9.1 THE CURRENT STATE OF SATELLITE DERIVED WIND FORECASTS AND POTENTIAL IMPROVEMENTS IN THE GOES-R ERA. EMPHASIS: A PARADIGM SHIFT IN TEMPORAL AND SPATIAL RESOLUTION FOR EARTH OBSERVATIONS

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Abstract

One of the most difficult areas in commercial aviation weather forecasting is providing accurate upper-level wind estimates. Geostationary satellite constellations, such as the GOES (Geostationary Observational Environmental Satellite) system, maximize the functionality of their temporal resolution by employing the Atmospheric Motion Vector (AMV) algorithm for the identification and characterization of surface to upper level wind vectors (Velden et al., 1998). The ABI and HES sensor suite included in the GOES-R system will allow for improved capabilities to observe the atmosphere and provide for more dependable upper-level wind forecast estimates for commercial aviation. These improvements will be a result of both the increased spatial resolution and the improved revisit rate of the ABI and HES sensors. The commercial aviation community will benefit from these forecast improvements with savings on fuel costs and schedule accuracy. This paper will observe the accuracy of current satellite derived wind products and highlight the key areas where the GOES-R sensor suite will improve the capability to observe and characterize upper-level winds and atmospheric motion.

1.0 INTRODUCTION

Aviation experts rely upon a variety of meteorological measurements to develop functional flight plans. NASA recently released a document entitled 'Blueprint for Aeronautics' in which weather is identified as having two significant challenges that must be addressed if the nation is to successfully implement its national airspace system of the future. These challenges include the reduction of in-flight traffic disruptions due to inclement weather and the elimination of delays in terminal-area airspace. Surface visibility, precipitation, wind patterns, moisture profiles and temperature all play a significant role in flight path determinations, fuel allocations, flight preparations and departure times. The accuracy of each measurement relates to the safety, efficiency and cost effectiveness associated with aviation assets. While the accurate measurement of each parameter is important in its own right, this paper will focus on the derivation and current status of wind vector products.

Currently, the majority of commercial airport locations utilize rawinsonde balloons for the measurement of surface to upper altitude atmospheric parameters. These measurements are ideal for site-specific wind measurements, providing highly accurate in situ data. Rawinsondes measure temperature, moisture and wind as a function of pressure. The values derived from these measurements are relied upon empirically. However, a shortcoming arises as rawinsondes only provide data for one specific point on the ground. Aviation planners require wind information throughout the entirety of an expected flight path to create sufficient flight plans.

Additionally, wind vectors are operationally derived from GOES datasets. These sensors provide coverage over the majority of North and South America, in addition to significant portions of the Atlantic and Pacific Ocean. This is achieved through the use of 2 geostationary platforms, (GOES-10 and GOES-12) located at 75°W and 135°W, both over the equator. Each platform has an imager and a sounder onboard, both of which contribute to the derivation of wind vectors.

Observing the motion of certain atmospheric features over a specified period of time derives wind vectors. The most frequently used approach in solving for atmospheric winds is the Atmospheric Motion Vector (AMV) algorithm (Velden, et al. 1998). Knowing the revisit rate of a sensor and the IFOV (Instantaneous Field of View) of each pixel, one can infer the motion vector of a feature. Three consecutive images are considered for the development of wind vectors.

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Both Cloud Drift winds and Water Vapor winds are operationally derived.

The first step of the Cloud Drift wind algorithm is the identification of prominent cloud features in GOES imager visible and IR bands. Visible imagery is commonly used for daytime detection, and IR imagery is used for night detection. Features of interest are defined as those pixels that have the greatest brightness temperature gradient from their neighboring pixels. The vertical location of each feature is determined by correlating the brightness temperature of a saturated cloud top with temperature pressure plot diagrams. Upon detection, 2 subsequent images are investigated for similar features within a predefined distance from the initial location. This predefined distance used to match the initial feature is determined by forecast model information. If an adequate correlation can be draw between features of subsequent images, the displacement vector is then calculated. This process is done again for an additional subsequent image, for verification purposes. For three images, we now have 2 vectors defining the wind pattern of the feature in the second image. If the two derived vectors are similar enough in direction and magnitude, and correlate sufficiently with both modeled forecasts and nearby rawinsonde measurements, it is accepted as a reliable atmospheric wind vector. Figure 1 provides a visual description of the AMV algorithm.

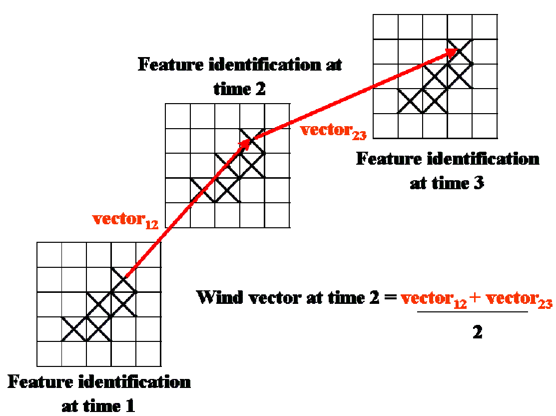

Figure 1.

The Water Vapor Wind vectors are derived in a very similar fashion to the Cloud Drift Winds. Water vapor winds are derived from data collected by the GOES sounder. The only significant differences are the features that are identified for displacement. Major brightness temperature gradients in water vapor features trending towards a local maximum are identified, and observed as they are displaced over time. This technique is performed with data from the 7.0μm and 7.3μm channels. Three images are used, as in the Cloud Drift wind description, to derive two wind vectors. These vectors, when sufficiently passing the verification step with local rawinsonde vectors and forecast information, are used to define the wind field at a certain location. The vertical location of a water vapor feature is inferred by the brightness temperature and weighting function on a band-by-band basis.

2.0 THE PROBLEM(S)

There are numerous regions where errors and inaccuracies can creep into these measurements. Exact determinations of cloud and water vapor height are difficult due to coarse spectral resolution resulting from insufficient spectral coverage. Coarse temporal resolution of the data capture provides the opportunity for more variations of cloud features to be introduced, causing less feature correlations to be observed. A decrease in feature correlation density directly relates to a decrease in wind vector density. A significant improvement in spatial resolution of both the sounder and imager allows for better feature identification densities.

2.1 Spectral Resolution

The weighting function for each specific imager and sounder band determines the optimal vertical location for atmospheric viewing in that band. The bands that have been chosen for the current GOES platform correlate to weighting functions with their peaks in important vertical regions. While the data gathered from these spectral bands provide valuable information, they have 2 fundamental deficiencies.

First, the weighting functions are very broad. Initially, this would seem to be beneficial, as a single spectral band would be capable of observing features in a wide vertical range. However, broad peaks in weighting functions create substantial ambiguity in assigning the vertical location to a feature of interest.

Second, there are significant gaps in the peaks of weighting functions. While many important regions have been covered, numerous atmospheric regions fall in the non-peak regions of weighting functions. Features are either assigned an inaccurate vertical location, or those features fail to be observed. Figure 2 depicts the weighting functions of the current GOES Sounder. As can be observed, certain regions, especially in the upper atmosphere, fail to be adequately covered by the current weighting functions.

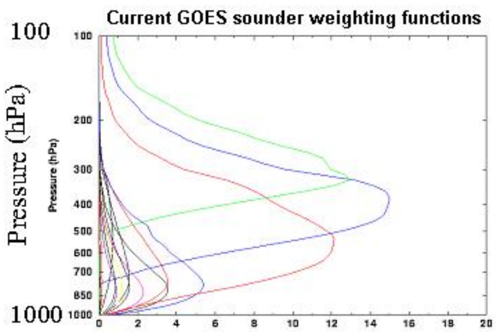

Figure 2.
Schmidt, et al 2002 The Hyperspectral Environmental Suite (pdf)

2.2 Temporal Resolution

The current GOES platforms, under normal operational modes, can revisit a given point on the ground every 30 minutes. Compiling sufficient data to develop a wind vector therefore requires 90 minutes, as three consecutive images are needed. While a 30 minute refresh rate is better than previous GOES missions, research has been completed by Velden investigating the functionality of a 5 minute rapid scan mode for use in determination of wind vector datasets. Continuous 5 minute sampling over the CONUS region was achieved in all spectral bands during this study.

Results have shown varied success with the rapid scan technique. When higher temporal resolution datasets are used, the AMV algorithm develops a greater density of wind vectors. Quite simply, there is less time (15/5 minutes vs. 30 minutes) for cloud features to deviate from their original identified pattern and more correlations are found between the shorter time-stepped images. Wind vectors developed with visible and IR imagery showed improved vector densities along with an improved accuracy of their measurements. Results from the water vapor wind derivation were similar in density and accuracy to the vectors inferred from the 30-minute resolution datasets. One could conclude that the current water vapor wind calculations have reached their peak performance capability, while cloud motion wind vectors would benefit from an improvement in temporal resolution.

2.3 Spatial Resolution

The spatial resolution of both the Imager and the Sounder aboard any GOES platform plays an important role in the determination of atmospheric wind vectors. A corollary can be drawn between the spatial resolution of an instrument with the size and accuracy of a feature it can detect. Better spatial resolution improves feature detection accuracy and volume, which in turn allows for better wind vector accuracy and density. The current GOES Sounder has an 8km resolution footprint across all bands at NADIR. The visible band on the imager has a resolution of 1km, while all other bands have 4km resolution, with the exception of band 6, with a resolution of 8km.

2.4 Image Registration

Image navigation and registration accuracy are essential parameters in understanding the accuracy of AMVs. To effectively understand the motion of a feature in earth's atmosphere, the motion of the detector must be effectively characterized. The GOES platforms have traditionally inferred their position in space in relation to stars and prominent landmark features. Identification of features with known locations allows the system to position data points acquired by the imager and sounder in relation to these fixed points. A dependable image feature position cannot be inferred until a dependable position of fixed features arte observed. Image motion compensation (IMC) and mirror motion compensation (MMC) are performed on the data to correct for spacecraft yaw, orbital deviations, and disturbed mirror motion. The current pixel-to-pixel registration accuracy within a GOES image is +/- 1.5 km, and its navigation accuracy is approximately 4 km.

3.0 THE GOES-R SOLUTION

The sensor suite aboard the GOES-R platform will provide information that exceeds the current GOES capabilities in numerous important areas. Significant performance advancements and resolution updates will equate to exciting technology and scientific opportunities. Atmospheric motion vectors derived from the GOES-R HES and ABI will be significantly improved.

Drastic updates of the weighting functions of the HES will provide highly improved vertical location capability for features of interest. Previous geostationary sounders have had approximately 10-20 bands. The HES will have something on the order of 2000 bands. Additionally, these bands will have sharper weighting functions providing for precise vertical location derivation. Specific locations in the atmospheric profile receive coverage from multiple sounder bands. Figure 3 shows a plot of the GOES-R HES weighting functions.

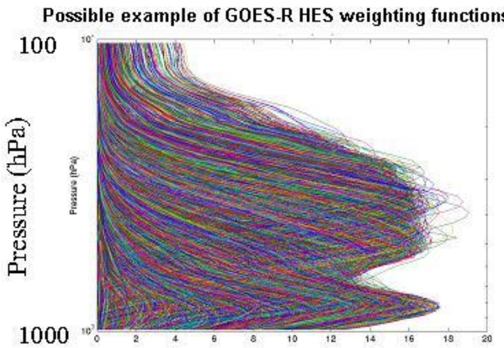

Figure 3.

The GOES-R ABI has 2 Full Disk operational coverage options. Scan mode 3 calls for a CONUS region to be imaged every 5 minutes, along with certain Full Disk and Mesoscale requirements. Scan mode 4 calls for a Full Disk to be imaged every 5 minutes. These high temporal resolution scan modes will operationalize the tests done by Velden that were so effective in improving atmospheric wind vectors density and accuracy. The Sounder data will cover a 62° LZA region in about an hour, and can cover the CONUS region much more quickly. These coverage improvements will be sufficient for the derivation of water vapor winds, as Velden's experiment showed no improvement of the accuracy of water vapor winds with temporal improvements. Temporal resolution advancements not only improve the spatial density, but also the temporal density of wind vector fields. These volume improvements allow for significant updating of flight path definitions.

Updates in spatial resolution can be counted upon to enhance feature detection. Smaller, previously undetectable features will now be observable with improved spatial resolution across all imager bands. The GOES-R ABI will have one visible band with a resolution of 0.5 km, three visible/near IR bands with 1km resolution and twelve IR bands with 2 km resolution. Each band in on the GOES-R ABI has at least a two-fold improvement in spatial resolution. Figure 4 provides a visual representation of the spatial resolution improvements that will be available.

1 km resolution

500m resolution

Figure 4.

Numerous specifications for the GOES-R system are still to be determined. One of these major specifications is the spatial resolution of the HES. The Mission Requirements Document (MRD-2A at the time of this publication) states the 'threshold spatial sampling of the IR bands shall be 10 km in both directions, measured at the satellite sub point.' The MRD then goes on to say "The goal sampling should be 2 km in both directions for the IR bands." This variance between possible resolutions of the sounder makes it difficult to infer future capabilities. Upon the decision of HES spatial sampling requirements, further investigation of the opportunities afforded by this data can be completed.

Better characterization of the detector motion allows for more dependable wind vector field determination. Whereas past GOES platforms have used star trackers and landmarking to infer satellite position, the GOES-R system will include a Global Positioning System (GPS) to assist in the derivation of its location. A platform with a GPS receiver needs only to be in the direct line of sight of 4 GPS satellites to infer its position (latitude, longitude, altitude). The accuracy of a GPS receiver's position is directly related to how many GPS satellites it can see. GOES-R operates at approximately 35,000km, allowing it to see numerous GPS satellites. The pixel-to-pixel accuracy of the GOES-R ABI must be 1.0 km and its navigational accuracy must be no greater 1.5km. These improvements in INR can be attributed to the inclusion of GPS navigational equipment.

4.0 DISCUSSION

Substantial data improvements are expected in the GOES-R era. Initial studies have shown how temporal resolution advancements will directly relate to more accurate satellite derived wind field products. What is poorly understood is how these temporal, spatial and spectral improvements in conjunction with INR advancements will together improve the accuracy of these products. The current water vapor motion vectors have their peak accuracy at a temporal resolution of 30 minutes. However, this conclusion was determined using rapid scan data of current GOES imagery. Water vapor fields do generally move at the same velocity as clouds, and a feature must be displaced by at least one full pixel for a vector to be developed. Ideally, a feature will be displaced several pixels from its original location to create an accurate wind vector. As the ability to observe smaller features arrives, the temporal resolution for the peak accuracy and vector density of water vapor winds can be expected to decrease. The future GOES imagery will not only be capable of the rapid scan experiment done investigated by Velden, but this scan mode will be done with improved spatial and spectral resolution datasets. As shown in section 2.2, improved spectral resolution equates to finer and more dependable vertical feature locations. In a three-dimensional sense, smaller features will be observable in a more accurate fashion.

5.0 CONCLUSION

Current techniques provide wind values at 9, 12, 15, 18, 24, 30, and 36 kft. At best, aviation planners receive winds at 3000 ft. vertical resolution. Wind fields are developed and disseminated four times a day. The insufficient vertical and temporal resolutions stated here typify the current state of wind vector field determinations. While these data provide important information to decision makers, there is substantial room for improvement. Atmospheric wind vector datasets will be denser in all 4 dimensions (latitude, longitude, altitude, time) in the GOES-R era. The improvements to be expected from the sensors aboard the GOES-R platform will provide aviation experts with significantly improved satellite derived wind information.

6.0 REFERENCES

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