DataHawk Obsevations During the Spring 2012 MATERHORN Campaign

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Overview of the DataHawk System

Unmanned Aircraft

- Wingspan: 1 m
- Weight: ~700 gm
- Payload: ~ 80 gm
- Electric propulsion

Duration: about 50 min.
Rear folding propeller
11-16 m/s airspeed
Power: LiPo battery
Cost: ~ $600
Airframe: EPP foam
Autopilot: custom
(CUPIC)

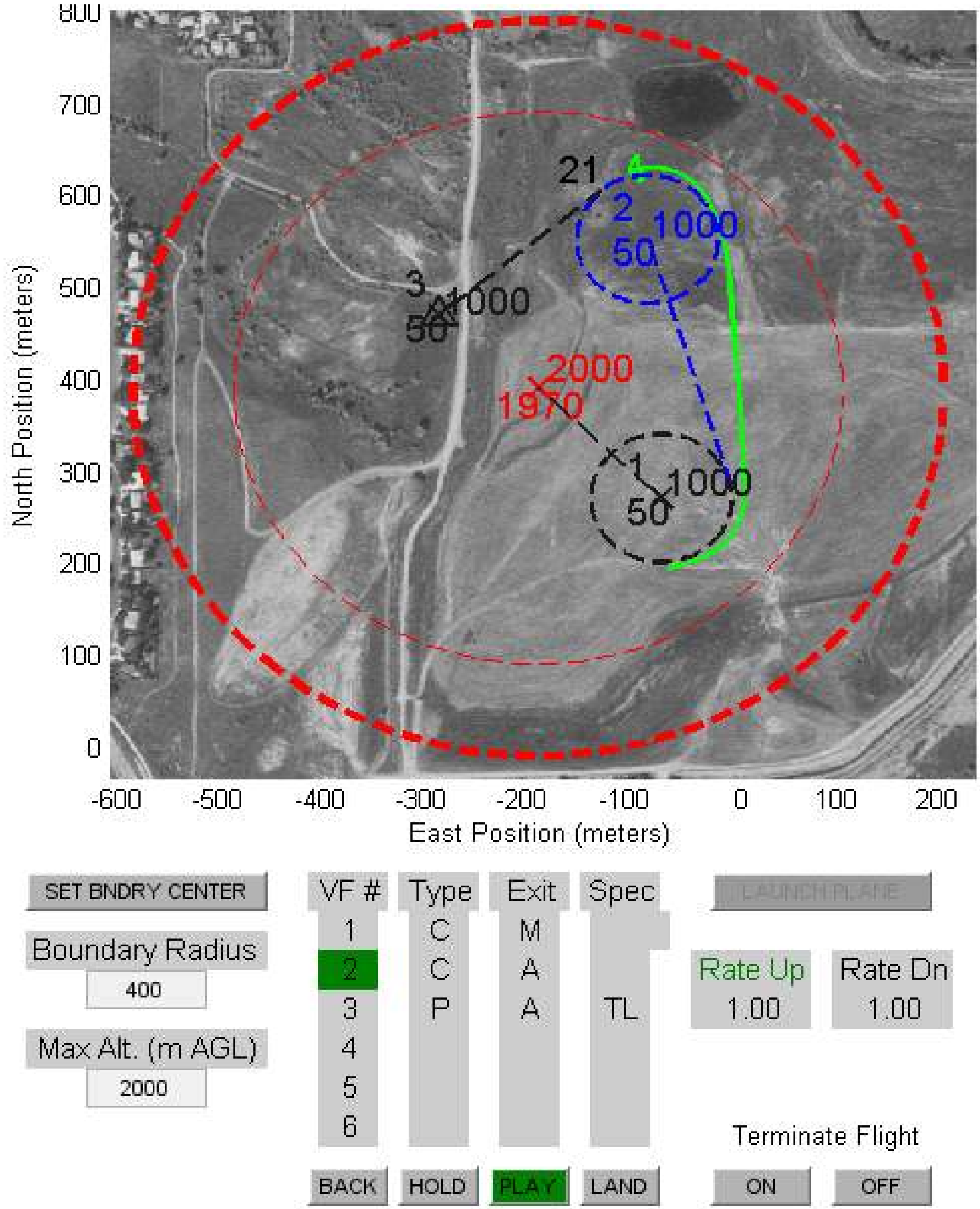
- Autonomous flight control with user supervision, real time changes in flight profile
- Flight termination mode prevents fly-away and conflict with other air traffic

Small, low-cost, safe, easy to operate

Overview of the DataHawk System

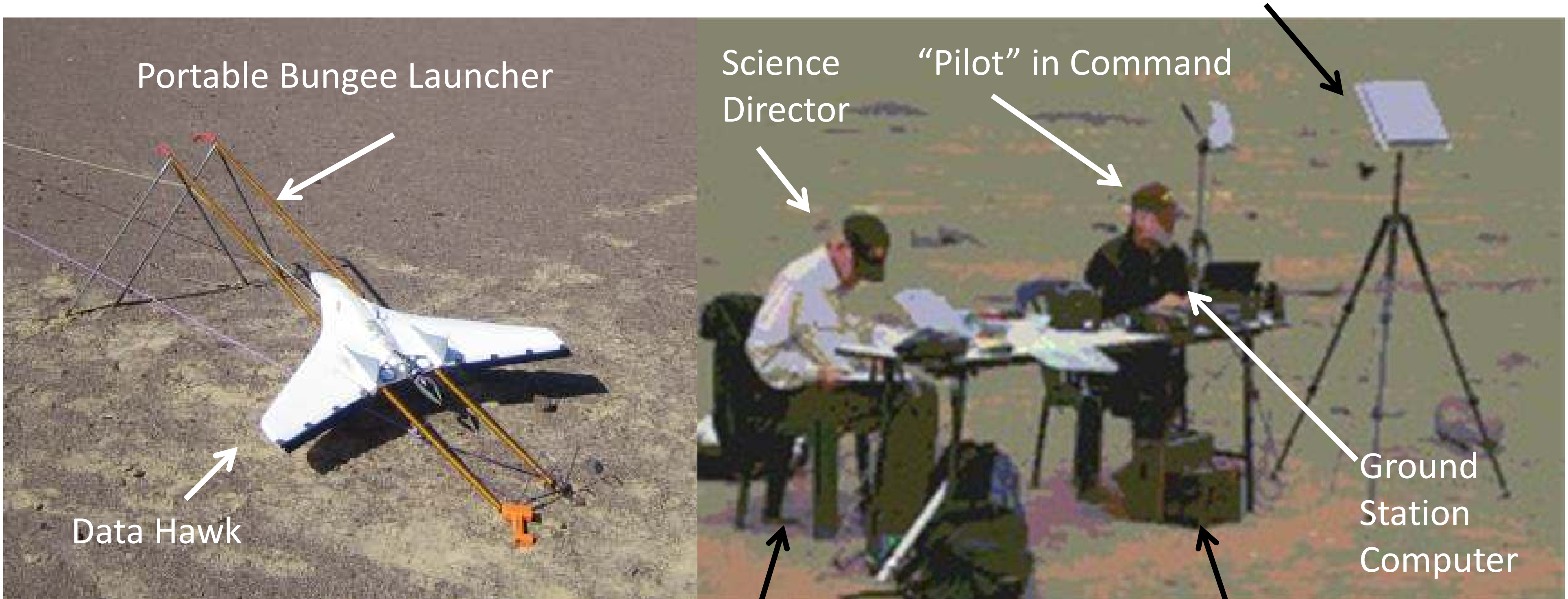
Ground Station

- Laptop computer running a Matlab user interface
- Data radio module and suitable antenna
- Real time aircraft location, status, and sensor data display
- Real time uplink of flight parameter changes and mode commands
- Tested radio range:
  3 km laterally
  10 km vertically



Overview of the DataHawk System

Typical Ground Support Equipment



Data Hawk Operating Modes

Deployment

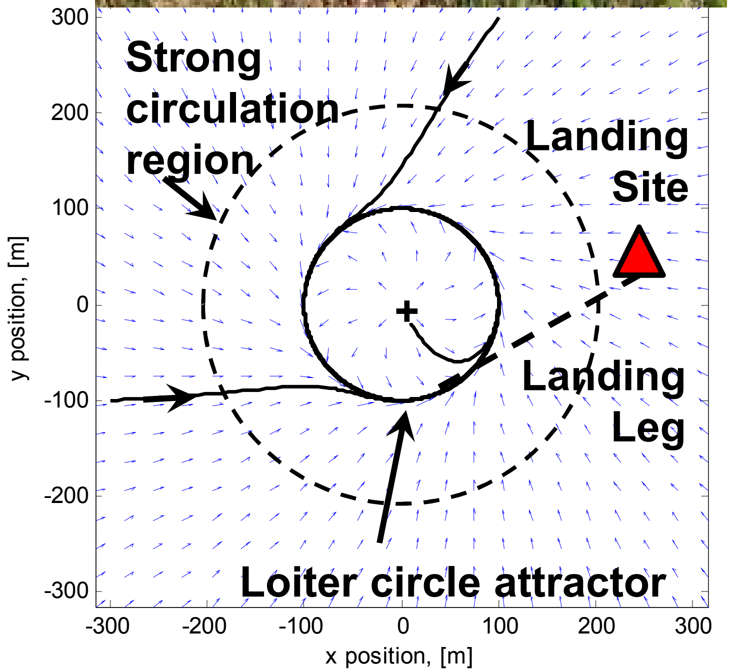
- Auto-Launch: bungee launch for flights up to about 3 km AGL
- Auto-Drop: release from a weather balloon for flights up to about 10 km MSL

In-flight

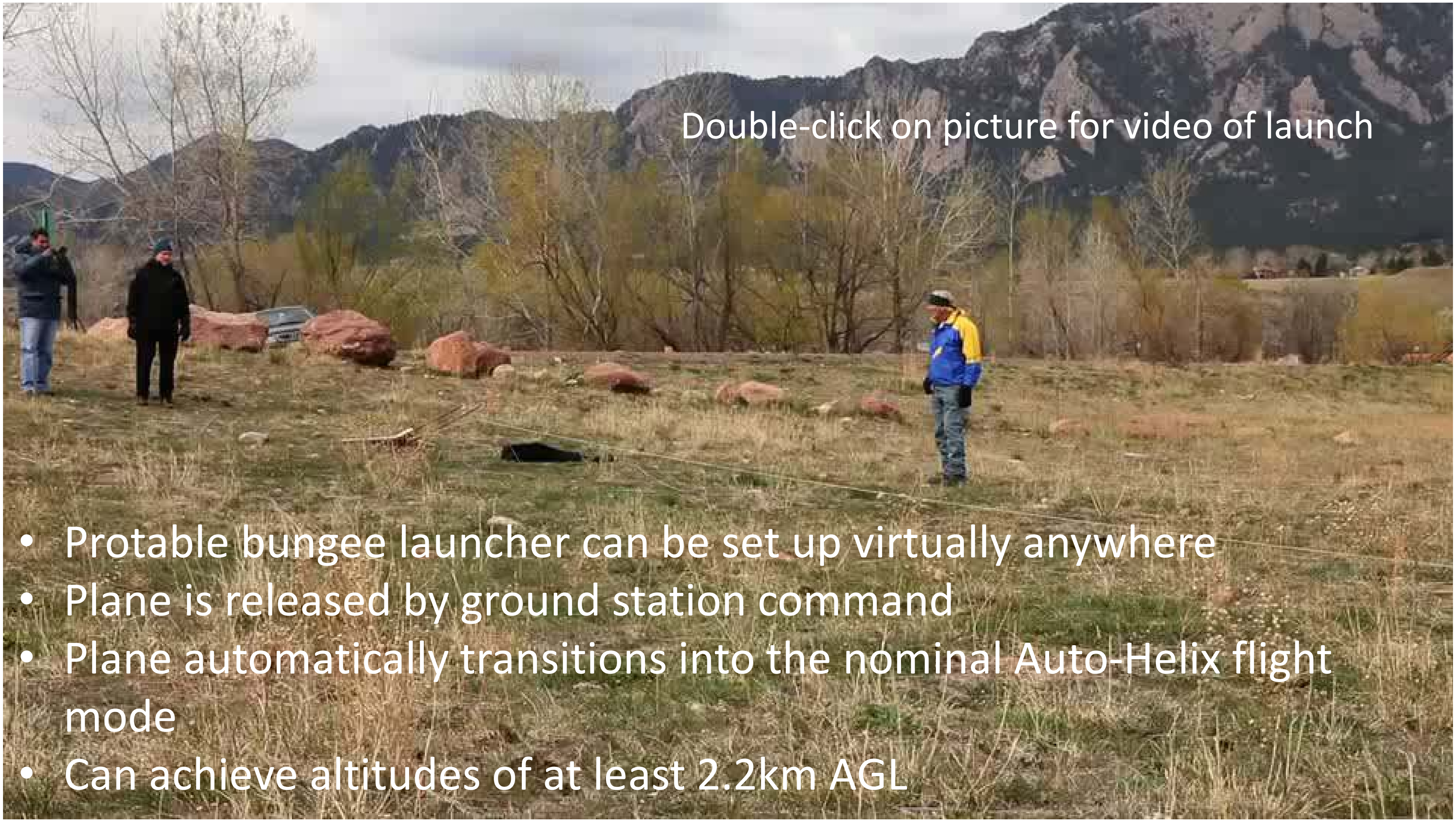
- Auto-Helix: vector field attraction to a loiter circle, with prescribed location and radius, and prescribed altitude ceiling/floor and ascent/descent rates
- All helix parameters can be changed in real time from the ground station

Recovery

- Auto-Land: Plane glides to designated landing coordinates upon ground station command



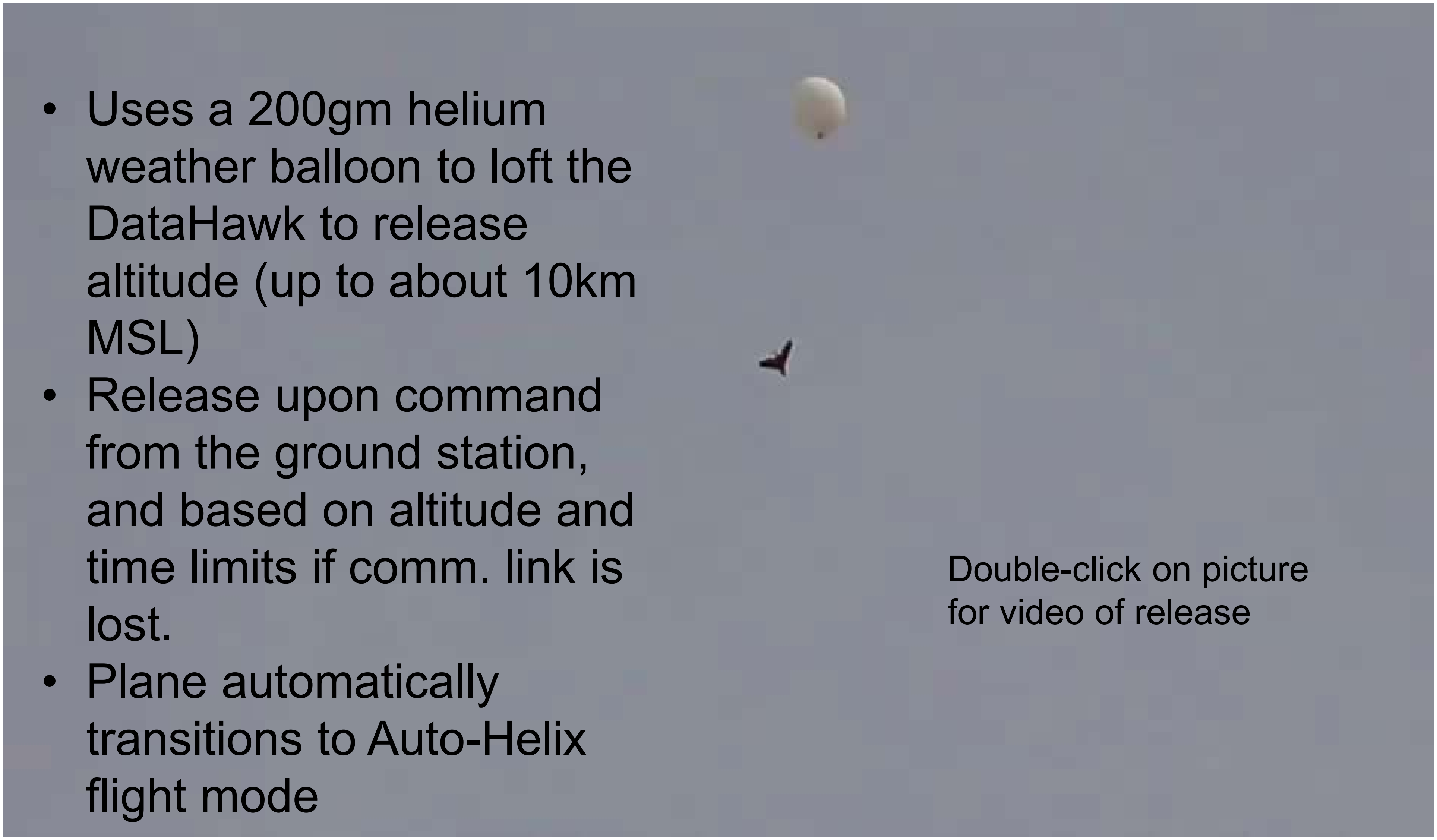
DataHawk Auto-Launch Deployment



Double-click on picture for video of launch

- Protable bungee launcher can be set up virtually anywhere
- Plane is released by ground station command
- Plane automatically transitions into the nominal Auto-Helix flight mode
- Can achieve altitudes of at least 2.2km AGL

DataHawk Auto-Drop Balloon Deployment :



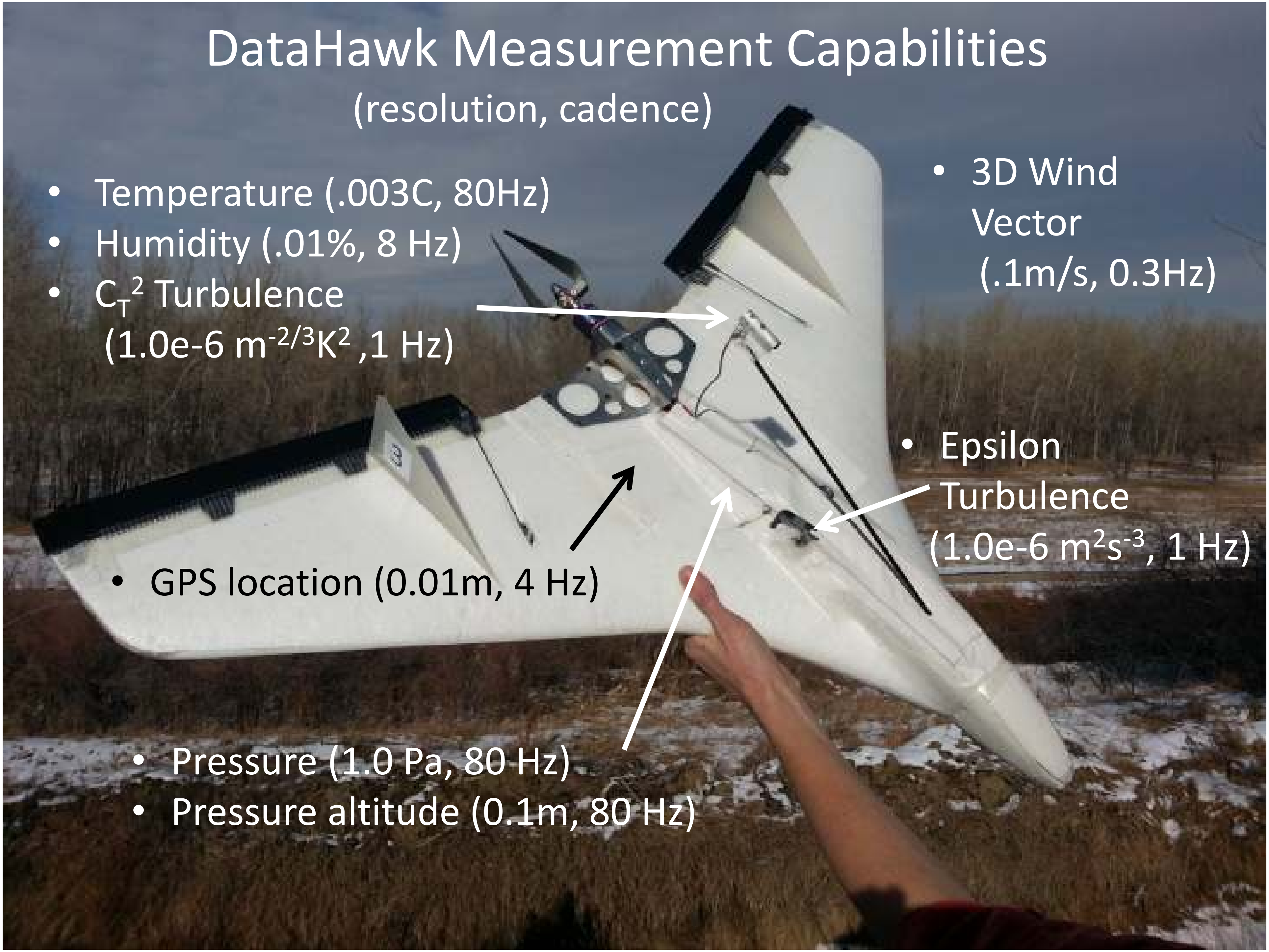
- Uses a 200gm helium weather balloon to loft the DataHawk to release altitude (up to about 10km MSL)
- Release upon command from the ground station, and based on altitude and time limits if comm. link is lost.
- Plane automatically transitions to Auto-Helix flight mode

Double-click on picture for video of release

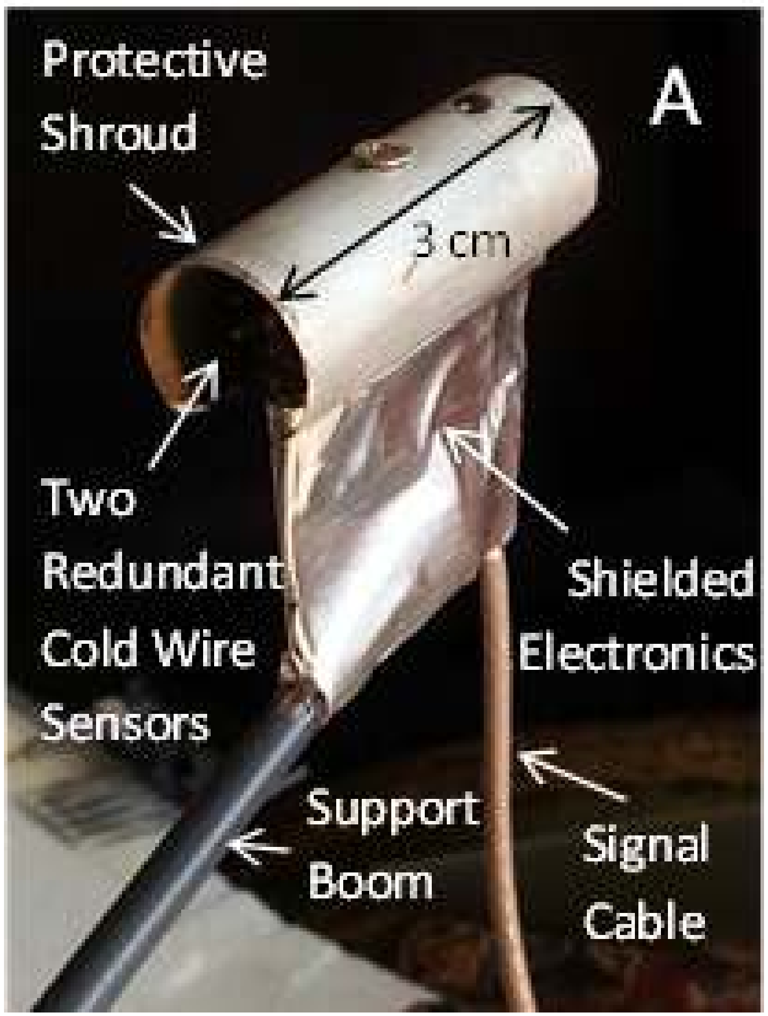
DataHawk Auto-Land Recovery

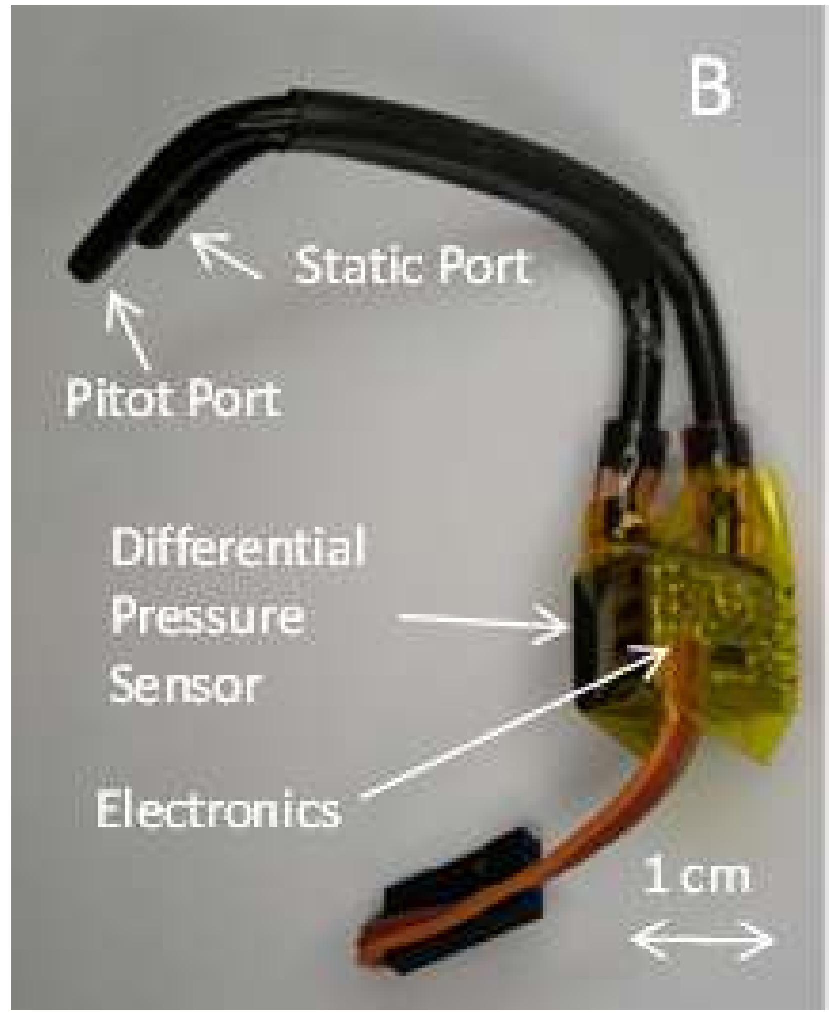
- Initiated by ground station command
- Plane glides to designated landing coordinates

Double-click on picture for video of landing

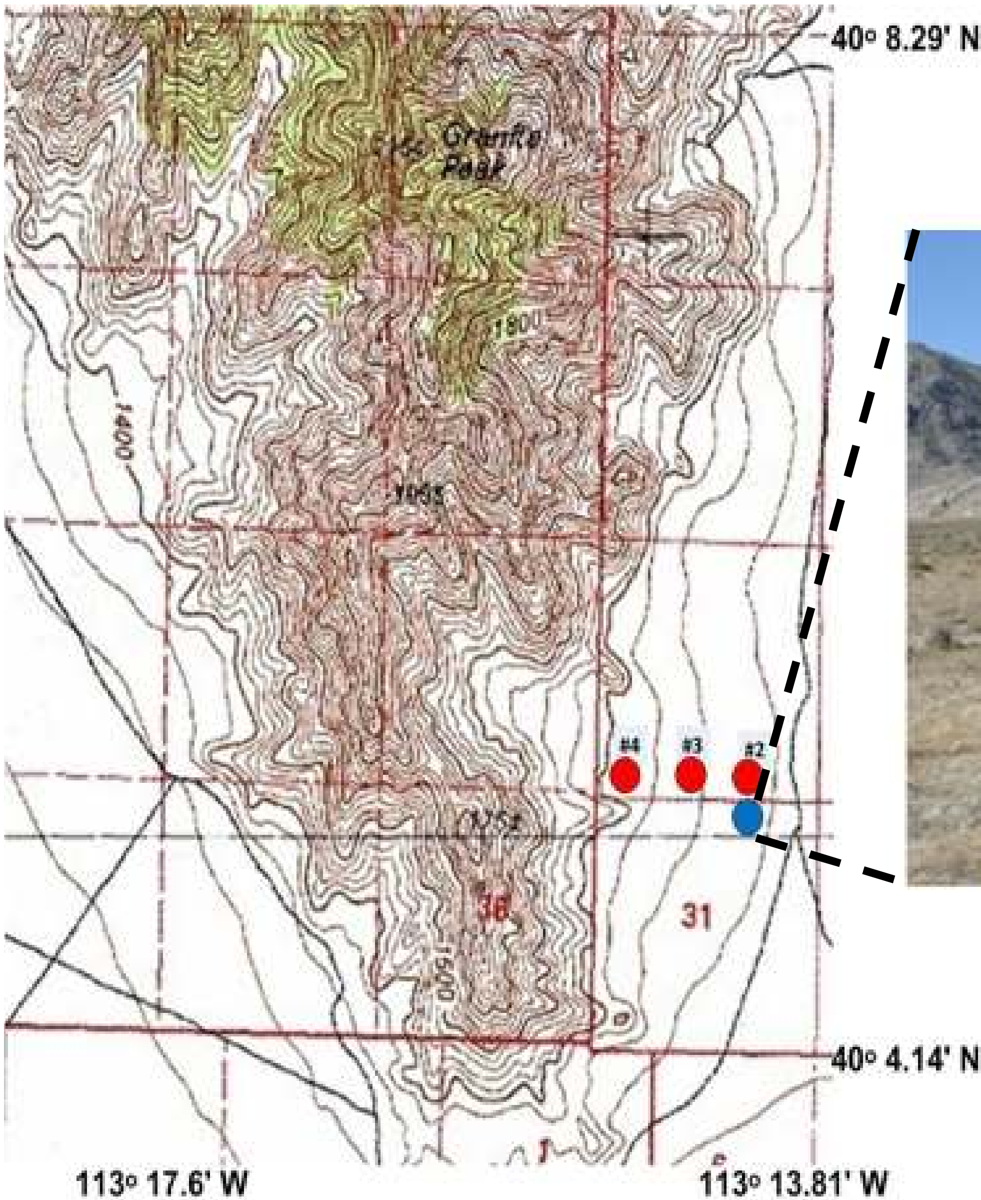

DataHawk Measurement Capabilities
(resolution, cadence)
• Temperature (.003C, 80Hz)
• Humidity (.01%, 8 Hz)
• C_T^2 Turbulence ($1.0e\text{-}6\ m^{-2/3}K^2$, 1 Hz)
• 3D Wind Vector (.1m/s, 0.3Hz)
• Epsilon Turbulence ($1.0e\text{-}6\ m^2s^{-3}$, 1 Hz)
• GPS location (0.01m, 4 Hz)
• Pressure (1.0 Pa, 80 Hz)
• Pressure altitude (0.1m, 80 Hz)

Temperature and Velocity Sensors





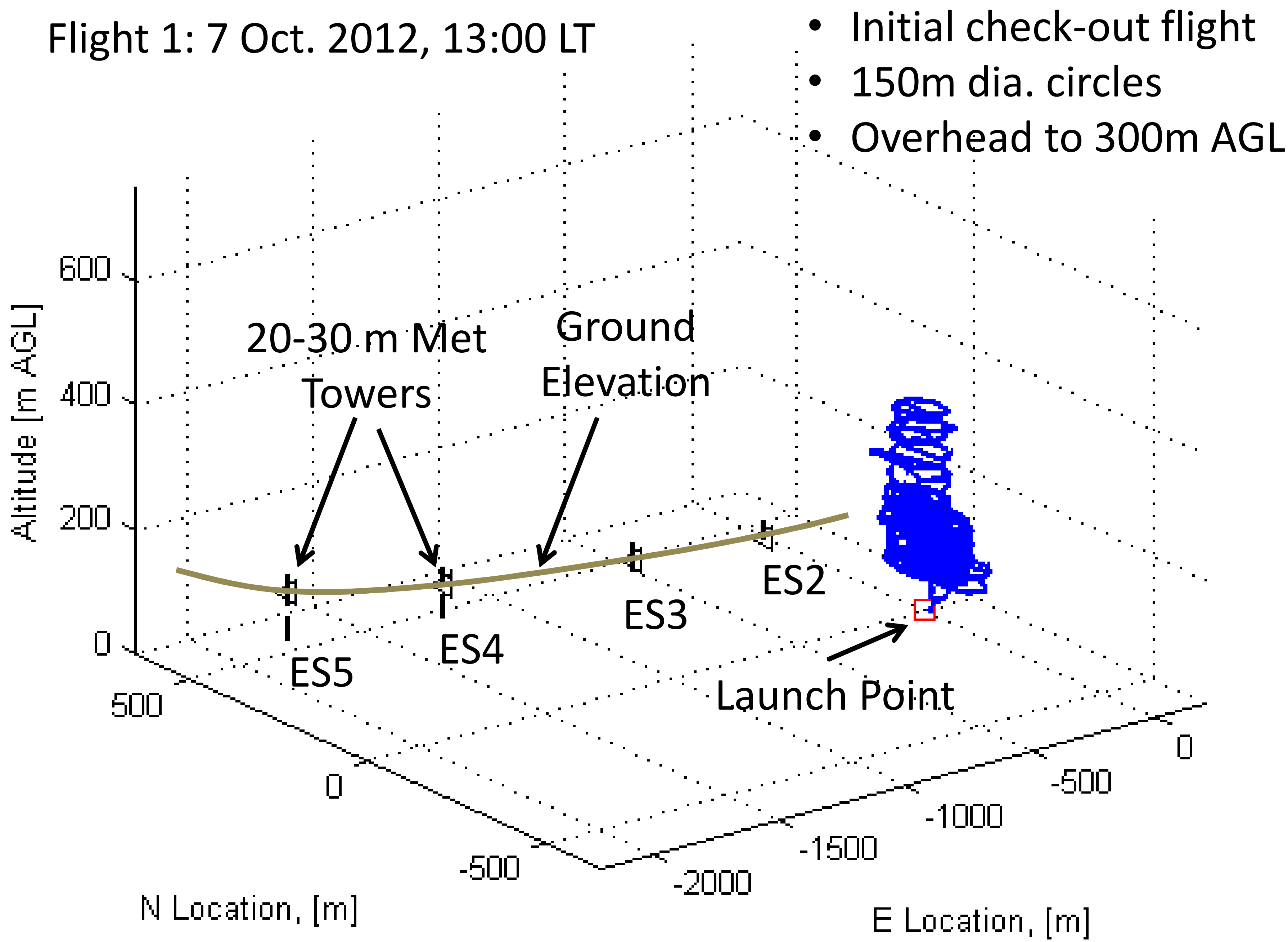
Ground Equipment and Flight Location



Dugway Proving Ground, Utah

October 7-12, 2013

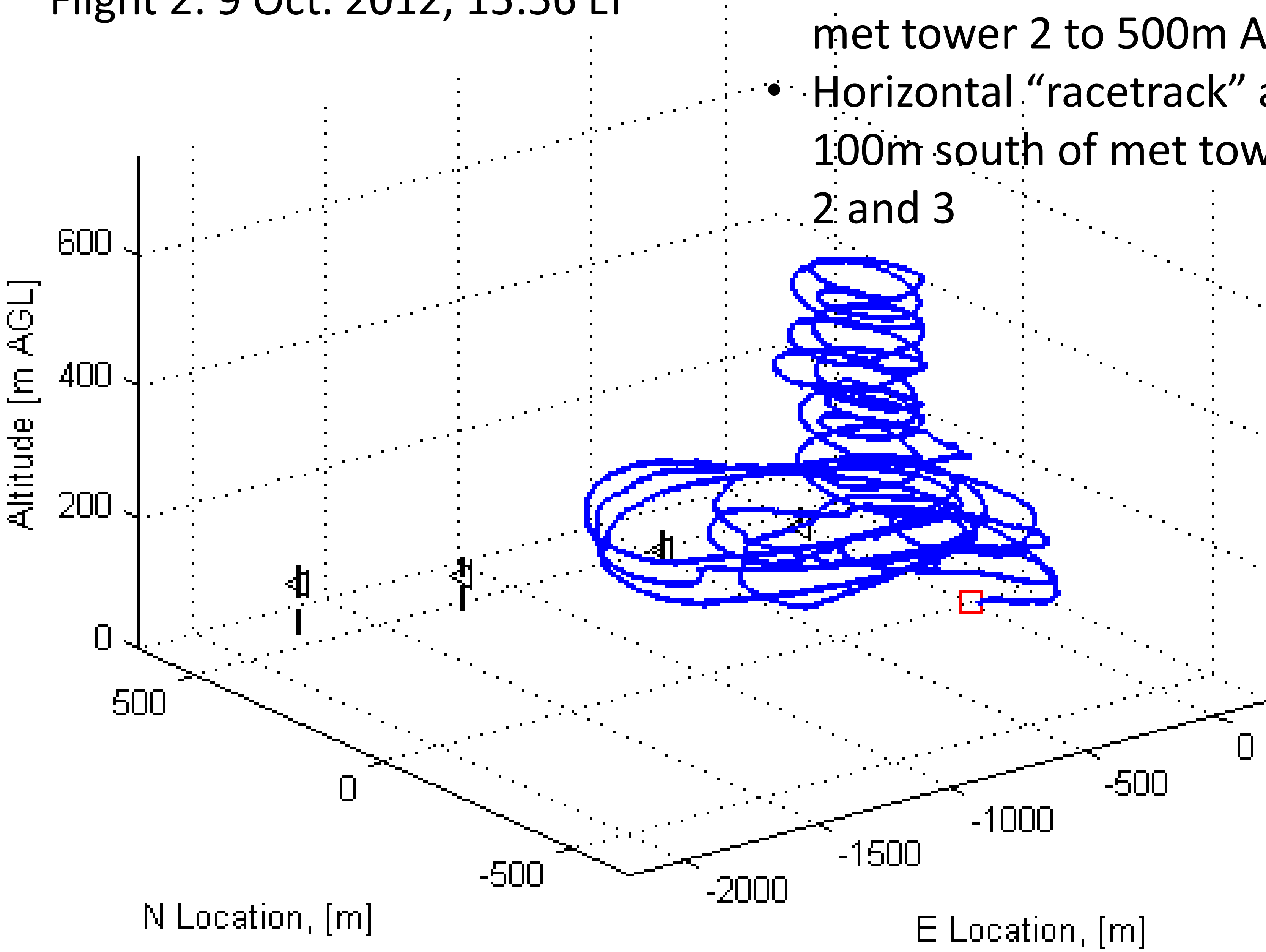
Photo provided by Dugway photographer and cleared for public release



Flight 1: 7 Oct. 2012, 13:00 LT
• Initial check-out flight
• 150m dia. circles
• Overhead to 300m AGL
20-30 m Met Towers
Ground Elevation
ES5
ES4
ES3
ES2
Launch Point
Altitude [m AGL]
600
400
200
0
500
0
-500
N Location, [m]
0
-500
-1000
-1500
-2000
E Location, [m]

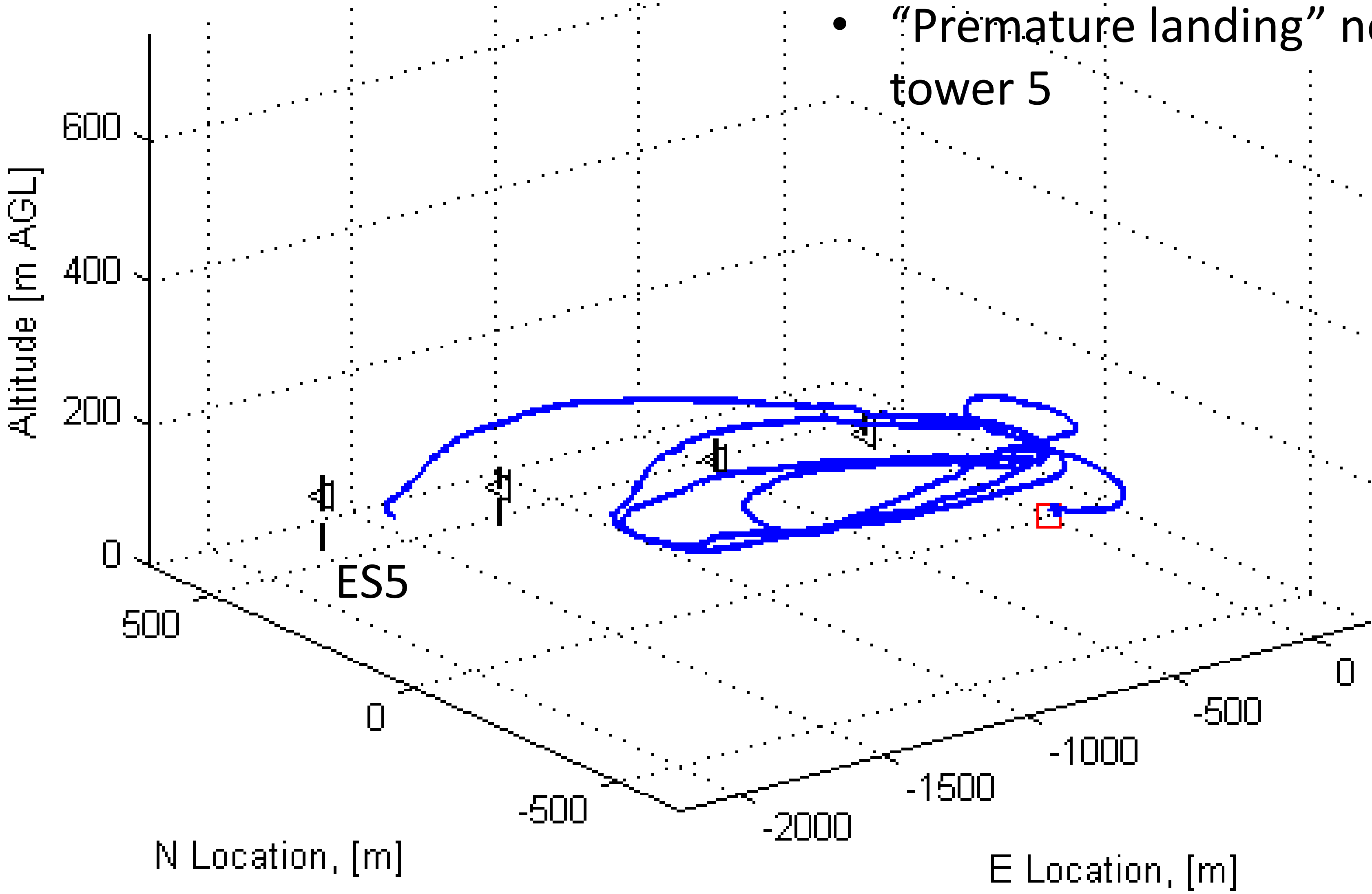
Flight 2: 9 Oct. 2012, 15:56 LT

- Vertical profile south of met tower 2 to 500m AGL
- Horizontal "racetrack" at 100m south of met towers 2 and 3



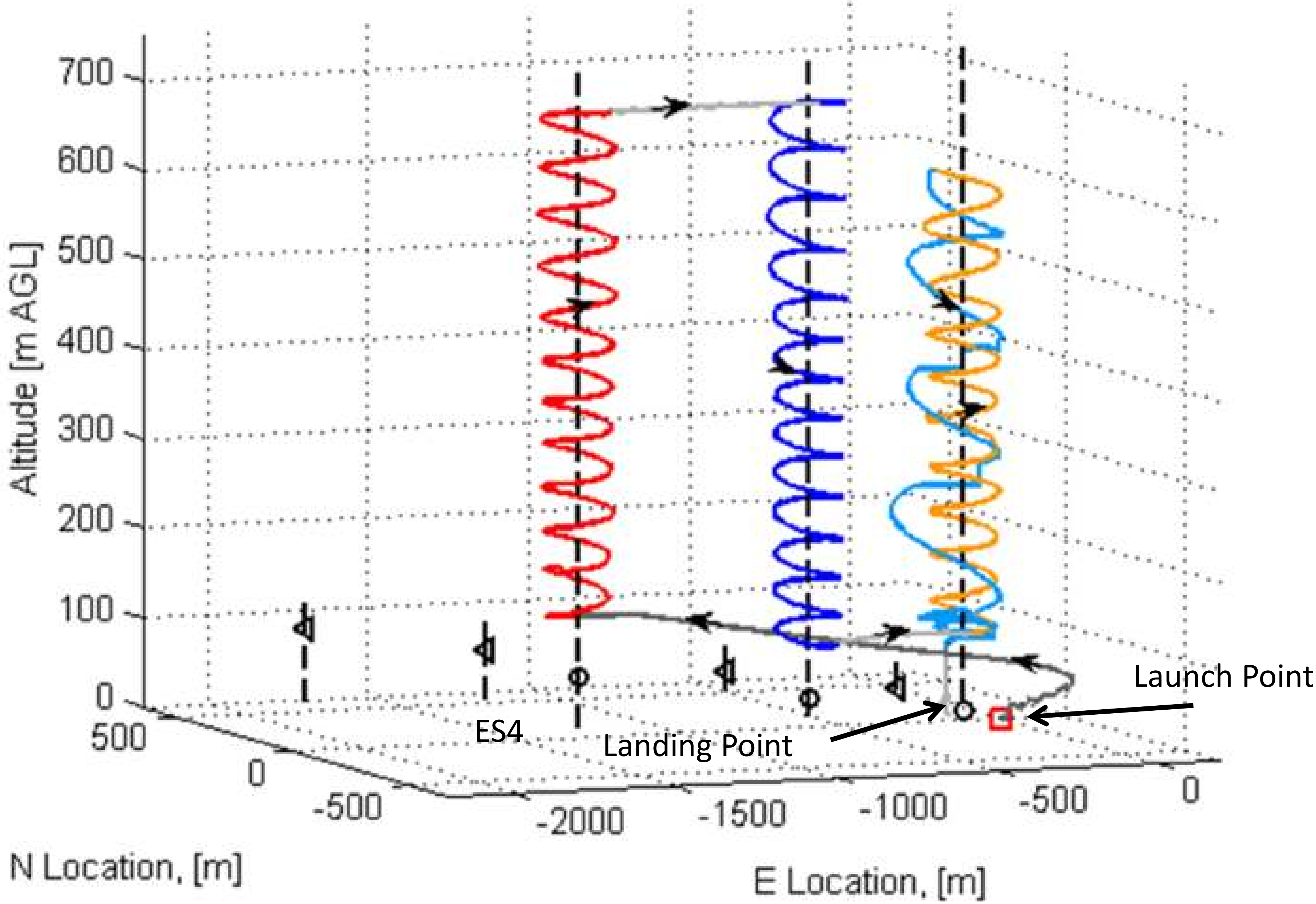
Flight 3: 9 Oct. 2012, 16:49 LT

- Horizontal "racetracks", at 100m enlarging to the west
- "Premature landing" near tower 5



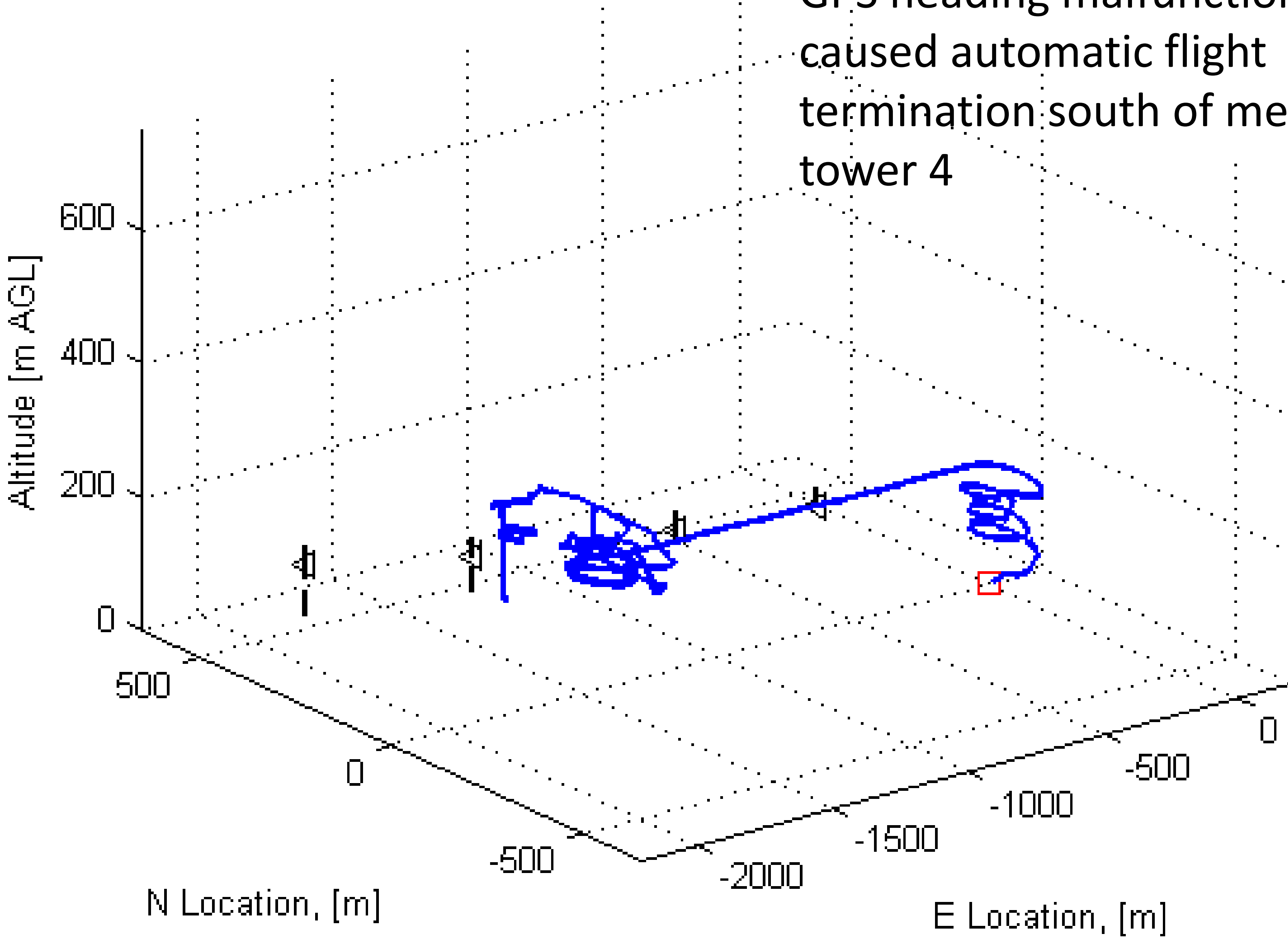
Flight 4: 10 Oct., 2012, 09:48 LT (IOP5)

- Vertical profiles to 700m AGL south of towers 2,3,4



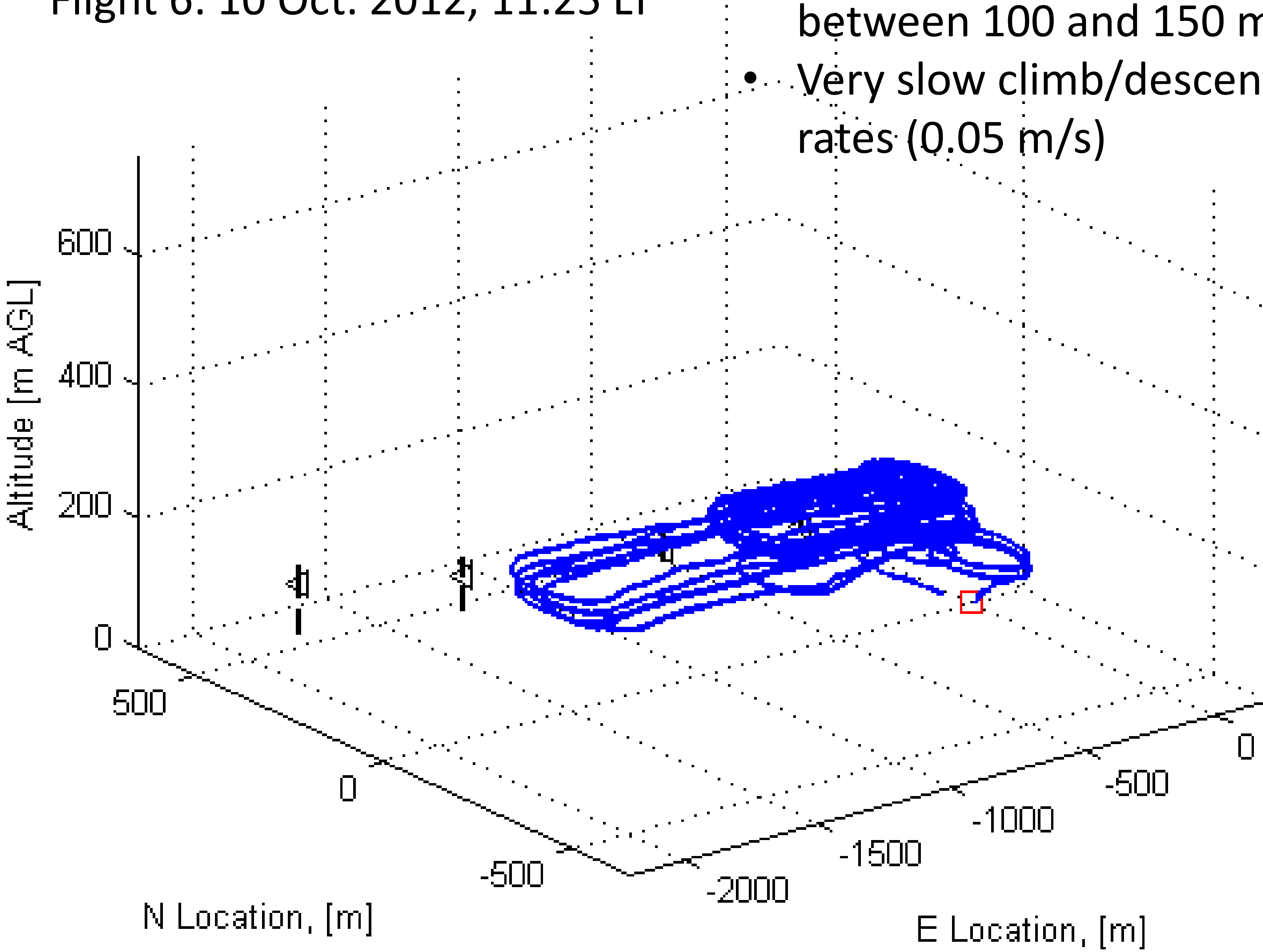
Flight 5: 10 Oct. 2012, 10:40 LT

- Attempted repeat of flight 4
- GPS heading malfunction caused automatic flight termination south of met tower 4



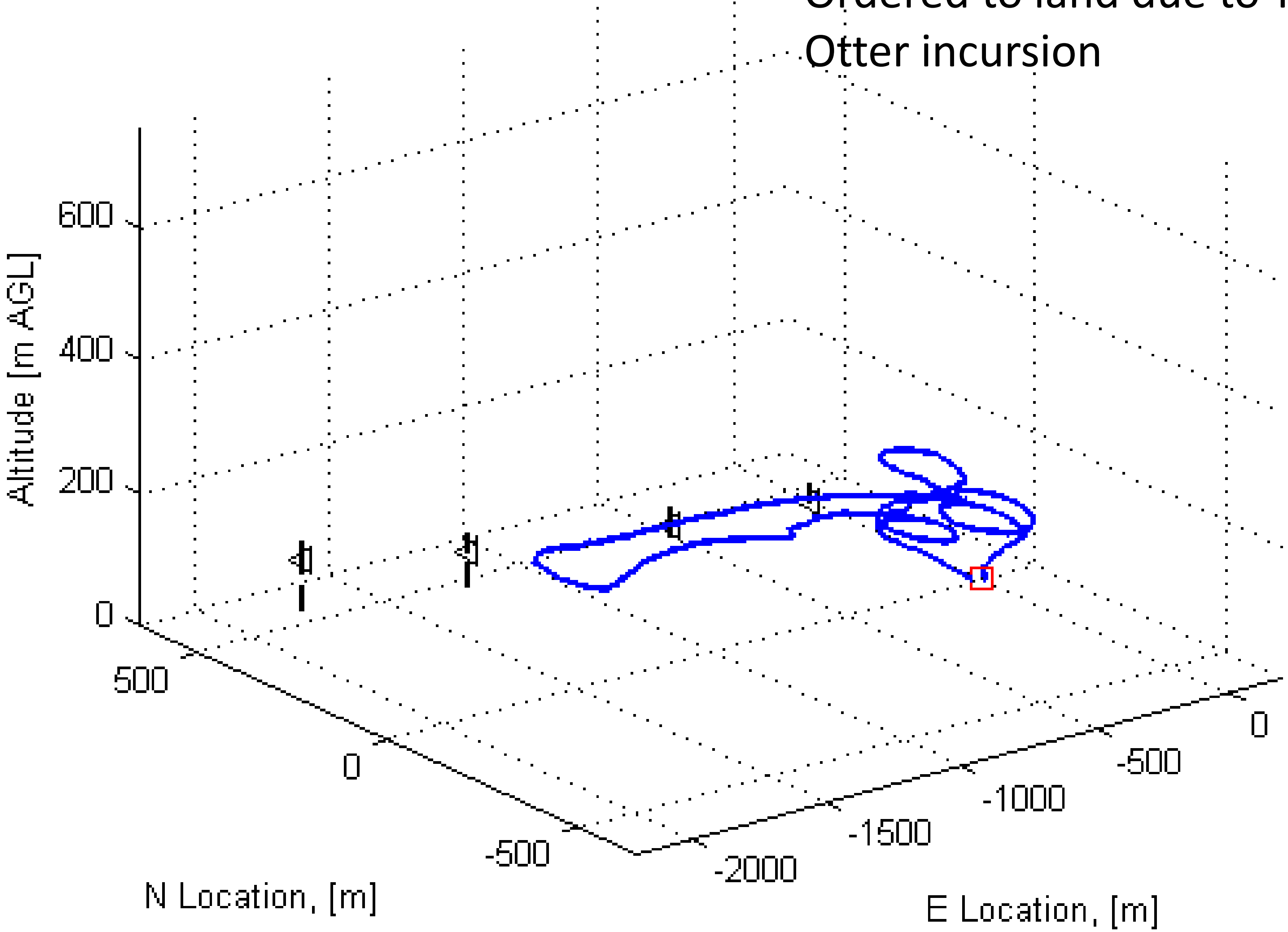
Flight 6: 10 Oct. 2012, 11:25 LT

- Racetrack horizontal surveys between 100 and 150 m AGL
- Very slow climb/descent rates (0.05 m/s)



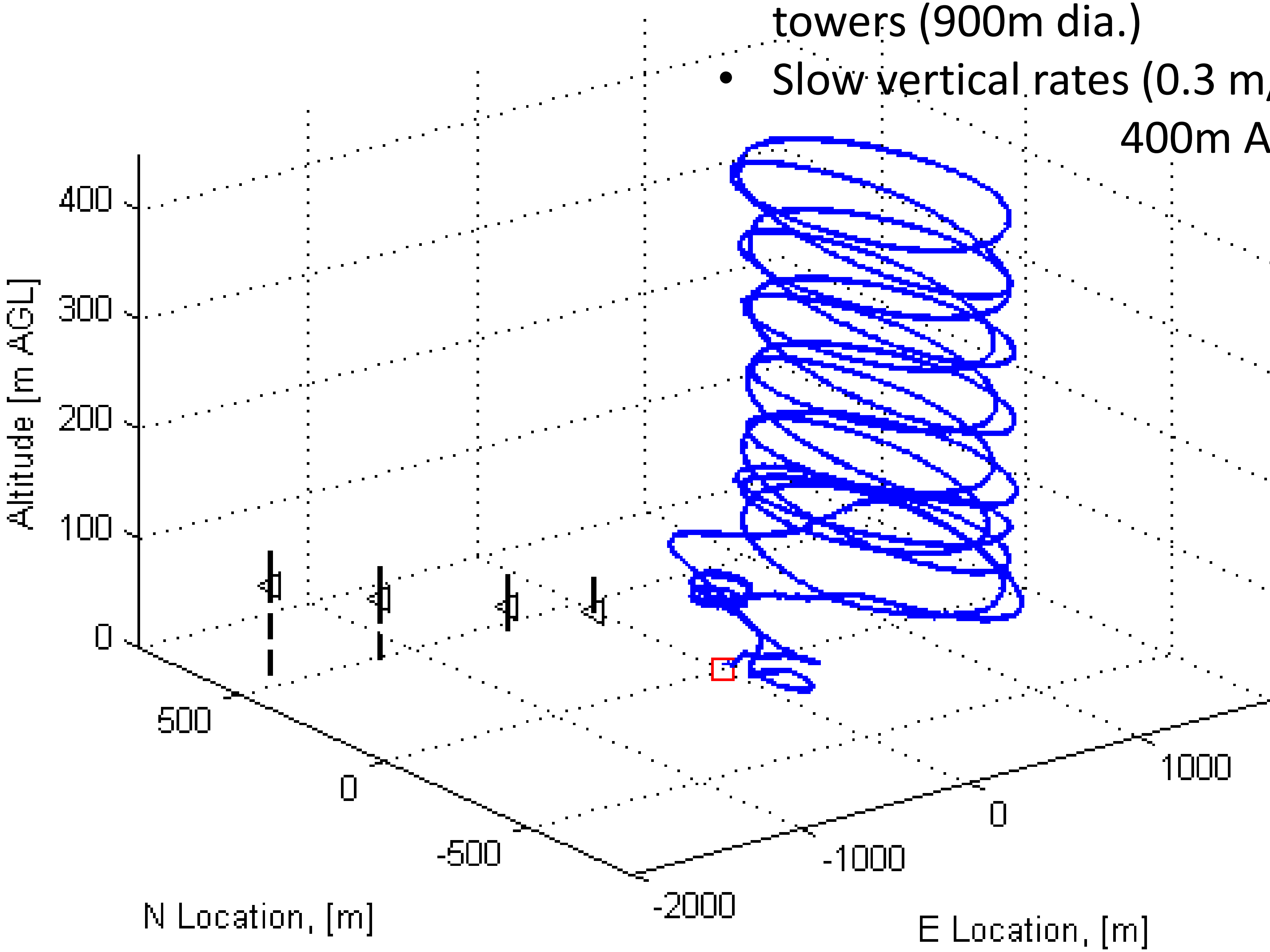
Flight 7: 10 Oct. 2012, 12:15 LT

- Attempted repeat of flight 6
- Ordered to land due to Twin Otter incursion



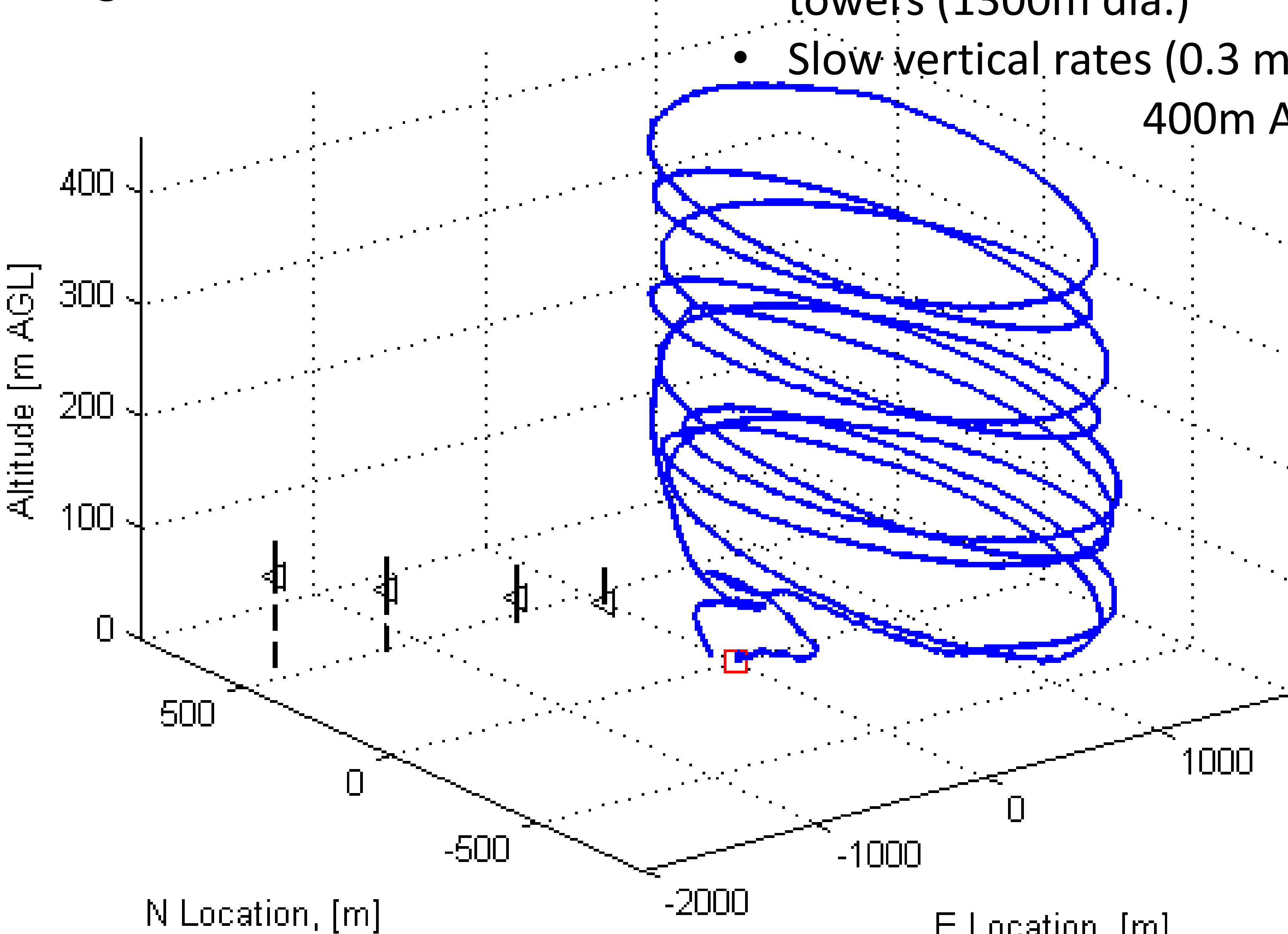
Flight 8: 11 Oct. 2012, 07:58 LT

- Large diameter circles east of towers (900m dia.)
- Slow vertical rates (0.3 m/s) to 400m AGL



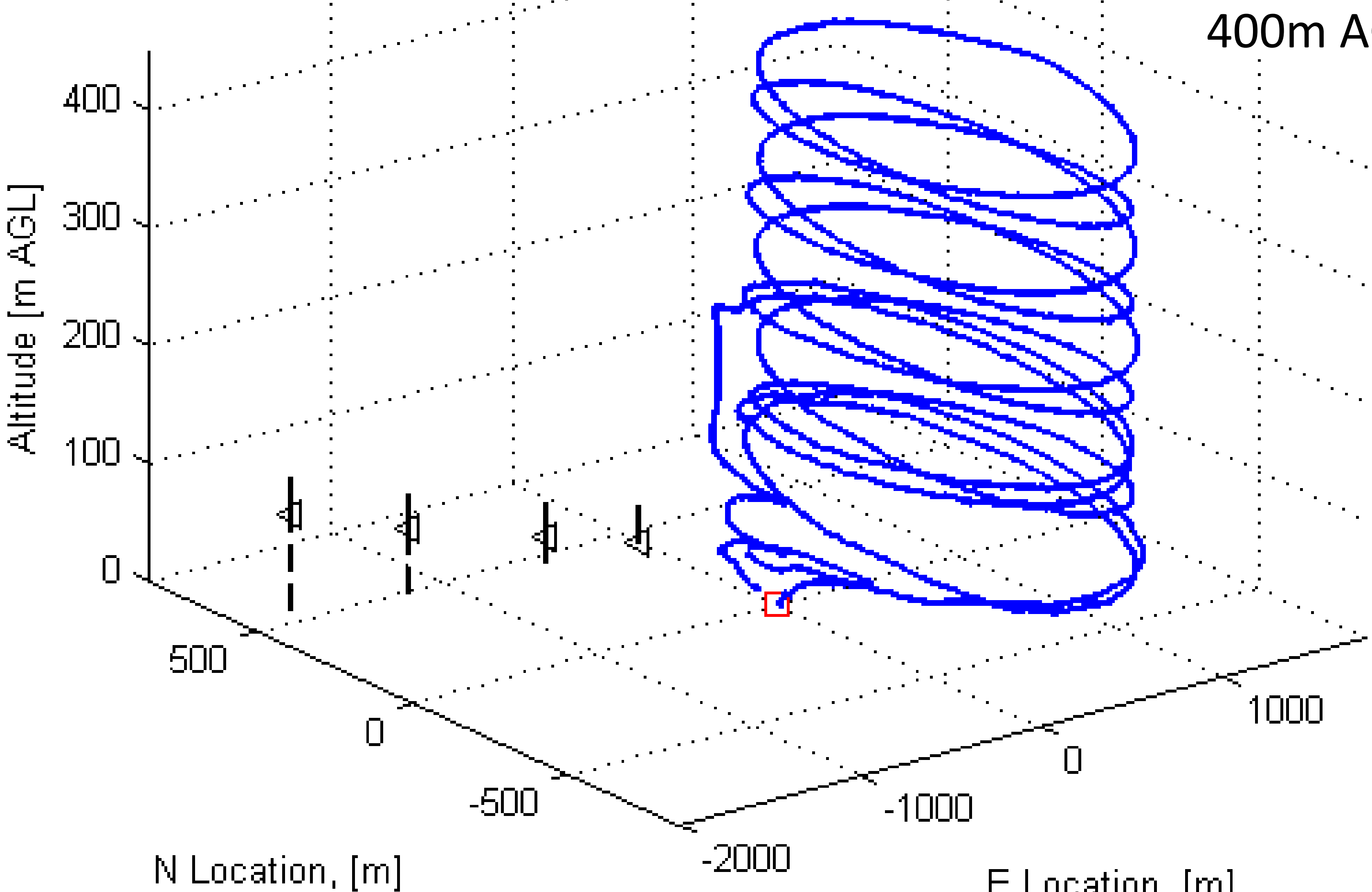
Flight 9: 11 Oct. 2012, 09:02 LT

- Larger diameter circles east of towers (1300m dia.)
- Slow vertical rates (0.3 m/s) to 400m AGL



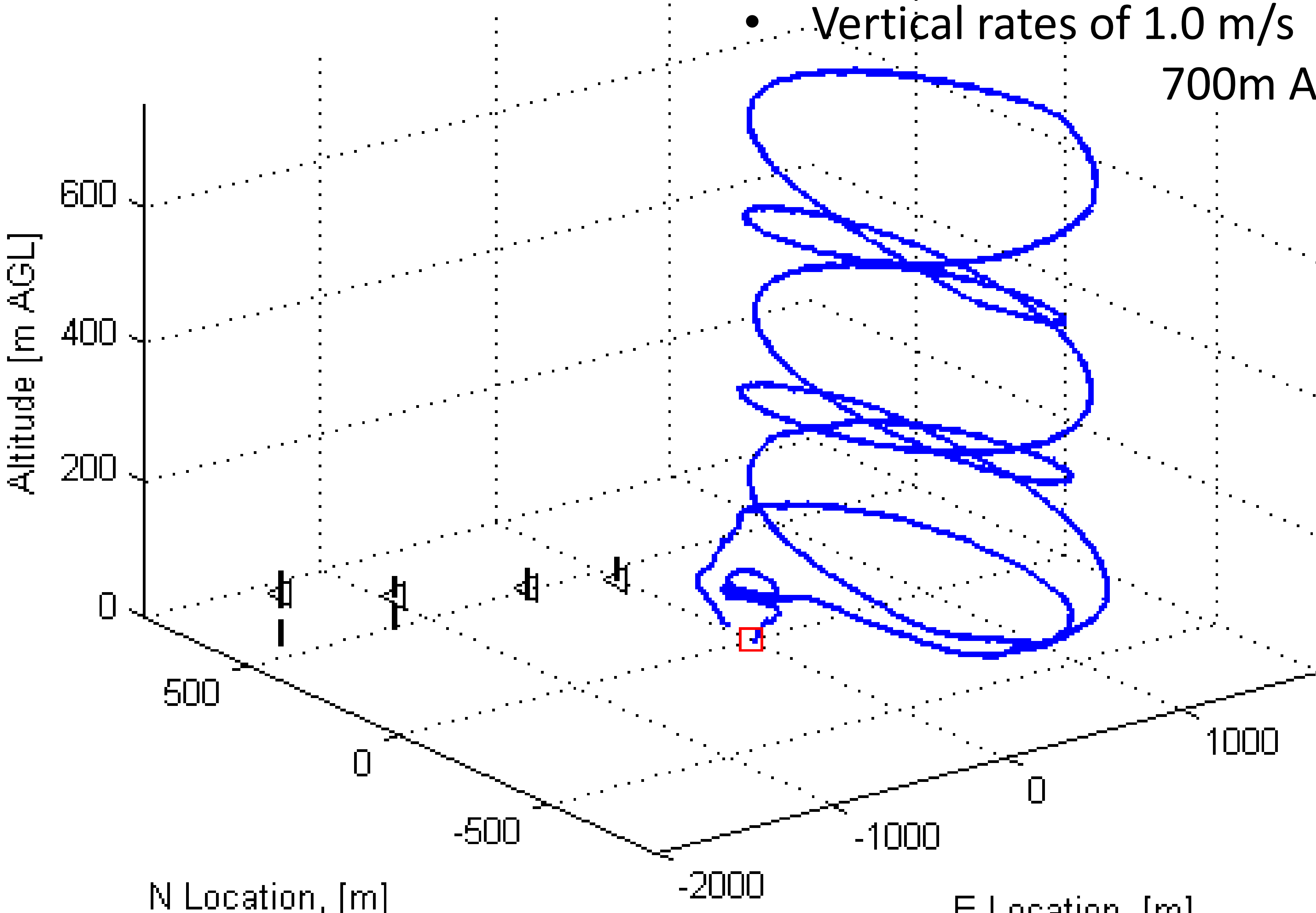
Flight 10: 11 Oct. 2012, 10:04 LT

- Large diameter circles east of towers (1100m dia.)
- Slow vertical rates (0.3 m/s) to 400m AGL



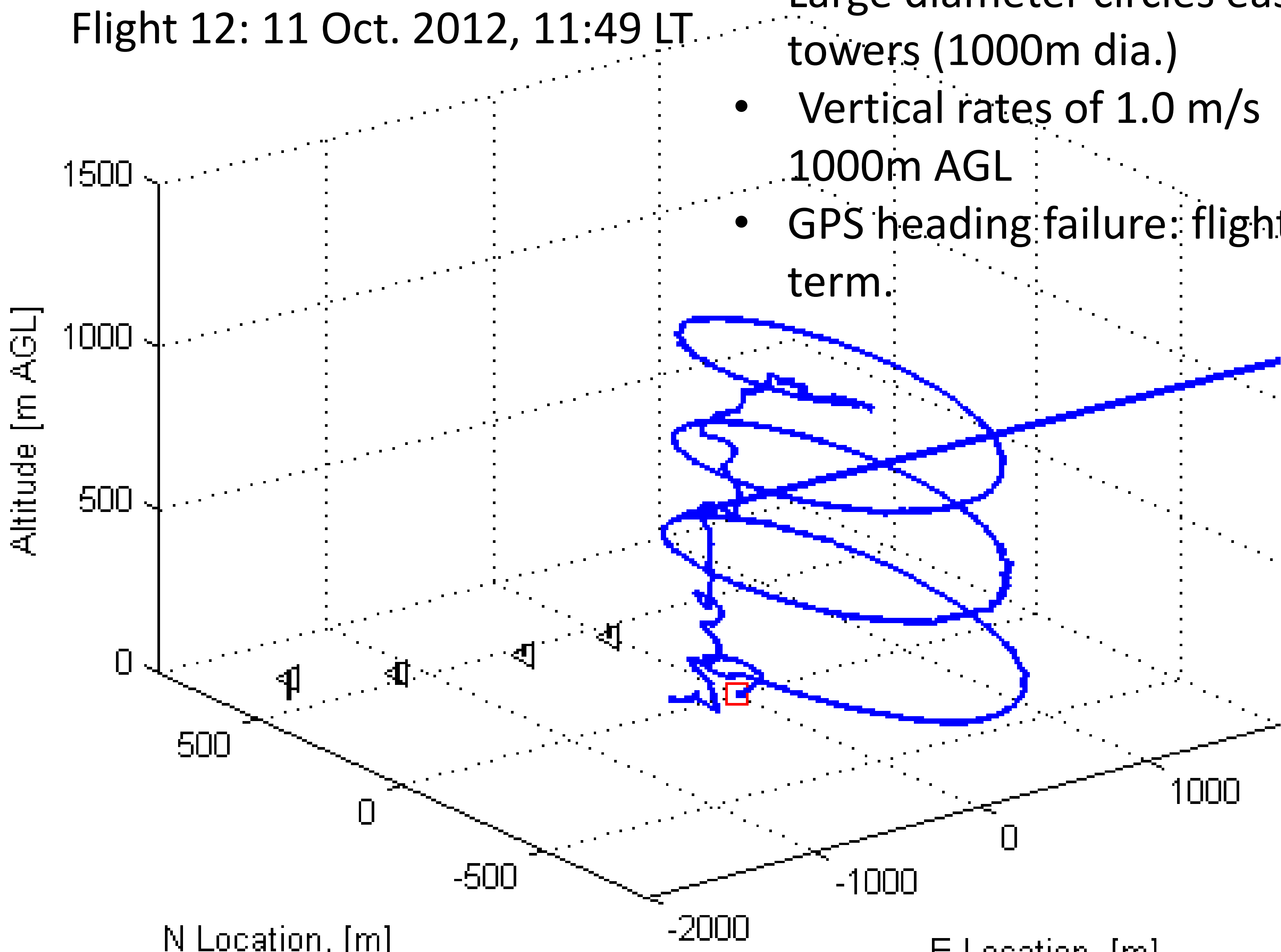
Flight 11: 11 Oct. 2012, 11:07 LT

- Large diameter circles east of towers (1000m dia.)
- Vertical rates of 1.0 m/s to 700m AGL



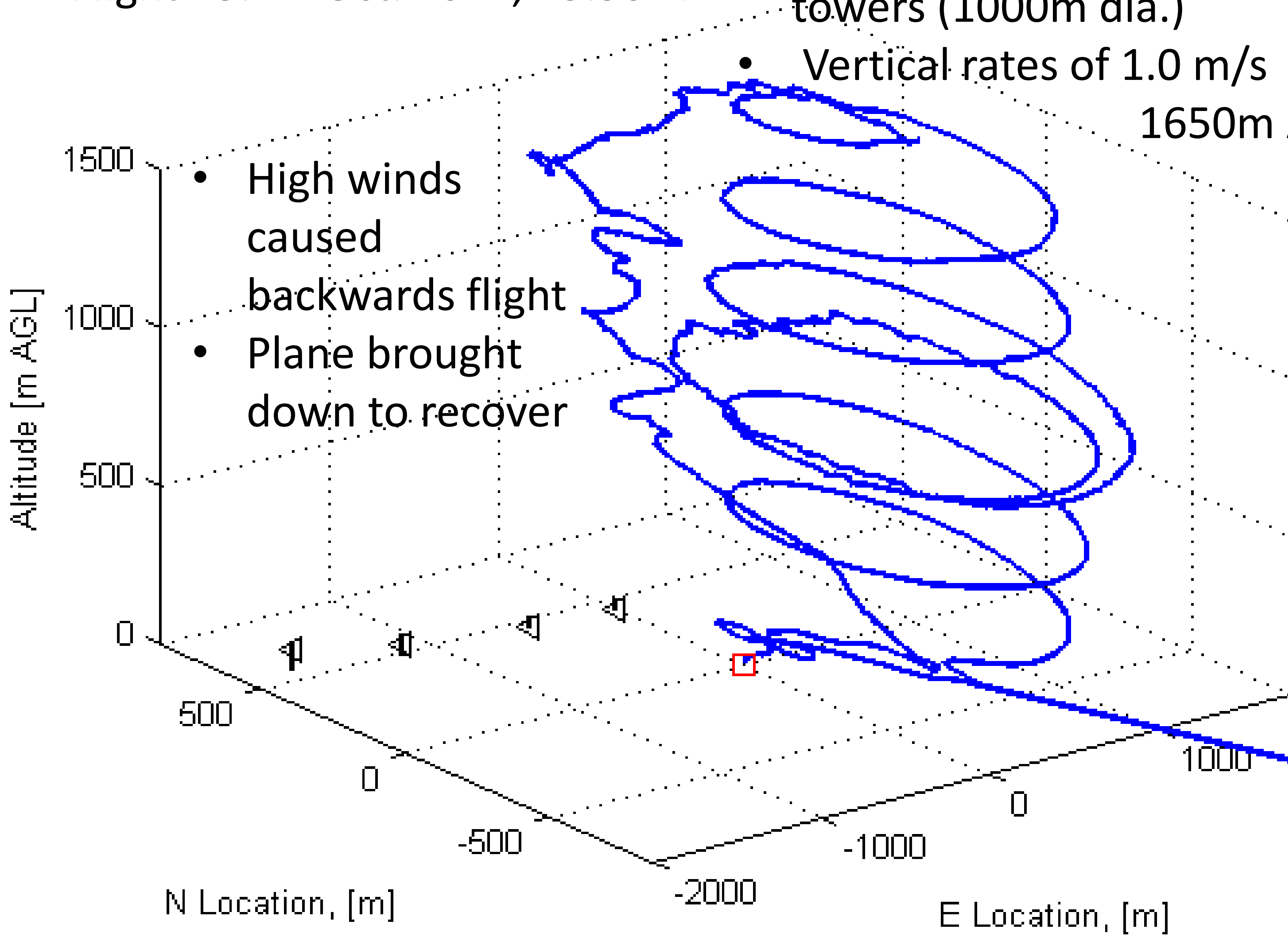
Flight 12: 11 Oct. 2012, 11:49 LT

- Large diameter circles east of towers (1000m dia.)
- Vertical rates of 1.0 m/s to 1000m AGL
- GPS heading failure: flight term.



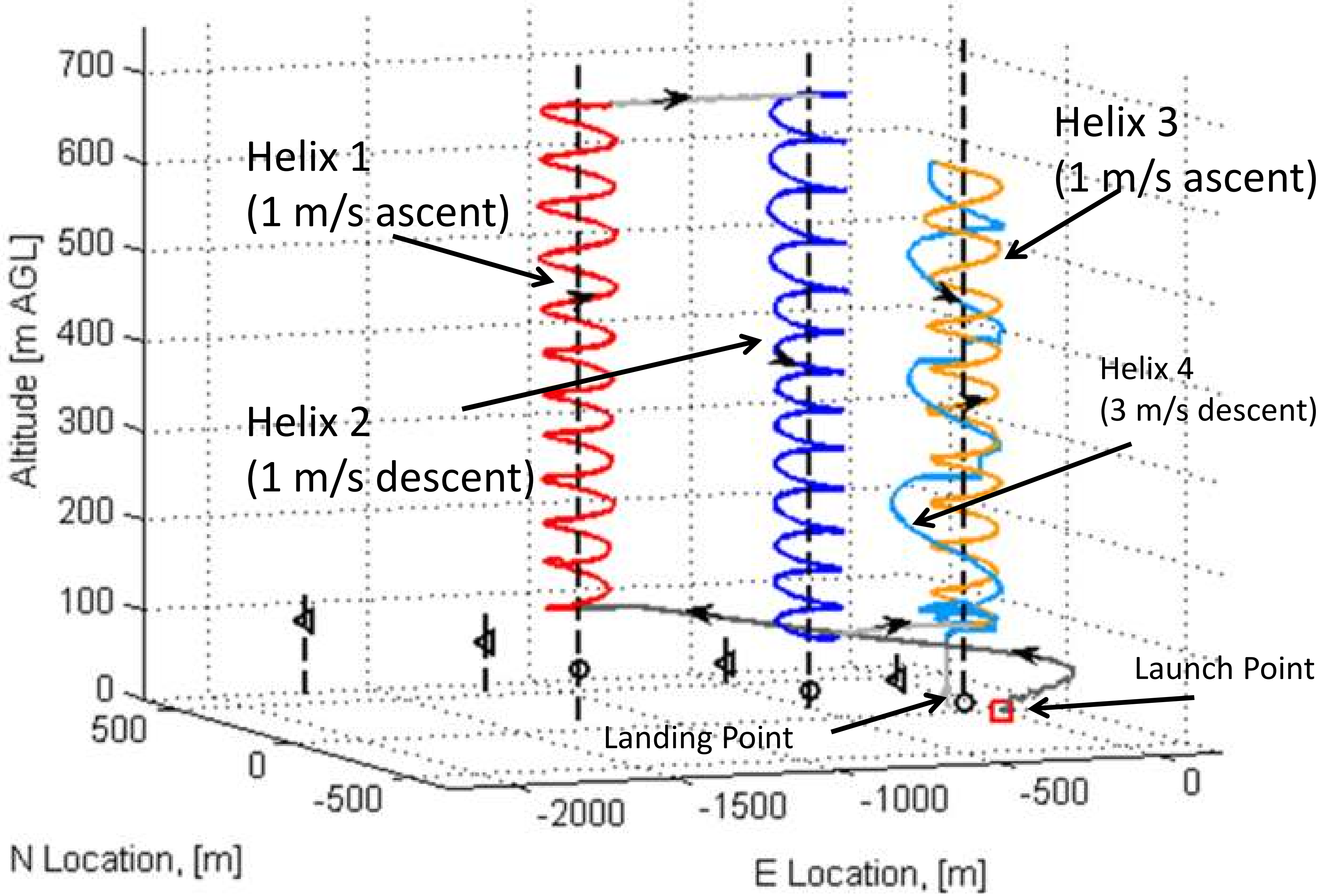
Flight 13: 11 Oct. 2012, 13:50 LT

- Large diameter circles east of towers (1000m dia.)
- Vertical rates of 1.0 m/s to 1650m AGL
- High winds caused backwards flight
- Plane brought down to recover



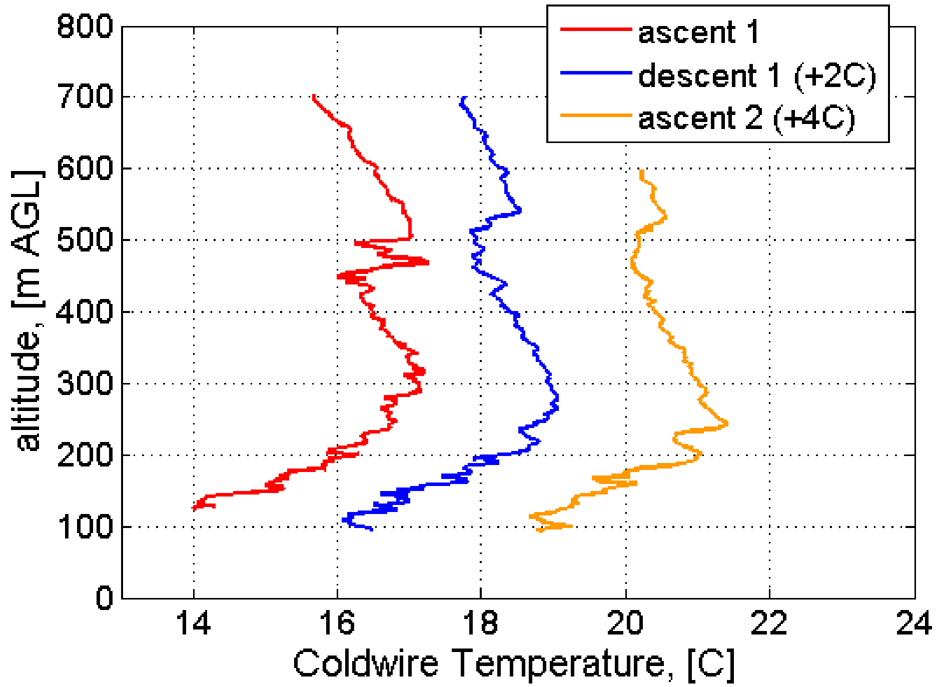
Flight 4: 10 Oct., 2012, 09:48 LT

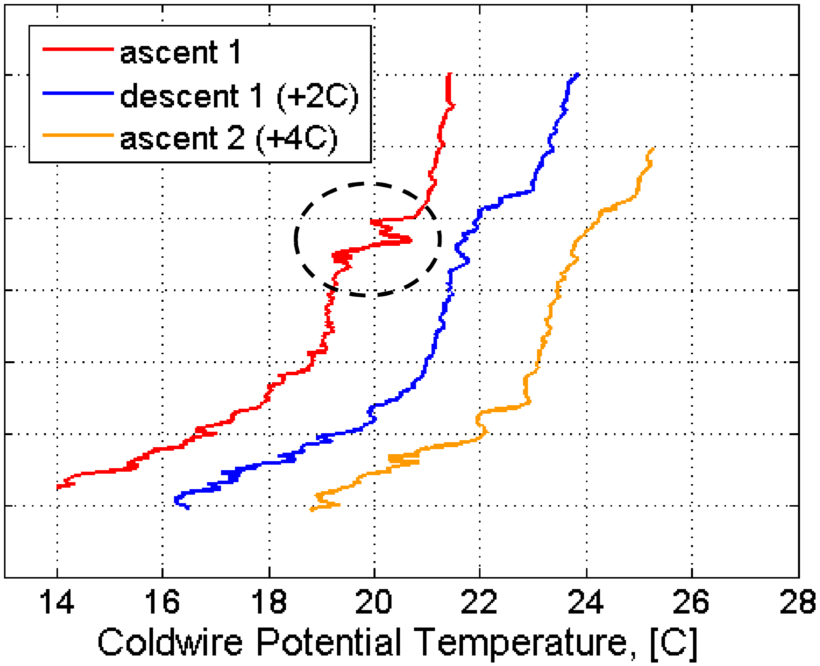
- Vertical profiles to 700m AGL south of towers 2,3,4



High-Resolution Temperature Measurements

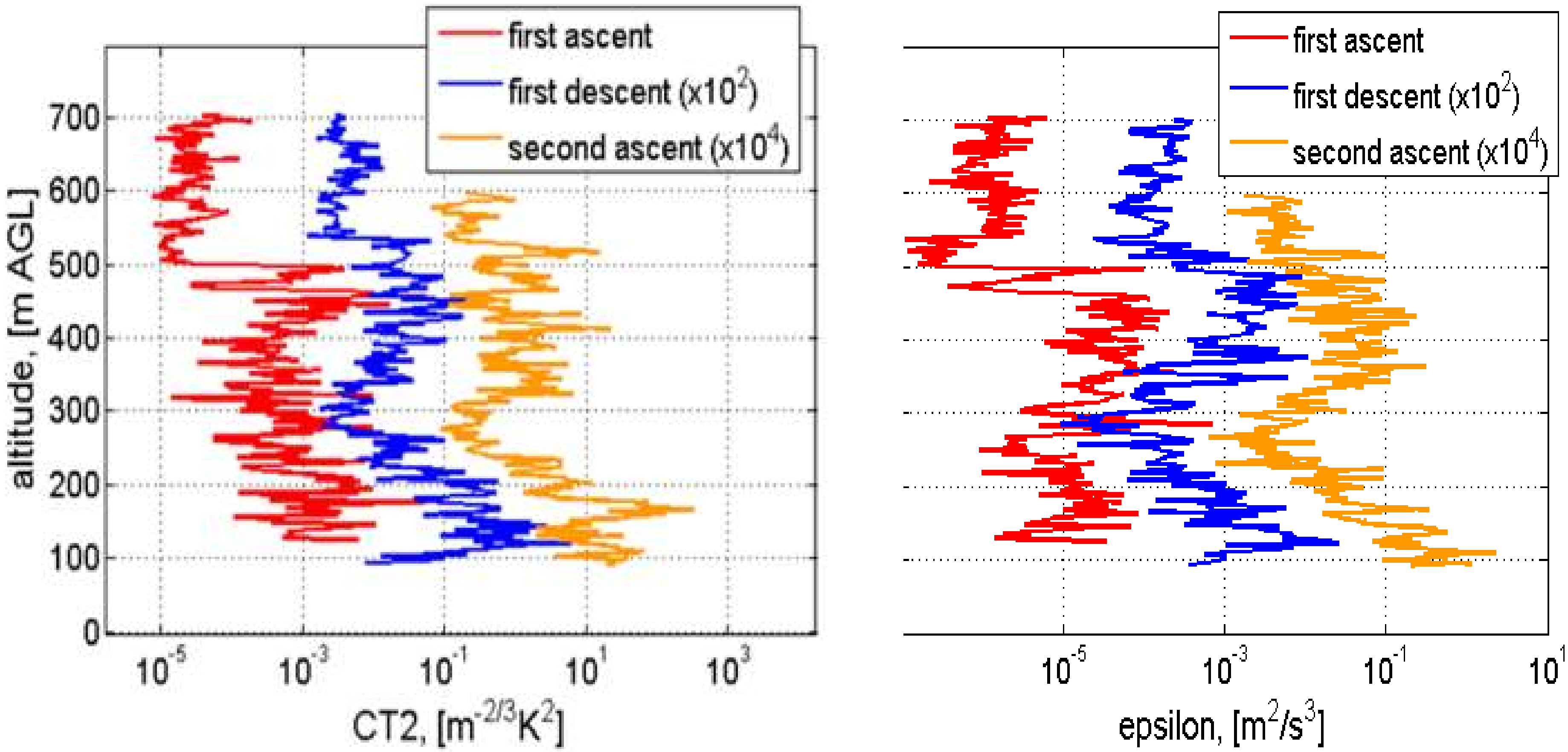
- Custom "Coldwire" RTD sensor designed for small UAS use
- Two wires for redundancy, but they rarely break
- 300Hz thermal bandwidth, anti-aliased at 40 Hz, sampled at 80 Hz, with range of -60 to +40 C, resolution of 0.003 C
- "Self-calibrating" in post-flight analysis using a calibrated (but slower) semiconductor temperature sensor





Turbulence Measurements

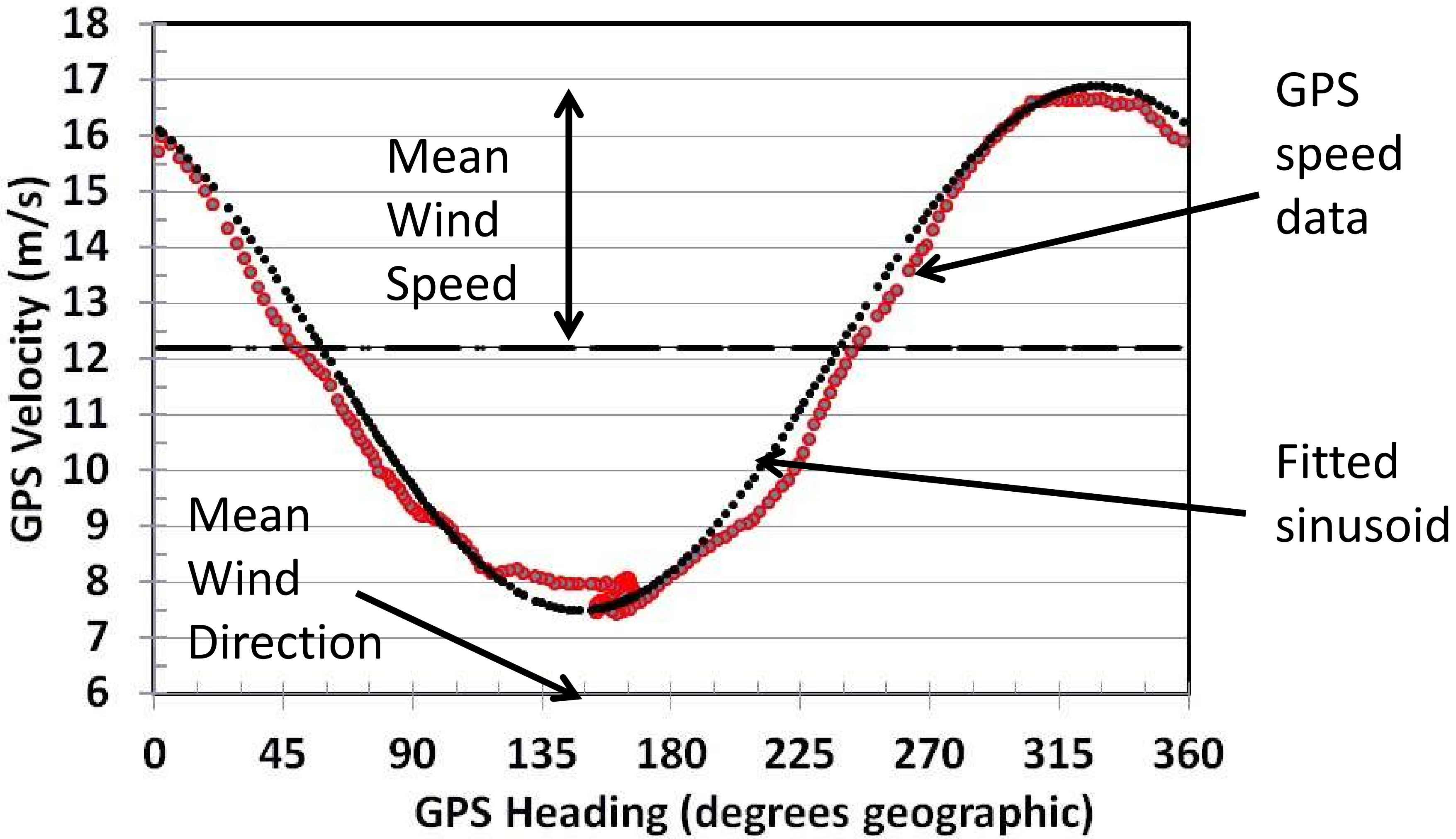
- High-rate coldwire data used to estimate the temperature structure constant C_T^2
- High-rate pitot data used to estimate the dissipation rate epsilon
- Both utilize 3 second time windows to compute power spectra over the inertial sub-range of the turbulence cascade, fitting to the Kolmogorov $f^{-5/3}$ slope
- At 1 m/s vertical rates, vertical resolution is 3 m.



Low Resolution Wind Estimation

Only requires GPS speed measurements

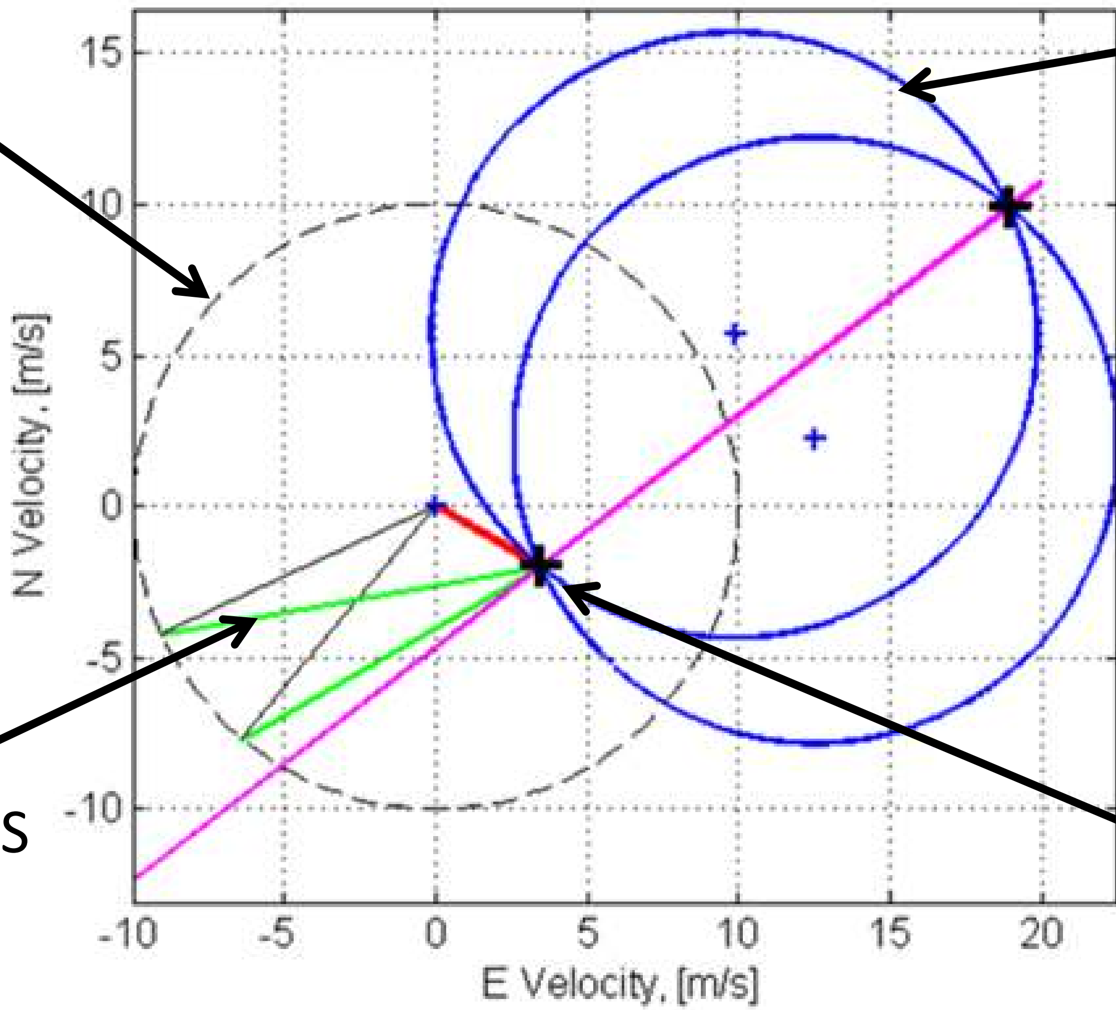
Produces a wind estimate every ½ loiter circle (about every 20 sec)



Medium Resolution Horizontal Wind Sensing using the GPS-Pitot Algorithm

Airspeed Circle: possible airspeeds with measured Pitot magnitude

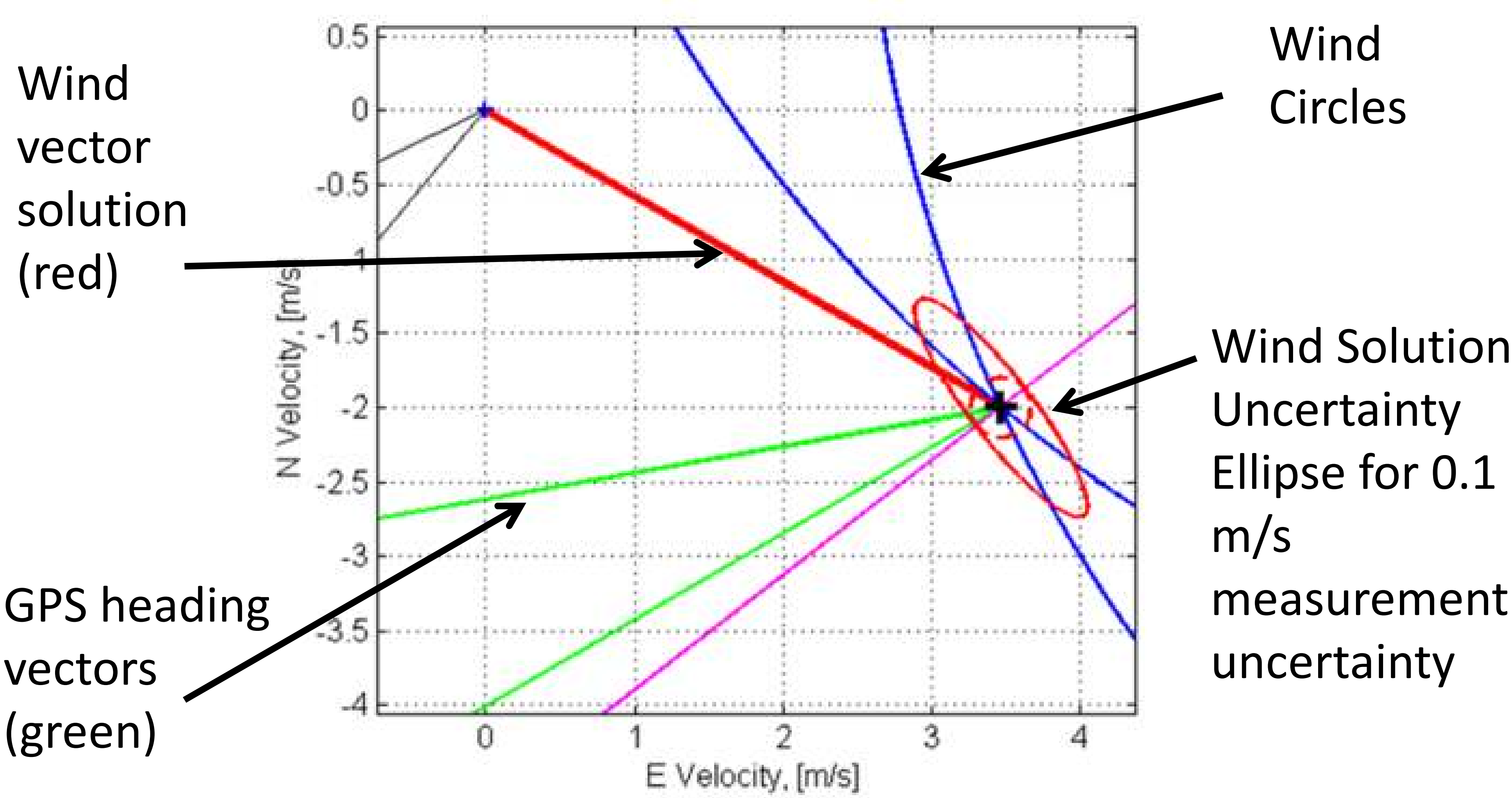
Two successive measured GPS heading vectors (green)



Wind Circles: possible wind vectors satisfying the "wind triangle" for each GPS heading

Wind vector solution (red)

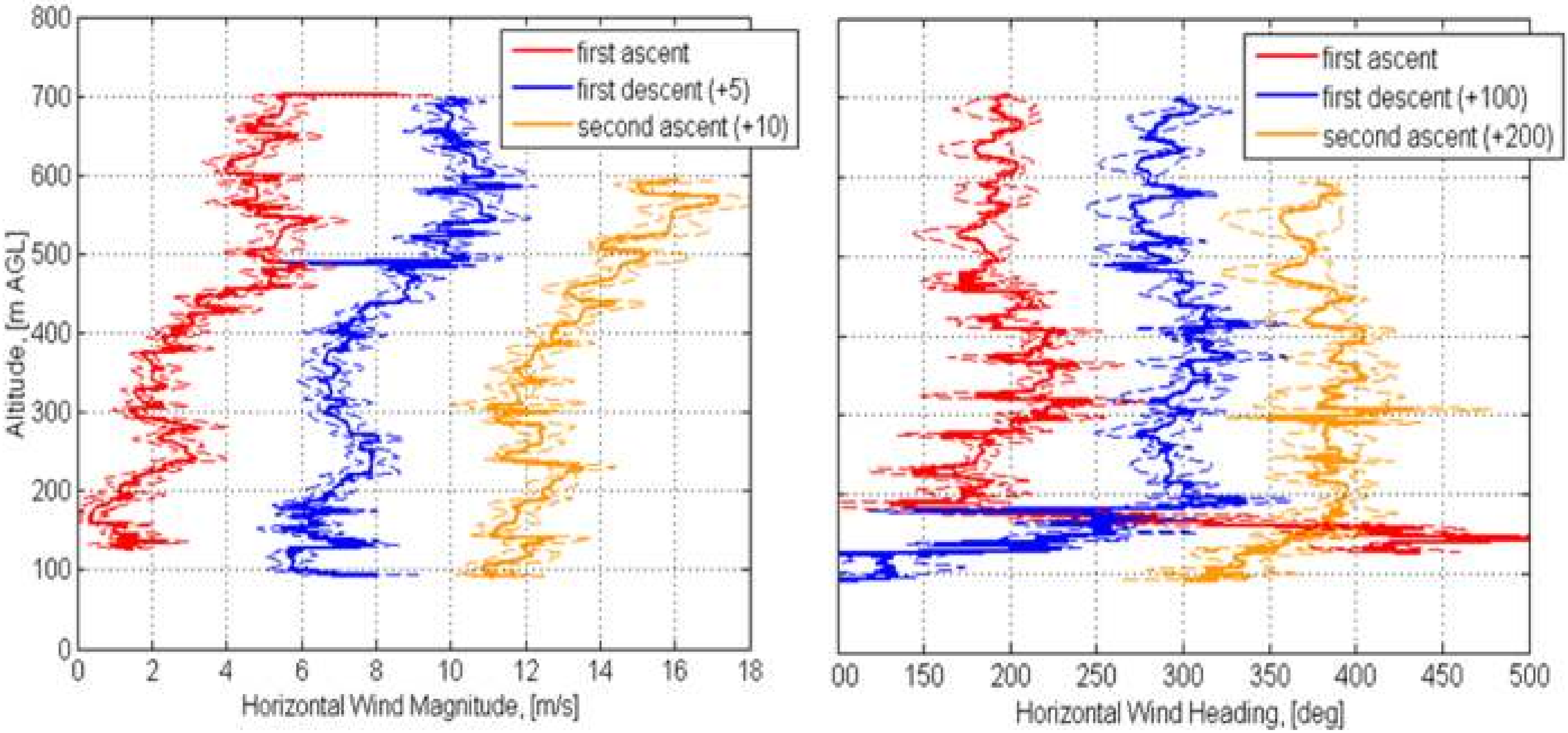
Quantifying Wind Solution Uncertainty



Worst case uncertainty is reduced by larger differences in GPS heading

Wind Profiles from the GPS-Pitot Algorithm

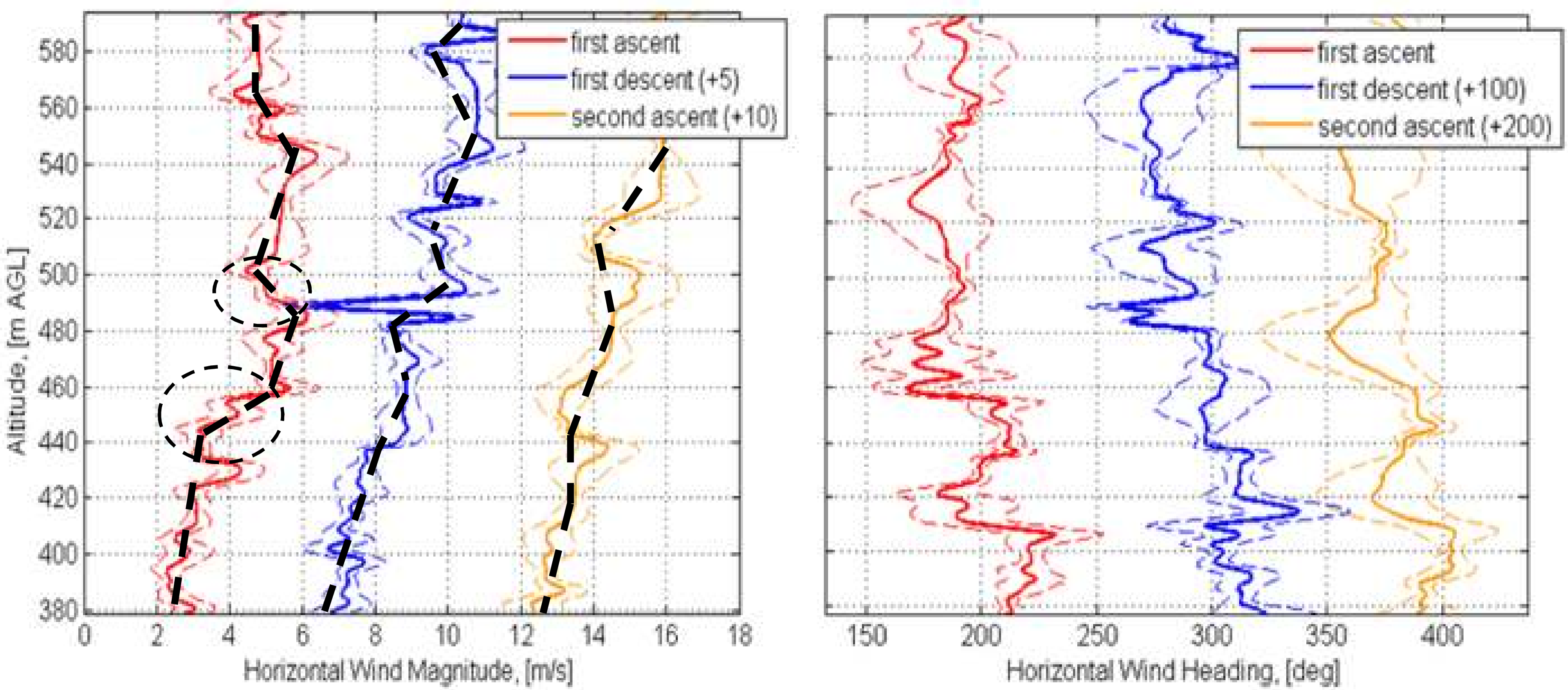
3 second GPS heading measurement separation yields a 3 m vertical resolution in horizontal wind estimates at a 1 m/s ascent/descent rate. Horizontal resolution is about 30m at 10 m/s flight speed.



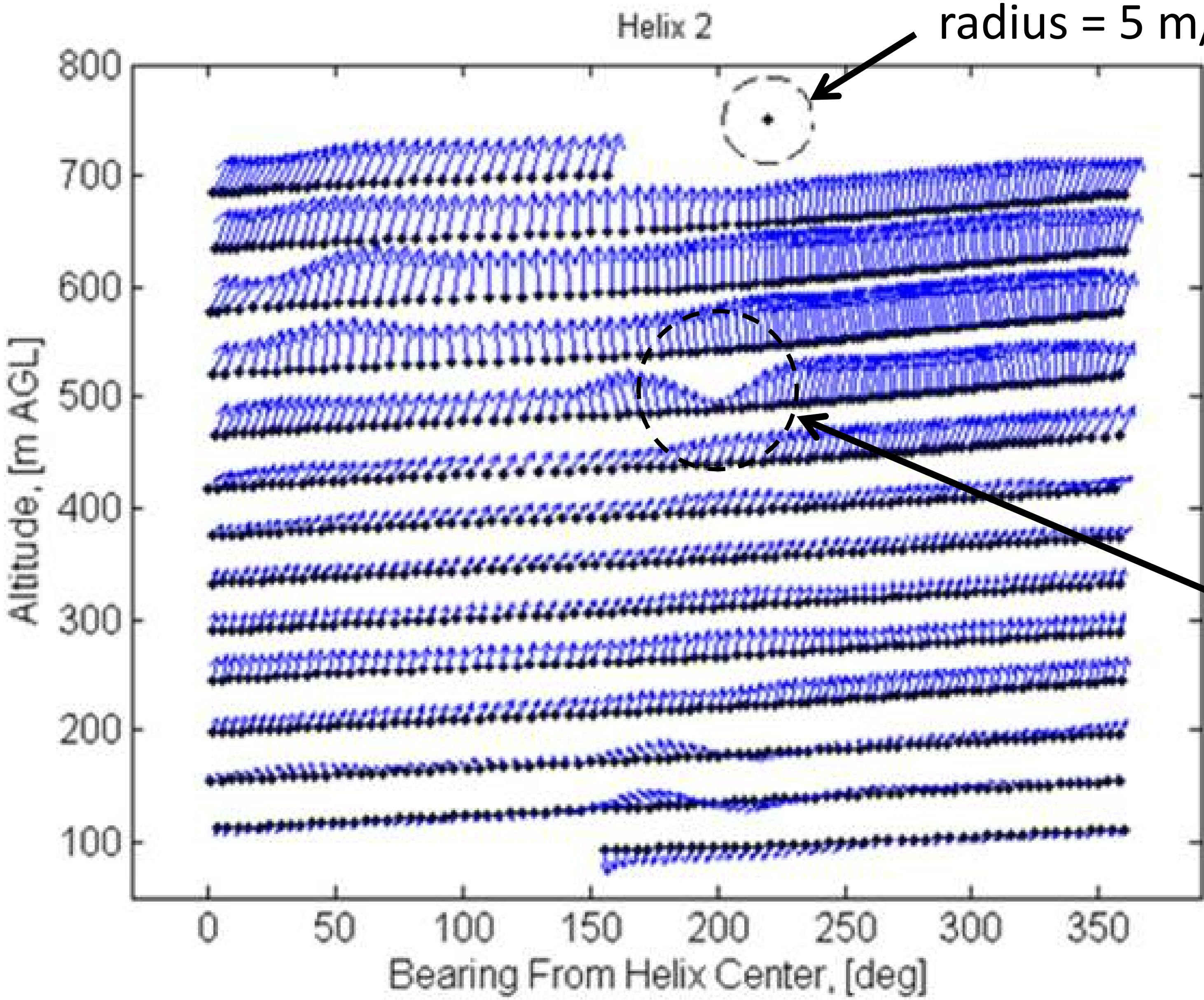
Wind Profiles from the GPS-Pitot Algorithm

Close-up view shows solutions (solid lines) and uncertainty bounds (dashed lines)

Uncertainty bounds vary with GPS heading vector separation; bounds are larger when flying into the wind, where GPS speeds are smaller and more similar over the 3 second measurement interval



Quiver Profile Display of Wind Estimates (Helix 2)



radius = 5 m/s wind speed

Wind direction : up = North right = East

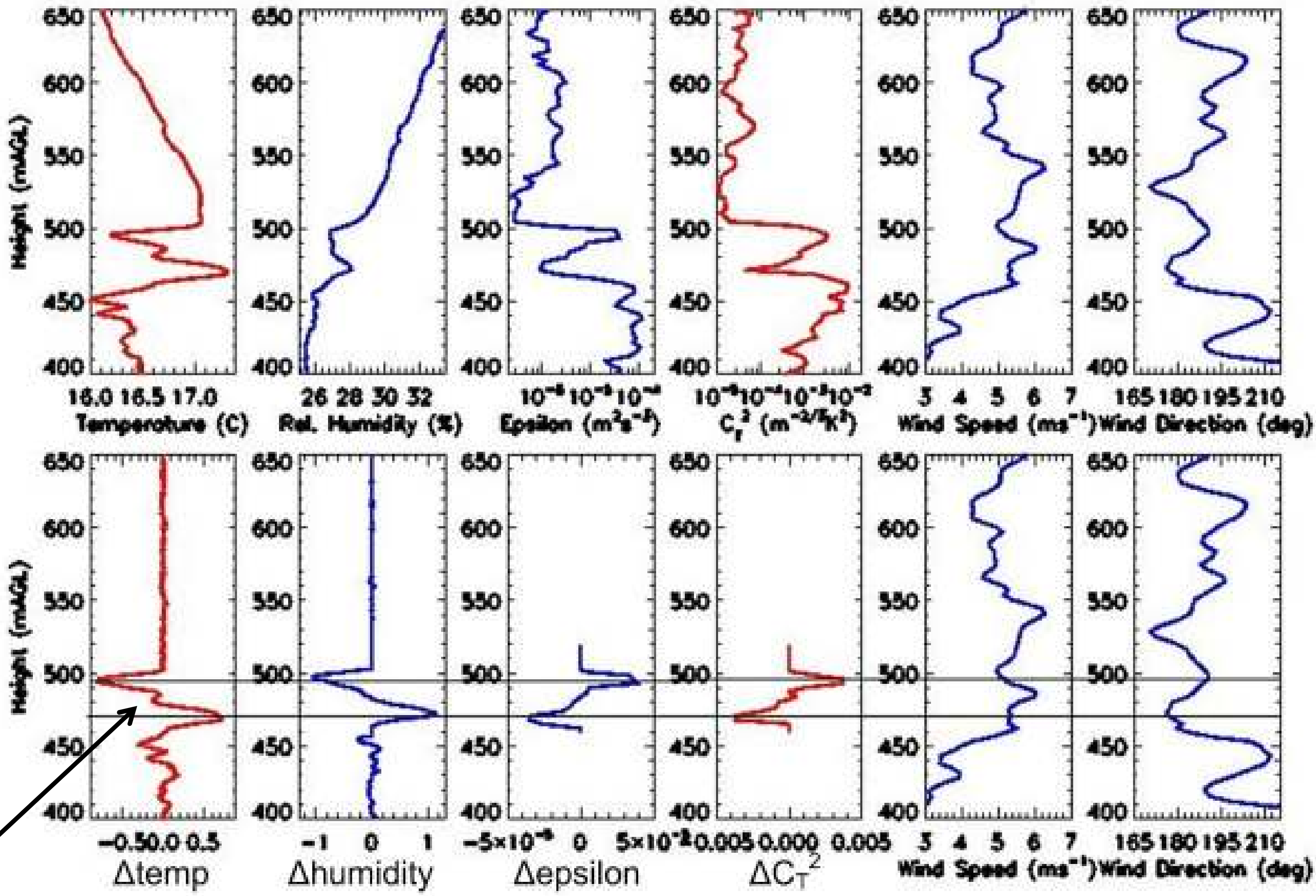
3 sec. resolution clearly resolves gusts

Detailed Profile Comparison for Helix 1 (Near Tower 4)

Profiles:

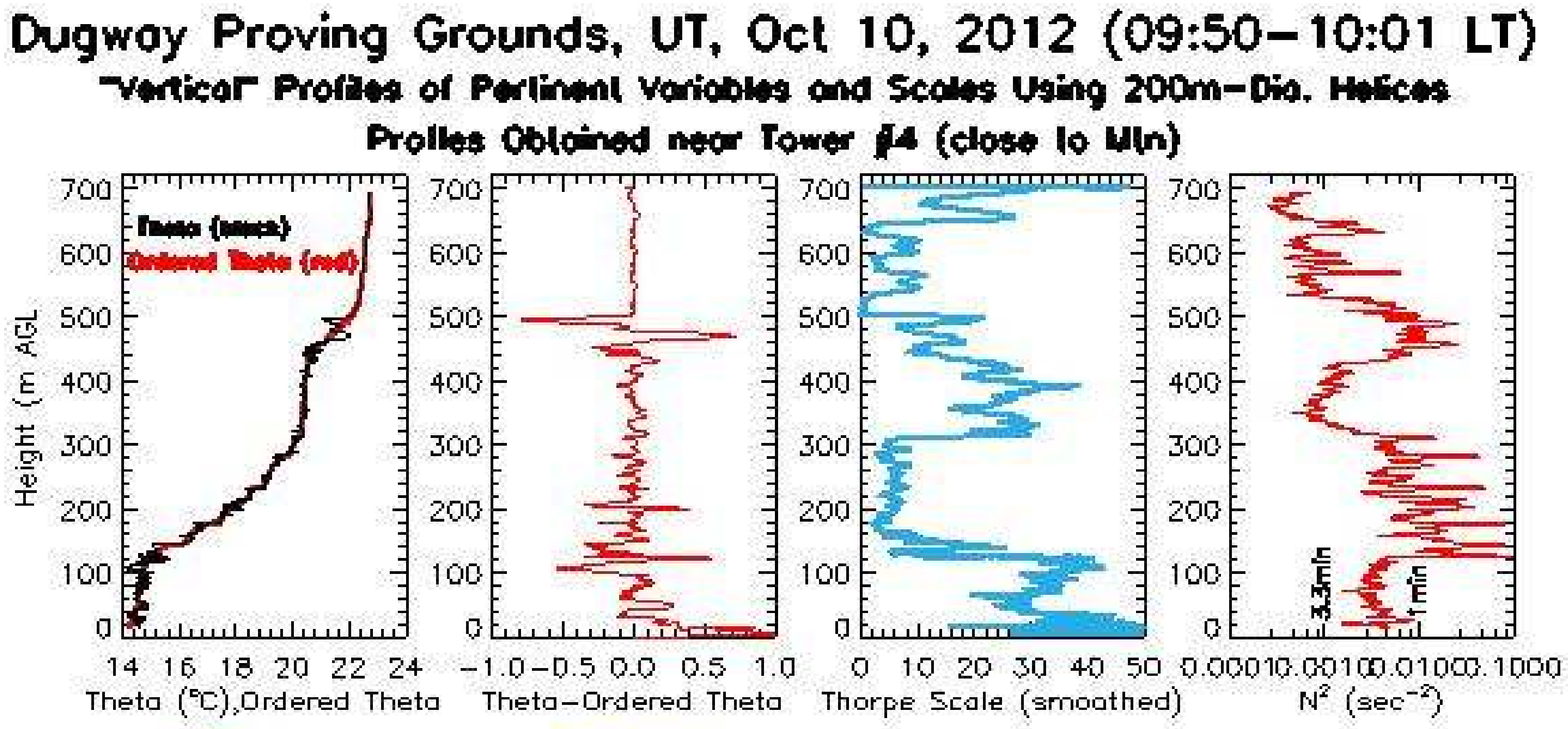
Profiles – Ordered Profiles

Obvious Overturn: cause?



Overturn Details for Helix 1

- Overturn occurs in a stable layer with buoyancy frequency ~ 0.1
- With 0.1 m/s/m shear, results in a Ri ~ 1, suggesting a K-H instability is not the cause of the overturn
- R-T instability (more solar heating near the ridge)?
- K-H due higher sheer at finer resolution?
- Ridge lee gravity waves?



Conclusions

- Small unmanned aircraft systems (sUAS) have the potential to greatly expand the reach of boundary layer observations due to their:
  - Low cost (< $1k per plane)
  - Safety (<1 kg mass, foam airframe, rear propeller, electric propulsion)
  - Portability (minimal ground support and no surface preparation)
  - Access to large volumes (about 40km laterally, and 10 km vertically)
  - Ability to provide high-resolution sensing (on the order of meters)
  - Autonomy (minimal operator training)
- High resolution atmospheric sensing is made possible by
  - Low flight speed (10-15 m/s), low vertical rates (1 m/s)
  - High sensor sampling frequency (~100Hz)
  - Trend toward miniaturization in electronics and sensors

Conclusions (cont.)

- DataHawk measurements from a 5 day, 13 flight campaign at Dugway, UT, include
  - Winds (3 sec/3m vert. res., 30m horiz res.)
  - Temperature and velocity turbulence structure (3m vert. res.)
  - Humidity (~10m vert. res.)
  - Vertical profiles to at least 1.6km, lateral surveys > 1 km
  - Step toward "routine" operations: 5-hour sequence of 5 flights
- Current development work includes
  - Higher resoluton, 3D winds (~0.1m vert. res., ~1m horiz. res.)
  - More capable flight planning (circles and paths, automatic sequencing)
  - Improved duration/range/height (50 min -> 90 min)
  - Multiple vehicle, coordinated measurements
  - Portable "pod" of 4-5 planes (ARO DURIP funding)
  - High bandwidth humidity
  - Ground-avoidance for ultra-low flights

MATERHORN Publications

De Wekker, S.F.J., J. Knievel, Y. Liu, G.D. Emmitt, S. Pal, B. Balsley, D. Lawrence, S. Hoch, Y. Wang, C. Hocut, and H.J. Fernando, "Multi-scale flows and boundary layer structure during the MATERHORN field study. Observations and simulations during the morning transition period", poster presented at the Davos Atmosphere and Cryosphere Assembly (DAVOS-13), Davos, Switzerland, July, 2013.

Lawrence, D. A and Balsley, B. B., "Design of a Low-Cost UAS for High-Resolution Atmospheric Sensing", Proc. AIAA Infotech@Aerospace conference, Boston, MA, Aug., 2013.

Acknowledgements

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