3.3 RECENT PROGRESS IN THE DEVELOPMENT OF AUTOMATED ANALYSIS AND FORECAST PRODUCTS FOR CEILING AND VISIBILITY CONDITIONS

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1. INTRODUCTION

Accident records compiled by the U.S. National Transportation Safety Board over the period 1989 though 1998 indicate that aircraft incidents in which adverse ceiling and visibility were cited as contributing factors claimed the lives of 1685 people (averaging 168 per year) within the U.S. general aviation and charter/air taxi communities. Key thrusts toward improving this safety record include improved methods supporting the analysis and forecast of ceiling and visibility (C&V) conditions and improved access to the resulting products for forecaster and end user alike.

Recent development of a test-phase automated C&V analysis/forecast system by the FAA's National Ceiling and Visibility (NCV) product development team utilizes expert system methodology to merge numerical and observational inputs in the synthesis of current analyses and forecasts out to nine hours. Its products covering the continental U.S. (posted at www.rap.ucar.edu/projects/cvis) have yielded encouraging early results and useful insight into directions for future development.

This paper describes several aspects of current and emerging work associated with use of surface and satellite data, and application of numerical and observations-based forecast models in development of the NCV analysis/forecast system.

2. OVERVIEW OF THE NCV SYSTEM

The NCV product development team is researching and developing products targeted for operational use directly by the flight service station briefer, pilot, dispatcher, controller, and other end user. Since automation is key to enabling frequent product updates and around the clock operation, our work relies upon unattended, computer-aided techniques. These include *(i)* expert system methods to conditionally manipulate data inputs and manage functional interactions among them, and *(ii)* fuzzy logic techniques to formulate a consensus product (*e.g.*, analysis, or forecast), generally based upon the selective merging of individual data and product sub-elements.

NCV works toward the development and support of two product families:

- <u>Gridded analyses</u> of current ceiling, visibility and flight category conditions. These are provided at the RUC forecast model native grid resolution (currently

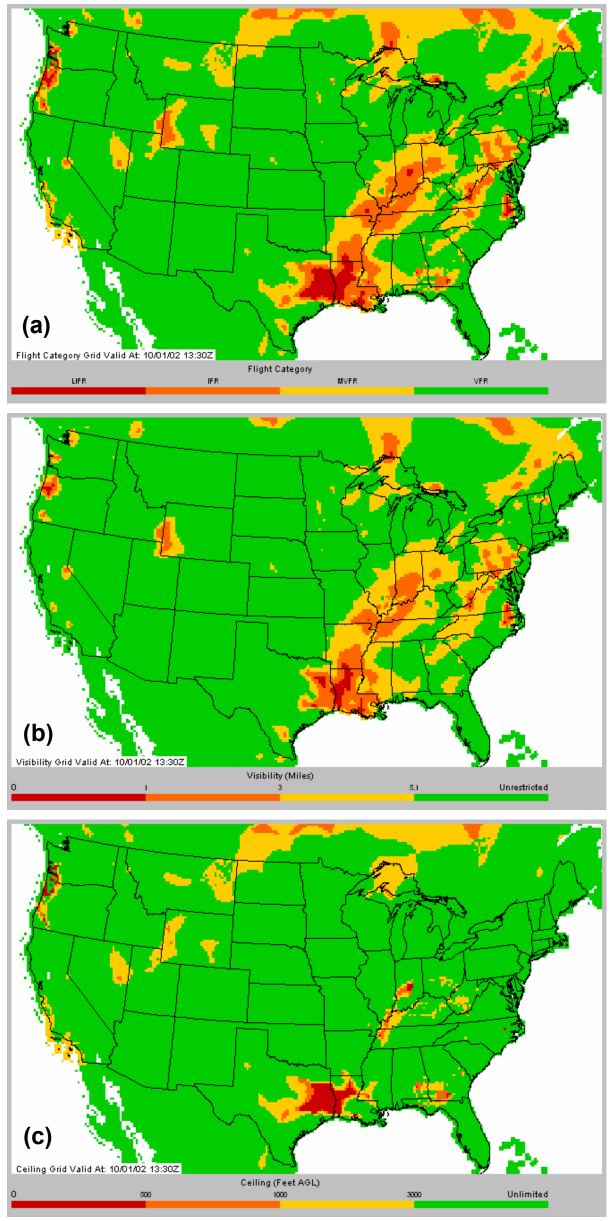

Figure 1. Current conditions as given by METAR reports analyzed by the NCV automated system. (a) Flight Category (Low IFR, IFR, Marginal VFR and VFR) as determined from the values in (b) and (c). (b) Visibility in statute miles. (c) Ceiling in feet AGL. Prototype display is continuously accessible at www.rap.ucar.edu /projects/cvis.

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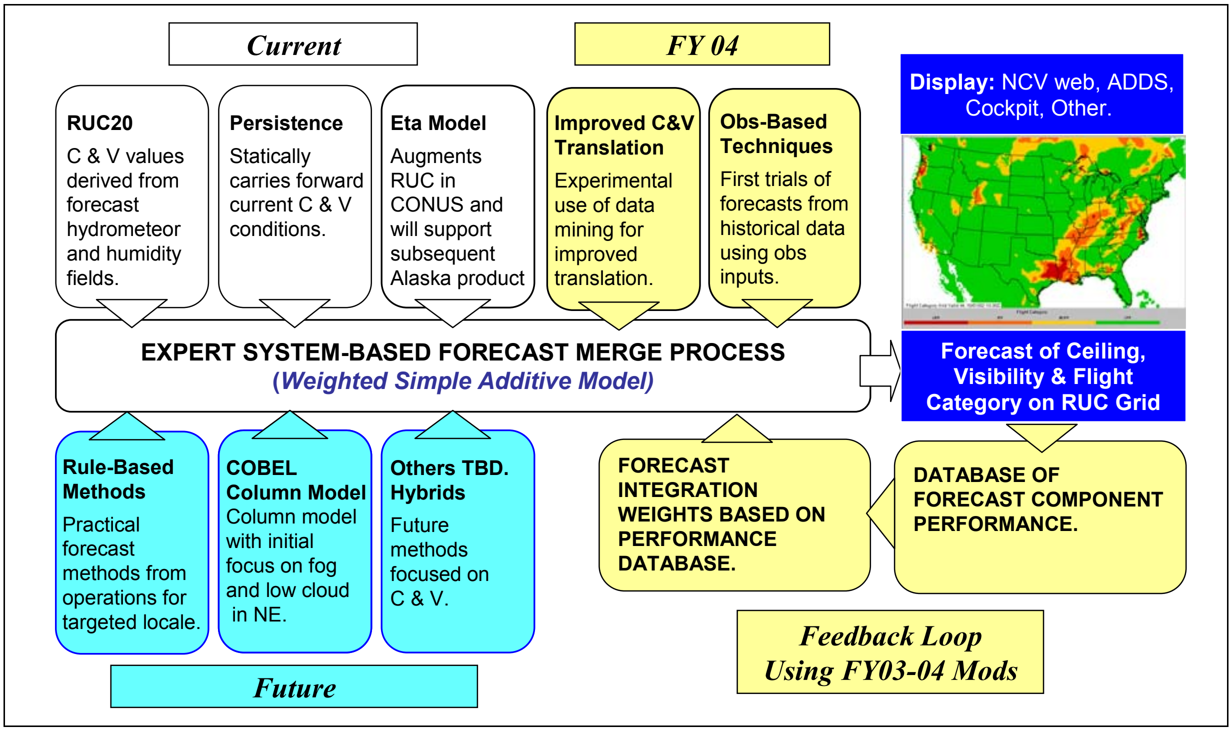

Figure 2. Schematic representation of NCV forecast system components for CONUS C&V in use today and those planned for future implementation. Forecast components flow to the expert system-based automated merging process shown at center. Real-time scoring of component forecast skill feeds back to optimize the weighting of forecast components in the automated merging process.

20 km) and provide ready access to supporting interactive data overlays. The concept here is to provide rapid (15 min) updates of current C&V conditions in graphical form while incorporating tools that allow concurrent examination of METARs, TAFs, AIRMETs, and satellite and NEXRAD imagery. The analysis of present conditions given by the current NCV prototype product covering the continental U.S. (CONUS) is illustrated in Fig. 1.

- Gridded 1-12 h forecasts of ceiling, visibility and flight category. The NCV forecast product is formulated as a consensus among a variety of parallel forecast techniques comprised of numerical modeling and observations-based approaches. The forecast product is updated hourly. The NCV plan makes use of several forecast components and techniques, and we are only at the beginning of that implementation. The key elements of the conceived forecast system are illustrated schematically in Fig. 2, which also shows the fuzzy logic-based system currently in place to weight and merge forecast information through an additive model.

3. IMPROVING CEILING ESTIMATES USING KNOWLEDGE DISCOVERY IN DATABASES

Current NCV Practice

Characterizing ceiling behavior in the regions *between* routine METAR observations is one of the key challenges to be met in improving regional analyses of ceiling height needed for flight planning and in-flight guidance. The NCV system uses a natural neighbor interpolation scheme to estimate ceiling height between METAR sites. This interpolation scheme is based on Voronoi polygons and takes into account the geometry of METAR site location with respect to the grid point in question. The ceiling value at a grid point is formed as a weighted sum of neighboring METAR reports. The choice of neighboring METAR sites affecting a grid point is determined by an analysis of the Voronoi polygons, and the weights are determined by an area weighting scheme.

Where GOES data indicate a cloud-free region, the interpolated ceiling height is raised to a value corresponding (effectively) to unlimited ceiling conditions. This is a simple, first-order approach to gap-filling. The approach can successfully represent clear areas within the analysis, but takes no step toward improvement of ceiling values in cloudy regions between METAR sites. Any information in the GOES data beyond that indicating cloudy vs. clear conditions is unused.

A second area under development is the accurate derivation of ceiling values (which are not a direct product of model predictions) from model-predicted meteorological fields. This translation is a critical step in extracting predicted ceiling fields from numerical model results. Common practice today is to apply the Stoelinga and Warner (1999) translation algorithm (or a related adaptation of that approach) to model output to derive ceiling and visibility fields. The Stoelinga-Warner (hereafter SW) technique utilizes theoretical and empirical relationships between light extinction and hydrometeor characteristics to translate model-predicted hydrometeor fields to useable ceiling and visibility values.

Overview of a KDD Approach

Operational meteorologists routinely depend upon satellite images and model data to fill in data gaps in data-void or data-denied regions within ground-based observation networks. This data need motivates some of the current research at the Naval Research Laboratory (NRL). The research reported in Bankert *et al*. (2003) and Hadjimichael *et al*. (2003) offers promise for new methodologies to better exploit both satellite and model data for information on ceiling height in situations where direct measurements are unavailable. This work applies methods for data collection, database formation, data mining, algorithm analysis and knowledge discovery that are collectively referred to as Knowledge Discovery in Databases (KDD) techniques (Fayyad *et al.*, 1996).

While there is no *direct* indication of ceiling height in GOES data, it is justified to reason that specific factors such as the existence of cloud and a variety of its detectable characteristics and patterns of occurrence should reflect significantly on the probability that certain ceiling characteristics are associated with the cloud. These detectable characteristics might include, for example, its type (*i.e*. stratus, cirrus, etc.), optical thickness, the height of cloud top, observed ceiling values at neighboring METAR sites, the ceiling values associated with similar GOES cloud signatures in the same region in the past, and many others. KDD techniques provide systematic means to find and categorize the patterns and relationships among factors that are found to affect a targeted characteristic – in this case the existence of a cloud ceiling and its height. In addition, KDD techniques provide means to develop a simple model from existing data and apply that model to retrieve estimates of the targeted characteristic. Such a data-derived model for ceiling height is outlined below.

The NRL KDD approach to ceiling estimation begins with selection of data sources and collection of hourly data over a multi-year period for the domain of interest. In the test example described here, a U.S. west coast domain was selected. A 2.5 year record of data was compiled to relate hourly observations made at 18 METAR sites across the domain with corresponding data (coincident in time and location) from satellite and numerical model sources. For example:

- Serving as ground truth, METAR data consisted of 14 measured parameters including ceiling height, ceiling/no ceiling indicator, cloud coverage, present weather, visibility, winds, temperature and humidity. Ceiling height is the ground truth parameter (dependent variable) used in the KDD process for this study. The other parameters could be used similarly in future studies.
- Satellite data covering each METAR site at each hour were taken (when available) from GOES-10, NOAA's polar-orbiting Advanced Very High Resolution Radiometer (AVHRR), and the Defense Meteorological Satellite Program's Special Sensor Microwave Imager (SSM/I). Satellite data selected included all sensor fields, plus results from a microwave sensor satellite rain rate algorithm, a cloud optical depth algorithm, a low cloud product, and a cloud top height algorithm.
- Model data covering each METAR site were taken hourly from COAMPS™ (Hodur, 1997; Hodur *et al*., 2002) triply-nested (81, 27, 9 km) mesoscale model runs (12 hour). Forty-two model parameters were selected according to assumptions as to which of those available might have the closest relation to cloud base height.

The data outlined above reside in a database whose structure is optimized to support efficient data mining. The database is continuously updated (daily) as new observations and model results are acquired.

Data mining was performed on the database to uncover relationships among the variables that balanced predictive skill with model generality for an algorithm focused on the estimation of cloud ceiling. Classification models (represented as a decision tree) were produced through use of the RuleQuest Research C5.0 data mining tool. Rule-based predictive models (numerical output) were produced through use of the RuleQuest's Cubist algorithm. Applying both C5.0 and Cubist, and through repeated testing and combination, a three-step system for estimating cloud ceiling conditions was developed. After establishing the algorithms at each step, the decision/estimation process for a given data record presented to the three-step system can be summarized as follows:

Step 1: Classification Algorithm (C5.0) – Ceiling vs. No Ceiling?

If classified as ceiling, proceed to Step 2; otherwise, no ceiling is output.

Step 2: Classification Algorithm (C5.0) – Is Ceiling Below 1000 m or Above 1000 m?

If ceiling is below 1000 m, proceed to Step 3; otherwise "high ceiling" is output.

Step 3: Rule-based Predictive Algorithm (Cubist) to Estimate Ceiling Height.

Cloud ceiling height estimate is output.

KDD Ceiling Estimation Results

To obtain an estimate of the performance capabilities of the 3-step system, the hourly data records were divided into training and testing sets for each step. Test results for step 3 (ceiling height estimate) under daytime conditions over the U.S. west coast have been excerpted from Bankert *et al.* (2003) and are briefly summarized in Fig. 3. Results from three KDD-derived models for ceiling height estimation (using GOES-10 inputs only, COAMPS inputs only, and GOES-10 plus COAMPS inputs) are compared with corresponding results of the SW translation algorithm as applied to COAMPS model results. Fig. 3 shows that the average error in ceiling height estimation is markedly lower for each of the KDD models than for the COAMPS plus SW estimator. In addition, the correlation between the estimated ceiling and actual ceiling (as given by METAR

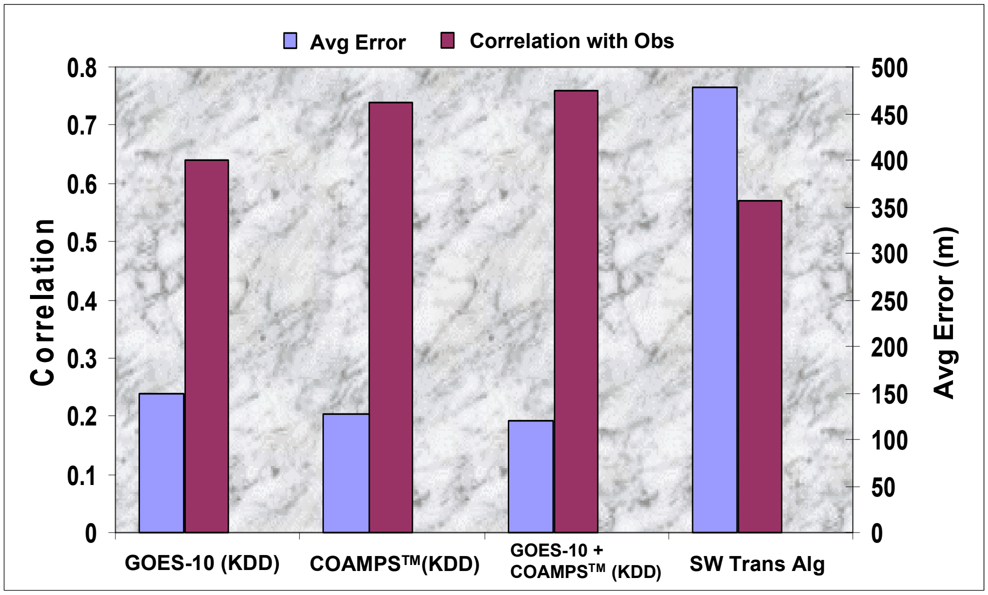

Fig. 3. *Comparison of results of four methods for estimation of ceiling height. The three KDD-based methods use GOES-10 input data (only), COAMPS model input (only), and both GOES-10 and COAMPS input, respectively. The SW method applies the Stoelinga-Warner translation algorithm to COAMPS model results. Each of the KDD methods showed significantly lower average error and higher correlation to ground truth measurements than did the SW method.*

observations) was markedly higher for each KDD model than for the COAMPS plus SW estimator. Each of the KDD models demonstrated higher skill than SW in the first two steps of the 3-step system as well (results not shown here).

These results provide strong encouragement for continued development of the KDD technique and corresponding establishment of data collection and database functionality as part of the NCV data handling infrastructure. Application of GOES-10 and GOES-12 KDD models to perform gap-filling between METAR sites should significantly benefit the ceiling analysis function within the NCV system. Since the NCV system makes use of the operational RUC20 model rather than COAMPS, development of KDD techniques for NCV use is currently addressing a change of model inputs. Use of a GOES plus RUC20 KDD model will enable comparison with the current RUC20 plus SW ceiling height prediction. Based upon the results shown in Fig. 3, it is expected that the KDD model will achieve significantly improved results, and thus improved skill in NCV ceiling height predictions.

4. ENSEMBLE ANALOG FORECASTING THROUGH FUZZY CASE-BASED REASONING

Persistence, and especially persistence climatology, are well recognized as skillful predictors of ceiling and visibility for short-term periods less than 6 hours. Thus, a short-term prediction process or system will benefit significantly through use of information on present conditions. The current NCV system utilizes a slightly modified form of persistence as one of its three input forecast modules, but does not yet contain a persistence climatology or other, more sophisticated, observations-based forecast component. Collaboration with the FAA Aviation Weather Research Program's Terminal Ceiling and Visibility product development team is moving toward production of statistical forecast tools that should add new skill to short-term point forecasts at airports throughout the NCV domain. However, observations-based techniques in use or under development by other groups offer promise of advantage as well, especially where leveraging of the associated development work is mutually beneficial to the organizations involved. One such opportunity is WIND-2, the fuzzy logic case-based reasoning (CBR) ceiling and visibility forecast system under development and testing within the Meteorological Research Branch (MRB) of the Meteorological Service of Canada (Hansen and Riordan, 2003; Riordan and Hansen, 2002).

The Meteorological Research Branch's WIND-2 fuzzy CBR system implements, in effect, an ensemble analog forecast method. The forecast is drawn from the behavior of an ensemble of past cases determined to be highly similar to the conditions representing the case to be forecast. Some key aspects of the forecast system and its method are outlined below:

- The WIND-2 forecast technique utilizes fuzzy set theory to quantify the degree of similarity between salient characteristics of past cases at the forecast location.
- The archive of past cases contains hourly reports over a period of tens of years. Fuzzy techniques are used to uniquely characterize each archived case according to 12 meteorological characteristics (time of day, Julian date, cloud cover, ceiling height, visibil-

ity, wind speed and direction, precipitation type and intensity, temperature, dew point and pressure tendency).

- The system uses data mining techniques applied to the archive of past cases to select an ensemble of k (typically 16) nearest neighbors that are most closely analogous to the case to be forecast, the present case. Present cases are composed of data from two sources: METAR data, to describe all 12 above-listed meteorological characteristics up to and including time-zero; and model-based data, to describe a subset of these same characteristics (the same set excluding the predictands, ceiling and visibility-related values) from 0-6 h.
- The resulting *H*-hour deterministic forecast is formulated as a weighted median of the end conditions of the ensemble of analog cases after *H* hours. The forecast can be expressed in probabilistic terms through use of the distribution of ensemble results.

Performance of MRB's WIND-2 forecast system is being evaluated as the system is further developed and refined. Verification results for 0-6 h ceiling and visibility forecasts for 12 major Canadian airports for the past year is quite promising. The accuracy of WIND-2 forecasts is routinely higher than that of persistence and is similar to that of official forecasts. It is important to note that these results are partly determined by arbitrary features of the particular verification method used (Stanski *et al.*, 1999), and that these results describe the accuracy of WIND-2 run autonomously, without real-time input from expert forecasters. We would expect higher accuracy if WIND-2 could benefit from such input, which would improve the description of the current weather situation and thereby help to intelligently guide the data mining of the climate archive toward an ensemble of analog cases of higher relevance to the forecast case.

Ongoing collaboration between MRB and NCV will center around further development of WIND-2, continued evaluation and verification, and, pending favorable results, trial implementation of the system as an additional forecast component within the NCV forecast system.

5. SUMMARY

This paper outlines the plans and early results of a long-term R&D program directed toward improved automated analysis and forecast tools to aid avoidance of in-flight C&V hazards. We principally target the needs for C&V information within the general aviation community, where improved access and utilization of briefing and in-flight guidance information can lead to a significant improvement in flight safety.

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