Continued Exploration of the Thermal Wake Below Ascending High-Altitude Balloons

University of Minnesota

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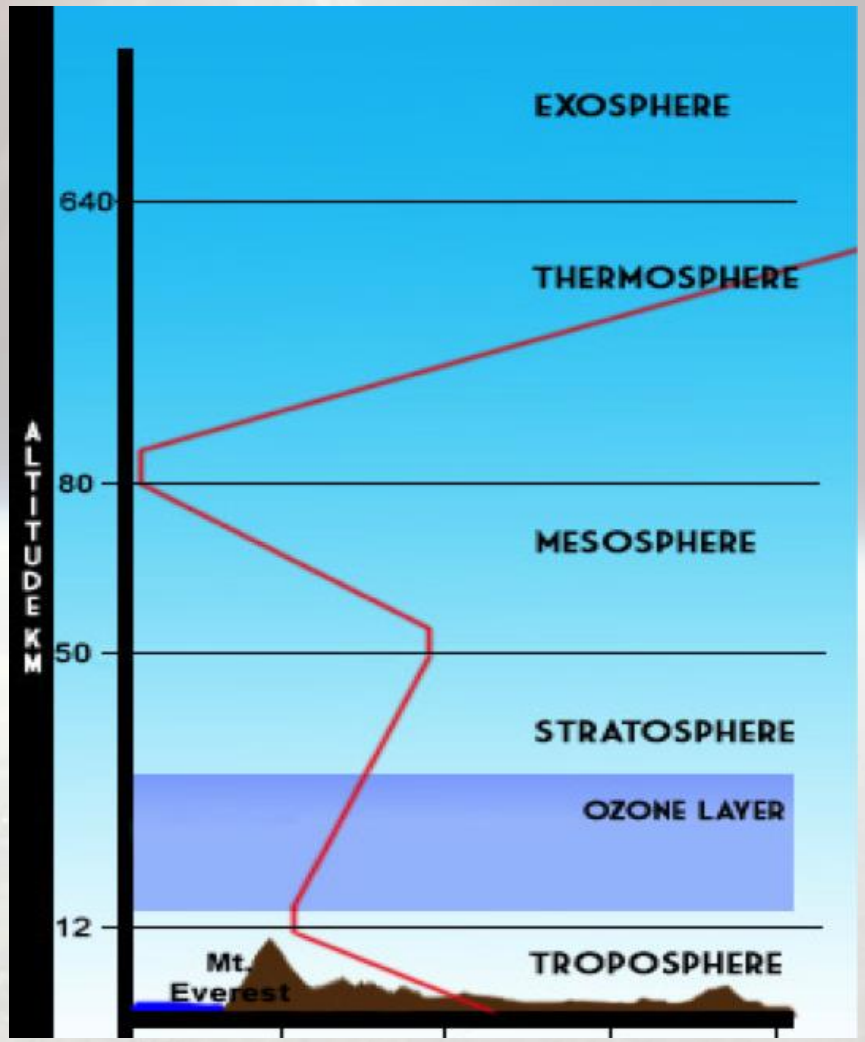
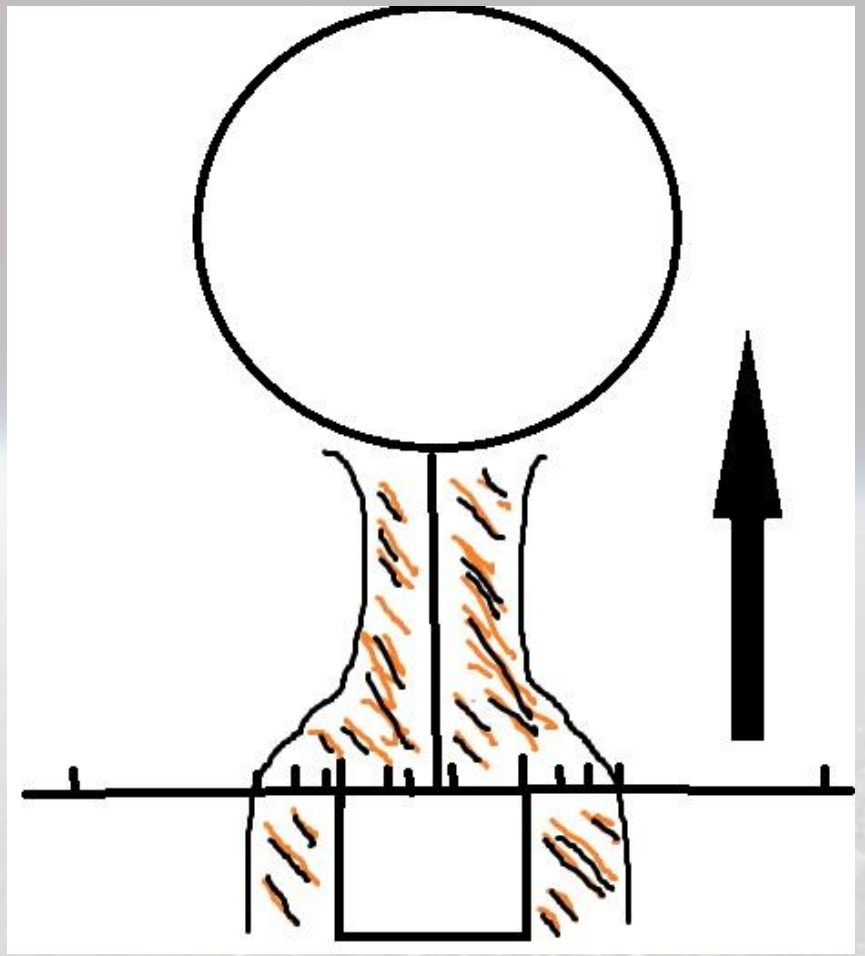
Regions of Earth's Atmosphere



Most of our recent flights have flown between 28 km and 32 km. The temperature characteristics we look for appear once the balloon has reached the stratosphere.

What Does the Thermal Wake Look Like?

As was discussed in a paper by Ney et. al. 1960 (6), the thermal wake can be represented by the cross hatched black/ orange region. The 1-D wake boom placement is also shown in the figure.



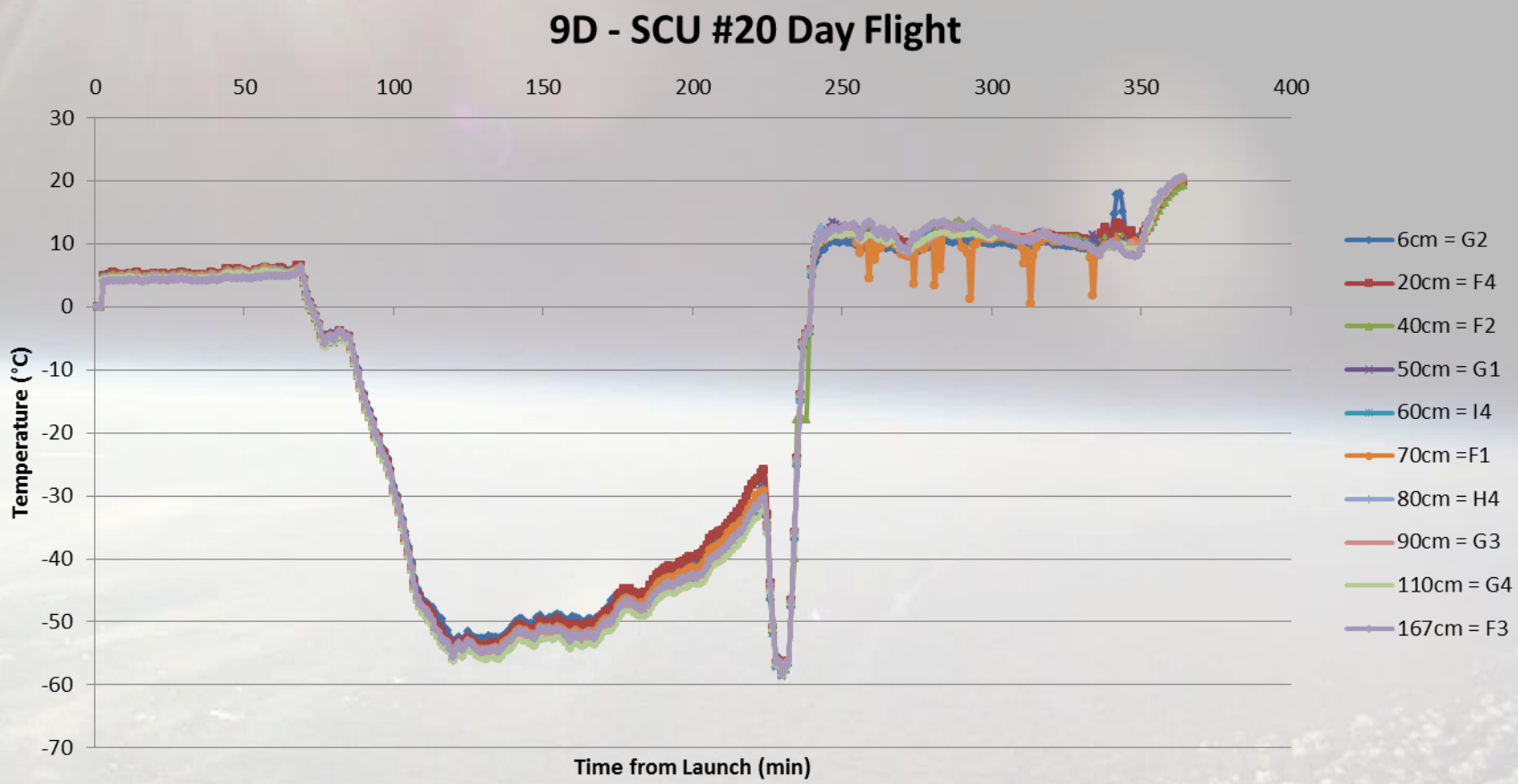
Hypothesis regarding a Day Flight:

- Solar radiation warms the balloon skin which in turn warms the air the balloon passes through. As the balloon ascends, this warm air is left behind, resulting in a thermal wake that is warmer than the ambient atmosphere.
- We expect to see a warm region toward the center of the wake boom.

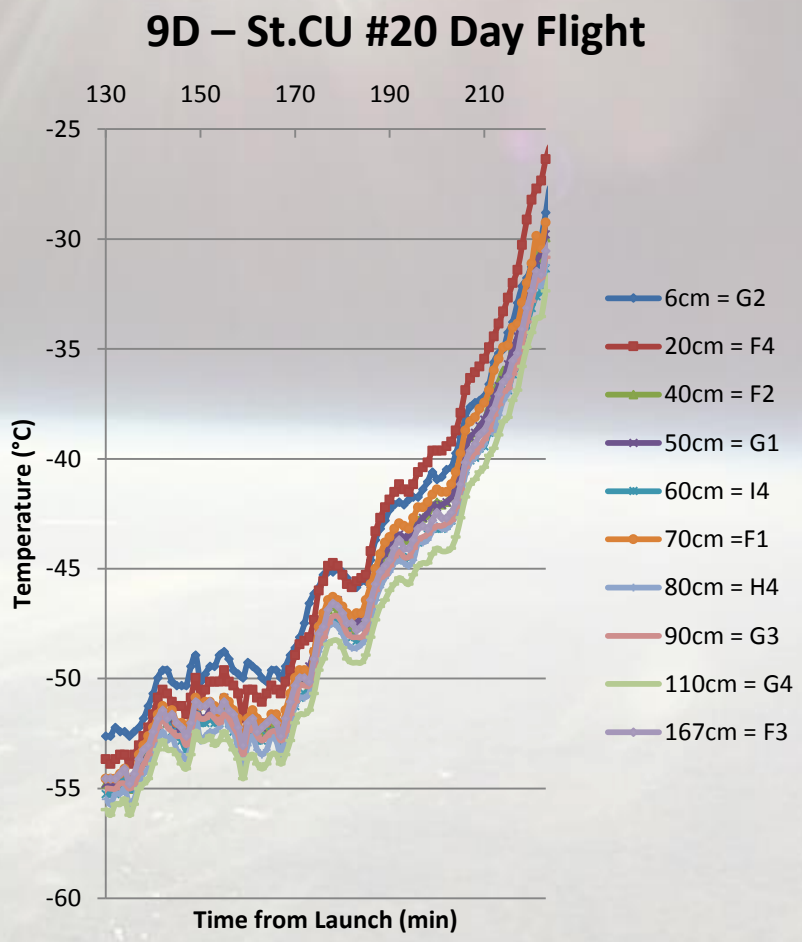
Day Flight Research Methods:

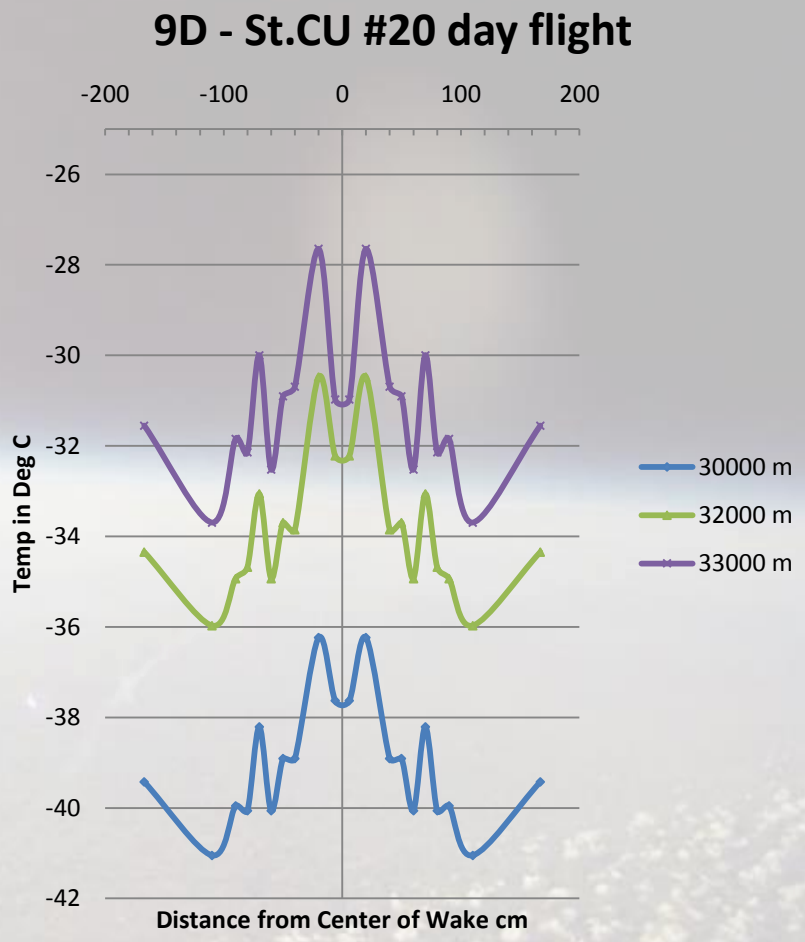
- We expanded from 6 HOBO air/soil/water temperature probes on one side of the wake boom to over 14 HOBO temp. probes located on both sides of the wake boom to get better spatial resolution of the wake profile.
- We also started using 8 digital temperature sensors (DS18B20) logged with Arduino microcontrollers on the same 1-D wake boom.
- Data presented utilize notation “D” to denote day flights.

A Typical Daytime Flight Temperature Profile (9D)



A Closer Look at Day Flight Data (9D)





Hypothesis Regarding a Night Flight:

- At night, the He gas inside the balloon expands adiabatically, cooling the skin of the balloon. The cool temperature is then transferred to air passing by the balloon, leaving a cool wake.
- We expect to see a cold region toward the center of the wake boom.

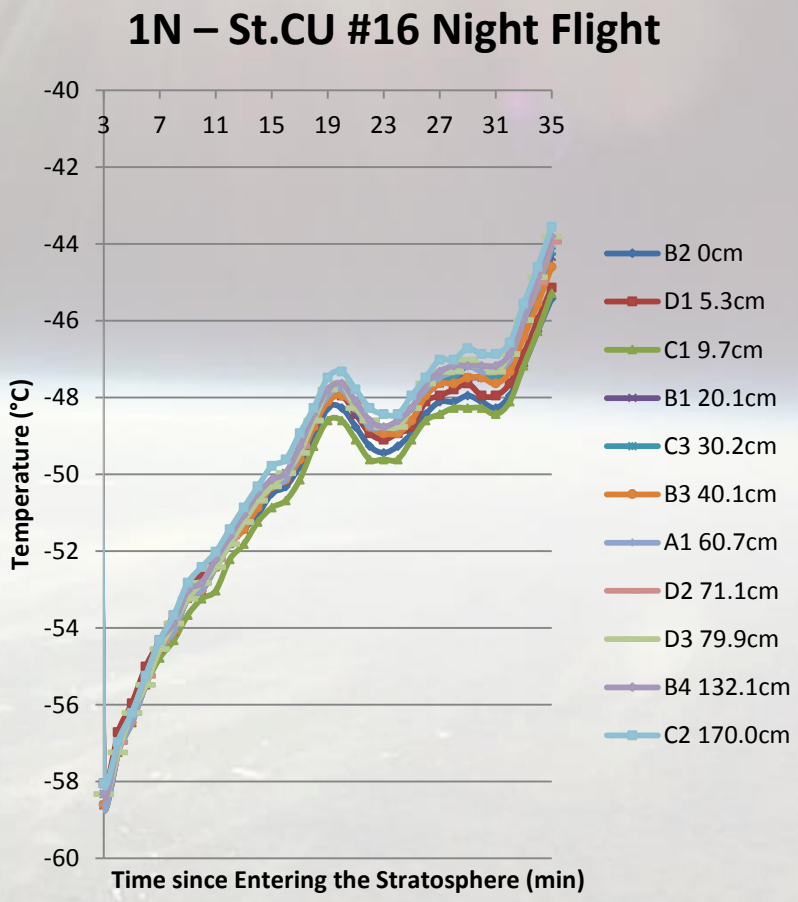
Night Flight Preparation

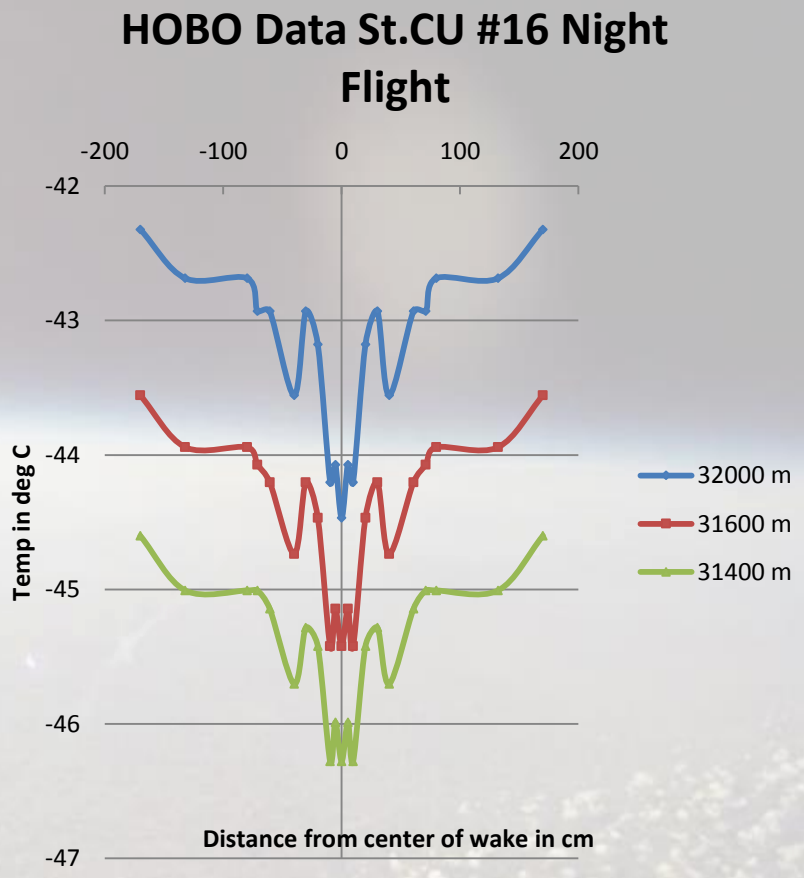
St. Catherine University students preparing the wake boom for flight.

Night Flight Research Methods:

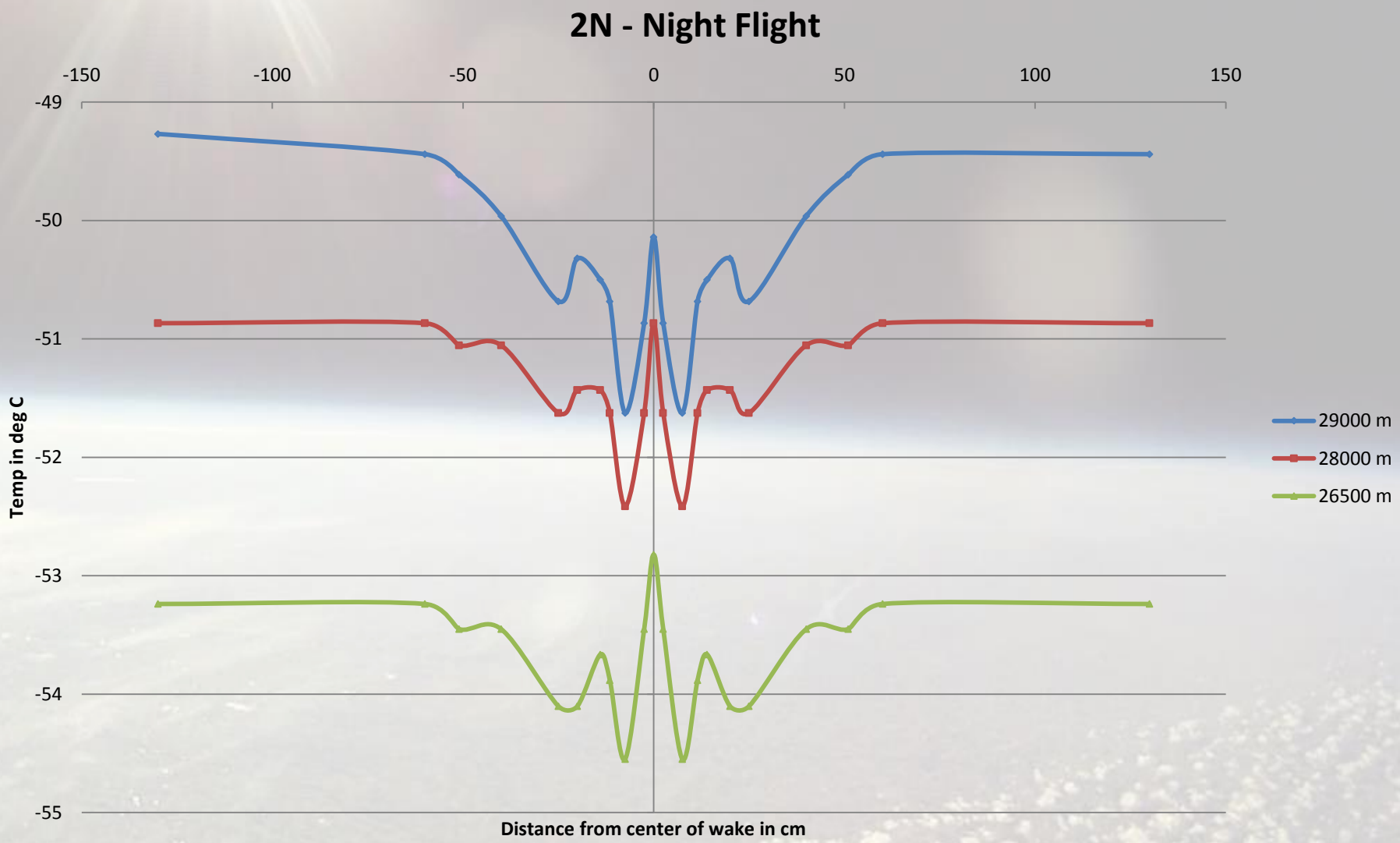
- The methods to collect temperature data are the same as the day flight.
- For safety, strobe lights are placed on the wake boom payload.
- We utilize notation “N” to denote night flights.

A Closer Look at Night Flight Data (1N)





Data from another Night Flight (2N)

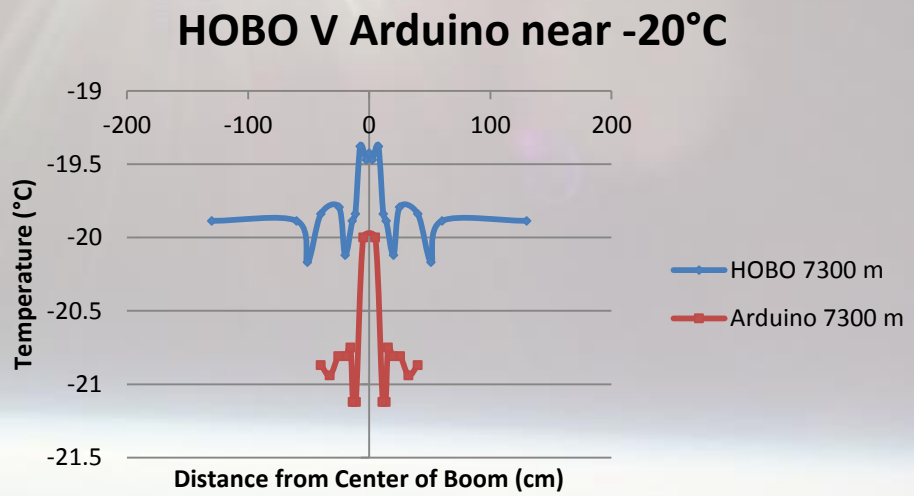


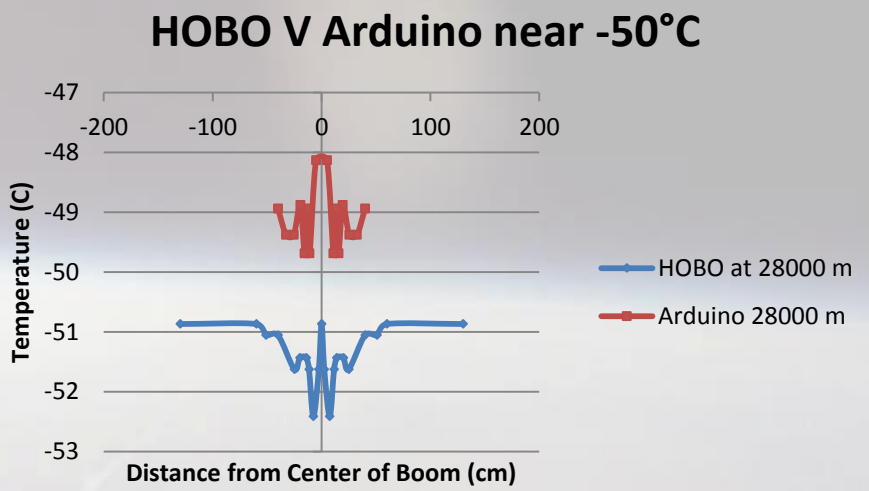
Temperature Sensor Comparison:

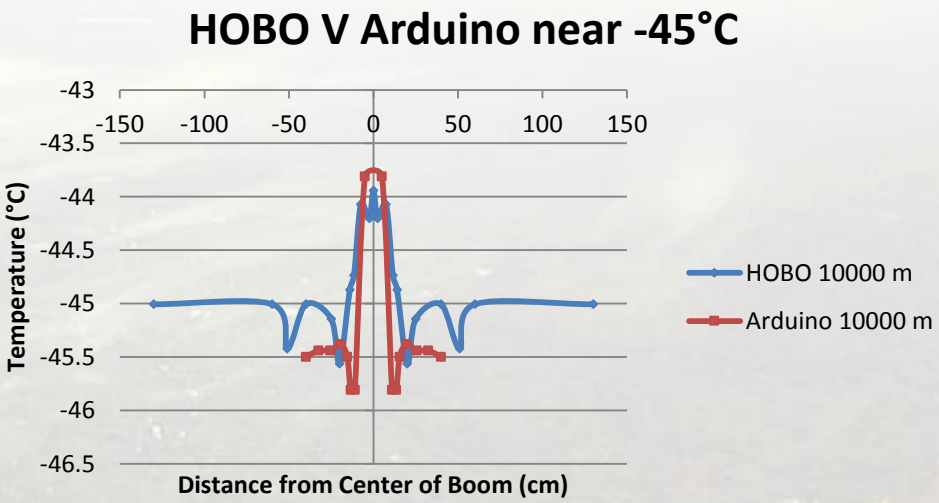
Temperature differences can occur:

- Sensor type
- Calibration
- Geometry differences
- Placement of sensors – e.g. “box proximity”

Comparing Temperature Sensors







1-D is enough?

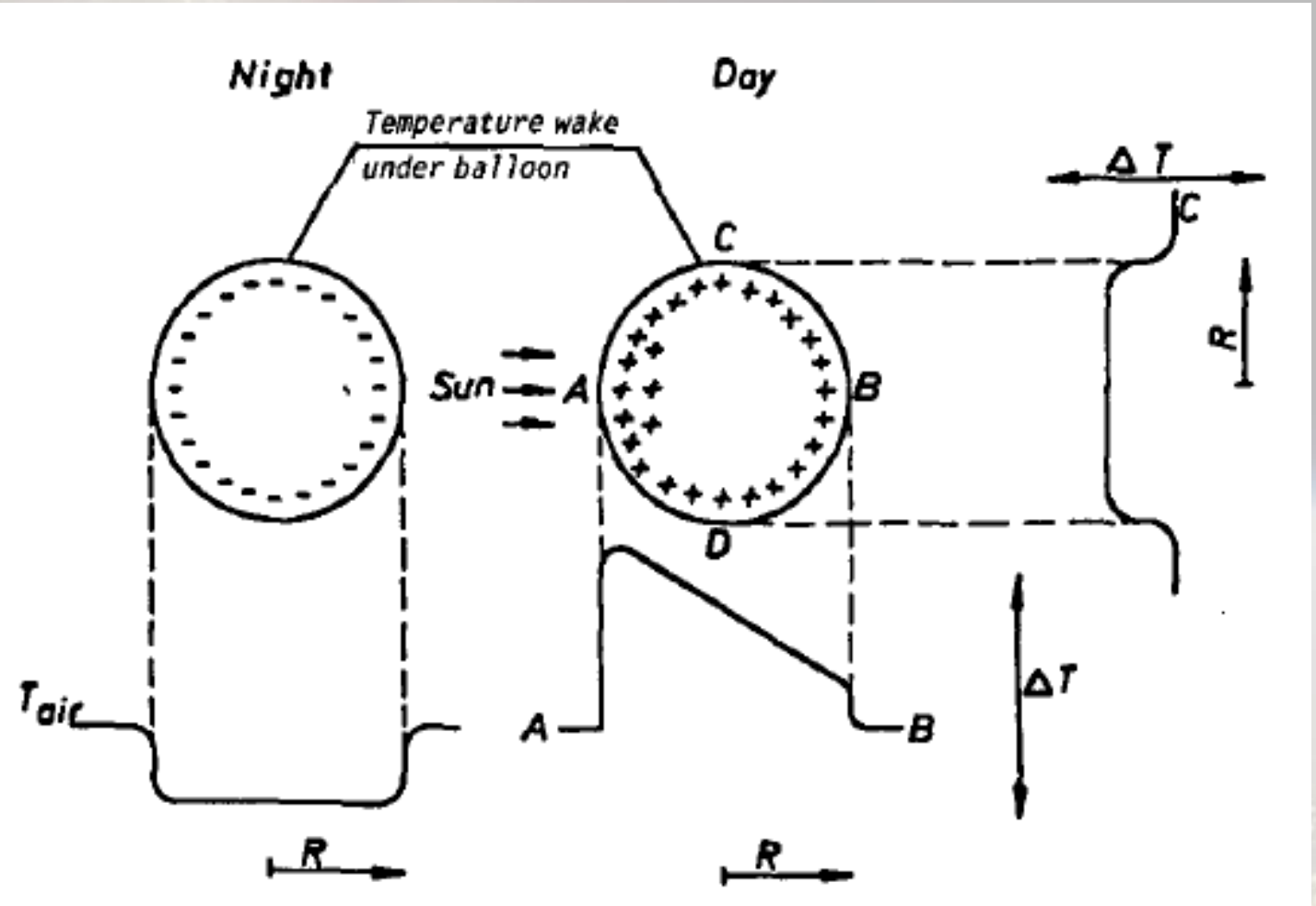


Figure taken from Tiefenau et. al., 1989 (5)

Hypothesis for “X-boom”:

- There will be a temperature anisotropy in the wake (for day flights only) due to a sun side vs an anti-sun side of the balloon.

X-boom Research Methods:

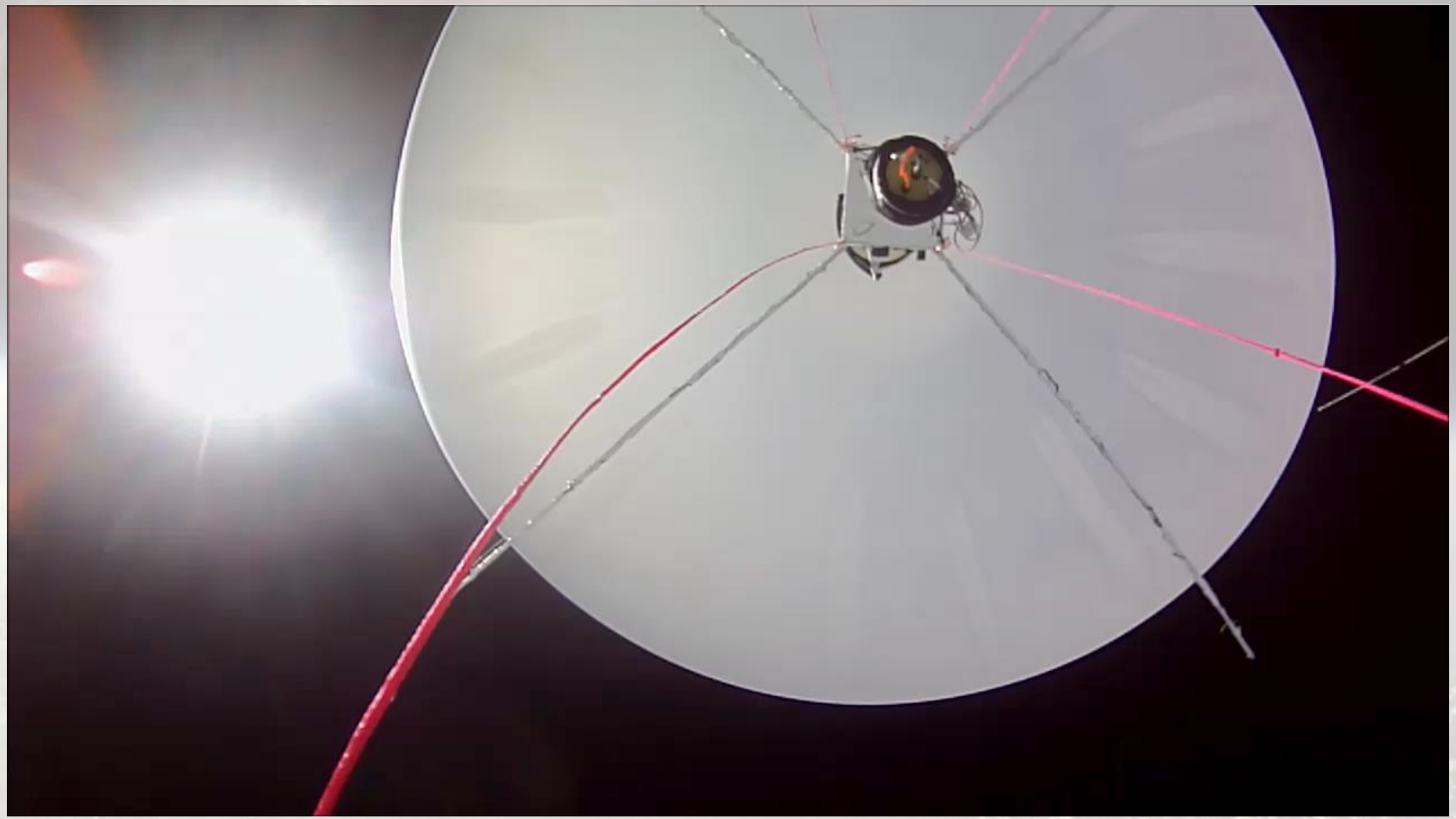
- An “X-boom” with perpendicular arms will be used to characterize temperature gradients in the wake in 2 dimensions simultaneously.
- More than 40 temperature sensors on 4 boom arms were monitored with Arduinos.
- Up-looking video is used to document the sun position in relation to the boom arms.
- The letter “X” will denote X-boom flights.

The X-boom (3 m by 3 m)

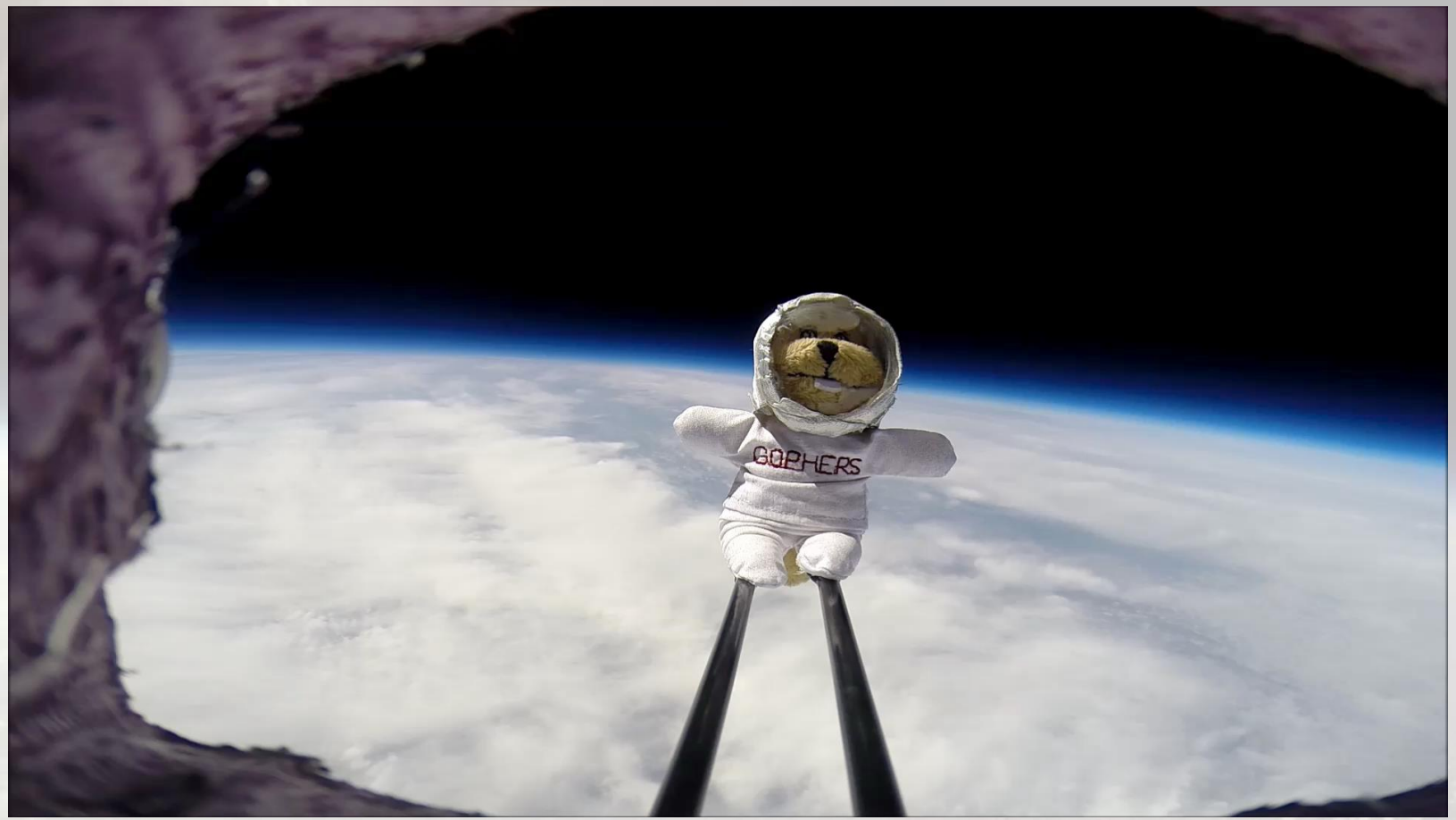
The U of MN students preparing the X-boom for its first flight.

The X-boom in flight.

Flight 1X: Steady up-looking video.

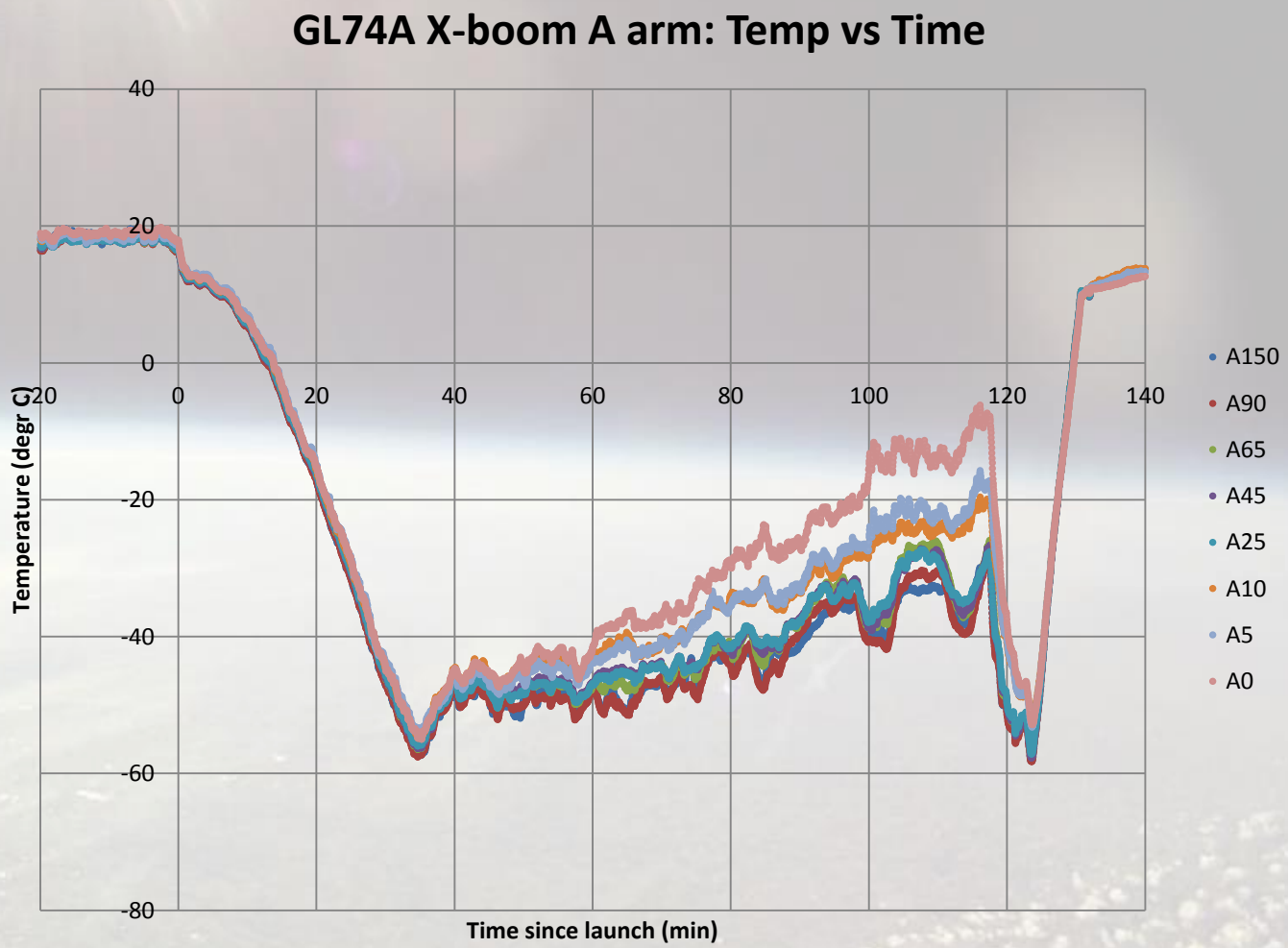


Flight 1X: Steady out-looking video.

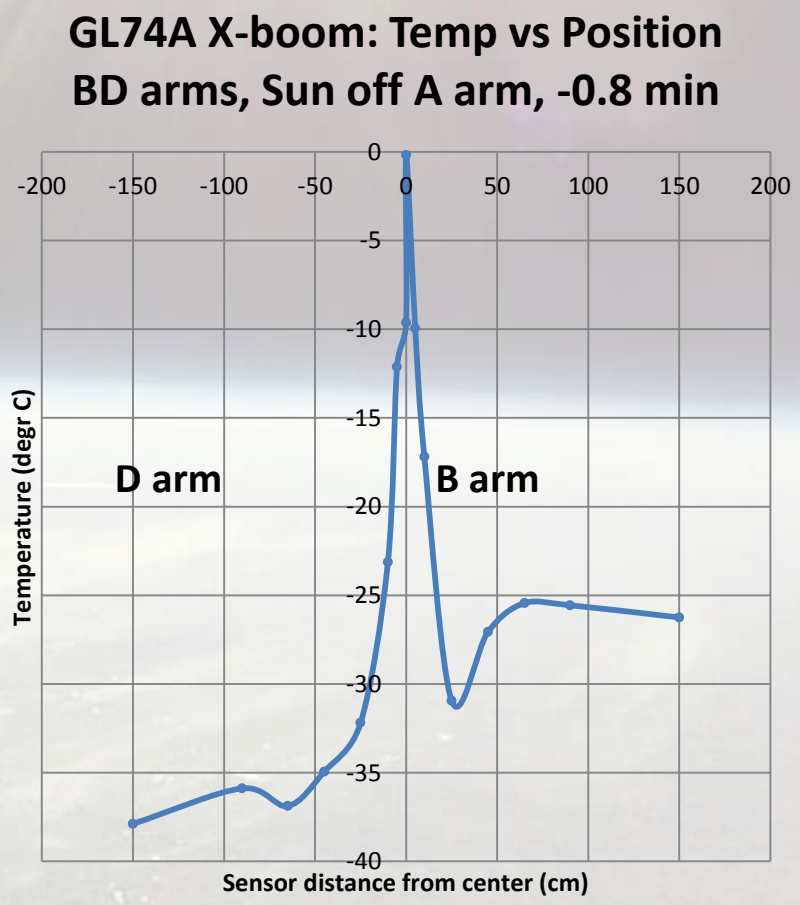


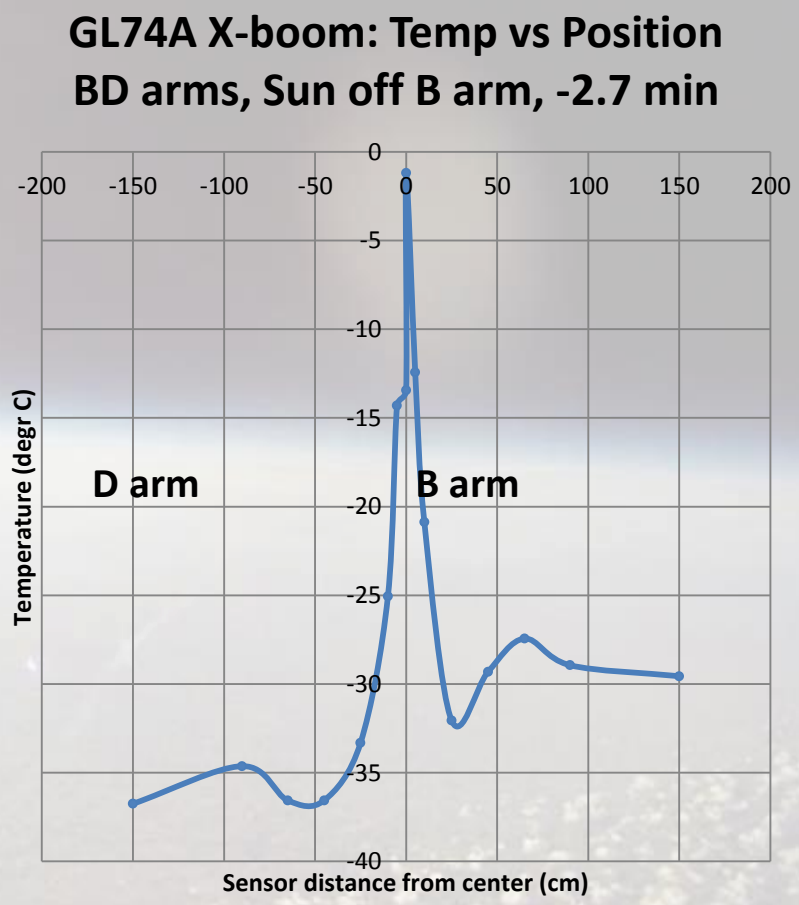
See video posted at https://www.youtube.com/watch?v=hxApfU8DqUs.

Temperature profile for Flight 1X:

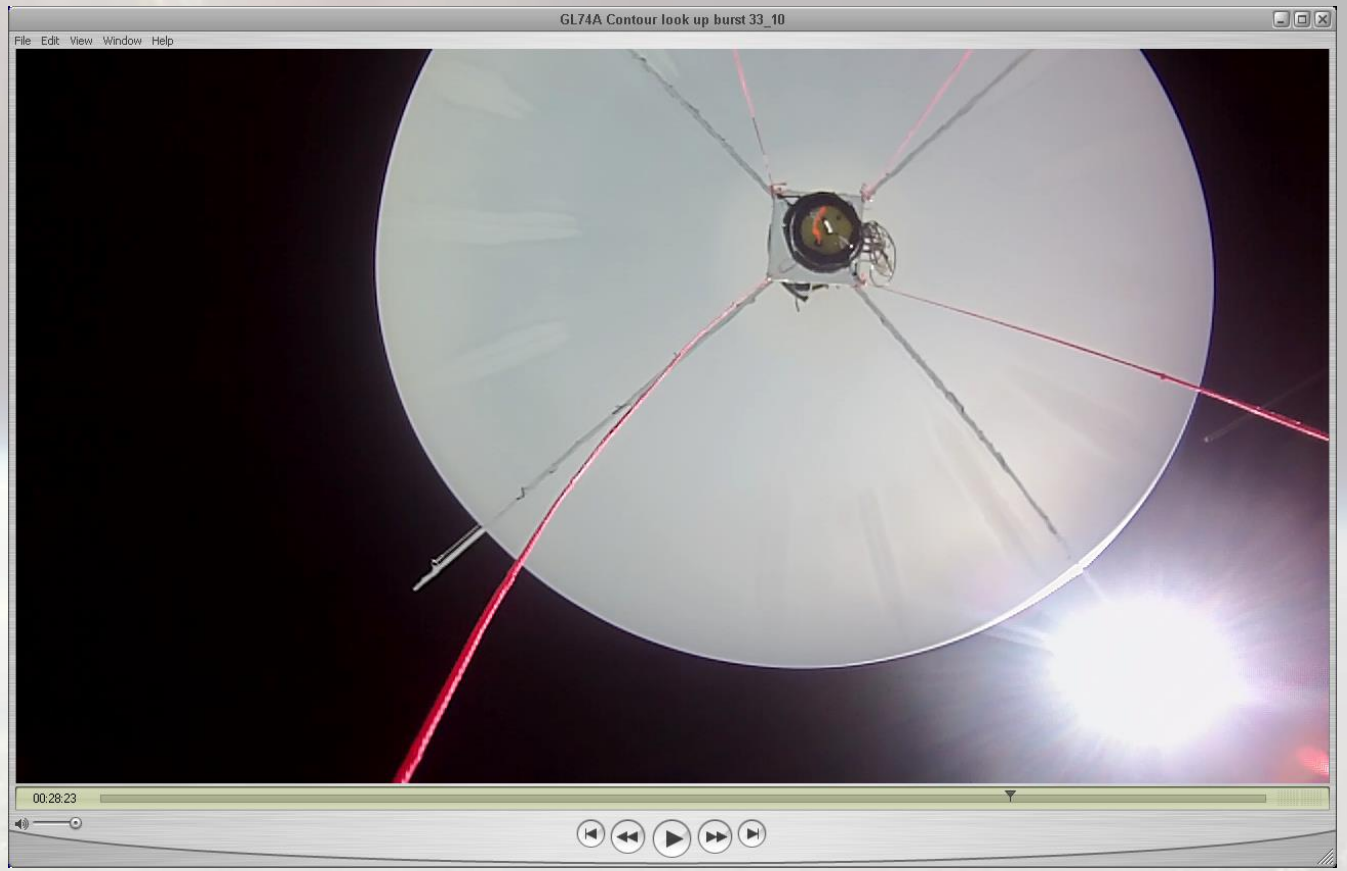


Temperature slices for Flight 1X:



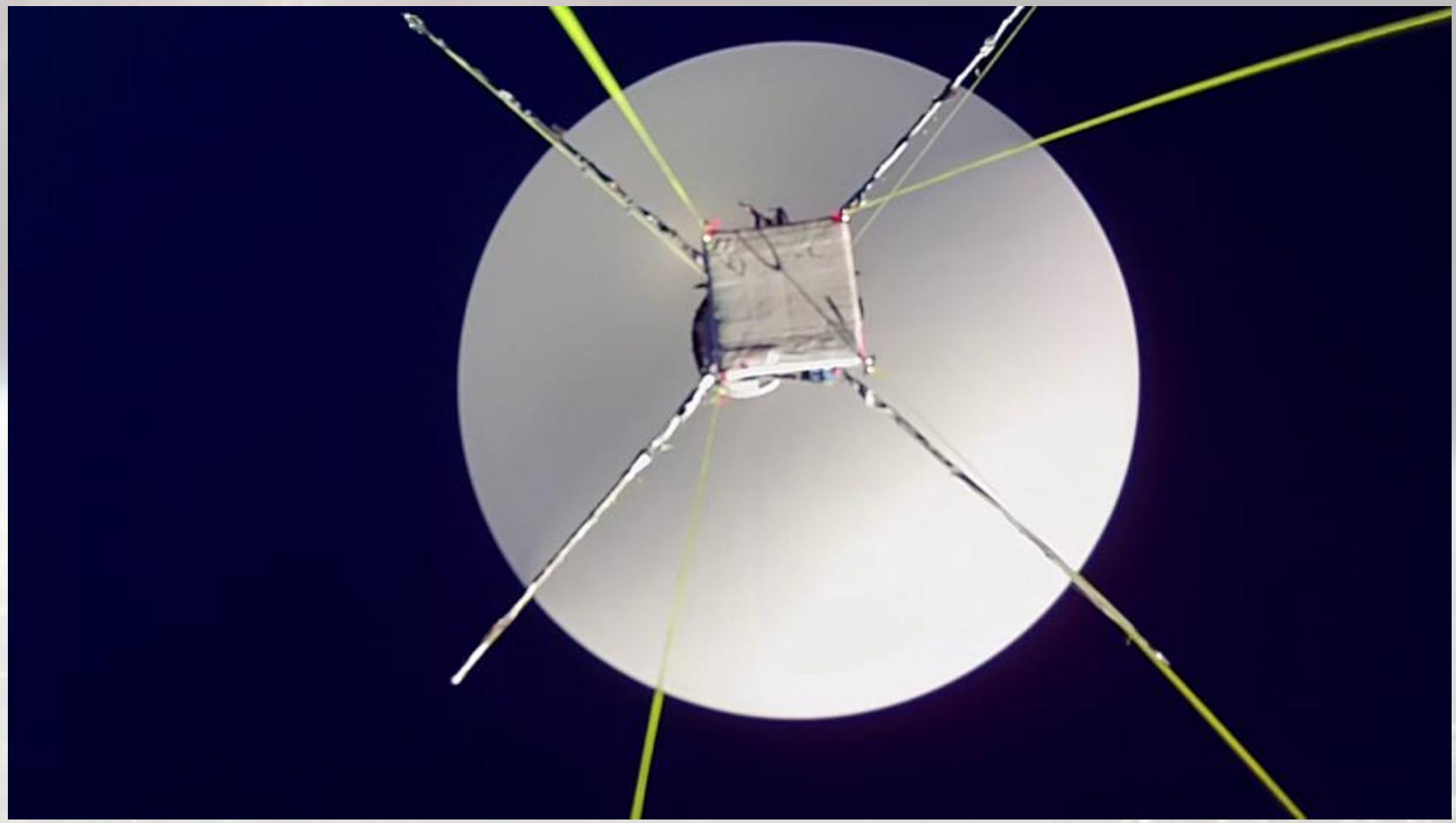


Explanation of 1X flight unexpected data:

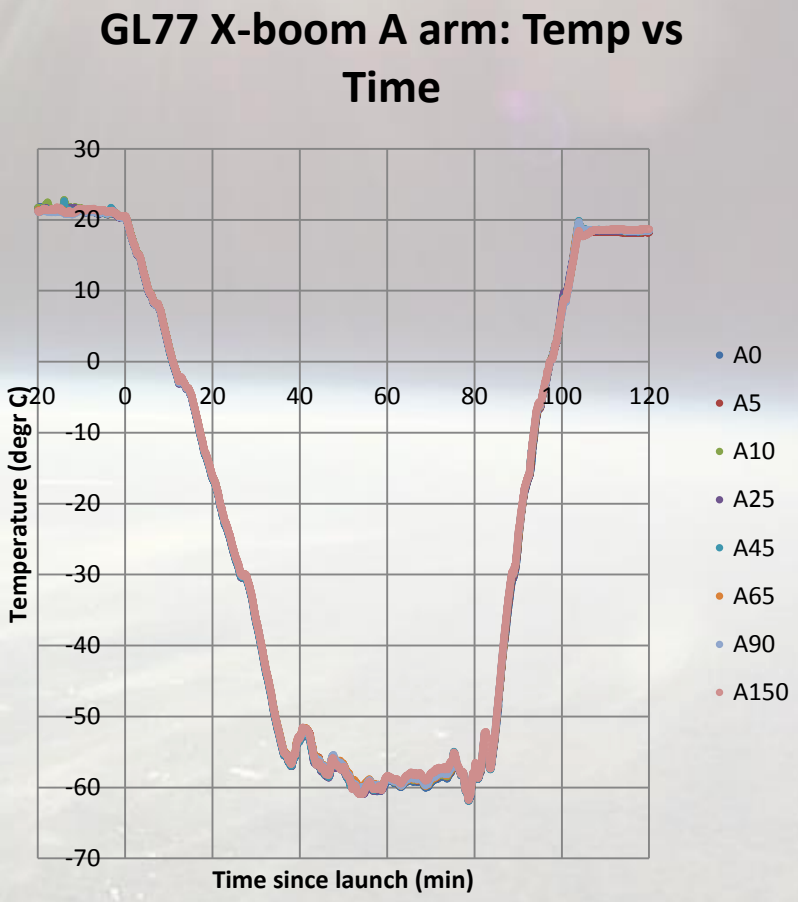


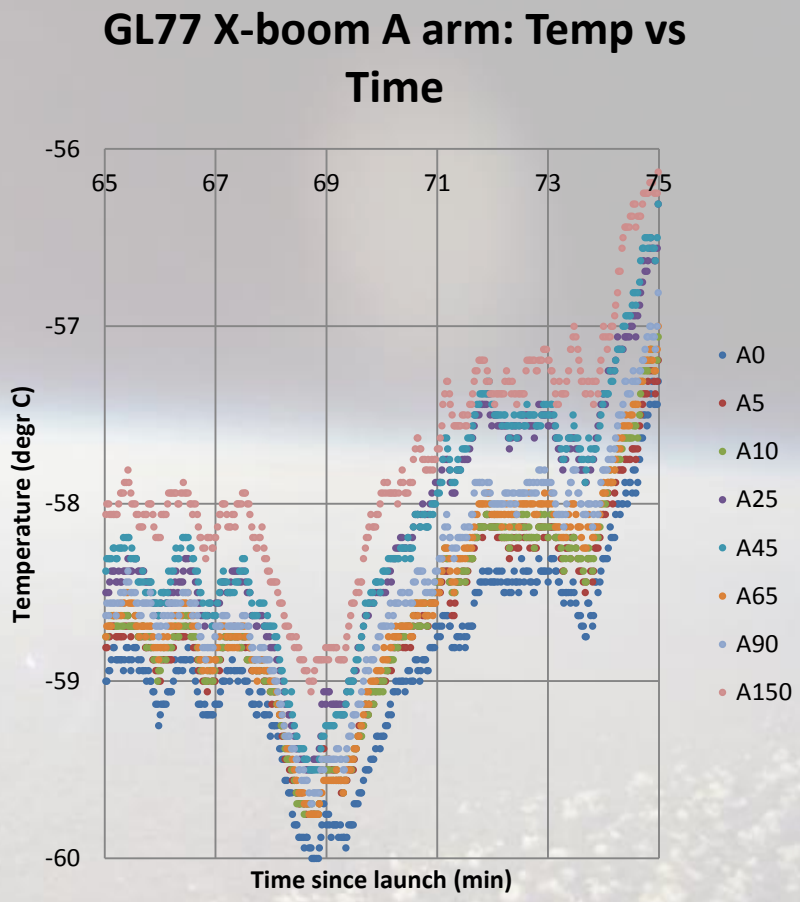
- Proximity effect? (separate by 1 m)
- Time of day? (fly when sun is at a lower angle)
- Balloon shadow?

Flight 2X: Flew close to sunset.

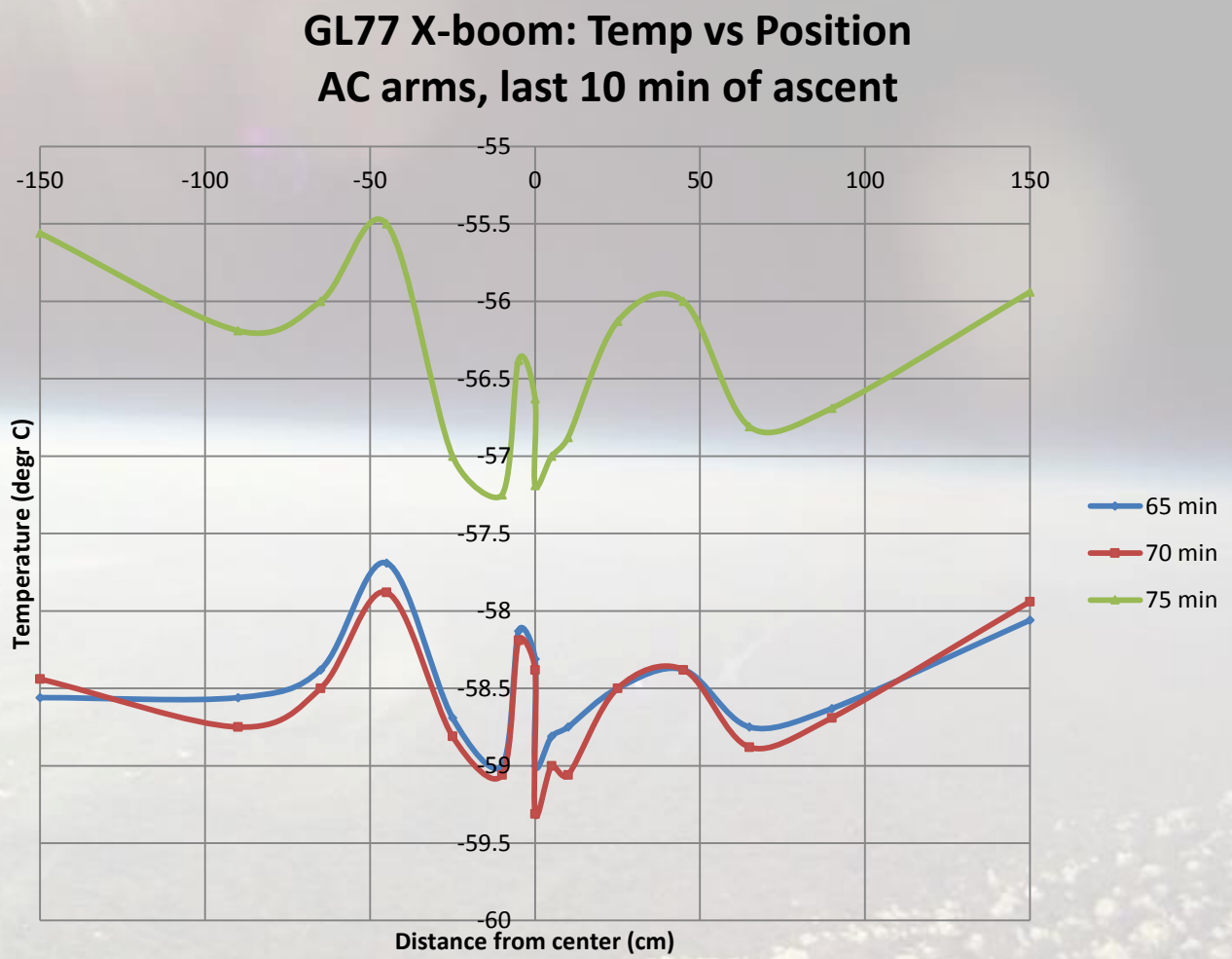


Temperature profile for Flight 2X:





Temperature slices for Flight 2X:



Conclusions:

- More sensors help to see wake structure detail – but come at weight and processor limitations. We are switching from Arduino Unos to Arduino Megas.
- Variables are extensive: calibration offsets, time of day, geometry, balloon type, etc.
- Box proximity effects appear to occur both during day and night flights.

Best Practice Suggestions

- Fly only one type of balloon brand (we now use Hwoyee 1600 gram balloons).
- Temperature sensors should be flown pointed upwards so as to eliminate self wake effects.
- Anti-rotation measures improve video and simplify data analysis (but may adversely impact wake air flow).
- The X-boom is too large to transport so must be assembled on site. Design should allow for quick assembly, with external connections preferred.

More Suggestions:

- Sensors should be painted white, along with having white boxes and a white wake boom.
- A hand-warmer placed on the back of the GoPro helps keep it warm during flight (but can actually overheat it on the ground).

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References

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