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SPACE-BASED DOPPLER LIDAR SAMPLING STRATEGIES -- ALGORITHM DEVELOPMENT AND SIMULATED OBSERVATION EXPERIMENTS

Final Report
Under
NASA Contract NAS8-37779

Submitted by

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Executive Summary

Simpson Weather Associates, Inc. has developed LAWS Simulation Models (LSM) to evaluate the potential impact of global wind observations on the basic understanding of the earth's atmosphere and on the predictive skills of current forecast models (GCM and regional scale). Under previous contracts, SWA has developed two basic algorithms for use with simulated doppler lidar wind profilers. The first, a Shot Management Algorithm (SMA), controls timing and placement of lidar pulses. The second, a Multi-Paired Algorithm (MPA), extracts horizontal wind components from the unique lidar radial velocity observations. Fully integrated 'top to bottom' LAWS Simulation Models for global and regional scale simulations were developed during this contract period. The algorithm development incorporated the effects of aerosols, water vapor, clouds, terrain and atmospheric turbulence into the models. Other additions include a new satellite orbiter, signal processor, line of sight uncertainty model, new Multi-Paired Algorithm and wind error analysis code. An atmospheric wind field library containing control fields, meteorological fields, phenomena fields, and new European Center for Medium Range Weather Forecasting (ECMWF) data was also added. SWA has used the LSM to address some key LAWS issues and trades such as accuracy and interpretation of LAWS information, data density, signal strength, cloud obscuration and temporal data resolution.

A synopsis of key work performed under this contract follows:

* LAWS Simulation Model Upgrades

  - Designed and developed a new satellite orbiter that simulates any orbital inclination angle from pure equatorial to sun-synchronous polar.

  - Developed a version of the Air Force Geophysical Laboratory (AFGL) LOWTRAN 7 model that provides water vapor attenuation and aerosol backscatter profiles on a 1° X 1° lat/long grid. ECMWF data profiles are used to approximated the natural variability of the optical properties.

  - Modeled shot scale atmospheric turbulence using a Von Karman turbulence technique. The model insures that the shot scale turbulence is consistent with the inter-shot scale turbulence flow structures that generate the shear and the finer scale turbulence. Turbulence due to the following phenomenas were added; convection, wind shear, mountain waves and jet streaks.

- Incorporated the baseline signal to noise equation into the LSM.

- Incorporated the baseline line of sight uncertainty equation into the LSM.

- Developed a Wind Field Generator Library that contains:

  Control fields such as divergence, vorticity, deformation and translation.

  Correlated meteorological fields from random generated fields.

  Phenomenas such as hurricanes, AVEVAS, mountain waves and jet streaks.

  ECMWF meteorological 1.875° X 1.875° lat/long profiles.

- Developed a LAWS error analysis model that provides measurement errors, sample errors and representativeness.

* Error Minimization Study

SWA examined simulated spaced-based lidar wind errors due to line of sight measurement errors. The wind errors were computed for co-located and non co-located laser shots (10km and 70 km shot separation). Decreasing the shot separation by 60 km resulted in a 12 to 20 % increase in the number of wind speed errors for the 0 to 1 m/s range.

* Wind and Aerosol Inhomogeneities

SWA examined sampling errors in the vicinity of wind and aerosol inhomogeneities. Two Situations were considered. First, the maritime boundary layer and second, an elevated temperature inversion within the troposphere. Simulated lidar measurement errors were found to be 5 to 10% due to coincident backscatter and wind speed gradients. These errors rival other errors expected from the current LAWS sampling strategy and anticipated signal to noise.

* Global Cloud Study

Cirrus clouds will have a significant impact on the performance of LAWS as currently designed. SWA performed a literature search to obtain a reasonable estimate of the global distribution of cirrus clouds. We examined several summaries of satellite-based cloud climatologies and produced an expected LAWS performance chart as a function of latitudinal zones. The table was later upgraded to include the presence of low, middle and high clouds coupled with the availability of atmospheric aerosols, where available.

* Signal to Noise sensitivity study

SWA performed a sensitivity study on expected signal to noise (SNR) using the baseline SNR equation. The study computed SNR as a function of nadir scan angle and considered the effects of aerosol backscatter, molecular attenuation and satellite altitude. For the current LAWS orbital configuration (i.e., a satellite altitude of 705 km and a scan angle of 45 degrees) in a maritime atmosphere, the surface and midlevel SNR (db) was 12.23 and -0.81, respectively.

* Observing System Simulation Experiments (OSSE)

1) SWA is conducting an OSSE with Florida State University (FSU) using a very high resolution global spectral model (Krishnamurti). SWA has provided 10 days of LAWS simulated wind data that along with World Weather Watch (WWW) data is being used as input winds to the FSU spectral model. Output from the assimilation is being compared to output using only WWW data as FSU wind input.

2) SWA prepared for a regional scale OSSE using the LAMPS model on the CRAY-XMP at MSFC. Tim Miller, MSFC, is exploring assimilation of LAWS data into mesoscale models. This OSSE also serves the Shot Management Algorithm by providing a testbed for evaluating various scan patterns and shot densities.

* Baseline Atmosphere for LAWS trade studies

SWA produced a baseline atmosphere for the LAWS Science Team. The baseline atmosphere is a gridded data base with prescribed aerosol backscatter, molecular attenuation, wind and turbulence profiles in a 100X100 km^3 volume. The aerosol backscatter profile is a composite based on ground-based lidar measurements taken at JPL and WPL. The attenuation profile is intended to be a severe mean maritime profile and is based on LOWTRAN 7 data.

During the period of this contract, SWA personnel participated in 1 workshop, presented 2 papers, wrote 2 additional papers and attended 4 LAWS oriented meetings.

The following appendices contain detail of the work described above:

Appendix A: Conference papers.

Appendix B: Other presentations.

Appendix C: Modified copies of monthly progress reports.

APPENDIX A

Conference Papers

List of Papers
(Papers Attached)

Emmitt, G.D. and S.A. Wood, 1989: Simulated space-based Doppler lidar performance in regions of backscatter inhomogeneities. Proc. Laser Applications in Meteorology and Earth and Atmosphere Remote Sensing, January 16-18, Los Angeles, CA, pp. 127-129.

Emmitt, G.D. and S.A. Wood, 1989: Simulation of a space-based Doppler lidar wind sounder - sampling errors in the vicinity of wind and aerosol inhomogeneties. Proc. Fifth Conf. on Coherent Laser Radar, June 5-9, Munich, FRG, pp. 63-66.

Emmitt, G.D., 1989: Advantages of approximate shot coincidence with a space-based Doppler lidar. Paper submitted to the Remote Sensing of the Atmosphere Topical Meeting, February 12-15, 1990, Lake Tahoe, NV.

Wood, S.A. and G.D. Emmitt, 1989: A reference atmosphere for LAWS trade studies. Paper submitted to the Remote Sensing of the Atmosphere Topical Meeting, February 12-15, 1990, Lake Tahoe, NV.

Simulated space-based Doppler lidar performance in regions of backscatter inhomogeneities

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ABSTRACT

The prospect of obtaining directly measured winds on a global scale has raised questions about the expected quality of the lidar wind measurements and the potential for biases due to sampling patterns and line-of-sight impediments. Extensive computer simulations are on-going to address these and other issues. One source of measurement bias is found in regions of the atmosphere where gradients in both lidar backscatter and the winds occur together. The potential biases that result are identified and their magnitudes estimated.

1. INTRODUCTION

A space-based Doppler Lidar Atmospheric Wind Sounder (LAWS) has been proposed by NASA as a facility instrument for its Earth Observing System.[1] Hardware feasibility and data impact studies are on-going.[2] The uniqueness of a lidar wind measurement gives rise to many questions regarding the accuracy and interpretation of the information. Fundamental questions are related to the data density (limited primarily by laser lifetime and scan rates), cloud obscuration and temporal resolution. A Lidar Simulation Model (LSM) has been developed to address some of these issues and to find ways to maximize the information content within the current hardware configurations and performance constraints.[3,4] In Figure 1, the general density of LAWS data is shown with vectors representing data combined in the highest resolution mode (which is not necessarily the most accurate mode since no averaging is performed).

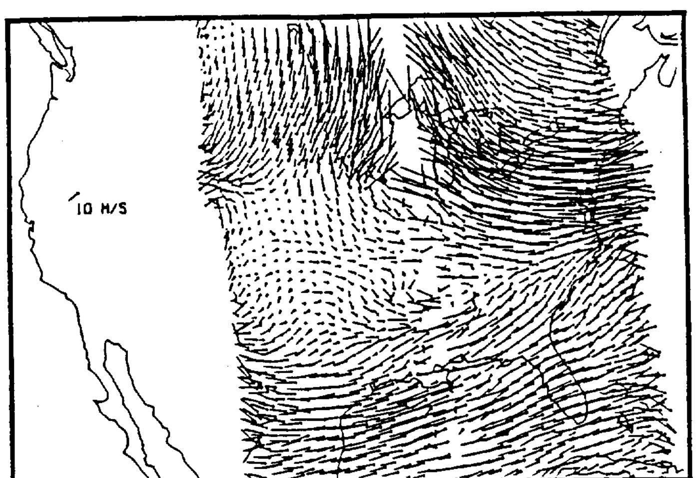

Figure 1. Simulated wind vectors at 500 mb obtained with LAWS Simulation Model (LSM). Each vector is computed from a pair of lidar line-of-sight measurements taken from two different perspectives. The different perspectives result from conically scanning the lidar mounted on a polar orbiting satellite.

Given our current expectations of global distributions of backscatter at 10.6 or 9.11μm, we anticipate useful LAWS data in the lowest 5 km over most of the globe and in upper regions of the troposphere where thin clouds, volcanic dust, or other aerosols may concentrate. The LSM is generally used to examine the global performance of various lidar scanning techniques, sampling patterns and algorithms. In this paper we use the model to look at a subset of circumstances where strong aerosol gradients occur in regions of significant wind gradients. While we do not have much observational support for this investigation, the likelihood that these conditions will exist quite frequently and in areas of great interest has motivated an "order of magnitude" study.

We have chosen to look at two situations: (1) the marine boundary layer (below 500 meters) and (2) elevated temperature inversions within the troposphere. In the marine layer one expects strong gradients in airborne sea salt near the ocean surface giving rise to large vertical gradients in backscatter in a layer where the typical wind profile also shows a strong change with height (Figure 2). In the vicinity of elevated temperature inversions, one often finds backscatter "spikes" (Figure 4) and wind velocity shears due to decoupling at the density interface. For both of these situations, the net effect is that when a weighted average of the winds within a lidar sample volume is obtained, errors are introduced in making height assignments of the velocity information.

This weighted sampling is not unexpected and is common to other remote sensing systems. However, the magnitude of the errors is noteworthy as are some of the implications of the resulting biases to the computations of such quantities as heat and moisture fluxes.

2. MARINE BOUNDARY LAYER

The distribution of backscatter and winds in the marine boundary layer have been generalized in Figure 2. The backscatter profiles result from a composite of the LOWTRAN 7 Navy Maritime Model as well as some special data sets compiled by surface based CO_2 lidars. The wind profile is the standard log (z/z_o) form and the surface roughness (z_o) is taken to be 0.1 meters (rough seas).

In Figure 3, we have plotted the errors due to sampling volumes of different lengths. For a 500 meter pulse length the errors approach 10% at 250 meters. The dotted lines are the errors that would have occurred if there had been no gradients in $\beta_{10.6}$. While some of these differences could be corrected by accounting for such sampling related problems, the general bias is towards an underestimation of the wind shear and therefore the heat and energy fluxes over the oceans.

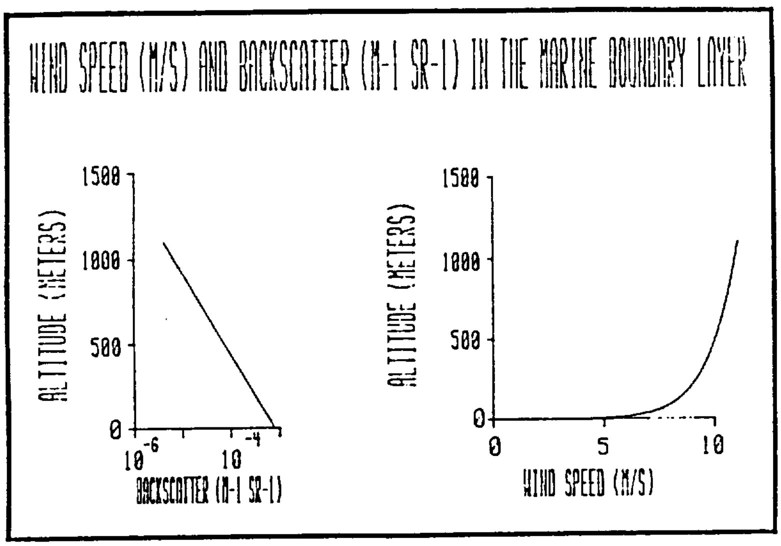

Figure 2. Ideal representations of the vertical distribution of backscatter (10.6 µm) and wind speed in the lowest 2 km of the atmosphere above the ocean. Backscatter gradients are consistent with observations near the ocean's surface.

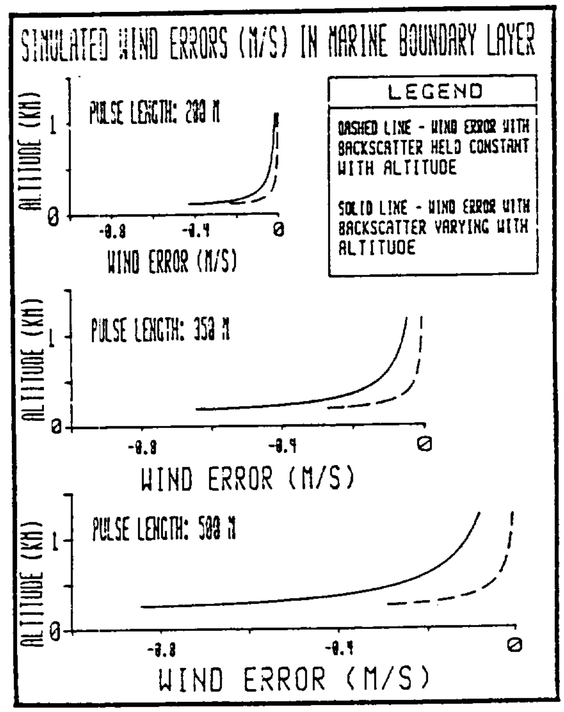

Figure 3. Comparison of lidar measurement errors (observed speeds-actual speeds) for different pulse lengths for both the case of no backscatter gradients and the case shown in Figure 2.

3. ELEVATED INVERSIONS

Marine inversions, nocturnal inversions or cloud generated inversions can cause aerosol flux convergence and result in a high concentration of aerosols near the base of the temperature structure. Figure 4 shows how the winds respond to the inversion by accelerating above it. Compared to the marine boundary layer case, the patterns of sampling errors are considerably different (Figure 5). Not only is the magnitude of the errors different but also the sense of the error. Without any backscatter structures the maximum lidar measurement error is an overestimate; with an assumed backscatter feature at the inversion, the maximum errors are underestimates. It is noteworthy that the magnitudes of the extreme errors increase with pulse length.

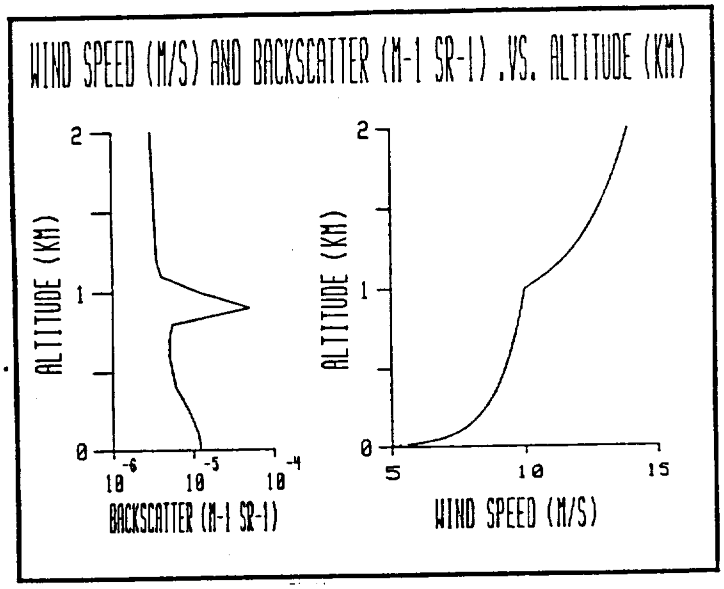

Figure 4. Ideal representations of the vertical distribution of back-scatter (10.6 µm) and wind speed in the vicinity of an elevated temperature inversions.

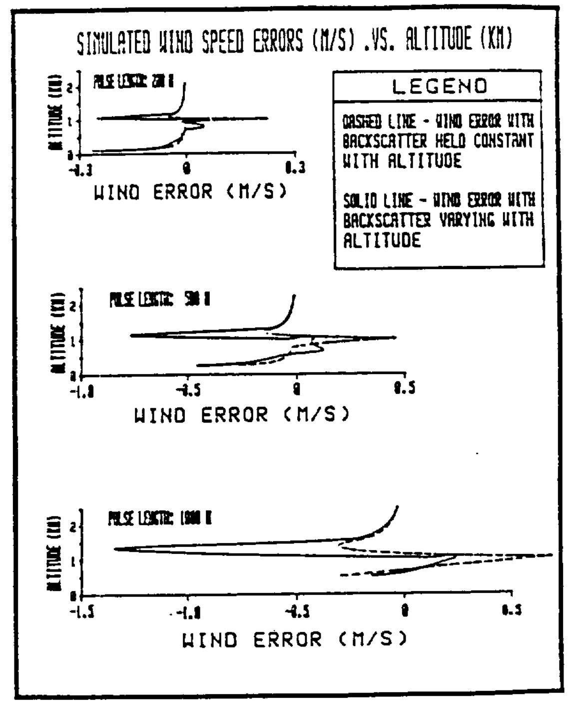

Figure 5. Wind speed errors (observed wind speed-actual wind speed) for three different lidar pulse lengths applied to the profiles in Figure 4.

4. SUMMARY AND CONCLUSIONS

The magnitude of the lidar measurement errors (5% to 10%) due to coincident β and wind speed gradients rival other errors that are expected from the proposed LAWS sampling strategy and anticipated Signal-to-Noise Ratio (SNR). Advanced signal processing and wind computation algorithms should be able to reduce the magnitude of the errors shown in Figures 3 and 5. However, the general biases towards lower wind speeds will be much harder to correct and must be addressed in the ongoing Observing System Simulation Experiments (OSSEs).

5. ACKNOWLEDGEMENTS

The work reported here has been funded through NASA contract NAS8-37779. The authors wish to recognize the contribution of M. Buffum for reviewing the manuscript and M. Morris for typing and layout.

6. REFERENCES

1. NASA, LAWS Instrument Panel Report (Chairman, R.J. Curran), NASA Earth Observing System, Volume IIg, NASA Headquarters, Washington, D.C. (1987).

2. G.D. Emmitt and S.H. Houston, Impact of a space-based Doppler lidar wind profiler on our knowledge of hurricanes and tropical meteorology, American Meteorological Society's 17th Conference on Hurricanes and Tropical Meteorology, Miami, FL, April (1987).

3. G.D. Emmitt and S.H. Houston, Assessment of measurement error due to sampling perspective in the space-based Doppler lidar wind profiler, Second Conference on Satellite Meteorology/Remote Sensing and Applications, Williamsburg, VA, May (1986).

4. J.W. Bilbro and G.D. Emmitt, Assessment of error sources for one component wind measurements with a space-based Doppler lidar, Optical Society of America's Fourth Conference on Coherent Laser Radar: Technology and Applications, Aspen, CO, July (1987).

Simulation of a Space-Based Doppler Lidar Wind Sounder - Sampling Errors in the Vicinity of Wind and Aerosol Inhomogeneties

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1. Introduction

A space-based Doppler Lidar Atmospheric Wind Sounder (LAWS) has been proposed by NASA as a facility instrument for its Earth Observing System (EOS) (NASA, 1987). Hardware feasibility and data impact studies are on-going (Emmitt and Houston, 1987). The uniqueness of a lidar wind measurement gives rise to many questions regarding the accuracy and interpretation of the information. Fundamental questions are related to the data density (limited primarily by laser lifetime and scan rates), cloud obscuration and temporal resolution. A Lidar Simulation Model (LSM) has been developed to address some of these issues and to find ways to maximize the information content within the current hardware configurations and performance constraints (Emmitt and Houston, 1986; Bilbro and Emmitt, 1987).

Given our current expectations of global distributions of backscatter at 10.6 or 9.11 μm, we anticipate useful LAWS data in the lowest 5 km over most of the globe and in upper regions of the troposphere where thin clouds, volcanic dust, or other aerosols may concentrate. The LSM is generally used to examine the global performance of various lidar scanning techniques, sampling patterns and algorithms. In this paper we use the model to look at a subset of circumstances where strong aerosol gradients occur in regions of significant wind gradients, giving rise to measurement biases which will require special interpretation.

We have chosen to look at two situations: (1) the marine boundary layer and (2) elevated temperature inversions within the troposphere. In the marine layer one expects strong gradients in airborne sea salt near the ocean surface giving rise to large vertical gradients in backscatter in a layer where the typical wind profile also shows a strong change with height (Figure 1, Top). In the vicinity of elevated temperature inversions, one often finds backscatter "spikes" (Figure 2) and wind velocity shears due to decoupling at the density interface. For both of these situations, the net effect is that when a weighted average of the winds within a lidar sample volume is obtained, errors are introduced in making height assignments of the velocity information.

This weighted sampling is not unexpected and is common to other remote sensing systems. However, the magnitude of the errors is noteworthy as are some of the implications of the resulting biases to the computations of such quantities as heat and moisture fluxes.

2. Marine Boundary Layer

The distribution of backscatter and winds in the marine boundary layer have been generalized in Figure 1 (Top). The wind profile is the standard log (z/z_o) form and the surface roughness

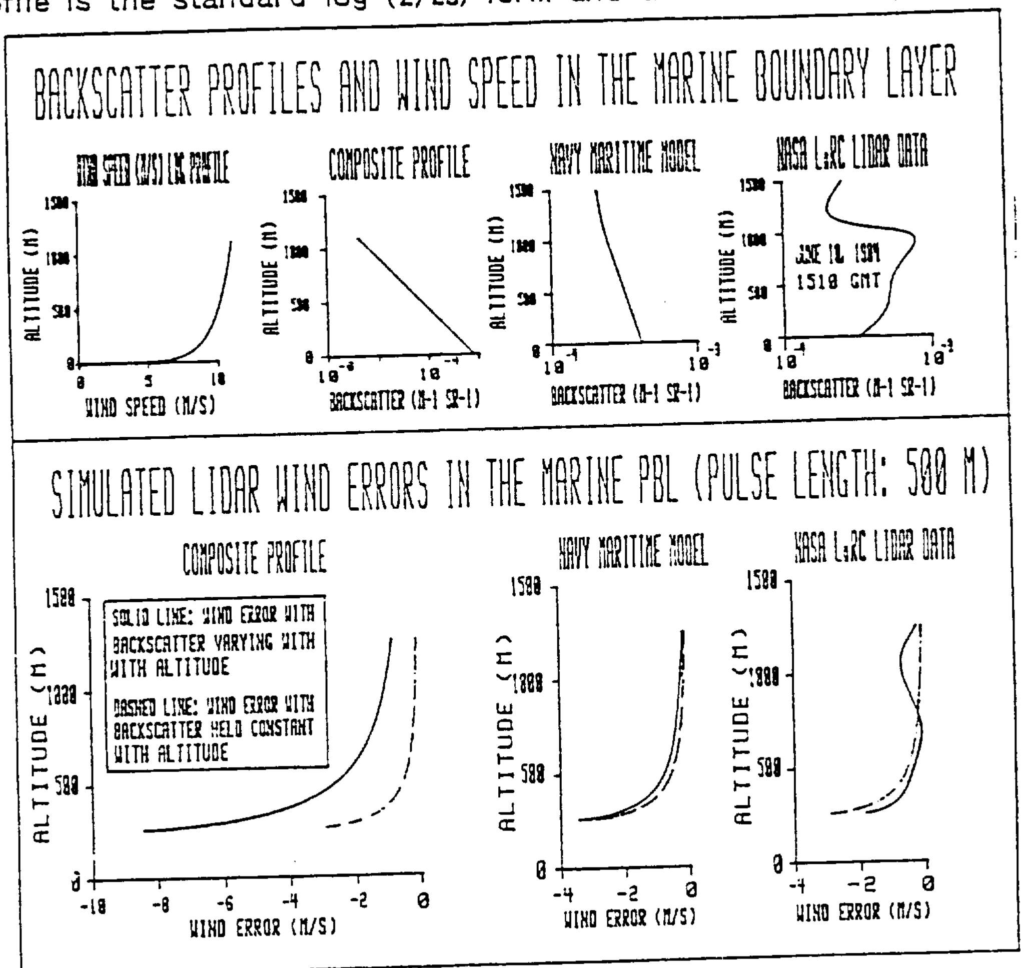

Figure 1. (Top) Ideal representations of the vertical distribution of backscatter (10.6 μm) and wind speed in the lowest 2 km of the atmosphere above the ocean.

(Bottom) Comparison of lidar measurement errors (observed speeds minus actual speeds) for different backscatter profiles including the case of no backscatter gradients. A 500 meter pulse length was assumed.

(z_o) is taken to be 0.01 meters (rough seas). The composite backscatter profile results from several special data sets compiled by surface based CO_2 lidars. The Navy Maritime Profile was obtained from LOWTRAN 7 and the NASA Lidar data was taken from data supplied by NASA Langley Rsearch Center (Ed Browell).

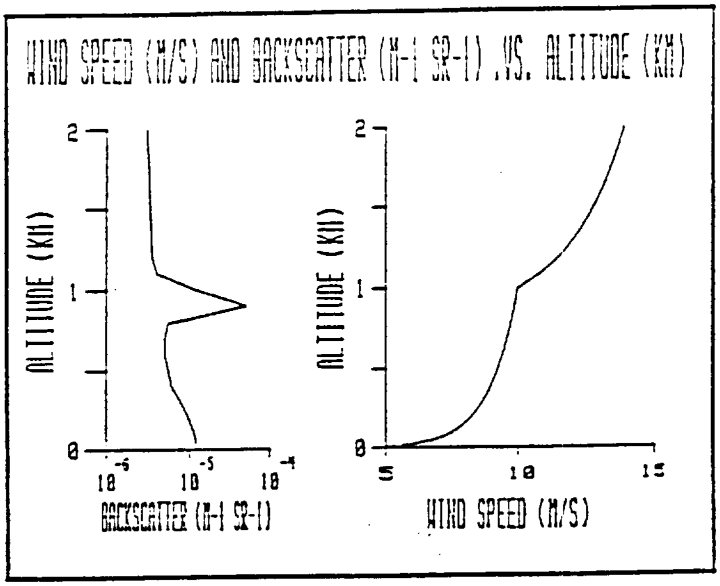

Figure 2. Ideal representations of the vertical distribution of backscatter (10.6 µm) and wind speed in the vicinity of an elevated temperature inversion.

In Figure 1 (bottom), we have plotted the errors associated with sampling with a 500 meter pulse. The free stream velocity was chosen to be 10 m s^{-1}. The dotted lines are the errors that would have occurred if there had been no gradients in backscatter. The error of −3 m s^{-1} at 250 m results from simple linear averaging of a logrithmic profile from the surface to 500 meters. The solid lines are for errors compounded by backscatter profile weighting. The last two backscatter profiles produce .2 - .8 m s^{-1} additional errors for the given wind profile. While some of these differences could be corrected by accounting for such sampling related problems, the general bias is towards an underestimation of the near surface wind speeds and therefore the heat and energy fluxes over the oceans.

3. Elevated Inversions.

Marine inversions, nocturnal inversions or cloud generated inversions can cause aerosol flux convergence and result in a high concentration of aerosols near the base of the temperature structure. Figure 2 shows schematically how the winds respond to the inversion by accelerating above it. Compared to the marine boundary layer case, the patterns of sampling errors are considerably different (Figure 3). Not only is the magnitude of the errors different but also the sense of the error. Without any backscatter structures the maximum lidar measurement error is an overestimate; with an assumed backscatter feature at the inversion, the maximum errors are underestimates. It is noteworthy that the magnitude of the extreme errors increases with pulse length.

4. Summary and Conclusions

The magnitude of the lidar measurement errors (5% to 10%) due to coincident backscatter and wind speed gradients rival other errors that are expected from the proposed LAWS sampling strategy and anticipated Signal-to-Noise Ratio (SNR). Advanced signal processing and wind computation algorithms should be able to reduce the magnitude of the errors shown in Figures 1 and 3. However, the general biases towards lower wind speeds will be much harder to correct and must be addressed in the ongoing Observing System Simulation Experiments (OSSEs).

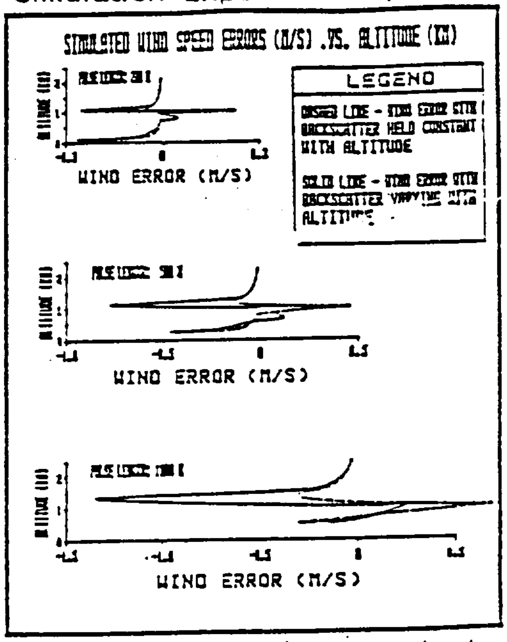

Figure 3. Wind speed errors (observed wind speed-actual wind speed) for three different lidar pulse lengths applied to the profiles in Figure 2.

5. References

Bilbro, J.W. and G.D. Emmitt, 1987: Assessment of error sources for one component wind measurements with a space-based Doppler lidar, Optical Society of America's Fourth Conference on Coherent Laser Radar: Technology and Applications, Aspen, CO, July.

Emmitt, G.D. and S.H. Houston, 1986: Assessment of measurement error due to sampling perspective in the space-based Doppler lidar wind profiler, Second Conference on Satellite Meteorology/Remote Sensing and Applications, Williamsburg, VA, May.

Emmitt, G.D. and S.H. Houston, 1987: Impact of a space-based Doppler lidar wind profiler on our knowledge of hurricanes and tropical meteorology, A.M.S. 17th Conference on Hurricanes and Tropical Meteorology, Miami, FL, April.

NASA, 1987: LAWS Instrument Panel Report, Chairman, R.J. Curran, NASA Earth Observing System, Vol. IIg, NASA Headquarters, Washington, D.C.

Advantages of Approximate Shot Coincidence with a Space-Based Doppler Lidar

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A space-based Doppler lidar wind sounder (LAWS) is being proposed as an EOS facility instrument. On a polar orbiting platform, LAWS is expected to provide a global set of wind profiles throughout the troposphere. These profiles will be bounded below by the earth's surface or opaque clouds and limited to those areas having sufficient aerosols and/or thin cirrus.

LAWS measures a line-of-sight (LOS) component of the total average wind vector (u, v and w) within a cylindrical sample volume of radius 10-20 m and length ~ 300-500 m. Laser lifetime, in addition to other engineering considerations, limits the density of samples to 1 per ~ 1200 km^2. The widely spaced LOS components obtained from relatively small sample volumes must then be combined to estimate the horizontal wind speed. It is clear that much of the time some averaging will be necessary to obtain reliable wind estimates. Just how much averaging will depend upon (1) the SNR for the individual samples, (2) the variance in the wind field at scales on the order of the sample spacing, and (3) the users requirements. The poorer the signal strength for samples within a given area the more averaging will be needed to reduce measurement uncertainty. The greater the variance within the real wind field, the more averaging is required to get a representative measurement. The user may define the level of averaging by specifying a desired resolution volume (e.g., 200 x 200 x 1 km^3 for GCM assimilation or 75 x 75 x .5 km^3 for mesoscale research).

The baseline configuration for the LAWS employs a fixed scan angle (~ 45°), a fixed scan rate (~ 6 rpm) and a fixed pulse repetition frequency (10 Hz). The pattern of shots resulting from these baseline parameters has been shown in Emmitt (1985). Better management of these shots to extend laser lifetime and to optimize sampling distribution has also been explored. Shot management options include scanner/pulse scheduled programming to achieve near coincidence for forward and aft shot pairs. The advantages of shot pair coincidence are under study within the context of general LAWS science objectives and desired accuracies.

The issue of shot coincidence is related primarily to the assessment of various algorithms that take a very limited number of radial (LOS) velocity measurements within a specified area and generally an estimate of the horizontal wind components.

Currently being considered are three basic ways that the LOS observations can be combined to obtain estimates of the horizontal wind vector. The first and most obvious way is to define a resolution volume and then use a weighted least squares analysis with the LOS components and their direction cosines. The weighting coefficients could be the SNR for each LOS sample. The result is a single estimate of the average horizontal wind components for the resolution volume.

A second method is to use a variational analysis scheme with a numerical weather model (e.g., GCM). In this case the LOS components are assimilated into the model as radial wind measurements and the model parameters are adjusted to optimize the agreement with the lidar data (and other data) with the resulting model wind used as the best estimate of the actual wind vector.

A third method is to combine the LOS measurements into pairs with each of the two shots having a different perspective on the wind flow. Each pair is used to compute the horizontal wind components. These pairs are then weighted depending upon SNR, location within the resolution volume and the shot geometry of the two shots in each pair. The weighted pairs are then averaged to obtain, not only an estimate of the volume average, but also a first order estimate of the wind structure within the resolution volume.

In developing the third approach, which we call the Multi-Pair Algorithm (MPA), it was clear that there were advantages to having the two shots in a pair occur in close proximity (< 1 km) to each other within a selected layer. When the SNR for each shot was high (> 5 dB), one could obtain the highest resolution (~ 50 km) product possible with LAWS. However, if necessary, the wind estimates for the pairs could be weighted and averaged to produce lower resolution data sets.

While shot coincidence can be argued for the MPA approach from first principles (i.e., common volume sampling), it is not so obvious that the first two approaches mentioned above benefit from such shot management. This issue will be addressed in the presented paper along with the results of some simulations currently underway. The first and third methods are currently being evaluated to address the following questions:

1) which method provides the best estimate of an area averaged wind profile?

2) which method provides the most accurate wind profile for a subgrid scale location?

3) what is the impact of managed shot-coincidence on each method?

Acknowledgement

This work is being funded under NASA Contract NAS8-37779 and monitored by Marshall Space Flight Center, Huntsville, AL.

Reference

Emmitt, G.D., 1985: Doppler lidar sampling strategies and accuracies--regional scale. Paper presented at the Symposium and Workshop on Global Wind Measurements, Columbia, MD, July 29-August 1.

A Reference Atmosphere for LAWS Trade Studies

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1. INTRODUCTION

A space-based Doppler Lidar Atmospheric Wind Sounder (LAWS) has been proposed by NASA as a facility instrument for the NASA Earth Observing System. A LAWS Simulation Model (LSM) has been developed to assess the impact of a spaced-based Doppler lidar wind profiler on global and regional features. Hardware feasibility and data studies are on-going.[1,2,3] The uniqueness of global Lidar wind measurements from space raises many fundamental questions that may impact the design of such a system. The distribution of aerosols that provide backscatter, the molecular attenuation that reduces signal strength, the effects of wind shear and turbulence that effect measurement accuracy, and the presence of thin cirrus clouds that can enhance the performance are all issues that must be considered.

This paper describes a candidate reference atmosphere from the LSM's atmospheric library. The reference atmosphere is used to examine LAWS baseline signal-to-noise and line-of-sight velocity errors.

2. REFERENCE ATMOSPHERE

The LSM atmospheric library provides a probabilistic aerosol backscatter profile, a probabilistic thin cirrus cloud backscatter profile, a molecular attenuation profile, a zig-zag wind shear profile, sub-pulse scale turbulence, and a correlated horizontal wind field within a 100 X 100 X 15 km^3 volume.

The probabilistic aerosol backscatter profile, shown in Figure 1., was constructed from ground based lidar data taken at JPL and WPL. The circles indicate the median value (including data "dropouts") as a function of altitude. The number in the circles is the percentage of total observations associated with that particular median. The $\pm$ 1 sigma error bars were computed from several hundred profiles. The model assumes that backscatter is log normal around the median at all levels. It is noted that the backscatter near the ocean surface is thought to be much higher than shown. The JPL and WPL lidar data sets did not have any contributions of thin cirrus clouds to the upper tropospheric backscatter. Therefore, the cirrus mode from 7 to 15 km has been estimated based on general reports high frequency of occurrence of thin subvisual cirrus clouds. The distribution of subvisual cirrus has been estimated as 30% at 7 km as seen from a ground perspective at JPL, Boulder and Hawaii and 50% at 14 km. This is believed to be underestimated for the tropics from a space perspective, where 70-80% may be the closer value. The cirrus relative backscatter is also assumed to be log normal.

The molecular attenuation profile, shown in Figure 2., was generated by LOWTRAN 7 model and represents attenuation in a tropical maritime atmosphere, Earth's surface. No cirrus cloud attenuation is included. The atmospheric generator creates a "zig-zag" wind shear profile, as shown in Figure 3. This shear profile allows the effects of wind shear to be considered at any level in the atmosphere. A very general sub-pulse scale turbulence due to wind shear is included. Using Von Karman (-5/3) turbulence spectra for wind shear[4], the LSM integrates the spectra over the pulse length scale, which is multiplied by an estimated total wind shear turbulence that is proportional to the "zig-zag" shear.

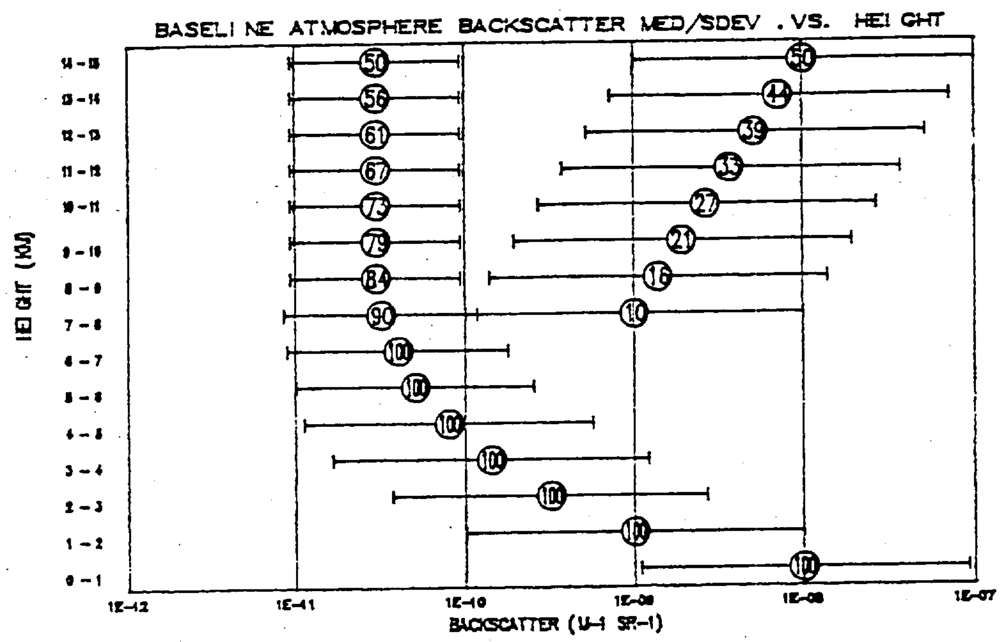

Fig. 1 Probabilistic backscatter profile where locations at the circles indicates the median value including data "drop outs" in the orginal WPL and JPL profiles. The number in the circles is the percentage of total observations associated with that median. The error bars +1 sigma in the log backscatter is based upon several hundred profiles. The cirrus mode above 7 km has been estimated.

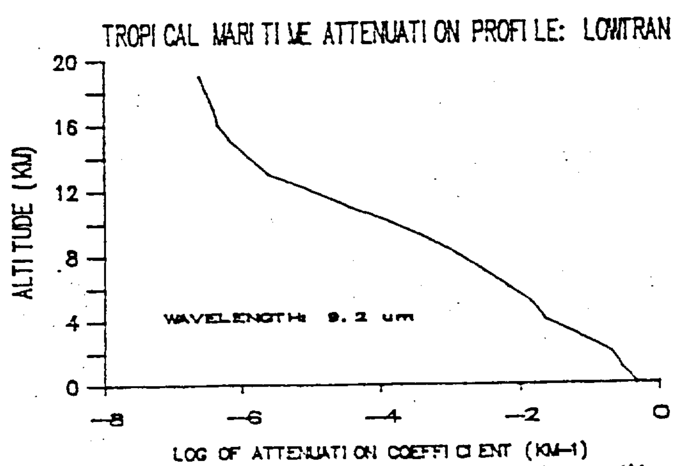

FIG. 7 Average tropical maritime attenuation profile taken from LOWTRAN 7 code.

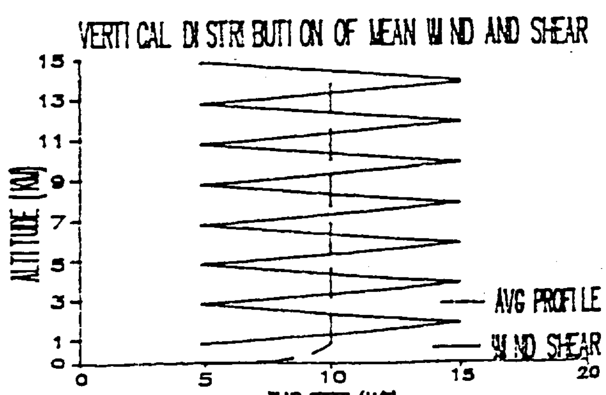

FIG. 3 Reference atmosphere's vertical distribution of mean horizontal wind and a "zig-zag" wind shear.

3. A REFERENCE ATMOSPHERE APPLIED TO SNR AND LOS UNCERTAINTY

The reference atmosphere's median backscatter profile, a tropical maritime attenuation profile and a shear layer of 0.005 s^{-1} was used to examine baseline LAWS signal to noise and line of sight velocity error, which is based upon pulse-pair autocorrelation processing of the Doppler signal. Figure 4. highlights that no SNR was near 5 db for the mid-levels nor at extreme scan angles at the surface. If 5 db is the threshold SNR for extracting useful line of sight wind measurements, then for a scan angle of 45 degrees, a backscatter greater than E-10 m-1 sr-1 is needed. Figure 5. shows that the probability of getting the backscatter needed to obtain a 5 db SNR is nearly 80 % of the time at the surface, but quickly decreases to below 50% in the mid-level to 17% at upper levels. Sub-visual cirrus can increase the probability of getting 5 db from 20 % around the tropopause to 50% at 14 km.

If we could extract information at a lower threshold SNR, via some advance signal processing, the picture changes significantly. Figure 6. shows that the probability of getting backscatter to obtain a -5 db SNR is much higher, on the order of 80 % at the upper levels. Figure 7. shows the radial velocity uncertainty as a function of signal to noise. Errors on the order of 1 - 2 m/s are expected at the surface layer, where SNR is 13 db. At a snr of 5 db, errors on the order of 8 m/s should be expected. Again, if an advance signal processing scheme could relax the 5 db threshold by 10 db, then radial velocity errors at 5 db could be on the order of 1 m/s.

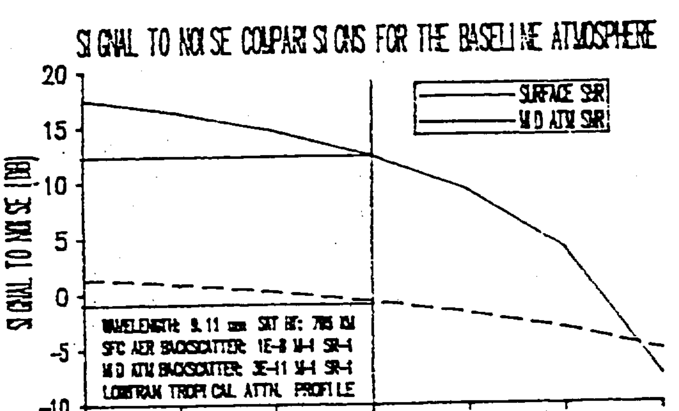

FIG. 4 Signal to noise comparision for a tropical maritime atmosphere as a function of nadir scan angle. A comparision at a scan angle of 45 deg is hightlighted for the surface and mid-altitudes.

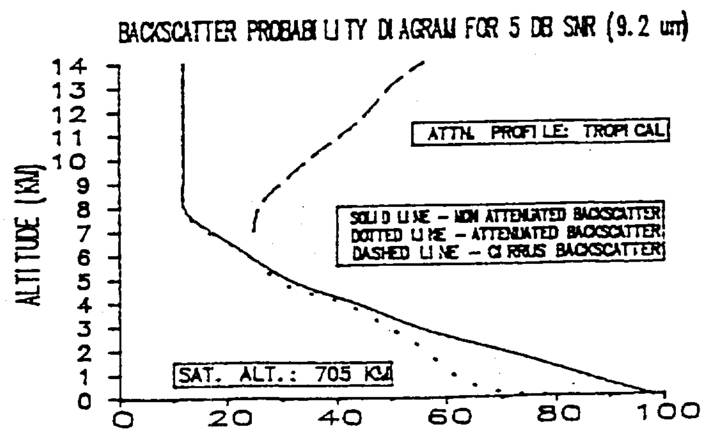

FIG. 5 Example of profile of resulting "successful shots" using 5 db as a threshold for the reference atmosphere.

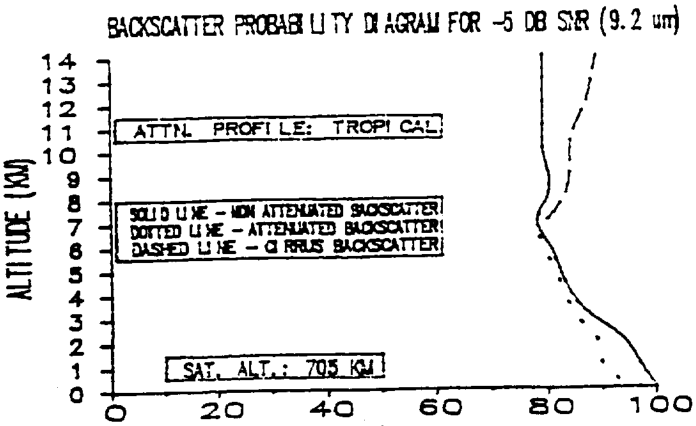

FIG. 6 Example of profile of resulting "successful shots" using −5 db as a threshold for the reference atmosphere.

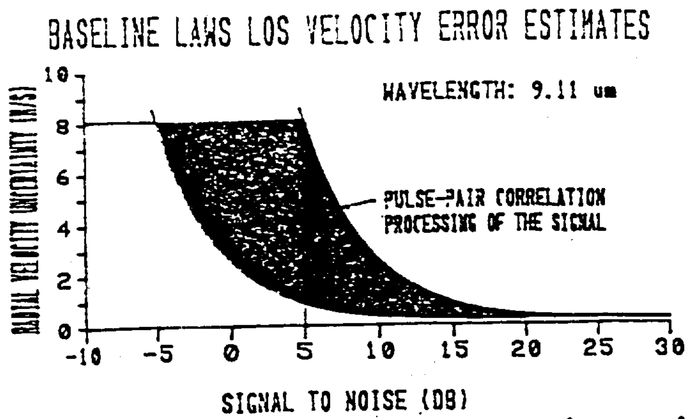

Fig. 7 Radial velocity uncertainty (m/s) as a function of signal to noise (db). The right hand curve is for a pulse-pair correlation processing of the doppler signal. The left-hand curve represent the potential velocity error if the threshold SNR was −5 db.

4. CONCLUSIONS

We have defined one possible candidate reference atmosphere from the LAWS Simulation Model. We have looked at the baseline signal to noise and radial velocity errors using the reference atmosphere. Based on a tropical maritime atmosphere, we have shown that obtaining wind information in the mid-levels will be difficult unless better signal processing is possible and/or sub-visual cirrus is present. This study does not consider cloud obscuration, particularly in the PBL. A current follow on study is including clear line of sight cloud statistics for penetrating cloudy regions.

5. REFERENCES

1. Emmitt, G. D. and S.H. Houston, 1987; Impact of a space-based Doppler lidar wind profiler on our knowledge of hurricanes and tropical meteorology. American Meteorological Society's 17th Conference on Hurricanes and Tropical Meteorology, Miami, Fl.

2. Emmitt, G. D. and S. A. Wood, 1988; Simulated Space-Based Doppler Lidar performances in regions of Backscatter Inhomogeneities. Presented at the SPIE's Symposium on Lasers and Optics, Los Angeles. Cal.

3. Emmitt, G. D. and S. A. Wood, 1989; Simulation of a Space-based Doppler Lidar Wind Sounder - Sampling Errors in the Vicinity of Wind and Aerosol Inhomogeneities. Presented at the 5th Conference on Coherent Laser Radars, Munich, Germany.

4. Rhyne, R. H., H. Murrow, and K. Sidwell, 1976; "Atmospheric Turbulence Power Spectral Measurements to Long Wavelengths for Several Meteorological Conditions", NASA Conference, Hampton, Va, pp. 271-286.

APPENDIX B

List of Other Presentations

Emmitt, G.D. and S.A. Wood, 1989: Review of proposed baseline atmosphere for Phase I LAWS configuration trade studies. Presented at 2nd LAWS Science Panel Meeting, August 9-11, Huntsville, AL.

Emmitt, G.D., S.A. Wood and S. Houston, 1989: Update on LAWS OSSEs and simulation studies. Presented at 2nd LAWS Science Panel Meeting, August 9-11, Huntsville, AL.

Miller, T. and G.D. Emmitt, 1989: Preparation for OSSE using a regional scale model - LAMPS. Presented at 2nd LAWS Science Panel Meeting, August 9-11, Huntsville, AL.

Review of Proposed Baseline Atmosphere for Phase I LAWS Configuration Trade Studies

G.D. Emmitt
S.A. Wood

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2nd LAWS Science Panel Meeting
9-11 August 1989
Huntsville, AL

BASELINE ATMOSPHERE FOR PHASE I LAWS CONFIGURATION TRADE STUDIES

Definition

The baseline atmosphere is a gridded data base with prescribed backscatter, absorption, wind and turbulence profiles within a 100 x 100 x 20 km^3 volume.

Purpose

The primary purpose for providing a baseline (or reference) atmosphere is to have a common basis for evaluating and comparing various LAWS lidar/scan configurations suggested by the two contractors. The intent is to generate a description of the atmosphere that will permit parametric expressions of LAWS system trades involving measurement accuracies (LOS and horizontal vector), representativeness, resolution and areal coverage.

It is anticipated that the resulting expressions of critical cost and performance trades between resolution, coverage and accuracy will enable the LAWS Science Team to define higher order simulations required to select the optimum LAWS configuration to meet the science objectives.

The baseline atmosphere is constructed with the following considerations and assumptions:

1) Each contractor will have their own higher order atmospheric models for more detailed or focussed trade studies;

2) The LAWS Science Team needs to know the <u>general</u> sense of the costs ($ and performance) associated with various system configurations;

3) The final LAWS configuration will be the product of several iterations between the engineering and science efforts;

4) The most critical questions to be addressed by the baseline atmosphere are:

   * with what frequency will LAWS obtain accurate ($\pm$ 1 m s^{-1}) winds along cloud-free line-of-sights (CFLOS) as a function of laser/optic parameter; scan angle; pulse length; pulse averaging; and height in the atmosphere.

   * what is the optimum set of baseline ($\pm$) system parameters that will achieve the most accurate LOS measurements; the most representative LOS measurements; the best global coverage; the most accurate horizontal wind estimates (primative*); the most representative horizontal wind estimates?

*primitive - a Level 2b wind vector computed using only information provided by the LAWS instrument.

<u>Description</u>

The baseline atmosphere contains information on aerosol backscatter, absorption and winds applicable to a 10.6 μm or 9.11 μm LAWS. Each component is treated independently while recognizing potential correlations in the real world. However, any attempt at this time to be more realistic is not justified. Therefore, the backscatter profiles, aerosol profiles, wind profiles and wind horizontal structures are designed to contain only information necessary to answer the critical questions listed above.

Backscatter

The GLOBE backscatter summary profile used in this baseline atmosphere is shown in Figure 1. This format is attractive in that it highlights the mode of backscatter return with height and at the same time allows the likelihood of a specific backscatter value to be expressed in terms of the distribution. Both aerosol and thin cirrus profiles are presented.

It is recognized that the GLOBE data set is based upon a limited body of observations and is probably a conservative representation of the backscatter over the entire globe.

Absorption

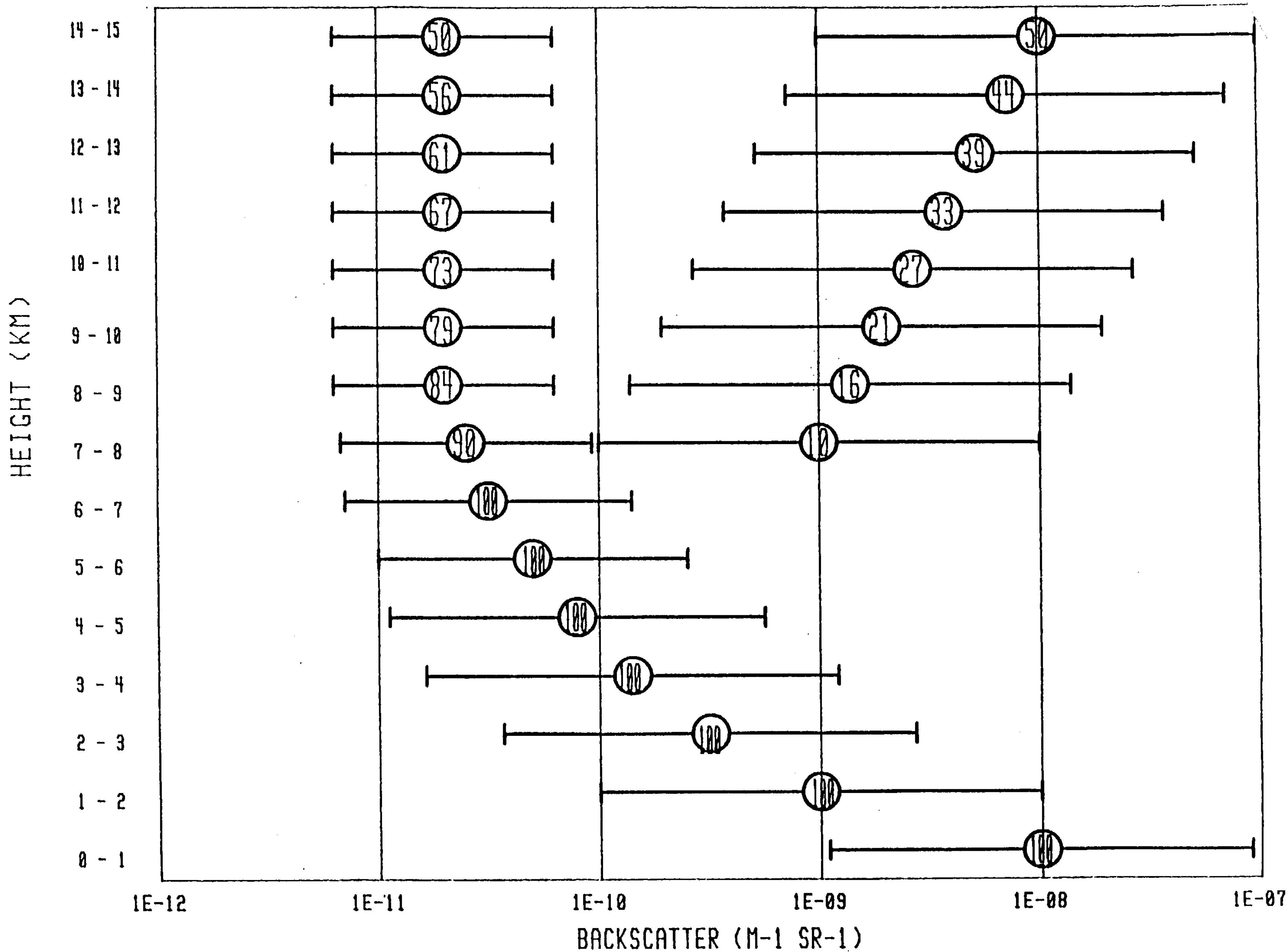
The water vapor and gas absorption profile was chosen to represent the tropical marine atmosphere. The arguments for this choice are that the current data sparse regions are the oceans (70% of the globe), the geostrophic approximation doesn't apply well in the tropics (40% of the globe), and the absorption will be greatest in this region due to water vapor. Figure 2 is taken from LOWTRAN 7..

Winds

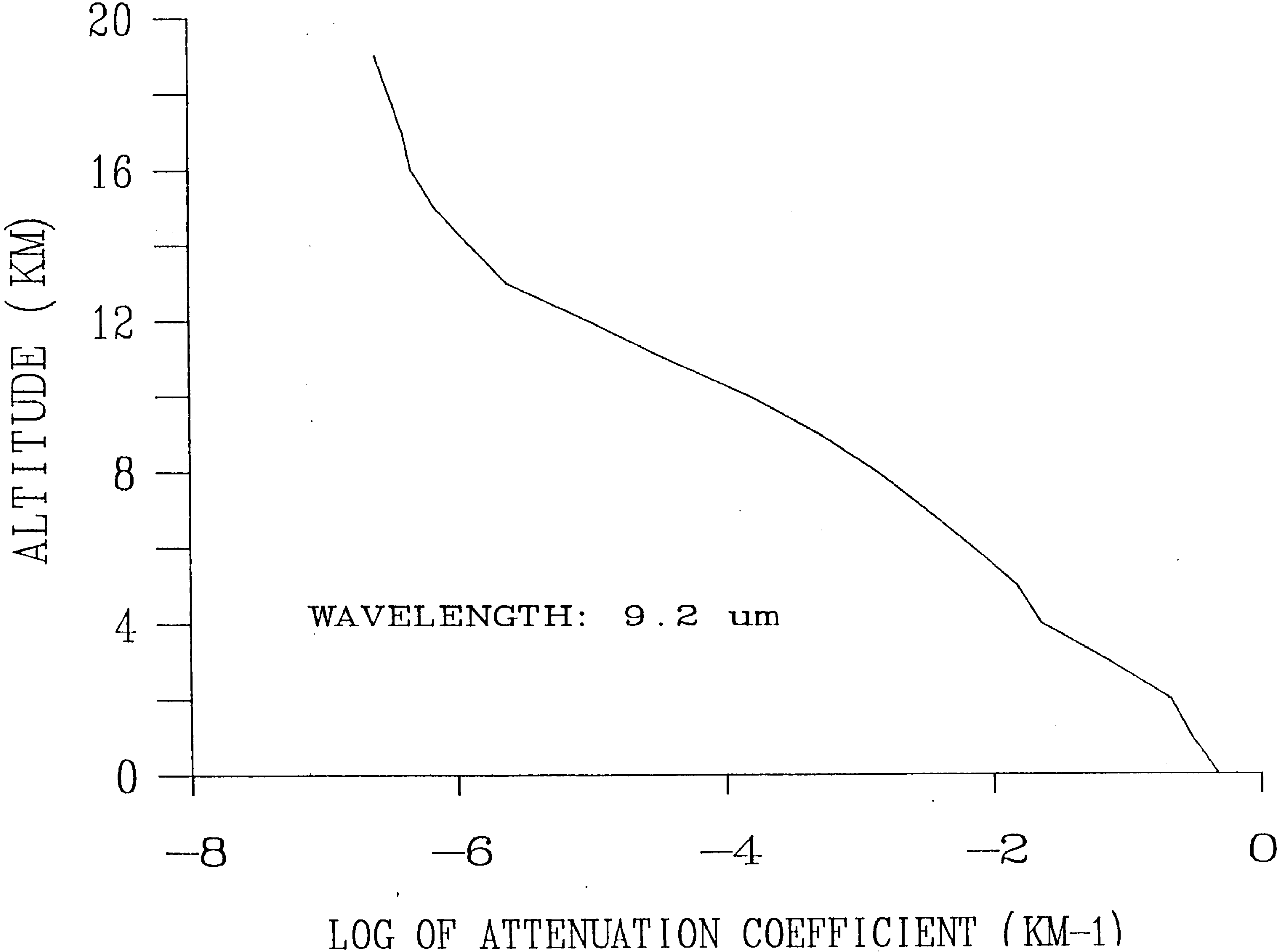
In keeping with the generally schematic nature of the baseline atmosphere we have chosen to describe a 3-D wind field that will test the general performance of any algorithm to estimate the LOS and/or horizontal wind vectors. The primary attributes of the reference field are:

1) vertical shear of the horizontal wind (selectable with 5×10^{-3} s^{-1} as a default);
2) horizontal coherent structure across the reference volume ($du/dx = dv/dy = 10^{-5}$ s^{-1} as a default);
3) isotropic turbulence scales below 1 km and a vertical structure ($\sigma^2 = 16$ m^2/s^2 to $\sigma^2 = 4$ m^2/s^2);
4) correlated variance at grid scale (1 km); and
5) vertical velocities not correlated from shot to shot - $\sigma_w^2 = 1$ m/s.

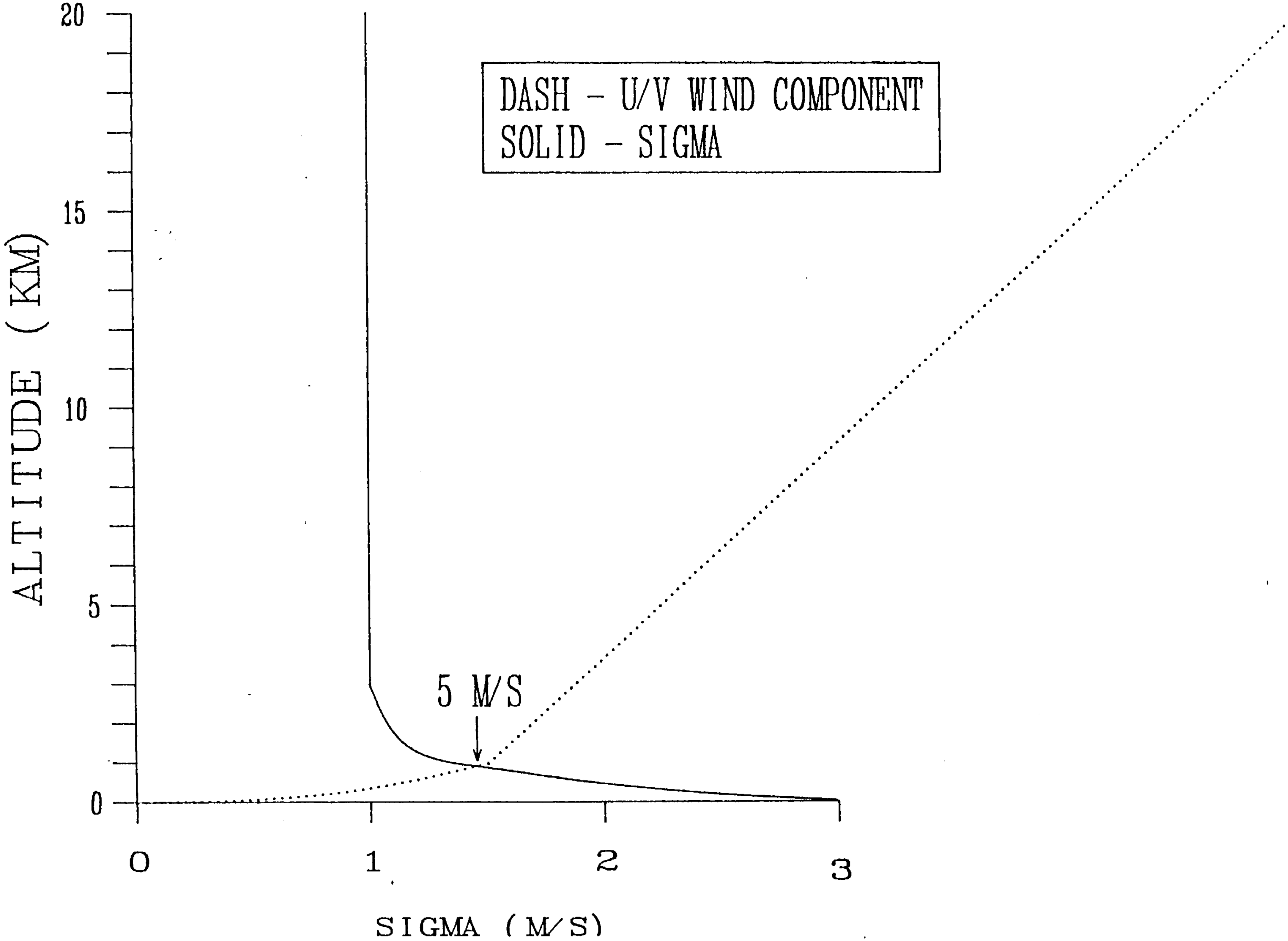
BASELINE ATMOSPHERE BACKSCATTER MED/SDEV .VS. HEIGHT



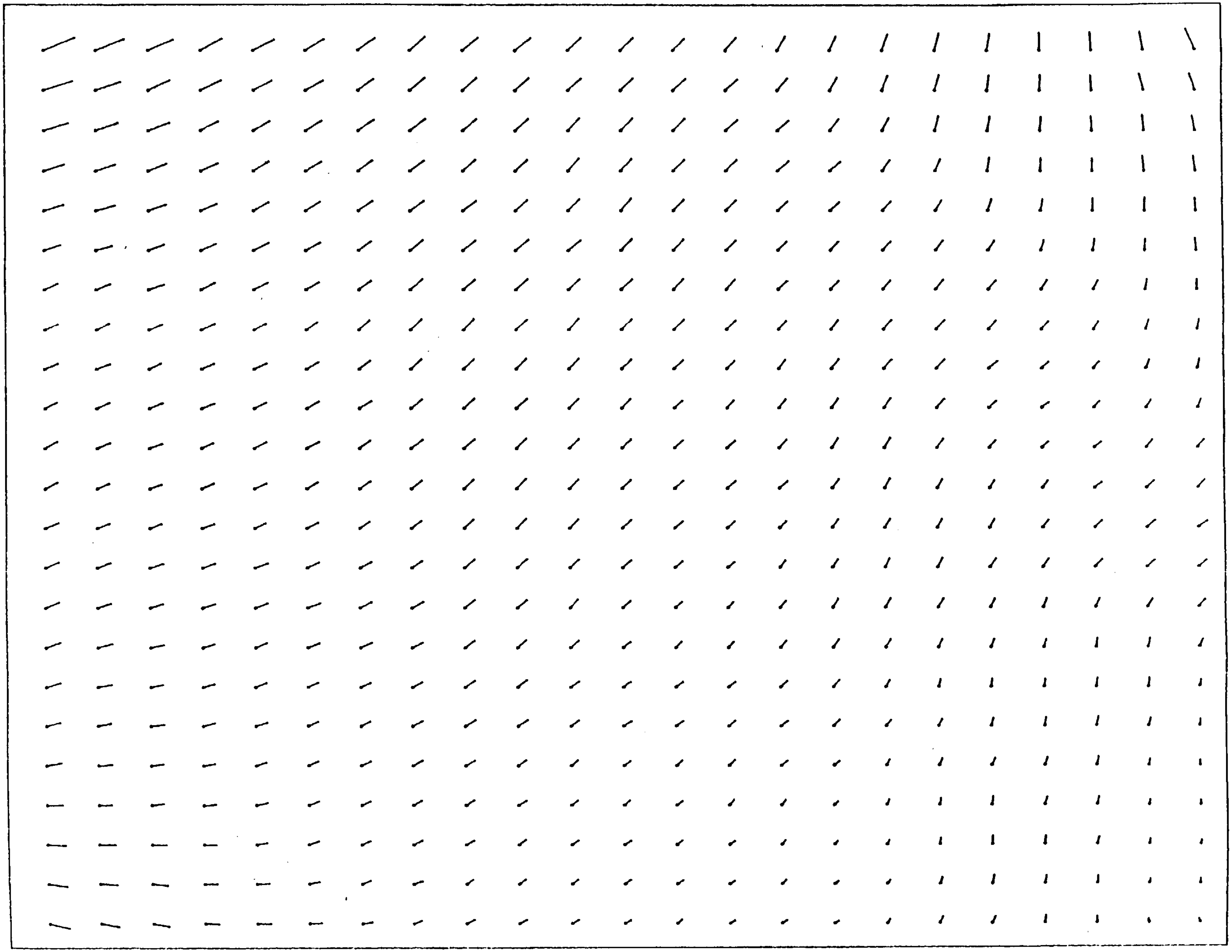
TROPICAL MARITIME ATTENUATION PROFILE: LOWTRAN



BASELINE ATMOSPHERE WIND PROFIL



LAWS BASELINE HORIZONTAL WIND FIELD



Subject: Contribution of shear to velocity spectrum broadening

Given horizontal and vertical linear shears of the wind within a LAWS sample volume, what is the contribution to the spectral broadening?

The following computations are based upon material presented in Doviak and Zrnic (1984), pp. 87-90.

For LAWS (baseline), the following assumptions are made:

τ = pulse length in seconds = 4.0 µs
σ_d = Gaussian diameter of beam at 1000 km range = 10 m
EL = scan elevation from horizontal = 37°
K_x = K_y = linear horizontal shear over 1 km = 10^{-3} s^{-1}
K_z = linear vertical shear over 20 km = 5×10^{-3} s^{-1}
σ^{s2} = variance in LAWS velocity spectrum due to linear shear across the sample volume

$$\sigma_s^2 = (\sigma_d\ K_\theta)^2 + (\sigma_d\ K_\phi)^2 + (\sigma_r\ K_r)^2$$

$$\sigma_r = .35\ c\ \tau/2 = 210\ \text{m}$$

θ,ϕ = angular direction around LOS, $r\theta$ is parallel to the ground

An order of magnitude argument yields:

$$\sigma_s^2 = (10 \times 10^{-3})^2 + (10 \times 10^{-3})^2 + (210 \times 10^{-3})^3$$

$$= 10^{-4} \quad + \quad 10^{-4} \quad + \quad 4.4 \times 10^{-2}$$

Thus: $\sigma_s^2 \approx (\sigma_r\ K_r^2)$

$$K_r = (K_x^2 + K_y^2)^{1/2} \cos\cdot EL + K_z \cdot \sin EL$$

$$= 1.12 \times 10^{-3} + 3.0 \times 10^{-3} = 4.12 \times 10^{-3}$$

$$\sigma_s^2 = (210 * 4.12 \times 10^{-3})^2 = .748\ m^2/s^2$$

Update on LAWS OSSEs and Simulation Studies

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S. Houston

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2nd LAWS Science Panel Meeting
9-11 August 1989
Huntsville, AL

LAWS OSSE Using FSU Global Spectral Model

FSU	SWA
T N Krishnamurti	G D Emmitt
K J Ingles	S H Houston
H S Bedi	S A Wood

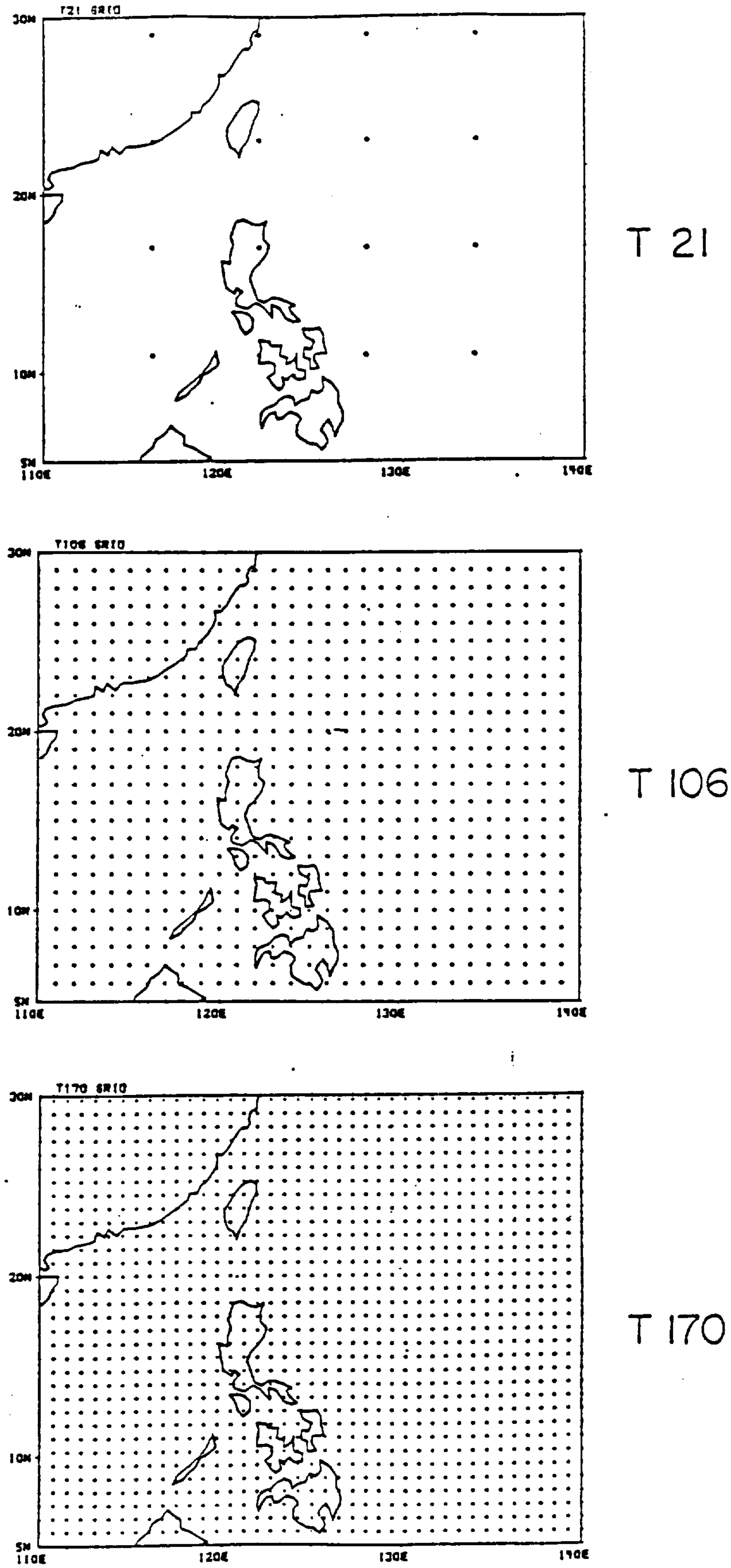

Fig. 1 An illustration of the transform grid at resolutions T21, T106 and T170 over a part of the globe. (Triangular truncation)

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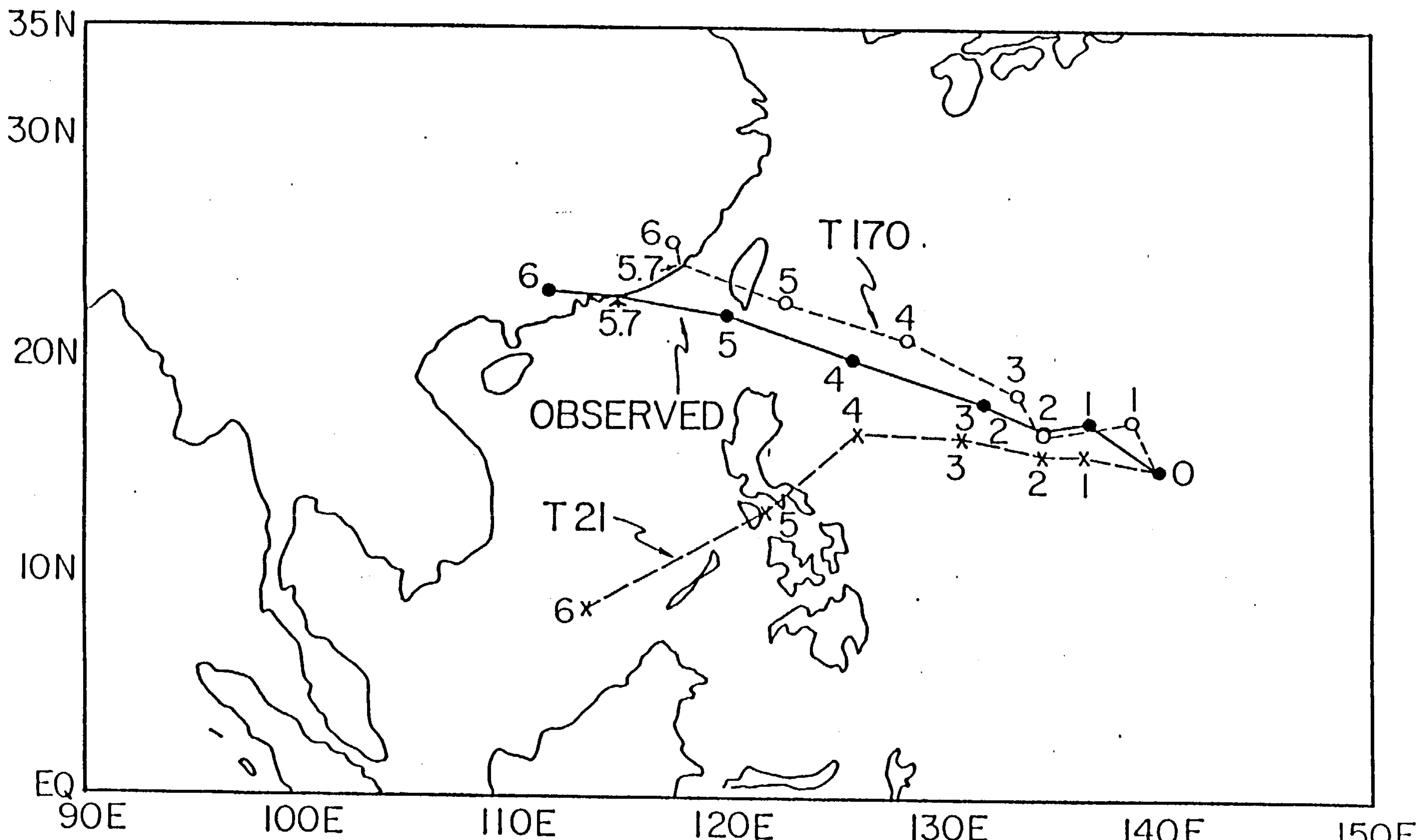


Fig. 9 Predicted tracks for T170 and T21 resolutions are compared with the best fit tracks. Days of forecast are indicated on the side of the tracks.

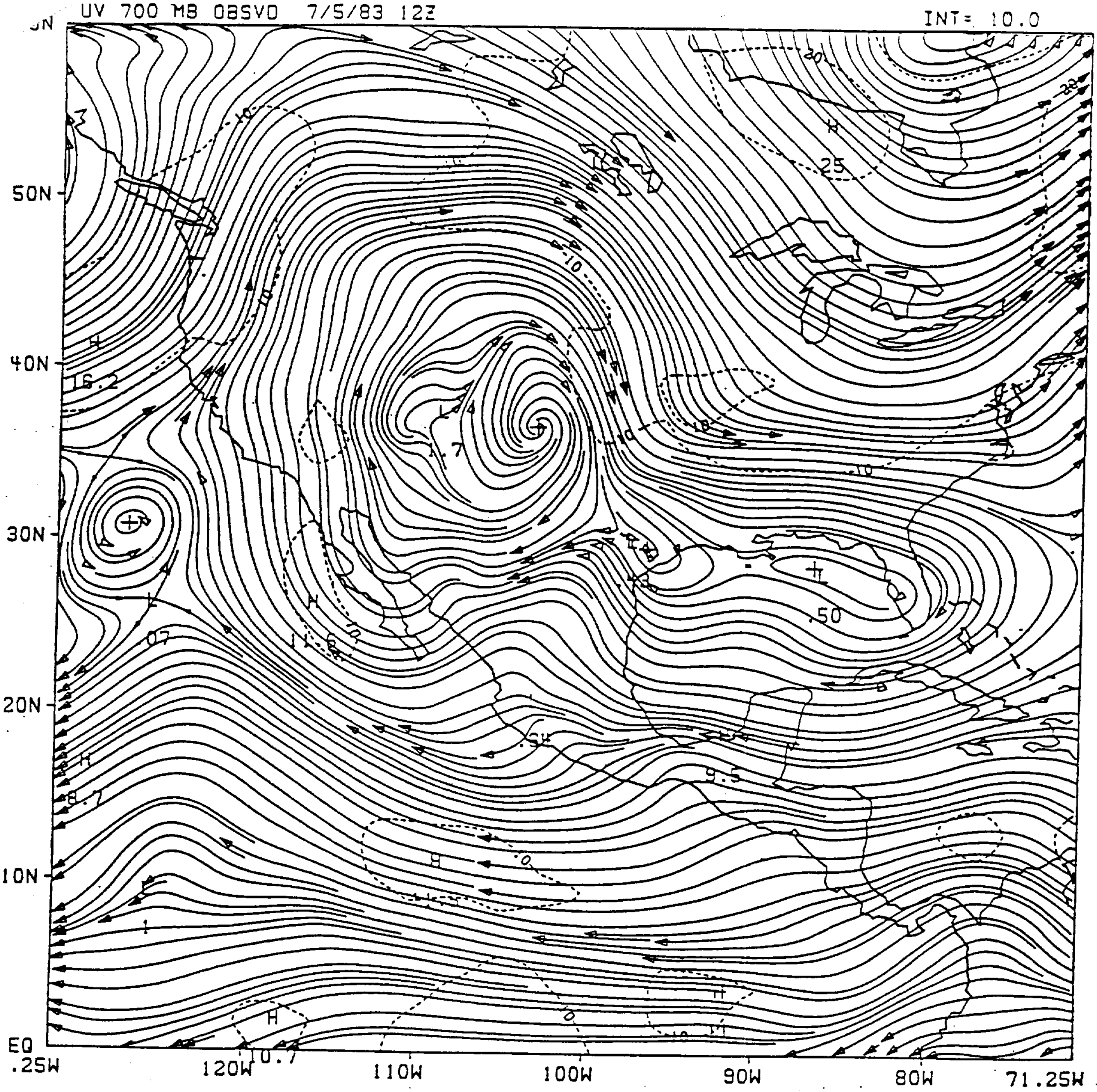
The SWA LAWS Simulation Will Include:

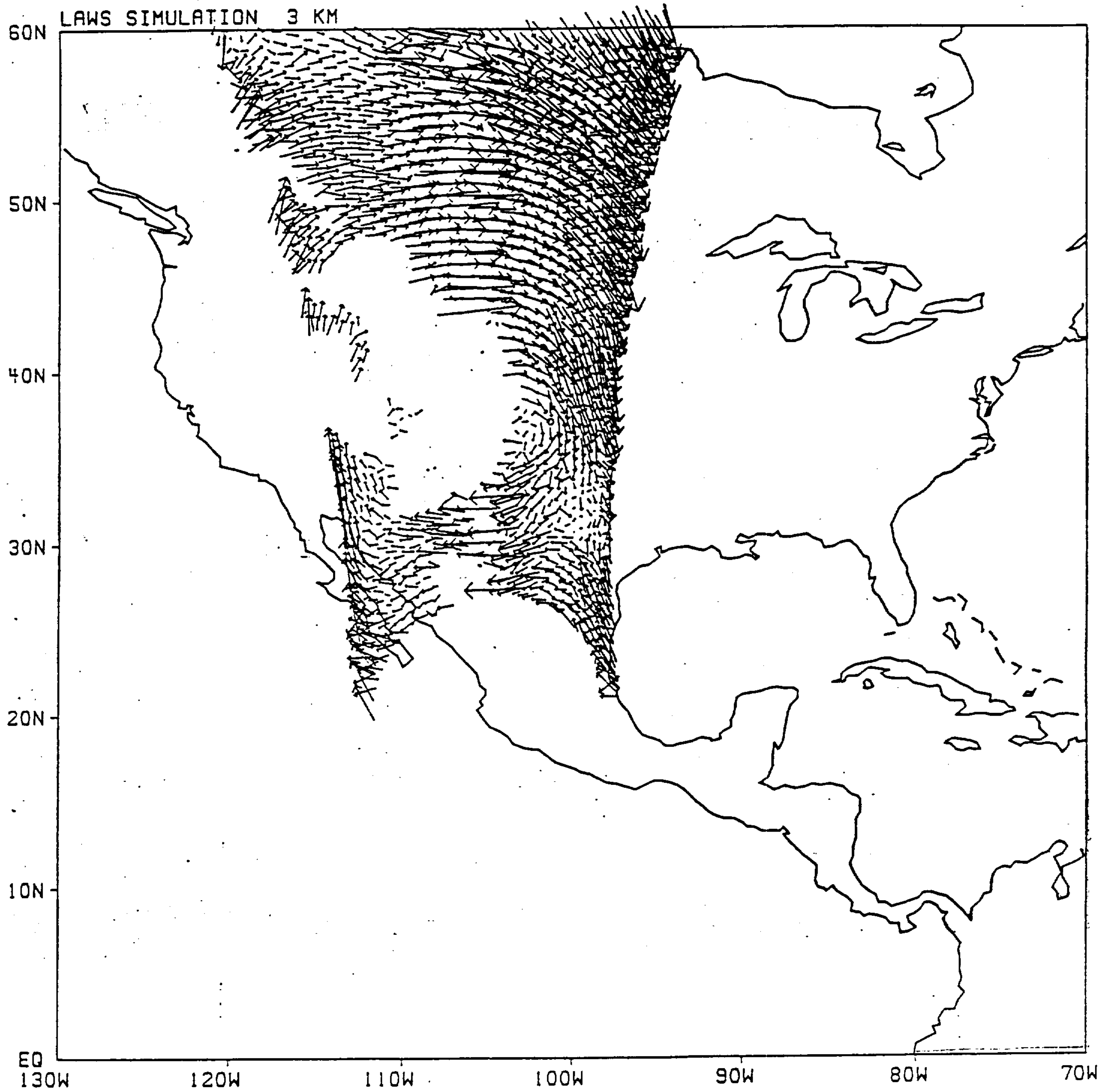
* SMA (ver. II)
* MPA (ver. II)
* Topography
* Optical Properties
  - Aerosol Backscatter
  - Cirrus Backscatter
  - Molecular Attenuation
* Signal to Noise Est.
* Turbulence
* Clouds

SWA LAWS Simulation of Laser Pulses Intercepting Clouds in the FSU OSSE

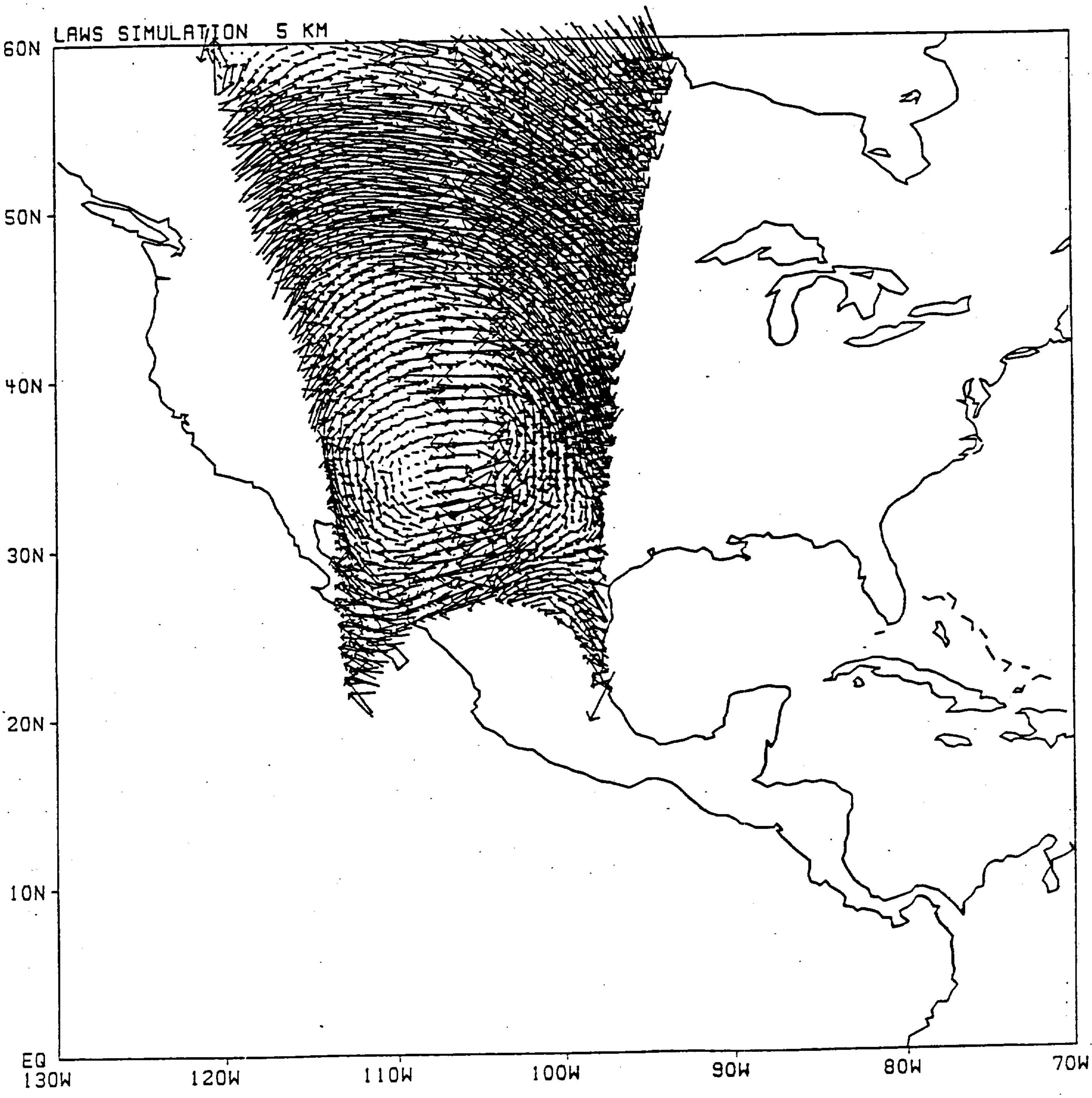
* Use ISCCP Data
  - Optical Depths < 1.3 are Cirrus
  - Atmospheric Layers (0–1000mb)
  - % Coverage (2.5 X 2.5 deg)
* At Each Level Calculate Probability of
  - Clear (No Clouds)
  - Thin Cirrus
  - Opaque Cloud
* Use ISCCP Data to Provide Probability of LAWS Receiving Backscatter from Sub-visibile Cirrus

UV 700 MB OBSVD 7/5/83 12Z INT= 10.0





LAWS SIMULATION 3 KM
60N
50N
40N
30N
20N
10N
EQ
130W
120W
110W
100W
90W
80W
70W



LAWS SIMULATION 5 KM
60N
50N
40N
30N
20N
10N
EQ
130W
120W
110W
100W
90W
80W
70W

Preparation for OSSE Using a Regional Scale Model - LAMPS

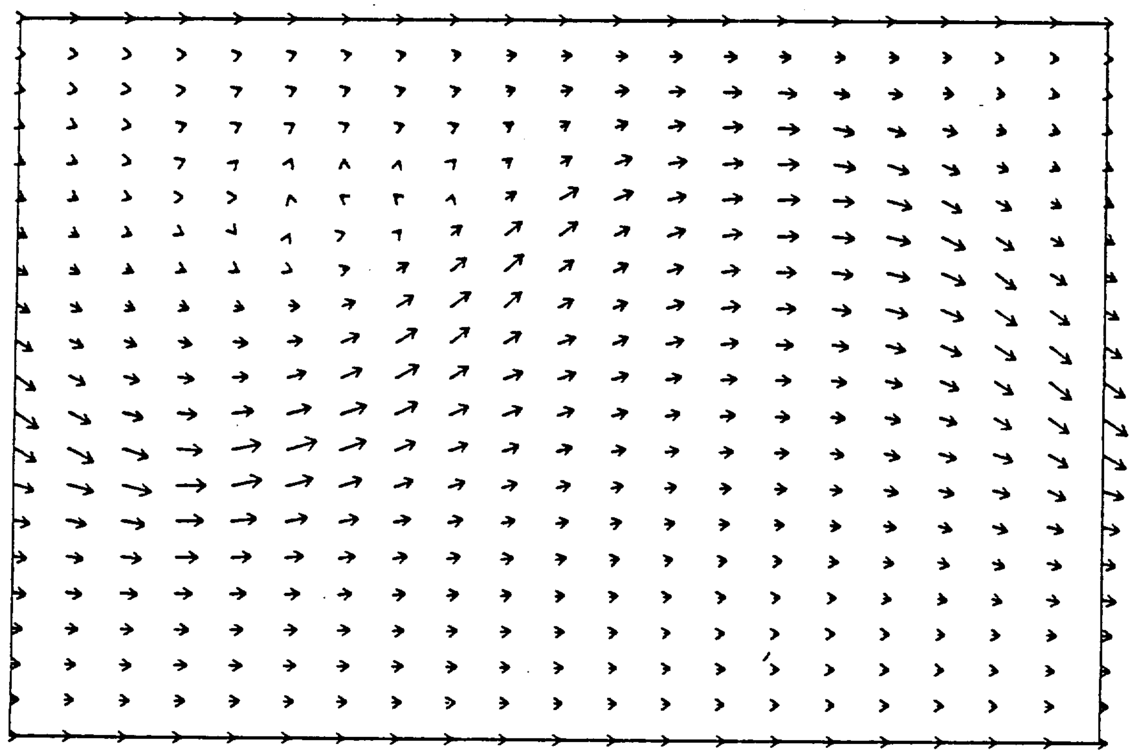
Tim Miller
NASA Marshall Space Flight Center

G.D. Emmitt
Simpson Weather Associates

Objectives:

- Develop strategies for assimulating LAWS data into a non-hydrostatic model - line-of-sight, horizontal vectors, hybrids, etc.
- Assess impact of LAWS data on model forecasts
- Provide testbed for evaluating various LAWS scan patterns and shot densities as part of the Shot Management Algorithm.

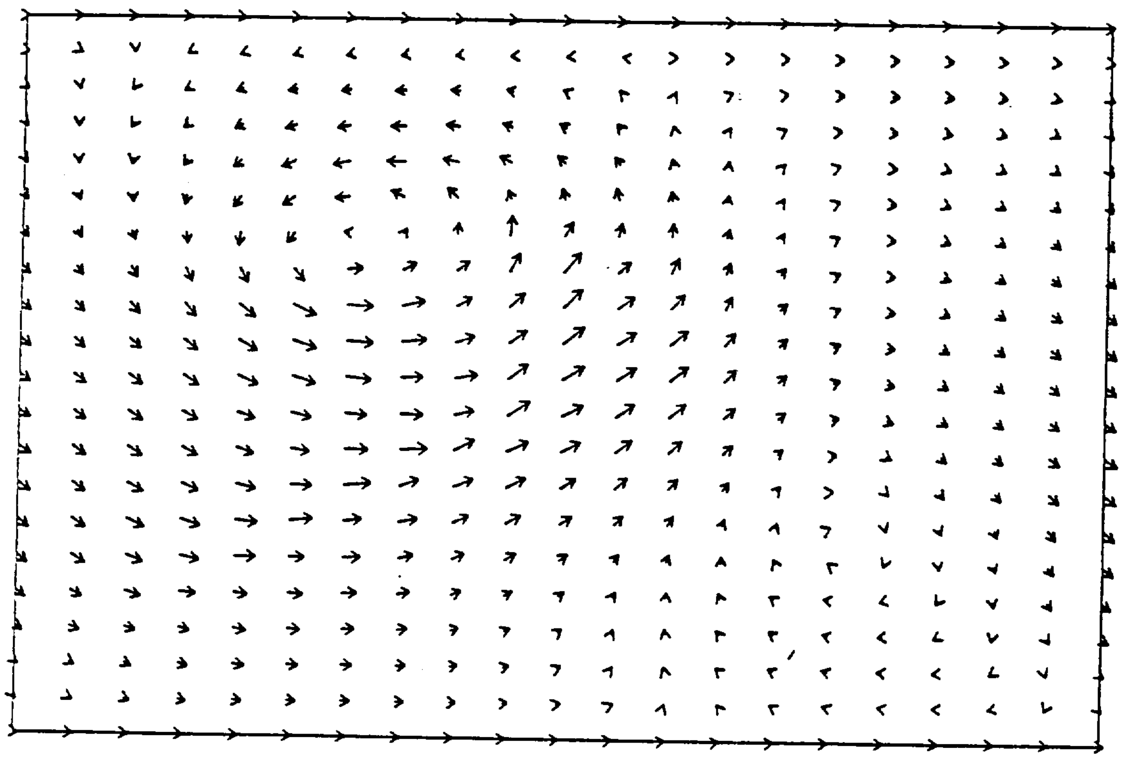
L9H 48 HRS 8 MB CYC27



VELOCITY VECTORS AT LEVEL 12

MAX WIND SPEED = 37.333

L9H 48 HRS 8 MB CYC27



VELOCITY VECTORS AT LEVEL 7

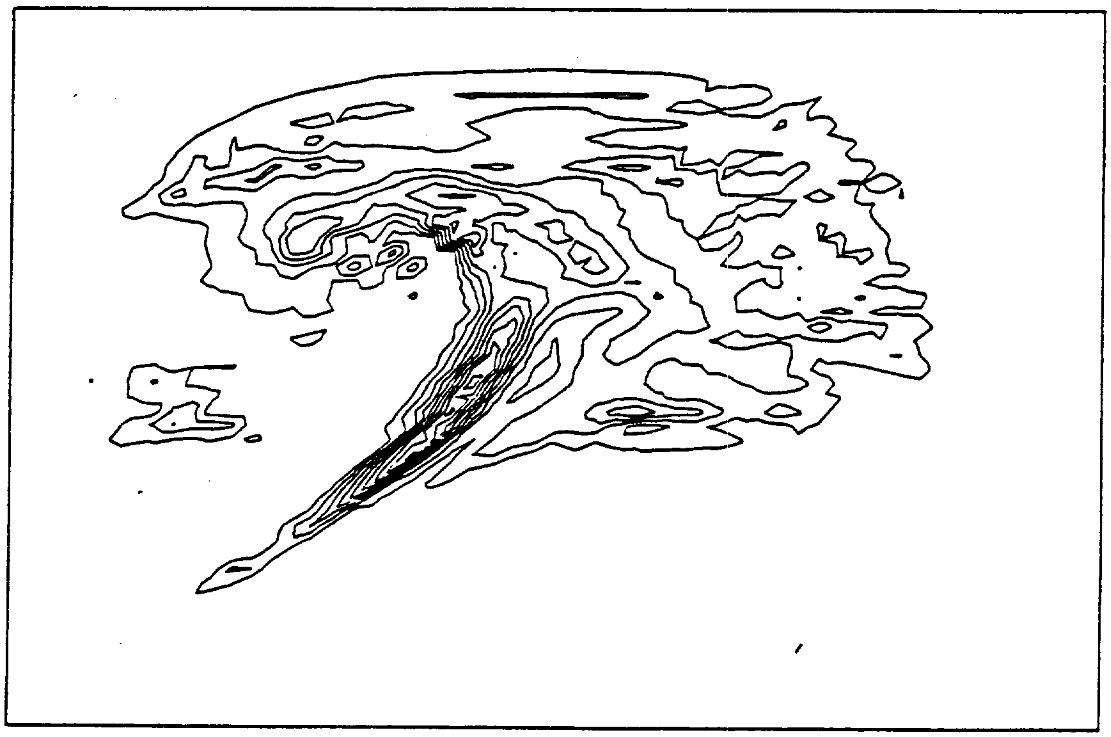
MAX WIND SPEED = 21.226

L9H 48 HRS 8 MB CYC27

VERTICAL VELOCITY AT LEV 4 MIN = −4.1640

CONTOUR INTERVAL = 1.00000 MAX = 7.3140

L9H 48 HRS 8 MB CYC27



INTEGR. RAIN + CLOUD (CM) MIN = 0.0000

CONTOUR INTERVAL = 0.02000 MAX = 0.1951

APPENDIX C

Modified Monthly Progress Reports

Space-Based Doppler Lidar Sampling Strategies -- Algorithm Development and Simulated Observation Experiments

NASA Contract: NAS8-37779

Monthly Progress Report
for the
period September 19, 1988 to October 18, 1988

Submitted by

George D. Emmitt
Simpson Weather Associates, Inc.
Charlottesville, VA 22902

28 October 1988

A. Monthly Activities

During the period 9/19-10/19 we returned to a full effort following a 6 month period without new funding. In the last month we have

1) Incorporated a modified SNR into our LAWS simulation model;
2) Using LOWTRAN 6 and the LAWS SNR we modelled the effects of subvisible cirrus on the velocity estimation error;
3) Began development of a tri-scale wind field model to be used in the LAWS Analysis Reference Wind Fields; and
4) Defined a new data quality function for use in the Goddard GCM OSSEs.

B. Next Month's Work Plan

We will be focusing upon the tri-scale wind model with the goal of having a preliminary set of reference fields ready by the end of December. We will also prepare a bi-monthly technical report with details on our simulation activities.

Space-Based Doppler Lidar Sampling Strategies -- Algorithm Development and Simulated Observation Experiments

NASA Contract: NAS8-37779

Monthly Progress Report
for the
period October 19, 1988 to November 18, 1988

Submitted by

George D. Emmitt
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Charlottesville, VA 22902

28 November 1988

A. Current Status

During the period 10/19/88-11/18/88 we completed the installation and checkout of LOWTRAN 7 absorption and backscatter profiles for the entire globe on a 1°x1° lat/long grid. These profiles will be used in the computation of the SNR of individual lidar shots used in conducting the OSSEs.

We are continuing the development of the "tri-scale" wind variance model for use in the LAWS Analysis Reference Wind Fields. Our basic approach is to use the Von Karman model for several wind phenomena such as mountain waves, jet streaks, tropical storms and dry convective boundary layers.

A technical report on the LAWS effort since June 1988 is being sent under separate cover since it reports on related work not funded under this contract.

B. Over the next two months we will continue to evaluate the "tri-scale" model as well as improving the LSM for execution on the PC-AT. We are also preparing a paper for presentation at the January meeting of SPIE.

Space-Based Doppler Lidar Sampling Strategies -- Algorithm Development and Simulated Observation Experiments

NASA Contract: NAS8-37779

Monthly Progress Report
for the
period November 19, 1988 to December 18, 1988

Submitted by

George D. Emmitt
Simpson Weather Associates, Inc.
Charlottesville, VA 22902

22 December 1988

A. During the last month, progress has been made in developing a fully programmable wind variance model covering the range of a few meters to several 100 kilometers. The purpose of is to be able to run Monte Carlo tests for LAWS sampling of various mesoscale phenomena such as jet streaks, mountain waves, tropical storms, etc. The variance model insures that wind variance on the lidar shot scale is consistent with the inter-shot scale flow structures generating the shear and thus the finer scale turbulence.

A paper has been written and submitted to SPIE for inclusion in the proceedings of the SPIE's OE/LASE '89 in January 1989. A copy is included in Appendix A.

B. During January, we hope to complete the prototype for the LAWS Reference Wind Field Package to be used in conducting system trades during the upcoming feasibility studies.

Space-Based Doppler Lidar Sampling Strategies -- Algorithm Development and Simulated Observation Experiments

NASA Contract: NAS8-37779

Monthly Progress Report
for the
period December 19, 1988 to January 18, 1989

Submitted by

George D. Emmitt
S.A. Wood
M.J. Buffum

Simpson Weather Associates, Inc.
Charlottesville, VA 22902

30 January 1989

A. Current Status

We are continuing the development and implementation of the "TRI scale" wind variance model into the LAWS simulation model. It is recognized that the wind variance on a given scale depends on the state of organization of the atmosphere and the use of a single value to represent variance is unrealistic. Our current approach is to use the Von Karman model to provide spatial and temporal estimates of natural wind variance for our LAWS analysis reference wind fields.

We have selected to model four basic turbulence fields: convective processes, wind shear, rotor waves and mountain waves based on experimental data described in Rhyne et al. (1976). Rhyne used turbulence sampling programs to describe each turbulence field using a power spectral density function, the Von Karman model (equation 1).

$$\Phi\ (1/\lambda) = 2\sigma^2 L \frac{[1 + 8/3(1.339\ L\ 2\pi/\lambda)^2]}{[1 + (1.339 L\ 2\pi/\lambda)^2]^{11/6}} \qquad (1)$$

In this equation Φ is the power, σ^2 is variance, λ is wavelength and L is the length scale of the turbulent phenomenon. Figure 1 shows a curve generated by the Von Karman equation depicting the variance at long wavelengths and at shorter wavelengths within the inertial subrange for different scales of organized turbulence.

We partitioned the Von Karman wind variance into three parts defined by the LAWS sampling geometry. The three divisions are based on three scales of sampling: (1) Shot Scale (SS), 1000 meters or less. Defined from the major axis of the cylindrical pulse volume; (2) Pulse Scale (PS), 1000 to 100,000 meters. Defined based on spacing between shot pairs for the estimation of wind; and (3) Large Scale (LS), greater than 100,000 meters, based on the stated goal of LAWS to provide wind profiles with a horizontal resolution of 100 km.

Using these scales, the area under the power density curve can be divided into three sections with the "knee" of the curve falling within the PS area. When determining the variance, we need only determine the area for SS and LS and by subtraction from one (the total normalized variance), we can determine the PS value of variance. We reduced equation (1) in the following manner to determine the percent variance in each of the three sampling ranges:

$$\begin{aligned}\Phi(1/\lambda) &= 2\sigma^2 L\ 8/3\ (1.339\ L\ 2\pi/\lambda)^{-5/3} \\ &= (2 * 8/3 * .0287) * \sigma^2 * L^{-2/3} * (1/\lambda)^{-5/3} \\ &= .153\ \sigma^2\ L^{-2/3}\ (1/\lambda)^{-5/3}\end{aligned}$$

The area in the SS region is:

$$A(SS) = \int_{10^{-2}}^{\infty} \Phi\ (1/\lambda)\ *\ d(1/\lambda)$$

$$= .23\ \sigma^2\ L^{-2/3}\ *\ (1/\lambda)^{-2/3}\ \Big]_{\infty}^{10^{-2}}$$

In the LR area Von Karman's equation reduces to:

$$\Phi(1/\lambda) = 2\ \sigma^2\ L$$

Integrating:

$$A(_{LR}) = \int_{0}^{10^{-5}} \Phi(1/\lambda)\ d(1/\lambda)$$

$$= 2\ \sigma^2 L \int_{0}^{10^{-5}} d(1/\lambda)$$

$$= (2*L*10^{-5})\ *\ \sigma^2$$

The σ^2 PS area we get by subtraction: $\sigma^2 PS = 1-\sigma^2_{LR} + \sigma^2_{SS}$.

The distribution of the total variance between the three areas can be substantially different for different atmospheric phenomena. With set bounds on the scale of the three divisions, it is the length scale of the turbulent phenomenon itself, L, which determines the apportionment of variance under the curve.

Rhyne et al. (1976) measured all three components (longitudinal, lateral and vertical) of the wind for the four classes of turbulence. Their data fit to the Von Karman power spectra at different length scales and their values for standard deviation for the three components (u, v and w) and the appropriate length scales are given in Table 1. To find the percent of total variance, we integrated equation (1) and based on the experimental standard deviation values, computed the actual variance, σ^2, for the four classes of turbulence.

In a general sense, using the proven relationship between the turbulence phenomena and the Von Karman model, we are now able to simulate total variance at three scales (i.e., shot scale, pulse scale and large scale). Next month we will be running LSM simulations on our LAWS analysis reference wind fields with the Von Karman turbulence representations. We are also continuing our development of a fully programmable wind variance model that will allow us to simulate LAWS sampling of various mesoscale phenomena.

Reference:

Rhyne, R.H., H.N. Murrow, and K. Sidwell, 1976: "Atmospheric Turbulence Power Spectral Measurements to Long Wavelengths for Several Meteorological Conditions", NASA Conference, Hampton, VA, pp. 271-286.

B. A paper was presented at the SPIE's OE/LASE '89 Anaheim, CA conference.

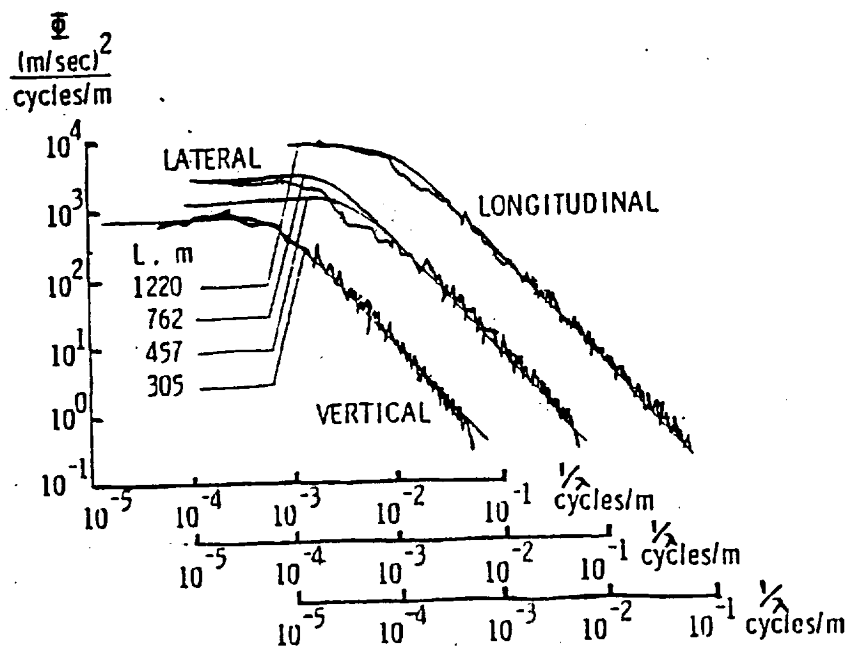


Figure 1.- Power spectra of turbulence components.
Convective case.

Table 1. Four cases of turbulent phenomena from Rhyne et al. (1976).

Meteorological Condition	Length Scale (m)	Std. Dev. (m/s) w	v	u		Calculated Variance w	v	u
Convective	vert= 305	1.15	1.18	1.35	SS	0.67	0.45	0.37
	lat= 600				SP	0.64	0.93	1.41
	long=1220				LS	0.01	0.02	0.04
Wind Shear	vert= 305	2.45	7.33	4.48	SS	3.05	8.27	3.09
	lat=1830				SP	2.92	43.52	16.26
	long=1830				LS	0.04	1.99	0.74
Rotor	vert=1830	3.82	5.51	3.57	SS	2.25	4.67	1.96
	lat=1830				SP	11.81	24.60	10.32
	long=1830				LS	0.54	1.12	0.47
Mountain Wave	vert=1830	1.34	5.39	4.30	SS	0.28	4.47	1.96
	lat=1830				SP	1.41	23.53	14.98
	long=1830				LS	0.07	1.07	0.68

Space-Based Doppler Lidar Sampling Strategies -- Algorithm Development and Simulated Observation Experiments

NASA Contract: NAS8-37779

Monthly Progress Report
for the
period January 19, 1989 to February 18, 1989

Submitted by

George D. Emmitt
S.A. Wood

Simpson Weather Associates, Inc.
Charlottesville, VA 22902

24 February 1989

A. During the period January 19-February 18, 1989, we have continued our development of the "LAWS Reference Fields" and the investigation of LAWS data interpretation in the vicinity of pulse scale inhomogeneities in the winds and backscatter. In particular, we have been simulating the advantages of achieving shot coincidence (intersecting pairs) compared to the improvements obtained with higher SNR for LOS measurements (see attached report).

In January, a paper entitled "Simulated Space-Based Doppler Lidar Performance in Regions of Backscatter Inhomogeneities" was presented by G.D. Emmitt at the 1988 SPIE conference in Los Angeles. A follow-on paper by Emmitt and Wood has been prepared and submitted for presentation at the 5th Conference on Coherent Laser Rdars to be held during June 1988 in Munich, FRG (see Appendix A).

B. Most of our effort for the next month will be focussed upon the documentation of the LSM, simulation of the current set of reference wind fields, and further investigation of a hybrid approach to the use of LAWS data, i.e., use of the LOS measurements by themselves (regressed against a model wind field) and/or shot pair estimates when available.

Error Minimization Study

The Lidar Simulation Model (LSM) was run for a pure convergent field with and without the Von Karman modeled convective turbulence. Figure 1 shows the error field produced from the input wind field and the lidar simulated wind field with random perturbations in the line of sight measurement (1 m/s). The shots were assumed to be co-located. Wind errors greater than 1 m/s have been highlighted in red (in original document). Figure 2 is the same as Figure 1 except that only random perturbations due to convective turbulence have been considered. In this second case the lidar shots were not co-located and had a separation distance of approximately 70 km. Both figures show a significant number of wind errors greater than 1 m/s.

The distribution of the wind errors was further examined for various scales of line of sight errors and convective turbulence, i.e., shot separation. Figure 3 is a histogram of the number of wind errors (u and v components and wind speed) falling within 1 m/s increment error bins. The error bins go from 0 to 15 m/s and the last bin represents errors 15 m/s and greater. The top graph is for a line of sight error of 1 m/s and the bottom graph is for a line of sight error of 0.5 m/s. The figure shows a shift to lower (47%) wind speed errors by decreasing the line of sight error.

Figures 4 and 5 are histograms of wind speed measurement errors for a convective turbulence case with shot separations at 10 and 70 km. The top graph as a LOS error of 1 m/s, the middle graph has a LOS error of 0.5 m/s and the bottom graph has no LOS error. Table 1 summarizes the approximate percentage increase of the number of wind speed errors in bin 0-1 m/s due to decreasing the shot separation by 60 km. The percentage increase is around 12-20% for the three LOS errors.

Figures 3-5 and Table 1 suggest that while improving the SNR has the potential of significantly decreasing the horizontal wind errors, the sampling related errors mask that advantage. This general result lends itself to a cost/benefit analysis involving SNR improvements vs active shot management (required for coincidence.

List of Figures

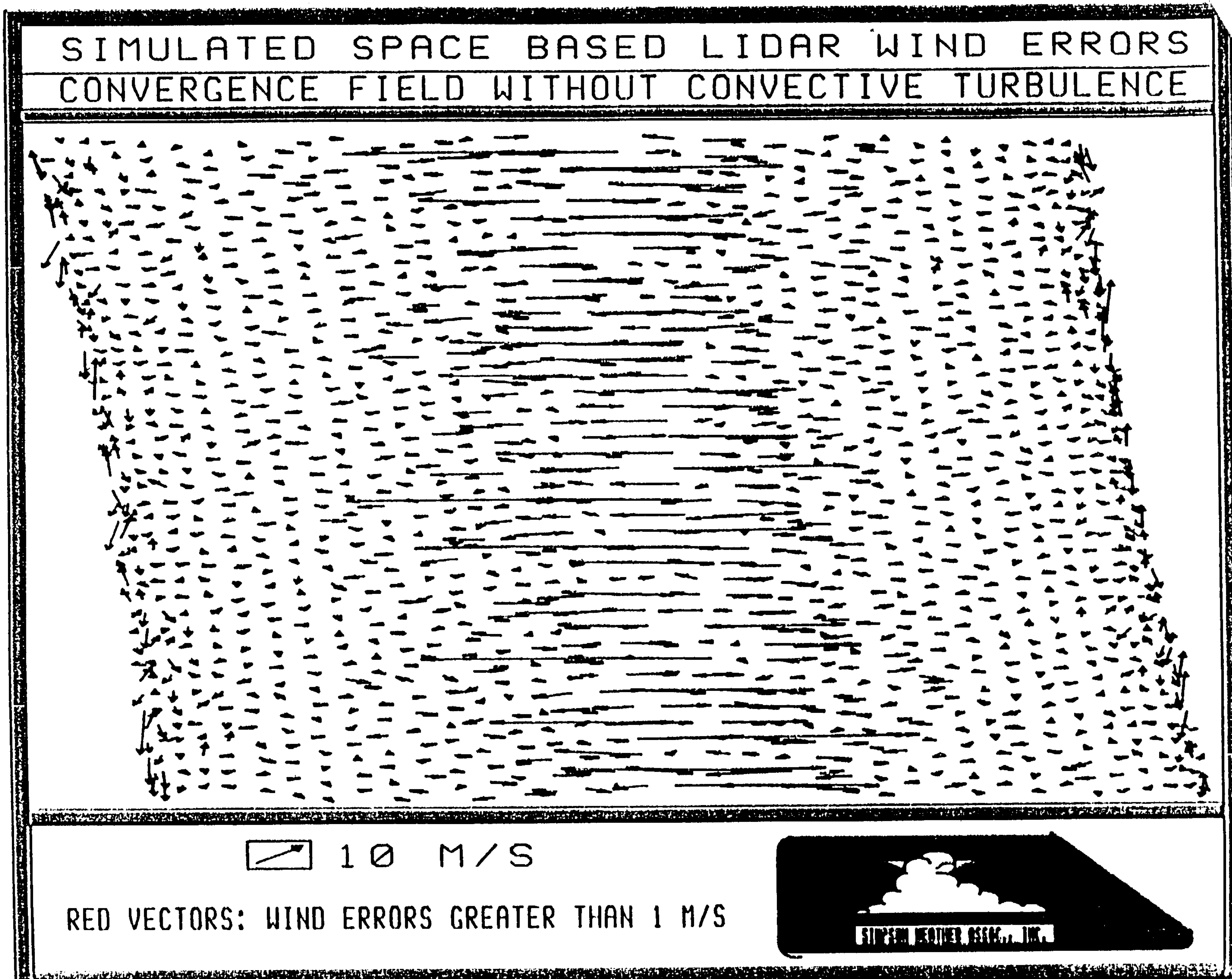
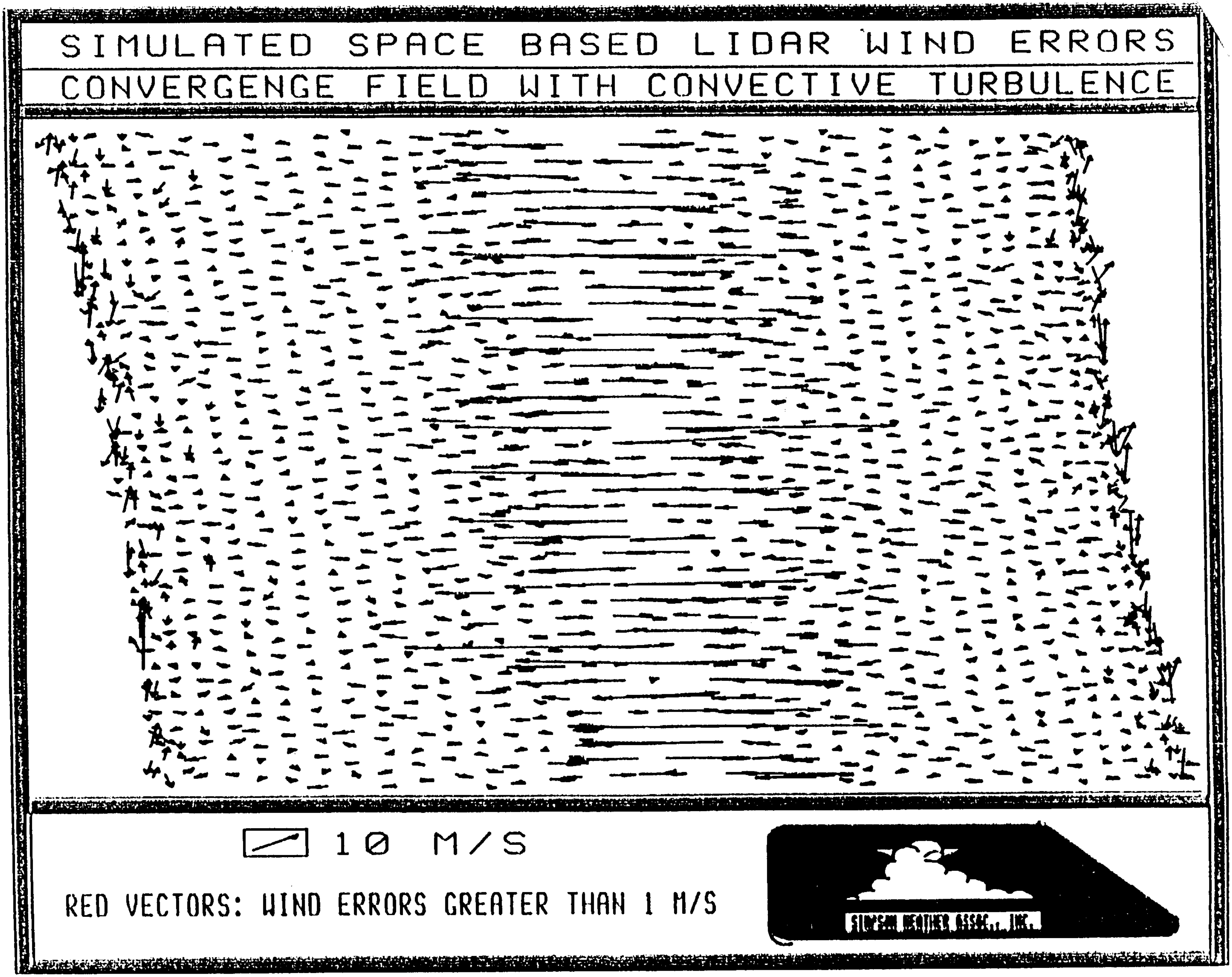

SIMULATED SPACE BASED LIDAR WIND ERRORS
CONVERGENCE FIELD WITHOUT CONVECTIVE TURBULENCE
10 M/S
RED VECTORS: WIND ERRORS GREATER THAN 1 M/S
SIMPSON WEATHER ASSOC., INC.

Figure 1.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CONVERGENGE FIELD WITH CONVECTIVE TURBULENCE
10 M/S
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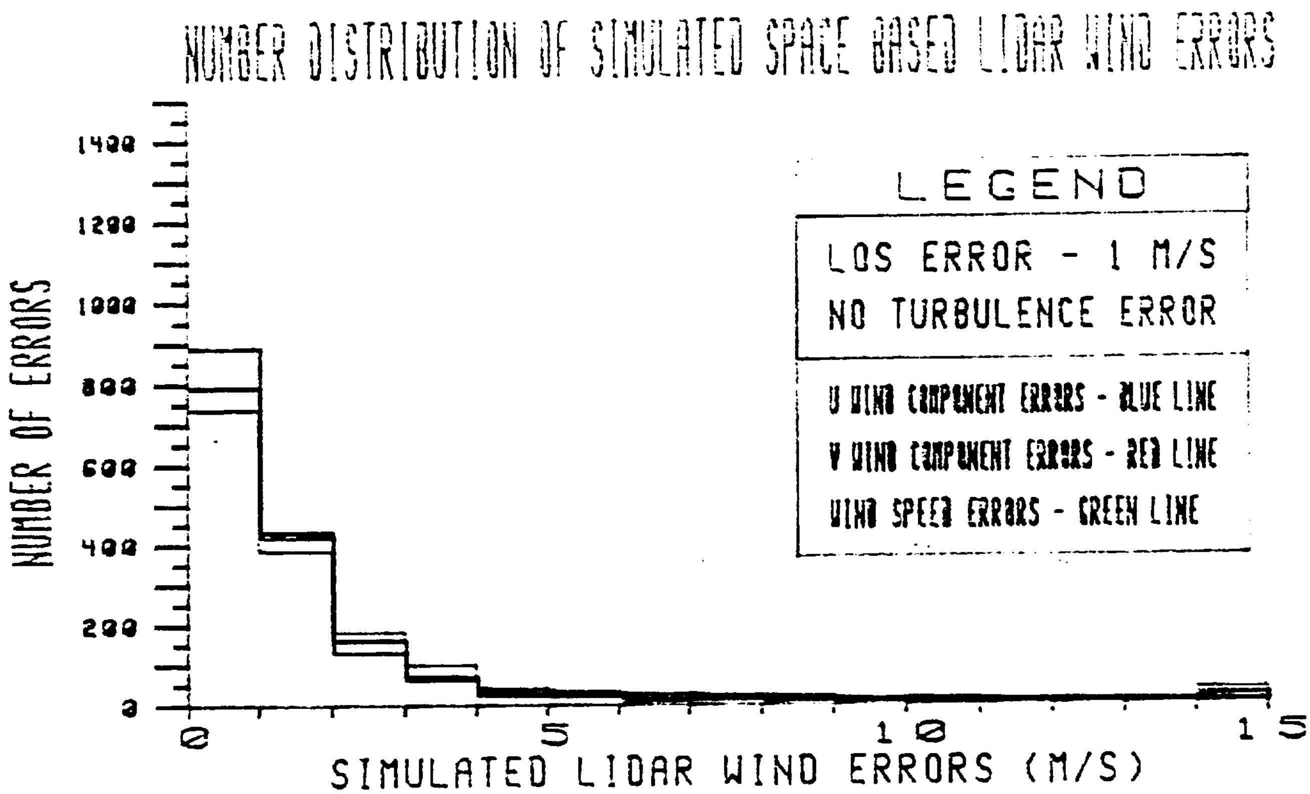
SIMPSON WEATHER ASSOC., INC.

Figure 2.


NUMBER DISTRIBUTION OF SIMULATED SPACE BASED LIDAR WIND ERRORS
LEGEND
LOS ERROR - 1 M/S
NO TURBULENCE ERROR
U WIND COMPONENT ERRORS - BLUE LINE
V WIND COMPONENT ERRORS - RED LINE
WIND SPEED ERRORS - GREEN LINE
NUMBER OF ERRORS
1400
1200
1000
800
600
400
200
0
0
5
10
15
SIMULATED LIDAR WIND ERRORS (M/S)

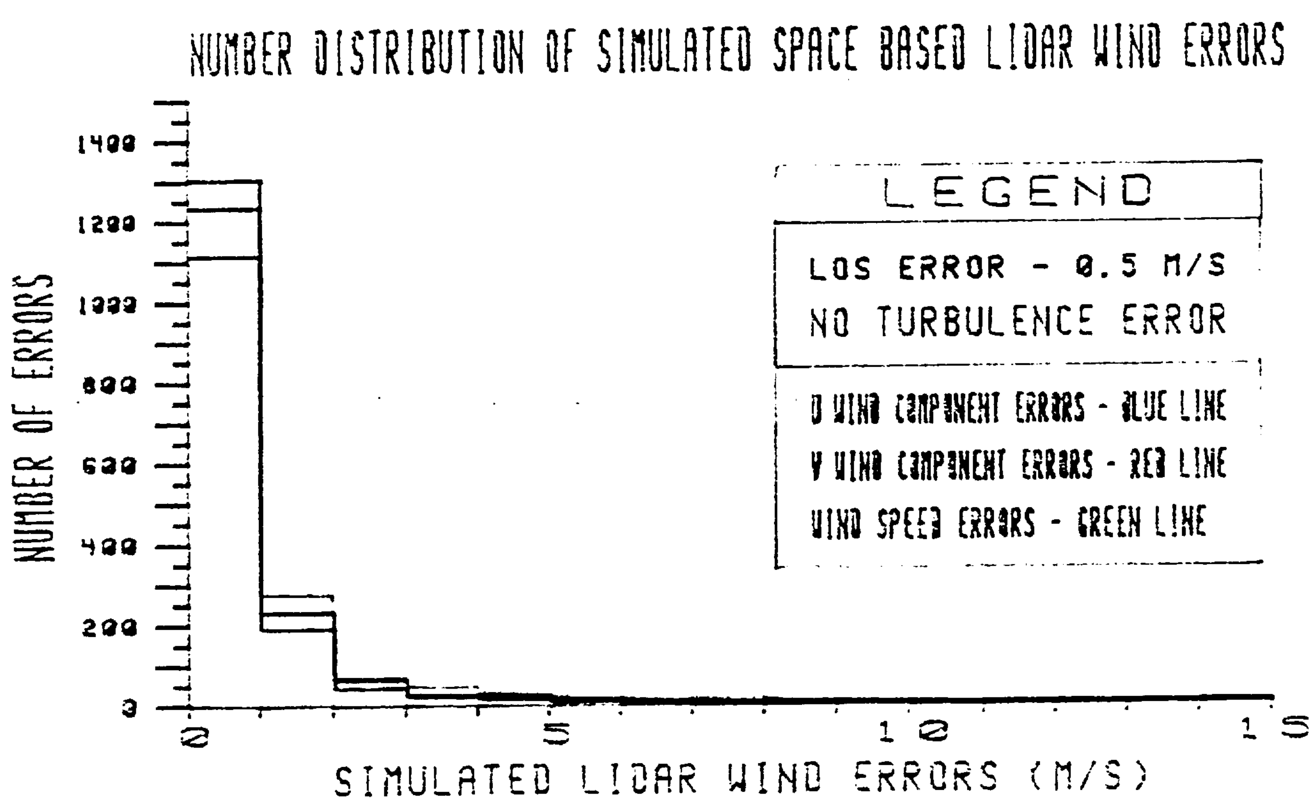
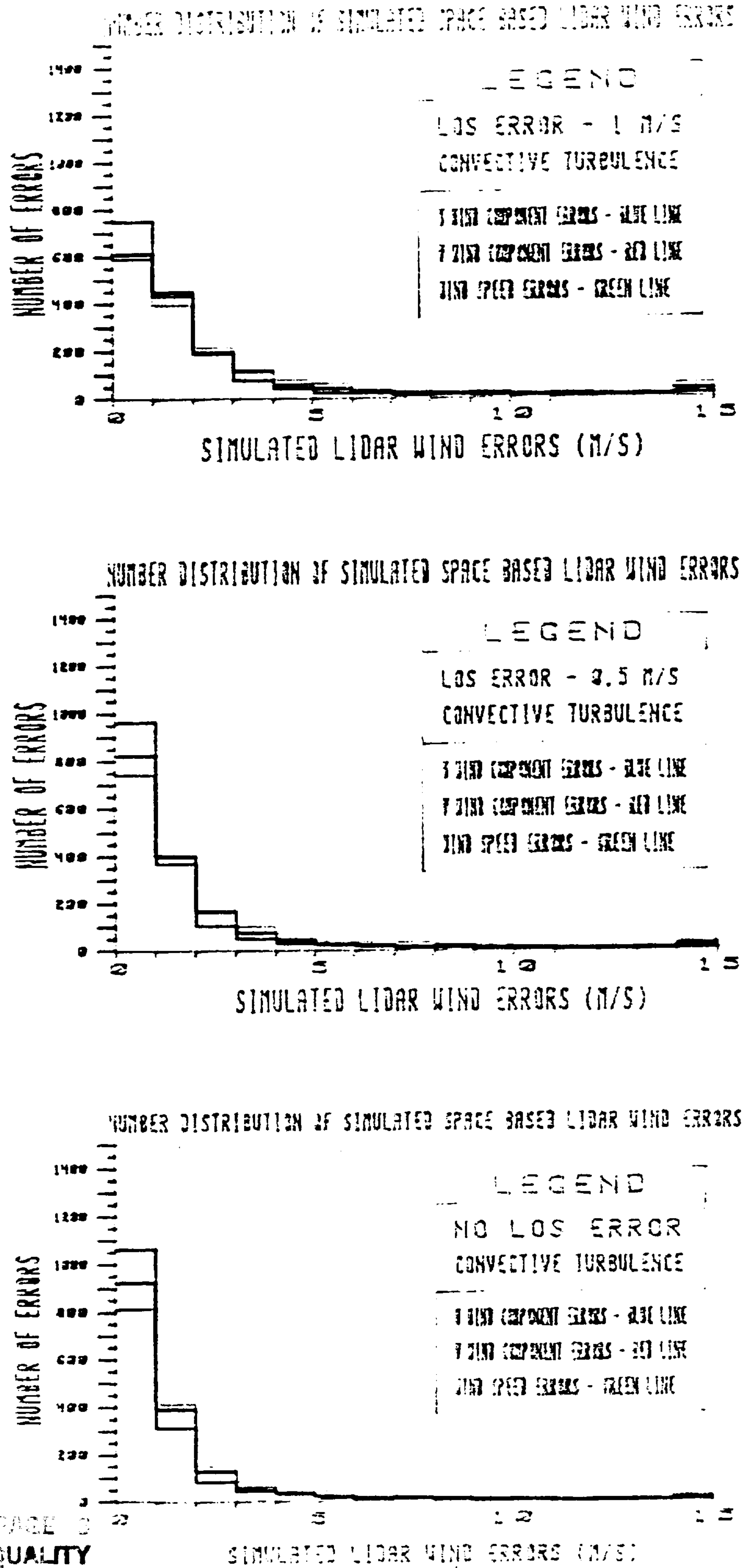

NUMBER DISTRIBUTION OF SIMULATED SPACE BASED LIDAR WIND ERRORS
LEGEND
LOS ERROR - 0.5 M/S
NO TURBULENCE ERROR
U WIND COMPONENT ERRORS - BLUE LINE
V WIND COMPONENT ERRORS - RED LINE
WIND SPEED ERRORS - GREEN LINE
NUMBER OF ERRORS
1400
1200
1000
800
600
400
200
0
0
5
10
15
SIMULATED LIDAR WIND ERRORS (M/S)

Figure 3.



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LOS ERROR - 1 M/S
CONVECTIVE TURBULENCE
NUMBER OF ERRORS
SIMULATED LIDAR WIND ERRORS (M/S)
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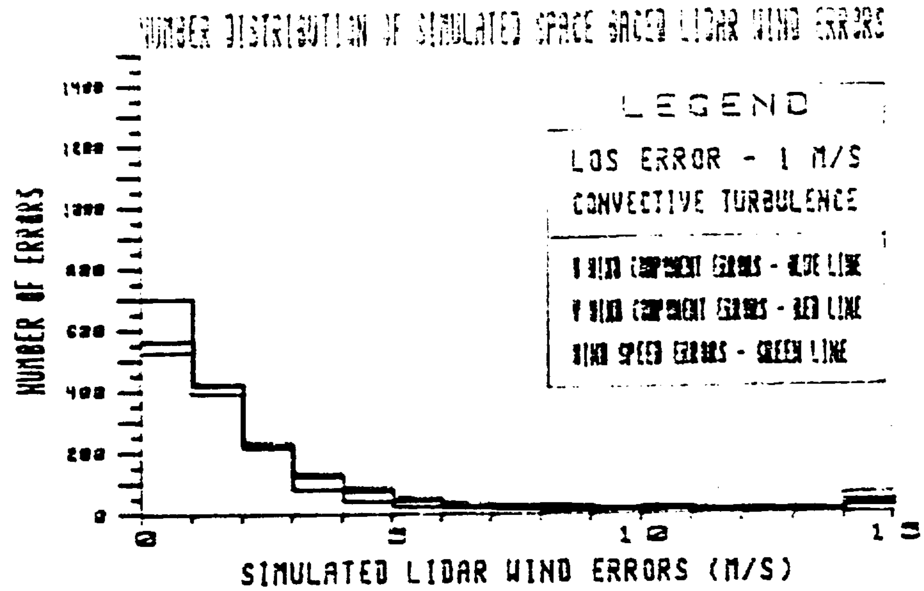
LEGEND
NO LOS ERROR
CONVECTIVE TURBULENCE
NUMBER OF ERRORS
SIMULATED LIDAR WIND ERRORS (M/S)

Figure 4.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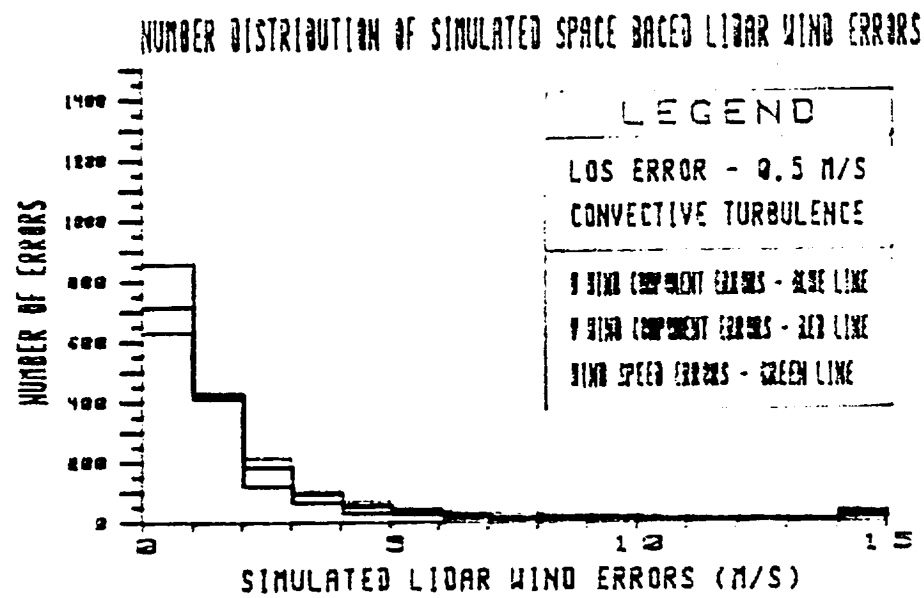
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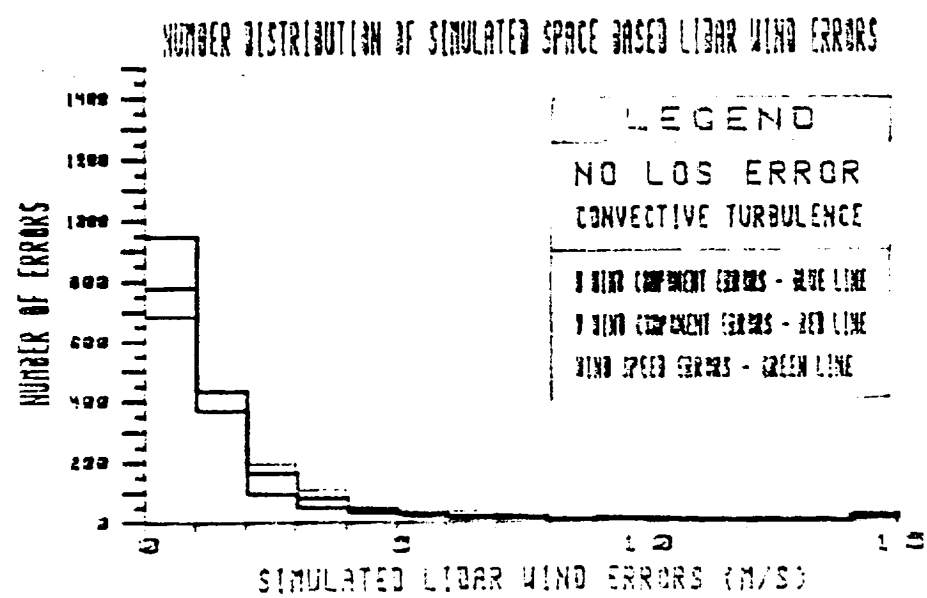
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WIND SPEED ERRORS - GREEN LINE
NUMBER OF ERRORS
1400
1200
1000
800
600
400
200
0
0
5
10
15
SIMULATED LIDAR WIND ERRORS (M/S)

Figure 5.

Approximate Percentage of Wind Speed Errors Increasing in the 0-1 m/s Bins in Figures 3-5

TYPE OF SIMULATION COMPARISION	%
LOS ERROR - CO-LOCATED SHOTS. NO TURBULENCE	
DECREASE THE LOS ERROR FROM 1 M/S TO 0.5 M/S	47
CONVECTIVE TURBULENCE - SHOT ARE SEPERATED	
DECREASE SHOT SEPERATION FROM 70 KM TO 10 KM	
LINE OF SIGHT ERROR - 1.0 M/S	14
LINE OF SIGHT ERROR - 0.5 M/S	20
LINE OF SIGHT ERROR - 0.0 M/S	18
CONVECTIVE TURBULENCE - SHOT SEPERATION - 10 KM	
LINE OF SIGHT ERROR COMPARISION	
DECREASE FROM 1.0 M/S TO 0.5 M/S	25
DECREASE FROM 0.5 M/S TO 0.0 M/S	08
DECREASE, FROM 1.0 M/S TO 0.0 M/S	35
CONVECTIVE TURBULENCE - SHOT SEPERATION - 70 KM	
LINE OF SIGHT ERROR COMPARISION	
DECREASE FROM 1.0 M/S TO 0.5 M/S	19
DECREASE FROM 0.5 M/S TO 0.0 M/S	08
DECREASE FROM 1.0 M/S TO 0.0 M/S	29

Space-Based Doppler Lidar Sampling Strategies -- Algorithm Development and Simulated Observation Experiments

NASA Contract: NAS8-37779

Monthly Progress Report
for the
period February 19, 1989 to March 18, 1989

Submitted by

G.D. Emmitt
S.A. Wood
M. Buffum

Simpson Weather Associates, Inc.
Charlottesville, VA 22902

07 April 1989

A. During the period 18 February to 19 March, we

1) continued to construct and evaluate reference wind fields for use in hardware trades and LAWS feasibility demonstrations.

2) updated cirrus global climatology with recently published reports.

3) prepared for and attended the EOS meeting in Washington, D.C.

4) prepared for a "bi-modal" OSSE using ECMWF nature runs, and

5) began preparation of a "LAWS scan geometry" packet for members of the LAWS facility team.

B. From 19 March to present we have been working on a no-cost extension. Anticipating a new contrct being in place by 7 April, we will begin focusing most of our effort on conducting the Global OSSE and preparing for some regional scale model OSSEs with Dr. Miller (NASA/MSFC) and with Dr. Krishnamurti (FSU).

<u>Expansion on A.2</u>

Cirrus clouds could have a potentially significant impact on the performance of LAWS as currently designed. Dr. M. Hardesty (NOAA, WPL) has proposed (as a member of the LAWS team) to examine the performance of LAWS in regions of cirrus clouds. In our case, we are interested in obtaining reasonable estimates of the global distribution of cirrus as input to our efforts to perform OSSEs.

A review of the most current published data and papers on global cloud distributions has revealed both useful yet ambiguous data - useful, in that the general distribution of clouds by season are reasonably represented using combinations of ground-based and satellite observations; ambiguous, in that the distinction between thin cirrus and opaque cirrus is vague enough to support a broad range of assumptions.

The accompanying figures represent the summaries of several satellite-based cloud climatologies. There are several notable features as far as LAWS is concerned:

1) A generally tri-modal distribution of cloud cover fraction between 70S and 70N with peaks near 60-80% at 60S, 5N and 60N (minimums of 30-40% at 20S and 30N) [Figures 1 and 2].

2) Conflicting reports of cloud cover near the poles ranging from 40-90% (seasonality may be an explanation) [Figure 1].

3) High (~ 10-14 km) clouds (opaque?) show a similar distribution with latitude - i.e., tri-modal but a lower fractional coverage (~ 10-30%) [Figure 3].

4) Cirrus (transparent?) coverage ranges from 30-75% with the maxima at 50S, 5N and 50N [Figure 4].

Figure 5 is a very preliminary attempt to integrate the information in Figures 1-4. The assumptions are that the high clouds in Barton's (1983) study (Figure 3) are opaque to 10.6 m and that both the cirrus and thin cirrus in the SAGE study (Woodbury and McCormick, 1986) are transparent.

The interpretation of Figure 5 (TROPICS) is as follows:

1) 90-100% of the time LAWS will get a return from the upper troposphere because of the presence of either opaque cloud or transparent cirrus. The return from aerosols at those levels is left as unknown at this time but expected to be certainly non-zero.

2) 40-50% of the time there will be clouds in the mid-troposphere from which LAWS will get a return. The degree to which aerosols will provide sufficient backscatter during the remaining 50-60% of the time is an unknown.

3) By definition, there are no clouds in the PBL and thus LAWS will get returns there only from aerosols. However, in the tropics we can expect to see into the PBL only 20-30% of the time.

While Figure 5 presents the general picture for LAWS returns, there are seasonal variations in cloud cover that would need to be incorporated into any comprehensive impact assessment. In the short term, these results can be used to address some basic questions regarding the "value" of PBL winds vs upper tropospheric winds in GCMs. We will continue to update and refine the interpretation of the available cloud climatologies, in particular those derived from SAGE II observations.

It should be noted that any estimate of thin cirrus coverage is likely to be an underestimate due to detection thresholds by current space-based sensors.

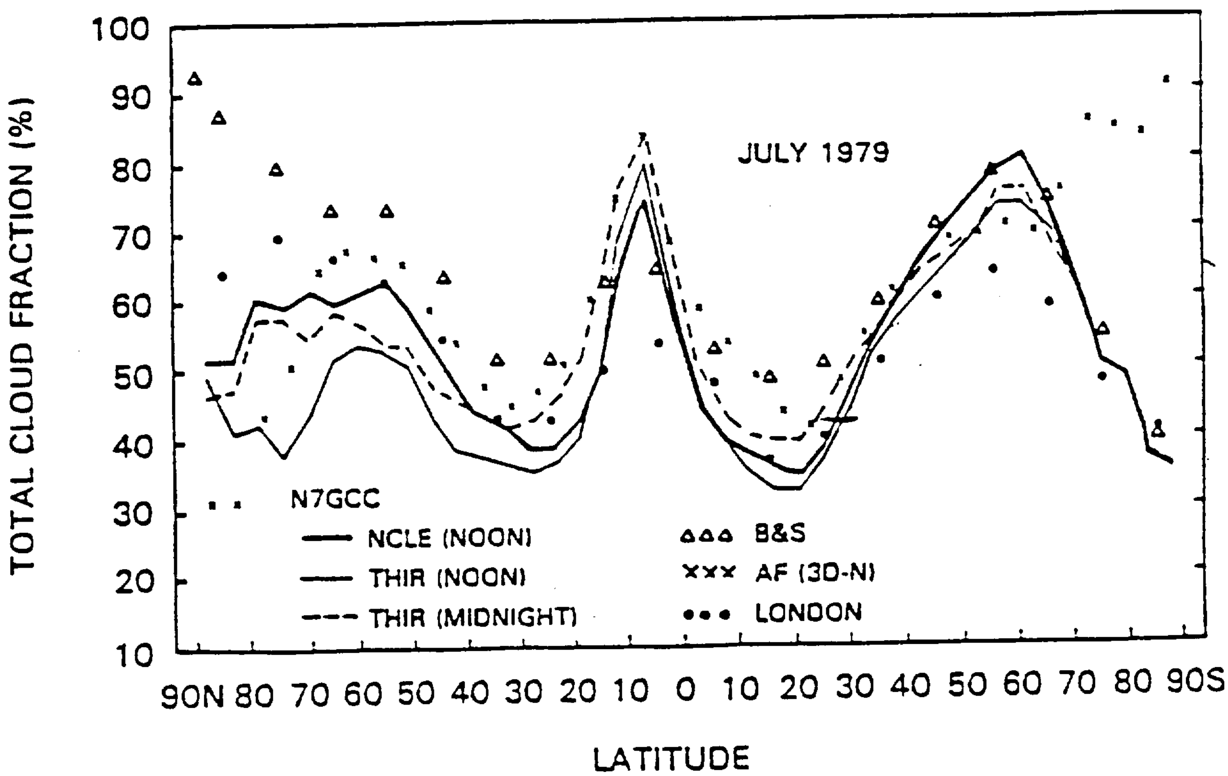


Figure 1. Zonally averaged total monthly mean cloud amount for July. The Nimbus (N7GCC) THIR infrared noon and midnight cloud fraction estimates are compared with the N7GCC bispectral noon-cloud-fraction estimates for July 1979. Also shown in the figure are results from Beryland and Strokina's (1980) 30-year cloud climatology (B&S), the Air Force three-dimensional-nephanalysis cloud data for 1979 (AF 3D-N); compiled by Hughes and Henderson-Sellers, 1985; and London's (1957) multiyear averaged (northern hemisphere) cloud climatologies. Note that London's southern hemisphere cloud amount is taken from the value in the northern hemisphere for the opposite season. (After Hwang, P.H. et al., 1988: The Nimbus-7 Global Cloud Climatology, BAMS, 743-752.)

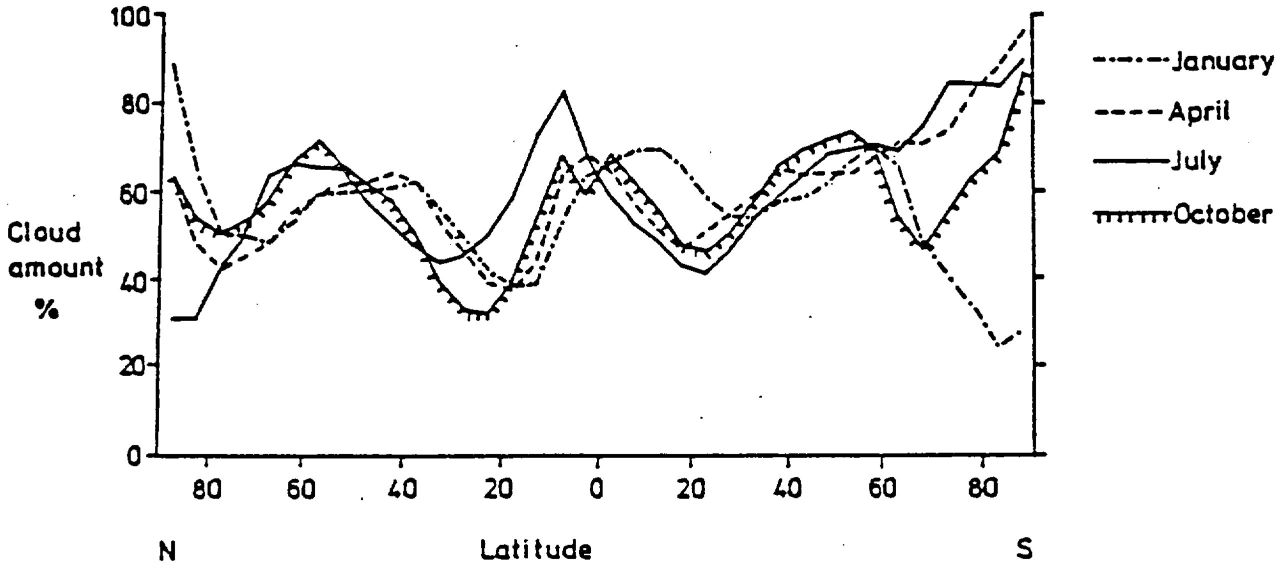


Figure 2. Zonally averaged 3D-nephanalysis cloud amount for January, April, July and October 1979. (After Hughes, N.A. and A. Henderson-Sellers, 1985: Global 3D-Nephanalysis of Total Cloud Amount: Climatology for 1979, JCAM, 669-686.

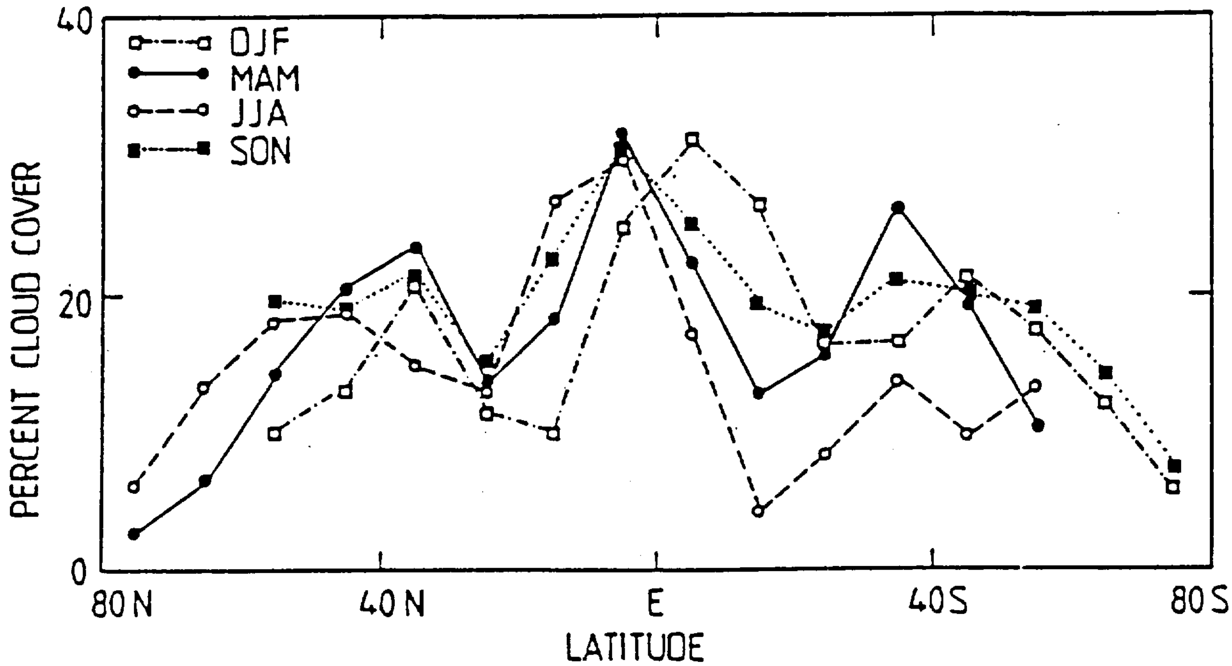


Figure 3. Seasonal zonal average distributions of the occurrence of high clouds with D1 reflectance greater than 0.01. (After Barton, I.J., 1983: Upper level cloud climatology from an orbiting satellite, JAS, 435-447.)

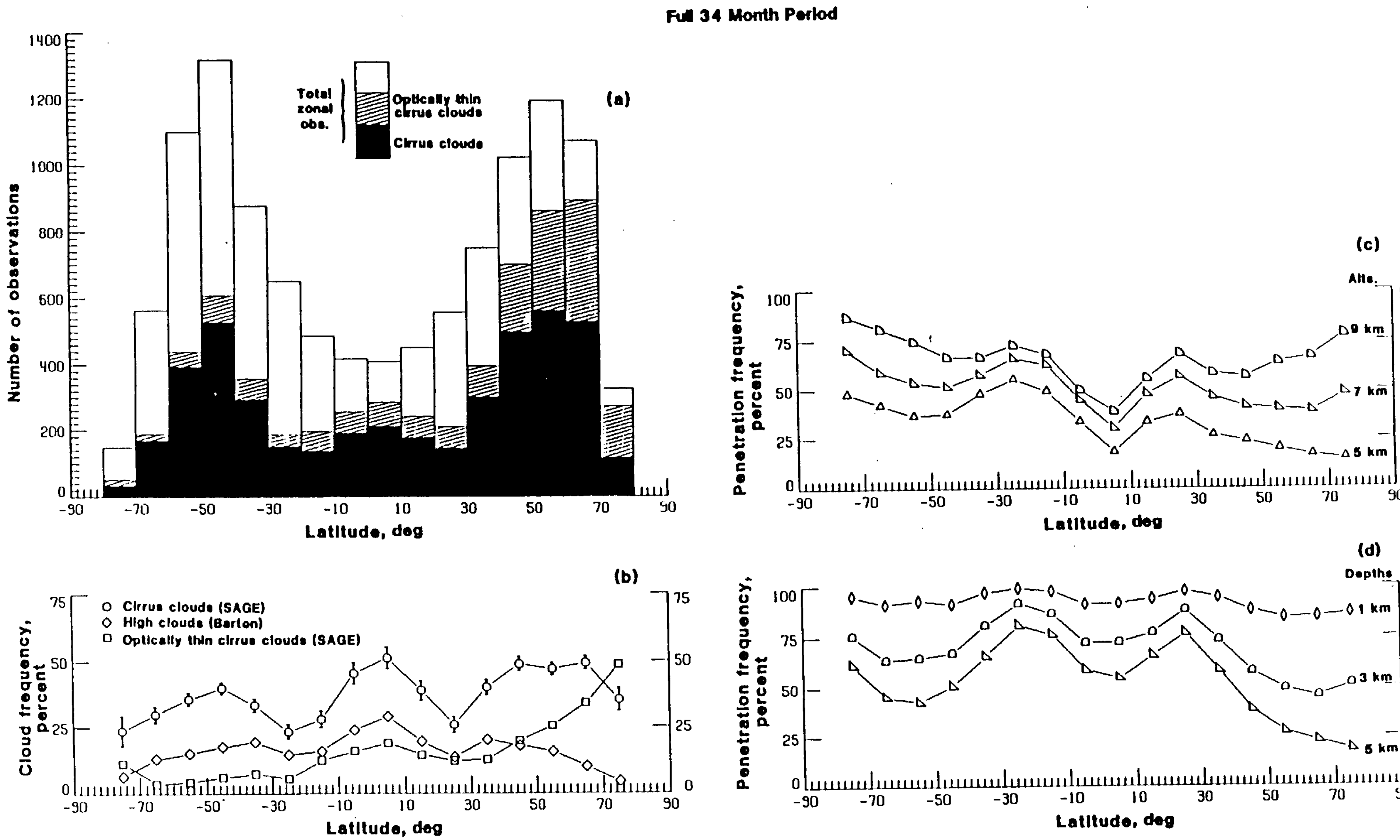


Figure 4. Zonal presentation of the 34-month results from February 1979 to November 1981; (a) Numerical SAGE cirrus and thin cirrus observations, (b) frequency of occurrence of SAGE cirrus, SCR high clouds (Barton, 1983), and SAGE thin cirrus, (c) frequency of penetrations to fixed altitudes of 5, 7 and 9 km, and (d) frequency of penetrations below the tropopause to depths of 1, 3 and 5 km. (After Woodbury, G.E. and M.P. McCormick, 1986: Zonal and Geographical Distributions of Cirrus Clouds Determined from SAGE Data, JGR 2775-2785.)

Zonal Percentage of LAWS Returns

TROPICS

Scatterers

	Cloud/Ice	Aerosols
High	90-100	?
Mid	40-50	?
PBL	0	20-30

30° N

	Cloud/Ice	Aerosols
High	50-60	?
Mid	15-25	?
PBL	0	60-70

Expansion on A.5

The LAWS facility team is composed of individuals familiar with past LAWS simulations as well as new people who have asked for a brief summary of LAWS scan geometry and spatial coverage. The following material will be included in a status paper on LAWS shot management being prepared for the LAWS team.

The perspective of LAWS on the earth's atmosphere is sketched in Figure 6. The values for the pertinent angles and distances are presented in Table 1 for several space platform altitudes.

PHI is the nadir scan angle at the satellite.

THETA is the angle to the horizon of the lidar beam at the earth's surface. Theta is always less than the compliment of the nadir scan angle PHI.

COS represents the percentage of the horizontal wind component sensed along the line-of-sight (LOS).

SIN represents the percentage of the vertical wind component sensed along the line-of-sight (LOS).

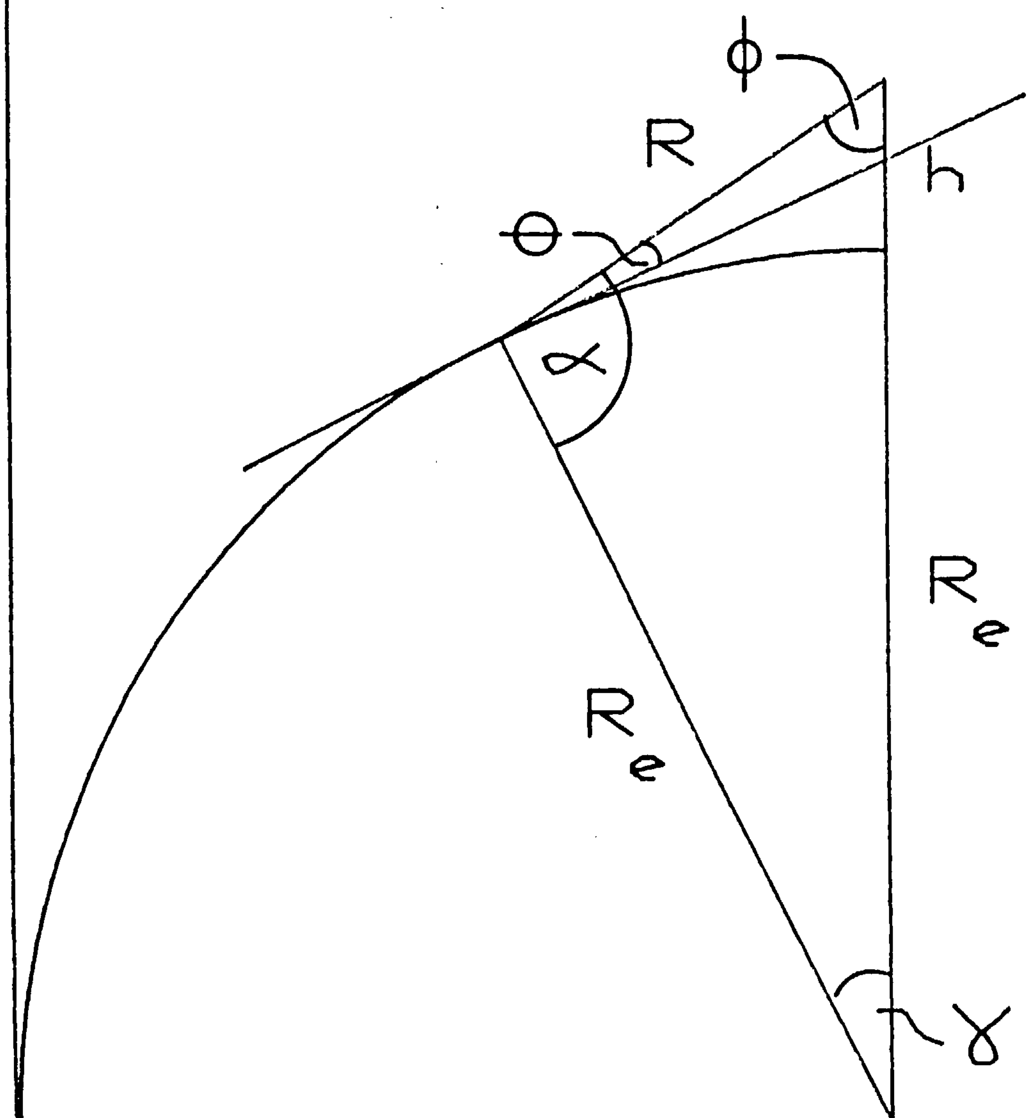
SWATH is the width (km) of the scan pattern on the ground. For the polar platforms, the spacing between satellite passes will be ~ 2800 km at the equator.

RANGE is the LOS distance (km) to the earth's surface.

SNR is the signal-to-noise ratio near the earth's surface using a backscatter value of 3×10^{-7} m^{-1} str^{-1}.

The trades between nadir angle, global coverage (SWATH) and SNR are clearly challenging. Better coverage and better sensitivity to the horizontal speeds are tied to available SNR and, in a sense, oppose the desire for greater shot density (given a fixed PRF).

LAWS SCAN ANGLE GEOMETRY



LEGEND

h - SATELLITE ALTITUDE

R_e - EARTH'S RADIUS

R - RANGE FROM SATELLITE

ϕ - SCAN ANGLE

$\alpha : \sin^{-1}[(h+R_e)/R_e \sin\phi]$

$\gamma : 180.0 - \phi - \alpha$

$\Theta : 90.0 - \phi - \gamma$

SAT. ALT. 824.0

PHI	THETA	COS θ	SIN θ	SWATH	RANGE	SNR
30.	55.63	0.57	0.83	973.87	1123.44	27.95
35.	49.63	0.65	0.76	1194.84	1269.67	26.02
40.	43.46	0.73	0.69	1455.60	1474.85	23.49
45.	37.02	0.80	0.60	1777.36	1771.62	20.11
50.	30.12	0.87	0.50	2200.53	2223.42	15.27
55.	22.34	0.93	0.38	2819.75	2976.34	7.21
60.	12.07	0.98	0.21	3992.75	4535.52	-15.05

SAT. ALT. 705.0

PHI	THETA	COS θ	SIN θ	SWATH	RANGE	SNR
30.	56.27	0.56	0.83	830.24	958.01	29.41
35.	50.43	0.64	0.77	1016.72	1080.83	27.55
40.	44.45	0.71	0.70	1235.20	1252.29	25.14
45.	38.25	0.79	0.62	1501.76	1498.29	21.96
50.	31.71	0.85	0.53	1845.64	1867.58	17.56
55.	24.54	0.91	0.42	2329.54	2465.29	10.78
60.	15.90	0.96	0.27	3139.58	3588.80	-3.22

SPACE STATION ALT. 350.0

PHI	THETA	COS θ	SIN θ	SWATH	RANGE	SNR
30.	58.17	0.53	0.85	407.98	471.02	35.80
35.	52.77	0.61	0.80	497.05	528.62	34.11
40.	47.31	0.68	0.74	599.40	608.43	31.99
45.	41.76	0.75	0.67	720.74	720.36	29.31
50.	36.09	0.81	0.59	870.26	883.01	25.84
55.	30.22	0.86	0.50	1064.31	1131.30	21.19
60.	24.00	0.91	0.41	1335.92	1539.77	14.43

SHUTTLE ALT. 185.0

PHI	THETA	COS θ	SIN θ	SWATH	RANGE	SNR
30.	59.04	0.52	0.86	214.67	247.87	41.47
35.	53.83	0.59	0.81	260.96	277.69	39.86
40.	48.59	0.66	0.75	313.73	318.54	37.85
45.	43.31	0.73	0.69	375.58	375.53	35.34
50.	37.98	0.79	0.62	450.52	457.38	32.18
55.	32.55	0.84	0.54	545.22	580.03	28.10
60.	26.98	0.89	0.45	671.80	775.37	22.59

LEGEND

ALL DISTANCES ARE IN KILOMETERS	WAVELENGTH: 10.6 UM
ALL ANGLES ARE IN DEGREES	ATMOSPHERE: TROPICAL

SIGNAL TO NOISE AT EARTH'S SURFACE - SNR (DB)

TABLE 1

ORIGINAL PAGE IS OF POOR QUALITY

Space-Based Doppler Lidar Sampling Strategies -- Algorithm Development and Simulated Observation Experiments

NASA Contract: NAS8-37779

Monthly Progress Report
for the period
April 17, 1989 to May 16, 1989

Submitted by

George D. Emmitt
Sidney A. Wood

Simpson Weather Associates, Inc.
Charlottesville, VA 22902

19 May 1989

A. During the past reporting period we have continued to work on the following LAWS issues:

1) Review of recent developments in Signal-to-Noise Ratio (SNR) equations and the Line-of-Sight (LOS) velocity uncertainty estimators;

2) Vertical distributions of atmospheric turbulence for 10 m < λ < 10,000 m;

3) Cirrus climatologies derived from several satellite based cloud climatologies;

4) Preparation of a LAWS team "white paper" on the subject of shot management;

5) Preparation for the Munich conference on Coherent Doppler lidars; and

6) Attendance at the GLOBE meeting in Huntsville, AL.

A review and computational comparison of SNR equations and LOS velocity estimates has raised several questions:

(1) What is the appropriate SNR equation for single shot lidar wind measurement?

(2) What is the proper estimation of uncertainty in the LOS velocity?

and

(3) If the performance of the LAWS is being overestimated by 5-10 db (Kavaya - personal communication) then there is cause for some concern regarding making measurements from a POP in regions where $\beta < 10^{-9}$ m^{-1} sr^{-1}. In Table 1, the following equation was used to compute the SNR for LAWS for various platform and scan angle combinations.

$$SNR = \frac{\pi\ \eta\ J\ c\ \tau\ D^2\ K\ \beta\ e^{-2\int \alpha\, dl/\sin\phi}}{8\ h\nu\ R^2\ (NF)}$$

where

π is a constant [3.14159]
η is the system efficiency [0.1]
τ is the pulse duration [6.77 E - 6] (s)
D is the telescope diameter [1.5] (m)
c is the speed of light [3.0 E 8] (m/s)
J is the power transmitted [10] (J)
K is the beam shape factor [0.46]
hv is the photon energy [1.88E-20] (J)

α is the molecular attenuation coefficient (m^{-1})
l is the path length (m)
Φ is the scan angle (radians)
R is the range (m)
ß is the backscatter coefficient (m^{-1} sr^{-1})
NF is hard coded noise factor due to speckle, jitter, etc. [1.5]

The noise factor is believed to be underestimated. From Table 1, it can be seen that for a 705 km polar orbit and a scan angle (PHI) of 45° that:

- the viewing angling at the earth's surface will be 38.25° from the horizontal.
- 79% of the u and v wind components will be projected into the LOS.
- 62% of the vertical wind component will be projected upon the LOS.
- the width of a data swath will be 1501 km.
- the LOS range from the lidar to the earth's surface will be 1498 km.
- the SNR for the boundary layer with a ß of 10^{-7} m^{-1} sr^{-1} will be 21.96 dB.
- the SNR for the mid-tropospheric layer with a ß of 10^{-10} m^{-1} sr^{-1} will be 1.18.
- there will be a 70% coverage of the globe's surface in 12 hours.
- there will be an 18% overlap of samples taken in 12 hours (mostly near the poles), and
- there will be an average of 7 shots into a 100 x 100 km area.

Figure 1, illustrates the relationship between scan angle angle and SNR in the tropical PBL as well as the percent global coverage during a 12 hour period.

If 5 dB is the minimum SNR for extracting a useful estimate of the LOS wind component and the equations overestimate the "real" SNR by 5 dB, then good measurements in the mid-troposphere will require a β greater than 10^{-9} m^{-1} sr^{-1}.

B. Effort will continue on the above items over the next month.

Table 1. SNR for LAWS Pattern Options.

SAT. ALT.: 824.0 (KM) SAT. SPEED: 7.450 (KM/S)

PHI	THETA	COS	SIN	SWATH	RANGE	SNRSFC	SNRMID	%GC	%GSS	SD
30.	55.63	.56	.83	973.87	1123.44	27.95	3.70	48.	11.	11
35.	49.63	.65	.76	1194.84	1269.67	26.02	2.63	57.	14.	9
40.	43.46	.73	.69	1455.60	1474.85	23.49	1.32	67.	17.	7
45.	37.02	.80	.60	1777.36	1771.62	20.11	-.28	78.	21.	6
50.	30.12	.87	.50	2200.53	2223.42	15.27	-2.27	90.	26.	5
55.	22.34	.92	.38	2819.75	2976.34	7.21	-4.82	100.	36.	4
60.	12.07	.98	.21	3992.75	4535.52	-15.05	-8.54	100.	55.	2

SAT. ALT.: 705.0 (KM) SAT. SPEED: 7.507 (KM/S)

PHI	THETA	COS	SIN	SWATH	RANGE	SNRSFC	SNRMID	%GC	%GSS	SD
30.	56.27	.56	.83	830.24	958.01	29.41	5.10	43.	10.	13
35.	50.43	.64	.77	1016.72	1080.83	27.55	4.04	51.	12.	11
40.	44.45	.71	.70	1235.20	1252.29	25.14	2.75	60.	15.	9
45.	38.25	.79	.62	1501.76	1498.29	21.96	1.18	70.	18.	7
50.	31.71	.85	.53	1845.64	1867.58	17.56	-.74	82.	22.	6
55.	24.54	.91	.42	2329.54	2465.29	10.78	-3.17	94.	29.	4
60.	15.90	.96	.27	3139.58	3588.80	-3.22	-6.47	100.	44.	3

SAT. ALT.: 350.0 (KM) SAT. SPEED: 7.703 (KM/S)

PHI	THETA	COS	SIN	SWATH	RANGE	SNRSFC	SNRMID	%GC	%GSS	SD
30.	58.17	.53	.85	407.98	471.02	35.80	11.35	**	**	27
35.	52.77	.61	.80	497.05	528.82	34.11	10.33	**	**	22
40.	47.31	.68	.74	599.40	608.43	31.99	9.10	**	**	18
45.	41.76	.75	.67	720.74	720.36	29.31	7.62	**	**	15
50.	36.09	.81	.59	870.26	883.01	25.84	5.83	**	**	13
55.	30.22	.86	.50	1064.31	1131.30	21.19	3.66	**	**	10
60.	24.00	.91	.41	1335.92	1539.77	14.43	.95	**	**	8

SAT. ALT.: 185.0 (KM) SAT. SPEED: 7.799 (KM/S)

PHI	THETA	COS	SIN	SWATH	RANGE	SNRSFC	SNRMID	%GC	%GSS	SD
30.	59.04	.51	.86	214.67	247.87	41.47	17.09	**	**	52
35.	53.83	.59	.81	260.96	277.69	39.86	16.08	**	**	43
40.	48.59	.66	.75	313.73	318.54	37.85	14.86	**	**	36
45.	43.31	.73	.69	375.58	375.53	35.34	13.41	**	**	30
50.	37.98	.79	.62	450.52	457.38	32.18	11.66	**	**	25
55.	32.55	.84	.54	545.22	580.03	28.10	9.57	**	**	20
60.	26.98	.89	.45	671.80	775.37	22.59	7.01	**	**	16

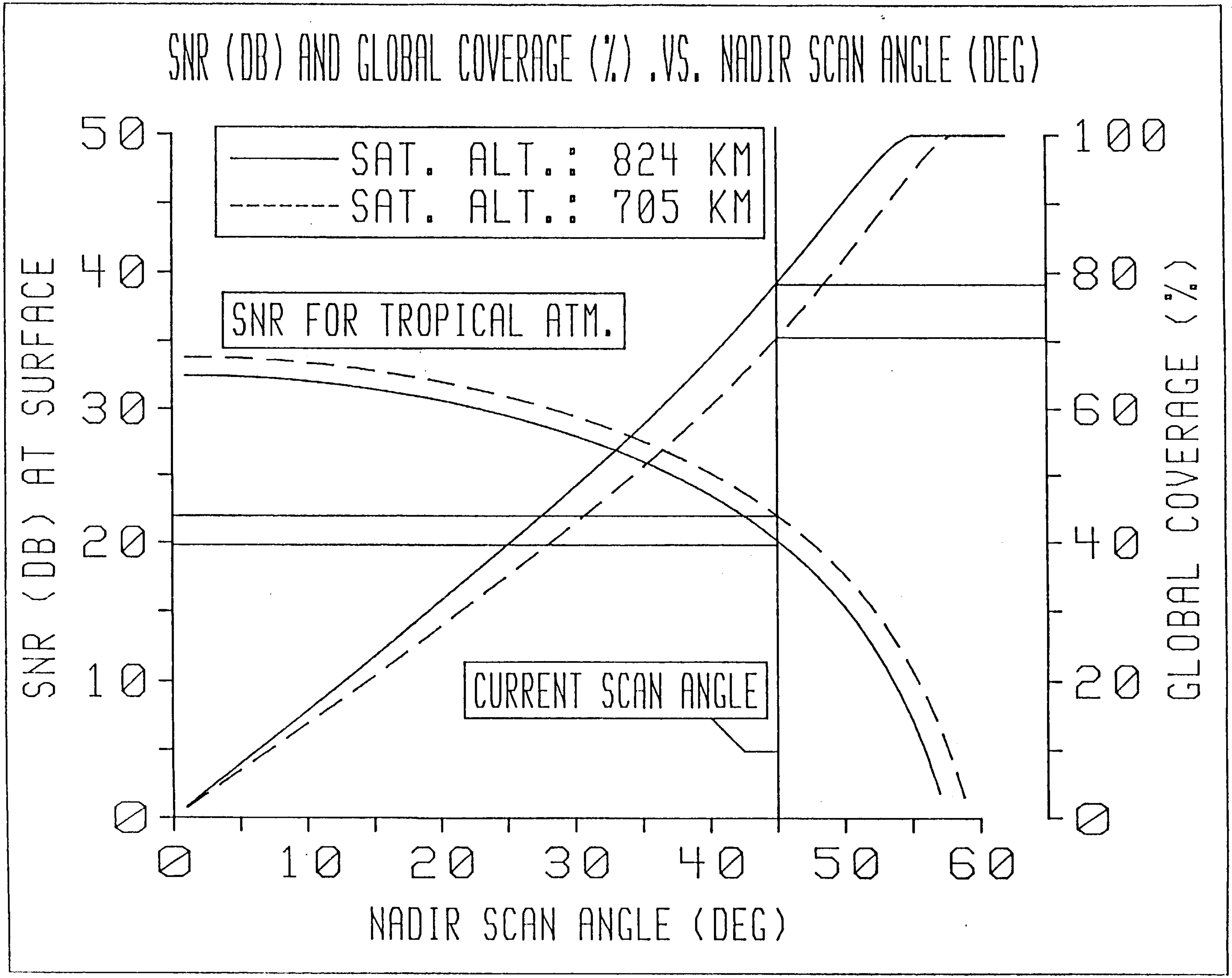
LEGEND

ALL DISTANCES ARE IN KILOMETERS | WAVELENGTH: 10.6 uM
ALL ANGLES ARE IN DEGREES | ATM. PROFILE: TROPICAL

SIGNAL TO NOISE AT EARTH'S SURFACE - SNRSFC (DB)
SIGNAL TO NOISE AT MID ATMOSPHERE - SNRMID (DB)
SURFACE BACKSCATTER: 1E-7 M-1 SR-1
MID ATM. BACKSCATTER: 1E-10 M-1 SR-1
ORBITAL GLOBAL COVERAGE IS FOR 12 HOURS
SHOT DENSITY IS FOR THE MID TRACK AREA - SD
** - NOT APPLICABLE FOR THIS SATELLITE

ORIGINAL PAGE IS
OF POOR QUALITY

Figure 1



SNR (DB) AND GLOBAL COVERAGE (%) .VS. NADIR SCAN ANGLE (DEG)
SAT. ALT.: 824 KM
SAT. ALT.: 705 KM
SNR FOR TROPICAL ATM.
CURRENT SCAN ANGLE
SNR (DB) AT SURFACE
GLOBAL COVERAGE (%)
NADIR SCAN ANGLE (DEG)
0
10
20
30
40
50
60
100
80

Space-Based Doppler Lidar Sampling
Strategies -- Algorithm Development and
Simulated Observation Experiments

NASA Contract: NAS8-37779

Monthly Progress Report
for the period
May 17, 1989 to June 16, 1989

Submitted by

George D. Emmitt
Sidney A. Wood

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27 June 1989

A. During June our efforts have been focused upon the development of a reference atmosphere for use by the Phase A/B contractors (GE and Lockheed) in their initial trade studies. The motivations for having an "initial trades" reference atmosphere are:

1) to provide a reasonable "link" between line-of-sight measurements and the estimates of horizontal wind components in a turbulent and inhomogeneous atmosphere;

2) to allow preliminary hardware configuration tracks to be explored prior to a full evaluation using more complete and globally representative simulations;

3) to allow comparisons to be made between GE and Lockheed trade studies.

Following discussions with M.J. Post (NOAA) and D. Bowdle (USRA/MSFC), we have decided to generate a "single situation" model that includes the most critical environmental elements for simulating a LAWS measurement - except, that is, for clouds. Some of the questions that can be addressed with the reference field are:

1) What is the contribution of pulse scale turbulence to the LOS wind estimate?

2) How critical is the choice of pulse length with regards tp SNR, wind shear (non-linear), aerosol inhomogeneities, etc.?

3) What is the most likely vertical distribution of velocity accuracy?

4) How does the LOS velocity estimate change with scan angle?

5) How representative are the LOS samples?

6) What order of accuracy can be expected for the horizontal wind estimate?

7) What are the trades between LOS accuracies and sample density?

The reference fields are not designed to answer the broader questions of global performance with cloud contamination, optimal configuration for GCM impacts, etc.

The goal is to deliver the reference fields by 7 July 1989.

Two Observing System Simulation Experiments (OSSE) have been initiated within the last month. One is with Florida State University (Krishnamurti) and the other with Marshall Space Flight Center (Tim Miller).

The OSSE at FSU is being conducted using a very high resolution global spectral model developed by Krishnamurti. S. Houston (SWA), is working on-site to install the LAWS Simulation Model on the MSFC's EADS and to obtain a simulated LAWS wind data set from an ECMWF analyses. A 10-day forecast impact will be evaluated with the spectral model. The simulation will include:

clouds - derived from satellite observations for case study

aerosols - profiles taken from LOWTRAN and modified with GLOBE findings

water vapor - output from model

winds - grid scale from model

turbulence - parameterized from grid scale winds and gradients.

The second OSSE is being conducted using the regional scale model, LAMPS, on the CRAY-XMP at MSFC. Tim Miller is beginning to explore issues regarding the assimilation of LAWS data into mesoscale models. A 3-D gridded field (LAMPS output) has been received at SWA. Simulations will begin within the month of July.

During June, Emmitt attended the LAWS feasibility study Requirements Review held in Huntsville, AL. One key issue raised during those meetings with GE and Lockheed was that of the reference atmosphere coupled with a baseline configuration. As mentioned earlier, SWA is preparing a "quick look" reference atmosphere for preliminary trades.

A presentation was made at the 5th CLRC in Munich, FRG - "Simulation of a Space-Based Doppler Lidar Wind Sounder - Sampling Errors in the Vicinity of Wind and Aerosol Inhomogeneities" (Emmitt and Wood). An additional presentation was made at the special session on SNR equations.

B. During the month of July we plan to deliver a reference atmosphere to MSFC for use by GE and Lockheed and to continue work on the two OSSEs.

Space-Based Doppler Lidar Sampling Strategies -- Algorithm Development and Simulated Observation Experiments

NASA Contract: NAS8-37779

Monthly Progress Report
for the period
June 17, 1989 to July 16, 1989

Submitted by

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Sam H. Houston

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27 July 1989

A.

We continue to work on the baseline (or reference) atmosphere for use by the Phase I/II contractors. Attempts to incorporate GLOBE backscatter data have raised some issues that need to be resolved before delivering the reference atmosphere.

Work also continues on preparing an OSSE at Florida State University. The global scale OSSE, proposed by Dr. Krishnamurti at Florida State University (FSU) to simulate LAWS, will include Simpson Weather Associates' (SWA) LAWS Simulation Model (LSM) output winds plus the World Weather Watch (WWW) data as input to the FSU Global Spectral Model for a 10-day simulation beginning with 12Z July 5, 1984. The output from this forecast will be compared with the forecast derived from using only the WWW data as input to the same Global Spectral Model. It was decided that SWA's polar orbiting LSM would use ECMWF wind data as input every 12 hours beginning 12Z, July 5, 1983. The ECMWF u and v wind component data are gridded on 1.875° latitude x 1.875° longitude and are available at the mandatory pressure levels. The data set also includes geopotential height, relative humidity and temperature at each of the mandatory levels. Topography data will be provided by FSU for the model to determine the lowest possible surface layer of wind output in the absence of clouds. Because the LSM requires the cloud inputs to simulate the lack of laser penetration in disturbed moist regions of the atmosphere, FSU will provide cloud heights and optical depths every 12 hours from the International Satellite Cloud Climatology Project (ISCCP). FSU will also provide input support for the parameterization of atmospheric turbulence in the model. Aerosol molecular optical properties will be estimated by the LSM to provide backscatter and attenuation effects on the simulated laser pulses. Relative humidity data from the ECMWF fields will be among the parameters to be used to estimate the aerosol distributions and natural variability. Sample output from the LSM for 12Z, July 5, 1983 will be provided to FSU to verify that the ECMWF data were input correctly.

A version of the LSM model has been transferred to the Engineering Analysis Data System (EADS) at Marshall Space Flight Center (MSFC). The model is now running with input from the ECMWF u and v wind component, geopotential height data and gridded topography data for the globe. Work is also underway to develop a means to include atmospheric turbulence in the LSM.

LAWS was represented by G.D. Emmitt at the recent EOSDIS Architecture Review held GSFC. A report on that review and actions taken by the EOSDIS Science Advisory Panel is being prepared for presentation at the LAWS Science Team meeting scheduled for August 10-11.

B.

We will continue work on the OSSE and baseline atmosphere.

Space-Based Doppler Lidar Sampling Strategies -- Algorithm Development and Simulated Observation Experiments

NASA Contract NAS8-37779

Monthly Progress Report
for the period
July 17, 1989 to August 16, 1989

Submitted by

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01 September 1989

A.

During the last month we have made progress on several tasks:

1) incorporated latest backscatter profiles into the LSM;

2) developed a Baseline Atmosphere for initial trade studies on LAWS configurations; (see Appendix A);

3) developed (but not tested) an algorithm for propagating LAWS shots through a cloudy atmosphere using ISCCP data; (for use in OSSE's);

4) attended and presented material at the 2nd LAWS Science Panel Meeting (9-11 August 1989) at Huntsville, AL;

5) attended (as an EosDIS Science Advisory Panel Member) the EosDIS Architecture Review meeting at GSFC (24-28 July 1989).

B.

In the remaining 2 months we intend to complete the Baseline Atmosphere checkout and provide a statistical module for data retrievals based upon Baseline ß profile (with and without cirrus).

Space-Based Doppler Lidar Sampling Strategies -- Algorithm Development and Simulated Observation Experiments

NASA Contract NAS8-37779

Monthly Progress Report
for the period
August 17, 1989 to September 16, 1989

Submitted by

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28 September 1989

A.

During this reporting period we have:

1) Delivered a LAWS Baseline Backscatter and Absorbtion profile and a baseline SNR equation for use by the Phase A/B contractors LAWS Team members. The Baseline Backscatter profile is based upon data taken at JPL and WPL and represents the LAWS team's best estimate of median values and variances. It must be noted that the profiles used to construct the baseline log normal distributions were the average of several 100 individual profiles. Therefore, they do not contain the contributions of speckle to single shot backscatter. At this point in time, the contractors will need to consider the implications this has to the interpretation of LAWS performance. However, as soon as possible we intend to provide a single shot probabilistic ß profile using the results of an analysis of RSRE data by Bowdle and Rothermel.

2) Hosted an EosDIS Science Advisory Panel meeting addressing (among other topics) the needs to prototype the integration of LAWS with the baseline EosDIS.

3) Participated in a GSFC workshop on using the NASA Climate Data System. Our specific interest is in using cloud climatologies based upon ISCCP and Nimbus-7 data sets to develop reasonable CFLOS statistics for LAWS as well as subvisual cirrus estimates based upon the average visual cloud properties.

4) Received a funded extension (~ $10K) to support the ongoing OSSE at FSU (Krishnamurti).

B.

During the next period we will focus upon the following:

1) providing a baseline velocity variance estimator for LAWS line-of-sight measurements. John Anderson, Bob Lee, Mike Hardesty and G.D. Emmitt are currently addressing this issue.

2) modifying the Baseline Backscatter profile to include speckle statistics.

3) providing a Baseline for $\sigma_v(z)$, dv/dz and correlated horizontal wind fields to complete the Baseline Atmosphere. The selection of $\sigma_v(z)$ is being done with consultation with other team members and active researchers in atmospheric turbulence.

4) preparing two papers for the Lake Tahoe meeting in February 1990.

BASELINE BACKSCATTER/ATTENUATION PROFILE

A probabilistic ß profile, Figure 1, and tropical maritime attenuation profile, Figure 2, are provided to the contractors (GE and Lockheed) for use in their system models and for communicating their performances with selected LAWS configurations.

The purpose of these profiles is to have a common basis for comparing the various trades that are being studied by not only the Phase A/B contractors but also the LAWS Science Team.

The ß profile is a smoothed version of a composite profile based upon ground-based observations at JPL and WPL. A consensus between several members of the LAWS Science Team (Bowdle, Post, Menzies and Emmitt) was reached regarding the following points:

1) not enough data is available at 9.11 or 10.6 µm above 15 km to include this area in the baseline profile;

2) the general distribution of backscatter values around the median are log normal at all levels;

3) both JPL and WPL data sets exclude the contribution of thin cirrus to the upper tropospheric backscatter;

4) in situations without identifiable cirrus, the median ß above 8 km is 3×10^{-11} m^{-1} sr^{-1} (note: this value is not the lowest that could be argued to be consistent with the data collected at Mona Loa in 1988. Furthermore, this value is more representative of current conditions rather than those during the JPL/WPL monitoring period (since 84)),

5) the distribution of thin cirrus ($\tau < 1.0$) above 8 km can be only estimated at this time. The value of 50% at levels above 14 km is a compromise between a value of ~ 30% seen from a ground perspective at JPL, Boulder and Hawaii and a value of 70-80% (tropics) that may be realized from a space perspective. The distribution of cirrus related backscatter is also assumed to be log normal; and

6) performance implied by these profiles will be modulated by opaque clouds. For example, only 25-35% of all lidar shots in the tropics may reach the earth's surface due to clouds.

The tropical attenuation profile is taken from LOWTRAN 7 code and is provided to represent nearly 30-40% of the earth's surface (tropical maritime). It is the most severe mean profile and therefore should be used to "bracket" the performance. However, attenuation due to cirrus has not been included at this time.

The software provided on disk is designed to return an answer to questions like the following:

> What % of the time will there be sufficient backscatter at 5 km to get a 5 dB SNR?

In Figure 3, we show an example of profiles of probable performance using the baseline LAWS system as described on the attachment entitled "Baseline LAWS SNR Equation".

Questions on the profiles and the software should be directed to Sid Wood or Dave Emmitt at SWA.

Baseline LAWS SNR Equation

Several forms of the lidar SNR equation are available for use with the Baseline Atmosphere. After discussion with Hardesty, Bilbro, Menzies and others we have selected the following version:

$$SNR = \frac{\pi \cdot c \cdot n_1 \cdot n_2 \cdot n_3 \cdot n_4 \cdot J \cdot D^2 \cdot \tau \cdot \beta \cdot e^{-2\int \alpha(r)dr}}{8 \cdot h\nu \cdot (R^2 + (.25 \cdot D \cdot D/\lambda)^2)}$$

c = speed of light (m/s) = 3.0×10^8

n_1 = heterodyne quantum efficiency = .40

n_2 = optical efficiency = .25

n_3 = beam shape factor = .46

n_4 = truncation factor = .70

J = laser power (Joules) = 10

D = mirror diameter (m) = 1.5

τ = pulse length (sec) = 6.67×10^{-6}

β = backscatter (m^{-1} sr^{-1}) = input [~ 10^{-10}]

e = 2 way attenuation = computed [~ .1 - 1.0]

$h\nu$ = photon energy (J) = 1.88×10^{-20}

R = slant range (m) = computed

λ = laser wavelength (m) = 9.11×10^{-6}

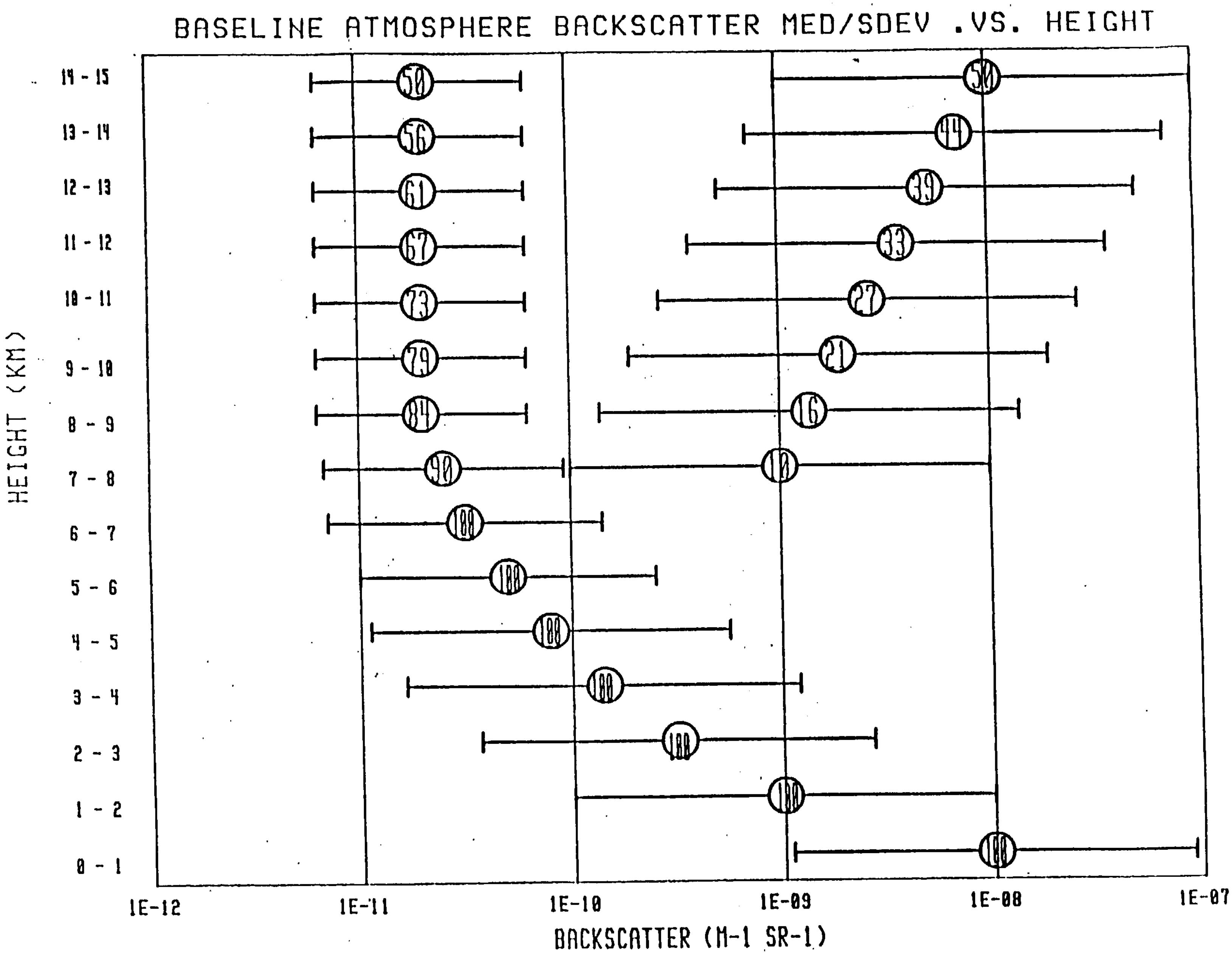


Figure 1. Probabilistic β profile where locations of O indicates the median value including data "drop outs" in the original WPL and JPL profiles. The number within the O is the % of total observations associated with that median. The error bars represent ± 1 σ in the log β based upon several 100 profiles. The cirrus mode above 7 km has been estimated from general reports of high frequency of occurrence of thin subvisual transparent cirrus at those altitudes.

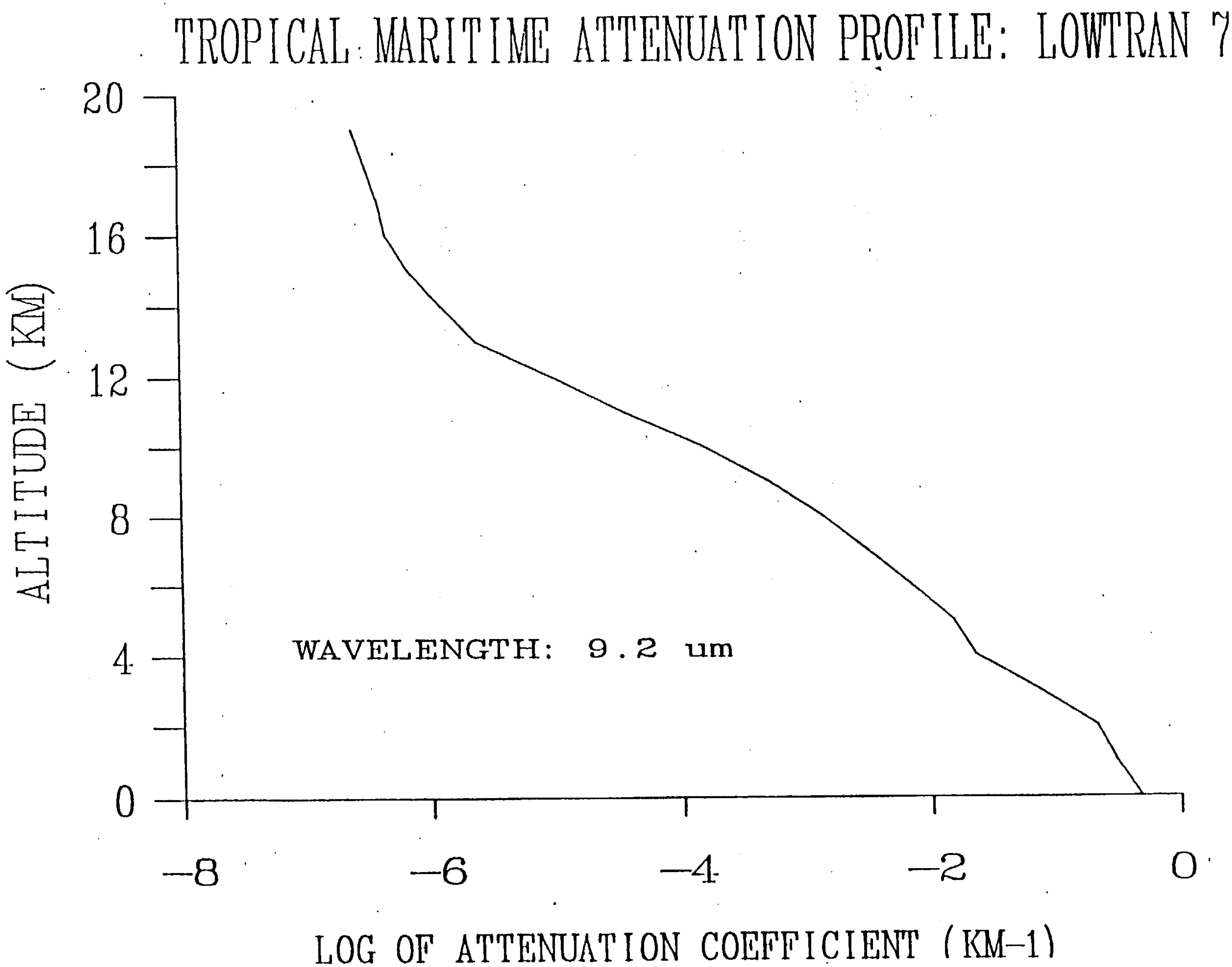


Figure 2. Average tropical maritime attenuation profile taken from LOWTRAN 7 code. While an average profile is shown here, it is recognized that there is a large variation about the mean in the real world. However, for trade studies this variation is not included.

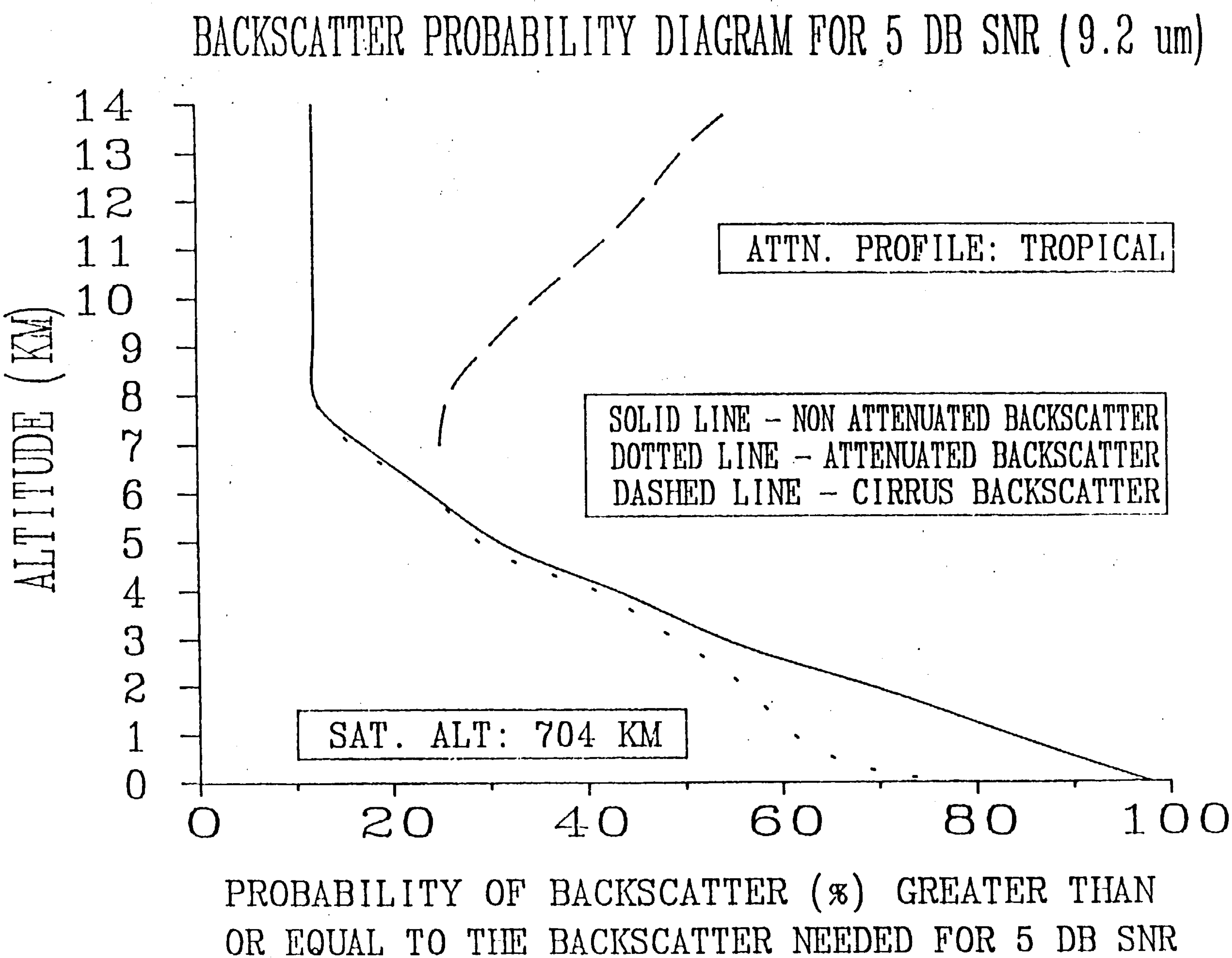


Figure 3. Example of profile of resulting "successful shots" using 5 dB SNR as a threshold and the profiles in Figures 1 and 2.

Baseline LAWS LOS Velocity Error Estimates

As with the lidar SNR equation, there are several radial or LOS velocity error estimates, σ_r, that have been suggested for use with LAWS. While the Cramer-Rao Lower Bound may provide a limit to the extraction of a velocity estimate from a noisy signal, we have chosen the more conservative estimate based upon pulse pair autocorrelation processing of the Doppler signal. The following is derived from Eq. 6.22a in Doviak and Zrnic (1984).

$$\sigma_r = \frac{\lambda}{4\pi} \cdot \left(\frac{f}{2t}\right)^{.5} (2\ \pi^{1.5}\ W + 16\ \pi^2\ W^2/SNR_w + 1/SNR_w{}^2)^{.5}$$

λ = wavelength (m) = 9.11×10^{-6}

V_{max} = maximum velocity measured = 50 m s^{-1}

f = sampling frequency = $2 \cdot V_{max}/\lambda = 10.98 \times 10^6$

t = pulse duration (sec) = 6.67×10^{-6}

W = normalized frequency spread of return signal (m/s)

= $1/\lambda f\ (V_{bw}{}^2 + V_{atm}{}^2)^{1/2}$

V_{bw} = uncertainty due to pulse bandwidth (m s^{-1}) = $\frac{\lambda}{2\pi t}$

V_{atm} = uncertainty due to turbulent eddies and wind shear within the pulse volume (m s^{-1}) = 1.0

$SNR_w = \sqrt{2\pi}\ W\ SNR$

<u>Example:</u>

Given: SNR_N = 5 dB = 3.162

SNR_w = .079 (= -11 dB)

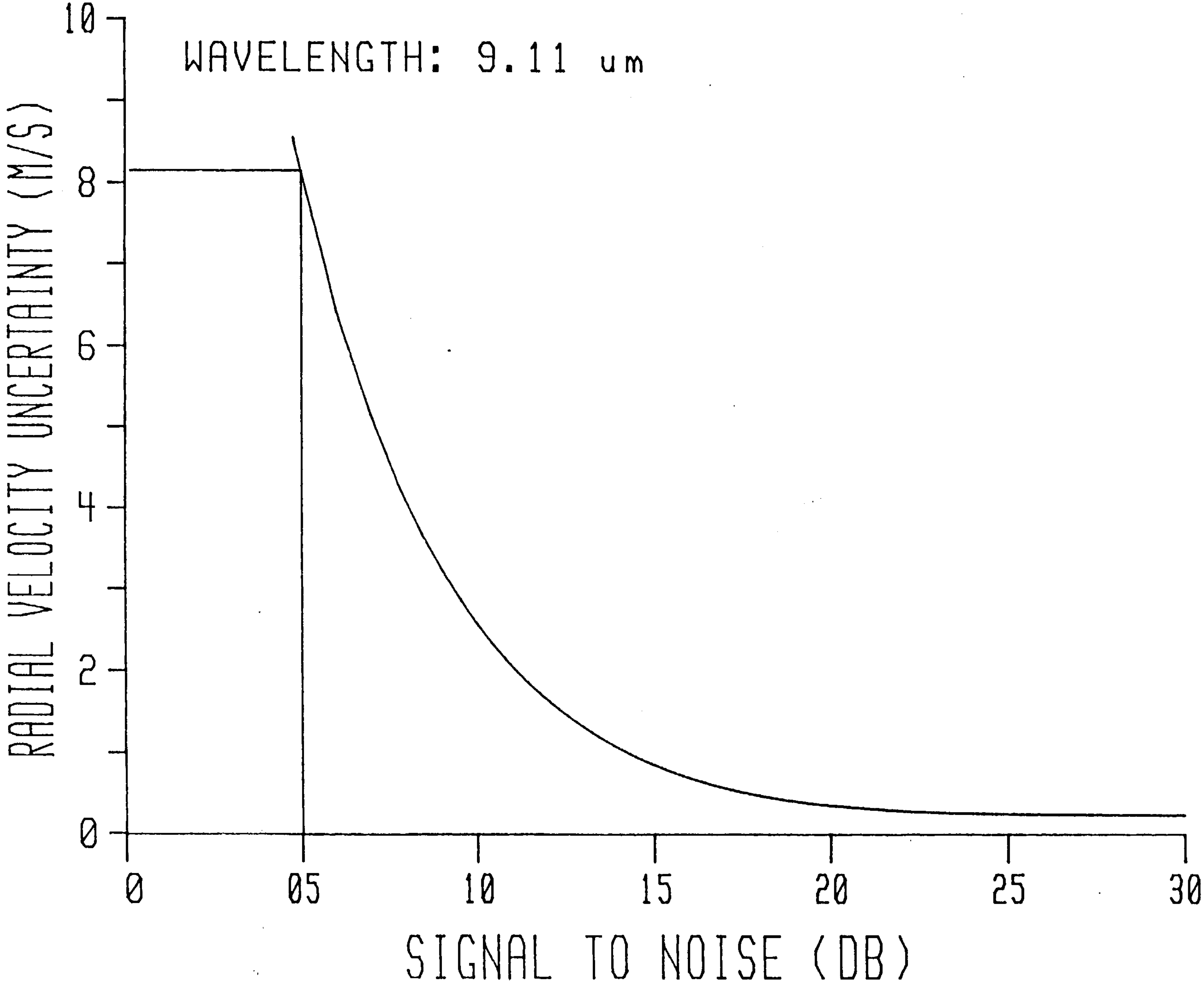
$W = .01 \cdot (.047 + 1.0)^{.5} = .01$

$\sigma_r = .658 \cdot (.112 + .200 + 160.2)^{.5}$

σ_r = 8.35 m s^{-1}

See Figure A for a plot of SNR_N vs σ_r.

BASELINE LAWS LOS VELOCITY ERROR ESTIMATES



Space-Based Doppler Lidar Sampling Strategies -- Algorithm Development and Simulated Observation Experiments

NASA Contract NAS8-37779

Monthly Progress Report
for the period
September 17, 1989 to October 16, 1989

Submitted by

G.D. Emmitt
S.A. Wood

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Charlottesville, VA 22902

9 November 1989

A.

We continue to focus our efforts on establishing baselines for evaluating various LAWS configurations. In particular, we are testing some LSM code that is used to generate simulated three-dimensional wind fields with prescribed shear, turbulence and mesoscale structures. We intend to present that simulation at the LAWS Team meeting in January.

Considerable effort has been directed towards LAWS matters related to the Eos program's science objectives and the EosDIS design activities. Many of the issues raised regarding expected LAWS standard data products have helped to define some areas for near term investigation. For example, the possibility of LAWS providing critical information on the presence and amount of low optical thickness cirrus needs to be carefully evaluated to ensure that appropriate attention is paid to calibration, shot management and signal processing options.

Two papers have been submitted for presentation at the February meeting in Lake Tahoe on Optical Remote Sensing of the Atmosphere (see Appendix A).

A memo was sent to the EosDIS Project Office advising them of a data masking plan for consideration by the LAWS team and the Eos project. A copy of the memo is attached along with a solicitation for comments.

B.

During our two-month no cost extension we will prepare a final report that will be submitted as a contractor's report for NASA publication.

November 8, 1989

MEMO TO: EosDIS Project Management

MEMO FROM: G.D. Emmitt, EosDIS Science Advisory Panel Member

SUBJECT: Draft Rationale for LAWS Default Data Mask

An underlying principle of the EosDIS philosophy is the prompt availability of remote sensing products expressed in commonly used engineering units and universal formats/projections. Prompt is defined for EOS as a day or so after sensor transmission of the data. The EOS program is dedicated to having a full-up DIS with fully implemented and evaluated processing algorithms that will provide 1st order data quality checking and sensor product generation.

With the emphasis on prompt product generation, we can appreciate a second EosDIS principle - data Quality Assurance (QA) will, in effect, be carried out by the thousands of users - each having different opportunities to expose data quality issues through different mixes of remotely sensed data, in situ data and model outputs. The consequences of this QA by the user are of concern to the LAWS panel, particularly because of the exploratory nature of a space-based lidar facility.

We recognize some of the advantages and disadvantages of the rapid dissemination of the EOS products. We also recognize that not all of the users of EosDIS products will appreciate or desire to have the burden of QA placed upon them in the first instance. Worse yet are the consequences of users of EosDIS not adequately experienced in recognizing "bad" data - users accepting a NASA product as reliable and therefore expending valuable time and resources in reconciliation of data set conflicts and inconsistencies.

Another perspective on this issue is that of the scientist responsible for providing a standard data product. Regardless of the accompanying documentation, error discussions and caveats, users will still associate a data set with a particular scientist or group of scientists - i.e., they are perceived as "signature" products. There is bound to be a reluctance on the part of many scientists to contribute any product not adequately QA'd by the producer.

The LAWS team is considering the following as a more desirable option for the EosDIS product line - particularly in the first few years after launch. The concept is a Default Data Mask (DDM). The DDM is simply a data quality mask placed over the complete delivered data set so that a casual user or even a user that does not want to be involved in the QA of someone else's data set will only receive those data that meet the highest quality standards. In other words, to get the entire standard product, a user has to consciously remove the mask and accept the responsibility of using data not fully evaluated or endorsed by the product generating scientist.

The advantages of the DDM option are:

1) Standard products that have received the best quick QA possible within the "production mode" time frame, are delivered in their entirety to EosDIS in the spirit of "prompt availability" principle;

2) While having done their best, scientists (who know that given time, better estimates of errors will be found for regions of marginal sensor performance) will be able to act more responsibly by masking those questionable data from the general user;

3) The entire data set is available, however, to be used by those who are trained and prepared to recognize the limits of sensor performance regardless of the plausibility of the data; and

4) The DDM can be slowly removed (or enlarged if necessary) as more is learned by the EosDIS community of users and confidence is established through validation and application.

While this DDM approach may be most desirable for "new technology" sensors like LAWS, other instruments with a space-based heritage (MODIS) may also find it desirable and an act of scientific responsiblity to the broader spectrum of users being courted by the EOS program.

It is requested that the EOS project provide the LAWS team with its reaction to this proposed way for a PI or Team Scientist to deliver a complete standard product to EosDIS while providing some measure of default protection to the user who expects a QAd product.

Comments and suggestions should be directed to:

Chairman of LAWS Algorithm Committee
G.D. Emmitt
Simpson Weather Associates, Inc.
809 E. Jefferson Street
Charlottesville, VA 22902

and copied to:

LAWS Team Leader
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WWB Room 204
Washington, D.C. 20233