

SWA Environment Laser Division: Doppler Wind Lidar Documents and Products

A Set of Requirements for Global Atmospheric Wind Observations

Global measurement of tropospheric wind has been widely recognized as potentially the most significant contribution of satellite remote sensing to existing global meteorological observations ("[Call for Winds](#)"). Most of the world's oceans are largely devoid of accurate wind measurements, a deficiency that can best be addressed from space. The deployment of such an instrument would provide the capability to address many of the key issues facing the Earth Sciences in the 21st century (e.g., hydrologic and biogeochemical cycles, planetary scale dynamics, atmospheric-oceanic heat transport). Equally important, it would provide critical wind information for improved operational weather forecasting, and for safe, efficient, and effective military and commercial aviation operations. Direct measurement of horizontal wind vectors in clear air has been demonstrated using lidar from the ground and from aircraft, based on determination of the wind-induced Doppler shift in the backscatter signal.

The global tropospheric wind sounder mission requirements are listed below in Table 1. Two sets of requirements are provided; the first set are operational prototype threshold requirements and the second set are operational mission threshold requirements which meet NOAA's operational mission requirements. These requirements are the results of discussions over the past several years with input from both the operational and research communities. The requirements listed here are threshold requirements, which are the minimal data specifications for a system to benefit both the earth science and the operational weather forecasting communities.

Table 1. Operational Prototype and Operational Mission Threshold Requirements

NOTE: Threshold numbers shown in parentheses are desirable.

Attribute		Operational Prototype Threshold Requirements			Operational Mission Threshold Requirements		
		PBL	Mid/Upper Trop.	Cloud Layers	PBL	Mid/Upper Trop.	Cloud Layers
Temporal Resolution (hr)		Orb/platform permit. (1)	Orb/platform permit (1).	Orb/platform permit (1)	24-hour refresh (2)	24-hour refresh (2)	24-hour refresh (2)
Spatial Coverage (km)	Vertical	0-3	3-20	0-20	0-3	3-20	0-20
	Horizontal (min. swath width)	300 (>1000)	300 (>1000)	300 (>1000)	1500 (>2000)	1500 (>2000)	1500 (>2000)
Spatial Resolution (km)	Vertical	0.25	1	N/A	0.25	1	N/A
	Horizontal	100	300 (100)	N/A	100 (<100)	200 (<100)	N/A
	Resolution Volume	0.25 x 100 x 100	1 x 300 x 300 (1 x 100	Variable	.25 x 100 x 100	1 x 200 x 200 (1 x 100	Variable

	(RV)		x 100)			x 100)	
Location Knowled ge (km)	Vertical	0.05	0.05	0.05	0.05	0.05	0.05
	Horizontal	10	10	10	10	10	10
Velocity (m/s)	Measure · Accurac y (3) (LOS projecte d)	1	2	2	1	2	2
	Total Observ. Error (horiz., 1 perspect .)	2	3	2	2	3	2
	Max. Horiz. Speed Detectio n	+/-50	+/-100	+/- 100	+/-50	+/-150	+/- 150
Alternati ve Samplin g Patterns	Cluster (w/ average.)	10	20	10	10	20	10

D X(km) (for lidar systems only)							
	Line (w/ average.)	10 - 100	20 - 200	10 - 200	10 - 100	20 - 200	10 - 200
	Conical (min average.)	<<10	<<20	<<10	<<10	<<20	<<10

- Regional
- Global
- For lidar systems only

General Notes:

1. Assume a baseline of at least two perspectives within a Resolution Volume (RV).
2. A single perspective is assumed if the range of azimuths for shots being accumulated or averaged is less than 10 degrees.
3. Total Observation Error (TOE) must include lidar instrument errors; pointing knowledge errors, pulse scale wind variance and sampling errors due to shot pattern and the variance of the winds within the RV. See Appendix 2 for further explanation.
4. At this time, the potential relative merits of Doppler Wind Lidars (DWLs) that only sense winds in the cloud free mid/upper troposphere vs. DWLs that sense winds within the Planetary Boundary Layer (PBL), aerosol rich areas of the mid/upper troposphere, and clouds are awaiting the execution of Observing System Simulation Experiments(OSSEs) at NOAA/NCEP. The impact of data voids and selective targeting of DWL observations are also being studied.

5. Product latency (i.e., maximum time period between actual space-based measurements and delivery of processed data) should be 2 hours or less.
6. Global coverage assumes a sun-synchronous orbit. Equator crossing time unspecified.

Appendix 1. Definition of Terms

Cloud Layer: Those atmosphere layers where the lidar return is predominantly from water particles (liquid or frozen).

Cluster Patterns: "Cluster" denotes a pattern of lidar shots that are nearly co-located ($\sim DX = 10\text{-}20$ km) to achieve a single line-of-sight measurement by averaging or accumulating multiple samples with the same geometric perspective (i.e., fixed azimuth and elevation angles). In this case, "cluster" further implies that a cluster of forward shots is nearly collocated with a cluster of aft shots. A pair of forward and aft clusters constitutes the domain of a "preferred wind vector product" (see notes). The nominal distance between cluster pairs measured in kilometers is expected to be at least the threshold horizontal resolution.

Conical Pattern: The conical pattern is achieved by either a continuous slewing of the lidar beam or a step-stare optical system that nearly simulates the shot pattern achieved by a continuous scanner. Little to no shot accumulation is envisioned due to the variable look angles. The assumed scan rate is on the order of 5 rpm or greater. This pattern provides the highest spatial resolution potential without the undesirable averaging over large footprints the size of the target resolution area.

GCM: Global Circulation Model

Horizontal Coverage: This term denotes the cross-track dimensions of the ground swath, i.e., limb-to-limb distance. This

dimension is determined by the orbit altitude, the nadir viewing angle, and the scanning method.

Horizontal Resolution: The nominal distance between velocity (u,v) measurements that meet the velocity accuracy requirements for high SNR situations (assuming no cloud obscuration).

Level 0 data: Raw data from the instrument and ancillary parameters such as attitude knowledge and ephemeris.

Level 1 data: Engineering unit data processed to the point of observation, e.g. line-of-sight wind profile measurements.

Line Pattern: A line pattern of lidar shots is distinguished from the cluster pattern by having a predominantly "along track" component (20-200) to the shot loci.

LOS: Line of sight

Maximum Horizontal This is the maximum horizontal speed for which the lidar signal Wind Component processing should be designed.

Measurement Accuracy: This figure of merit is an expression (1 sigma) of how well an instrument measures the speed of the wind just within the volumes illuminated by the laser beam without regard to variability of the winds or the ratio of the sampled volume dimensions to the spacing between the processed data products (profiles). For example, the accuracy of an anemometer may be .1 m/s, but, as far as the GCMs are concerned, the observation has an RMSE of 2-4 m/s. (See Total Observation Error).

Mid/Upper Troposphere: That portion of the earth's troposphere bounded below by the top of the PBL and above by the tropopause.

PBL: *Planetary Boundary Layer*. In this case, the PBL is defined by a layer of fairly well mixed aerosols bounded on top by a sharp negative gradient of the backscatter coefficient.

Resolution Volume (RV): The combination of the vertical and horizontal resolution into a single geometric metric that can serve as a design point for a lidar system. Clouds will have variable RVs since they represent high backscatter and attenuation gradients.

Total Observation Error: Error variance of observations (as used by models) difference between observed value and the true value defined as the average value of the parameters within a radius $\frac{1}{2}$. [D is either the model or utility grid resolution or the distance between data clusters. The utility grid is aligned with the satellite track and is used to aggregate shots to produce single u,v estimates.]

Vertical Coverage: This is the range of altitude for which the instrument signal processing should be designed. This term is meant to denote only the vertical extent over which velocity measurements will be attempted. Clouds or lack of aerosols may prevent some observations.

Vertical Resolution: The vertical distance (DZ) over which raw lidar signal can be processed to produce a single LOS wind estimate. In clouds, the vertical extent of usable lidar signal will be determined by the extinction ratio. In the PBL, 250 m is desirable but it is expected that in low backscatter situations, a greater depth of return may need to be used to obtain a meaningful LOS estimate. Thus the design resolution should be thought of as being applicable to high SNR situations.

Appendix 2. Total Observation Error

$$\sigma_o^2 = \frac{\sigma_m^2}{P \bullet N_T} + \frac{\sigma_c^2}{P \bullet N_c} + \frac{\sigma_a^2}{P \bullet N_a}$$

σ_o^2 = error variance of observations (as used by model) - difference between observed value and the true value defined as the average value of the parameters within a radius $1/2 D$. [D is either the utility grid resolution or the distance between data clusters. The utility grid is aligned with the satellite track and is used to aggregate shots to produce single LOS estimates.]

σ_m^2 = variance (mostly uncorrelated) in the horizontally projected LOS measure that is due to the combined effects of instrument errors, signal processing uncertainties and atmospheric turbulence/shear on all scales less than $2 \cdot l$ (l = processing range gate).

σ_c^2 = variance (mostly correlated) in the horizontal wind field (single component) on all scales $2 \cdot l < \lambda < 2 \cdot L$ (L is the length scale for any shot clustering).

σ_a^2 = variance in the horizontal wind (single component) on all scales $2L < \lambda < 2D$ within "area of regard".

$\sigma_t^2 = \sigma_m^2 + \sigma_c^2 + \sigma_a^2$ = total variance in the horizontal wind in a single direction on all scales affecting the u, v measurements

P = probability of a "good" measure ($0 < P < 1$)

N_T = total number of shots attempted from a single perspective into an area ($D * D$).

N_c = number of shots (out of N_T) clustered to achieve LOS accuracy enhance merit. "Cluster" is a relative term. Here it is assumed that the spacing between shots is no more than .10 of that between the centers of clustered information.

N_a = number of shots or clusters of shots that are effective in reducing the σ_a^2 wind variance.

$$N_a \cdot N_c = N_T$$

Based upon correlated variance distribution in Figure 1, σ_c^2 and σ_a^2 are computed as follows:

$$\sigma_c^2 = (14/400) * 2 * (L-l)$$

$$\sigma_a^2 = (14/400) * 2 * (D-L)$$

To minimize σ_o^2 :

$$N_c = \frac{\sigma_c}{\sigma_a} \sqrt{N_T}$$

Examples

$$D = 200 \text{ km } l = 1 \text{ km } N_T = 20$$

$$\sigma_m^2 = 2 P = 1 \text{ (high SNR region)}$$

Step-Stare System	Conical System
$L = 30 \text{ km}$	$L = l = 1 \text{ km}$
$\sigma_o^2 = 2.03$	$\sigma_c^2 = \phi$
$\sigma_a^2 = 11.90$	$\sigma_a^2 = 13.93$
$N_c = 20$	$N_c = 1$
$N_a = 1$	$N_a = 20$
$\sigma_o^2 = 2/20 + 2.03/20 + 11.90/1$	$\sigma_o^2 = 2/20 + \phi/1 + 13.93/20$
$= .1 + .1 + 11.9$	$= .1 + f + .7$
$\sigma_o = 3.48 \text{ m/s}$	$\sigma_o = .89 \text{ m/s}$

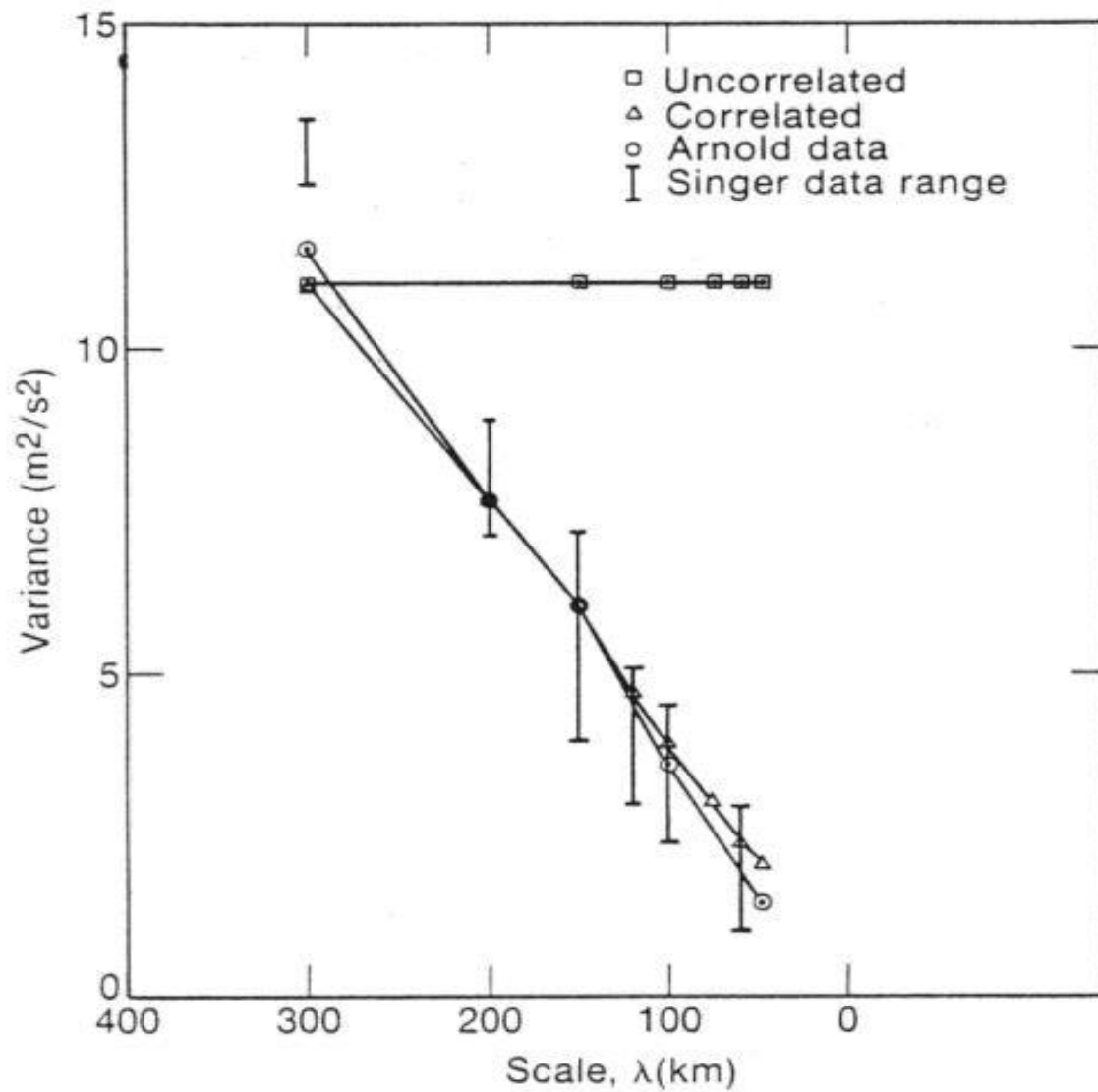


Figure 1 Wind variance at scales less than λ . Average and uncorrelated wind field models are compared with experimental data. PROCEEDINGS OF THE 1980