Investigating Atmospheric Numerical Models using Meteorological and Glider Flight Recorder Data

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Abstract

An on-line, glider-pilot meteorological self-briefing system was investigated. Initially, the Colorado State University Regional Atmospheric Modeling System (CSU-RAMS) was connected to the TopTask (TT) flight planning algorithm for Colorado USA and the system had success in predicting long-distance flights. Then, the system was investigated for the northeast USA using meteorological and glider flight recorder data primarily from glider contests. As a result, fundamental problems with the RAMS predictions of surface temperatures and dew points were discovered and minimized by improving the solar-radiation and the surface-flux models. Additionally, coincident RAMS-TT and TOPTHERM-TT predictions for the northeast USA were comparable. This result is encouraging because the RAMS is three-dimensional while TOPTHERM is two-dimensional. Further, using the TOPTHERM-TT system in the northeast USA appears feasible. But, accurate predictions of surface dew-points from both models remained a challenge.

Background

The German Weather Service (DWD) revolutionary on-line, glider-pilot self-briefing system in pc_met [1] is based on the TopTask (TT) algorithm [2]. The system enables a pilot to “fly” through a numerical weather prediction (TOPTHERM) to estimate the feasibility of the flight. After the flight, the prediction can be checked using the flight-recorder file. Files from the top finishers of glider contests were used in this paper because these pilots best utilized the atmospheric energy.

The initial USA system was developed for Colorado [3]. The Colorado State University (CSU) Regional Atmospheric Modeling System (RAMS) [4] was coupled to the TT algorithm. The RAMS was used because it could produce the meteorological predictions at the 12 km space-resolution and 30 min time-resolution required by TT. Using the longest flights from May 2006 (average flight 553 km), the predictions of the flight speeds, convective boundary layer (CBL) depths and climb rates were verified. These results demonstrated that the RAMS predictions could be used with the algorithm for planning and analyzing soaring flights in Colorado.

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Consequently, in the fall of 2006, the RAMS-TT 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. These east-coast USA contests provided data in conditions almost opposite of those found in Colorado.

The RAMS-TT system was evaluated using data from the 2006 and 2007 R4N contests plus the 15m Nationals [5]. The weather prediction, 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. The data from the 2008 18m National and the R1 contests were combined with the data from the earlier east coast contests. We reported [6] the RAMS had, in the fall, a time-lag in warming up in the morning and cooling down in the evening and, in the spring, too warm T and too dry T_d predictions (Fig. 1).

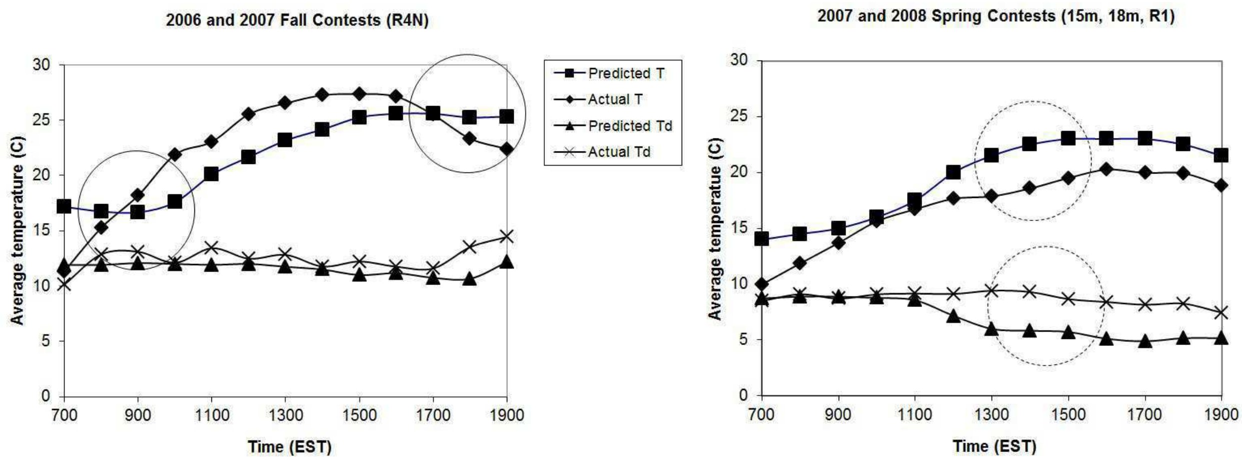

Figure 1: The surface temperature and dew-point values partitioned into the fall and spring contests and averaged. The too-late fall T predictions are identified by the solid circles and the too warm T and too dry spring T_d predictions are identified by the dashed circles.

It is well known the difference between surface T and T_d values is directly related to the CBL depth: the greater the difference, the greater the depth and vice versa. So, accurate surface temperature predictions are crucial. As seen in Fig. 2, the early morning time-lag in surface T predictions caused CBL development too late (gliders were soaring before the CBL was predicted to develop) and the too-warm T and too-dry T_d predictions caused over-prediction of the CBL depth.

Objectives

The problems with the RAMS surface temperatures were addressed during the spring and summer of 2009. The successful procedures and improved predictions are reported. Additionally, the improved predictions were compared with the coinciding TOPTHERM predictions made by the DWD. The satisfactory results and their implications are reported.

Procedures

Improve fall T predictions

The RAMS solar radiation predictions were compared with fall solar radiation measurements made at CSU. It was found that the predictions were lagging about 30–40 minutes behind the measurements. Improved equations for computing the sun angles were used and, near sunrise and sunset, the radiation model was run much more frequently than during the day or night. With these two changes, the modeled shortwave radiation matched nearly exactly the measurements.

Additionally, the minimum wind speed used in computations of ground heat and moisture fluxes was increased and the temperature predictions improved dramatically. It turned out that the surface-flux model became unreliable in still air. The flux of heat and moisture require some wind near the surface for reasonable values to be computed. So, in the early morning when winds tend to be calm, the boundary layer model was under-fluxing heat and moisture. This caused the model surface temperature to be too warm at night and too dry (if the soil was wet). By increasing the minimum wind, surface fluxing occurred which cooled the nighttime temperature and created an inversion layer as one would expect.

Improve spring T and T_d predictions

Two major changes were made in spring 2009. First, the "cold" start procedure (initializing the model with only external initial conditions and daily restarting the model which "shocks" the system) was replaced with the "warm" start procedure (initializing the model with a mixture of "yesterdays" predictions plus external conditions and continuously running the model which does not "shock" the system). Second, the constant and homogeneous soil moisture in the RAMS was replaced with the USA National Centers for Environmental Prediction's NAM model soil moisture values. The synoptic-scale NAM initializes the meso-scale RAMS. This change provided more realistic soil moisture initial values.

Results

Improved fall T predictions

This study was conducted in the late summer of 2009; fall had not arrived. So, the latest summer 2009 predictions and measurements are displayed in Fig. 3. The results are the average values for measurements obtained on 16 August 09 (Frederick MD, Worcester MA) and on 17–22 August 09 (Elmira, NY). It can be seen, when compared with results in Fig. 1, the inaccurate T predictions have been largely solved.

Improved spring T and T_d predictions

Table 1 contains the results of a series of experiments with the RAMS surface-flux model and the validation of the results:

- Between 15 and 23 May 2009, the RAMS was initialized with 100% of the NAM soil moisture with "cold" starts. It can be seen the gliders climbed 464m above the predicted

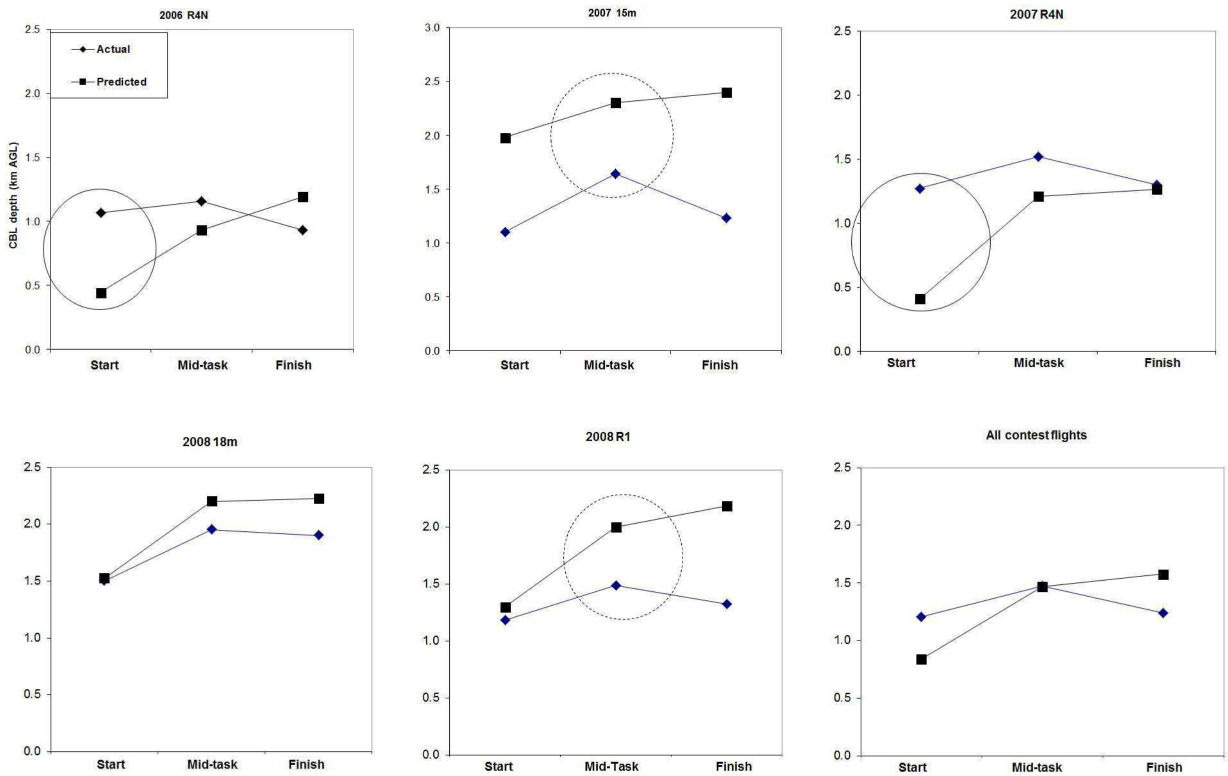

Figure 2: The actual and predicted convective boundary layer (CBL) depths (km AGL) for the five northeast USA contests investigated and all the contest flights combined. The early morning lag in T predictions caused CBL development too late (solid circles) and the too-warm T and too-dry T_d predictions caused over prediction of the CBL (dashed circles).

CBL depth due to too cool and too moist T and T_d predictions. Thus, the soil moisture was reduced by 30% and the "warm start" initiated between 24 May and 7 July but the results did not change.

- Between 8 and 14 July, the turbulence parameter was increased and the soil moisture reduced further and the results flip-flopped: the gliders climbed 673m less than the predicted CBL depth due to too warm and too dry T and T_d predictions.

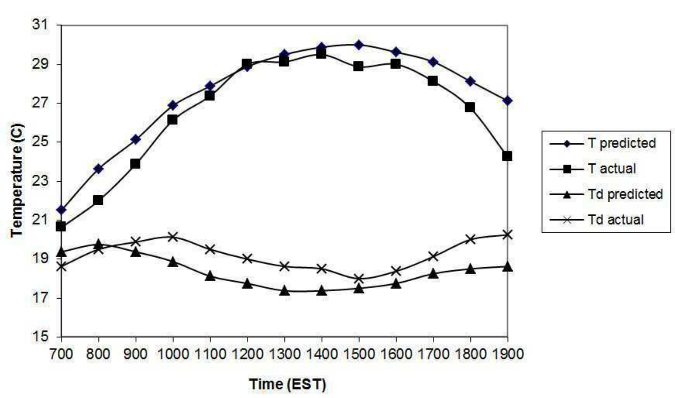

Figure 3: Average surface temperatures on 16 August 2009 at Frederick MD and Worcester MA and on 17–22 August 2009 at Elmira NY.

- Finally, between 14 July and 13 September, the soil moisture was increased slightly and the results improved: the gliders climbed 431m less than the predicted CBL depth due a bit too dry T_d predictions. But, some of the difference in height is due to the fact that the glider pilots often do not climb to the top of the CBL due to reduced lift rates near the top especially in cumulus-free CBLs.

RAMS-TOPTHERM comparison

The TOPTHERM-TT system is imbedded in the DWD's pc_met [1] where a regional model (7 km grid spacing) initializes TOPTHERM. To make the system operational for the northeast USA, the TOPTHERM was initialized by the DWD global model (40 km grid spacing). So, TOPTHERM was predicting with "one hand tied behind its back."

Further, the RAMS and TOPTHERM have different constructions. The RAMS is four-dimensional (x, y, z, t) and predicts atmospheric state variables which are diagnosed to produce the required TT CBL depths and glider climb rates. The TOPTHERM is a two-dimensional convective model that predicts the required CBL depths and glider climb rates.

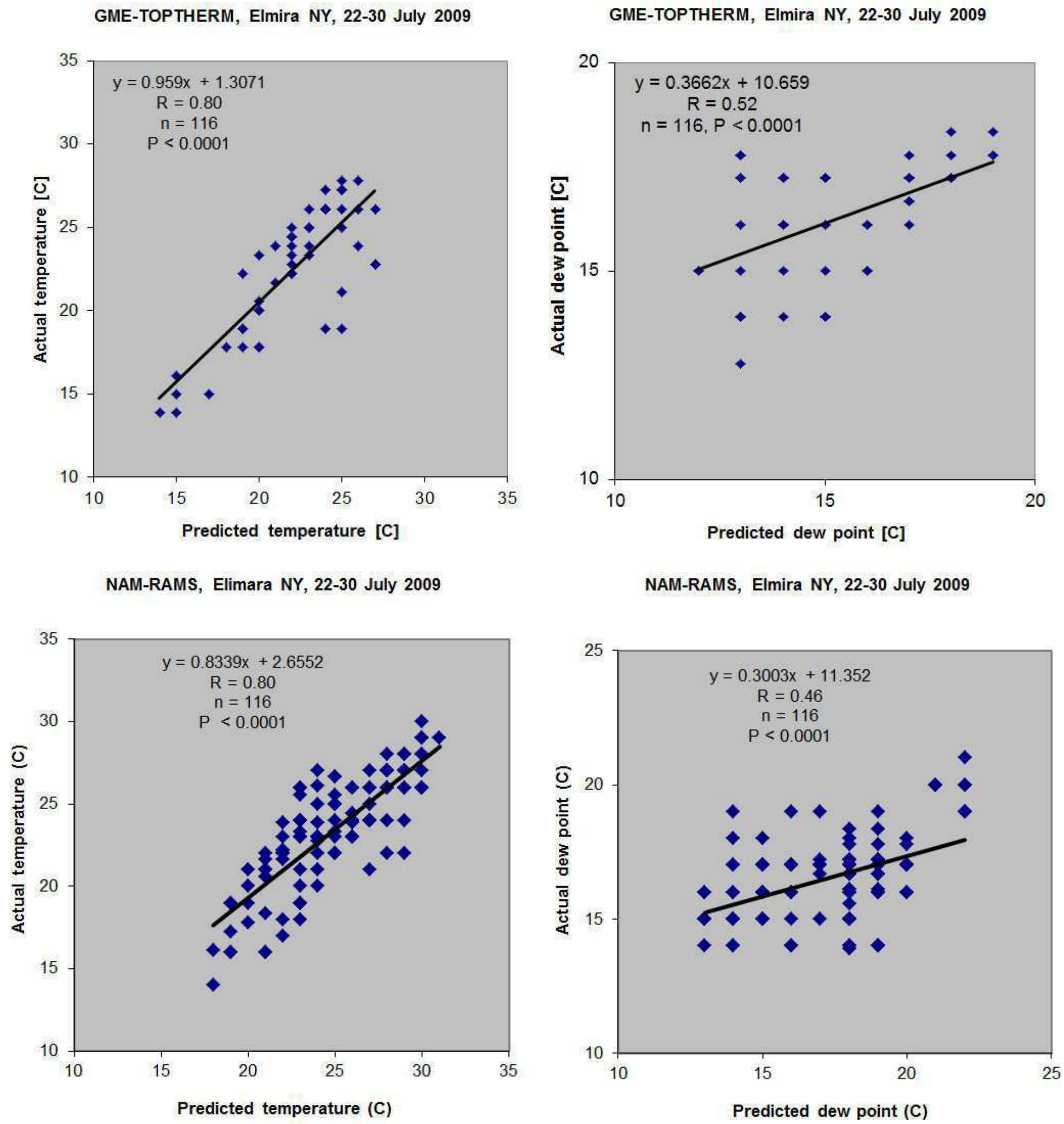

Figure 4: Comparison of surface temperature predictions with measurements. The predictions were from the RAMS-TT system initialized using the NOAA-NCEP NAM model and from the TOPTHERM-TT system initialized using the DWD global model (GME).

The RAMS and TOPTHERM made predictions for the USA Sports Class Nationals held 22–30 July 2009 at Elmira NY. The results are displayed in Table 2.

It can be seen in the table that the CBL depths, surface temperatures, dew-points and flight speeds were comparable except for the Potential Flight Distance (PFD) values. The TOPTHERM predicted longer soaring days than the RAMS; the RAMS predictions were shortened by a greater sensitivity to afternoon precipitation. Further, it can be seen that both systems over-predicted the CBL depths leading to too-fast task speeds. Nevertheless, these results indicate the TOPTHERM-TT system can be used to plan glider flights in the northeast USA. This conclusion is validated by the successful DWD-AuK-CCNY experiment conducted for the 2009 and 2010 soaring seasons [7]. Likewise, Liechti, et al. [8] have demonstrated usefulness of the TOPTHERM-TT system in Europe.

The RAMS-TOPTHERM challenge

Figure 4 illustrates the results of comparing hourly T and T_d predictions from the RAMS and TOPTHERM with the actual temperature measurements for the forecast region surrounding Elmira NY. It can be seen for both models the T predictions are quite good (correlation coefficients R of greater than 0.8 with significance P of less than 0.01%). But, the T_d predictions are

Table 1: Improved spring T and T_d predictions

RAMS boundary layer configuration; date range	Statistic	Maximum altitude (m ASL)	Corresponding predicted CBL depth (m ASL)	T, °C		T_d, °C	
				Predicted	Actual	Predicted	Actual
100% of NAM soil moisture, "cold" start; 15–23 May 2009	Average	2147	1653				
	Std. Error	169	53				
30% of NAM soil moisture, "warm" start; 24 May – 7 July 2009	Average	1916	1313	23	24	14	9
	Std. Error	68	120	1	1	1	1
Increased the imposed turbulence parameter and reduced the soil moisture flux term to 25% of computed amount based on soil to canopy moisture gradient; 8–14 July 2009	Average	1833	2506	26	24	7	11
	Std. Error	62	82	1	0	1	1
Increased soil moisture flux term to greater than 25% but less than 30% of NAM soil moisture; 14 July – 13 Sept. 2009	Average	1724	2155	26	25	10	12
	Std. Error	39	66	0	0	0	0

Table 2: RAMS and TOPTHERM predictions for the USA Sports Class Nationals, 22-30 July 2009, at Elmira NY

Atmospheric Model		Maximum Altitude (m ASL)	Predicted CBL-top (m ASL)	T, °C		T_d, °C		Speed (kph)		Distance flown (km)	PFD
				Predicted	Actual	Predicted	Actual	Actual	Predicted		
RAMS	Avg.	1722	2000	27	27	16	15	85	90	198	272
	Std. Error	28	133	1	0	1	0	2	5	12	42
TOPTHERM	Avg.	1728	1894	25	27	13	15	84	94	197	504
	Std. Error	29	59	0	0	0	0	2	5	11	52

systematically too-dry for small values and too-moist for large values (R values of 0.46 (RAMS) and 0.52 (TOPTHERM) are both highly significant). Thus, the prediction of more nearly accurate surface T_d's remains a challenge for both models.

In the European GME/COSMO-EU/TOPTHERM operational runs, the CBL moisture is assimilated in the morning runs of TOTPHERM using the most recent surface measurements of temperature and dew-point. Note, the GME/TOPTHERM runs for the northeast USA were entirely based on GME hourly profiles, no measurements were assimilated. If measurements had been assimilated the T_d predictions might have been better; this feature needs to be added in future runs. Liechti [9] has additional suggestions for improving moisture predictions in numerical weather prediction models.

Atmospheric moisture is one of the most difficult-to-measure atmospheric constituents. Now, it is also one of the most difficult to predict. As has been shown here, studies utilizing simultaneous meteorological measurements and glider flight records are a means to overcome this problem.

Conclusion

Glider flight-recorder data helped identify a fundamental problem with the CSU-RAMS predictions of surface temperatures and dew-points. The predictions were improved by adjusting the surface radiation and flux models guided by meteorological measurements and the flight-recorder data analyzed using the TT algorithm. But, both the RAMS and TOPTHERM predictions of surface dew points need further improvement.

The DWD TOPTHERM-TT system is expected to be useful for task setting at contests as well as on-line for northeast USA glider pilots.

Acknowledgements

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