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A GLIMPSE INTO THE PAST: RESCUING HYPERSPECTRAL SI-1 DATA FROM METEOR-28 AND 29

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Abstract

This paper presents an overview of the measurements performed using the Fourier spectrometer SI-1 (Spektrometer Interferometer -1) which was developed by the Academy of Science of the GDR (German Democratic Republic) and was flown onboard three of the Soviet Meteor satellites between 1976 and 1979. EUMETSAT has been granted access to those measurements that are potentially of great interest as they bridge the time gap between the first satellite infrared spectral measurements with medium spectral resolution and the hyperspectral space meaurements nowadays. The SI-1 dataset was analyzed and completed with additional parameters originally missing. Each spectrum was visually inspected, its consistency with the provided meta-data assessed, and removed from the dataset in case of discrepancy. The comparison with IASI spectra shows the excellent quality of the data and its potential in the detection of climate change.

INTRODUCTION

Hyperspectral measurements of the Earth radiation from space are powerful means to remotely sense atmospheric and surface parameters. Continuous spectral measurements in the infrared with high spectral resolution allow extraction of many valuable information on the state of the atmosphere and the underlying surface without stringent a-priori hypotheses. Several hyperspectral infrared sensors are operating today on Earth observation satellites (for instance the Atmospheric InfraRed Sounder AIRS on AQUA, the Infrared Atmospheric Sounding Interferometer IASI on MetOp). The first satellite infrared spectrometers were flown on the Nimbus 3 and 4 satellites, namely the InfraRed Interferometer Spectrometer IRIS [Hanel et al., 1970] with 2.8 cm^{-1} spectral resolution and the Satellite Infrared Spectrometer SIRS [Wark et al., 1970], a grating spectrometer with a couple of fixed channels and a spectral resolution of 5 cm^{-1}. The technology at that time was, however, not robust enough to allow operational measurements and explains the absence of this kind of measurements during more than 25 years (Figure 1). First attempts to compare the data of the current hyperspectral instruments with those of the first-generation-spectrometers performed Harries et al. [2001] and Griggs and Harries [2007] demonstrating significant increase of the greenhouse effect during the years.

Interestingly enough, multispectral measurements of medium spectral resolution were also performed onboard of some of the Soviet „Meteor“ Low-Earth-Orbiting (LEO) meteorological satellite family which became operational in 1969. It was designed and developed by VNIIEM (All-Russian Scientific and Research Institute of Electromechanics) in Moscow and sponsored by the ROSHYDROMET agency, the Russian Federal Service for Hydrometeorology and Environmental Monitoring. The payload of three of these satellites included a model of the Fourier spectrometer SI-1 (Spektrometer Interferometer -1), developed by the Academy of Science of the GDR (German Democratic Republic). It flew first on Meteor-25, launched on the 15th May 1976. This first flight was, however, hampered by technical problems and the data were not useable. Two subsequent flights followed on Meteor-28, launched on the 29th June 1977, which provided measurements during 19 days between July and September 1977, and Meteor-29, launched on the 25th January 1979, which provided measurements during 40 days between January and June 1979.

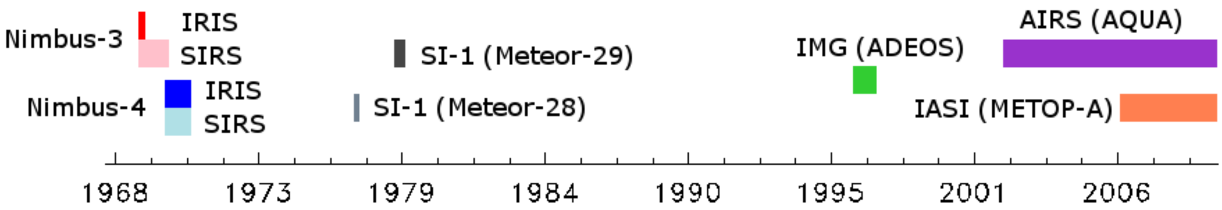

Figure 1: **Time series of infrared multi/hyper-spectral measurements of the Earth radiation from space.**

After reading the original products and merging with them the available meta-data, parameters originally missing in the products and needed for the analysis were added. They include orbital parameters which were retrieved from the reconstructed two lines elements using measurement time and location. A second step consisted in checking the spectrum quality and removing inconsistencies with the provided meta-data (e.g. cloudiness). A comparison of SI-1 spectra with the corresponding IASI ones spectrally degraded according to the SI-1 characteristics seems promising to use these spectra further on.

DESCRIPTION OF THE DATASET

SI-1 was designed to remotely sense the atmospheric temperature and humidity structure (Spänkuch 1980) and the atmospheric total ozone content (Feister 1980). It covered a wide spectral domain, from 6.25 to 25 µm with a spectral resolution of 5 cm^{-1} after apodisation. The Meteor spacecraft flew on circular orbits at an altitude comprised between 600 km and 700 km with an inclination of 98 degrees giving a footprint of about 2 x 2 degrees. Most measurements were acquired in real time when the satellite was visible from the receiving stations situated one north of Berlin, another one near Moscow. In that case, measurements were performed every 15 seconds (i.e. about every 100 km) with a calibration (deep space plus onboard blackbody) every 4 minutes. When the satellite was not visible, measurements were performed every minute (i.e. 400 km) with a calibration every 16 minutes, stored onboard and dumped during the next visibility period. Only measurements performed from Meteor-28 and 29 dumped to the german station are still available.

Meteor-28

The Meteor-28 dataset consists in 1087 spectra covering 19 days (22 orbits) in the period 5th July to 23rd September 1977. The geographical distribution of the measurements is given in Figure 2, which shows the brightness temperature at 10.4 µm. The high-density of datapoints over Europe corresponding to real-time measurements is clearly noticeable. A couple of full orbits are available and complete the dataset so that all latitudes are covered.

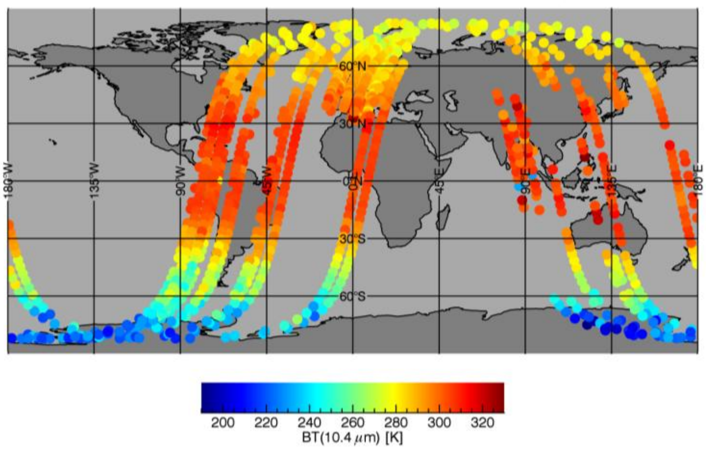

Figure 2: **Map of SI-1 measurements performed from Meteor-28.**

The number of measurements as a function of latitude and time is shown on Figure 3. Also on this plot, the expected slightly higher density of datapoints over the mid-latitudes is visible. The onboard recorder stopped working at the end of August 1977 and only real-time measurements were then performed.

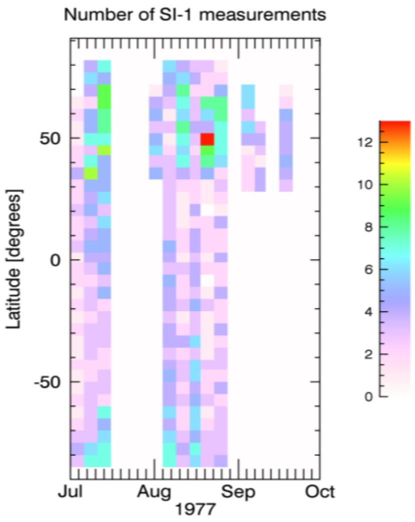

Figure 3: **Latitude-time histogram of the number of SI-1 measurements performed from Meteor-28.**

Meteor-29

The Meteor-29 dataset consists in 1675 spectra over 40 days (56 orbits) in the period 26th January to 19th June 1979 for Meteor-29. The geographical distribution of the measurements, quite similar to the Meteor-28 one, can be seen on Figure 4, which shows the brightness temperature at 10.4 µm.

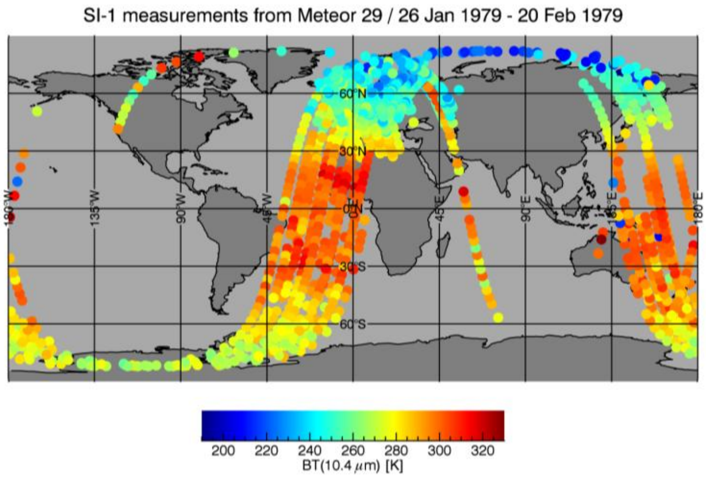

Figure 4: **Map of SI-1 measurements performed from Meteor-29.**

The number of measurements as a function of latitude and time (Figure 5) shows two distinct periods, the first period with both real-time and offline measurements in February 1979 and a second one in May 1979 where only real-time data could be obtained over mid-latitude in Europe due to the failure of the onboard recorder.

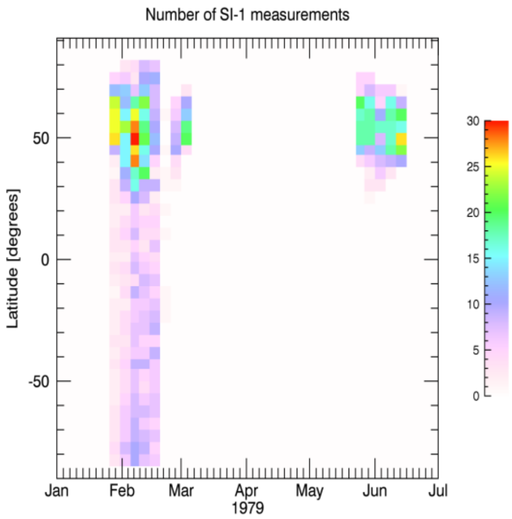

Figure 5: **Latitude-time histogram of the number of SI-1 measurements performed from Meteor-29.**

DATA FILTERING

Both datasets were screened to remove unreliable spectra obviously affected by instrumental artefacts. Additionally, a consistency check was made between the spectrum and the corresponding cloud coverage indicator. As a result, about 5% of the spectra were removed from the database.

We have checked the cloud coverage indicator using the method of radiances differences. It turned out that the indicator is reliable enough and that it was not possible to improve it in the frame of this study. We thus decided to keep original information, computed from a set of reference spectra that are compared to the actual measured spectra. The cloud coverage distribution is shown on Figure 6 for Meteor-28 data and Figure 7 for Meteor-29. The limited computer capacity available that time allowed only a reduced cloud classification scheme with the estimation of cloud coverage in steps of two octas [Güldner 1980]. As expected, most of the scenes are either cloud-free or overcast.

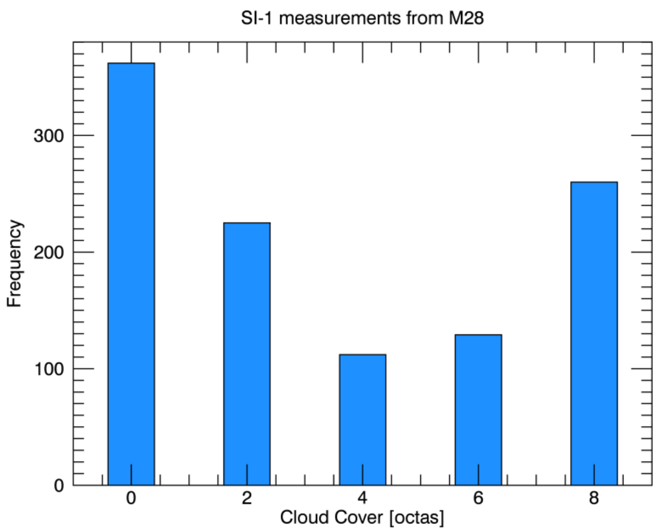

Figure 6: **Histogram of the cloud coverage indicator in the dataset from Meteor-28.**

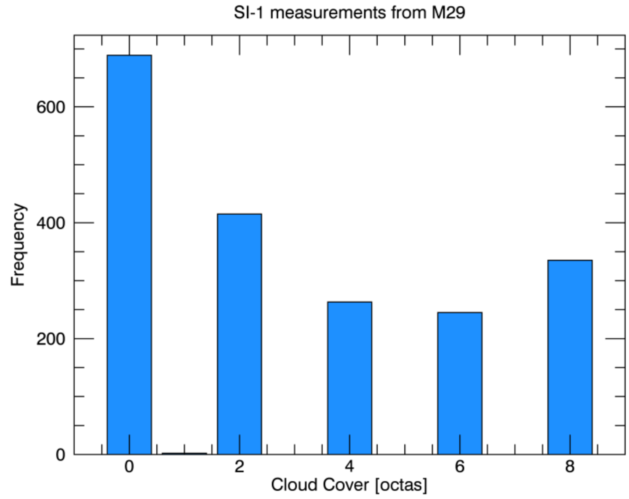

Figure 7: **Histogram of the cloud coverage indicator in the dataset from Meteor-29.**

DATA COMPLETION

Orbit reconstruction

The original dataset was delivered without any information about the characteristics of the orbit, apart from the altitude of the perigee and apogee as well as the inclination and date of launch. We have thus attempted to retrieve the orbital parameters, first using data from the North American Aerospace Defense Command (NORAD) that archives the so-called Three Line Elements (TLEs) of all spacecraft that have been launched. Interestingly enough, the orbit reconstructed from the NORAD TLE does not match the time-stamped geolocations of the measurements. An independent orbit determination was thus needed based on the actual time-stamped longitudes-latitudes and the velocity module from the TLEs that was considered as sensible. Using this method, we achieved good agreement between the positions and times of the reconstructed orbit and the positions and times of the actual measurements. This is illustrated on Figure 8 that shows that the difference in latitude and longitude between simulated and actual positions is of the order of -0.1 degree and does not exceed -0.55 degree.

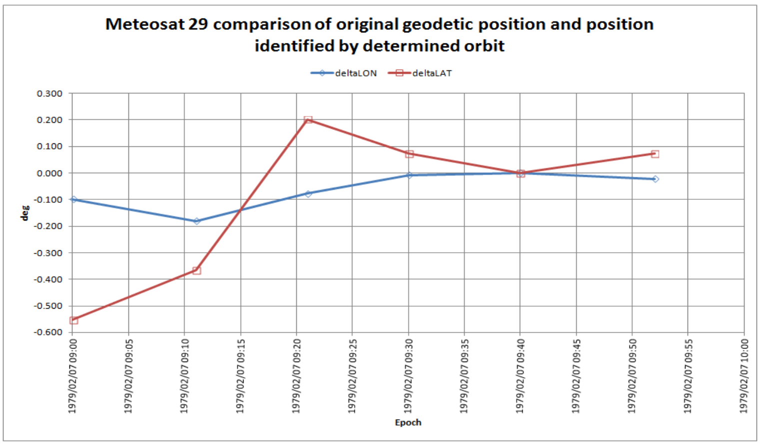

Figure 8: **Difference in latitude (red line) and longitude (blue line) between simulated and actual positions of the measurements.**

Sun azimuth and zenith angles, land-sea flag

The dataset have been completed with auxiliary parameters: the sun azimuth and zenith angle (Figure 9), as well as a land-sea flag computed from the ECMWF land-sea mask at 0.25 degree resolution.

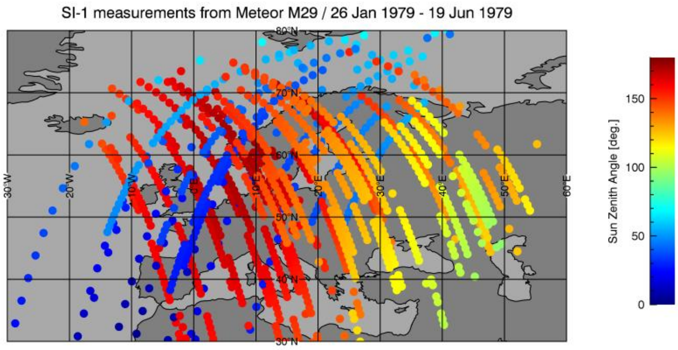

Figure 9: **Sun zenith angle as computed for each spectra of the Meteor-29 dataset**

COMPARISONS WITH IASI

Figure 10 shows a typical clear-sky spectrum acquired from Meteor-28 over sea. The aspect of this 38 years old spectrum is remarkable~~.~~ encouraging comparison with the most actual hyperspectral measurements performed by IASI on both Metop platforms.

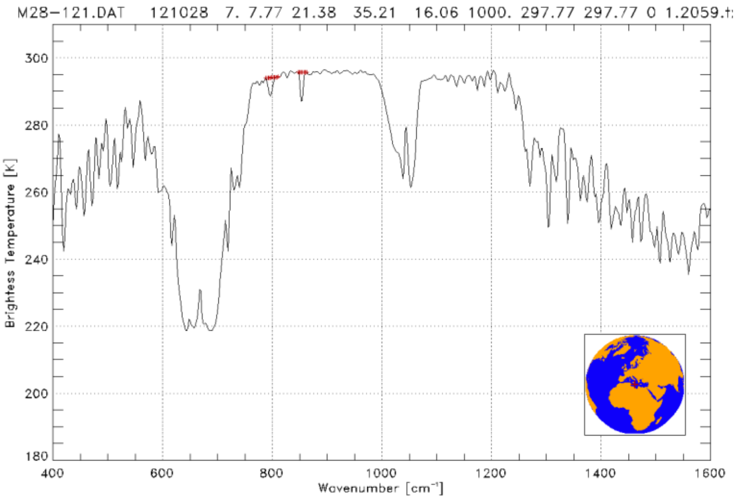

Figure 10: **typical clear-sky spectrum from SI-1 (Meteor-28, 7th July 1977 over the Mediterranean Sea).**

In order to ease the comparison, we have performed an average of three SI-1 cloud-free spectra taken over the tropical Atlantic. On the other hand, three hundred IASI spectra taken in the same region and in the same conditions have been degraded to the SI-1 spectral and spatial resolution, averaged and compared to the mean SI-1 spectrum. The agreement of both spectra shown on Figure 11 is striking, in particular in the CO2, O3 and the CH4 bands and in the window channels. IASI brightness temperatures seem to be slightly lower than the SI-1 ones by 1 K almost everywhere except in the CO2 band. It is not yet clear and needs further consideration whether this difference is attributable to a calibration problem or a geophysical effect.

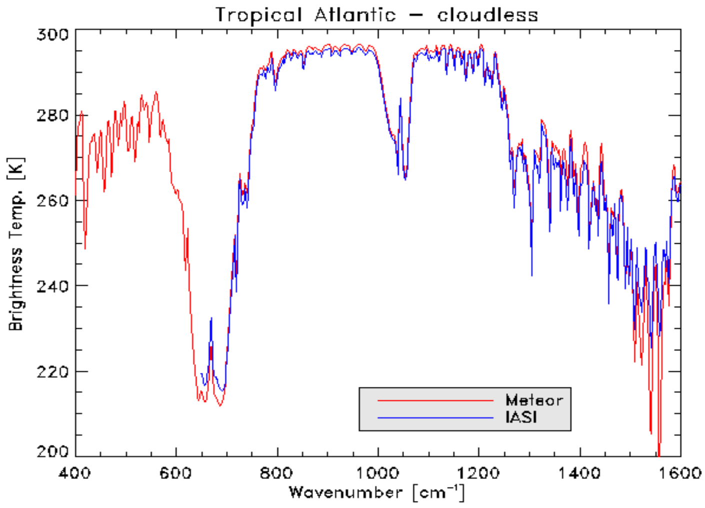

Figure 11: **Comparison between an averaged cloud-free SI-1 spectrum over tropical Atlantic (red) and a mean IASI spectrum taken in the same conditions 38 years later (blue).**

CONCLUSION

Rescuing SI-1 data from Meteor-28 and -29 were successful despite the lack of documentation and auxiliary information. All spectra were thoroughly checked one by one. The dataset was cleaned and completed with additional information as much as possible without large post-processing. Then, the data were reformatted into NetCDF and provided to ECMWF for possible use into their reanalyses efforts. The first comparison with IASI measurements seems to be very promising.

These measurements can help to bridge the gap between the early IRIS measurements from Nimbus and the operational measurements performed nowadays on various platforms. They can contribute to the detection of changes in the spectrum of the outgoing longwave radiation as well as constraining reanalyses of the past weather, thus contributing to the assessment of climate change.

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