6.3 A REAL-TIME AUTOMATED CEILING AND VISIBILITY ANALYSIS SYSTEM

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1. INTRODUCTION

From 1994 through 2003, impacted ceiling and visibility (C&V) was the second-most prevalent cause of weather-related accidents in the United States [AOPA, 2006]. These C&V-related accidents predominantly affect the general aviation and commuter/air taxi communities, and often could be avoided if existing weather data from a variety of sources could be more effectively used in the pilot pre-flight and in-flight decision-making processes.

In this paper, the National Ceiling and Visibility (NCV) Research Team of the Federal Aviation Administration's Aviation Weather Program will introduce a real-time continental United States (CONUS) C&V analysis product that is planned for release to the aviation community in 2008.

This new product combines METAR surface observations and GOES satellite cloud information to yield what can be described as a space-cast: an analysis of CONUS C&V conditions on a high-resolution (5-km) grid. The analysis presents ceiling heights, visibility and flight category, as well as a confidence assessment for each field. All fields are generated at a 5-min frequency to include the most current data.

The space-cast aspect of this product is its most important feature. Conditions between observation stations are estimated in a manner that is easily interpreted by users.

This paper outlines the data processing utilized in product generation, a demonstration of product displays, and a statistical overview of product skill.

2. OVERVIEW OF THE NCV ANALYSIS PRODUCT

The product was developed to provide real-time conditions of ceiling height, visibility, and flight category to operational forecasters, pilots, and other end-users. As such, data ingest, computation and dissemination are completely automated.

2.1. Terminology and Definitions

In aviation, Visual Meteorological Conditions (VMC) are weather conditions in which Visual Flight Rules (VFR) flight is permitted; that is, conditions in which pilots have sufficient visibility (vertical and horizontal) to fly the aircraft without reference to instruments and can maintain visual separation from terrain and other aircraft.

Instrument Flight Rules (IFR) take effect when the ceiling is less than or equal to 1000' above ground level (AGL), or when the visibility is ≤3 statute miles.

Flight category is a derived field, determined by the lowest (worst) condition of either ceiling or visibility. There are four flight categories: VFR, MVFR (Marginal Visual Flight Rules), IFR, and LIFR (Low Instrument Flight Rules). The conditions for each are summarized in Table 1.

Flight Rules	Ceiling (ft)	Visibility (mi)
Visual (VFR)	> 3000	> 5
Marginal Visual (MVFR)	< or = 3000	< or = 5
Instrument (IFR)	< or = 1000	< or = 3
Low Instrument (LIFR)	< or = 500	< or = 1

Table 1: Flight Rules and Associated Ceiling and Visibility Limits.

2.2. Product Domain and Resolution

The analysis product is valid over the CONUS. The domain includes areas over the Great Lakes, but does not extend over oceanic areas.

The analysis system produces gridded analyses of cloud ceiling height, visibility, and flight category. Additionally, a confidence field is established for all three parameters. Each field is constructed using the National Weather Service's National Digital Forecast Database (NDFD) 5-km grid. The grid points are populated by a nearest neighbor interpolation [Skiena, 1997].

An example of the product can be seen in Figure 1 below. By way of comparison, an operational product from the Aviation Weather Center displaying flight category at reporting stations is presented in Figure 2.

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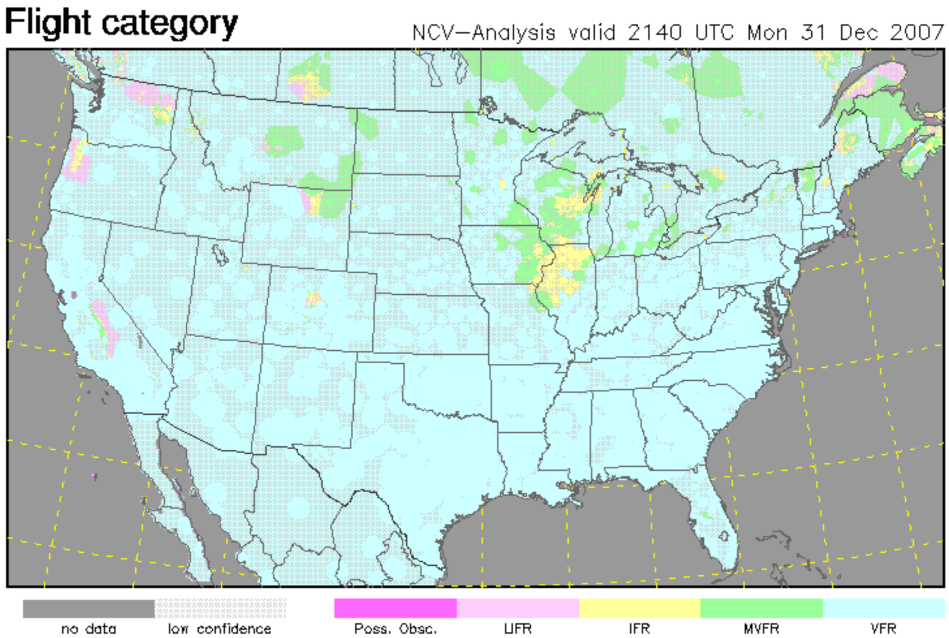


Figure 1. NCV Analysis domain for Dec 31, 2007 at 2140Z: flight category field shown.

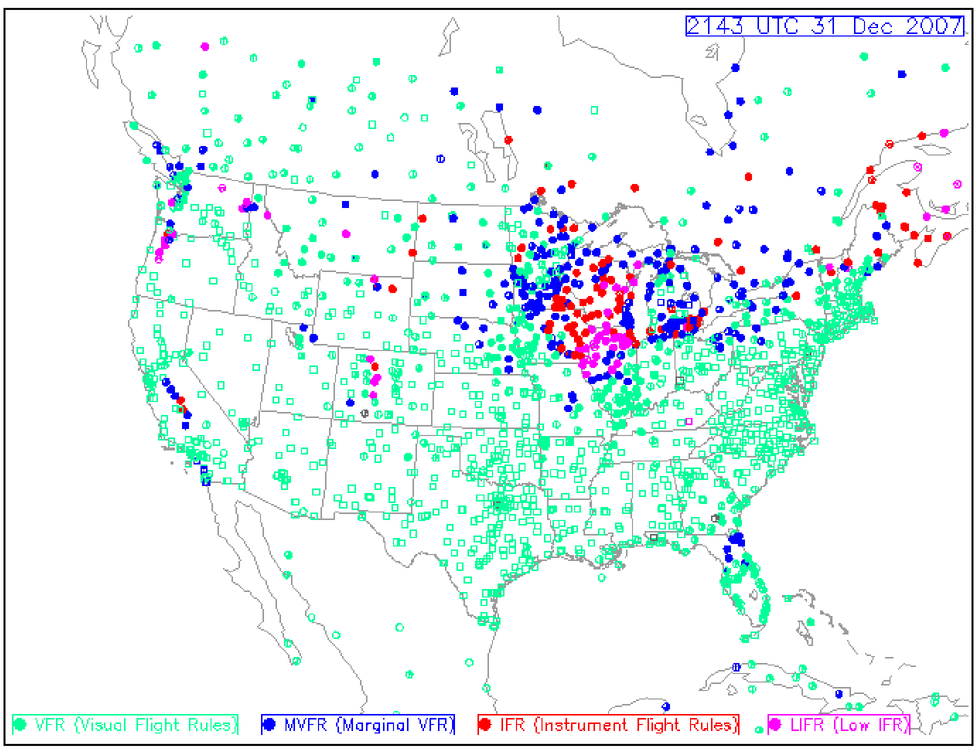


Figure 2. Operational display of Aviation Flight Categories from the Aviation Weather Center's Aviation Digital Data Service [ADDS]. Date and time match that of Figure 1.

3. DATA PROCESSING

3.1. METARs and Interpolation

Beginning at the top of the hour, and every five minutes thereafter, the NOAA FTP METAR site is queried. In this way, the standard hourly reports as well as 'specials' triggered by significant changes in ceiling, visibility, or other fields, are captured.

Some stations in Canada and Mexico are included in this query. This provides valid data across the U.S. borders and allows for a more representative interpolation.

Similar reasoning provides an explanation for not providing data over oceanic areas: it was decided, after examination of station reporting history, that off-shore observation stations had less reporting reliability than the METAR network. Thus, these sites were not incorporated.

Each METAR report is checked to ensure reported values fall within a range of reasonable, expected values. Negative ceilings or visibilities, or positive out-of-range values are flagged and withheld from system use.

Ceiling data, reported as height above ground level, and visibility are horizontally interpolated across the product domain. Quantitative performance tests [Fowler, 2006] showed that a methodology called nearest neighbor interpolation yielded the best overall analysis results. This method utilizes a simple, unsmoothed distance-related methodology. One drawback is that the output field appears piecewise and discontinuous, making the fields somewhat difficult to examine by eye in certain cases.

Ceiling data are interpolated in agl-space (above ground level), then are converted to msl (mean sea level) values and interpolated again in msl-space. Unlimited ceilings and terrain obscuration are better handled in agl-space while interpolation of non-unlimited and non-obscured ceiling values is physically more meaningful in msl-space as opposed to agl-space.

Ceiling values are then converted back from msl-space to agl-space by subtracting the model terrain height value at each grid point. Any resultant negative values indicate terrain obscuration by cloud.

In contrast, visibility values are interpolated only once across the NDFD grid since they are not dependent upon terrain height.

Finally, flight category values are determined at each grid point by taking the worst condition of either ceiling or visibility. For instance, if the ceiling value at a grid point is categorized by IFR conditions while the visibility can be categorized by VFR conditions, the flight category condition at that grid point is assigned the IFR condition. Then, nearest neighbor interpolation is applied to this field.

3.2. NCV Cloud Masking

Regions between METAR stations, or "gap areas", constitute the majority of space within the domain. GOES satellite data fulfills an important role in distinguishing cloudy from cloud-free (i.e., no ceiling) regions within the gap areas.

However, cloud detection is very challenging. All cloud masks have to contend with the following: satellite viewing angle over the CONUS, optically thin clouds, often missed at night, differences between high and low cloud detection, background thermal and radiative characteristics, and seasonal and diurnal changes in clear sky background data.

The NCV Analysis product uses a combination of GOES-11 (west) and GOES-12 (east) infrared channel imagery at 3.9 μm and 11μm. The cloud mask used is a derivative of a technique developed at the National Aeronautics and Space Agency Global Hydrology and Climate Center (NASA/GHCC) [Jedlovec et al., 2003]. It consists of a series of threshold and comparison tests that are applied to the data at each pixel to determine whether cloud is detected or not. An example of a cloud mask is shown in Figure 3.

In order to be used, the newest satellite (GOES-11 and -12 separately) file must be received within 45 minutes of the scheduled scan start time. If a file from each satellite is available, the most recently available GOES-11 and GOES-12 cloud masks are combined within that same time-frame.

Otherwise, data from a single satellite is used as the final cloud mask. A new cloud mask is created only when new data are available by keeping track of which GOES-11 and GOES-12 scan start times have been used in the construction of previous cloud masks.

The cloud mask is only used to add information to the underlying METAR interpolated ceiling height field. METAR data constitute the final authority in this system. In order to differentiate from clear condition reports by METARs, 'clear' reports by the cloud mask generate 100,000 foot ceiling heights, for grid points located away from METAR stations. The same value is reported in areas close to and over METAR stations only when the report is for no ceiling within its operational range.

As mentioned above, in all cases, the METAR report is considered to be more representative of conditions. For instance, in cases where the

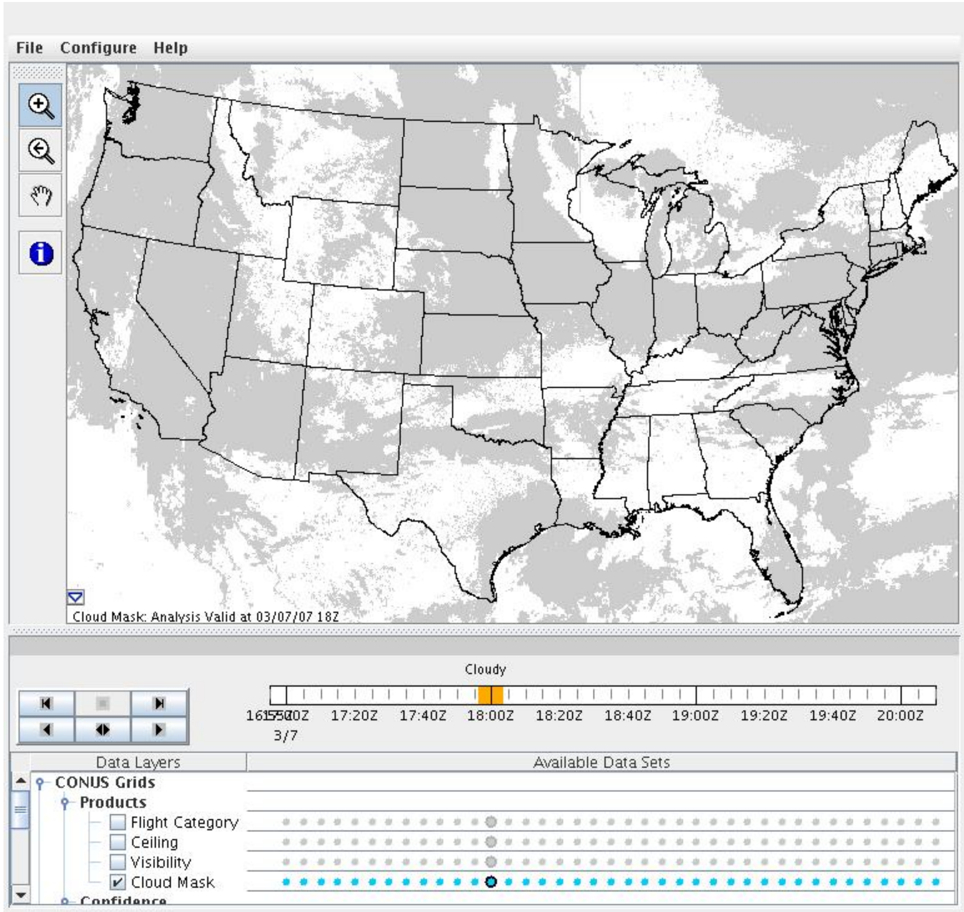


Figure 3. An example of the NCV cloud mask product is shown as derived from merged GOES-11 and GOES-12 data. Cloud coverage is given in white and clear areas are shown in grey.

METAR reports a ceiling below 12,000 feet and the cloud mask determines the grid point is clear, the grid point is assigned the METAR ceiling height value.

Due to the difficulties of correctly identifying cloudy areas during the night, the analysis product currently applies the cloud mask to the ceiling grid only during times when the entire domain is in sunlight. If future cloud mask performance is reliable enough, incorporation during the night will be tested and implemented.

3.3. Confidence Fields

After calculating values of ceiling and visibility for each grid point, a series of tests are applied to those grid points to determine how much reliance should be placed on the values. Each grid point is assigned a label of high, medium or low (H-M-L) confidence. Generally speaking, the confidence is an indication of how close measurements of ceiling and visibility are available. To a reasonable degree, observations of the state of the atmosphere should extend from the locations of direct measurement. The tests applied to each grid point are discussed below.

1. Calculate distance from the nearest METAR: As the range from the nearest METAR increases, the confidence at the grid point decreases from H to M to L. This distance effect is modified by incorporating derived dew point depression values. Drier surface conditions tend to increase the limit of High and Medium confidence away from METAR stations. Further, if neighboring METAR observations' categories do not agree, the confidence at points between them is reduced. This has the effect of lowering the ranges that define the regions of High and Medium confidence.

2. Determine the elevation difference from the nearest METAR: This test provides a first-order representation of the uncertainty introduced by significant changes in elevation over relatively short horizontal distances, such as grid points in mountainous areas. This test is applied after the test above and takes effect as a modification to results from the distance to METAR test. Modifications act toward less confidence. High values are dropped to Medium and Medium values are dropped to Low. There is no effect to previously-set Low values.

3. Cloud mask clearing test: This is a correction-type test that is applied to the results of the two previous tests. This test's objective is to assign High confidence to regions that unambiguously show clear conditions using timely satellite information. This objective is mitigated somewhat by the age of the satellite data used to create the cloud mask. If the data is older than 45 minutes, the cleared pixels are assigned a confidence of Medium.

4. FINAL OUTPUT

After all the fields are assembled, the CONUS-scale data are subdivided into 18 over-lapping regional views. All of the domains will be made available on the ADDS website [ADDS]. The regional views provide an easy way to see the impact of small-scale hazards and abrupt changes in conditions, especially those due to terrain.

The graphical output was designed to display only two types of confidence: Low and Medium or better. This was done to minimize the interpretive requirements for users. Low confidence is indicated by stippling, which appears as slightly darker shades than the regions evaluated to be Medium or better confidence.

Two sets of the final ceiling, visibility and flight category fields are presented in Figures 4 and 5. The first set of examples show the entire domain; the second are an example of a regional view around Las Vegas, NV.

In the CONUS ceiling example (Figure 4), clearing by the cloud mask is evident from Nebraska to Texas by the large, unbroken areas with no stippling.

In the regional ceiling example (Figure 5), the METAR area-of-influence in the confidence data can be visualized by three cases in central California. There are two distinct circles of 3000-5000' ceiling heights (labeled "A" in Figure 5a) , two larger over-lapping circles of 5000-10000' ceiling heights directly south-east (labeled "B" in Figure 5a), and a larger still circle of >10000' ceiling height further south-east (labeled "C" in Figure 5a).

The effect of the cloud mask clearing test in the confidence field can be seen when the regional visibility and ceiling plots are compared. In the visibility plot, there are circular areas of Medium or greater confidence in Arizona. The same area in the ceiling plot, by contrast, shows evidence of cloud mask clearing: the Medium or greater areas appear less geometric in nature.

Plots of METAR stations and their observations are not shown in these examples. They will be available as a selectable overlay within the real-time web version.

5. VERIFICATION

5.1. Methodology

The NCV analysis product went through a statistical evaluation test [Braid et al., 2007] as part of the NWS/FAA Aviation Weather Technology Transfer process to determine operational suitability status. The test was administered over two time periods in 2006: June 29th through July 28th (summer) and September 1st through December 20th (fall).

At the top of each hour of the dataset, the test compared METAR observations with the worst ceiling and visibility condition from the four surrounding NCV analysis grid points. The test accomplished this by using a cross-validation technique which involved randomly removing 20% of the METAR stations prior to NCV grid construction. Those stations were then used to verify interpolated conditions at grid points in between METAR stations.

This process was repeated 10 different times in order to reduce the likelihood of skewed statistics as a result of removing geographic clusters of stations.

It is important to note that the verification process was conducted between METAR stations, not directly at them. The NCV analysis product provides users information about ceiling and visibility conditions in areas where there are no direct observations available. If the test evaluated conditions only at each site, the skill of the product would have been nearly perfect (small differences between grid construction by NCV and deconstruction by the AWRP Quality Assessment Research Team prevent perfect skill). The result of testing points away from sites meant that product skill should decrease as distance from METARs increases.

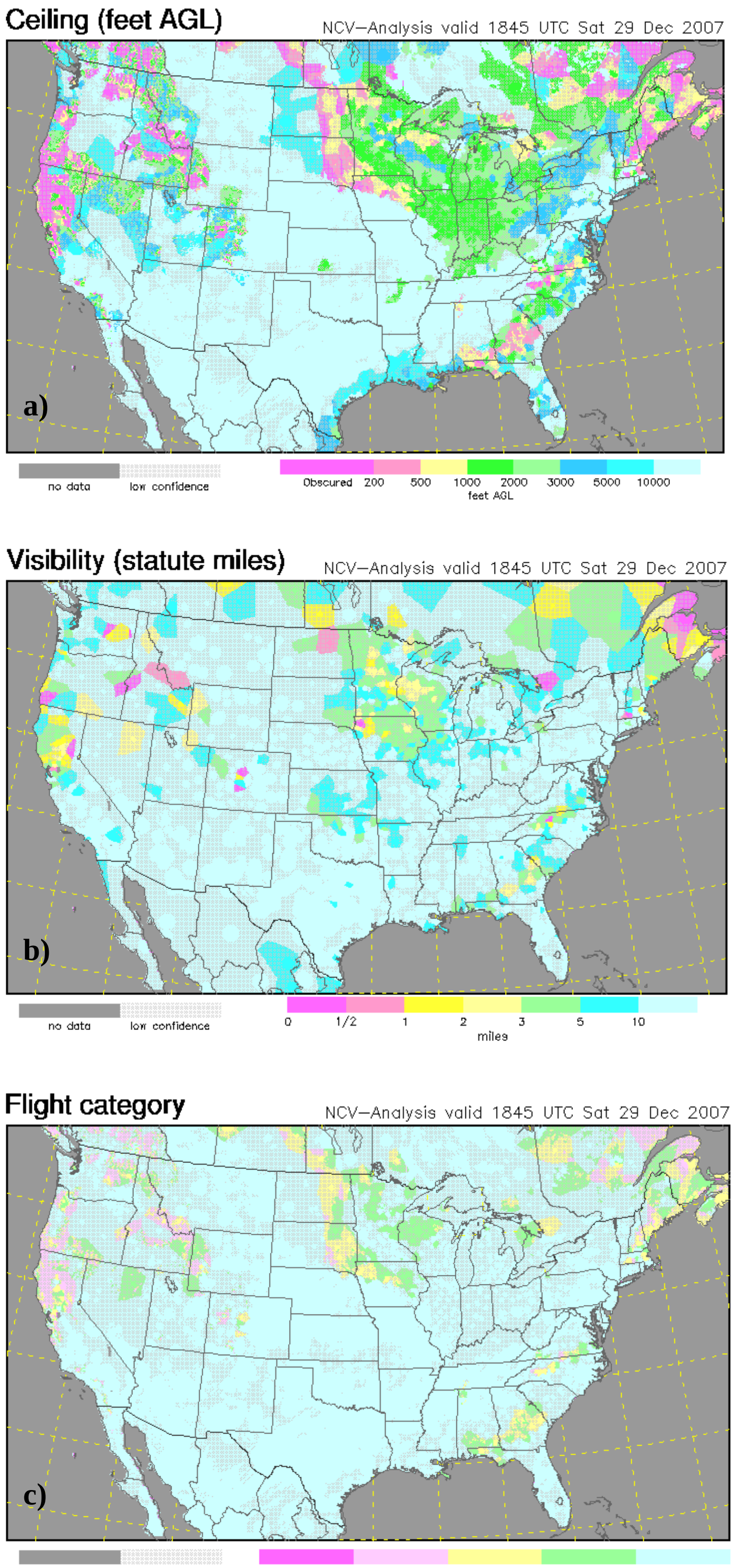
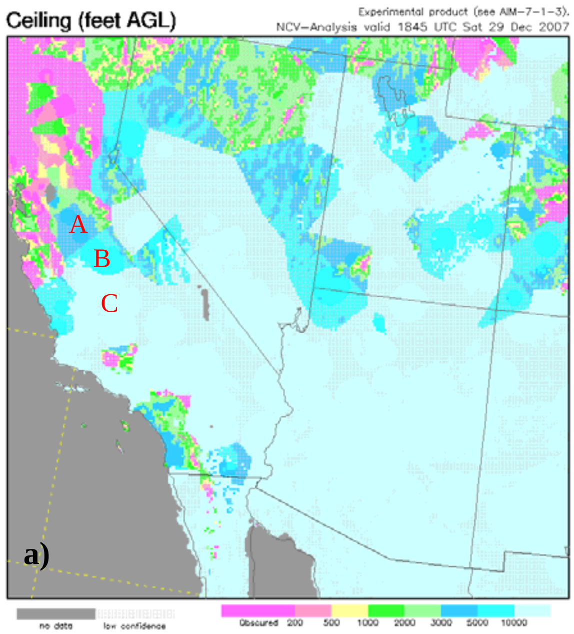
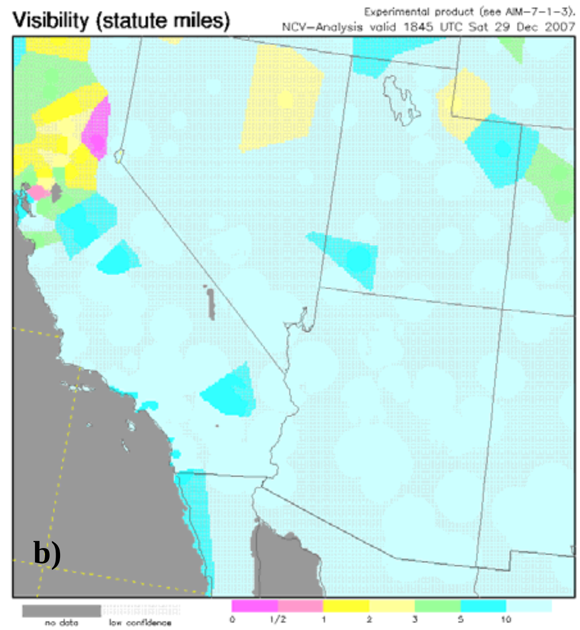


Figure 4. Final CONUS-scale fields: (a) ceiling, (b) visibility and (c) flight category, valid at 1845Z on Dec 29, 2007. The displays indicate low regions of confidence by stippling, most obvious in the western U.S.





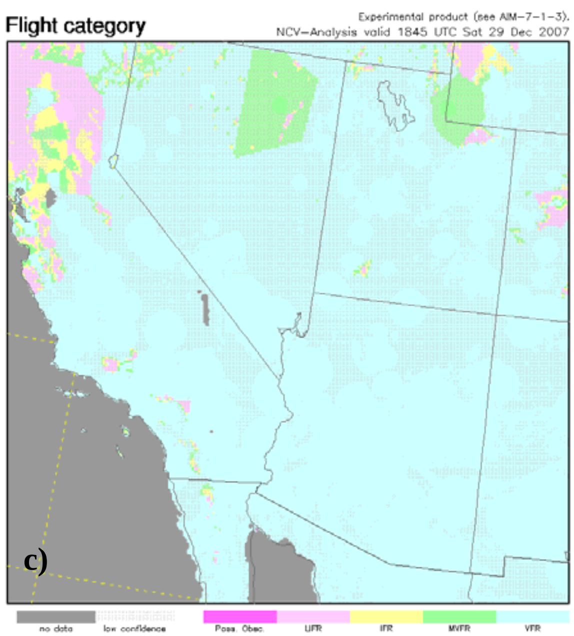


Figure 5. Final regional view (centered on KLAS) of (a) ceiling, (b) visibility and (c) flight category, valid at 1845Z on Dec 29, 2007. The difference between the regional ceiling and visibility plots in Arizona show the effects of clearing by the cloud mask.

5.2. Results

Overall, Braid et al. (2007) determined that the analysis product has positive skill in diagnosing ceiling and visibility conditions.

The evaluation's flight category results confirm the distance-skill relationship described above. During the summer over the entire domain, the analysis product had a Probability Of Detection-yes (PODy) score of 0.523, a Bias of 0.859 (dimensionless because flight category was assigned a numerical value per category), a True Skill Statistic (TSS) of 0.493, and a False Alarm Ratio (FAR) of 0.329.

The same bulk skill scores improved during the fall season. The product had a PODy score of 0.685, a Bias of 0.911, a TSS of 0.650. The FAR during this period rose to 0.372, slightly worse than during the summer period. These results are in part indicative of a higher frequency of impacted conditions.

The evaluation found that, with regard to ceiling heights in the summer, the product had a low bias (interpolated values were less than observed values) when validation METARs reported ceilings less than 3,000ft. (IFR conditions). When reported ceilings were greater than 3,000ft., the product had a high bias (higher interpolated values than reported values).

In the fall, there was essentially no difference between product values and observed values when ceilings were reported to be below 3,000ft. The product continued to exhibit a high bias when reported ceilings were above 3,000ft.

When the visibility analyses were assessed, the product was found to have a high bias (interpolated values were higher than observed values) during both the summer and fall when reported visibilities were less than 3 mi (IFR conditions).

When VFR conditions were reported (> 3mi), the product was evaluated as having a neutral to slightly low bias.

6. SUMMARY

This paper outlines the automated NCV analysis product. This product relies heavily on METAR observations, sampled every 5 min. GOES satellite data are incorporated as a cloud mask when they can add value. Interpolation between sites is accomplished by a nearest-neighbor method at 5-km resolution over the CONUS.

Gridded fields of ceiling, visibility, and a derived flight category are constructed. Corresponding confidence fields for each are produced to aid users in assessing the representativeness of conditions in gap areas.

This product has demonstrated positive skill in constructing and disseminating information regarding the current state of ceiling and visibility conditions away from observation sites.

It is expected that the NCV product will aid the general aviation community by providing the latest information available to all users simultaneously. With training and familiarization, this product should improve flight safety by aiding users' decision making processes.

7. ACKNOWLEDGEMENTS

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