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Assessing reanalysis quality with early sounders Nimbus-4 IRIS (1970) and Nimbus-6 HIRS (1975)

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Abstract

This paper revisits the data collected by early sounders Nimbus-4 IRIS (1970) and Nimbus-6 HIRS (1975), after recovery of ageing tapes by NASA GES DISC. New quality controls are proposed to screen out erroneous or suspicious mission data, based on instrument health status data records and other inspection of the data. Radiative transfer coefficients are derived for the fast computation of clear-sky radiative transfer simulations. Atmospheric profiles from ERA-40 and ERA-20C reanalyses are used in input. These spatio-temporally complete datasets are interpolated to each sounding location, using the closest estimate in time. A modern cloud detection method derived for current hyperspectral sounders is applied to IRIS and yields maps of cloud cover that are in line with current knowledge of cloud climatology. For clear scenes, the standard deviation of brightness temperature differences between IRIS observations and simulations from ERA-20C is around 1 K for the lower-peaking temperature channels of the 15 μm CO_2 band, and lower than 1 K for simulations from ERA-40. The IRIS and HIRS instrumental data records are projected in a common sub-space to alleviate issues with different field-of-view resolutions and spectral resolutions. A proxy cloud detection scheme screens out clouds in the same manner in both data records. Considering the month of August, common to both missions, a detailed analysis of the departures from observations suggests that ERA-40 suffers from spurious tropospheric warming, possibly caused by changes in the observation input during the 1970s including a known error in ERA-40 radiance assimilation bias correction. This result, confirmed by considering a climate model integration, demonstrates that it is possible to exploit early sounder data records to derive detailed insight from reanalyses, such as attempting to qualify separately random and systematic errors in reanalyses, even at times when few other independent observation data are available.

Keywords: Satellite data rescue; Atmospheric sounding; Climate reanalysis; Cloud detection; Infrared radiative transfer

1. Introduction

Sixty years after the launch of the first man-made satellite in 1957, this paper revisits two of the missions that collected some of the first records of atmospheric remote sounding. Both initiated by the U.S. National Aeronautics and Space Administration (NASA), these two missions were the InfraRed Interferometer Spectrometer (IRIS) on the Nimbus-4 satellite (Hanel et al., 1970a) and the High Resolution Infrared Sounder (HIRS) on the Nimbus-6 satellite (Smith et al., 1975). They were both unprecedented as, respectively, the highest-resolution infrared interferometer ever launched (and that operated for as long as about 10 months), and the first multi-spectral infrared sounder for temperature and humidity with cross-track scanning and covering several regions of the infrared spectrum.

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The IRIS instrument was a precursor to other instruments aimed at the solar system exploration. Further IRIS instruments flew on Mariner 9 (Hanel et al., 1973), as well as on Voyager-1 and Voyager-2 (Hanel et al., 1980), two spacecraft that went on to leave the solar system (Jokipii, 2008). The IRIS and HIRS instruments also proved to be precursors to missions aimed at observing the Earth's atmosphere. Indeed, a few years earlier before the first IRIS and HIRS, the breakthrough work of Chahine (1968) had proposed an exact mathematical method to invert the radiative transfer equation to sound the Earth's atmosphere. This application was gaining interest in the late 1960s, and in 1970 the 13th plenary meeting of the Committee on Space Research (COSPAR) already featured a symposium dedicated to this topic (e.g., Hays et al., 1971; Conrath et al., 1971). After these two missions, many more followed, based on the same principles (e.g., Edwards et al., 2006), delivering improved sounding capabilities, including enhanced scanning patterns (to cover a wider swath), higher horizontal and spectral resolution, improved calibration, and improved detector accuracy (resulting in lower instrument noise or higher precision). These followers generally retained the initial measurement concepts, and one has today a far better understanding of the sounding principles.

These developments were enabled by more accurate and more precise data, along with better characterized instruments to simulate them through models such as the Radiative Transfer for the TIROS Operational Vertical Sounder (RTTOV; Saunders et al., 2013). This enhanced understanding has opened the way to new techniques for data processing and exploitation such as radiance data assimilation (e.g., Andersson et al., 1994). Among these advances, and relevant to infrared sounding, are in particular improved techniques to detect clouds that may dominate the infrared signal (e.g., McNally and Watts, 2003; Joiner et al., 2004). Curiosity suggests trying out these new methods onto the initial missions, and assessing whether new insight can be gained from old data using current advanced methods, unavailable at the time of the early missions.

This seemingly simple concept is not straightforward however, because one has today, with present satellite missions, much more documentation of the satellite data quality, including about instrument pre- and post-launch calibration; one is also assisted by many other ancillary datasets that can help characterize a given atmospheric scene or background (surface state), and thereby better inform a priori the satellite data quality control. In addition, the atmosphere may have changed in subtle ways that one may not fully understand. For example, there is a dependence of surface emissivity, aerosols, and methane in infrared sounding (e.g., Prabhakara et al., 1974), but our knowledge of the past for these variables is too insufficient to use anything else other than near-stationarity or global trends. This fuzzy past, along with the retirement of mission experts, explains partially why historical satellite datasets have received gradually less attention, as new datasets have come along, offering more numerous (with several collocated instruments) views of the same scene, with reduced errors (improved precision, calibration, resolution).

Nevertheless, the past decade has witnessed attempts to reproduce accurately the weather and climate evolutions of the past century (e.g., Compo et al., 2011). The reanalyses combine observations with the latest advances in atmospheric modelling (e.g., Dee et al., 2014). They represent both an opportunity and an impetus to reconsider these early data records: an opportunity, for they provide ancillary data to better understand the satellite data collected then, and an impetus, for their exploitation could eventually help improve or better qualify the reanalysis record. In addition, outside the reanalysis context, these ancient data can also help tackle the problem of climate change monitoring (e.g., Brindley and Bantges, 2016), for they offer high-resolution information collected more than forty years ago. There is also raising awareness that these past missions, to be accessed through satellite data rescue when needed, offer information of interest to advance our understanding (Poli et al., 2017). The present article attempts to answer the following two questions: can new insight be gained about early mission IRIS and HIRS data, and what can be learnt about the quality of reanalyses by a comparison exercise with data from these early sounder.

The outline of the paper is as follows. Section 2 presents the data used in the study, Section 3 explains the methodology, Section 4 presents results of comparisons to IRIS, and Section 5 discusses findings obtained by comparing the reanalyses to IRIS and HIRS instrumental data records in a common sub-space. Conclusions and perspectives for future work are given in Section 6.

2. Data

2.1. Nimbus-4 IRIS

The two satellite missions considered in the present study are indicated in Table 1. The Nimbus-4 satellite was initially named Nimbus-D before launch; it was later assigned the COSPAR designation 1970-025A. It carried an IRIS instrument designed using the measurement concept proposed by Michelson and Morley (1887) and that of Fourier transform spectroscopy established thereafter (e.g., Loewenstein, 1970), such as the relationship between mirror displacement and spectral resolution (e.g., Connes, 1958). Michelson interferometer Fourier transform spectrometers were first flown on balloon-borne gondolas in the 1960s (e.g., Murcray et al., 1962). In 1966, a balloon carried a first version of the IRIS instrument (IRIS-A; Bartman, 1967), which would later evolve and be taken to space. Built by Texas Instruments in Dallas (Texas, USA), the IRIS-B flight model flown on Nimbus-3 (Hanel et al., 1970b) covered the spectral range 400–2000 cm^{-1} (wavelengths 5–25 μm) at a nominal spectral resolution of 5 cm^{-1} apodized (2.5 cm^{-1} unapodized). However,