Using UAV Technology to Collect Vertical Temperature and Relative Humidity Profiles over a Tropical Montane Rainforest

Elizabeth Prior[1], James Brumbelow[2], Gretchen Miller[2], and Georgianne Moore[2]

[1]Auburn University
[2]Texas A&M University College Station

November 26, 2022

Abstract

Unmanned aerial vehicles (UAV) have been increasingly used for field data collection and remote sensing purposes. Their ease of use, ability to carry sensors and cameras, low cost, and precise maneuverability and navigation makes them a versatile tool for a field researcher. Procedures and instrumentation to use UAVs in the field are largely undefined, especially for atmospheric and hydrologic applications. A field study was conducted to test the UAV's ability to collect atmospheric data in order to locate and analyze the canopy boundary layer (CBL) above a Costa Rican tropical montane rainforest. This study aims to give further insight on the changes of the CBL throughout the day and for atmospheric comparison to land development. Through the study, it was found that there was little previously defined procedures and preferred instrumentation that directly applied to the UAV field study. Because of this, the methodology of using an UAV for atmospheric and CBL remote sensing and data collection was developed and refined by testing and comparing precision and performance of sensors and executing systematic flight patterns throughout the day. The UAV allowed for quick and specific access to sampling locations and for all of the variables to be measured by sensors over vertical profiles. Flights were scheduled at different locations throughout the day over the Texas A&M Soltis Center and surrounding forest in San Isidro, Costa Rica. Vertical profiles were also measured over the Soltis Center grounds to determine how development has affected the presence of the CBL. The UAV was successful in gathering data above the forest canopy and the Soltis Center at varying elevations during clear and cloudy conditions. The procedure produced reliably consistent vertical profiles over small domains in space and time, validating the general approach. The technique also identified unique profiles at spatially and temporally distinct sample sites including response to meteorological events. These findings suggest a healthy ability to diagnose CBL characteristics of interest. It was also found that there is a distinct increase in temperature and dew point over land development when compared to over forest. Future studies include flights at other locations and determining preferred instrumentation for UAV atmospheric data collection.

Pioneering Analysis of the Canopy Boundary Layer Using UAV Technology to Collect Vertical Profiles over a Pre-Montane Tropical Rainforest

Elizabeth M. Prior[1], Dr. Kelly Brumbelow[2], Dr. Gretchen Miller[2], Dr. Georgianne Moore[3]

[1]Department of Civil Engineering, Auburn University, AL; [2]Zachry Department of Civil Engineering, Texas A&M University, TX; [3]Department of Ecosystem Science and Management, Texas A&M University, TX

Introduction

Unmanned aerial vehicles (UAV) are being increasingly utilized for field data collection and remote sensing purposes. UAVs are a versatile tool for field researchers because of their ability to carry sensors and cameras, ease of use and maneuverability and their low cost. We conducted a field study to test the UAV's ability to collect atmospheric data as to locate and analyze the Costa Rican pre-montane tropical rainforest canopy boundary layer (CBL). We aim to give further insight on the CBL hourly changes and atmospheric comparison to land development. The CBL is important because it is a key component of water and gas exchange between the atmosphere and land surface, thus potentially influencing future climate models.

Study Sites

Texas A&M Soltis Center in San Isidro, Costa Rica

- Soltis courtyard: 452 masl (m above sea level)
- Mountain Sites 1, 2, and 3: profiles taken at 525-600 masl
- Far Ridge Site: profiles taken at 500-610 masl (35-145 magl)
- Near Ridge Site: profiles taken at 470-610 masl (35-175 magl)

Figure 1: Map of Sample Sites, Image from Google Earth

Equipment

UAV: Autel Robotics X-Star Premium
- GPS/GLONASS satellite navigation

Sensor 1: Kestrel DROP D3FW Fire Weather Monitor
- 17.35mm diameter, 5.89mm height
- Measures air temperature, relative humidity and barometric pressure
- Calculates heat stress index, dew point, and wet bulb temperature

Sensor 2: DS1923-F5# Humidity and Temperature iButton
- 6 x 4.5 x 2.3 cm
- Measures air temperature and relative humidity

Figure 2: (from left to right) sensor 2, sensor 1, UAV

System Setup

1. We did several tests to determine how far underneath the UAV the air was undisturbed
   - The UAV hovered at varying elevations while the wind was measured at 1m above ground level (see Figure 3).
     - We determined that the air was undisturbed at 7.5m below the UAV

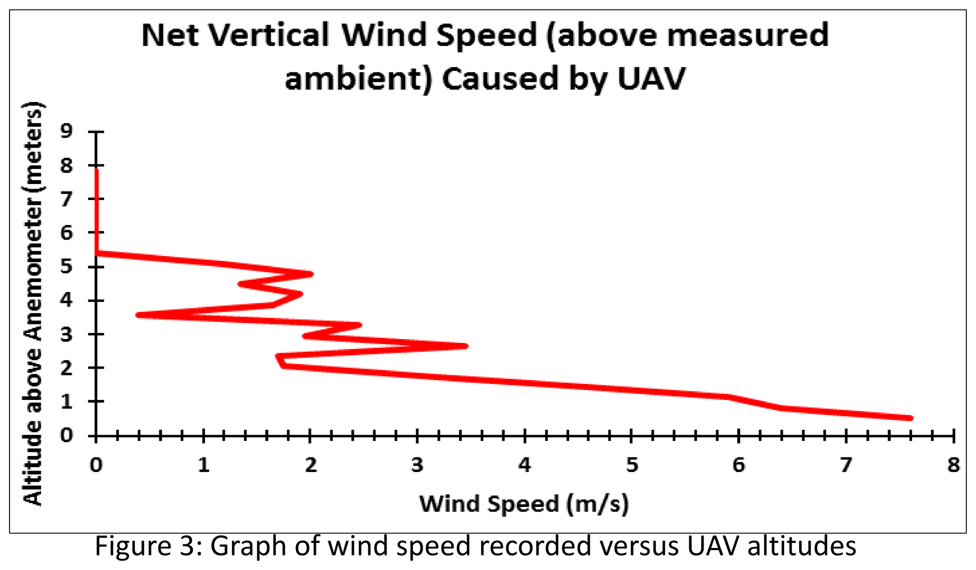

Figure 3: Graph of wind speed recorded versus UAV altitudes

2. The Kestrel and iButton sensors were hung approximately 7.5m from the UAV landing gear using monofilament.
3. Sensors were reset to record measurements.

Figure 4: Before launch setup

Methods

1. The UAV launched from the Soltis Center parking lot. While the UAV was taking off, the sensors and monofilament were held taut and slowly released as the UAV rose to prevent the monofilament being tangled in the propellers.
2. The UAV flown vertically upwards to 600 masl.
3. Then it was flown at 600 masl to one of the sample sites.
4. Once over the sample site, the UAV was then lowered at approximately 1 m/s until the sensor was as close to the forest canopy as possible. A second person with binoculars acted as a spotter to assist this process.
5. The UAV was then flown back upwards to 600 masl.
6. The other nearby sample sites were then visited, and vertical profiles were taken using the same procedure.
7. Videos were recorded for each flight to verify consistency in procedure and locations.

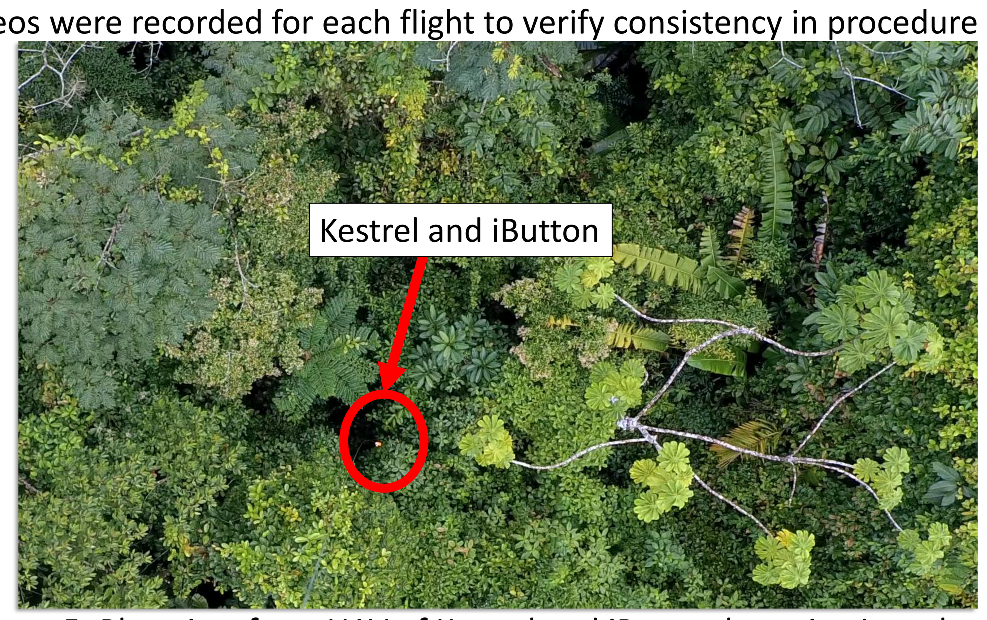

Figure 5: Plan view from UAV of Kestrel and iButton lowering into the canopy

Results and Discussion

Result 1: Comparing Sensors

Table 1: Sensor Comparison

Comparison	iButton	Kestrel
Measured Variables	• Measures air temperature and relative humidity. • Dew point was calculated using Arden Buck Equation (Bolton 1980).	• Measures air temperature, relative humidity, dew point and barometric pressure
Precision	• Air Temperature: 0.5°C • Relative Humidity: 0.6% RH	• Air Temperature: 0.1°C • Relative Humidity: 0.1% RH •Pressure: 0.1 mbar • Dew Point: 0.1°C
Durability	Worked every time	Stopped working after 10 flights
Cost	$165.52	$99.00
Conclusion	Durable, but does not measure enough variables and precision is lacking for our needs	Not durable, but measures all variables needed with great precision

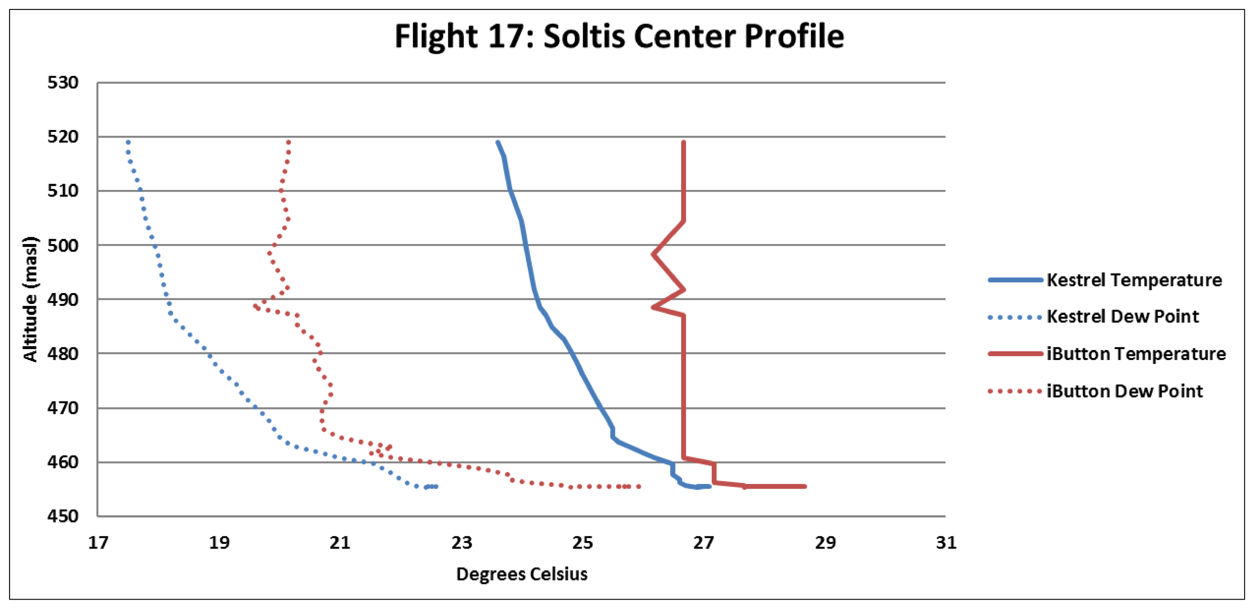

Figure 6: Example graph comparing iButton and Kestrel data

Result 2: Mountain Sample Set

- This data set consists of two flights on the same day. The common route for the flights included the three Mountain Sites (see Figure 1).
- This data was taken to see if air temperature or dew point would vary when measured at the same location, but at different parts of the day along an elevation gradient.
- The data set shows that the temperature throughout the period stays within a range of 22.3 to 22.9 °C for air temperature and within a range of 20.5 to 21.5 °C for dew temperature.
- **Overall, this dataset shows high consistency over relatively small scales of time and space with minimal meteorological variation, validating the overall methodology.**

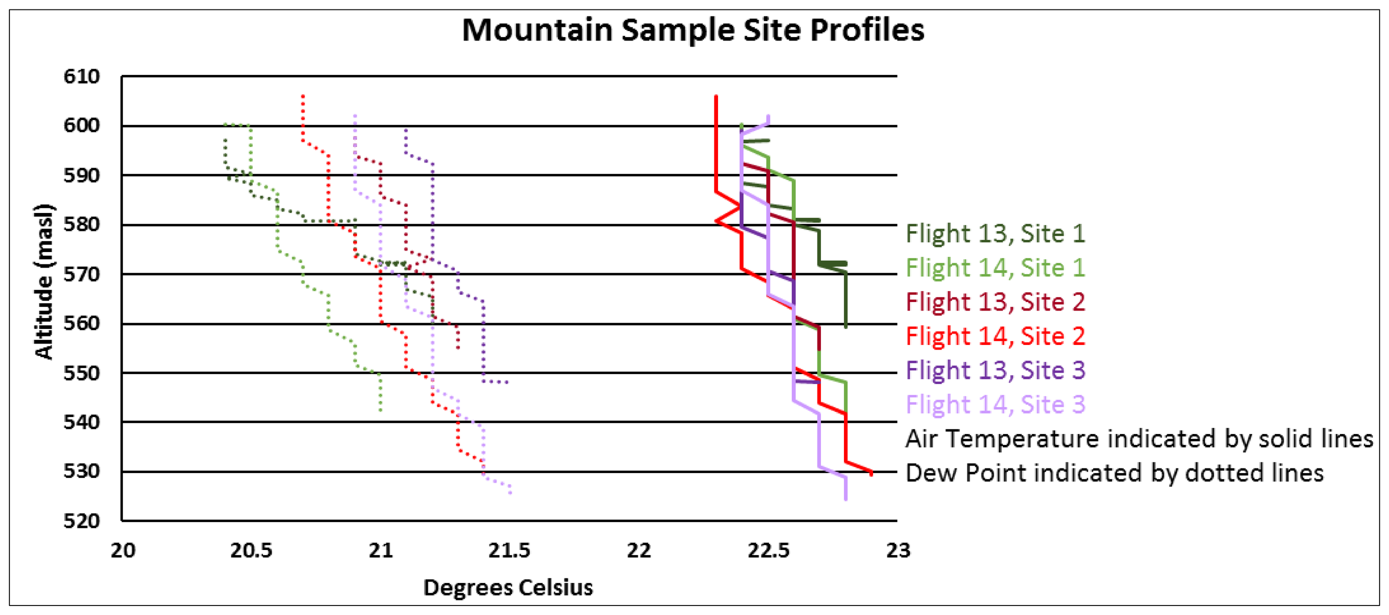

Figure 7: Over of Mountain Sample Site Descents

Table 2: Flight Weather Information

Flight #	Start	End	Met Tower Weather Status
13	16:03:14	16:19:38	No rain since 9AM, air temp and solar rad decreasing, RH increasing
14	18:02:54	18:16:42	No rain since 9AM, air temp decreasing, no solar rad, RH increasing

Results and Discussion Continued

Result 3: Far and Near Ridge Sample Set

- Three flights were done over the course of one day to measure profiles at the Far and Near Ridge Sites (see Figure 1).
- These locations were chosen due to their separation in distance (~130 m) and topography – the deep Howler Monkey stream ravine lies between them.
- **Profiles at both sites (see Figures 11 and 12) show that the dew point at the canopy is constant over the day, suggesting CBL influence over humidity even while humidity values vary away from the canopy.**
- Air temperature profiles were very consistent throughout the day at the Far Ridge Site (like the Mountain sites).
- However, the Near Ridge Site shows significant variation in profiles during the day with various inflections and temperature inversions present. These changes may have been influenced by meteorology during the day.

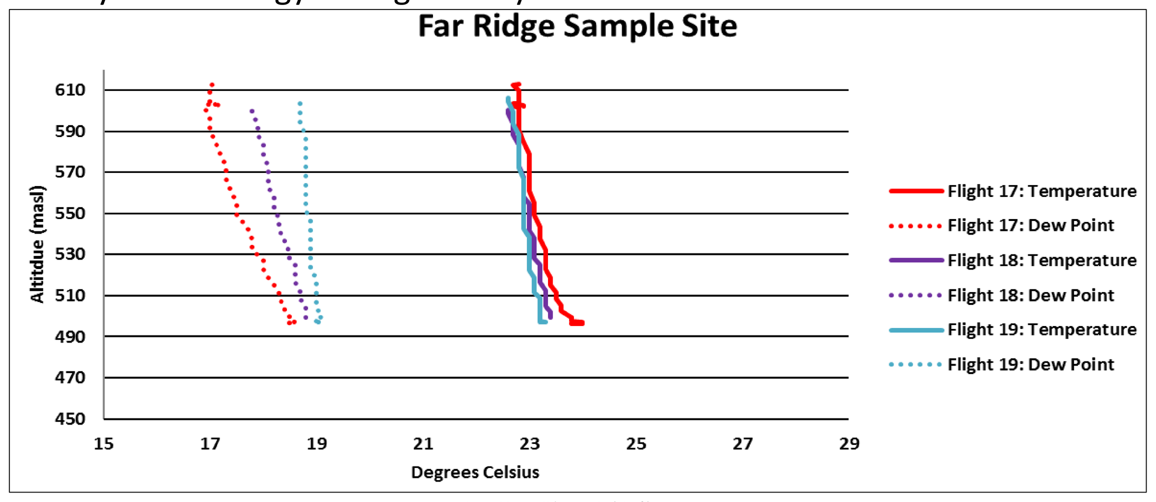

Figure 10: Far Ridge Vertical Profiles

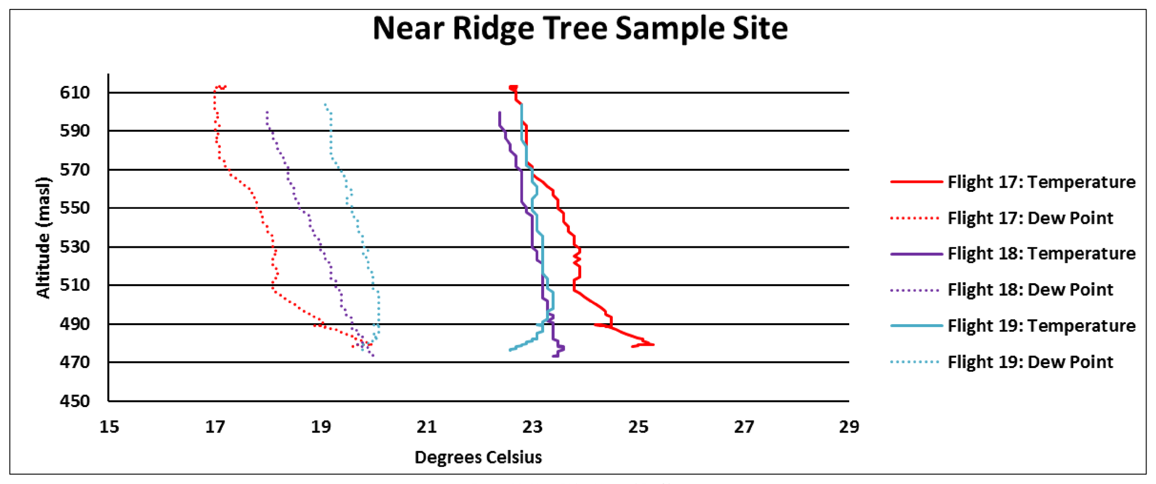

Figure 11: Near Ridge Vertical Profiles

Figure 11: Near Ridge Vertical Profiles

Flight #	Start	End	Met Tower Data Status
17	10:51:19	11:07:36	Highest air temp, lowest RH, highest wind speed, similar 18 solar rad
18	12:48:52	13:01:58	Higher air temp than 19, higher RH than 17, similar 19 wind speeds, similar 17 solar rad
19	16:36:33	16:51:17	Right after rain event, lowest temp, highest RH, similar 18 wind speeds, lowest solar rad

Result 4: Boundary Layer Due to Land Development

- Each flight started and ended with a vertical profile of the Soltis Courtyard.
- Throughout all 19 flights, there was a distinct jump in air temperature and dew point in a short amount of altitude change (from 490 to 460 feet) when lowering down to the Soltis Courtyard.
- **These profiles demonstrate a pronounced boundary layer effect due to development.**

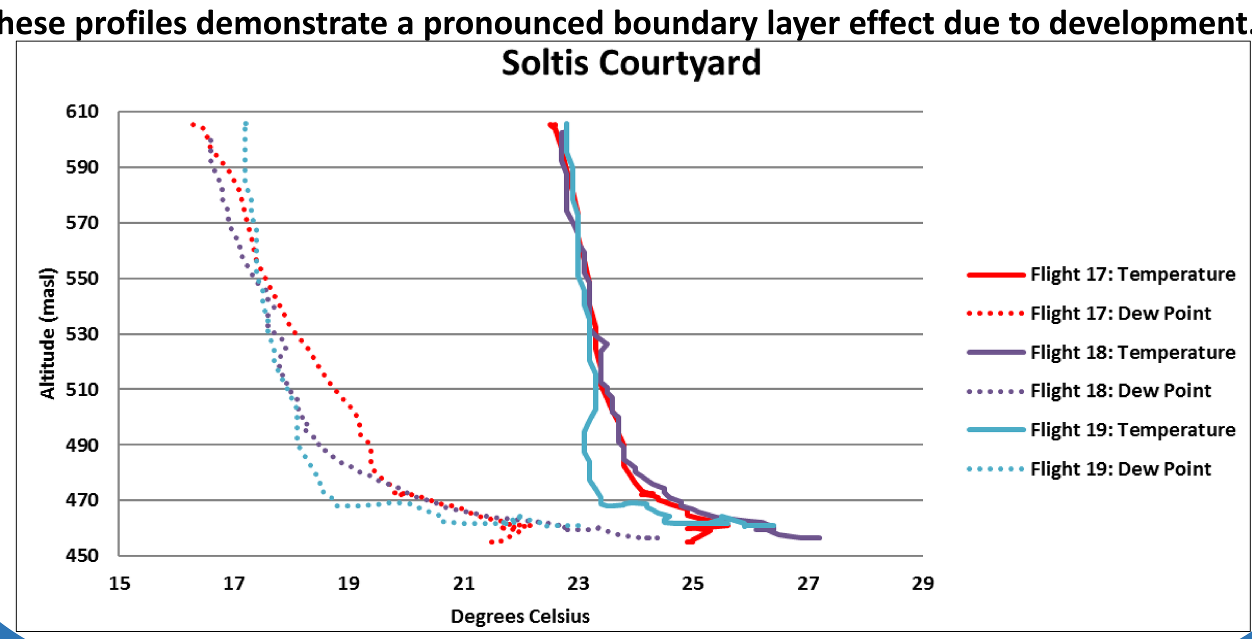

Figure 12: Soltis Courtyard Vertical Profiles

Conclusions and Future Studies

- UAV usage for locating, measuring and analyzing the CBL microclimate seems to be a promising methodology and viable alternative to other remote sensing technology such as tethered balloons and dropsondes.
- The Kestrel meteorological instrument recorded more parameters with more precision and was cheaper when compared to the iButton instrument. However, during the field study, the Kestrel stopped working after 10 flights.
- The Mountain Sample Set shows that the vertical atmospheric profiles measured using these techniques are relatively consistent over small scales of space, time and topographic gradient without exogenous meteorological events.
- The Far and Near Ridge Sample Set demonstrates that the technique can identify CBL phenomena in both temperature and humidity profiles.
- Graphs generated of the Soltis Courtyard show the boundary layer of the land development to be pronounced and closer to ground elevation when compared to canopy data.
- Further study includes repeating flights at the Texas A&M Soltis Center and other locations
- Methodological refinements are needed to determine standardized procedures and instruments.

Acknowledgements: Funding for this Research Experiences for Undergraduate program is provided by the National Science Foundation's Division of Earth Sciences (EAR-1659848).

References: Bolton, D. 1980. The computation of equivalent potential temperature. Monthly weather review 108:1046-1053.