N95-11008

# MEASUREMENTS OF STRATOSPHERIC CONSTITUENTS BY ISAMS.

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## ABSTRACT

ISAMS is a limb sounding radiometer flying on the UARS, and designed to measure temperature, pressure, $O_3$, CO, NO, $NO_2$, $N_2O_5$, $HNO_3$, $CH_4$, $H_2O$, $N_2O$ and aerosol. Its capabilities are described, together with the present status of validation of its data products, and plans for future improvements.

## 1. INTRODUCTION

The Improved Stratospheric and Mesospheric Sounder (ISAMS) is a limb sounding infrared pressure modulator radiometer, which is a part of an integrated payload to study the energetics, chemistry and dynamics of the Middle Atmosphere, the Upper Atmosphere Research Satellite (UARS). The main objectives of the ISAMS project are to study: (1) the circulation and dynamics of the Middle Atmosphere, using measurements of thermal structure and tracers ($CH_4$, $N_2O$, $H_2O$); (2) the middle atmosphere water budget and associated chemistry, using measurements of $H_2O$, $CH_4$ and CO and the circulation; (3) the nitrogen chemistry and ozone depletion, using measurements of $N_2O$, NO, $NO_2$, $HNO_3$, $N_2O_5$ and $O_3$, together with chemical models. Other objectives include the study of aerosols, using data from spectral window regions and a range of other topics involving data from more than one UARS instrument, and from correlative measurements.

## 2. THE INSTRUMENT

Measurements are made of thermal emission in infrared spectral vibration bands of the individual molecular constituents, using limb scanning geometry. Radiation in each channel is spectrally selected by an interference filter, providing a 'wideband' signal, and then further selected using a pressure modulator cell (PMC) to select radiation from just the individual lines of the target species (the 'pressure modulated' signal). Thus each detector provides two signals. The optics allows the field of view to be scanned both vertically, in steps of 1.18 or 2.36 km on the limb, and horizontally, to compensate for doppler shift of the atmospheric lines relative to the spacecraft. Each channel uses an array of four detectors, each 2.36 km wide when projected onto the limb, and separated by one detector width. The detectors are cooled to 80-90 K by means of a miniature Stirling cycle cooler developed specifically for ISAMS. (Taylor et al, 1992)

The nominal vertical resolution of the instrument is 2.36 km, and the horizontal resolution, which is determined by the scan pattern, is about 200 km along the view point (tangent) track and about 200-400 km along the line of sight. Details of the spectral intervals used and the altitude ranges of each measurement are given in the table.

The spacecraft is in a 57° inclination orbit, at an altitude of 585 km. Consequently the limb view at 90° to the orbit track gives a view point track extending from

| Channel | Wavenumber | Objective | Interfering Species |
|---|---|---|---|
| 0 | 2139-2221 | CO | $CO_2$, $O_3$, $N_2O$, $H_2O$ |
| 1 | 1425-1513 | $H_2O$ | $O_2$, $CH_4$ |
| 2 | 1250-1290 | $N_2O$ | $CH_4$, $H_2O$, $CO_2$, $HNO_3$ |
| 3.0 | 626-660 | $CO_2$ | $O_3$, $H_2O$ |
| 3.1 | 605-625 | $CO_2$ | $O_3$, $H_2O$, $N_2O$ |
| 3.2 | 860-900 | $HNO_3$ | $CO_2$, $O_3$, $H_2O$, F11, F12 |
| 3.3 | 990-1010 | $O_3$ | $CO_2$, $H_2O$ |
| 4 | 1839-1941 | NO | $H_2O$, $CO_2$, $O_3$ |
| 5 | 1580-1612 | $NO_2$ | $H_2O$, $O_2$, $CH_4$, $N_2O$ |
| 6 | 1320-1380 | $CH_4$ | $H_2O$, $CO_2$, $N_2O$, $HNO_3$ |
| 7.0 | 626-660 | $CO_2$ | $O_3$, $H_2O$ |
| 7.1 | 605-625 | $CO_2$ | $O_3$, $H_2O$, $N_2O$ |
| 7.2 | 1230-1250 | $N_2O_5$ | $CH_4$, $N_2O$, $CO_2$, $H_2O$, $O_3$ |
| 7.3 | 821-836 | aerosol | $O_3$, $CO_2$, $H_2O$, F11 |

34° in one hemisphere to 80° in the other. ISAMS normally views on the side of the spacecraft away from the sun, but when the spacecraft is in darkness it can view the sun-side. This allows coverage from 80° N to 80° S at favourable parts of the orbital precession cycle.

## 3. DATA PROCESSING

Data is processed along with all the other spacecraft data at the UARS Central Data Handling Facility, using software developed and maintained by the ISAMS team. The retrieval technique uses a sequential optimal estimator, or Kalman Smoother, to obtain distributions of temperature, pressure and constituents from the measured radiances. (Marks and Rodgers, 1992)

A critical component of the retrieval method is the forward model. This calculates the radiance that would be seen by the instrument for a given atmospheric profile. The optimal estimator adjusts the profile until the calculated radiance matches the measured radiance to within experimental error. The forward model does a radiative transfer calculation for the spherical geometry of the limb geometry, including refraction and line-of-sight variation, using all the emitting gases and aerosol that are relevant in each channel. The estimator also requires derivatives of the radiance with respect to the temperature and constituent profiles.

After data quality checks and radiometric calibration, radiances from the $CO_2$ 15 $\mu$m band are used to retrieve the temperature distribution. Subsequently, the temperature profile and radiances from each of the constituent channels in turn are used to retrieve the corresponding constituent. The order of retrieval is significant, as emission from more than one gas is present in most of the spectral regions, and for example the previously retrieved concentration of water is required as a correction in the $NO_2$ retrieval.

## 4. CURRENT VALIDATION STATUS

To date the ISAMS team has been involved in checking out the instrument and in validating the data processing software and retrieval techniques. Except for a period from January 18 to March 27 1992, when there was a hardware problem with the chopper, the instrument has performed extremely well, and good quality data is being received.

Details of this process for some channels will be found in companion papers presented at this meeting, on ozone (Connor et al, 1992), aerosol (Lambert et al, 1992) and $NO_x$ (Kerridge et al, 1992). The current status is that the data are mainly of such a quality that they can be released to the rest of the UARS Science Team for further evaluation and intercomparison, but are not yet suitable for general scientific use in the refereed literature. There are some known deficiencies that are still being worked on by the ISAMS team.

## 5. TEMPERATURE MEASUREMENTS

Temperature is obtained from the $CO_2$ 15 $\mu$m band emission, as measured in two separate groups of detectors. The forward model $CO_2$ emission includes the effects of gradients of temperature along the line of sight, and emission by ozone and aerosol as spectral contaminants. The ozone effect is small, and is currently neglected. Due to the eruption of Mt Pinatubo, the aerosol effect is extremely significant, especially below 10 mb, and work is continuing on the best approach to allowing for it. For example a preliminary aerosol retrieval may be carried out using climatological or NMC temperatures, The preliminary aerosol retrieval then being used to allow for the aerosol emission in the $CO_2$ channels when carrying out the temperature retrieval.

The accuracy of the temperature retrieval is important not only for dynamical studies, but also for the retrieval of constituents. Consequently, validation of temperature retrieval is critical to the overall success of ISAMS.

Figure 1 shows averaging kernels (Rodgers, 1990) for a typical temperature retrieval. These indicate the vertical resolution of the retrieved temperature and its sensitivity to the atmospheric temperature. Figures 2 show some typical retrieved profiles, compared with coincident lidar data from the site at Obervatoire Haute-Provence. These indicate the extent to which ISAMS can retrieve the small scale wave motions seen by the lidar. Figure 3 shows a cross section along a view point track through a recent stratospheric warming event, showing the familiar pattern of cooling in the mesosphere corresponding to warming in the stratosphere.

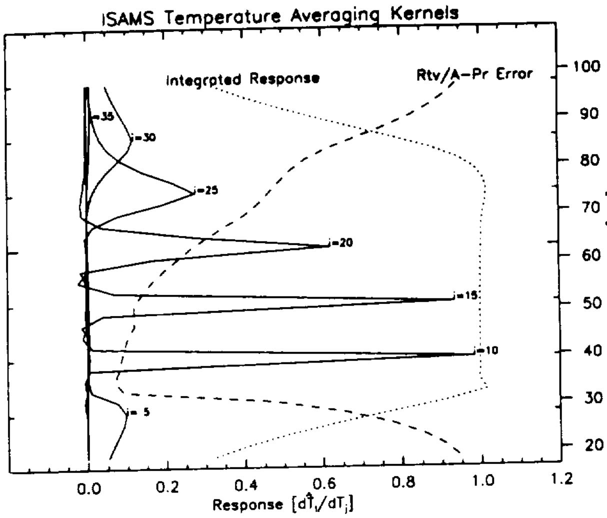



Figure 1. A selection of averaging kernels for an ISAMS temperature retrieval. The solid line is the derivative of the retrieved profile with respect to the true profile. The width of the peak indicates the vertical resolution of the retrieval, and its area (the dotted line) indicates qualitatively the partition of the retrieved profile between the true profile and the a priori. The dashed line is the formal error on the retrieval divided by the a priori standard deviation.

## 6. AEROSOLS

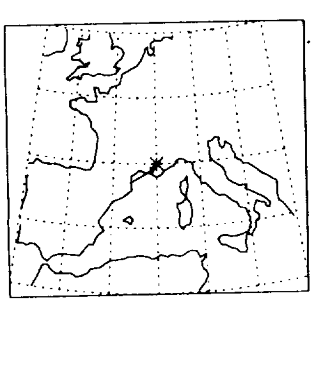
Emission from aerosol from the Mt Pinatubo eruption is present in all channels up to about 10 mb, so it is important to understand this well. Retrieval of the optical depth in the window channel at 12.1 $\mu$m gives a good indication of the amount present, although conversion of optical depth to e.g. mass loading is problematical. To allow for aerosol emission in other channels, it is necessary to know the emission spectrum relative to 12.1 $\mu$m. This varies with time and position, as it depends on the nature of the aerosol and its drop-size distribution, and so cannot be precomputed exactly. However retrieval of aerosol optical depth in other bands, assuming that the constituents mixing ratios have their climatological values, gives an empirical estimate of the spectrum (Lambert et al, this meeting), so that approximate corrections can be made. The accuracy of corrections made by this method are still being studied, and retrieved constituents below about 10 mb are suspect at present.

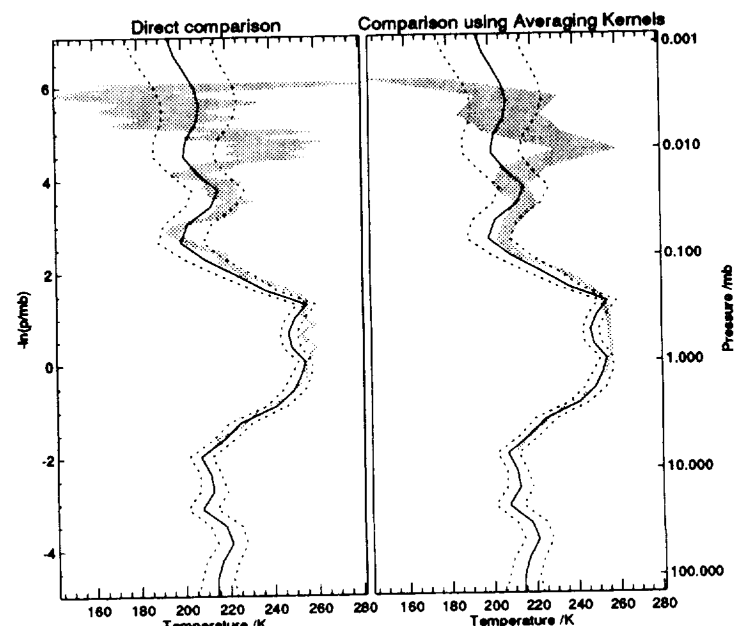
## 7. GASEOUS CONSTITUENTS

Ozone is measured in a wideband channel only, as it is too reactive to contain in a pressure modulator cell. The only significant spectral contaminant is aerosol. The current status of Ozone retrieval validation is described by Connor et al (this meeting).

Of the nitrogen species, ISAMS measures NO, $NO_2$, $N_2O_5$, $N_2O$ and $HNO_3$. The validation status of the first three of these gases is described by Kerridge et al (this meeting).

CH4 and N2O are retrieved jointly since each is the major contaminant in the signal measured by ISAMS for the other gas. Since both the CH4 and N2O channels contain PMCs, there are four channels (two PM and two wideband) which may be used to provide radiances for the joint retrieval. However, the channels must also provide consistent information and due to aerosol contamination in the wideband signal, so far only the two PM channels have been used. Much of the data appears to be of good quality and produces retrieved CH4 and N2O similar to






Shaded region = Lidar +/- 1SD. Solid Lines = ISAMS. Dotted lines = ISAMS +/- 1SD

Figure 2. ISAMS temperature profile for 22.41 UT on 10 December 1991 at 43°N, 4.3°E, compared with a Lidar profile taken at Observatoire Haute Provence (44°N, 6°E). In the right hand panel, the lidar profile has been smoothed using averaging kernels similar to those of figure 1, in order to make a more direct comparison.

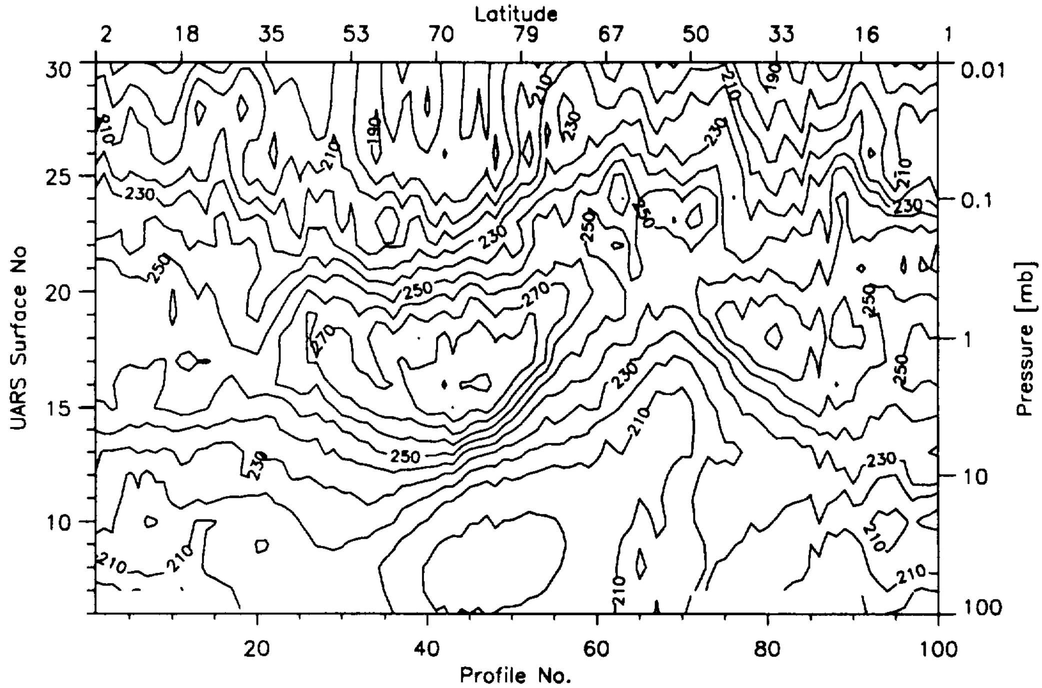



Figure 3. A retrieved temperature section along the view point track on 20 December 1991, passing through the warm and cold areas of a stratospheric warming.

that from SAMS (Jones and Pyle ). Some days in January are a little anomalous and these are under investigation.

Nitric acid, like ozone, is a wideband channel only. Its signal, however, is much weaker. Furthermore it is concentrated in the lower stratosphere. For both of these reasons, the effects of the aerosol contamination on the $HNO_3$ channel has been severe. We have therefore deferred any attempt at correcting the aerosol effects until they are better understood through work on other channels.

Nitric oxide is proving to be difficult to calibrate at present, owing to thermospheric emission which shows large variation with solar activity (Ballard et al, this meeting).

Retrieval of CO is particularly complex, because of departures from local thermodynamic equilibrium, and in the daytime, resonance fluorescence scattering sunlight. The latter allows us to see emission from CO up to about 100 km in the daytime, but makes the validation of the retrieval difficult. Qualitatively reasonable results have been obtained, showing the expected increase in CO with height into the upper mersosphere, and an increase towards high latitudes in the winter, as predicted by Solomon et al (1985).


ACKNOWLEDGEMENT: Our thanks are due to Dr M.L. Chanin for permission to show the OHP lidar data.


REFERENCES


Ballard, J. et al., Evidence from ISAMS data of nitric oxide production in the earths thermosphere following solar flare activity, this meeting.

Connor, B.J. et al., 1992, Validation of ISAMS Measurements of Ozone, *this meeting*.

Kerridge, B.J. et al., 1992, Preliminary results concerning validation of ISAMS measurements of NO, $NO_2$ and $N_2O_5$, *this meeting*.

Lambert, A. et al., 1992, ISAMS Observations of Stratospheric Aerosol, *this meeting*.

Marks C.J. and C.D. Rodgers, 1992. A retrieval method for atmospheric composition from limb emission measurements. Submitted to *J. Geophys. Res.*

Rodgers, C.D., 1990, Characterisation and Error Analysis of Profiles Retrieved from Remote Sounding Measurements, *J. Geophys. Res.* **95** pp5587-5595.

Solomon S. et al., 1985, Photochemistry and transport of Carbon Monoxide in the Middle Atmosphere, *J. Atmos. Sci.*, **42**, p1072-1081.

Taylor, F.W., C.D. Rodgers, J.G. Whitney, S.T.Werrett, J.J. Barnett, G.D. Peskett, P. Venters, J. Ballard, C.W.P. Palmer, R.J. Knight, P. Morris, T. Nightingale, A. Dudhia, 1992. Remote sensing of atmospheric structure and composition by pressure modulator radiometry from space: the ISAMS experiment on UARS. Submitted to *J Geophys. Res.*