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EARTH GLOBAL REFERENCE ATMOSPHERIC MODEL (GRAM-99) AND TRACE CONSTITUENTS

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ABSTRACT

Global Reference Atmospheric Model (GRAM-99) is an engineering-level model of the Earth's atmosphere. It provides both mean values and perturbations for density, temperature, pressure, and winds, as well as monthly- and geographically-varying trace constituent concentrations. From 0-27 km altitude, thermodynamics and winds are based on National Oceanic and Atmospheric Administration Global Upper Air Climatic Atlas (GUACA) climatology. Above 120 km altitude, GRAM is based on the NASA Marshall Engineering Thermosphere (MET) model. In the intervening altitude region, GRAM is based on Middle Atmosphere Program (MAP) climatology that also forms the basis of the 1986 COSPAR International Reference Atmosphere (CIRA). MAP data in GRAM are augmented by specially derived longitude variation climatology. Atmospheric composition is represented in GRAM by concentrations of both major and minor species. Above 120 km, MET provides concentration values for N_2, O_2, Ar, O, He, and H. Below 120 km, species represented also include H_2O, O_3, N_2O, CO, CH_4, and CO_2. Water vapor in GRAM is based on a combination of GUACA, Air Force Geophysics Laboratory (AFGL), and NASA Langley Research Center climatologies. Other constituents below 120 km are based on a combination of AFGL and MAP/CIRA climatologies. This report presents results of comparisons between GRAM constituent concentrations and those provided by Naval Research Laboratory (NRL) climatology. GRAM and NRL concentrations were compared for seven species (CH_4, CO, CO_2, H_2O, N_2O, O_2, and O_3) for months January, April, July, and October, over height range 0-115 km, and latitudes –90° to + 90° at 10° increments. Average GRAM-NRL correlations range from 0.878 (for CO) to 0.975 (for O_3), with an average over all seven species of 0.936 (standard deviation 0.049).

INTRODUCTION

The NASA/MSFC Global Reference Atmospheric Model (GRAM) was originally conceived as a design reference atmosphere incorporating complete global geographical variability, complete altitude coverage (surface to orbital altitudes), and complete seasonal and monthly variability of thermodynamic variables and wind components (Justus et al., 1974). Through a series of improvements (Justus et al., 1980, 1988, 1991, 1995), GRAM has evolved the capability to simulate not only the geographical, height, and monthly variation of the mean atmospheric state, but also spatial and temporal perturbations in these atmospheric parameters (e.g., fluctuations due to turbulence and other atmospheric perturbation phenomena). GRAM has proved useful in diverse applications, including trajectory simulations for atmospheric drag and atmospheric dispersion analysis.

GRAM-99 (Justus and Johnson, 1999; Justus et al., 2000) represents the current version of the Global Reference Atmospheric Model. In addition to traditional variables of pressure, density, temperature, and wind components, GRAM-99 provides estimates of atmospheric species concentrations for water vapor (H_2O), ozone (O_3), nitrous oxide (N_2O), carbon monoxide (CO), methane (CH_4), carbon dioxide (CO_2), nitrogen (N_2), molecular oxygen (O_2), atomic oxygen (O), argon (Ar), helium (He), and hydrogen (H). The MET (Jacchia, 1970; Hickey, 1988; Owens et al., 2000) model provides species concentrations for N_2, O_2, O, Ar, He and H above 90 km. Air Force Geophysics Laboratory (AFGL) atmospheric constituent profiles (Anderson et al., 1986) are also used extensively for the constituents up to 120 km altitude.

The GUACA data set (Ruth et al., 1993) provides water vapor data from the surface to the 300 mb pressure level. The NASA Langley Research Center (LaRC) water vapor climatology (McCormick and Chiou, 1994) includes H_2O values from 6.5 to 40.5 km altitude. Middle Atmosphere Program (MAP) data (Keating, 1989) include H_2O data from 100 mb to the 0.01 mb pressure level. Monthly mean water vapor concentrations in GRAM-99 are based on height (or pressure level) ranges shown in Table 1, with fairing used to insure smooth transition between data sources. For standard deviations in water vapor, GUACA data are used from the surface to 300 mb; an extrapolation of GUACA values, based on relative humidity, is used from 300 mb to 100 mb; MAP data are used from 100 mb to 0.01 mb; and values based on a standard deviation/mean ratio of 0.36 (Harries, 1976) are used from 0.01 mb to 120 km.

Table 1. Summary of the atmospheric regions and data sources used for monthly mean water vapor concentration in GRAM-99

Height (km) or Pressure Level (mb) Range	GRAM Data Source for H_2O Mean Values
surface - 300 mb	GUACA CD ROM Data Base (Ruth et al., 1993)
300 mb - 100 mb	Fairing between GUACA and LaRC data
100 mb - 39.5 km	LaRC data (McCormick and Chiou, 1994)
39.5 km - 40.5 km	Fairing between LaRC and MAP data
40.5 km - 0.02 mb	MAP Data (Keating, 1989)
0.02 mb - 0.01 mb	airing between MAP and AFGL data
0.01 mb - 120 km	AFGL Data (Anderson et al., 1986)
Above 120 km	No data available (output = 0.0)

For mean ozone values, AFGL data are used from the surface to 20 mb and from 0.003 mb to 120 km. MAP values are used between 15 mb and 0.004 mb and MAP-AFGL fairing is used between 15 and 20 mb and between 0.003 and 0.004 mb. For N_2O and CH_4 mean values, AFGL data are used from the surface to 20 mb and from 0.1 mb to 120 km. MAP values are used between 15 mb and 0.125 mb and MAP-AFGL fairing is used between 17.5 and 20 mb and between 0.1 and 0.125 mb. For atomic oxygen concentrations, MAP values are used from 40 km to 90 km. MET model values are used above 100 km and MAP-MET fairing is used between 90 and 100 km. Atomic oxygen is output as 0.0 below 40 km. For N_2, O_2, Ar, and He values, AFGL data are used from 0 - 90 km; MET values are used above 120 km; and MET-AFGL fairing is used from 90-120 km. AFGL data values are used for CO and CO_2 from the surface to 120 km and are output as 0.0 above that altitude. H values are output as 0.0 below 90 km and come from the MET model above this height. With the exception of water vapor, for which both mean and standard deviation values are provided, only mean values are given for the atmospheric species constituents.

WATER VAPOR AND OTHER ATMOSPHERIC SPECIES CONCENTRATIONS IN GRAM

Water vapor and other atmospheric species concentrations are included in GRAM-99, with values above 90 km from the MET model and, below 90 km, from a new species concentration data base, discussed more fully by Justus and Johnson (1999). Water vapor output from GRAM-99 includes both monthly means and standard deviations. Water vapor values vary with month, height, latitude and longitude within the GUACA height range and vary with month, height and latitude above this altitude (see Table 1).

Means and standard deviations in water vapor are represented in the form of vapor pressure (N/m^2), vapor density (kg/m^3), dew point temperature (K), and relative humidity (%). Mean water vapor values in the form of volume concentration (parts per million volume) and number density ($molecules/m^3$) are also output. Conversions amongst these various forms from the form in the input data (dew point temperature for the GUACA data and volume
concentration for the other water vapor data sources) are performed by various subroutines, using methods described by Wexler (1976), Flatau et al. (1992), Buck (1981), and Elliott and Gaffen (1991). Only monthly mean concentration values are output for species other than water vapor, and their values are output only in the form of volume concentration and number density.

Interpolation of the GUACA dew point temperature for altitudes between input pressure levels, and for latitude and longitude between input grid points, is handled the same as for other GUACA variables. Interpolation methods are discussed by Justus and Johnson (1999). Height and latitude interpolation between input height-latitude grid points for water vapor above the GUACA range, and for the other species, is done by an adaptation of the two-dimensional interpolation discussed by Justus and Johnson (1999).

In GRAM-99, species concentrations c(t) are assumed to change with year t, according to the relation

$$c(t) = c(t_0)\,(1 + r_t)^{t-t_0}\ , \tag{1}$$

where t_0 is 1976 for the AFGL data and 1981 for the MAP concentration data and r_t is 0.005 for CO_2, 0.009 for CH_4, 0.007 for CO, and 0.003 for N_2O. For ozone, r_t varies linearly from 0.003 at the surface to 0 at 15 km, linearly from 0 at 30 km to -0.005 at 40 km, and again linearly from -0.005 to 0 at 120 km. The rate of change, r_t, for water vapor and the other constituents is assumed to be zero. These rates of change were estimated from data in Table 14.5 and Figure 17.1 of Graedel and Crutzen (1993).

COMPARISON OF GRAM WITH NAVAL RESEARCH LABORATORY (NRL) CONSTITUENT CLIMATOLOGY

Summers and Sawchuck (1993) have summarized a combination of observed trace constituent data with results from both one-dimensional and two-dimensional chemical-dynamical models. The report of their results, prepared for the Naval Research Laboratory (NRL), is referred to here as the NRL climatology.

Figures 1 and 2 compare GRAM height-latitude cross sections for July water vapor for NRL and GRAM climatologies, while Figures 3 through 6 provide similar results for ozone (Figures 3 and 4) and methane (Figures 5 and 6). Time-dependent GRAM concentrations were evaluated from Eq. (1) for year 1999.

A number of similarities and differences between the July climatologies may be noted in Figures 1 through 6. NRL water vapor is more symmetric between northern and summer hemisphere than is GRAM water vapor. Anomalous low water vapor concentrations are seen north from 70 degrees North in the NRL data. Latitude variation of tropopause altitude, as exhibited by vertical gradients of water vapor concentration, appears to be more realistic for GRAM than for NRL climatology. Ozone cross sections are quite similar for NRL and GRAM, except for a small anomaly in the NRL data between 10 and 20 km near 35 degrees South. GRAM methane concentrations are significantly higher than NRL methane concentrations, with differences in details of the height-latitude cross-section contours also evident in Figures 5 and 6.

As a means of providing simple comparisons between NRL and GRAM climatologies, cross-correlations were computed for concentrations of several species for seasonal months January, April, July, and October, for altitudes 0-115 km and latitudes –90 to +90 degrees (in 10-degree increments). Correlation results are given in Table 2. Average GRAM-NRL correlations range from a low of 0.878 (for CO) to a high of 0.975 (for O_3), with an average

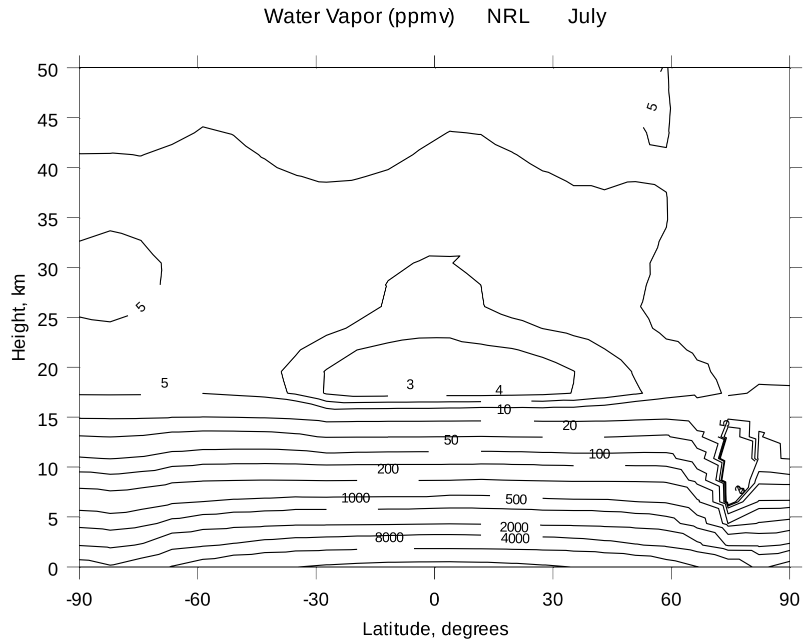

Fig. 1. July water vapor height-latitude cross section from NRL climatology.

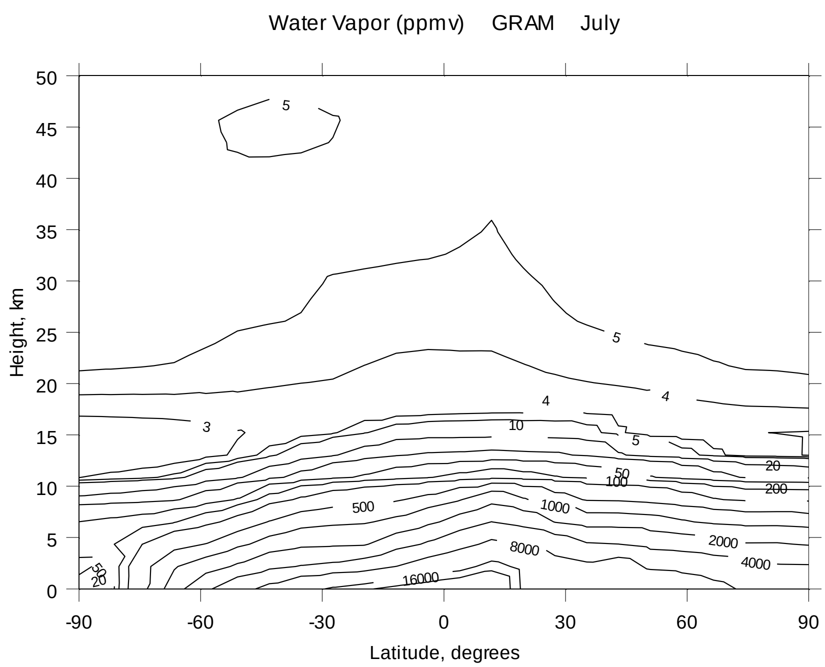

Fig. 2. July water vapor height-latitude cross section from GRAM climatology.

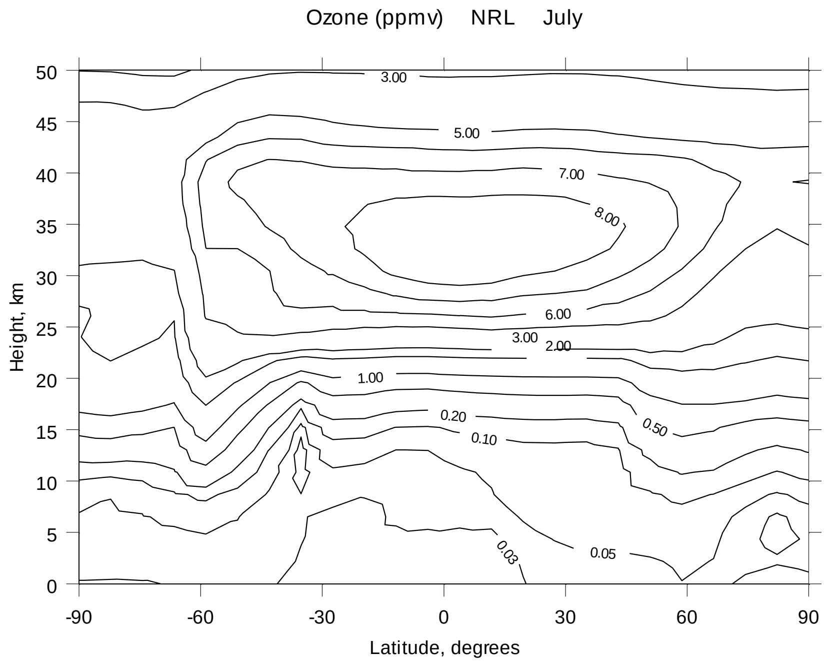

Fig. 3. July ozone height-latitude cross section from NRL climatology.

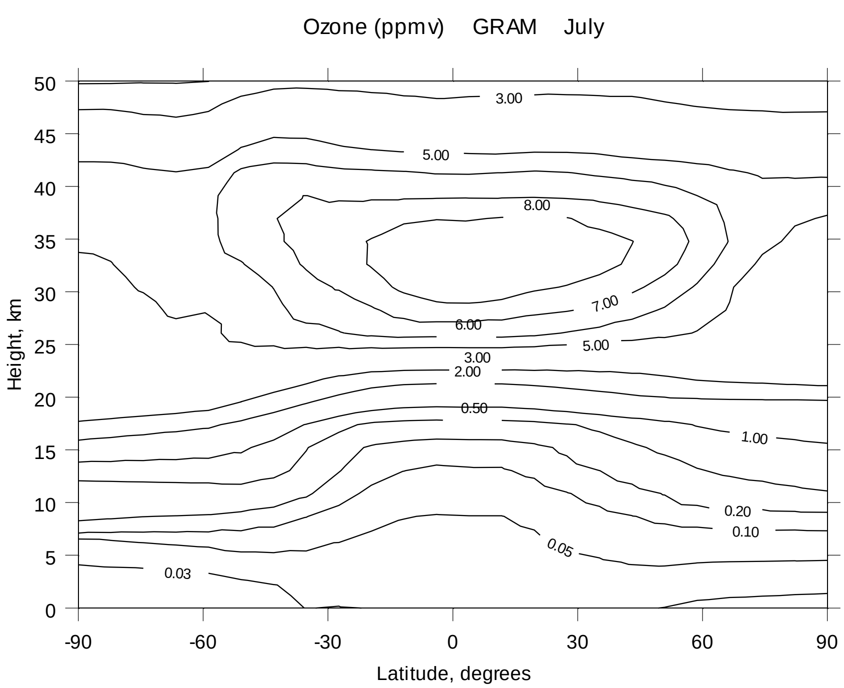

Fig. 4. July ozone height-latitude cross section from GRAM climatology.

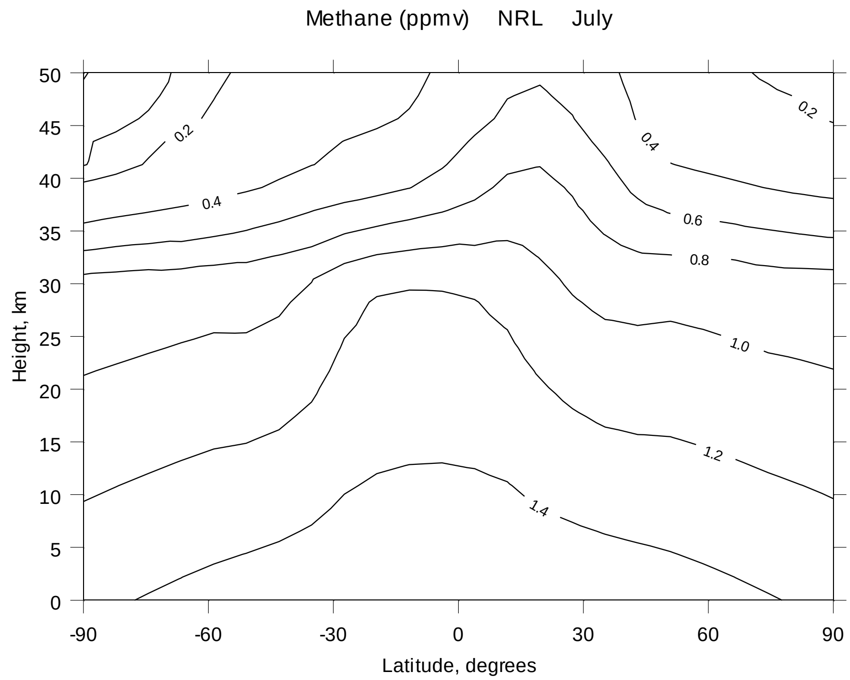

Fig. 5. July methane height-latitude cross section from NRL climatology.

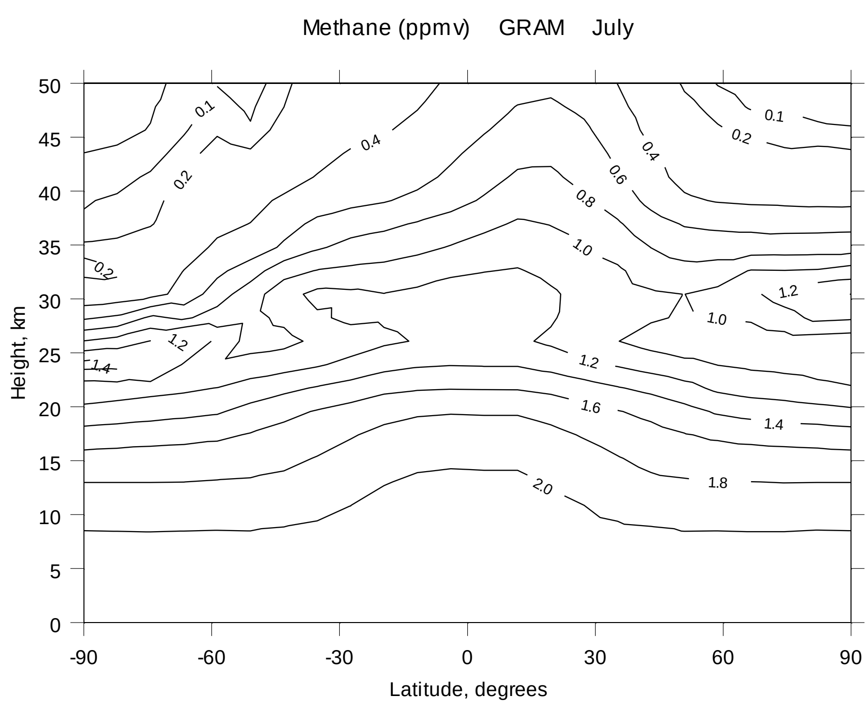

Fig. 6. July methane height-latitude cross section from GRAM climatology.

Table 2. Cross correlation coefficients for GRAM versus NRL constituent climatologies

Species	January	April	July	October	Average	Std. Dev.
CH_4	0.969	0.957	0.975	0.956	0.964	0.009
CO	0.815	0.921	0.842	0.932	0.878	0.058
CO_2	0.933	0.994	0.903	0.993	0.956	0.045
H_2O	0.877	0.867	0.891	0.898	0.883	0.014
N_2O	0.973	0.966	0.965	0.967	0.968	0.004
O_2	0.880	0.973	0.884	0.970	0.927	0.052
O_3	0.977	0.987	0.957	0.979	0.975	0.013
Average	0.918	0.952	0.917	0.956	0.936	-
Std. Dev.	0.062	0.044	0.050	0.032	-	0.049

over all seven species of 0.936 (standard deviation 0.049). Correlations are generally higher for all species in the near-equinox months (April and October) than in the near-solstice months (January and July). Based on results of this comparison, no evidence was found for a need to update the GRAM constituent climatology.

SUMMARY

GRAM and NRL concentrations were compared for seven species (CH_4, CO, CO_2, H_2O, N_2O, O_2, and O_3) for months January, April, July, and October, over height range 0-115 km, and latitudes –90° to + 90° at 10° increments. Average GRAM-NRL correlations range from 0.878 (for CO) to 0.975 (for O_3), with an average over all seven species of 0.936 (standard deviation 0.049). Based on results of this comparison, no evidence was found for a need to update the GRAM constituent climatology at this time.

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