Climate-Aquatics Workshop Blog Mailing #6: Thoughts on monitoring air temperatures in complex, forested terrain.

Hi Everyone,
As a follow up to last week's blog post regarding the utility of developing high resolution climate models from massive sensor networks, this week we have Zack Holden, Ph.D. and Data Analyst out of Forest Service Region 1, guest blogging regarding some of the work he's involved in to monitor air temperatures using inexpensive sensors across the northern Rockies...

By Zack Holden
Most available climate/weather stations (e.g., COOP stations) are located in valleys. The few high elevation stations we have (RAWS, SNOTEL) and are relatively sparse, so do not adequately capture temperature variation in steep complex topography. There is growing awareness of just how much information current air temperature models are missing in complex mountainous terrain. For example, cold air drainage and lapse rates vary from night to night. Many terrestrial management decisions (tree planting, growth and yield, species occurrence, etc.) are made at the stand or aspect scale, due to variation in solar insolation, and temperature predictions must match that scale in order to be useful for site-level predictions. For aquatics applications, one of the most important questions is understanding the mechanisms associated with how streams warm up & whether that information can be used to predict which types of streams will be more/less sensitive to future changes. As a result, there is growing interest in using inexpensive sensors to develop massive air temperature monitoring arrays in mountains. We are now beginning to make progress in using sensor networks to empirically downscale temperatures in complex topography (see Holden et al. (2011); Holden et al. (in press); and attachments). However, there are some real challenges to accurately measuring air temperature in forested environments. I'm now in my 3rd year of deploying air sensor arrays across the northern Rockies, I've learned a lot mainly from mistakes that I've made and will try to share some of that information here (see attachment on tradeoffs).

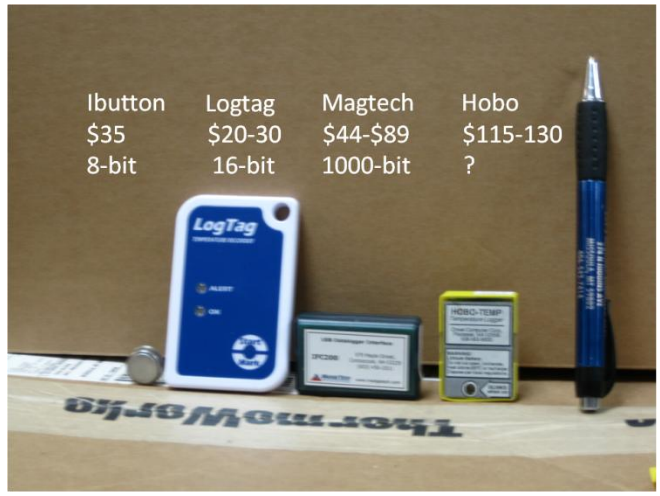
In short, it's a significant challenge to measure air temperature accurately but it's also a very important to try and minimize bias associated with solar radiation. Note that we are inherently dealing with a highly modified radiation environment, because of the presence of trees and vegetation, which all absorb and re-emit radiation. In the end, as a user community, ecologists and climatologists should work toward standardizing our methods for monitoring air temperatures in forested environments. I don't claim to have all the answers, but if interested in discussing further or if you'd like more information on our radiation shield design, you can contact me at: zaholden@fs.fed.us.

References
Holden, Z.A., Crimmins, M.C., S. Cushman and J. Littell (2011) Empirical modeling of spatial and temporal variation in warm season nocturnal air temperatures in two North Idaho mountain ranges, USA. Agric. For. Meteor. 261-269

Holden, Z.A., J. Abotzaglou, C. Luce and L.S. Baggett (in press). Empirical downscaling of minimum temperature at very fine resolutions in complex terrain. Agric. For. Meteor.

Tradeoffs associated with different types of sensors (cost, memory, quality).

A number of inexpensive (< 50 dollars) temperature sensors are now available. This kind of low cost equipment allows us to intensively sample many locations in space, with the caveat that we get lower precision observations, and the sensors have limited memory storage and limited battery life. Here are the cheap sensors I'm aware of.



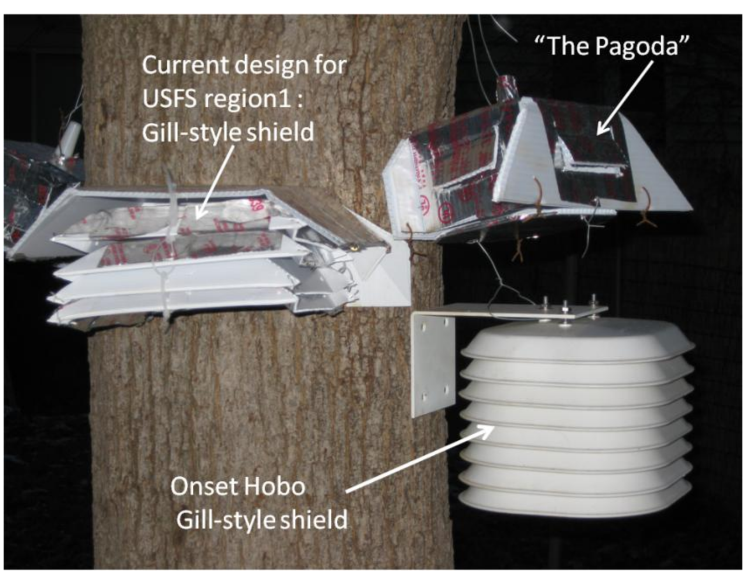
Thermochron ibuttons were some of the first sensors to be widely used. These cost ~$35 dollars ($30 in bulk) and are about the size of 7 dimes stacked on top of each other. These are not waterproof. They can store 8000 measurements, which translates into approx. 15 months at a sampling interval of 90 minutes (18 measurements per day).

Thermoworks Logtags have emerged as a competitor to the ibutton. These cost $30 each ($19 in bulk) and have nearly the same specifications as ibuttons. They are also not waterproof. They have begun custom building these sensors for our USFS monitoring project that have 2x the memory (16,000 measurements). This means we can now sample for a full year at 1 hour interval, or 2.5 years at 90 minute intervals.

A new type of sensor, developed by **MadgeTech inc.** has recently become available. Their temperature sensor (the IFC200) can store 1 million observations and claims a 10 year battery life. I have not tested this unit. It costs $89 dollars per unit, but I was quoted $44 if I bought 1000 units. This may be a good option as we seek to develop longer-term monitoring designs. These are the relatively inexpensieve sensors that I know of. After that, it's Hobo, Decagon, Campbell scientific, etc., which are higher quality and higher cost (>100 dollars per sensor) equipment.

Radiation is King: Shielding sensors to get unbiased air temperature measurements

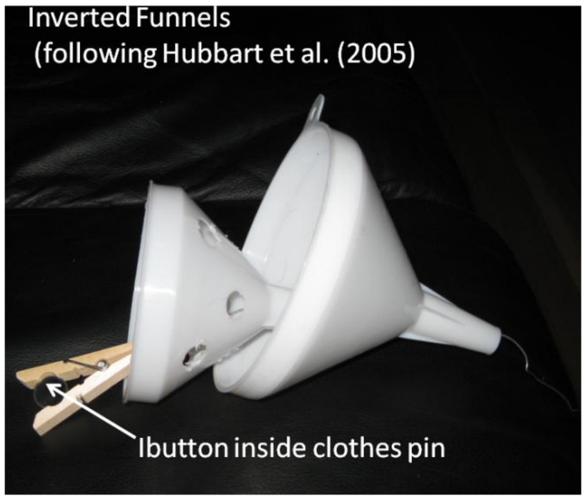
The main challenge of accurately measuring ambient air temperature is to block incoming solar radiation so the measurement device does not heat up. We know that bank thermometers in the summer, your outdoor thermometer etc. are often biased if they are not well shaded. A sensor, placed outdoors that receives direct sunlight will heat above ambient air temperatures, oftentimes by 10 degrees Celcius or more. Housing your sensor in something that blocks incoming radiation, but allows air to flow easily across the sensor is essential to accurately measuring the air



temperature. This turns out to be a fairly difficult thing to do.
The standard shield used in most weather/climate stations is called a Gill radiation shield, named after it's creator Richard Gill. It is a series of plates that are highly reflective, and block most incoming radiation. Different versions of these can be purchased from e.g. Hobo, Decagon, Campbell for 50-80 dollars each. I would recommend using these if you can afford it. However….they sort of the defeat the purpose of "inexpensive" monitoring because they cost more than the sensor. Below, I'll review what I've tried to do in the past, what seems to work and what does not.

Current USFS radiation shield design
I spent several months testing out different radiation shields. I tried out at least six different designs, which all showed serious bias when exposed to sun. Basically, anything that is even partially enclosed will heat up (even if it is white) when exposed to the sun (See "the pagoda" as an example of a bad design in the picture above). I finally settled on a cheap, homemade version of a gill-style radiation shield (see picture above) that I make out of white corrugated plastic and HVAC aluminum tape.

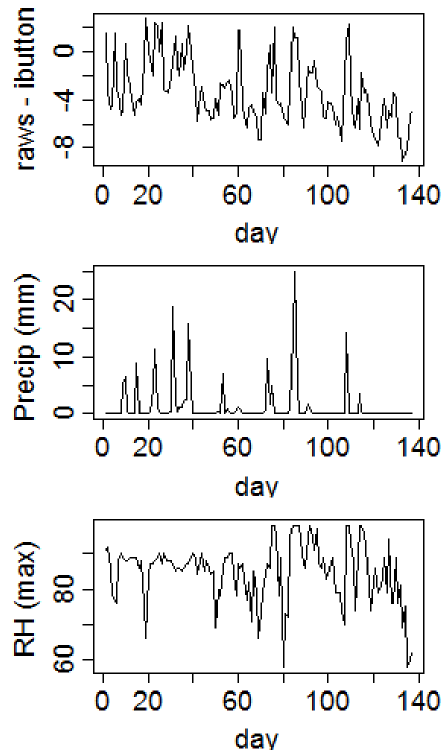
Inverted funnels
Jason Hubbart, my office mate in graduate school was the first person I'm aware of to start using ibuttons (See Hubbart et al. 2005). He proposed using 2 inverted plastic funnels hung from a tree (PHOTO) to shield the sensor, suspended inside. I placed 200 of these around Missoula in 2009. I saw spikes in temperature when the sun hit these funnels in the morning and late evening. This may have been because the funnels were more opaque than those used by Hubbart et al. (2005)? For nocturnal air temperatures, they are fine, and allow adequate airflow. According to Jessica Lundquist (Professor at U. Washington) the other major problem with this design is that the bottom of the funnels is open, so that radiation reflecting off snow will strike the sensor and cause huge (10 degree C) spikes in temperature. This is only a problem for a short period of time, but it's a big problem.



Using Vegetation as a shield.

Jessica Lundquist, is among the first researchers to start using ibuttons to monitor air temperatures in mountains. She advocates using trees and vegetation to shield sensors (see Lundquist and Huggett (2008)). Because of the massive (>20 ft) snowpacks they have toward the Pacific coast, they would launch their sensors housed in funnels up into trees and count on the vegetation to block incoming radiation. When I compared data from an ibutton suspended in inverted funnels and suspended in nestled in the branches of a small Douglas-fir tree, I saw huge biases at night. The figure below shows nightly differences between Tmin from the ibutton compared with Tmin from the adjacent West Fork RAWS station and Relative Humidity and Precipitation from the same RAWS.

Notice that on most nights, the ibutton, which is surrounded by vegetation, is much warmer. The transpiring vegetation creates a moist, warm boundary layer that reduces outgoing longwave radiation (cooling) and insulates the ibutton. Notice that this pattern becomes more pronounced as the season progresses and soils dry down. On wet nights when it rains, the humidity around the RAWS station is similar to the microenvironment created by the tree and the temperatures are more similar. This is scary stuff, because it shows us just how much microclimatic variation there is in forested environments, where trees, vegetation and the ground create all kinds of radiation microenvironments. I would urge folks to NOT USE VEGETATION alone as a primary radiation shield, and BE CAREFUL about how much Vegetation is nearby. Better understanding of these issues will require different types of finer-scale analyses. Also, photograph your air sensor, so that if something strange turns up later during analysis, you can look at what might be different at that site.



References

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Hubbart, J., T. Link, C. Campbell and D. Cobos (2005). Evaluation of a low-cost temperature measurement systemfor environmental applications. Hydrologic Processes. Vol. 19 pp. 1517-1523.

Lundquist, J. and B. Huggett (2008). Evergreen trees as inexpensive radiation shields for temperature sensors. Water Res. Research vol. 44, W00D04, doi:10.1029/2008WR006979