMQ-17. The FMQ-17 does not seem to be far off the mark when comparing speeds and directions to the RAOB plot in figure 3(d), suggesting the possibility that the CIMSS data might be too strong. Don't forget, however, that figure 3(d) is ONLY the 500 mb level, whereas the CIMSS and FMQ-17 plots in figures 3(a), (b), and (c) all incorporate a range of mid-level and upper level winds.

Looking at both maps, qualitatively, we get a great deal of information. We would like to obviously improve the objectivity of our analysis, since the previous comparisons of the charts are strictly subjective. The most objective method to determine data value for the FMQ-17 would be to have the FNMOC/NRL data assimilation team bring in the data and calculate model impact values, then observing the potential innovations that the inclusion of this data would bring to the model. However, this is a long process, which is generally accomplished over months of time. This effort is underway, but is incomplete as of the time of this report.

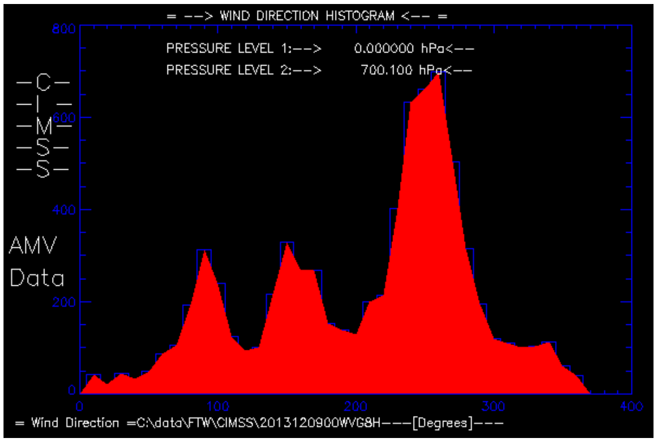
As a temporary measure of skill, it was decided to calculate plots of wind direction and speed into statistical frequency distributions, then display the data in the form of histograms. For simplicity, the Wind Direction Histograms are referred to as "Direct-o-grams", and Wind Speed as "speed-o-grams". The idea behind this technique is to compare the FMQ-17 distributions to similar plots for the CIMSS data.

In the case of the direct-o-grams, we made groups of 10 degrees each from 0 to 360 degrees, and simply performed the proverbial bean counting tasks. We expect to see modes (relative maxima) appear at those wind directions that appear most often in the data set. This is illustrated in figure 4(a), (c), and (e). Figure 4(a), which is colorized, shows the CIMSS data, with three modes. The FMQ-17 WV data is shown in Fig. 4(c), with the IR in figure 4(e). The FMQ-17 direct-o-grams do show modes in similar places when compared to the CIMSS data, but there are other modes that seem to make the agreement less clear. This technique illustrates that the CIMSS data is much higher density than either the WV or IR versions of the FMQ-17, suggesting greater dispersion of energy among a larger number of wind directions. It does, however, suggest that there is rough agreement between CIMSS and FMQ-17.

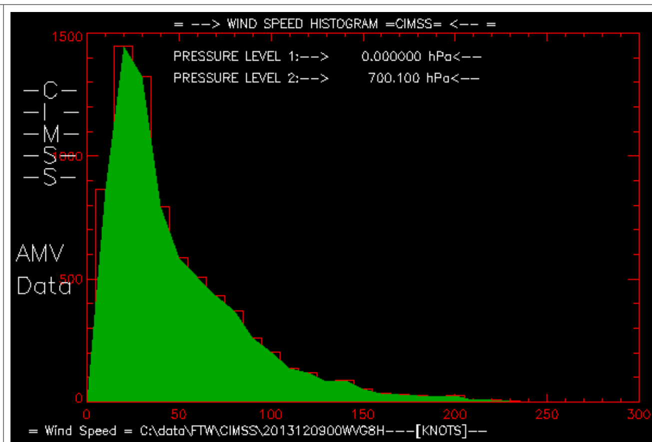
Figure 4

Statistics gathered from both CIMSS and FMQ-17 AMV data sets

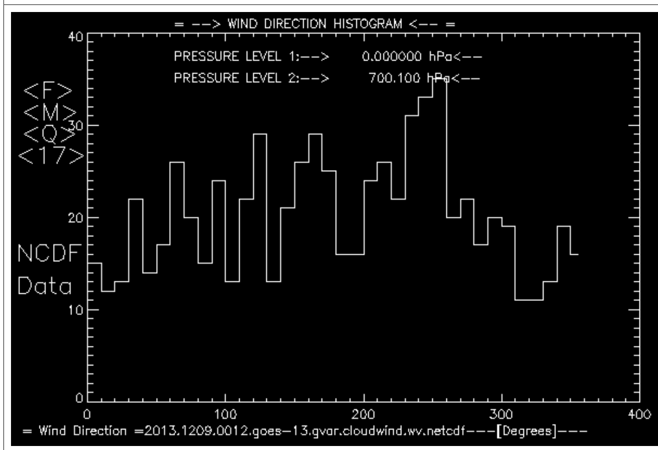
Wind Direction Histograms (Direct-o-grams)	Wind Speed Histograms (Speed-o-grams)



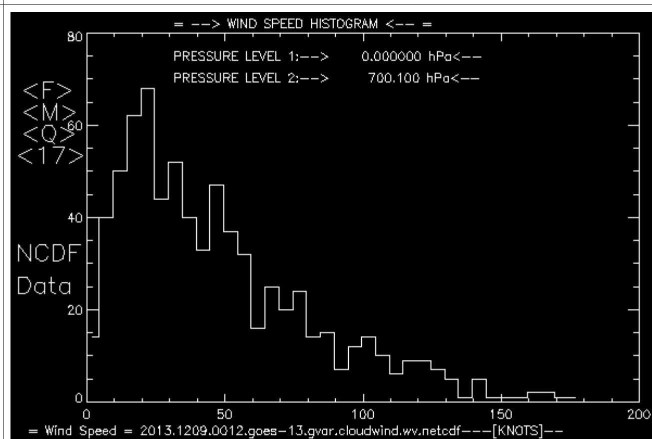
(a)



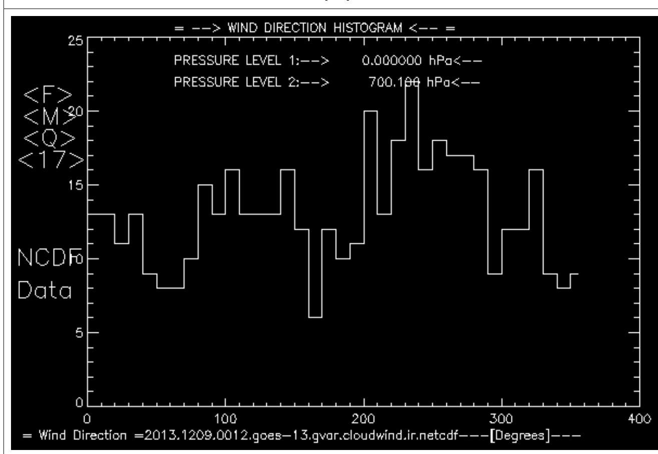
(b)



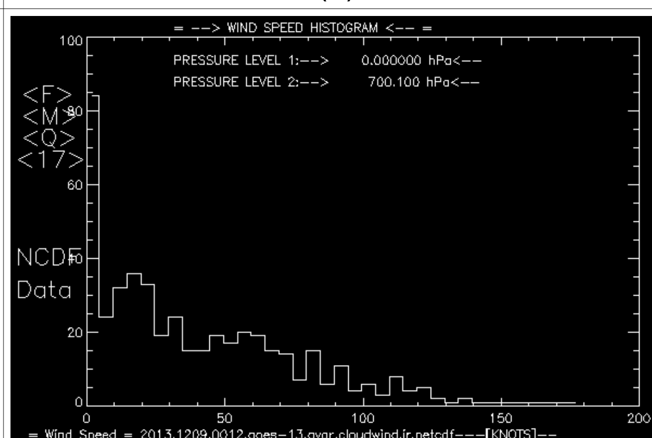
(c)



(d)



(e)



(f)

In the case of the speed-o-grams, we made groups of 5 knots each from 0 to 5, 5-10, etc. Again, the counting tasks were performed. The results are illustrated in figures 4(b), (d), and (f). Figure 4(b), which is colorized, shows the CIMSS data, has one main mode. The FMQ-17 WV data is shown in Fig. 4(d), with the IR in figure 4(f). The FMQ-17 speed-o-grams do show modes in similar places when compared to the CIMSS data. Again, This technique illustrates that the CIMSS data is much higher density than either the WV or IR versions of the FMQ-17. It does, however, suggest that there is rough agreement between CIMSS and FMQ-17. The speed-o-grams for CIMSS and FMQ-17 WV seem to agree reasonably well.

V. FINAL COMMENTS

When one considers the subjective plots of the winds, compared to RAOBs as well as the advanced CIMSS data, we begin to see that the FMQ-17 appears to be capturing the synoptic patterns of the middle and upper atmosphere with a basic, rough skill. The FMQ-17 Water Vapor data appears to perform reasonably well when compared to the 500 mb RAOB plot. Similarly, when considering the histograms of the various data sets, we also see approximate, of only rough, agreement between the data sets (CIMSS and FMQ-17).

However, This effort is clearly not complete at this point. Without the final word from the data assimilation team, we cannot proclaim the FMQ-17 data to be fit for operational usage.

BIBLIOGRAPHY

Nieman, S.J., W. P. Menzel, C. M. Hayden,D. Gray, S. T. Wanzong, C. S. Velden, and J. Daniels, 1997: Fully Automated Cloud-Drift Winds in NESDIS Operations. Bulletin of the American Meteorological Society, Vol. 78, No. 6, June 1997,

Olander, T. L., 2001: UW−CIMSS Satellite−Derived Wind Algorithm USER'S GUIDE (version 1.n) . The Cooperative Institute for Meteorological Satellite Studies, Space Science and Engineering Center, University of Wisconsin−Madison, 1225 West Dayton Street, Madison, WI 53706 [http://cimss.ssec.wisc.edu/iwwg/Docs/windcoug.pdf]

Baker, N.L., 2012: R. Langland, P.M. Pauley, L. Xu, D. Merkova, R.Gelaro and C. Velden: "The Impact of Satellite Atmospheric Motion Vectors in the U.S. Navy Global Data Assimilation System – NWP Results", http://cimss.ssec.wisc.edu/iwwg/iww12/iww12_programme.html,

Forsythe, M., 2007: Atmospheric Motion Vectors: Past, Present and Future. ECMWF Annual Seminar, Sep 2007, Met Office, Exeter, UK
http://www.ecmwf.int/newsevents/meetings/annual_seminar/2007/presentations/forsythe.pdf

SEASPACE CORPORATION TERASCAN SOFTWARE DOCUMENTATION, 2012:
http://www.seaspace.com/software.php
http://marine.rutgers.edu/~lojanen/tscan4/html/
http://marine.rutgers.edu/~lojanen/tscan4/html/man1/cloudvec_script.html