High Resolution In-Situ Turbulence Observation System

Dale Lawrence
Abhiram Doddi

Aerospace Engineering Sciences
University of Colorado

AFOSR MURI HYFLITS Program Objectives

- Conduct extensive, geographically distributed measurements of in-situ turbulence and particulates between 20 km and 40 km altitude

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- ~ 100 Observations/year
- Sites in Colorado, Florida, Minnesota
- Other sites of opportunity (e.g., BOLT I in Sweden, BOLT II at NASA Wallops)

- Acquire measurements under normal and very strong meteorological forcing conditions

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- Convective Storms
- Mountain Waves
- Jet Stream Shear

- Use measurements and modeling to guide specification of turbulence and particulate characteristics and spatiotemporal statistics as functions of the underlying meteorology

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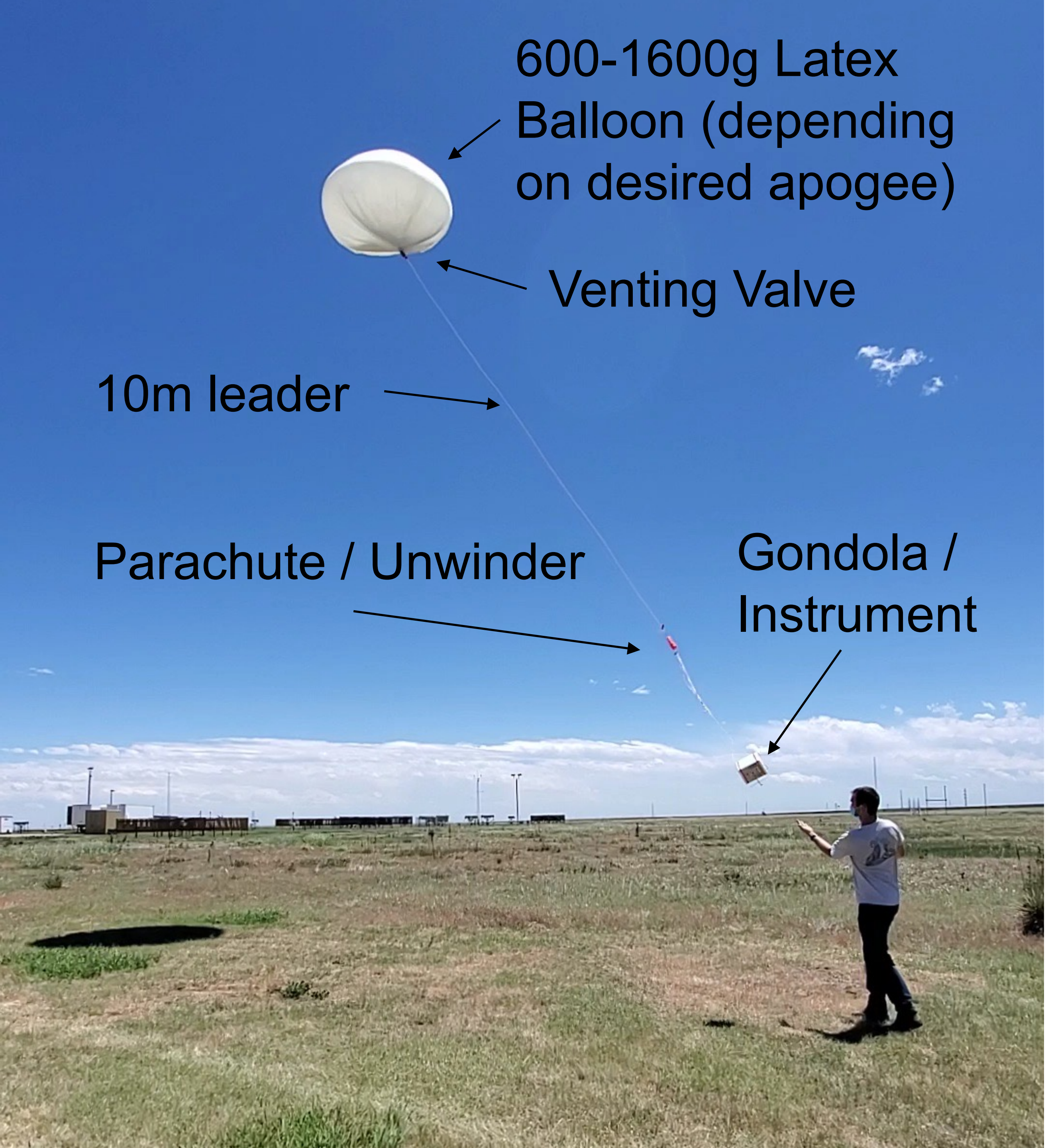
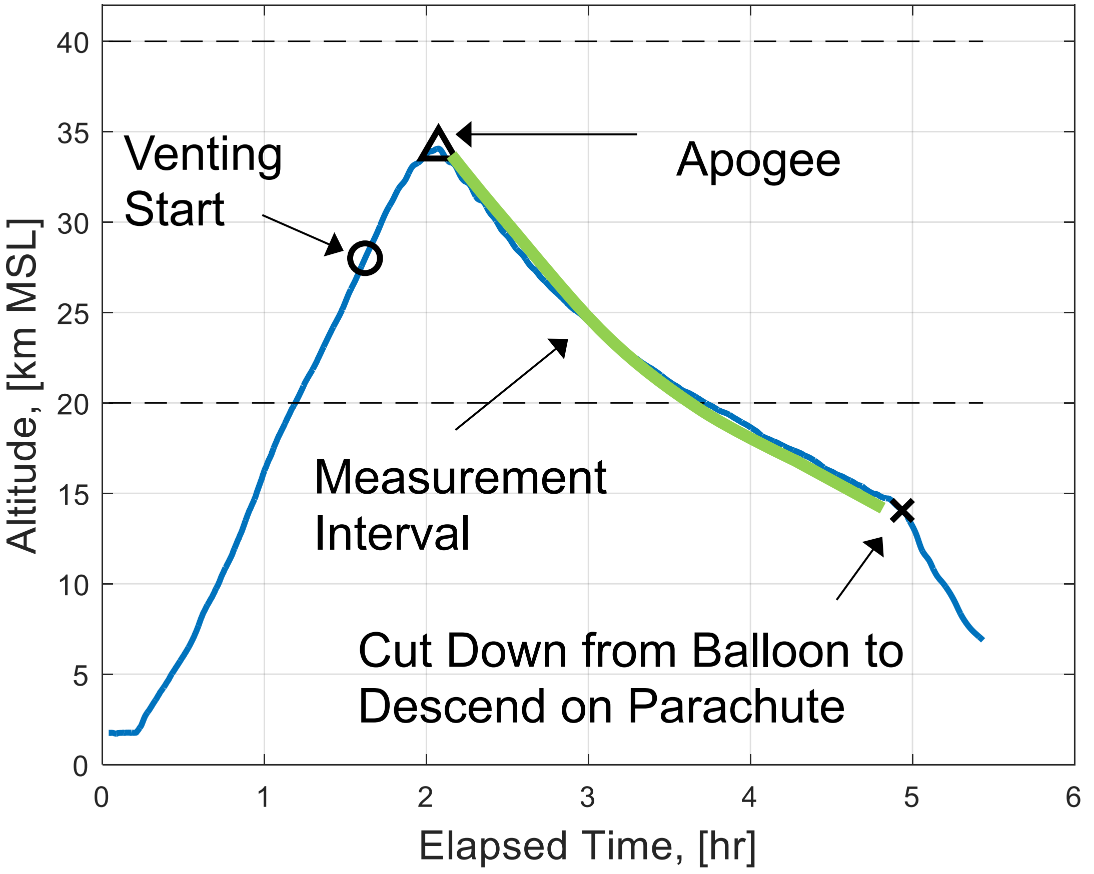
- Validation of numerical models
- Realistic model initialization
- Interpretation of sparse measurements
- Predictive models of high-altitude turbulence likelihood and severity

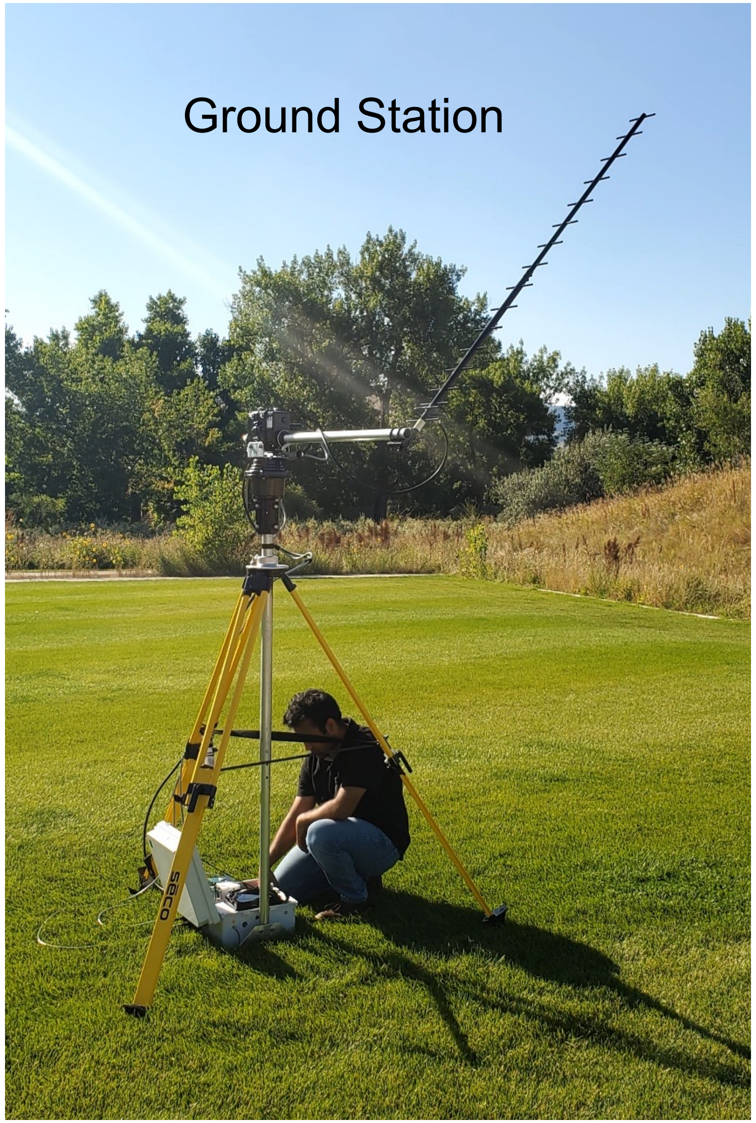


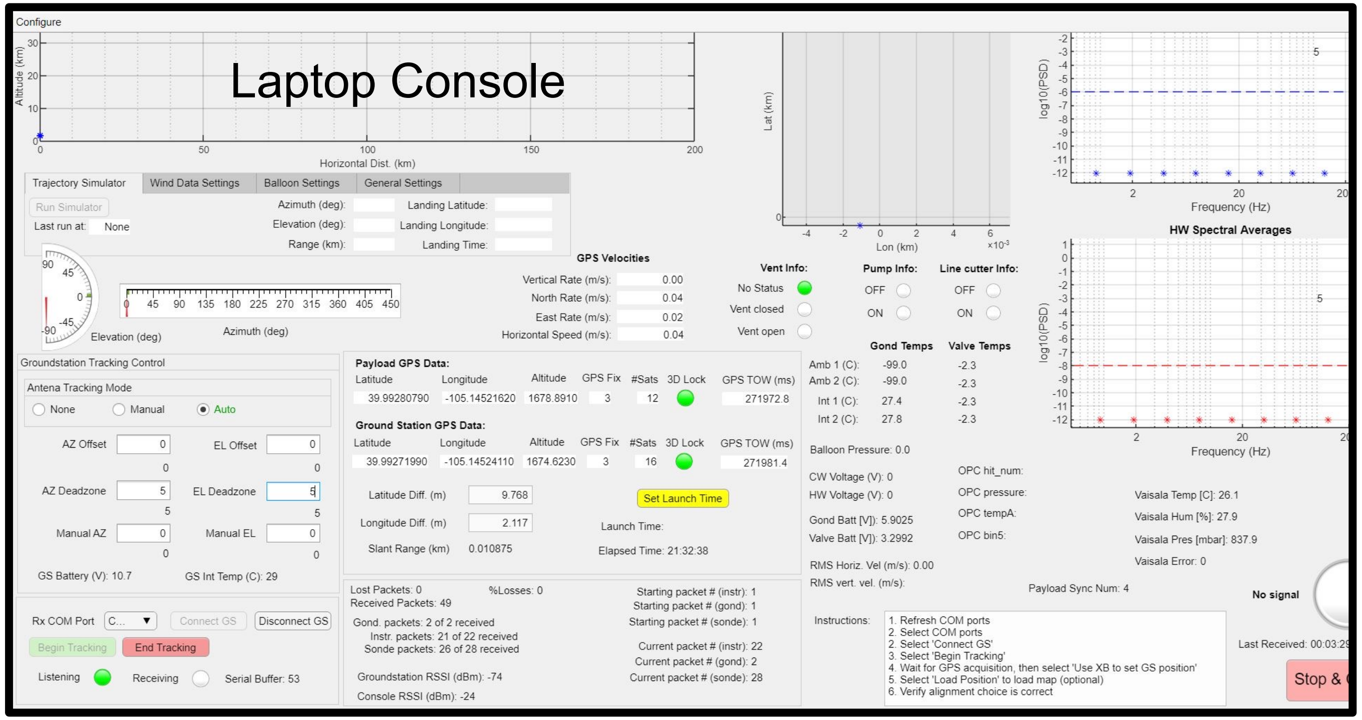
HYFLITS Measurement System

Slowly-descending measurements by controlled venting of Helium/H2 from a low-cost weather balloon platform provides reliable access up to 32km altitude



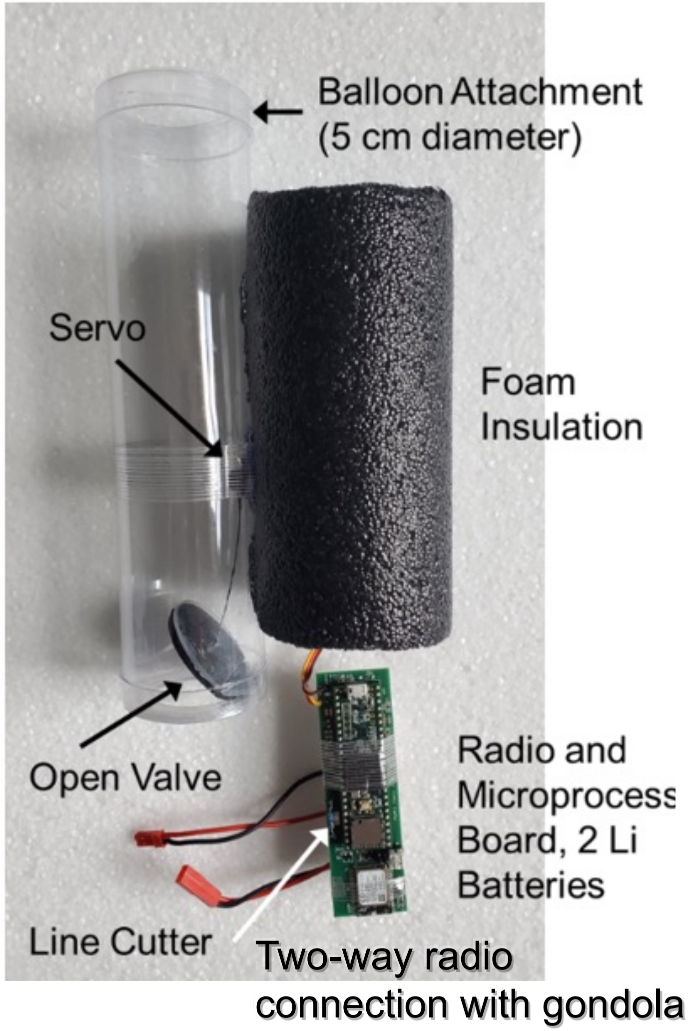
Ground Equipment

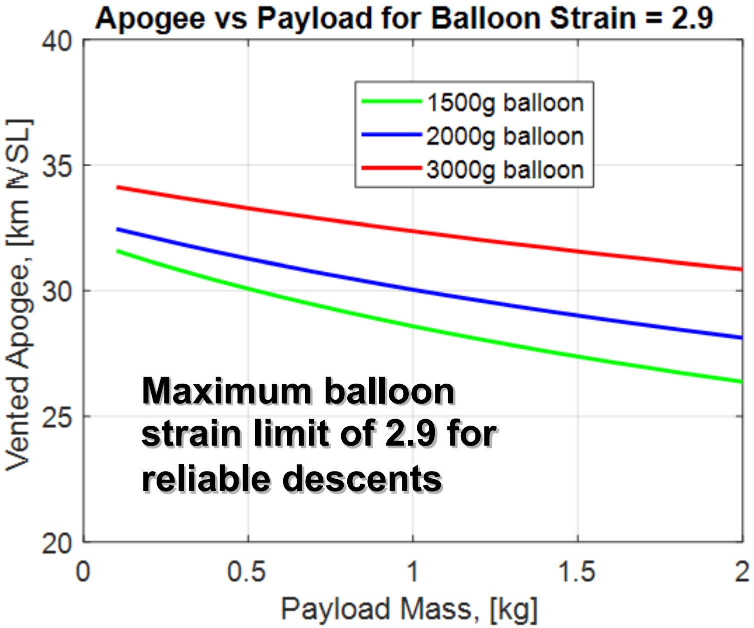


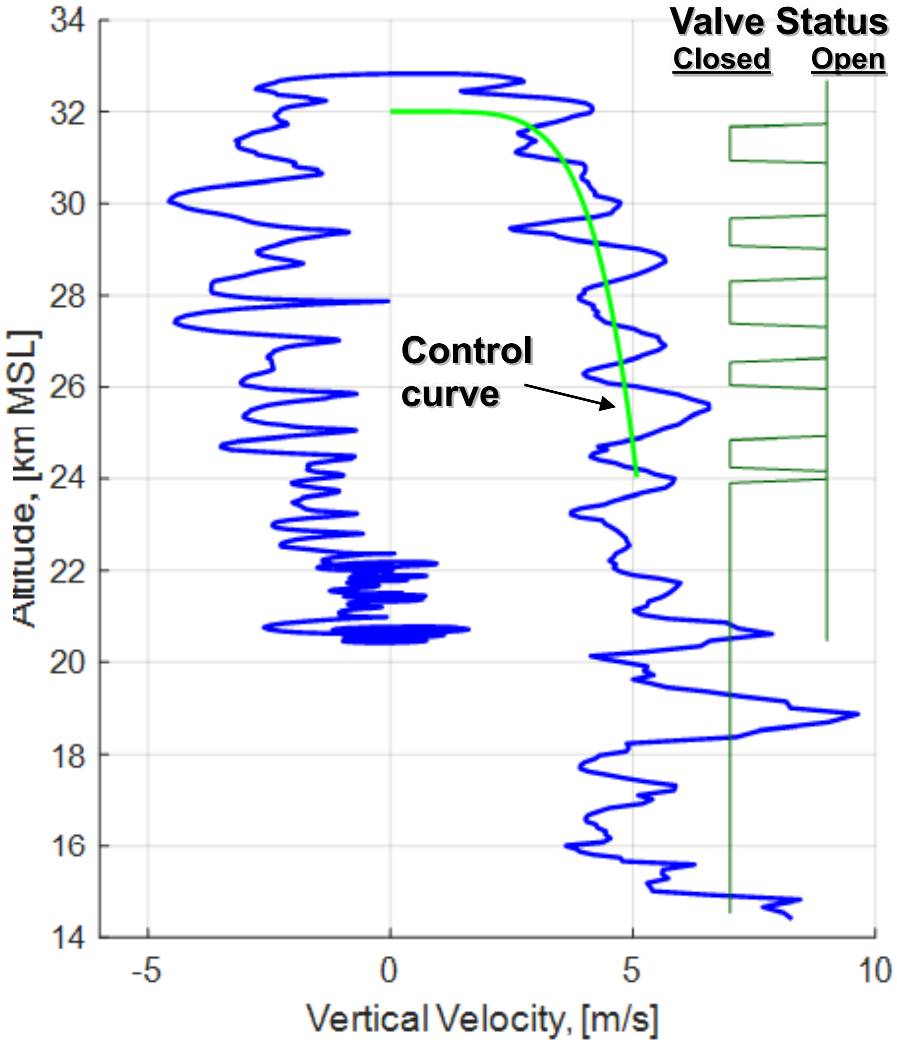


- Automatic Balloon Tracking to range > 200 km.
- Raw payload data relayed to a separate (e.g., indoor) Laptop Console for real time display and archival.
- Post-flight processing to calibrate turbulence measurements and produce additional data products.

Venting Control For Reliable Descent

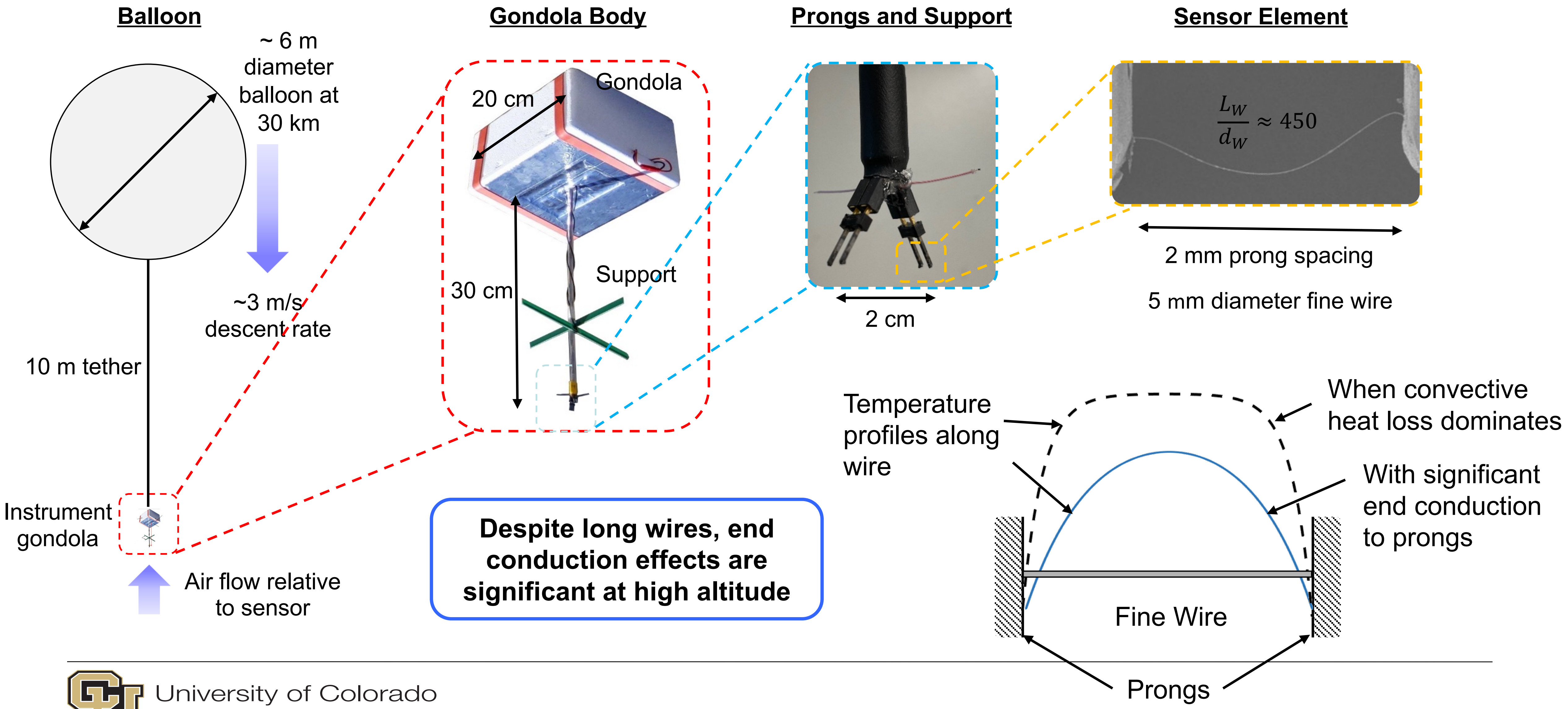






University of Colorado
Boulder

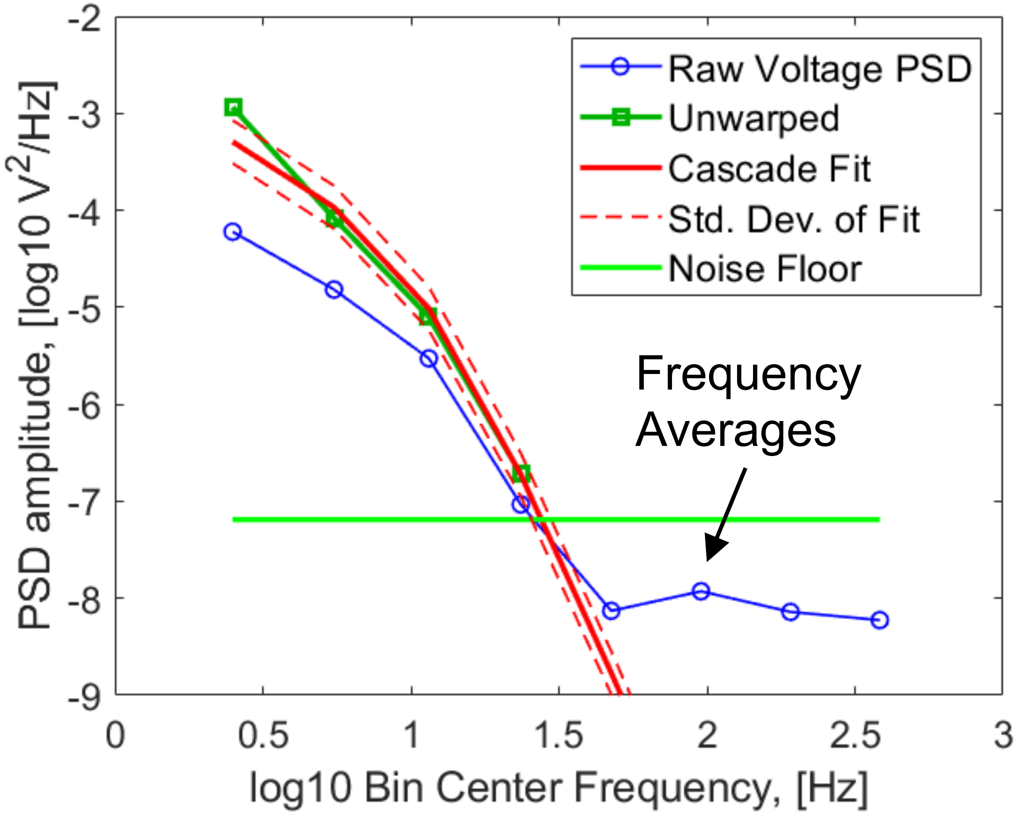
Fine Wire Turbulence Instrument



Despite long wires, end conduction effects are significant at high altitude

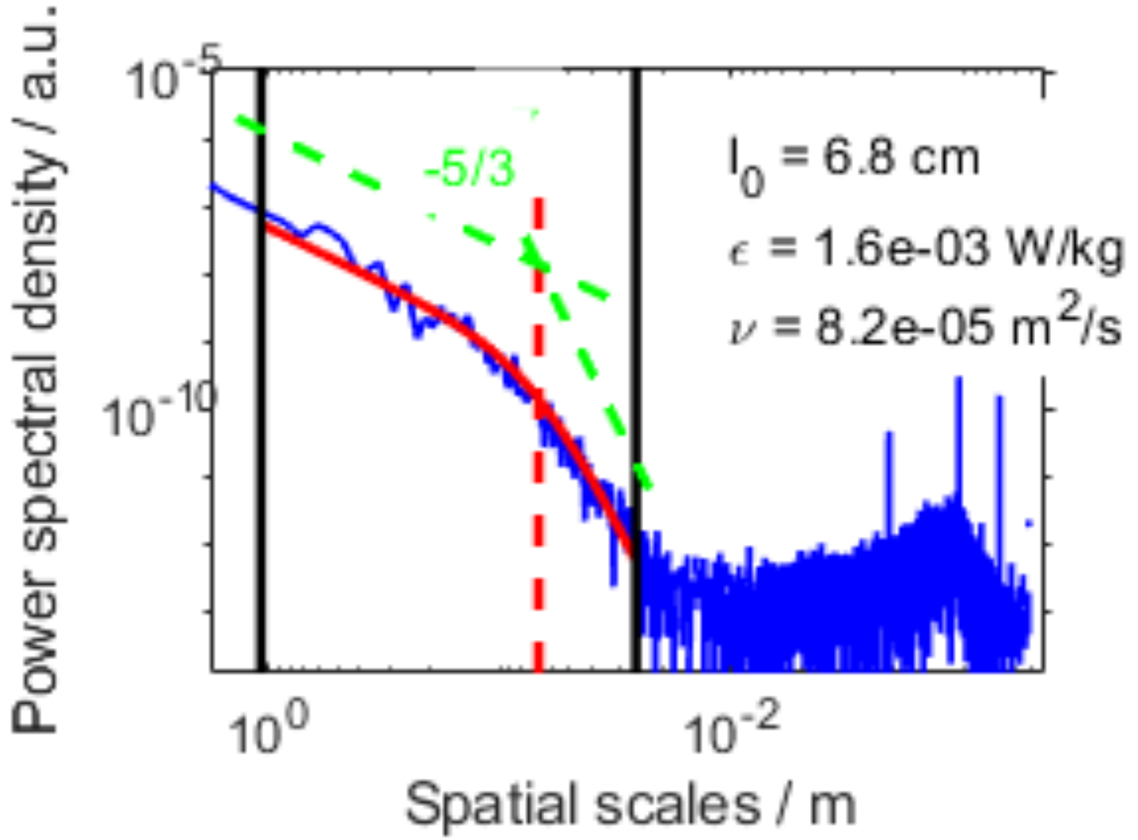
Spectral Turbulence Parameter Estimation

HYFLITS Spectral Method



Fits Inertial Subrange with Knee, Calibrating Amplitude

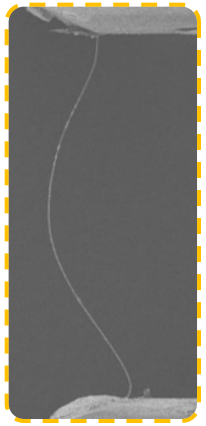
LITOS Spectral Method



Fits Viscous Knee using Heisenberg model, Uncalibrated Amplitude

Turbulence Instrument Calibration Overview

Turbulent variations in temperature and velocity around fine wire



$d_w = 5\ \mu m$
$L_w = 2\ mm$

Fine Wire Heat Transfer Model

ΔT_A → $\bar{H}$

Estimated Using "Chopping" Self-Calibration

ΔU → $\frac{\partial H}{\partial U}$ → ΔH → $(\bar{T}_w - \bar{T}_a)$

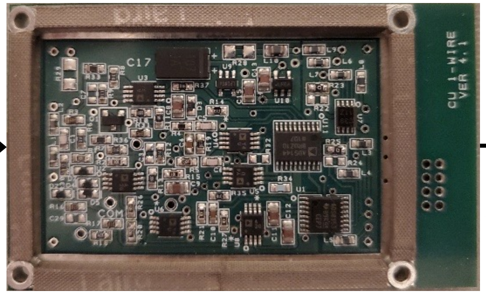
$+$ / $-$ → $\Delta \dot{Q}$

Wire overheat amount
Cold Wire Phase ≈ 1℃
Hot Wire Phase ≈ 30℃

Electronics Model

Custom 1-Wire Board
x2 On Each Payload

- Hotwire anemometer
- Coldwire thermometer

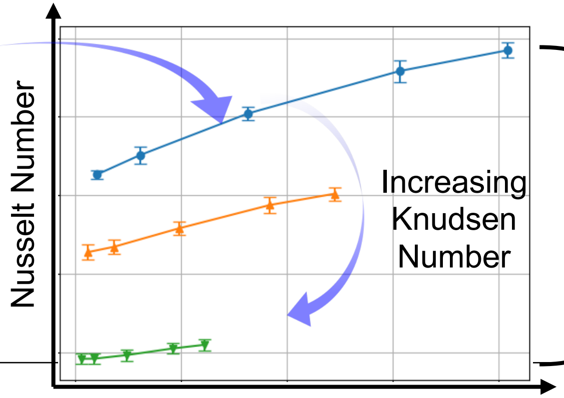


Instrument Voltage Output

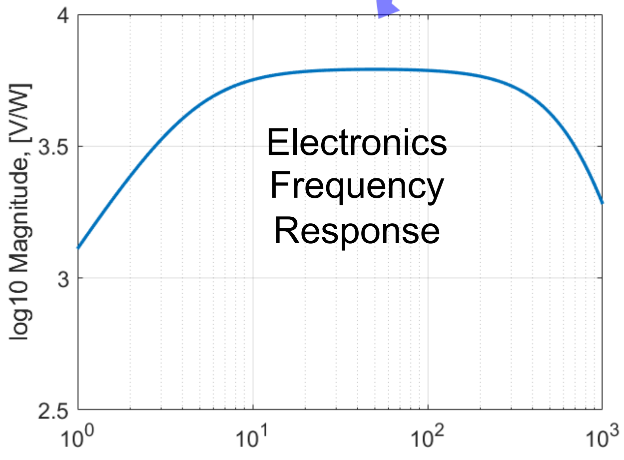
ΔV_G

$$\frac{\partial H}{\partial U} = \pi k L_W \frac{\partial Nu}{\partial Re}\frac{\partial Re}{\partial U}$$

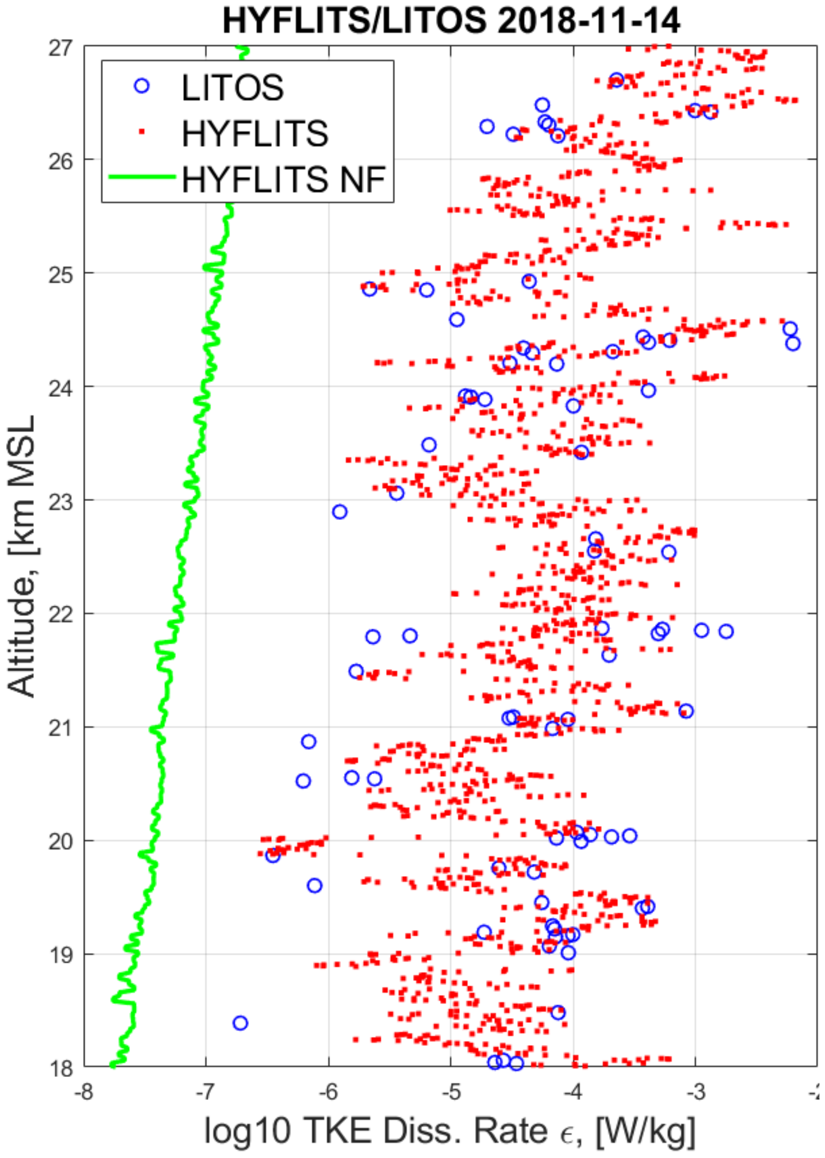
$$\frac{\partial Re}{\partial U} = \frac{\rho d_w}{\mu}$$



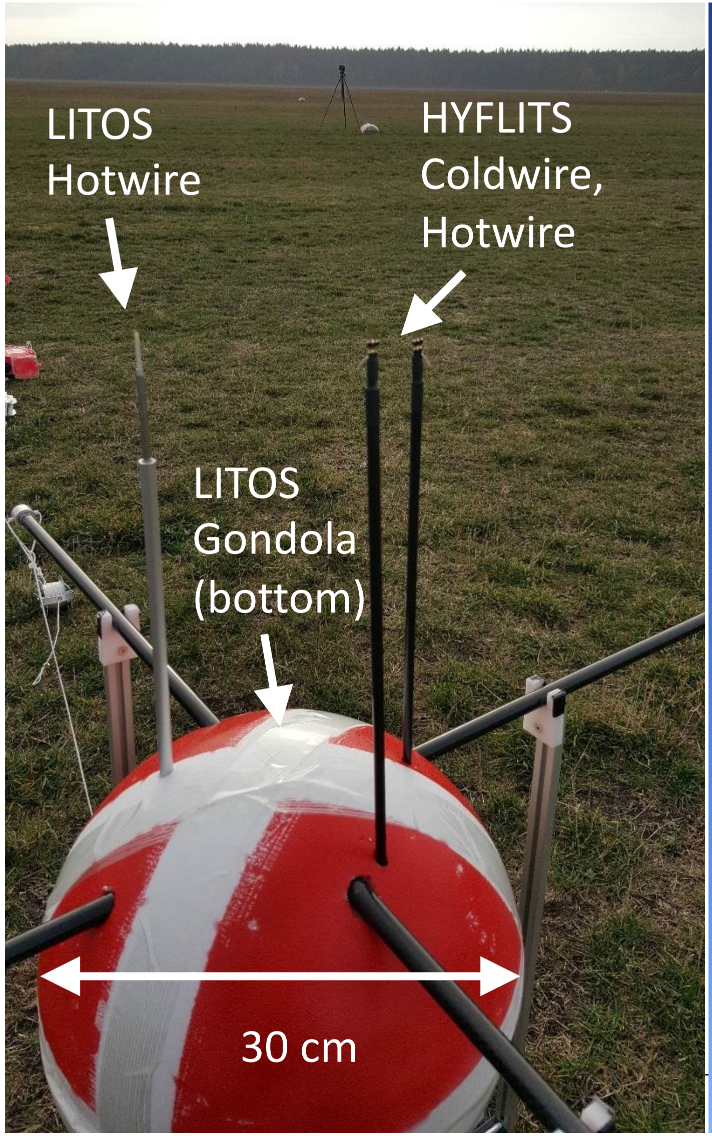
Empirical relations available in work by *Xie et al., 2017.*

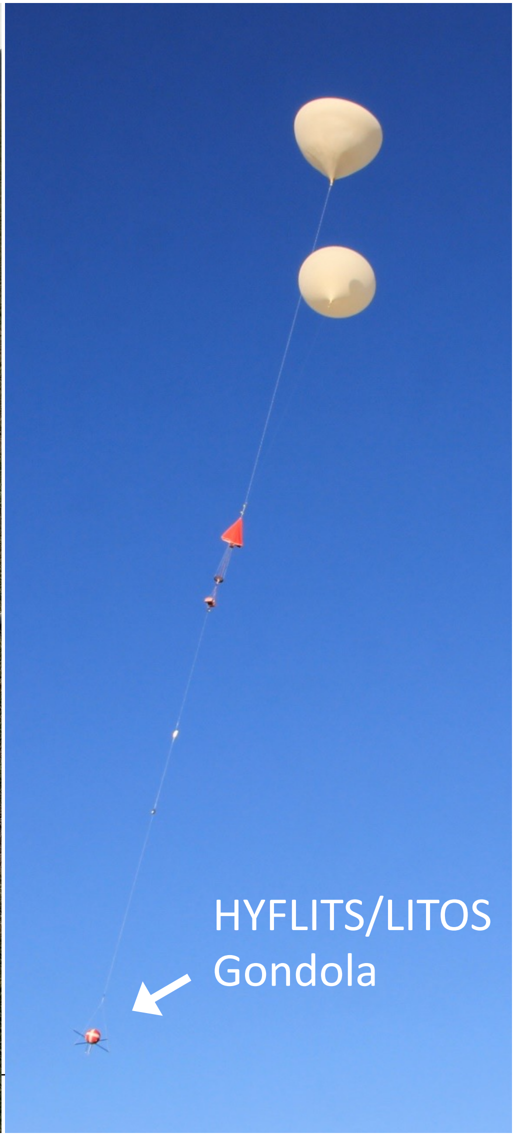


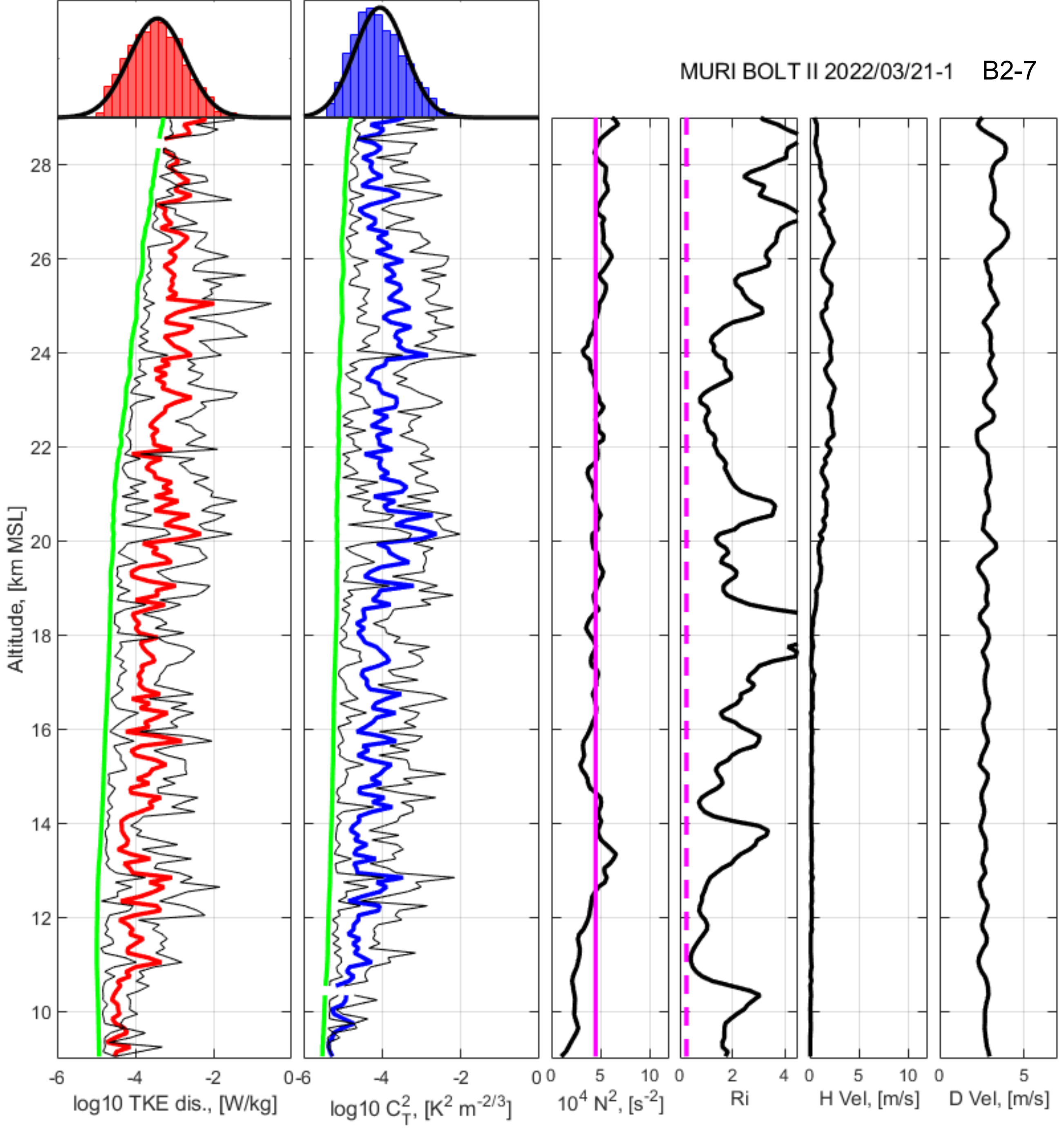
HYFLITS-LITOS Comparison



- Flight in Germany on Nov. 14, 2018
- Co-located instruments inside a single gondola with downward facing probes
- Double balloon ascent, single balloon descent from 27km
- Selection criteria for the LITOS data is not clear
- Remarkable correspondence when the recent calibration procedure is used for HYFLITS!



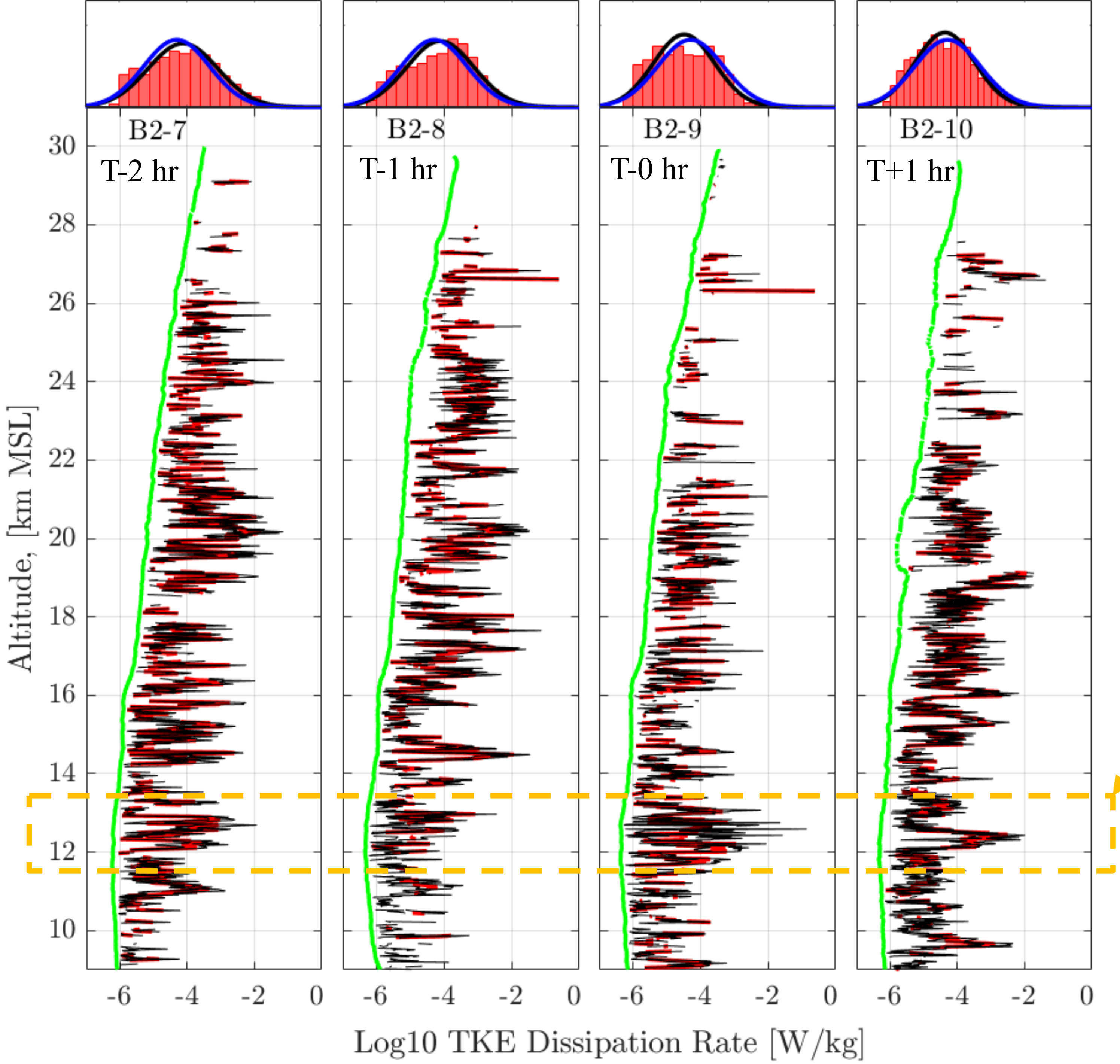




Per-Flight Turbulence Data Products

- Turbulent kinetic energy dissipation rate epsilon
- Temperature structure parameter C_T^2
- Brunt-Vailaila frequency N (squared), purple line shows average for the lower stratosphere
- Gradient Richardson number Ri, dashed line shows critical value of 0.25
- Horizontal pendulation velocity of the balloon payload (H Vel)
- Inertial payload descent velocity (D vel)
- Filtering at various bandwidths to display large scale/small scale features of interest.

TKE Dissipation Rate Data Example



- 4 Balloon launches during the BOLT II countdown, 1 hour apart, designed to bracket the BOLT II descent in time
- Descending measurements began at approximately T-2 hr to T+1 hr
- Distributions of dissipation rate over the 9-29 km range are approximately log normal
- Distributions of dissipation rate are very similar---blue distribution is the fit to the population of all 14 flights (for reference)
- Some features persist over this 4 hour time period, e.g., the elevated layer between 12 and 13 km.
- Intense turbulence exists in thin layers 100m to 500m in thickness
- 95% probability contains dissipation rate variation spanning 4 decades

AIAA SciTech, 2023.

Summary Status

- Over 160 HYFLITS observations conducted as part of the AFOSR MURI Project in Colorado, Florida, Minnesota, Virginia (Wallops), and Sweden (Esrange). Data analysis is ongoing.
- Apogee for most of these flights was 32 km, but this is programmable.
- Vertical resolution of epsilon and CT2 is 3 m for 1 sec spectral analysis records and 3 m/s descent velocity. Other record lengths and descent velocities can be programmed.
- Low-cost drivers resulted in
  - $1500 equipment cost per launch (not including ground station).
  - Data is compressed and telemetered. Recovery is expensive!
  - Lightweight enough to be FAA “Unregulated”, EU “Light” class
  - Small enough for 1 or 2 person launch crew.
- Current NSF/NIPR project will deploy 44 HYFLITS payloads at the Syowa Antarctic Station in Jan/Feb 2024.