# Simulating Observations for use in Observing System Simulation Experiments

G. D. Emmitt
Simpson Weather Associates
Charlottesville, Va.

IS&T Colloquium
April 11, 2012

# Outline

- Description of the OSSE
- Description of the DLSM
  - Use with Nature Run (NR)
  - Errors
- Examples of the data products
  - Performance profiles
  - GWOS and WISSCR evaluations
- Challenges for future OSSE
  - New nature runs
  - Costs to prepare for OSSE
    - Assessing the realism of the NR
    - Simulating observations
      - Use ideal competition
      - Bracketing
  - Impact metrics
- Number of slides: 72

# Observing System Simulation Experiments

# Basic OSSE definition

- Model based experiments designed to test hypothesized impacts of future observing systems on numerical weather prediction (NWP).

# OSSE Objectives (1)

- Provide quantitative basis for defining the optimal mix of atmospheric observations for NWP
  - Assess potential analyses/forecast impacts of new observing systems under consideration for deployment
  - Provide feedback to the instrument developers including rationale for de-scoping

# OSSE Objectives (2)

- Accelerate transition of observations from newly developed instruments to operational use
  - Enables the forecast centers to develop data processing and assimilation software prior to the launch of the new instrument
  - Provide the operational community early insight to synergisms with other instruments

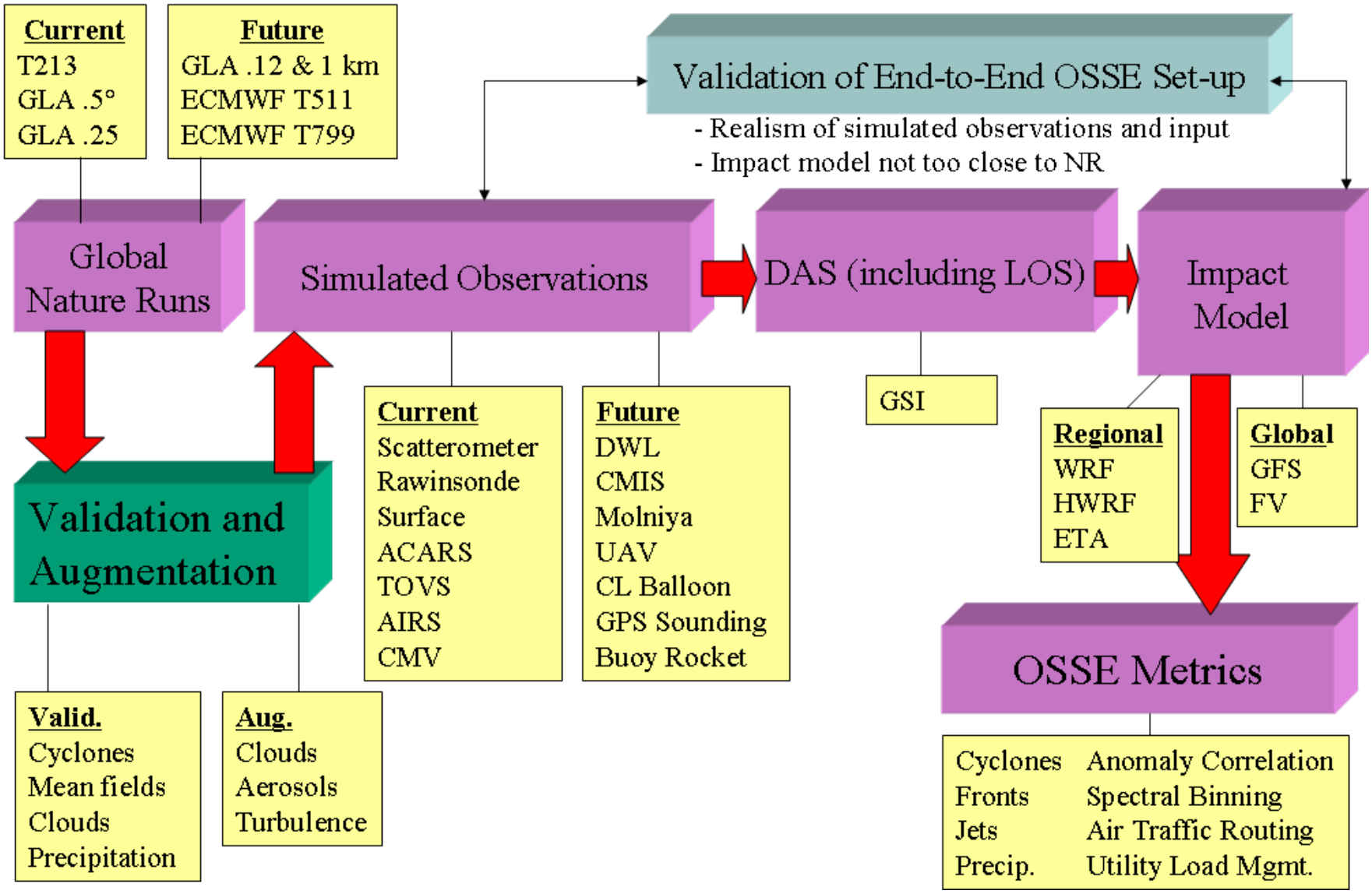
# Definitions & Hierarchy

- Observing System Simulation Experiment (OSSE)
- Observing System Experiment (OSE)
- OSSE-Like Experiments
  - Partial OSSES (POSSEs)
  - Quick OSSEs (QOSSEs)
  - Rapid Observing System Simulation Experiments (ROSSEs)
  - Simple OSSEs (SOSSEs)

# OSSE Rules

- Proposed by Kalney, Halem and Atlas (1986)
- Fraternal Twin vs. Identical Twin models
- Realism checks
- Calibration checks
- Simulation of existing sensors
  - RAOBs, ACARS, AIRS, ASCATT, CMV,…
- Simulation of imagined sensors

# OSSE TESTBED COMPONENTS



# Simulating Doppler Wind Lidar Observations for Use in OSSEs and Technology Trade Studies

# Overview

- General discussion of the Doppler Lidar Simulation Model (DLSM) www.swa.com/ald/DLSM4.2/index.htm
- Use of DLSM in SIVO's Sensor Web Simulator (includes video of adaptive targeting)
- Calibration of DLSM using GLAS and CALIPSO data
- Simulating ADM, GWOS and WISSCR

# Background

- Simulating Doppler Wind Lidar(DWL) data for use in OSSEs began in 1989 (Emmitt and Wood).
  - Used Nature Run T106 Nature Run to conduct first series of NWP impact studies.
  - Followed with T213, MM5, GEOS (25km) and now T511 and T799.
- Simulating Cloud Motion Vectors (CMV) began in 2003 (O'Handley, Emmitt and Greco) using Nature Run clouds.
- Simulation of scatterometer Ocean Vector Winds (OVW) for OSSEs.

# The Doppler Lidar Simulation Model

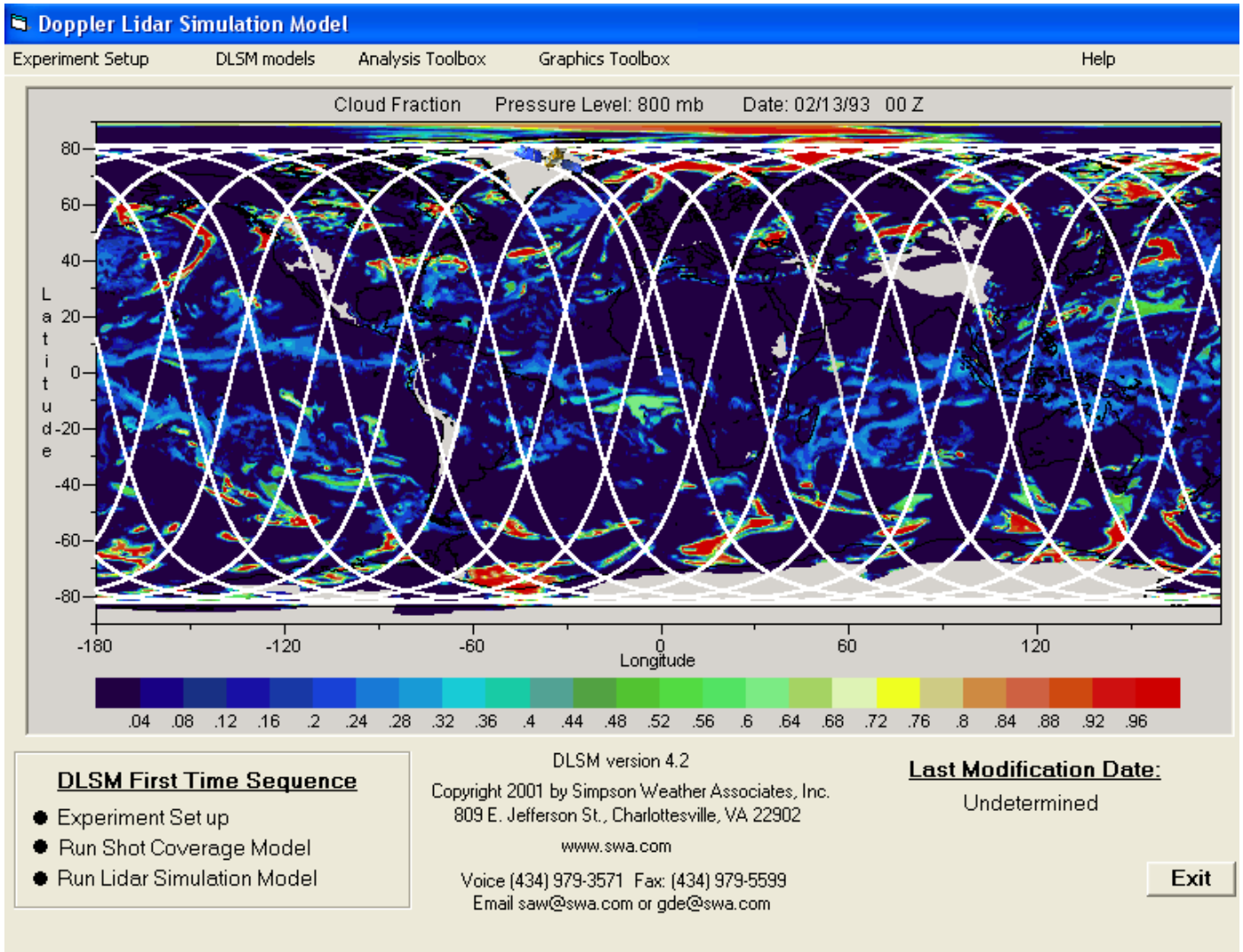
- Allows configuration of  mission including orbits, DWL instruments and data processing
- Allows choice of input Nature Runs and atmospheric optical properties
- Subgrid scale turbulence and cloud properties are dealt with in ways best suited for sampling with a <100m diameter beam.

# The DLSM

(Doppler Lidar Simulation Model)

- Used since 1988 to simulate DWL performance for OSSEs using inputs from Nature Runs.
  - Clouds
  - Subgrid scale wind variability
  - Aerosol distributions
- Simulate both direct and coherent detection
- Stress realistic characterization of random and systematic errors.

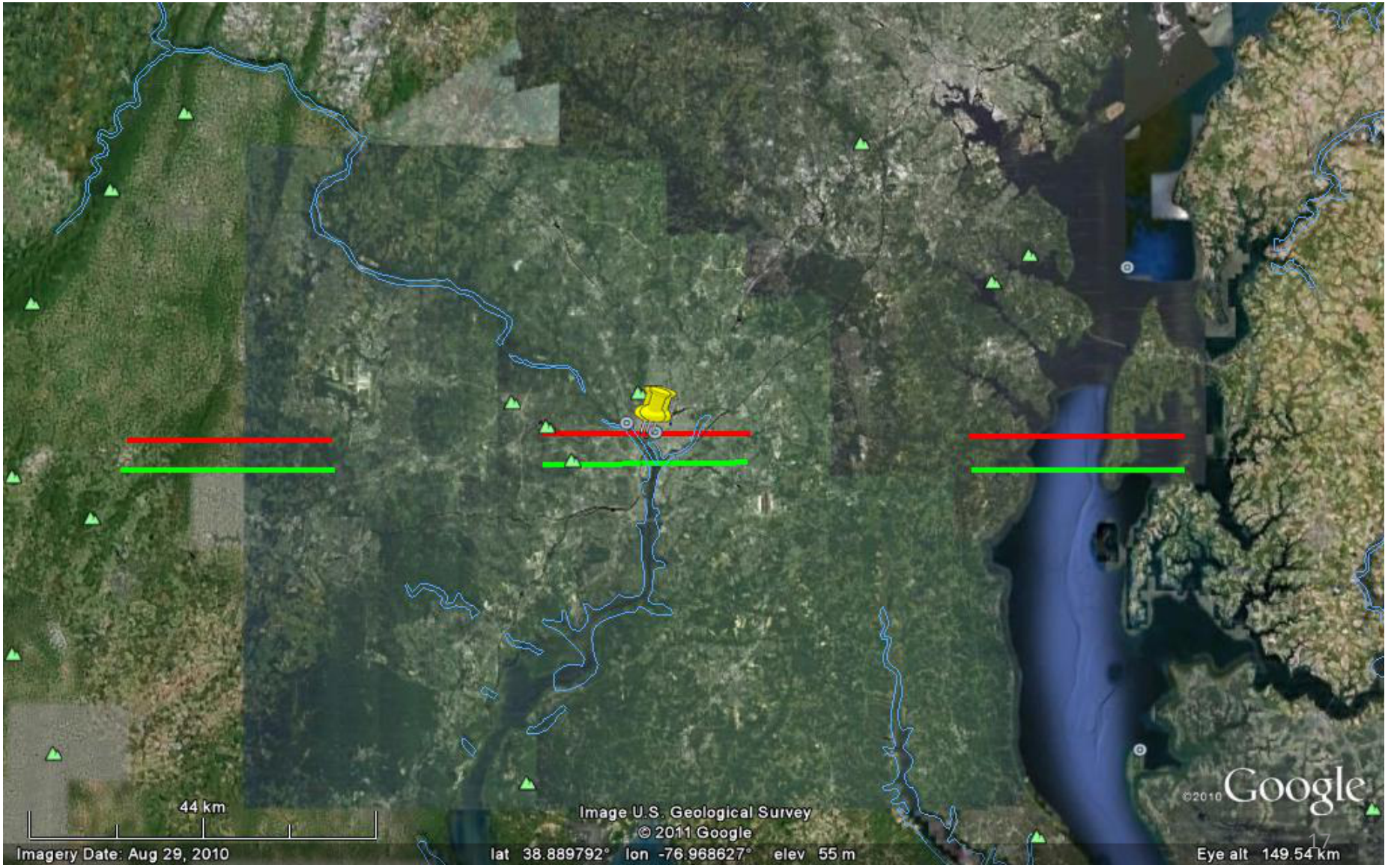
# Doppler Lidar Simulation Model



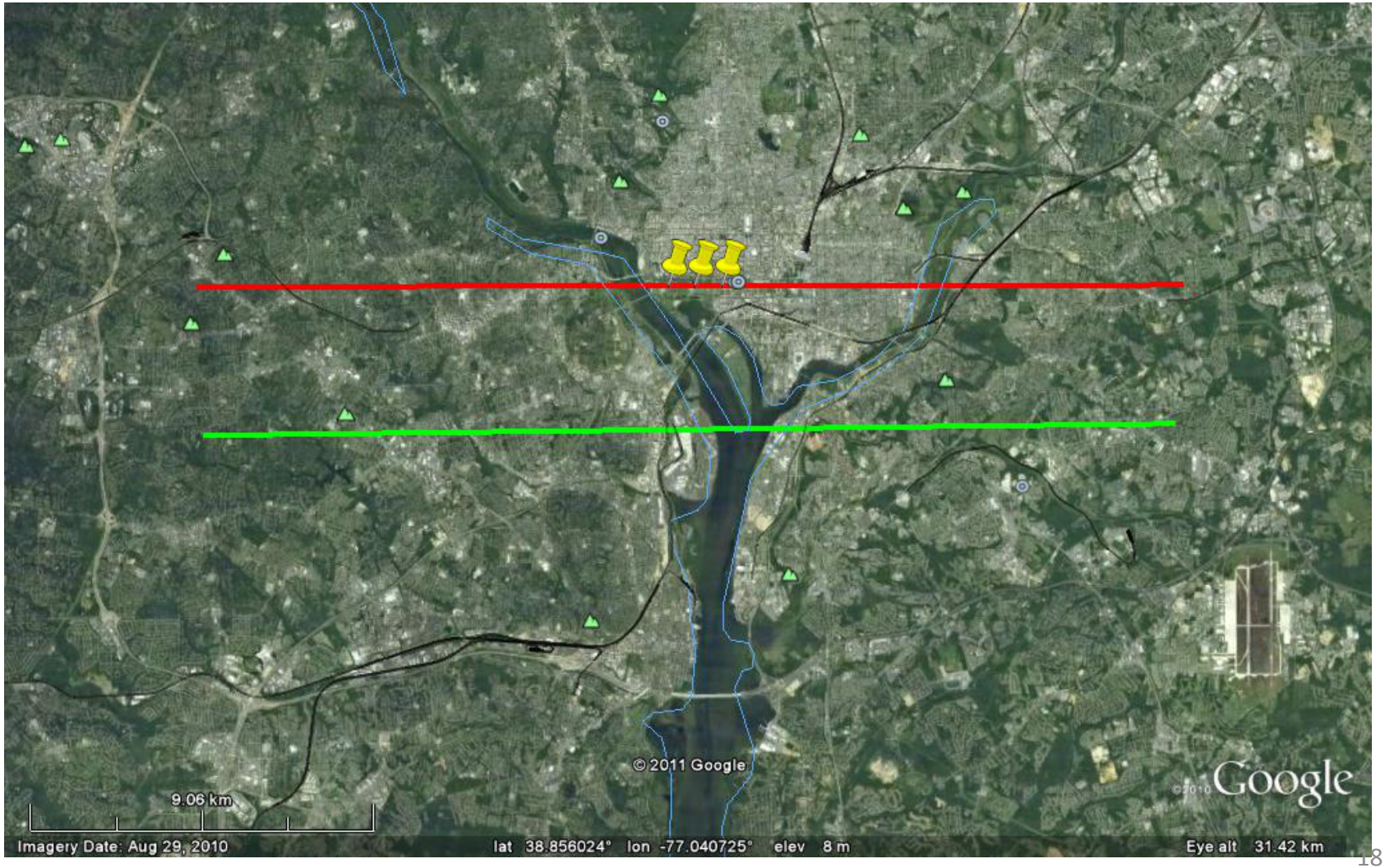
# The Sampling Pattern

- Illuminated volume
  - Coherent (250m long cylinder, ~ 2m diameter footprint)
    - Spectral domain processing provides information on turbulence intensity, BL depth, precipitation fall velocities
  - Direct (2000m long, ~ 50m diameter)
    - Accuracy  a function of intensity of return, presence of clouds/aerosols could be derived.
- Sampling pattern, a ground perspective
- Pattern over a hurricane

# 4 second dwell pattern for both direct and coherent (fore and aft perspectives)

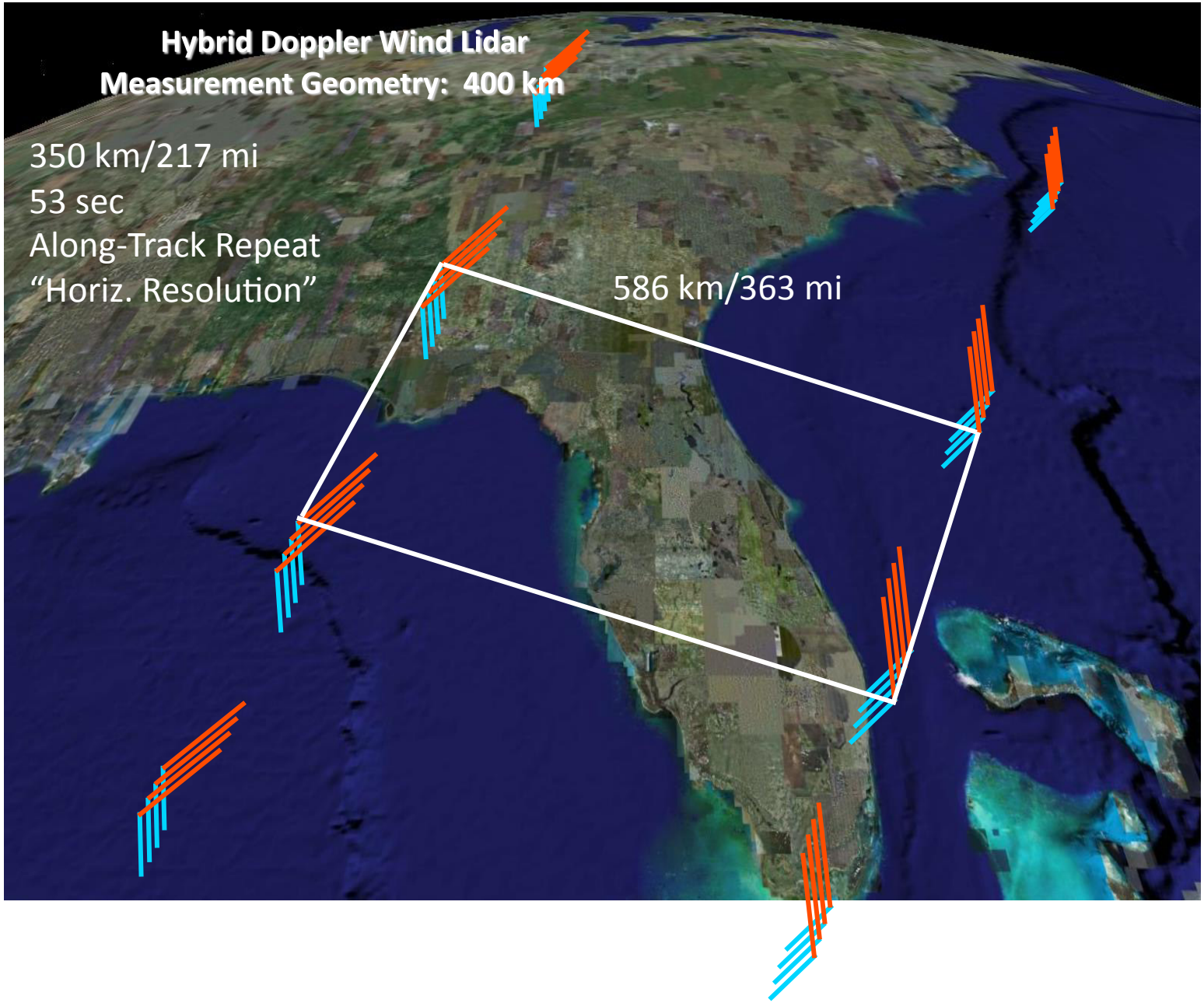


# 4 second dwell pattern (fore and aft sampling)



# Single shot coherent samples (~ 700meter intervals)

# GWOS Sampling

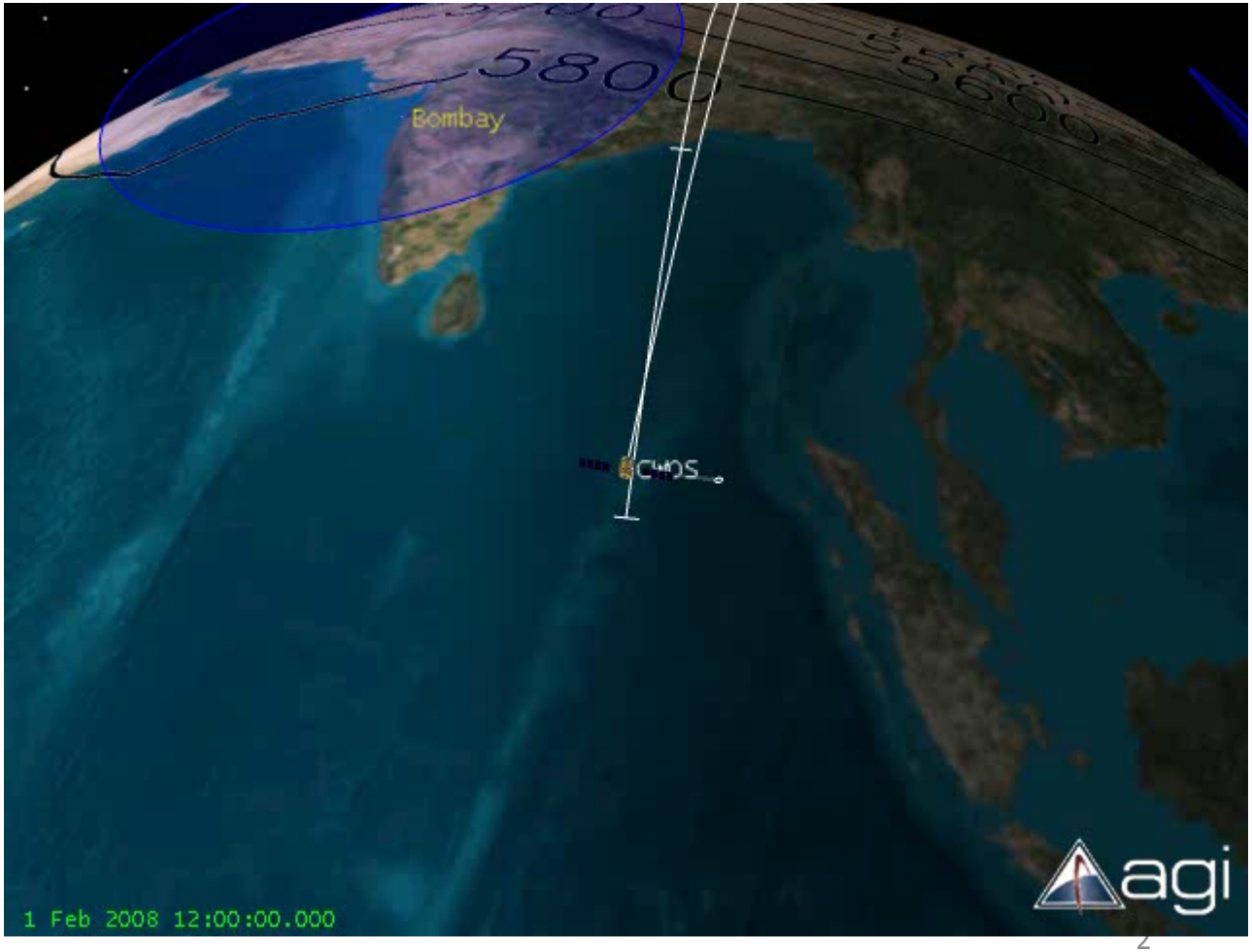


# Sensor Web Simulator (*)

A model-driven sensor web is an Earth observing system that uses information derived from data assimilation systems and numerical weather prediction models to drive targeted observations made from earth-orbiting spacecraft as well as from atmospheric- and ground-based observing systems.

* Developed at GSFC with funding from ESTO

CLIP



# Observation Errors

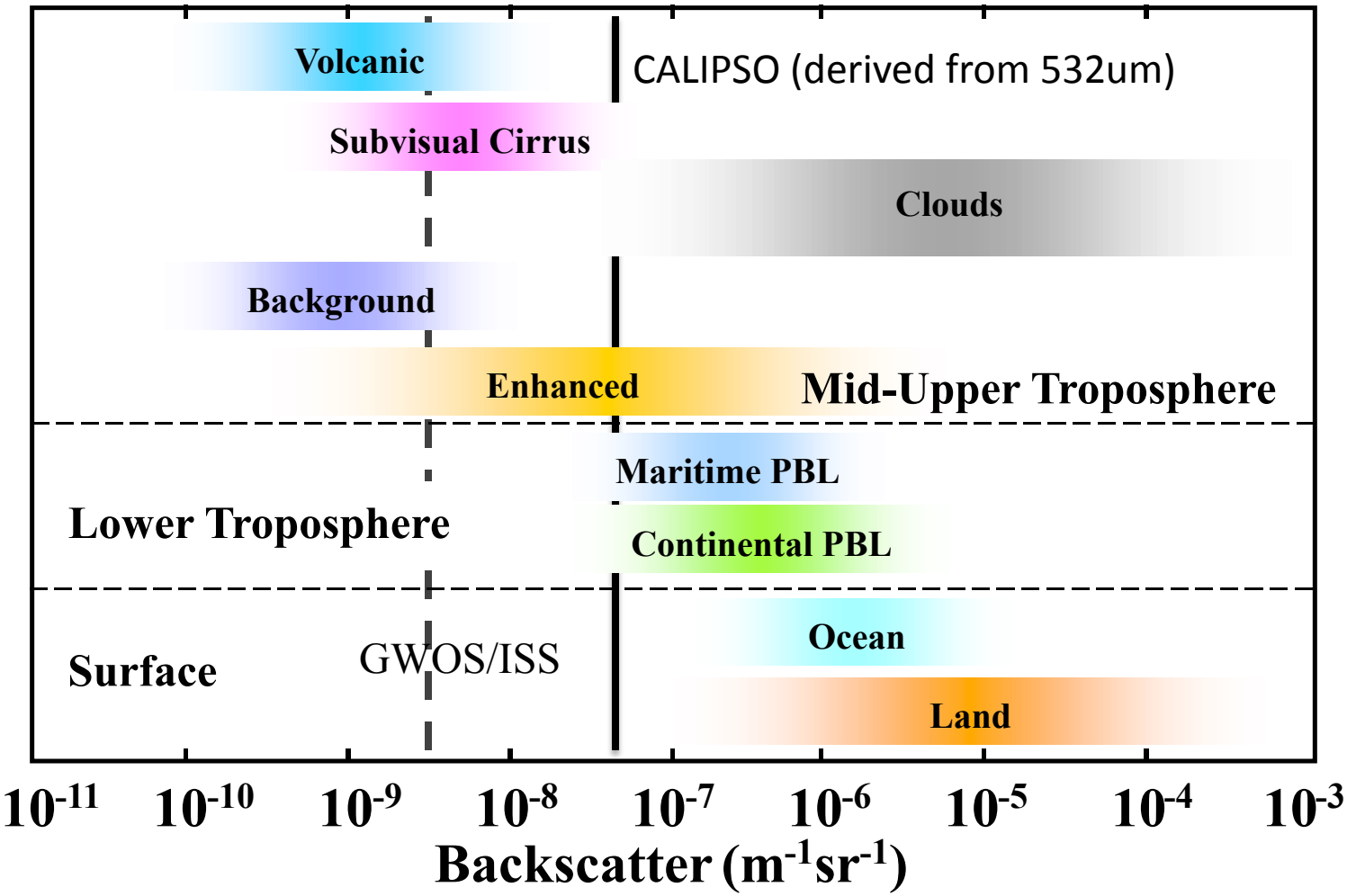
$$(\sigma_{obs})^2 = (\sigma_{meas})^2 + (\sigma_{sample})^2$$

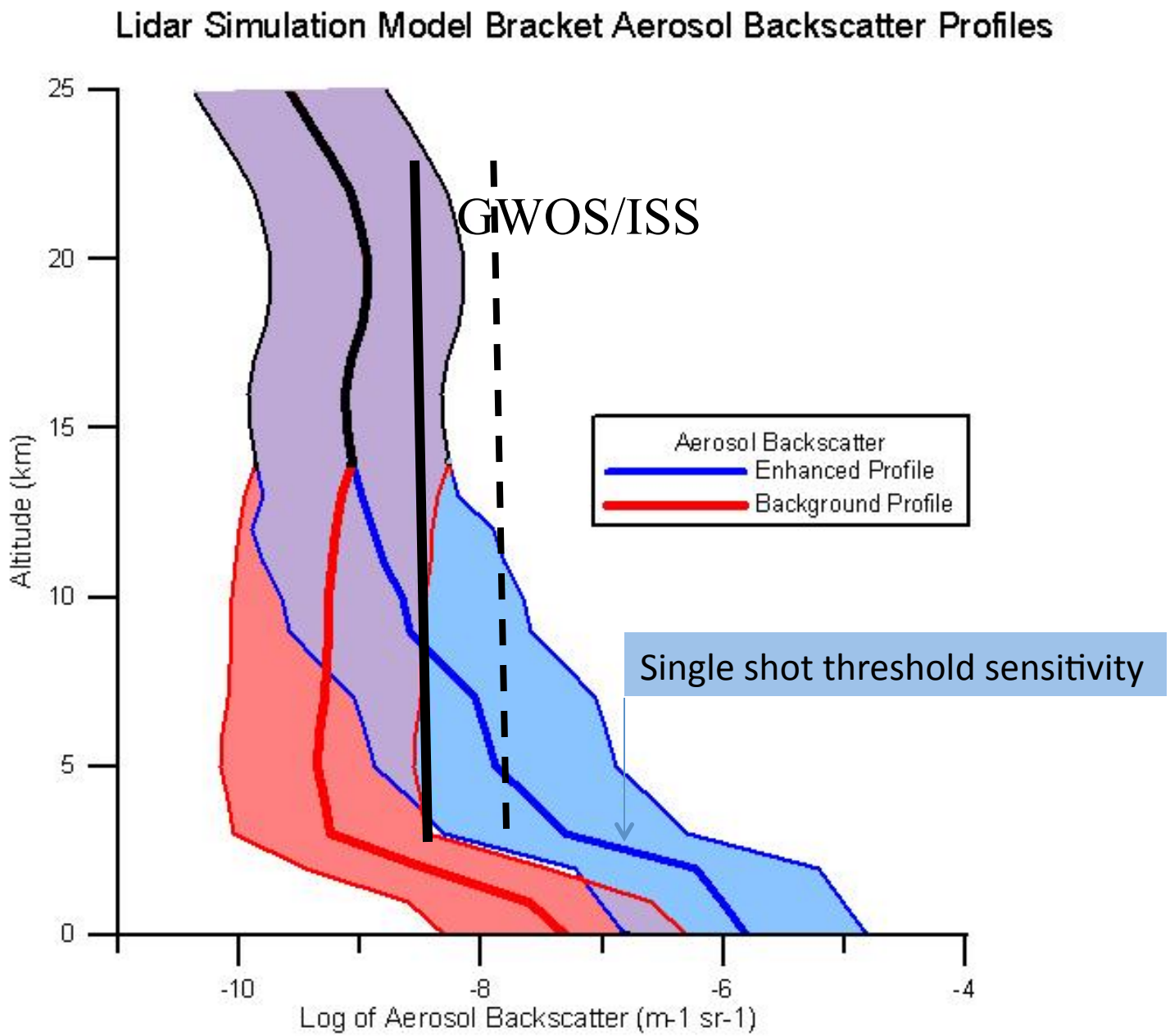
$\sigma_{obs}$ = Observation Error

$\sigma_{meas}$ = Measurement Error

$\sigma_{sample}$ = Sampling Error
(non-representativeness)

# Natural Variability of 2 μm Backscatter

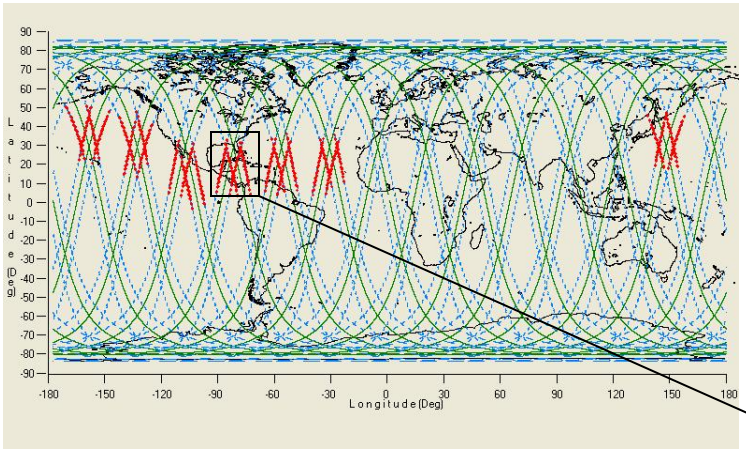



Lidar Simulation Model Bracket Aerosol Backscatter Profiles
GWOS/ISS
Aerosol Backscatter
Enhanced Profile
Background Profile
Single shot threshold sensitivity
Altitude (km)
25
20
15
10
5
0
-10
-8
-6
-4
Log of Aerosol Backscatter (m-1 sr-1)

# Recent DLSM simulations for use in OSSEs

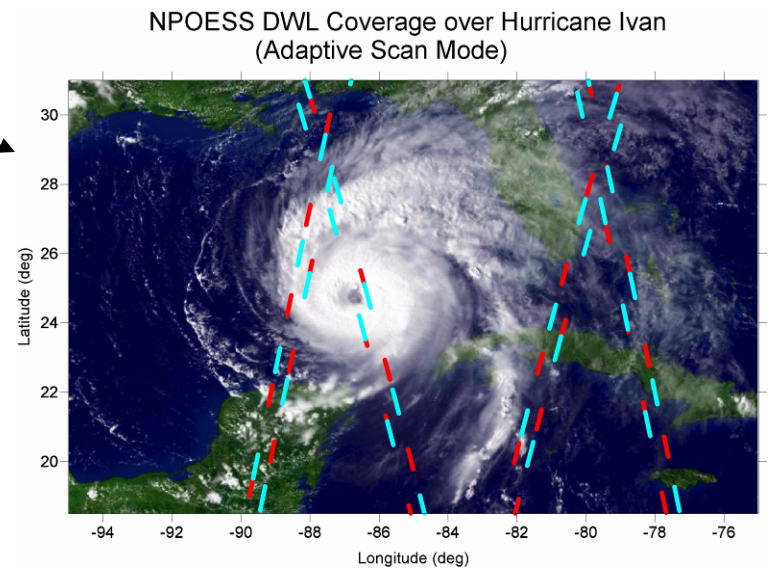
- Emphasis on the tropics.
- Scaling GWOS down to 350km for ISS
- Clouds in T511 Nature Run modified to conform to ISCCP coverage statistics; added subvisual cirrus
- Have been understating very thin to subvisual cirrus effects which  would be very positive for coherent detection coverage yet only slightly negative for direct detection accuracies.

# Adaptive Targeting

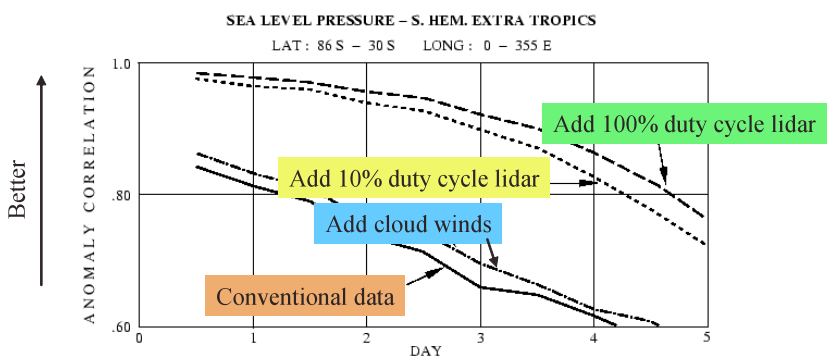



Adaptive targeting with emphasis on CONUS interests

( Blue is coherent coverage
Red is both coherent and direct)




## Adaptive Targeting Experiments




Model: GEOS-2 Recon.
Verification: ECMWF Nature Run

| | |
|---|---|
| Control: | - Conventional Data + Perfect TOVS |
| CTW | - Control + Cloud Tracked Winds |
| 1 m/s Wind | - Control + Doppler Wind Lidar (RMSE = 1 m/s) |
| Adaptive Targeting | - Control + Adaptive Targeting of DWL Observations (~10% duty cyde) |

Example of targeting a hurricane as it approaches the Gulf coast. (blue segments: forward looks; Red segments: aft looks; Blue plus red Provide full horizontal wind vector)

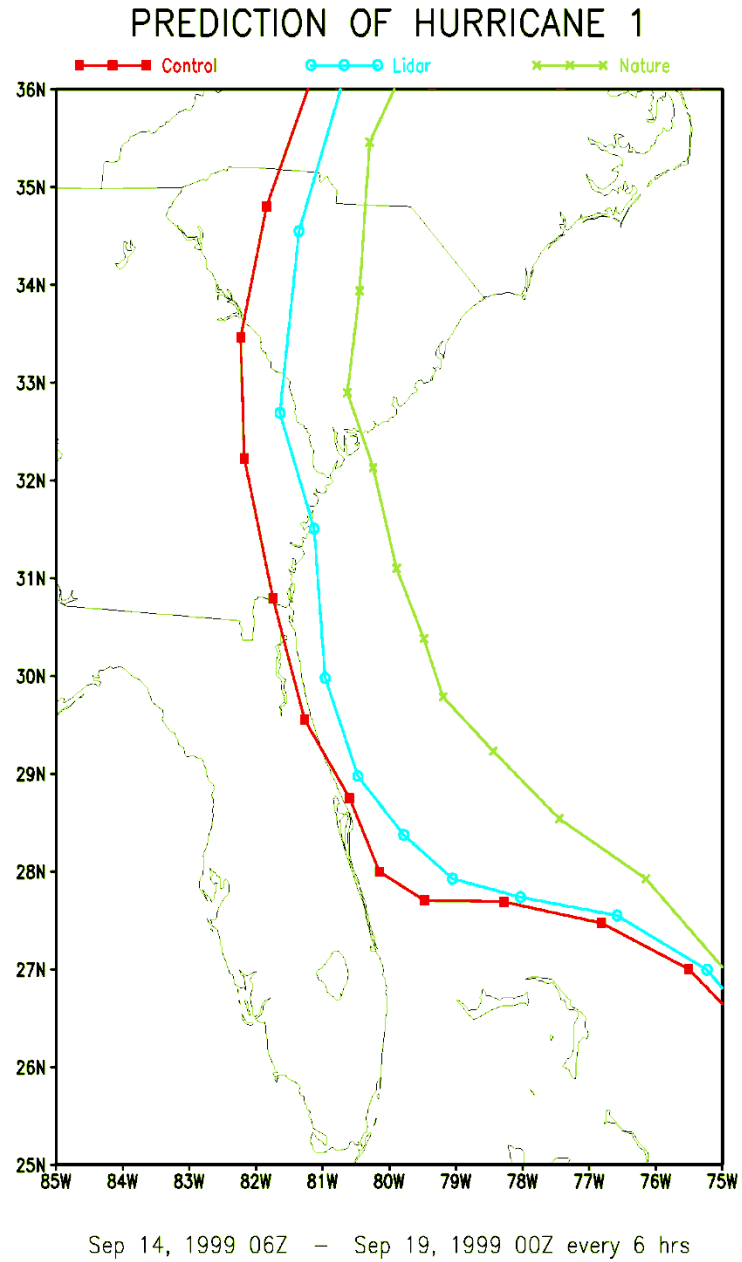
# DWLs greatly improve hurricane track predictions

Potential Impact of new space-based observations on Hurricane Track Prediction

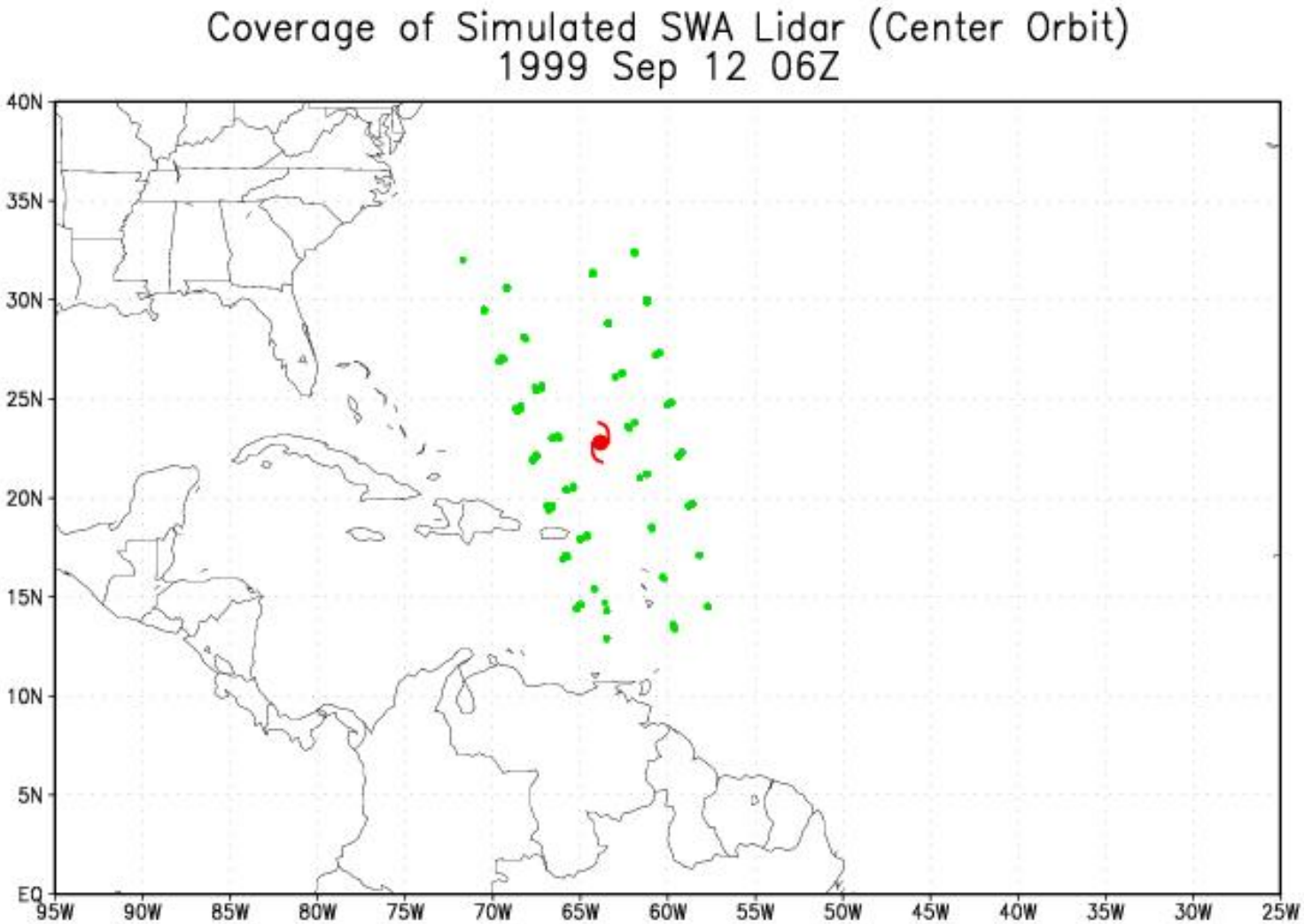
Based on OSSEs at NASA Laboratory for Atmospheres

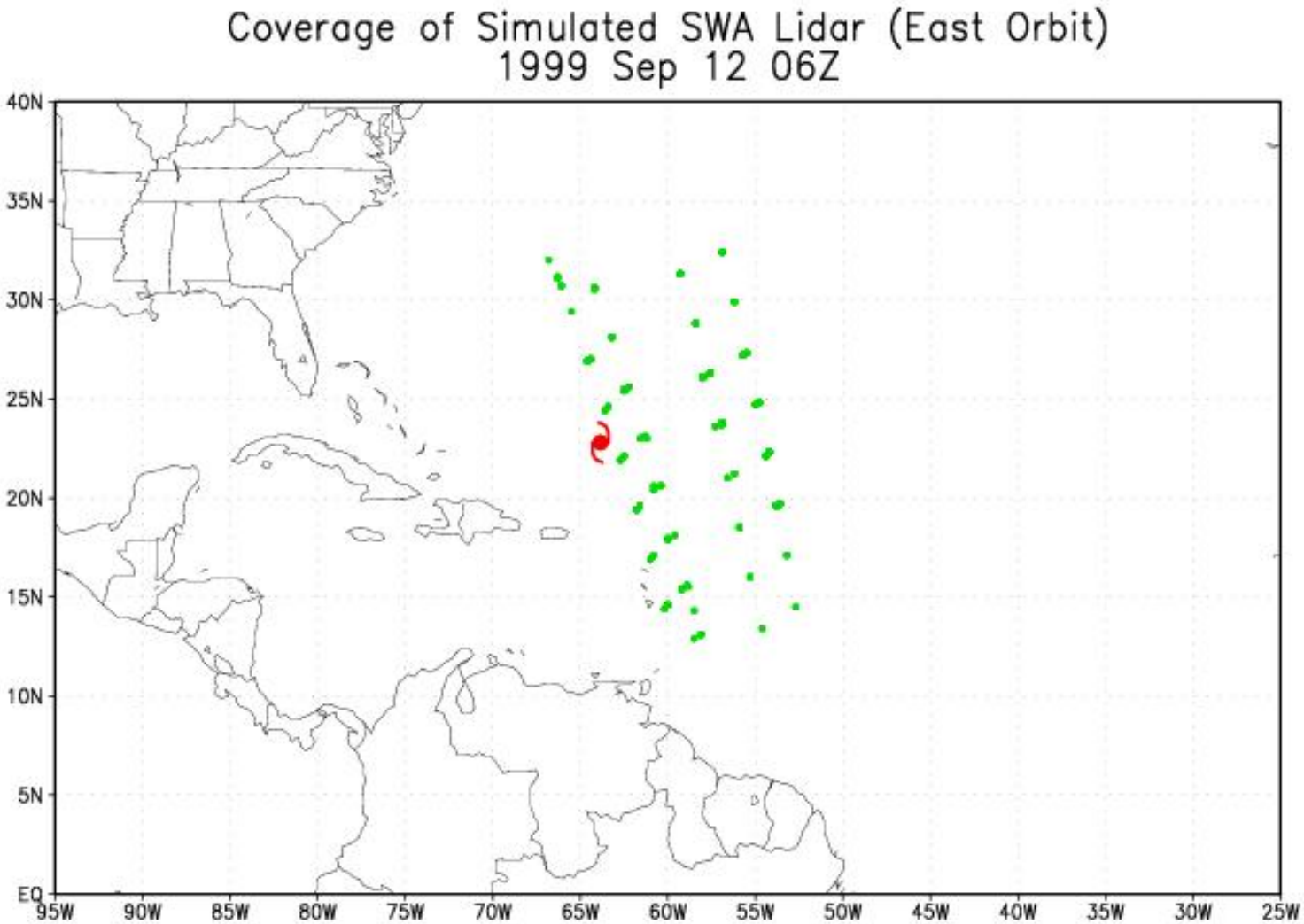
- Tracks
  - Green: actual track
  - Red: forecast beginning 63 hours before landfall with current data
  - Blue: improved forecast for same time period with simulated wind lidar

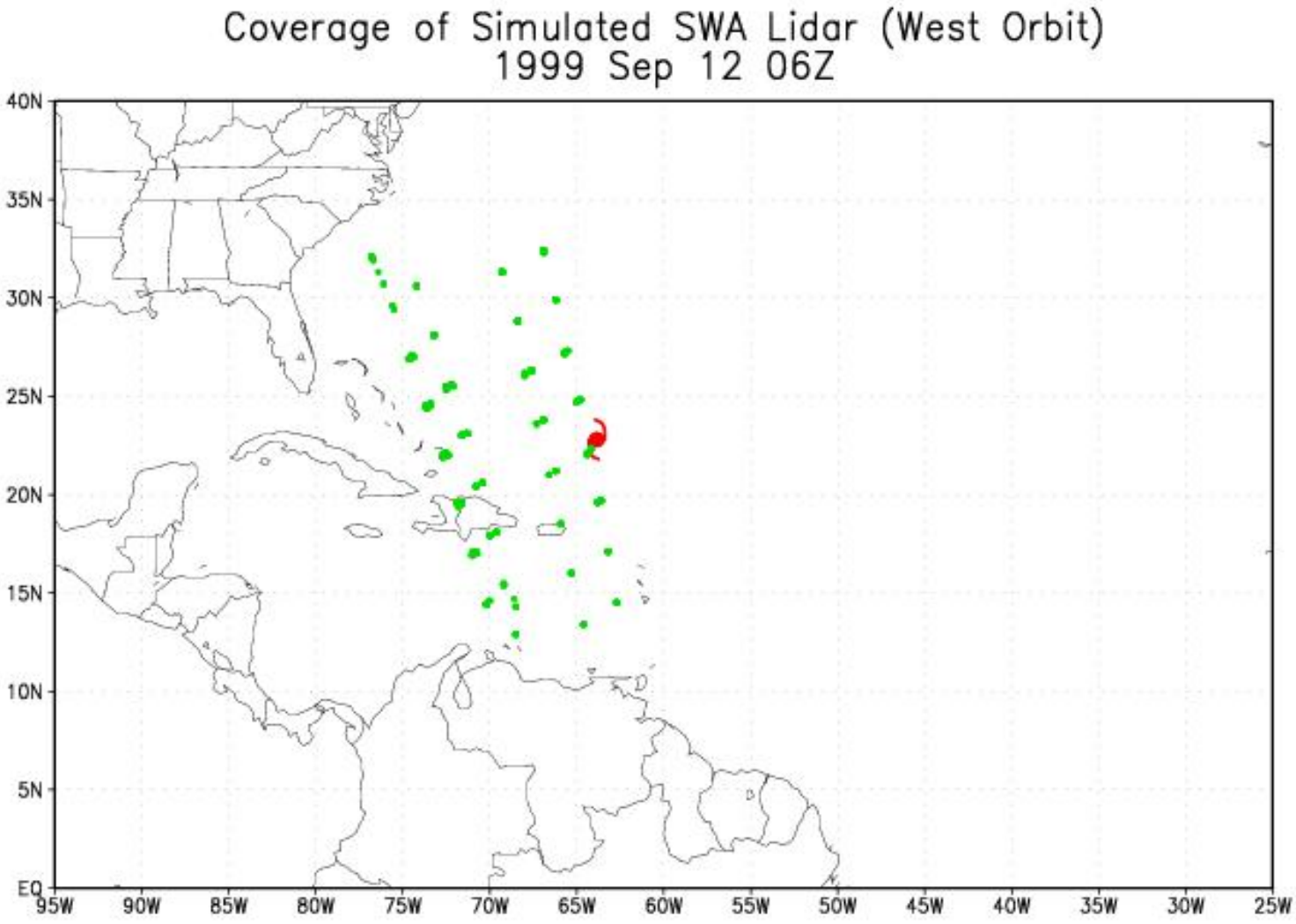
- Lidar in this one case
  - Reduces landfall prediction error by 66%

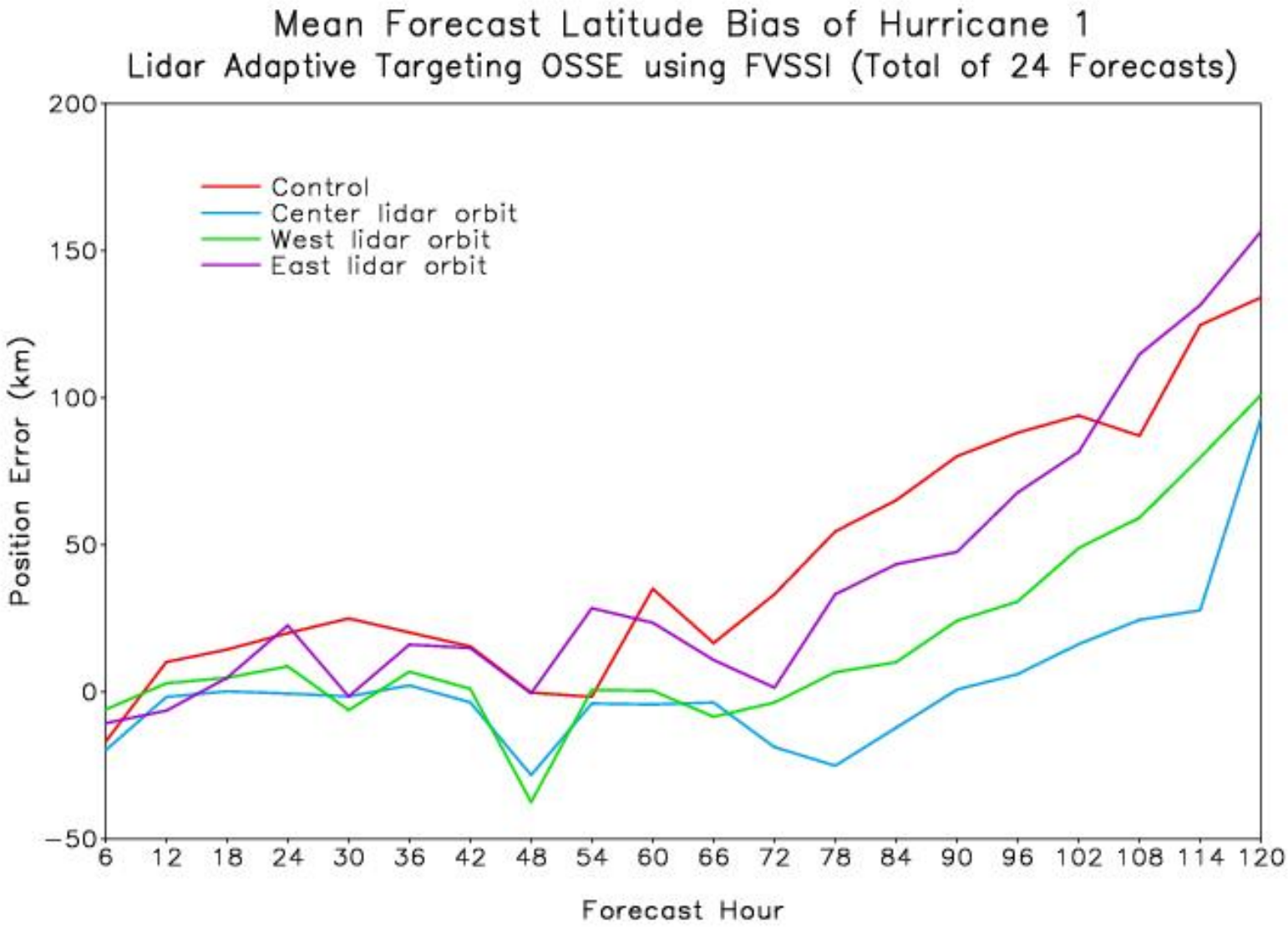


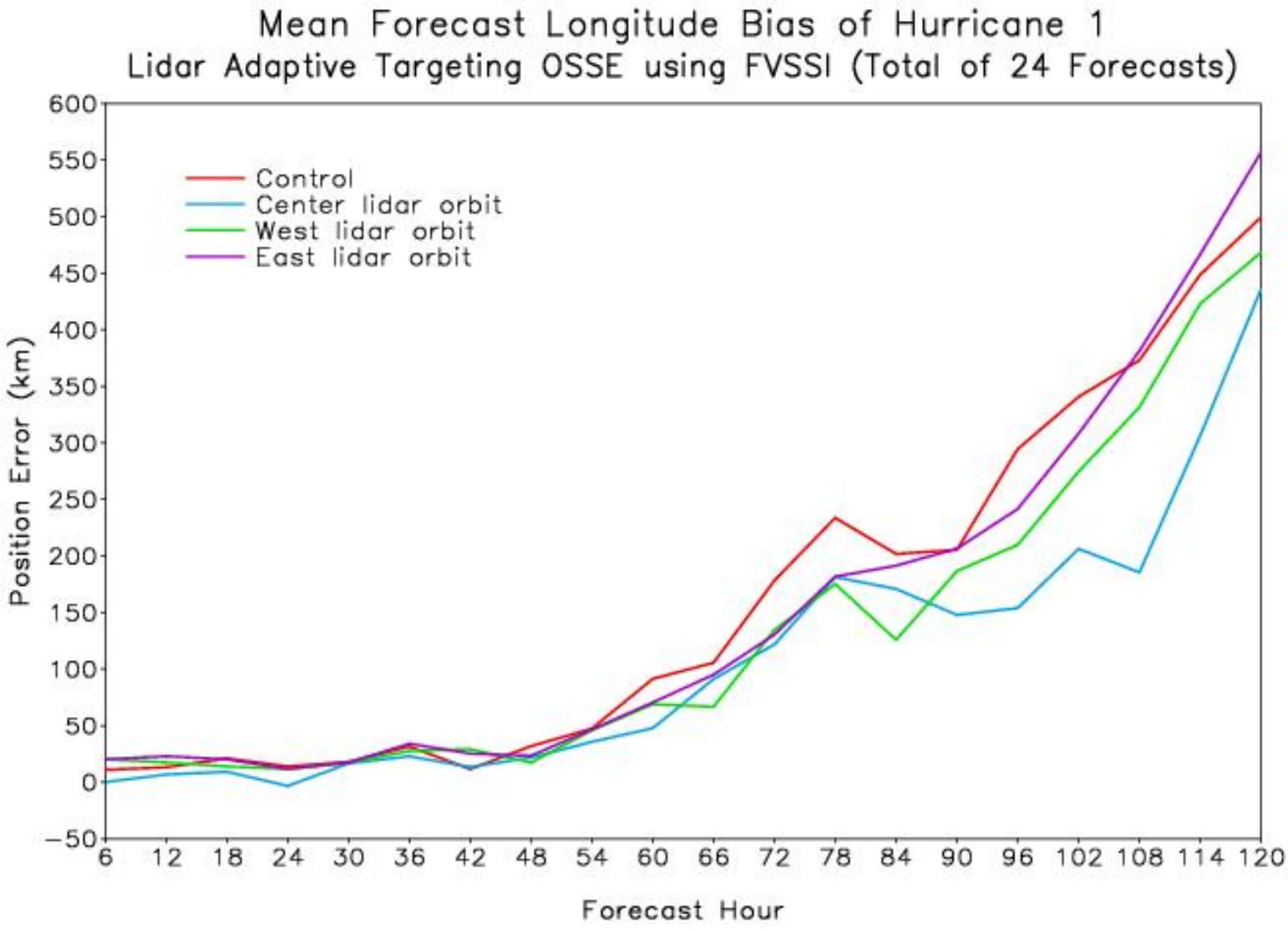

Courtesy R. Atlas

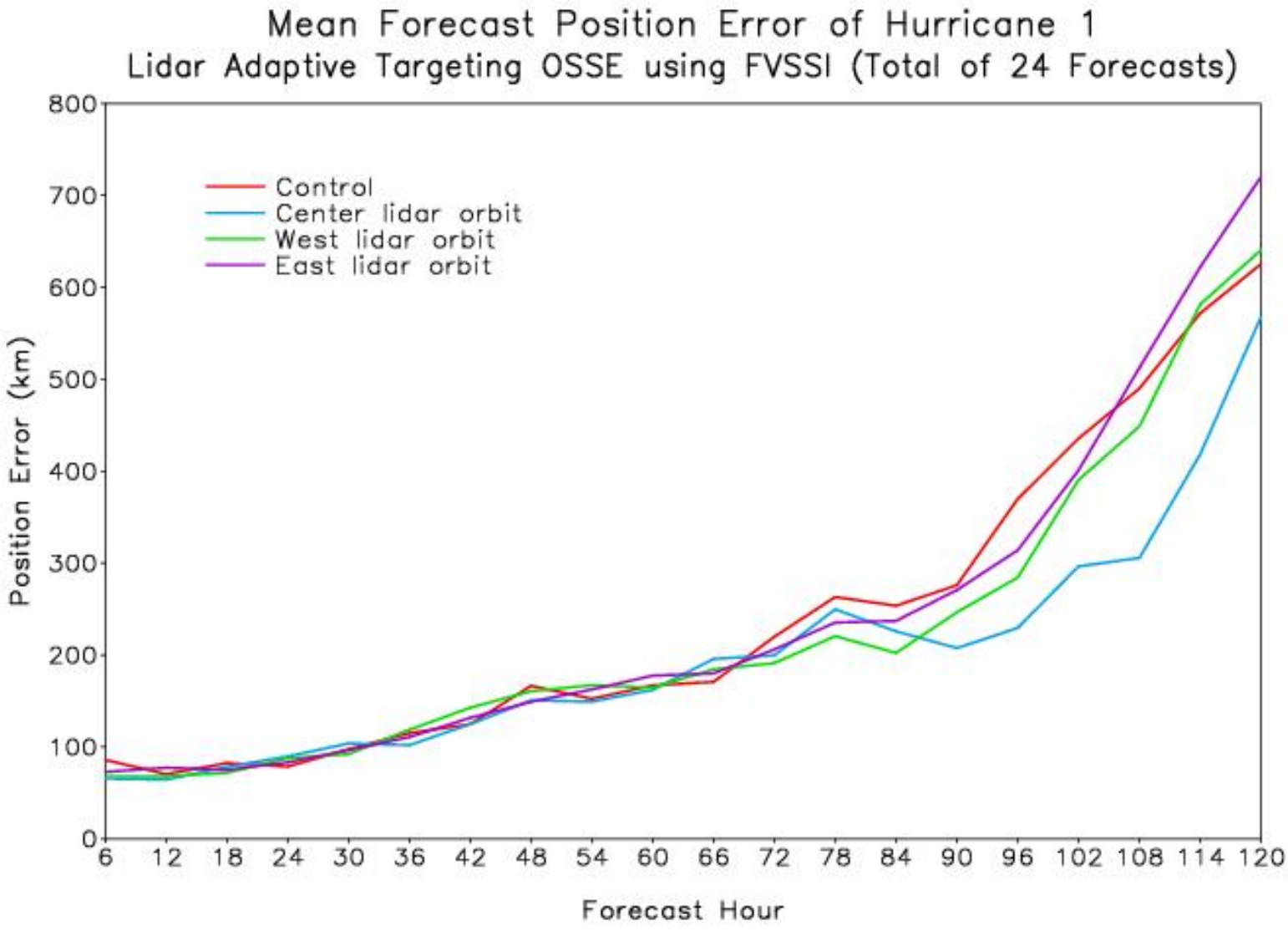

Coverage of Simulated SWA Lidar (Center Orbit)
1999 Sep 12 06Z
40N
35N
30N
25N
20N
15N
10N
5N
EQ
95W
90W
85W
80W
75W
70W
65W
60W
55W
50W
45W
40W
35W
30W
25W


Coverage of Simulated SWA Lidar (East Orbit)
1999 Sep 12 06Z
40N
35N
30N
25N
20N
15N
10N
5N
EQ
95W
90W
85W
80W
75W
70W
65W
60W
55W
50W
45W
40W
35W
30W
25W

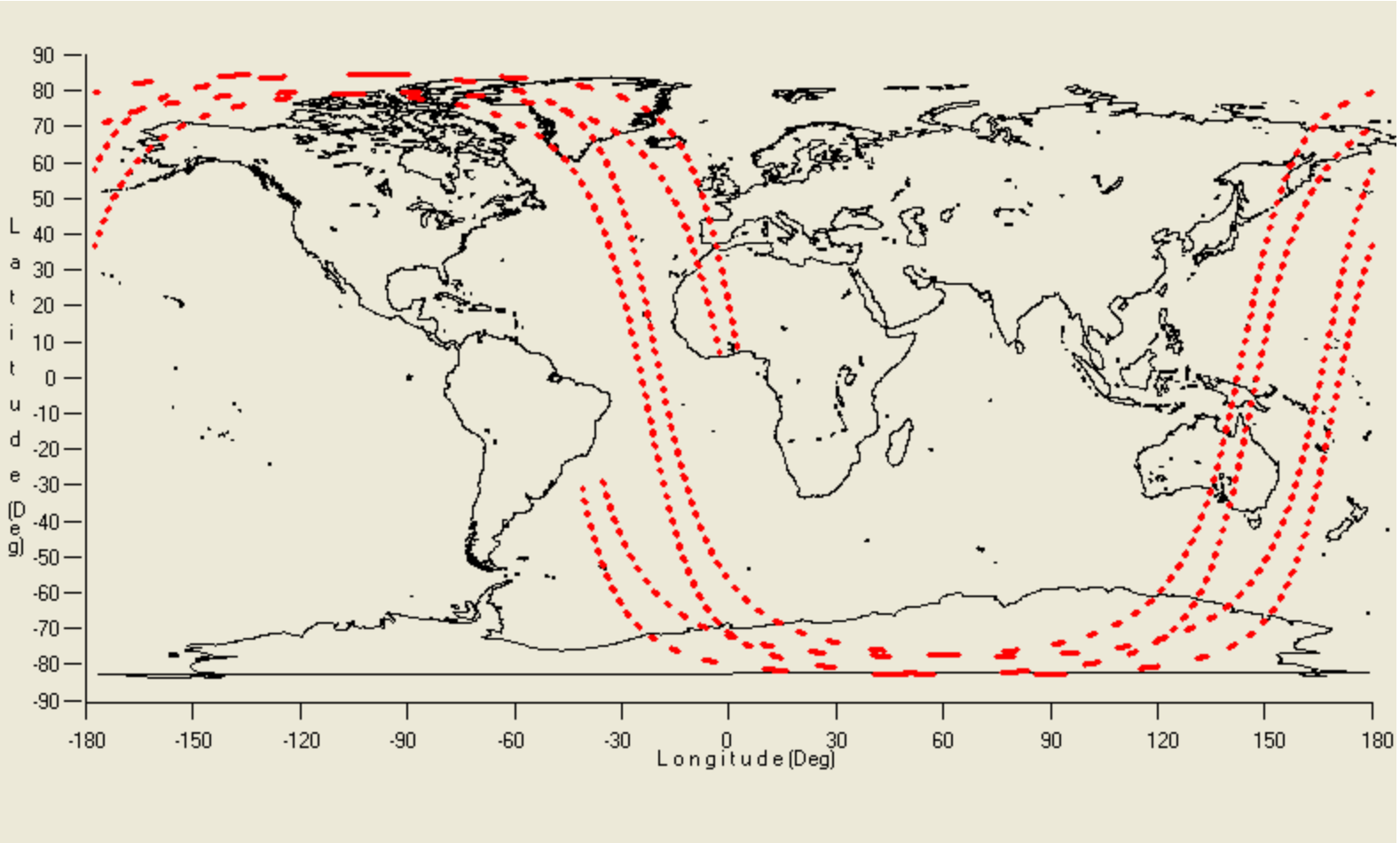

Coverage of Simulated SWA Lidar (West Orbit)
1999 Sep 12 06Z
40N
35N
30N
25N
20N
15N
10N
5N
EQ
95W
90W
85W
80W
75W
70W
65W
60W
55W
50W
45W
40W
35W
30W
25W


Mean Forecast Latitude Bias of Hurricane 1
Lidar Adaptive Targeting OSSE using FVSSI (Total of 24 Forecasts)
Control
Center lidar orbit
West lidar orbit
East lidar orbit
Position Error (km)
200
150
100
50
0
−50
6
12
18
24
30
36
42
48
54
60
66
72
78
84
90
96
102
108
114
120
Forecast Hour

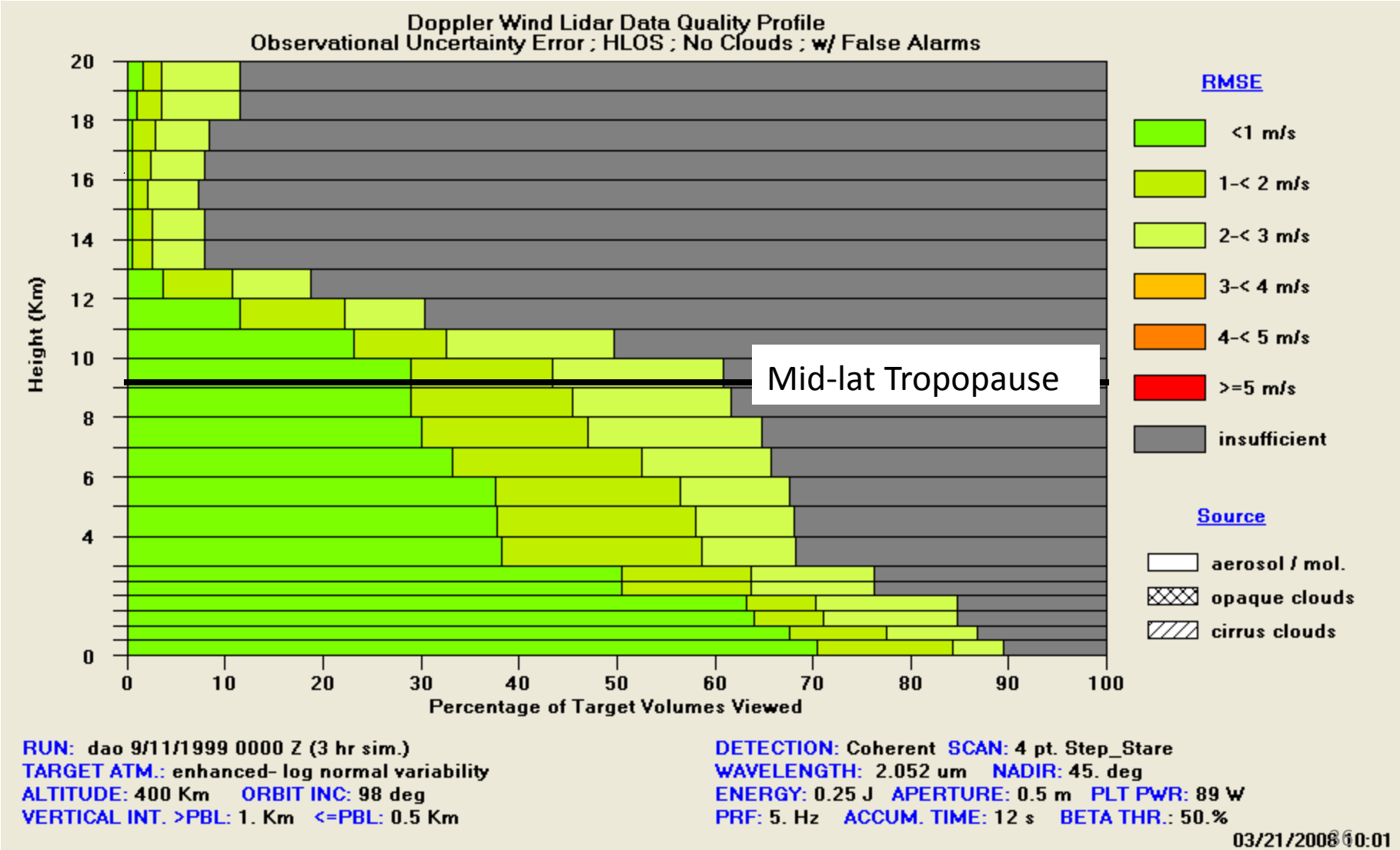

Mean Forecast Longitude Bias of Hurricane 1
Lidar Adaptive Targeting OSSE using FVSSI (Total of 24 Forecasts)
Control
Center lidar orbit
West lidar orbit
East lidar orbit
Position Error (km)
600
550
500
450
400
350
300
250
200
150
100
50
0
−50
6
12
18
24
30
36
42
48
54
60
66
72
78
84
90
96
102
108
114
120
Forecast Hour


Mean Forecast Position Error of Hurricane 1
Lidar Adaptive Targeting OSSE using FVSSI (Total of 24 Forecasts)
Control
Center lidar orbit
West lidar orbit
East lidar orbit
Position Error (km)
0
100
200
300
400
500
600
700
800
6
12
18
24
30
36
42
48
54
60
66
72
78
84
90
96
102
108
114
120
Forecast Hour

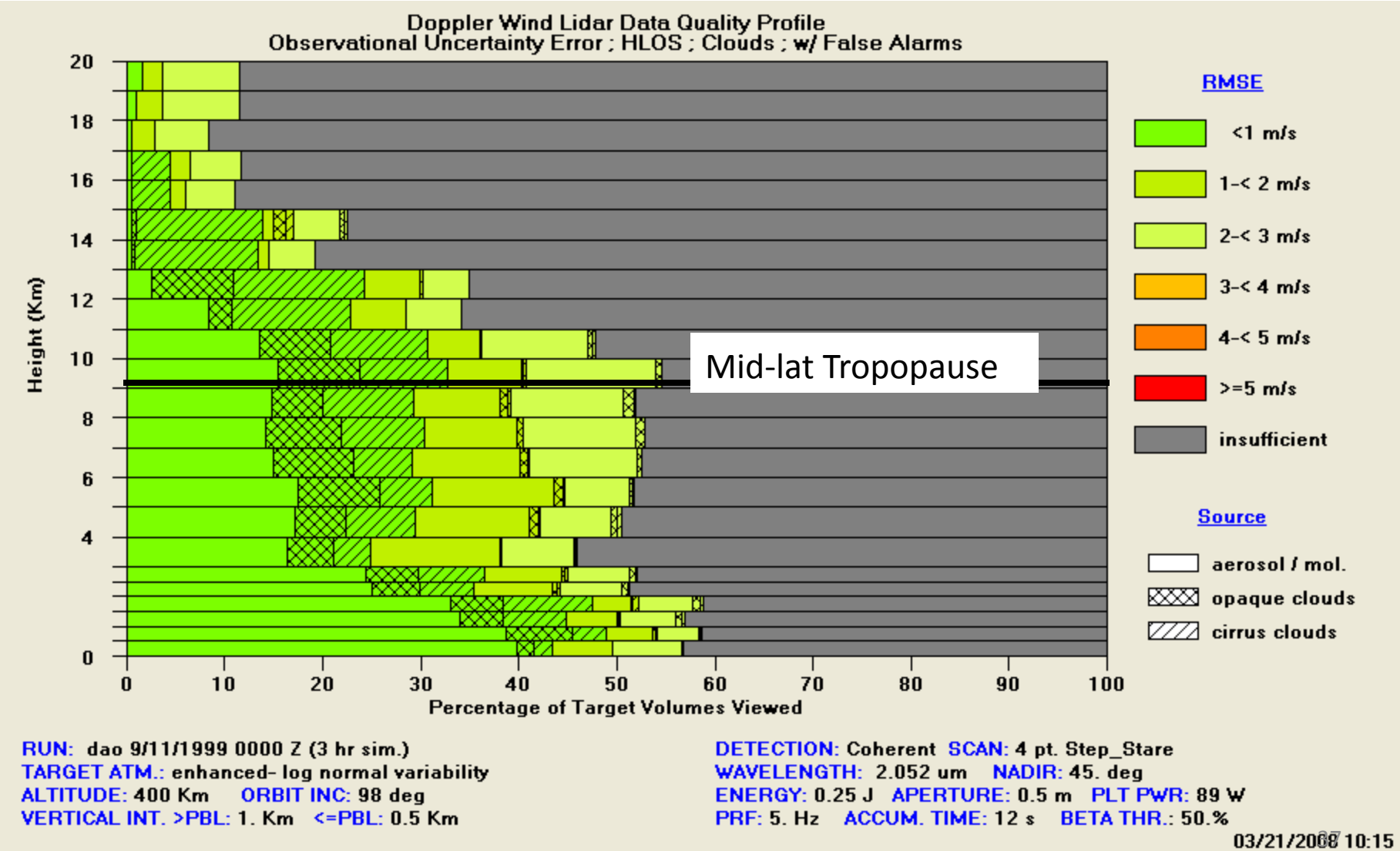
# GWOS 4 beam coverage



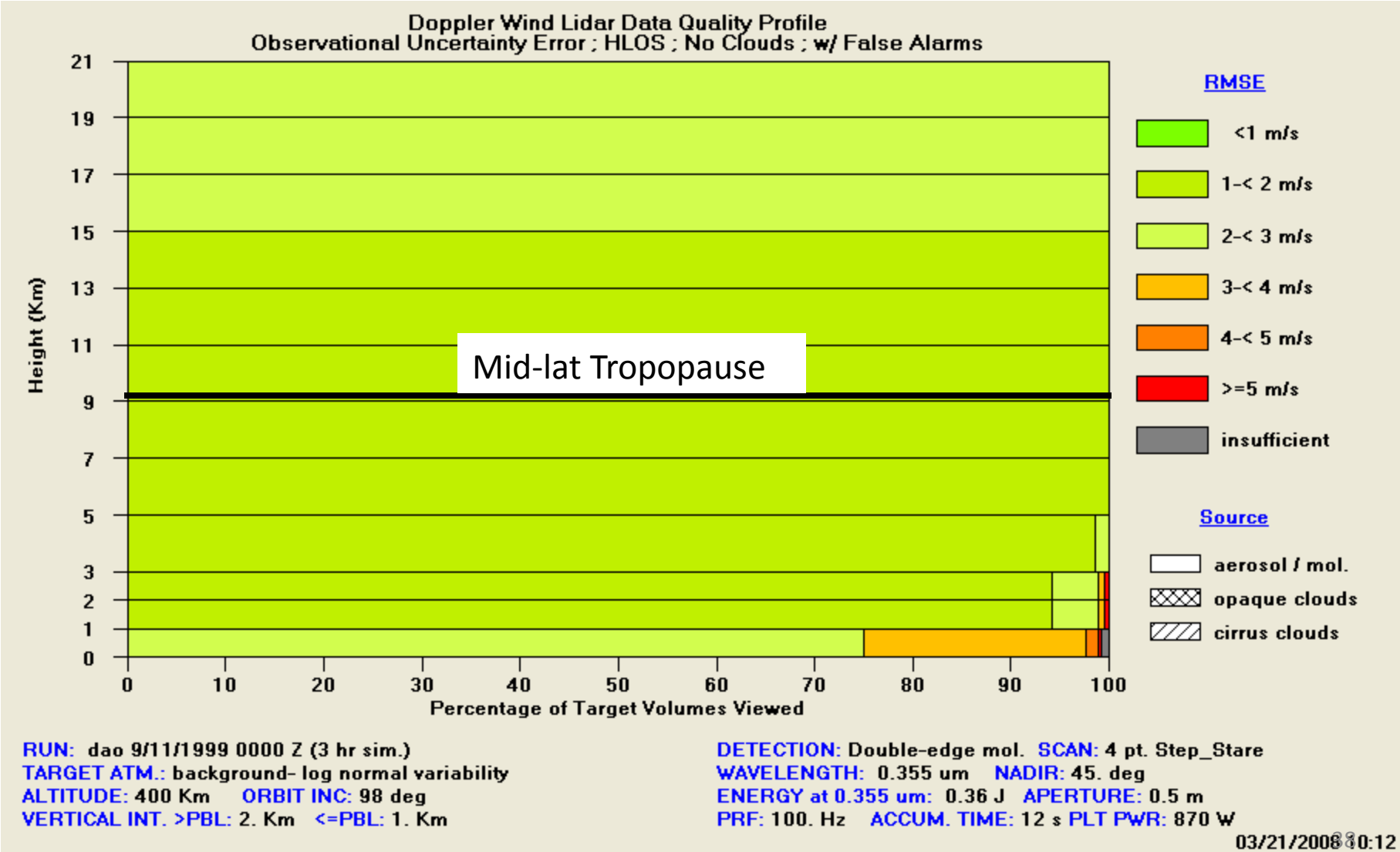
# GWOS Coherent: no clouds



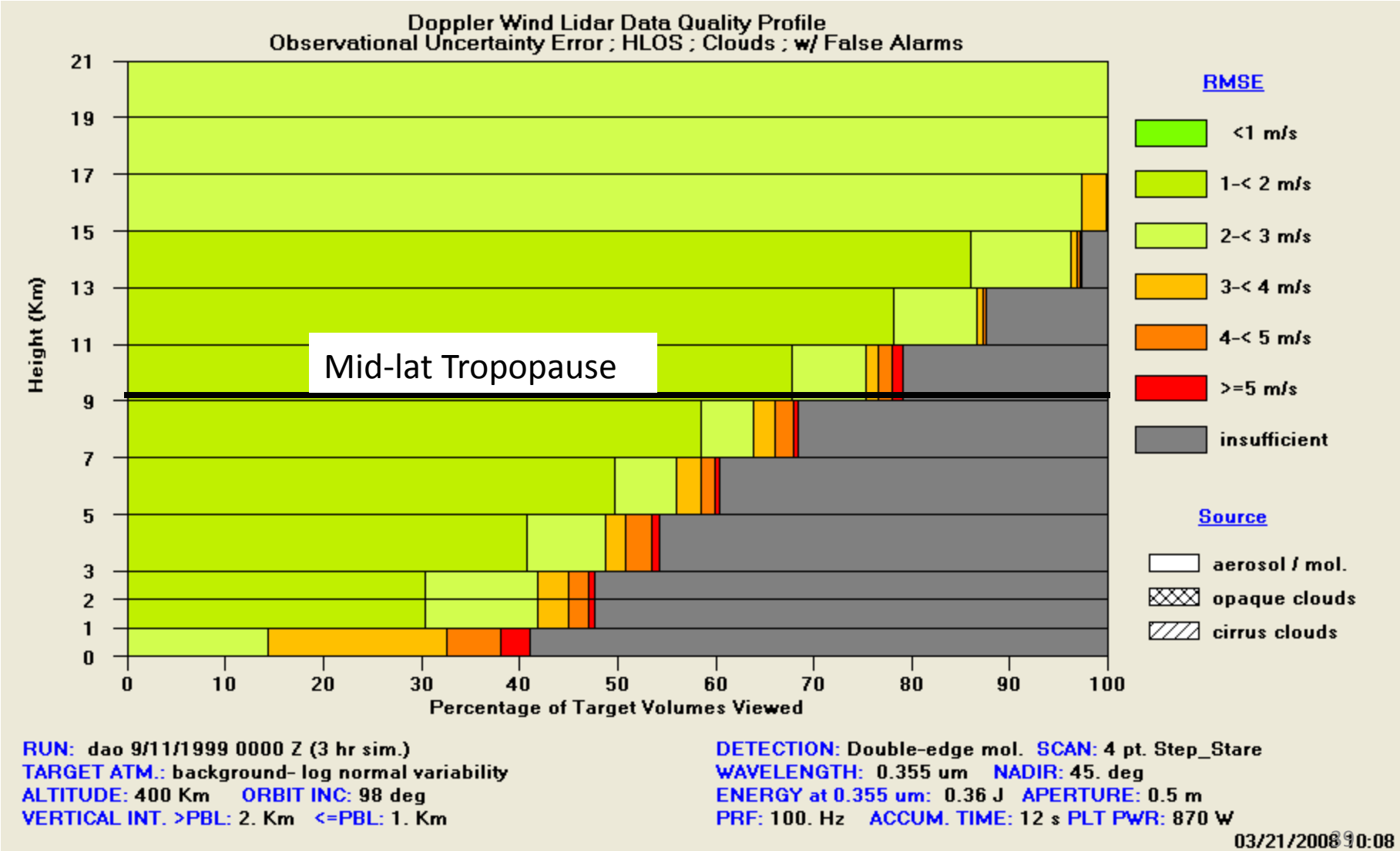
# GWOS Coherent: w/clouds



# GWOS Direct: no clouds



# GWOS Direct: w/clouds



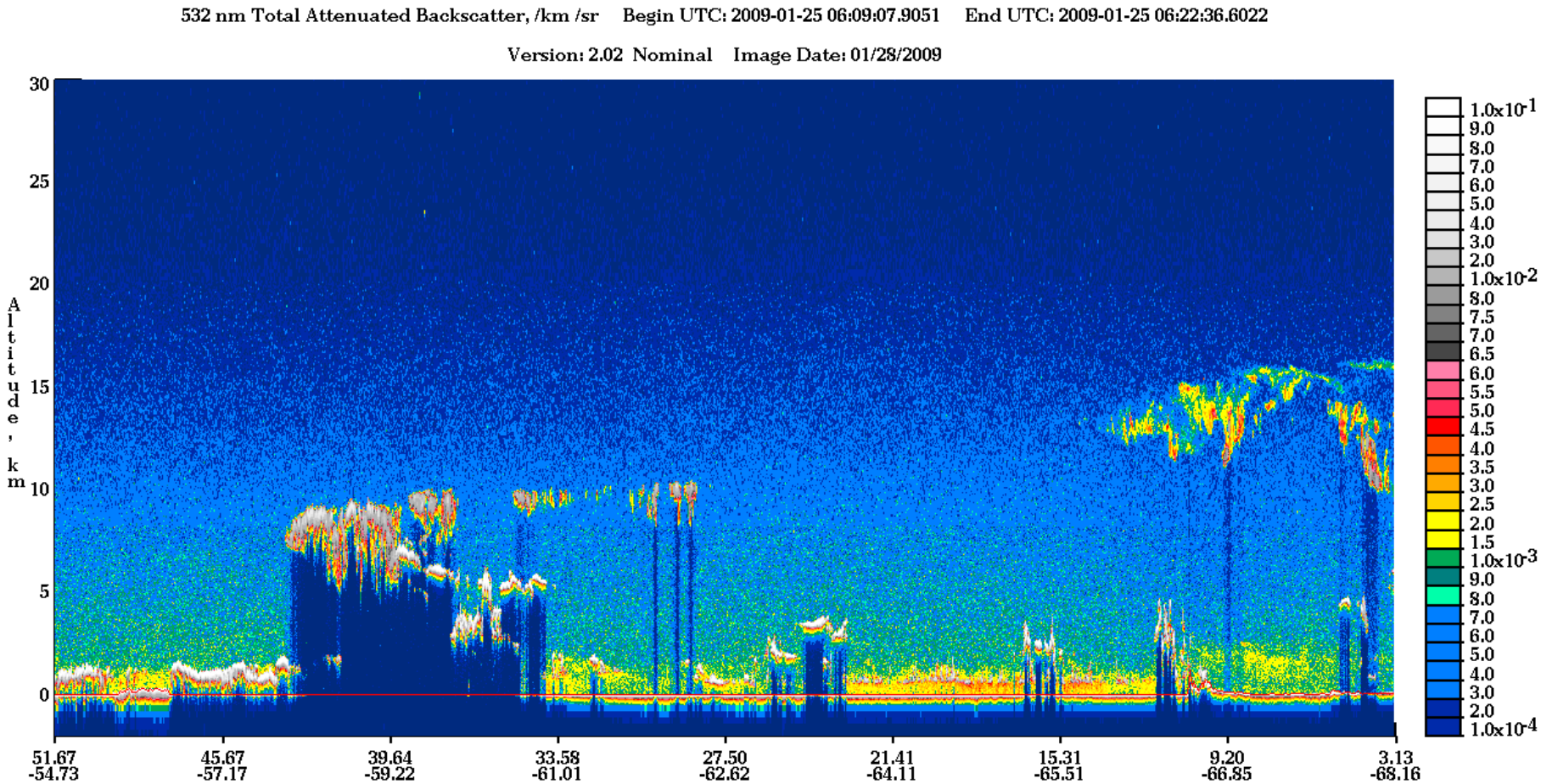
# Impact of thin and sub-visual cirrus on space based DWL simulations

# Overview

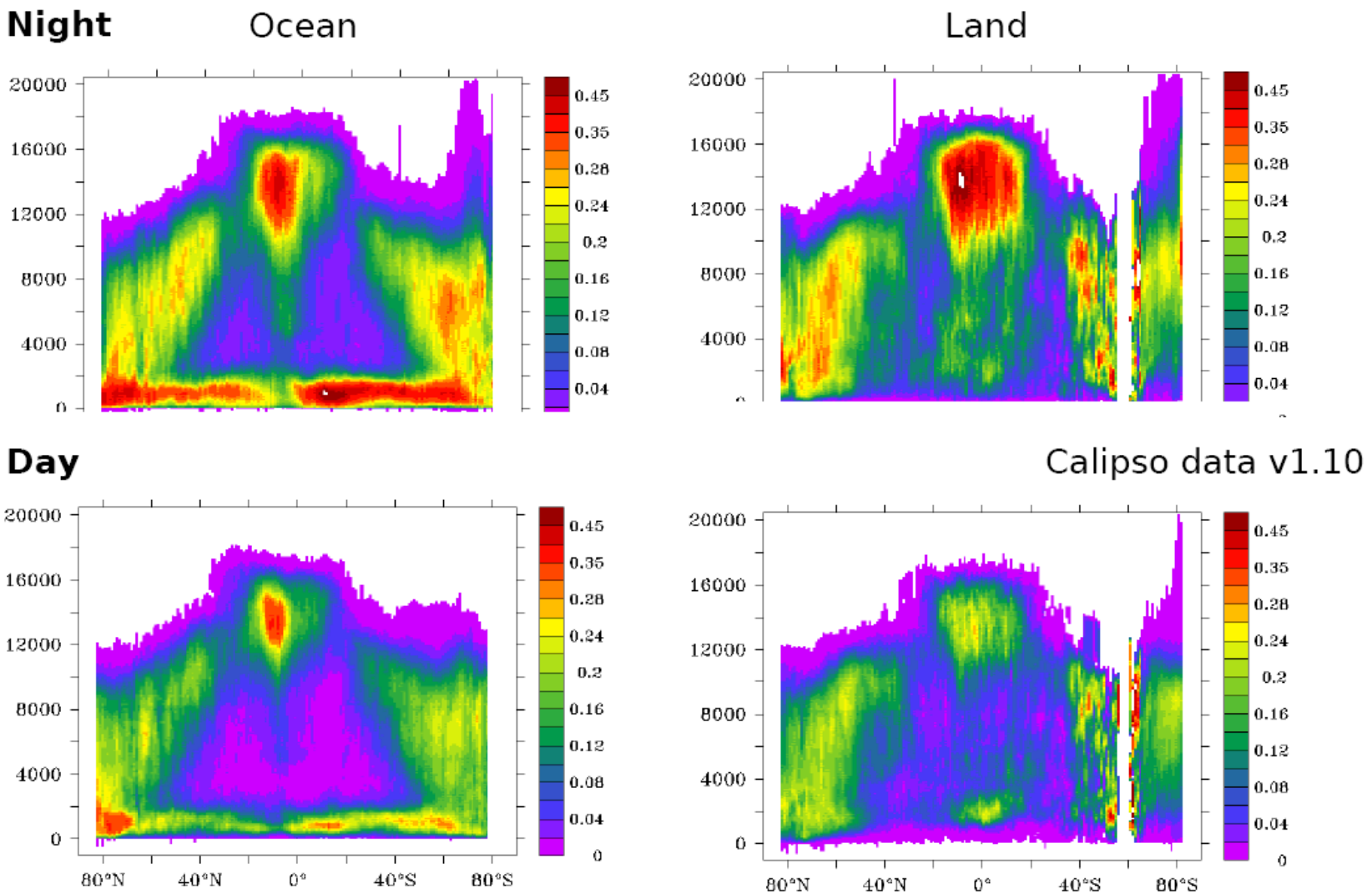
- Sub visual cirrus has been understated in DLSM simulations prior to this year; now included in 3 months of T511 simulations for OSSEs.
- CALIPSO and other satellite data regarding sub-visual cirrus
  - Global distribution
- WISCCR/GWOS simulations with and without sub-visual cirrus
  - Focus on equatorial band and the Somalia Current

# Clouds and Aerosols

# 532 nm Total Attenuated Backscatter

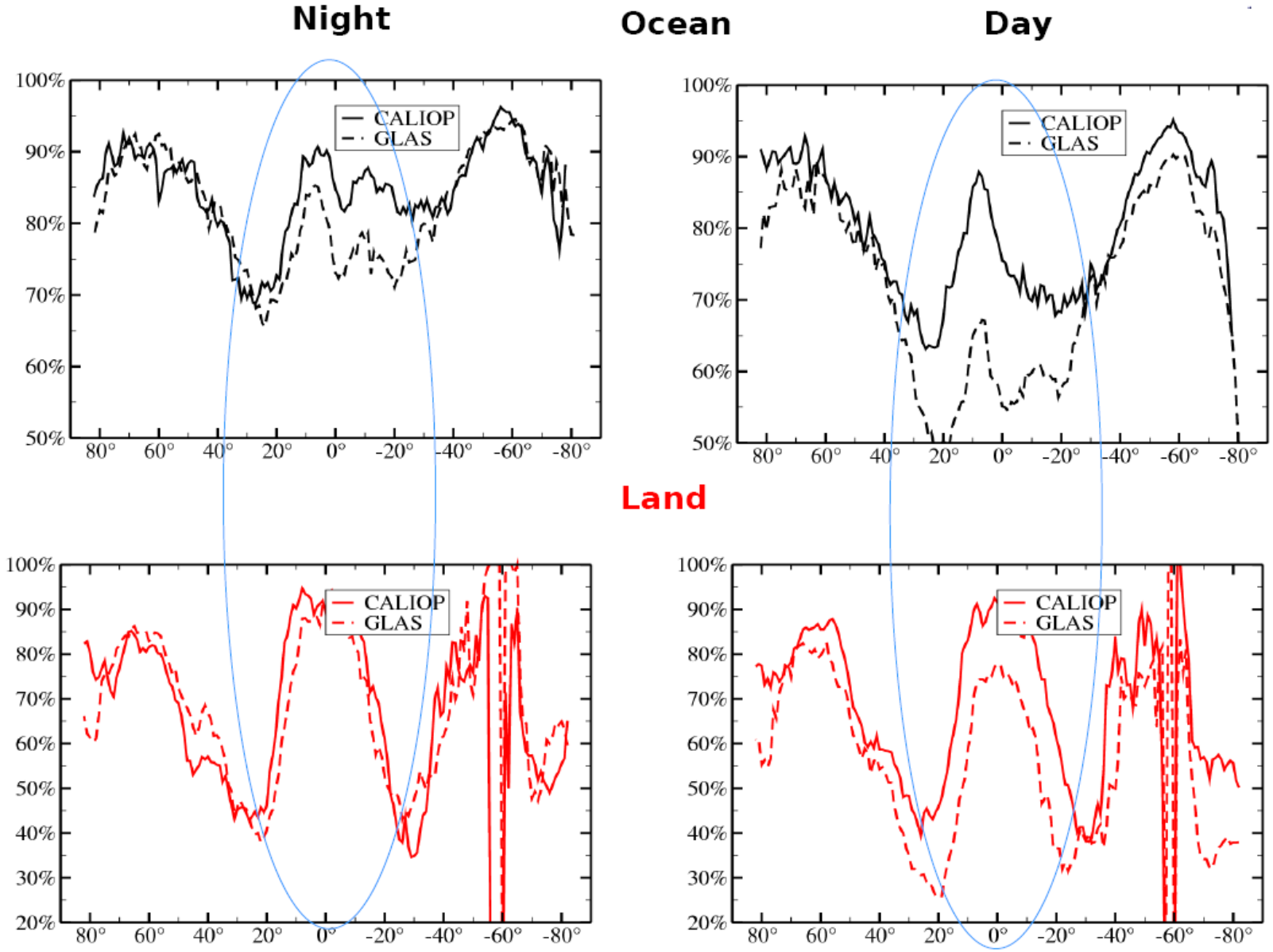


# WHAT IS OBTAINED From CALIOP/CALIPSO October 2006



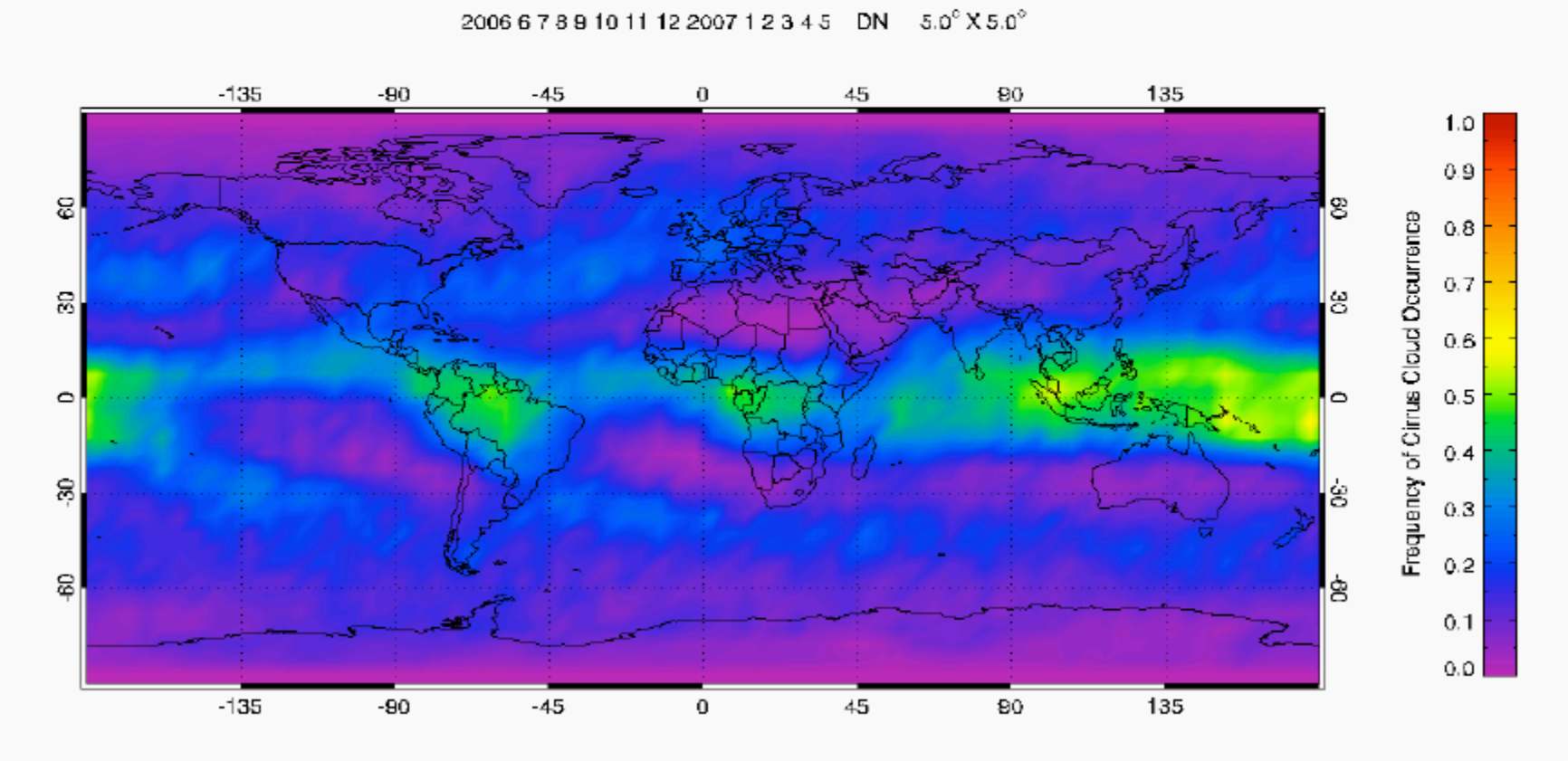

Earthcare workshop, ESTEC, 8 May 2007

Seze, Pelon, Flamant, Vaughn, Trepte and Winker



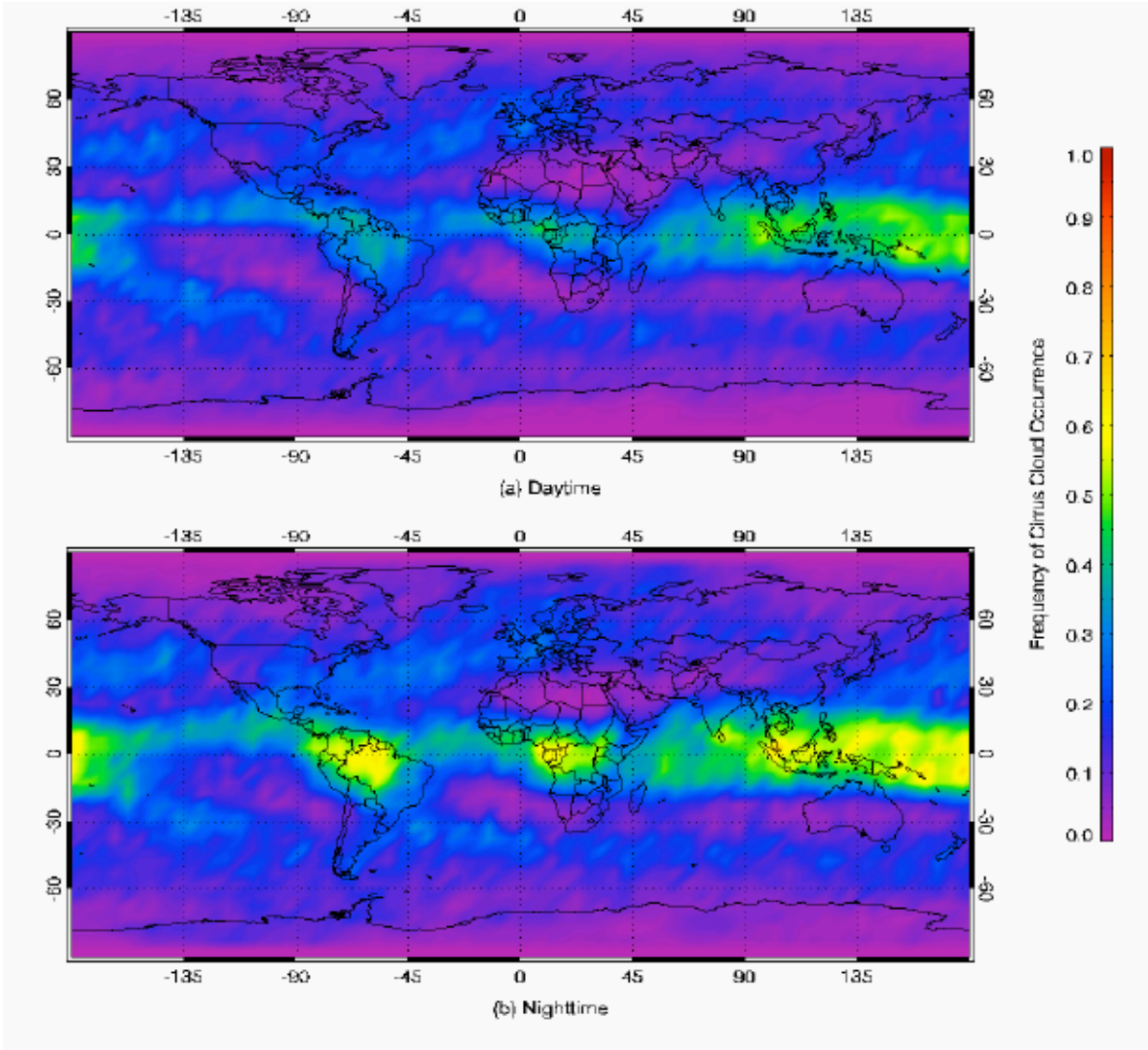

**GLAS october 2003 – CALIOP october 2006**

# Average 1-Y Global Cirrus Frequency

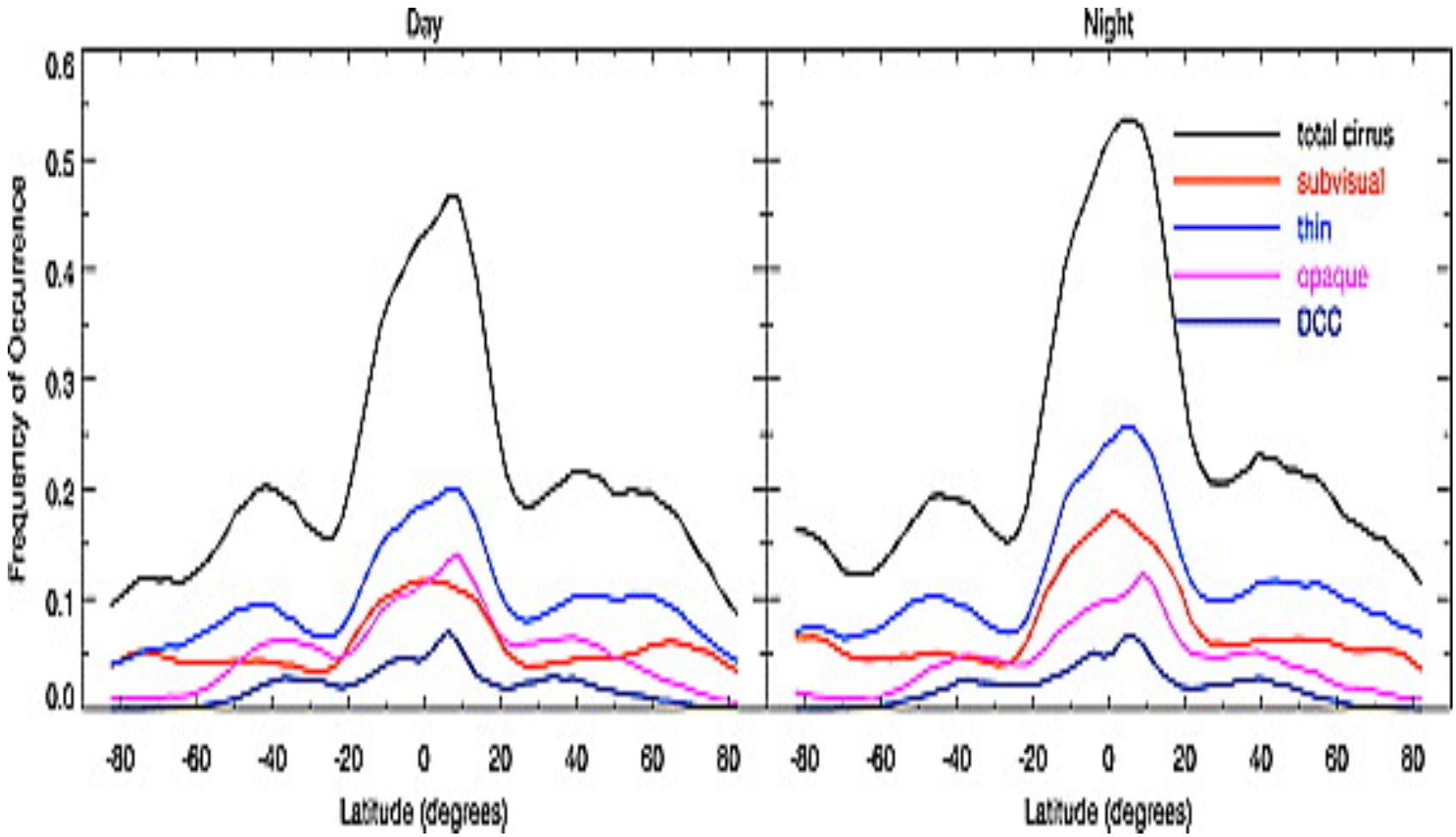



Sassen et al., (2008)

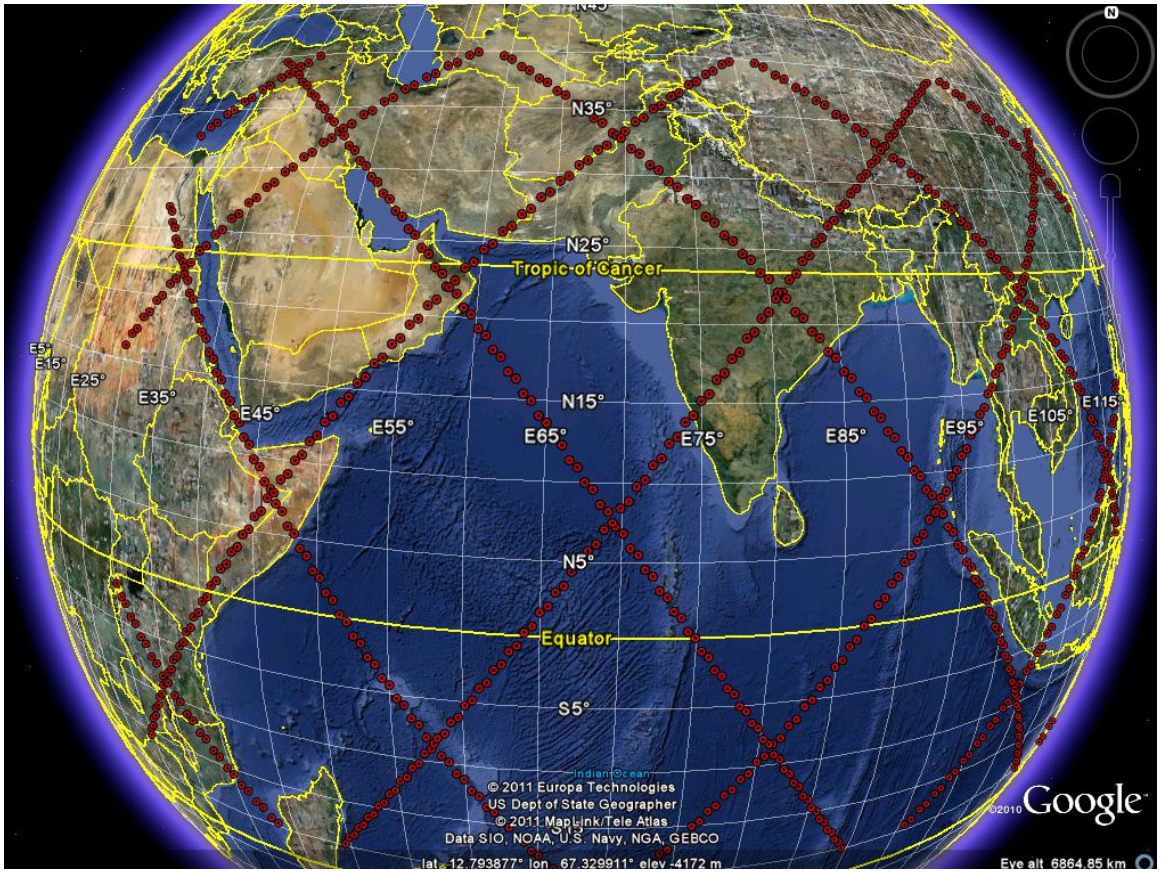
# Global Cirrus Day Vs. Night




Sassen et al., (2008)



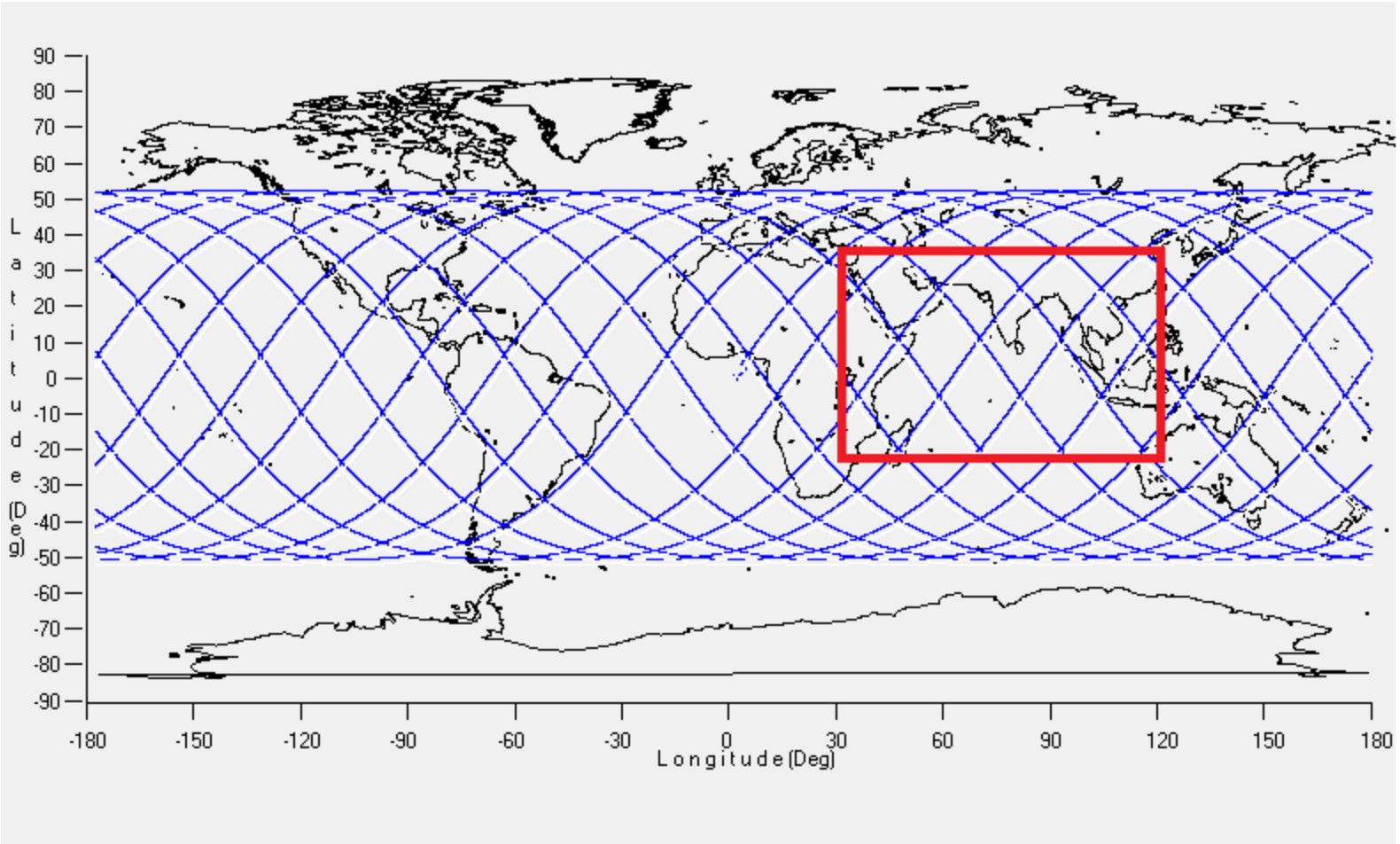

Sassen et al., (2009): Total, SUBVISUAL Cirrus, Thin Cirrus, Opaque Cirrus



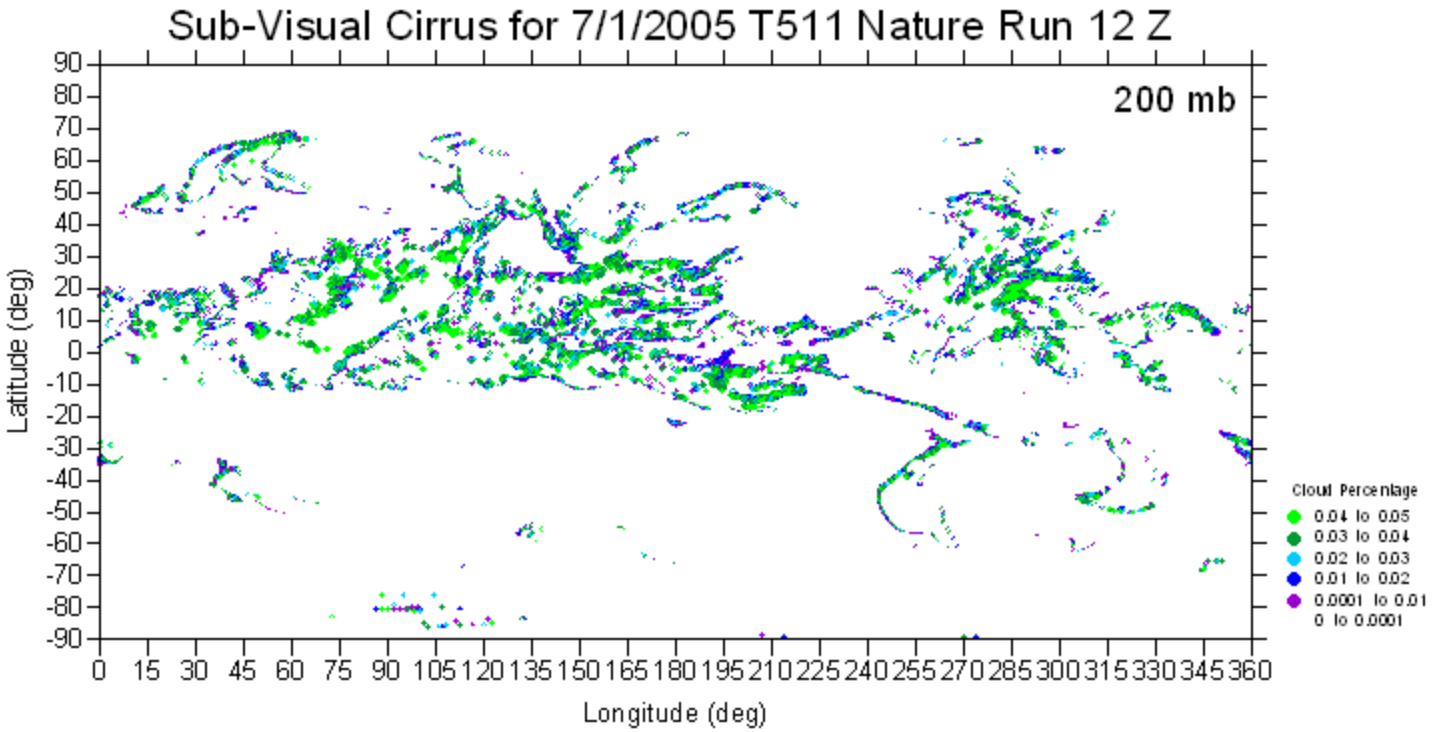

# WISSCR Sampling Coverage

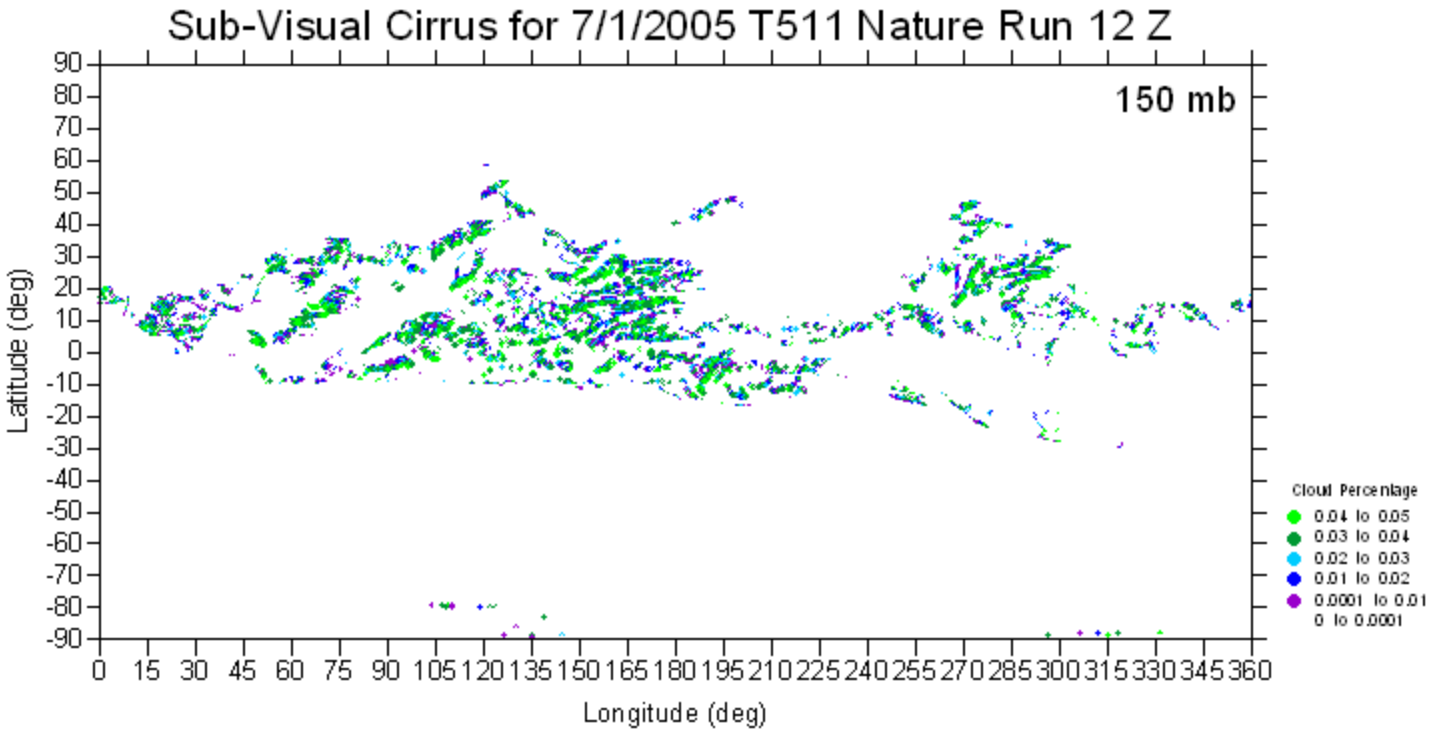
WISSCR sounding locations over 24 hours within the Monsoon Region. There are 720 LOS products, each the result of averaging 120 individual laser pulses with 1 km vertical resolution above 2km and 250m resolution within the lowest 2km.

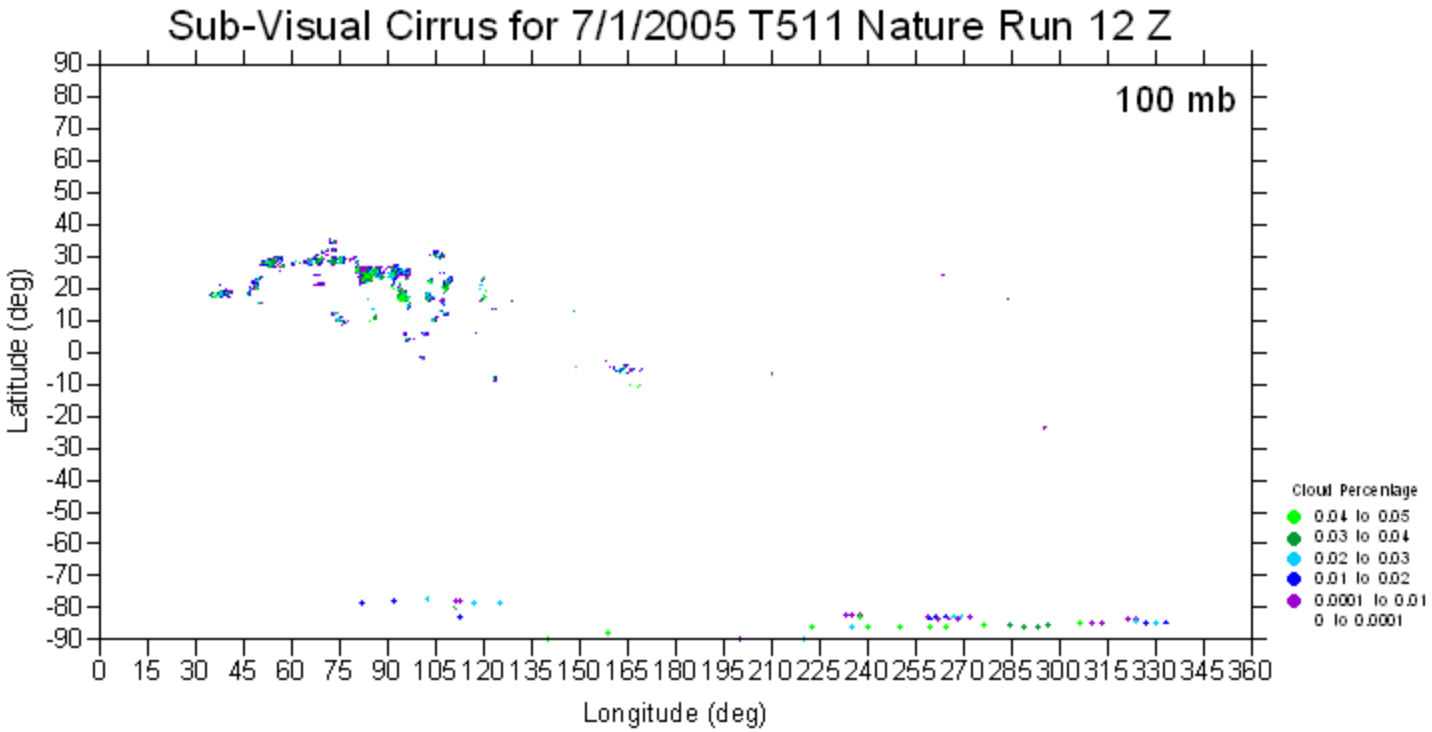
# Global coverage of WISSCR for 24 hours

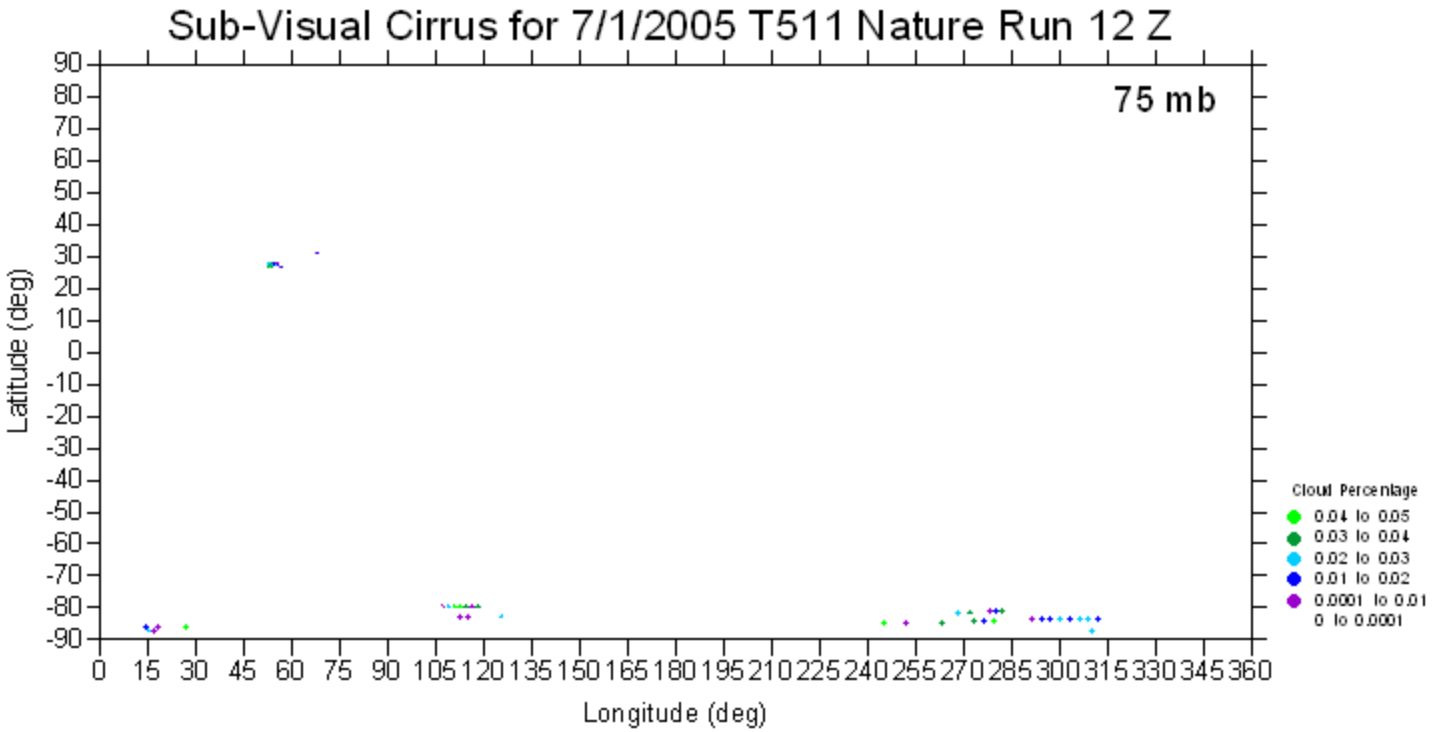


# Simulated thin and sub-visual cirrus


Sub-Visual Cirrus for 7/1/2005 T511 Nature Run 12 Z
200 mb
Latitude (deg)
Longitude (deg)
Cloud Percentage
0.04 to 0.05
0.03 to 0.04
0.02 to 0.03
0.01 to 0.02
0.0001 to 0.01
0 to 0.0001

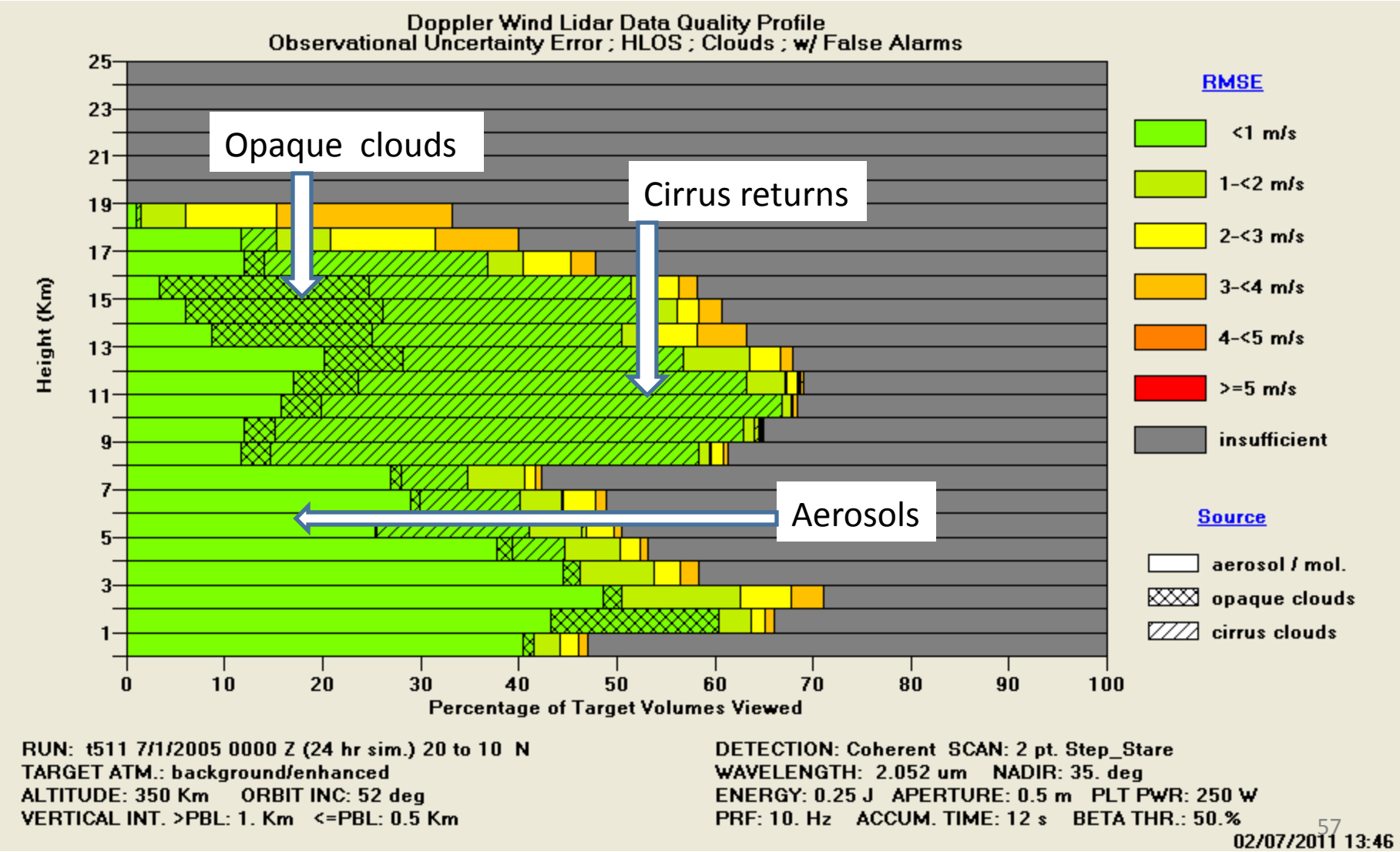

Sub-Visual Cirrus for 7/1/2005 T511 Nature Run 12 Z
150 mb
Latitude (deg)
Longitude (deg)
Cloud Percentage
0.04 to 0.05
0.03 to 0.04
0.02 to 0.03
0.01 to 0.02
0.0001 to 0.01
0 to 0.0001


Sub-Visual Cirrus for 7/1/2005 T511 Nature Run 12 Z
100 mb
Latitude (deg)
Longitude (deg)
Cloud Percentage
0.04 to 0.05
0.03 to 0.04
0.02 to 0.03
0.01 to 0.02
0.0001 to 0.01
0 to 0.0001

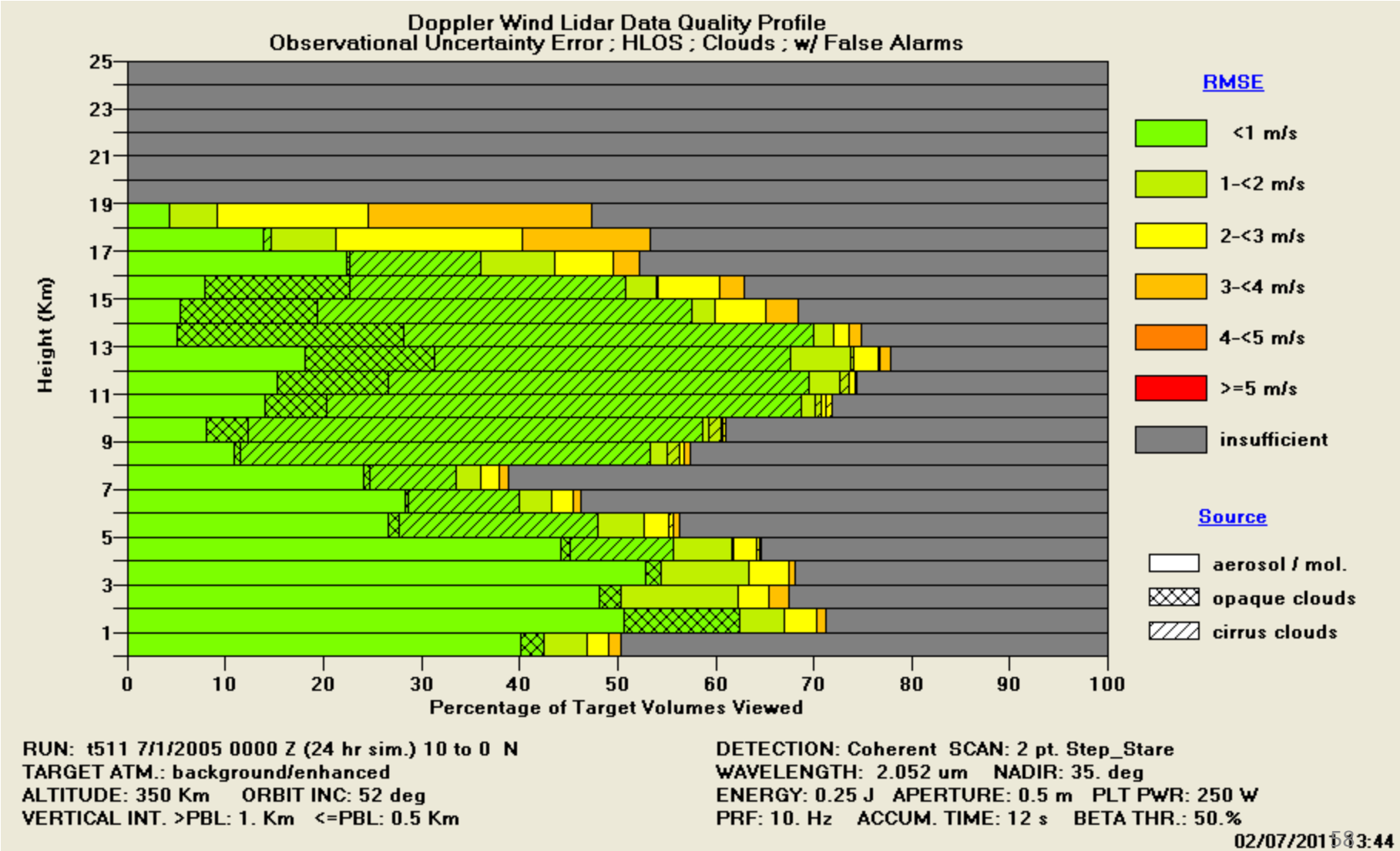

Sub-Visual Cirrus for 7/1/2005 T511 Nature Run 12 Z
75 mb
Latitude (deg)
Longitude (deg)
Cloud Percentage
0.04 to 0.05
0.03 to 0.04
0.02 to 0.03
0.01 to 0.02
0.0001 to 0.01
0 to 0.0001

# Simulated WISSCR's performance using the DLSM with the T511 ECMWF Nature Run

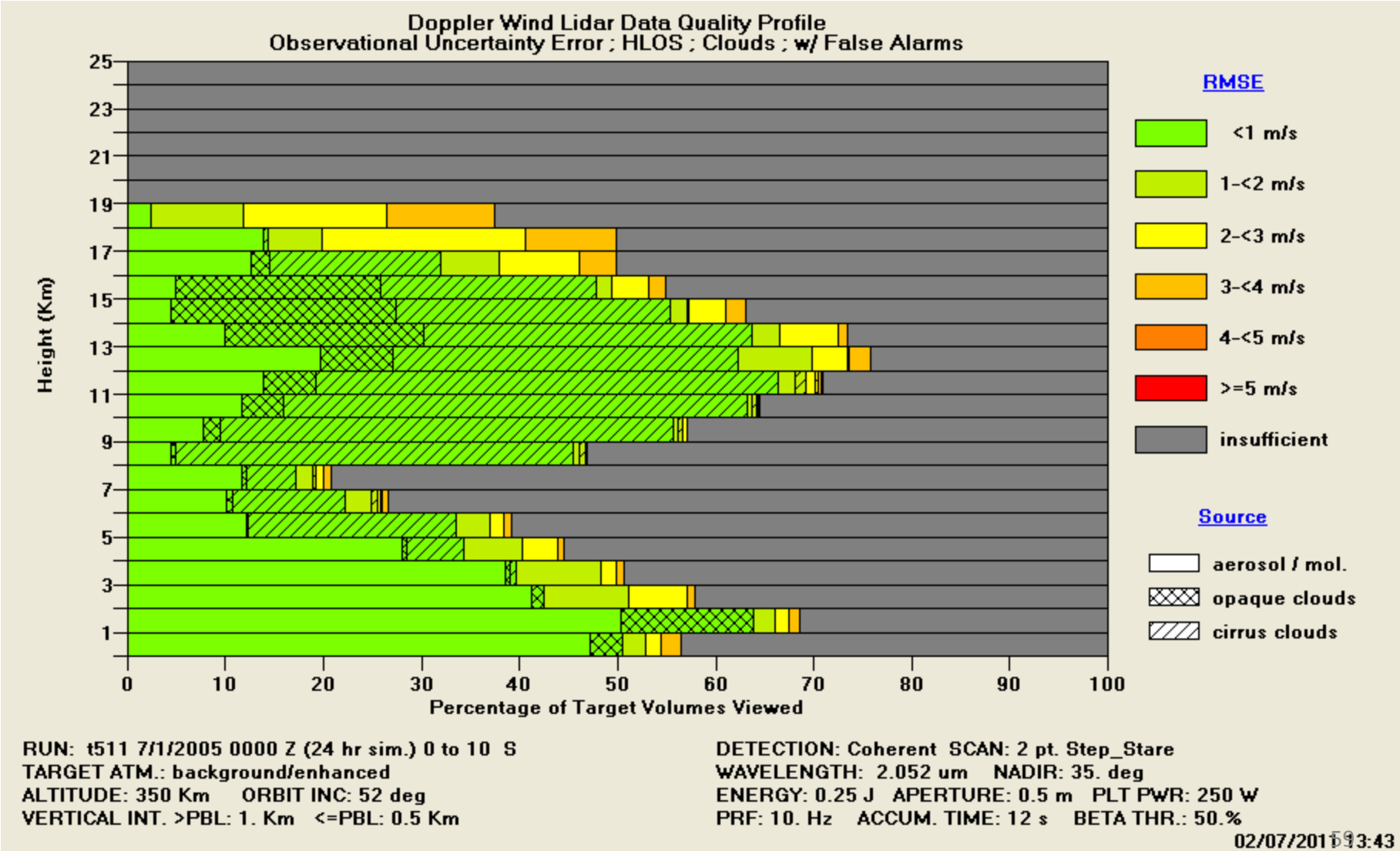
# Aerosol/cloud subsystem of the Wind Lidar on ISS 20 – 10 N



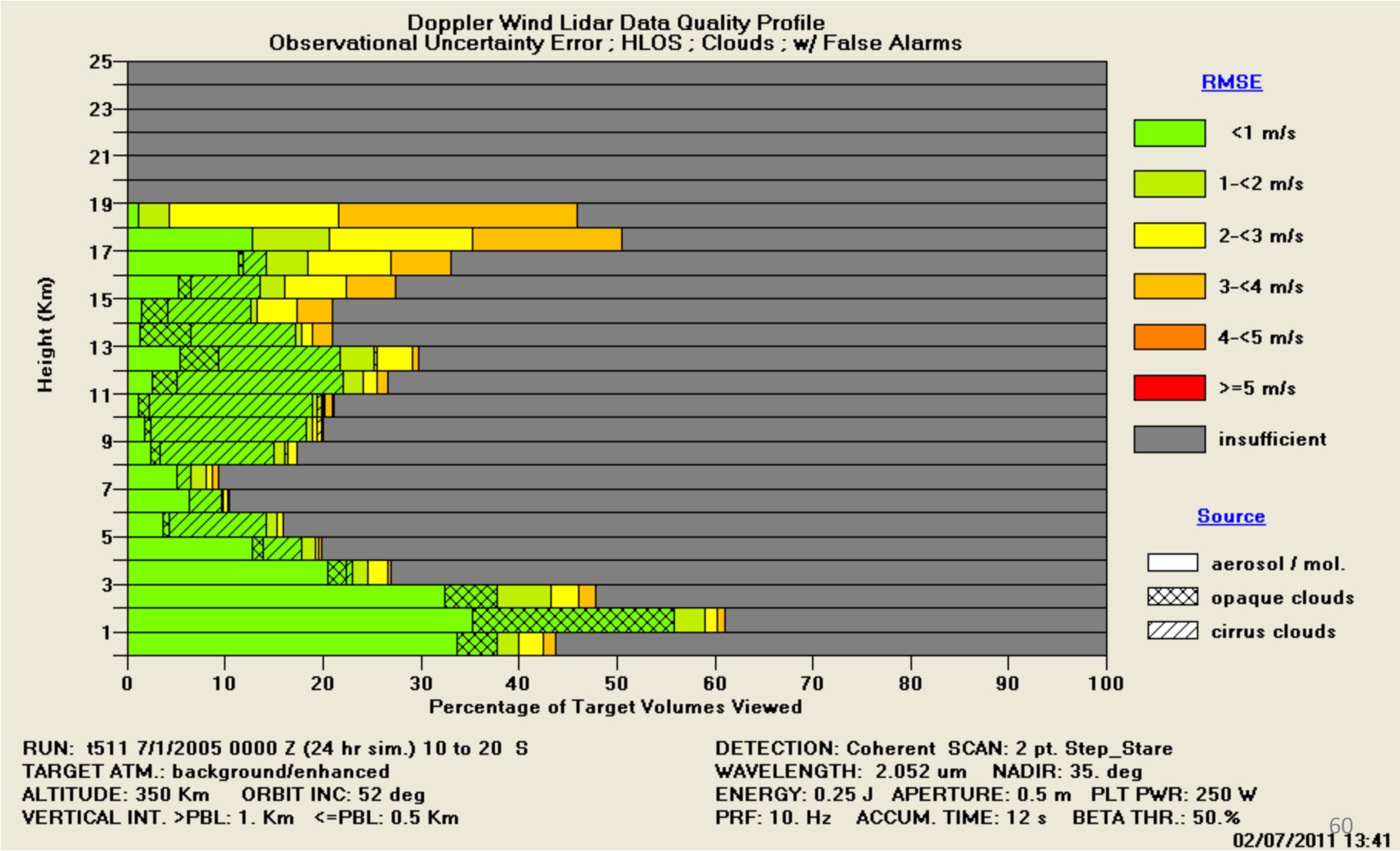
# Aerosol/cloud subsystem of the Wind Lidar on ISS 10 -0 N



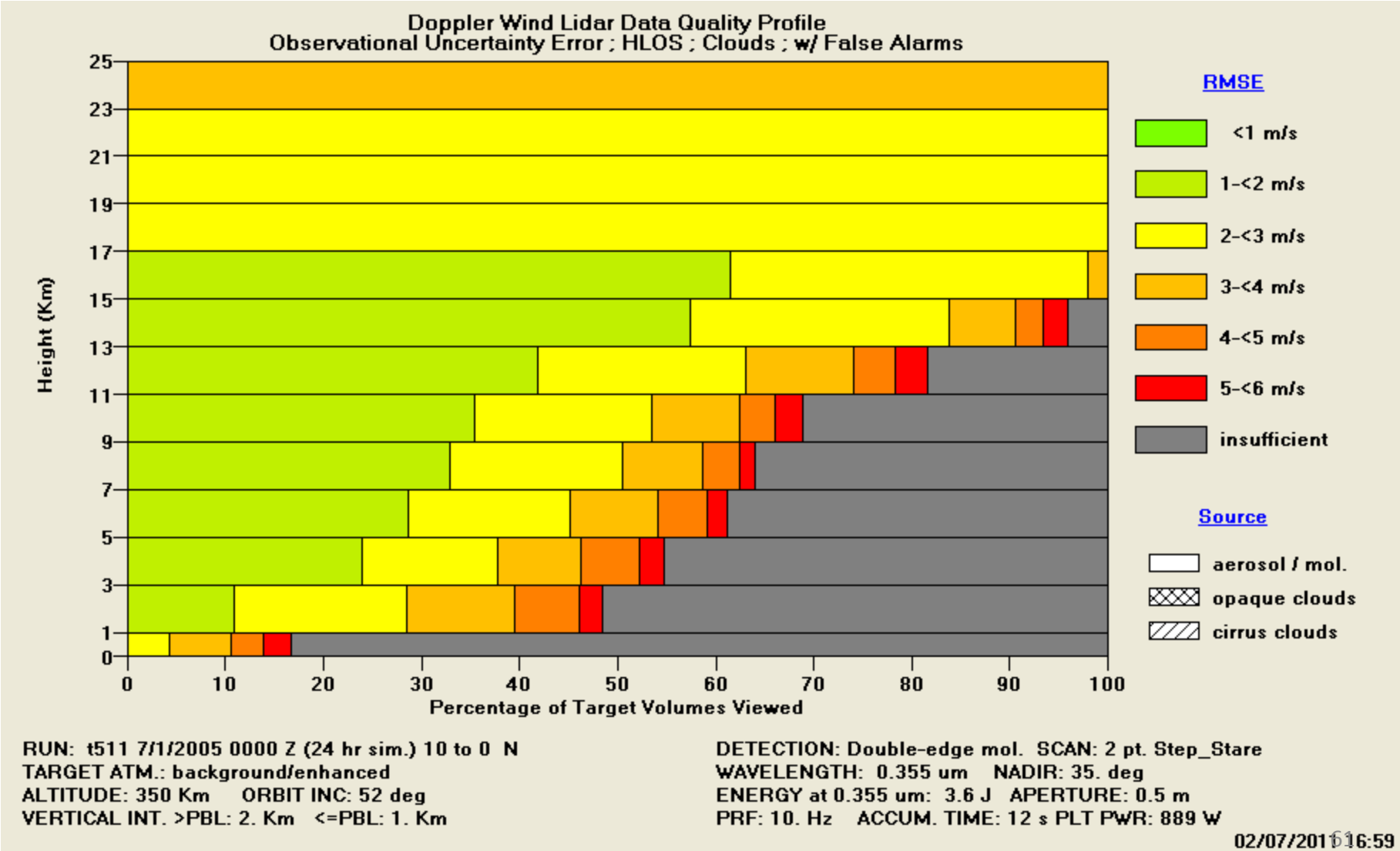
# Aerosol/cloud subsystem of the Wind Lidar on ISS 0 – 10 S



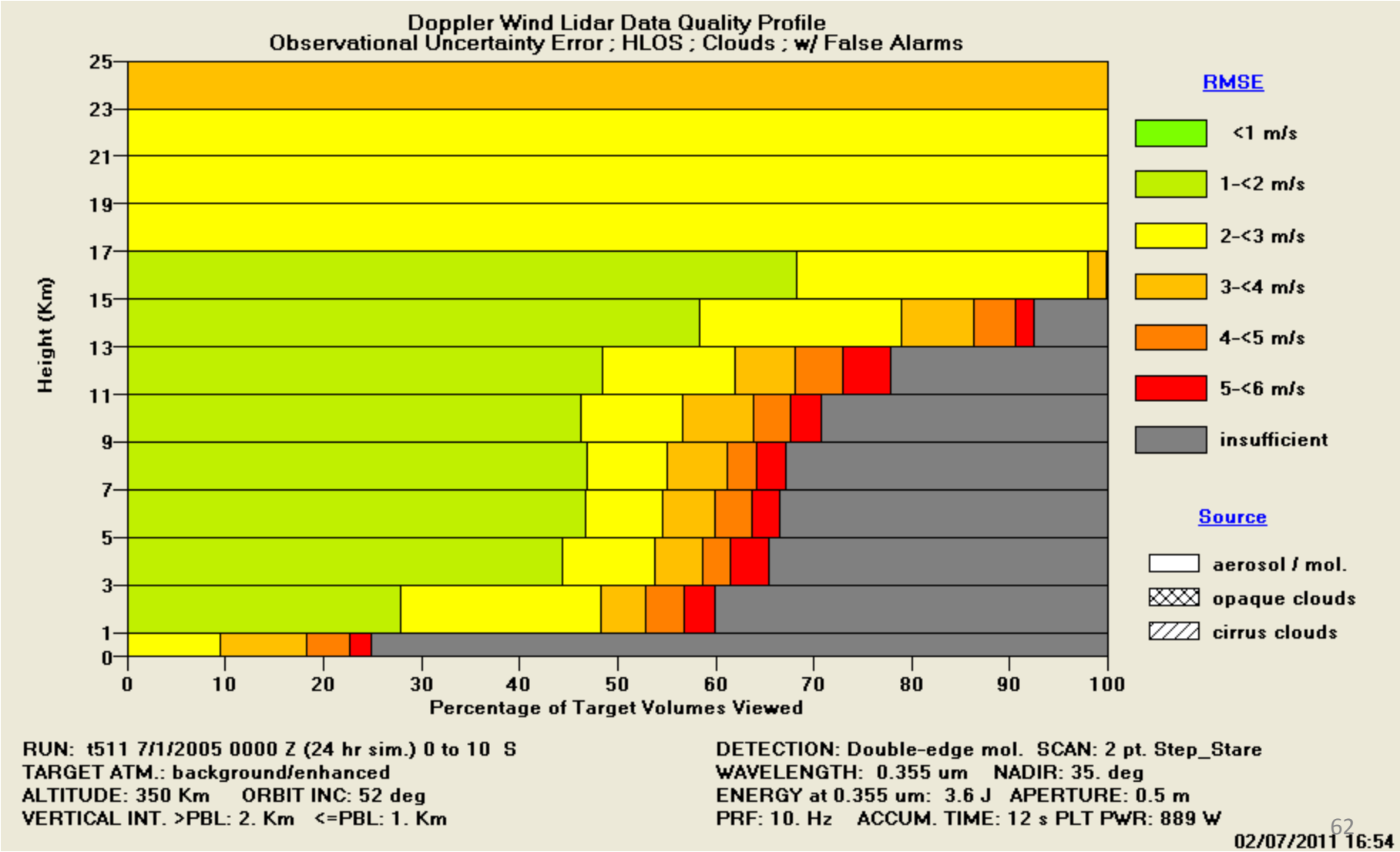
# Aerosol/cloud subsystem of the Wind Lidar on ISS 10 -20 S



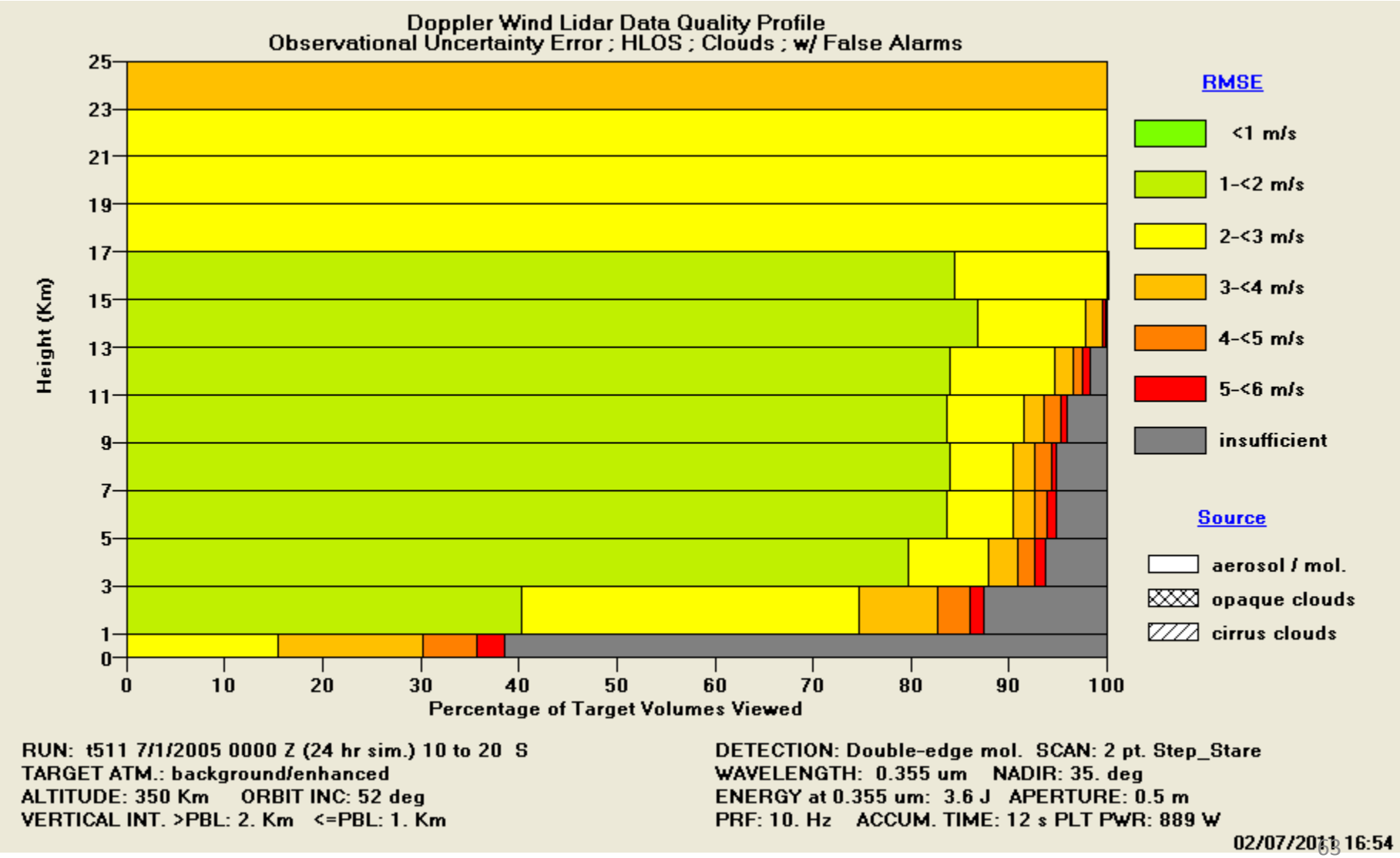
# Molecular subsystem of the Wind Lidar on ISS 10 – 0 N



# Molecular subsystem of the Wind Lidar on ISS
# 0 - 10 S



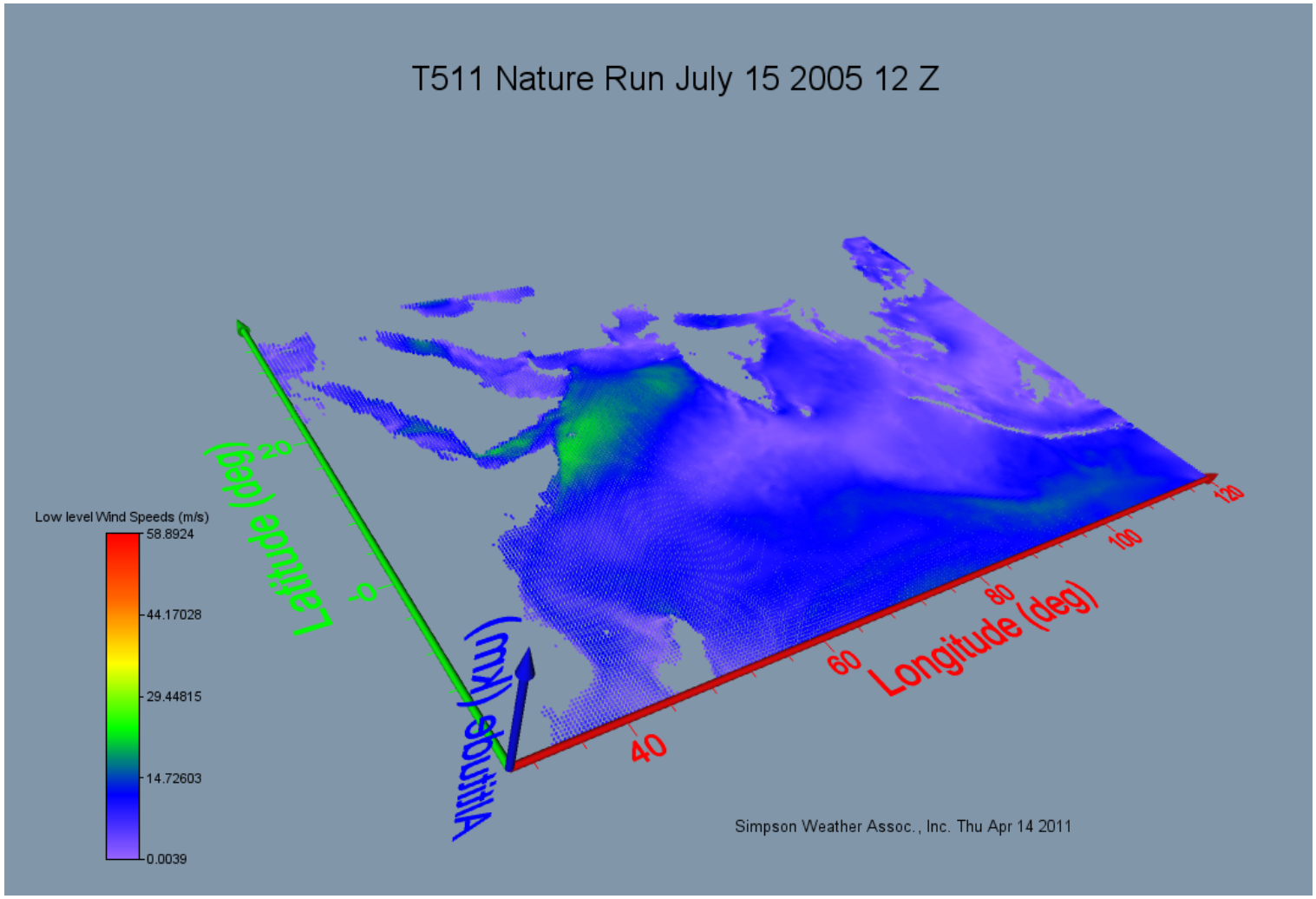
# Molecular subsystem of the Wind Lidar on ISS 10 -20 S



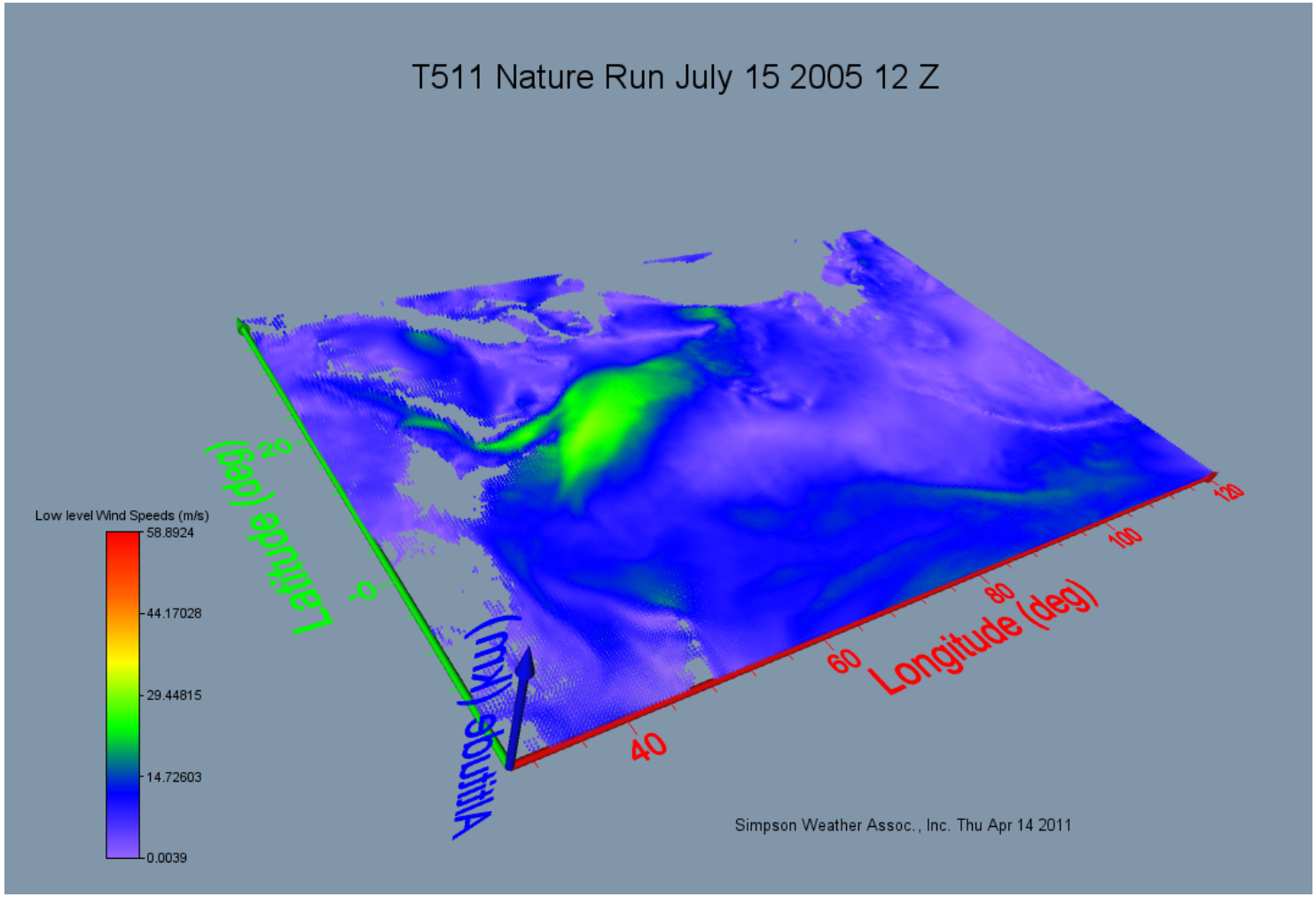
# Simulation of WISSCR over Monsoon Region

- Use the Doppler Lidar Simulation Model (DLSM) developed for instrument concept evaluations and potential Numerical Weather Prediction model impact studies.
- Simulate WISSCR observations using ECMWF Nature Run (T511).
- Select days in July and August with Somalia Low Level Jets with varying intensities and locations.

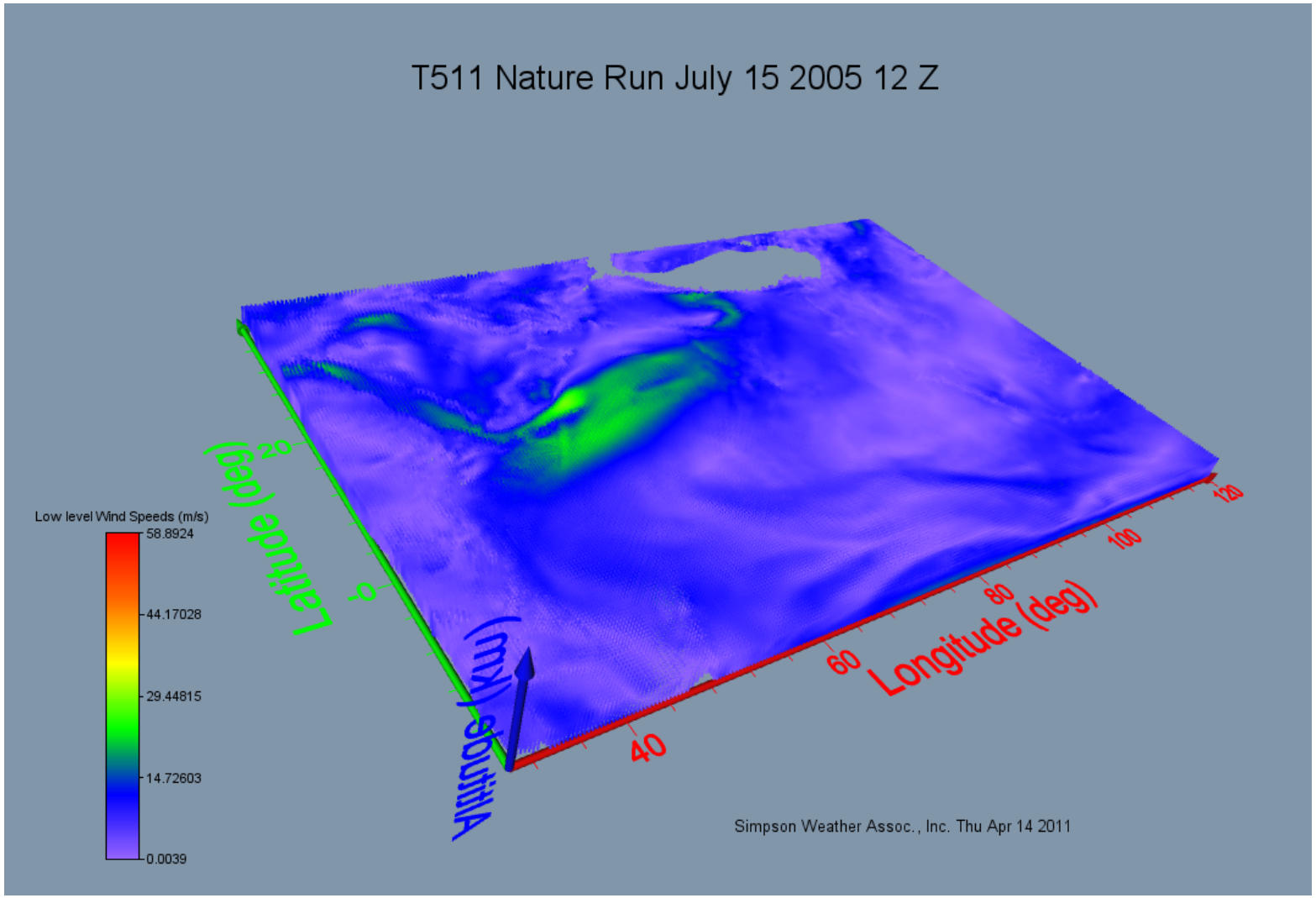
# Somalia LLJ within 250 meters MSL



# Somalia LLJ at 1000 meters MSL

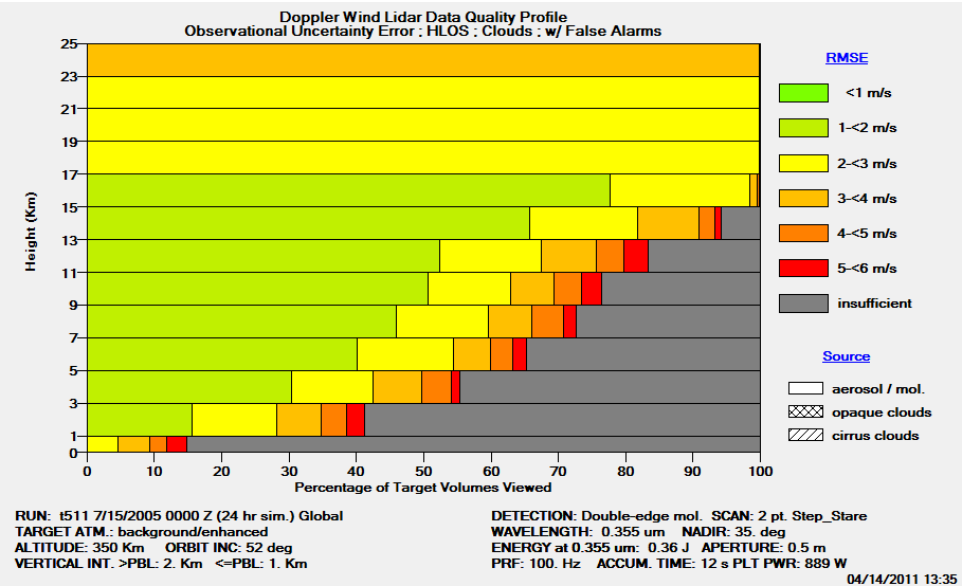


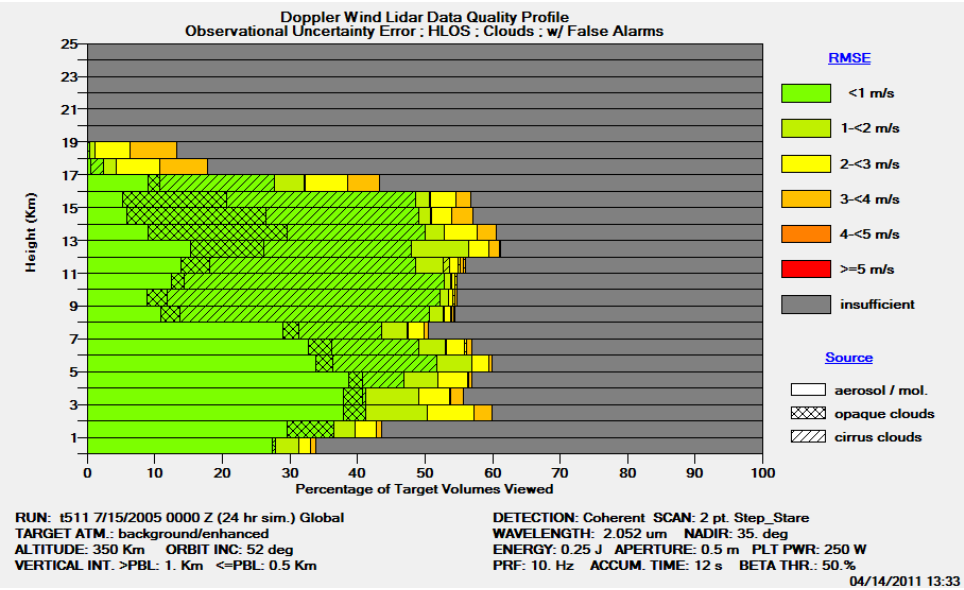
# Somalia LLJ at 1500 meters MSL



# Summary of WISSCR data products for 24 hours over Monsoon Region

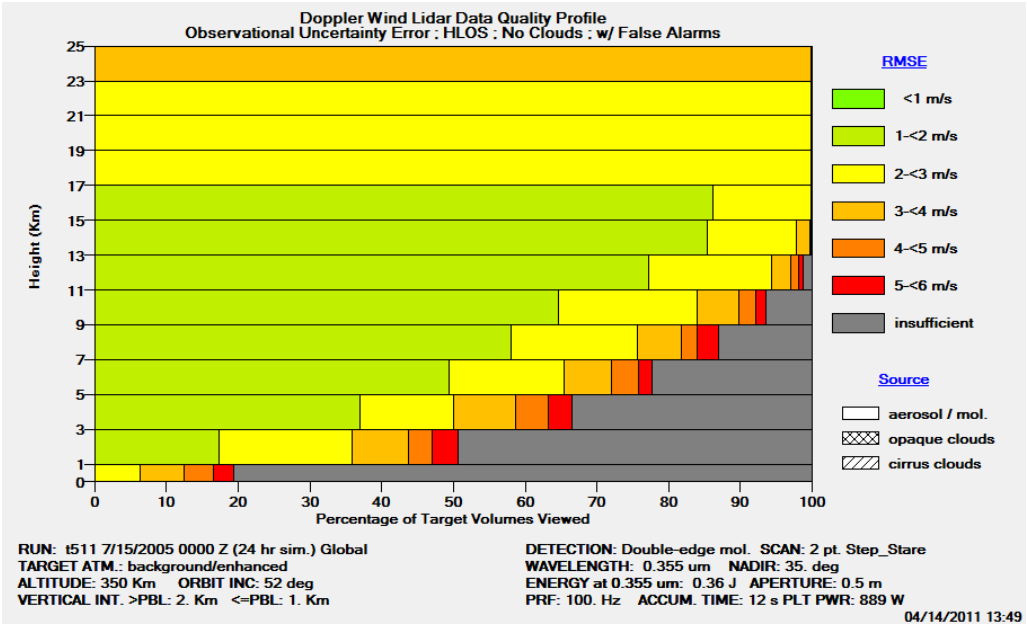
The charts show the percentage of the attempts to make a wind observation at each level below 25km during a 24 hour period over the Monsoon Region. The colors denote accuracy (m/s) and the hatching in the lower figure denote returns from clouds, including those that are penetrated by the laser beam. The top figure represent the performance of the direct detection subsystem of the hybrid technology WISSCR. Note the 2 km vertical resolution and the best accuracy of 1-2 m/s RMSE. The lower figure represents the performance of the coherent subsystem. Note the vertical resolution of 1 km and the returns from clouds (cirrus, subvisual cirrus and opaque. The accuracies are mostly in the < 1 m/s level.

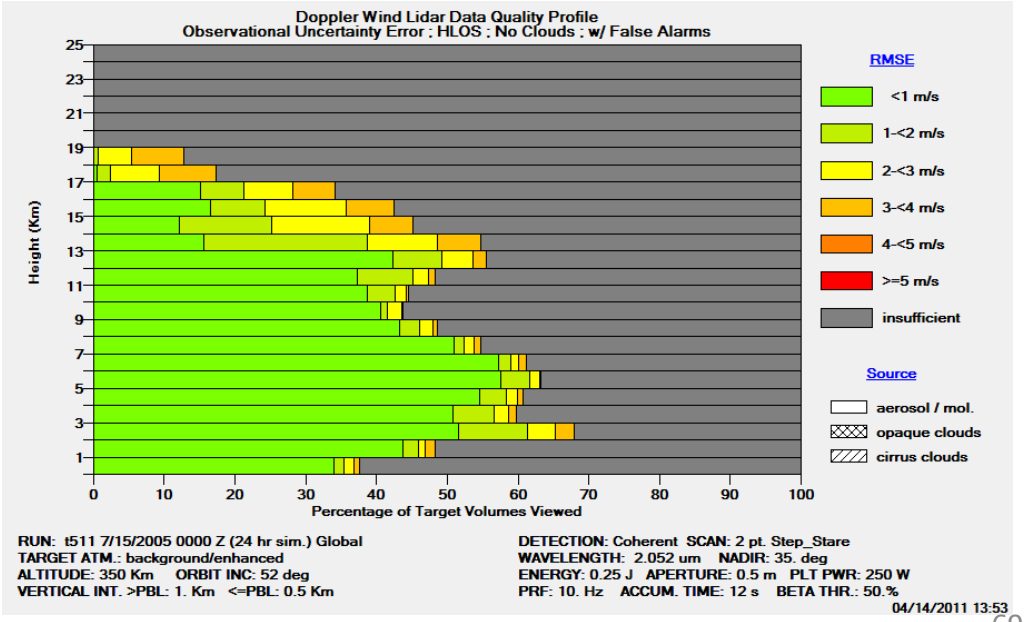


# Summary of WISSCR data products for 24 hours over Monsoon Region

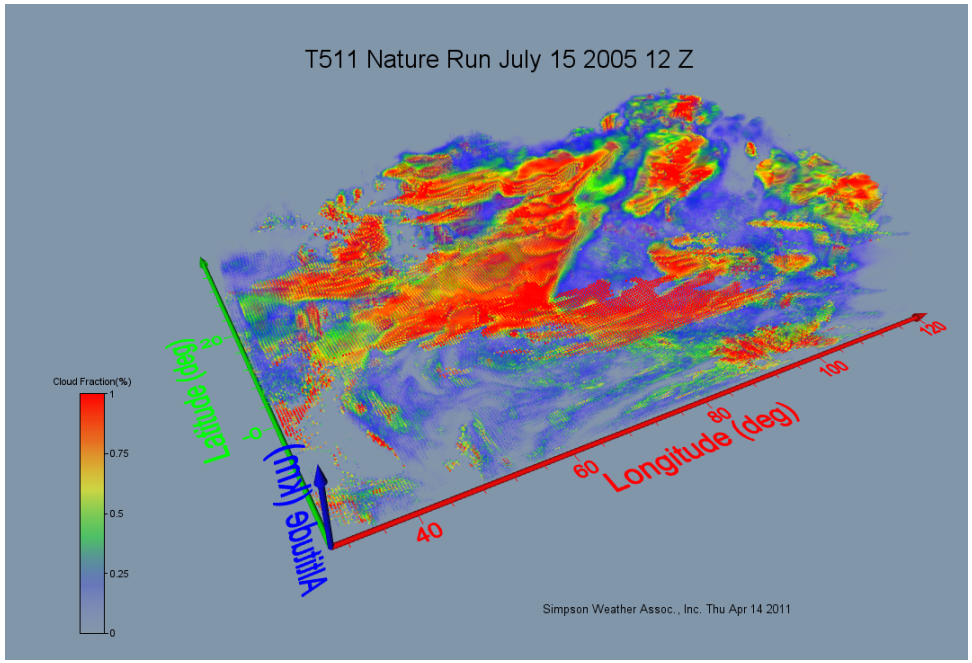
This is a similar presentation as that in the previous slide except that the simulation was done with no clouds were used from the T511 Nature Run. Note that there is actually more useful wind measurements available from the coherent system when clouds are present.

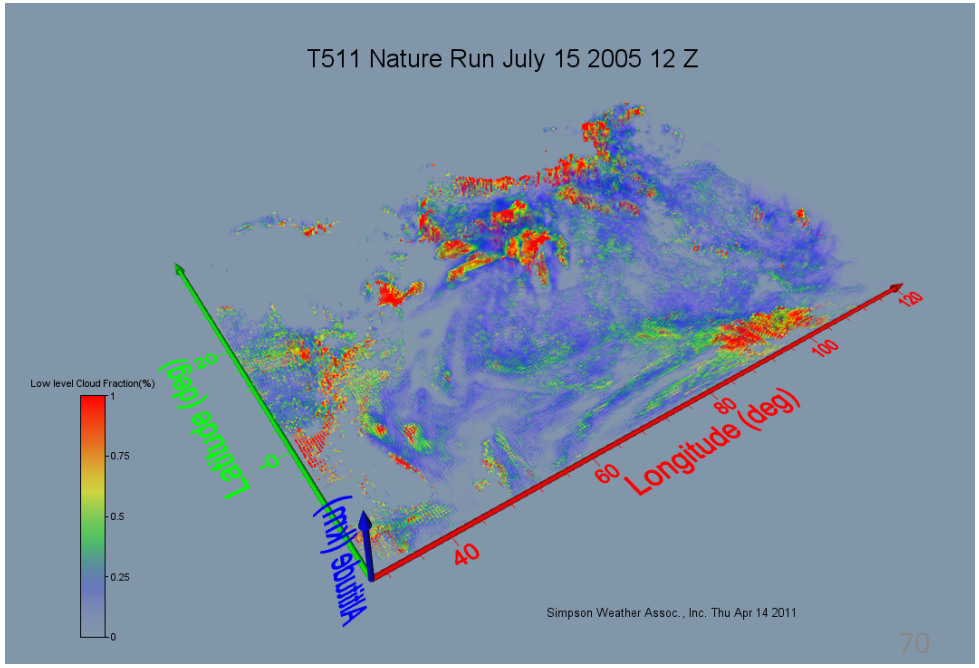


# Cloud Coverage as represented in T511 Nature Run

The top figure illustrates the cloud coverage provided by the T511 Nature Run for all levels within the troposphere. The lower figure represents only those clouds below 5000 meters. Note that much of the upper level cloud is of sufficiently low optical depth that the coherent subsystem can obtain a good wind measurement within the cloud layer and also penetrate to aerosol and cloud layers below.

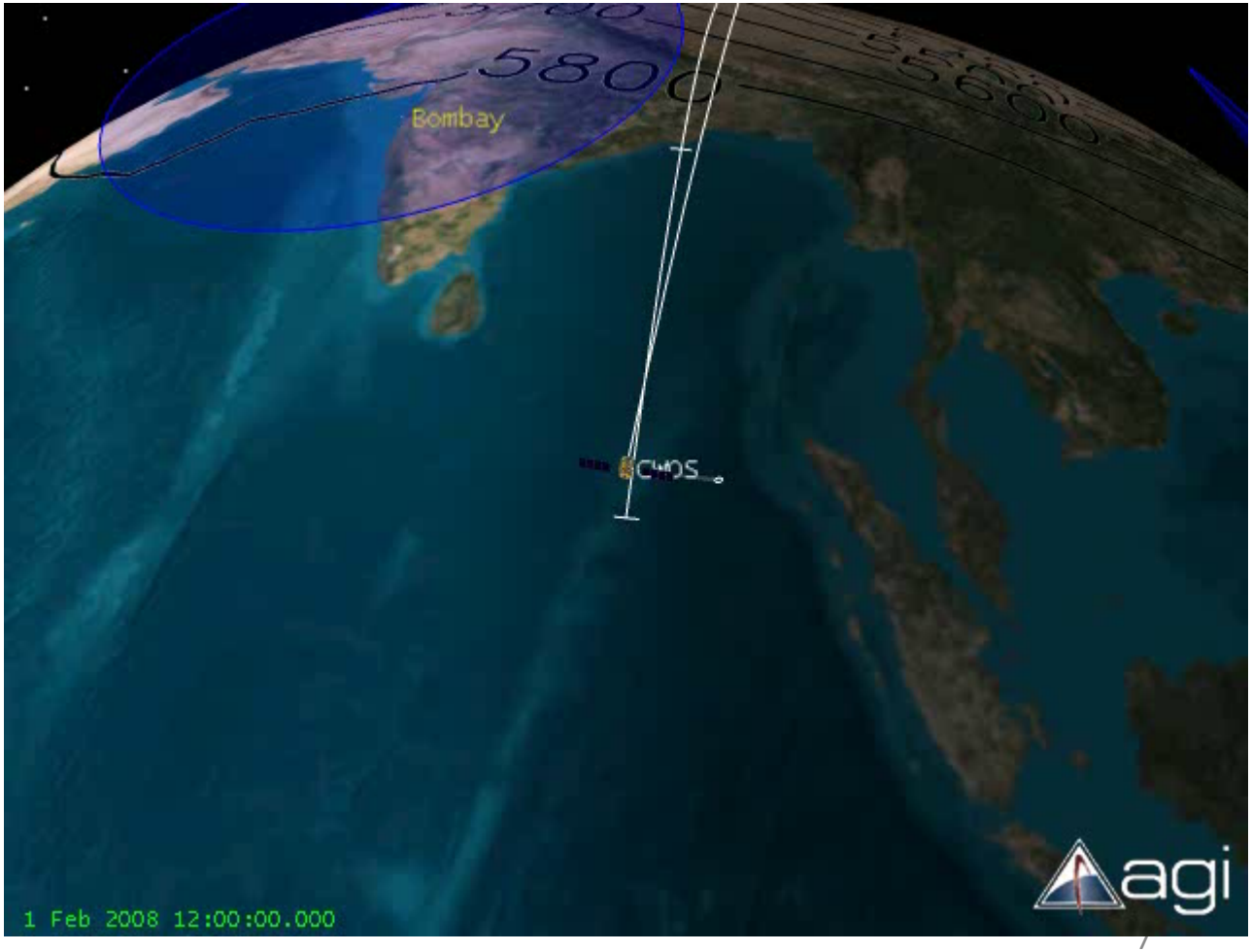


# Summary

- Clouds will be a major factor in DWL coverage of significant weather features
  - A molecular system will be negatively effected by the high clouds in the tropics.
  - An aerosol system will provide winds within most of the high level clouds and within the lower troposphere below.
- The hybrid technology approach provides the best vertical coverage for science investigations in the tropics
  - A molecular subsystem is critical to tropospheric/stratospheric exchange investigations
  - The aerosol subsystem is critical for accurate, high spatial resolution measurements in cloudy scenes and in the lower troposphere.

CLIP



# Cloud Motion Vectors

- Challenge was to determine subset of model clouds that would be suitable for use by CMV algorithms.
- Simulation of navigation errors and height assignment errors produced CMVs with both the random (~ 3 -5m/s) and bias (~ 1.5 m/s slow) errors.
- Number of CMVs available to DA is controlled by simple  random thinning.

# Objectives

- Generate simulated Cloud Motion Winds (CMW) using a “Nature Run” from a global numerical model
- Provide CMW where the model indicates “trackable” cloud targets
- Produce velocity errors (e.g. slow speed bias) similar to those experienced with real CMWs
- Apply similar approach to simulating WVMW

GOES-E observed CMWs for 0000 UTC Sep 9, 2002.
(a) distribution of CMWs by pressure
(b) distribution of CMWs by wind speed.

# Distribution of GOES-E simulated CMWs by pressure for 1200 UTC Feb 7

# Speed Bias

- Identify trackable clouds
- Determine physical thickness of cloud
- Assign wind speed from middle of cloud to the height of the cloud top (limited to 300 mb thickness)

TABLE III: Speed bias (m/s) for all simulated CMWs listed in TABLE II.

| | BIAS VS CMW SPEED | | BIAS VS RAOB SPEED | |
|---|---|---|---|---|
| Wind Speed (m/s) | BIAS (m/s) | Pct of Winds | BIAS (m/s) | Pct of Winds |
| | | | | |
| 0 – 10 | -0.52 | 49 | -0.02 | 45 |
| 10-20 | -1.73 | 32 | -1.65 | 31 |
| 20-30 | -3.50 | 14 | -3.25 | 14 |
| 30-40 | -3.97 | 4 | -5.02 | 8 |
| 40-50 | -3.85 | 1 | -6.50 | 2 |
| TOTAL | -1.48 | | -1.48 | |

Results consistent with published values:(exception is the reported "fast bias" in the mid-levels of the tropics)

Tomassini et al, 1999

Bormann et al 2001

Lalaurette and Garcia-Mendez 2001

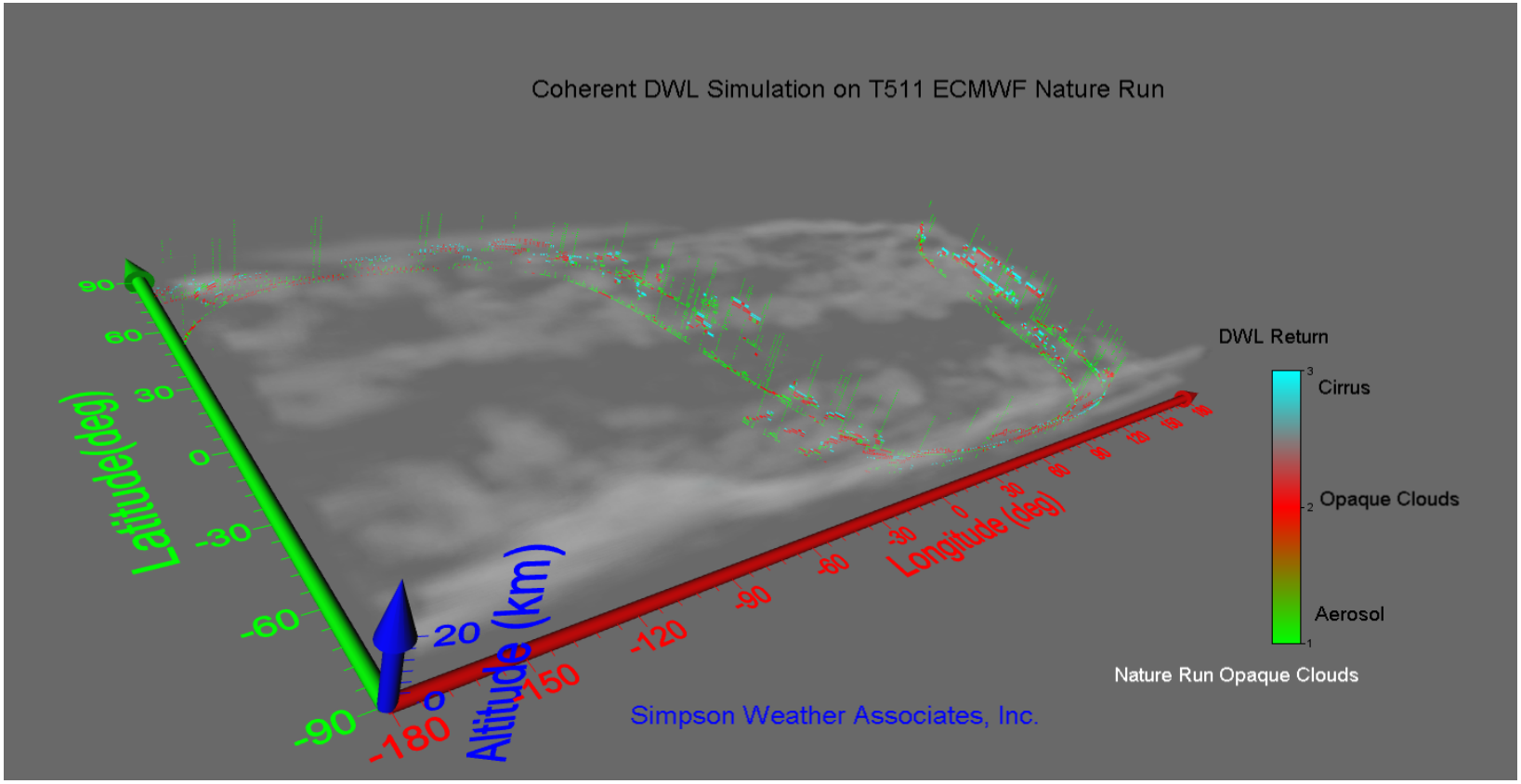
Rao et al 2002

# Current DWL/CMV effort at SWA

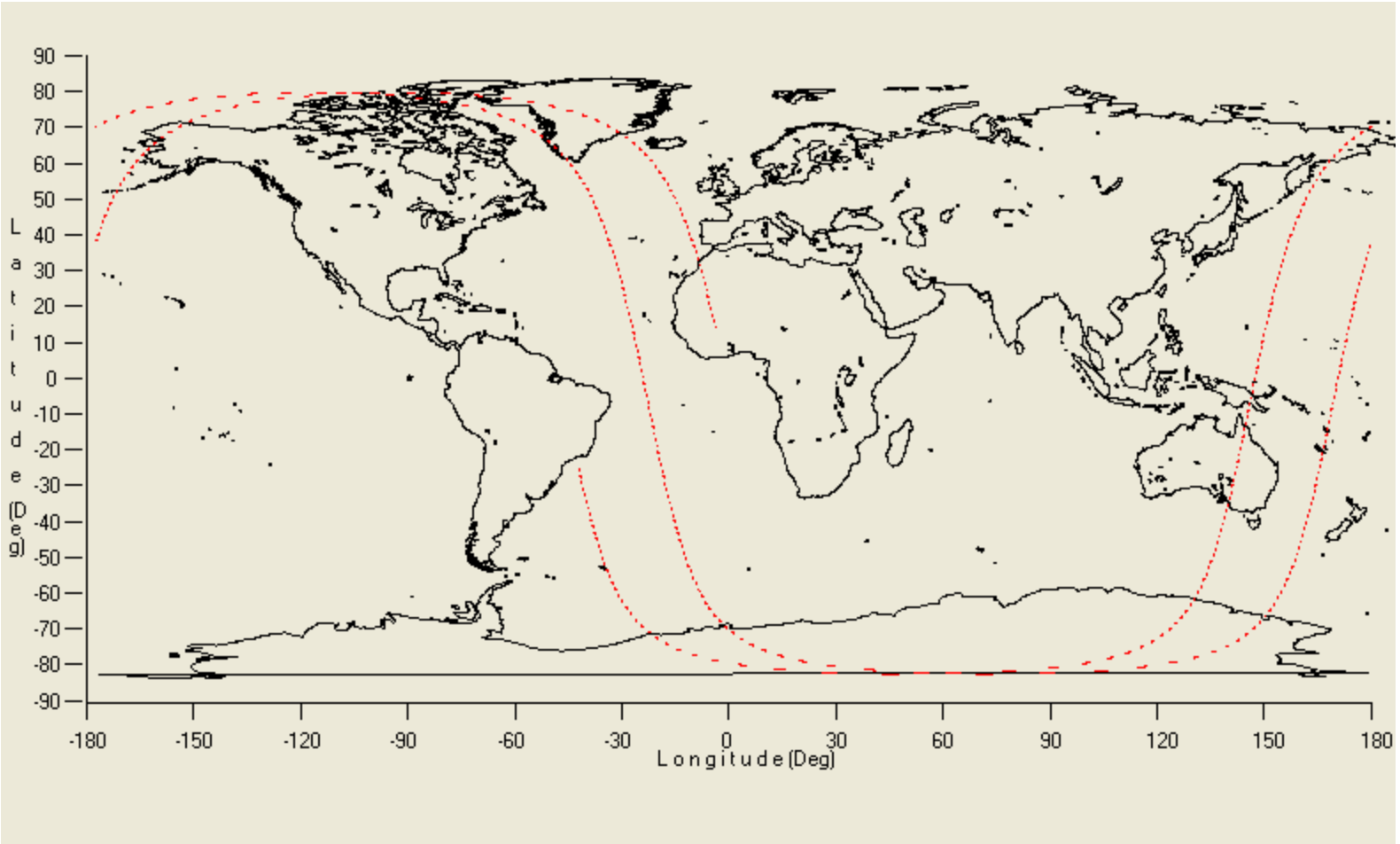
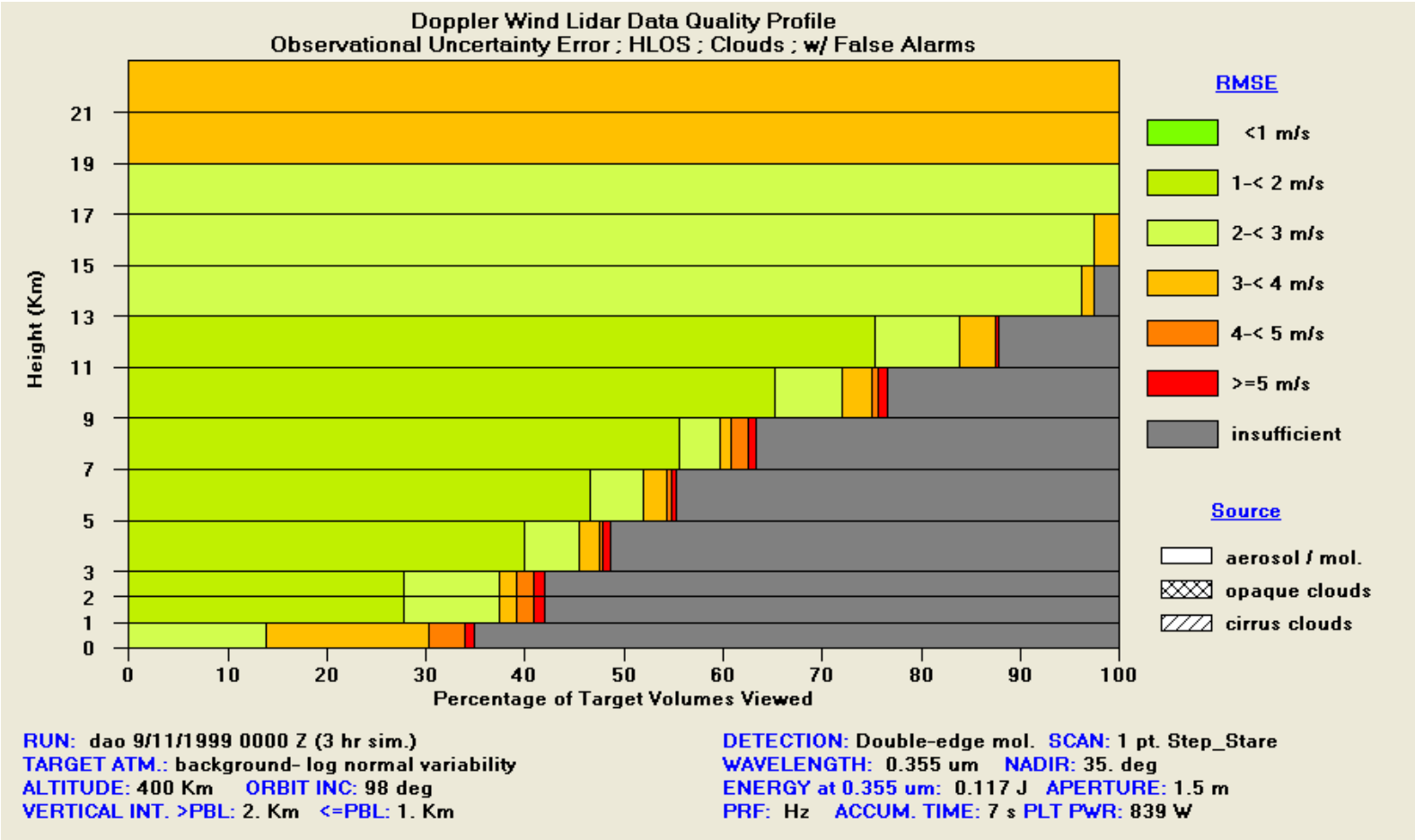
- Simulating realistic and proposed DWL instrument concept(s) for use in SIVO (NASA/GSFC) experiments and NCEP OSSEs.
  - Currently producing data products from a hybrid DWL as endorsed in the NRC Decadal Survey and various DWL advisory groups
- Simulating CMVs for SIVO and NCEP.
- Simulating various ADM follow-on missions.

# Simulation of GWOS data

Simpson Weather Associates



# ADM coverage



# ADM Molecular