Expected Characteristics of Global Wind Profile Measurements with a Scanning, Hybrid, Doppler Lidar System

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Outline

- Geometry
- Sensor
- Measurement Requirements
- Comparison to Rawinsonde Network
- Tradeoffs

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Wayman E. Baker
G. David Emmitt
Rod G. Frehlich
Bruce M. Gentry
many others

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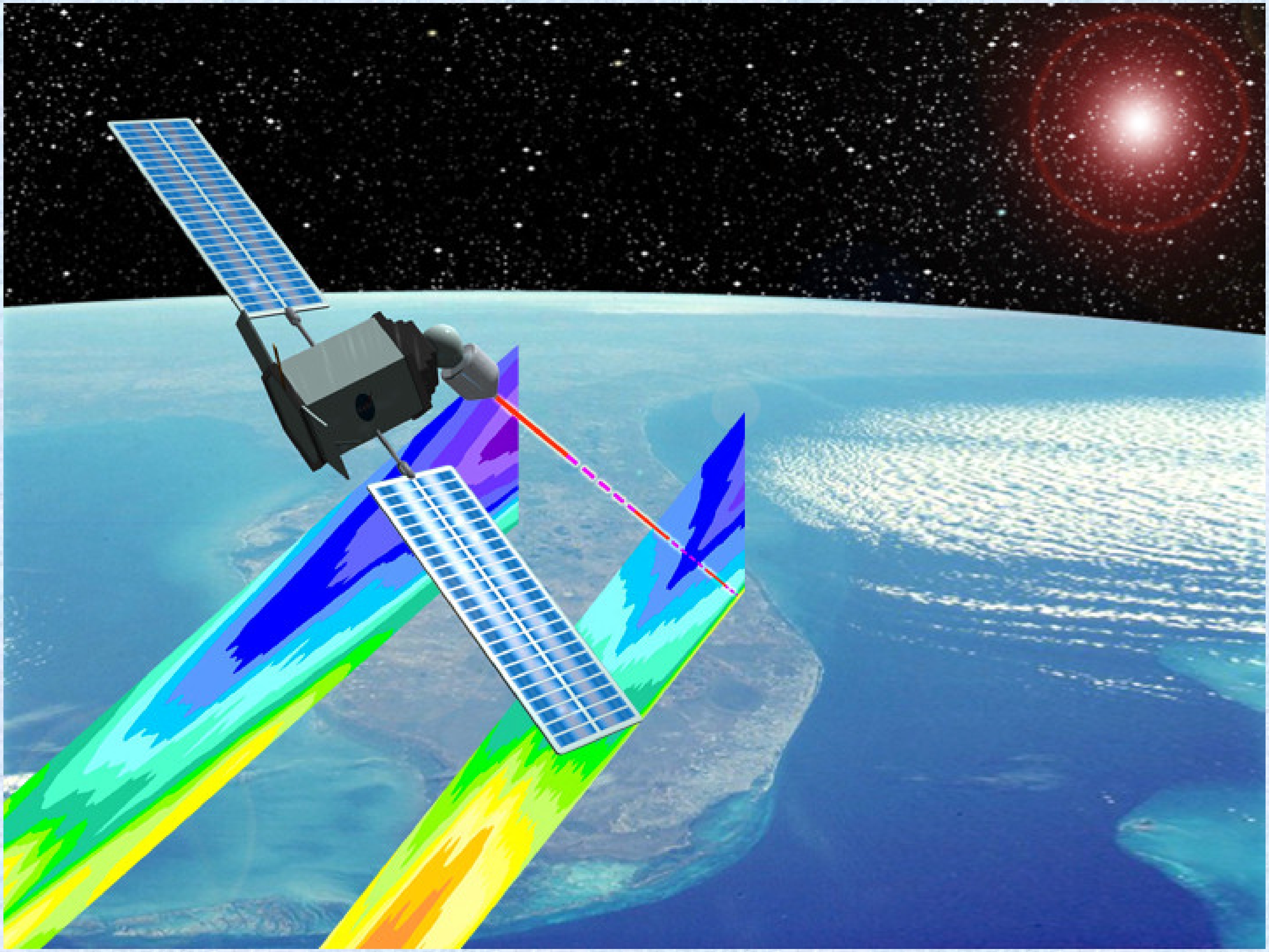
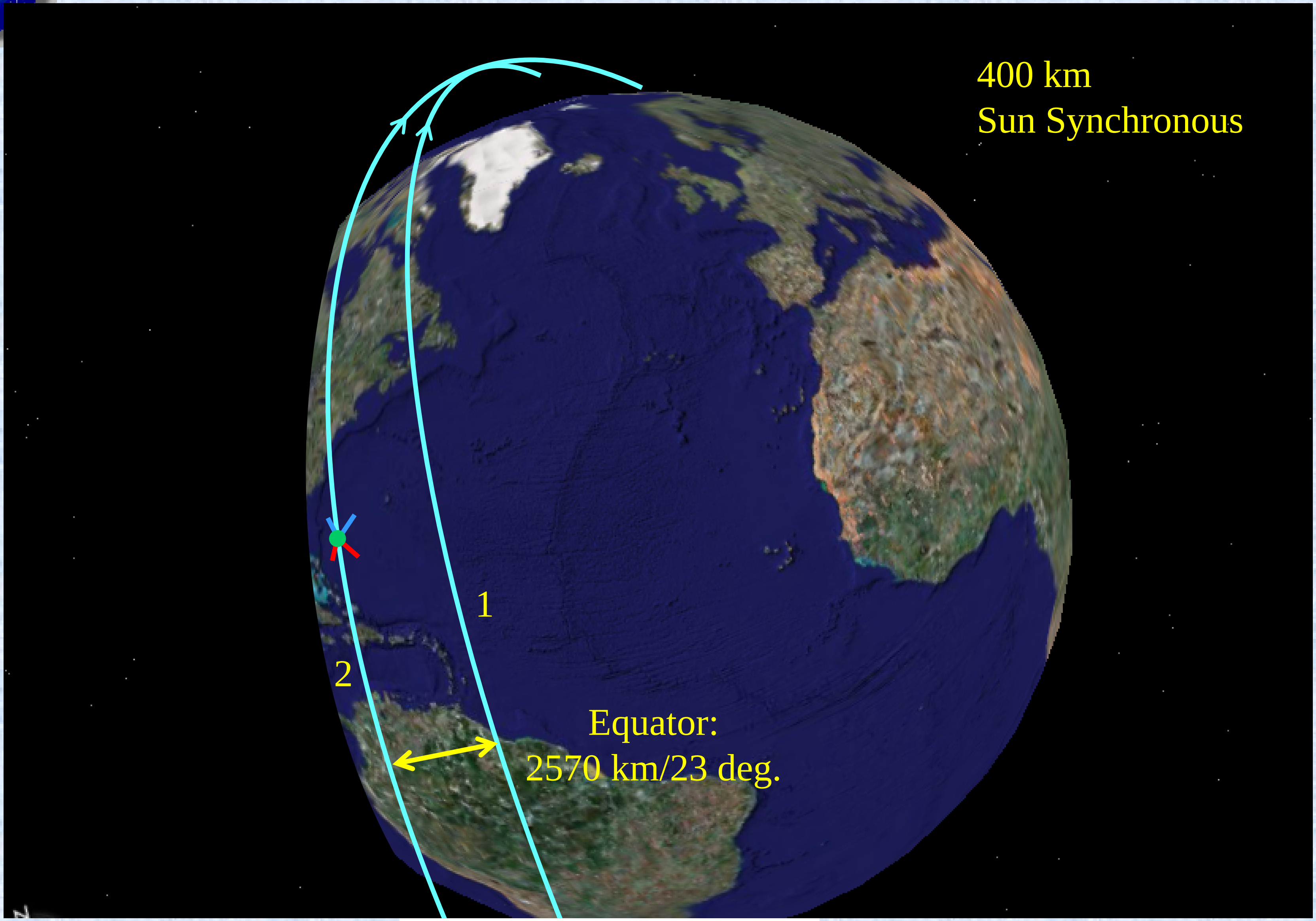
Two “Horizontal” Wind Profile “Tracks”



Hybrid Doppler Wind Lidar – Two Successive Orbits



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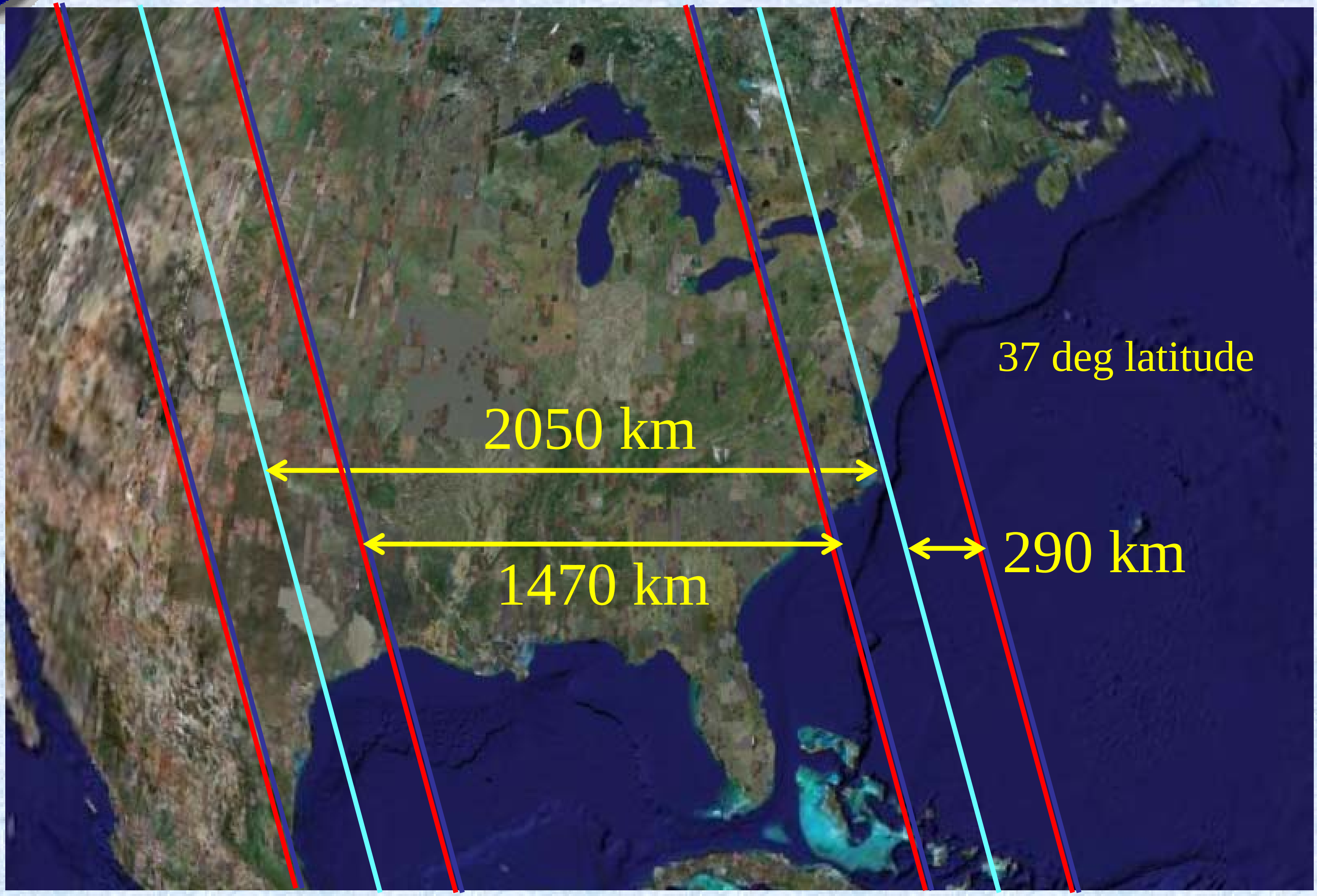
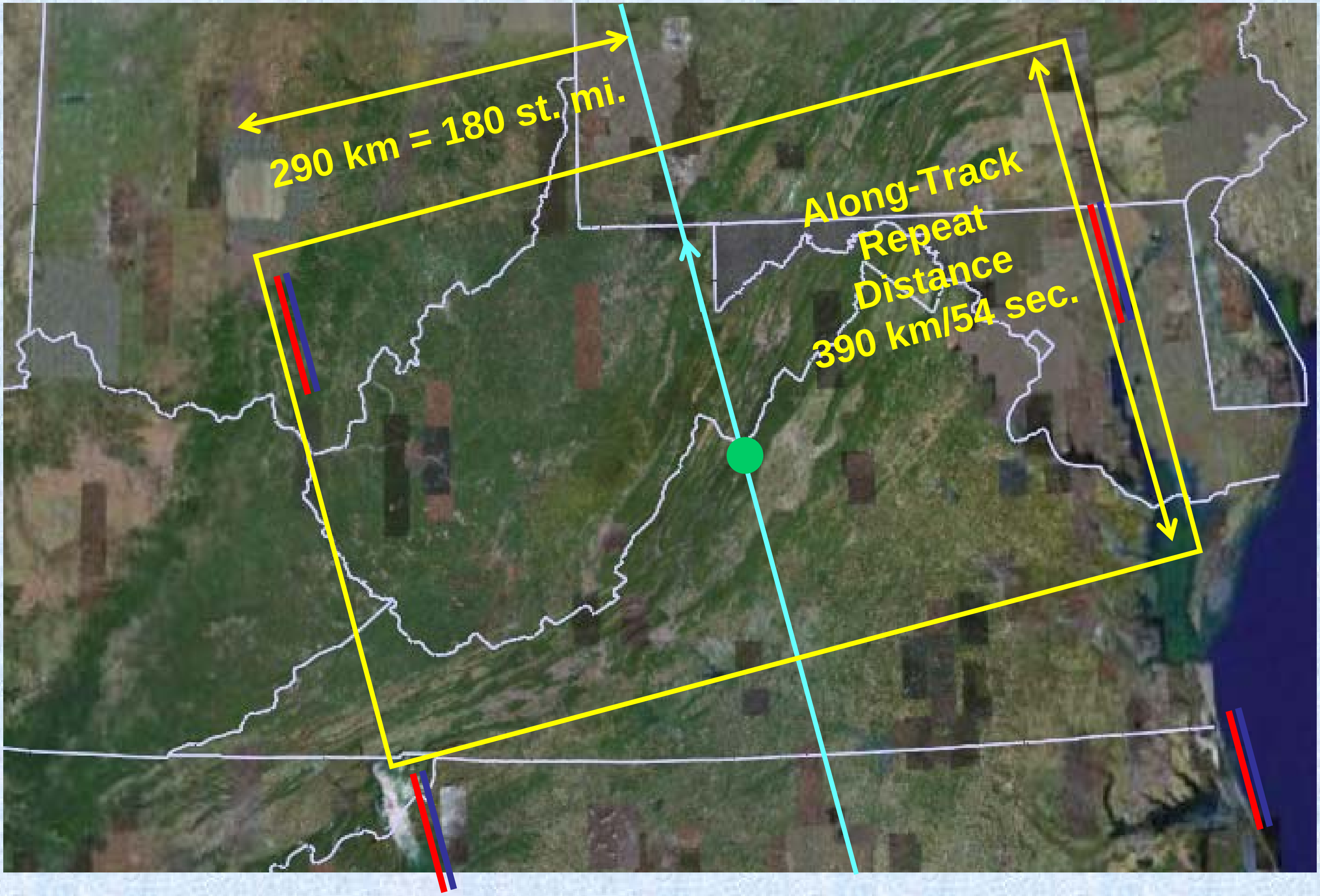
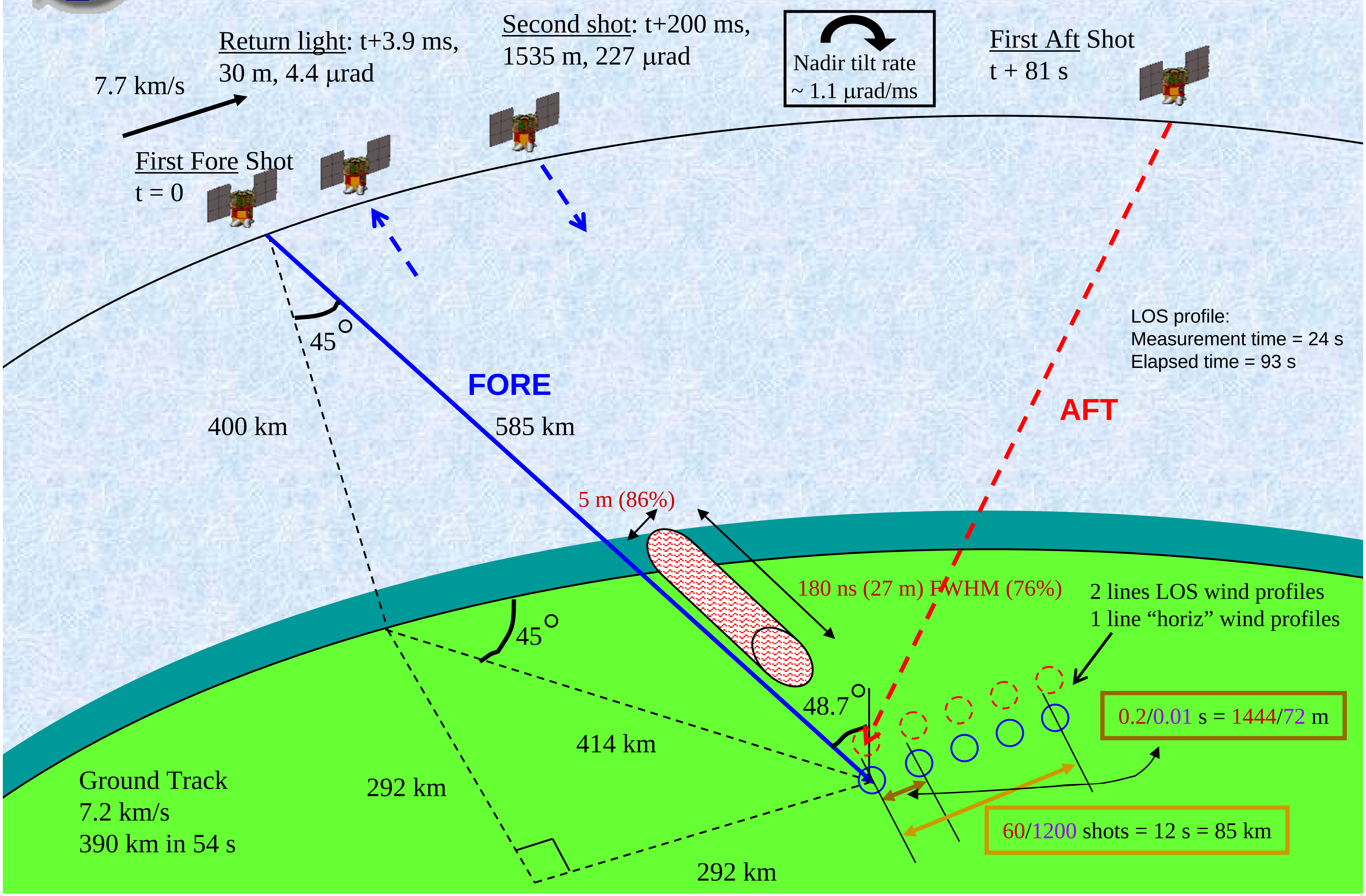


Hybrid Doppler Wind Lidar – One Measurement Pattern



Hybrid Doppler Wind Lidar
Lidar Shot Accumulation for LOS Wind Profile



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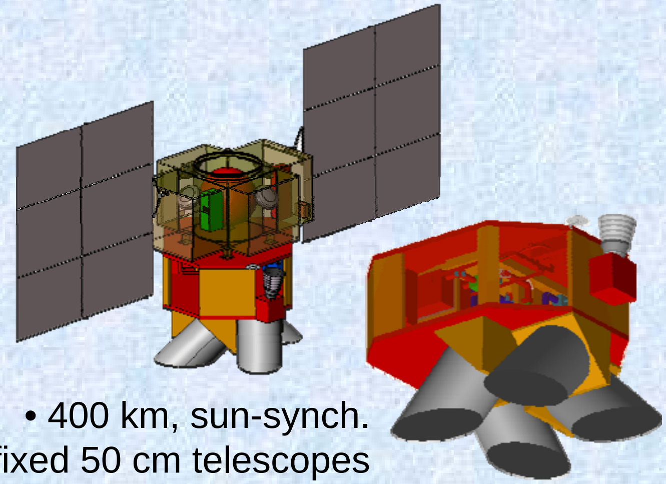
Wind Sensor

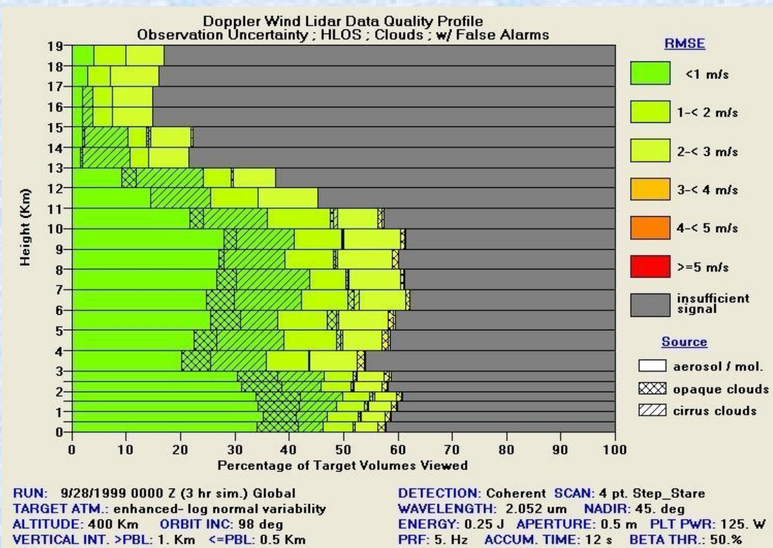
Hybrid Pulsed Doppler Wind Lidar System

Direct Detection Pulsed Doppler Lidar – 355 nm	← GSFC
Coherent Detection Pulsed Doppler Lidar – 2053 nm	← LaRC

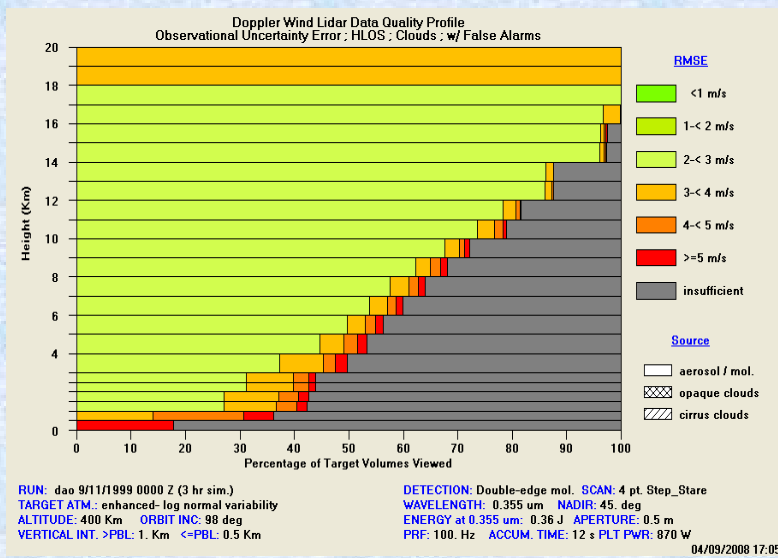


- 400 km, sun-synch.
- 4 fixed 50 cm telescopes
- 45 deg. nadir angle

Coherent Detection
250 mJ x 5 Hz = 1.25 W
WPE ~ 2%



Direct Detection
800 mJ x 100 Hz = 80 W
WPE ~ 10%



Courtesy: G. David Emmitt

Wind Sensor

Hybrid Doppler Lidar Synergisms

- Coherent works better as altitude goes down
- Direct works better as altitude goes up
- Overlapping altitudes provide intercomparison checks
- Coverage of coherent will be improved if direct measurement is used as guide for velocity search
- Coherent surface returns can be used to calibrate spacecraft attitude for both lidars
- Coherent can measure below a cloud deck by poking through holes

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Wind Measurement Requirements

Societal Benefit Requirements

↓

Science Requirements

↓

Wind Measurement Requirements

↓

Assumed Atmospheric Parameters

Assumed Orbit Parameters
Assumed Earth Surface Parameters

↓

Assumed Lidar Efficiencies

↓

Coherent Doppler Lidar Parameters
Direct Doppler Lidar Parameters
Spacecraft Requirements

↓

Mission Design & Cost

Wind Measurement Requirements

NASA/NOAA

- Large effort to formulate wind measurement requirements occurred in 2001 by NASA, NOAA, university, and private industry scientists under purview of NASA's Global Tropospheric Wind Sounder program
- Complete requirements including definitions, comments, and design atmospheres fill 24 pages in:
    - A. Valinia, J. Neff, S. Ismail, M. J. Kavaya, U. N. Singh, et al, "Lidar Technologies Working Group Report," Final Report of the NASA Earth Science Technology Office (ESTO) Laser/Lidar Technology Requirements Working Group (June 2006)
- Published requirements are "almost" current. Some tweaking has occurred since.

Wind Measurement Requirements

NASA/NOAA (Partial List)

	Science Demonstration	Operational	
Minimum Vertical Depth of Regard (DOR)	0-20	0-20	km
Maximum Vertical Resolution: Tropopause to Top of DOR Top of BL to Tropopause (~12 km) Surface to Top of BL (~2 km)	 4 2 1	 3 1 0.5	 km km km
Maximum Horizontal Resolution[A]	350	350	km
Minimum Number of Horizontal[A] Wind Tracks[B]	2	4	-
Minimum Number of Collocated LOS Wind Measurements for Horizontal[A] Wind Calculation	2 = pair	2 = pair	-
Maximum Velocity Error[C] Above BL In BL	3 2	3 2	m/s m/s
Minimum Wind Measurement Coverage[D]	50	50	%

[A] Horizontal winds are not actually calculated; rather two LOS winds with appropriate angle spacing and collocation are measured for an "effective" horizontal wind measurement. The two LOS winds are reported to the user. [B] The 4 cross-track measurements do not have to occur at the same along-track coordinate; staggering is OK. [C] Error = 1σ LOS wind random error, projected to a horizontal plane; from all lidar, geometry, pointing, atmosphere, signal processing, and sampling effects. The true wind is defined as the linear average, over a 100 x 100 km box centered on the LOS wind location, of the true 3-D wind projected onto the lidar beam direction provided with the data. [D]Scored per vertical layer per LOS measurement not counting thick clouds

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Doppler Lidar Mission Compared to Rawinsonde Network

World rawinsonde network
- 850 worldwide locations (81 in USA)
  - average earth spacing = 775 km
  - average land spacing = 425 km
  - average coterminous USA spacing = 310 km
- 2/day launches
- 1700 rawinsonde launches/day
- <u>1700 vector wind profiles/day</u>

Orbiting Hybrid Doppler Lidar System
- 2 vector wind profiles/350 km
- 2 vector wind profiles/48.5 s
- <u>3566 vector wind profiles/day</u>

Factor of 2.1 more vector wind profiles

More evenly distributed including oceans and lakes

Quality and calibration knowledge

Consistent delivery and latency

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Tradeoffs

Coherent Detection Doppler Wind Lidar

Velocity measurement performance is a function of

$$\frac{E \times \sqrt{PRF} \times \sqrt{\text{Vert Res}} \times D^2 \times e^{-\left[\frac{1.1 D \theta_{MISAL}}{\lambda}\right]^2}}{R^2}$$

Direct Detection Doppler Wind Lidar

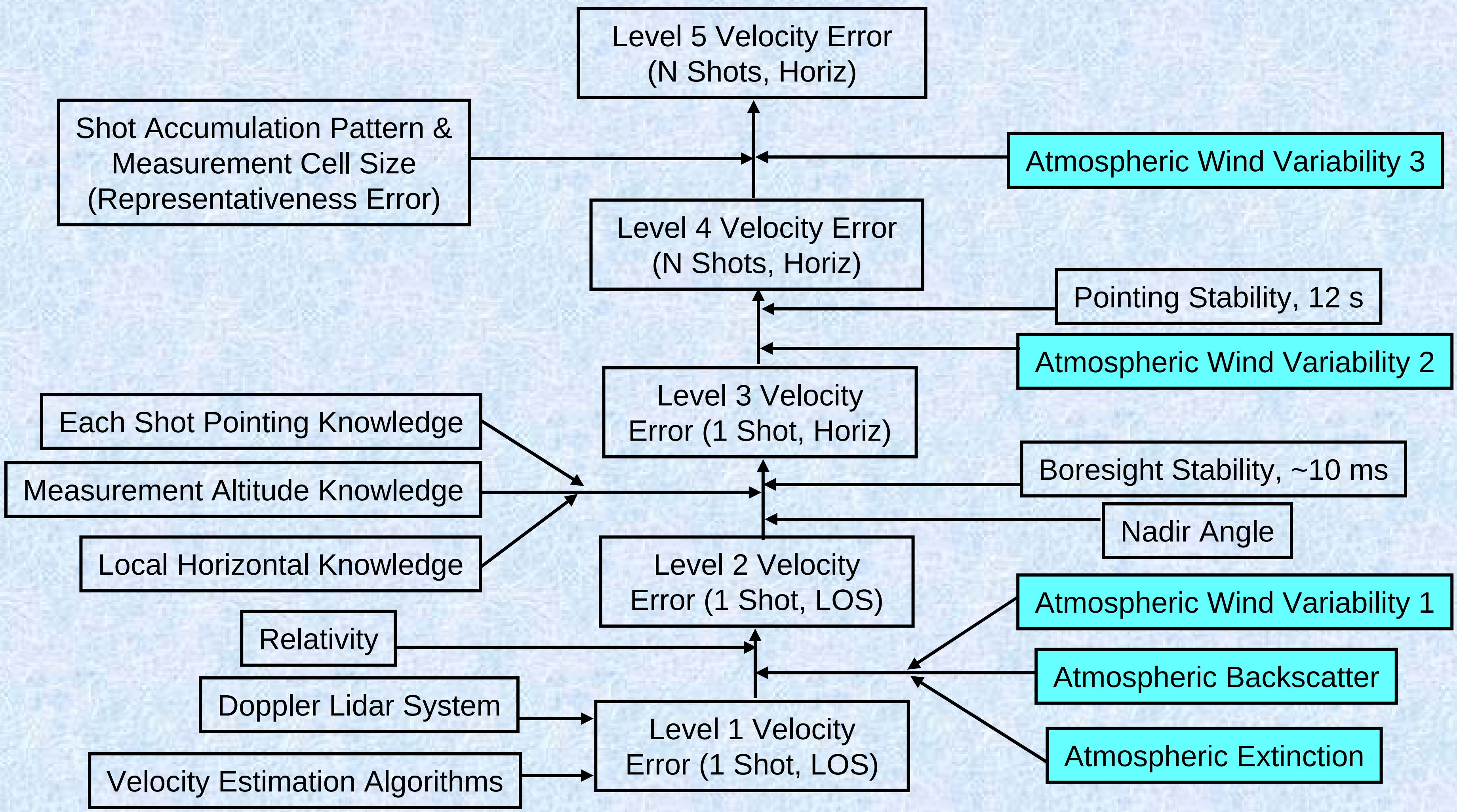
$$\text{Velocity Error} \propto \frac{R}{D\sqrt{E \times PRF \times \text{Vert Res}}}$$

Tradeoffs	Coherent	Direct
Vertical Resolution, VR Horizontal Resolution, HR Number Wind Tracks, WT Velocity Performance, VP (Direct VP = velocity error) (Coherent VP = minimum backscatter requirement)	VR x HR / WT = constant	
	VR x VP^2 = constant	
	HR x VP^2 = constant	
	WT / VP^2 = constant	
	PRF x VR X HR x VP^2 / WT = constant	
	E^2 x VR X HR x VP^2 / WT = constant	E x VR X HR x VP^2 / WT = constant
	D^4 x VR X HR x VP^2 / WT = constant If θ_{misal} x D = constant	D^2 x VR X HR x VP^2 / WT = constant

Questions

Backup Slides

LOS Velocity Error Budget



LOS Velocity Error Budget

• Level 1 – Basic Doppler lidar system with processing algorithms
• Level 2 – Add atmospheric effects and relativity for single shot
• Level 3 – Add conversion to horizontal and correct tagging of measurement for user
• Level 4 – Add accumulation of N shots for one LOS profile
• Level 5 – Add sampling or representativeness error

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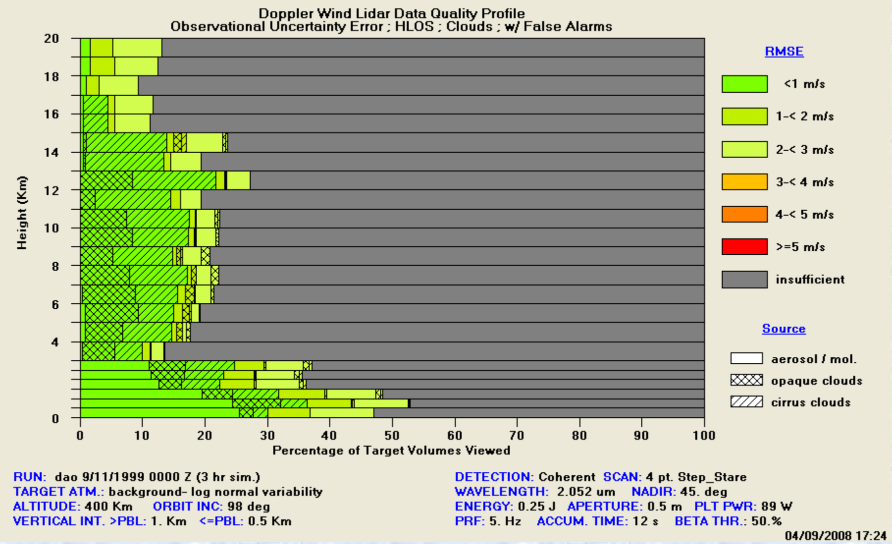

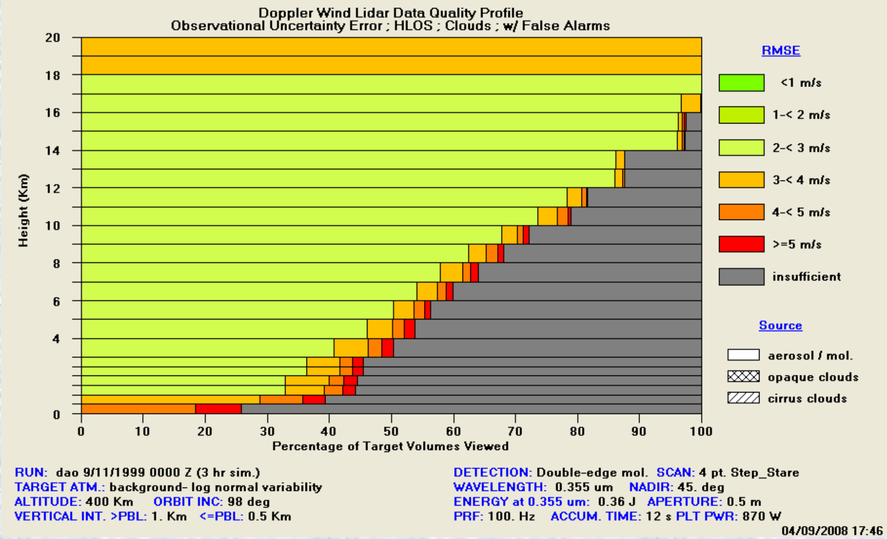

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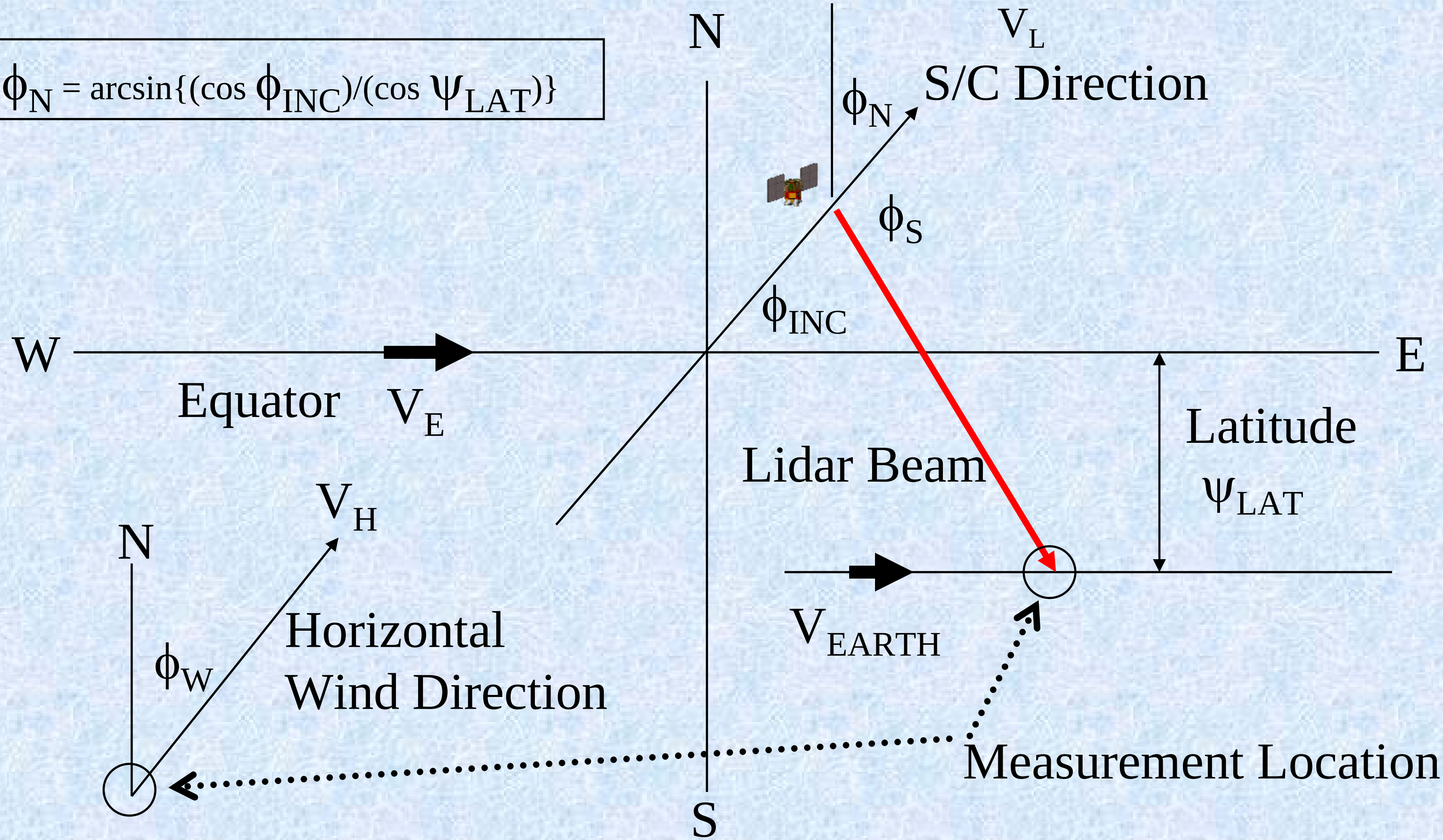
Orbiting Doppler Wind Lidar

Pointing Geometry - Top View

$\phi_N = \arcsin\{(\cos \phi_{INC})/(\cos \psi_{LAT})\}$



Orbiting Doppler Wind Lidar at 400 km

Pointing Geometry - Side View

$\theta_T = \arcsin[(R_E + Z_L) \sin\theta_L / (R_E + Z_T)]$

Z_L = 400 km
θ_L = 45 deg.
Z_T = 0 km (example)
θ_T = 48.7 deg.
V_L = 7676 m/s
R_T = 585 km
R_R = 414 km
R_E = 6371 ±10.7 km