The Tropospheric Wind Lidar Technology Experiment (TWiLiTE): Status and future plans

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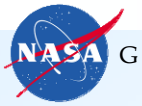
Working Group on Space-based Lidar Winds
August 24-26, 2010
Bar Harbor, ME



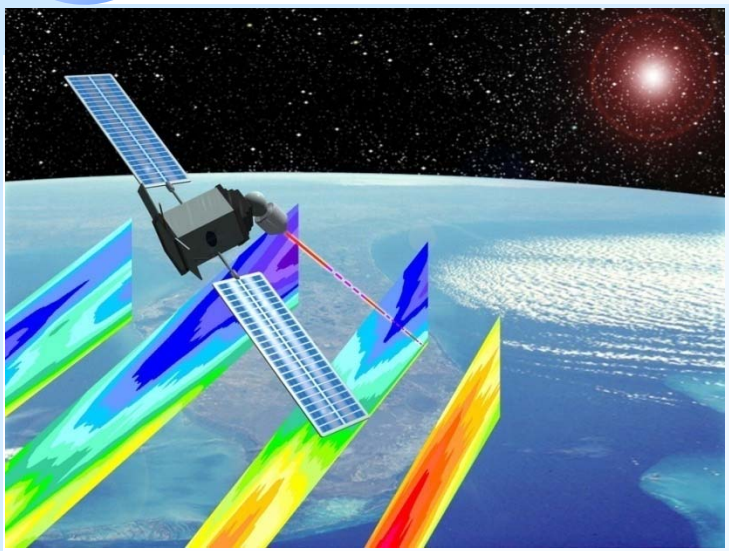
GODDARD SPACE FLIGHT CENTER

Outline

- Motivation
- TWiLiTE IIP Recap
- 2009 ER-2 Engineering Flights
- Future Plans
- Summary

Acknowledgements:
TWiLiTE was developed with support provided by the NASA ESTO IIP program. Additional support was provided by NASA SMD as part of the Airborne Instrument Technology Transition program,Dr. Ramesh Kakar, Program Manager

2007 NRC Decadal Survey Recommendations for Tropospheric Winds



3D Tropospheric Winds mission called "transformational" and ranked #1 by Weather panel. with concurrence by Water panel. Overall prioritized in 3rd tier of 15 NASA recommended missions.

"The Panel strongly recommends an aggressive program early on to address the high-risk components of the instrument package, and then design, build, aircraft-test, and ultimately conduct space-based flights of a prototype Hybrid Doppler Wind Lidar (HDWL)."

"The Panel recommends a phased development of the HDWL mission with the following approach:

- ***Stage 1:* Design, develop and demonstrate a prototype HDWL system capable of global wind measurements.**
- ***Stage II:* Launch of a HDWL system that would meet fully-operational threshold tropospheric wind measurement requirements**

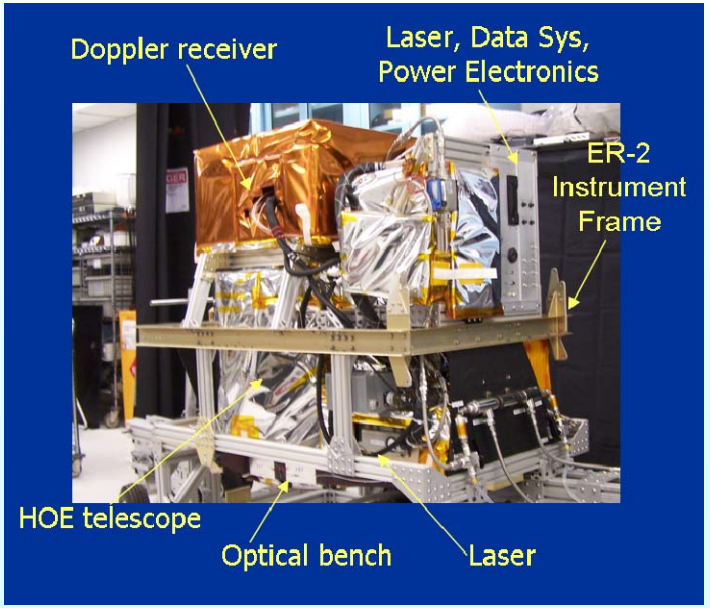
Tropospheric Wind Lidar Technology Experiment (TWiLiTE) Instrument Incubator Program

•The TWiLiTE instrument is a compact, rugged direct detection scanning Doppler lidar designed to measure wind profiles in clear air from 18 km to the surface.

• TWiLiTE operates autonomously on NASA research aircraft (ER-2, DC-8, WB-57, Global Hawk).

• Initial engineering flight tests on the NASA ER-2 in 2009 demonstrated autonomous operation of all major systems.

• TWiLiTE will be reconfigured to fly on the NASA Global Hawk as part of the Hurricane and Severe Storm Sentinel Venture Class Mission.

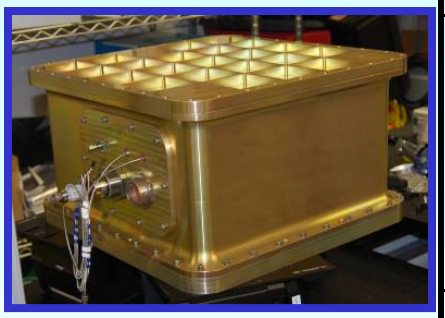


TWiLiTE system configured for ER-2 QBay

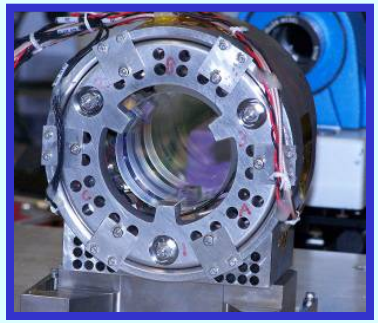
Data products	Vertical profiles of u,v wind field from aircraft to surface, clouds permitting
Velocity accuracy (m/s)	< 2.0
Range of regard (km)	0 -18 (ER-2,WB57); 0-12 km (DC-8)
Vertical resolution (km)	0.250 (programmable)
Horizontal integration per LOS (s)	10 s (programmable)
Nadir angle (deg)	45
Scan pattern	8 position conical step-stare (programmable)

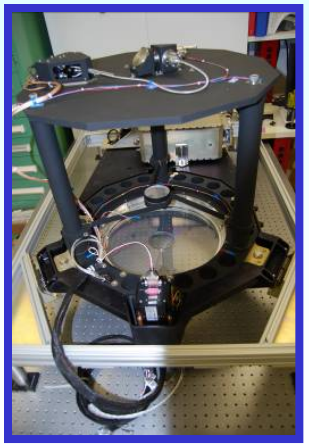
TWiLiTE ER-2 Integration
September, 2009

TWiLiTE Direct Detection Wind Lidar Key Technologies

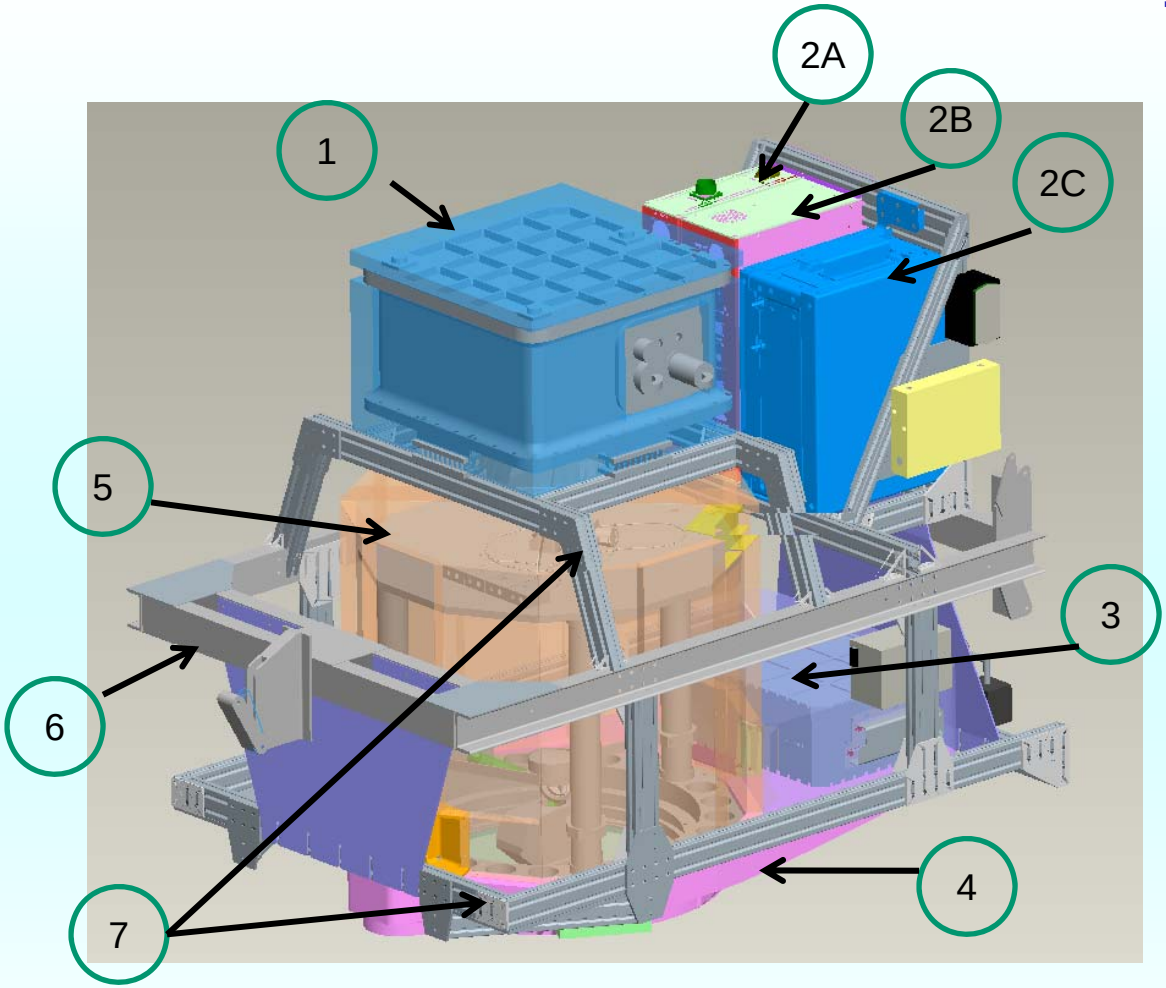


	Entrance TRL	Exit TRL
• High spectral resolution all solid state laser transmitter	4	5
• High spectral resolution optical filters	4	5
• Efficient 355 nm photon counting molecular Doppler receiver technologies	4	5
• Novel UV Holographic Optical Element telescopes and scanning optics	3	5



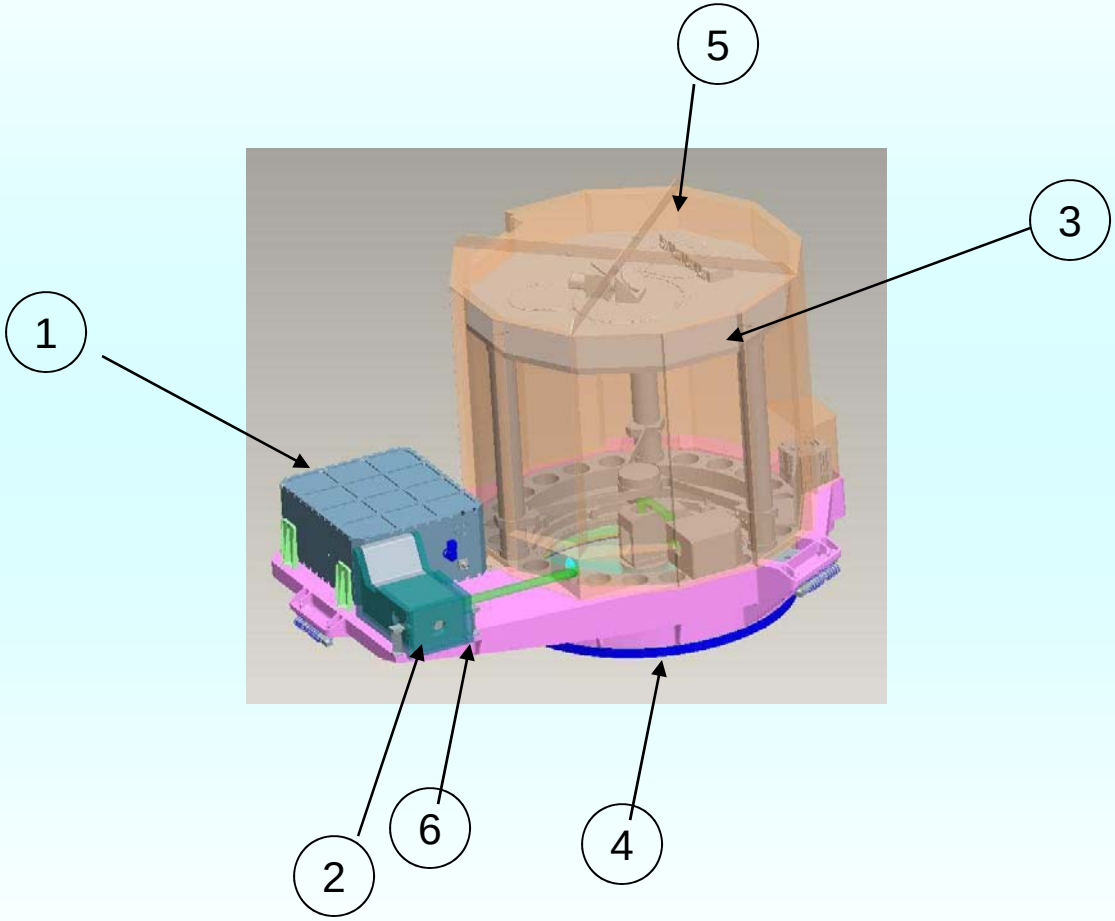


TWiLiTE Modular Assembly



1. Doppler receiver (Notes: insulated pressurized box; vibration isolated from frame; on liquid cooling loop; weighs about 100 lbs)
2. A) Data system electronic box; B) power distribution box; C) laser electronics module (LEM)
3. Laser Optical Module (LOM) (Notes: insulated pressurized box; on liquid cooling loop; 3 pt titanium flex mounts to opt bench)
4. Optical Bench
5. HOE telescope
6. ER-2 Qbay instrument pallet (mechanical interface defined by aircraft.)
7. 80-20 structure (modular framework can be easily redesigned for diferent aircraft)

Optical Bench Detail



1- Laser Optical Module

2- Beam expander

3- Telescope

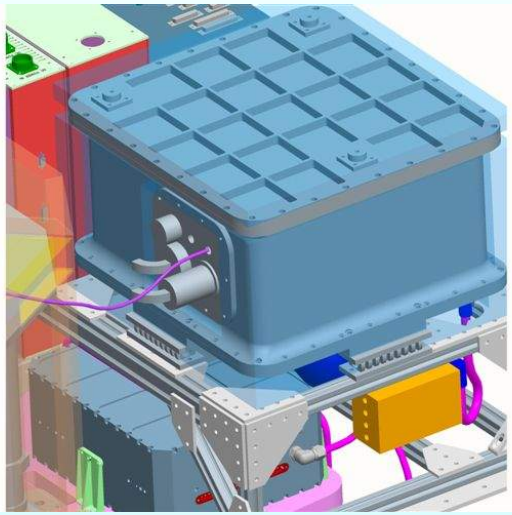
4- Window

5- Telescope Cover

6- IMU integrated in bench

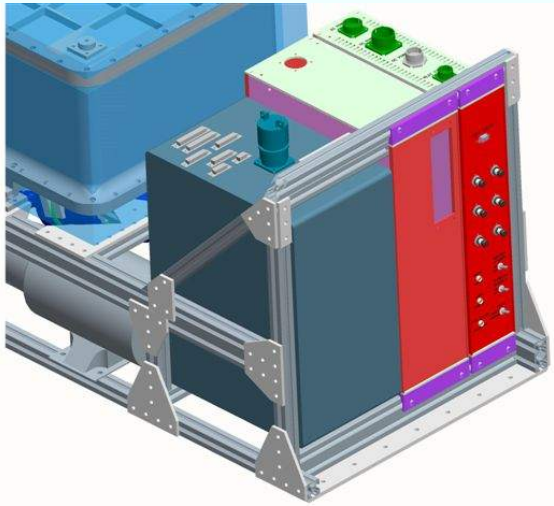
Mass: 237lbs

Electronics Detail



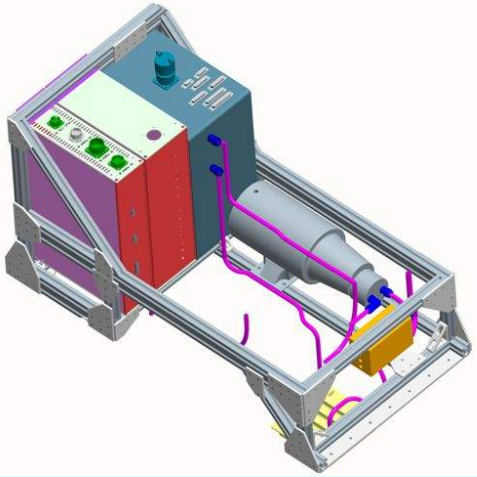
*Receiver mounted on wirerope isolators

*All cooling connections w/ flex tubing



*LEU, Power, & Data boxes rack mounted w/ extra rear support

*Connections top & rear. UI on front



*Pump mounted on 8020 frame

*Most interconnections made before install in pallet

TWiLiTE Compatible
NASA Airborne Science Platforms

36 hrs duration
Unmanned vehicle

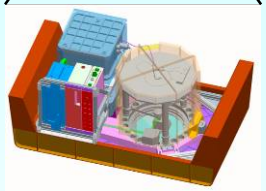
Global Hawk

TWiLiTE will be configured for Global hawk Zone 25 (EV-1)

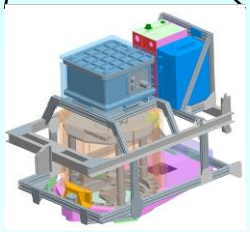
6-8 hrs duration
Unattended operation

ER2

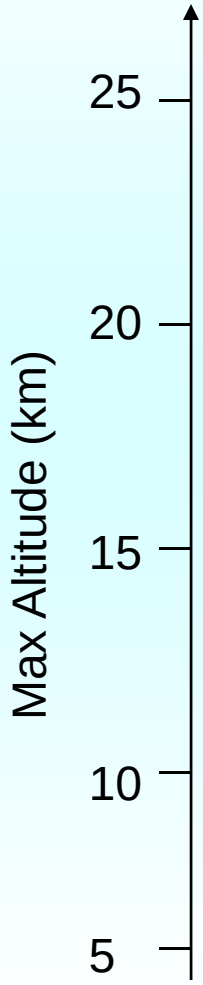
WB57



TWiLiTE configured for WB57 3' Pallet (ESTO IIP04)

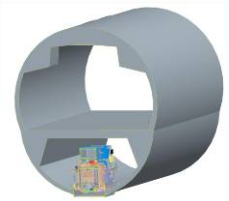


TWiLiTE configured for ER-2 Q-Bay (ESTO IIP04)

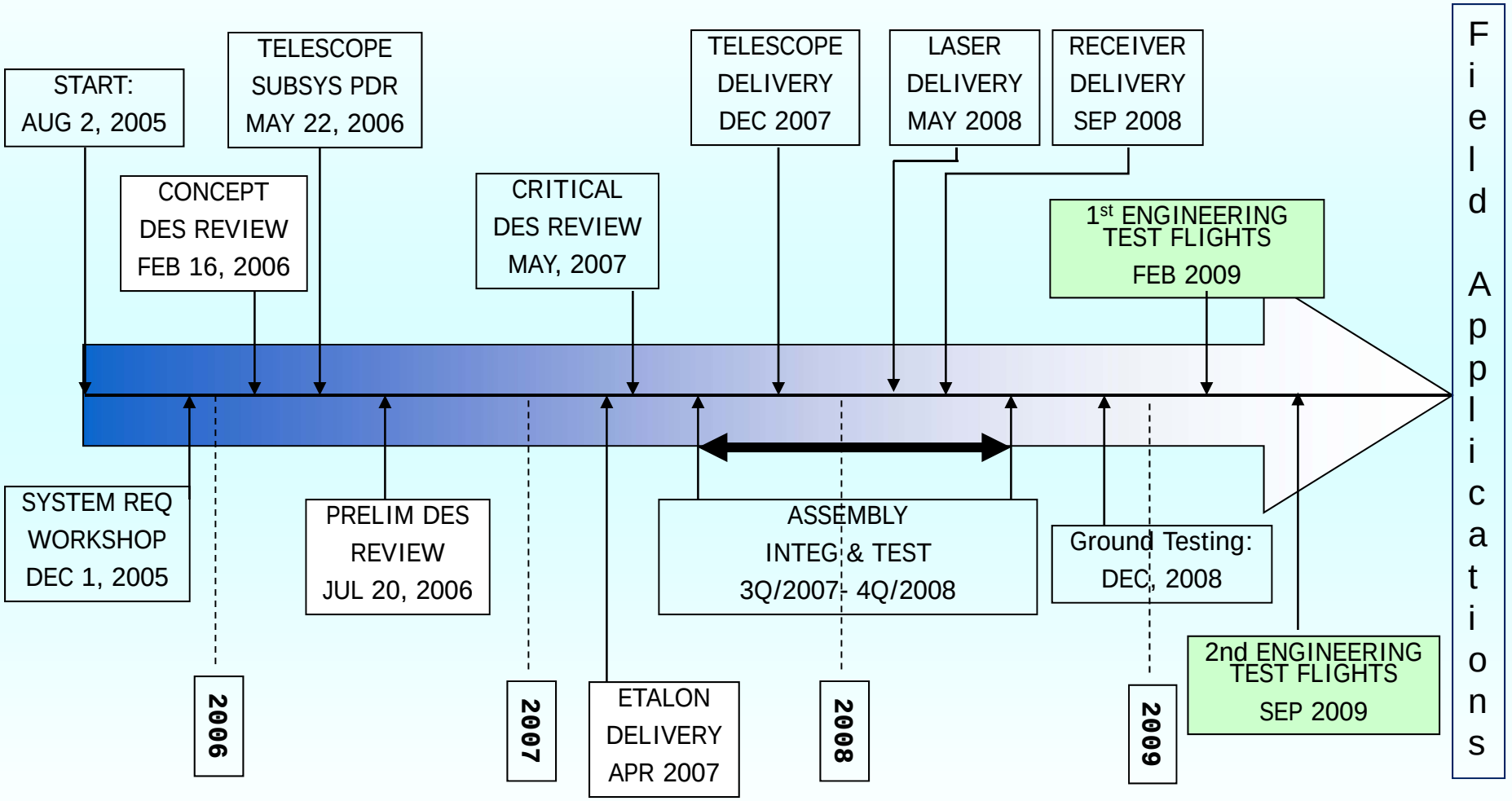


TWiLiTE configured for DC8 Nadir Port 7 (ROSES07-AITT)

DC8



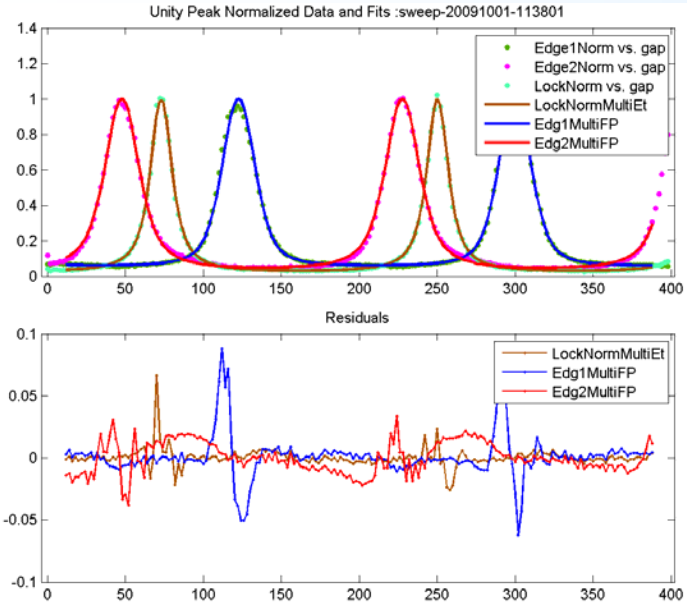
TWiLiTE IIP Project Timeline



ER-2 Engineering Flights
February, 2009 and September, 2009

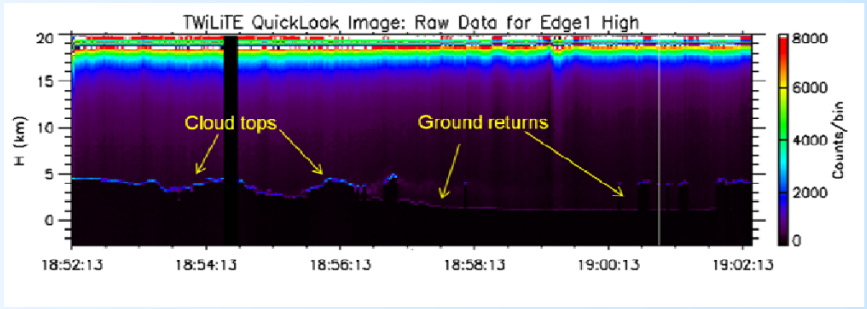
September, 2009 Engineering Flights

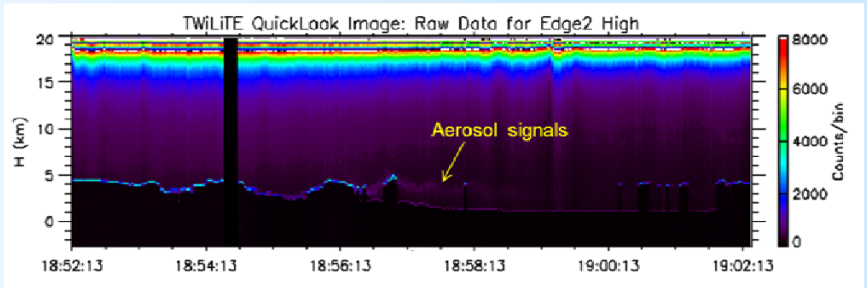
Objectives: Collect engineering data and science data to validate performance of TWiLiTE new technologies (laser, etalon filter, holographic telescope, Doppler receiver) and sub-systems (thermal control system, auto alignment system, data acquisition electronics, autonomous flight software) by flying TWiLiTE on ER-2 high altitude research aircraft.



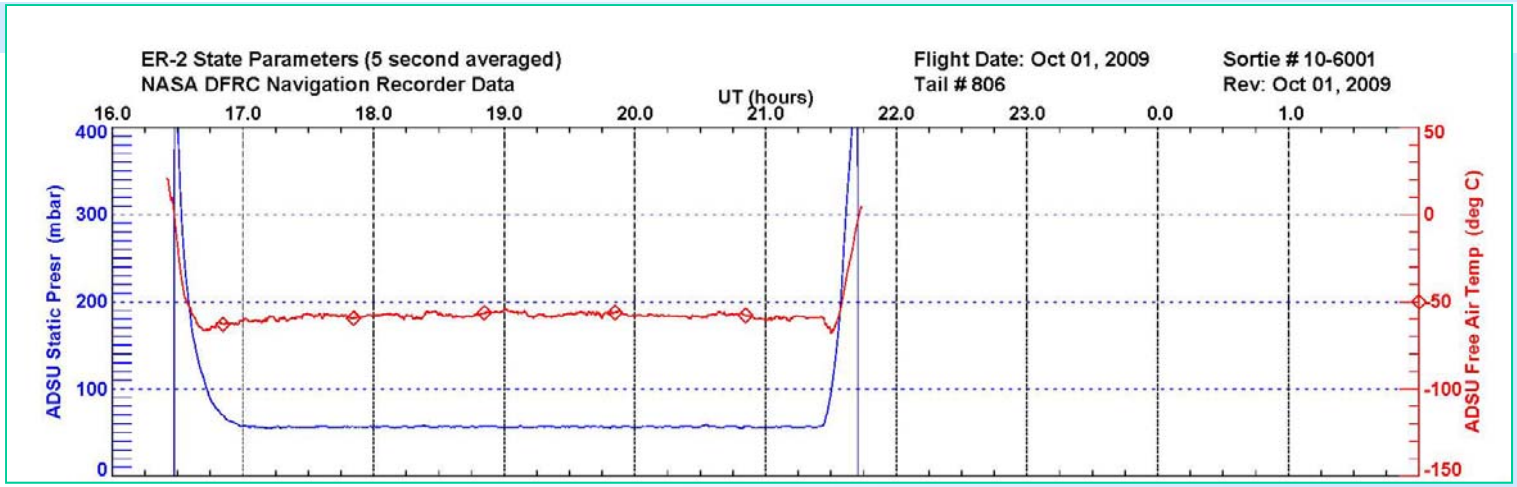
Data Collection Period S1

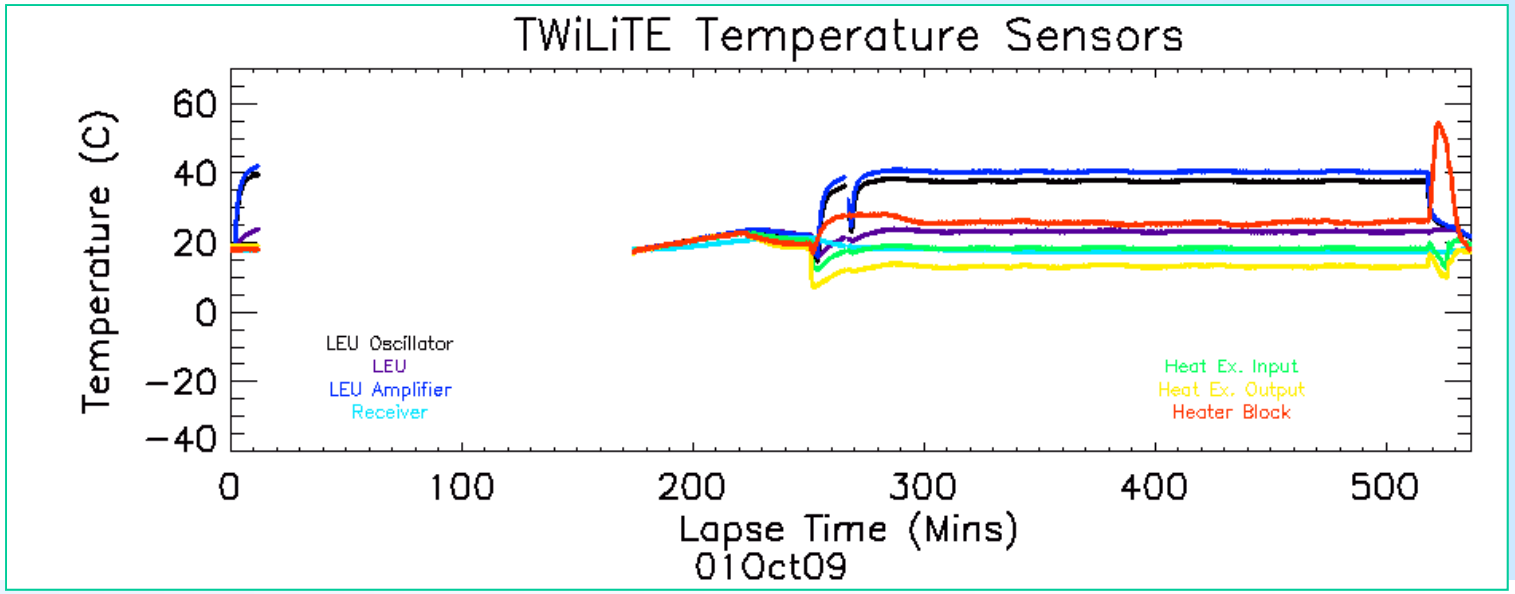
18:52 to 19:02 UT





Thermal Management Challenge





TWiLiTE ER-2 2009 Flight Test Summary

- Demonstrated fully autonomous operation of TWiLiTE including in flight calibration, bore sight alignment and data acquisition
  - Established liquid cooling system operational parameters
  - Tested auto alignment system in flight
  - Demonstrated etalon calibration and alignment holds for >6 hours continuous operation in aircraft
  - Photon counting data acquisition of clear air molecular backscatter returns, as well as low level aerosols, clouds and surface returns
- Last flight included ground validation in Boulder, CO area
  - NOAA Doppler lidar, sondes, Vaisala and NOAA profilers

Unfinished Business – Need for additional ER-2 test flights

- At least one more round of test flights on the ER-2 are planned to complete engineering testing.
  - Fine tune thermal system control to achieve +/- 2 deg for critical elements (etalon, laser optical module, HOE)
  - Increase precision of auto-alignment algorithm to optimize and maintain boresight
  - Collect and store all onboard GPS/IMU data for post-processing
  - Test HOE scanning
  - Test all systems in presence of high clouds

Future plans

- Additional ER-2 flight testing planned in Nov-Dec, 2010 timeframe
- Reconfigure TWiLiTE to participate in Hurricane and Severe Storm Sentinel (HS3) Earth Venture Mission (EV-1)

Hurricane and Severe Storm Sentinel (HS3)

Application of the Global Hawk for Hurricane Studies

PI: Scott A. Braun (GSFC)

Science Goal:

To understand hurricane genesis and intensification.

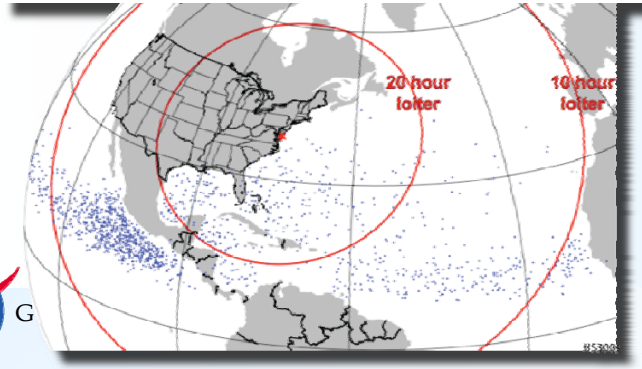
Key Science Questions:

- How do hurricanes form?
- What causes rapid intensity changes?
- How are intensity changes after formation related to upper-tropospheric flow features?
- What's the role of the Saharan Air Layer?

Science Objectives:

- Observing the genesis of tropical cyclones and the intensification from a tropical storm to a hurricane over an extended period - surveillance rather than reconnaissance
- Providing 3-D observations of the wind field both within tropical cyclones and in the environment
- Measuring moisture fields, clouds, aerosols, and precipitation

Genesis Locations and Loiter Times



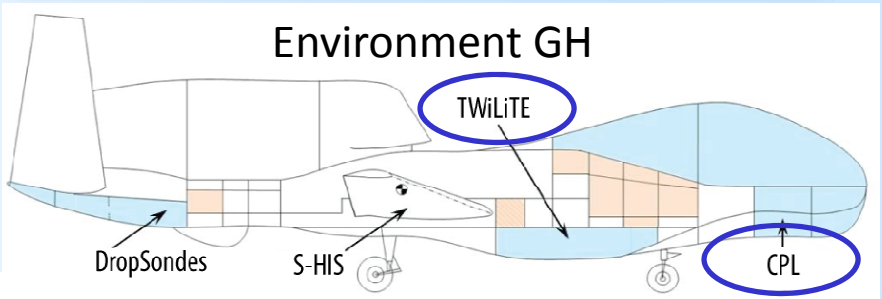
Two Global Hawk (GH) aircraft

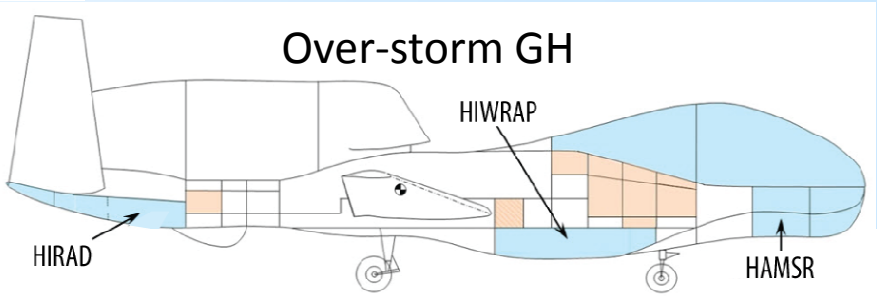
Environment GH instrumentation

- TWiLiTE (direct detection wind lidar)
- CPL (cloud & aerosol lidar)
- Scanning HIS (T, RH)
- Dropsondes (wind, T, RH)

Over-storm GH instrumentation

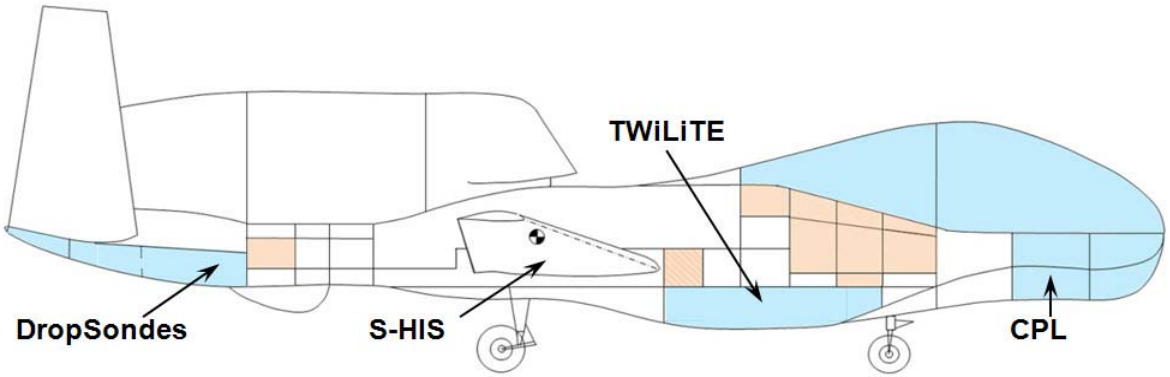
- HIWRAP (3-D winds plus sfc winds)
- HIRAD (sfc winds and rain)
- HAMSR (T, RH)



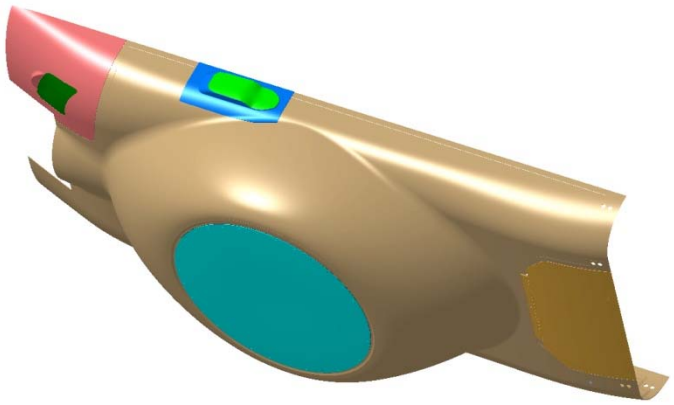


Hurricane and Severe Storm Sentinel (HS3)

Environmental Aircraft Payload



MODIFIED AESA RADOME FAIRING ASSY



Global Hawk w/ AESA deep fairing in flight testing for GRIP - 8/15/2010 (courtesy Gerry Heymsfield)

Summary

- The TWiLiTE IIP program concluded in 2009 with two deployments to integrate the instrument in the ER-2 aircraft and fly 26 hours of engineering test flights
- During these flights TWiLiTE demonstrated fully autonomous operation of the major lidar functions including etalon calibration, telescope/laser bore sight alignment and science data acquisition.
- By demonstrating the key technologies of the direct detection lidar (laser, etalon, receiver, holographic optical element telescope) in a system configuration we are advancing the TRL for a space based system – a primary objective of the IIP.
- We will continue flight testing TWiliTE on the ER-2 in the fall of 2010 and will then begin reconfiguring the instrument to fly on the NASA Global Hawk as part of the multi-year Hurricane and Severe Storm Sentinel Venture Mission

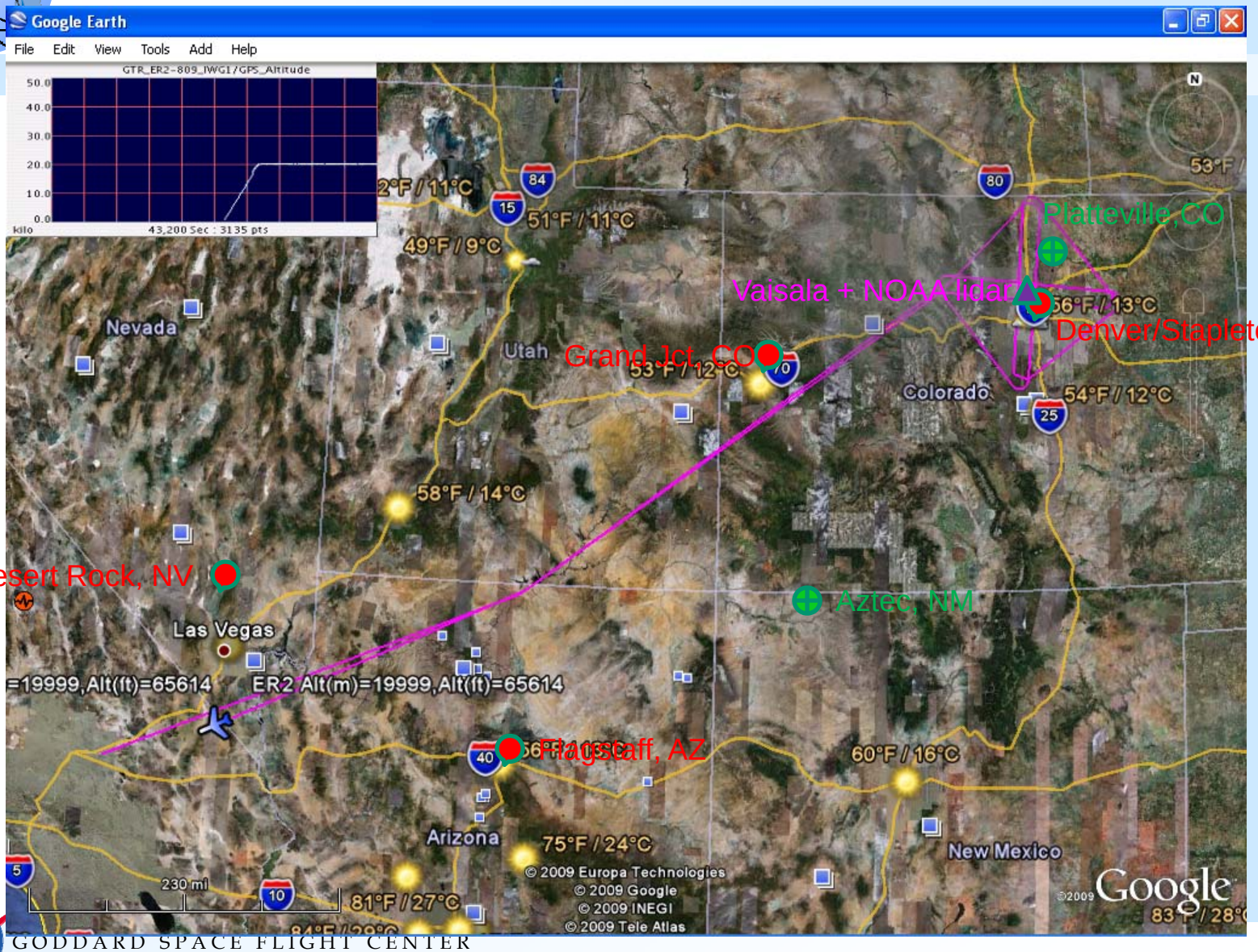
Backups

Example: October 1, 2009 Flight
Edwards AFB to Boulder CO

- 6 hour flight with ER-2 flying at 20 km
  - 1.5 hour flight to Boulder and 1.5 hour return
  - ~3 hours flying diamond pattern with North, South crossing legs
  - Pattern centered on sounding site just North of Denver
  - Ground validation NOAA lidar, multiple sonde launches, Vaisala and NOAA profilers
- TWiLiTE running fully autonomously
  - Multiple data streams: Housekeeping data sampled every 1 sec starting at instrument power on; Etalon calibration scans run every 10 minutes starting at laser power on (> 55000 ft altitude); 10 minute science data acquisition periods following calibration sequence; Auto-alignment system runs every 30 minutes or on fault detect); Instrument GPS/IMU data stored at 100Hz.
  - Telescope fixed pointing in at 90 deg relative to flight track. No scanning.

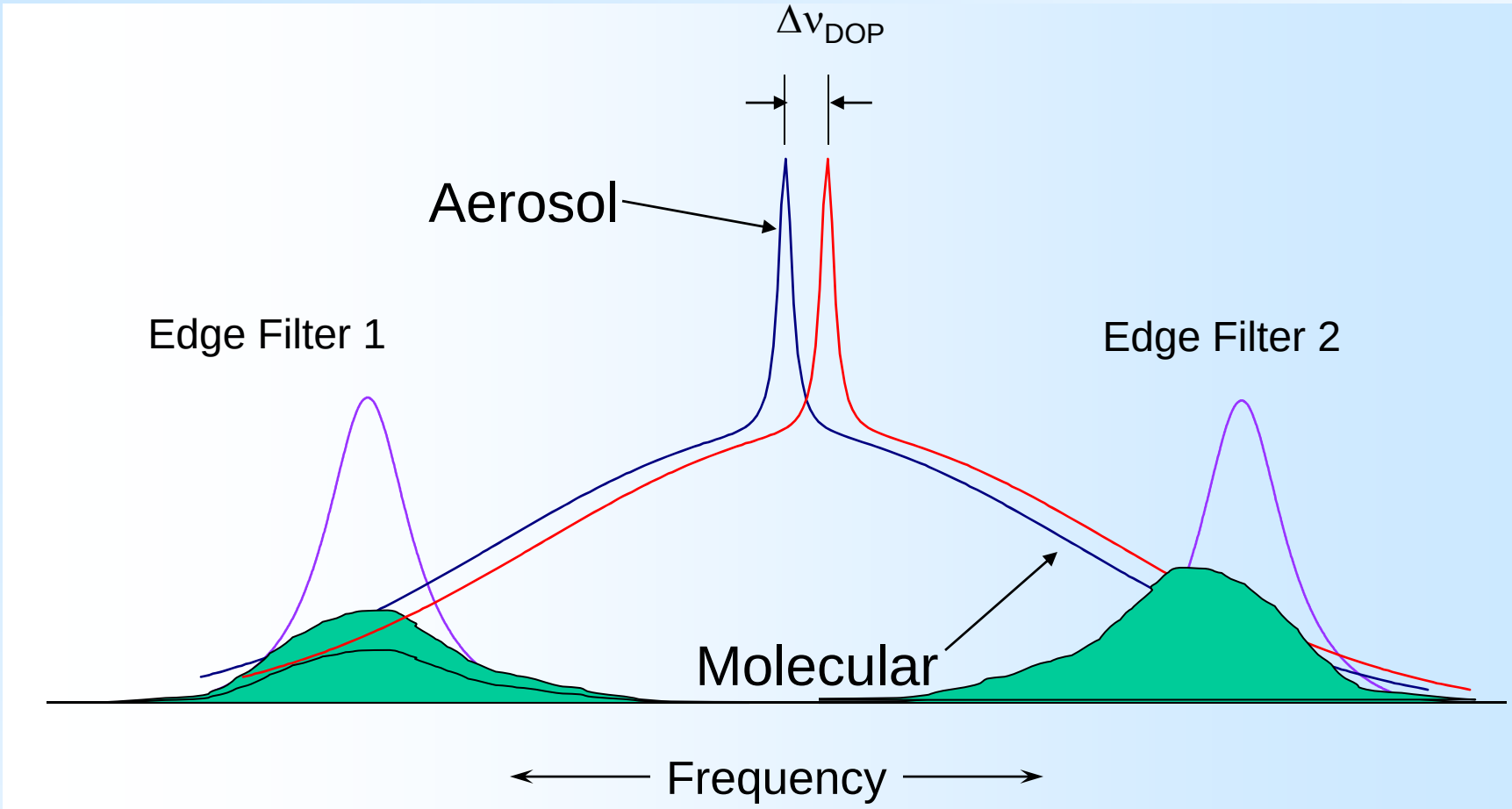
October 1, 2009 flight track – 9:25 PDT launch; 5.4 hours; DFRC to Boulder

NWS sonde site NPN 404 MHz Profiler Vaisala + NOAA lidar

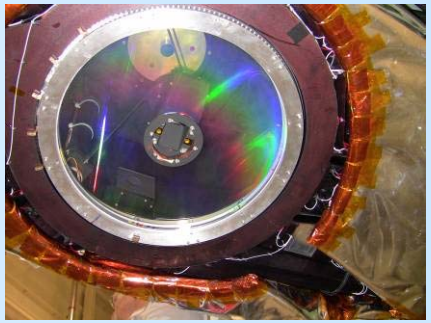


Double Edge Measurement Principle

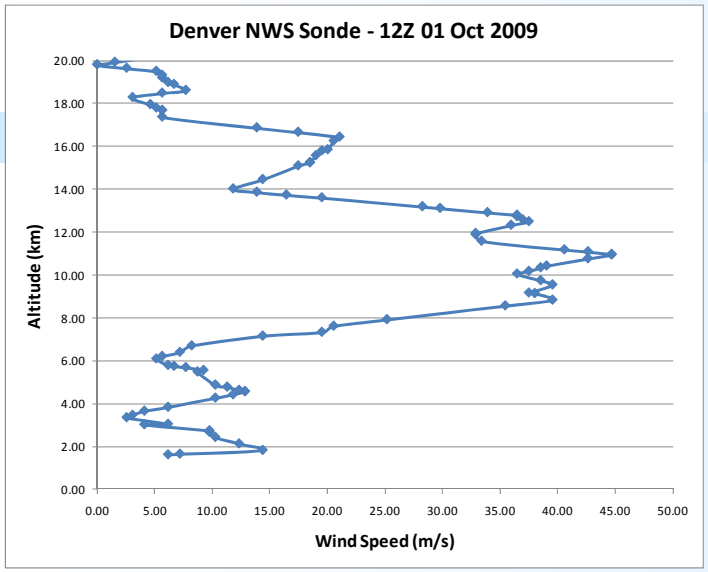
Molecular Channel at 355 nm

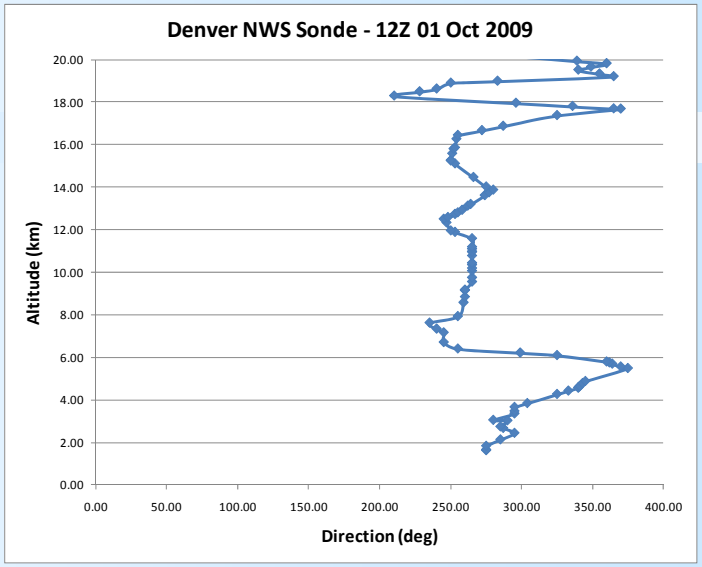


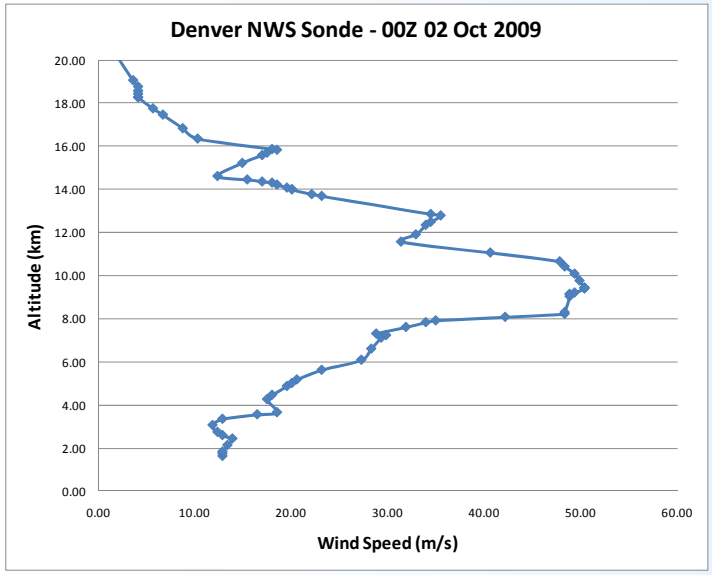
ER-2 Engineering Flights
February, 2009 and September, 2009

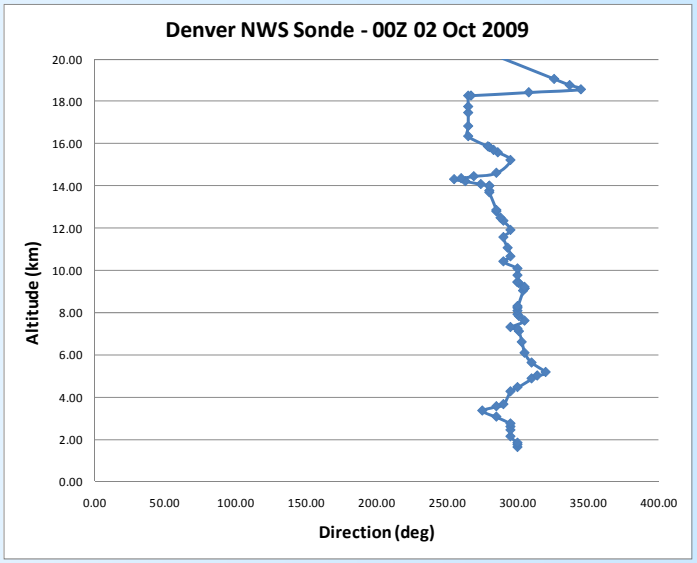


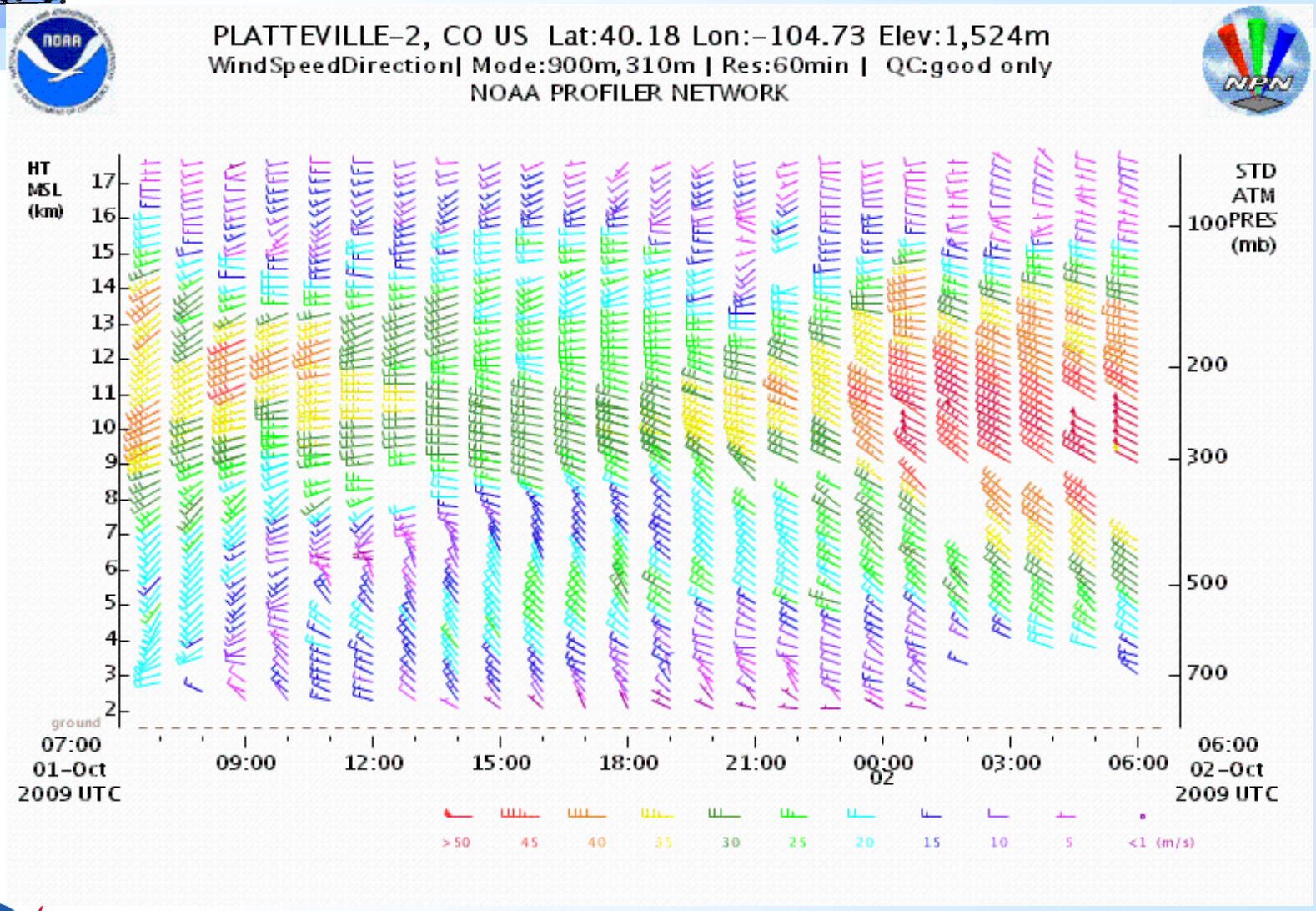
October 1, 2010 Ground Validation


Denver NWS Sonde - 12Z 01 Oct 2009
Altitude (km)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
Wind Speed (m/s)

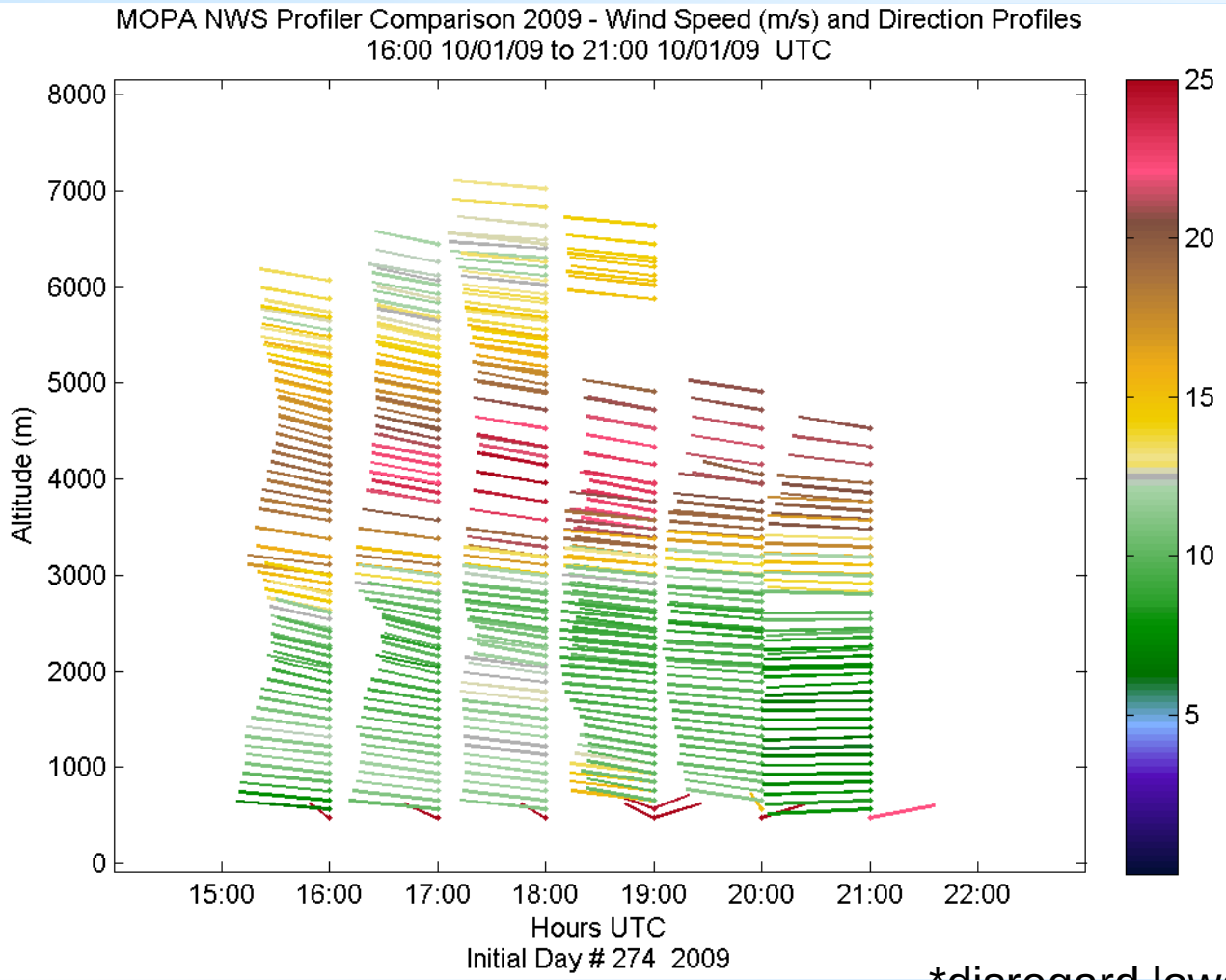

Denver NWS Sonde - 12Z 01 Oct 2009
Altitude (km)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00
Direction (deg)


Denver NWS Sonde - 00Z 02 Oct 2009
Altitude (km)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
Wind Speed (m/s)


Denver NWS Sonde - 00Z 02 Oct 2009
Altitude (km)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00
Direction (deg)

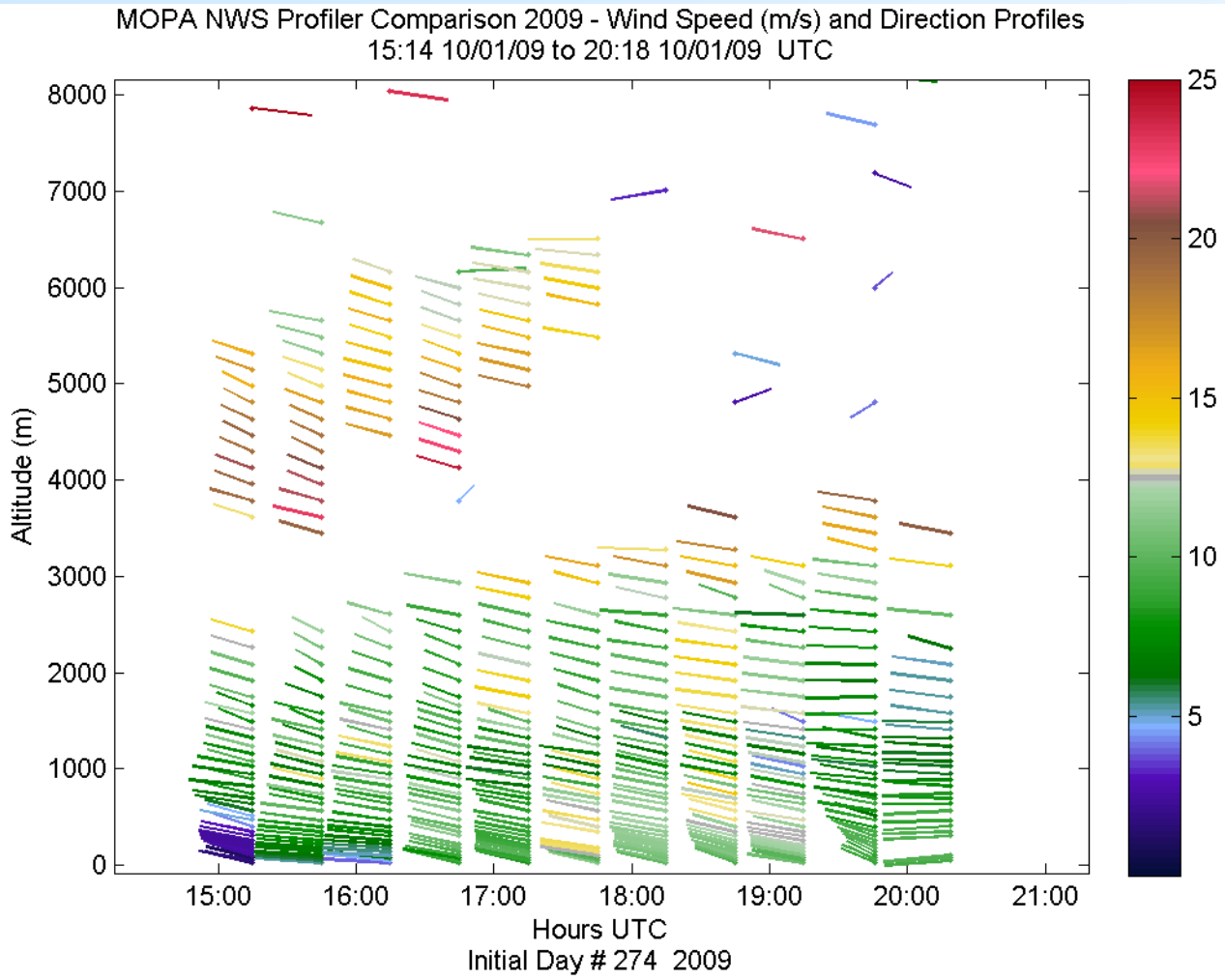

PLATTEVILLE-2, CO US Lat:40.18 Lon:-104.73 Elev:1,524m
WindSpeedDirection| Mode:900m,310m | Res:60min | QC:good only
NOAA PROFILER NETWORK
HT MSL (km)
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
ground
STD ATM PRES (mb)
100
200
300
500
700
07:00 01-Oct 2009 UTC
09:00
12:00
15:00
18:00
21:00
00:00 02
03:00
06:00
06:00 02-Oct 2009 UTC
>50
45
40
35
30
25
20
15
10
5
<1 (m/s)

NOAA Boulder Validation
60min – Lidar wind profiles from staring Lidar data*
(W. A. Brewer and R. M. Hardesty)

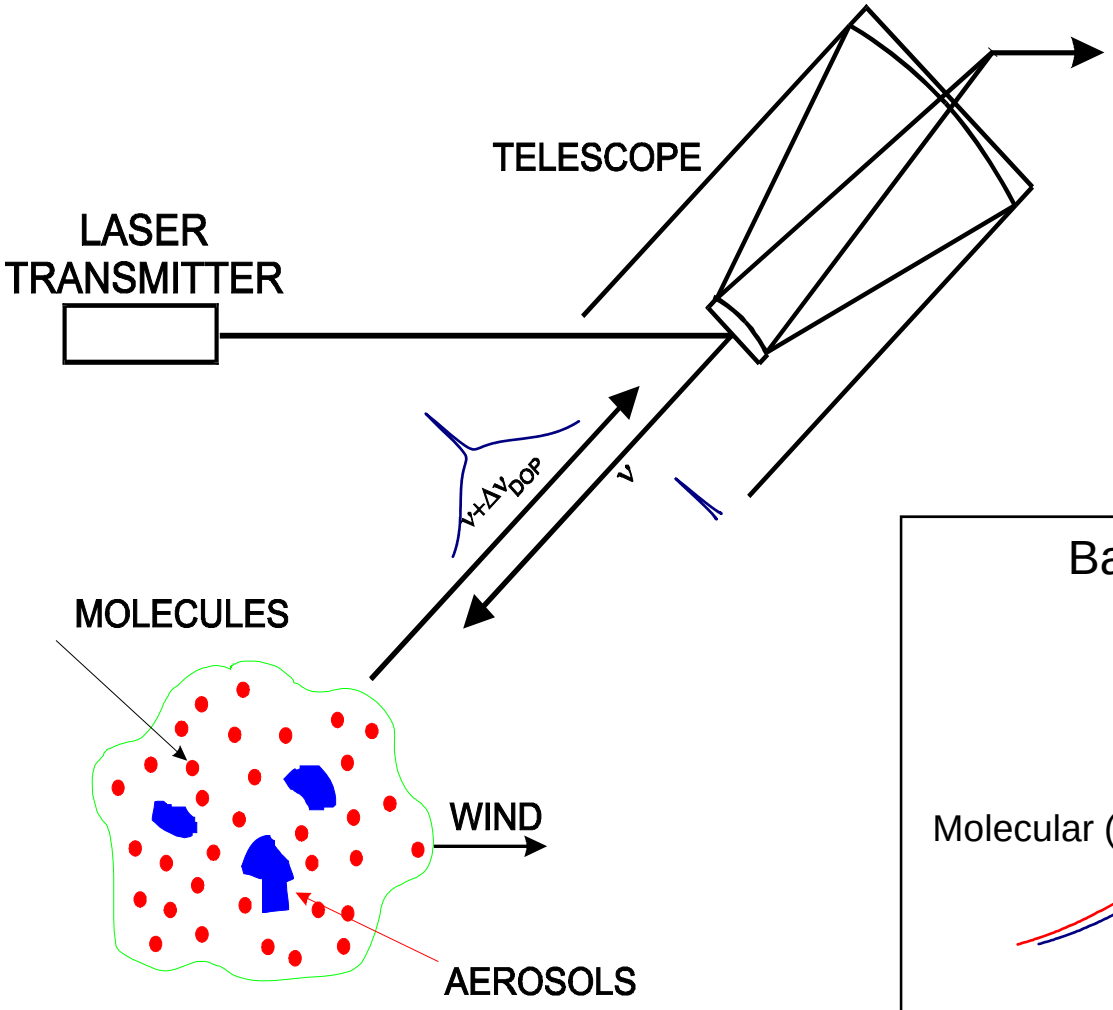


*disregard lowest gate

NOAA Boulder Validation
30 min Lidar wind profiles (from azimuthal scans)
(W. A. Brewer and R. M. Hardesty)

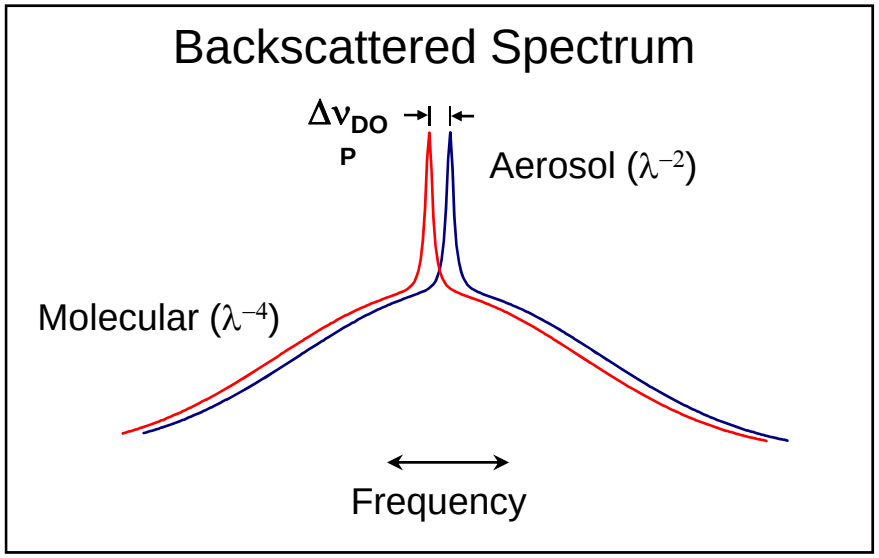


Doppler Lidar Measurement Concept

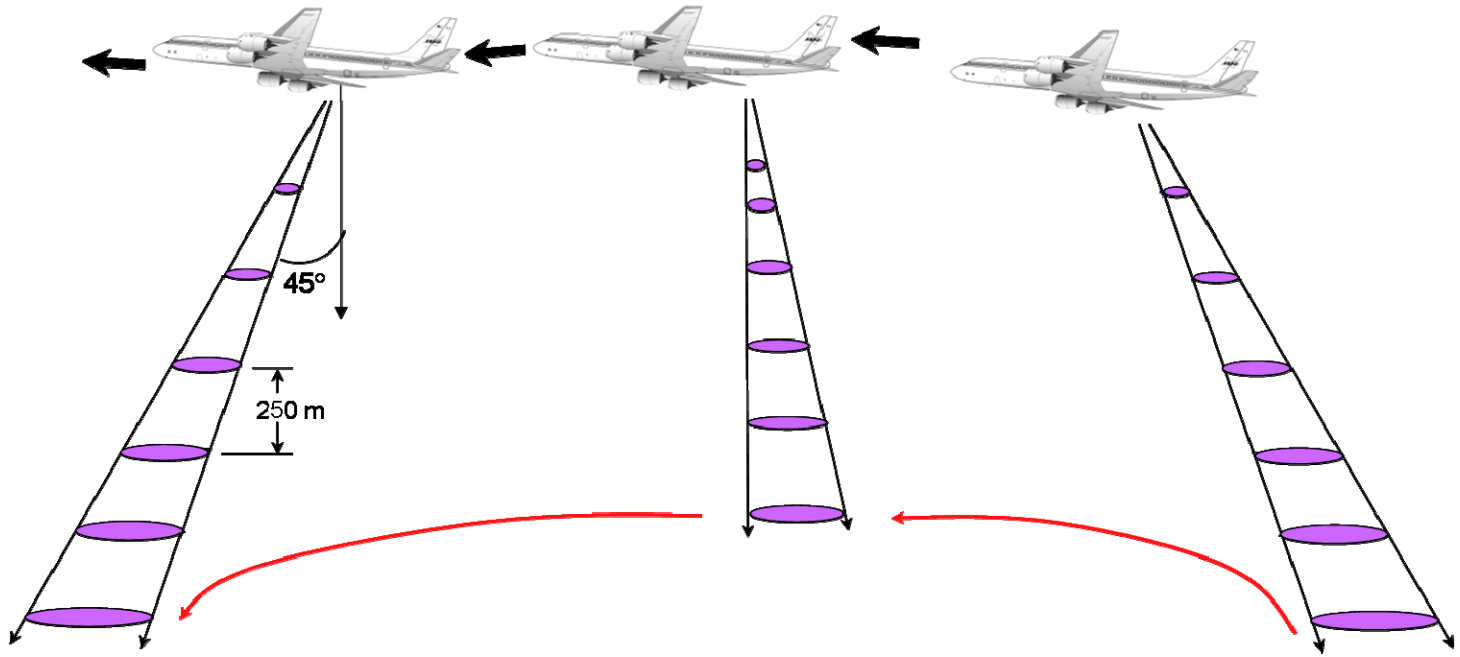


DOPPLER RECEIVER -
Multiple flavors dependent on scattering target -

- Aerosol return gives high accuracy and high spatial and temporal resolution ***when aerosols present***
- Molecular return gives lower accuracy and resolution but ***signal is always there***



Airborne Lidar Wind Measurement



Lidar ranging permits determination of wind speed as a function of altitude.
Multiple look angles permit determination of vector wind.

Direct Detection Doppler lidar profiling at Howard Beltsville Research Facility

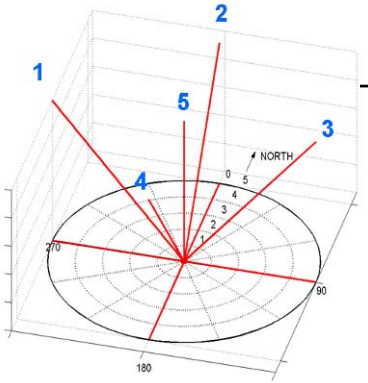
Goddard Lidar Observatory for Winds (GLOW) mobile Doppler lidar

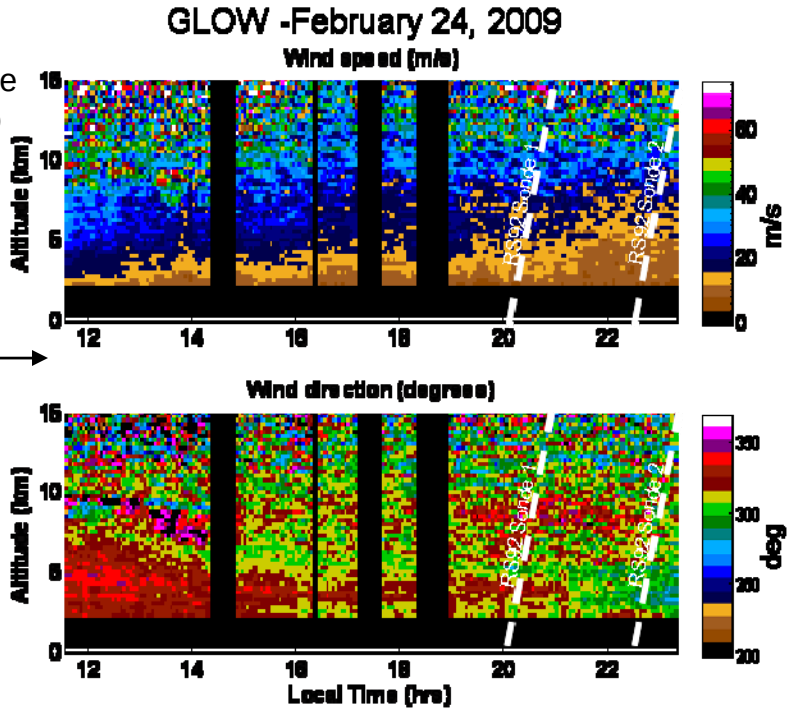
- Direct detection Doppler Lidar system
- Measures clear air wind profiles using molecular backscatter
- Serves as testbed for air and space based lidar technologies
- Multiple field campaigns since 2000

Measurement summary

- Vertical resolution=250 m
- Δt=3 min
- Altitude range= 2 to 20 km
- Elevation angle= 45 deg
- Scan pattern = 4 directions: (N,S,E,W)+vertical
- Dwell per LOS = 30 sec

Line of sight wind profiles are sequentially measured at 4 azimuth angles (N,S,E,W)+vertical. The multiple direction LOS profiles are combined to produce vertical profiles of horizontal wind speed and direction (right)





GLOW Lidar Parameters

- Wavelength = 355 nm
- Laser energy = 25 mJ @ 50 pps
- Telescope diam. = 45 cm
- Azimuth/Elevation scanner
- Double Edge molecular receiver
- Photon Counting PMTs
- QE=0.25