BACKSCATTERED UV OZONE AND AEROSOL MEASUREMENTS FROM THE GEOSTATIONARY ORBIT: FEASIBILITY AND INTERPRETATION

C. Muller and P.C. Simon
Institut d'Aéronomie Spatiale de Belgique
B-1180 Bruxelles, Belgium

ABSTRACT

The implications of the geostationary geometry on the feasibility of a backscattered U.V. monitoring instrument are studied at wavelengths ranging from 250 nm to the blue region of the spectrum. Simulations of the data show a coverage from the equator for 80 degrees of latitude, the technique is shown to be very effective for the monitoring of upper stratospheric and total ozone, however total aerosols, NO_2 and tropospheric ozone will be difficult to survey due to the strong effects of clouds and varying ground albedo. Specific channels must however be included for the study of these phenomena so that the obtained data can be fed back in order to refine the ozone inversion process.

INTRODUCTION

Up to now, remote sensing of stratospheric ozone has been made from low Earth orbit (altitude lower than 1200 km) which limits both the geographical area that could be observed at any time (200 km for SBUV) and the time scale during which one scene can be continuously observed. The use of the geostationary orbit will allows to obtain synoptic views of both total ozone contents and its vertical distribution above 35 km over one half of the Earth surface on time scales of a few hours. This type of data is crucial to any studies of ozone distributions related to atmospheric dynamics. The high negative correlation that exists between total ozone content and tropopause heights can be used to study short-term variations in the dynamics of the upper troposphere. Synoptic observations of the distribution of total ozone content will permit to identify regions of large gradient which are related to the location of the polar jet stream. Therefore ozone observations from a geostationary orbit will complement the meteorological data obtained from the same platforms.

The observation of the back scattered solar ultraviolet radiation is well adapted for monitoring ozone levels from a geostationary orbit; it is a well established remote sensing technique, based on physical processes, which have been extensively studied. In addition, with the experience of previous back scattered radiation instruments used in space to drawn in, a very good assessment of the technique is possible producing a clear identification of instrumental problems.

ASSESSMENT OF THE IMPACT OF THE GEOSTATIONARY ORBIT ON THE BACK SCATTERED ULTRAVIOLET OZONE OBSERVATIONS

The geostationary orbit is very different in respect of backscattered light observation from the nadir looking geometries which have been the rule in previous ozone observation instruments. Figure 1 gives the different angular parameters which are important for such an observation, in the case of 12h U.T., the satellite being positionned on the Greenwich meridian, the angle of incidence of solar radiation on an observed ground location is then given by its latitude and the solar declination of the day. For example, at the summer solstice, the solar elevation is equal to the sum of 23° and the difference between 90° and the latitude. An other important point is the latitude where the observation is no longer possible. It is expressed by :

$$\phi_{max} = \arccos (R/z + R)$$

where R is the Earth radius and z the satellite altitude which in the case of the geostationary orbit is 81°. It means that the Antarctic ozone "hole" which has been discovered at Halley Bay (76°S) and Syowa (69°S) can be followed from the geostationary orbit as well as the high ozone belts which surround the Antarctic vortex in the Spring and Summer.

A simulation program has been endeavored in order to determine the radiation levels expected from a BUV instrument in the meridian case given in figure 1. The atmosphere is divided in 1 km layers from the ground to the altitude of 100 km and the radiation is computed in the direction of the satellite taking into account, as a source, the Rayleigh scattering of UV solar radiation and, as sinks, the losses by ozone absorption, Rayleigh scattering and losses by aerosol extinction and other absorbing gases. This permits to compare the intensities in the different wavelengths with extraterrestrial solar energy and gives the necessary input to instrument designers, the maxima of the Rayleigh phase functions being in forward and back-scattering, this meridian geometry gives the maximum of radiation possible. The results are indicated on figure 2 for the wavelengths of 250 nm (corresponding to the ozone maximum) and 280 nm. The ozone values have been varied above the altitude of 40 km to cover the ranges from 100% of current value down to 20%. It is seen that ozone variations are well observed from 0°

ISBN 0-937194-15-8

to 80° latitude using this technique, however the sensitivity decreases at high latitudes and, as expected, latitudes higher than 67° cannot be observed at the Winter solstice.

The following step was to introduce in the computation the effects of albedo, NO_2 and aerosols at these two wavelengths (250-280) and at 300 nm, 350 nm, 435 nm and 440 nm. The wavelength of 300 nm corresponds to a range typically used for total ozone observations while 350 nm is at the extreme limit of the ozone spectrum measured in the laboratory. The two last wavelengths are a couple which can be used for NO_2 determinations. The albedo is represented here by a reflecting layer of 0.4 efficiency, corresponding to a value for a snow cover or complete cloud cover. At 250 nm, no effects are obtained while at 280 nm, this reflecting layer has to be elevated up to 20 km to produce a significant difference in received signal. At 300 nm, the results for a 10 km and a ground layer are shown in figures 3 and 4. One important result is that ozone variations above 40 km still have an influence on the results of this channel. In the 350 nm case, ozone absorption does not affect the results anymore and this wavelength can already be used as albedo monitor, the results being evidently as good for this purpose at wavelengths as 360 and 400 nm which are known to be completely free of ozone absorption.

The effects of NO_2 have been considered at 435 and 440 nm, the computation performed at 440 nm used two NO_2 vertical distributions, one was as determined by the Spacelab 1 grille spectrometer and the other one was a factor of ten higher. The results are compared with the NO_2 = 0 value and unfortunately, the observation seems to require a much higher sensitivity than the one necessitated for ozone. This can only be achieved through correlation between a NO_2 minimum and maximum, absolutely requiring two channels (figure 5).

Aerosols were introduced in the form of a unimodal distribution of particles of a scattering efficiency of 2 (corresponding grosso-modo to 0.12 μm radius stratospheric aerosols at 440 nm). Three distributions were introduced : first a uniform distribution of 2.5 particles/cc, second, 10 particles/cc and finally 10/cc plus a stratospheric layer of 100 particles/cc between 17 and 23 km. The results on figure 6 show an effect at 440 nm which is much more significant than the one of NO_2, fortunately the aerosol extinction and scattering wavelength dependence is weak compared to the NO_2 and even ozone spectral variations. At high latitudes, especially, in the Summer solstice case, the aerosol effects tend to cancel itself, as both a source and an absorber of light. Their importance makes them a critical factor of all inversion algorithms, as their phase function is critically dependant on their size distribution, this one will have to be determined first and this

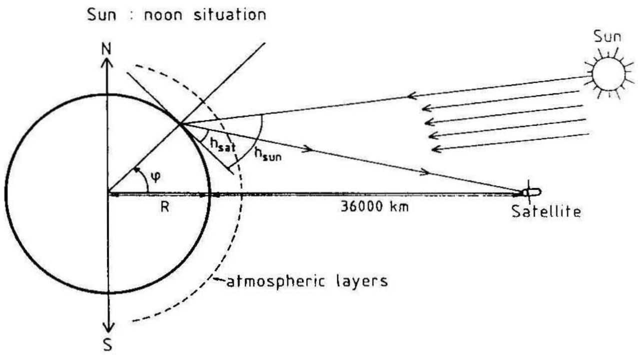

Fig. 1. Geometrical GBUV situation, the satellite at geostationary altitude, sees at noon the backscattered solar radiation over an entire hemisphere.

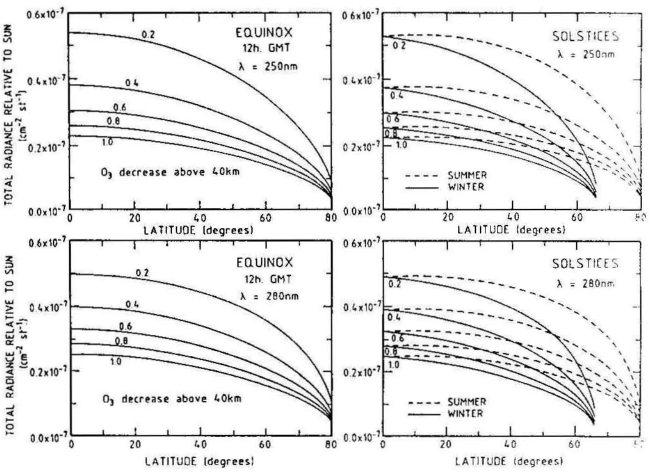

Fig. 2. Computation of the radiation received at the geostationary altitude in terms of solar radiance at 250 and 280 nm, the different curves correspond to an 03 variation above the 40 km altitude, the lower curve corresponding to present and the upper curve corresponding to an eighty percent ozone decrease. The indicated latitudes show that the Antarctic ozone hole can be monitored using this technique.

requires several wavelengths, preferably as far apart as possible and decoupled from ozone absorptions. Unfortunately, due to the importance of the albedo parameter, nadir sounding will always yield coarser results on aerosol distributions than limb sounding as exemplified by the SAGE satellite and aerosol models deduced from simultaneous specialised observations will always have to be tested against the GBUV aerosol data in order to check its accuracy. However, GBUV will provide unique data on long term trends and exceptional events as volcanic explosions.

A further computation must include multiple scattering effects, realistic albedo phase functions and aerosols distributions and should also include variations of the hour angle. However the present computation, if insufficient to provide a data base for the testing of inversion algorithms, provides the range of possible values for light received at the satellite.

This analysis shows that a range from 1% of direct solar radiation down to 10^{-8} has to be measured with accuracies of better than 1%. The albedo of the ground and cloud cover are found to be a major component of the signal above 280 nm as well as aerosols, which, as was already well known from previous visible NO_2 observations, act both as a source of scattered light and absorber. Ozone, especially above 40 km, can be efficiently monitored by the technique using simple algorithms where the layers below 20 km are crudely modelled while monitoring of ozone below the maximum and minor constituents (NO_2) will demand an extensive study of aerosols and albedo data from the observation itself before a final version.

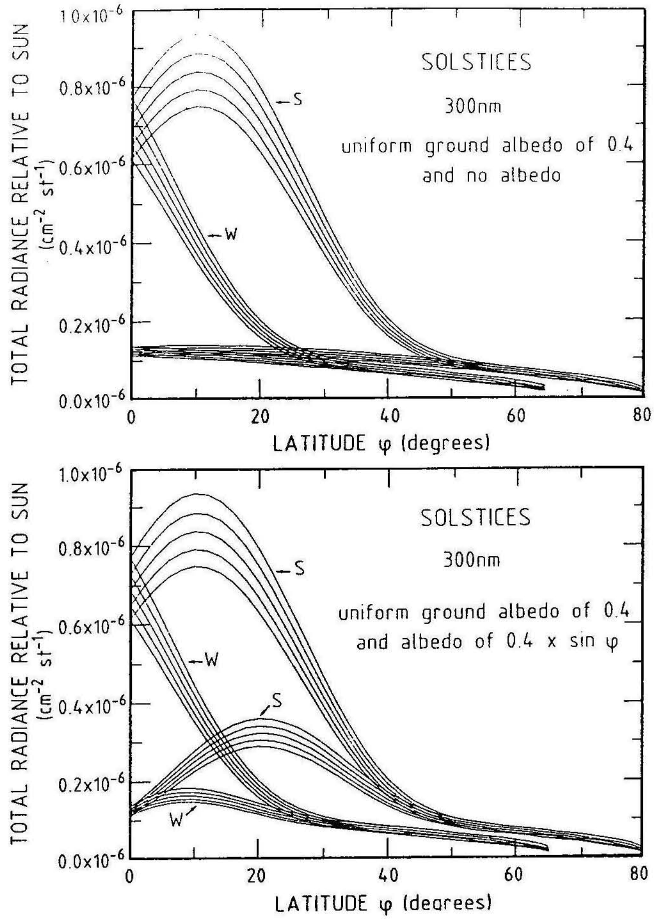

Fig. 3. Effect of a 10 km altitude reflecting layer of albedoes of 0.4 and 0.1 on the signal level at 300 nm, the different curves correspond to an ozone variation over 40 km and to the Summer and Winter equinoxes as in figure 2.

CONCLUSIONS

As several new geostationary meteorological satellite programs are now in the course of evaluation within the large space agencies, attention should be given to the use of these platforms for monitoring of long term climatic parameters and especially the ozone. The back-scattered U.V. technique permits a large number of possible designs for spectral imaging radiometers using the new developments of detector arrays. One of these instruments used from the geostationary point would generate maps of total ozone and vertical distributions on an entire hemisphere, ideally completing the lower-altitude present sounders which are limited by their ground-track coverage.

Aerosol and other gases measurements are more difficult with this instrument than by using a limb sounder due to the strong albedo signal present outside the ozone absorption, however they can and must be achieved using the same instrument in order to refine the ozone inversion algorithms, by including all possible perturbations.

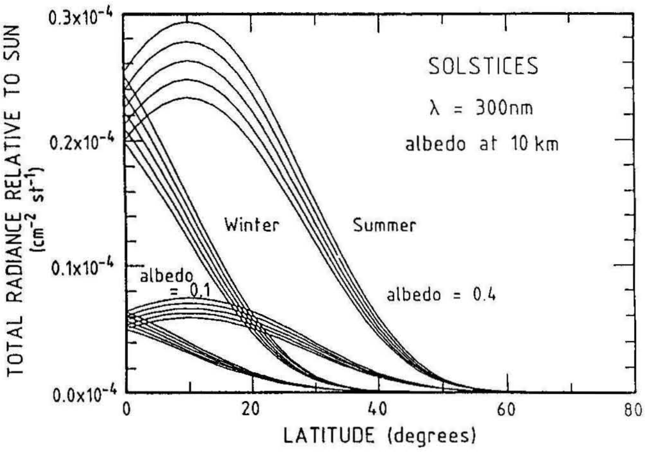

Fig. 4. Effect of a ground reflecting layer on the signal level at 300 nm, two computations are shown in order to determine the incidence of an albedo latitude variation. The other indications correspond to Fig. 2.

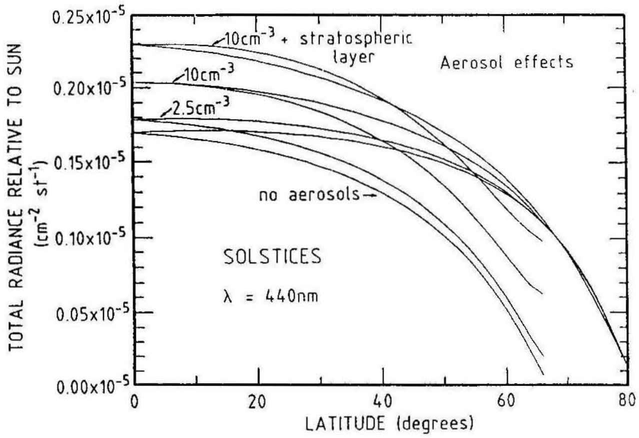

Fig. 6. Aerosol effects for three different aerosol models, unfortunately, the effects tend to cancel themselves at high latitudes, while at low latitudes outside the ozone spectral region, the aerosol variations, if optically thin are difficult to distinguish from the ground albedo effects.

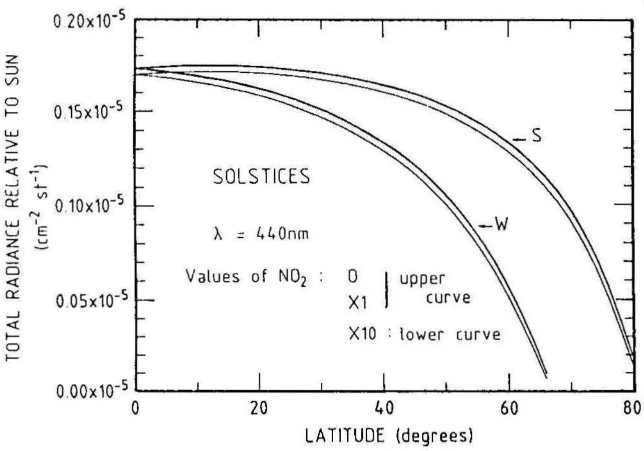

Fig. 5. Effect of a NO_2 variation of a factor of 10 on the received signal, this effect, in absolute, is negligeable compared to albedo variations and differential measurements are necessary in order to observe NO_2.