STATUS OF A METEOROLOGICAL SYSTEM FOR GLIDER FLIGHTS USING THERMALS FOR THE NORTHEAST USA

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Abstract

The meteorological system was first developed for Colorado and used successfully in the spring of 2006. As a result, the system was developed for eastern Pennsylvania for use in the fall of 2006 and spring of 2007. The fall results were unsuccessful because the convective boundary layer (CBL) was predicted to develop too late. The spring results were more successful. Consequently, in the spring of 2008, the system was developed to cover northern New England. It was partially successful due to predictions of too warm surface temperature and too dry dew-point values. Procedures are identified to solve the late-developing fall CBL and the inaccurate spring surface temperatures. Then, the system will be useful for planning contest tasks and for on-line use by pilots for planning and evaluating their flights.

Background

At the 2003 World Gliding Championships in Leszno Poland, the German Weather Service (DWD) on-line, glider-pilot self-briefing system in pc_met was presented[1]. This revolutionary system, based on the “TopTask” algotithm[2], enables a pilot to ‘fly’ a proposed task through a numerical weather prediction to estimate the feasibility of the flight. No such system existed in the USA, so the first author began a campaign to construct one.

The initial USA system was developed for Colorado[3] during the first author’s 2005-06 sabbatical at Colorado State University (CSU). The CSU Regional Atmospheric Modeling System (RAMS)[4], was coupled to the TopTask Competition (TTC) algorithm[2]. The RAMS was employed because it could produce the meteorological predictions at the 12 km space- and 30 min time-resolution required by TTC. Using the longest flights from May 2006 (average flight 553 km), the predictions of the flight speeds, convective boundary layer (CBL) heights and climb rates were verified. These results demonstrated that the RAMS predictions could be used with the TTC algorithm for planning and analyzing soaring flights in Colorado and, no doubt, elsewhere in the USA.

Consequently, in the fall of 2006, the RAMS-TTC system was adapted for the region surrounding Fairfield, Pennsylvania (PA), the site of the Region 4 North (R4N) contest. The system was expanded in the spring of 2007 to cover the adjacent region surrounding Reedsville PA, the site of the 15m and 18m Nationals (15m, 18m). These east-coast USA contests provided data with which to investigate the system in climatic conditions almost opposite of those found in Colorado.

Hindman, et al.[5] evaluated the RAMS-TTC system using data from the 2006 and 2007 R4N contests plus the 15m Nationals. They reported the weather prediction and flight planning and evaluation capabilities of the system, on average, were accurate for contest days with winds < 20 knots (convective lift > ridge lift) and for days with accurately predicted surface temperatures (T) and dew-points (T_d).

In the spring of 2008, the system was expanded to cover the region surrounding Warren Vermont (VT), the site of the Region 1 (R1) contest. In this paper, the data from the 2008 18m National and the R1 contests are combined with the data from the earlier east coast contests.

We report the RAMS, on average, predicted meteorological conditions for the spring contests more accurately than the fall contests. However, we discovered the RAMS requires fundamental work to correct inaccurate fall T and T_d predictions and too warm T and too dry T_d spring predictions. Suggestions are made to make the corrections.

Problem

The RAMS-TTC system predicted weather conditions and the subsequent glider flights for five (5) east coast contests: the fall 2006 and 2007 R4N contests, the spring 2007 15m and 2008 18m National contests and the spring 2008 R1 contest. The problem is to evaluate the predictions using weather data and glider flight-recorder data from the contests. For the TTC algorithm to produce useful simulated flights, the RAMS must accurately predict the daily evolution of the CBL depth, thermal updraft speeds (transformed into glider climb rates) and boundary-layer winds.

Procedures

Data were collected for all of the days of the five contests, a total of 47 days. Not every day was a contest day mainly due to unsatisfactory weather. Thus, a total of 25 contest days occurred: five days during the 2006 R4N contest (8-10, 13, 14 October), eight days during the 2007 15m Nationals (15, 17-19, 21-24 May), five days during the 2007 R4N contest (7-10, 13 October with a practice day on the 6th), five days during the 2008 18m Nationals (13, 15, 18, 19, 22 May) and two days during the 2008 R1 (17, 21 June with a practice day on the 15th). The following data were collected.

Collect the flight recorder files

To determine the characteristics of the glider flights, the GPS flight recorder files (*.igc) were obtained from the scorer at the end of each contest. The files for the 1st and 2nd place finishers in each class were selected for each contest day. These flights were chosen because they represented the best flights. Maul and Niesner[14] detail this fact

Collect weather data

To validate the RAMS forecasts, the atmospheric sounding data, satellite images and surface observations and measurements (METARS) were collected for each day of the contests. The sounding data came from www.arl.noaa.gov/ready-bin/mainarc.pl (sounding, NAM (12km, 3hr) The locations of Fairfield PA (FFD), Reedsville PA (RED) and Warren VT (SGB) were entered (respectively, 39.7N, 77.3W; 40.7N, 77.7W; 44.1, 72.8). The NAM soundings (12km) for 12, 15, 18, 21, 00 GMT (07, 10, 13, 16, 19 EST) were saved both as *.gif images and as *.txt files. The satellite images and METARS came from www.rap.ucar.edu/weather/. The images were downloaded using the following sequence: BWI (for FFD and RED) and ALB (for SGB), hourly, large-size, Visible 1145 through 2345 GMT and Infrared (B/W) 1143 through 2343 GMT. Likewise, the hourly-METARS were downloaded from the BWI and ALB locations.

RAMS predictions for TTC

The meteorological predictions (T, T_d, horizontal winds, cloud and precipitation mixing ratios, etc) were made by the RAMS on horizontal grids with 12km resolution. In the vertical, the grids were spaced at about 75m intervals from the surface to about 3km; above 3 km, the vertical resolution was progressively coarser.

The TTC requires predictions every 30-minutes of the CBL depth, glider climb rates and horizontal wind speed in the CBL. Extraction of these parameters from the RAMS predictions have been detailed elsewhere[3].

The predictions were made between 06 and 18EST (2006 R4N) and between 07 and 19EST (15m, 18m, 20007 R4N and R1). The calculations took about 3 to 4 hours on a standard computer workstation. The 00GMT (19EST) NOAA-NCEP NAM data were used to initialize and 'nudge' the model to produce, by the early-morning of the next-day, the required predictions. The length of the computer runs depended primarily on the area-coverage of the predicted precipitation; a slow run meant a large area and vice versa.

The meteorological predictions were partitioned into forecast regions[3] to interface with the TTC. The regions were areas with relatively similar topography (e. g. ridges, valleys, etc). Figure 1 illustrates the regions surrounding FFD, RED and SGB and the RAMS grid-points in the regions. The predictions at all grid points in a region were averaged to produce one set of values.

Results

Potential flight distance (PFD) predictions

The distance a standard class glider is expected to fly from the first-to-last thermal of the day, called the PFD[6], is calculated by TTC for each forecast region (Fig. 2). To evaluate the PFD, the PFD for the forecast region containing a contest airfield was compared with the actual distances flown.

The contests covered 47 days. Eighteen (18) of the 47 days were unsuitable for the PFD comparison: there were 11 days when the wind speeds were greater than 20 knots and there were 7 days when PFDs were predicted and flying was not possible. The remaining 29 days had an average PFD of 275 +/- 44 km and an average distance flown of 201 +/- 30 km (note, +/- values in this paper are standard errors). The predicted values are greater than the actual values because the predictions are for the first-to-last thermal of the day and the contest pilots fly only a few-hours when the CBL is best developed.

As shown in Fig. 3, the PFD values are significantly correlated with the actual distances flown: $R = 0.92$, $P << 0.01$. Hence, the regression analysis in Fig. 3 can be used with confidence to estimate actual flight distances from PFD predictions.

The RAMS-TTC system, as currently developed, is designed for flights which use only isolated thermals[5]. Hence, the system was not suitable for the 11-days with wind speeds > 20 knots; 23% of the forecasts. On these days the pilots were utilizing 'aligned' lift: cloud streets, ridge and wave. The TTC has been expanded to include these conditions[7, 8]. Additional studies are required to extract the necessary information from the RAMS predictions to 'drive' the TTC that includes 'aligned' lift.

The 7-days where PFDs were predicted but no flying was possible were due to incorrect RAMS predictions. So, 85% [(7/47-1) x 100] of the RAMS-TTC predictions produced useful PFD values; a value similar to the forecasting skill achieved by professional forecasters using numerical weather prediction guidance.

CBL depths

The depths of the CBL were determined for all contest days when the wind speeds were less than 20 knots. These days produced seventy-four (74) 1st and 2nd place flights. For each flight, the CBL depths were estimated at the start, mid-point and final-glide as follows.

The TTC superimposed the GPS barogram trace of a flight and the predicted CBL height as illustrated in Fig. 4. From these superpositions, the actual depths of the CBL were estimated by subtracting the surface elevation from the barogram trace: at the top of the initial climb (start), at the top of the highest climb midway through the task (mid-task) and at the top of the climb at the beginning of the final glide (finish). The predicted depths were estimated by subtracting the surface elevation from the corresponding predicted CBL height. For example, for the data in Fig. 4, the actual CBL depth at the start, at mid-task and at the finish were, respectively, 0.7 km (0.9-0.2), 0.9 km (1.1-0.2) and 0.6 km (0.8-0.2). Similarly, the predicted depth was, respectively, 0.6 km (0.8-0.2), 0.7 km (0.9-0.2) and 1.0 km (1.2-0.2).

The results from the individual flights were averaged for each contest and were averaged for all contest flights. The CBL depths are listed in Table 1 and displayed in Fig. 5.

It can be seen in Fig. 5, that for the R4N contests, the actual depths at the start and mid-task were significantly larger than the predicted depths but the depths at the finish were not significantly different (significance is established by the fact that the average values in Table 1 did not overlap when the standard errors were included). In contrast, for the 15m, 18m and R1 contests the actual depths always were significantly smaller than the predicted depths.

The reason the actual CBL depths were larger than the predicted depths in the R4N contests was explained by Hindman, et al.[5]. The fall predicted morning surface temperatures were underestimated causing the CBL depth to develop too slowly; *contestants were soaring before the CBL was predicted to develop*. In contrast, the spring surface temperatures were more accurately predicted for the 15m Nationals.

It can be seen in Fig. 5 the inaccurate results from the R4N contests 'contaminate' the 'all contest flights' results. That is, the actual and predicted CBL depths agree reasonably well at mid-task and finish but not at the start.

Inspection of the 'all contest flights' in Fig. 5 reveals a trend of increasing predicted CBL depths with increasing flight time but not a similar trend in the actual depths. This result suggests the predicted depths may have developed too slowly in all the contests, not just the R4N contests. The slow development would result from late prediction of maximum temperatures.

Accordingly, the actual and predicted surface T and T_d values were partitioned into fall and spring contests and averaged. The results are given in Fig. 6. It is seen the maximum temperature in the fall contests was predicted late but not in the spring contests. So, the predicted CBL development was more accurate in the spring contests. However, the predictions of too-warm T and too-dry T_d values seen in Fig. 6 led to the too deep CBL predictions for the 15m and R1 contests shown in Fig. 5.

Also in Fig. 6, the actual surface T values at 0700 EST were at least 5C cooler than the predicted values for both the fall and spring contests. In contrast, the actual and predicted T_d values were almost identical. The inaccurate early-morning surface T predictions are an additional factor to the slow development of the CBL.

Climb rates

The CBL depths govern the glider climb rates[3], the deeper the CBL the stronger the climb rates and vice versa. Since the depths were not accurately predicted for the fall contests and for the 15m and R1 contests, it is not possible to validate the climb-rate predictions.

Boundary-layer winds

Hindman, et al.[5] report satisfactory predictions of boundary-layer winds from their analyses of the fall R4N contests and the spring 15m contest.

Soil-moisture sensitivity

The moisture content of the soil is a major factor determining the latent heat flux which, in turn, affects the surface air temperature. Large moisture contents cause large fluxes which reduce temperatures and vice versa. An example is the large temperature differences between the equatorial and sub-tropical desert regions.

The soil moisture content for the RAMS predictions were set at a constant 25%. However, during the R1 contest, significant precipitation occurred nearly saturating the soil. This affected the CBL depth and surface T and T_d predictions as demonstrated in, respectively, Figs. 7 and 8. Shown are RAMS runs with 25 and 50% soil moisture. These results are for 20 June, a non-contest day due to persistent scattered showers. As seen in Fig. 7, the increased soil moisture 'snuffed out' the brief, shallow CBL and, as seen in Fig. 8, caused the actual and predicted T values to converge.

Model inter-comparison

To give perspective to RAMS predictions of the CBL height, they were compared to predictions made at RED by two other meso-scale atmospheric models: the Weather Research and Forecasting-Regional Atmospheric Soaring Prediction (WRF-RASP) model[9] and the Rapid Update Cycle (RUC) model[10]. The predictions were made for 18, 19, 25 and 26 July 2008, days with no synoptic disturbances hence only fair-weather cumulus occurred and filled an insignificant portion of the CBL depth. Additionally, the maximum seasonal surfaces temperatures occur during mid- to late-July, hence the sensible heat fluxes should be a maximum. Presumably these should be the 'easiest' CBLs to predict. The 'actual' CBL heights were calculated using RAOB (www.raob.com) with the NAM soundings because no flights were posted on the On-line Contest[11] for RED.

The CBL heights are listed in Table 2. It can be seen the predictions, in general, follow the actual depths with two glaring exceptions. First, the WRF-RASP model significantly over predicted the 1000EST CBL height and, second, the

RAMS significantly over predicted the 1600EST height. The RAMS predictions are explained by the too warm and dry temperature predictions (Table 3), a result consistent with the spring findings (Fig. 5, right). The WRF-RASP result could not be explained because the predicted T_d values were not displayed. Nevertheless, the RAMS CBL predictions were within the variations of the other two models ignoring the 1600EST value. This result demonstrates no one meso-scale model accurately predicts the CBL height. But, the RUC appears the best in this evaluation (Table 2).

Discussion

The PFD predictions from the RAMS-TTC system are useful. Eighty-five percent (85%) of the predictions produced useful values. And, the regression analysis in Fig. 3 can be used to estimate actual flight distances from PFD predictions.

The RAMS-TTC system, in its present 'convection-only' configuration (valid for CBL wind speeds < 20 knots), produced encouraging results for Colorado[3] due to the deep spring-time CBLs. The results for Pennsylvania[5] were encouraging when the surface T and T_d values were accurately predicted; they were not for the fall contests.

Here we have included results from two more east-coast spring contests (18m and R1). The inaccurate predictions of surface temperatures reported by Hindman et al.[5] persisted. Thus, the inaccurate fall CBL predictions and the less-than-satisfactory spring CBL predictions are limiting the usefulness of the TTC.

The RAMS-TTC CBL predictions were compared with the WRF-RASP and RUC model predictions for four undisturbed days in July 2008. The RAMS-TTC over-estimated 1600EST CBL heights because of too-warm T and too-dry T_d predictions, a result consistent with the spring findings (Fig. 5, left).

Two major problems have been identified with the RAMS predictions: a temperature delay in the fall and too warm and too dry surface conditions in the spring.

Thoughts on possible solutions

The RAMS may not be totally at fault. For example, the 'nudging' data from the NAM model may be feeding inaccurate data to the RAMS. An experiment was conducted to test this possibility: Using October data for a May simulation produced a reasonable temperature rise in the morning. In contrast, using October data for an October simulation produced the vexing temperature lag. So, the RAMS has a problem, not the NAM data.

The RAMS model physics appears to need tuning for CBLs with weak sensible heat fluxes (season, latitude, high latent heat flux). With summertime and arid Colorado sensible heat fluxes, the weak flux regime did not appear in the Colorado studies.

The radiation models have been ruled out as the culprit. They produce accurate incoming solar radiation values. Thus, the surface model (sensible heat, latent heat and momentum fluxes) is most likely the problem.

Soil moisture is a necessary focus for investigations regarding the CBL development predicted by RAMS. The latent heat flux is a critical process in CBL development, as it can be of the same order of magnitude as the sensible heat flux.

In Toptherm (Regtherm)[13] the Bowen ratio (sensible vs. latent heat flux) is fixed during the diurnal cycle. A seasonal modulation of the Bowen ratio, however, accounts for the variable evapotranspiration of vegetation..

By differentiating the CBL content of both heat and moisture with respect to time, the diurnal cycle of the Bowen ratio produced by RAMS can be diagnosed. Additionally, the synchronization should be checked of both the latent and sensible heat fluxes with the radiative flux. If the sum of the latent and sensible heat fluxes is synchronized with the radiative flux, a surface temperature lag indicates that the Bowen ratio is far from constant in RAMS.

Since the predicted CBL is sensitive to soil-moisture, the NAM initial conditions, which include soil-moisture but not currently used, should be utilized with the RAMS.

Conclusions

The Potential Flight Distance (PFD) predictions of the RAMS-TTC system were calibrated for east-coast use.

The initial encouraging results with the system in Colorado and Pennsylvania[3, 5] have been shown to be limited due to inaccurate CBL predictions. In the spring, the surface temperature and dew-point values were too warm and too dry. In the fall, the temperatures rose too slowly in the morning producing an anomalously late CBL development.

Procedures have been identified to solve the CBL development problems. Once the problems have bee solved, the system is expected to be useful for task setting at contests as well as on-line for northeast USA glider pilot use. Liechti, et al.[12] have demonstrated such usefulness of the Toptherm-TopTask system in Europe.

Glider flight-recorder data has helped find a fundamental problem with the RAMS.

Acknowledgements

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Figure 1 The grid-points for RAMS Grid 2 (12km grid spacing). The polygons are the forecast regions covering the contest areas. The location of Fairfield PA (FFD), Reedsville PA (RED) and Warren VT (SGB) are indicated.

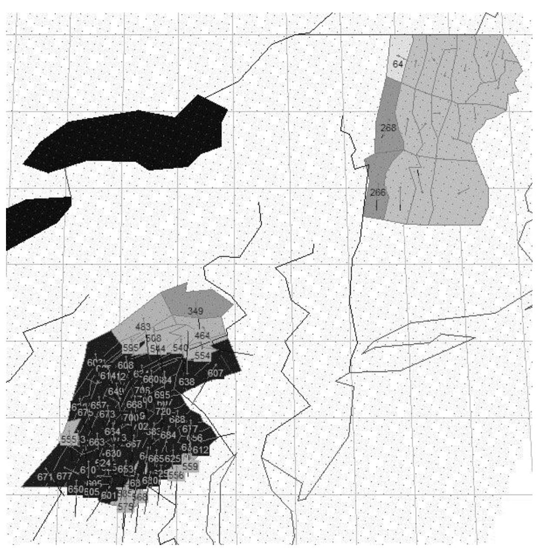

Figure 2 Potential Flight Distances (PFDs) for 15 June 2008. The values range from less than 64 km in the vicinity of SGB to over 700 km in the vicinity of RED. The barbs indicate the direction the wind is blowing to in the convective boundary layer; the longer the barb, the stronger the wind.

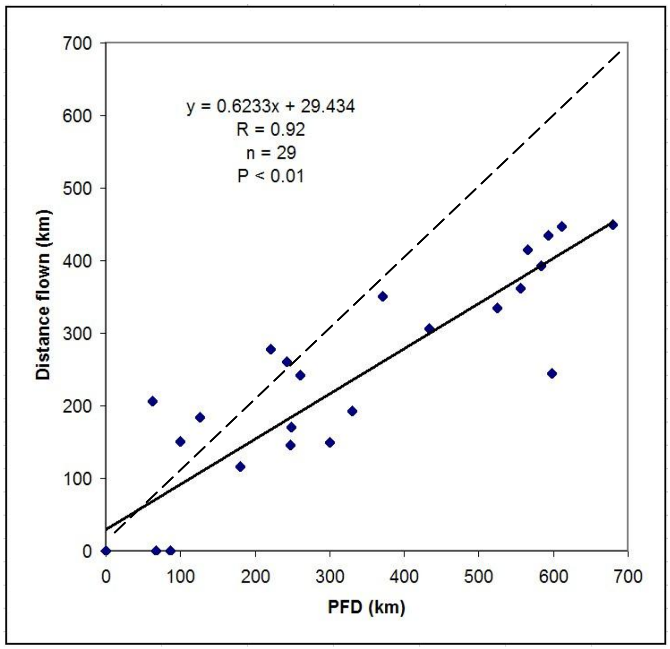

Figure 3 Predicted Potential Flight Distance (PFD) correlated with actual distances flown. The dashed line is the 1:1 correspondence.

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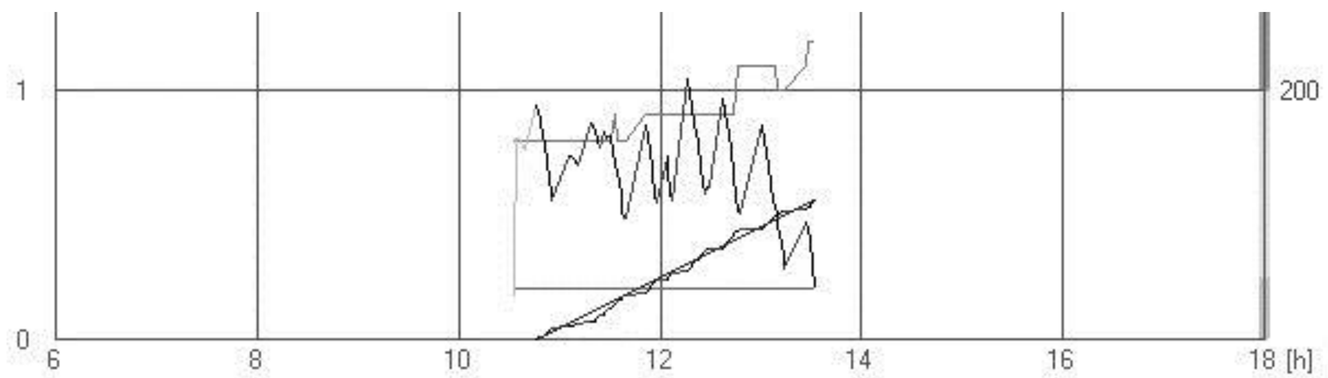

Figure 4 The TTC superposition of a barogram trace (jagged vertical line) and the predicted CBL height (step-wise horizontal line). The left-hand vertical scale is CBL height in km above MSL. The horizontal scale is time (EST). The right-hand scale is flown distance (km). The right-hand scale relates to the diagonal lines (the straight line is time versus distance and the wavy line is the actual time versus distance). The horizontal line is the mean elevation of the surface.

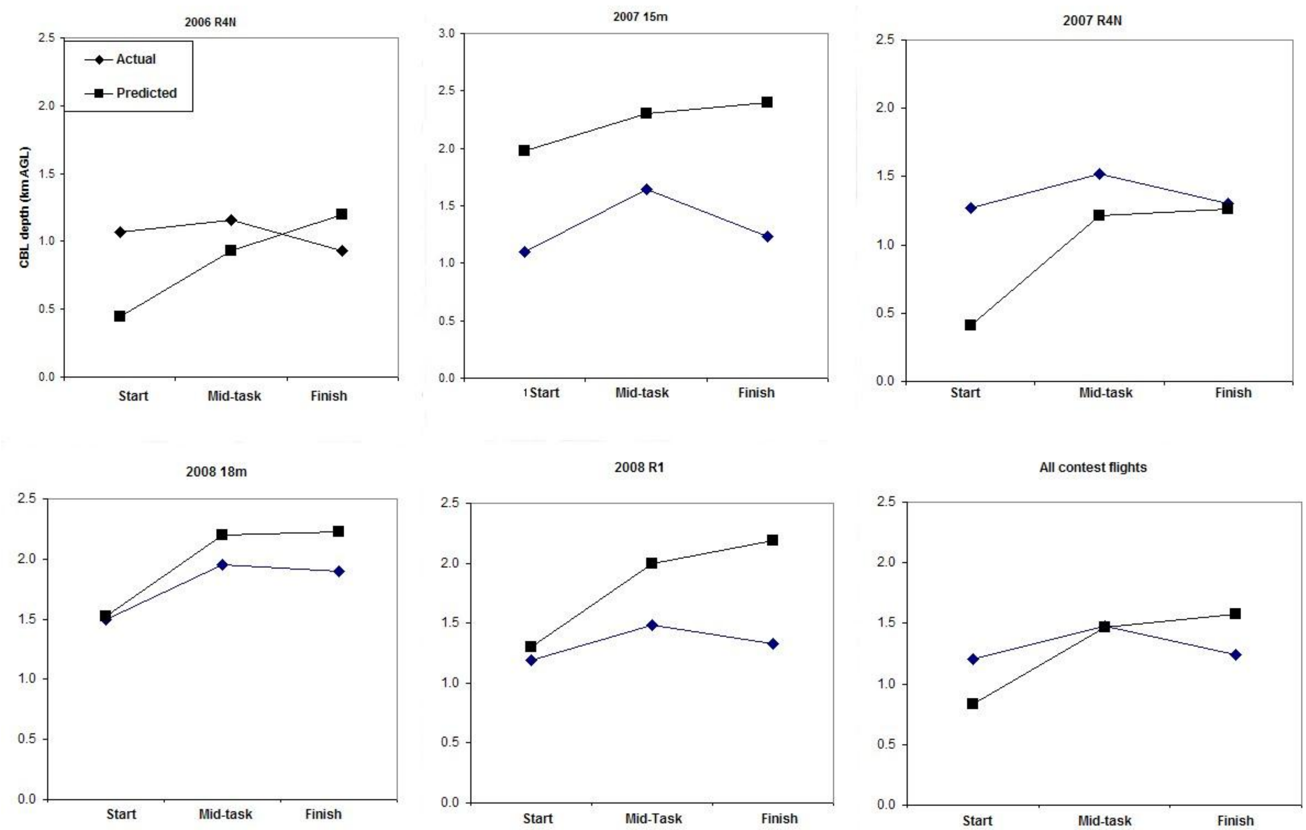

Figure 5 Actual and predicted convective boundary layer (CBL) depths (km AGL) for the five northeast USA contests investigated and all the contest flights combined.

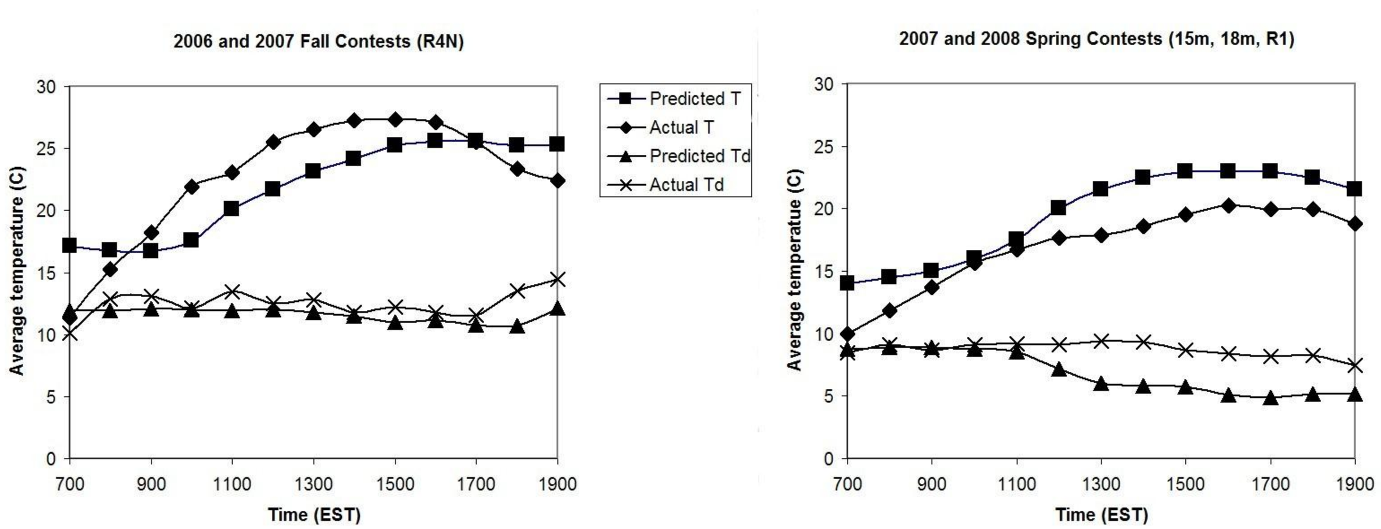

Figure 6 The surface temperature and dew-point values partitioned into the fall and spring contests and averaged.

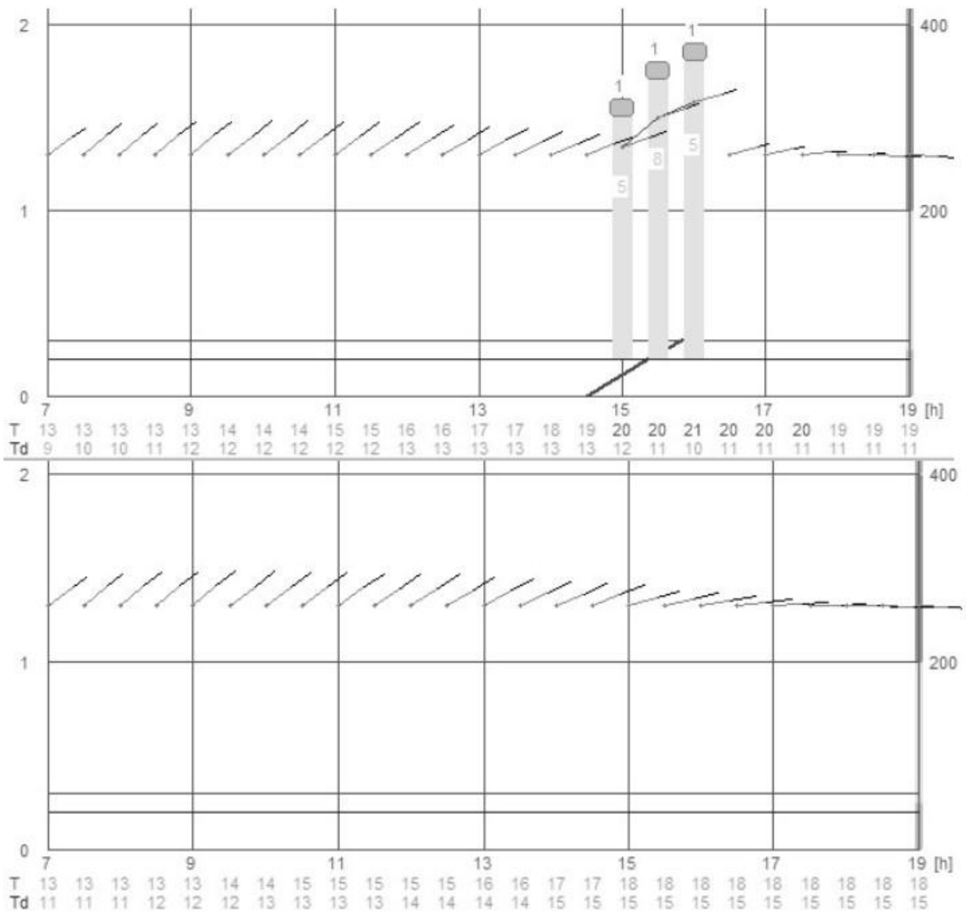

Figure 7 RAMS-TTC predictions of the depth of the CBL on 20 June 2008 for the forecast region containing SGB: 25% soil moisture (top) and 50% soil moisture (bottom). The left-hand vertical axis is height (km MSL), the right-hand axis is PFD (km), the top horizontal axis is time (EST), the middle axis is surface T (C) and the bottom axis is T_d (C). The flags are the mid-CBL winds.

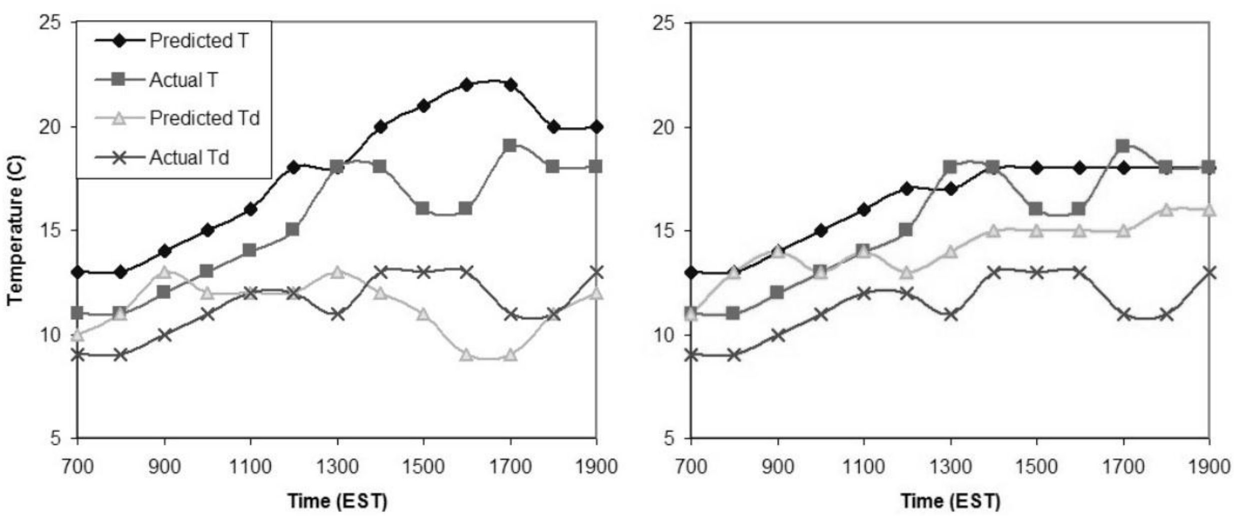

Figure 8 Surface T and T_d values for SGB for 20 June 2008: 25% soil-moisture (left) and 50% soil-moisture (right).

Table 1

Average convective boundary layer (CBL) depths plus standard error values for the five contests investigated and all the contest flights combined

Contest	Flights	Actual CBL depth (km AGL)			Predicted CBL depth (km AGL)		
		Avg. start	Avg. mid-task	Avg. finish	Avg. start	Avg. mid-task	Avg. finish
October 2006 R4N	16	1.1	1.2	0.9	0.4	0.9	1.2
StdError		0.08	0.07	0.09	0.09	0.07	0.05
May 2007 15m Nats	12	1.1	1.6	1.2	2.0	2.3	2.4
StdError		0.06	0.06	0.12	0.10	0.10	0.08
October 2007 R4N	34	1.3	1.5	1.3	0.4	1.2	1.3
StdError		0.05	0.06	0.08	0.09	0.12	0.12
May 2008 18m Nats	4	1.5	2.0	1.9	1.5	2.2	2.2
StdError		0.12	0.06	0.12	0.22	0.05	0.03
June 2008 R1	8	1.2	1.5	1.3	1.3	2.0	2.2
StdError		0.07	0.10	0.14	0.20	0.11	0.10
All flights	74	1.2	1.5	1.2	0.8	1.5	1.6
StdError		0.03	0.04	0.05	0.09	0.08	0.08

Table 2

Average convective boundary layer (CBL) heights for 18, 19, 25 and 26 July 2008 for Reedsville PA from the Regional Atmospheric Modeling System (RAMS), the Weather Analysis and Forecasting-Regional Atmospheric Soaring Prediction (WRF-RASP) model and the Rapid Update Cycle (RUC) model. Average 'actual' heights were calculated from the NAM archive soundings

Model	CBL height (kmMSL)		
	1000EST	1300EST	1500EST
RAMS	1.2	2.1	3
RASP	2.5	2.8	2
RUC	1.4	2	2
NAM archive snding	1.5	2	2

Table 3

Average surface temperatures from the RAMS and RUC models for 18, 19. 25 and 26 July 2008 for Reedsville PA (the WRF-RASP output contained T but no T_d values so T values were not included)

Model	T predicted	T actual	Td predicted	Td actual
	(C)	(C)	(C)	(C)
1000EST				
RAMS	25	25	16	18
RUC	29	25	18	18
1300EST				
RAMS	29	28	15	16
RUC	30	28	19	16
1600EST				
RAMS	32	28	13	16
RUC	31	28	19	16