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MODEL EVALUATION OF THE RADIATIVE AND TEMPERATURE EFFECTS OF THE OZONE CONTENT CHANGES IN THE GLOBAL ATMOSPHERE OF 1980-IES

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ABSTRACT

Radiative and temperature effects of the observed ozone and greenhouse gases atmospheric content changes in 1980 - 1990 are evaluated using the two-dimensional energy balance radiative-convective model of the zonally and annually averaged troposphere and stratosphere. Calculated radiative flux changes for standard conditions quantitatively agree with their estimates in WMO/UNEP, 1991 review. Model estimates indicate rather small influence of ozone depletion in the lower stratosphere at the greenhouse tropospheric warming rate, being more significant in the non tropical Southern Hemisphere. The calculated cooling of the lower stratosphere is close to the observed temperature trends there in the last decade.

1. INTRODUCTION

Significant ozone content changes in the lower stratosphere and troposphere as observed in 1980-ies with enhanced intensity during the recent years [WMO/UNEP, 1991] result in variations of radiative and temperature climate of the global atmosphere. The preliminary estimates of these variations have been used for important conclusions about their influence on the rate of greenhouse warming of the global troposphere [WMO/UNEP, 1991; Ramaswamy et al., 1992]. In these publications the meridional distributions of radiative flux variations at the tropopause level are evaluated, as caused by the observed changes of ozone and greenhouse gas content at various latitudes and levels of the global atmosphere in 1980-1990.

As the tropospheric temperature changes only to some extent are determined by the above radiative flux variations, more precise evaluation of the climatic radiative and temperature effects by the comprehensive climatic models is necessary [Ramaswamy et al., 1992]. However, the relative small amplitude of ozone changes makes difficult to reveal the effect "signal" over the considerable "noise" level in such models [IPCC, 1990].

In this paper the mean annual, zonally averaged solar and thermal radiation fluxes and temperature variations at various levels of the global atmosphere are estimated using the two-dimensional Energy Balance Radiative Convective Model (EBRCM), described in [Karol and Frolkis, 1984]. As indicated in this paper and in [Karol et al., 1986] the radiative and temperature changes, caused by CO_2 concentration increase in the atmosphere estimated by this model, are very close to these, obtained in the three-dimensional comprehensive atmospheric climate models.

In the first part of the paper after the short description of the model, the radiative forcing caused by ozone and greenhouse gases (GG) content changes in conditions used in [WMO/UNEP, 1991; Ramaswamy et al., 1992] are calculated and compared with results in these publications, making in a such way the comparison of the radiative schemes codes and models. Then the annually averaged mean zonal radiative flux and temperature changes are estimated [IPCC, 1990] as caused by the observed GG and ozone content changes for the time period 1980-1990. Some observed evidences of these changes are discussed in the conclusion of the paper.

2. SHORT DESCRIPTION OF THE MODEL

The model is presented in details in [Karol and Frolkis, 1984]. Annually and zonally averaged radiation fluxes and temperature distributions in the global atmosphere up to H=0.64 hPa (50 km) level with prescribed radiatively-active atmospheric constituent concentrations and other parameters are determined by successive approximation up to equilibrium state. At each step the vertical temperature profiles are determined from eight Radiative-Convective Models (RCM) at 80°, 60°, 40°, 15° N and S with 15 horizontal layers, and with surface air temperature To, taken from the previous approximation step. These profiles and other information are used for computation of solar and thermal radiation fluxes S_H and F_H at the considered upper atmospheric boundary. To distributions are the solutions of the energy balance equation

$$\frac{d}{dx} j(x)\cdot(1-x^2)\,\frac{dT_o(x)}{dx} = F_H(x) - S_H(x)\,,$$

where ϕ is the latitude; $x=\sin\phi$; $j(x) = j_o K(x)$; $j_o = c_p p_o/gR_a^2$; $K(x)$ is the effective horizontal heat transport coefficient. "Heat walls" at the poles are the boundary conditions for this equation solution, which is used for eight RCM at the next step of successive approximation. Besides the coarse grid of eight zonal belts the fine grid of 36 belts with $\Delta\varphi=5^{\circ}$ is used in computations.

Solar radiation flux calculations are based on the two-stream delta-Eddington scheme. The UV band (197.5-312.5 nm) is divided into 11 spectral intervals, where O_2, O_3, NO_2 and aerosol effects are accounted. Visible band contains two spectral intervals with inclusion of O_3, NO_2, molecular, aerosol and cloud scattering and reflectance. NIR band (750-4000 nm) is divided into 12 spectral intervals, in which the selective H_2O, CO_2, O_3, N_2O and CH_4 absorption is accounted approximated by the Goody transmission function for the statistical model of the absorption band. An original approach is used for the approximate calculation of selective gas absorption and scattering of photo ns by aerosol and clouds with multiple reflection from the cloud layer boundaries.

The thermal radiation fluxes are calculated for 17 spectral intervals in the 4.4-1000 micrometers band. The transmission functions for the same gas selective absorption are approximated as in NIR with the atmospheric vertical density layering accounted by Curtis-Godson approximation. Weak absorption approach is used for CFCs. H_2O continuum absorption and diffusivity approximation are included, but the cloud and aerosol transmission functions are non-selective. The ground surface and clouds are considered as black bodies.

The external data and conditions, used in the calculations of the radiation flux variations, caused by the GG and ozone changes are presented in Tables 1 and 2. These data are taken from the sources and are the most close to used in [Ramaswamy et al., 1992], for model comparison. In Table 2 the daily averaged cosine of the solar zenith angle φ_*, the clear day relative duration t_* and surface albedo A_s for selected cases used in our calculations are also presented, being not indicated in [WMO/UNEP, 1991; Ch.7 and Ramaswamy et al., 1992]. For comparison purposes the clear sky Mode A with fixed temperature profiles Model I radiative forcing values are used from the above publication.

Table 1. Globally and annually averaged GG tropospheric mixing ratios in 1980 and their increases to 1990 [IPCC, 1990; WMO/UNEP, 1991].

Gas	CO_2	CH_4	N_2O	CFC 11	CFC 12	CFC 113	CFC 22
Units	ppmv		ppbv				
1980	337	1.57	302.6	0.158	0.27	0.015	0.05
1980-1990	17	0.15	8.0	0.111	0.17	0.050	0.07

3. RESULTS OF CALCULATIONS.

The radiative forcings (the net total long + short wave radiative flux variations at the tropopause level) are compared in Table 3 for the above conditions as calculated by EBRCM and by Mode A, Model I in [WMO/UNEP, 1991] and caused by ozone, CFC and other GG content change separately. The agreement between the two model results are good, not only at the tropopause, but at the ground surface also, being the worst for CFC, as in EBRCM only the radiative forcing of CFC-11 and 12 are included.

Table 2. Cases selected for radiative forcing calculations due to ozone depletion in the lower stratosphere $\Delta(O_3)$ for standard temperature profiles: tropical-T; midlatitude summer-MLS and winter-MLW; subArctic winter-SAW [WMO/UNEP, 1991]. Daily averaged solar zenith angle φ_*, clear day relative duration t_* and surface albedo A_s, which are used in calculations.

No.	Latitude	Month	Temp. Profile	$\Delta(O_3)$ (%)	$\cos\varphi_*$	t_*	A_s
1	0°	July	T	-0.5	0.586	0.500	0.076
2	45°N	July	MLS	-2.0	0.570	0.640	0.123
3	45°N	Feb.	MLW	-8.0	0.301	0.399	0.271
4	45°S	Jan.	MLS	-6.0	0.570	0.639	0.067
5	45°S	Aug.	MLW	-5.0	0.296	0.396	0.098
6	70°N	Mar.	SAW	-17.0	0.134	0.372	0.641
7	75°S	Oct.	SAW	-32.0	0.205	0.588	0.799

Fig.1 demonstrates the meridional distribution of solar and thermal net radiation flux changes at the tropopause level for January and July, calculated by EBRCM for ozone and non-ozone GG content variations, indicated in Tables 1 and 2, for Mode A and clear sky conditions.

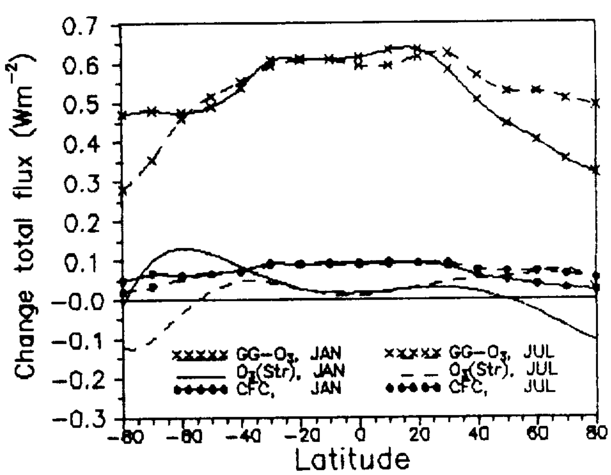

Fig. 1. Total net flux changes at the tropopause level (for Mode A) for January and July due to only O_3 (O_3(Str)), to non-ozone GG (GG-O_3) and to CFC (CFC) content variations.

Ozone depletion leads to increasing of the solar radiation flux coming to the surface-troposphere system at all latitudes throughout the year. The long wave cooling of this system by ozone depletion in Mode A is exceeding its solar warming only in the polar winter. The influence of the atmospheric temperature changes on the radiation flux variations may be assessed from Table 4 with the meridional variations of annually and zonally averaged changes of solar and thermal radiation fluxes at the tropopause level for Mode C, for the cloudy atmosphere, for GG content increase in Table 1 and for annually averaged ozone depletion estimates in Table 5. The Mode C difference from the Mode B in [WMO/UNEP, 1991; Ramaswamy et al., 1992]

Table 3. Net radiation flux changes at the tropopause and at the surface levels due to GG and ozone content variations and for the cases and conditions indicated in Table 1 and 2, as evaluated in [WMO/UNEP,1991, Ch.7]-Mode A and in this work-F.

Case	$CO_2+CH_4+N_2O$ Tropopause A	F	$CO_2+CH_4+N_2O+CFC$ Surface A	F	CFC A	CFC F[a]	Ozone A	Ozone F
1	.54	.520	.14	.154	.16	.096	.01	.006
2	.51	.460	.20	.231	.13	.074	.08	.024
3	.41	.400	.35	.369	.08	.053	.03	.026
4	.51	.457	-	-	.13	.071	.06	.064
5	.41	.400	-	-	.08	.053	.05	.025
6	.34	.347	.28[b]	.284[b]	.05	.034	-.17	-.041
7	.34	.342	.37[c]	.377[c]	.05	.033	-.41	-.066

a/ - For CFC-11 plus CFC-12 only.
b/ - For SAS temperature profile.
c/ - For SAW temperature profile.

is that in Mode C the radiation variations induced by the temperature changes are calculated by KBRCM with account of clouds. In the Mode B the tropospheric temperature and humidity remain unchanged, while the stratospheric temperature is in the radiative equilibrium under the assumption of a so-called Fixed Dynamical Heating concept [WMO/UNEP, 1991].

Fig. 2 demonstrates the calculated zonally and annually averaged surface air temperature changes, induced by the radiative forcing due to GG and ozone content changes in Tables 1 and 5, calculated for Mode C conditions and for cloudy atmosphere assumed not to be changing during the period under consideration. The meridional distribution of calculated air cooling in the lower stratosphere, due to ozone depletion being maximal at the 80 mb level is also presented at Fig.2.

4. DISCUSSION OF RESULTS.

The comparison of the net radiation flux variations for the seven standard cases, indicated in the Table 2 and evaluated in [WMO/UNEP, 1991,Ch.7] and in this work as presented in Table 3, reveal the good agreement of calculation results for all cases, bearing in mind the possible deviations in surface short wave albedo, which is not indicated in [WMO/UNEP, 1991, Ch.7]. The agreement of CFC radiative forcing estimates in Table 3 will be improved substantially by increasing our estimates by about 40-60% for account of radiative effects of CFC content increase, other than CFC-11,12.

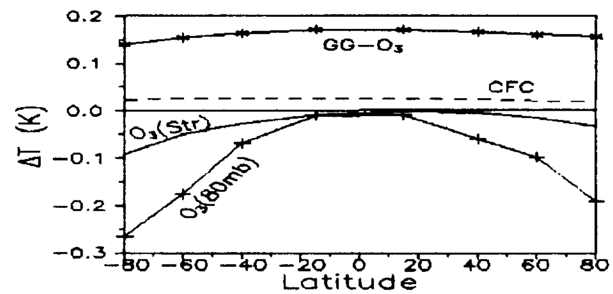

Fig.2. The calculated ΔT_0 obtained for all GG without O_3 (GG-O_3), for CFC only (CFC), for lower stratospheric O_3 only (O_3(Str)) and ΔT at 80 mb level divided by 10 (O_3(80mb)) all for Mode C.

Table 4. The net fluxes of solar ΔS and total ΔR radiation changes (Wm^{-2}) at the tropopause level for modes A and C due to gas content variations, indicated in Tables 1 and 5.

Gas	Flux	Southern Latitudes 80°	60°	40°	15°	Northern Latitudes 15°	40°	60°	80°
-	-	Mode A							
O_3	ΔS	.12	.24	.125	.014	.013	.12	.17	.14
O_3	ΔR	-.074	.090	.074	.018	.019	.18	.18	-.050
CFCs	ΔR	.022	.034	.046	.056	.058	.048	.037	.028
GG[a]	ΔR	.31	.37	.435	.47	.48	.44	.38	.34
GG[a]	ΔS	.004	-.012	-.025	-.016	-.016	-.024	-.014	-.004
O_3[b]	ΔS	.10	.21	.112	.012	.012	.10	.14	.11
O_3[b]	ΔR	-.064	.073	.051	.009	.008	.09	.10	-.051
-	-	Mode C							
O_3	ΔS	.012	.25	.13	.015	.013	.12	.18	.15
O_3	ΔR	-0.14	-.14	-.01	.040	.016	.038	.009	-.29
CFCs	ΔR	-.003	-.004	9E-4	.003	.002	.002	-.003	-.002
GG[a]	ΔR	-.0033	.0042	.018	-2E-4	-6E-4	.017	.0012	-.033

a/ - The sum of greenhouse gases, omitting the ozone variations.
b/ - Ozone content changes only in the lower stratosphere.

The meridional profiles of radiation flux changes at Fig.1 and in Table 4 are close to relevant curves at Figs. 7.3 and 7.4 in [WMO/UNEP, 1991, Ch.7] for Mode A with fixed atmospheric temperatures. Flux changes are somewhat greater in the cloudless atmosphere (Mode A) as compared to those of a cloudy atmosphere (Mode C). Therefore our radiation flux calculations schemes and Mode A (fixed temperature) results are close to those in [WMO/UNEP, 1991; Ramaswamy et al., 1992]. The radiative cooling of the lower stratosphere by the ozone depletion effects enhances the negative mean annual total radiation change in the Southern Hemisphere outside of tropics and in the northern polar zone. This ozone caused negative change overweights by several times the positive (thermal) radiation forcing, caused by the CFC in north polar and south non-tropical latitudes, as it has been found in [WMO/UNEP, 1991], but not in the north temperate latitudes. (The account of other CFCs increases the forcing by 30-50% only [IPCC, 1990] and will not change the above conclusion qualitatively.) Due to above explained differences in temperature change evaluation, the radiation flux variations in the affected temperature fields in EBRCM and in [Ramaswamy et al., 1992] are incomparable in principle and GG and ozone content variation effects assessed by EBRCM may be estimated better by the temperature change analysis.

Table 5. Annually and zonally averaged ozone content changes (%) during 1980-1990 at indicated latitudes and layers, as estimated in [WMO/UNEP, 1991] and used in calculations.

Layer (km)	N. Latitudes			20°N-	S. Latitudes		
	80°	60°	40°	-20°S	40°	60°	80°
Troposph.	0	8	8	2	0	0	0
$h_{TP}-h_{TP+7}$	-20	-10	-8	-1.6	-10	-20	-30
37 - 45	-10	-5	-3	-0.8	-5	-10	-17

The ΔT_o-surface air annually averaged "radiative" temperature profiles at Fig.2 demonstrate, that negative ΔT_o produced by the observed ozone depletion in the lower stratosphere, surpass the positive CFC ΔT (underestimated, as pointed out above) only in the polar zones. Maximal ozone produced ΔT_o around the South Pole attains of about 70% of GG warming in this area, but in the Northern Hemisphere the ozone produced reduction of GG warming does not exceed 25%, being maximal in the North Pole area. This small reduction of the greenhouse warming rate in the lower atmosphere due to observed ozone depletion may be even less in reality with account of the known oceanic thermal inertia effect [IPCC, 1990, Ch.6]. According to several estimates the time delay of the surface air greenhouse warming due to this effect is about 10-20 years [IPCC, 1990; Karol and Jagovkina, 1992] and therefore the actual To increase in 1980-ies is reflecting the greenhouse radiative forcing in previous decades, when ozone depletion forcing was nonsignificant.

The globally averaged ΔT_{oa}=0.129K and ΔR_a=0.50 Wm^{-2} from Table 4 for all GG increase except ozone in 1980-1990 is in good agreement with ΔT_{oa}=0.139K and ΔR_a=0.54 Wm^{-2} estimated in [IPCC, 1990]. The negative ΔT_{soa} in the lower stratosphere at Fig.2, when globally averaged is ΔT_a= -0.58 K and it is close to the globally averaged observed temperature negative trend of 0.4 K/decade in the layer between 100 and 50 hPa [WMO/UNEP, 1991, Ch.2].

The observed ozone concentration changes outside the lower stratosphere are much less influencing the radiation and temperature regime in the lower troposphere, as revealed by Table 4, where the solar and net radiation flux changes are compared as caused by all the ozone variations, indicated in Table 4, and by its variations in the lower stratosphere only.

The consequences of "ozone compensation" of the greenhouse warming in the southern polar zone in 1980-ies may result in different changes in the total areas of snow and of ice in the Antarctic and in the Arctic [Cloersen and Campbell, 1991]. While this area decreases in the Arctic, it does not undergo any changes in the Antarctic.

An express Bulletin [GECR, 1992] announced recently that UARS satellite measured 10% lower ozone concentration in 10° S - 20° N zone in January 1992 as a possible result of Mt. Pinatubo volcano aerosol plume effects. Ten percent ozone reduction in the 7 km layer over the tropopause of the 20° S - 20° N zone leads to calculated ΔS= 0.13 Wm^{-2} and ΔR= 0.15 Wm_{-2} of solar and total flux changes for Mode A, filling up by this the tropical minimum of ozone induced change of flux meridional profile (see Fig. 1 and Table 4). Due to short period radiative forcing, caused by volcano plumes, and its transient effect on the air temperature, the stationary EBRCM is not suited for evaluation of such effects.

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