The TWiLiTE airborne direct detection molecular Doppler lidar

Bruce Gentry[1], M. McGill[1], G. Schwemmer[6], M. Hardesty[2], A. Brewer[2], T. Wilkerson[5], R. Atlas[2], M.Sirota[3], S. Lindemann[4], F. Hovis

[1]NASA GSFC; [2]NOAA; [3]Sigma Space Corp.; [4]Michigan Aerospace Corp.; [5]Space Dynamics Lab; [6]SES, [7]Fibertek Inc

ISS Winds Mission Science Workshop

February 8-9, 2011

Miami, FL

Outline

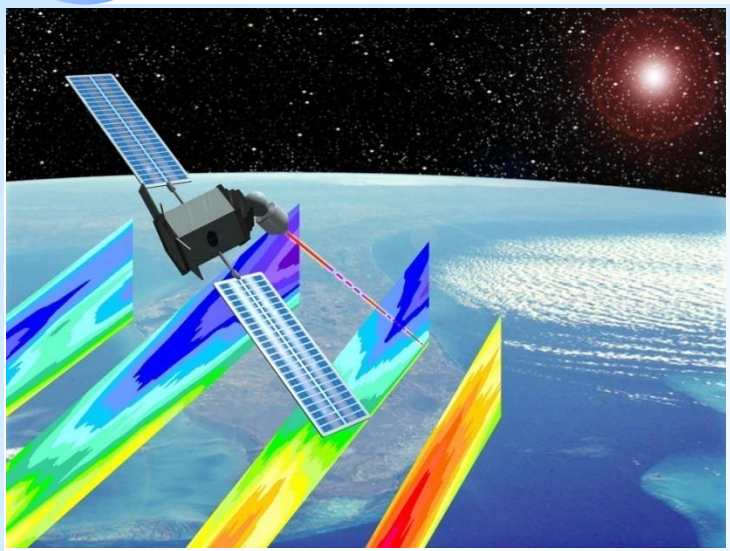
- Motivation
- TWiLiTE Overview
- Requirements and Performance Simulations
- 2009 ER-2 Engineering Flights
- Future Plans
- Summary

Acknowledgements:

We would like to acknowledge support for TWiLiTE instrument development 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.

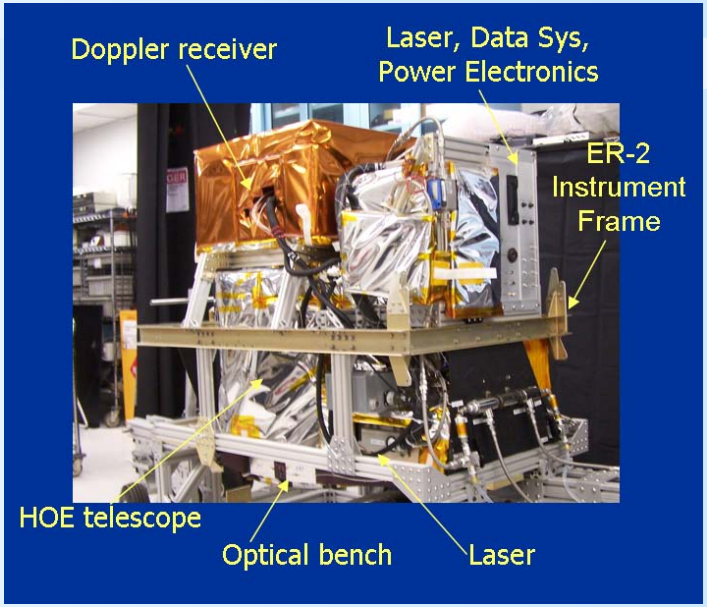
"The Panel strongly recommends an aggressive program early on to address the high-risk components of the instrument package, and then design, build, aircraft-test, and ultimately conduct space-based flights of a prototype Hybrid Doppler Wind Lidar (HDWL)."

"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.

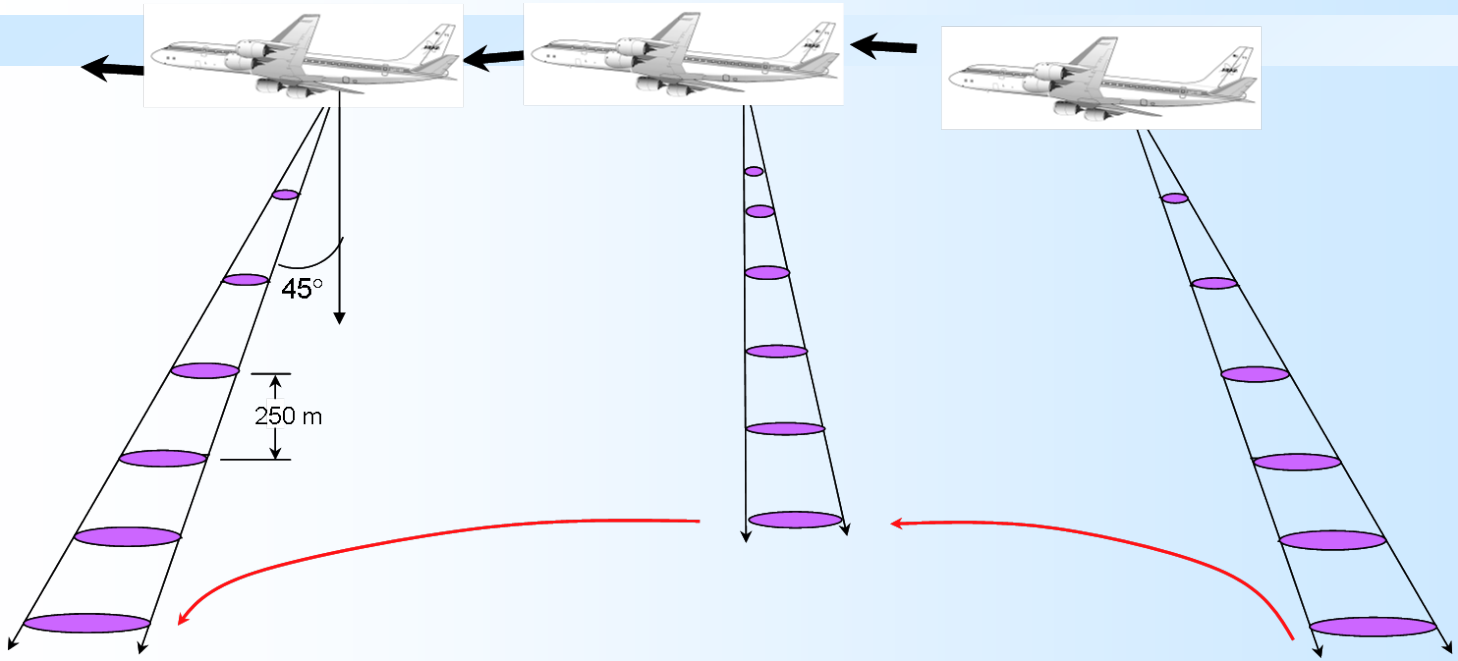


TWiLiTE system configured for ER-2 QBay

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)

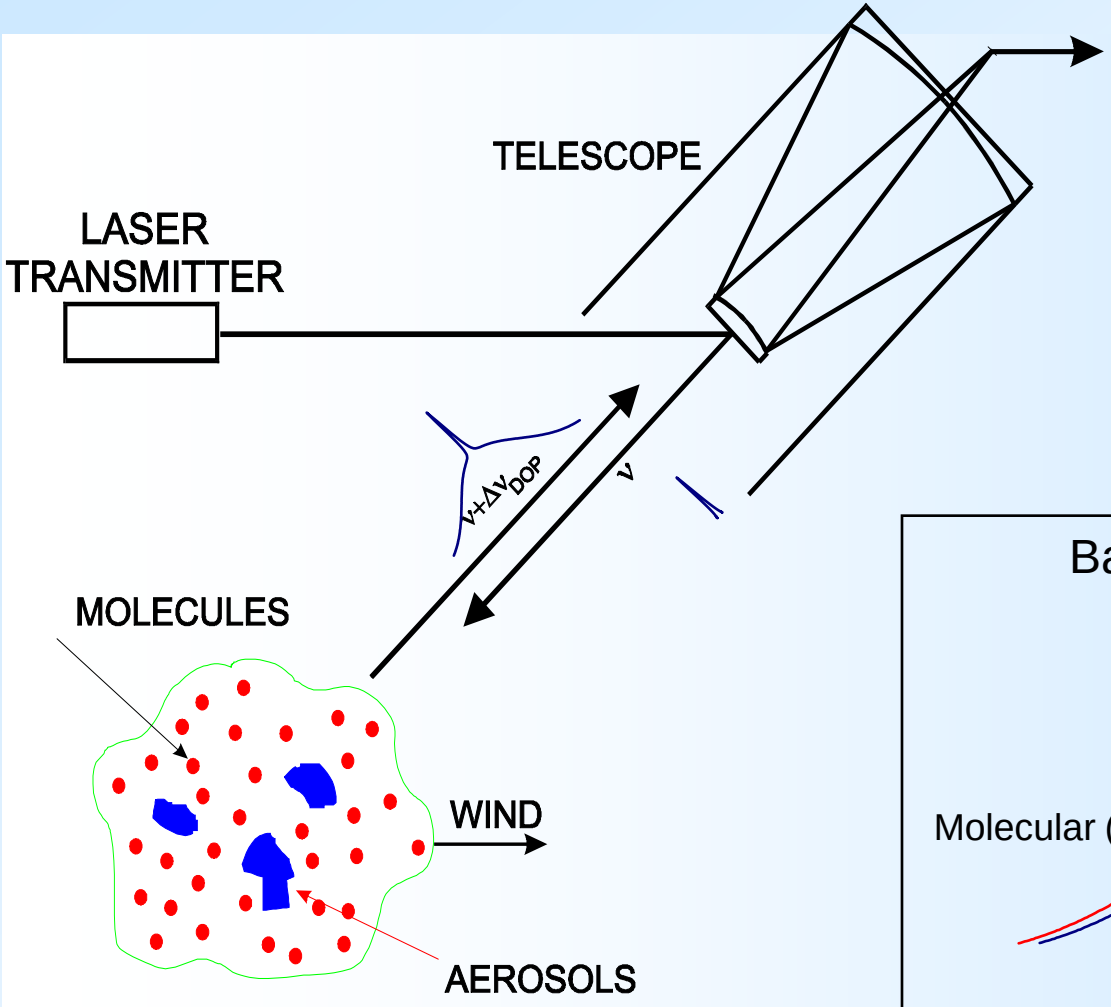
TWiLiTE ER-2 Integration
September, 2009

Airborne Lidar Wind Measurement



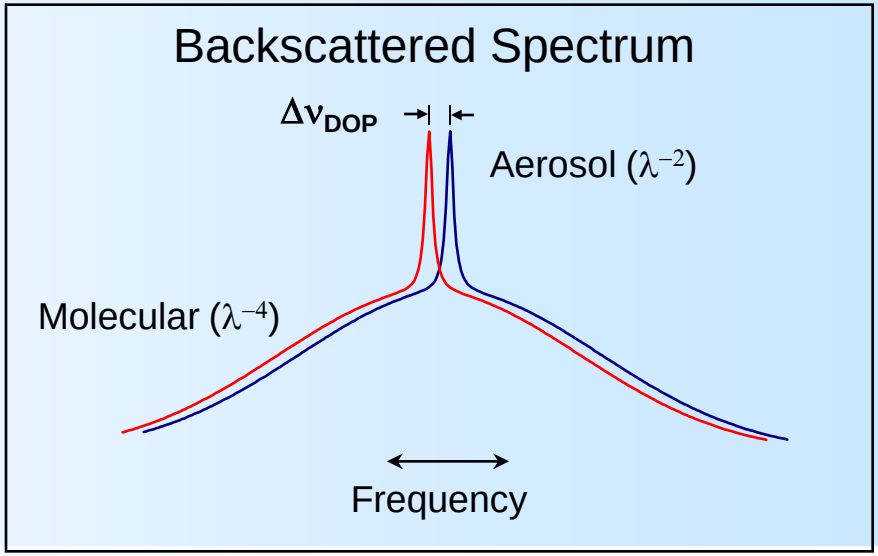
Lidar ranging permits determination of wind speed as a function of altitude.
Multiple look angles permit determination of vector wind.

Doppler Lidar Measurement Concept



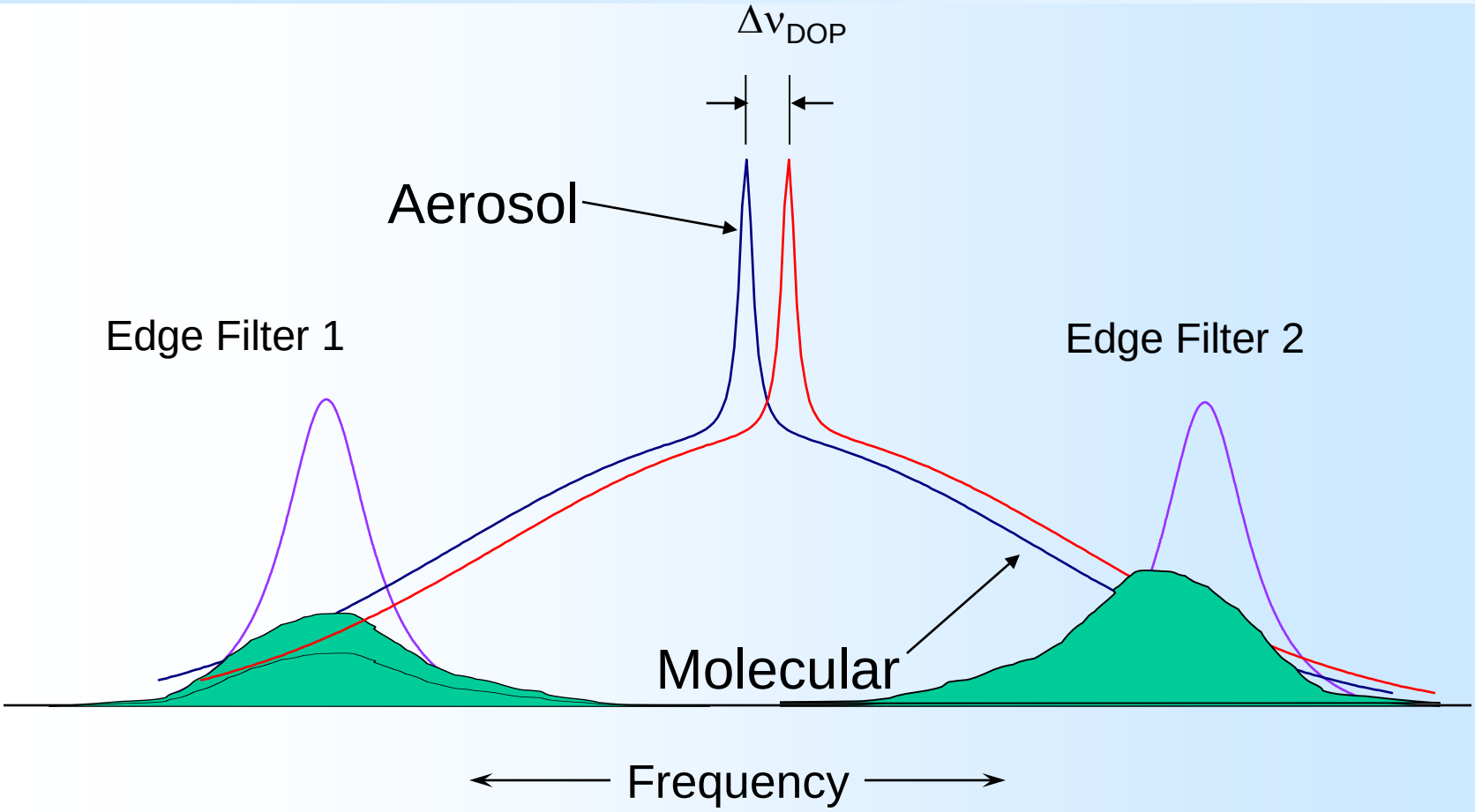
DOPPLER RECEIVER -
Multiple flavors dependent on scattering target -

- 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***



Double Edge Measurement Principle

Molecular Channel at 355 nm

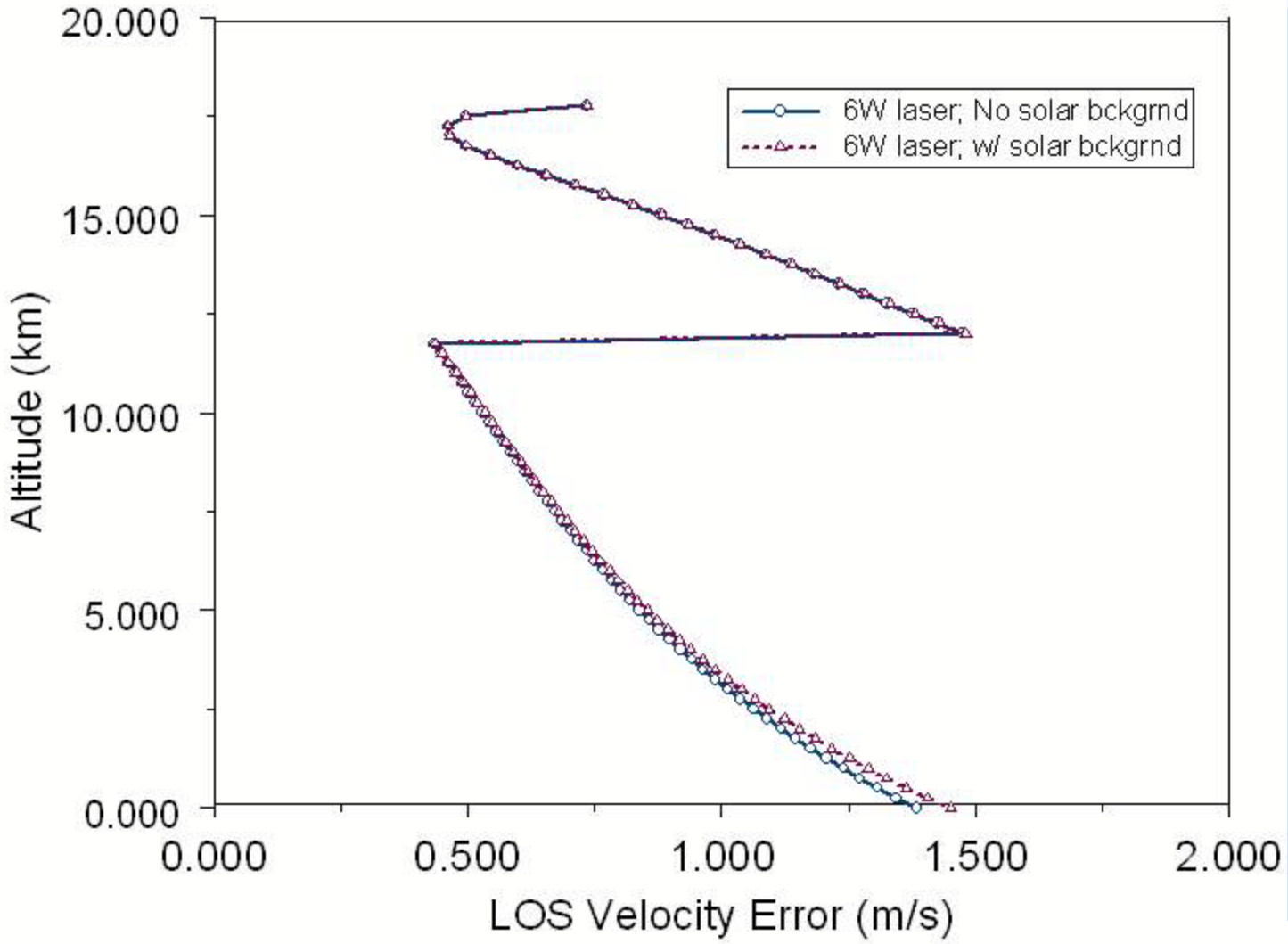


TWiLiTE Instrument Parameters

Wavelength	354.7 nm
Telescope/Scanner Area	0.08 m^2
Laser Linewidth (FWHH)	150 MHz
Laser Energy/Pulse (8 W)	30 mJ @ 200 pps
Etalon FSR	16.65 GHz
Etalon FWHH	2.84 GHz
Edge Channel Separation	6.64 GHz
Locking Channel Separation	4.74 GHz
Interference filter BW (FWHH)	120 pm
PMT Quantum Efficiency	25%
Optical Efficiency (Edge w/o BS or etalon)	0.37
BS	0.41

TWiLiTE Predicted LOS Error

2000 shot average, 250 m vertical resolution, background aerosol



TWiLiTE Compatible NASA Airborne Science Platforms

36 hrs duration
Unmanned vehicle

6-8 hrs duration
Unattended operation

Max Altitude (km)

25

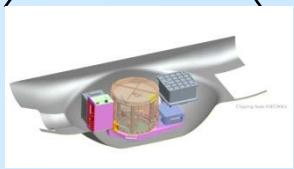
20

15

10

5

Global Hawk

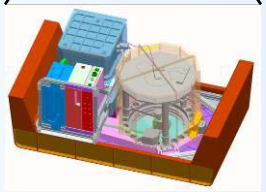


TWiLiTE configured for Global Hawk Zone 25 (HS3)

ER2

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

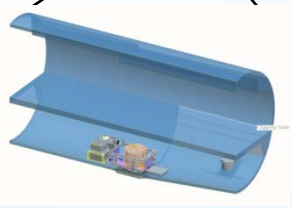
WB57



TWiLiTE configured for WB57 3' Pallet (ESTO IIP04)

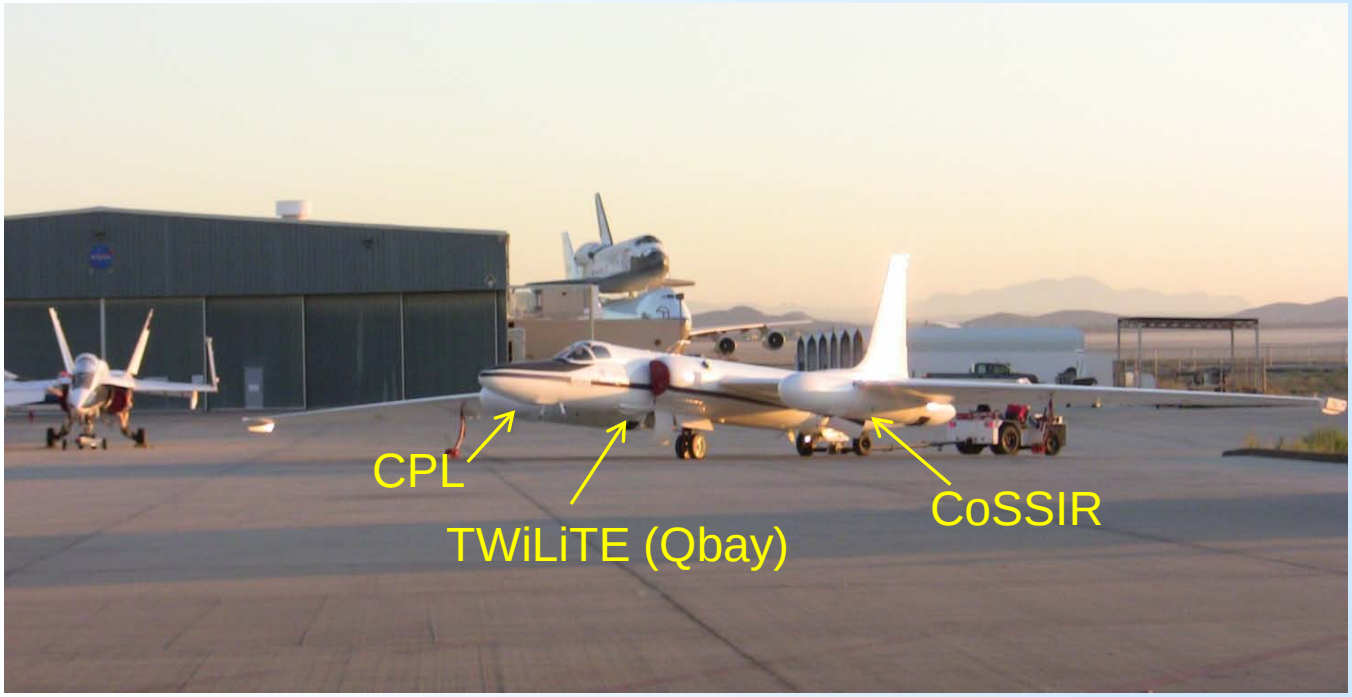
TWiLiTE configured for DC8 Nadir Port 7 (AITT)

DC8

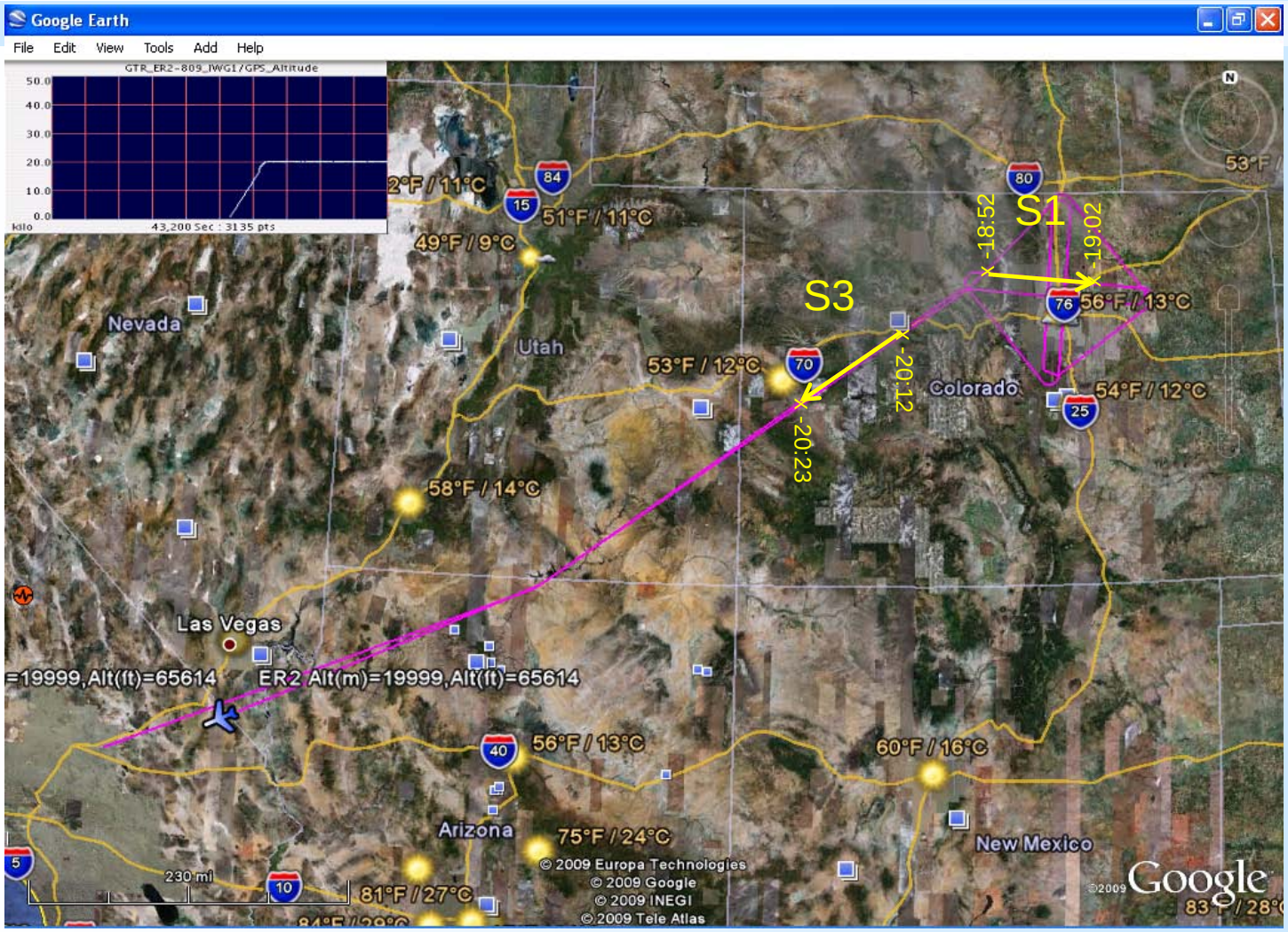


September, 2009 Engineering Flights

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.



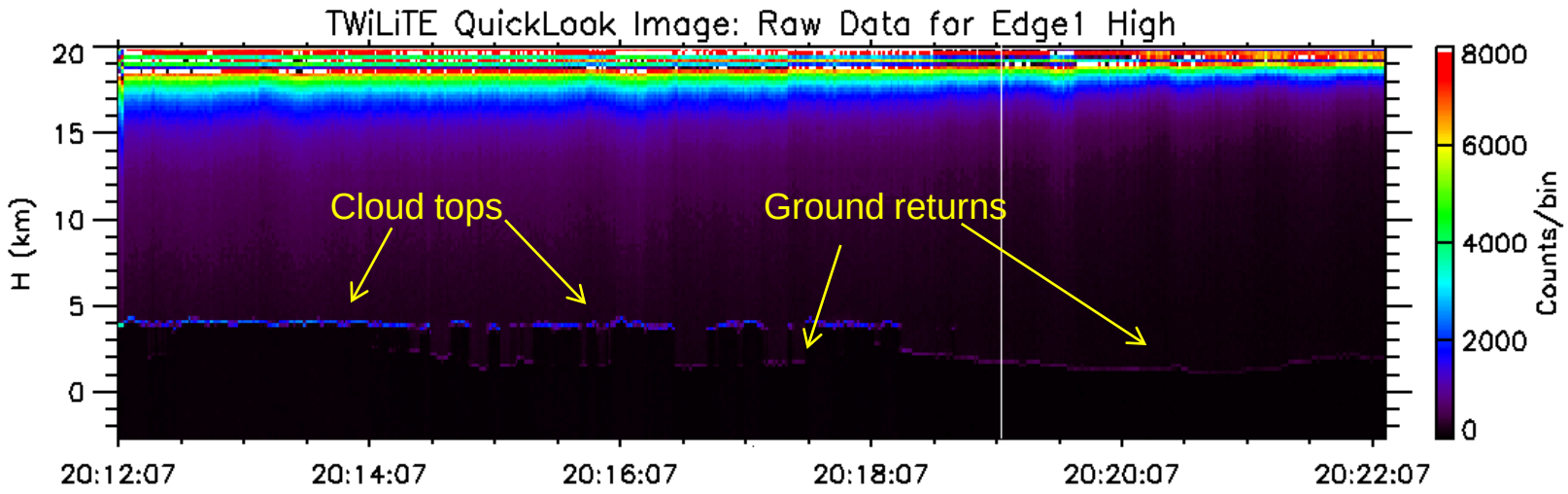
October 1, 2009 flight track
Edwards AFB to Boulder, CO
9:25 PDT launch; 5.4 hours

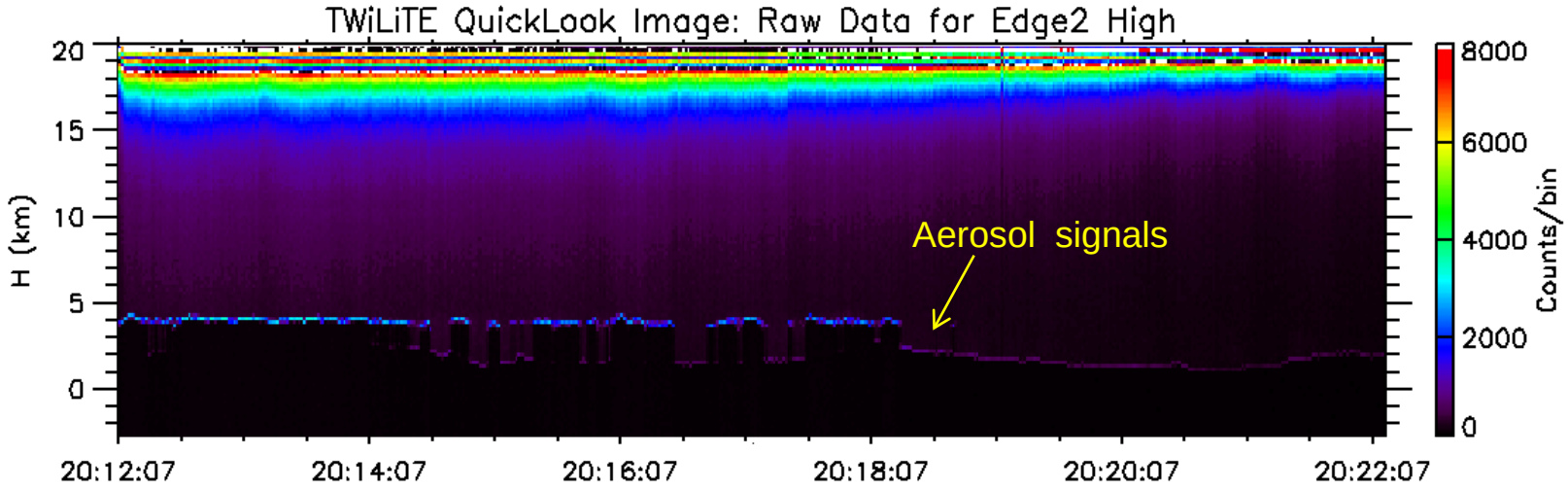


Edge Channel Signals

Data Collection Period S3 - 20:12 to 20:22 UT

1 second average; Δz=70 m

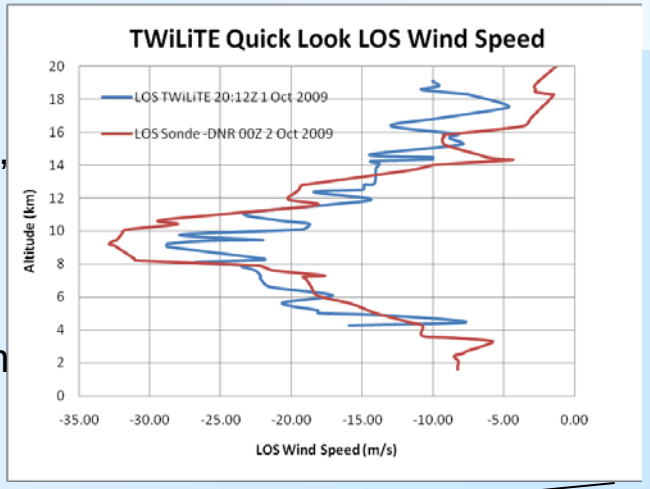


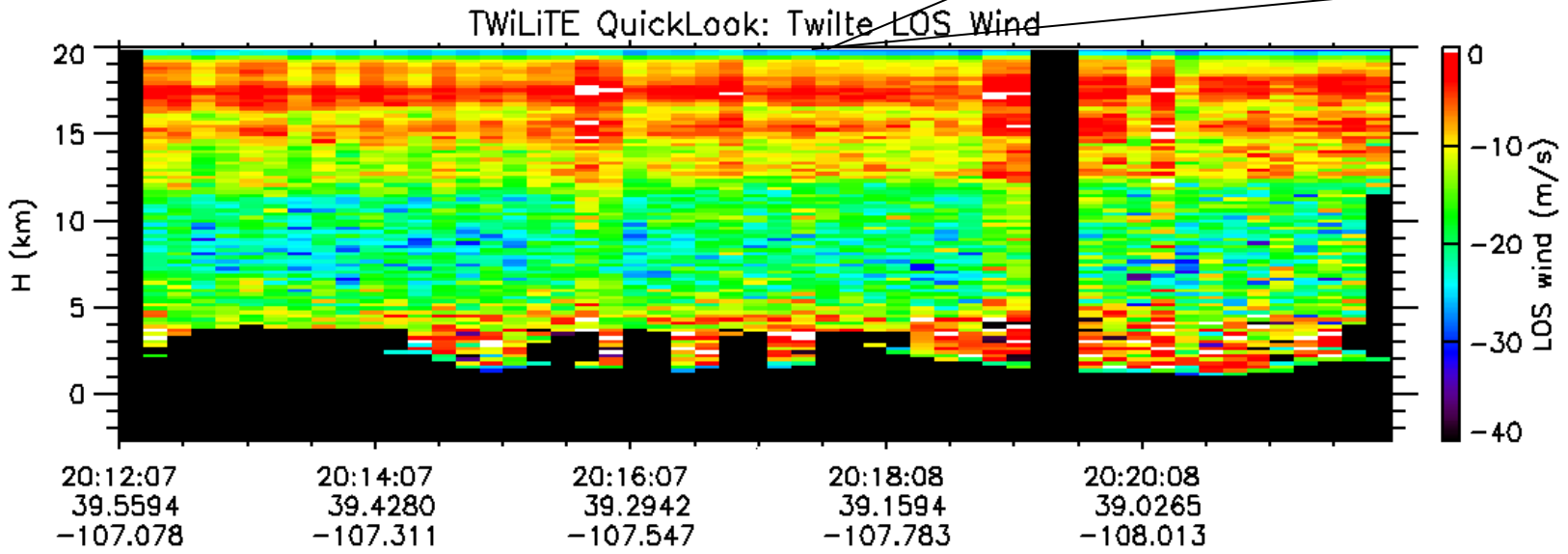


TWiLiTE Quick Look LOS Winds

October 1, 2009 – Period S3, 20:12 to 20:22 UT

- A Quicklook algorithm is used to process the Edge1 and Edge2 PMT signals to determine uncalibrated LOS wind profiles.
- Below: LOS wind profiles from a 10 minute segment from the Oct 1, 2009 ER-2 flight are shown. Ten second averaging is used (~2 km along track resolution). Vertical resolution is 210m.
- Right: A 10 sec TWiLiTE LOS profile (20:17:07 UT) is shown along with wind data from the NWS sonde launched from Denver at 00Z on October 2, 2009. For this comparison the sonde speed is projected to the TWiLiTE LOS direction determined from the ER-2 nav data.





TWiLiTE ER-2 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. Identified software algorithm issues and fixes.
  - 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
- Additional test flights on the ER-2 to complete engineering testing are in progress.

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.

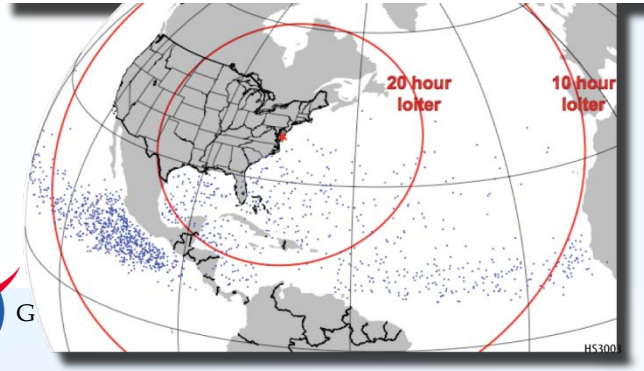
Key Science Questions:

- 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



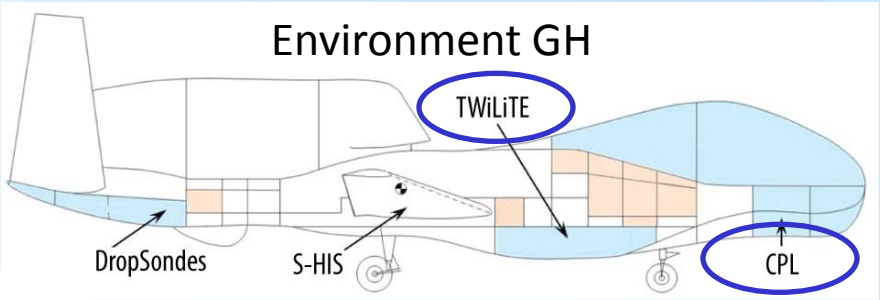
Two Global Hawk (GH) aircraft

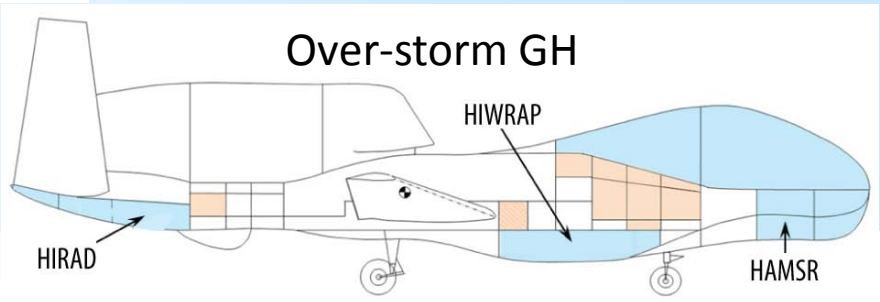
Environment GH instrumentation

- 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)

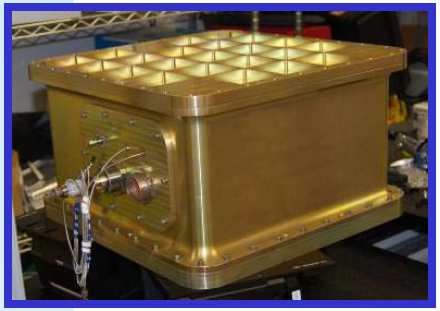




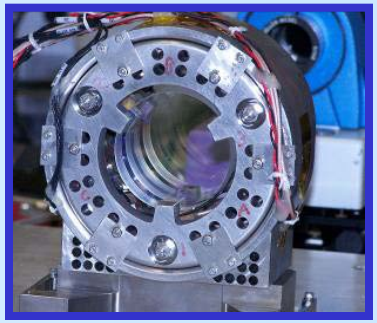
Conclusions and Future plans

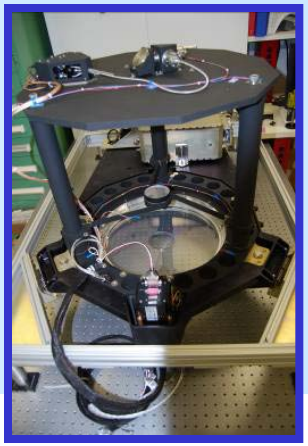
- During the TWiLiTE flight test program we completed two deployments to Edwards AFB to integrate in the ER-2 Q-Bay and fly 26 hours of engineering test flights.
- During these flights TWiLiTE demonstrated fully autonomous operation of the major lidar functions including etalon calibration, telescope/laser bore sight alignment and science data acquisition including initial LOS wind profile measurements.
- Remaining issues: Azimuth scanning **with the rotating HOE** still needs to be demonstrated. Auto-alignment algorithm needs to be fine tuned and stability demonstrated in flight.
- Additional flight testing of TWiLiTE on the ER-2 to address these **issues is in progress (Deployment: Feb 3 - Feb 16, 2011).**
- Future plans: TWiLiTE will be reconfigured to fly in Zone 25 of the NASA Global Hawk for the HS3 EV-1 Mission.

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





Direct Detection Doppler lidar profiling at Howard Beltsville Research Facility

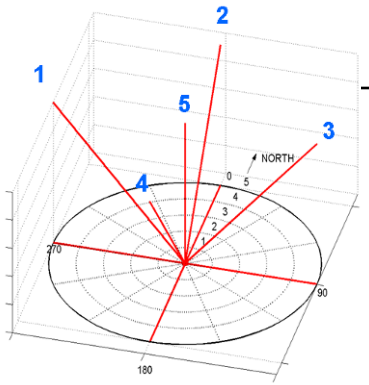
Goddard Lidar Observatory for Winds (GLOW) mobile Doppler lidar

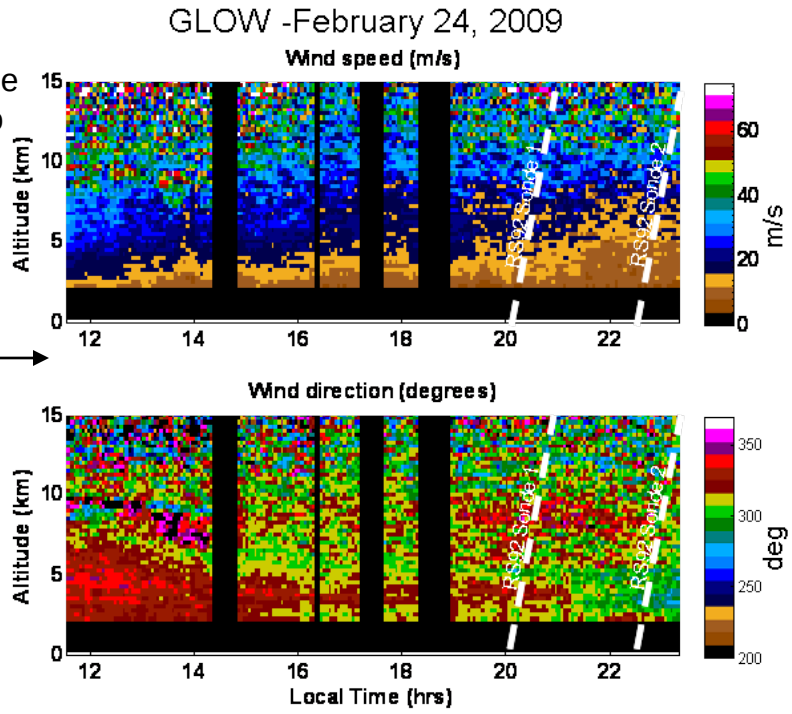
- Direct detection Doppler Lidar system
- Measures clear air wind profiles using molecular backscatter
- Serves as testbed for air and space based lidar technologies
- Multiple field campaigns since 2000

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)





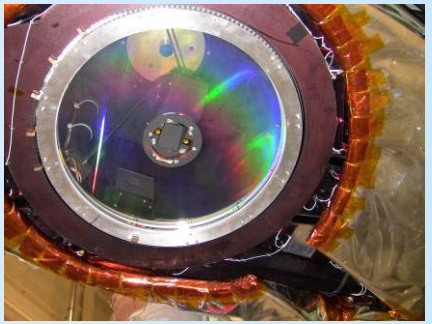
GLOW Lidar Parameters

- 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

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.

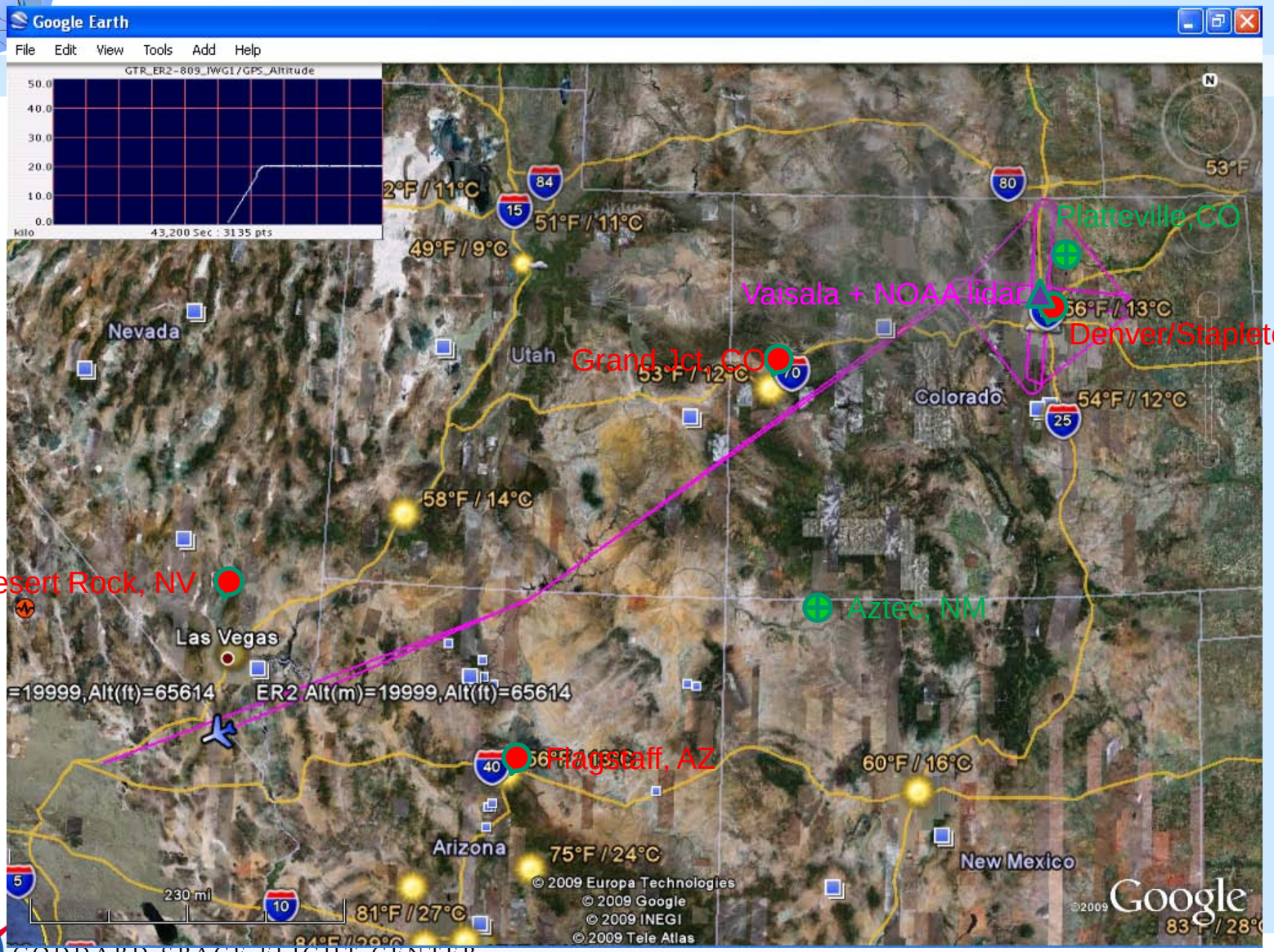
ER-2 Engineering Flights
February, 2009 and September, 2009

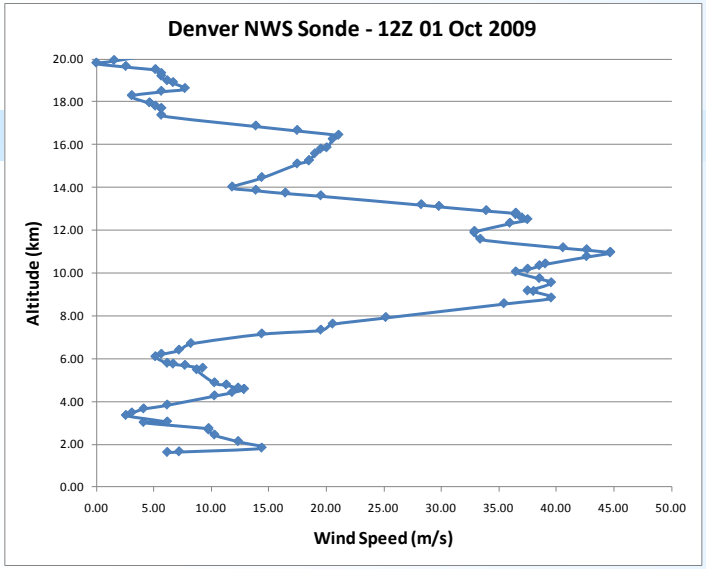


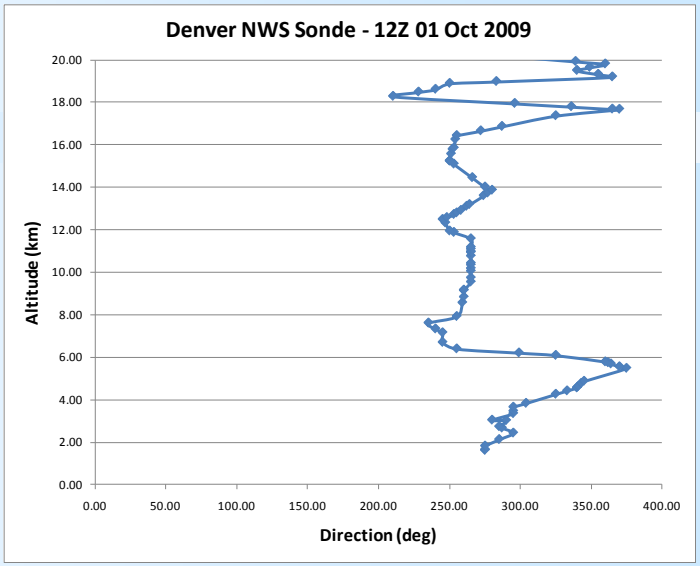
October 1, 2010 Ground Validation

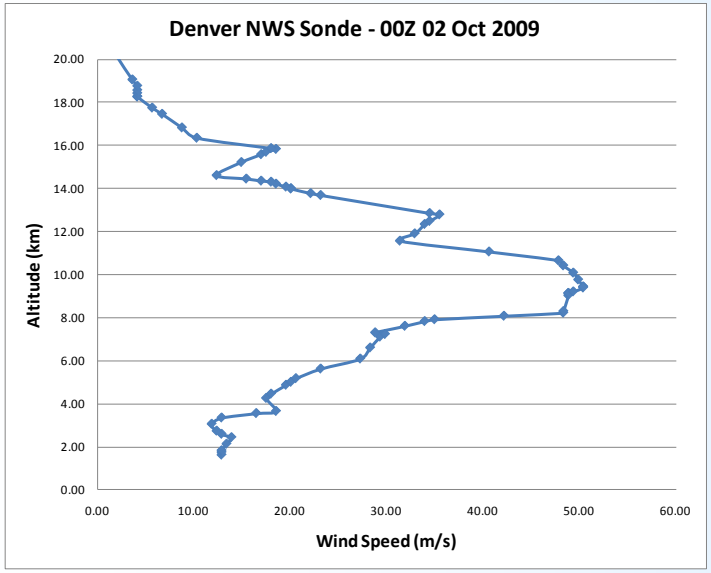
October 1, 2009 flight track – 9:25 PDT launch; 5.4 hours; DFRC to Boulder

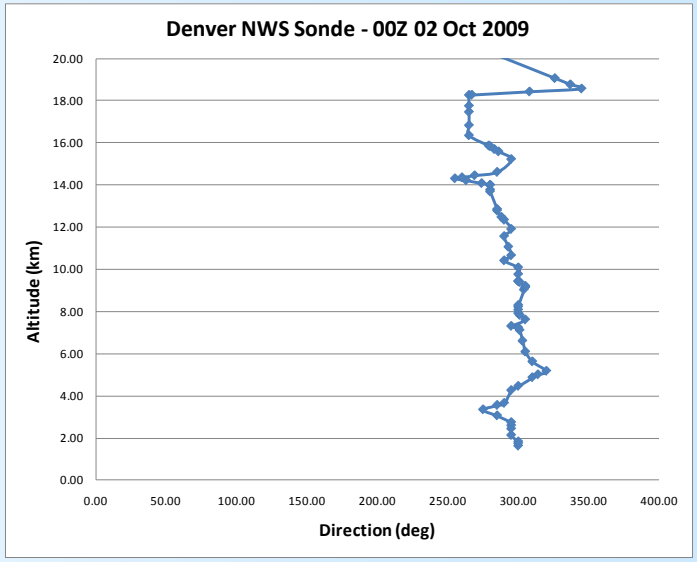
NWS sonde site NPN 404 MHz Profiler Vaisala + NOAA lidar

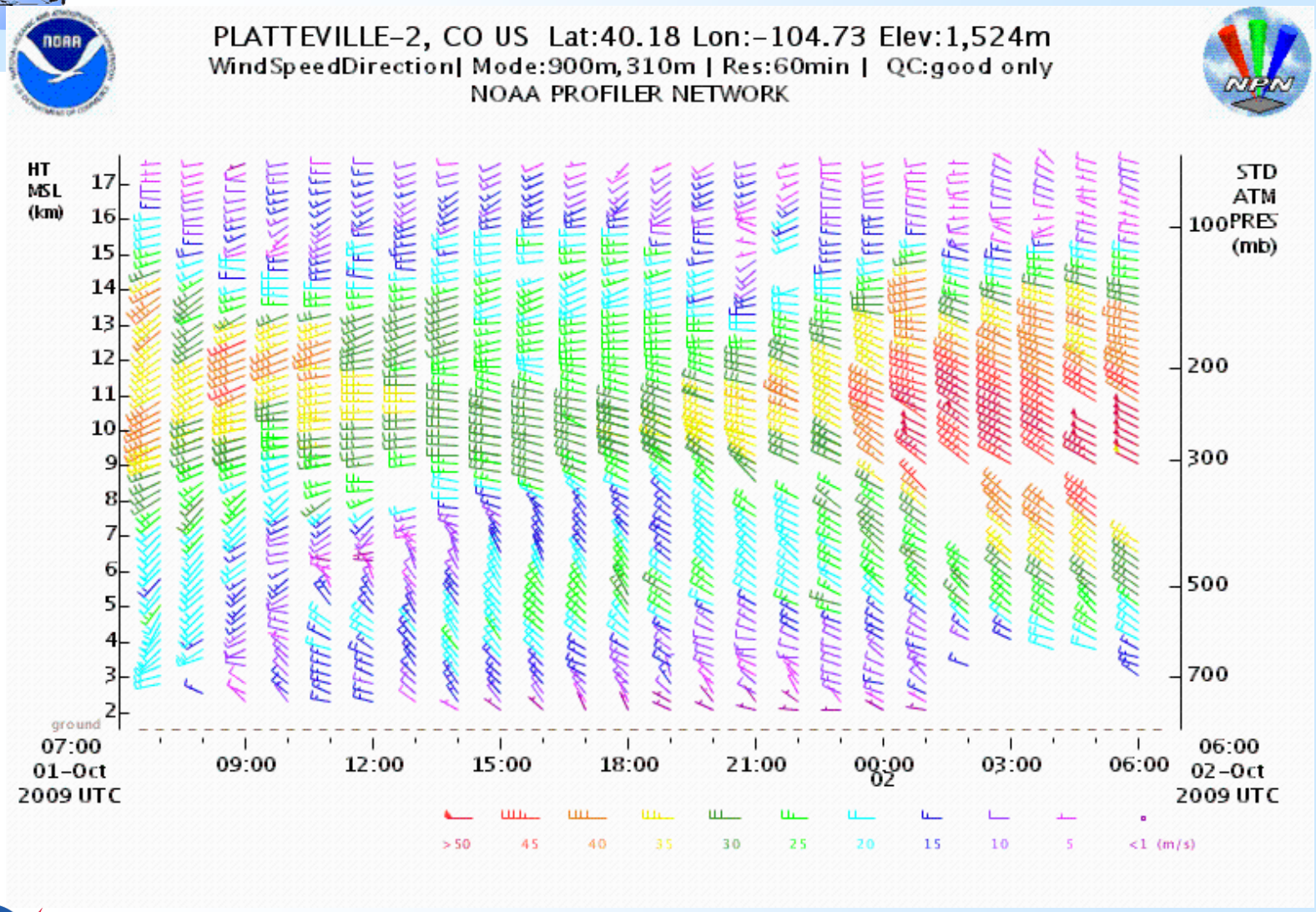



Denver NWS Sonde - 12Z 01 Oct 2009
Altitude (km)
Wind Speed (m/s)
0.00 2.00 4.00 6.00 8.00 10.00 12.00 14.00 16.00 18.00 20.00
0.00 5.00 10.00 15.00 20.00 25.00 30.00 35.00 40.00 45.00 50.00

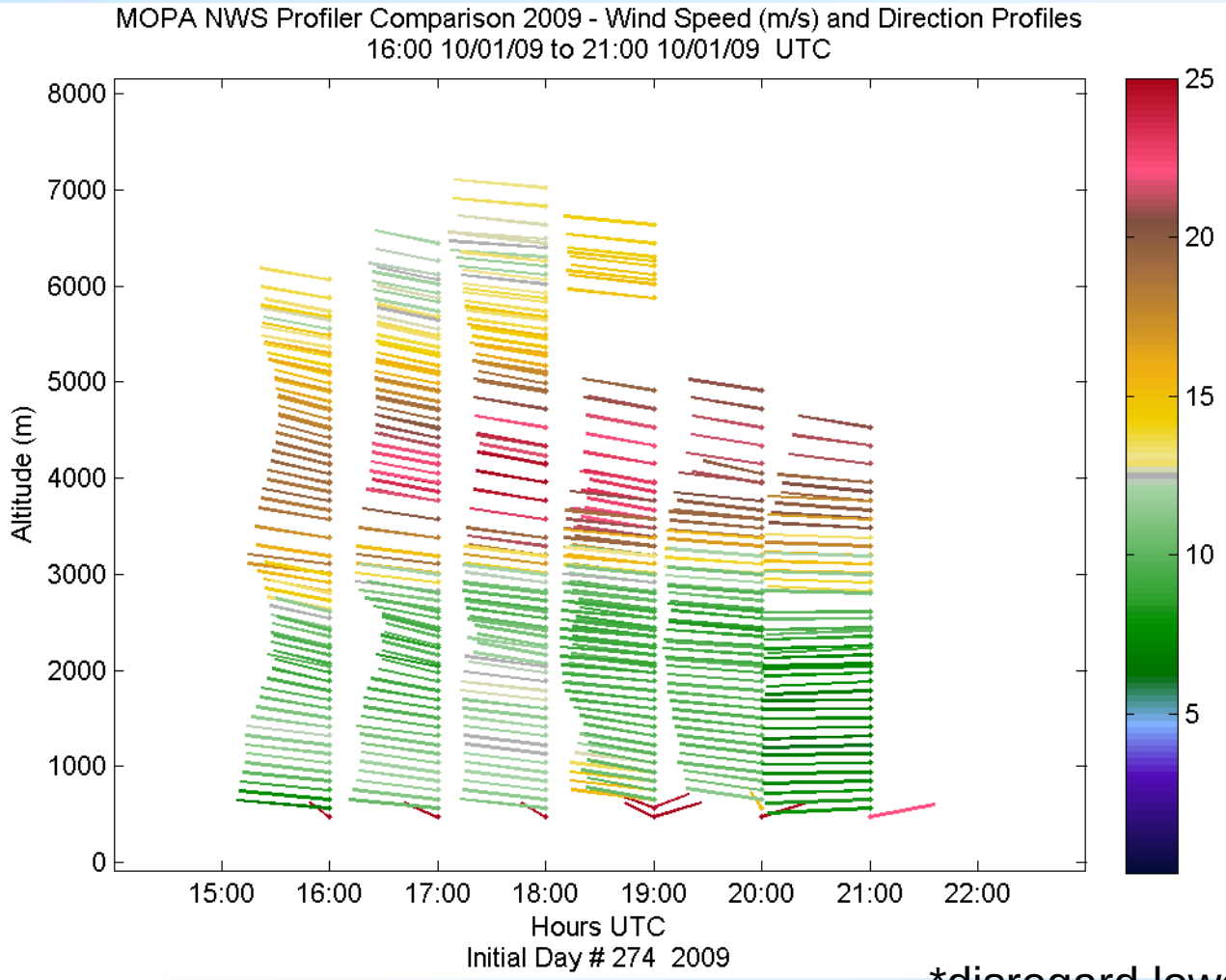

Denver NWS Sonde - 12Z 01 Oct 2009
Altitude (km)
Direction (deg)
0.00 2.00 4.00 6.00 8.00 10.00 12.00 14.00 16.00 18.00 20.00
0.00 50.00 100.00 150.00 200.00 250.00 300.00 350.00 400.00


Denver NWS Sonde - 00Z 02 Oct 2009
Altitude (km)
Wind Speed (m/s)
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


Denver NWS Sonde - 00Z 02 Oct 2009
Altitude (km)
Direction (deg)
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


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)