When wave soaring, do not get caught on top!

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Abstract

Climbing 5000m in a glider to earn the *Fédération Aéronautique Internationale (FAI)* Altitude Diamond is most often achieved using fast rising air generated by mountain lee-waves. During these flights, a primary concern should be an under-cast forming below the glider and/or a wave cloud enveloping the glider. These phenomena can be forecast by interpreting on-line atmospheric profiles (soundings, thermics) from numerical weather prediction (NWP) models. Profiles are presented and interpreted from actual wave flight incidents/accidents to help you anticipate these meteorological conditions: *recognize*, *understand* and *act* to fly safe and achieve the climb.

Introduction

During my gliding career – which started in 1970 – as a way of progressing, I earned the FAI Badges. I earned the Silver Badge in 1981 (B. Sc. of soaring), the Gold Badge in 1983 (M. Sc.) and the Diamond Badge (Ph. D.) has yet to be completed. I flew the 300km distance-to-a-goal in 1983, the 500km distance in 1998 and am missing the 5km climb. I plan to make the climb using the stationary, rising air produced downwind of a mountain barrier called the mountain lee-wave. I've made attempts in the west and east of the US. Often the clouds forming in the wave have interfered with the climbs. Thus, I will describe the clouds, their behavior and how to forecast the behavior so that you **recognize**, **understand** and **act** to fly safe and achieve the climb.

Methodology

The common atmospheric profile and clouds generated by mountain lee-waves are depicted in Fig. 1. Notice, the clouds form upwind and downwind of the mountain barrier; they form in the rising air and dissipate in the sinking air. Also, notice clouds do not form in the layers where there is insufficient moisture; layers where the Temperature and Dew-point values are widely separated.

Most successful Diamond climbs occur in the rising air in the Föhn gap between the Föhn wall cloud and the fractus Cumulus (fractus Cu) and Rotor cloud and ahead of the Altocumulus-standing-lenticular clouds (Ac len) in the "primary wave". By flying into the wind, the glider's ground speed can be adjusted to match the wind speed and, if the rising air is greater than the sinking speed of the glider, the glider rises vertically like riding an elevator. But, because of small fluctuations in the Temperature and Dew Point profiles and the air flow, these clouds can quickly increase and/or decrease in area and depth as illustrated in this time-lapse video made downwind of the Colorado Rockies Front Range: `https://www.youtube.com/watch?v=_roxFGsfzto`.

My greatest concern while climbing is the Föhn gap closing beneath me "trapping me on top" of an under-cast (opposite of an overcast) or a wave cloud enveloping me at altitude. Here are three examples of IMC affecting wave flights.

First example

The flight track and barogram from the flight are illustrated in Fig. 2. On 17 October 2014, I attempted a Diamond climb downwind of the Presidential Range in New Hampshire (NH)

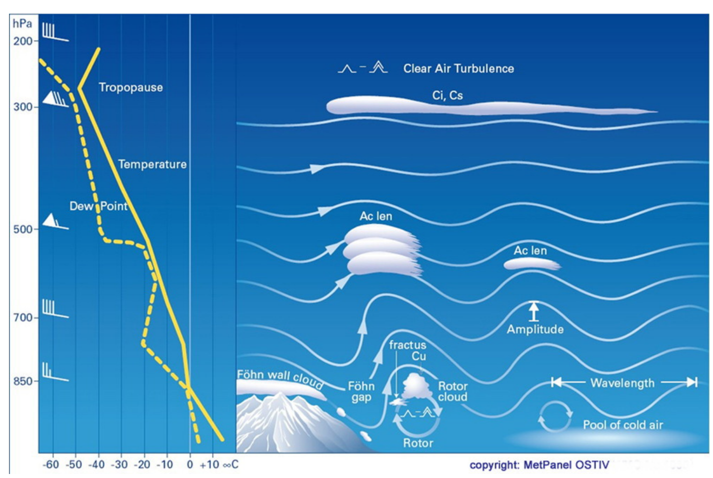

Fig. 1: Common profile (left) and clouds (right) during mountain lee-wave condition, based on Fig. 1.15 in [1].

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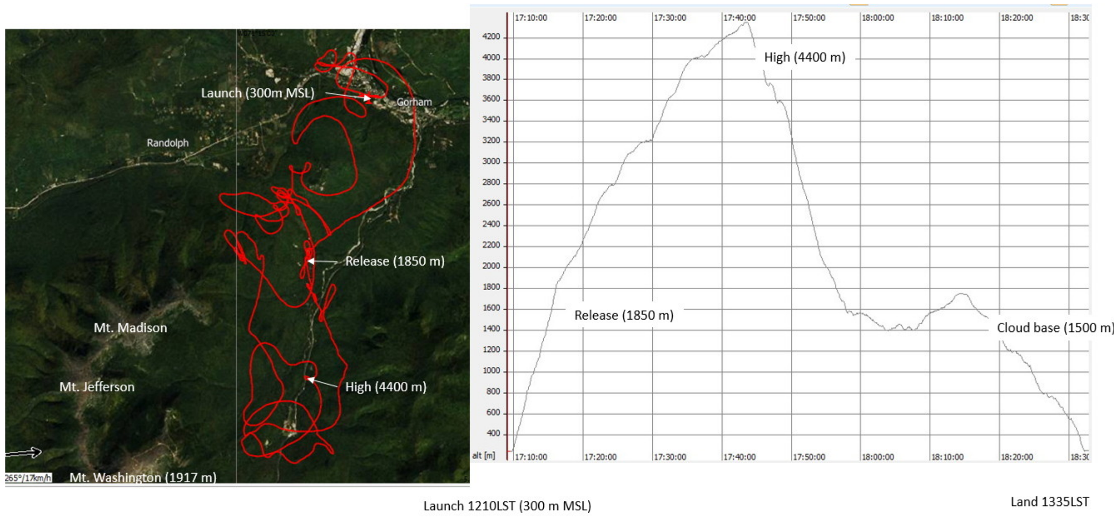


Fig. 2: Flight track (left) and barogram (right) of my 17 October 2014 wave flight from Gorham, NH, USA.

USA, Mt. Washington being the highest peak at 6289ft MSL (1917m). The flight occurred early in the afternoon because the forecast was for drying of the moist morning conditions. I launched at 1210 LST (1710 Z), released at 1850m MSL in the Föhn gap and climbed in 30min to 4400m. But, the gap began to fill – cloud tentacles began to reach from the Föhn wall cloud that was obscuring the mountain summit in front of me to the rotor cloud behind me. So, I abandoned the climb and quickly descended below the 1500m MSL cloud base. There it was too rough for me to wait for the predicted drying. So, I landed at 1335 LST (1835 Z).

Other pilots, also chased down, persevered and three were rewarded with Diamond climbs when the predicted drying occurred. Figure 3 illustrates Timothy Chow's Diamond climb flight data. When compared with mine, his release, dive below cloud base and high point locations were near mine but one to two hours later. So, I've got to be at the right location, on the right day and right time to earn my Diamond climb; not an easy task when I consider all the required pre-flight logistics! Plus, I must fly as patiently and accurately as Chow; look at his dense and precise track!

The US Geosynchronous Orbiting Environmental Satellite (GOES) visible images for 17 October 2014 (Fig. 4) reveal the closing of the F̈hn gap (in the circle) shortly after my 1210 LST launch (compare the 1215 and 1245 LST images). Also, the 1315 and 1345 LST images reveal the unstable gap forcing Chow to dive below cloud base. Thereafter, the gap opens and remains open.

I took a sequence of images (Fig. 5) looking south from the Gorham NH airport throughout the day (except when I was fly-

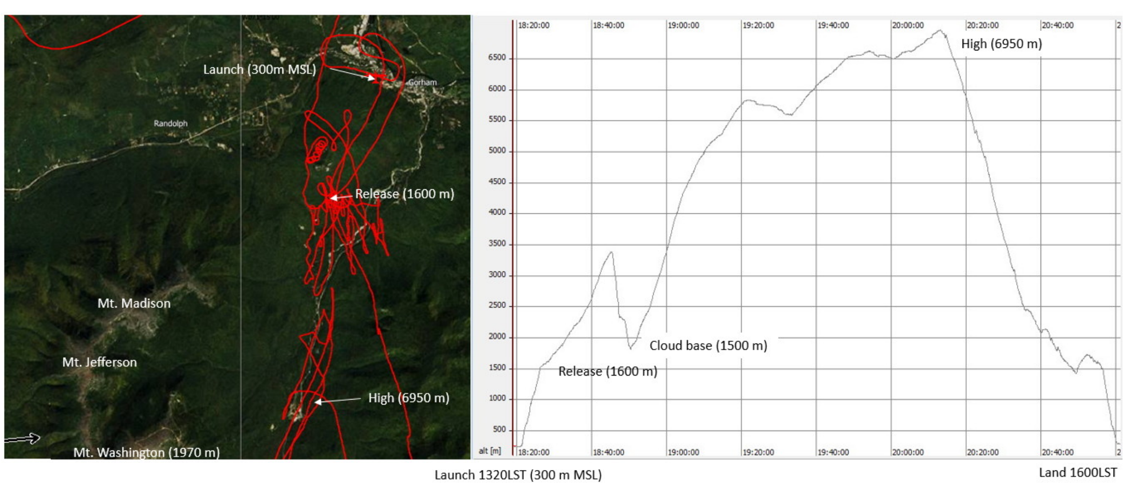


Fig. 3: Flight track (left) and barogram (right) of Tim Chow's 17 October 2014 wave flight from Gorham, NH, USA.

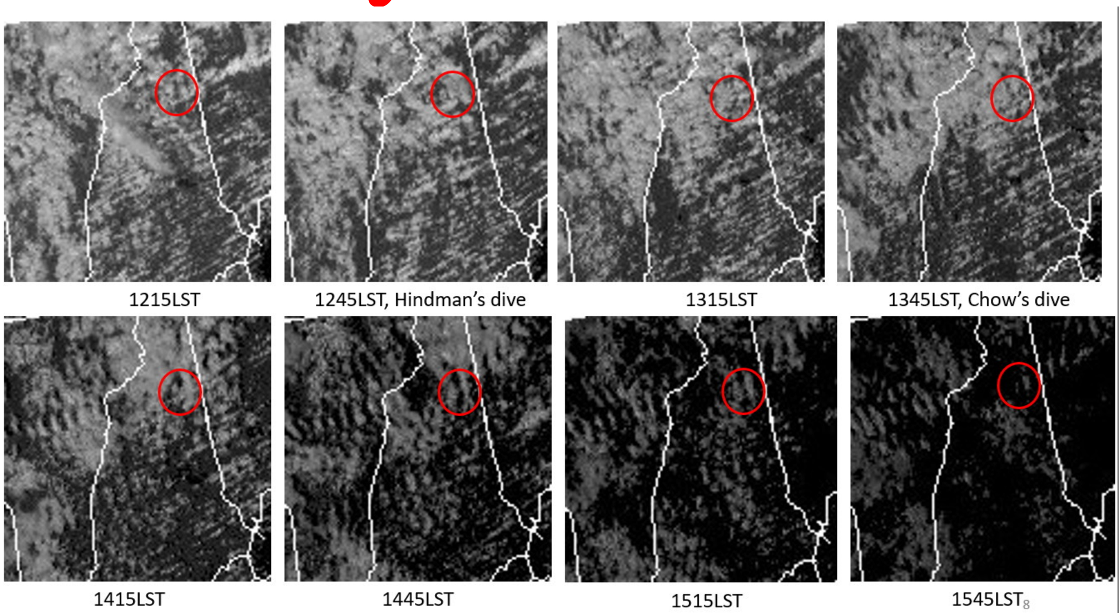


Fig. 4: US GOES visible images of the clouds associated with the 17 October 2014 wave flights from Gorham, NH, USA. The red circle identifies the Föhn gap.

ing). They show the morning moisture (rainbow in 0853 LST image which looks west) and the gradual drying as the day progressed. But, the drying was not continuous. Occasionally clouds formed obscuring the Fhn gap confirming what was illustrated in the GOES images.

Second example

On Easter Sunday, 5 April 2015, at about 15 PST (18 Z), while descending in the Sierra wave near Reno Nevada (NV) USA, Bob Spielman was not far enough ahead of the rotor cloud, was enveloped and had to bail out when his ship disintegrated inside the turbulent cloud [2]. Heres what Spielman wrote: ".....As I was heading back south, passing the western edge of Reno at 14,000ft and indicating 120kt, I went between two clouds. The gap was wide and I could see all the way to the ground. But, suddenly I saw moisture coming up from the rotor below me instantly filling in the gap. I tried to fly my Garmin296 but it was so rough that things went to hell in a hurry. Just seconds after I

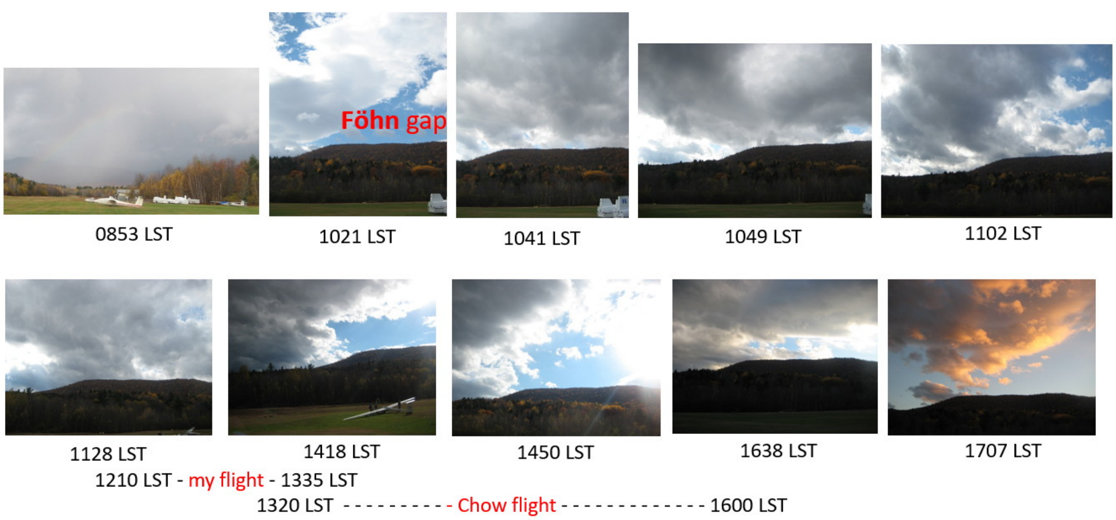


Fig. 5: Images of the clouds associated with the 17 October 2014 wave flights looking south from Gorham, NH, USA. The periods of my flight and Chow's flight are identified.

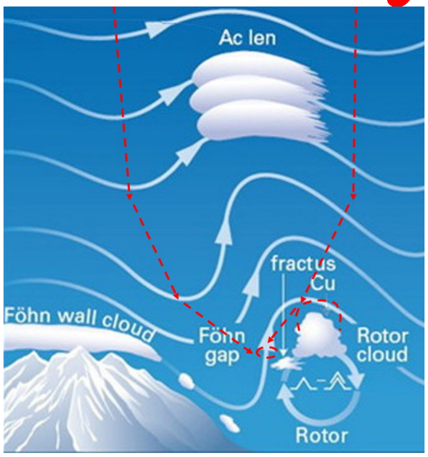
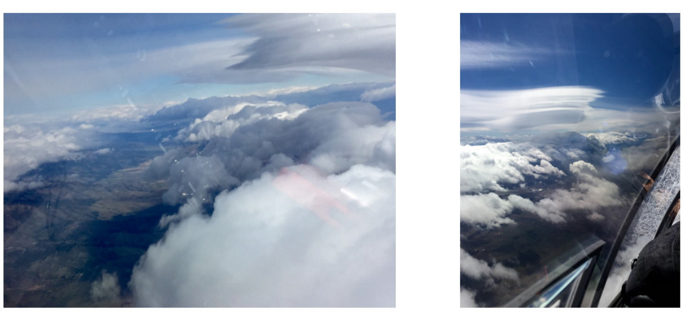


Fig. 6: Probable Spielman descent paths (red dashed lines).

was in the cloud, it was so rough I couldn't keep my wings level on the Garmin and I felt a stall. I decided to watch my airspeed and it increased really fast, 120, 140, 160, then 180 kt. I heard 'pop-pop', and thought 'uh oh', as the canopy broke......"

My reasoning from his writing is as follows and is illustrated in Fig. 6. After reaching his high point of 17,000 ft, Spielman descended most likely upwind or, possibly, just downwind of the primary wave. If he chose the latter path, he had to cross through the wave and descend ahead of the fractus Cus to be upwind of his landing field. When he reached the top of the rotor cloud, he was too close to the cloud and the cloud grew vertically (dashed extension of the cloud-top) engulfing him in severe turbulent IMC. Jim Payne and Alan Coombs were 'surfing' the same wave system making a multi-record-setting flight (`https://www.onlinecontest.com`). In Fig. 7 are images, taken by Coombs, that illustrate the clouds that Spielman may have attempted to negotiate in the afternoon. The left image was taken above Minden NV looking north towards Reno at 0940 PST (1740 Z) and the right image was over Reno at 1010 PST (1810 Z) looking south (from `https://soaringblog.tumblr.com`).



Above Minden NV looking north towards Reno at 0940PST (1740Z)

Over Reno at 1010PST (1810Z) looking south

Fig. 7: Images, taken in the vicinity of the Spielman flight, that illustrate the clouds that he may have attempted to negotiate.

The GOES images at the time of the Coombs images (Fig. 8, left) and at the time of the Spielman bail-out (Fig. 8, right) illustrate the wave system to be roughly in the same location. Thus, the Combs cloud images were likely similar to the cloud system Spielman attempted to negotiate.

The Spielman accident is remarkably similar to the famous Edgar ship breakup and bail-out during the Sierra Wave project 60-years earlier to the month (25 April 1953) [3], [4].

Third example

On 14 October 2015, while descending in the Mt. Washington NH wave, Chris Giacomo had the Föhn gap close on him enveloping him in IMC. He chose to bail out rather than continue the descent risking colliding with the mountain. He documented the incident *The Mountains Win Again* on-line at `http://www.mtwashingtonsoaring.org/Documents.asp`.

Figure 9 are the GOES images during Giacomos flight. They illustrate these important excerpts from his detailed account:

1130 EST: I launched and the weather was clearing with a visible Föhn gap over Mts. Adams and Madison

1130-1135 EST: Quite turbulent tow, released at 5000ft just downwind of Mt. Madison and headed immediately towards the Föhn gap. The gap seemed marginally stable, but rather small. Upon arriving at this small window, I decided that it was too risky to attempt to climb much as the gap appeared to be closing.

1135-1140 EST: After descending back below the cloud deck, I moved slightly farther down the valley in zero sink to the much larger and better defined primary window. I was greeted with a fantastic climb to 17,500 feet in under 20 minutes.

1140-1200 EST: As I was nearing FL180, I was forced to push upwind in order to maintain 17,500ft until the airspace could be opened (12 EST). At this time, there were still multiple open holes that I could have descended through, as well as the entire east behind me was still open. While waiting in this stable configuration, I began to hear reports on the ground of precipitation moving in, as well as the cloud deck thickening and beginning to close the window.

1210-1216 EST: I decided it would be best to retreat down through the last two remaining holes in front of me and then jump back onto the ridge until conditions improved. As I dove for the hole, with sink rates averaging around 20kts and peaking at over 30kts, the primary window closed completely and I was forced to divert to the last remaining window which was farther south.

1224 EST: I was soon unable to maintain VFR flight. I performed three stable spirals that allowed me to descend an additional 2000ft down to 6000ft MSL without clearing cloud.

1227 EST: I decided my safest option left was to bail out while I still had enough altitude for the chute to open.

Results

These wave flights demonstrate the clouds can "reach out and bite you". What can we do in our pre-flight weather studies

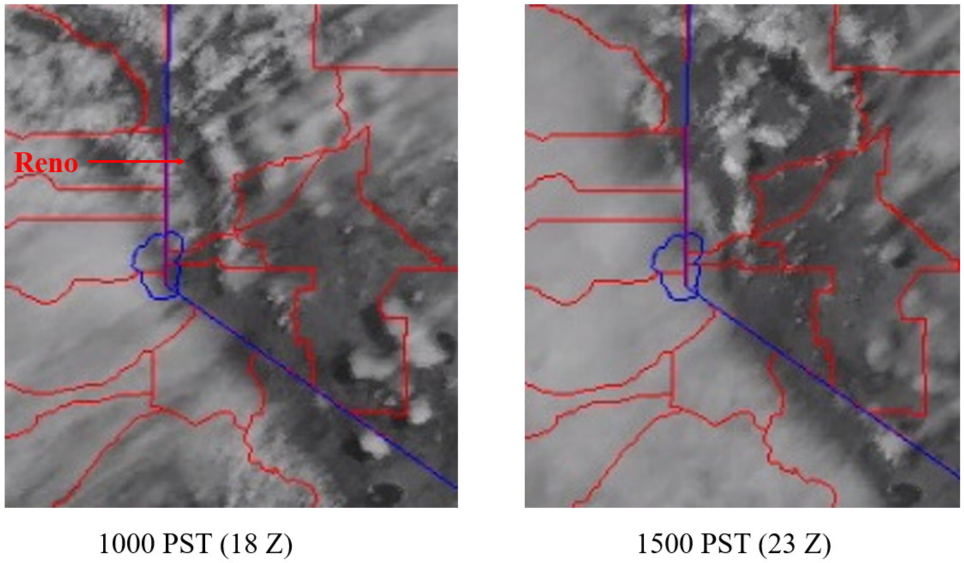


Fig. 8: The GOES images at the time of the Coombs images (left) and at the time of the Spielman bail-out (right).

to anticipate such cloud behavior? Study the forecasted atmospheric profiles of temperature, dew point and winds.

The profiles are freely available from the Internet. I describe how to obtain the profiles and use them to forecast mountain wave conditions in [5]. The profiles that follow are from the NOAA-READY "archived meteorology" section; the forecasted soundings are found in the "current meteorology" section. I do not know how to obtain the forecasted soundings after-the-fact. Nevertheless, I think these profiles would have been close to the forecasted profiles if the pilots had performed their preflight briefing just prior to launch.

For my flight, it can be seen in Fig. 10 the 12h forecast sounding, valid at the time of my flight (13 EST) showed a significant dry 900-to-800mb layer (a wide separation between the temperature (red) and dew point (green)). Thus, when I observed the Föhn gap to be cloud-free, I launched. But, as can be seen, the

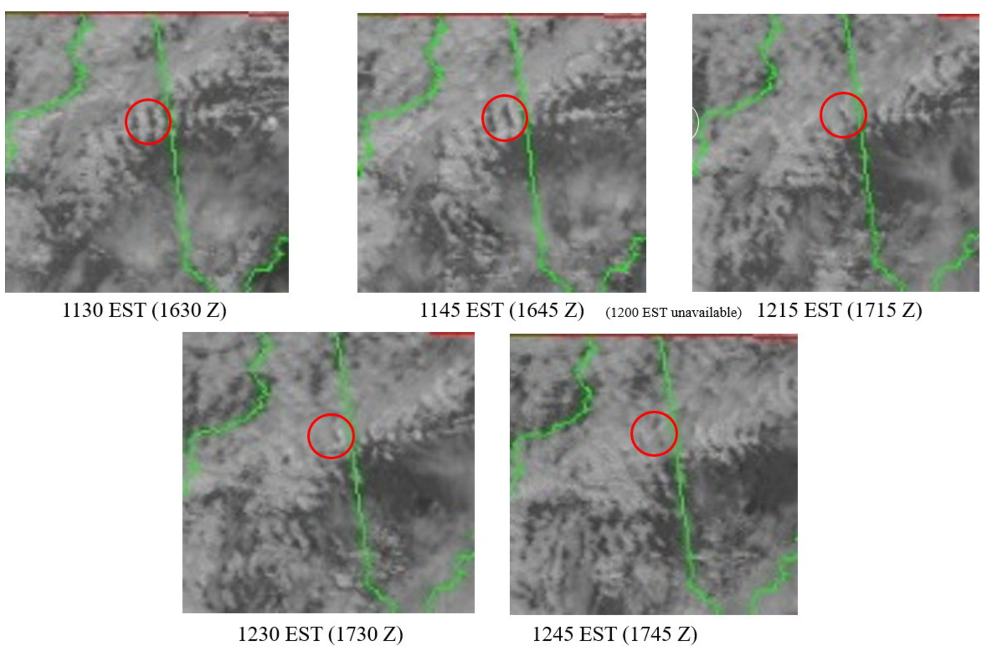


Fig. 9: The GOES images at the time of the Giacomo flight, 14 October 2015 from Gorhan, NH, USA. The red circle identifies the Föhn gap.

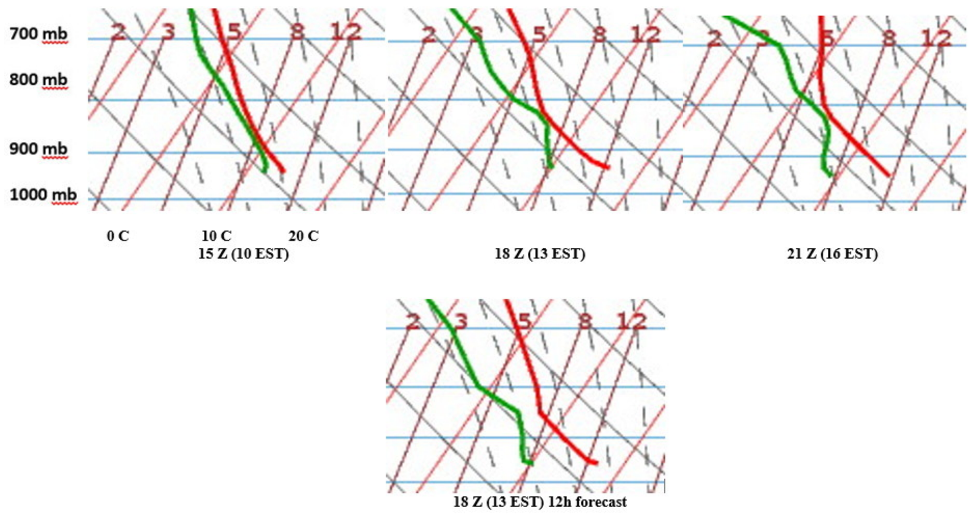


Fig. 10: Top row: the actual atmospheric profiles (0h soundings) during the 17 October 2014 Hindman flight; the rapid descent occurred between 1243 and 1257 EST. Bottom: The 12h (06 Z) forecasted sounding valid for 18 Z.
In these schematics, and those in Figures 11 and 11, the lines denote the following atmospheric properties: the environmental temperature and dew-point values are denoted by the red and green lines, respectively; the isobars are the horizontal blue lines; the isotherms are the diagonal red lines; the mixing ratio isopleths are the diagonal brown lines; the dry- and moist-adiabats are the grey solid and dashed lines, respectively.

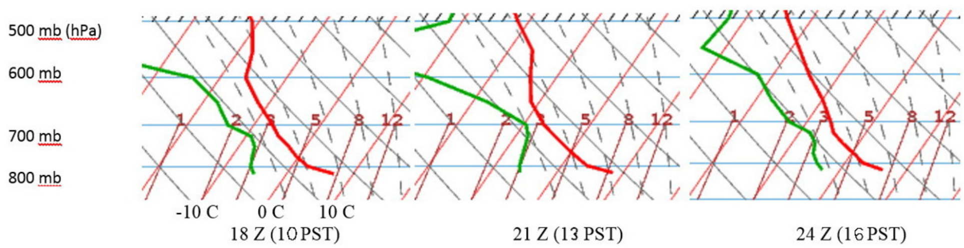


Fig. 11: The actual atmospheric profiles during the 5 April 2015 Spielman flight; the bail out occurred around 15 PST.

actual sounding showed the layer to be saturated. Thus, the 12h forecast was inaccurate. But, the actual sounding at 16 EST showed a slight increase in the separation between the temperature and dew point values which is consistent with the observed drying and successful Diamond climbs.

For the Spielman flight, it can be seen in Fig. 11 that the 700mb level (about 10,000ft MSL) moistened significantly between 10 and 13 PST (the separation diminished between the temperature (red) and dew point (green)) most likely causing the rotor cloud to expand engulfing Spielman. The increase in moisture most likely was caused by an increase in the depth of the boundary layer. The increase in depth is consistent with theoretical studies [6] and observations [7] of rotors in the nearby Owens Valley.

For the Giacomo flight, it can be seen in Fig. 12 that the 850mb level became saturated (cloud-filled) between 10 and 13 EST causing the Föhn gap to close engulfing Giacomo. In fact, the cloud layer thickened between 13 and 16 EST.

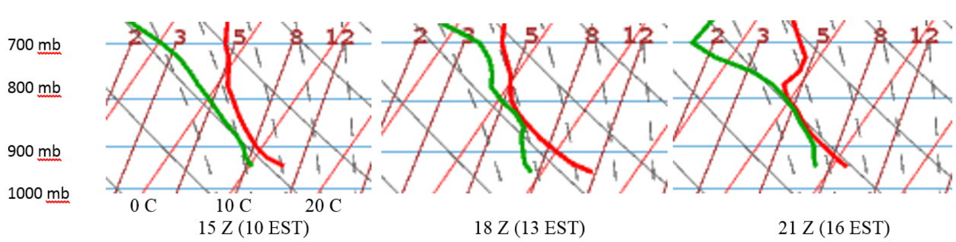


Fig. 12: The actual atmospheric profiles during the 14 October 2015 Giacomo flight; the bail out occurred around 1230 EST.

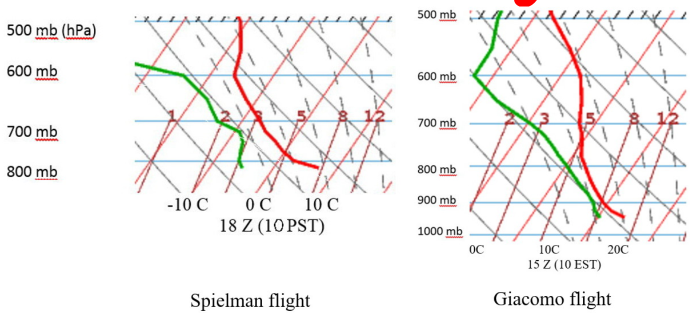


Fig. 13: Comparison of the soundings for the Spielman and Giacomo flights.

The soundings during the Spielman and Giacomo flights are compared in Fig. 13. It can be seen the atmosphere was much colder and drier for the higher altitude Spielman flight than for the Giacomo flight. This difference, in part, explains why a pilot is less likely to get caught-on-top in a western US mountain wave than in an eastern wave.

As shown in Fig. 14, Ac len and Rotor clouds formed during the Spielman flight in a stable, unsaturated environment. This is contrary to the schematic in Fig. 1. How can this happen? As illustrated in the figure, a parcel of air at the "bottom" of the primary wave, probably the 700mb pressure level (10,000ft MSL), rises in the stable air and condensation occurs at about the 640mb level or about 13,000ft MSL. This is about the altitude that the Rotor cloud "bit" Spielman. Thus, in Fig. 1, saturated layers are not necessary for Ac len and Rotor clouds to form. Only moist layers are necessary. But, the layers have to be sufficiently moist so the stable air forced to rise in the wave becomes saturated before the air begins to sink.

Discussion

What can we do during a wave flight to avoid getting bit? I asked an unusually experienced and skilled northeastern US wave pilot, Timothy Chow, what he does during a wave flight to avoid "getting bit". Here's his advice: "Probably my most stressful wave flight was on 17 October 2014, the day in Gorham

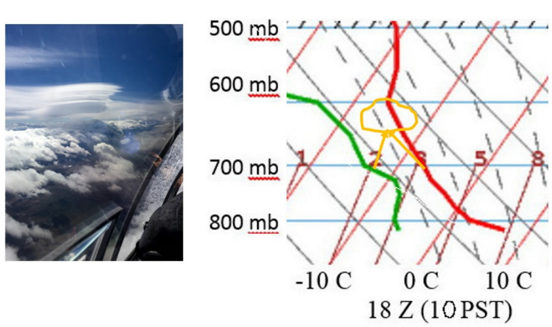


Fig. 14: Schematic of the process that produces rotor clouds in a stable, unsaturated environment. The yellow lines illustrate the cloud formation process.

NH that I shared with you. The depth of the cloud layer was problematic that day (I remember it being about 3,000ft (915m)). As you start climbing you want to be above cloud base in the hole where the lift is good (Föhn gap). But, if you're worried about the hole closing you shouldn't climb more than (maybe) 2,000ft MSL (610m) above cloud base. There is a danger-zone where you can be too high to dive down through the hole but you are not high enough to see secondary holes downwind. On that day, I think the danger-zone was between 7,000 and 13,000ft MSL (2134-3963m). When you're at those altitudes, you need to be sure that the hole isn't going to close. If you are not sure, you should wait it out at lower altitudes (or land)."

Chow continued: "Sometimes we rely on the wave to create a Föhn gap. For example we have flown (successfully) when the upwind Mount Washington valley (Whitefield) is overcast but there is a large and persistent hole downwind of Mt. Washington. I have heard of people "waiting it out on top" when the gap closes. But, if the gap closes maybe it's because the wave lift has stopped and "waiting it out" is probably not an option. You better have a downwind option (airport or field) and you should be willing to use it quickly."

Conclusions

Carefully studying and interpreting the most recent forecasted atmospheric soundings, freely available on the Internet, can help pilots anticipate moistening of the atmosphere that could produce IMC while climbing in mountain waves. Getting to the top is optional, getting down is mandatory!, a fact I learned from my studies of Mt. Everest weather for the ultimate ascent - using a sailplane [8].

Recognize, **understand** and **act** to fly safe!

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