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Technical Soaring

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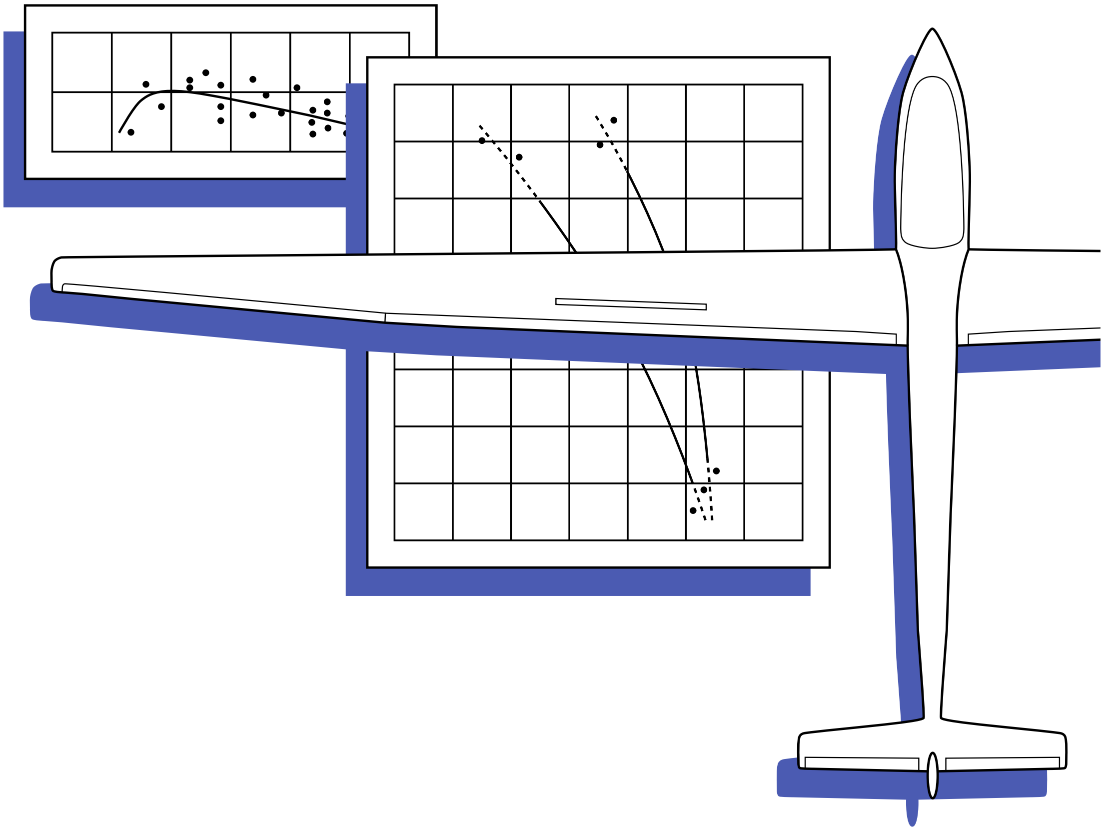

- **Investigation of the Vegetation Effects on Convection**
- **When wave soaring, do not get caught on top!**

OSTIV
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Technical Soaring (*TS*) documents recent advances in the science, technology and operations of motorless aviation.
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From the Editor

Publication Date

This issue is the third of Volume 41 of *TS*, corresponding to July-September 2017. For the record, the issue was published in March, 2019.

About this issue

In this issue, the main articles deal with meteorological topics. The first paper, contributed by Nilcan Akataş et al. and titled "Investigation of the Vegetation Effects on Convection by Using COSMO-CLM", was presented at the XXXIII Congress of the OSTIV held in Benalla, Australia, in January 2017. It was honored with a best students paper award. Congratulations!

The second article, prepared by Edward Hindman, focusses on an important safety aspect everyone should be well aware of when soaring gravity waves: Don't get caught on top!

Right after the editor's section, a short note follows on weather forecasting for soaring flight based on numerical weather prediction models (NWP). This contribution was also provided by Ward Hindman. It is not a full, reviewed article but I think it contains valuable information on the current status of NWP that is of interest for the soaring community. I will continue these informal notes in *TS* whenever I receive interesting stuff. For example, in one of the next issues you will find a short note on new handicap factors for club class gliders that are used in German glider competitions.

AIAA Aviation 2019

If you get the chance to visit the 2019 AIAA Aviation and Aeronautics Forum and Exposition held on 17–21 June at the Hilton Anatole, Dallas, Texas don't miss to attend the "Special Session: Low Speed and Motorless Flight". The session is scheduled for the first day, starting at 9:30am in hall Cortez D. Chair will be Judah Milgram, who made me aware of this event. The following technical papers will be presented:

- Flight Testing Stability and Controllability Otto Lilienthal's Monoplane Design from 1893.
- Aerodynamic Design of a Morphing Wing Sailplane
- Studies of Anisotropic Wing Shell Concepts for a Sailplane with a Morphing Forward Wing Section.
- Flight Trajectory optimization of a Sailplane after Rope Break during Tow-Assisted Takeoff.
- Stability and Stability Augmentation of Dynamic Soaring Orbits.

Sounds interesting!

Acknowledgments

We gratefully acknowledge Associate Editor Zafer Aslan, who oversaw the review of the Hindman paper in this issue.

Very Respectfully,

Arne Seitz
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Status and future of weather forecasting for soaring flight based on predictions from numerical weather prediction (NWP) models

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The status – as of 2009 – of weather forecasting for soaring flight was detailed by the OSTIV Meteorological Panel in a World Meteorological Organization publication [1]. The aim of the publication is to provide an internationally agreed set of guidelines for meteorological forecasting in soaring flight and related activities.

Since that publication, Liechti [2] presented a NWP-based system for predicting soaring flight in isolated and aligned lift for Europe. Hindman [3] presented a less sophisticated system for predictions world-wide. Both investigators reported the forecasts to be accurate.

Three additional NWP-based soaring weather prediction

Presented at the meeting of the OSTIV Meteorological Panel, Benalla, Australia, 13 January 2017

systems, used world-wide, are found on the Internet. To my knowledge, the systems have yet to be reported in the peer-reviewed literature. First, regional atmospheric soaring predictions (RASP), using a locally-run US weather research and forecasting (WRF) model, are user-generated following guidance from the RASP web site `www.drjack.info/DRJACK/RASP/index.html`. Second, global soaring weather forecasts are available at the XC Skies website `www.xcskies.com`. They are derived from predictions made by the US North American mesoscale (NAM) and global forecast system (GFS) models. Third, soaring weather forecasts for Europe and the US are available from the TopMeteo site `www.topmeteo.eu/weather/gliding`. They are derived from predictions made by unspecified NWP models. Presumably these three systems, the last two require subscriptions, produce accurate forecasts otherwise they would not be on the Internet? Rogers [4] reports "my impression from many flying seasons is that XC Skies thermal strengths are too strong, TopMeteo's and DrJack's too conservative ....I'd say plus or minus 30%".

A significant contribution to soaring meteorology would be a peer-reviewed report of a comparison of predictions made by the Liechti, Hindman, RASP, XC Skies and TopMeteo systems with flights from a World Gliding Championship, following Liechti's validation procedure [2].

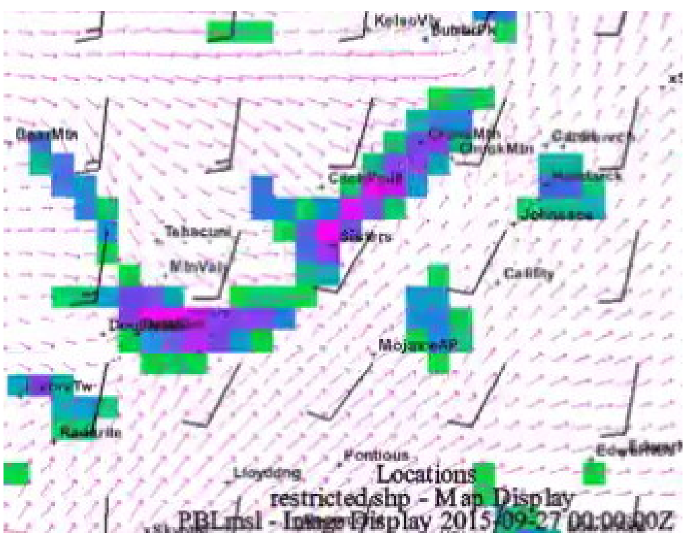

Fig. 1: One frame of an animation of surface winds that reveal convergence zones and the resulting regions of expected rising air (colors). The animation is available via wrogerswx@gmail.com.

The US has developed a high-resolution (3km), rapid-refresh (15min) NWP model, called the HRRR (`ruc.noaa.gov/hrrr/`), which resolves isolated and aligned convection and mountain waves. US meteorologist and glider-racing pilot Walter Rogers has developed unique displays of soaring weather using HRRR model predictions. For example, Fig. 1 is one frame of an animation of surface winds that reveal convergence zones that led to convection. As I understand, these animations have been shown at morning pilot briefings and the actual zones were flown in the afternoon. A careful comparison of the predictions with glider flight recorder data would establish their accuracy and usefulness.

The Perlan Project (`www.perlanproject.org`) is attempting to fly an engineless aircraft to the edge of space. As reported on the website, "three groups of phenomena have been simulated with numerical models in the mid-latitude atmosphere; however, experimental data is rare with which to validate these simulations". Further, the project claims to represent a balanced effort among modeling, observations and theory. To date, the project has measured 3-dimensional wind fields in mountain waves using sailplane flight data as reported by Zhang, et al. [5]. And, Millane et al. [6] reported that Jim Doyle of the US Naval Research Laboratory numerically simulated the atmospheric flow for the 2016 Perlan world-record-altitude flight with the following significant result: the location of the predicted rising air corresponded well to the actual location of the flight. Bravo!

Now, imagine, prior to another Perlan launch, the Doyle model is used to predict the atmospheric flow. And, using the flow, a flight path is proposed. Then, after the flight, the flight recorder data is compared to the proposed path and the path is validated! And, if this result is reported in the peer-reviewed literature, the project could add immensely to our knowledge of predicting mountain waves.

In conclusion, the future is bright for using glider flight data to validate soaring weather predictions resulting from NWP models and reporting the results in the peer-reviewed literature.

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Investigation of the Vegetation Effects on Convection by Using COSMO-CLM

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Abstract

Convection is affected by vegetation cover considering variation of water and heat retention of different soil surfaces. Vegetated areas also change the amount of incoming and outgoing components of the surface energy budget, therefore the areas affect the atmospheric convection. In this study, vegetation effects on convection were investigated using a non-hydrostatic, limited-area, atmospheric prediction model (COSMO-CLM) with different land cover maps that use different vegetation fractions and normalized difference vegetation index (NDVI) values. The model domain covered especially forested regions from the northeastern part of Turkey and Black Sea to the eastern coasts of Caspian Sea. In this context, changes of atmospheric parameters considered as indicators of convection obtained by model simulations were investigated.

Introduction

Vegetation covered area promotes convection both by extraction of soil moisture and by shading the soil so that conduction of heat into the soil was reduced (thereby increasing the available energy) [1]. Considering surface energy budget, vegetated area change the amount of incoming or outgoing components of the budget. Fig. 1 shows the schematic illustration of the surface heat budget over different types of covers [2]. In order to better understand the effects of vegetation on convection, fluxes over the surfaces should be examined.

There are several studies about varying of surface fluxes and precipitation by vegetation covered area. Some examples of these studies can be found following:

Lyons et al. found a reduction of sensible heat flux in southwestern Australia as a result of the conversion of land to agriculture [3]. In other studies it is found that the leafing out of vegetation in the spring has a dramatic effect on a reduction in sensible heat flux [4, 5]. Machado et al. investigate the variability of convection over different vegetation types. It is shown that the main differences between rainforest and savanna or deforested sites occur in the dry season, whereas the magnitude and diurnal cycle of convection as well as amount of rainfall [6].

In this study, vegetation effects on convection has been investigated by COSMO-CLM simulations using different land cover maps covering especially forested regions.

Presented at the XXXIII OSTIV Congress, Benalla, Australia, 8-13 Jan. 2017.

Data and Method

Vegetation effects were simulated by using COSMO-CLM. The COSMO model is the non-hydrostatic operational weather prediction model applied and further developed by the national weather services joined in the COnsortium for SMall scale MOdeling (COSMO). COSMO was developed from the Local Model (LM) of the German Meteorological Service by CLM-Community which is an open international network of scientists (`http://www.cosmo-model.org`). In 2005, the CLM-Community improved the COSMO-Model to be capable of long-term simulations so it is called COSMO model in CLimate Mode (COSMO-CLM or CCLM), then CCLM became the regional Community-Model for the German climate research. This model version has been applied on time scales up to centuries and spatial resolutions between 1 and 50 km in different regions of the world (`http://www.clm-community.eu`). The COSMO model is based on primitive thermo-hydrodynamical equations that define compressible flow in a moist atmosphere without using any scale approximations. The general aim is to be used for both operational numerical weather prediction (NWP) and research applications on meso-scale. COSMO model flowchart is shown in Fig. 2.

In order to obtain the simulations, ERA-Interim data set with six hour interval belonging to the year 2012 was used as input data for COSMO-CLM. ERA-Interim by European Centre for Medium-Range Weather Forecasts (ECMWF) is a global atmospheric reanalysis from 1979, continuously updated in real time. The ERA-Interim reanalysis is produced with the ECMWF Integrated Forecasting System (IFS), which incorporates a forecast model with three fully coupled components for the atmosphere, land surface, and ocean waves [7]. Fig. 3 shows the ERA-Interim variables used as the initial values (`http://rda.ucar.edu/datasets/ds627.0`).

Study area locates from the northeastern part of Turkey and Black Sea to the eastern coasts of Caspian Sea. Fig. 4 shows the study area used as base map for the model. The model runs with one hour temporal and 30km spatial resolutions. GLC2000 and GLOBCOVER were used as land use cover maps for the simulations. They differ from each other according to the satellites and sensors that they use. GLC2000 land cover map uses SPOT 4 satellite and has 1km spatial resolution. GLOBCOVER land cover uses 300m MERIT sensor of ENVISAT satellite.

Results

Model results were obtained as six hourly data and then converted to the daily values. The figures of model outputs shows the monthly averages for temperature, sensible heat flux, latent heat flux and total cloud cover and the monthly total values for precipitation data. Analyses illustrates on both GLC2000 and GLOBCOVER land use maps. Land use maps shows different vegetation fractions and normalized difference vegetation index (NDVI) values. For GLC2000 land use, plant cover and leaf area index for the COSMO-Model and for a special day are produced by using only the data set for vegetation and an averaged NDVI ratio by NDVI type choosing. For GLOBCOVER land use plant cover, leaf area index and roughness length for the COSMO-Model and for a special day are produced by using 12 monthly climatological mean values for plant cover, leaf area index and roughness length. The difference for the vegetation area fractions for GCL2000 and GLOBCOVER are shown in Fig. 5.

Different land use maps caused different results although the initial data and boundary conditions are the same. Distribution of simulated temperature (Fig. 6) and precipitation (Fig. 7) show similar distribution to the vegetation fractions. Especially precipitation values are highest where the vegetation fractions are also high. This situation may be caused by the forest area due to gas exchanges by photosynthesis and also respiration. Because GLC2000 land use map has higher values of vegetation fraction, maximum precipitation amounts are also higher than GLOBCOVER land use.

Sensible heat flux (Fig. 8) and latent heat flux (Fig. 9) have not much difference for different land use maps but where vegetation fraction is high for GLOBCOVER, values are higher than GLC2000. Especially in summer times, over the Caspian Sea and the western part of the sea, lower negative values can be seen. Sensible heat flux values are lowest in the western part and also in the southeast part of the Black Sea. Heat fluxes cannot be linked to only vegetation cover of the surface. Sea-land distribution and topographic effects should also be considered. However, in winter times, heat fluxes have highest values where vegetation fractions also high.

Total cloud cover mainly affected by moisture sources. In this study, existence of sea trigger in convection by evaporation and air masses pass over the Black Sea. However, vegetation cover is also a source for connectivity by the gas exchange between plants and atmosphere. Total cloud cover distribution is illustrated in Fig. 10.

Conclusions

The impacts of vegetation on convection occur as affecting surface fluxes of gases (CO_2, O_2, H_2O etc.) and wind speed over the plant canopies and extraction of soil moisture. Surface fluxes over canopies have different behavior from bare soil. Because vegetation processes and change directly affect the surface energy and moisture fluxes into the atmosphere. Of course convection in the atmosphere depends on many other factors and causes the change of many other parameters. Thus, for the future studies, changes of other parameters like wind shear and wind shift need to be examined. Beside monthly variations, daily and hourly variations need also to be considered in the examinations. It is hard to examine only vegetation effects, so atmosphere-ocean-cloud-agriculture coupled models need to be applied in future studies.

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Figures

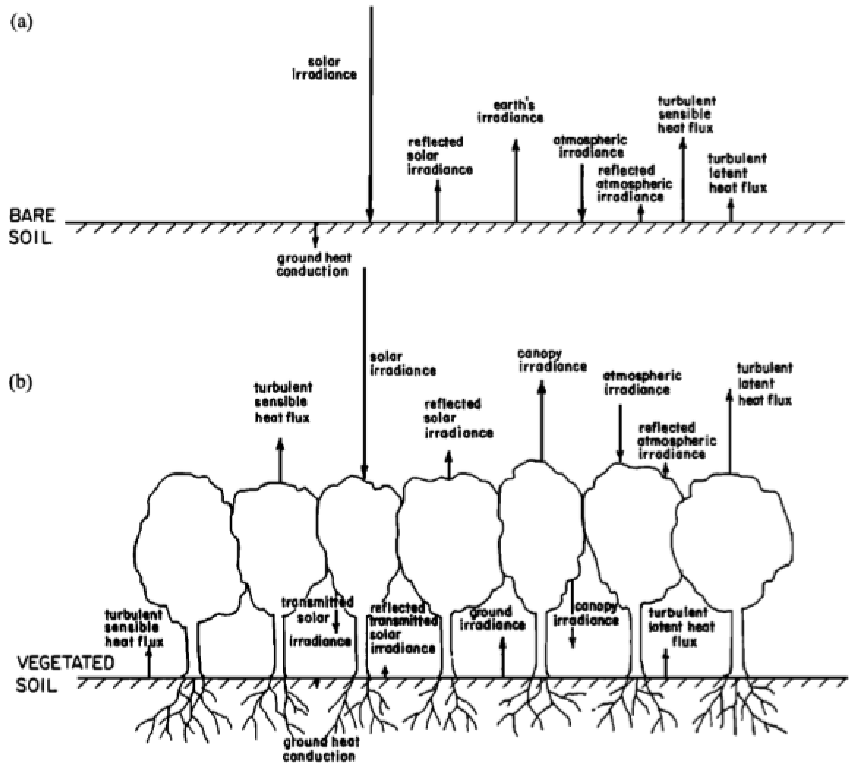

Fig. 1: Schematic illustration of the surface heat budget over (a) bare soil and (b) vegetated land [2].

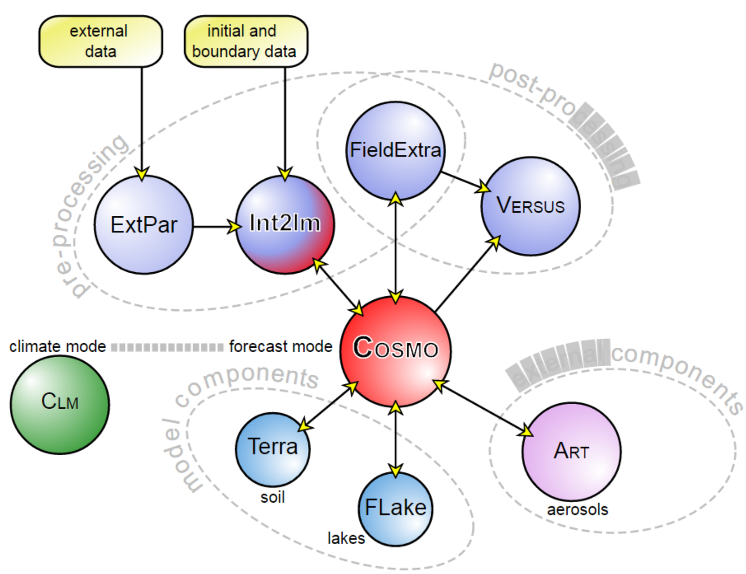

Fig. 2: COSMO-CLM flow chart [7].

Air Temperature	Albedo	Cloud Amount/Frequency	Cloud Liquid Water/Ice
Convection	Convergence/Divergence	Dew Point Temperature	Evaporation
Geopotential Height	Gravity Wave	Heat Flux	Humidity
Hydrostatic Pressure	Ice Extent	Incoming Solar Radiation	Longwave Radiation
Maximum/Minimum Temperature	Outgoing Longwave Radiation	Planetary Boundary Layer Height	Potential Temperature
Precipitable Water	Precipitation Amount	Runoff	Sea Level Pressure
Sea Surface Temperature	Shortwave Radiation	Skin Temperature	Snow
Snow Density	Snow Depth	Snow Melt	Snow/Ice Temperature
Soil Moisture/Water Content	Soil Temperature	Streamfunctions	Sunshine
Surface Air Temperature	Surface Pressure	Surface Roughness	Surface Winds
Terrain Elevation	Tropospheric Ozone	Upper Level Winds	Vegetation Cover
Vegetation Species	Vertical Wind Motion	Vorticity	Water Vapor
Wind Stress			

Fig. 3: ERA-Interim variables.

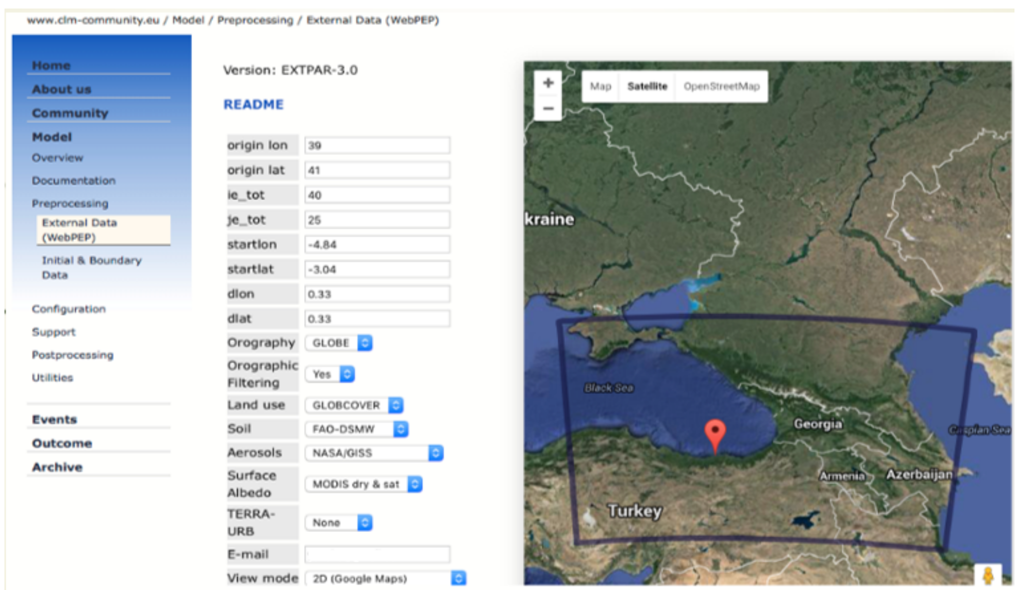

Fig. 4: Study Area.

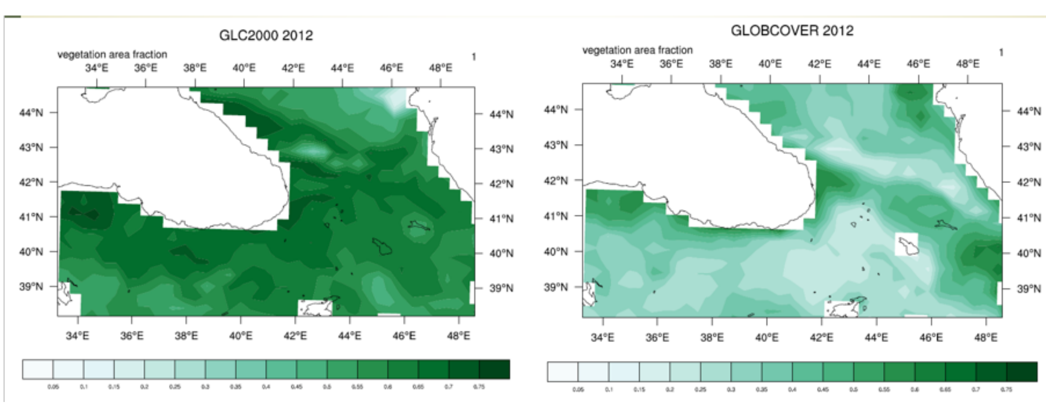

Fig. 5: Vegetation area fractions for GLC2000 and GLOBCOVER land use maps.

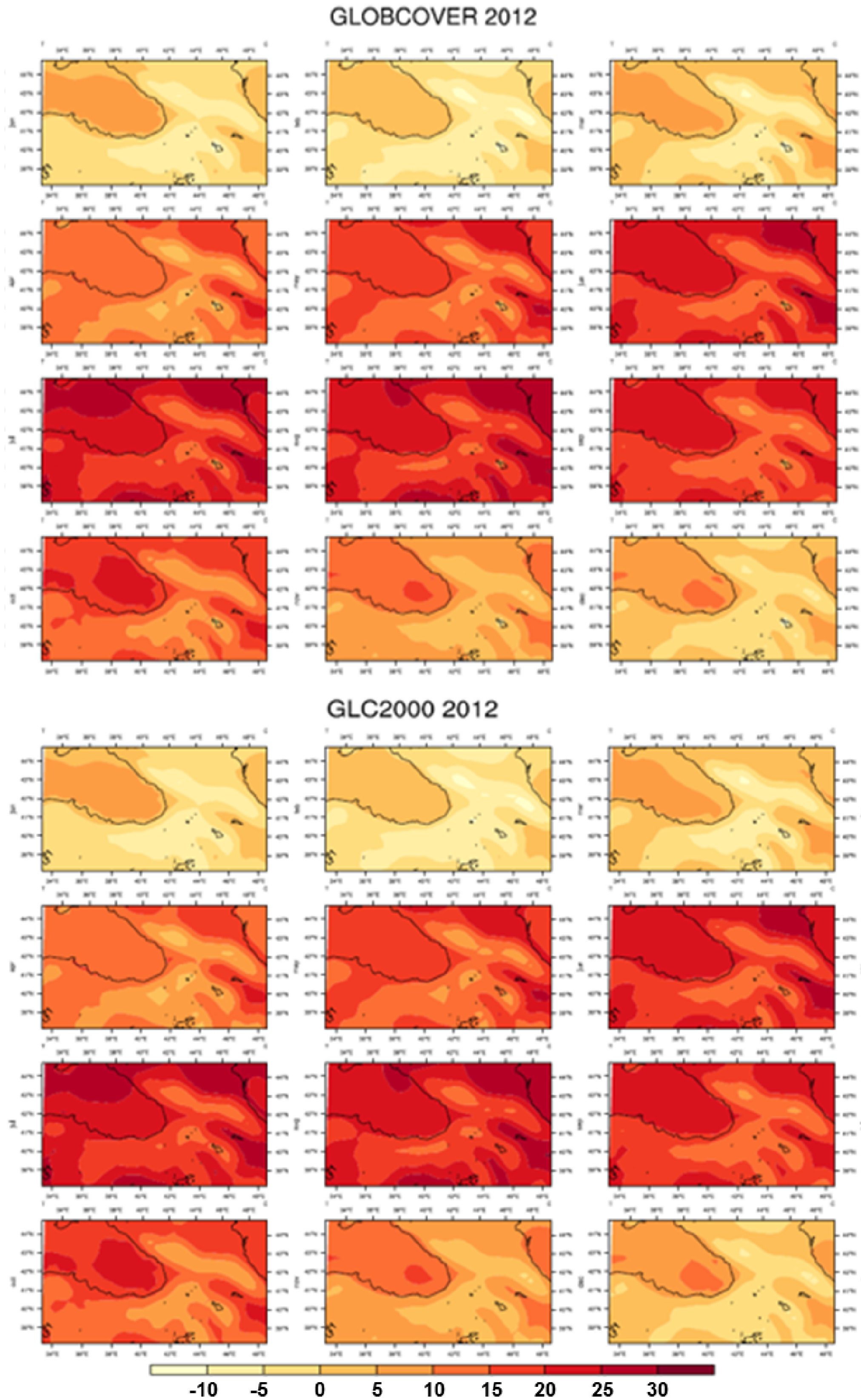

Fig. 6: Monthly mean temperature for GLC2000 and GLOBCOVER land use maps.

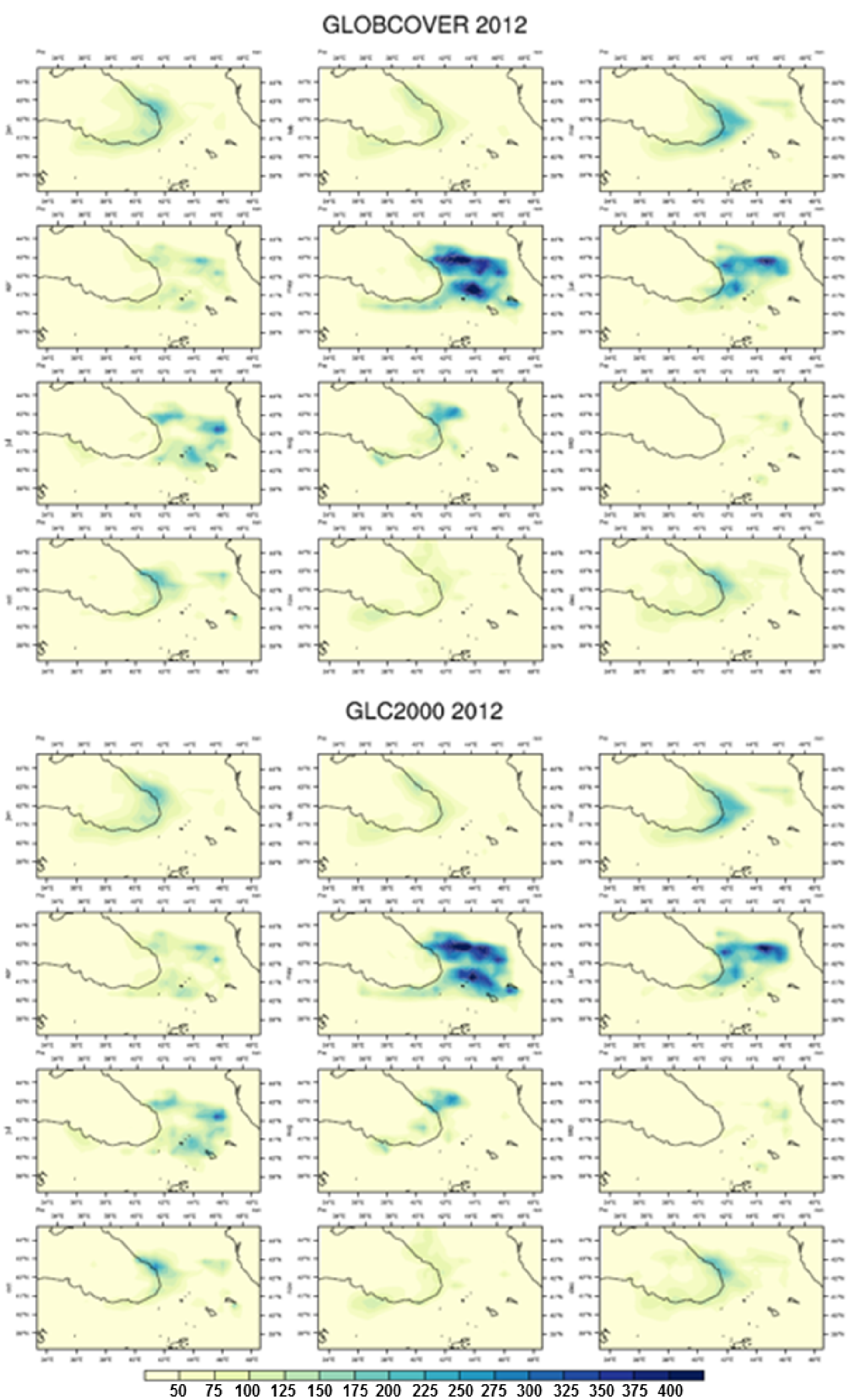

Fig. 7: Monthly total precipitation for GLC2000 and GLOBCOVER land use maps.

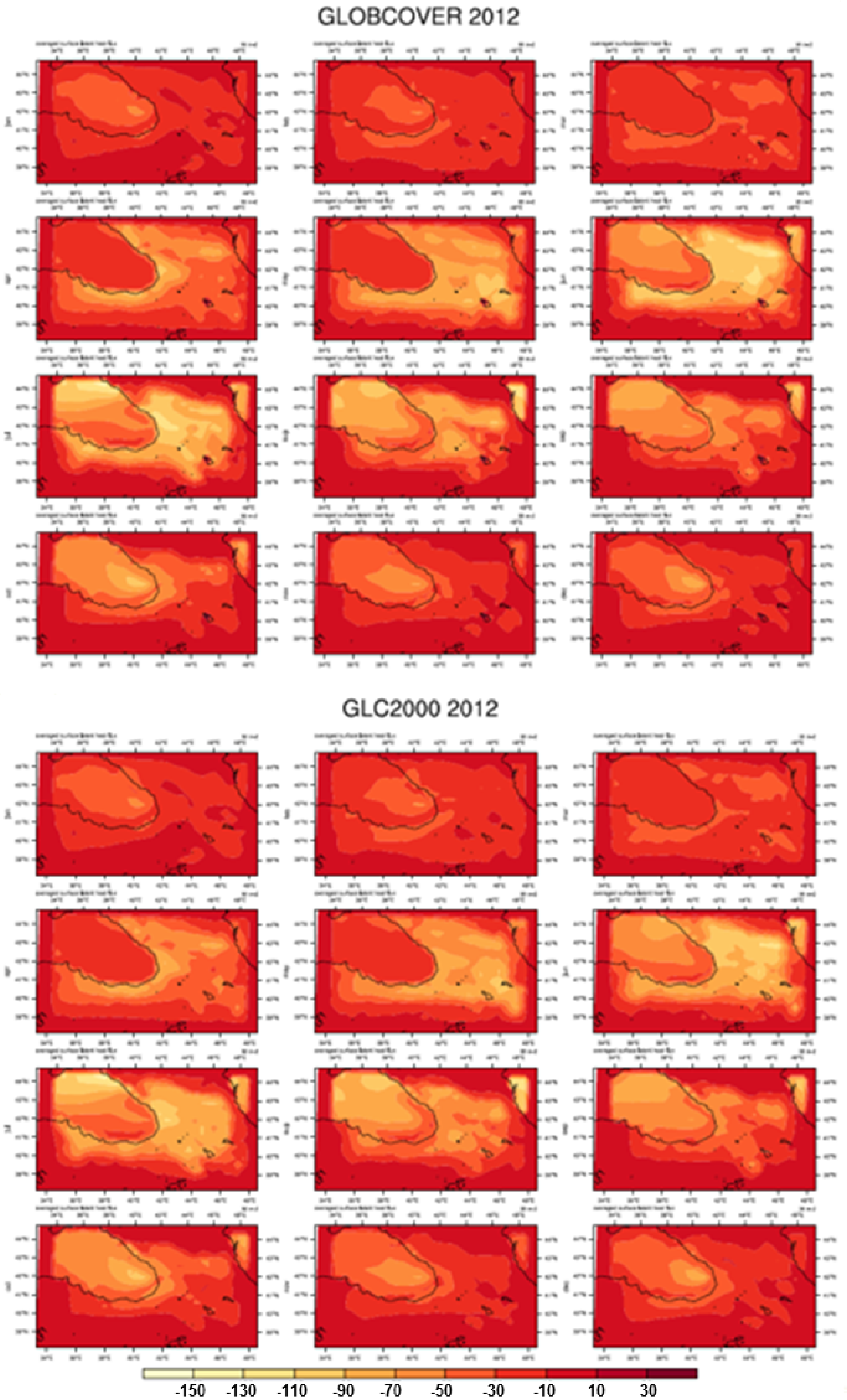

Fig. 8: Monthly mean latent heat flux for GLC2000 and GLOBCOVER land use maps.

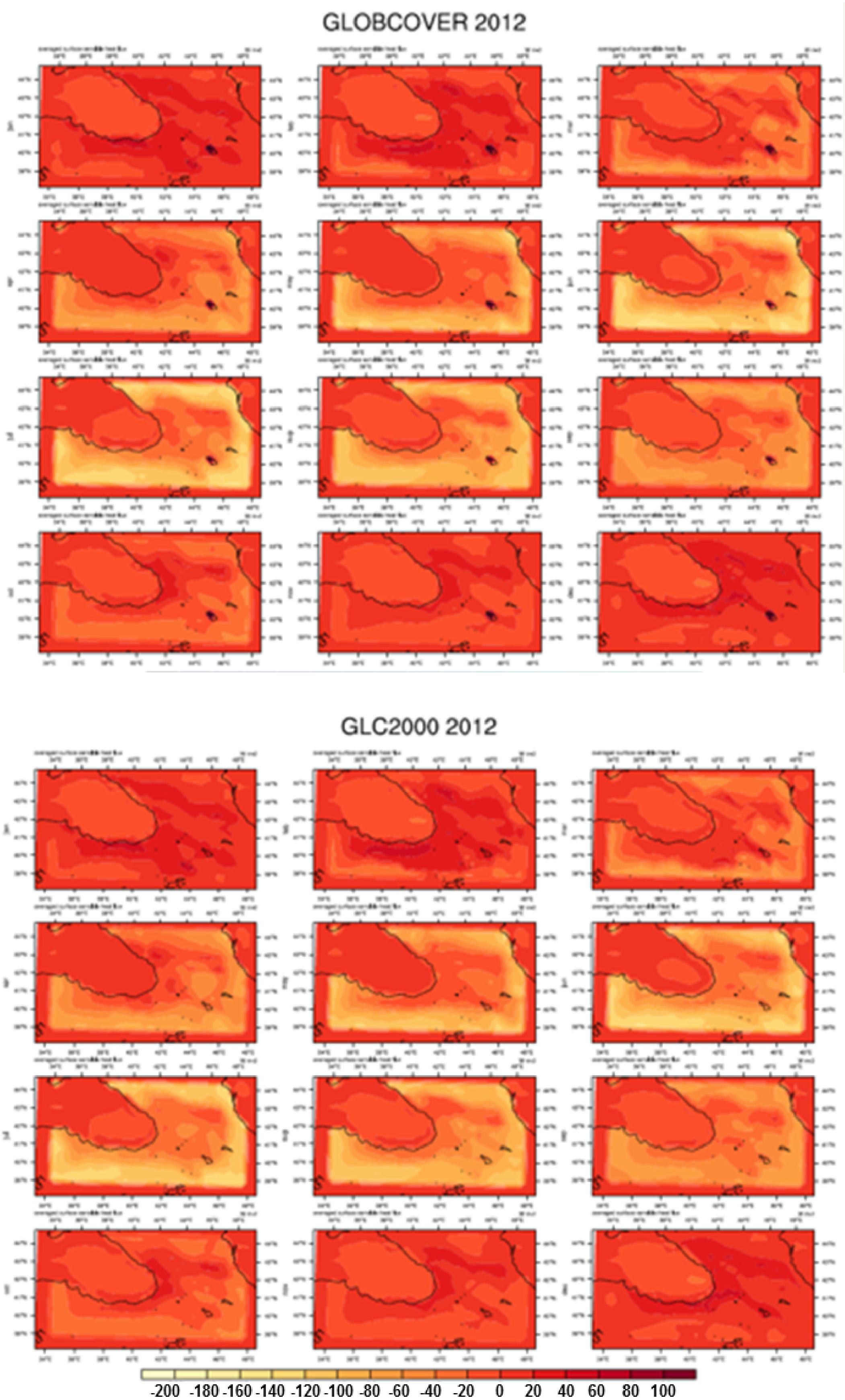

Fig. 9: Monthly mean sensible heat flux for GLC2000 and GLOBCOVER land use maps.

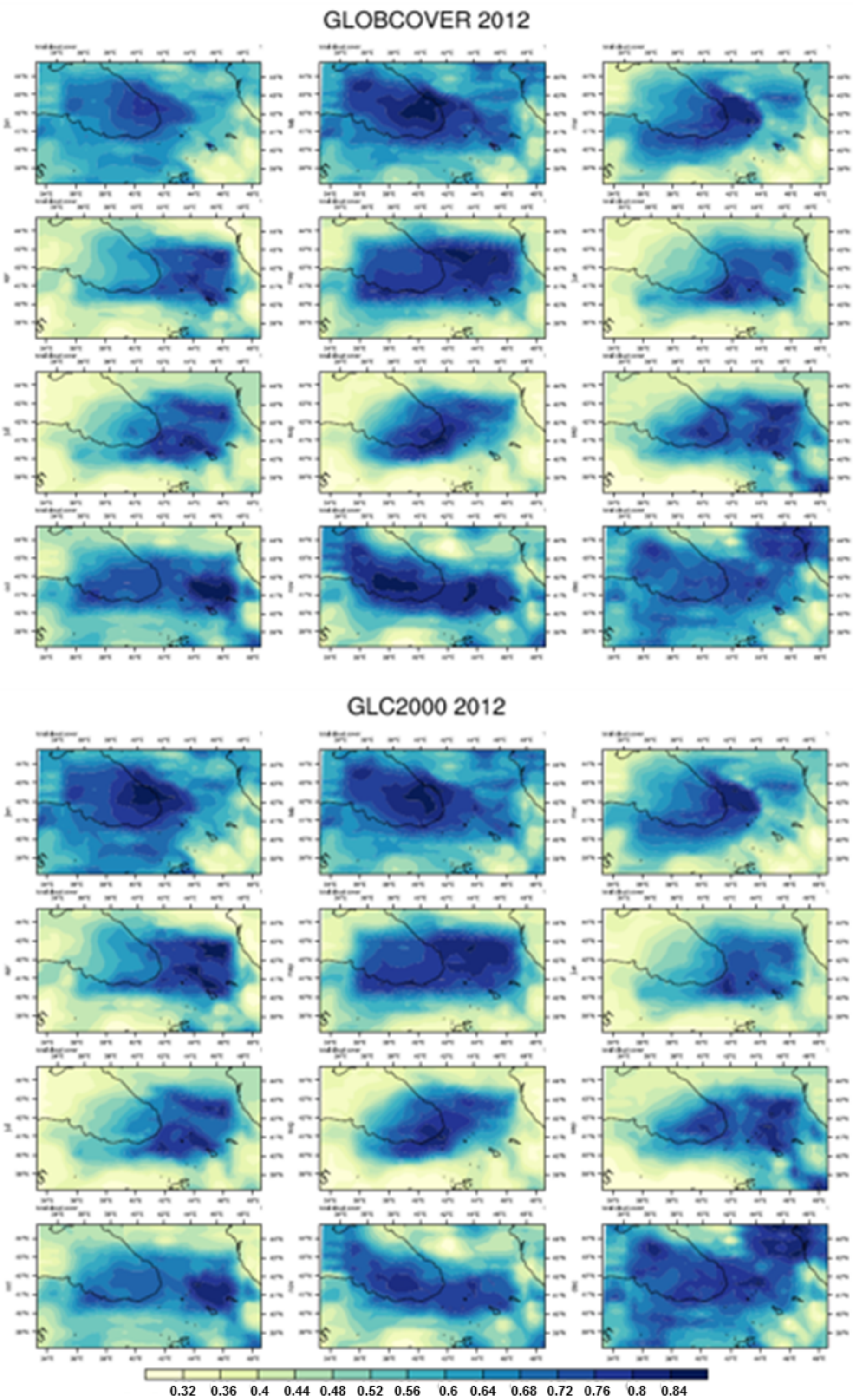

Fig. 10: Monthly mean total cloud cover for GLC2000 and GLOBCOVER land use maps.

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) USA, Mt. Washington being the highest peak at 6289ft MSL (1917m). The flight occurred early in the afternoon because

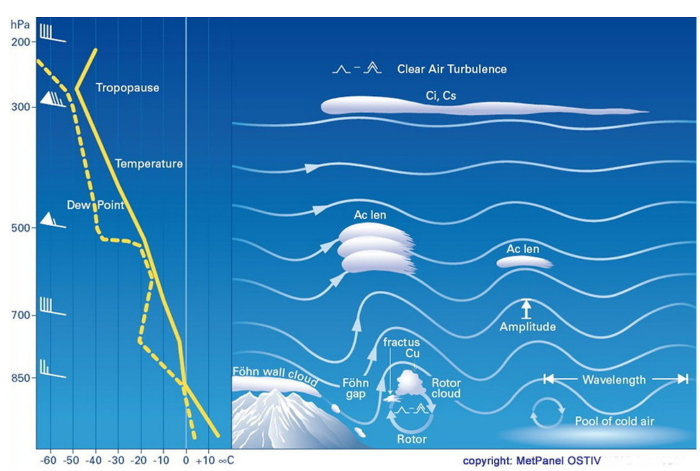

Fig. 1: Common profile (left) and clouds (right) during mountain lee-wave condition, based on Fig. 1.15 in [1].

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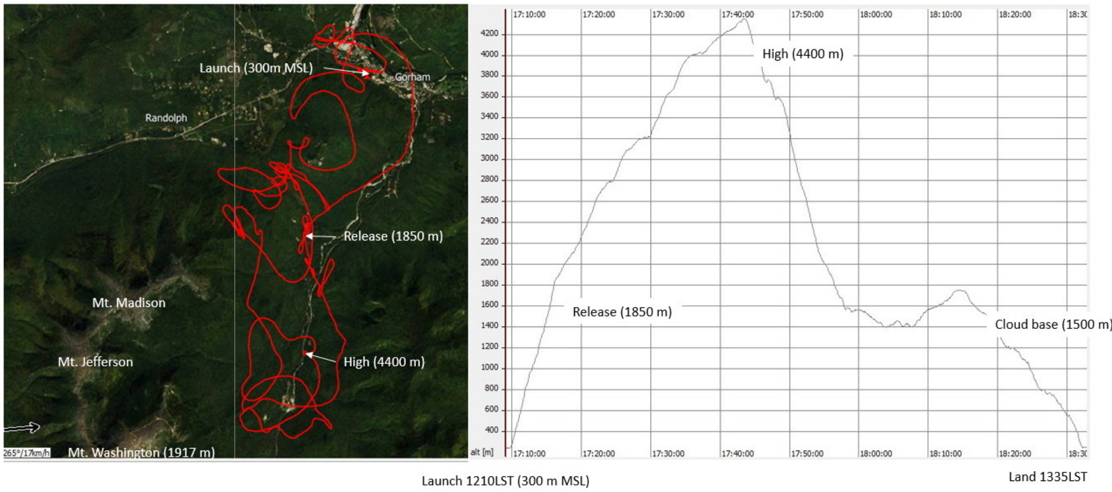


Fig. 2: Flight track (left) and barogram (right) of my 17 October 2014 wave flight from Gorham, NH, USA.

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 USA Geosynchronous Orbiting Environmental Satellite (GOES) visible images for 17 October 2014 (Fig. 4) reveal the closing of the Föhn 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 flying). They show the morning moisture (rainbow in 0853 LST image which looks west) and the gradual drying as the day

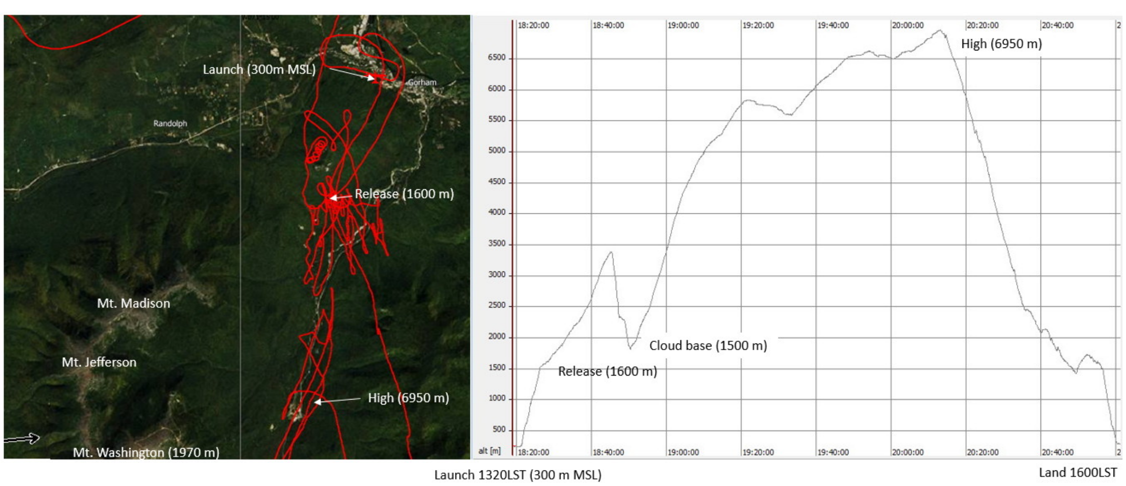


Fig. 3: Flight track (left) and barogram (right) of Tim Chow's 17 October 2014 wave flight from Gorham, NH, USA.

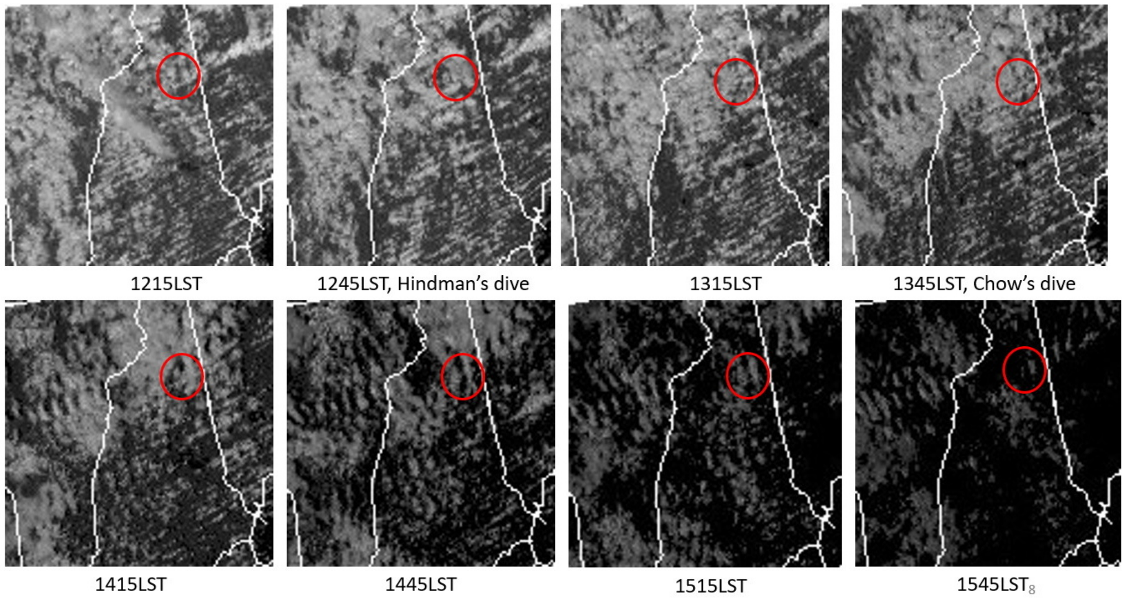


Fig. 4: USA GOES visible images of the clouds associated with the 17 October 2014 wave flights from Gorham, NH, USA. The red circle identifies the Föhn gap.

progressed. But, the drying was not continuous. Occasionally clouds formed obscuring the Föhn 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 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

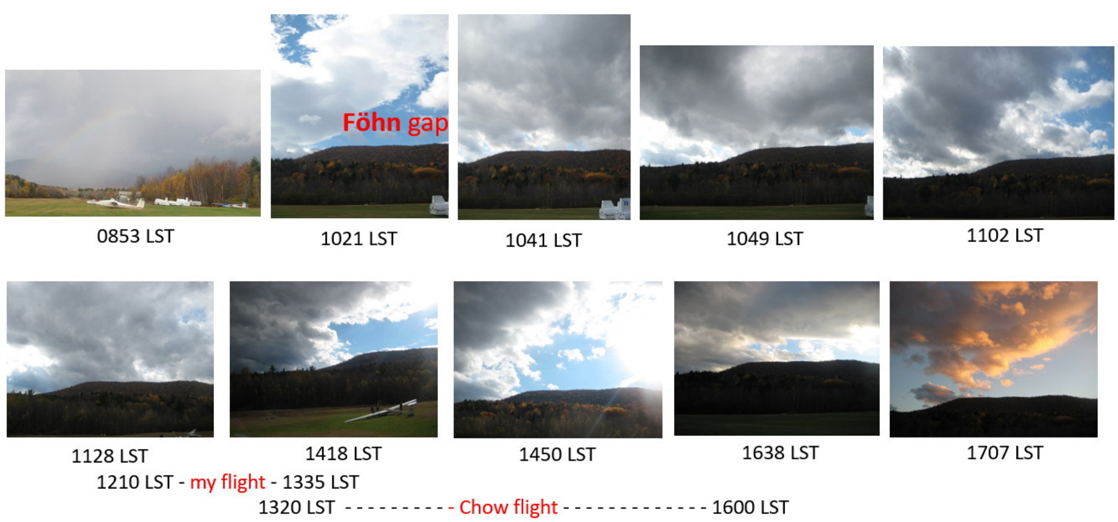


Fig. 5: Images of the clouds associated with the 17 October 2014 wave flights looking south from Gorham, NH, USA. The periods of my flight and Chow's flight are identified.

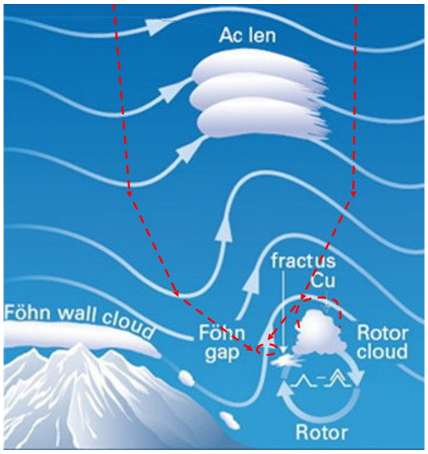
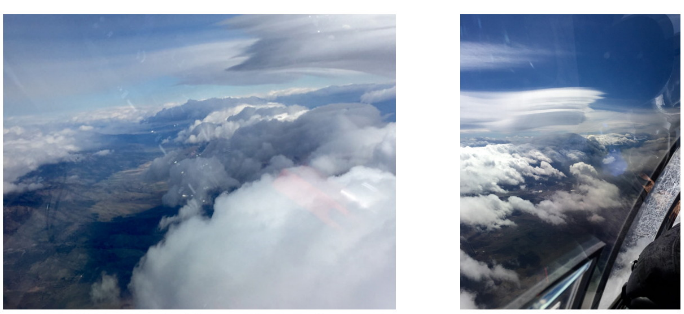


Fig. 6: Probable Spielman descent paths (red dashed lines).

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`).

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 Coombs cloud images were likely similar to the cloud system Spielman attempted to negotiate.



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 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.

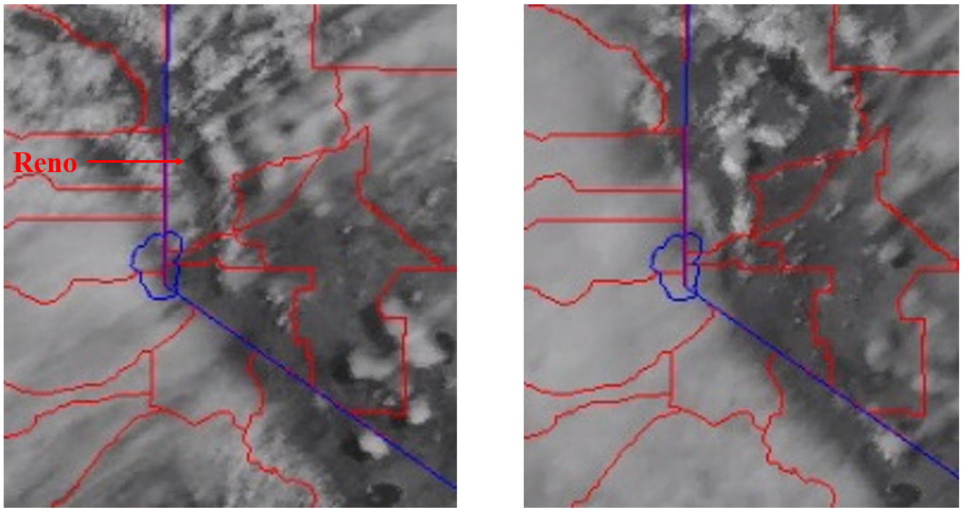
1210-1216 EST: I decided it would be best to retreat down through the last two remaining holes in front of me and then jump back onto the ridge until conditions improved. As I dove for the hole, with sink rates averaging around 20kts and peaking at over 30kts, the primary window closed completely and 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 to anticipate such cloud behavior? Study the forecasted atmospheric profiles of temperature, dew point and winds.

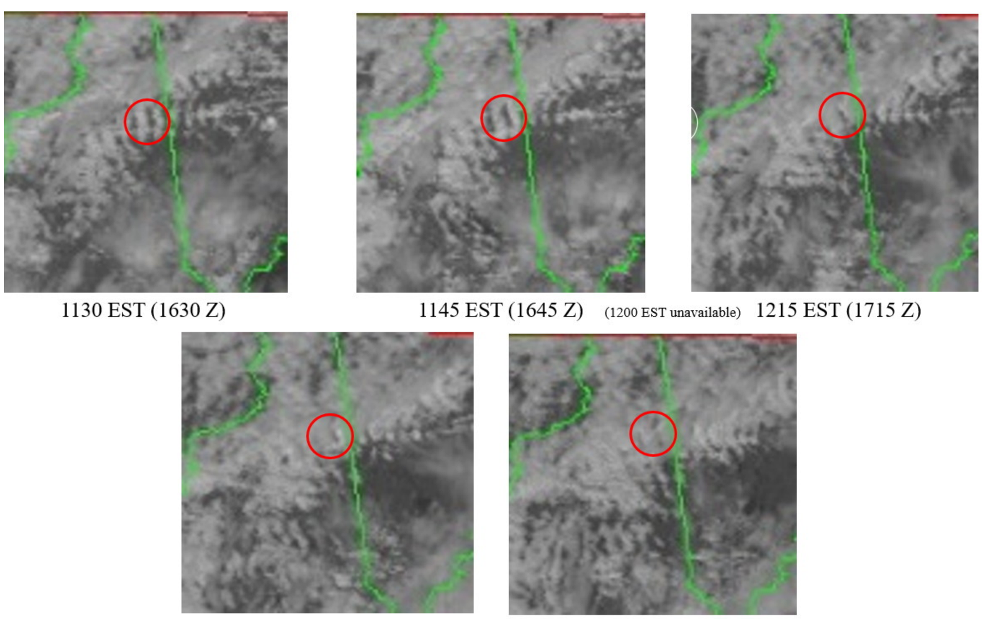


1000 PST (18 Z) 1500 PST (23 Z)

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

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 actual sounding showed the layer to be saturated. Thus, the 12h forecast was inaccurate. But, the actual sounding at 16 EST



1130 EST (1630 Z) 1145 EST (1645 Z) (1200 EST unavailable) 1215 EST (1715 Z)

1230 EST (1730 Z) 1245 EST (1745 Z)

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.

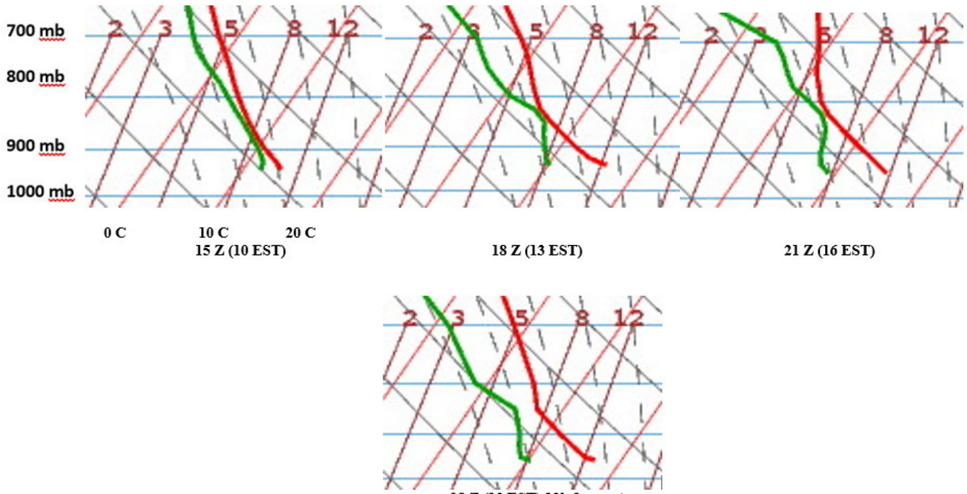


Fig. 10: Top row: the actual atmospheric profiles (0h soundings) during the 17 October 2014 Hindman flight; the rapid descent occurred between 1243 and 1257 EST. Bottom: The 12h (06 Z) forecasted sounding valid for 18 Z.

In these schematics, and those in Figures 11 and 12, 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.

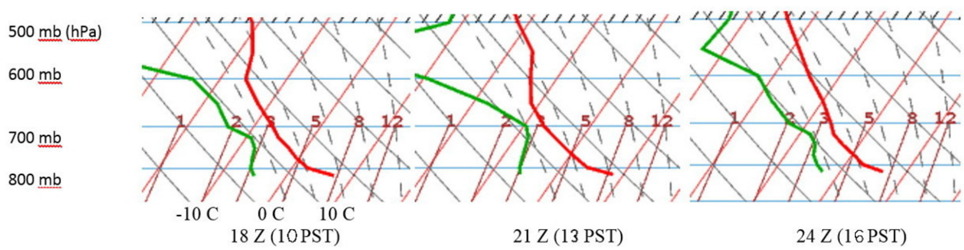


Fig. 11: The actual atmospheric profiles during the 5 April 2015 Spielman flight; the bail out occurred around 15 PST.

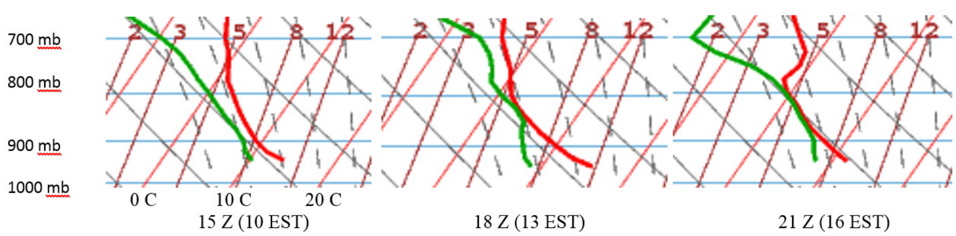


Fig. 12: The actual atmospheric profiles during the 14 October 2015 Giacomo flight; the bail out occurred around 1230 EST.

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.

The soundings during the Spielman and Giacomo flights are compared in Fig. 13. It can be seen the atmosphere was much

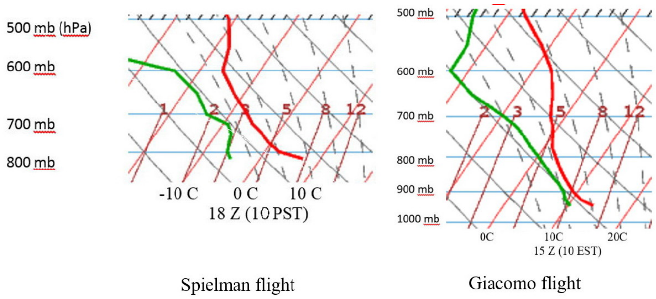


Fig. 13: Comparison of the soundings for the Spielman and Giacomo flights.

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 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

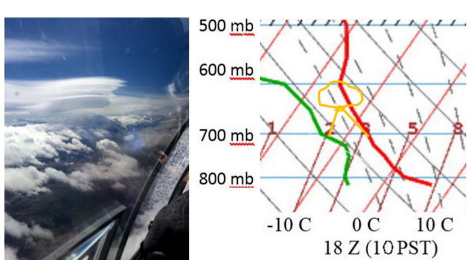


Fig. 14: Schematic of the process that produces rotor clouds in a stable, unsaturated environment. The yellow lines illustrate the cloud formation process.

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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