MODEL – LIDAR COMPARISON OF DUST VERTICAL DISTRIBUTIONS OVER ROME (ITALY) DURING 2001-2003

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INTRODUCTION

Mineral dust particles loaded into the atmosphere from the Sahara desert represent one major factor affecting the Earth's radiative budget. In order to improve the accuracy of climate predictions, we need to include the aerosol effects, both anthropogenic and natural, in atmospheric models. In order to determine the dust radiative effect in climate models, in spite of the large gaps in observations of dust vertical profiles, averaged 3D-fields of dust, obtained by the regular dust forecasts, can be used [1, 2]. Of course, possible incorrect estimates of these 3D distributions may add a bias to the model-predicted results. In order to feel confidence in the model's correctness, a comprehensive verification of model outputs should be made. In this study, dust forecasts by the Tel Aviv University (TAU) dust prediction system were compared to lidar observations to better evaluate the model's capabilities. The lidar remote soundings over Rome, Italy (41.8^{o}N, 12.6^{o}E) were taken in the 3-year period 2001-2003 for the high dust activity season from March to June.

TAU DUST MODEL

The TAU dust model was initially developed at the University of Athens and later modified at Tel Aviv University [3]. Results of the daily model predictions are available at the website: http://earth.nasa.proj.ac.il/dust/current/. The model includes packages for dust initialization, transport, and wet/dry deposition. Dust forecasts are initialized with the aid of the Total Ozone Mapping Spectrometer aerosol index (TOMS AI) measurements. The model domain is 0^o – 50^{o}N, 50^{o}W – 50^{o}E. Horizontal resolution of the model is 0.5° and its vertical resolution – 32 model levels. The dust particles in the TAU prediction model were assumed to have one characteristic size with effective radius of 2-2.5 microns. This choice remained in the model for all period of its operational use without changes. Hence all model results used in this study are homogeneous. We understand, however, that the single-size aerosol is a major shortcoming of the TAU model version, and we are currently experimenting with a number of aerosol sizes.

The dust is considered as a passive substance. No dust feedback effects are included in the radiation transfer calculations. The feedback, however, could be an important factor in the energy balance, because of dust radiative effects. Unfortunately, the model does not take the dust feedback into account. The effect of such feedback on the vertical distribution of dust is not well understood and is currently under investigation. To compare the dust forecast with lidar-derived volume profiles, modeled mass concentration profiles over Rome were divided by dust density, assumed as 2.5 g/cm^3.

LIDAR SOUNDINGS

Lidar measurements employed in this study were collected by a single-wavelength, polarization-sensitive lidar system (VELIS), operational since February 2001 in the ISAC laboratories (41.84N - 12.64E, 130 m asl) at the outskirts of Rome. The lidar-derived dust vertical profiles were used for obtaining statistically significant reference parameters of dust layers over Rome, and for model-lidar dust comparing. The Barnaba and Gobbi approach [4] was used in the current study to derive height-resolved dust volumes from lidar measurements. This approach has been proved to provide reliable dust volume profiles as well as backscatter and extinction profiles in dust load conditions [5-7]. An evaluation of the lidar derived aerosol physical properties in Saharan dust conditions was performed comparing lidar estimates of desert dust surface area (S) and volume (V) with simultaneous, co-located in situ measurements of S and V. Outcomes of that closure study show a slight lidar tendency to underestimate desert dust volume, with mean lidar - in situ measurements discrepancies within 20%.

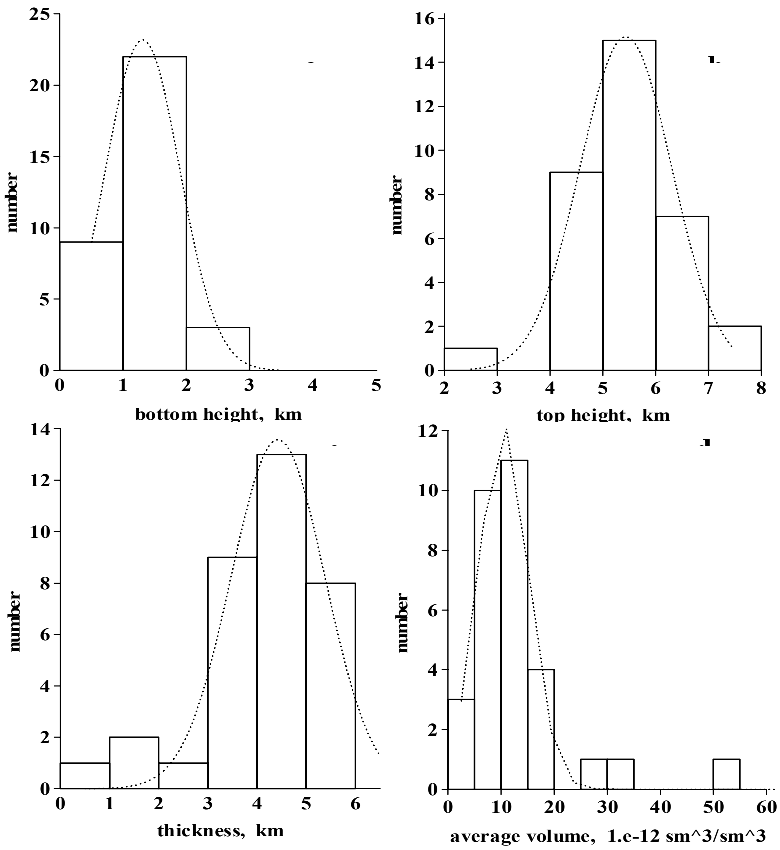


Fig. 1. Statistical distributions of lidar-derived parameters of the dust layer over Rome from March to June: bottom (a) and top (b) heights (km), thickness, km (c), and average volume 10^{-12} cm^3/cm^3 (d). Fitting curves of the Gaussian distribution are shown by dotted lines.

DUST LAYER CARACTERISTICS IN ROME

The data set of regular lidar soundings, used in the current study , is important in obtaining reference values of dust layers over Rome during the season from March to June. Fig. 1

presents histograms of the main parameters of these dust layers. In particular, the bottom boundary was found to range from 0.5 km to 3 km with the mean value 1.3 $\pm$ 0.6 km; the top boundary ranges from 2.7 to 7 km with mean value 5.4 $\pm$ 0.9 km, and the thickness of dust layers ranges from 0.9 km to 5.8 km with mean value 4.4 $\pm$ 0.9 km. Hence, on average, dust over Rome is distant from the surface. Finally, average dust volumes range from 4×10^{-12} cm^3/cm^3 to 392×10^{-12} cm^3/cm^3 with mean value V = (10.4 $\pm$ 4.7) $\times 10^{-12}$ cm^3/cm^3. For each variable, Gaussian fitting curves are also shown in Fig. 1 by dotted lines. One can see that these Gaussian distributions sufficiently suit the histograms of lidar-derived data.

MODEL-LIDAR QUALITATIVE COMPARISON

In order to classify the model-lidar agreement, four different categories (I – IV) have been defined as listed below:

I) the model profile corresponds well with the lidar one (some examples are provided in Figure 2);

II) the model and lidar profiles do not coincide, but are similar in shape;

III) only a part of the model profile (for example, the top or the bottom of dust layers) fits the lidar sounding;

IV) the model profile does not fit the lidar one at all.

It was found that 13 cases (38 %) belong to category I, even though the model usually underestimates dust volume derived from the lidar sounding. Category II is also considered to be tolerable; 10 cases (29%) fall into this category. Five cases (15%) fall into categories III, while six ones (18%) into category IV. It can be observed that, representing 67 % of all cases, categories I and II, (i.e, accurate and acceptable forecasts) are prevalent here.

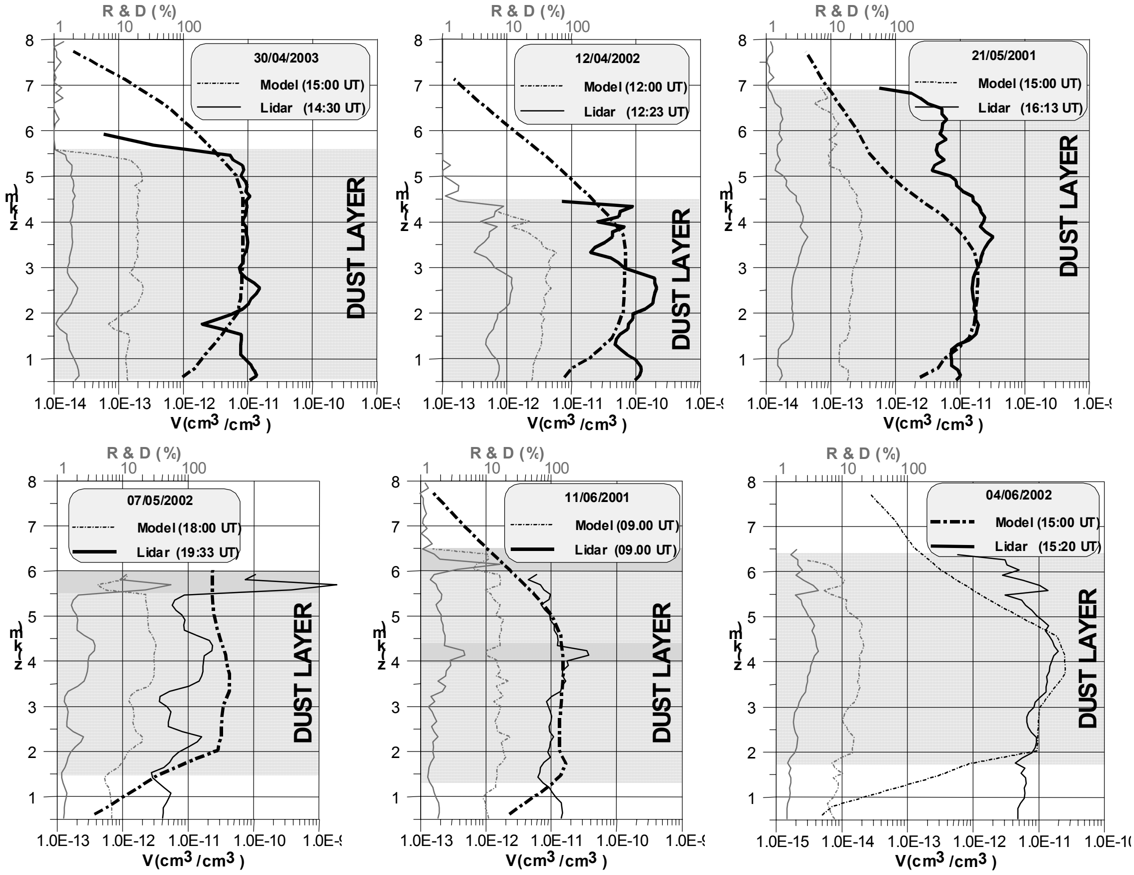
QUANTITATIVE INTER-COMPARISON

The correspondence between model data and lidar measurements is evaluated by means of scatter plots. For this purpose, lidar-derived versus model-simulated dust volumes are shown in Fig. 3. Three different parameters of the dust vertical distribution are analyzed in Fig. 3: 1) the averaged dust volume within the dust layer (Fig.3a), 2) the maximum dust volume within the dust layer (Fig. 3b), and 3) dust volume at standard altitudes with vertical resolution 0.1 km, obtained by spline interpolation from available model and lidar profiles (Fig. 3c).

In Figure 3, the bisector indicates ideally accurate forecasts, i.e. the points on or close to the bisector represent the best correspondence between the model-simulated data and the lidar ones. The root-mean-square intervals of deviations of points from the bisector (the dashed lines in Fig. 3, can be used in order to characterize the range of forecast accuracy.

The distribution of points in the scatter plot in Fig. 3a reveals significant deviations from the bisector when the model-simulated dust volume is less than approximately $1\cdot 10^{-12} cm^3/cm^3$, which coincides with the lidar minimum detectable dust volume. This means the model's inability to simulate correctly weak dust events. It should be noted, however, that points to the right of the vertical line are located mainly within the root-mean-square interval. Thus, for intensive (moderate or heavy) dust events we get more or less accurate forecasts of dust volume. Moreover, the majority of those points, which correspond to intensive dust events, are located above the bisector, revealing the model tendency to underestimate the lidar-derived data. As a whole, the correlation coefficient between the lidar data and the model-predicted ones is 0.44.

Fig. 2. Examples of dust volume profiles over Rome from March to June used in the model-



lidar comparison. The solid lines designate the lidar profiles while the dashed lines - the model profiles. For completeness, relevant lidar profiles of both backscatter ratio (R, grey solid line) and depolarization (D, grey dashed line) are also presented.

Similar results can be seen in Fig. 3b for maximum dust volume values, even though the deviation of points from the bisector in this scatter plot is larger. These results suggest that a threshold of $1 \cdot 10^{-12} cm^3 / cm^3$ should be defined under which we cannot consider the model-predicted dust values to be reliable.

The bottom scatter plot in Fig. 3 (Fig. 3c) was aimed at generalizing the comparison along the whole dust vertical profile. In order to specifically evaluate the capability of the model results to correspond with lidar soundings near the top, bottom and middle parts of dust layers, three different symbols were used in Fig. 3c: triangles corresponding to points at altitudes below 1.5 km, circles between 1.5 and 3.5 km and crosses above 3.5 km. One can see that the most remote points from the bisector correspond to crosses. Conversely, as expected, we get more accurate forecasts in the middle part of dust layers.

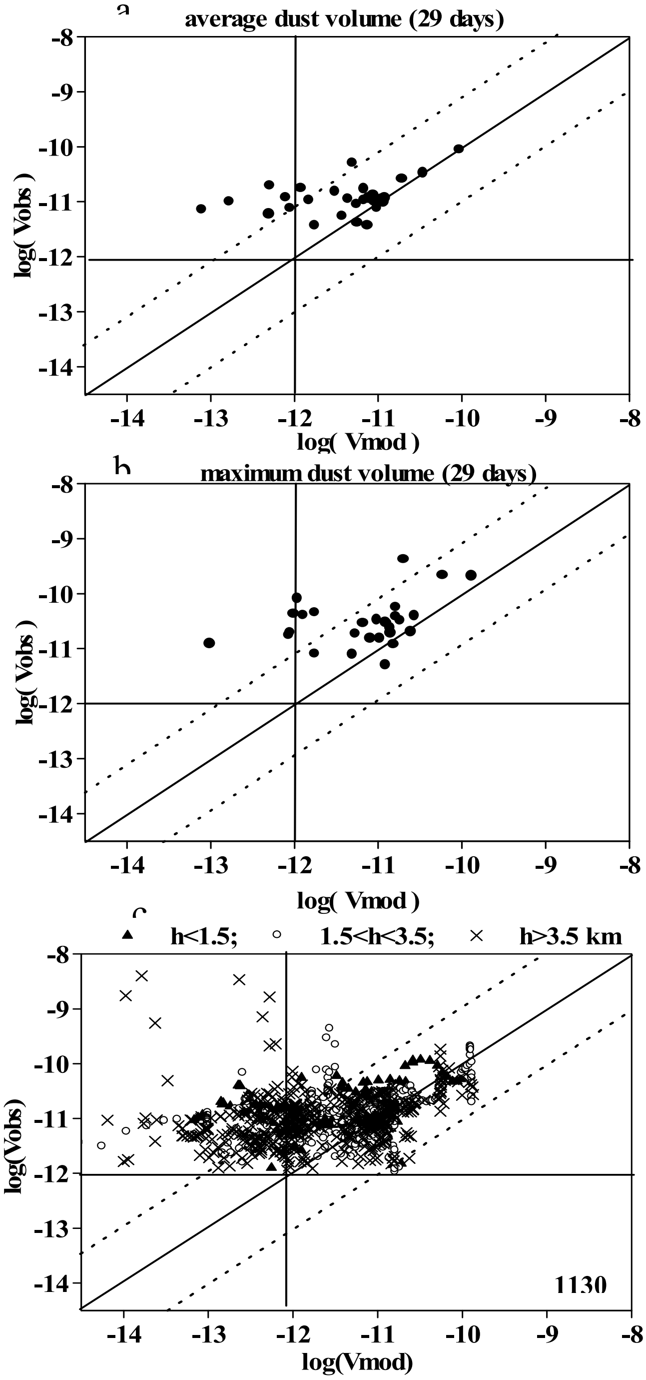


Fig. 3. The scatterplots between the common logarithm of model-simulated dust volumes (Vmod, cm^3/cm^3) over Rome and the ones retrieved from lidar soundings (Vobs). Fig. 3a corresponds to the averaged dust volume within the dust layer, Fig. 3b to the maximum dust volume within the dust layer, and Fig. 3c to dust volumes at different altitudes along the dust profiles. Dashed lines show the root-mean-square intervals of deviations from the bisector. In Fig. 3c the triangles designate dust volume at altitudes below 1.5 km, the circles – between 1.5 and 3.5 km, and the crosses – above 3.5 km. The horizontal solid lines,

intersecting the vertical axis (lidar data) at $1 \cdot 10^{-12} cm^3 / cm^3$, correspond to the minimum dust volume detectable by the lidar. The vertical solid lines, intersecting the horizontal axis (model data) at $1 \cdot 10^{-12} cm^3 / cm^3$, correspond to a threshold of trustworthy dust forecasts.

There could be a few reasons for the model to underestimate the lidar-derived dust volume profiles: a) the model initialization based on TOMS aerosol indices; b) some assumptions on particle size in the model; and c) some assumptions on dust sources in the model.

In particular, the model initialization still remains as one of the major shortcomings of short-term dust forecasting. The presence of non-absorbing anthropogenic air pollution and/or reflective clouds leads to the decrease of TOMS AI. Besides, one can suspect that the dust particles used in the model could be too heavy for long-range dust transport. Our model simulations with different dust particle sizes are currently being carried out. And finally, it was found that some sources over Tunisia and Libya were missing, which could be of importance for dust predictions over Rome.

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