Modeled Performance of a Coherent DWL in a Pathfinder Mission

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Working Group on Space-based Lidar Winds

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Prologue

- Option born and being supported at NASA/LaRC for the community to consider a concept focused on retrieving useful wind data for partly cloudy situations in the mid and lower troposphere.
- Sensitivity of baseline instrument is ~2-6X of any coherent system previously proposed.
- There is an expectation of exploiting synergisms with other passive/active wind observing systems
- I, personally, am most comfortable projecting the performance of a DWL technology I have used for science investigations for more than 35 years
- I am a strong supporter of the OAWL concept and look forward to co-flying with that technology in future field campaigns.

Scoping of WIND-SP (Space Pathfinder)

- Instrument and preliminary mission design funded by NASA through LaRC
- DWL pathfinder concept is a follow-on to White Papers submitted to National Academy of Sciences in 2017 by LaRC and SWA.
- Focus upon atmospheric boundary layer is consistent with National Academy of Sciences Boundary Layer Workshop (10/17) and the Decadal Survey recommendations. Mid and upper troposphere still well represented with a WIND-SP pathfinder mission.
- Mission is being designed to explore various sampling strategies suitable for lower tropospheric atmospheric research and follow-on operational NWP **in the presence of clouds**.

Integrating a Doppler Wind Lidar into a network of wind observing systems: capitalizing on synergisms with a high precision, cloud scene penetrating lidar.

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Executive Summary

……we argue for an initial pathfinder/survey mission that **recognizes the preponderance and impact of clouds and favors high precision/representativeness** over global coverage. The suggestions offered here are, in part, a response to NASA's recent recommendation "It is important to avoid all or nothing strategies for the three dimensional wind vector measurements, as important progress is possible with less than comprehensive observing strategies."

This white paper from NASA LaRC is guided, in part, by decades of discussions/deliberations within the NASA/NOAA funded Working Group on Space-based Lidar Winds and the following three assertions: a) **No single technology** is likely to deliver, at a reasonable cost, full tropospheric/lower stratospheric wind profiles at the horizontal/vertical coverage and precision desired by the communities associated with the Earth System Science Themes; b) **Capitalization on synergisms** between a DWL and existing or promising future wind observing systems is key to optimizing the Nation's investment in enhancing the collection of global wind data for both the research and operational communities; c) It is highly desirable to seek international and/or private sector **partnerships** to achieve the most cost effective DWL space missions. ……

General science attributes of the WIND-SP instrument for an ISS mission concept

- High aerosol backscatter threshold sensitivity (Beta50% ~ 2.0 E-9 m/sr)
- High "inherent" single shot LOS velocity precision from ISS (~ 1-2m/s)
- Very low bias in velocity measurements (<<.5m/s)
- High vertical potential resolution (~50m) in BL and clouds
- High horizontal sampling interval (~35m) from ocean/land and clouds.
- Optimal DWL technique for probing partly cloudy scenes
- No solar background degradation of signals (equal day/night data quality)
- Well suited to post collection "sliding range gate and adaptive sample integration" to maximize science data product utility
- Spectral based frequency estimation in software provides inherent high photon/electrical efficiency and derivation of other spectral moments
- Global coverage between +/- 52 degrees latitude with seasonal variability and surface conditions including ice and snow

Guidelines for mission definition

- The WINDSP instrument will provide high quality wind vector measurements with variable coverage (vertical and horizontal) depending upon several factors:
  - An attenuated backscatter threshold (~2 x 10-9 for baseline system)
  - The size and distribution of cloud gaps of > 10km and contiguous low ODs
  - The variance of the LOS wind component during a stare (1.4 -12 seconds)
  - The spacing between the forward and aft line of sight samples used in wind profile construction
  - Platform motions, including vibrations, of the ISS

Additional considerations

- Mission could be designed to allow variable stare times to develop basis for sampling parameters of a follow-on mission.
- Defining science experiment modules will take advantage of “situations of opportunity” rather than designing the instrument/mission to meet the most demanding conditions.
- This is a pathfinder mission with a focus on probing the lower troposphere in the presence of clouds.

Science experiments

- The following represent an initial set of science experiments/objectives
  - Investigate inter-hemispherical transports via LLJs and within tropical convergence zones (ITCZ); How prevalent and energetic are LLJs over the oceans?
  - Develop improved parameterization schemes for PBL depths and growth rates for use in global weather and climate models…especially marine BLs.
  - Investigate the role of vertical shear of the horizontal wind in regions of deep convection and in tropical cyclone maintenance and suppression.
  - Investigate dynamic impacts such as speed and directional shear on the global trans-oceanic transport of pollution.

Science data products

- Primary data products
  - Vertical profiles of the horizontal wind vector (surface reflectance, clouds and aerosols permitting)
  - Vertical profiles of the variability of the winds within reference sampling volumes (derived from 12 and 1.4 second integrations)
  - LOS wind components for use in 3 and 4DVAR data assimilations for NWP
  - LOS speed variance as a function of range for integrated retrievals
  - SNR as a function of range and height
- Secondary data products
  - Derived aerosol attenuated backscatter
  - 10m wind estimates using power and log models
  - Surface reflectance “climatology” for 2um
  - Cloud backscatter and shot scale structures (compare to CALIPSO, LITE, CATS, AEOLUS, GLAS)

Observation strategy investigations

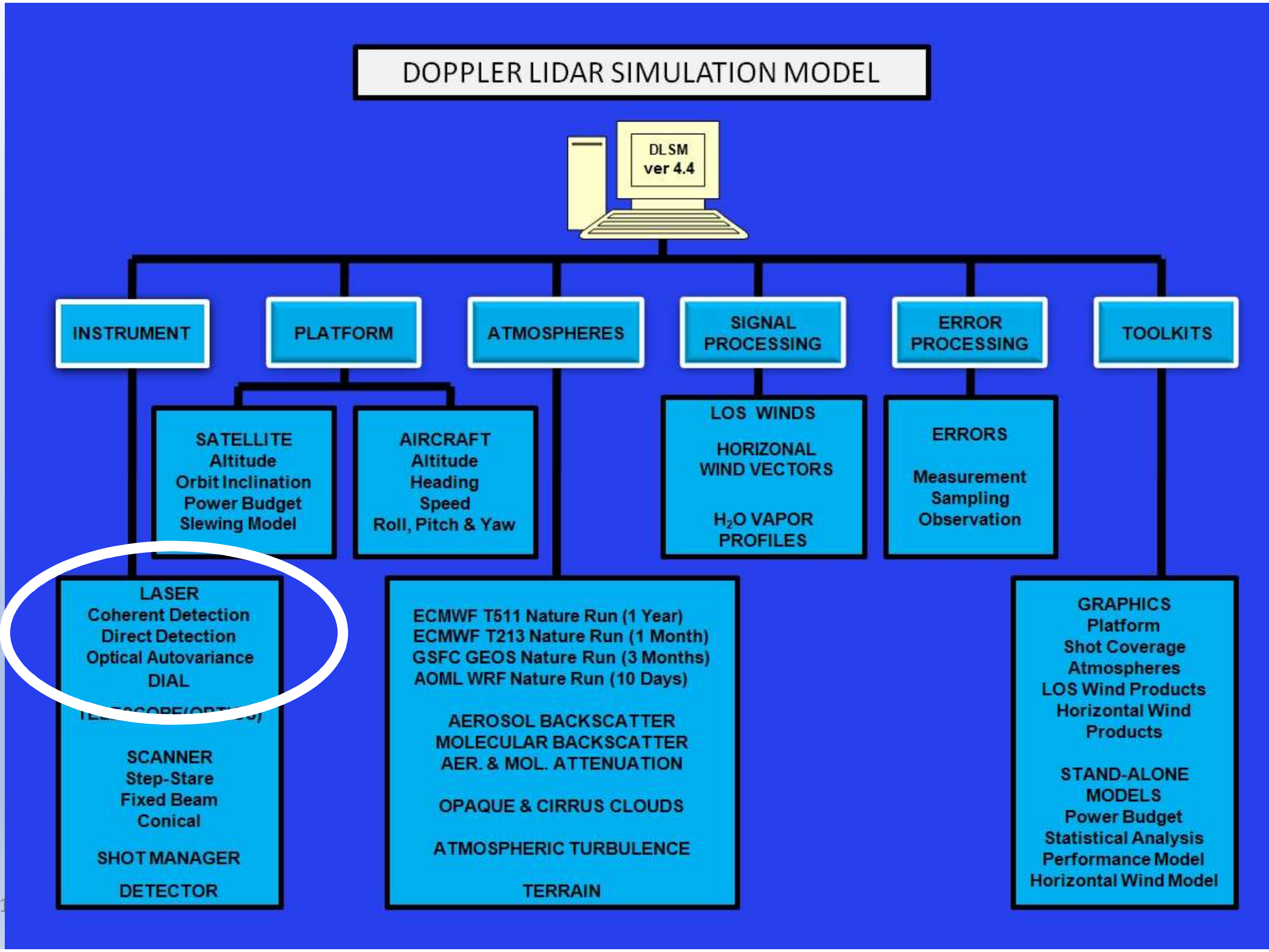
- Investigate two look vs single look comparisons for a range of atmospheric conditions
  - Cloud cover
  - Wind variability (including vertical shear)
- Validate global attenuated backscatter distributions used to design WINDSP and establish coverage expectations, especially over oceans
- Validate end-to-end LOS engineering models
- Establish cloud gap statistics unique to bi perspective sampling.
- **Develop techniques for taking advantage of synergisms between the DWL and scatterometers (ASCAT), CYGNSS, AMVs and other wind observing systems such as ACARS, rawindsondes, buoys, etc.**

Baseline and threshold WIND-SP instruments

Parameter	Baseline	Threshold	dB ratio (B/T)
Energy Per Pulse (mJ)	56	39	2.1
Pulse Duration (nsec)	180	180	N/A
PRF (Hz)	200	200	N/A
Diameter(cm)	70	50	2.9
Optical Efficiency (%)	16	10	2.0
Vertical Integration(m)	250	250	N/A
Beta(50) at 250m	2.1E-9 (log=-8.68)	9.5E-9 (log=-8.0)	
Beta(90) at 250m	4.9E-9 (log=-8.32)	2.2E-8 (log=-7.7)	

Performance expectations

- Simulated multiple orbit performance (vertical coverage and HLOS precision)
  - Use ECMWF's T511 Nature Run employed by NOAA and NASA in several OSSEs related to quantifying the potential impacted of a space-based DWL .
  - Use SWA's NASA/NOAA/DoD funded simulator of space-based DWLs, CMVs and OVWs to generate performance profiles
  - <u>**Use several profiles**</u> of expected global aerosol backscatter distributions
    - NMP and GTWS based primarily on GLOBE campaigns
    - ESA profiles derived, in part, from SABLE/GABLE campaigns
    - CALIPSO derived attenuated backscatter profiles (532nm) converted to 2050nm.


DOPPLER LIDAR SIMULATION MODEL
DLSM
ver 4.4
INSTRUMENT
PLATFORM
ATMOSPHERES
SIGNAL PROCESSING
ERROR PROCESSING
TOOLKITS
SATELLITE
Altitude
Orbit Inclination
Power Budget
Slewing Model
AIRCRAFT
Altitude
Heading
Speed
Roll, Pitch & Yaw
LOS WINDS
HORIZONAL WIND VECTORS
H_2O VAPOR PROFILES
ERRORS
Measurement
Sampling
Observation
LASER
Coherent Detection
Direct Detection
Optical Autovariance
DIAL
SCANNER
Step-Stare
Fixed Beam
Conical
SHOT MANAGER
DETECTOR
ECMWF T511 Nature Run (1 Year)
ECMWF T213 Nature Run (1 Month)
GSFC GEOS Nature Run (3 Months)
AOML WRF Nature Run (10 Days)
AEROSOL BACKSCATTER
MOLECULAR BACKSCATTER
AER. & MOL. ATTENUATION
OPAQUE & CIRRUS CLOUDS
ATMOSPHERIC TURBULENCE
TERRAIN
GRAPHICS
Platform
Shot Coverage
Atmospheres
LOS Wind Products
Horizontal Wind Products
STAND-ALONE MODELS
Power Budget
Statistical Analysis
Performance Model
Horizontal Wind Model

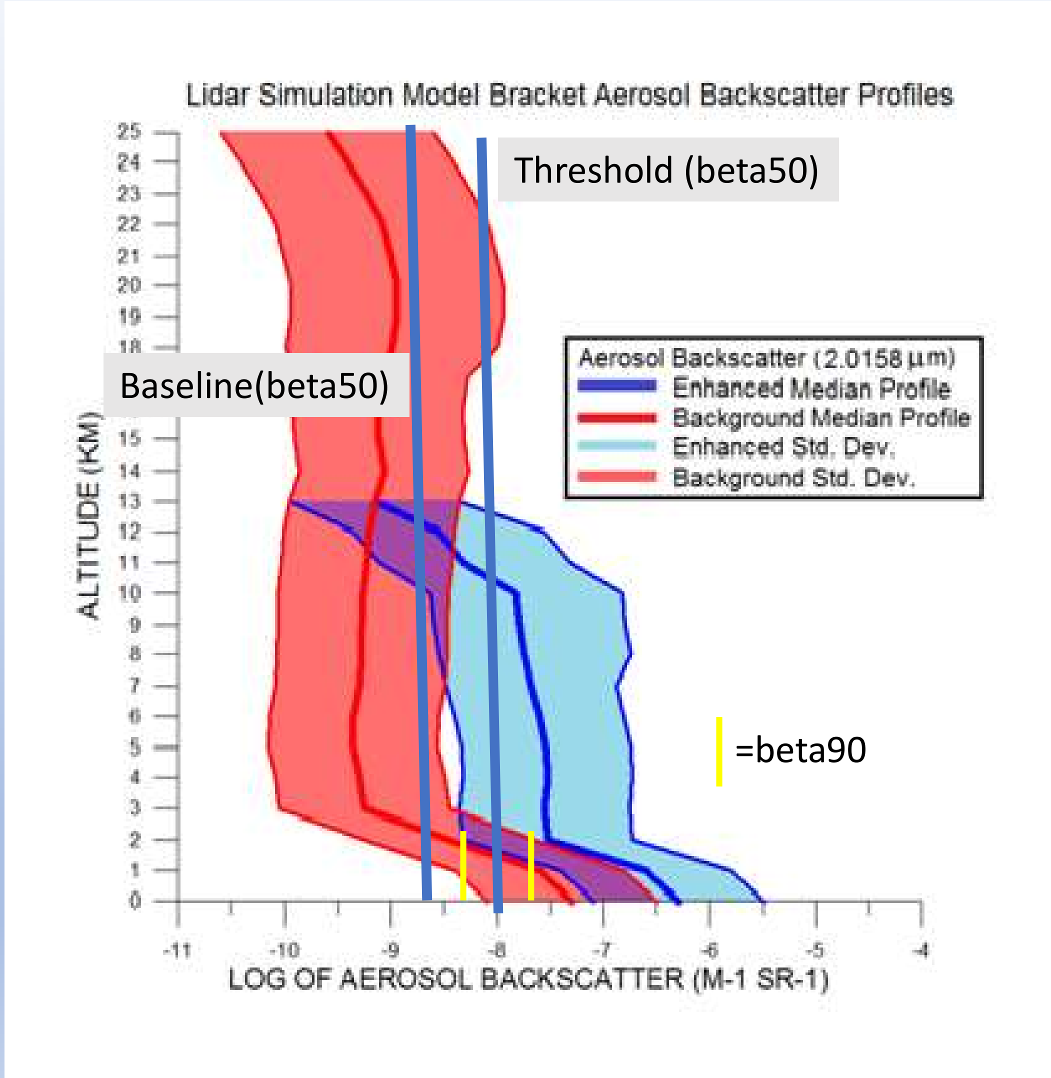
Background on “target” atmospheres

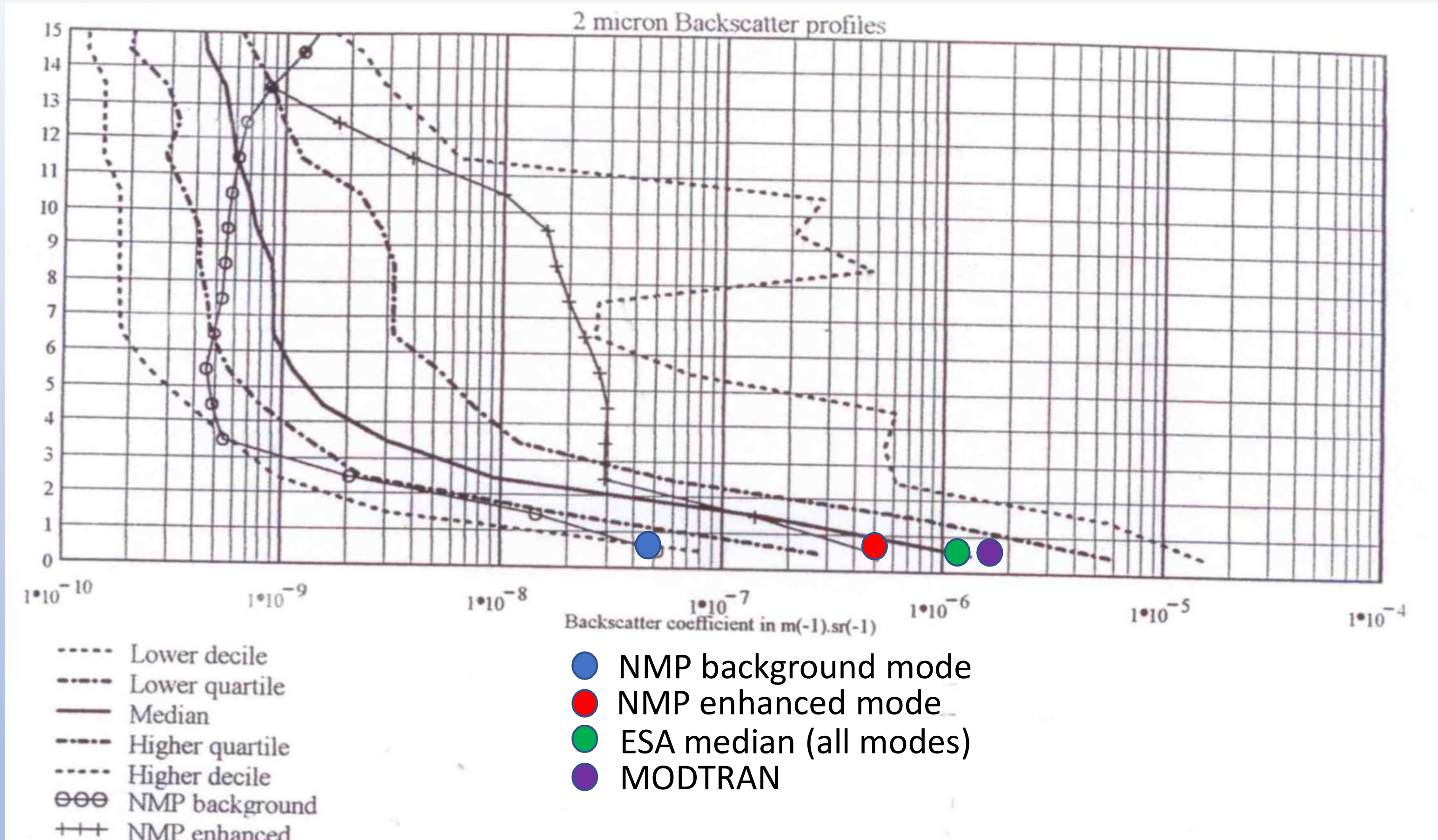
- Developed in 1997 for use in trade studies and comparisons of DWLs operating at differing wavelengths.

- Co-authored by Emmitt, Spinhirne, Menzies, Winker and Bowdle

- Underwent several revisions as new data with 2 um, 1.06 um and 0.532 um observations became available.

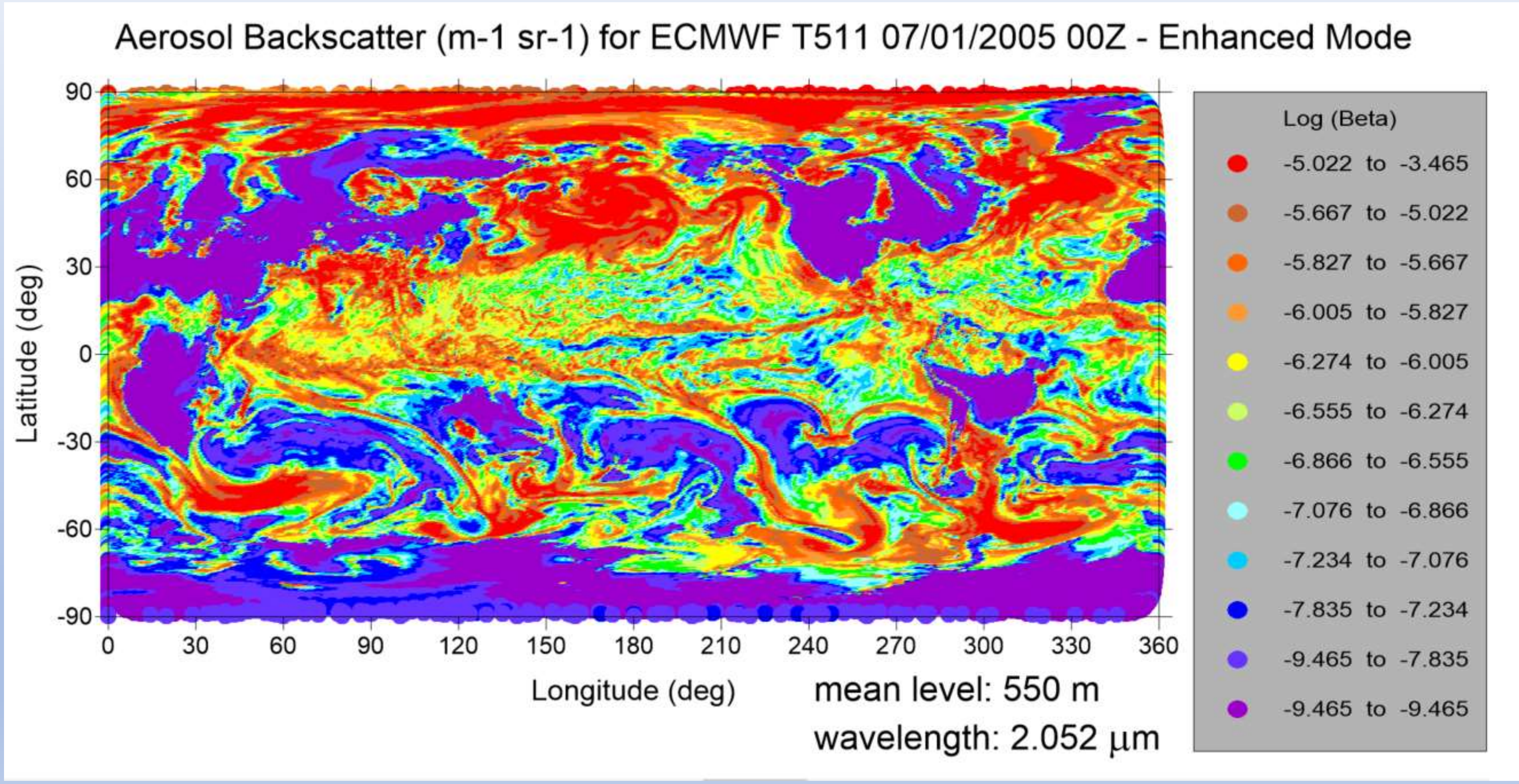
- Published on www.swa.com

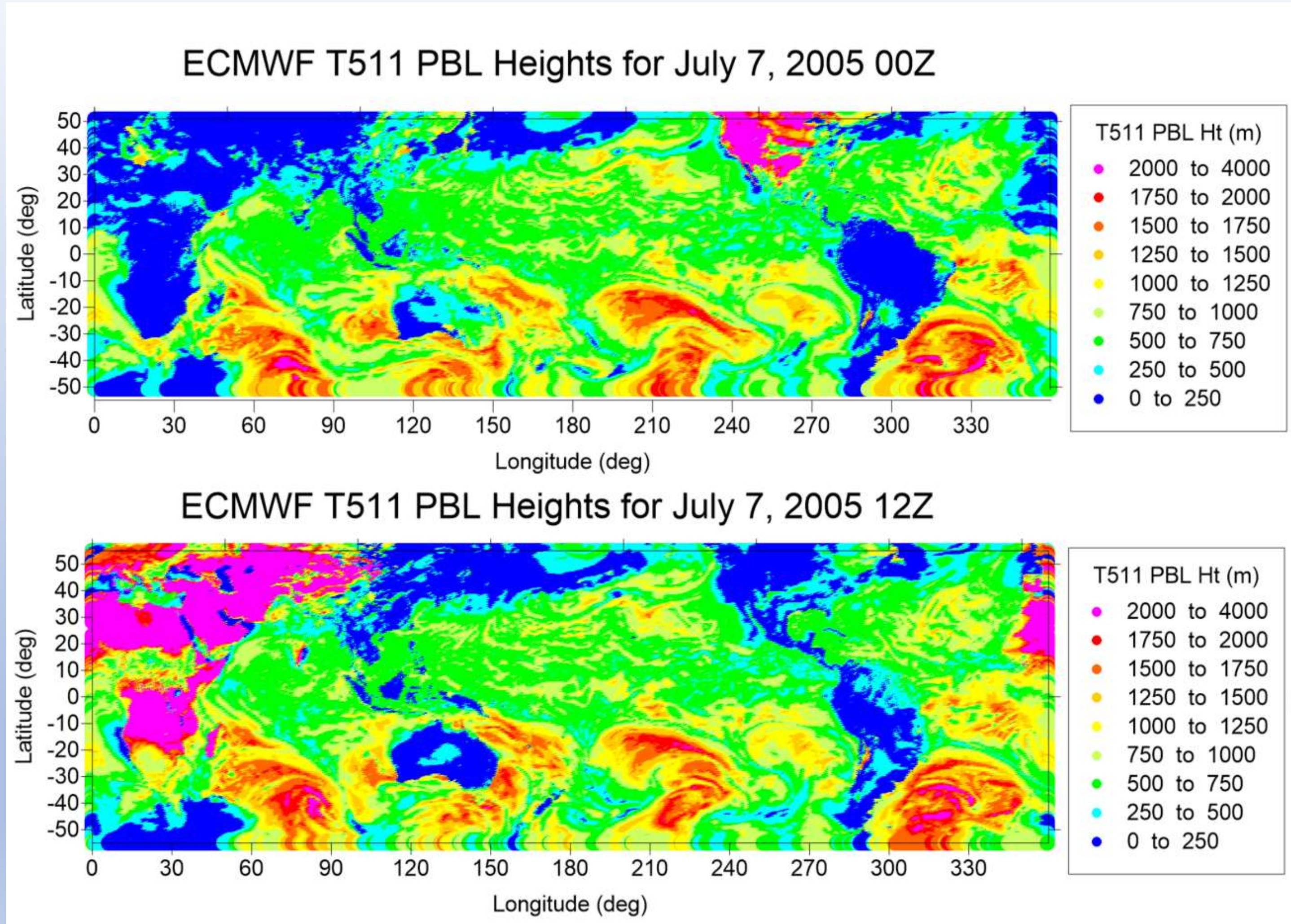

Lidar Simulation Model Bracket Aerosol Backscatter Profiles
Threshold (beta50)
Baseline(beta50)
Aerosol Backscatter (2.0158 µm)
Enhanced Median Profile
Background Median Profile
Enhanced Std. Dev.
Background Std. Dev.
=beta90
ALTITUDE (KM)
LOG OF AEROSOL BACKSCATTER (M-1 SR-1)



Graph taken from: “Establishment of a backscatter coefficient and atmospheric database” DERA/EL/ISET/CR980139/1.0

Global Aerosol Backscatter using Relative Humidity for Scaled Spatial Coherence

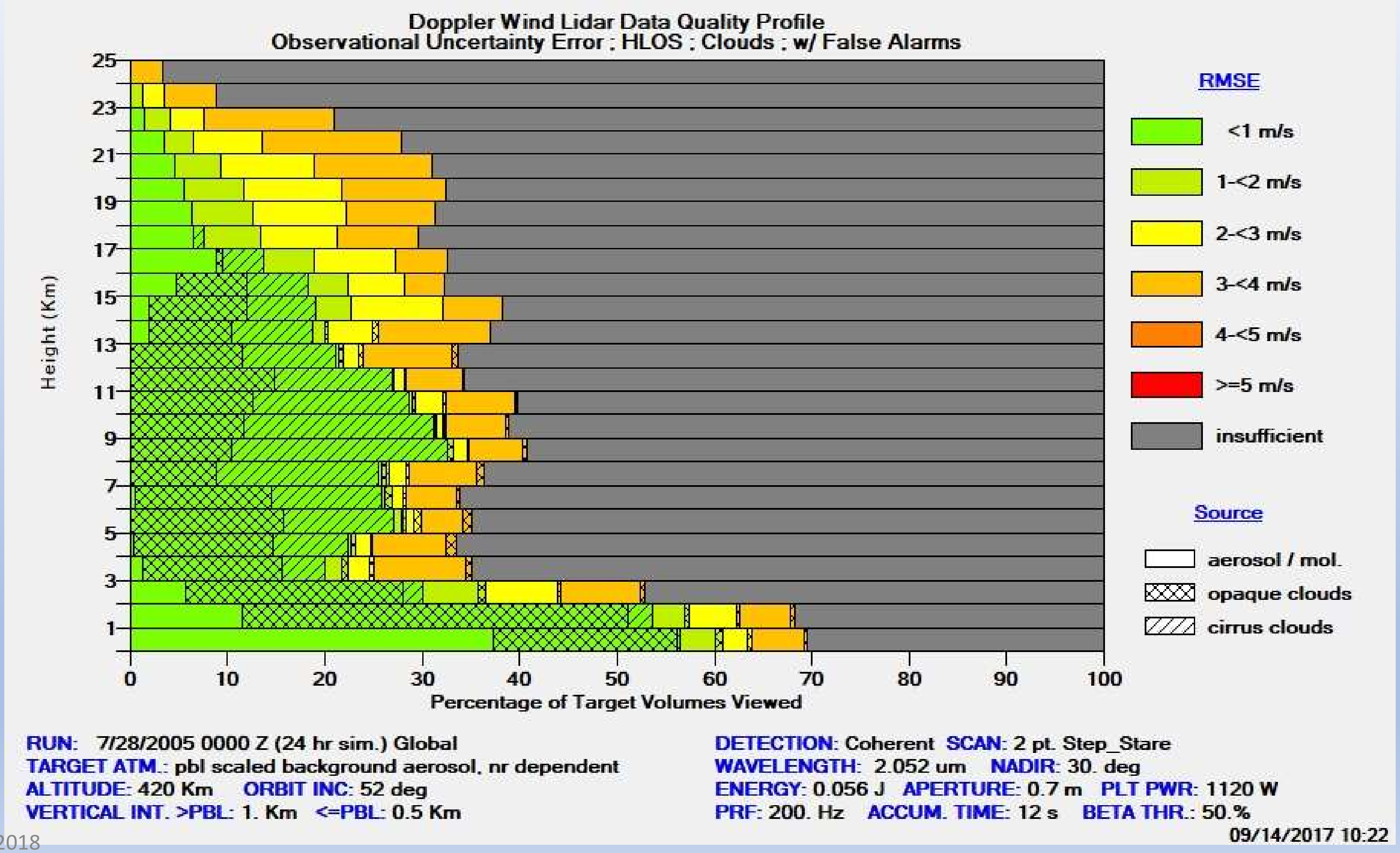



ECMWF T511 PBL Heights for July 7, 2005 00Z
Latitude (deg)
Longitude (deg)
T511 PBL Ht (m)
2000 to 4000
1750 to 2000
1500 to 1750
1250 to 1500
1000 to 1250
750 to 1000
500 to 750
250 to 500
0 to 250
ECMWF T511 PBL Heights for July 7, 2005 12Z
Latitude (deg)
Longitude (deg)
T511 PBL Ht (m)
2000 to 4000
1750 to 2000
1500 to 1750
1250 to 1500
1000 to 1250
750 to 1000
500 to 750
250 to 500
0 to 250

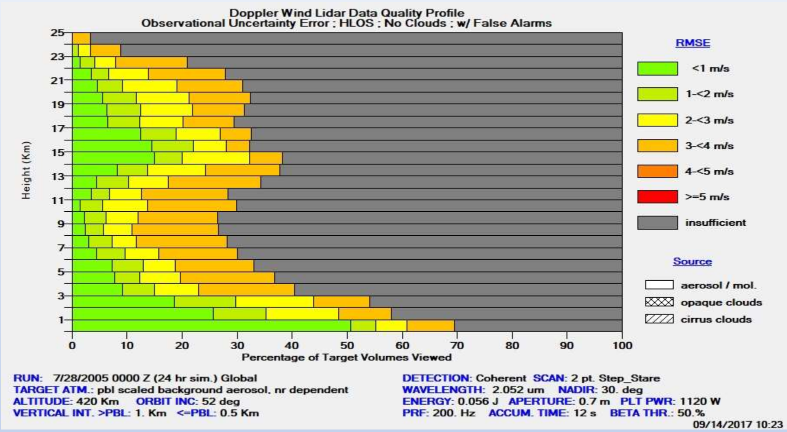
Backscatter modes

- Simulations (baseline and threshold instrument)
  - Background mode (NMP)
    - 12s WINDSP
      - Cloud and cloud free
    - 1.4s WINDSP
      - Cloud and cloud free
  - Enhanced mode (NMP)
    - 12s WINDSP
      - Cloud and cloud free
    - 1.4s WINDSP
      - Cloud and cloud free
  - Composite background mode (NMP, ESA, MODTRAN, CALIPSO)
    - 12s WINDSP
      - Cloud and cloud free
    - 1.4s WINDSP
      - Cloud and cloud free

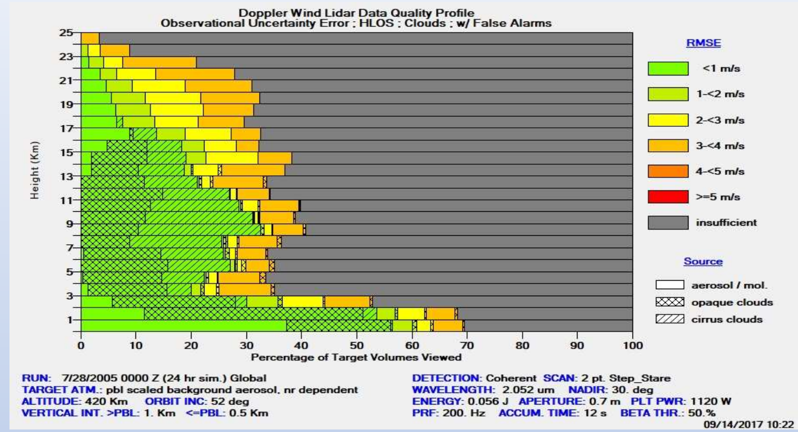
SPACE-BASE DWL PERFORMANCE PROFILES

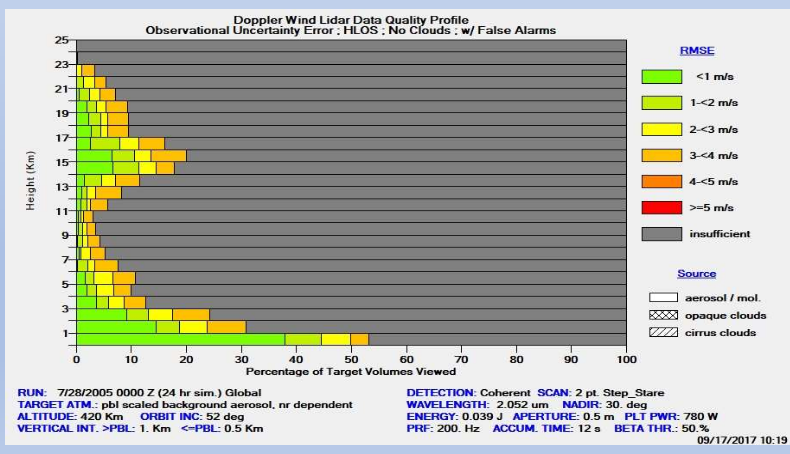


Composite background, 12S (design maximum ~80km dwell)

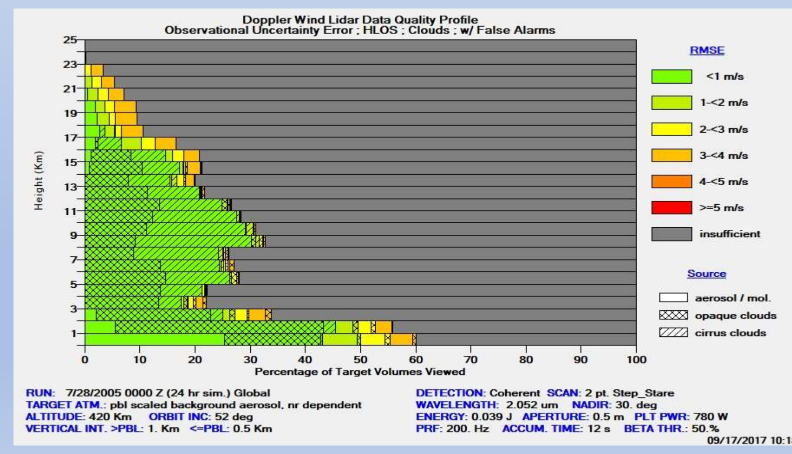


Baseline



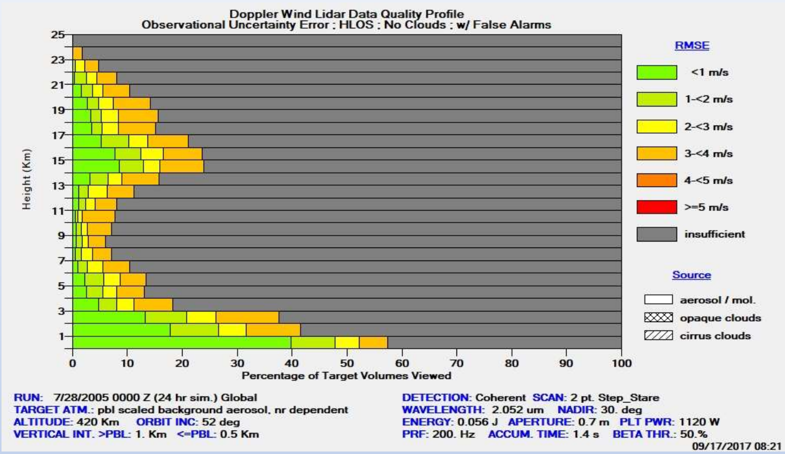


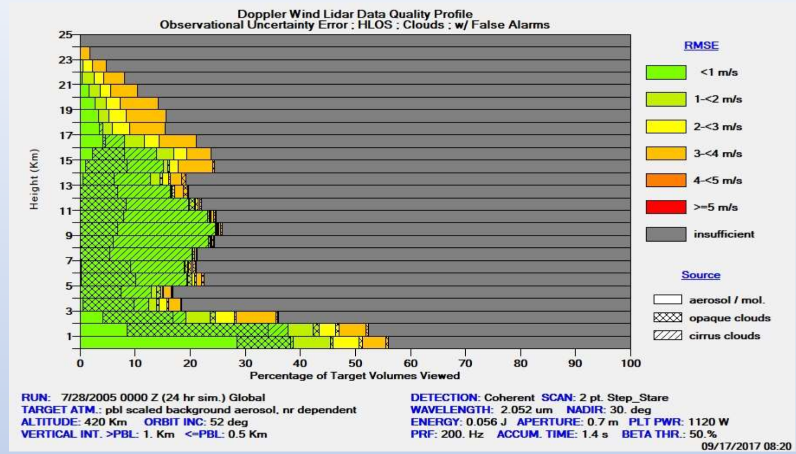
Threshold



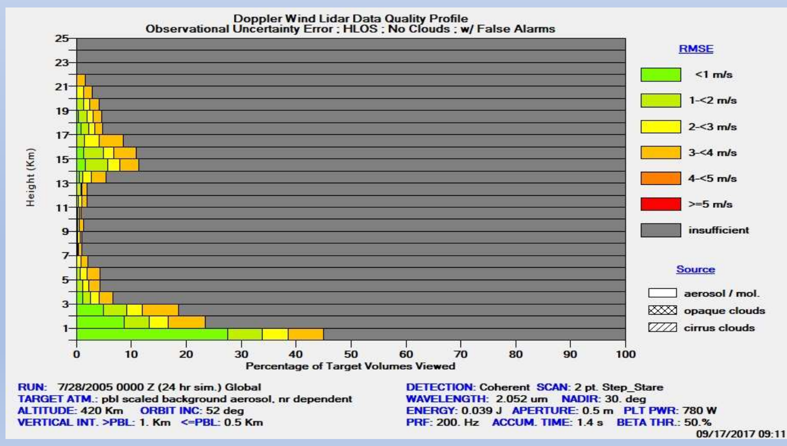
Composite background, 1.4 S (10 km cloud gap case)

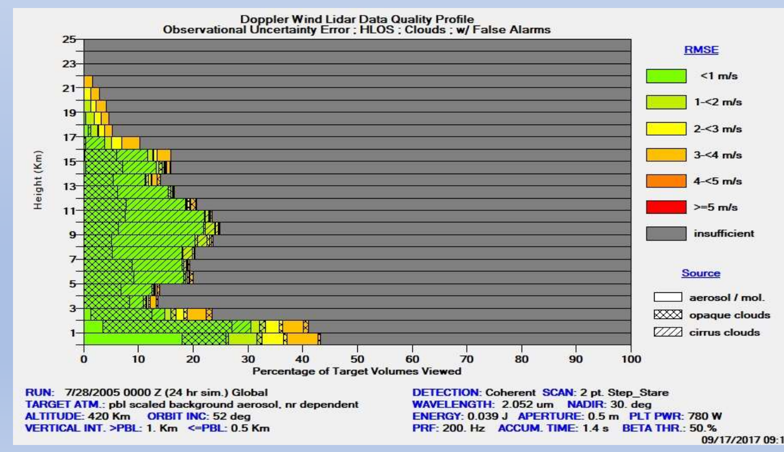
Baseline



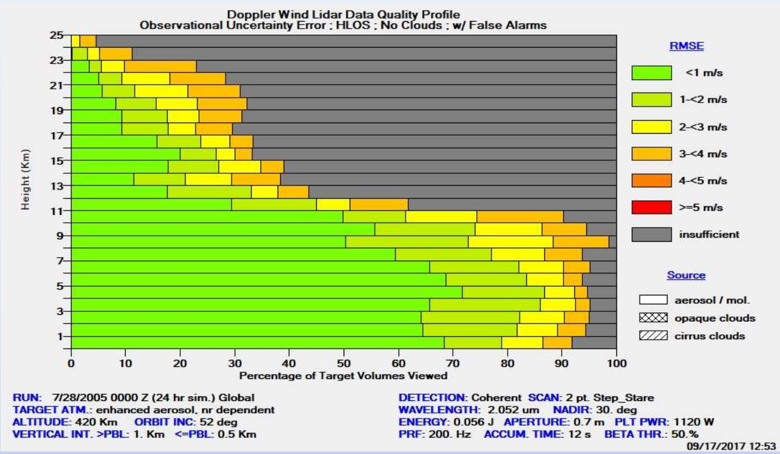


Threshold

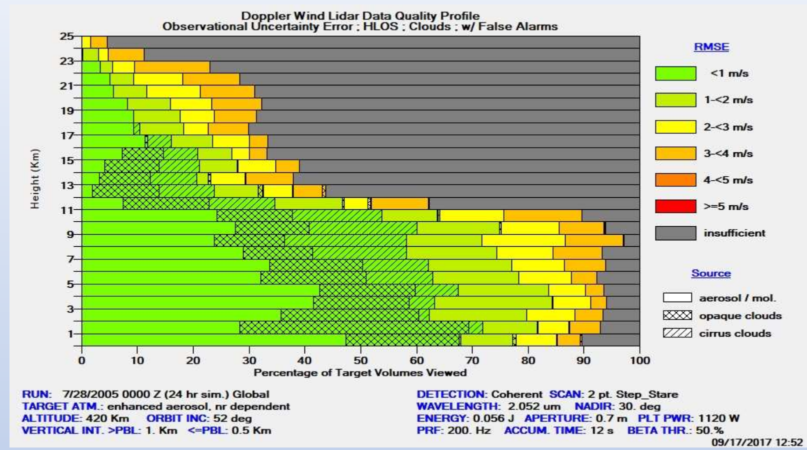


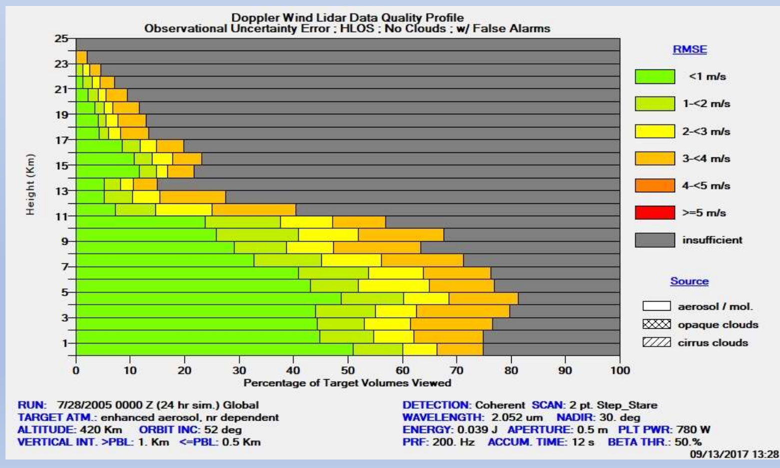


Enhanced, 12S

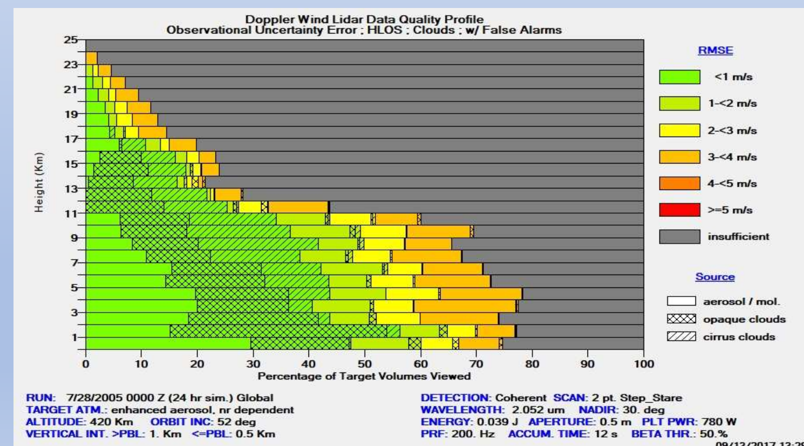


Baseline





Threshold



Summary (1)

- Ongoing work at NASA/LaRC by the Engineering Directorate, contractors (BP, SWA and DA) and managed by the Science Directorate.
- Subset of science experiments/objectives
  - Investigate inter-hemispherical transports via LLJs and through tropical convergence zones (ITCZ); How prevalent are LLJs over the oceans?
  - Develop improved parameterization schemes for PBL depths and growth rates for use in global weather and climate models…especially marine BLs.
  - Investigate the role of vertical shear of the horizontal wind in regions of deep convection and in tropical cyclone maintenance and suppression.
  - Investigate dynamic impacts such as speed and directional shear on the global trans-oceanic transport of pollution.

Summary (2)

- Pathfinder mission employing coherent DWL designed to:
  - Investigate two look vs single look comparisons for a range of atmospheric conditions
    - Cloud cover
    - Wind variability (including vertical shear)
  - Validate global attenuated backscatter distributions used to design WINDSP and establish coverage expectations, especially over oceans
  - Validate end-to-end LOS engineering models
  - Establish cloud gap statistics unique to bi perspective sampling.
  - **Develop techniques for taking advantage of synergisms between the DWL and scatterometers (ASCAT), CYGNSS, AMVs and other wind observing systems such as ACARS, rawindsondes, buoys, etc.**