Validation of SCIAMACHY by International Space Station based instruments.

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ABSTRACT

The International Space Station will fly simultaneously with important Earth Observation programmes and satellites. Most notably the ESA ENVISAT satellite will fly an extended atmospheric chemistry payload which will require a complete validation exercise. Among these instruments, the three-national SCIAMACHY atmospheric sounders presents commonalties with SAGE III which is already manifested on the ISS, the validation possibilities are discussed from an orbital point of view while a brief description of the capabilities of both instruments is given.

SCIAMACHY description.

SCIAMACHY is a joint project of Germany ,The Netherlands and Belgium for global atmospheric measurements. It has been selected by ESA to fly on the ENVISAT-1 polar platform, to be launched in 1998/1999. SCIAMACHY comprises a moderately high resolution (0.2-0.4 nm) spectrometer to observe transmitted, reflected and scattered light from the atmosphere in the UV, visible and near infrared wavelength regions over the range 240-1700 nm, and in 2 selected regions between 2.0 and 2.4 micron. The goal is to allow small optical absorptions (as small as 2E-4 in some regions of the spectrum) to be detected. SCIAMACHY is designed to operate in nadir mode as does the present GOME ozone sensor on ERS2 which is actually a SCIAMACHY derivative. SCIAMACHY will also operate in occultation mode using the Sun and the Moon as sources, a sunlit limb observation mode is also planned, the field of view is 0.045° X 2.3° and thus permits to scan the solar disk during occultation. The present objectives and philosophy of operation are still best described in the proposal (Burrows et al, 1988), however the instrument has evolved during seven years of design until its final integration in the fall of 1996, its most complete description of readable size is now the "SCIAMACHY Instrument Requirements Document" (Burrows et al, 1995).

SCIAMACHY is designed to measure both tropospheric and stratospheric abundances of a number of atmospheric constituents, which take part in Ozone break-off or in the greenhouse effect. Targeted species are: in the troposphere - Ozone, O_4, N_2O, NO_2, CH_4, CO, CO_2, H_2O and aerosols and, in polluted conditions, SO_2 in the stratosphere - Ozone, NO, NO_2, NO_3, CH_4, CO_2, H_2O, ClO, OClO, BrO, aerosols, stratospheric clouds, and possibly, HCHO and CO.

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Table 1: Properties of the SCIAMACHY instrument.

Band	Full performance range (nm)	Pixel resolution (FWHM approximately twice)
1	240-309	0.12
2	314-394	0.13
3	394-620	0.22
4	604-805	0.24
5	785-1050	0.27
6	1000-1750	0.74
7	1940-2040	0.11
8	2265-2380	0.13

SAGE III description.

The Stratospheric Aerosol and Gas Experiment III (SAGE III) will measure vertical profiles of O_3, NO_2, H_2O, NO_3, OClO, temperature, neutral air density, and aerosols from the cloud tops in the troposphere through the stratosphere, and into the mesosphere for O_3 using the solar and lunar occultation measurement techniques. An extensive description can be found in Chu (1996) where all the details reported here have been extracted. SAGE III continues the SAM/SAM II/SAGE/SAGE II lineage of UV/VIS radiometers used for monitoring stratospheric aerosols and gases with a grating spectrometer and a Charge Coupled Device (CCD) linear array detector providing measurements in nine channels between 280 nm and 1550 nm. Presently manifested on board a polar-orbiting Meteor-3M satellite and the International Space Station the SAGE III instruments will provide global, long-term measurements of atmospheric composition in the period between 1999 and 2005.

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SAGE III incorporates two new concepts: a CCD linear array of detectors and a 16 bit A/D converter; combined these new features allow wavelength calibration, self-consistent determination of the viewing geometry, lunar occultation measurements, and expanded wavelength coverage. While retaining the proven design concepts of the SAM/SAGE instruments, the optical configuration had to be significantly redesigned to accommodate the array detector.

The spectrometer with the CCD array of detectors provides continuous wavelength coverage between 280 and 1030 nm at 0.94 nm resolution will permit the measurement of multiple absorption features of each gaseous species and multi-wavelength measurements of broadband extinction by aerosols. In the present configuration, 9 channels (66 sub-channels) will be routinely utilised in the solar occultation measurements and 3 channels (340 sub-channels) in the lunar occultation measurements, greatly decreasing the random error in the measurements (precision), and allowing for more accurate modelling of the multi-wavelength aerosol extinction. The field of view covers 3 pixels in solar occultation and corresponds to 0.008°X 0.24° (decimal degrees as indicated for SCIAMACHY). This high resolution allows to account for sunspots and even the enlarged field of view (ten pixels) planned for Moon observations will allow to consider the inhomogeneities in the Moon albedo.

Table 2: SAGE Channel Specifications

Solar

Channel	Wavelength (nm)
1	290
2	385
3	430-450
4	525
5	600
6	740-780
7	920-960
8	1020
9	1550

Lunar

1	380-680
2	740-780
3	920-960

Comparison between SCIAMACHY and SAGE III operations and orbits.

The main difference between both instruments in occultation is in the balance between spectral resolution and field of view, the extremely narrow field of view of SAGE is compensated by a lower spectral resolution in order to conserve signal to noise ratio and integration speed. The characteristics of SAGE III would probably forbid its use as a nadir instrument. An other fundamental difference resides in the orbits of the spacecrafts, while the heliosynchronous orbit has been studied for occultation by Vercheval (1987) in relation with SCIAMACHY and has been shown to yield a latitude coverage of two bands, one in each hemisphere, for the 10 hours ascending node, sunset will be around 60°N while sunrise will be around 55° S; similar computations performed for the 57° orbit of SPACELAB I (Vercheval, 1978) and the MIR station (Vercheval, 1995, Sukhanov, 1995) show a wide variety of latitudes. New computations using the computer program developed by A. Sukhanov (1995) for the planning of the infrared occultation spectrometer MIRAS are shown on figures 1 and 2. The β angle is the angle between the orbital plane and the solar direction, it determines the conditions for solar occultation, a value of 0° correspond to an orbit in the earth orbital plane, while a 90° value correspond to a completely sunlit orbit, for the heliosynchronous orbit the occultation condition is that β should be lower than 60° in absolute value and is not met by the orbits of ascending nodes between 4h. and 8h. and reciprocally between 16h. and 20h. Coincidence between the observations is not evident and is constrained by the orbital parameters of the station which will be known only after the launch of the main station block. It should be noted that the β occultation condition for the ISS is of about 70° for a circular orbit of 400 km altitude and is thus reached on some rare occasions, in these events, the station sees a space equivalent of the midnight sun where the sun comes down in the earth's atmosphere and then comes back up with a very short or without occultation. These conditions are usually considered as negative because the ground track of the observations is too long to allow for coherent inversion of limb data in terms of vertical distribution but they yielded unique scientific data for both the GRILLE spectrometer on SPACELAB 1 (Laurent et al, 1985). The high β conditions also allow a limb sounder on the station to go above the 60° latitude (fig. 2). The β angle and thus the observation latitudes depend both on the longitude of the ascending mode of the orbit, the consequence of this is that the dates of observation of occultation at high latitude will be constrained for the entire station life by the orbital insertion time of the first element of the station.. Supplemental β conditions correspond to the field of view obstructions present on a complex spacecraft as the station, it should be kept in mind that on the contrary of SPACELAB which could define its attitude on the basis of scientific operations, the station has to give in priority solar access to the solar panels of the main module and also the size and the complexity of the station will limit possible manoeuvres, thus each remote sensing instrument will have to consider specific target access problems which will vary with the lifetime of the station and the additions of new modules and panels.

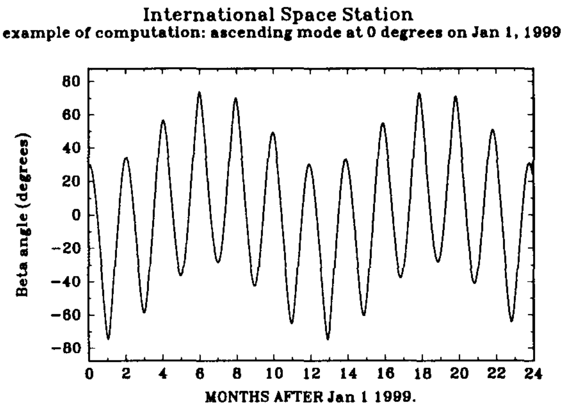

Fig 1: computation of the β angle in space station conditions with a circular orbit of 400 km. and a longitude of 0° for an ascending node at 0h. on Jan 1, 1999

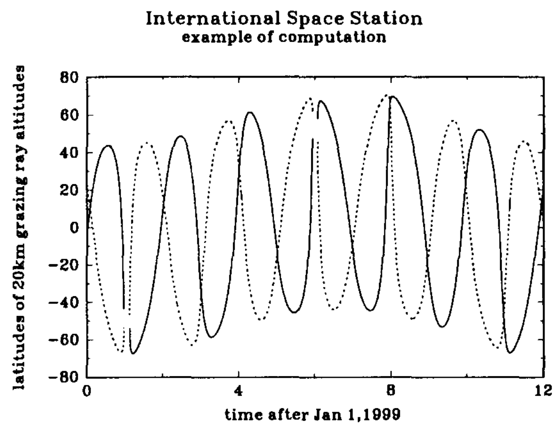

Fig 2: example of computation of latitude of solar tangent point at the altitude of 20 km for a station flying in the conditions of fig 1. Solid line is for sunset while dashed line is for sunrise (time in months).

The validation exercise will thus only exceptionally be possible on collocated occultation observations but will mostly concern the comparison of the high altitude resolution SAGE III ozone and aerosol profiles with profiles inverted from the main SCIAMACHY mode which is nadir observation.

Other possible atmospheric chemistry instruments on the ISS.

On NASA side, no other instruments are manifested, however, the infrared occultation interferometer ATMOS which successfully flew on SPACELAB during four missions from SPACELAB 2 to ATLAS 3 is clearly proposed and would be the perfect complement to SAGE III. On Russian side, several possibilities exist as complete modules can be transferred from the present MIR 1 to the new station as was planned when the project began as MIR 2, an evident solution would be to add a refurbished PRIRODA module to the station, PRIRODA (Timofeyev, 1996, see also the Institute of Space Research (IKI) PRIRODA WWW page) launched on April 23 1996 is a complete earth observation payload combining nadir and limb observations. The SPEKTR module carries the MIRAS infrared solar occultation spectrometer, now in standby mode and waiting for the replacement of a power conditioning unit, it houses also the PHOENIX occultation U.V. instrument in testing phase (September 1996). MIRAS was originally planned for the MIR 2 station which was close to the main station module and thus needs minimum adaptation to fly on the ISS at its planned location between the main solar panels.

Table 3: PRIRODA payload.

•Infrared spectrometer ISTOK-1 (limb-scanning) from 4 to 16 microns (Russia, Czechia)
• Imaging spectrometers MOS-A and MOS-B (17 channels from 400 to 1010 nm, Germany)
• Spatial high resolution multispectral and stereo scanner MOMS-2P (VIS/NIR, Germany)
• Conical scanner MSU-SK, 5 channels in the VIS and NIR bands, tilt capability
• Lidar ALISSA (France)
• Profile-meter "OZONE-M" for determination of ozone-profiles from occultation measurements at 0.26 and 1.02 microns (Russia)
waiting for launch: ATMOS class DOPI interferometer (Germany

A similar payload flying simultaneously with SCIAMACHY would constitute a validation tool in the sense that all the SCIAMACHY wavelengths are covered and that all SCIAMACHY results can be checked against similar end-products from other instruments. The PRIRODA value for validation of other instruments will be easily assessed after the operational period which is due to begin at the end of September 1996. In the same order of ideas, several instruments of the MARS96 payload, if they prove successful in Mars orbit could be proposed for earth observation, their light design and sturdy building make them ideal candidates for station use. Especially, the SPICAM-S (Ackerman et al, 1996) solar occultation instrument covers the U.V. between 280 and 525 nm with a resolution of 1 nm and the infrared between 2 and 5 μm, the stellar occultation instrument SPICAM-E (Bertaux et al, 1996) achieves the functions of GOMOS. No documents on Japanese intents could be found to the date of September 1996, but here again, the ADEOS payload demonstrates NASDA interest for earth observations and will certainly lead to proposals on the ISS.

Conclusions

The scientific objectives of an atmospheric chemistry payload on the ISS and SCIAMACHY on ENVISAT are close and cross-validation of the end-results will bring confidence in both data set. Moreover, the only presently manifested atmospheric instrument (SAGE III) presents commonalties with SCIAMACHY which will lead to request Sun or Moon occultation operations for the events where simultaneous occultations happen in the same air-mass, orbit analysis show these opportunities to be rare and they should be searched as soon as a reliable ephemeris can be issued for both spacecrafts. The ISS development process should be followed in order to propose in due time relevant atmospheric chemistry instruments using the opportunities of the 51.6° orbit.

References

Ackerman, M., Bertaux, J.-L. Deceuninck, H., Dimarellis, E., Korablev, O., Moroz, V., Muller, C. Neefs, E. Peetermans, W. Simon, P.C. and. Rodin, A., SPICAM-S: Spectroscopy for the investigation of the characteristics of the Martian atmosphere using the solar occultation technique, MARS96 WWW page, IKI, Moscow, 1996.

Bertaux, J.L. Ackerman, M. Korablev, O. Moroz, V. Chassefiere, E. Widemann, T. Dimarellis, E. Taulemesse, C. Dubois, J.P.. Simon, and Muller, C. SPICAM-E: a versatile imaging spectometer for sounding the atmosphere of Mars, MARS96 WWW page, IKI, Moscow, 1996.

Burrows, J.P., Chance, K., Crutzen, P.J., Geary, J.C., Johnson, T., Harris, G.W., Moortgat, G.K., Muller, C., Perner, D., Pommereau, J.P., Schneider, W., Simon, P.C. and Vercheval, J., The SCIAMACHY project, A European proposal for the ESA Polar Platform, MPI (Mainz), 1988.

Burrows, J.P., Chlebek, C., Muller, C. and Goede, A, The SCIAMACHY Instrument Requirement Document, DARA, Bonn, 1995.

Chu, W.P., Sage III instrument description, SAGE III WWW site, NASA Langley Research Center, 1996.

Laurent,J., Lemaitre,M.P., Besson,J., Girard,A., Lippens,C., Muller,C., Vercheval,J. and Ackerman,M. Middle atmospheric NO AND NO observed by means of the Spacelab One GRILLE spectrometer. NATURE, 315, 126-127, 1985.

Sukhanov, A, private communication, 1995.

Timofyev, Y.M. and Tonkov, M.B., Molecular absorption models in the atmospheric remote sensing, to be published in the proceedings of the "12th International Symposium on high resolution molecular Spectroscopy", St. Petersburg, 1996.

Vercheval, J., Détermination des conditions de lancement de Spacelab en vue de satisfaire les exigences d' un projet d' expérience par spectrométrie d' absorption, ESA journal, 2, 19-26, 1979.

Vercheval, J. Latitude coverage of solar absorption spectrometry observations of the middle atmosphere from a heliosynchronous orbit, ESA journal, 11, 233-238, 1987.

Vercheval, J., private communication, 1995.