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REPORT ON CLIMATE DATA SET FROM HYPERSPECTRAL IR INSTRUMENTS

In response to CGMS action R33.04

This working paper reports on the potential of hyper-spectral infrared sounding instruments to provide climate data records. Hyper-spectral instruments like the Atmospheric Infrared Sounder (AIRS), flying on the AQUA satellite, and the forthcoming interferometers IASI (Infrared Atmospheric Sounding Interferometer) on Metop and CrIS (Cross Track Infrared Sounder) on NPOESS provide the means to pursue relevant and comprehensive climate monitoring. The advantage of high-spectral resolution spectrometers is the inherently good instrument characterisation and the possibility for very accurate calibration. A potential problem is the high data volume which calls for a real-time production of a reduced data set.

REPORT ON CLIMATE DATA SET FROM HYPER-SPECTRAL IR INSTRUMENTS

1 INTRODUCTION

This working paper reports on the potential of hyper-spectral infrared sounding instruments to provide climate data records. Hyper-spectral instruments like the Atmospheric Infrared Sounder (AIRS), flying on the AQUA satellite, and the forthcoming interferometers IASI (Infrared Atmospheric Sounding Interferometer) on Metop and CrIS (Cross Track Infrared Sounder) on NPOESS provide the means to pursue relevant and comprehensive climate monitoring. The advantage of high-spectral resolution spectrometers is the inherently good instrument characterisation and the possibility for very accurate calibration. A potential problem is the high data volume which calls for a real-time production of a reduced data set.

The background for this paper is Recommendation 33.04 which requests CGMS members to consider definition and production of a climate data set from hyperspectral sounders with substantially reduced data volume. This would substantially ease the analysis of long time series. It is also noteworthy that Goody et al. (1998) propose a spectrometer with high-spectral resolution for climate monitoring and for the testing of climate models. The second observing system that Goody et al. (1998) propose is radio occultation measurements of refractivity using signals from satellites of the global positioning system.

The utility of hyperspectral measurements for climate observations has been shown by Harries et al. (2001). Clearly an advantage of hyperspectral instruments is the wealth of climate variables that can be inferred. Generally speaking one can distinguish three types of variables, which describe the development of climate. Forcing variables are external and influence and control the climate. Response variables describe the response of the climate to this forcing. And there are feedback variables, which respond to the forcing and through this response (which is a change) feed back into the forcing and modify it.

Examples of climate forcing are the incoming solar irradiance, absorption and emission of radiation by gases such as carbon dioxide, carbon monoxide etc. in the atmosphere. Typical response variables are atmospheric temperature, winds, precipitation, sea level etc. Feedback variables are typically cloud cover, snow and ice coverage, vegetation, etc.

With infrared high spectral resolution data a large number of these variables can be measured / derived. As such a spectrum measured at high spectral resolution is a climate data record, as it contains a wealth of information on climate key variables.

This paper discusses briefly the potential of those spectra and reports on efforts to produce a volume-reduced data set from IASI.

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2 CLIMATE DATA SET FROM HYPERSPECTRAL IR INSTRUMENTS

2.1 Contents of an infrared spectrum

Typically infrared sounding instruments probe the atmosphere in the spectral region from about 650 cm^{-1} to about 2750 cm^{-1}. Some instruments like the IASI instrument cover this whole region, whereas others like AIRS and CrIS provide spectral coverage only in parts of the IR spectra (Figure 1). Classical products derived from such spectra include profiles of temperature and humidity.

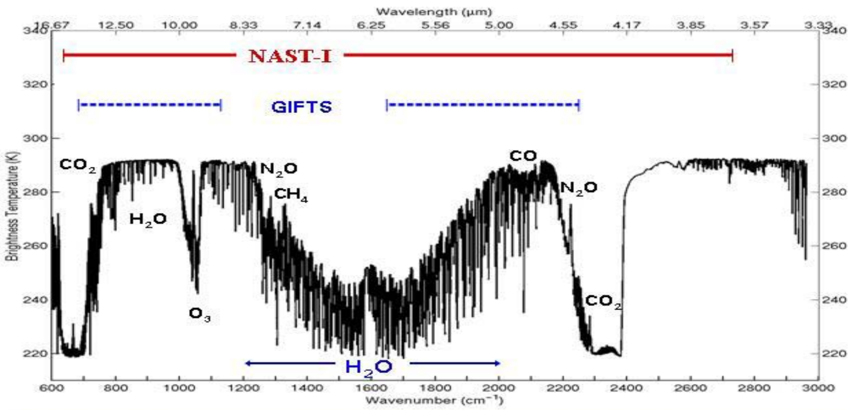

Figure 1: Infrared Spectrum at the top of the atmosphere as emitted by the Earth-atmosphere system (Goldberg, 2006)

Due to the high spectral resolution more pieces of information can be derived, leading to higher resolution and accuracy of temperature and water-vapour profiles, when compared to previously flown infrared sounders.
In other parts the infrared measurements are sensitive to greenhouse gases. Thus trace gases like carbon monoxide, carbon dioxide, methane, and nitrous oxide can be derived. In addition there is the possibility to derive Ozone total columnar amount and the ozone profile at coarse resolution.
Other climate relevant factors like cloud amount, cloud properties and aerosol properties can be derived from the spectral information.

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The AIRS instrument has already demonstrated the capability of hyper spectral infrared sounding to generate key products for climate monitoring (Goldberg, 2006). Key factors are a stable calibration and high radiometric accuracy. This is expected for both the IASI and CrIS instruments as well.

2.2 Products

A whole palette of products can be derived from hyper spectral measurements. This includes the synergetic use of companion instruments like imagers to assess the cloud cover within a sounder field of view, microwave observations to complement the soundings in cloudy areas and to clear cloudy infrared fields of view. Possible products comprise:

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- Cloud Cleared Radiances
- Temperature profiles
- Moisture profiles
- Ozone profiles
- Land/Sea Surface Temperature
- Surface Spectral Emissivity
- Cloud Top Pressure
- Cloud Fraction.
- Carbon Monoxide
- Carbon Dioxide
- Methane
- Cirrus Cloud Optical Depth and Particle Size

Retrieval accuracies of temperature and moisture profiles are expected to be 1 K and 15 % respectively over 1 km layers. This has been demonstrated with AIRS data already and is expected to be similar with IASI.

High spectral resolution sounders allow the observation of trace gases relevant for the greenhouse effect and for atmospheric chemistry. The columnar amount of Carbon Dioxide, Carbon Monoxide, Methane, and Ozone will be derived from IR sounding data with accuracy of 1.5%, 5%, 2%, and 1.5%, respectively. For Ozone it is also expected to obtain vertical profile information, about three to four pieces of information with accuracy between 10 and 30%.. With the AIRS instrument it was demonstrated already that the flask measured seasonal variation of CO_2 could be tracked with an accuracy of 0.43 ± 1.20 ppmv. Carbon monoxide is the direct product from fossil fuel combustion and biomass burning. Global scale measurements are important for atmospheric chemistry and the monitoring of biomass burning. With the hyper-spectral sounders on polar orbiters nearly global coverage may be achieved, subject to identification of cloud-free areas.

The retrieval of Ozone will help to monitor the extent of the polar ozone holes, in synergy with the measurements of the Global Ozone Monitoring Experiment (GOME-2).

Hyper-spectral sounders are also able to yield “non classical” products. Aerosol absorption peaks in the 900 – 1100 cm^{-1} region, and show minimal absorption around 1232 cm^{-1}. Using the spectral signature dust and aerosol features can be retrieved. Sulphur dioxide is introduced into the atmosphere during volcanic eruptions. With AIRS it has been demonstrated that a simple subtraction algorithm of channels 1258.9 cm-1 and 1354.10 cm-1 reveal the SO_2 signature in volcanic eruption plumes.

2.3 Climate Products

If the radiometric accuracy and stability and the necessary precision of hyper-spectral measurements fulfils climate quality requirements, a wealth of variables important for the monitoring of climate change and variability can be derived from them and their companion instruments. It is necessary to provide the possibility for a reprocessing of the complete climate record, in case calibration is improved and scientific knowledge is advanced. A high quality of the climate data record must be provided and maintained by adequate stewardship.

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It is recommended to produce climate data sets from each hyper-spectral sounding instrument. It is recommended to generate a standardized thinned data set, which is defined on a geographic grid. There shall be two data sets per day, one for the ascending and one for the descending orbits, respectively. The NOAA/NESDIS approach could serve as a model.

It should be noted that The MetOffice in UK has a project to generate a climate data set from IASI. In the frame of this project IASI Level 1c global data from EUMETSAT and AMSU-A and MHS level 1b global data are used as input to generate a climate data record. IASI data will be thinned by a factor of 4 compared with the original data, choosing the data of one detector out of four in the IASI fields of view. No spectral thinning is foreseen. The output will have to be compressed, the method to be determined. Options are BUFR encoding, HDF format or simple gzip. All data will be archived. The archive need to assure long term storage, similar to EUMETSAT's UMARF, which contains all EUMETSAT mission data.

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3 CONCLUSIONS

Hyper-spectral infrared sounding instruments support both operational meteorology and climate monitoring requirements. Main requirements were focused on temperature and moisture profile observations at high precision and resolution to provide the necessary improvement in numerical weather prediction. Simulation of IASI capabilities and the experience with AIRS in orbit have shown that the spectral resolution and coverage of hyper-spectral sounding instruments allows the measurement of greenhouse gases the amount of which undergoes modifications by anthropogenic activities.

As discussed above efforts are currently under way to generate climate data records from hyperspectral sounder data. The resulting volume reduced data sets need to be stored over long periods. Easy access to the stored data is essential.

References

Goody, Richard, James Anderson and Gerald North, 1998: Testing Climate Models: An Approach. Bull Am. Meteorol. Soc., 79, No. 11, pp. 2541-2549.

Harries, John E., Helen E. Brindley, Pretty J. Sagoo and Richard J. Bantges, 2001: Increases in greenhouse forcing inferred from the outgoing longwave radiation spectra of the Earth in 1970 and 1997. Lett. to Nature, Vol. 410, pp. 355 – 357.