

# Visualizing Local Weather Characteristics Interpreted from Glider GPS Flight Logs

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## Abstract

*Visualization can aid in improving the validation and evaluation of glider flight logs, which in turn can make the logs more meaningful in flight evaluation and planning. This paper presents techniques to interpret and visualize local weather characteristics derived from glider flight logs. Although glider flight logs only contain discretely sampled position and elevation records, local weather characteristics such as thermal lift and wind velocity can be interpreted from the temporal and spatial components in the logs. A total number of 397 flight logs were used in this study, statistics were performed to identify strong thermal locations, maximum flight altitudes, and weather patterns along flight routes. When the derived thermal features are geo-referenced with 3D terrain models, results support post-flight evaluation and pre-flight planning. For a given flight task, the pilot can derive an optimal flight path based on the presented visualization techniques and the statistics obtained from the historical records.*

Categories and Subject Descriptors (according to ACM CCS): I.3.8 [Computer Graphics]: Applications—

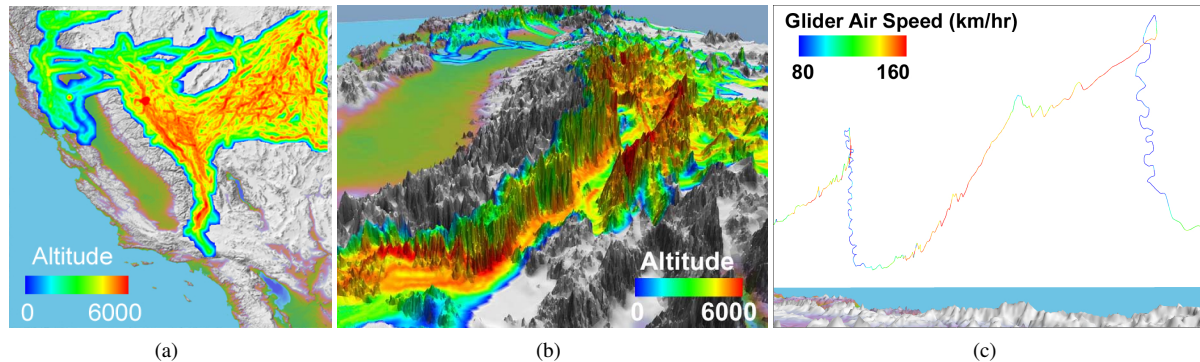
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## 1. Introduction

The proliferation of GPS technology has opened many new application domains in need of precise spatial tracking [Gra99]. In the early 1990's GPS technology was introduced and adopted by the gliding community, initially as a navigational aid, and subsequently as a device to document cross country flights. Rather than having to use a camera to document turning points during a cross country flight, GPS black boxes are now used to track the plane's position (longitude, latitude) and elevation in a certain time interval. While these records are traditionally used to validate that a particular task has been completed, they contain supplementary information that is not yet utilized. For example, during a gliding competition, every single glider is equipped with a flight recorder and its flight path is recorded. As a result, dozens of flight logs spanning many hours are created each day, providing a very detailed record of local weather conditions. While these records are currently only used to determine if a pilot reached all of the defined turning points, when the start gate or finish line were crossed and if all air traffic restrictions (control zones, etc.) were observed, the records also contain important information about the local weather (micro climate) since the plane's longitude, latitude and ele-

vation are recorded in combination with a GPS time stamp. From these records, it is possible to derive other information such as the lift or sink of the surrounding air, wind direction and velocity, as well as location and structure of thermals (lift). In addition, the encoded information reveals insight into geological and topological features, since a direct correlation exists with the development of thermals. With this information in place, data fusion and 3D visualization can provide a means to conceptualize this multi-dimensional data in a geo-referenced format. That is, 3D digital elevation maps, satellite images, flight path information, derived data and meteorological referenced data can be combined into one model and visually represented to provide further insight into local weather phenomena.

From the pilot's perspective, these records also contain valuable information for post-flight evaluation. When correlated with other records obtained that day, it is possible to evaluate which flight segments were chosen and timed well, if thermals were selected efficiently in regards to strength, elevation gain and wind induced displacement, if the best elevation band was selected as a function of local wind profiles, or if decisions were too cautious or too aggressive. Ultimately this holds the promise for gaining an ever better un-



**Figure 1:** (a) Maximum recorded flight altitude map (Latitude: 33-35 N; Longitude: 117-119 W). (b) Digital Terrain models overlapped with maximum altitude map. (c) A segment of flight path revealing a series of thermals, used to gain altitude before further continuing on the cross-country flight.

Understanding about local micro climate and development of strategies that allow these conditions to be fully utilized by pilots. In addition, meteorological visualization allows pilots to extract knowledge from flight records [HBH\*00].

## 2. Visualization of Glider Flight Logs

The visualization methodology developed includes techniques for (i) out-of-core, view-dependent terrain rendering (ii) topographic terrain texture mapping, (iii) glider GPS flight log fusion, and (iv) weather data interpretation. Using this methodology, complex flight datasets can be intuitively presented, enabling detailed evaluation of correlations between flight paths, terrain landforms and local weather patterns.

A flight recorder logs the plane's position at a user specifiable time interval, which is commonly set to 4 seconds. A typical flight log of an 8-hour flight contains 7,200 sample points with a time interval of 4 seconds. Each sample point includes 35 bytes of data including UTC time, latitude, longitude, validity bit, pressure altitude, and Global Navigation Satellite System (GNSS) altitude [Int]. The recorded glider position, also called a fix point, can be connected to reveal the flight path of a glider. The fix points can also be projected onto the ground plane to form a 2D trace. To accurately represent the flight logs, the latitude and longitude values are converted to the northing and easting values using Universal Transverse Mercator (UTM) coordinate, commonly found for USGS topographic maps and many aeronautical charts. Glider flight logs and the statistics can be used to create a variety of statistical maps illustrating, for example, maximum recorded altitude and maximum velocity. Figure 1(a) shows a maximum altitude map compiled from the 397 flight logs used in this study. Figure 1(b) shows the terrain models texture mapped with the recorded maximum altitude map. This map clearly shows that pilots tend to fly higher above ridge

lines in the studied area, benefiting from ridge induced lift and ridge triggered thermals. Ridge lift is the result of the wind striking the hill and rising over its windward side. Long flights can be achieved by traveling solely in ridge lift, but for the flights shown, are commonly dominated by thermals.

### 2.1. Identifying Thermal Lifts from Flight Logs

Thermal formation can be directly linked to geological attributes such as the characteristic of the ground (soil, rock) and its ability to accumulate heat to the extent where the surface temperature exceeds that of the surrounding air and can heat it in turn. Surface density, color, moisture content and orientation in respect to sun position and wind direction, are some of the attributes that will contribute. In addition, topological features such as surface discontinuities contribute as a trigger for the separation of a hot air pocket and the subsequent formation of a thermal. Examples are a vertical elevation change between a field and an adjacent forest or a ridge line. All of these attributes are directly encoded when a thermal is present and to some extent can be extracted from the flight logs.

The criteria used to automatically detect a thermal from the logs, are: (i) changes in heading, (ii) glider velocity, and (iii) altitude gain. Table 1 shows the algorithm to identify thermal lifts for a given glider flight log. Thermal diameters vary in size but are generally big enough to fully enclose a circling gliding plane allowing it to spiral upward. For the gliding plane to climb, the upward motion has to exceed the sink rate of the plane. Pilots in California, will regularly find lift with a relative strength of 2 to 4 m/s but significantly stronger thermals may be encountered. With a common gliding ratio of 40:1, pilots will be able to fly 40 km in distance in exchange for 1,000 m of altitude. The challenge of extended cross country flights is to find the strongest thermals allowing swift altitude gain before continuing to the next lift

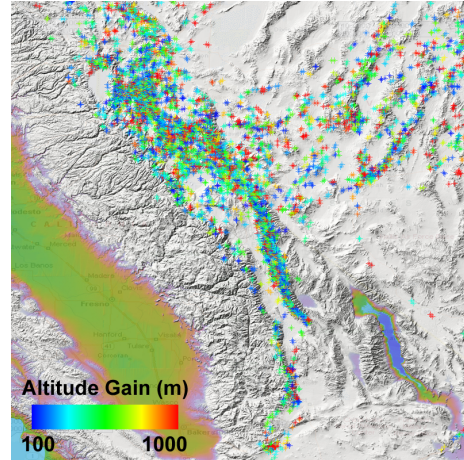
to climb again. Hundreds to thousands of kilometers can be covered this way during a single flight, providing extensive flight logs encoding the discussed weather information. Figure 1(c) shows a series of thermal lifts.

**Table 1:** Pseudocode for identifying thermal lifts of a given flight log. Assume that we are given an array  $P$  which contains the entire sample points from element 1 through  $n$  of a glider flight log.

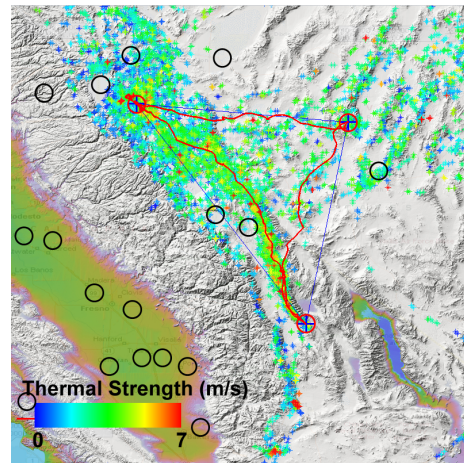
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IDENTITY-THERMALS-OF-A-FLIGHT-LOG( $P$ )
01  $n \leftarrow \text{length}(P)$  // number of sample points in  $P$ 
02 thermals  $\leftarrow \emptyset$ 
03  $c \leftarrow 0$  // counter
04 insideThermal  $\leftarrow \text{FALSE}$  // flag
05 insideThermalPre  $\leftarrow \text{FALSE}$  // flag
06
07 // for every sample point in the flight log
08 for  $i \leftarrow 1$  to  $n$ 
09   insideThermalPre  $\leftarrow$  insideThermal
10
11   // a window of 20 sample points is used to determine
12   // thermal entering and leaving point
13   for  $j \leftarrow 1$  to 20 // for every sample point in window
14      $v1 \leftarrow P[i+j] - P[i+(j-1)]$  // heading direction
15      $v2 \leftarrow P[i+(j+1)] - P[i+j]$  // heading direction
16      $A[j] \leftarrow \text{AngleBetween}(v1,v2)$  // yaw angle change
17
18   // judge this sample point is inside a thermal or not
19   if ( $\forall a \in A : a \geq 30^\circ$  and  $\text{velocity}(P[i]) < 100 \text{ km/hr}$ )
20     insideThermal  $\leftarrow \text{TRUE}$ 
21   else
22     insideThermal  $\leftarrow \text{FALSE}$ 
23
24   // this sample point is entering a thermal
25   if (insideThermal = TRUE and insideThermalPre = FALSE)
26     thermalStart  $\leftarrow P[i]$  // entering a thermal
27     timeStart  $\leftarrow$  recorded time of this sample point
28     positionStart  $\leftarrow$  recorded position of this sample point
29     altitudeStart  $\leftarrow$  recorded altitude of this sample point
30
31   // this sample point is leaving a thermal
32   if (insideThermal = FALSE and insideThermalPre = TRUE)
33     thermalEnd  $\leftarrow P[i]$  // leaving a thermal
34     thermals[ $c$ ]  $\leftarrow$  (thermalStart, thermalEnd) // add to list
35      $c \leftarrow c + 1$  // increase counter
36
37   timeEnd  $\leftarrow$  recorded time of this sample point
38   positionEnd  $\leftarrow$  recorded position of this sample point
39   altitudeEnd  $\leftarrow$  recorded altitude of this sample point
40
41   // compute weather characteristics of this thermal lift
42   altitudeGain  $\leftarrow$  (altitudeStart - altitudeEnd)
43   climbRate  $\leftarrow$  altitudeGain / (timeStart - timeEnd)
44
45   // assume thermal lift is tilted caused by wind
46   horizontalDistance  $\leftarrow$  (positionStart - positionEnd)
47   windSpeed  $\leftarrow$  horizontalDistance / (timeStart - timeEnd)

```



**Figure 2:** Thermal map of identified thermal lifts interpreted from flight logs. A red star indicates an altitude gain of more than 1,000 meters, a blue star indicates a gain of 100 meters. (Latitude: 35-40 N; Longitude: 116-121 W)



**Figure 3:** Stars represent identified thermal lift. Red path is a speed optimized flight log. Blue triangle and red circles (turning points) are the given task route. Black circles are airports that provide weather observation information.

Figure 2 shows the locations of the identified thermals from the flight logs. Color coding is used to present average elevation gain. It shows that most pilots have followed ridge lines closely and have capitalized on a combination of thermals and ridge lifts. Figure 3 shows the strength of thermals in terms of altitude gain per second with a thermal location and strength distribution that visibly follows major mountain ridges. Each star indicates a thermal. The aggregation of all thermal records provides an indicator about the most desirable flight path for a pilot to choose, which on average provides the highest likelihood of good lift. A

speed optimized flight (actual flight shown in red color) for a given task route (blue triangle), overlaid on the thermal map is shown. The black circles in Figure 3 mark locations of weather reports from airports' meteorological observations (METARs), which contain wind direction and speed, temperature, visibility, etc. Available METAR data is sparse for the area of interest but still could be used to identify overall trends to further refining flight route planning. Unfortunately, historic records are not yet readily available (data is only provided publicly for the most recent 24 hours).

## 2.2. Interpretation of Local Weather Patterns

Flight logs can also be used to identify local weather characteristics. For example wind direction and velocity can be determined by further analyzing the derived thermal data. A thermal can be considered a stationary straight column on entirely calm days. However, if a wind component is present, thermals will be displaced according to the wind characteristics at a particular altitude. This means that the column will be reshaped vertically based on the wind profile, which may vary with height. The displacement of the circling plane above ground over time, can then be used to estimate wind direction and velocity at its current elevation.

In Figure 4(a), a semi-transparent cylinder is rendered to illustrate the location of an identified thermal and the gliders flight path is rendered as a continuous polyline. The flight path is color-coded to reveal the velocity of the glider. Red color represents 150 km/h and blue color 90 km/h. Note that there is a difference between plane velocity and above ground velocity. A thermal can be visually identified by correlating plane velocity and continuous changes in flight direction (circling). Figure 4(b) shows a segment of flight path entering a thermal lift. The horizontal red lines illustrate the horizontal offset from the vertical line that marks where the glider first enters this thermal lift. The 3D arrows in Figure 4(c) visualize the horizontal wind direction interpreted from the flight data. Arrow direction and length are used to encode wind direction and velocity, respectively. Color coding is added to the arrow as an additional means to map wind speed. Figure 4(d) shows a regional view of the wind direction interpreted from a flight log. This plot shows drastic directional changes for the wind direction, which have also been observed with other measurement techniques. To ease data interpretation, thermals can be subdivided into several segments. For this example, a fixed vertical interval of 100 meters was chosen to bin the available information. Semi-transparent cubes are then rendered (Figure 4(e)) to represent the calculated wind speed of a segment within a thermal. For each segment, the wind speed and direction are calculated from the glider's horizontal offset. Figure 4(f) shows that thermal lifts are rendered as scalable self-oriented surfaces to speed up rendering performance [SM02]. For the studied example, it can be observed that wind speed varies over different elevation bands.

## 3. Conclusions

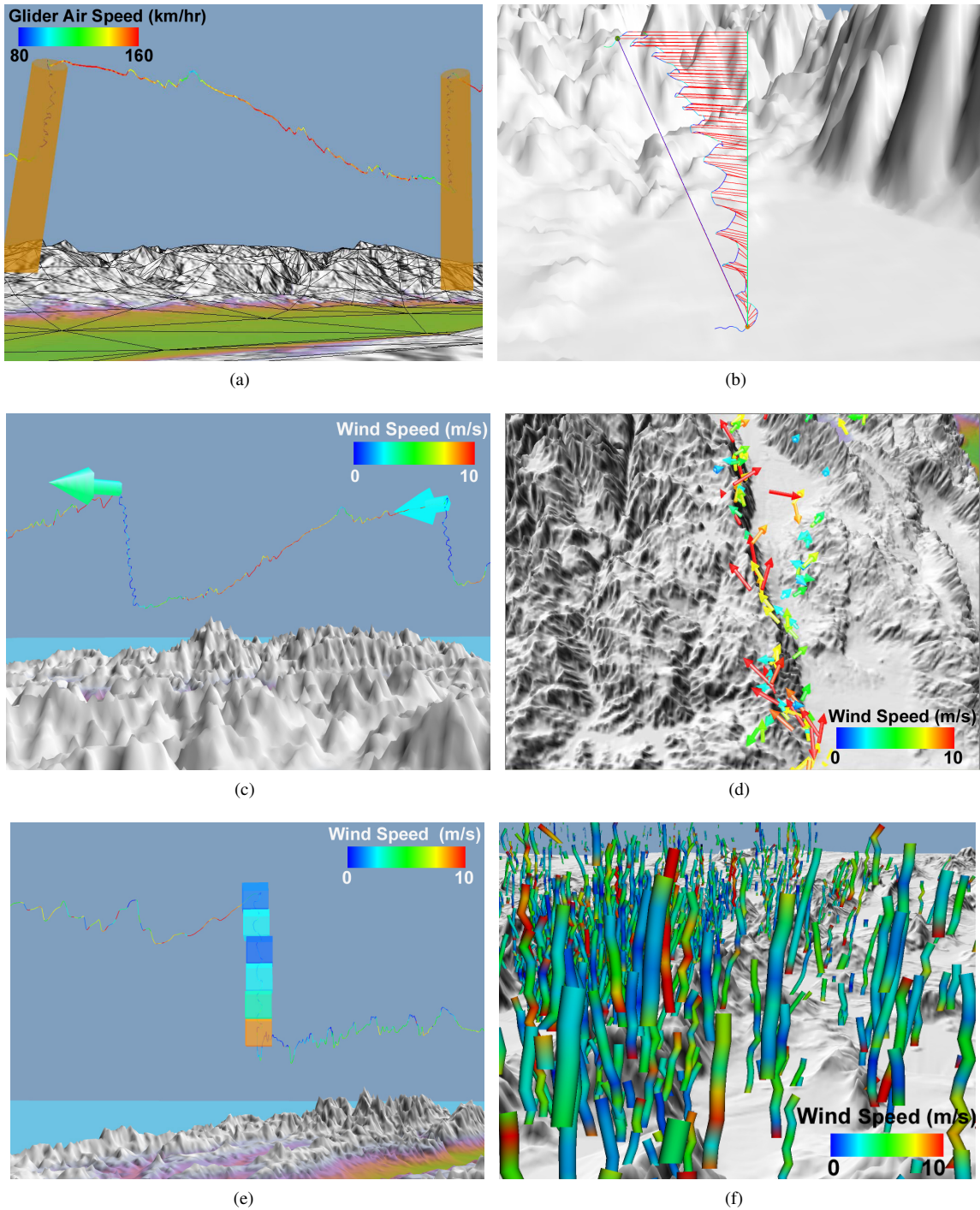
This paper presents data mining and visualization techniques for glider flight logs that can be used to derive local weather characteristics. A visualization strategy that geo-references flight path information and derived meteorological data with texture mapped 3D digital elevation models is presented to aid with data interpretation. The flight logs used in this study provide a continuous sample of the traversed atmosphere and provide a unique data source that can be used to augment more traditional acquisition techniques such as weather balloons and other ground and space-based remote sensing platforms. However, compared with weather balloons, which provide only a coarse sampling rate along a wind directed path, flight logs provide detailed samples that are generally aligned with thermally active areas, which can especially affect local climatic, regional changes. Furthermore, such datasets cover a broader area than ground weather observation stations. Visualized flight log data and extracted weather patterns can be used to derive an optimal flight path for a given task, taking advantage of those hot spots of strong thermals that are most likely to occur. Although glider flights occur during daytime, the extracted weather characteristics are useful not only for flight planning, but also for interpreting shifts in regular patterns. It should also be pointed out that weather-based data, which provides optional glider conditions also provides indication for the aviation industry in general. For example, thermals provide indication for other airborne vehicles about the sources of locations of undesirable turbulence regardless of whether the airborne vehicle is motorized or not. Local phenomena such as lift, sink, wind speed and direction can be derived and correlated with land surface properties providing information about local weather characteristics.

## 4. Acknowledgements

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## References

- [Gra99] GRAHAM J.: The impact of new technology on general aviation: global positioning system receivers, the Federal Aviation Administration, and the small aircraft pilot. In *Proceedings of 1999 International Symposium on Technology and Society* (1999), pp. 99–104. 1
- [HBH\*00] HAASE H., BOCK M., HERGENRÖTHER E., KNÖPFLE C., KOPPERT H., SCHRÖDER F., TREMBILSKI A., WEIDENHAUSEN J.: Meteorology meets computer graphics - a look at a wide range of weather visualisations for diverse audiences. *Computers & Graphics* 24, 3 (2000), 391–397. 2
- [Int] INTERNATIONALE F. A.: *Technical Specification for GNSS Flight Recorders*. International Gliding Commission. 2
- [SM02] SCHUSSMAN G., MA K.-L.: Scalable self-orienting surfaces: A compact, texture-enhanced representation for interactive visualization of 3D vector fields. In *Proceedings of the 10th Pacific Conference on Computer Graphics and Applications* (2002), pp. 356–365. 4



**Figure 4:** (a) Semi-transparent cylinders are thermal lifts identified from flight logs. (b) A segment of flight path entering a thermal lift. (c) 3D arrows indicate wind direction interpreted from flight path analysis. (d) Regional view of wind direction (California and Nevada). (e) Calculated wind speed of the airspace above Fresno, California. Semi-transparent cubes show wind speed at a 100-meter interval. (f) Each thermal lift is rendered as a scalable self-orienting surface.