Concept for a U.S. Space-Based Wind Lidar: Status and Current Activities

JCSDA and EMC Seminar

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Outline

- Background
- Which Upper Air Observations Do We Need for NWP?
- Forecast Impact Results
- Need for Improved Accuracy of Transport Estimates for Climate Applications
- Why Wind Lidar? *Societal Benefits at a Glance*. . .
- A U.S. Wind Lidar Effort – Why now?
- Concept for a U.S. Space-Based Wind Lidar
- Recent Advances in Technology Readiness
- Concluding Remarks

Background

- The National Research Council (NRC) Decadal Survey report published in 2007 recommended a global wind mission
  - The NRC Weather Panel determined that a hybrid Doppler Wind Lidar (DWL) in low Earth orbit could make a **transformational** impact on global tropospheric wind analyses

- Independent modeling studies at NCEP, ESRL, NASA and ECMWF show tropospheric wind profiles to be the single most beneficial measurement now absent from the Global Observing System

- A number of recent papers have suggested that the general circulation of the atmosphere has considerable variability on decadal timescales, some of which may be due to greenhouse forcing.[1,2] Each of those studies, however, relies on imperfect climate models and datasets that are limited in their ability to provide a complete picture of large-scale circulation change.

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[1] **Chen, J.Y., B. E. Carlson, and A. D. Del Genio, 2002: Evidence for strengthening of the tropical general circulation in the 1990s, *Science*, *295* (5556), 838 – 841.**

[2] **Mitas C. M., and A. Clement, 2006: Recent behavior of the Hadley cell and tropical Thermodynamics in climate models and reanalyses, *Geophys. Res. Lett*., *33*, L01810, doi: 10.1029/2005GL024406.**

Background (Cont)

- ESA planning to launch first DWL in June 2011: Atmospheric Dynamics Mission (ADM)
  - Only has a single perspective view of the target sample volume
  - Only measures line-of-sight (LOS) winds
- A joint NASA/NOAA/DoD global wind mission (Global Wind Observing Sounder – GWOS) offers the best opportunity for the U.S. to demonstrate a wind lidar in space in the coming decade
  - Measures profiles of the horizontal vector wind for the first time

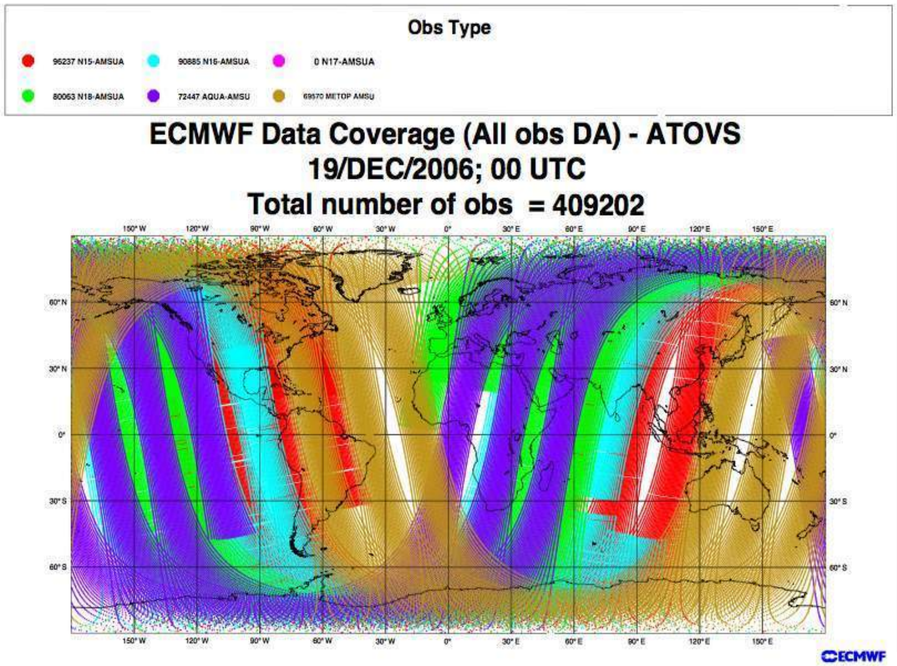
Which Upper Air Observations Do We Need for NWP?

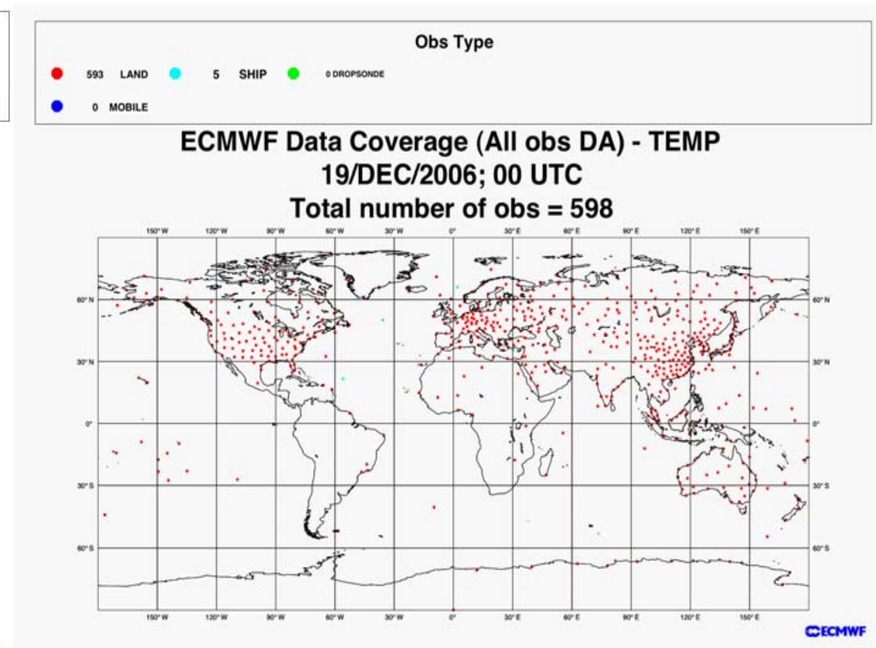
- Numerical weather prediction requires independent observations of the mass (temperature) and wind fields

- The global three-dimensional mass field is well observed from space

- No existing space-based observing system provides vertically resolved wind information

Current Upper Air Mass & Wind Data Coverage

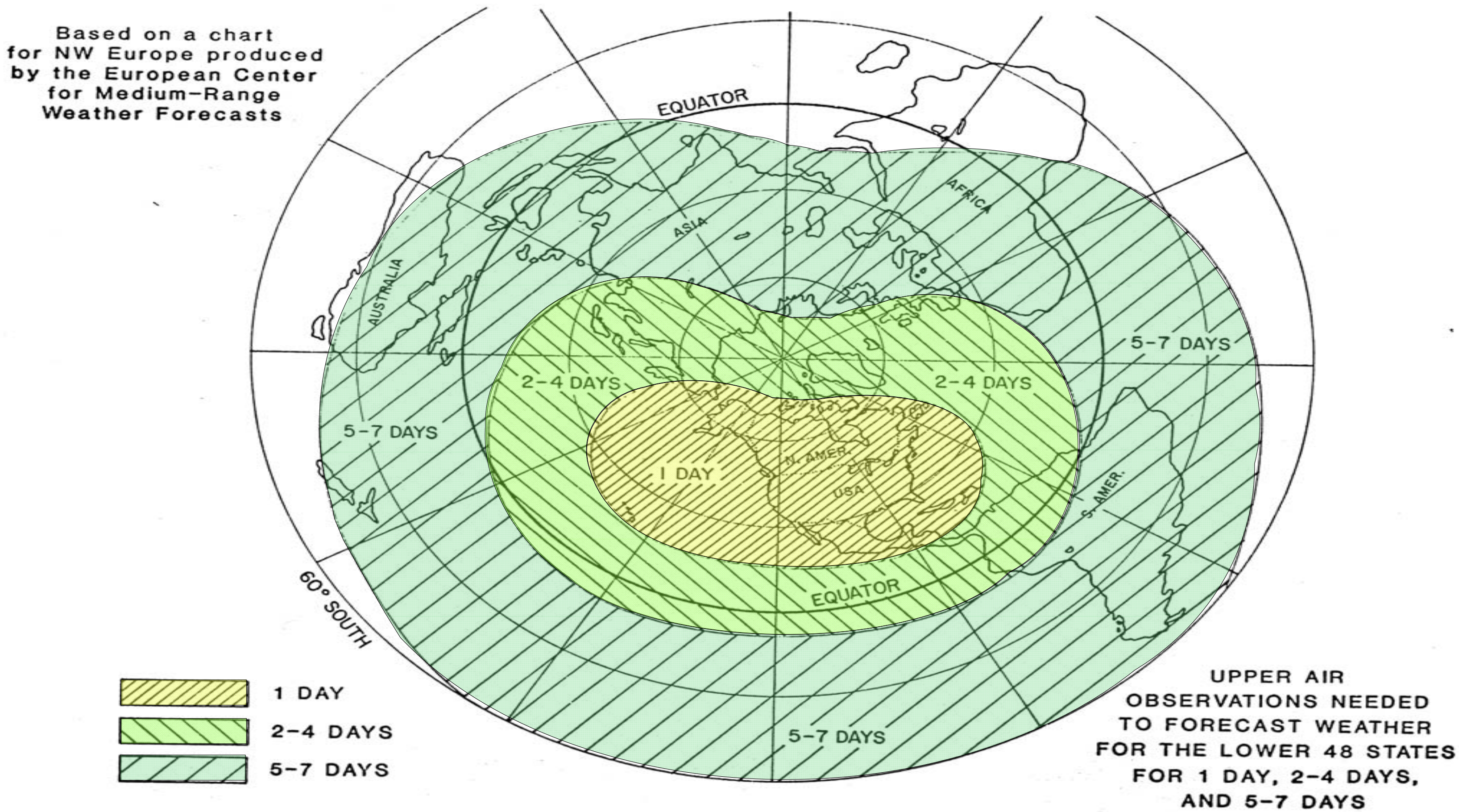




Upper Air
Mass Observations

Upper Air
Wind Observations

Observations Needed as a Function of Forecast Length



Return

Wide Lidar OSSE Results with NCEP Global Model (Masutani et al., 2006)

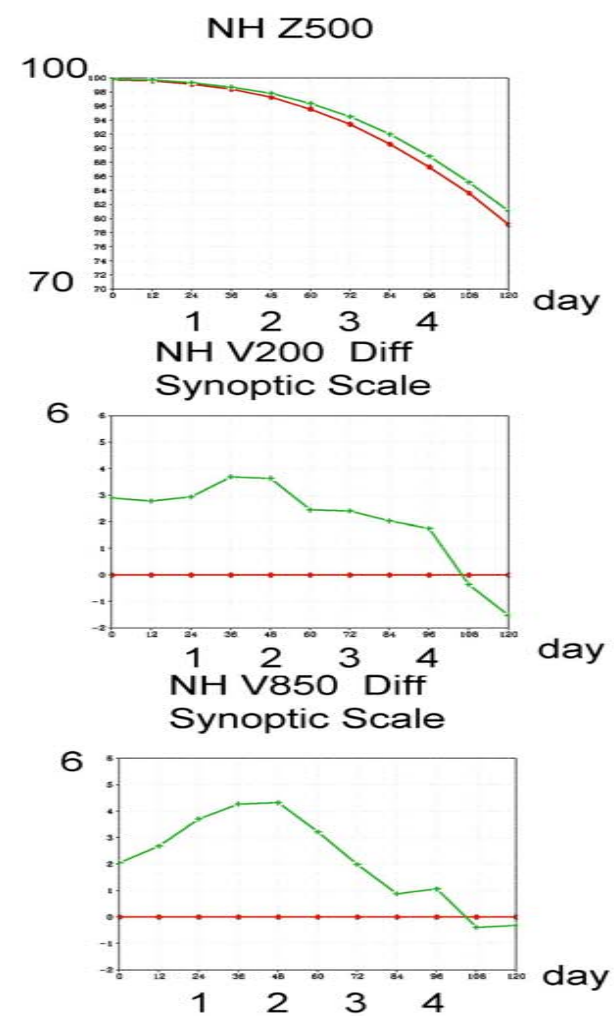
Red: Conventional data + TOVS data only
Green: Conventional data + TOVS + wind lidar

Top: Northern Hemisphere 500 hPa height anomaly correlation

Middle: Northern Hemisphere 200 hPa wind field – synoptic waves only (n = 10 – 20)

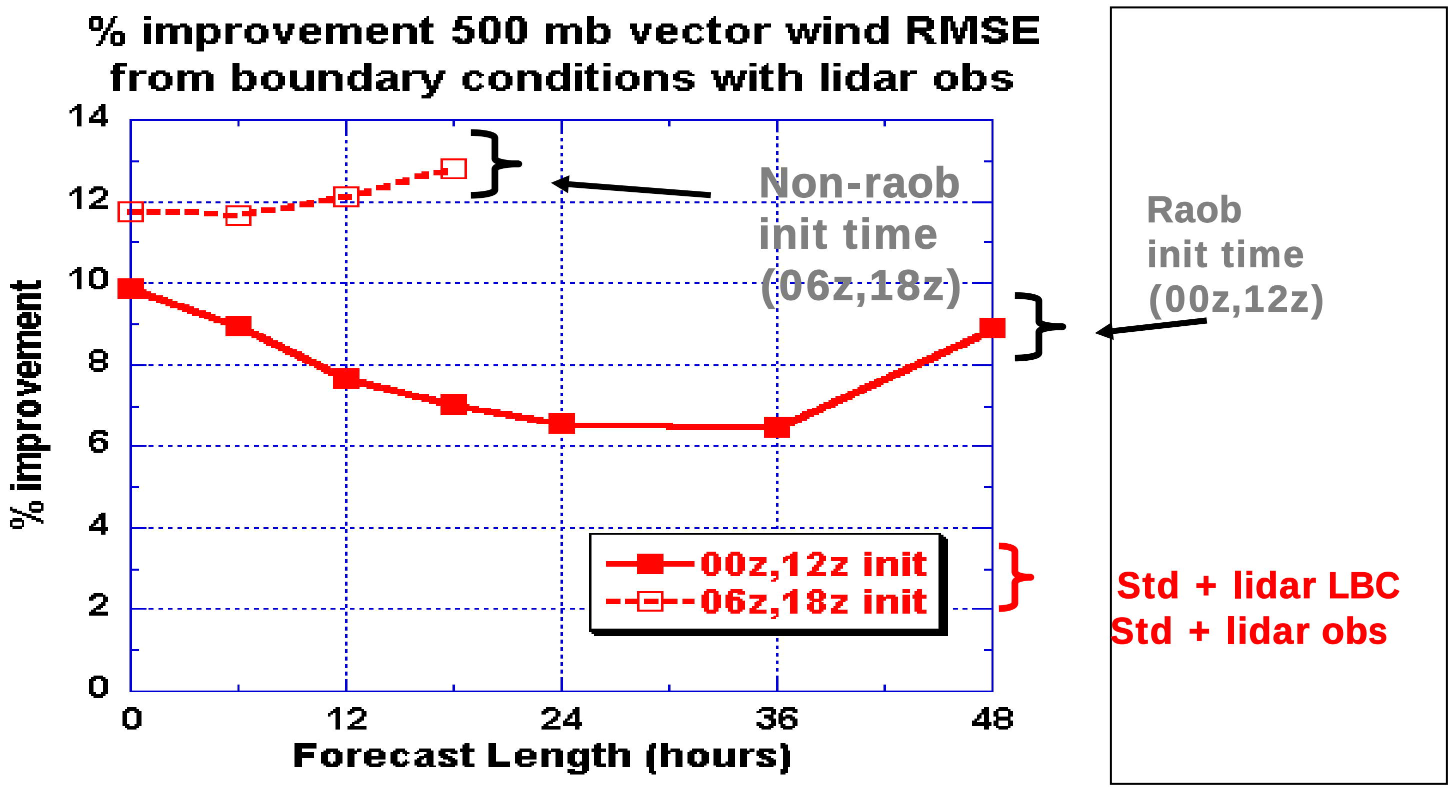
Bottom: Northern Hemisphere 850 hPa wind field – synoptic waves only

Note: Only random error applied to TOVS data; results with coarse resolution (T62) model



ESRL Regional Lidar OSSE Results - Assimilation of Lidar Obs + Lidar Obs in Boundary Conditions

- >6% improvement for all forecast times
- Positive impact greater for non-raob initial times
- Contributions from lidar assimilation and boundary conditions nearly additive
- From briefing by S. Weygandt et al.



Simulated DWL Impact on a Hurricane Track Forecast (R. Atlas et al.)

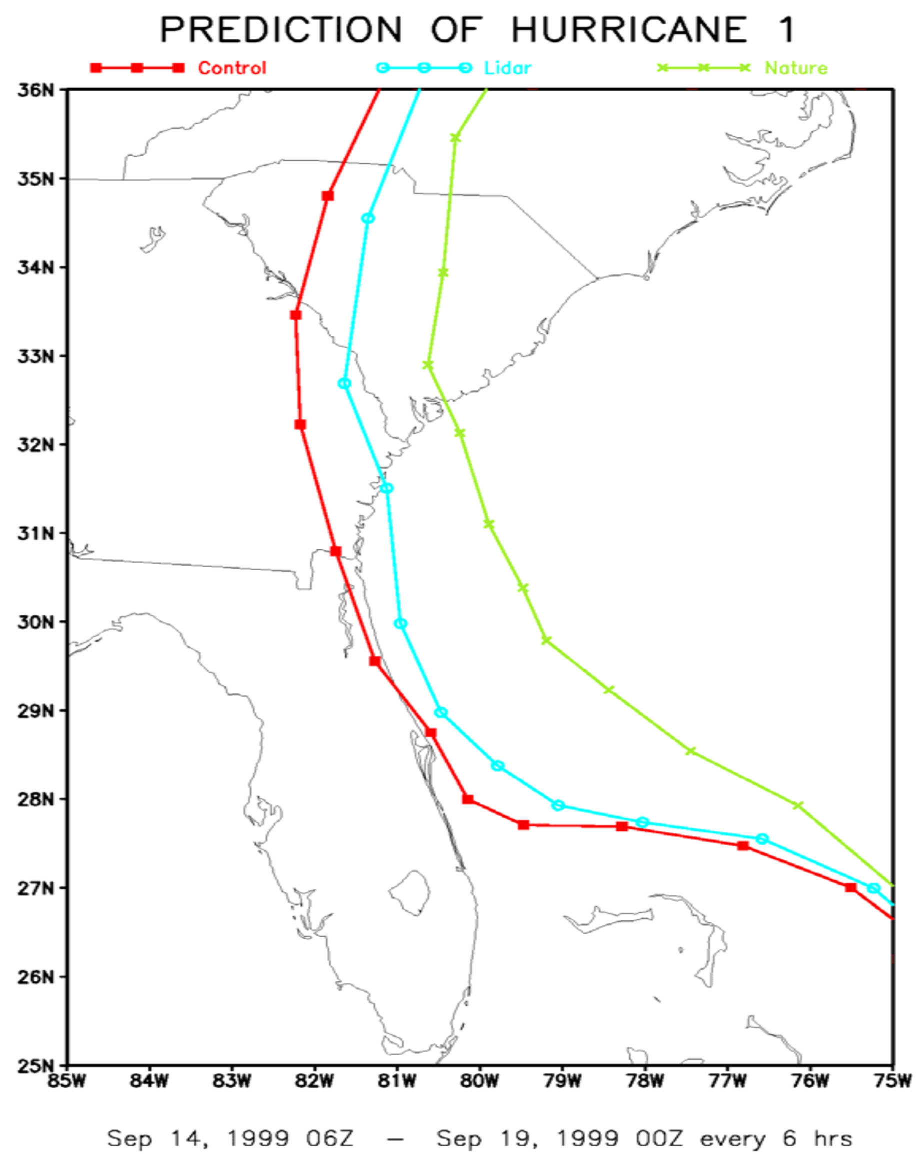
Hurricanes Tracks

Green: Actual track

Red: Forecast beginning 63 h before landfall with current data

Blue: Improved forecast for same time period with simulated DWL data

Note: A significant positive impact was obtained for both land falling hurricanes in the 1999 data; the average impact for 43 oceanic tropical cyclone verifications was also significantly positive

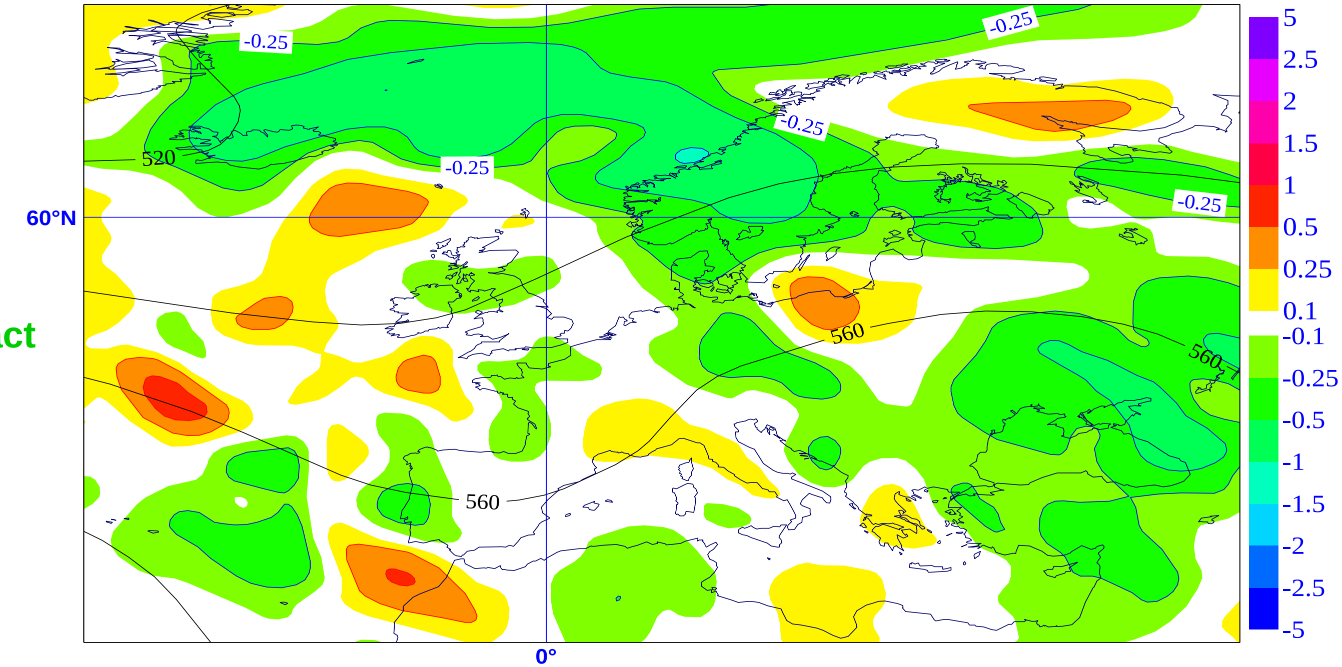


Forecast Impact Using Actual Aircraft Lidar Winds in ECMWF Global Model (Weissmann and Cardinali, 2007)

- **DWL measurements reduced the 72-hour forecast error by ~3.5%**
- **This amount is ~10% of that realized at the oper. NWP centers worldwide in the past 10 years from *all* the improvements in modelling, observing systems, and computing power**
- **Total information content of the lidar winds was 3 times higher than for dropsondes**

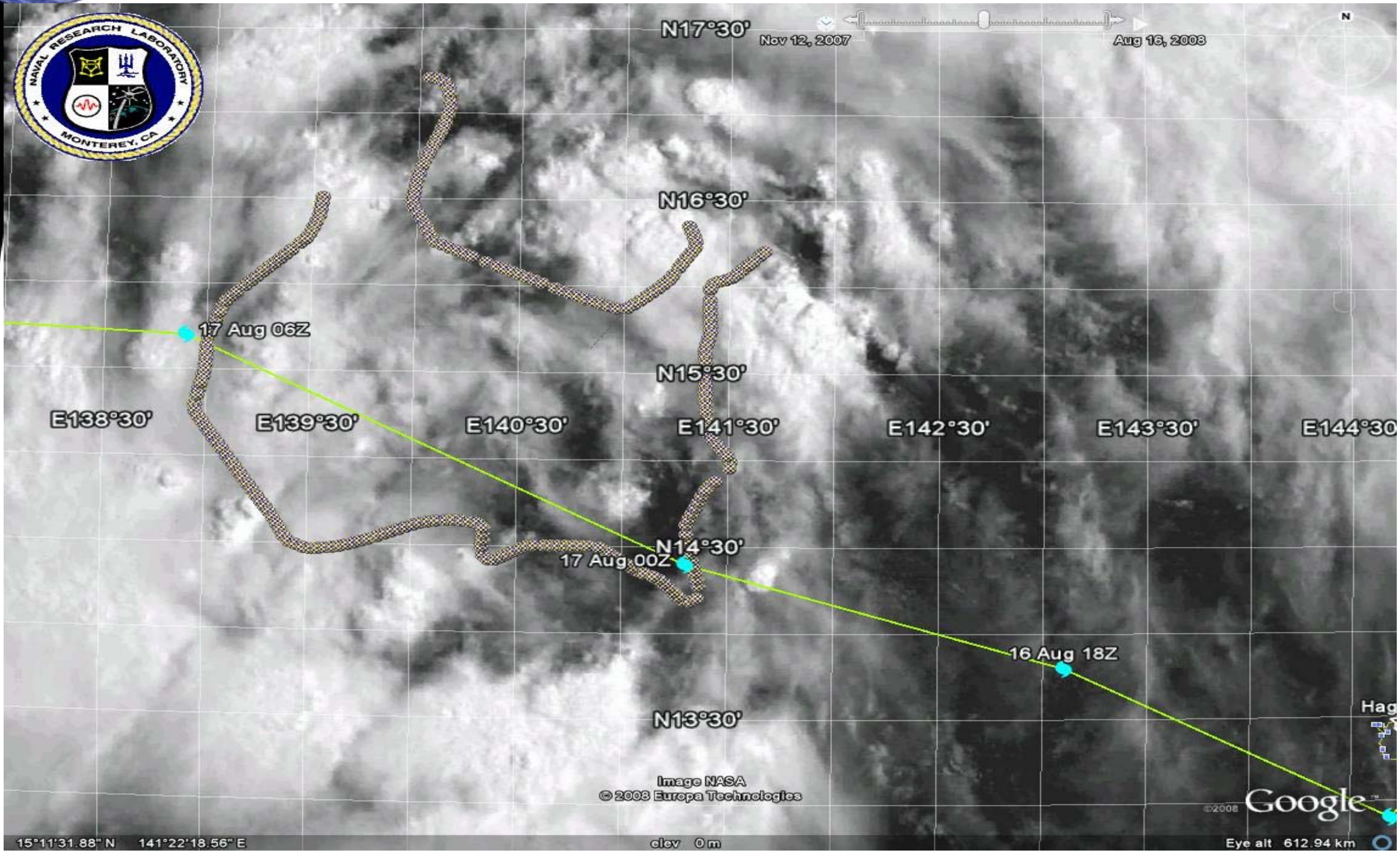
Diff in RMS of fc-Error: RMS(fc_en5t - an_eiz3) - RMS(fc_eiz3 - an_eiz3)
Lev=500, Par=z, fcDate=20031115-20031128 00/12 UTC, Step=96
NH=-4.14 SH= 6.82 Trop= 0.05 Eur=-14.54 NAmer= -6.13 NAtl= 2.84 NPac= -7.9

Green denotes a positive impact

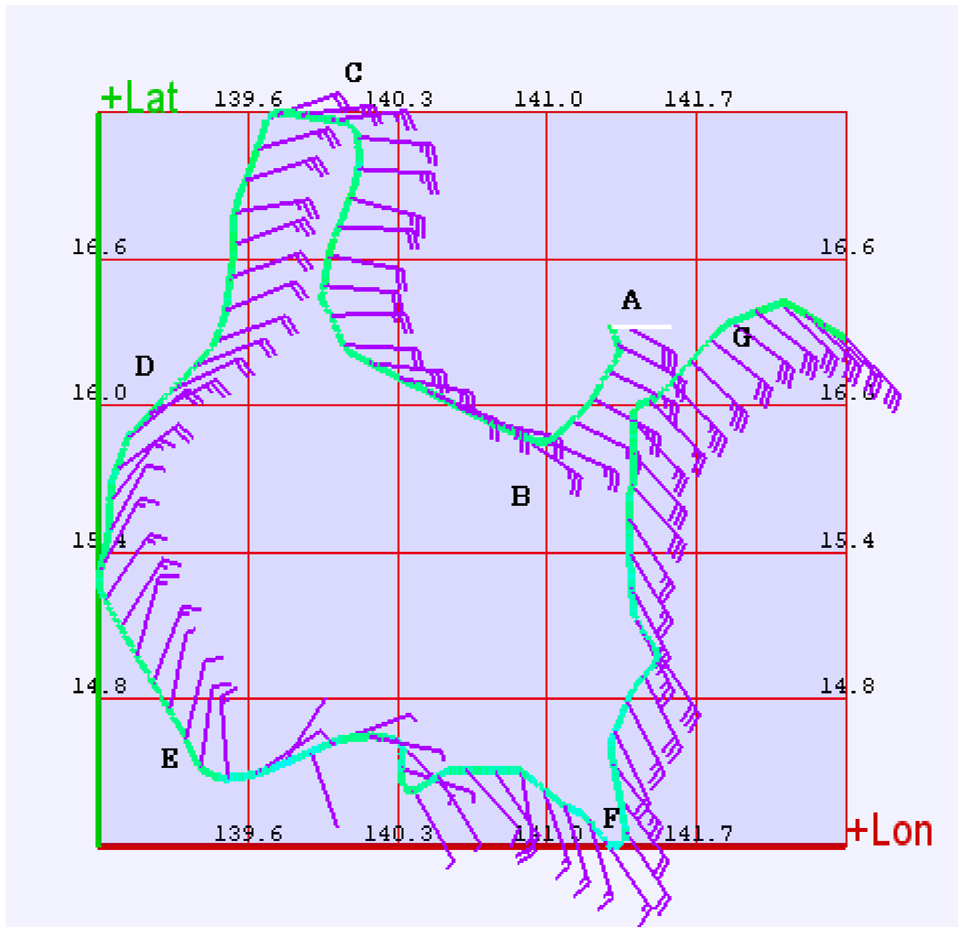


Mean (29 cases) 96 h 500 hPa height forecast error difference (Lidar Exper minus Control Exper) for 15 - 28 November 2003 with actual airborne DWL data. The green shading means a reduction in the error with the Lidar data compared to the Control. The forecast impact test was performed with the ECMWF global model.

Observed Track of Typhoon Nuri and Path of Navy P3 Aircraft (P3DWL) during T-PARC 2008 (D. Emmitt)



Flight Level Winds from P3DWL
(Provided by D. Emmitt)



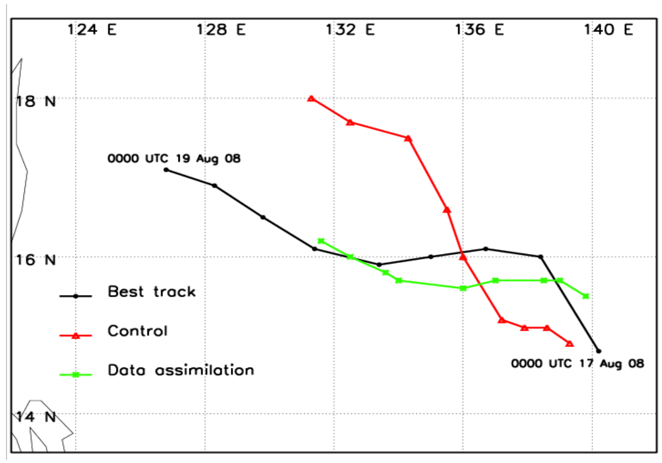
A –G denote location of dropsondes

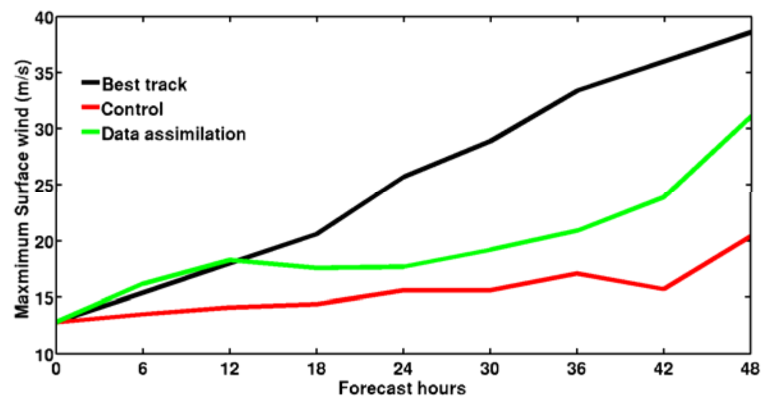
Impact of Airborne DWL Profiles on Prediction of Tropical cyclones: First snapshot with Typhoon Nuri (2008)

Zhaoxia Pu and Lei Zhang, ***Department of Atmospheric Sciences, University of Utah***
G. David Emmitt, ***Simpson Weather Associates, Inc.***

Model: Mesoscale community Weather Research and Forecasting (WRF) model
Data: Doppler wind Lidar (DWL) profiles during T-PARC for the period of 0000UTC –0200 UTC 17 August 2008
Forecast Period: 48-h forecast from 0000UTC 17 August 2008 to 0000UTC 19 August 2008
Control: without DWL data assimilated into the WRF model.
Data Assimilation: With DWL data assimilated into the WRF model

Data impact: Control vs. Data assimilation





- **Assimilation of DWL profiles eliminated the northern bias of the simulated storm track .**

- **Assimilation of DWL profiles resulted in a stronger storm that is more close to the observed intensity of the storm.**

Need for Improved Accuracy of Transport Estimates for Climate Applications

- Improved reanalysis data sets are needed to provide a more accurate environmental data record to study global warming; for example, recent studies[1,2] indicate that the recent dramatic reduction in sea ice extent observed in the Arctic may be due, in large part, to heat transport into the Arctic, but this finding is based on reanalysis wind data with large uncertainty in the Arctic because of lack of actual wind measurements
- The measurement of accurate, global winds is critical for climate monitoring: **"The nation needs an objective, authoritative, and consistent source of . . . reliable. . . climate information to support decision-making. . ."[3]**

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1 JCSDA Seminar by Erland Kallen, April 23, 2009

2 Graverson et al., 2008, in *Nature*; Graverson et al., 2006, in *Quart. J. Royal Meteor. Soc.*

3 NOAA Annual Guidance Memorandum, Internal Draft, May 10, 2009

Why Wind Lidar?

Societal Benefits at a Glance…

Improved Operational Weather Forecasts

Civilian	*Military*
Hurricane Track Forecast Flight Planning Air Quality Forecast Homeland Security Energy Demands & Risk Assessment Agriculture Transportation Recreation	**Ground, Air & Sea Operations Satellite Launches Weapons Delivery Dispersion Forecasts for Nuclear, Biological, & Chemical Release Aerial Refueling**

- **Estimated potential benefits ~$940M per year***
- **Including military aviation fuel savings ~$130M per year****
- **Roughly 1/3 of the $940M per year total is due to reduced airline fuel consumption which supports the "Energy Security and Sustainability" goal in the NOAA AGM*****

* K. Miller, "Aviation Fuel Benefits Update," Lidar Working Group Meeting, July 2008, Wintergreen, VA, http://space.hsv.usra.edu/LWG/Index.html

** AF aviation fuel usage estimate provided by Col. M. Babcock

*** NOAA Annual Guidance Memorandum, Internal Draft, May 10, 2009

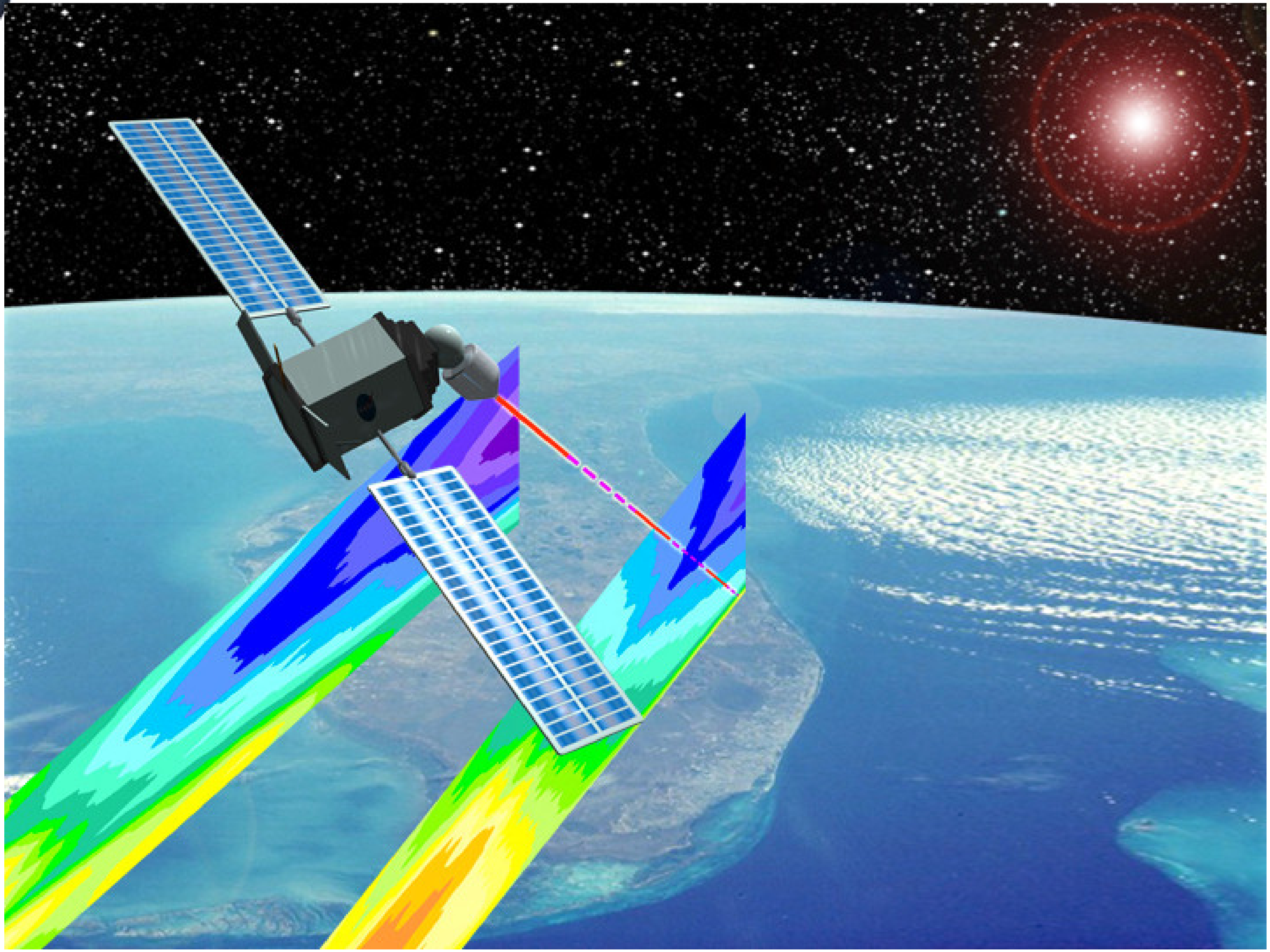
A U.S. Wind Lidar Effort – Why Should NOAA Move Forward Now?

- OSSEs and experiments with actual airborne wind lidar measurements (Pu et al., 2009; Weissmann and Cardinali, 2007) show these data will improve forecast skill

- The European Space Agency will launch the ADM/Aeolus lidar wind measuring satellite in June 2011

- NOAA will have access to ADM/Aeolus data, but NOAA needs to start developing the data assimilation capability now

Concept for a U.S. Space-Based Wind Lidar

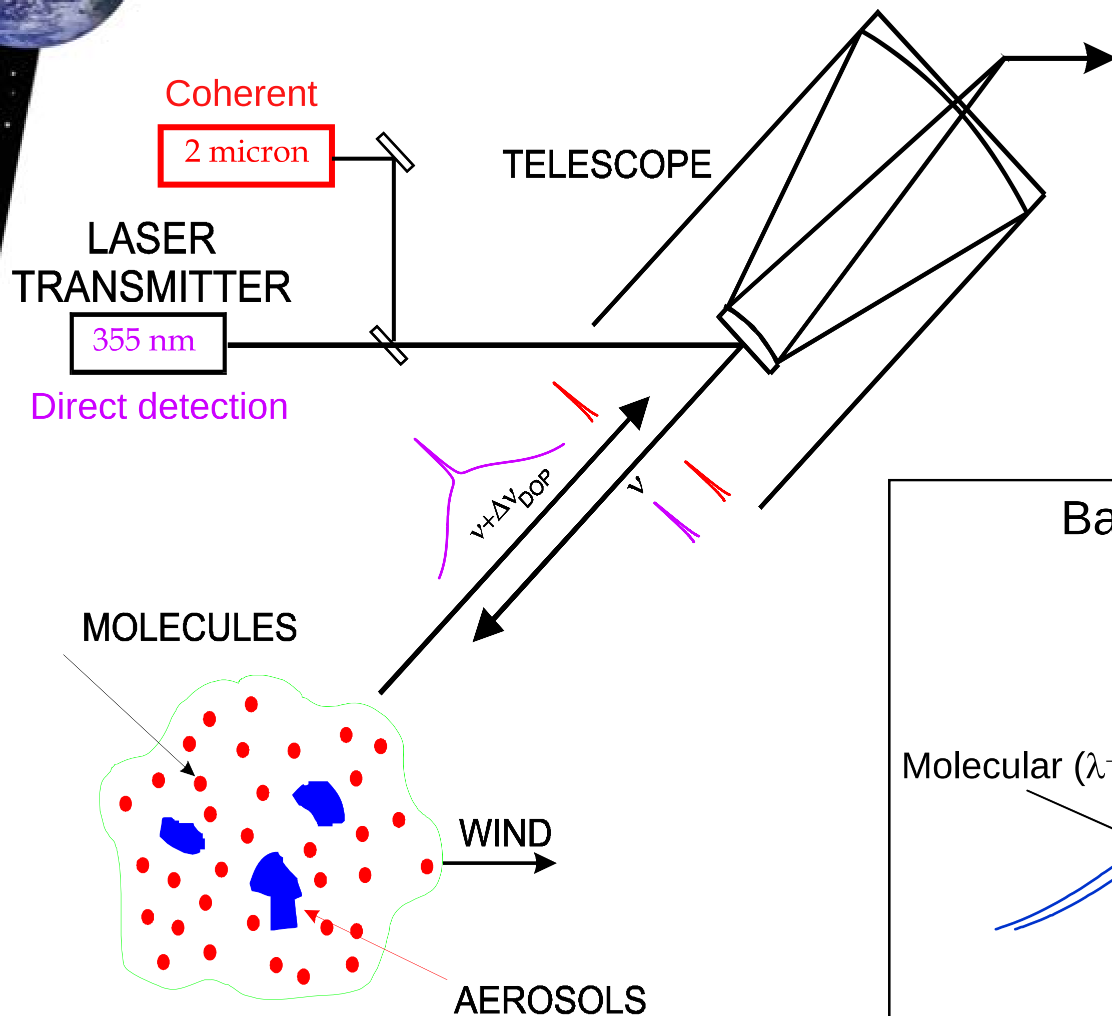


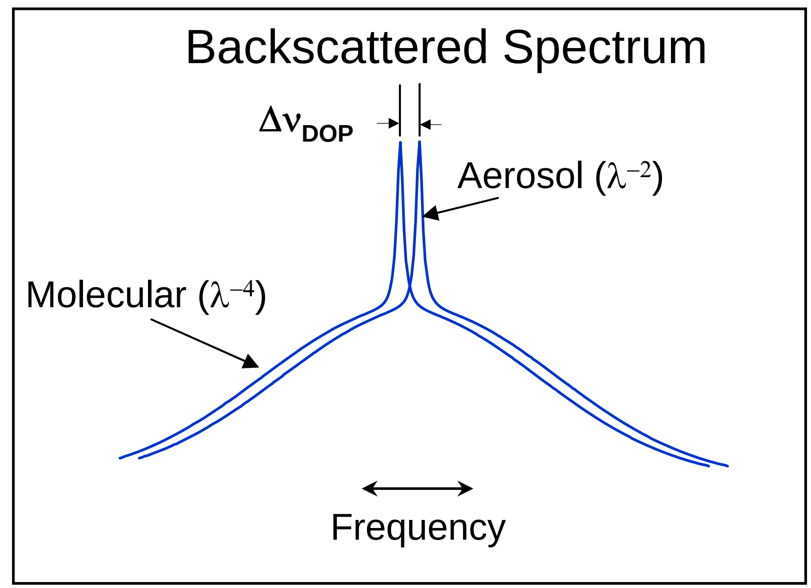
Global Wind Observing Sounder (GWOS)

Measuring Wind with a Doppler Lidar

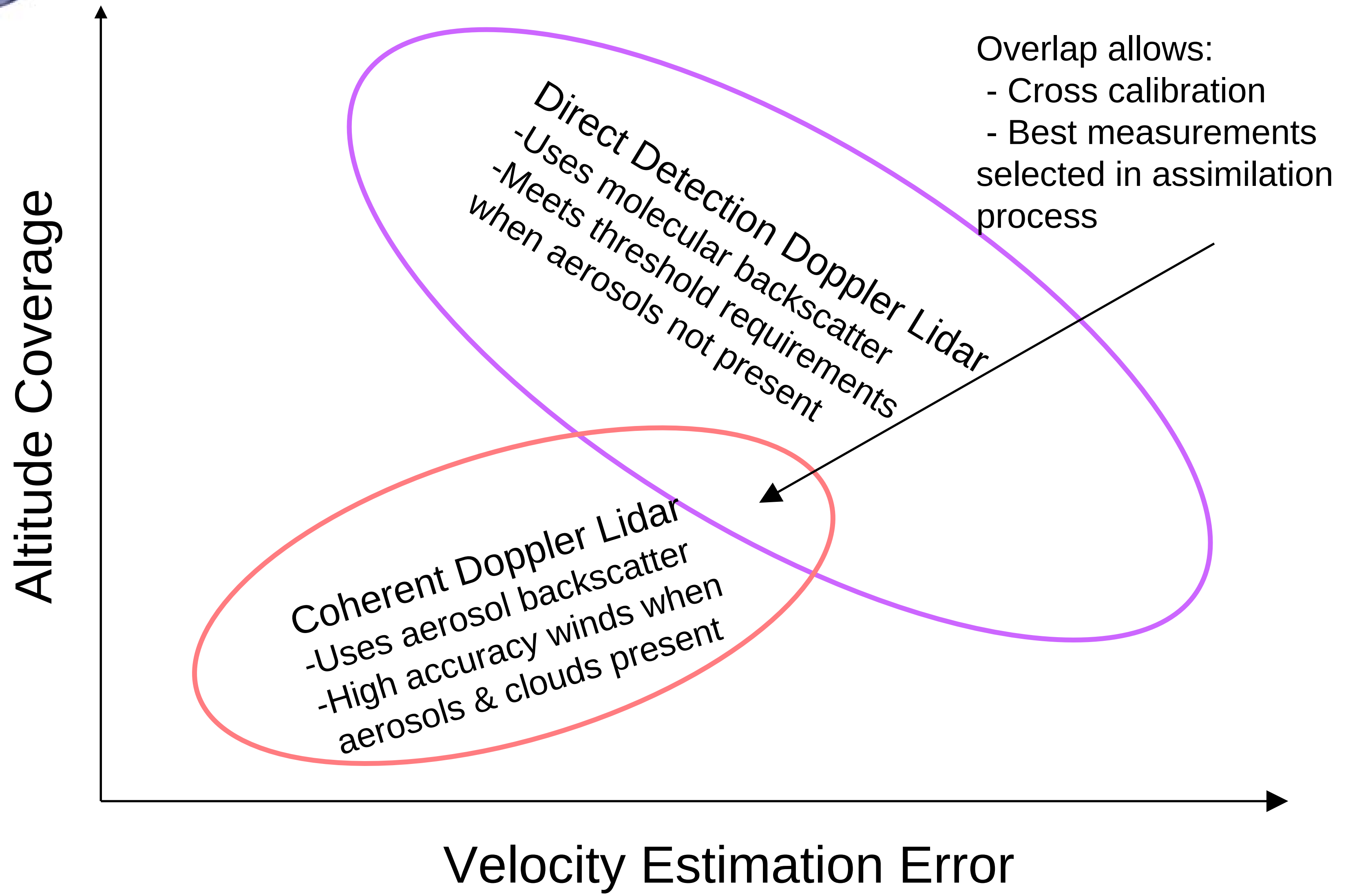
DOPPLER RECEIVER - Multiple flavors - Choice drives science/ technology trades

- Coherent or heterodyne aerosol Doppler receiver
- Direct detection molecular Doppler receiver





GWOS Hybrid DWL Technology Solution



NASA GWOS Concept: Employ Hybrid DWL Technology

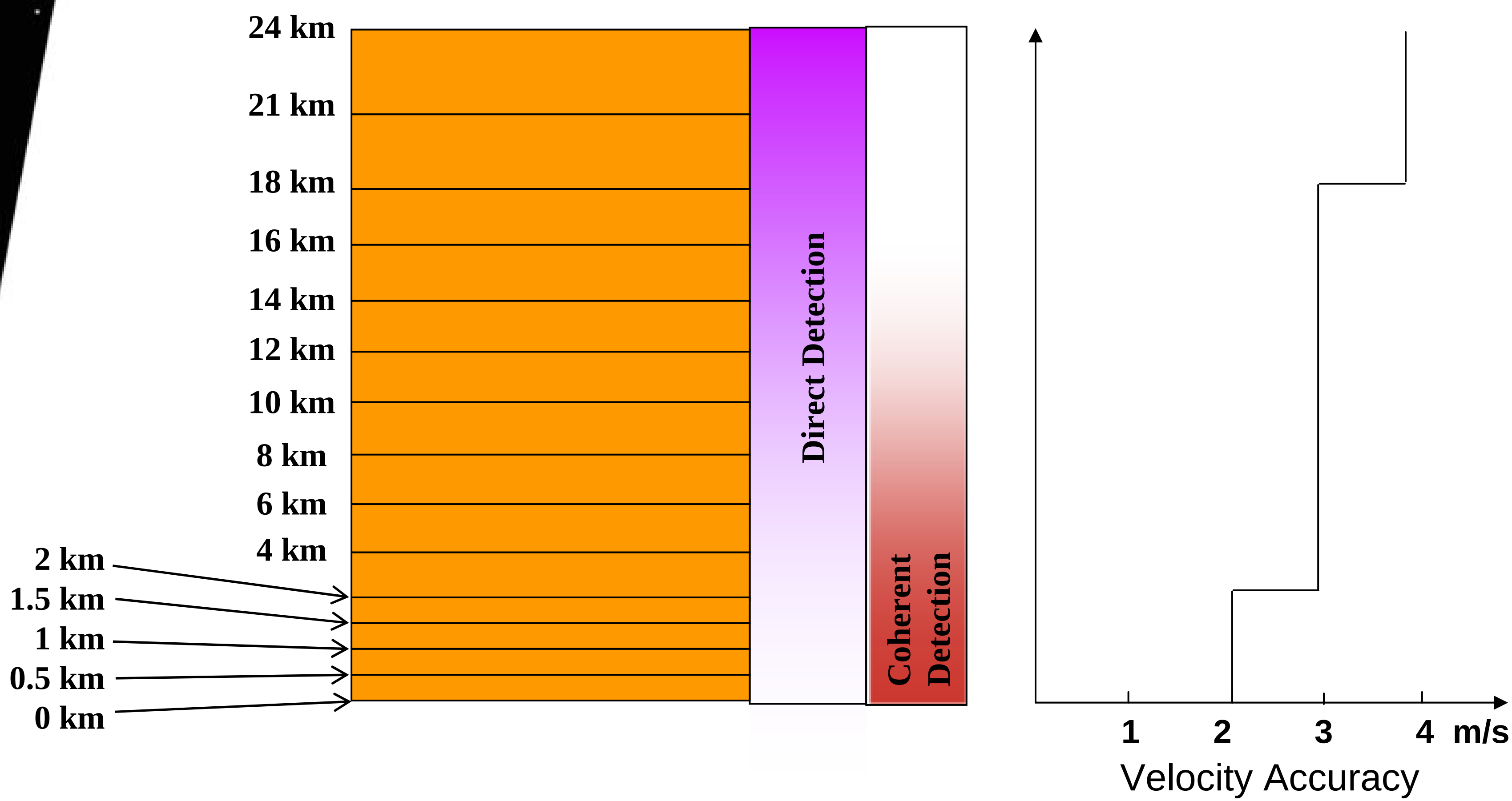
- The coherent subsystem provides very accurate (<1.5 m/s) observations when sufficient aerosols (and clouds) exist.

- The direct detection (molecular) subsystem provides observations meeting the threshold requirements above 2 km, clouds permitting.

- When both sample the same volume, the most accurate observation is chosen for assimilation.

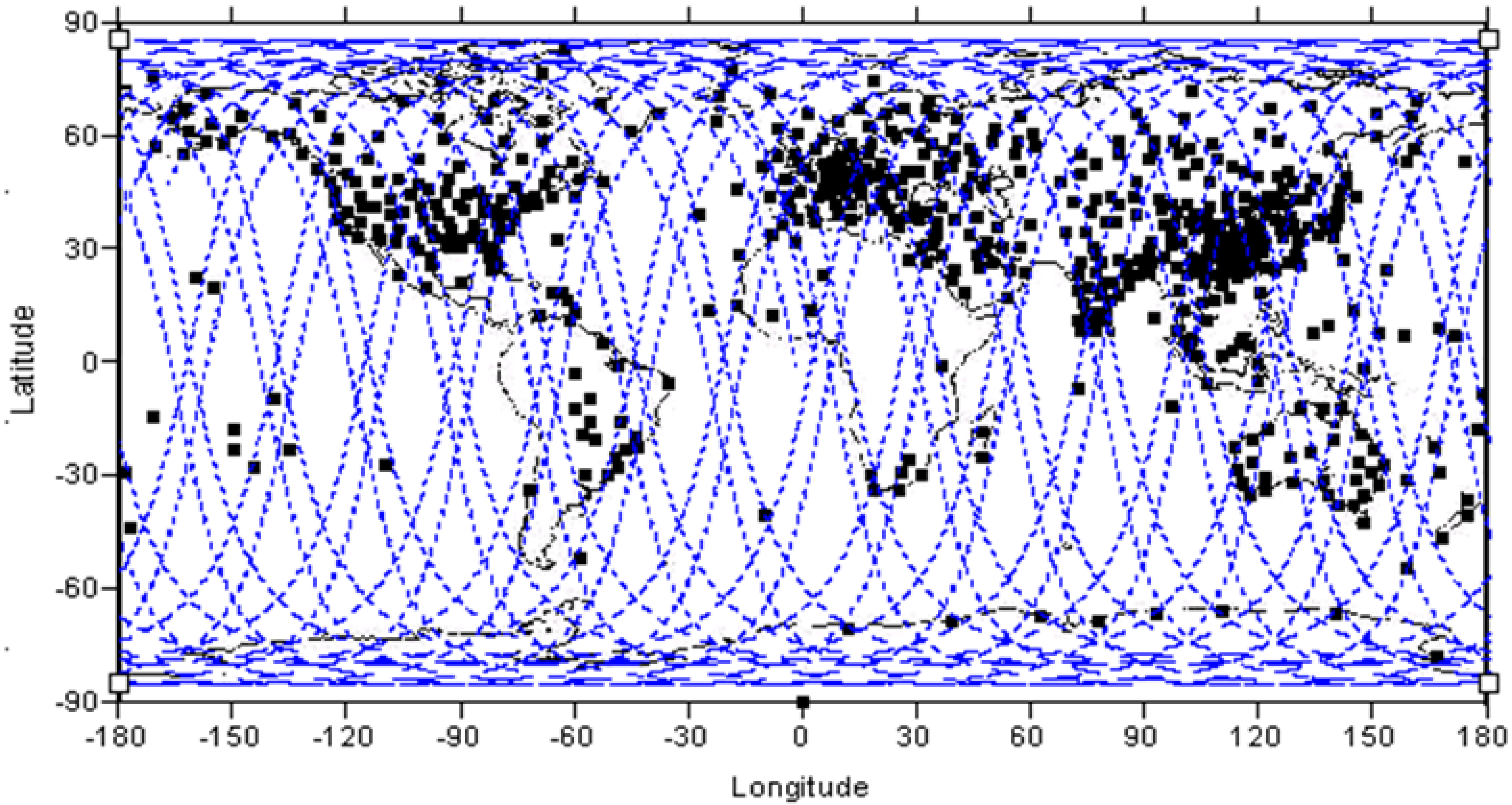
- The combination of direct and coherent detection yields higher data utility than either system alone.

GWOS Measurement Capability



GWOS Coverage

- Around 600 radiosonde stations (black) provide data every 12 h
- GWOS (blue) would provide ~3200 profiles per day



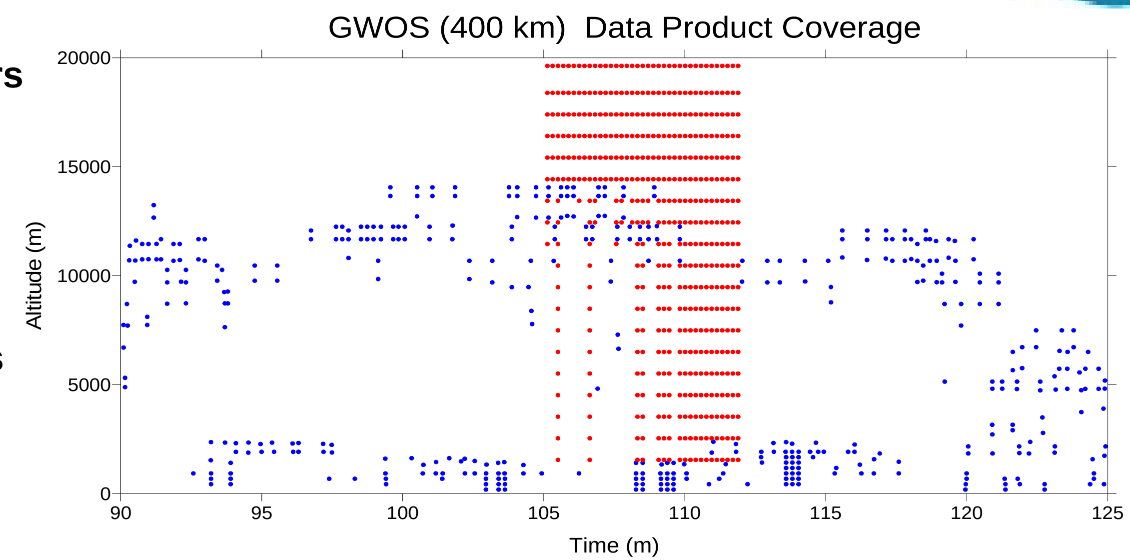
Simulated GWOS Measurements from Cloud Returns (Provided by D. Emmitt)

Observation source and errors

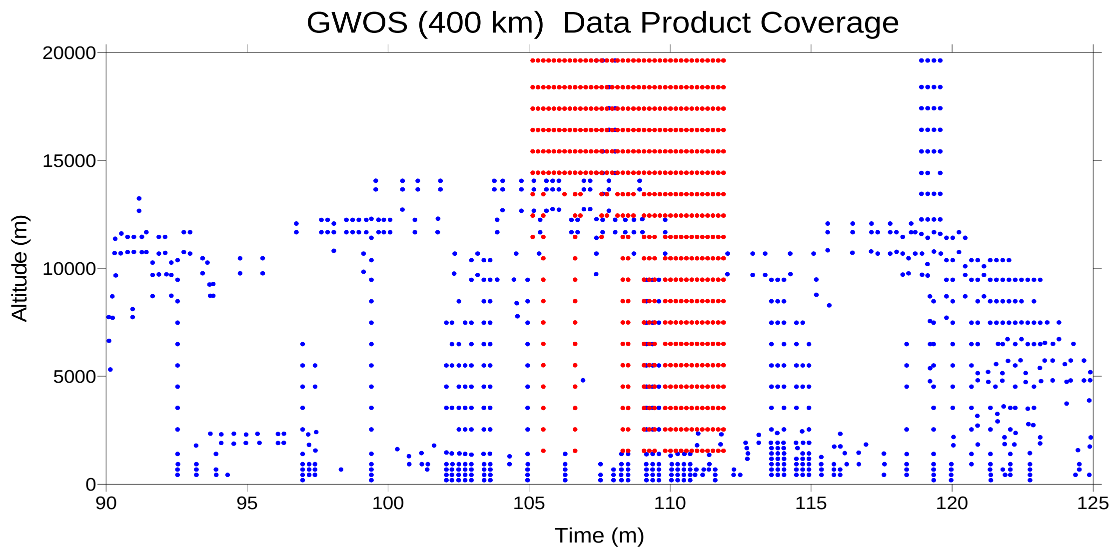
Blue: Coherent w/ < 1.5 m/s

Red: Direct w/ < 3.0 m/s; 10% duty cycle

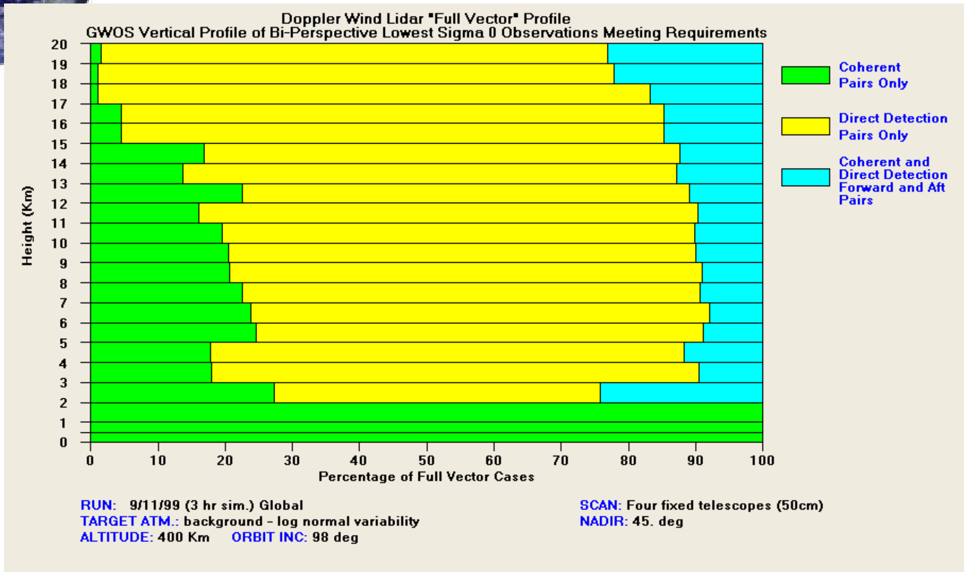
With background aerosol concentrations



With enhanced aerosol concentrations



Simulated GWOS Synergistic Vector Wind Profiles* (Provided by D. Emmitt)



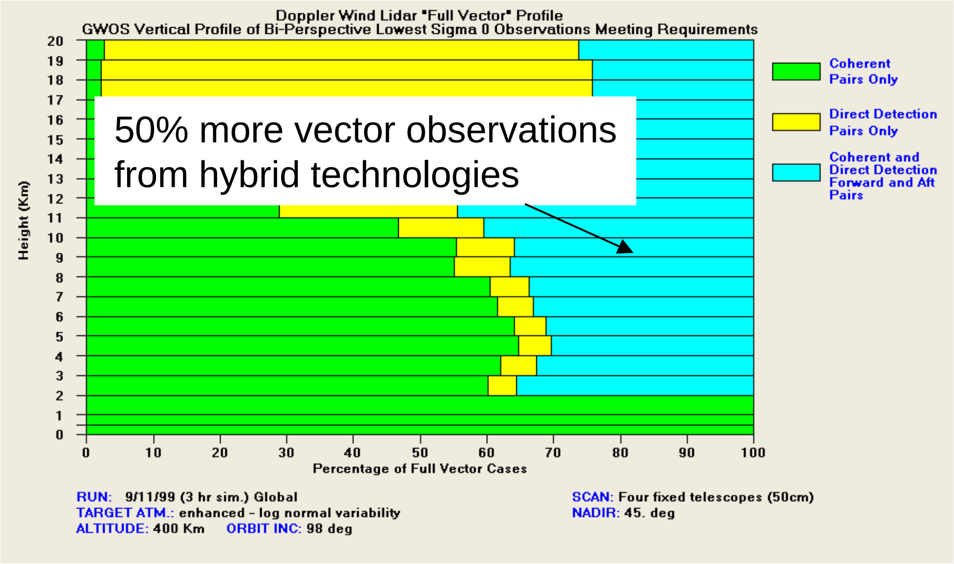
Background aerosol mode

Green: both perspectives from coherent system

Yellow: both perspectives from direct molecular

Blue: one perspective coherent; one perspective direct

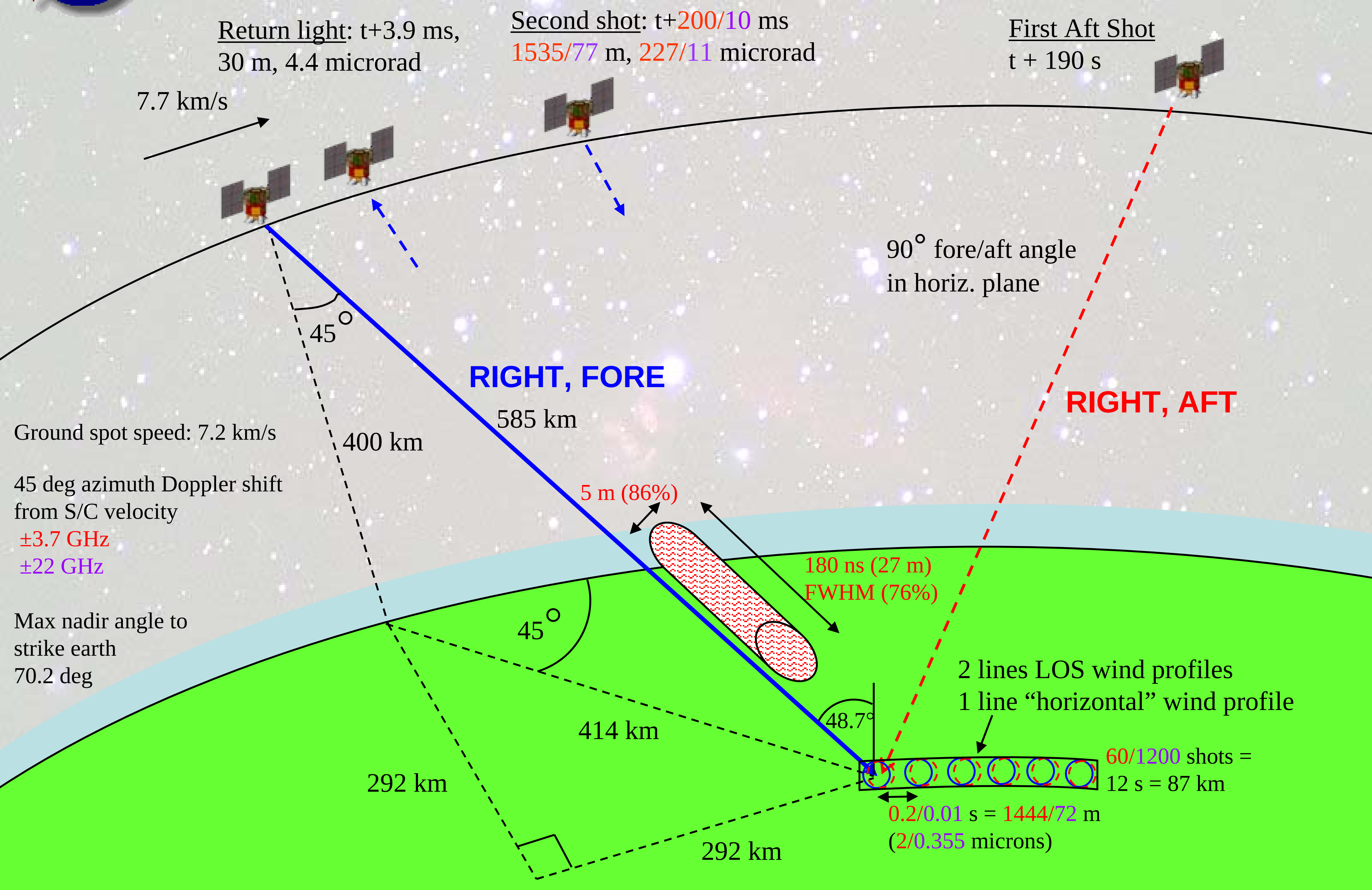
Enhanced aerosol mode

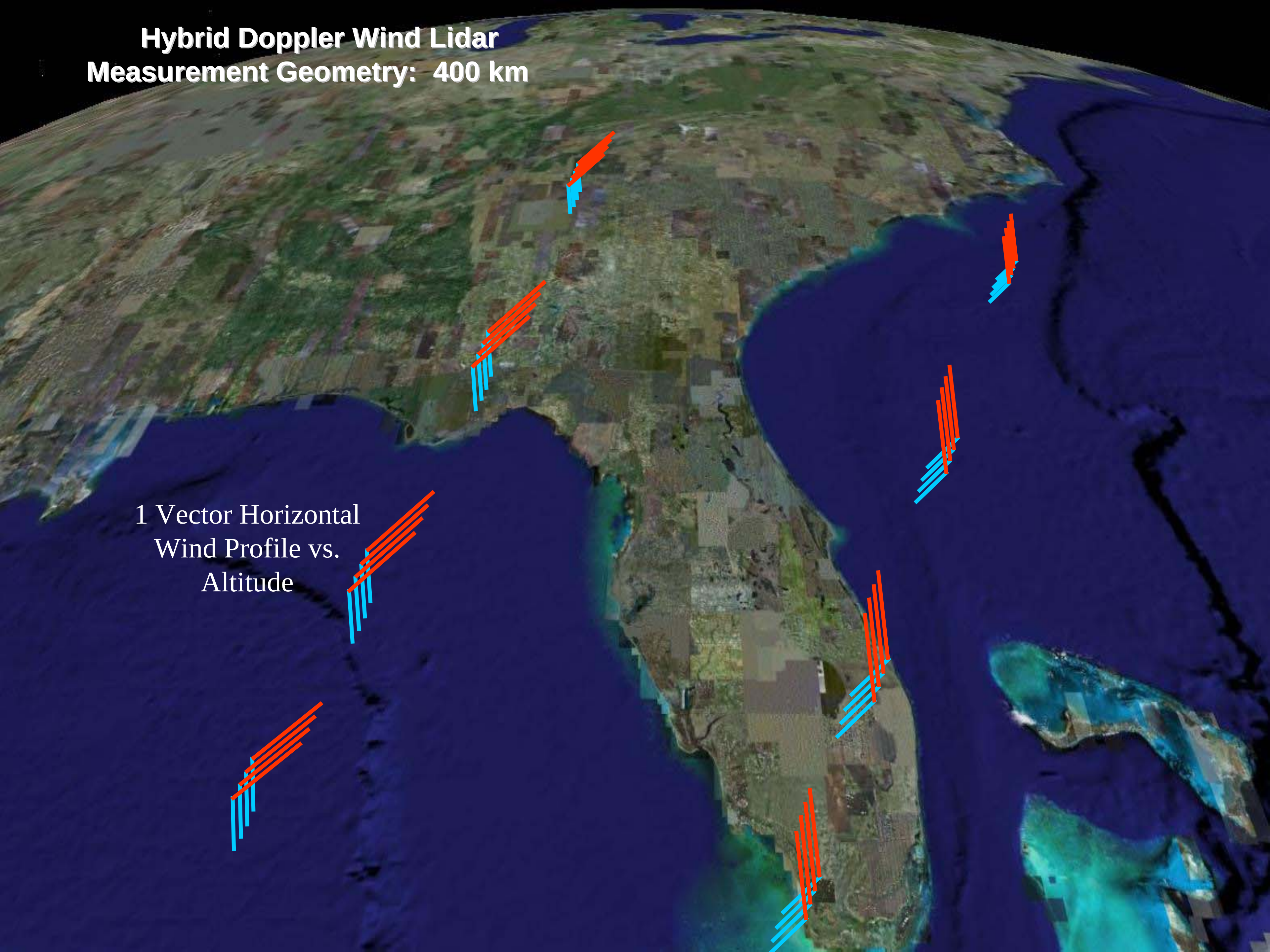


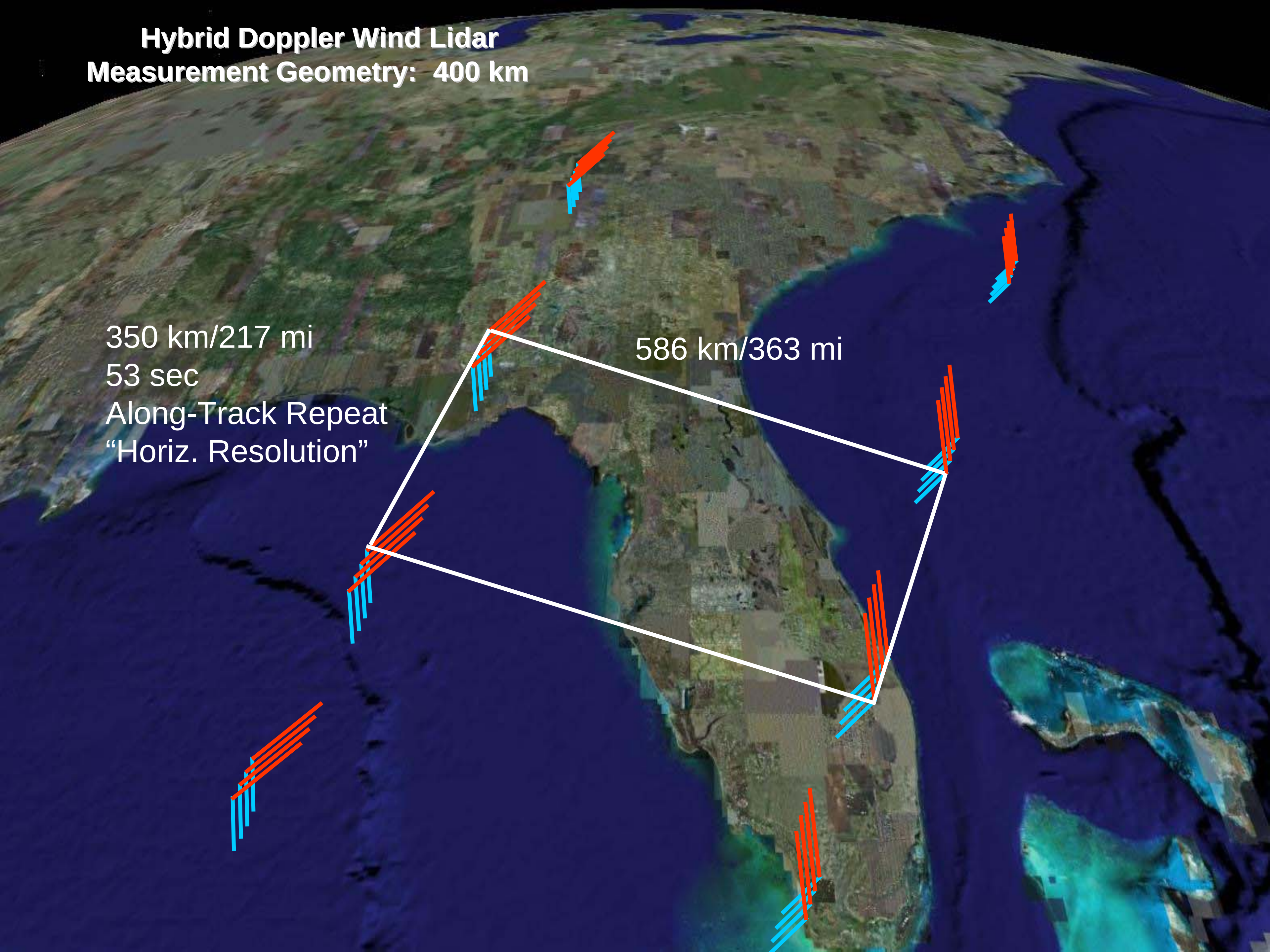
Coherent aerosol and direct detection molecular channels work together to produce optimum vertical coverage of bi-perspective wind measurement

*** When two perspectives are possible**

Hybrid Doppler Wind Lidar Measurement Geometry: 400 km




Hybrid Doppler Wind Lidar
Measurement Geometry: 400 km
1 Vector Horizontal
Wind Profile vs.
Altitude

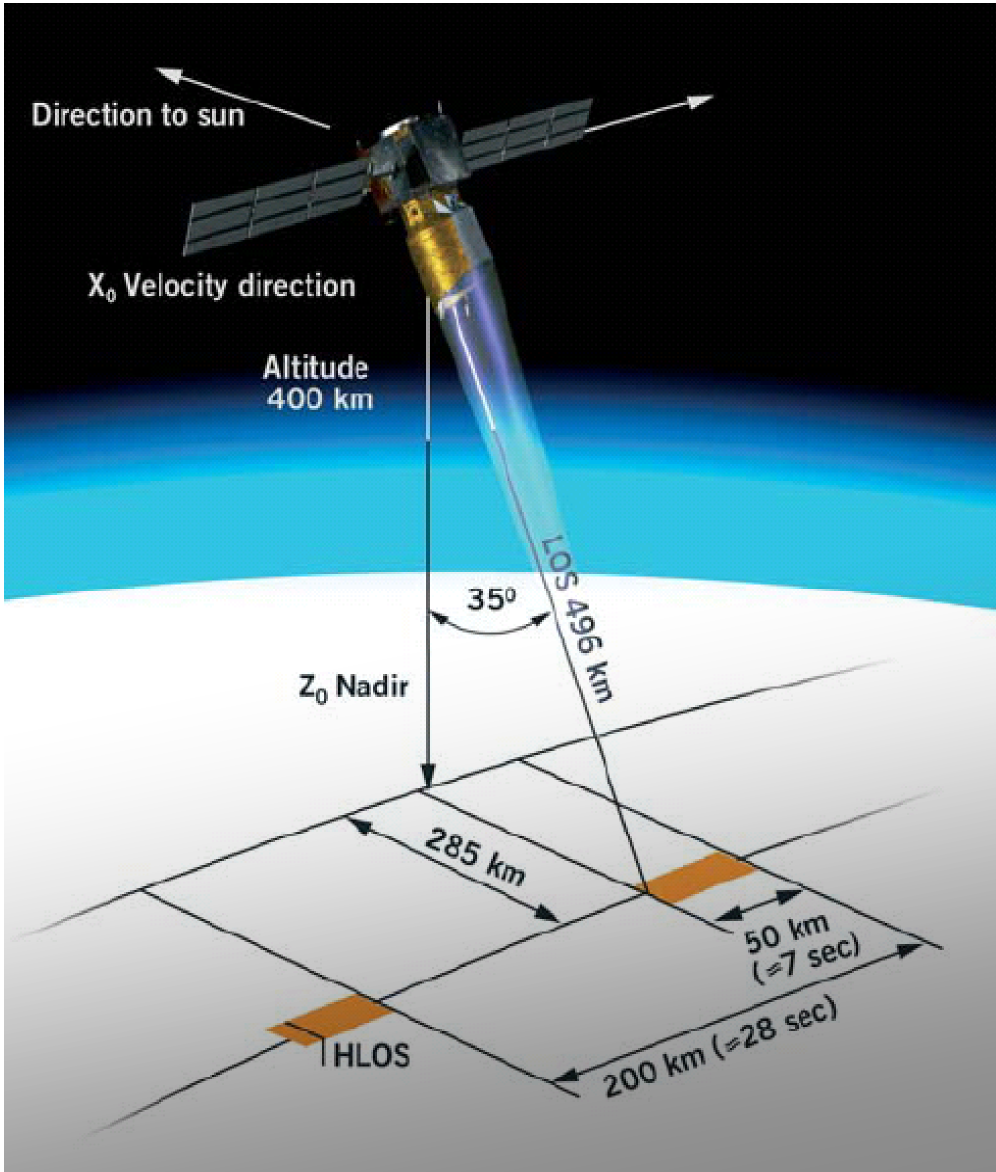

Hybrid Doppler Wind Lidar
Measurement Geometry: 400 km
350 km/217 mi
53 sec
Along-Track Repeat
"Horiz. Resolution"
586 km/363 mi

ADM-Aeolus

- **D**oppler **W**ind **L**idar
- Cross-track HLOS winds
- σ_{HLOS} (z) = 2-3 m/s
- Profiles 0–30 km@0.5-2 km
- Once every 200 km length
- Aerosol and molecular measurement channel
- Dawn-dusk polar-orbiter
- Launch date June 2011

www.esa.int/esaLP/LPadmaeolus.html

(Stoffelen et al., BAMS, 2005)



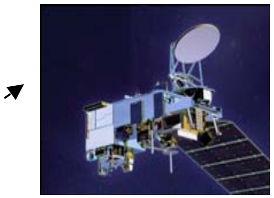
GWOS Comparison with ADM

Attribute	ADM	GWOS	NWOS*
Orbit Altitude	400	400	824
Orbit Inclination	98 sun-synch	98 sun-synch	98 sun-synch
Day/Night	Night only	Day/Night	Day/Night
Number of LOS	1	4	4
Profiles per orbit	~200 single LOS	~229 vector	~250 vector
Components per profile	Single –Model estimated second component	Two components - full horizontal vector	Two components - full horizontal vector
Horizontal Resolution	200 km between single LOS profile one side of ground track	350 km with full profile both sides of ground track	350 km with full profile both sides of ground track
Vertical Resolution	PBL 0.25 – 0.5 km Troposphere 1 km	PBL 0.25 - 0.5 km Tropo 1 – 2 km	PBL 0.25 - 0.5 km Tropo 1 – 2 km

*** NexGen NPOESS Wind Observing Sounder**

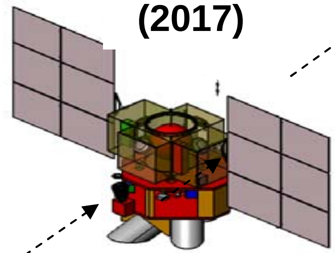
Roadmap to Operational Space-Based DWL on NexGen NPOESS

NexGen NPOESS
(2026)



Operational 3-D global wind measurements

GWOS
(2017)



Demo 3-D global wind measurements

ESA ADM
(2011)

Single LOS global wind measurements

TODWL
(2002 - 2008)

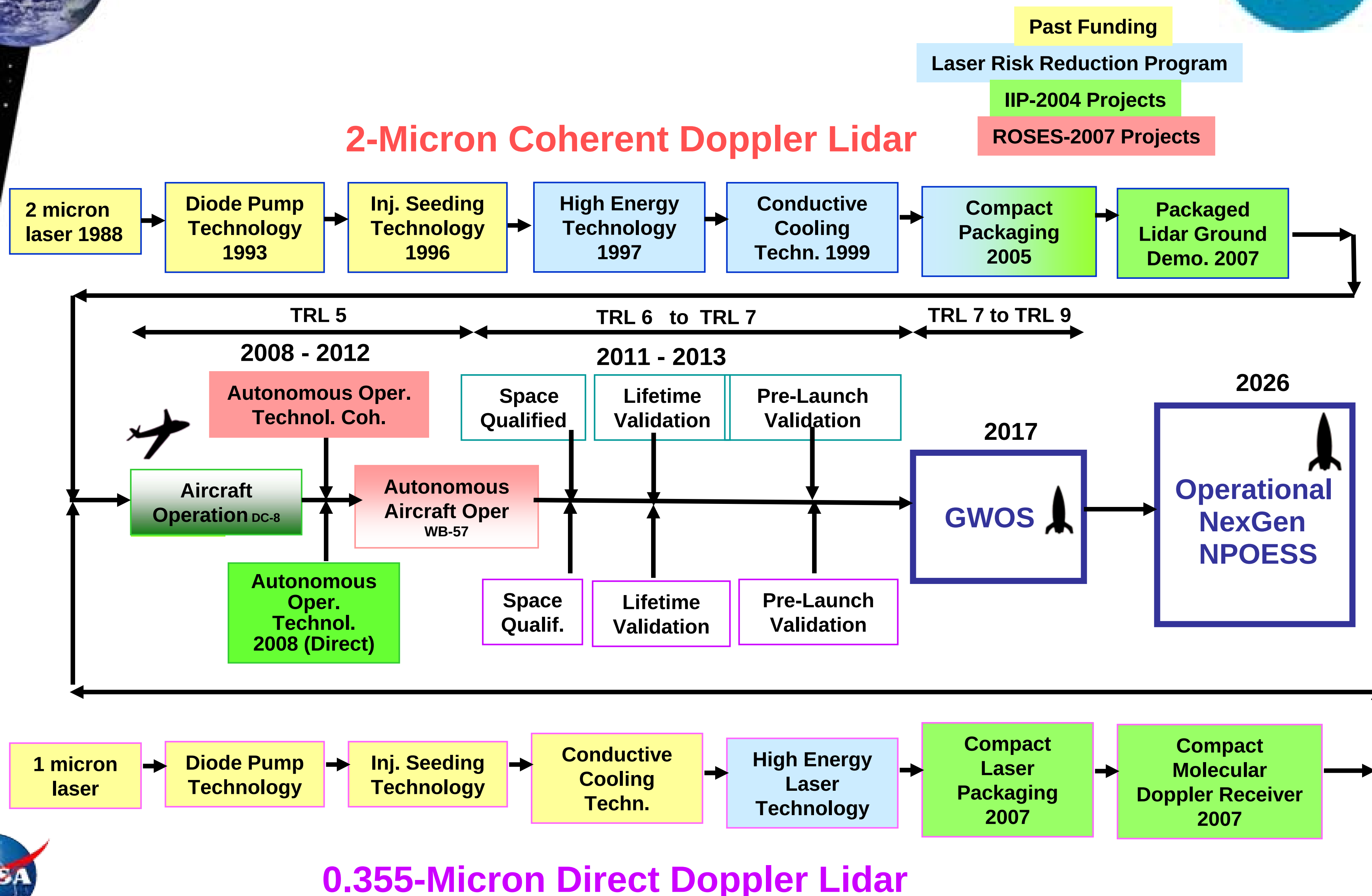
DWL Airborne Campaigns, ADM Simulations, etc.

TODWL: Twin Otter Doppler Wind Lidar [CIRPAS NPS/NPOESS IPO]
ESA ADM: European Space Agency-Advanced Dynamics Mission (Aeolus) [ESA]
GWOS: Global Winds Observing System [NASA/NOAA/DoD]
NexGen: NPOESS [2nd] Generation System [PEO/NPOESS]

Recent Advances in Technology Readiness

- Recent infusion of NASA funding has accelerated advances in both direct and coherent wind lidar technologies
- Initial airborne campaign of hybrid instrument (TWiLiTE--GSFC-led; DAWN--LaRC-led) planned for Fall 2010
- The DWL whitepaper (Hardesty et al., 2005), submitted to the NRC Committee on the Decadal Survey, was based on lidar technology readiness circa 2001, is now significantly outdated, and will be updated in the next few months
- Recent technology advances will also be highlighted in a new *BAMS* article to be prepared in the near future

HDWL Technology Roadmap



Concluding Remarks

- A U.S. GWOS mission would fill a critical gap in our capability to measure global wind profiles, and,
- Significantly improve the skill in forecasting high impact weather systems globally (i.e., hurricanes, mid-latitude storms, etc.),
- Reduce the uncertainty in transport estimates derived from reanalysis data for climate applications,
- Provide major societal benefits, both civilian and military,
- Make a ***transformational*** impact on global tropospheric wind analyses, according to the NRC Weather Panel, and provide major benefits to the NASA, NOAA and DoD missions, and to the Nation
- Recent lidar technology advances are consistent with a GWOS mission in 2017, if the funding is available

- The upcoming ESA ADM in 2011 will provide the first direct wind measurements from space and serve as a prototype for the development of the data assimilation capability for a U.S. winds mission

Backup Slides

DWL Measurement Requirements

	NASA-NOAA-DoD Science GWOS	NPOESS Operational NexGen	
Vertical depth of regard (DOR)	0-20	0-20	km
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
Horizontal resolution[A]	350	350	km
Minimum Number of horizontal[A] wind tracks[B]	2	4	-
Number of collocated LOS wind measurements for horizontal[A] wind calculation	2 = pair	2 = pair	-
Velocity error[C] Above BL In BL	3 2	3 2	m/s m/s
Minimum wind measurement success rate[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 = 1s 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