A Free, On-line, Soaring Weather Forecasting System for World-wide Use

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Abstract

Forecasts of the important weather elements to plan a soaring flight are freely available online from a US National Oceanic and Atmospheric Administration (NOAA) website for any location in the world. The pilot enters the location, selects a meteorogram and the forecast model for the period of the flight, then, selects the corresponding forecasted atmospheric profiles and map of thermal depths. This system of products is studied to determine the expected weather. The system has been used successfully to produce convection as well as mountain wave forecasts. Examples of the forecasts and their validations are presented. It was found the 'trigger' times for convection are accurate to ±19 min, the maximum thermal heights, minus 81m, accurately represent the maximum achieved altitudes and the climb rates are over estimated by an average 1.4 knots. The widely-used 'rule-of-thumb', 1m/s achieved average climb rate for every 1km depth-of-convection, should be interpreted as a maximum value not an average value.

Introduction

A state-of-the-art, on-line, weather forecasting system for glider pilots developed in Europe was investigated for application in the US in Ref. 1. The system, available by subscription in Europe, contains unique presentations of forecasts important to soaring flight (onset, depth and areal distribution of thermals, winds, cloud cover, precipitation) that are easily interpreted by a glider pilot. The system is not available in the US. However, with a presentation similar to the European system, a free web-server developed and maintained by the Air Resources Laboratory of the United States National Oceanic and Atmospheric Administration [ready.arl.noaa.gov/READYcmet.php] displays many of the same weather forecasts. Additionally, the server can be used to forecast for any soaring location in the world if the Global Forecast System model is chosen from the list of offered models. And, the forecasted information is produced every three hours up to a maximum of eight days; a long-range soaring forecast capability unequaled in any on-line system known to the author.

There are two limitations with the server. First, the disclaimer from the server reads "this web-server is not maintained in an operational environment and should not be relied upon for 24/7 access." The author can report that in many years of use, the server has been down just a couple of times. Second, the language of the server is English-only. If these are not limitations for the reader, it is worth reading further.

Note, *Technical Soaring* is a permanent archive for new knowledge. Thus, the instructions that follow are valid as of the publication of this paper. However, the world-wide-web is constantly in a state of flux; new servers appear and existing servers disappear and servers may change at any time. Hopefully, the NOAA-ARL-READY server will be stable for many years to come.

This paper describes a soaring weather forecasting system: use of the server to produce soaring forecast data, interpretation of the data to produce forecasts and, most important, validation of the forecasts.

Obtaining forecast data

The NOAA-ARL-READY server is extremely flexible and provides not only forecasts of many meteorological variables but provides archives of meteorological variables with which to validate the forecasts. Thus, what follows is the author's 'recipe' for using the server to produce a soaring forecast.

Convection Forecast

It is suggested that the reader connect to the server and, as you read, execute the following commands to produce a meteorogram (time-section of winds aloft and at the surface, depth of convection, cloud cover, precipitation, surface temperature and

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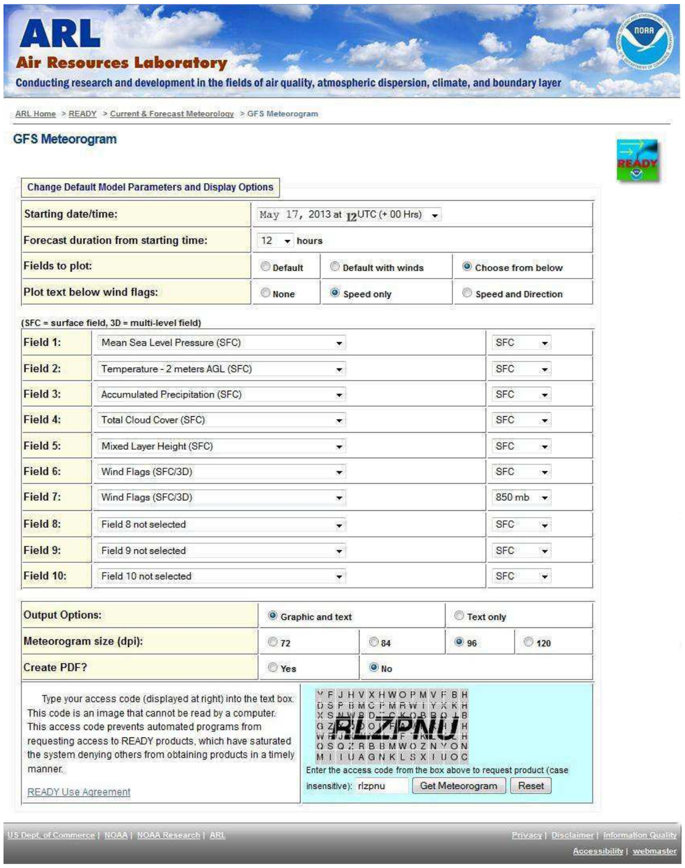


GFS Meteorogram

Change Default Model Parameters and Display Options

Starting date/time:	May 17, 2013 at 12UTC (+ 00 Hrs)		
Forecast duration from starting time:	12 hours		
Fields to plot:	○ Default	○ Default with winds	● Choose from below
Plot text below wind flags:	○ None	● Speed only	○ Speed and Direction

(SFC = surface field, 3D = multi-level field)

Field 1:	Mean Sea Level Pressure (SFC)	SFC
Field 2:	Temperature - 2 meters AGL (SFC)	SFC
Field 3:	Accumulated Precipitation (SFC)	SFC
Field 4:	Total Cloud Cover (SFC)	SFC
Field 5:	Mixed Layer Height (SFC)	SFC
Field 6:	Wind Flags (SFC/3D)	SFC
Field 7:	Wind Flags (SFC/3D)	850 mb
Field 8:	Field 8 not selected	SFC
Field 9:	Field 9 not selected	SFC
Field 10:	Field 10 not selected	SFC

Output Options:	● Graphic and text		○ Text only	
Meteorogram size (dpi):	○ 72	○ 84	● 96	○ 120
Create PDF?	○ Yes	● No		

Type your access code (displayed at right) into the text box. This code is an image that cannot be read by a computer. This access code prevents automated programs from requesting access to READY products, which have saturated the system denying others from obtaining products in a timely manner.

READY Use Agreement

Enter the access code from the box above to request product (case insensitive): rlzpnu [Get Meteorogram] [Reset]

Fig. 1: Commands to produce the meteorogram in Fig. 2

dew point, sea-level pressure) for a soaring flight utilizing convective lift:

1. Enter either the WMO Identification or the latitude and longitude of the location.
2. Choose the METEOROGRAM feature and the GFS Model (0-192h).
3. Choose the most recent Meteorological Forecast Cycle.
4. To build the meteorogram, make the entries illustrated in Fig. 1 (the entries are for 17 May 2013 at Jefferson SC US (Bermuda High Soaring), the site of the 18m US National Soaring Contest.

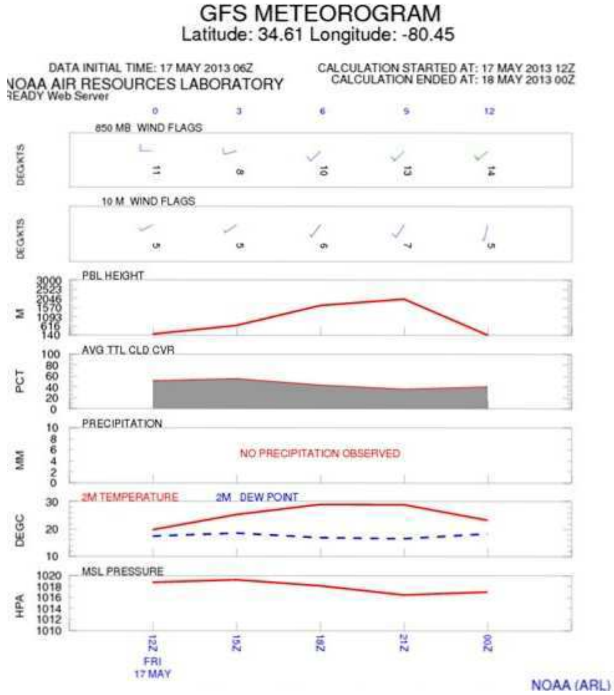


Fig. 2: Forecast meteorogram for Jefferson SC US (55ft AMSL, 34.61N, 80.45W) for 17 May 2013

GFS Sounding

Change Default Model Parameters and Display Options

Time to plot (start time for animation):	May 17, 2013 at 12 UTC (+ 00 Hrs)				
Animation:	○ None	○ GIF	○ Java	● Javascript	Duration: 12 hours
Type:	○ Full Sounding	● Only to 400 mb			
Output Options:	● Graphic and text		○ Text only		
Graphics:	○ Text Listing	● Skew-T Log-P	○ Theta	○ All	
Profile graphic size (dpi):	○ 72	○ 84	● 96	○ 120	
Create PDF?	○ Yes	● No			

Type your access code (displayed at right) into the text box. This code is an image that cannot be read by a computer. This access code prevents automated programs from requesting access to READY products, which have saturated the system denying others from obtaining products in a timely manner.

READY Use Agreement

Enter the access code from the box above to request product (case insensitive): rsfkyp [Get Sounding] [Reset]

Fig. 3: Commands to produce the atmospheric profiles which correspond to the meteorogram in Fig. 2. The profiles appear in Fig. 4.

The resulting meteorogram appears in Fig. 2. The 850 mb level was chosen for the upper-air winds because the location was near sea-level and the convectively-mixed layer typically reaches the 850 mb level. If the location is well above sea-level and the mixed layer extends to near 500 mb (as sometimes occurs in the western US), the winds at 700 mb should be chosen. The GFS model was chosen because it is the only model offered with world-wide coverage and long-range forecasts. US pilots may find the RAP model more desirable; it is higher resolution in time and space than the GFS. But, as of this writing, it is limited to hourly forecasts out to 18 hours.

To produce the atmospheric profiles that correspond to the meteorogram, execute the following commands:

1. Open another tab in your browser and connect to the NOAA-ARL-READY server.

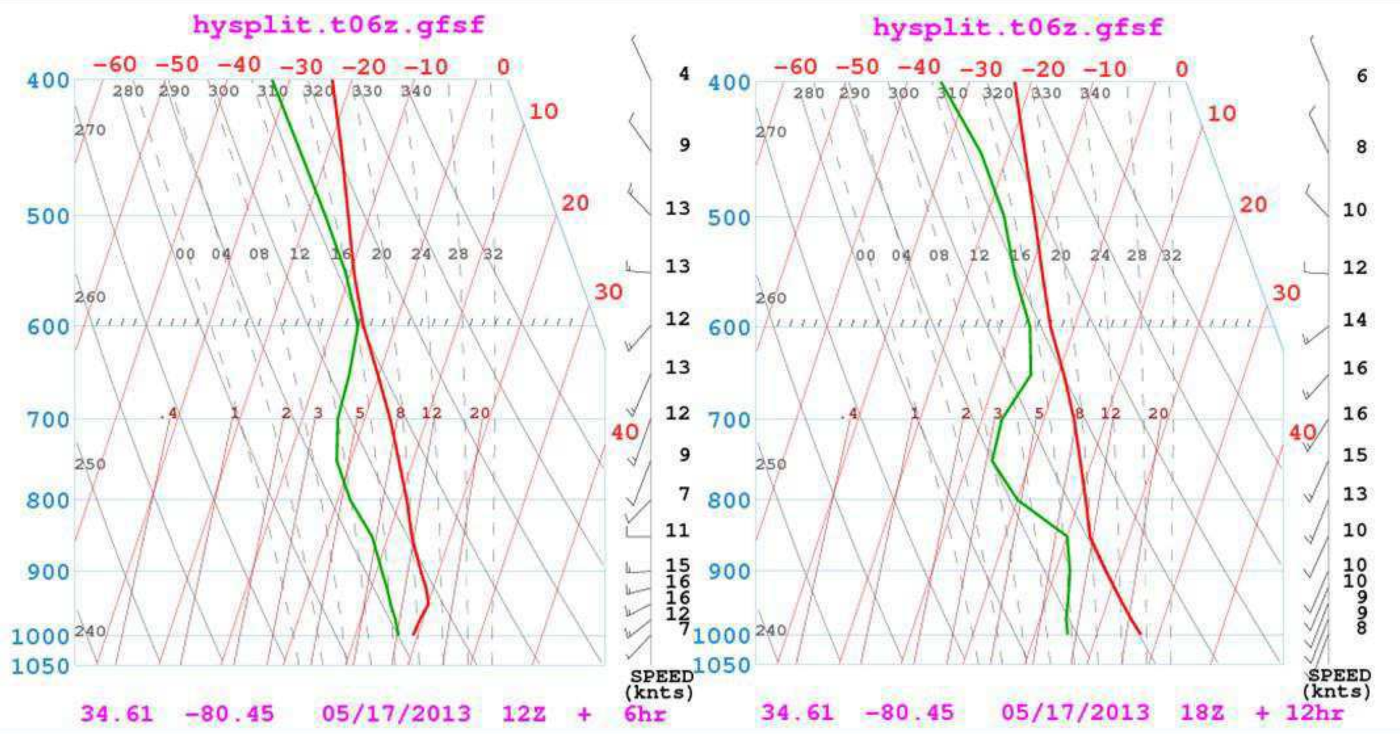


Fig. 4: Forecast atmospheric profiles for Jefferson SC US on 17 May 2013 at (left) 12Z (08EDT) and (right) 18Z (14EDT)

2. Enter either the WMO Identification or the latitude and longitude of the same location.
3. Choose the SOUNDING feature and the GFS Model (0-192h).
4. Choose the most recent Meteorological Forecast Cycle.
5. To display the profile for the forecast period make the entries illustrated in Fig. 3.

The result is a series of profiles, one every 3-hours, can be looped through the forecast period. The morning and afternoon profiles that correspond to the meteorogram in Fig. 2 appear in Fig. 4.

To illustrate the world-wide capability of the forecast system, these procedures were used to produce a meteorogram and the corresponding profiles at Sion, Switzerland (CH) (1577 ft AMSL, 46.22N, 7.33E) located in the deep, mountain valley of the Rhône River. This location is just the opposite of the flat terrain of Jefferson SC. Sion was the site of the AFG Zürich's spring 2014 glider camp the author attended. The resulting meteorogram and profiles are given in Figs. 5 and 6.

At the XXXII Congress, it was brought to the author's attention that the '2D MAPS (PSPLOT)' feature of the NOAA-READY web server will display the areal distribution of the depth of thermals with the superimposed surface winds. Using this display, the most favorable location for a task can be

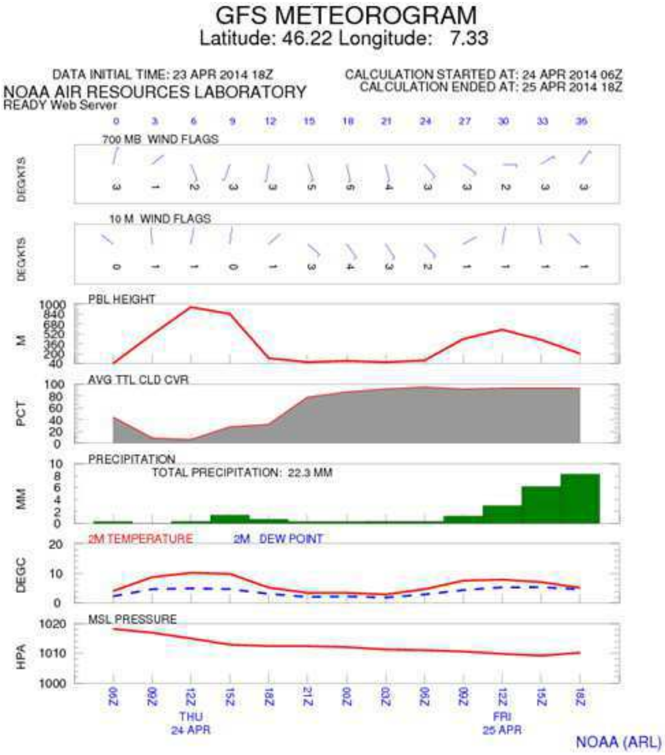


Fig. 5: Forecast meteorogram at Sion CH for 24 and 25 April 2014

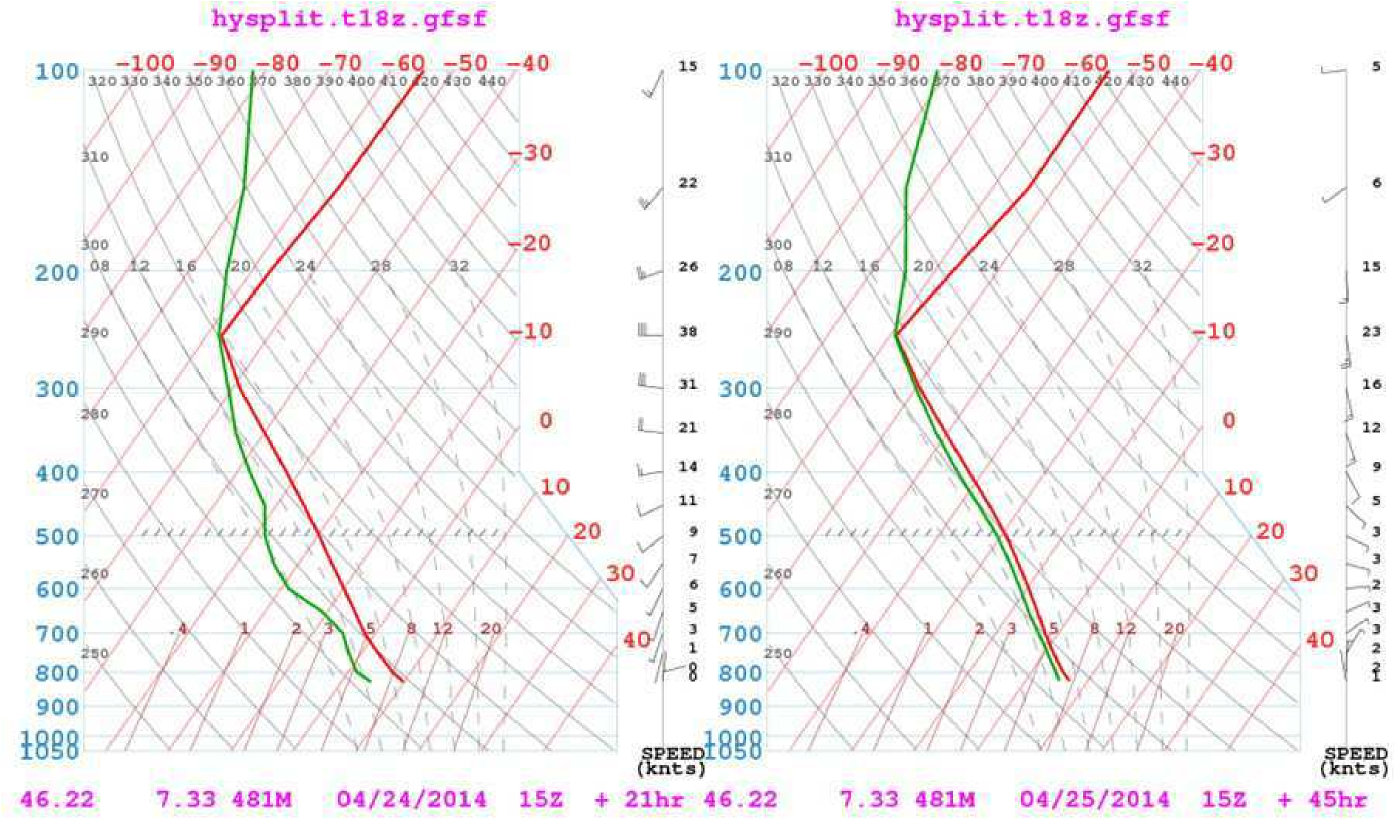
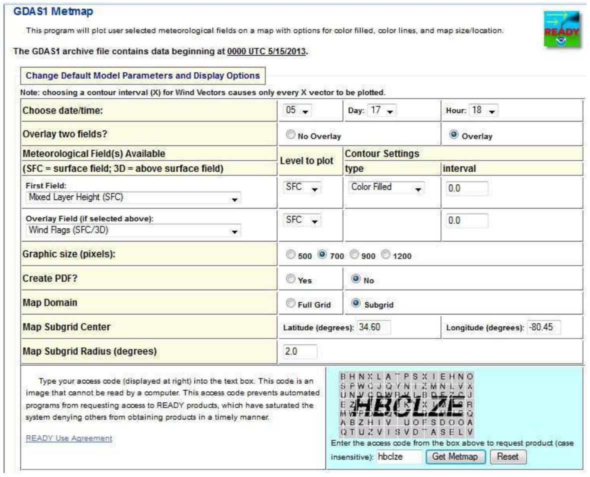


Fig. 6: Atmospheric profiles at Sion CH (1577 ft AMSL, 46.22N, 7.33E)

forecasted. So, open a third tab in your browser and follow the commands in Fig. 7 to produce the map that corresponds to the meteorogram in Fig. 2 and the 18Z profile in Fig. 4, the resulting map is shown in Fig. 8. The maps for Sion are shown in Fig. 9. The maps in Fig. 8 and 9 were generated using the data from the 'Archived Meteorology' section of the server. The commands are identical to produce a forecast map from the 'Current and Forecast' section. For completeness, the map used to guide setting the task for the 17 May 2013 contest day was from XC Skies at www.xcskies.com; the map is consistent with Fig. 8.

Wave forecast

To produce a meteorogram for a soaring flight utilizing wave lift, repeat the earlier instructions specified in Fig. 1 and add additional upper-air wind levels: in Field 8 display 700mb winds, in Field 9 display 500mb winds and in Field 10 display 400 mb winds. Also, extend the forecast period to encompass the early morning when the wave may be the strongest. By way of example, we consider a wave camp on 4 March 2013 at Grant County Airport, Petersburg WV US (W99). A northeast-southwest oriented mountain barrier with an average elevation of about 3,500ft (1067m) AMSL is about 10km to the northwest of the airport. The resulting meteorogram is illustrated in Fig. 10.



GDAS1 Metmap

This program will plot user selected meteorological fields on a map with options for color filled, color lines, and map size/location.

The GDAS1 archive file contains data beginning at 0000 UTC 5/15/2013.

Change Default Model Parameters and Display Options

Note: choosing a contour interval (X) for Wind Vectors causes only every X vector to be plotted.

Choose date/time: 05 Day: 17 Hour: 18

Overlay two fields? ○ No Overlay ● Overlay

Meteorological Field(s) Available (SFC = surface field; 3D = above surface field) | Level to plot | Contour Settings type | interval

First Field: Mixed Layer Height (SFC) | SFC | Color Filled | 0.0

Overlay Field (if selected above): Wind Flags (SFC/3D) | SFC | | 0.0

Graphic size (pixels): ○ 500 ● 700 ○ 900 ○ 1200

Create PDF? ○ Yes ● No

Map Domain ○ Full Grid ● Subgrid

Map Subgrid Center Latitude (degrees): 34.60 Longitude (degrees): -80.45

Map Subgrid Radius (degrees) 2.0

Type your access code (displayed at right) into the text box. This code is an image that cannot be read by a computer. This access code prevents automated programs from requesting access to READY products, which have saturated the system denying others from obtaining products in a timely manner.

READY Use Agreement

Enter the access code from the box above to request product (case insensitive): hbclze

Fig. 7: Commands to produce the map of mixed layer depths and surface winds which correspond to the meteorogram in Fig. 2 and 18Z atmospheric profile in Fig. 4. The map appears in Fig. 8.

To produce the atmospheric profiles that correspond to the meteorogram in Fig. 10, follow the earlier instructions listed in Fig. 3 except construct a 'Full Sounding' instead of 'Only to 400 mb'. The resulting atmospheric profiles are illustrated in Fig. 11.

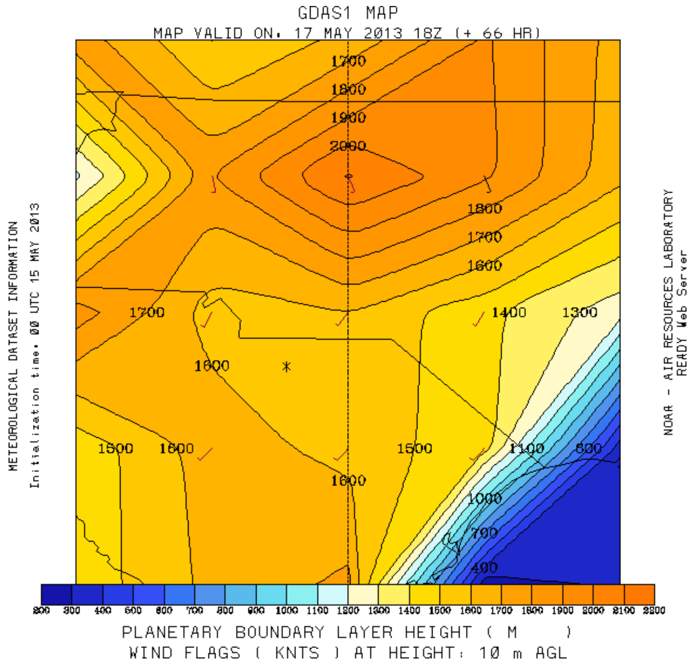
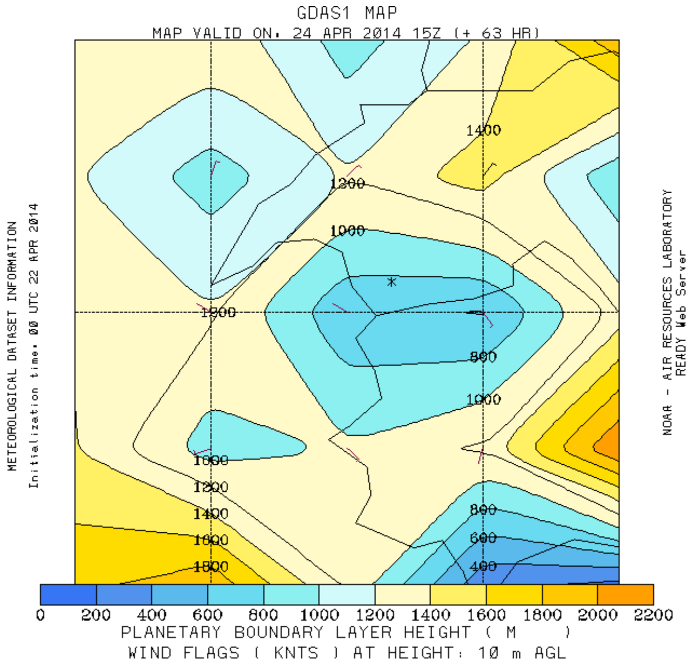


Fig. 8: Forecast depth of the convectively mixed layer (m AGL) and surface winds (knots) for Jefferson SC US for 17 May 2013, 18Z (14EDT). The * is the location of Jefferson SC.

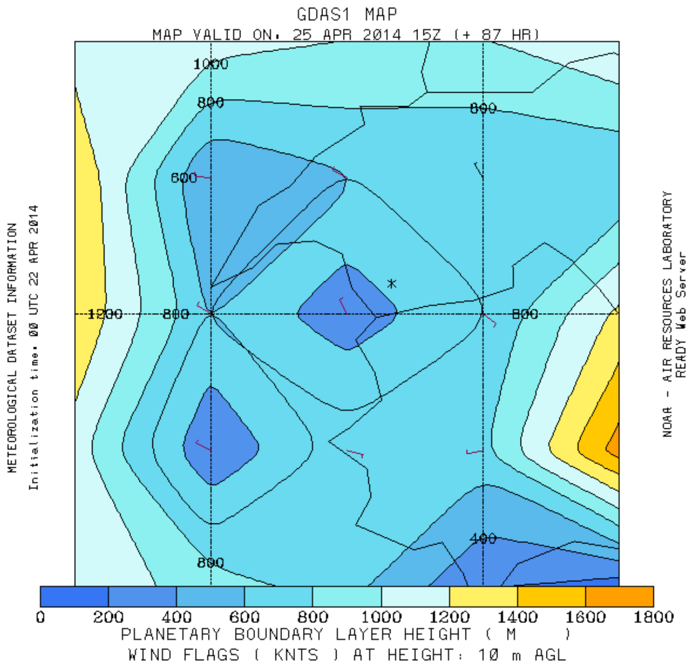
Interpreting the forecast data

Convection forecast: Jefferson SC US

The following predictions were made from a careful examination of Fig. 2 starting at the top. During the 14 to 17EDT (Eastern Daylight Time, 18-21Z) racing period, winds at 5,000ft (about 850mb) should be from the SW at 10kt and winds at the surface are expected from the SW at 6kt. The maximum PBL (Planetary Boundary Layer) height, or depth of convection, is expected to be 2,500ft AGL ($\sim$762 m, 'trigger' depth) at around 1130EDT (1530Z) at a temperature of 79F (26C) [The 'trigger' depth is the minimum thermal depth to keep sailplanes aloft prior to the start of the task]. A peak of 6,746ft AMSL (2,040m AGL) in the average depth is expected at 17EDT (21Z). The average achieved climb rate is expected to be 4kt ('rule-of-thumb': 2kt/1km or 1m/s per 1km PBL depth in clear skies, larger with Cu above [2]). During the racing period, scattered cumulus clouds are expected and initially broken mid-level clouds becoming scattered late (the types-of-clouds were estimated from the corresponding atmospheric profiles in Fig. 4 following procedures presented in the next paragraph). No precipitation is expected. The maximum temperature of 86F (30C) is expected at about 15EDT (19Z). No significant change is expected in mean-sea-level (MSL) pressure.



(a) 24 April 2014 at 15Z (14h local)



(b) 25 April 2014 at 15Z (14h local)

Fig. 9: Maps for Sion CH (indicated by the asterisk) for 24–25 April 2014

An excellent tutorial written by a knowledgeable glider pilot for interpreting atmospheric profiles for convective soaring is given in Ref. 4. Armed with this knowledge, the profiles in Fig. 4 were examined to expand the convection forecast. The predicted surface temperature inversion at 08EDT (12Z) is expected to mix away in the developing morning convection. The top of the convectively-mixed layer at 14EDT (18Z) is expected to reach 850mb (5,500ft AMSL, 5,445ft AGL) and the areal distribution of the depth of the layer (Fig. 8) indicates the deepest

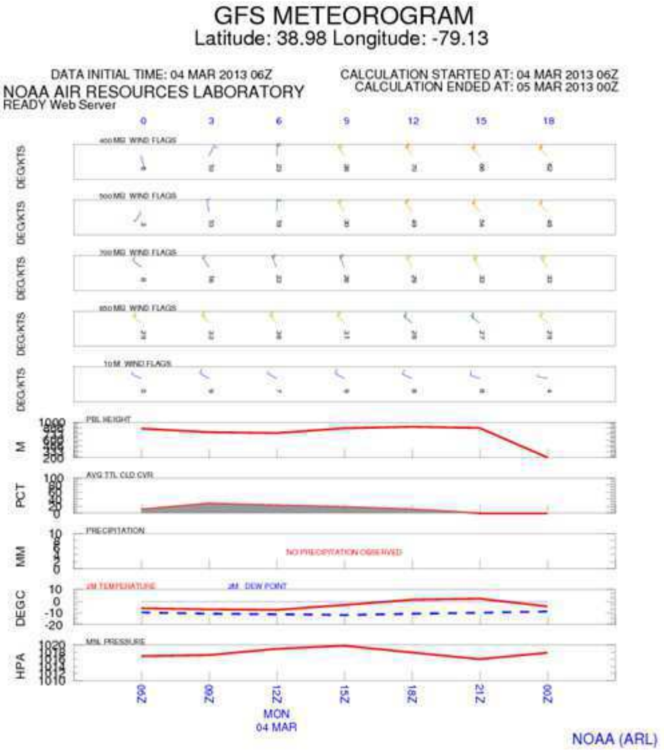


Fig. 10: Forecast meteorogram for Petersburg WV US (964 ft AMSL, 38.98N, 79.13W) for 4 March 2013

thermals should be in the northeast section of the contest region. The layer should rise to about 2,000m (6560ft) AGL by 17EDT (21Z) as shown in Fig. 2. From an analysis of the 14EDT temperature and dew-point profiles, there should be scattered cumulus at the top of the mixed layer. The nearly identical temperature and dew-point values at about 600mb in the 08EDT profile indicate the presence of a thin-broken cloud layer. The layer is expected to become scattered by 14EDT because the temperature and dew-point values have separated. Finally, the low-level strong winds predicted at 08EDT are expected to weaken by 14EDT as the mixed layer develops.

Table 1: ***K*** **index values (Table 5-12 in Ref. 3)**

K Index West of Rockies	 East of Rockies	 Coverage of general thunderstorms
< 15	< 20	None
15–20	20–25	Isolated thunderstorms
21–25	26–30	Widely scattered thunderstorms
26–30	31–35	Scattered thunderstorms
> 30	> 35	Numerous thunderstorms

Note: *K* Index may not be representative of air mass if 850mb level is near the surface

The potential for thunderstorm development (*K* Index) [4] can be estimated graphically from the forecasted morning (12Z) atmospheric profile:

$$K = (T_{850} - T_{500}) + (T_{\mathrm{d}\,850} - T_{\mathrm{dd}\,700})$$

where T_{850}, T_{500}, and $T_{\mathrm{d}\,850}$ are the temperatures (C) at those pressure levels (mb) and T_{dd} is the dew-point depression at the 700mb level. The value from the morning profile in Fig. 4 was 25. This value corresponds to a potential for isolated thunderstorms (see Table 1).

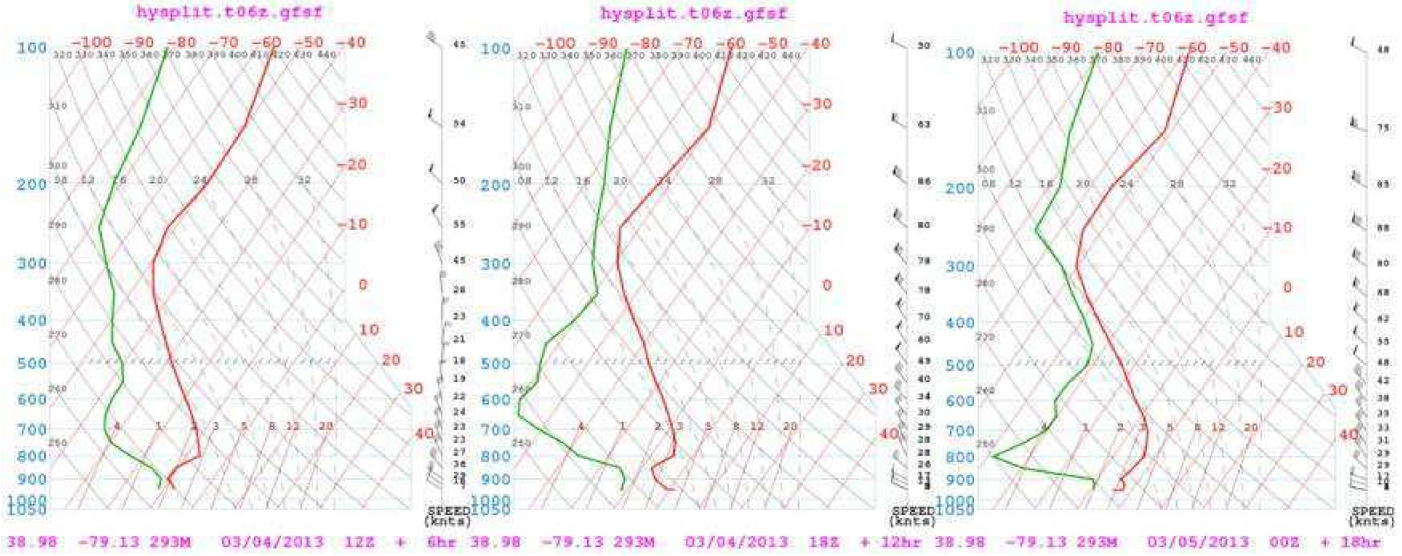


Fig. 11: Forecast atmospheric profiles for Petersburg WV US for 4 March 2013 at (left) 12Z (08EDT), (center) 18Z (14EDT) and (right) 00Z (18EDT).

Table 2: Results from the 18 Meter Nationals, Contest Day 7 (last contest day), 17 May 2013

Cumulative		Pilot			Day					
Rank	Points	ID	Name	Glider	Rank	Points	Speed	Distance	Start Time	TOC
1	6187	DJ	Jacobs, D.	Ventus	4	905	66.85	237.09	13:47:33	03:32:47
2	6173	XG	Szemplinski, J.	ASG-29	1	1000	73.86	260.92	13:50:04	03:31:57
3	6153	P7	Ittner, G.	ASG-29	2	968	71.50	250.63	13:47:12	03:30:19
4	5882	JW	Walker, J.	Ventus	5	896	66.20	235.40	13:50:20	03:33:21
5	5695	F2	Fidler, S.	LAK	9	847	62.59	226.81	13:49:50	03:37:25
6	5575	CG	Garner, C.	Duckhawk	3	930	68.67	241.64	13:53:00	03:31:08

Convection forecast: Sion CH

The meteorogram (Fig. 5) indicates that thermals will be about 1000m (3280ft) deep the afternoon of the 24th and shallower on the 25th. The maps of the depths of thermals (Fig. 9(a) and (b)) show the deepest on the slopes of the deep Rhône Valley in which Sion is located (* in the figures). The profiles (Fig. 6) show the surface to be at about 815mb (about 6,000ft AMSL). This value is well above the 1,577ft AMSL elevation of Sion. This discrepancy is a result of the smoothing by the 12km GFS grid of the deep valley. Adding the 3280 and 6000 values results in thermals expected to rise to about 9,280ft (2,829m) AMSL on the 24th and 7,706ft AMSL on the 25th. From an analysis of the 15Z temperature and dew-point profiles on the 24th, there should be cumulus at the top of the mixed layer. In contrast, on the 25th the mixed layer is expected to be shallower and moister, consistent with the expected late-day precipitation.

Wave forecast: Petersburg WV US

An excellent tutorial written by a knowledgeable glider pilot for wave soaring forecasts is given in Ref. 5 (the theory for mountain waves is given in Ref. 6). Briefly, to produce a wave downwind of a mountain barrier, the atmosphere over the barrier should be absolutely stable (environmental temperature lapse-rate always less than the dry-adiabatic lapse-rate) from the mountain-top to the Tropopause, and the wind speed should increase with height from the surface with a constant direction perpendicular to the barrier and be greater than about 20 knots at the level of the barrier.

With these ideas in mind, carefully inspect Figs 10 and 11. In Fig. 10, focusing on the rows of wind flags, it can be seen that the wind criteria are not met until after 10EST (15Z) and remain favorable through the remainder of the forecast period. In Fig. 11, the extremely stable surface layer is expected to be about 800m deep providing a strong 'foundation' for the wave above. Returning to Fig. 10, the morning widely scattered low-level 'rotor' clouds ('AVG TTL CLD CVR' row) are expected to disappear by the afternoon as the surface layer dries out. The lack of clouds will make it difficult to locate the wave. But, the lack of clouds will lead to a lack of precipitation in the form of snow showers (the surface temperatures are expected to be near 0° C), a welcome prediction because such showers make

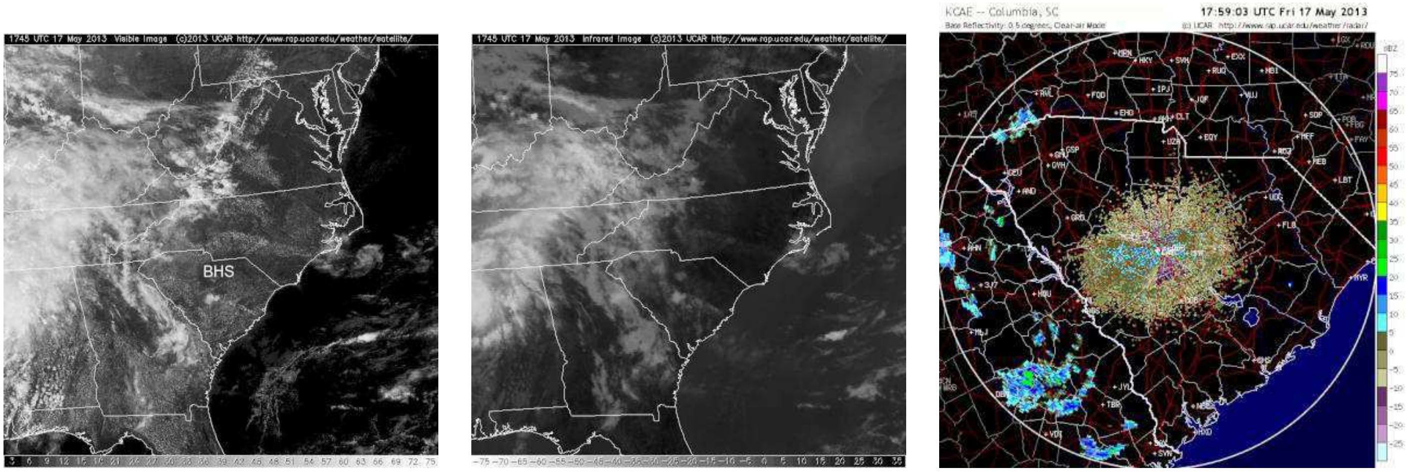


Fig. 12: Visible (left) and infrared (center) satellite images and radar image (right) for 14EDT on 17 May 2013. The Bermuda High Soaring contest region is identified (BHS) in the visible image.

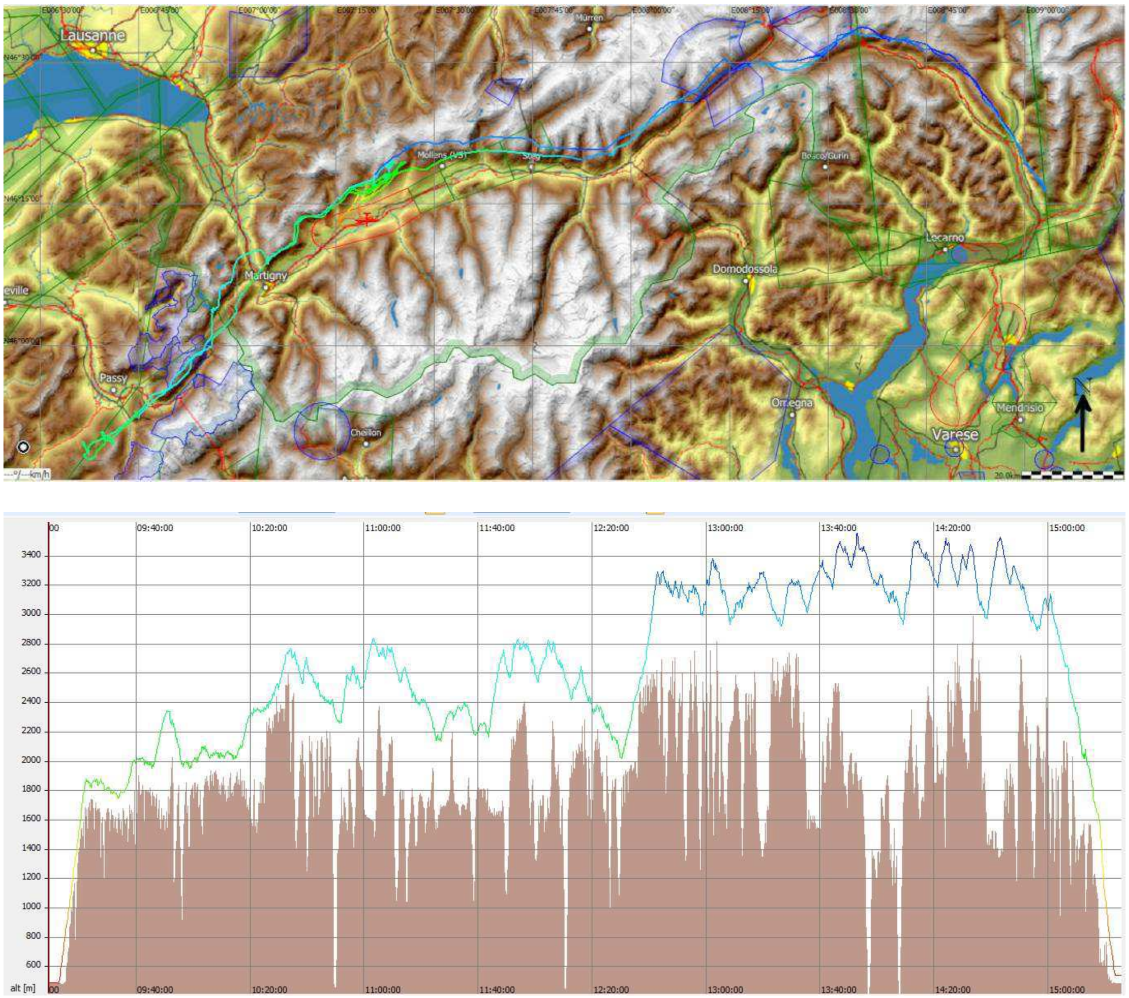


Fig. 13: **Plan view (top) and barogram (bottom) of the Hiegemann/Zimmermann Duo Discus flight between 0912Z (1012 local) and 1523Z (1623 local) from Sion on 24 April 2014.**

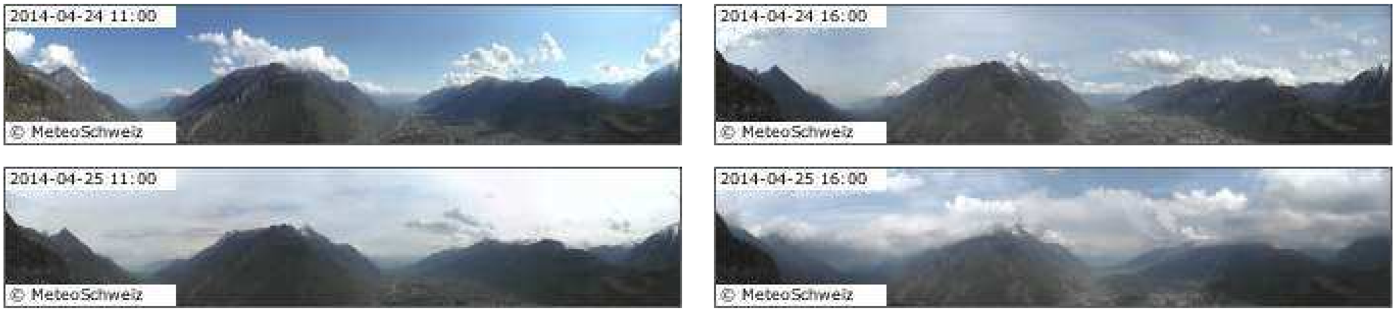
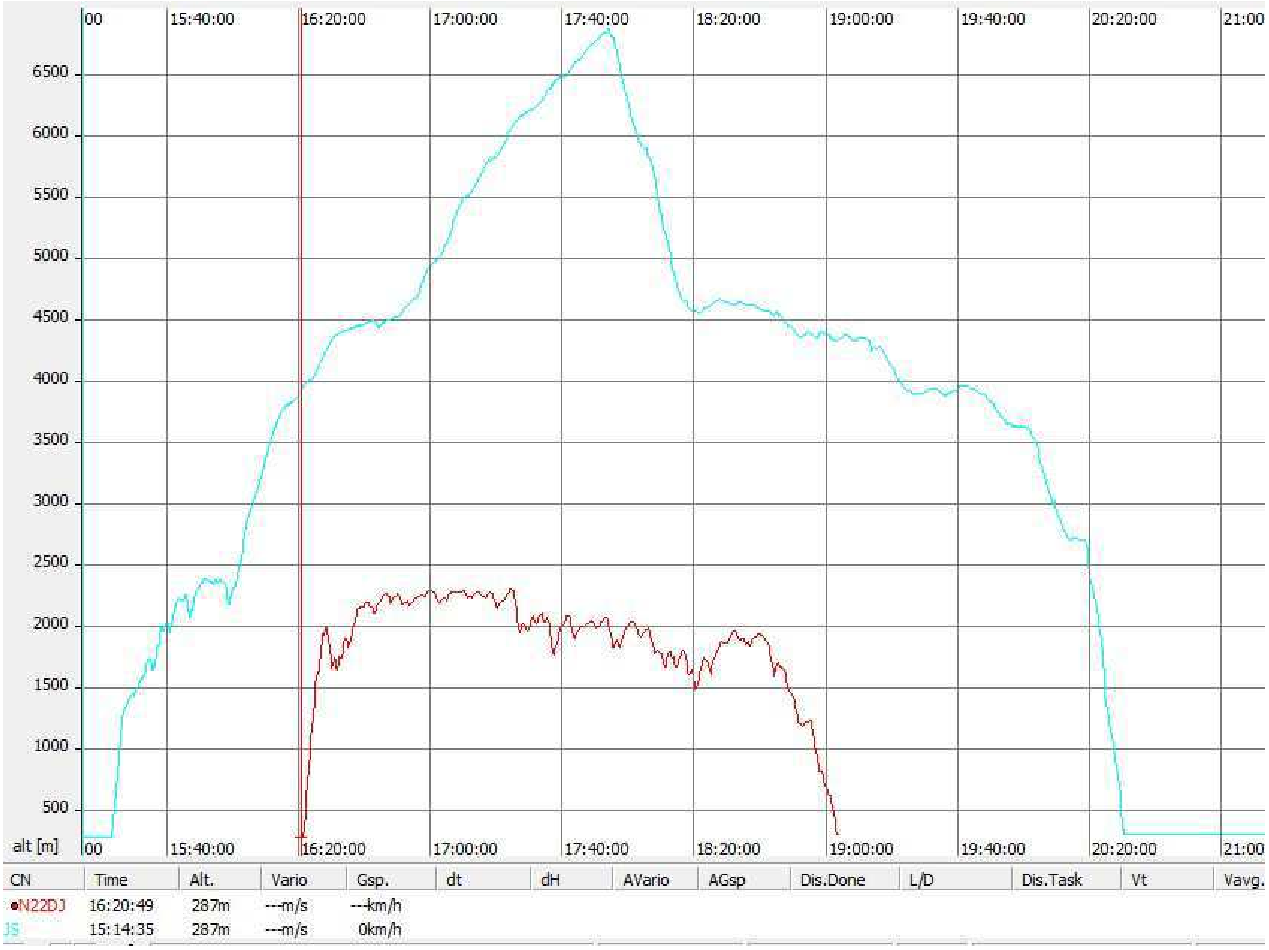


Fig. 14: **Web-camera images of the atmospheric conditions at 11Z and 16Z on 24 April 2014 (top pair) and 25 April 2014 (bottom pair). The camera was located at Ravoire CH which is at the west end of the Rhône Valley (valley at left) where the river makes a 90-degree turn to enter Lake Geneva. The left-side of each image is directed toward the NE and the right-side is toward the SE.**

towing into the wave difficult. Also, returning to Fig. 11, clouds are not expected to form in the 400 to 300 mb layer until late, which is near the top of the wave. Thus, there is little chance of an undercast forming which would obscure the airport while the pilot is in the wave. It is important for the pilot to have visual contact with the ground at all times because ground references define the air space above FL 180 (the 'wave window') in which the pilot is permitted to fly by Air Traffic Control.



CN	Time	Alt.	Vario	Gsp.	dt	dH	AVario	AGsp	Dis.Done	L/D	Dis.Task	Vt	Vavg.
●N22DJ	16:20:49	287m	---m/s	---km/h									
JS	15:14:35	287m	---m/s	0km/h									

Fig. 15: Barograms of two wave flights on 4 March 2013 from Grant County Airport (W99), Petersburg WV US. The trace of N370JS is teal (top) and the trace of N22DJ is red (bottom). Time is Z (EST+5) and height is in m AMSL.

The expected climb rates in the wave are qualitatively estimated from the atmospheric profiles (Fig. 11) in the following manner. The updrafts are the strongest where the atmosphere is most stable and the vertical wind-speed shear the greatest. It can be seen in the 18Z sounding that the atmosphere is most stable between 850 and 800mb with the greatest wind-speed shear. This region is just ahead of the turbulent ‘rotor’ at the base of the wave and here the pilot should expect the largest climb rates. Thereafter, the stability remains strong to the Tropopause and the wind-shear as well. So, the expected wave should have strong updrafts from its base to its top near the Tropopause.

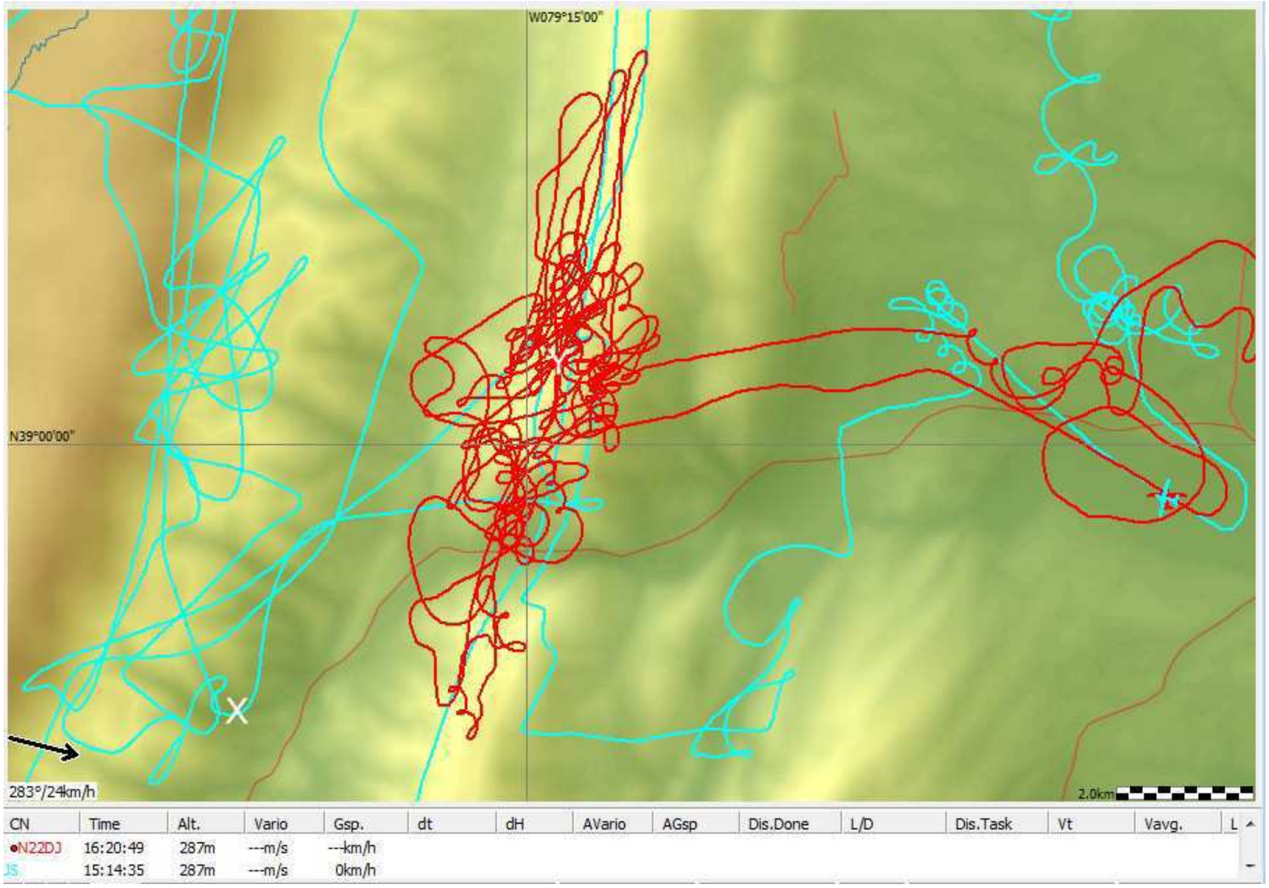
Validating the forecasts

Convection forecast: Jefferson SC US

A soaring forecast for a contest is a success if the task that was set based on the forecast had a large number of completions (few land-outs) and close first, second, and third finishers. The forecast based on the data in Figs. 2, 4 and 8 led to a 207 nautical mile (nm) turn-area-task (TAT) in the northeast section of the contest region, with a minimum and maximum distance of, respectively, 105 and 319nm with a minimum time on course of 3.5 hours.

The results of the top finishers for the day are given in Table 2. Twenty pilots flew the task, all completed the task (there were no land-outs) and the top finisher earned 1000 points, the maximum possible. The top three finishers, XG, P7, and CG, flew, respectively, 270, 251 and 242nm (500, 464 and 448km) (within the minimum and maximum task distances), at 74, 72 and 69kt (137, 134, 128km/h) and were on course 3.53, 3.50 and 3.53h (almost exactly the minimum time). These results indicate the convection forecast was valid. Notice, the cumulative points of the two top finishers for the contest, DJ and XG, were separated by a mere 0.22%. This means these pilots flew well on the seven contest days even though each day had different weather conditions and tasks. Thus, the author’s forecasts and the resulting called tasks were accurate.

Additional validation of the convective forecast is as follows. Contest gliders all carry GPS-flight recorders which record the 3D position every four seconds. The records for the top three finishers on 17 May 2013 were analyzed using the SeeYou soft-



CN	Time	Alt.	Vario	Gsp.	dt	dH	AVario	AGsp	Dis.Done	L/D	Dis.Task	Vt	Vavg.	L
●N22DJ	16:20:49	287m	---m/s	---km/h										
JS	15:14:35	287m	---m/s	0km/h										

Fig. 16: Ground tracks of two wave flights on 4 March 2013 from Grant County Airport (W99), Petersburg WV US. The trace of N370JS is teal and the trace of N22DJ is red. The locations of the two ships upon wave entry are marked, respectively, by the X and Y. The Y is located in the center of the image nested in the track of N22DJ.

Table 3: 18 Meter Nationals, 17 May 2013, Predicted and Actual Meteorology

	Max thermal heights m AMSL		Average climb rates m/s		Winds aloft deg/(m/s)	
ID	Predicted	Actual	Predicted	Actual	Predicted	Actual
XG	2040	2200	2.0	1.4	225/19	222/15
P7	2040	2200	2.0	1.7	225/19	218/14
CG	2040	2200	2.0	1.5	225/19	217/16

ware at www.naviter.com to determine the maximum height of the thermals, the average climb rates (the SeeYou 'Total Circling Vario' value) and the winds aloft. The results are in Table 3. It can be seen, the predicted values were close to the actual values. Hence the forecast was accurate.

Inspection of the 14EDT (18Z) visible and infrared satellite images and radar image (Fig. 12) shows the forecasted cumulus clouds (bright spots on the visible image and grey spots on the infrared image) and mid-level clouds (bright layer on the visible and infrared images) occurred over the contest region (BHS) with no cumulonimbus anvils (thunderstorms) in the region. These results are consistent with the forecast indicating the forecast was accurate.

Forecasts of the time of the 'trigger' temperature, the maximum depth of thermals and the expected climb rates are the minimum values required by a contest committee to set a launch time and a day's task. So, in the Appendix, these forecasted values are calibrated using the weather data and flight records from the Jefferson SC contest as well as a 2013 contest in Hobbs NM.

Flight records for soaring flights world-wide are available from the Online Contest (OLC) at www.onlinecontest.org. Hence, soaring forecasts made with the system world-wide can be validated. Hopefully, such studies will be conducted and reported at the next OSTIV Meteorological Panel meeting and in *Technical Soaring*.

Convection forecast: Sion CH

M. Hiegemann and R. Zimmermann flew a Duo Discus up and down the Rhône Valley using the convection generated by the steep, south facing slopes as illustrated by the GPS trace in Fig. 13. The corresponding barogram in Fig. 13 shows the flight started mid-morning in the developing thermals and ended late-afternoon in the deepest thermals that reached 3,400m AMSL (11,152ft AMSL). This value is larger than the predicted 9,280 ft AMSL for the tops. There were no flights on 25 April due, in part, to the forecasted weaker conditions.

Images of the atmospheric conditions in the Rhône Valley and adjacent valleys on 24 and 25 April 2014 are shown in Fig. 14. It can be seen on the 24th, soarable convective clouds occurred at 11Z and 16Z while on the 25th, cloud bases were lower with showers by 16Z.

The GPS data in Fig. 13 and images in Fig. 14 qualitatively support the forecasted conditions. However, to produce more accurate forecast data for this location, a much higher resolution numerical weather prediction model will be required. Liechti and Lorenzen [7] have produced such a model (Toptherm-JavaTopTask) for the region which is available by subscription from the German Weather Service at www.dwd.de in the pc_met section.

Table 4: Measured and predicted winds aloft for 18Z (13EST) on 4 March 2013 at Petersburg WV US

Pressure Level mb	Altitude km AMSL	Measured deg/(km/h)	Predicted deg/(km/h)
450	6.22	308/48	318/104
500	5.47	308/48	314/80
550	4.77	308/48	310/63
600	4.12	308/48	312/60
650	3.52	308/48	317/57
700	2.95	308/48	322/54
750	2.41	308/46	323/55
800	1.90	307/43	318/55
850	1.43	307/41	309/42
900	0.98	290/16	298/29
950	0.28 (surface)	300/18*	295/19

*From METAR

Wave forecast: Petersburg WV US

The forecast was for the day after the scheduled end of the wave camp. The forecast using the system was so promising that the organizers agreed to keep the tow plane at the camp one more day. However, a significant snowstorm was forecasted to arrive early the following day. So, the organizers would provide only morning tows; they needed the afternoon to fly the tow plane to its home base to avoid the storm. Because the wave was forecasted to be strongest in the afternoon, the author took the last launch in his HP-14T glider (N22DJ). Two other pilots launched before him, one flying a PIK-20 glider (N9Z) and the other an LS-4 glider (N370JS).

The pilot of N9Z chose to fly the ridge in the strong NW flow attempting to fly 1,250km to earn his 1250km FAI Diploma. Between his launch at 0957EST and landing at 1349EST, he covered about 400 km.

The pilot of 'JS' and the author were attempting to earn the FAI Diamond-altitude, a documented climb of 5 km from low- to high-point. The flight recorder data from our flights were analyzed using the SeeYou software. The resulting flight traces are given in Fig. 15 (barograms) and in Fig. 16 (plan-views).

It can be seen in Fig. 15 that 'JS' entered the wave at 16Z (11EST) and that 'DJ' entered what the author thought was wave lift at 1636Z (1136EST). Thereafter, 'JS' climbed steadily in the wave topping at 6,860m AMSL; the low point was 1,363m AMSL just after release; $6860 - 1363 = 5,497$m, a Diamond climb, indeed. During the climb by 'JS', 'DJ' was maneuvering below (Fig. 16) using every bit of lift in an attempt to contact the invisible wave above; there were no cloud markers (see Figs. 17 and 18). 'DJ' could climb no higher than 2,100m AMSL. The Diamond climb validates the forecast of wave made from the predictions in Figs. 10 and 11. Further, the diminishing amount of clouds from morning to evening shown in Fig. 18 validates the cloud cover forecast in Fig. 10.

The winds-aloft forecast was validated as follows. Winds aloft were computed by SeeYou from the 'JS' flight recorder data. These data are compared with the predicted winds (Fig. 11, 18Z) in Table 4. It can be seen the measured and predicted winds tracked well up to the 700 mb level. Thereafter, the measured winds became unreliable because of the near-zero ground speeds as 'JS' climbed in the wave.

One explanation why the author did not contact the wave is illustrated in Fig. 16. The wind (283 deg/24 km/h) was perpendicular to the ridge (brown feature) producing a wave just downwind of the ridge where 'JS' entered the wave. The author was flying about 2 km downwind of that wave in a 'secondary' wave (unfortunately 'JS' and 'DJ' did not have radio contact). Apparently the primary portion of the wave was further upwind. The author did see transient wisps of cloud in that direction but because of his relatively low altitude and lower performance glider, the author was reluctant to penetrate too far upwind in through the strong downdraft spilling off the approximately 4000ft AMSL (1,220m) eastern escarpment of the Allegheny Plateau (Fig. 18). The author thought he would be 'flushed' out of the wave through the Hopewell Gap and back to an ignominious landing at W99. Another explanation may be the wave length shortened and the amplitude increased between 1600 and 1636Z (Fig. 15) and 'JS' caught the wave and the author did not; we were like two surfers attempting to ride a wave, one caught the wave and the other failed.

Conclusions

This paper describes how to use the NOAA-ARL-READY web server to produce forecasted meteorological data, how to

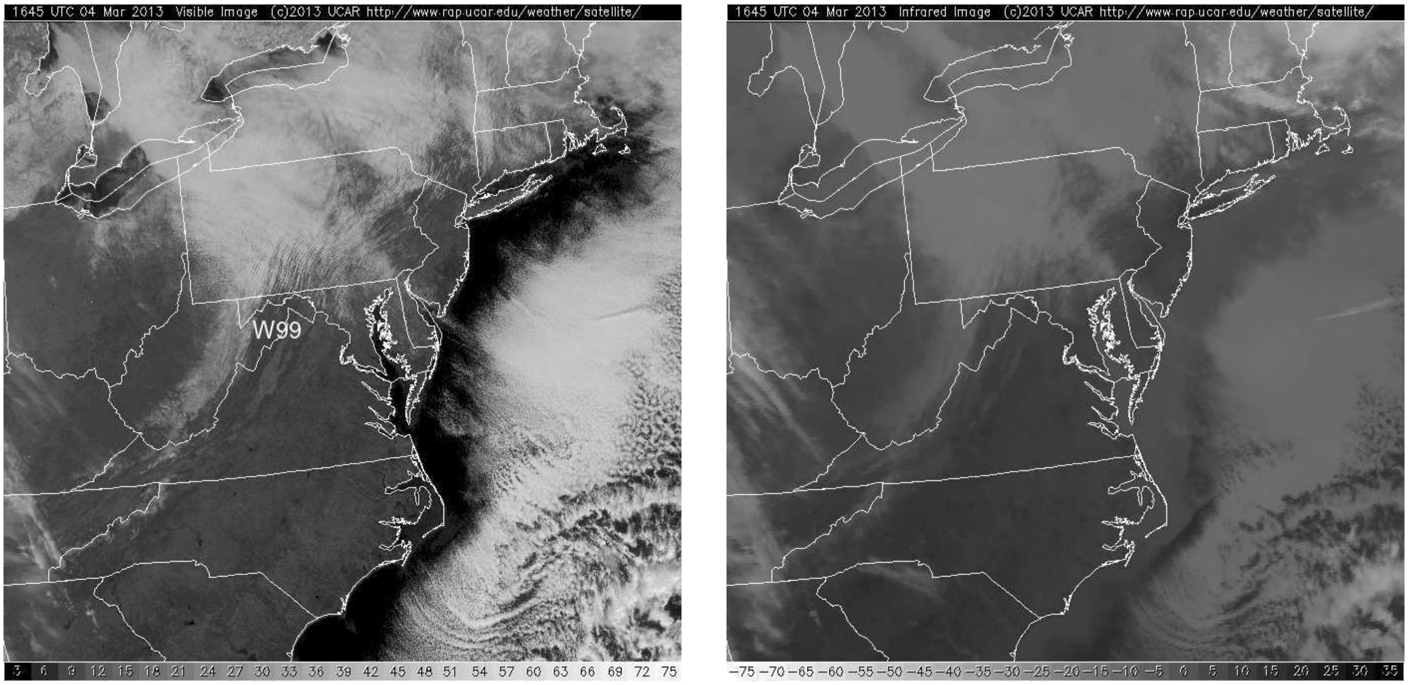


Fig. 17: Visible (left), infrared (right) satellite images for 1645EST (2145Z) on 4 March 2013. The location of Petersburg WV is identified (the lower-left corner of the 'W' in W99) in the visible image.

interpret the data to produce a soaring forecast and how to validate the forecast.

A convection forecast is presented for 17 May 2013, a day during a glider contest in the Piedmont region of southeastern US. The following predictions were made: winds at the surface and at the top of the convectively-mixed boundary layer (CBL), evolution of the CBL, areal distribution of the depth of the CBL, cloud cover and the potential for thunderstorm development. These predictions were validated using analyses of glider flight recorder data, meteorological satellite and radar images and results from the day's task. The predictions were shown to be valid and a 1000-point day was flown. Additionally, predictions of the time of 'trigger' temperature, maximum achieved altitudes and climb rates were calibrated using weather and flight recorder data from all the days of the Piedmont contest as well as a 2013 contest in the desert southwest of the US. It was found the forecasted 'trigger' times are accurate to ±19 min, the forecasted depth-of-convection minus 81m accurately represents the expected maximum achieved altitude, the forecasted climb rates are over estimated by an average 1.4 knots and the slope but not the magnitude of the climb rate 'rule-of-thumb' is valid. The magnitudes should be interpreted as maximum, not average, expected climb rates.

In contrast to the relatively flat Piedmont region of the southeast US, convection forecasts are presented for 24 and 25 April 2014 for a glider camp in the deep Rhône River Valley of CH. Flight recorder data and weather images from a significant flight qualitatively supported the forecasted conditions. However, to produce more accurate forecast data, a much higher resolution numerical weather prediction model than the GFS model will be required to faithfully reproduce the rugged terrain. This requirement is likely for all soaring regions with rugged terrain.

A wave forecast is presented for 4 March 2013, a day during a wave camp in the mountains of West Virginia US. The following predictions were made: winds and the surface and aloft to near the Tropopause, strength of updrafts, the base and top of the wave and cloud cover. These predictions were validated using analyses of glider flight recorder data, meteorological satellite images and photographs from the surface. The predictions were shown to be valid and a 5 km Diamond altitude ascent was flown.

To determine the robustness of the forecast system, the system needs to be employed at other locations in the soaring world with reports, especially validations, at the next OSTIV Meteorological Panel meeting and made permanent in *Technical Soaring*.

Acknowledgment

At the end of my presentation at the XXXII OSTIV Congress, Olivier Sven, a pilot from the South African team, reminded me of the '2D MAP' feature which exploits the 4D capability (x, y, z, t) of the NOAA-READY website.

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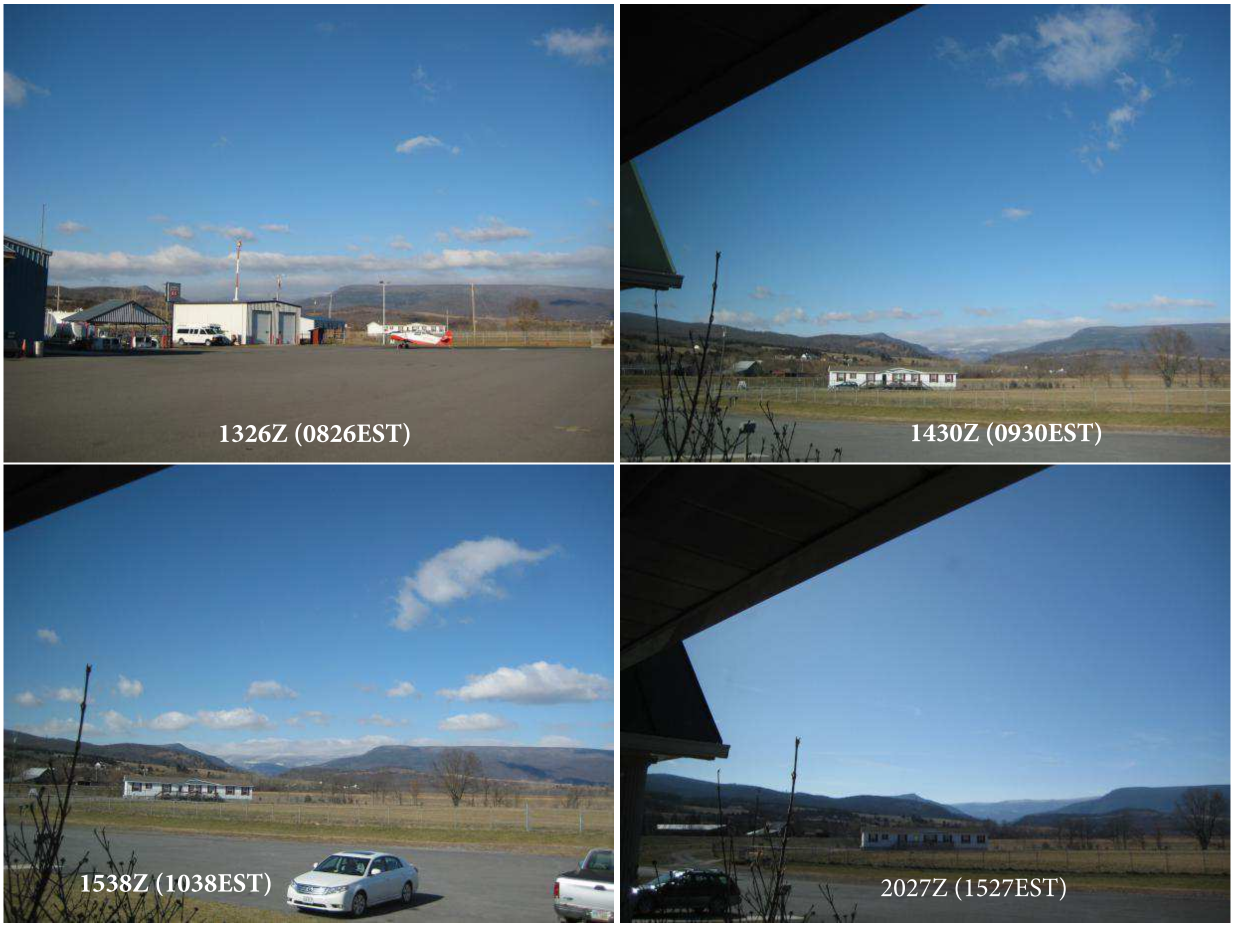

Fig. 18: Photos taken on 4 March 2013 by the author looking west from W99 towards the escarpment of the Allegheny Plateau. The plateau is visible through the Hopewell Gap.

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Appendix

'Trigger' time

A careful inspection of Fig. 2 shows the ∼762 m AGL 'trigger' depth is expected around 1130EDT (1530Z) at a temperature of 79F (26C). This 'trigger' depth value has been used at all contests in the US at which the author served as meteorologist. In contrast, at the Hobbs contest, the depth was chosen by the CD to be 915m AGL so pilots could climb quickly after release to higher altitudes to cool off from the searing grid temperatures.

The meteorograms from both contests were graphically analyzed to determine the expected 'trigger' time and the corresponding temperature. Then, the measured surface hourly temperatures were compared with the expected 'trigger' temperatures to determine the time at which the 'trigger' temperature occurred (linear interpolation was used to esti-

Table A-1: Calibration of the time of 'trigger' temperature

Contest	Forecast	Actual
Jefferson SC US	1015EST ±19 minutes	1046EST ±39 minutes
Hobbs NM US	1010MST ±23 minutes	1003MST ±30 minutes

mate the time when the forecasted temperature fell between two hourly temperatures). The values of the forecasted and actual values were averaged and the uncertainties of the means were determined; the results appear in Table A-1. It can be seen from the table the forecasted times, on average, were early by 31 minutes for the SC contest in the southeast US and the times were late by 7 minutes for the NM contest in the southwest US. These results are interpreted as the forecasted 'trigger' times were accurate to ±19 min (difference between +31 and -7 divided by 2).

Maximum altitude

A careful inspection of Fig. 2 shows an expected peak of 6,746ft (2,056m) AMSL (2,040m AGL) in the depth of convection while in Table 3 the achieved maximum altitude was 2,200 m AMSL. Correspondingly, all the daily meteorograms and flight traces (from the top-three daily finishers) from the two contests were inspected to determine, respectively, the expected maximum depth-of-convection and actual achieved maximum altitudes. The values were tabulated and the average values and uncertainties were determined. The results are shown in Fig. A-1. In the figure, the forecasted maximum depth of convection averaged 3024 ±325m AMSL, 81m higher than the actual achieved altitudes (2943 ±280m AMSL). This is a reasonable result because it is well known that racing glider pilots do not climb to the top of thermals because the climb rates decrease significantly near the tops. So, the forecasted depth-of-convection minus 81m accurately represents the expected maximum achieved altitude. The forecasted and actual values are significantly correlated with a linear regression analysis at better than 1% [8].

Climb rates

A careful inspection of Fig. 2 shows an expected average climb rate of 4kt ('rule-of-thumb': 2kt/1km or 1m/s/1km PBL depth in clear skies, larger with Cu above [2]) while in Table 3 the actual rate was 1.4 to 1.7m/s. Correspondingly, all the daily meteorograms and flight traces (from the top-three daily finishers) from the two contests were inspected to determine the expected average and actual average rates. The values were tabulated and the average values and uncertainties were determined. The results are shown in Fig. A-2. The forecast average climb rates averaged 4.6 ± 0.5 kt, 1.4 kt higher than the actual rates of 3.2 ± 0.3 kt. The forecasted and actual values are correlated, with a significant linear-regression analysis at better than the 1% level.

Using these results, the 'rule-of-thumb' [2] was investigated and the findings are shown in Fig. A-3. The linear-regression analysis is significant at better than the 1% level. It can be seen the results validate the 'rule' if the 0.7m/s underestimation (illustrated by the horizontal line with two arrowheads) is accounted for. The most likely explanation for the underestimation is the SeeYou analysis includes the weak pre-start thermals and post-finish circling. Further, the 'Circling' analysis includes both climbing and sinking during circling flight; the altitude lost while attempting to 'center' a thermal is included. Thus, the 'Total Vario' value is an accurate representation of the average achieved climb rate.

Maul [9] removed pre-start and post-finish thermals from a detailed analysis of flight recorder data from an international contest and his

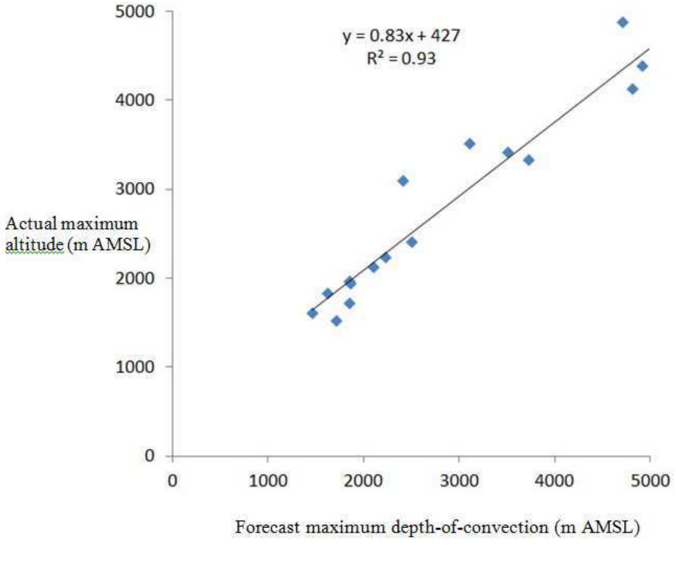

Fig. A-1: **Results from analyzing the daily meteorograms and flight records from the southeast US contest (nine smallest-valued points) and the southwest US contest (nine largest-valued points)**

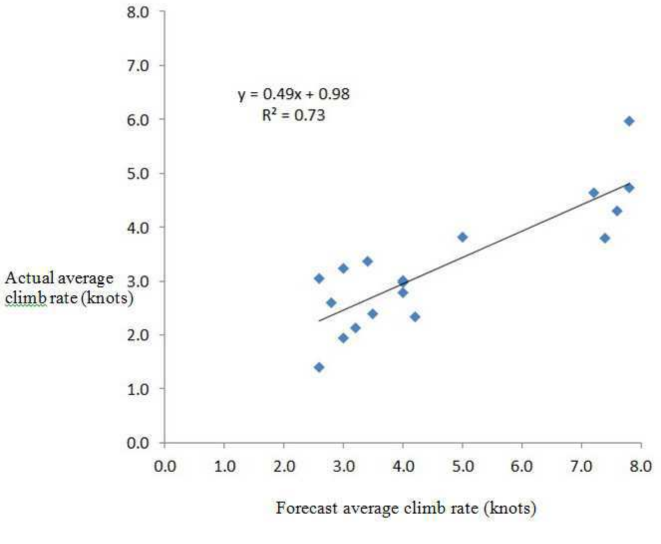

Fig. A-2: **Results from analyzing the daily meteorograms and flight records from the southeast US contest (nine smallest-valued points) and the southwest US contest (nine largest-valued points)**

results are compared with the 'rule' in Fig. A-4 (Fig. 5–7 from [10], focus on the 'height' vs 'climb rate' axes). It can be seen the 'rule' lies between the Maul 'maximum flight level' and 'most likely level' results but the results have a significantly different slope. Additionally, it can be seen the results from this study (the dry, high-desert of southeastern NM and the moist, temperate central SC) are strengthened because they are almost identical to an earlier study 'Hindman (2007)' [11] conducted in the same manner for the high plains of Colorado US. The fact that the 'rule' is valid in three significantly different regions of the US casts doubt on the slope of the Maul results. Thus, the slope but not the magnitude of the climb rate 'rule-of-thumb' is valid. The magnitudes from the 'rule' should be interpreted as maximum, not average, expected climb rates.

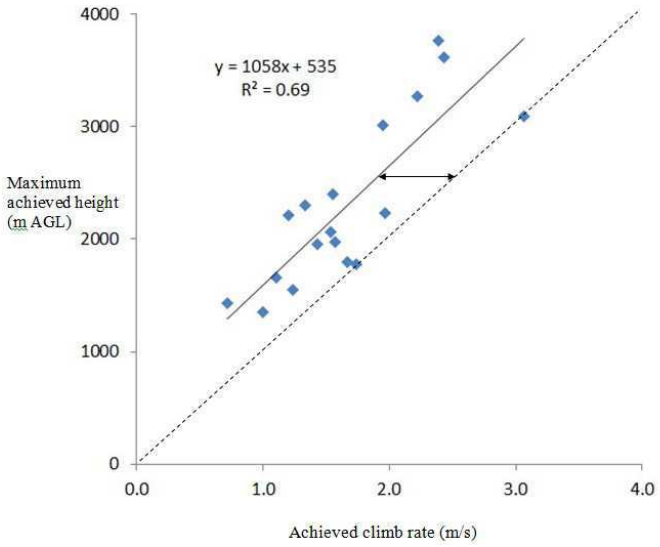

Fig. A-3: **Results from analyzing the daily meteorograms and flight records from the southeast US contest (nine smallest-valued points) and the southwest US contest (nine largest-valued points). The dashed line is the 'rule-of-thumb' from Ref. 2.**

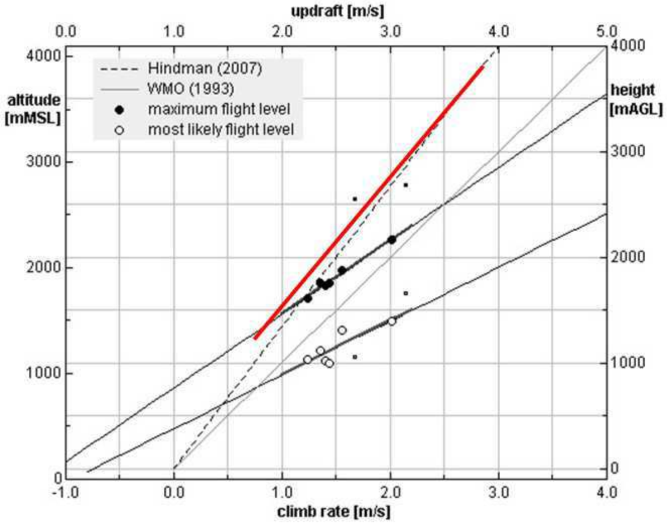

Fig. A-4: **A check of the 'rule of thumb' in WMO (1993) [2]; by Hindman (2007) [11]; by Maul [9] ('maximum flight level', 'most likely flight level'); and this study (thick red line).**