

The Mars Lidar Simulation Model (MLSM)

by

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1.0 Overview

Planetary winds have implications to understanding planetary weather and planetary exploration. In the case of Mars, the interplay between winds, dust storms and the radiative feedback is critical to the prediction of operational meteorology but remains poorly understood. The Mars Lidar Simulation Model (MLSM) (Upendra et al., 2006) is a simulation model that is intended to help develop several lidar concepts that would provide critical observations of winds, aerosols and gases on Mars. The Mars Lidar Simulation Model (MLSM) is an evolution of existing Earth based Doppler lidar simulation models (Wood and Emmitt, 2004; Wood and Emmitt, 2002; Wood et al., 2000; Emmitt and Wood, 1996; Wood et al., 1995; Wood et al., 1993, Emmitt et al., 1990; Emmitt and Wood, 1988) that are currently used for spaced-based Doppler lidar wind simulations (Lord et al, 2002; Emmitt and Wood, 2001; Wood et al., 2001; Wood et al., 1997; Atlas and Emmitt, 1995; Emmitt and Wood, 1995).

2 μm coherent lidar technology has been and continues to be developed to making remote wind measurements. However, the 2 μm wavelength region also contains strong absorption lines of CO_2 that has the potential to be explored with the differential absorption lidar (DIAL) technique to make gas species concentration measurements (Koch, 2001). A breadboard prototype coherent Doppler/DIAL has been built and tested in the Earth's atmosphere for performance in both wind and CO_2 measurement (Koch et al., 2004). The MLSM provides an interactive coherent DWL and DIAL simulation on Mars that allows a user to address issues ranging from lidar system trade studies to global numerical model assimilation and impact studies.

The MLSM version 1.0 is built on the architecture framework of the existing 2003 PC-based DLSM. The Lidar Simulation Model (LSM) and the Shot Coverage Model (SCVM) are coded in Fortran 90/95. New algorithms include a Doppler Dial option, Martian global climate databases and new optical property models. The aircraft, balloon and ground lidar platforms, direct detection lidar, horizontal wind processing, atmospheric generator model, power budget model and forward model options are not part of the first model delivery to NASA. One day of the Global Climate Model (GCM) database developed by Laboratoire de Météorologie Dynamique du CNRS, France is currently provided.

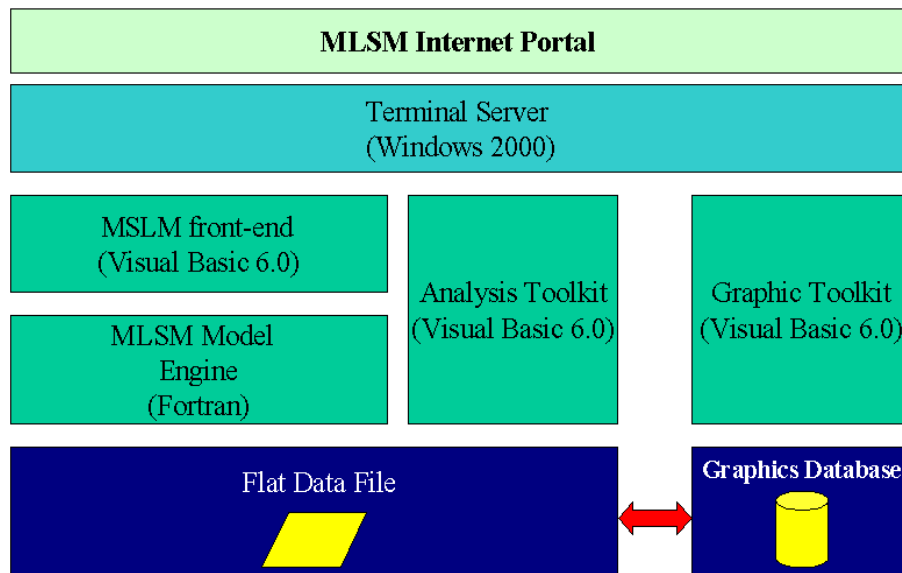
1.1 Computer System Description

1.1.1 HARDWARE/OPERATING SYSTEM

The MLSM was originally designed to run on a MS Windows 2000 terminal server via network or as a deliverable series of DVDs operating under the MS Windows 2000/XP operating system. In 2010, the model was ported to a Windows 7 operating system environment on a Dell PC.

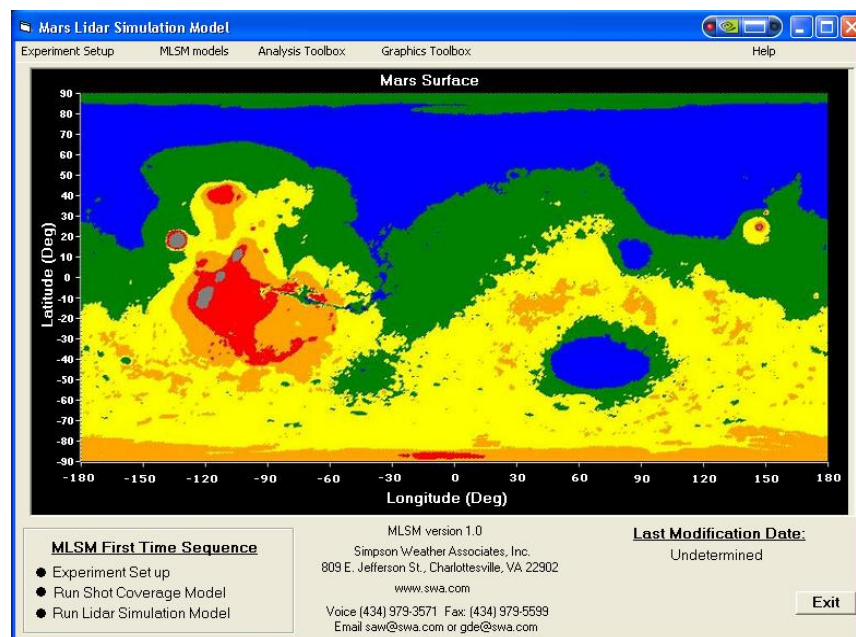
1.1.2 MLSM SYSTEM ARCHITECTURE AND PROGRAMMING LANGUAGES

All MLSM inputs and graphic routines are coded in MS Visual Basic 6.0. The Lidar Simulation Model and Shot Coverage Model are coded in FORTRAN 90/95 using Compaq Visual Fortran professional edition 6.6.



1.2 MLSM EXECUTION

Execution of the MLSM invokes the MLSM Main Screen: the model's control screen.



The MLSM Main Screen has five options: Experiment Manager, MLSM Models, Analysis Toolbox, Graphics Toolbox and Help.

For a first time user, the user should click on the Experiment Setup top menu option. This will invoke the Experiment Manager where the user customizes model inputs for a Mission Scenario. A Mission Scenario is defined as the platform/lidar inputs, atmospheric inputs, and simulation time block inputs. From the Experiment Manager, the user enters the necessary inputs to run the MLSM Fortran models, reviews inventory of past input files, loads existing files, and edits existing files. Once model inputs have been set up, the user should choose to run the Shot Coverage Model from the MLSM

models menu which will create a global coverage data file of lidar shot information. Next, the user should choose to run the Lidar Simulation Model from the MLSM models menu which, in liaison with the shot coverage file and atmospheric inputs, will produce simulated lidar products. The MLSM models menu also allows the user to review the last processing message from the SCVM or LSM.

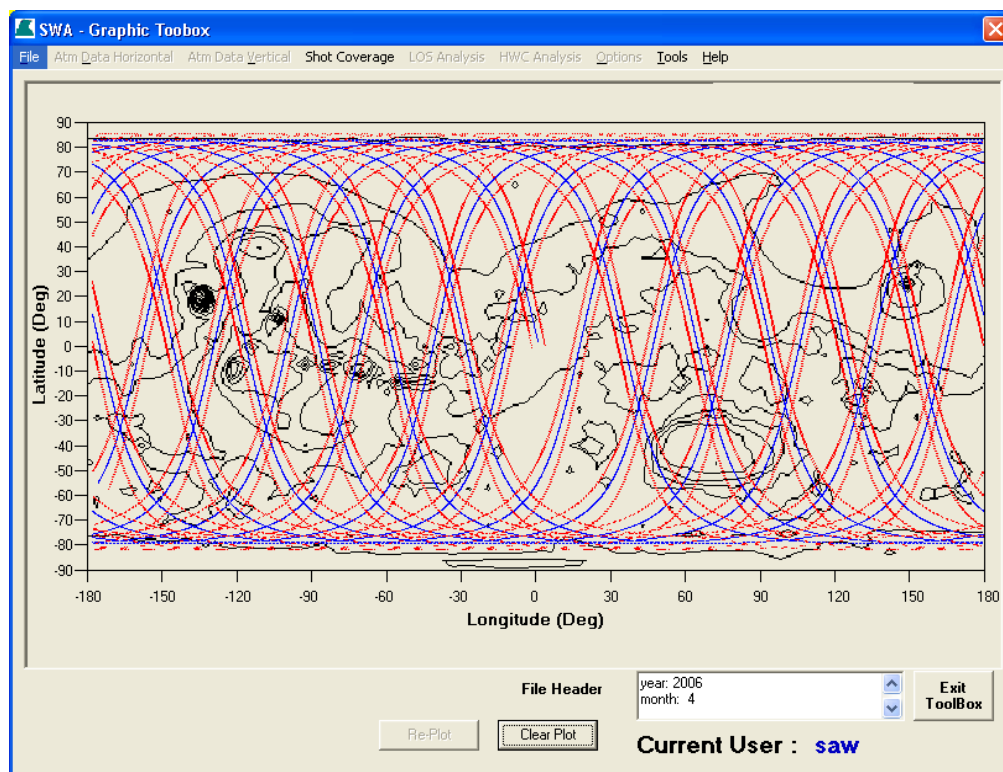
From the MLSM's Analysis Toolbox menu, the user can produce global statistics on the DWL line of sight wind results or DIAL CO₂ results via the Performance Graphic Model. The Graphics Toolbox allows the user to graph platform coverage and lidar shot coverage. The graphics that display three dimensional atmospheric variables, simulated lidar products and corresponding errors are not operational in this version of the MLSM.

2.0 LIDAR SIMULATION MODEL TECHNICAL

The MLSM's Lidar Simulation Model (LSM) (Emmitt and Wood, 1996; Wood et al., 1995) is an evolution of existing Doppler lidar simulation models (Wood et al., 1993; Emmitt et al., 1990) that are currently used for spaced-based Doppler lidar wind simulations (Lord et al, 2002; Wood et al., 2001; Baker et al., 1995) and airborne Doppler lidar wind simulations (Wood et. al., 1997). The LSM is a fully integrated Doppler lidar simulation model that produces simulated lidar winds and corresponding errors, CO₂ density information using either global or mesoscale atmospheric model fields. The LSM can address various types of questions on the feasibility and optimal functionality of a space-based Doppler lidar system. The LSM is also designed to address engineering trades, measurement accuracies, measurement representativeness, resolution and areal coverage.

2.1 SHOT COVERAGE MODEL

The Shot Coverage Model (SCVM) is a stand-alone FORTRAN 90 model that allows the user to simulate satellite and aircraft missions with a variety of laser scanner patterns. The SCVM provides ASCII records of platform track and laser shot coverage (spatial and temporal) for the LSM.



Shot Coverage Model Output records

Variable Record	units
Satellite latitude	(deg)
Satellite longitude	(deg)
Time laser shot was taken	(s)
Azimuth scan angle	(deg)
Sequence number of azimuth angle	#
Satellite heading	(deg)
Platform Altitude	(km)
Number of altitude levels (0 for satellite)	#
Nadir scan angle	(deg)
Scan pattern indicator 0-conical 1-stare 2-gap	
Laser shot latitude f(z)	(deg)
Laser shot longitude f(z)	(deg)
Laser shot altitude f(z)	(deg)
Orbit quadrant indicator f(z)	

2.2 ATMOSPHERIC LIBRARY

The LSM's atmospheric library is made up of an extensive set of integrated atmospheric data bases created by the Atmospheric Generator Model (AGM). The library can provide meteorological inputs from control fields, generated fields, mesoscale fields to global meteorological fields. The library also includes aerosol backscatter, molecular and aerosol attenuation, atmospheric turbulence and terrain.

2.2.1 GLOBAL ATMOSPHERIC DATA SET (GADS)

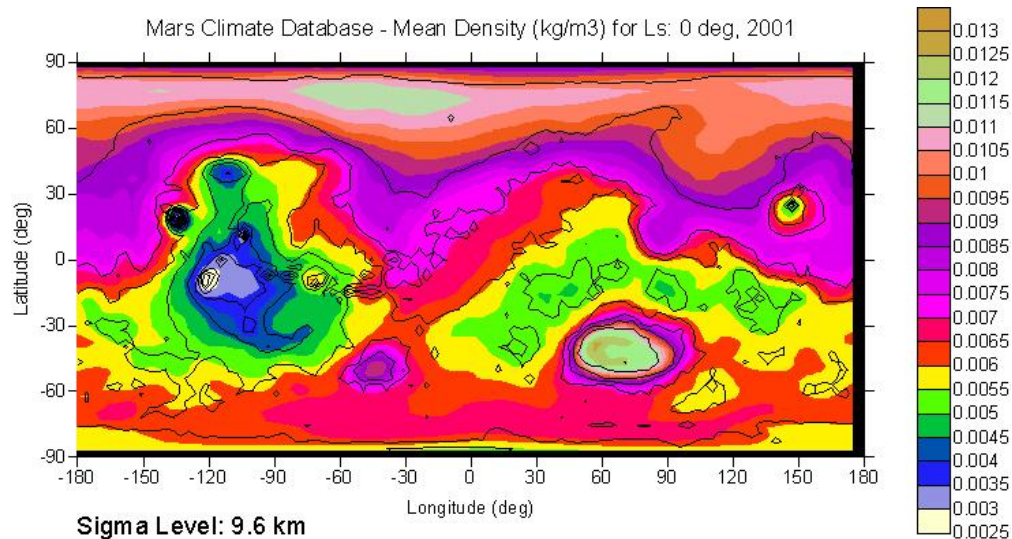
The Atmosphere Generator Model (AGM) creates Global Atmospheric Data Sets (GADS) that the LSM uses for global type simulations. A GADS is a FORTRAN 90 direct access file created by using a "Nature Run" data set in liaison with the AGM optical property models and terrain data set. The LSM retrieves atmospheric profiles as a function of latitude and longitude for each laser shot and linearly interpolates in time and space to estimate the atmospheric variables for each 4D lidar location.

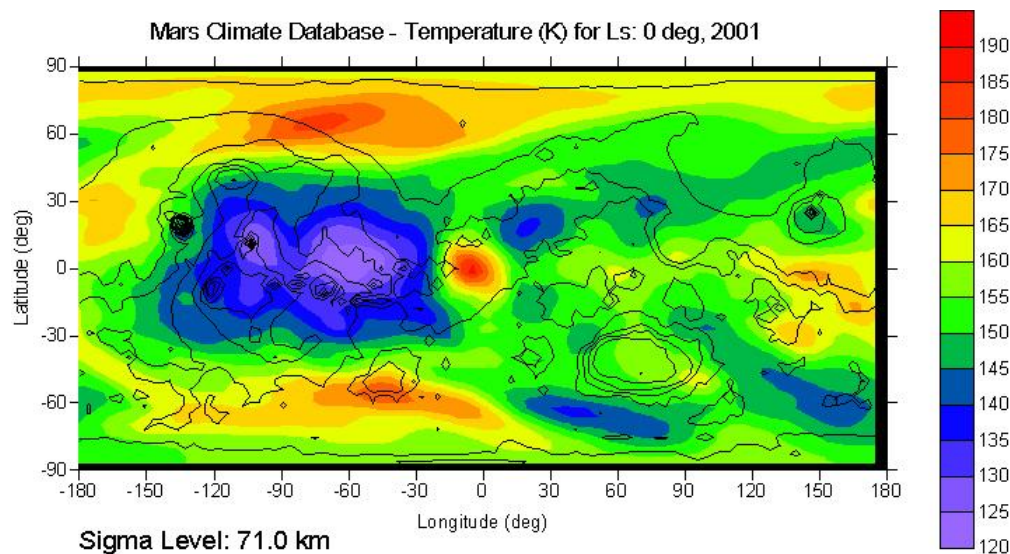
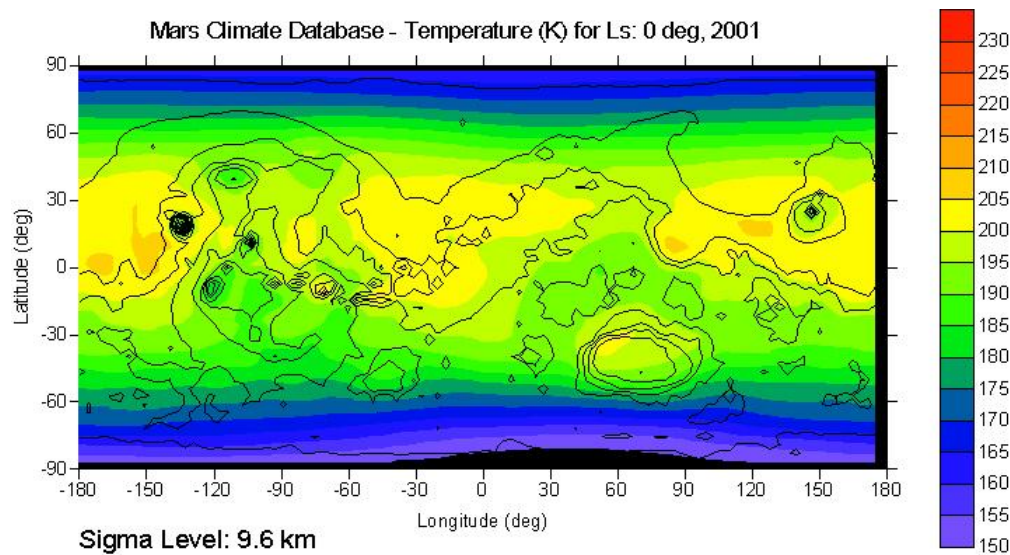
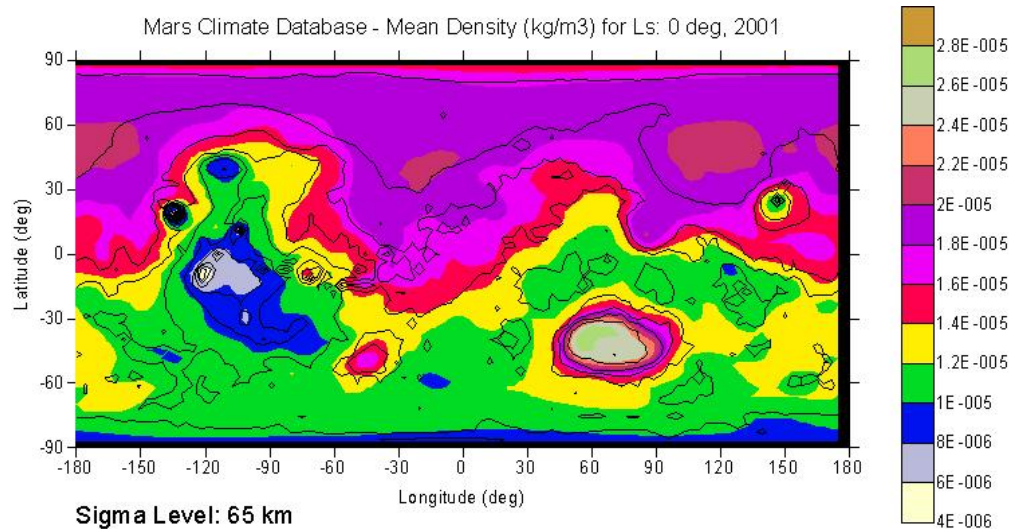
The MLSM version 1.0 has one day of a Mars GADS in the atmospheric file inventory. The AGM used a Global Climate Model (GCM) database (Laboratoire de Météorologie Dynamique du CNRS, France) for the "Nature Run" candidate in making the GADS.

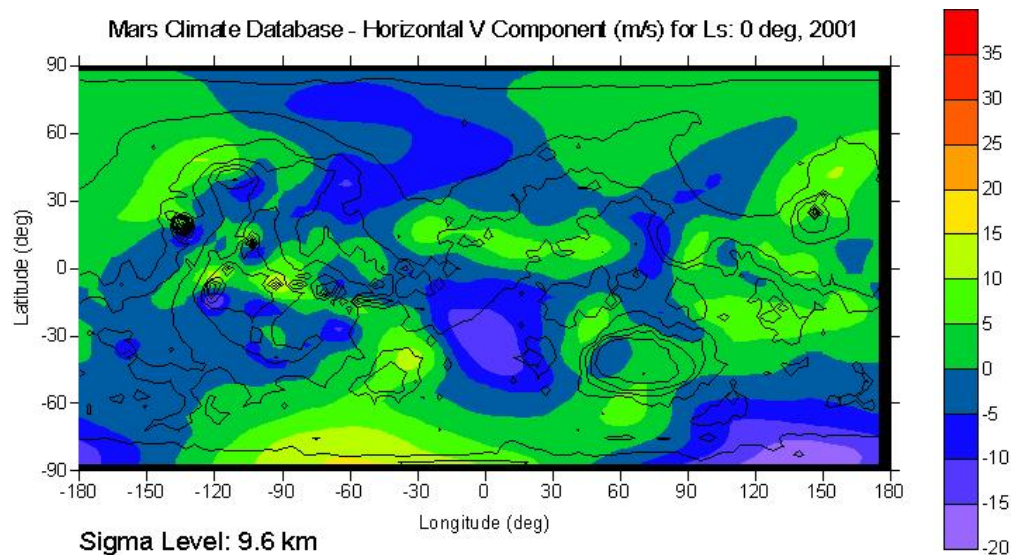
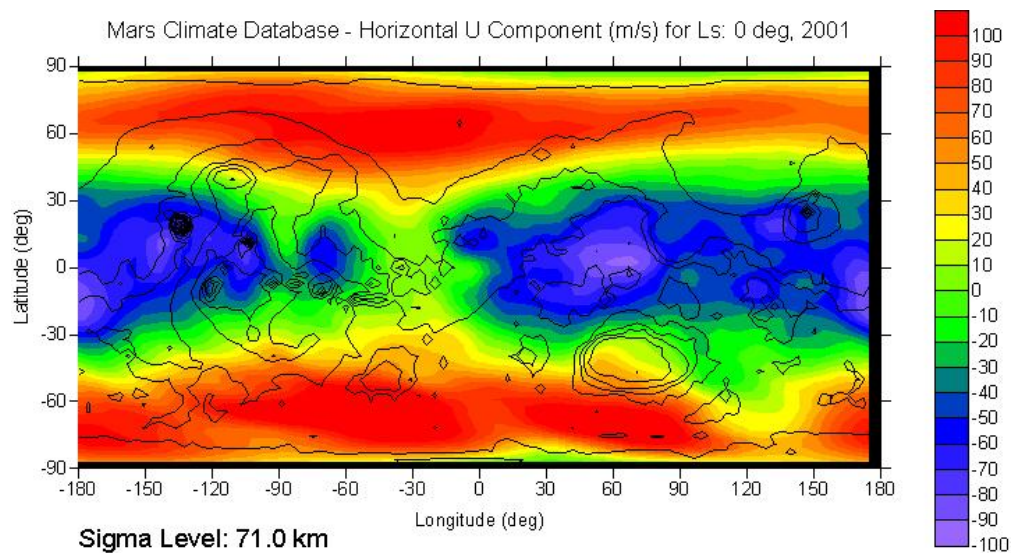
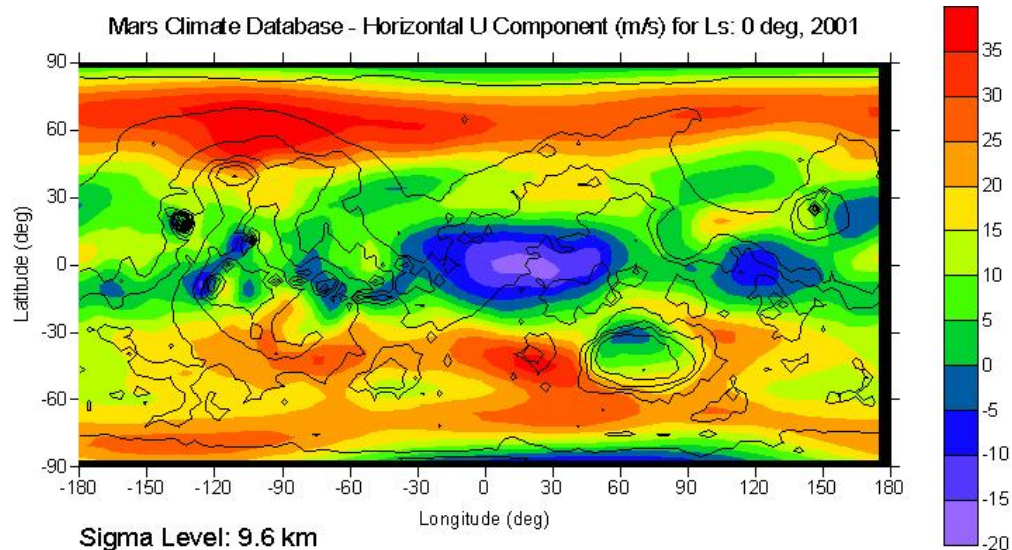
During the course of this contract, SWA researched various Mars GCM models such as Mars Climate Database, NASA AMES Mars GCM and NASA MARS-GRAM and attended a NASA workshop; Proper Use of Mars Atmospheric Models. While it is planned that a future version of the MLSM will be able to simulate on many AMES and MCD databases for various time of the year and dust events, currently the MLSM is set up to only simulate on a 1 day MCD database. The Mars Climate Database Surveyor for spring 2001 (Ls 0-30) from the Martian Global Circulation Model (Lewis et. al., 1999) was selected as the Nature Run first candidate due to the ease of obtaining the data set over the web. The horizontal resolution of the database is $5^{\circ} \times 5^{\circ}$ for every two hours. A record's content is

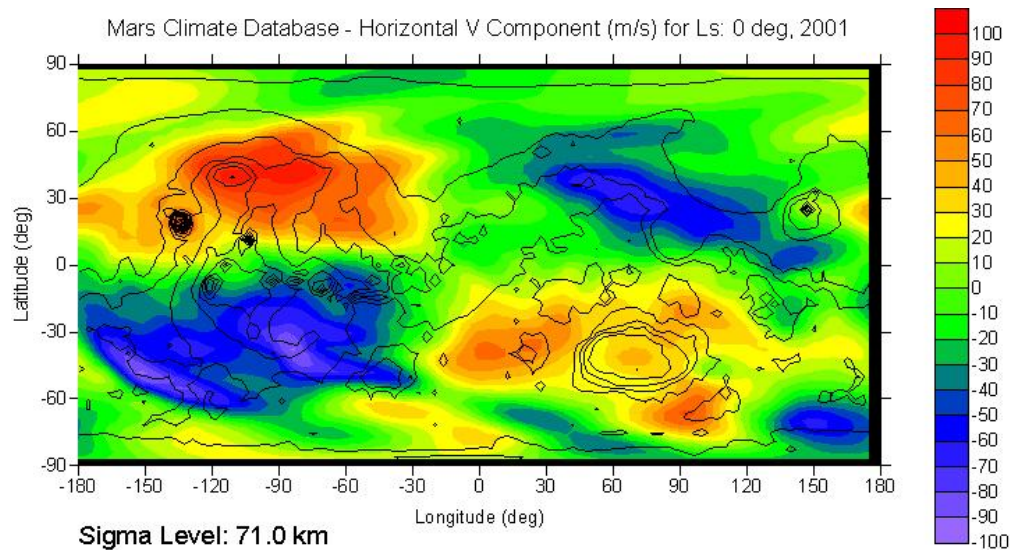
shown for each GADS type below. The data profiles are for 32 atmospheric sigma levels. Graphic examples of selected profile variables for hour 00z are provided.

Mars Climate Database Surveyor-based GADS Data Record
adjusted MOLA terrain (m)
surface Pressure (pa)
surface Temperature (k)
Profile of Height referenced from minimum terrain (km)
Profile of mean "boundary layer" eddy kinetic energy (m2/s2)
Profile of mean density (kg/m3)
Profile of mean temperature (K)
Profile of horizontal Wind Component U (M/S)
Profile of horizontal Wind Component V (M/S)
Profile of subgrid scale standard deviation in U (9 point) (M/S)
Profile of subgrid scale standard deviation in V (9 point) (M/S)
Profile of subgrid scale standard deviation in W (9 point) (M/S)









Since the VB graphic tool for displaying GADS variables is not operational in the MLSM version 1.0, SWA provides a simple Fortran model to read the GADS and create an ASCII atmosphere file for the user to use in their graphic tools.

2.2.2 OPTICAL PROPERTIES

The MLSM version 1.0 estimates a background mode Martian aerosol backscatter profile plus an additional enhanced mode aerosol backscatter if desired. The simple aerosol model uses optical property databases from available literature (Ockert-Bell et al., 1997, Forget, 1998).

Single-Scattering Properties of the Martian Dust Particles

Wavelength	Single Scattering Albedo	Asymmetry Parameter	Extinction Coefficient	Index of refraction (real)	Index of refraction (img.)
0.21	0.72	0.81	2.60	1.47	0.008
0.30	0.61	0.88	2.58	1.48	0.038
0.35	0.61	0.86	2.61	1.50	0.039
0.40	0.63	0.84	2.65	1.51	0.034
0.50	0.78	0.73	2.82	1.52	0.011
0.60	0.91	0.67	2.98	1.51	0.004
0.67	0.93	0.65	3.04	1.51	0.003
0.70	0.94	0.65	3.06	1.51	0.003
0.80	0.95	0.64	3.13	1.50	0.003
1.02	0.95	0.63	3.24	1.50	0.003
1.21	0.95	0.63	3.32	1.50	0.004
1.39	0.96	0.63	3.36	1.50	0.004
2.20	0.95	0.63	3.25	1.49	0.006
2.49	0.95	0.63	3.11	1.49	0.007
2.90	0.80	0.67	2.77	1.50	0.045

3.00	0.81	0.67	2.77	1.51	0.039
3.19	0.88	0.65	2.76	1.52	0.022
3.40	0.93	0.64	2.69	1.52	0.013
3.60	0.95	0.63	2.59	1.51	0.009
3.78	0.96	0.63	2.49	1.51	0.008
3.98	0.95	0.63	2.36	1.50	0.008
4.15	0.88	0.65	2.23	1.50	0.025

Since 2.2 μm wavelength is the closest to the on and off channels, 2.2 μm optical properties are used in the MLSM. The aerosol backscatter phase function is approximated using the asymmetry parameter in the Henyey-Greenstein equation (Henyey L. and J. Greenstein, 1941).

$$P_{\pi} = (1.0 - g^2) / (1 + g^2 - 2 \cdot g \cdot \cos(\pi))^{1.5}$$

where

P_{π} - aerosol backscatter phase function

g - asymmetry parameter.

The scattering efficiency and backscatter efficiency is approximated by

$$Q_s = Q_e \cdot \omega$$

$$Q_{\pi} = Q_s \cdot P_{\pi}$$

where

Q_e - extinction efficiency

ω - single scattering albedo

Q_s - scattering efficiency

Q_{π} - backscatter efficiency

A modified gamma size distribution (Deirmendjian, 1969) is used to compute particle size distribution as follows

$$\mathbf{b} = \alpha / (\gamma \cdot \mathbf{r}_m^\gamma)$$

$$\mathbf{c} = (\mathbf{b} \cdot \gamma \cdot \mathbf{r}_m^\gamma)$$

$$\mathbf{n}(\mathbf{r}) = \mathbf{a} \cdot \mathbf{r}^c \cdot \exp(-\mathbf{b} \cdot \mathbf{r}^\gamma)$$

where

n(r) - particle size distribution

r - particle radius (μm)

r_m - mode radius (μm)

MLSM default - 0.3

a - particle concentration (cm³)

MLSM default - 500000

(Deirmendjian, 1969)

α - constant

MLSM default - 2

(Toon et al. 1977)

γ - constant

MLSM default - 0.5.

(Toon et al. 1977)

Surface layer aerosol backscatter, scattering and extinction is computed respectively by integrating over particle radius size from 0.01 to 10.0 μm as follows

$$\beta_\pi = \int \pi \cdot r^2 \cdot Q_\pi \cdot n(r) dr$$

$$\beta_\sigma = \int \pi \cdot r^2 \cdot Q_s \cdot n(r) dr$$

$$\beta_e = \int \pi \cdot r^2 \cdot Q_e \cdot n(r) dr$$

The MLSM uses atmosphere density from the GADS to scale the vertical distribution of the aerosols either assuming a constant dust mixing ratio or a varying dust mixing ratio that is a function of pressure.

CONSTANT DUST MIXING RATIO

$$\beta_{\pi}(z) = \rho(z)/\rho_o \cdot \beta_{\pi}$$

$$\beta_s(z) = \rho(z)/\rho_o \cdot \beta_s$$

$$\beta_e(z) = \rho(z)/\rho_o \cdot \beta_e$$

VARYING DUST MIXING RATIO

$$Q/Q_o = \exp(0.007 \cdot (1.0 - \max((P_o/P(Z))^{(70.0/Z_{\max})}, 1)))$$

$$\beta_{\pi}(z) = Q/Q_o \cdot \rho(z)/\rho_o \cdot \beta_{\pi}$$

$$\beta_s(z) = Q/Q_o \cdot \rho(z)/\rho_o \cdot \beta_s$$

$$\beta_e(z) = Q/Q_o \cdot \rho(z)/\rho_o \cdot \beta_e$$

where

$\rho(z)$ - Atmospheric density profile (kg/m³)

ρ_o - Surface atmospheric density profile (kg/m³)

Q/Q_o - Dust mixing ratio

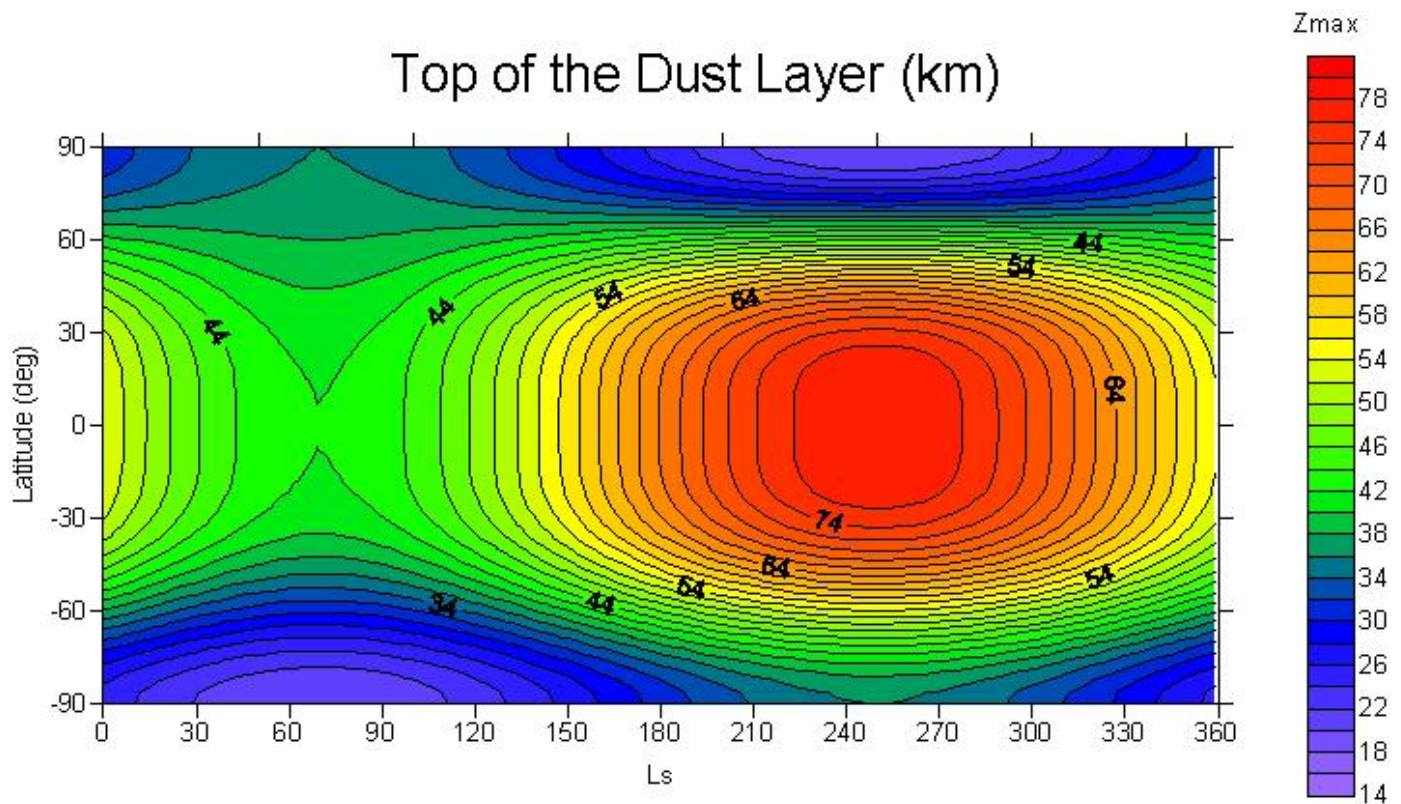
$P(Z)$ - Atmospheric pressure profile (pa)

P_o - Surface atmospheric pressure (pa)

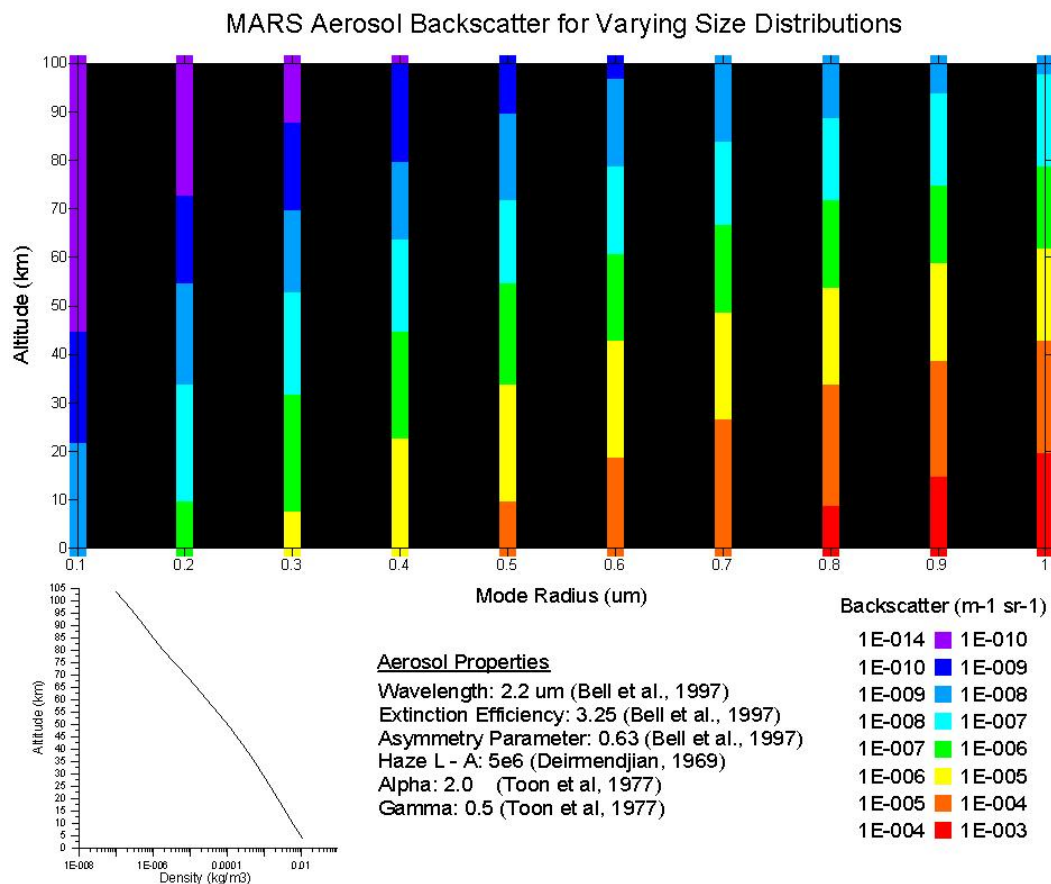
Zmax - maximum height for aerosol and dust vertical scaling. (km)

Zmax is computed from the Forget empirical formula based upon the solar longitude, L_s and latitude, θ .

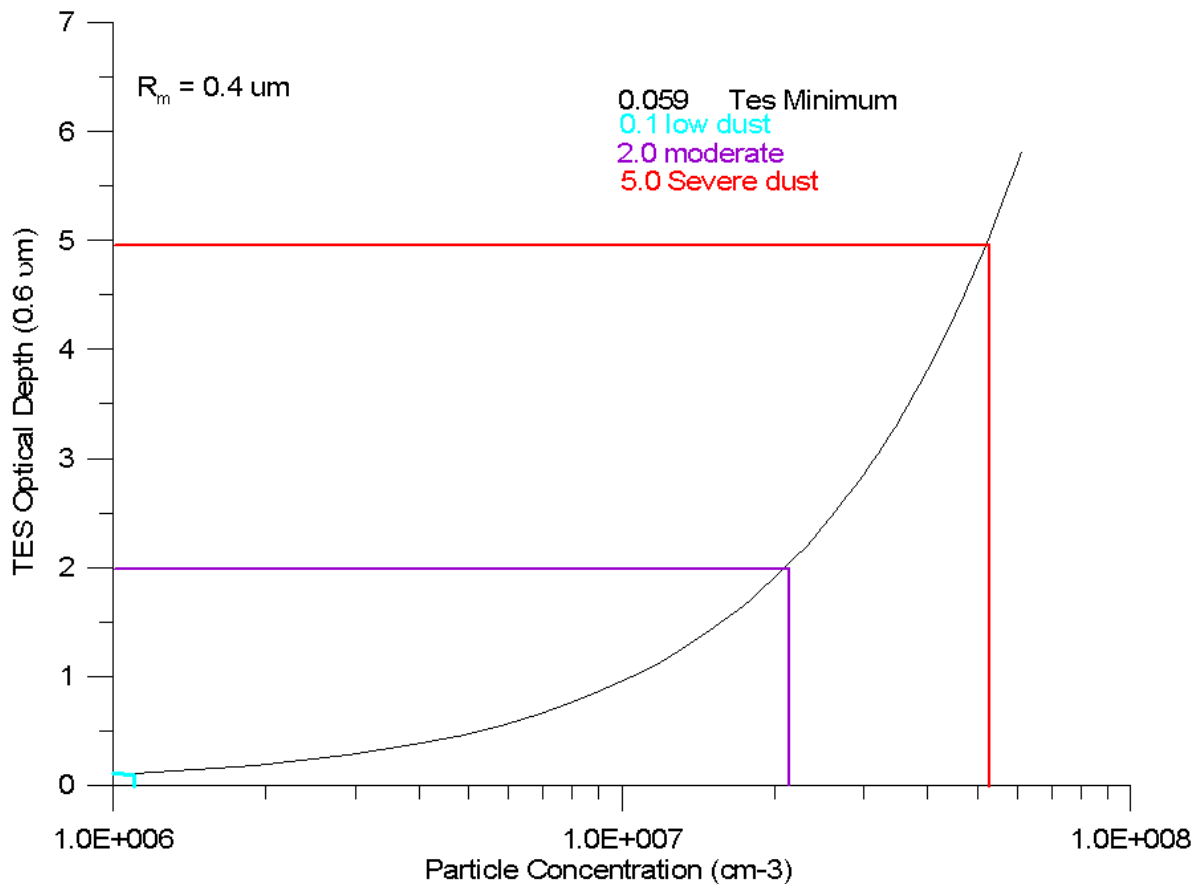
$$\begin{aligned} z_{\max} = & 60 + 18 \cdot \sin(L_s - 160) - (32 + 18 \cdot \sin(L_s - 160)) \\ & \cdot \sin(\theta)^4 - 8.0 \cdot \sin(L_s - 160) \cdot \sin(\theta)^5 \end{aligned}$$



A sensitivity simulation is shown for the potential Mars backscatter ($2.2\ \mu\text{m}$) with a constant dust mixing ratio as a function of altitude and various mode radius. A mode radius of $0.1\ \mu\text{m}$ represents a very clean atmosphere and a mode radius of $0.4\ \mu\text{m}$ represents a moderate dusty atmosphere.



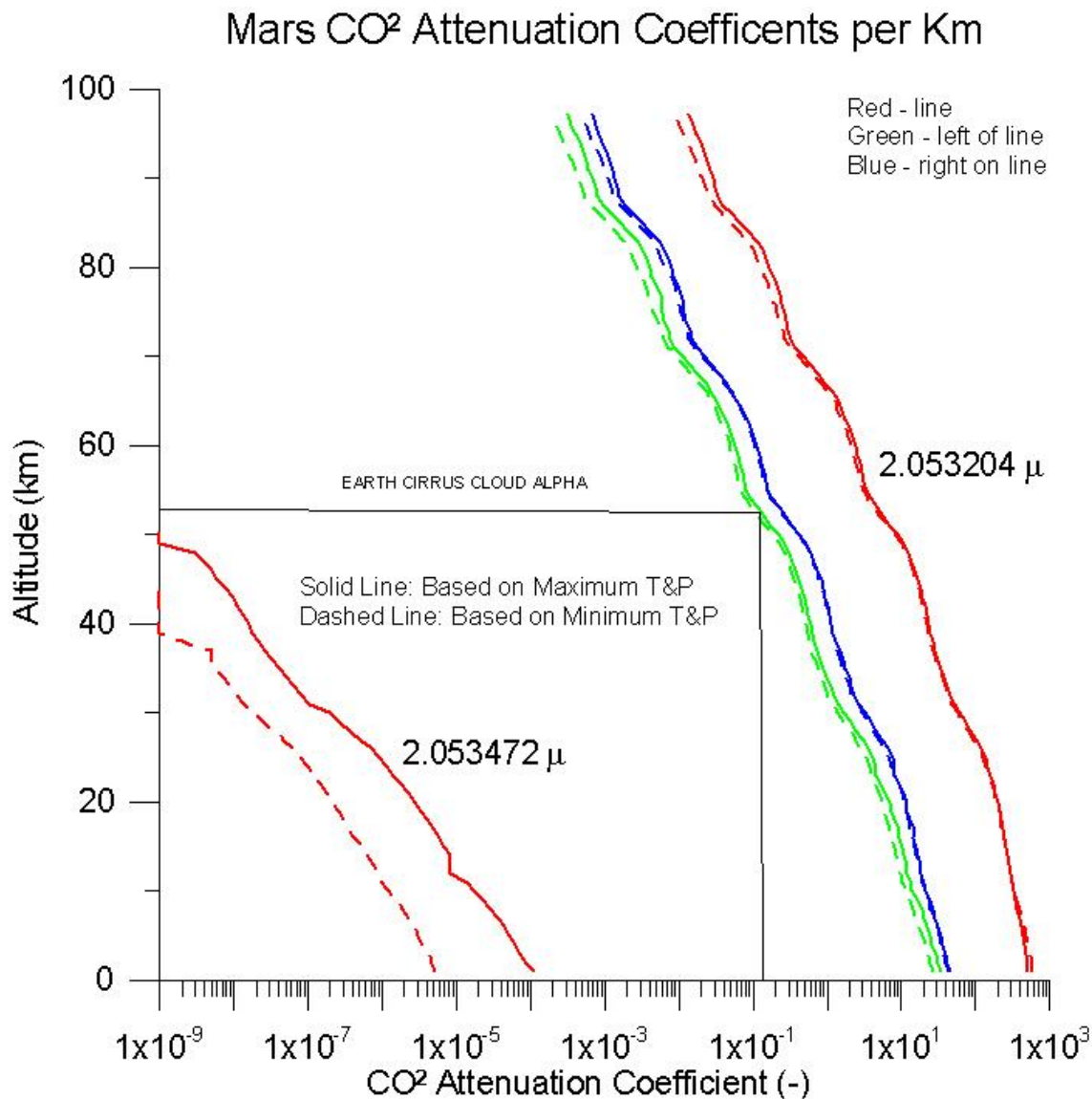
An additional enhanced backscatter mode can be added to the background mode via user supplied particle concentration or a particle concentration suggested by the TES data for low, moderate and extreme dust. SWA computed total column optical depths (Tau at 0.6 μm) for a wide range of backscatter profiles and compared them to total column optical depths from the visible (0.6 μm) TES (Justus et al., 1996; Justus et al., 2002; Clancy et al., 2003) data. Assuming a dust mode radius of 0.4 μm (Toon et al., 1977), the comparison suggests that a particle concentration of around $1.1 \times 10^6 \text{ cm}^{-3}$ should be used for a low dust background event, $2.1 \times 10^7 \text{ cm}^{-3}$ should be used for a moderate dust event and $5.31 \times 10^7 \text{ cm}^{-3}$ should be used for an extreme dust events. Currently these enhanced options are applied to the global statement of backscatter. In a future version it is intended that the variability of the global distribution of TES backscatter be tied to the nature run atmosphere.



The MLSM allows the user to choose the median profiles or to use the median profiles with aerosol backscatter randomly distributed with log normal variability. **However, the user should use the variability option with caution, since the MLSM aerosol variability is based upon Earth's aerosols.** The MLSM uses the same random data seed for an entire lidar line of sight path. The aerosol attenuation is not adjusted for the varying backscatter.

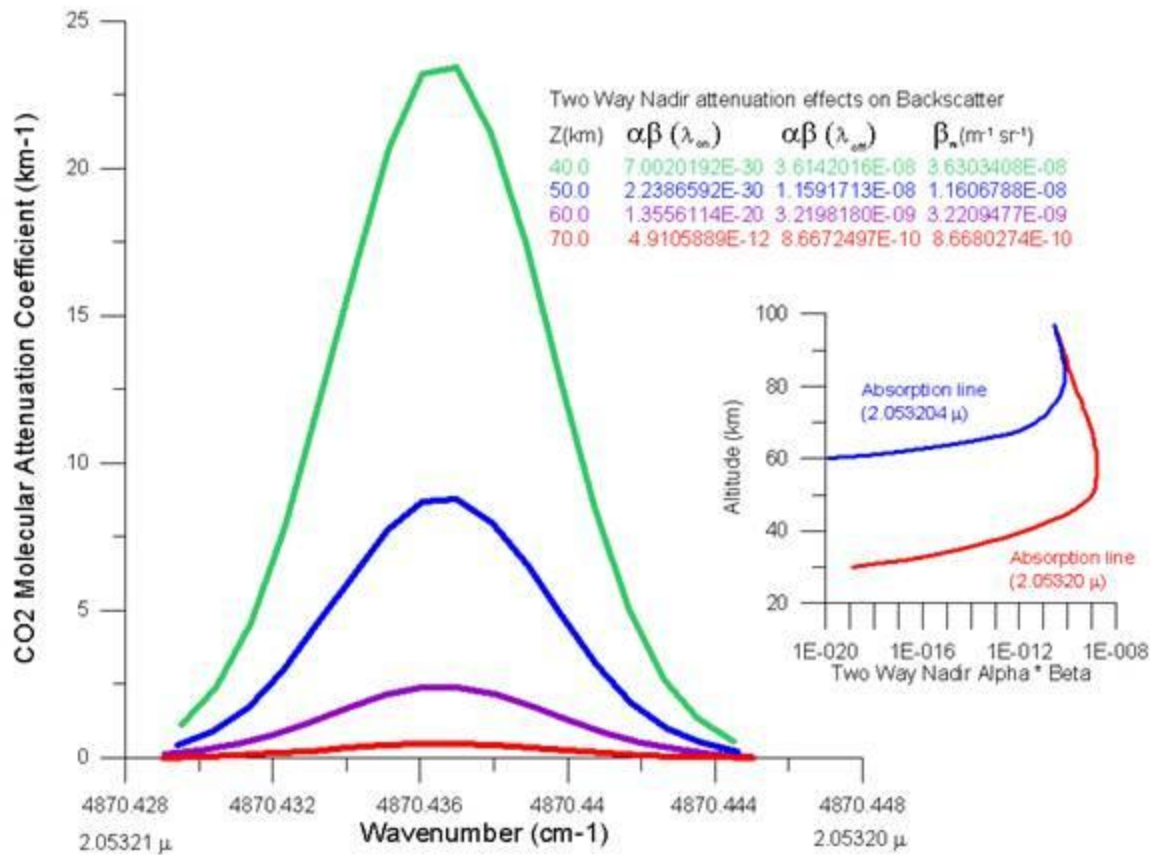
For molecular CO_2 attenuation, the MLSM needs per km attenuation coefficients databases. Since it is not practical to compute the attenuation for every instantiation of each lidar shot, SWA decided to build bracketing databases. The AFGL line-by-line optical property model, FASCODE, was run with minimum and maximum expected Mars temperature and pressure profiles from the MCD atmospheres. The variability is very little for pressure, however there is a small variability in some temperature. SWA generated CO_2 attenuation coefficients for the following on channel wavelengths; 2.0531997, 2.0532002, 2.0532007, 2.0532012, 2.0532018, 2.0532023, 2.0532028, 2.0532033,

2.0532040 (center), 2.0532044, 2.0532049, 2.0532054, 2.0532059, 2.0532065, 2.0532070, 2.0532075, 2.0532080 μm and the off channel; 2.053472 μm .



The MLSM spatially and temporally interpolates upon the attenuation databases using the temperature and pressure profiles from the GADS. SWA performed a sensitivity study on two way nadir attenuation effects on expected aerosol backscatter as a function of altitude. As the figure below shows, there is a quick fall off in attenuated backscatter around 70 km for the on line (center). Using an on line shifted the far left or right of the center line will allow the DIAL to make measurement further down into the Martian atmosphere.

Wavelength spread of CO₂ Molecular Attenuation Coefficient (km⁻¹) as a function of Altitude

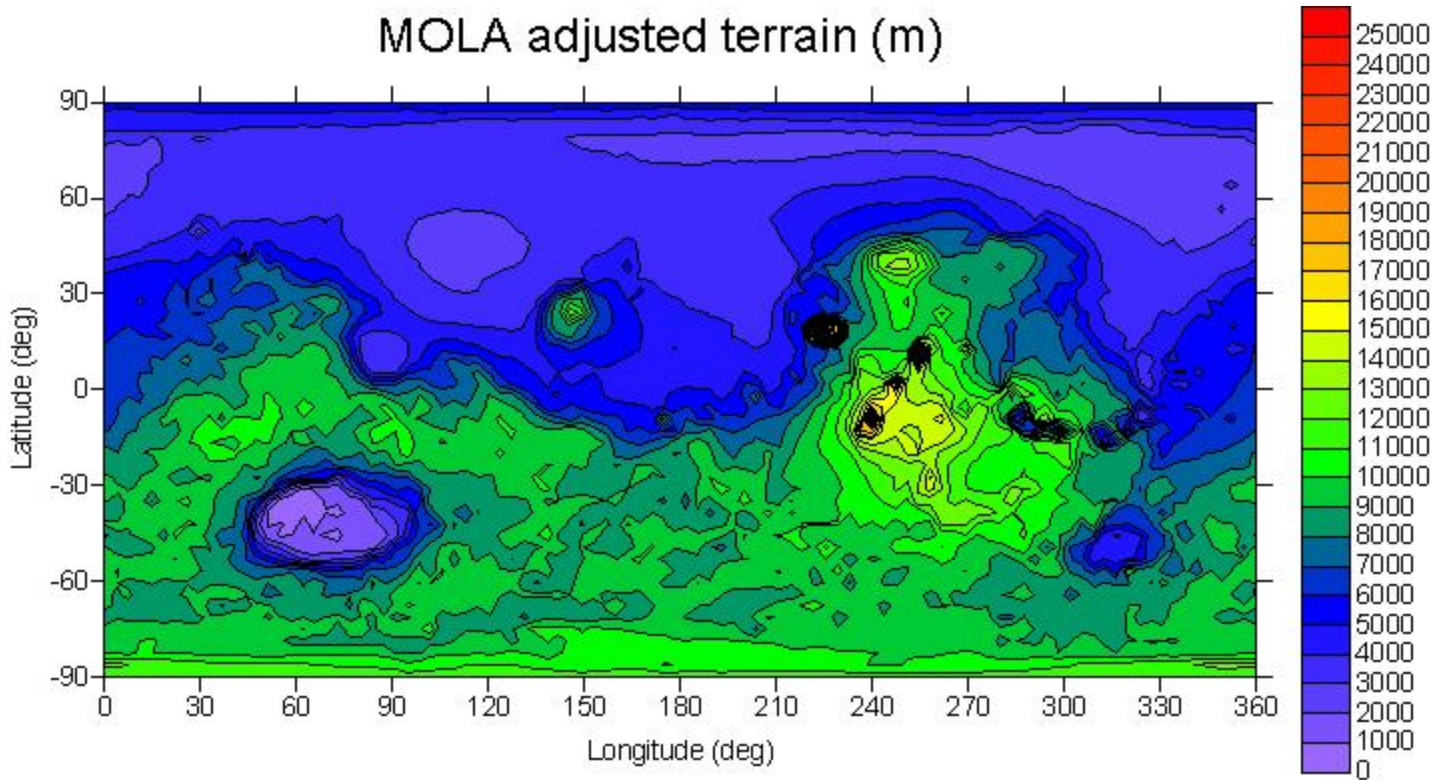


2.2.3 TURBULENCE MODELS

The MLSM version 1.0 has two options for estimating the wind variance on the sub-grid scale of the model. The first method computes the wind variance on the grid scale (3 x 3 x 3) and then scaling the variance to smaller scales by the Von Karman relationship. This “reasonable” approach has been used on Earth for many years but has not been fully verified by real data. The second method represents the uncertainties by scaling them to 20 % of the mean model wind speed. Comparisons of the uncertainties on Earth with the NMC rawinsonde profiles suggest that the simulated variances using the 20 % rule are not unreasonable. The user can also choose not to include turbulence.

2.2.4 TERRAIN

Mars terrain is derived from the Mars Orbiter Laser Altimeter-MOLA(Zuber, M.T., et al.,1992) and is included in the GADS at the Mars Climate Database 5°x5° gridded resolution. Since the MOLA topography is referenced from the Mars Areoid, the AGM adjusted the MOLA terrain data by adding the lowest elevation point on Mars ,-7626.81 m, to the data (i.e. the lowest point becomes 0 m and the highest point is 28643.84 m)



2.3 DOPPLER WIND LIDAR MODEL

The LSM simulates the performance of coherent Doppler wind lidars as space-based remote sensors of winds with an emphasis upon realistic representations of the atmosphere along individual line of sights. The MLSM version 1.0 optical property data bases supports a $2.053472 \mu\text{m}$ coherent Doppler wind lidar.

2.3.1 COHERENT DWL SIGNAL PROCESSING MODEL: PHI-CAPON METHOD

A simplified version of the Effective Gaussian Signal Spectrum Model (Frehilch and Sharman, 2003; Frehilch, 1997; Frehilch, 1996) is used to estimate the performance of a coherent DWL for general conditions in the threshold regime of weak signals.

The wide band SNR equation used in the LSM is defined as

$$\text{SNRW} = (\pi \cdot \eta_1 \cdot \eta_2 \cdot \eta_3 \cdot \eta_4 \cdot \eta_5 \cdot J \cdot D^2 \cdot \lambda^2 \cdot \beta_\pi \cdot e^{-2} \int \alpha(r) dr) / (8 \cdot h \cdot \nu \cdot 2 \cdot V_{\max} \cdot R^2)$$

where

η_1 - heterodyne quantum efficiency

η_2 - transmit optical efficiency

η_3 - receive optical efficiency

η_4 - mixing efficiency

η_5 - coherent system margin

J - fundamental laser energy per pulse (Joules)

D - mirror diameter (m)

β_π - backscatter ($\text{m}^{-1} \text{sr}^{-1}$)

$e^{-2} \int \alpha(r) dr$ - 2 way attenuation

$h\nu$ - photon energy (J)

R - slant range (m)

λ - laser wavelength (μm)

$V_{\max}$ - signal velocity bandwidth.

An effective wideband SNR (db) is computed by accumulating all the samples in an user's defined grid volume.

$$\text{SNRW}_{\text{eff}} = 10 \cdot \log_{10}((\sum (\text{SNRW}_i)^2)^{0.5})$$

The number of data samples per LOS range gate is given as

$$m = (2.0 \cdot d \cdot 2.0 \cdot V_{\max}) / (c \cdot \lambda \cdot 1\text{E-}6)$$

where

λ - wavelength (μm)

$V_{\max}$ - maximum velocity measured

c - speed of light (m/s)

d - range gate (m).

Thus the effective photons per LOS range gate is

$$\phi = m \cdot \text{SNRW}_{\text{eff}}.$$

The percentage of bad estimates described by the following fraction of random outliers is

$$B = \exp(-(0.1 \cdot \phi/B_0)^\alpha)$$

where

B_0 - constant

α - constant

The percentage of bad estimates is used to decide whether the DWL performance produces a failed attempt, false alarm or a good wind measurement. If B is greater than the user's entry of the gross error probability threshold, then it is considered a failed attempt. If the performance is considered to be a "good" performance, then the estimates have a random chance of producing a false alarm in which ϕ is set to 0.1. The line of sight uncertainty spread for the "good" estimates is defined as

$$\sigma_{los} = X (1.0 + (\phi \cdot 0.1/G_0)^\varepsilon)^{(-\delta) + \mu}$$

where

σ_{los} - the line-of-sight uncertainty (m/s)

X - constant

G_0 - constant

ε - constant

δ - constant

μ - constant.

2.3.2 LINE-OF-SIGHT WIND PRODUCTS

For each DWL line of sight perspective, a profile of forward model winds at each range gate is computed using the input horizontal wind components from the "Nature Run" (converted to along track and cross track perspectives), platform geometry and the sampling scale uncertainties.

$$V_{for} = ((U_{ct} + \sigma_u \cdot GN) \cdot \cos(\theta) + (V_{at} + \sigma_v \cdot GN) \sin(\theta)) \cos(\phi) + W_{vv} + (\sigma_w \cdot GN) \sin(\phi)$$

where

V_{for} - the forward model line-of-sight wind velocity (m/s)

U_{ct} - the cross track wind velocity at the shot location (m/s)

σ_u - the sampling scale uncertainty in the cross track wind (m/s)

GN - gaussian distributed random number

θ - heading angle (rad)

V_{at} - the along track wind velocity at the shot location (m/s)

σ_v - the sampling scale uncertainty in the along track wind (m/s)

ϕ - the elevation angle (rad)

W_{vv} - the vertical velocity at the shot location (m/s)

σ_w - the sampling scale uncertainty in the vertical velocity (m/s)

The simulated DWL line-of-sight wind velocity is calculated by adding the line-of-sight uncertainty derived from the DWL's signal-to-noise model to the forward model wind as follows:

$$V_{los} = V_{for} + \sigma_{los}$$

where

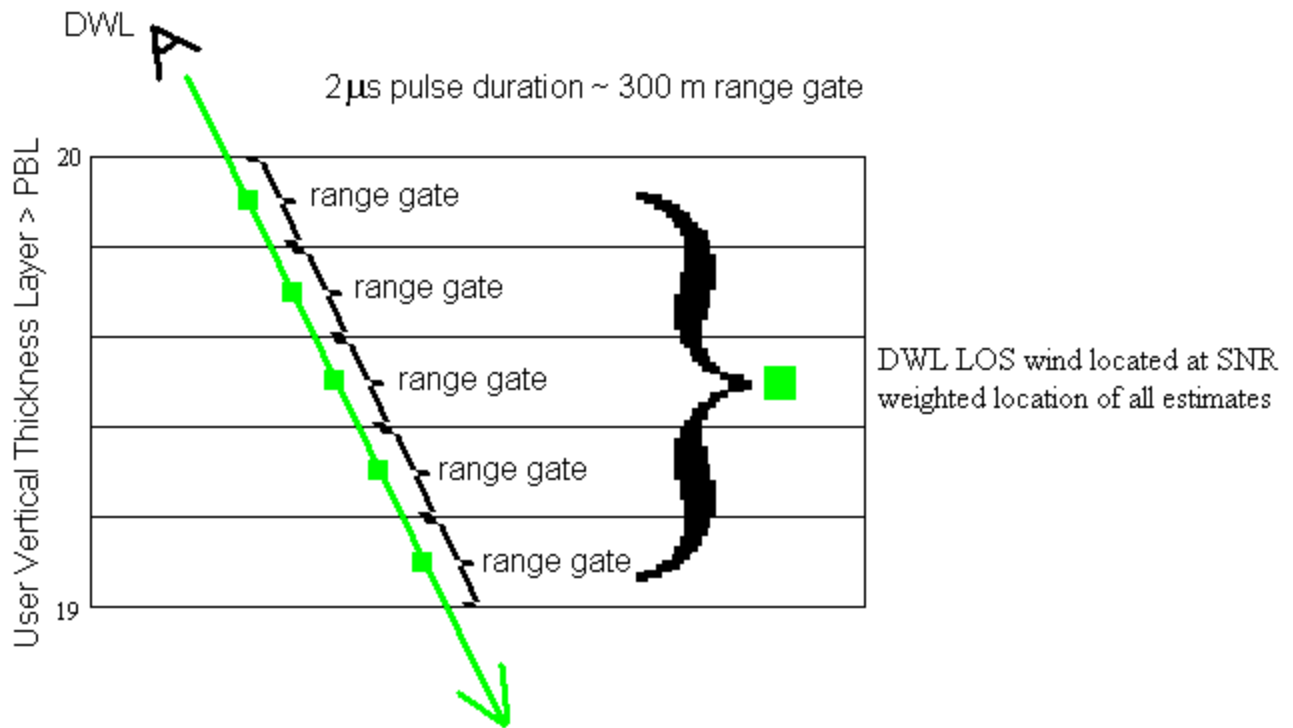
V_{los} - the line-of-sight wind velocity (m/s)

σ_{los} - the line-of-sight uncertainty (m/s).

2.3.3 DWL SHOT ACCUMULATION (GRID VOLUME AVERAGING)

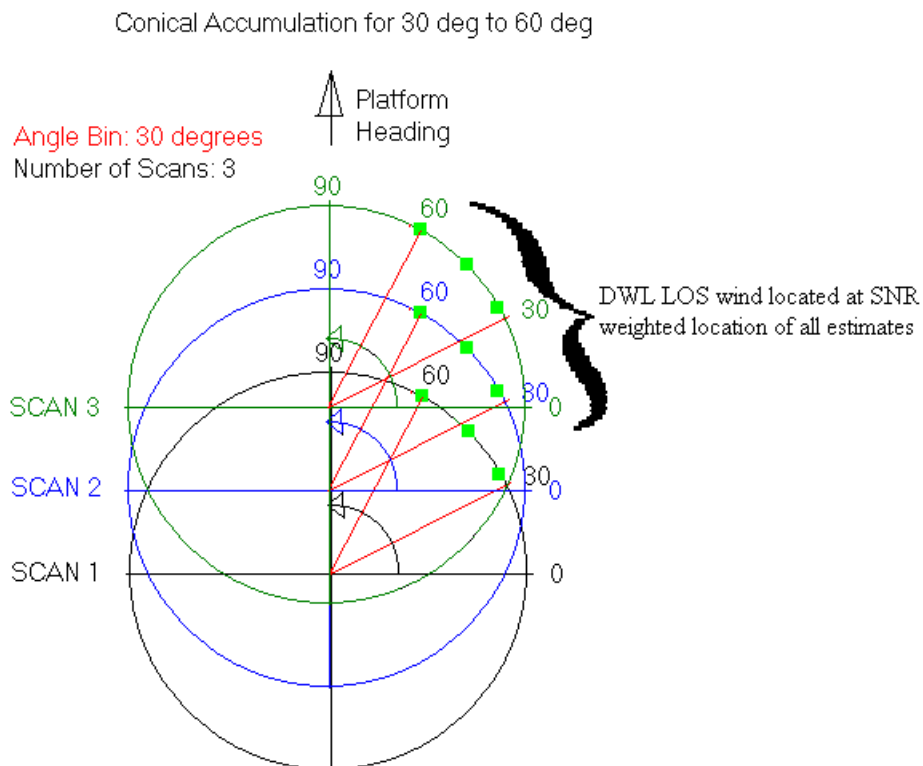
The Lidar Simulation Model estimates the performances of a pulsed DWL for a user-defined grid volume in order to define a lidar measurement of the line of sight wind. The LSM supports two methods; single measurement LOS accumulation and multiple measurement volume accumulation.

Single shot mode: Along each DWL line of sight, each pulse within the user's defined vertical thickness resolution (with respect to the ABL) is accumulated to contribute to the DWL LOS wind estimate as depicted in the following figure:



Accumulation Mode: The method the MLSM accumulates each pulse over an user-defined grid volume depends upon the user's scan mode: either conical or step/stare.

For a conically scanned DWL, the grid volume is defined horizontally by the user's angle bin and number of scans for shot accumulation (shown in figure below) and the previously discussed vertical accumulation. Since this configuration is not likely and is only included in the MLSM for statistical purposes, the user is strongly cautioned when using this option.



For step/stare DWL, the grid volume is defined horizontally by each dwell time of the stare and the previously discussed vertical accumulation. The percentage of shots to accumulate in a stare is preset to 100% in the MLSM Version 1.0.

2.3.4 HORIZONTAL WIND PRODUCTS

(The LSM's Horizontal Wind Models are not included in the MLSM version 1.0)

2.4 DIFFERENTIAL ABSORPTION LIDAR SYSTEMS

The LSM simulates the performance of coherent lidars as space-based remote sensors CO₂ concentration with an emphasis upon a realistic representation of the atmosphere along individual line of sights. The MLSM version 1.0 optical property data bases supports DIAL wavelengths for a 2.053472 μm off line channel and 2.053208 - 2.0531997 μm on line channels.

2.4.1 COHERENT DIAL SIGNAL PROCESSING MODEL

The coherent wide band SNR equation used in for the coherent DWL is used for the coherent DIAL and is defined as

$$SNRW = (\pi \cdot \eta_1 \cdot \eta_2 \cdot \eta_3 \cdot \eta_4 \cdot \eta_5 \cdot J \cdot D^2 \cdot \lambda^2 \cdot \beta_\pi \cdot e^{-2} \int \alpha(r) dr) / (8 \cdot h \nu \cdot 2 \cdot V_{max} \cdot R^2)$$

where

η_1 - heterodyne quantum efficiency

η_2 - transmit optical efficiency

η_3 - receive optical efficiency

η_4 - mixing efficiency

η_5 - coherent system margin

J - fundamental laser energy per pulse (Joules)

D - mirror diameter (m)

β_π - backscatter ($m^{-1} sr^{-1}$)

$e^{-2} \int \alpha(r) dr$ - 2 way attenuation

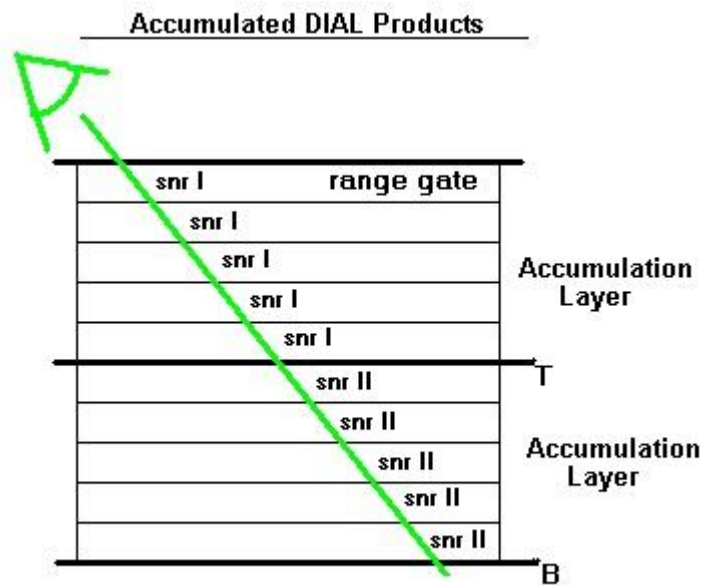
hν - photon energy (J)

R - slant range (m)

λ - laser wavelength (μm)

V_{max} - signal velocity bandwidth.

The MLSM simulates the user's prescribed DIAL system compared to what the same DIAL system would measure for a chosen Martian standard atmosphere. The current standard atmosphere is considered to be the median atmosphere. The measured and the standard atmosphere wideband signal to noises are accumulated for the on and off channels as follows



$$P_{on_m} = (\sum SNR_{won_m}(z))/N$$

$$P_{off_m} = (\sum SNR_{woff_m}(z))/N$$

$$P_{on_s} = (\sum SNR_{won_s}(z))/N$$

$$P_{off_s} = (\sum SNR_{woff_s}(z))/N$$

where

SNR_{won_m} - measured signal to noise for range gate, on channel

SNR_{won_s} - standard atmosphere signal to noise for range gate, on channel

SNR_{woff_m} - measured signal to noise for range gate, off channel

SNR_{woff_s} - standard atmosphere signal to noise for range gate, off channel

Pon_m - accumulated measured signal for on channel

Pon_s - accumulated standard atmosphere signal for on channel

Poff_m - accumulated measured signal for off channel

Poff_s - accumulated standard atmosphere signal for off channel

N - Number of samples in the grid volume

T and B - top and bottom of the accumulation layer, respectively.

The MLSM output product is the vertical profile of the density of the CO₂ atmosphere to the density of the CO₂ Standard Atmosphere.

$$\frac{\rho_{\text{CO}_2\text{m}}}{\rho_{\text{CO}_2\text{s}}} = \frac{\ln \left[\frac{\bar{P}_{\text{on}_T} * \bar{P}_{\text{off}_B}}{\bar{P}_{\text{on}_B} * \bar{P}_{\text{off}_T}} \right]_m}{\ln \left[\frac{\bar{P}_{\text{on}_T} * \bar{P}_{\text{off}_B}}{\bar{P}_{\text{on}_B} * \bar{P}_{\text{off}_T}} \right]_s}$$

Where

ρ_{CO2m} - density DIAL measurement product of CO₂

ρ_{CO2s} - density DIAL Standard Atmosphere product of CO₂

NASA/LaRC and SWA developed a first attempt representation of the DIAL CO₂ measurement error for the MLSM. This equation is ongoing review. Using the parameter, PHI, from the coherent lidar model the MLSM estimates the percent error in making a CO₂ concentration as follows.

The effective wideband SNR (db) is computed by accumulating all the samples in an user's defined grid volume.

$$\text{SNRW}_{\text{eff}} = 10 \cdot \log_{10}((\sum(\text{SNRW}_i)^2)^{0.5})$$

The number of data samples per LOS range gate is given as

$$m = (2.0 \cdot d \cdot 2.0 \cdot V_{\max}) / (c \cdot \lambda \cdot 1E-6)$$

where

λ - wavelength (m)

$V_{\max}$ - maximum velocity measured

c - speed of light (m/s)

d - range gate (m).

Thus the effective photons per LOS range gate is

$$\phi = m * SNRW_{\text{eff.}}$$

ϕ is the average number of coherently detected photoelectrons per estimate (Frehlich)

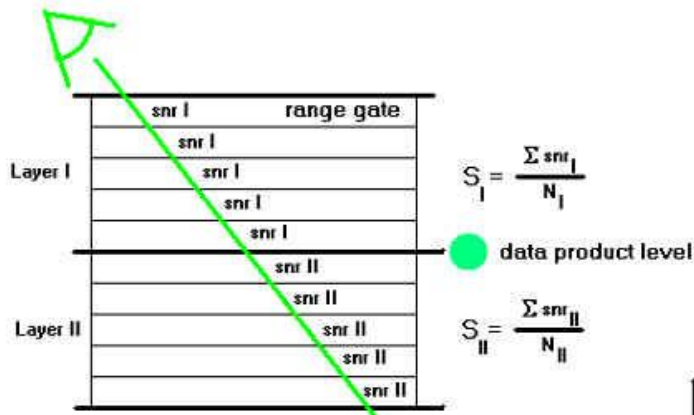
ϕ_{thr} is the user input threshold for ϕ

N is the number of estimates in a grid volume

S is the average signal in a layer

ϵ is the percent error in calculating CO_2 concentration due to the uncertainty in the absorption line due to temperature, pressure and wavelength uncertainties

For $\phi_{\text{on}} > 1$ and $\phi_{\text{off}} > 1$



if $\phi_{\text{on}} > \phi_{\text{thr}}$, then $\omega = 1$

if $1 < \phi_{\text{on}} < \phi_{\text{thr}}$, then $\omega = (\phi_{\text{thr}} + 1) - \phi_{\text{on}}$

$$\text{Error} = \left[\epsilon^2 + \frac{\omega \left(\frac{1}{N_{I_{\text{on}}}} + \frac{1}{N_{II_{\text{on}}}} + \frac{1}{N_{I_{\text{off}}}} + \frac{1}{N_{II_{\text{off}}}} \right)}{\left[\ln \left(\frac{S_{I_{\text{on}}} \cdot S_{II_{\text{off}}}}{S_{I_{\text{off}}} \cdot S_{II_{\text{on}}}} \right) \right]^2} \right]^{1/2}$$

2.5 SIMULATED PRODUCTS

Model Line of Sight (LOS) outputs consist of averages and standard deviations of variables related to the DWL measurements accumulated in the user defined grid volume. The MLSM LOS output files are in ASCII format.

LOS WIND Output records

average of the along track input wind components (m/s)
average of the cross track input wind components (m/s)
average of the velocity input wind components (m/s)
average of the sub-grid scale uncertainty for the cross track component(m/s)
average of the sub-grid scale uncertainty for the along track component(m/s)
average of the sub-grid scale uncertainty for the vertical velocity component (m/s)
average of the forward model LOS wind (m/s)
signal weighted average of the platform latitude (deg)
signal weighted average of the platform longitude (deg)
signal weighted average of the platform heading (deg)
signal weighted average of the platform altitude (km)
signal weighted average of the sequential time (s)
signal weighted average of the azimuth scan angle (deg)
signal weighted average of the nadir scan angle (deg)
signal weighted average of the elevation angle (deg)
signal weighted average of the latitude (deg)
signal weighted average of the longitude (deg)
signal weighted average of the height assignment (km)
signal weighted average of the Range (km)
number of estimates in grid volume
number of estimates above user set thresh hold in grid volume
average of the backscatter (m-1 sr-1)
standard deviation of the backscatter (m-1 sr-1)
average of the attenuation (km-1)
standard deviation of the attenuation (km-1)
average of the transmission
standard deviation of the transmission
average of the SNRw (coherent) or sum of the dark noise (direct detection)
standard deviation of the SNRw
average of the effective SNRw (coherent) or sum of the photons (direct detection)
source medium indicator
shot passed indicator (0-no 1-yes)

shot failed indicator (0-no 1-yes)
shot false alarm indicator (0-no 1-yes)
along the LOS uncertainty (m/s)
target volume error (instant LOS uncertainty) (m/s)
DWL LOS wind velocity (m/s)
forward LOS wind minus the DWL LOS wind (m/s)
ABL height (km)

Model CO2 density file (CO2) outputs consist of averages and standard deviations of variables related to the measurements accumulated in the user defined grid volume. The MLSM CO2 output files are in ASCII format.

CO2 density Output records

signal weighted average of the platform latitude (deg)
signal weighted average of the platform longitude (deg)
signal weighted average of the platform heading (deg)
signal weighted average of the platform altitude (km)
signal weighted average of the sequential time (s)
signal weighted average of the azimuth scan angle (deg)
signal weighted average of the nadir scan angle (deg)
signal weighted average of the elevation angle (deg)
signal weighted average of the latitude (deg)
signal weighted average of the longitude (deg)
signal weighted average of the height assignment (km)
signal weighted average of the temperature for the Off Channel
signal weighted average of the density for the Off Channel
average of the backscatter (m-1 sr-1) for the Off Channel
average of the Attenuation (km-1) for the Off Channel
average of the Transmission for the Off Channel
SNRw (DB) for the Off Channel
SNRw effective (DB) for the Off Channel
SNRw for the Off Channel
SNRw effective for the Off Channel
signal weighted average of the temperature for the On Channel
signal weighted average of the density for the On Channel
average of the backscatter (m-1 sr-1) for the On Channel
average of the Attenuation (km-1) for the On Channel
average of the Transmission for the On Channel
SNRw (DB) for the On Channel
SNRw effective (DB) for the On Channel

SNRw for the On Channel
SNRw effective for the On Channel
Phi
Percent Error in calculating CO2 Concentration due to Uncertainty in the Absorption Line
omega
Simulated CO2 Density Difference from Standard Atmosphere CO2
ABL height (km)
signal weighted average of the platform latitude (deg)
signal weighted average of the platform longitude (deg)
signal weighted average of the height assignment (km)
number of estimates for the Off Channel
number of estimates for the On Channel

3.0 REFERENCES

- Atlas, R and G. D. Emmitt. Simulation studies of the impact of space-based wind profiles on global climate studies. Proc. AMS Sixth Symp. on Global Change Studies, Dallas , TX , January, 1995.
- Baker, W.E., G.D. Emmitt, F. Robertson, R.M. Atlas, J.E. Molinari, D.A. Bowdle, J. Paegle, R.M. Hardesty, R.T. Menzies, T.N. Krishnamurti, R.A. Brown, M.J. Post, J.R. Anderson, A.C. Lorenc and J. McElroy. Lidar-measured winds from space: A key component for weather and climate prediction. Bull. Amer. Meteor. Soc., 76, 869-888, 1995.
- Betts, A.K. A new convective adjustment scheme, Part I: Observational and theoretical basis. Quart. J. Roy. Meteor. Soc., 112, 1306-1335, 1986.
- Clancy, R. T., M. Wolff and P. R. Christensen: Mars Aerosol Studies with the MGS TES Emission Phase Function Observations: Optical-depths, Particle Sizes, and Ice Cloud Types Versus Latitude and Solar Longitude. J. Geophys. Res., Vol. 108, no.E9, 5098, 2003.
- Deirmendjian D.: *Electromagnetic Scattering on Spherical Polydispersions*. Elsevier, Amsterdam, 1969.
- Doviak, R.J. and D.S. Zrnic. Doppler Radar and Weather Observations, Academic Press, New York, 458 pp., 1984.
- Emmitt, G.D. and S.A. Wood, 2001: Simulating space-based lidar performance using global and regional scale atmospheric numerical models. Optical Remote Sensing Topical Mtg., Coeur d' Alene , ID , February.
- Emmitt, G.D. and S.A. Wood. Lidar Mapping of Cloud Tops and Cloud Top Winds, 1996. PL-TR-96-2129, F19628-93-C-0196, 1996

Emmitt, G.D. and S.A. Wood. Simulating clouds within a space-based Doppler lidar wind sounder simulation model. Paper presented at the Cloud Impacts on DOD Operations and Systems 1995 Conference, Hanscom AFB/Phillips Laboratory, October, 1995.

Emmitt, G.D., S.A. Wood and M. Morris. Space-based Doppler lidar sampling strategies -- algorithm development and simulated observation experiments. Report under NASA Contract NAS8-37779, Marshall Space Flight Center, 1990.

Emmitt, G. D. and S. A. Wood. Influence of Coherent Mesoscale Structures on Satellite-Based Doppler Lidar Wind Measurements II. NASA Contract # NAS8-36902, Final Report, 1988.

Emmitt, G. D. Doppler Lidar Sampling Strategies and Accuracies-- Regional Scale. Presented at the Symposium and Workshop on Global Wind Measurements, Aspen, CO, 1987.

Forget, Francois: Improved optical Properties of the Martian Atmospheric Dust for Radiative transfer Calculations in the Infrared. Geophysical Research Letters. Vol. 25-7 1105-1108, 1998.

Frehilch, R. and B. Sharman, Predicting Effects of Wind Variability on Doppler Lidar Performance. Presented at the Lidar Working Group Meeting, Oxnard, Ca, 2003.

Frehilch, R., Effects of Wind Turbulence on Coherent Doppler Lidar Performance. J. Atmos. Oceanic. Technol., 14, p54-74., 1997

Frehlich, Rod "Coherent Doppler Lidar Measurements of Winds," in "Trends in Optics: Research, Developments and Applications," Anna Consortini, editor, Academic Press, 1996

Justus, C. G., A. Duvall and D. I. Johnson: Mars Global Reference Atmospheric Model (MARS-GRAM 3.34): Programmer's Guide, Tech. Rep. NASA TM-108509, NASA, Washington DC, 1996b.

Justus, C, G. G., A. Duvall and D. I. Johnson: Global Summary MGS TES data and MARS-GRAM Validation. Abstract COSPAR 02-A-02047, 34th COSPAR scientific Assembly - The second world space Congress, Houston, TX, 2002.

Lewis, S. R. , M. Collins, P. L. Read, F. Forget, F. Hourdin, R. Fournier, C. Hourdin and O. Talagrand: A Climate Database for Mars. J. Geophys. Res., 104, pp 24177-24194,1999.

Heney L. and J. Greenstein: Diffuse radiation in the galaxy. Astrophys. Journal, vol. 93, pp. 70-83, 1941.

Kells, L.M., W.F. Kern and J.R. Bland. Plane and Spherical Trigonometry, McGraw-Hill Book Company, New York, 2nd ed., pp. 309-321, 1940.

Koch, G.J., B.W. Barnes, M. Petros, J.Y. Beyon, F. Amzajerdian, J. Yu, R.E. Davis, S. Ismail, S. Vay, M.J. Kavaya, and U.N. Singh: Coherent differential absorption lidar measurements of CO₂. Appl. Opt. 43, 5092-5099, 2004.

Koch, G. J: Coherent Differential Absorption Lidar for Combined Measurement of Wind and Trace Atmospheric Gases. Ph.D. Dissertation, Old Dominion University , Norfolk , Virginia , 2001.

Lord, S. L., M. Masutani, J. C. Woollen, J. C. Derber, G. D. Emmitt, S. A. Wood, S. Greco, J. Terry, R. Atlas, and T. J. Kleespies. Impact Assessment of a Doppler Wind Lidar for NPOESS/OSSE.

Presented at the AMS Sixth Symposium on Integrated Observing Systems.13-17 January 2002, Orlando Florida.

Mellor, G.L. and T. Yamada. Development of a turbulence closure model for geophysical fluid problems. Rev. Geophys. Space Phys., 20, 851-875, 1982.

Ockert-Bell, M.E., J.F. Bell III, J.B. Pollack, C. P. McKay, F. Forget: Absorption and Scattering Properties of the Martian Dust in the Solar Wavelengths. J. Geophys. Res., 102, pp 9039-9050., 1997.

Upendra N. S., G. J. Koch, S. Ismail, S. A. Wood and G. D. Emmitt: Combined 2-mm DIAL and Doppler Lidar: Application to the Atmosphere of Earth or Mars. To Be Presented at the International Laser Radar Conference, 2006.

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

Toon, O. B., J. B. Pollack, and C. Sagan: Physical Properties of Particles Composing the Martian Dust Storms of 1971-1972. Icarus, 30, 663-696, 1977.

Wood, S. A. and G. D. Emmitt. , 2004: The DLISM online. Presented at the NOAA Working Group on Space-Based Lidar Winds, Sedona, Arizona, 27 - 29 January, 2004.

Wood, S. A. and G. D. Emmitt. , 2002: The Doppler Lidar Simulation Model (DLISM) for GTWS. Presented at the NOAA Working Group on Space-Based Lidar Winds, North Conway, New Hampshire 15-18, July 2002.

Wood, S., G.D. Emmitt, and S. Greco, 2001: The challenges of accessing the future impact of space-based Doppler wind lidars while using today's global and regional atmospheric models. AMS 5th Symp. Integrated Observing Systems, Albuquerque , NM , January.

Wood, S., G. Emmitt and S. Greco, 2000: DLISM: A coherent and direct detection lidar simulation model for simulating space-based and aircraft-based lidar winds. Proceedings SPIE's 14th Annual Internat. Symp. Aerospace Defense Sensing, Simulation and Controls, Orlando , FL , April.

Wood, S. A., G. D. Emmitt. and S. Greco. Optical Remote Sensors as Components of an Airborne Hurricane Observing System. Presented at the American Meteorological Society Conference, Long Beach, Ca, 1997.

Wood, S.A., G.D. Emmitt, D. Bai, L.S. Wood and S. Greco. A coherent lidar simulation model for simulating space-based and aircraft-based lidar winds. Paper presented at the Optical Society of America's Coherent Laser Radar Topical Meeting, Keystone, CO, July, 1995.

Wood, S.A., G.D. Emmitt, M. Morris, L. Wood and D. Bai. Space-based Doppler lidar sampling strategies -- algorithm development and simulated observation experiments. Final Rept. NASA Contract NAS8-38559, Marshall Space Flight Center, 266 pp., 1993.

Wood, S. A. and G. D. Emmitt. A Reference Atmosphere for LAWS Trade Studies: An Update. Presented at the American Meteorological Society Conference, New Orleans, LA, 1991.

Wood, S. A. and G. D. Emmitt. A Reference Atmosphere for LAWS Trade Studies. Presented at The Optical Remote Sensing of the Atmosphere Topical Meeting, Lake Tahoe, NV, 1990.

Zuber, M.T., et al.: The Mars Observer Laser Altimeter Investigation. J. Geophys. Res., 97, 7781-7797, 1992.