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WAVE SIGNATURE IN STRATOSPHERIC AEROSOLS

Marcel Ackerman and Carlos Lippens

Belgian Institute for Space Aeronomy

Dirk De Muer

Royal Meteorological Institute

Avenue Circulaire, 3, B-1180 Brussels

Abstract. Regularly spaced vertical structures have been observed in stratospheric aerosols revealed by the observation of scattered sunlight. The simultaneous observations of this phenomenon and of regularly spaced vertical fluctuations of temperature is presented. The aerosol structure is interpreted in terms of particle size as a function of temperature on the basis of the limited theoretical studies available about the effects of temperature and humidity on the growth and optical properties of sulfuric acid-water dropplets in the stratosphere.

Introduction

Vertical small scale structures are known to exist in stratospheric aerosols. Thin layers appear for instance soon after stratospheric injections of volcanic material. These are attributed to the horizontal transport of aerosol enriched thin air layers away from a main volcanic plume. However stratospheric aerosol layering is a quasi permanent feature so that other parameters must be involved.

In particular, photographic observations (Ackerman et al, 1981) reveal the occurence in the stratosphere of series of horizontal layers exhibiting a striking regular vertical spacing. In order to try to elucidate the origin of this phenomenon a photographic balloon gondola has been integrated into a payload comprizing also an aerological set of instruments allowing to instantaneously and accurately measure the vertical perturbations of velocity, temperature and density of air simultaneously with aerosols (Barat and Cot, 1984).

Observation

In the afternoon of October 15, 1980, a balloon flight of the instrumented package took place from the CNES range in Aire sur l'Adour, France (0.3°W, 43.7°N). Earth limb photographs of the stratosphere showed the presence of a system of regularly spaced aerosol layers above the Junge layer, from 18 to 28 km altitude as it can be seen on Figure 1. As reported by Barat and Cot (1982), a depression was centered at the surface level position of (10°E, 45°N); it was also observed in altitude. Related to the pressure configuration, a jet stream flowed SW-NE over the Pyrenee mountains and downstream over the launch site. A remarkably constant direction of the mean air flow was observed at all covered altitudes. The observation of the vertical air velocity profile gave evidence of a wave group with a well defined wavelength. The propagation of a gravity wave induces a relationship between the velocity and temperature perturbations. These two perturbations as deduced by Barat and Cot (1984) are reproduced on the left hand side of Figure 2. They appear well correlated. The observation of atmospheric waves motions are often complicated by the presence of multiple wave modes. In our case there is evidence of the a wave system of great purity in the lee of the Pyrenean mountains.

On the right hand side of Figure 2, the observed forward scattering of solar radiation at the wavelength of 0.65 μm is shown versus altitude. This was derived from a photograph taken at 32 km altitude during the balloon ascent. The sunlight scattering angle was 20° at 20 kilometer altitude. Most of the scattering is due to aerosol scattering with a negligeable contribution due to Rayleigh scattering. It should be emphasized that the size equilibrium of the aerosol can be established almost instantaneously with water molecules while the temperature changes (Steele and Hamill, 1981). The aerosol droplets can thus follow the evolution of meteorological parameters within seconds.

Discussion

The regularly spaced vertical wavelike structure appears clearly correlated with the temperature and related vertical velocity perturbations. The amplitude of the scattering peak to peak perturbation is roughly 10 to 20% of the mean while the mean amplitude of the temperature perturbation is 2 K. Since Barat and Cot (1984) have evaluated that the air density perturbation shows a 0.07 % amplitude from the mean and since the Rayleigh scattering is relatively negligeable the scattering perturbation lies in the aerosol. Temperature effects on stratospheric aerosol extinction, which is closely related to forward scattering at an angle of 20°, have been theoretically evaluated by Steel and Hamill (1981) and by Yue and Deepak (1981). It can be seen from this work that at the wavelength of 1 μm, for a water volume mixing ratio of 3.5 ppmv and at the stratospheric temperature near 220 K, observed during the flight, a temperature change of 2 K produces an extinction change of 2 to 3%. As we shall see now this last quantity may be 3 to 4

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Fig. 1. Photograph of the earth limb on October 15, 1980, taken at 32 km altitude. Above the cloud top, a heavy aerosol layer is seen up to 18 kilometer altitude. The striations observed above this altitude correspond to the wavy structure shown in figure 2.

times larger at 0.65 μm leading to values in rough agreement with our observation at this wavelength, within theoretical and experimental uncertainties.

Figure 3 shows vertical aerosol structures as they more commonly appear. In this case, observed on November 10, 1984, the stratospheric temperature varies from 210 K to 220 K in the

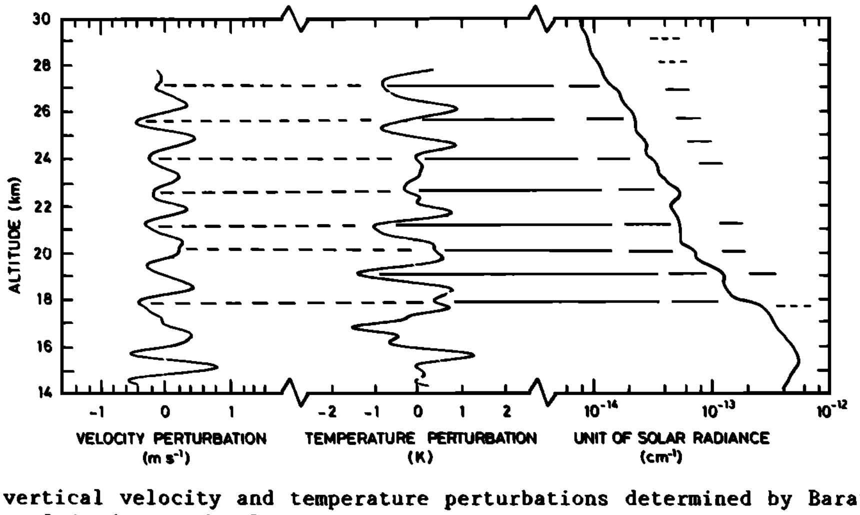

Fig. 2. The air vertical velocity and temperature perturbations determined by Barat and Cot (1984) are plotted versus altitude on the left part of the figure. On the right hand side, the inverted scattering radiance in unit of solar radiance deduced from the observed slant radiance is shown versus altitude. To the right of the curve horizontal marks indicate the aerosol scattering maxima which appear at regular altitude intervals. The correlation between the aerosol maxima and the correlated temperature and velocity perturbations appears significant.

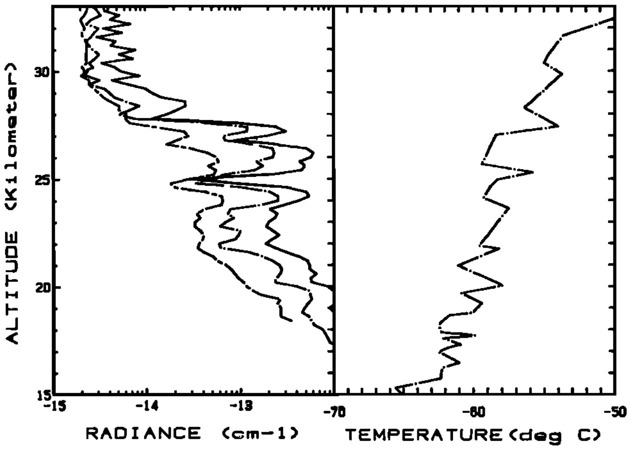

Fig. 3. Left : from slant radiances observed on November 10, 1984, radiances per centimeter of optical path have been deduced at 0.44 µm (continuous line), 0.65 µm (dotted line) and 0.84 µm (dashed line) wavelengths. After substraction of the Rayleigh scattering radiance, these are shown on a logarithmic scale in unit of solar radiance versus altitude. Right : air temperature versus altitude.

altitude range from 15 to 25 km as shown on the right hand side of the figure. A temperature perturbation is also present of which the amplitude reaches a 6 K maximum near 26 km altitude. The sunlight scattering angle of the observation was 13 degrees at this altitude. The temperature maxima are well correlated with the minima of aerosol scattering and the temperature minima are in good correspondence with the aerosol scattering maxima. The radiance was in this case observed at three different wavelengths : 0.44, 0.65 and 0.84 µm. It appears clearly that the scattering increases nearly 3 times from 0.84 to 0.65 µm at the perturbation minimum near 23 km while it increases 10 times at 26 km altitude. This increase is likely to be even larger when the wavelength of the scattered light changes from 1.0 µm to 0.65 µm.

The observed increase of scattering with decreasing wavelength is expected from currently known stratospheric aerosol properties such a the sizes and the refractive index of the particles. The steepness of the increase could indicate a narrow size distribution at the scattering maxima. More information on this aspect requires however more measurements.

Conclusion

Atmospheric aerosol fine vertical structure is a common feature in the stratosphere, "although no serious effort has been made to explain it or to investigate its relation to other parameters" (CIAP-I, 1975).

Knowing that temperature fluctuations induce variations of optical properties of stratospheric aerosols through particle growth and evaporation processes, we have shown a relationship between waves and aerosol layering through the simultaneous observation of a spatially correlated, regularly spaced train of aerosol scattering, temperature and related vertical velocity perturbations. Due to the lack of microphysics studies on the wavelength dependence of aerosols light scattering and extinction properties on temperature in stratospheric conditions, a tentatively quantitative evaluation of the effect could only be assessed.

The data reported here confirm the highly variable wavelength dependence of aerosol scattering and extinction, the Angström coefficient, in the stratosphere (Ackerman and Lippens, 1984; Lenoble et al., 1984). They may help in the development of highly needed more comprehensive theoretical studies in this field.

If, with volcanic perturbations, atmospheric waves may not be the only origins of stratospheric aerosol layering, they appear to both contribute to it.

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