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ITWS CEILING AND VISIBILITY PRODUCTS

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1. INTRODUCTION

A major function of the Integrated Terminal Weather System (ITWS) is to provide weather products that can be used in traffic planning and management to increase the actual capacity of an airport (Sankey and Hansen, 1993 and Evans and Clark, 1993). The ITWS ceiling and visibility products are directed towards the management of the arrival traffic. The planned rate of arriving traffic at an airport is based on the Airport Acceptance Rate (AAR), the number of arriving airplanes per hour that it is believed can be safely handled by Air Traffic Control. Ceiling and visibility conditions near the airport are a major consideration in setting the AAR.

Low ceilings and obscured visibility restrict the ability of pilots to see the runway and other aircraft. Necessary increased caution and separations in these conditions impede traffic flow near the airport. Unexpected, rapidly degrading low ceiling or visibility conditions can reduce the airport arrival capacity below the AAR with the result of holding large numbers of airplanes in terminal airspace before they can be safely landed. In extreme circumstances, pilots may be required to divert to their alternate destination. Conversely, unexpected rapidly improving low ceiling or visibility conditions can increase the airport arrival capacity at a time when there is insufficient approaching traffic to take advantage of the situation. Accurate short–term forecasts of these changing situations will provide the information needed by traffic managers for planning realistic acceptance rates and by pilots for diversion decisions.

We present an overview of the product development strategy and discuss some of the technical considerations. It will be necessary to overcome significant scientific challenges in order to be successful. Our optimism comes from the improved operational meteorological data in the terminal area, from the ability to access and to process these data rapidly, and from ongoing advances in data assimilation for mesoscale models. Our role is to coordinate the fusion of these technical and scientific advances into operational aviation weather products and to evaluate the effectiveness of these products. Major scientific contributions are anticipated from the Forecast Systems Laboratory (FSL), the National Center for Atmospheric Research (NCAR), Pennsylvania State University, and Colorado State University.

*The work described here was sponsored by the Federal Aviation Administration. The United States Government assumes no liability for its content or use thereof.

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2. CEILING AND VISIBILITY PRODUCTS

The ITWS Ceiling and Visibility (C&V) products are short–term forecasts (nowcasts) of the airport ceiling height, regional visibility, and the RVR value (Runway Visual Range instrument) for each equipped runway. The effective times of these nowcasts range from 15 minutes to 1 hour. They are based on a high resolution, three–dimensional gridded analyses of the State–of–the–Atmosphere Variables (SAVs) (winds, temperature, pressure, and humidity) and prognostic models. Coupled with the 1 to 6 hour forecasts from the Aviation Gridded Forecast System (AGFS)(Sherretz, 1993), these products will provide the information that is needed for efficient traffic management during changing ceiling and visibility situations.

In the United States the maximum airport capacity is based on an assumption of non–disruptive weather, and restrictions are imposed based on a variety of inhibiting weather situations. These restrictions are based on a combination of general rules and rules that are specific to the individual airport. These rules are invoked by requiring changes in allowed operations based on specific ceiling heights and visibility ranges, the decision points of the system. Examples of general rules are the distinction between Visual Flight Rules (VFR) and Instrument Flight Rules (IFR), which are based on national regulations regarding the regional visibility and the ceiling height. Examples of airport–specific rules are the ceiling–height rules relating to independent parallel approaches, dependent parallel approaches, and single file approaches to close parallel runways at a particular airport. When restrictions are in effect at an airport, the AAR is reduced below the maximum for that airport. A believable forecast of a change in ceiling height, regional visibility, or RVR may translate into a change in the projected AAR. In order that these forecasts be of operational use, they must be accurate in time and location, especially when they forecast a change through a decision point of the aviation system.

Display concepts for two of these products are illustrated in Figures 1 and 2. These displays are intended for use by the Traffic Management Unit and others involved in air traffic planning. The concept is to display the recent RVR and Ceilometer measurements and the short–term forecast of the expected measurements by these instruments. One area of investigation is whether or not confidence indicators should be included on these displays.

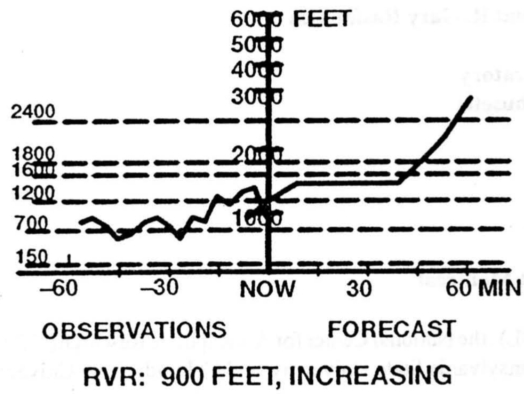

Figure 1. Display of recent and forecasted RVR values. Decision points are indicated by the dashed lines.

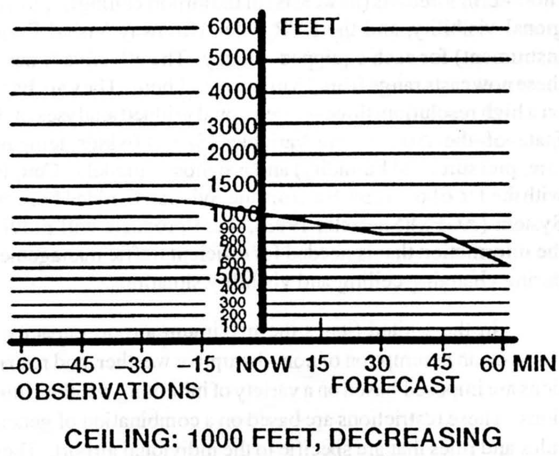

Figure 2. Display of recent and forecasted ceilings.

3. TECHNICAL STRATEGY

Obtaining the information about the boundary layer that is required to support specific C&V products is the fundamental problem. Precise C&V products rely on fine–scale knowledge of the horizontal winds, the vertical motions, the temperature profile, and the humidity profile in the boundary layer. Accurate boundary layer profiles are critical for the diagnosis and prognosis of low ceiling heights and radiation fog. This information can be obtained through a combination of observations and numerical modeling.

An important issue is the determination of which parameters should be measured and which should be deduced through modeling. Considerations are the capabilities of sensors, the capabilities of the various models, and the costs of each approach. The ITWS gridded analysis (Cole, et al, 1993) will provide a rapid update of the observed horizontal winds near the airport, based on Doppler radar and other sensors. It will also provide a temperature profile, based on the AGFS and ACARS (Julian and Steinberg, 1975) measurements, which has coarser resolution in space and time than the winds analysis. This system may be enhanced to provide nowcasts of winds and temperature based on advection and evolution. The temperature profile could be further enhanced by a PBL PROFILER/RASS (Martner, et al, 1993). A modified PROFILER could provide a measure of vertical motion. The only operational humidity measurements are at the surface; these could be augmented by mircowave radiometers and other technologies, such as an airborne humidity sensor, that are under development. The alternative is to generate some of this information by numerical models. Two different approaches to numerical modeling are being considered: mesoscale weather prediction models and column models.

The C&V products come from interpretations of this atmospheric information. Some physical process models contain cloud and visibility products that are tightly coupled to their analysis. In addition, specific C&V products can be enhanced by rule–based and statistical interpretations of the model outputs and recent observations. For example, the humidity profile is difficult to observe and analyze and the ceiling height is sensitive to the humidity profile. Ceiling height itself is readily observed by airport ceiliometers. Comparison of the recent ceiling height nowcasts and the actual experience might be useful for compensating for a systematic ceiling height bias, which is the result of an error in the analysis of the humidity profile.

The aviation community is concerned with reduction of visibility for airplanes, and often blurs the distinction between low ceiling and visibility. From the scientific viewpoint, the situation is much more complex. There are two major classes of clouds that dominate the occurrences of low ceilings, stratocumulus and stratus. There is sufficient difference in the physical processes associated with the formation and dissipation of these clouds that it is expected that different diagnostic models will be required to accurately nowcast their evolution. Fog processes are even more complicated. It may be necessary to consider separately the diagnosis of various fog types, such as radiation fog, advection fog, valley fog, etc. Nimbostratus and fog in rain are other special situations. The plan is to maintain a unified analysis and modeling for as long as possible and to append separate diagnoses for the special situations as they are needed.

4. MESOSCALE WEATHER PREDICTION MODELS

Mesoscale numerical weather prediction models continue to evolve to greater levels of sophistication. The AGFS is a national mesoscale analysis, which is under development at the Forecast Systems Laboratory and which will provide 1 to 6 hour forecasts of the state of the atmosphere, and of ceiling and visibility events with resolution of fifteen kilometers and fifteen minutes. AGFS will be run operationally by the National Weather Service. FSL is evaluating the effectiveness of finer scale models for ceiling and visibility forecasts, working in cooperation with Colorado State University (RAMS) (Tripoli and Cotton, 1982), with Penn State University (MM4)(Warner and Seaman, 1990), and with NCAR (MM5, an extension of MM4 that is under development). Model tendencies from AGFS and these higher resolution models will be an important input to the C&V system. These models are the basis for C&V

forecasts in the 1–6 hour time–frame. In addition, they will provide regional information to support the column models used in the ITWS C&V nowcasts.

It is yet to be demonstrated that operational mesoscale models can provide the detailed vertical structure that is required for nowcasts of airport-specific C&V products. Despite their sophistication, it may be many decades before the new generation of mesoscale models are by themselves able to provide real–time operational nowcasts of ITWS C&V products with the accuracy in location and time that are desired for terminal operations. Until mesoscale models can demonstrate the required fine–scale skill, we expect to augment their output by column models and statistical models.

5. COLUMN MODELS

The column models combine the regional information and trends from the mesoscale models with special observations to provide an accurate nowcast of the vertical structure at an airport site. They represent a currently available technology to prognose vertical structure. The current thinking is to use the output of a mesoscale analysis to support column models at critical positions near the airport. A high resolution nested–grid mesoscale model would be a possible future alternative.

Column models require inputs of the regional behavior of the atmosphere, local surface conditions, and local sensor data. Regional behavior, taken from the mesoscale models, includes the structure of the free atmosphere and grid–scale tendencies in the boundary layer. Surface conditions include soil or sea surface temperature, soil moisture, and surface cover. The required sensor data are atmospheric winds, pressure, temperature, and humidity.

The primary output from these models is a forecasted, high resolution sounding, and the vertical distribution of boundary layer cloud. There are additional output products that can be used as input for diagnostic models, including vertical profiles of turbulent heat and moisture fluxes.

Two column models have been identified as being closely matched to the ITWS C&V problem: the Oregon State University One–Dimensional PBL (OSU1DPBL) model (Mahrt et al, 1991), and METEO France's Couche Broulliard Eau Liquide (COBEL) model (Bergot and Guedalia, 1993). Their physical parameterizations have been tailored so that each has its own particular strength for applications to the C&V problem. The OSU1DPBL model has most often been applied to studies of boundary layer clouds, while COBEL's physics is designed to optimize its performance in forecasting radiation fog events.

6. STRATUS LOW CLOUD DIAGNOSTIC (LCD) MODEL

Second generation knowledge–based systems provide the framework for combining heuristic rules with numerical model output, computer assisted physical analyses, and objective forecasting techniques. Different systems will be required for different types of clouds and fog.

The STRATUS LCD model (Desmarais et al 1992, Desmarais et al 1991a and b) is an example of this technique that diagnoses stratocumulus. It has been under development at the Centre de Recherche Informatique de Montreal and the University of Quebec at Montreal over a period of about 5 years. While the column models discussed above can be used to forecast vertical soundings, the STRATUS LCD model uses a provided vertical sounding to diagnose the existence and nature of cloud layers. The STRATUS LCD model relies partly on an estimation of many of the physical processes included in the column models, but also includes a set of low cloud rules based on heuristics which are adjusted empirically. The current set of 450 rules decides the amount of cloud cover at each level in the vertical sounding. It is important to note that in successive applications of STRATUS to a time series of soundings, each application is treated as a separate trial, i.e., there is no logic for evaluating and adapting to recent performance.

The STRATUS LCD model has been applied to STORMFEST data (STORM Project Office, 1992). In these analyses, STRATUS rules were applied to sounding data and the cloud analysis was compared with the surface observations. There were no available estimates for the vertical motions above the boundary layer, one of the standard STRATUS inputs. Preliminary evaluations were conducted with vertical motions set to zero. They indicate that STRATUS has skill for diagnosing cloud amounts and ceiling heights, but that it tends to overestimate the amount of cloud cover and the ceiling height estimates are biased low. The results from Topeka, Kansas are typical (Figure 3).

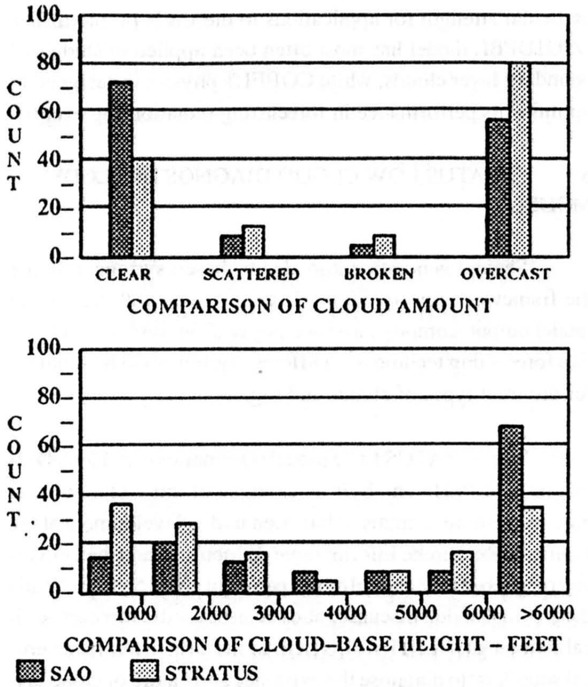

Figure 3. Comparison of distributions of cloud amount and cloud–base heights for STRATUS and SAO's based on STORMFEST data from Topeka.

7. STATISTICAL TECHNIQUES

Statistical techniques play an important role in the development of C&V products. We anticipate five different types of contributions:

1. Prioritizing of product development
2. Adapting to model bias
3. Adapting to product bias
4. Indicating product confidence
5. Naive nowcasting

Even these broad categorizations may underestimate the role that statistical methods may play in these developments.

Priorities for product development will be determined by a combination of benefit to the aviation system and current scientific tractability. The needs of the aviation system are determined by which airports have the most significant C&V problem and which types of ceiling and fog dominate the climatology at those airports. Delay statistics reveal that the most C&V impacted airports are at New York, Chicago, and San Francisco. Studies are underway to determine which types of events are most disruptive to their operations. For example, uncertainty about the time of the stratus burn–off is the major operational problem at San Francisco.

All models have biases. Understanding and compensating for these biases leads to more accurate forecasts. Model Output Statistics (MOS) (Glahn and Lowery, 1972, Glahn and Unger, 1986, and Unger, 1987) is the most successful statistical correction technique. Its major drawback is the need for a prolonged tuning period whenever the model is altered. One approach is to initialize the MOS equations with estimated biases, provided by the model developer, and to provide for a continuing adaptation based on experience. An alternative is to actively track a few key model biases and to automatically adapt to changes in these biases.

Product bias is an observed time–varying average offset between the forecasted ITWS C&V products and the observed situation at the validation time. Because of the frequent updates of these products and the availability of validation data, it is possible to track the pattern of these offsets. One use of this information would be to attempt to predict the expected offset for use as a correction in the near future. An alternate strategy is to apply sensitivity analysis to allocate the most likely cause of the problem, e.g. the lapse rate of the dewpoint profile is too steep. Such information would be useful in adjusting the inputs to a subsequent application of a column model.

The traditional position of the aviation community is that meteorological products should require little interpretation. This position is usually taken to mean that there is no use for probabilistic forecasts in the aviation system. This position is understandable for those situations where the forecasts are used by non–meteorologists as part of the operational decision process. Statistical analysis can produce a variety of confidence indicators, which can greatly enhance the information content of a forecast. In those cases where these products are used as inputs for automated traffic management algorithms, confidence indicators may have significant value. One example of such use is in the optimal allocation of ground delay vs airborne delay as discussed by Andrews, 1993, which suggests that air traffic decision–aids may be required to obtain the full operational benefit from the ITWS C&V products.

Nowcasts of the SAVs for the next 15 to 30 minutes may be especially important for sharpening the precision of the nowcast of when there will be a transition of the ceiling or RVR reading through an aviation decision point. By a naive nowcast, we mean an extrapolation method based on statistical and digital filter techniques, rather than on the integration of physical process equations. An example is nowcasting by tracking and predicting an advecting feature. Wind shift algorithms based on tracking of fronts by Doppler radar are an example (Hermes, et al 1993). Machine intelligent pattern recognition technology provides a powerful extension of this technique (Delanoy and Troxel, 1993). One important application would be the tracking of an advecting rain–band for use in the prediction of when fog will clear. Kalman filter techniques have been suggested as an alternative nowcast mechanism (Cicciamani and Simone, 1992).

8. ITWS C&V TEST BEDS

An important part of this product development is the design and operation of C&V test beds. The role of a test bed is to collect data to match the anticipated operational capability of the end state system, to collect additional data for product validation, and to provide an opportunity for operational demonstrations and evaluations of the ITWS C&V products. A reliable, consistent data archive is especially important for the development of statistical models. Previous studies have been conducted on data collected from a single season. These data are valuable and will be used for product development when possible. The deficiencies in these data sets are that they do not contain TDWR and NEXRAD winds data, they cover too short a time span for the development of statistical models, and the data collection is often focused at times of events, rather than being continuous over the entire season, as is required for the development of operational models. For these reasons, we plan to collect data at an appropriately instrumented site for a period of several years. Cost can be minimized by collocating the test bed with an ITWS operational demonstration site, one of several major airports where other ITWS products are being developed and tested.

The selection of a test bed site involves considerations of frequency of occurrence of the weather events and impact of these events on aviation. Experience shows that the cities that have the greatest C&V air traffic delay impact are New York, Chicago, and San Francisco. There are many meteorological similarities in the C&V problems in New York and Chicago. By contrast, San Francisco C&V problems are primarily associated with marine stratus and may require special consideration.

9. SUMMARY

The strategy for addressing the terminal ceiling and visibility nowcast problem emphasizes the integration of current and anticipated technologies into a real-time prototype system. Although significant scientific challenges must be overcome, the design of an operational system that supports short-term nowcasts of ITWS ceiling and visibility seems technologically feasible. We are encouraged by improved data provided by sensors that will be in place at major airports, more efficient data communication systems, and the continuing advances in data assimilation and modeling. Product development will be based on a combination of mesoscale models, column models, and statistical forecast models, in conjunction with rules-based and statistical diagnostic models. These products will be evaluated for scientific accuracy and for usefulness in the aviation system at selected test beds.

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