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THE 2001 DEMONSTRATION OF AUTOMATED CLOUD FORECAST GUIDANCE PRODUCTS FOR SAN FRANCISCO INTERNATIONAL AIRPORT

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1. INTRODUCTION[†]

The airspace surrounding San Francisco International Airport (SFO) is prone to regular occurrences of low cloud ceiling conditions from May through October due to the intrusion of marine stratus along the Pacific coast. The low clouds prohibit dual-parallel approaches of aircraft to the airport's closely spaced parallel runways (Strach, 1991). The stratus evolves on a daily cycle, filling the San Francisco Bay region overnight and dissipating during the morning, with a median clearing time of roughly 18 GMT (11AM Local Time). Days with persistent morning cloudiness result in a substantial number of delayed flights into SFO. Air traffic managers receive guidance from aviation weather forecasters to anticipate the time of stratus clearing so that traffic may be properly metered to the airport to minimize delay.

A system for providing cloud prediction guidance to aviation weather forecasters was demonstrated during the summer of 2001. The system was sponsored by the FAA, and developed by MIT Lincoln Laboratory in collaboration with San Jose State University (SJSU), the University of Quebec at Montreal, Penn State University, and the Central Weather Service Unit (CWSU) at Oakland Center. Products were provided to forecasters at the CWSU, the NWS in Monterey, and the Weather Center at United Airlines. Real-time data are processed to support a display of weather graphics, and to provide input to a suite of four independent cloud forecast models developed specifically for the marine stratus application. The forecast models were run hourly each morning to provide updated forecasts during the evolution of cloud dissipation in the Bay area. As part of each update cycle, the four model forecasts were combined to provide a Consensus Forecast product. Weather observations and forecasts were provided to users on a web browser display.

2. SYSTEM DESCRIPTION

2.1 Sensors and Data

The forecast system utilizes data from a network of sensors, primarily within the San Francisco Bay region, with more concentrated data collection at two sites along the Approach Zone at SFO and San Carlos Airport (SQL). Data are collected every 15 minutes and processed in the system basestation computer located at SJSU. Following is a summary of system sensors and data. A more complete description of sensors and data acquisition is provided in Clark and Wilson (1997).

Hourly surface observations: From the standard NWS network, generally from the central California region.

High update surface observations: 5-minute data from SFO and the San Mateo Bridge (SMB), directly below the approach flight path. 1-minute measurements of wind, temperature and humidity from SFO and SQL.

Vertical temp/wind profile: From the Oakland sounding.

Solar radiation: Measured at SFO and SQL.

Inversion base height: Measured from acoustic SODARs located at SFO and SQL.

Satellite imagery: From GOES-10 visual channel.

2.2 Forecast Models

Four separate models were developed for forecasting the time of sufficient clearing to allow dual approaches of arrival aircraft. These four "component" forecasts are combined to provide a "consensus" forecast.

2.2.1 COBEL Model

COBEL is a high-resolution 1-dimensional (column) numerical model of the planetary boundary layer that simulates the evolution of marine stratus dissipation. It is unique to the system in that it is the only component forecast derived from a physics-based model. It was adapted at the University of Quebec at Montreal from a model developed for forecasting fog behavior in northern France (Bergot and Guedalia, 1994).

The model is initialized at 12 GMT with a vertical profile of temperature, humidity, and wind at SFO. The initialization uses a hybrid of the 12 GMT Oakland balloon sounding and high resolution lower atmosphere measurements at SFO. This profile is used to characterize the stratus cloud deck in terms of total vertically integrated liquid water content. As the model steps forward, physical processes are modeled to approximate the evolving decrease of the cloud liquid water with time. The model forecast time of cloud dissipation is declared when the liquid water content reaches zero.

Since the model is adapted for a single point (SFO), the forecast is adjusted to account for the spatial difference from the aircraft Approach Zone. This is done via historical analysis of the relationship between cloud burnoff at the model point location and the recorded time of transition to dual approaches.

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The model is re-initialized and run hourly, using updated high resolution measurements of surface temperature, humidity, wind, and solar radiation. In particular, the re-initialization includes an adjustment to ensure that the model's interpretation of liquid cloud water amount is consistent with the amount of observed solar radiation transmitted through the cloud layer.

2.2.2 Local Statistical Forecast Model

The Local Model was adapted by SJSU and MIT Lincoln Laboratory from an empirical forecast method employed at the CWSU. The model is considered "local" in that its predictions are derived primarily from weather observations that are in close proximity to the Approach Zone, in particular the airports at SFO and SQL. Important predictors from these two locations are the height of the inversion base, cloud layer heights, surface wind, pressure differentials between regional surface observations (to estimate local impact of geostrophic wind), and trends in these parameters. Regression analysis was performed to correlate the behavior of these parameters to historical "side-by approach" times. Separate forecast equations were developed for each hour from 13 GMT to 18 GMT.

Statistically, the forecast equation development was based on nonlinear regression of nonlinearly re-scaled predictors. The nonlinear scaling of each potential predictor was selected to maximize the correlation with the residuals from conditional climatology. Once the re-scaling strategy was set and the predictors were selected, the model weights were computed by minimizing a penalty function based on error residuals.

2.2.3 Regional Statistical Forecast Model

The Regional Model, adapted for this application by Vislocky and Fritsch (1997), uses weather observations from the entire Central California region, including upper air data. The model operates in two stages. In the first stage, a host of weather observations are used as predictors for forecasting the probability of cloud-free conditions at both SFO and SQL. Predictors include:

Surface Variables: Dew point depression, wind direction, height of cloud layers (SCT, BKN, OVC), visibility, current precipitation (yes/no).

Upper Air Variables): Temperature difference (1000-950 mb, 1000-900 mb, 1000-850 mb), relative humidity (950, 900, 850, 800 mb), inversion height and strength.

In the second stage, these predictions are then correlated with the historical database of “side-by approach” times to determine the mostly likely time of clearing in the Approach Zone. The model produces a forecast each hour from 13 GMT to 18 GMT.

2.2.4 Satellite Statistical Forecast Model

The Satellite Model was developed at MIT Lincoln Laboratory and is based on statistical correlation of the observed cloudiness in the Bay Region, as characterized by GOES-10 visible satellite imagery, and the ultimate cloud burnoff time in the Approach Zone. Hourly forecast equations were developed for 14Z through 18Z. There are three main processes involved in the generation of the Satellite Model forecasts:

Data preparation: Steps include: 1) geographical re-registration of data 2) mapping to 2 x 2 km grid, 3) 9-point median filter, and 4) normalization for sun angle, so that the brightness indicated by the satellite visible channel is more closely related to cloud characteristics (i.e. solar radiation reflectance by the cloud liquid water) rather than the changing sun angle.

Satellite sector statistics: Individual data points are grouped into fixed geographical "sectors", representing areas throughout the Bay region. The sector boundaries were strategically chosen to contain data grid points covering a homogenous area with respect to either a meteorological or operational characteristic. Statistics are computed on the data gridpoints within each sector, namely, mean and standard deviation of the brightness values, and the percent area cloud coverage.

Satellite statistical forecast: The statistics from each sector are treated as representative observations for that sector. Using a database from a period of several years, the sector statistics were correlated with the approach clearing time.

2.3 Consensus Forecast

The Consensus Forecast provides a unified forecast of clearing time in the Approach Zone. It is derived from the four component model forecasts.

Generation of the Consensus Forecast is a three-step process. First, specific weather observations are examined to characterize the day as a particular "type" meteorologically. The second step is computation of the Consensus Forecast by assigning a weight to each of the four component forecasts, based on the historical performance of each model at each runtime on each of the various day types. The final step is to quantitatively assess the confidence in the current forecast. This is done by using the current forecast weights to compute a hypothetical Consensus Forecast for each similar day type in the historical database, and comparing the forecast with the verification time on those days. The Confidence Index is computed as the fraction of days that the Consensus Forecast would have fallen within an acceptable range of error (described later).

3. USER PRODUCTS

The user interface to the SFO automated cloud forecast system is a web browser display. The left side of the display provides graphics showing current observations, while the right side is used to present the model forecasts and to access additional archived data and analysis information. All components of the display (observations and forecasts) are supported by hypertext links to help information.

3.1 Observations

The observation portion of the display (Figure 1) provides a text listing of key 5-minute surface reports, time-height profiles of acoustic SODAR data indicating the marine inversion height, time-series of measured solar radiation plotted against the theoretical profile of incoming solar radiation on a cloud-free day for that date and location, and a visible satellite image whose brightness values have been normalized to account for changes due to sun angle. The page refreshes approximately every two minutes to check for new observations being collected by the realtime system.

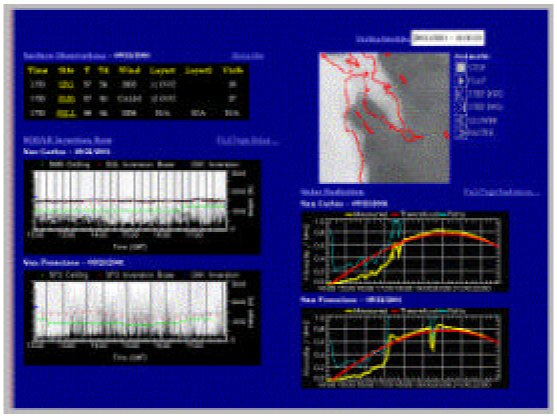
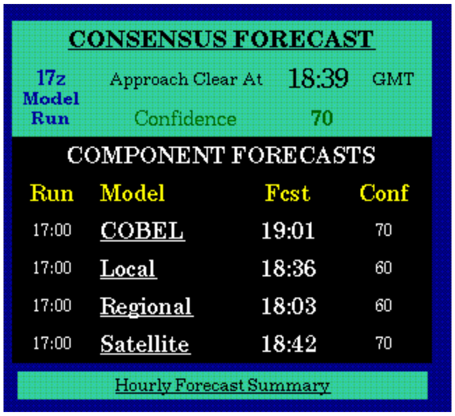


Figure 1: Observation portion of display.

3.2Model forecast guidance

The upper right hand portion of the display (Figure 2) provides a tabular presentation of the model forecast times of clearing in the Approach Zone. Included are the forecast times from the four component models, as well as the Consensus Forecast derived from the component forecasts. Accompanying each forecast is an index of forecast confidence, ranging from <50 (lowest confidence) to 90 (highest confidence). Models were run hourly between 6 AM and 11 AM local time.



CONSENSUS FORECAST

17z Model Run — Approach Clear At 18:39 GMT

Confidence 70

COMPONENT FORECASTS

Run	Model	Fcst	Conf
17:00	COBEL	19:01	70
17:00	Local	18:36	60
17:00	Regional	18:03	60
17:00	Satellite	18:42	70

Hourly Forecast Summary

Figure 2: Model forecasts of Approach Zone clearing time, including confidence indices.

3.3 Supporting information

Below the forecast box (not shown here) is a series of “buttons” which allow the user to access additional information to support the forecast decision process:

Hourly Forecast Summary: Shows all forecasts made previously on that day, allowing forecasters to track the trend in model forecasts throughout the morning.

Model Performance Summary: Provides a summary table indicating each model’s performance to date.

Regional Maps/Data: Links to a web site, which provides a series of more general weather analysis maps for the central California region.

View Previous Days: Launches a separate web browser that allows the user to review the observations and model forecasts for any previous day during the current stratus season. This is useful for examining stratus behavior and forecast performance on analogous days.

4. RESULTS

In general, users were pleased with the display interface of the system, and with the observational data provided. Of particular note was the high value attributed to the inversion height information provided by the SODARs. User feedback regarding these aspects of the system are provided in detail by Fidalgo et al. (2002). Feedback regarding the forecast models was mixed. Users were at first reluctant to incorporate the model information into their operational forecasts, which is not unusual for new forecast models released to the operational community. Although forecasters did exhibit a higher comfort level later in the demonstration period, it was evident that they would like to see improvement in the skill exhibited by the models, which will be the focus of this discussion.

Performance of the four component models and the Consensus Forecast are summarized in Table 1. For each forecast model and each model initialization time, the table indicates the percentage of time that the models yielded a *successful* forecast, and the number of forecasts made. As a performance metric, a successful forecast was defined as one in which the actual clearing time occurred no more than 30 minutes *after* the forecast time, and no more than 60 minutes *prior to* the forecast time. This 90-minute asymmetric window was defined in coordination with system users at the CWSU at Oakland Center, and represents a greater tolerance for a “pessimistic” forecast of clearing time. The table also separates model performance by the Confidence Index that accompanied each forecast.

Intermodel comparison shows a variation in performance by model and forecast time, but a comparison of all high confidence forecasts (shown in far right column) gives a general sense of relative performance. By this measure, the COBEL model was the top performer with a 70% success rate, with the three statistical forecast models showing a success rate of 62-63%, and the Consensus Forecast scoring 67%.

There are some important considerations to make when comparing model performance. For example, the top performing COBEL Model failed to make a single high confidence forecast at 13 GMT, while the Local Model performed at an impressive success rate of 69% at that early hour. Similarly, COBEL dropped off to 50% by 18 GMT, at which time the Regional Model (which performed poorly at 13 GMT) was performing at 69%. (The general decrease in performance at 18 GMT is explainable in that the 18 GMT development data set is largely comprised of cases where the stratus persisted well into the afternoon, which tends to be associated with more complex meteorological scenarios.)

TABLE 1. Model performance summary, showing success rate (see text) for both High (>50) & Low (<50) confidence forecasts, for each hour plus ALL High Confidence forecasts combined. Size of forecast sample is shown in parentheses.

MODEL	CONF	13 GMT	14 GMT	15 GMT	16 GMT	17 GMT	18 GMT	ALL
Consensus	>50	59% (32)	51% (37)	59% (63)	73% (60)	76% (49)	63% (32)	67% (263)
Consensus	<=50	44% (36)	50% (32)	40% (5)	25% (4)	0% (2)	N/A	
COBEL	>50	N/A	56% (32)	76% (34)	74% (39)	65% (37)	50% (20)	70% (152)
COBEL	<=50	52% (60)	50% (28)	33% (24)	40% (15)	0% (2)	0% (1)	
Local	>50	69% (32)	50% (30)	63% (49)	69% (45)	75% (48)	39% (23)	63% (227)
Local	<=50	47% (30)	50% (26)	53% (17)	36% (14)	0% (2)	100% (1)	
Regional	>50	21% (14)	46% (35)	58% (33)	73% (45)	74% (46)	69% (29)	63% (202)
Regional	<=50	50% (24)	43% (28)	41% (27)	57% (14)	0% (2)	N/A	
Satellite	>50	N/A	45% (20)	62% (55)	64% (50)	69% (45)	56% (27)	62% (197)
Satellite	<=50	N/A	50% (22)	50% (4)	25% (4)	N/A	0% (1)	

The value of the Consensus Forecast must also be emphasized. In addition to performing above median for nearly all forecast times, it was able to generate far more "high confidence" forecasts than the component models from which it is derived. For instance, it yielded nearly 75% more high confidence forecasts than the top performing COBEL model. Another feature was that it tended to produce a more stable hour-to-hour estimate of the cloud burnoff time compared to individual component models.

5. CONTINUING AND FUTURE EFFORTS

A follow-up demonstration of the SFO automated cloud forecast system will be conducted during the summer of 2002. As such, focus has been on making modifications to improve the performance of the forecast models. The 2001 demonstration yielded considerable evidence as to where performance gains may be made.

First, a substantial modification was made to the algorithm which generates an automated estimate of the height of the inversion base (generally considered one of the most reliable predictors of cloud burnoff time). This height is estimated automatically within the real-time system, using the Oakland sounding at 12 GMT, and SODAR data collected every 15 minutes throughout the day. Subsequent to the demonstration, this algorithm was re-evaluated and modified to provide a more reliable and stable estimate.

Second, an improved automated procedure has been developed for rank-ordering the correlation of potential predictors to be used in the statistical forecast models, and for deriving the most suitable predictor equations for each hourly forecast. This will allow for a larger set of predictors to be considered, and for a more expedient evaluation of candidate forecast equations. We expect this to yield a noticeable increase in performance of the three statistical forecast models.

Third, a new strategy will be used to assign and utilize a stratus "day type" that varies with meteorological conditions. Rather than classify each day as one particular type, a separate classifier will be developed specifically for each model. This will allow separate forecast equations to be developed for different day types within a single model. For example, it was observed that the Satellite Model performed poorly on days when the cloud base was unusually high. This subset of days degraded the overall performance scores of the model. By providing a separate day type classifier specific to the Satellite Model, it will allow for separate forecast equations to be developed depending upon cloud base height. A similar classifier consideration will be made for each of the statistical models. In general, this will allow a better exploitation of the complementary strengths of the models.

These changes are expected have a favorable impact on model forecast skill, particularly that of the statistical models. The project database has been updated to include data from the 2001 demonstration season, and re-built with inversion base height values derived from the improved inversion algorithm. Redevelopment of the forecast equations will be performed during the spring of 2002, with a follow-up demonstration using the new forecast model equations to be conducted during the summer of 2002.

6. REFERENCES

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