Development of a hyperspectral temperature and water vapor sounder at 5µ.

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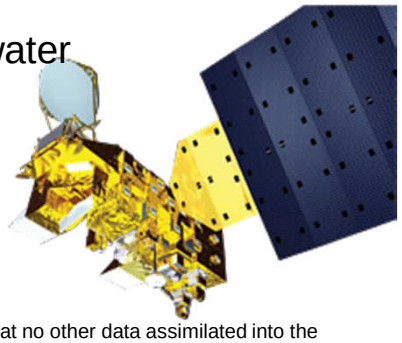
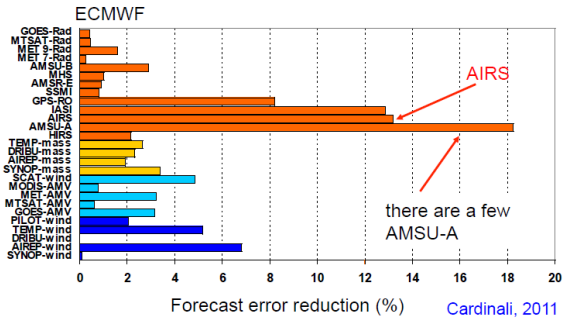


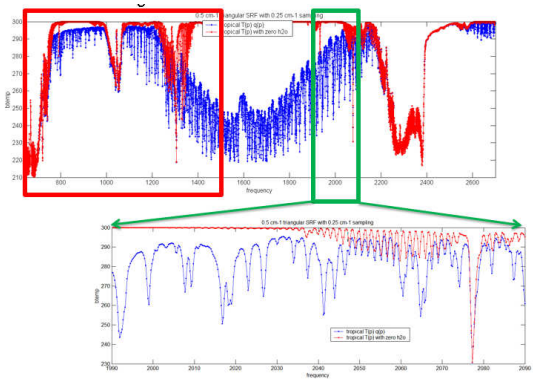
Summary: The high impact of AIRS and IASI data to the improvement of the short-term forecast accuracy is likely due to the fact that no other data assimilated into the forecast other than AIRS and IASI provide data on temperature and water vapor profiles in the lower tropopause. We use information content analysis and retrievals from IASI to show that the same day and night accuracy in the lower tropopause can be achieved with a hyperspectral sounder which covers only a narrow slice of the spectrum near 5 um, between 1960 and 2090 cm-1. This results on a order of magnitude simplification of the instrument compared to CrIS and IASI. A prototype design of this sounder, code name CIRAS, has been funded by NASA for launch into polar orbit in late 2019.



AIRS and IASI have the highest forecast for ECMWF impact after 8 AMSU-A. The likely reason for the disproportionate impact of AIRS and IASI is that none of the other data assimilated by ECMWF sound temperature and moisture globally in the lower troposphere (surface to 400 hPa)

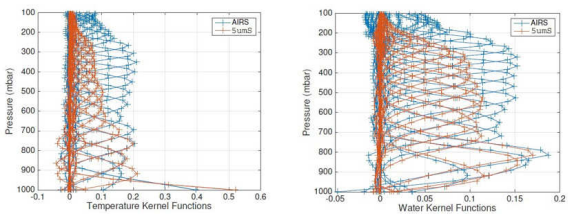
The spectral coverage of hyperspectral sounders is illustrated with a tropical spectrum calculated for IASI with 0.5 cm-1 resolution and 0.25 cm-1 sampling (blue). Shown in red is the calculated spectrum if all water vapor is removed. This highlights the temperature and water vapor sounding regions.

AIRS, CrIS and IASI sound in the 7-15 um region. The shorter wavelength are not used due to historical concern about reflected sunlight and non-LTE.



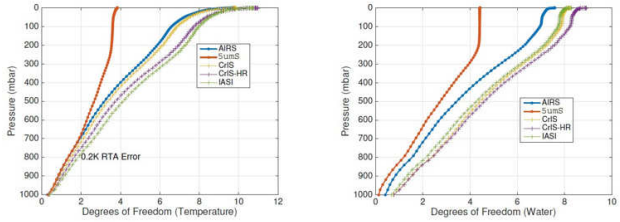
The 5um sounder covers the 4.8-5.1um region, shown expanded above, with 500 spectral channels and IASI like spectral resolution and sampling. The spectrum is imaged onto a 500 x 500 array, which allows for 0.5 km spatial sampling from a 800 km altitude orbit. The array technology at 5um is far superior to that at 15 um and requires much less cooling of the array. Photon-noise limited performance is achieved with the array at 120K and by passive cooling of the spectrometer to 180 K. This results in an order of magnitude decreases in the cost of the instrument.
In order to show that a 5um temperature and water vapor sounder is competitive with CrIS and IASI in the lower troposphere, we first use Degree Of Freedom and Kernel function analysis. We then use clear and cloudy IASI data from the 5um region to show that the lower tropospheric information can be retrieved with competitive accuracy.

The averaging Kernel Functions (KF) provide information about the retrieval sensitivity for a change in the true temperature or water vapor profile at some altitude as function wavelength. KF are related to the spectral resolution only. Degree of Freedom (DOF) is the number of independent pieces of information related to temperature and water vapor sounding. Numerically the KF can only be interpreted in a relative sense, i.e. a comparison of AIRS, IASI, CrIS and the 5um sounder.



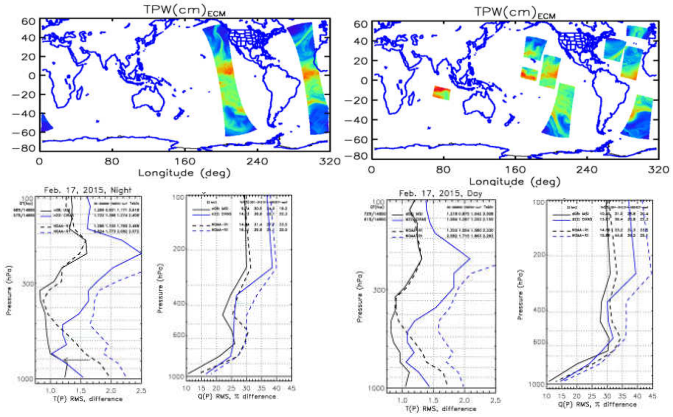
It can be seen that the temperature and water sounding performance of the 5um sounder is potentially equal to that of AIRS between the surface and 600 hPa. The performance is degraded compare to AIRS by about a factor 2 between 600 and 300 hPa.

The Degree of Freedom (DOF) is the number of independent pieces of information related to temperature and water vapor sounding. DOF are a function of spectral resolution and Signal-to-Noise-Ration (SNR), which is a function of the Noise Equivalent Delta Temperature (NeDT). DOF have to be evaluated in an OE environment. Numerically the DOF can only be interpreted in a relative sense, i.e. a comparison of AIRS, IASI, CrIS and the 5um sounder. For AIRS, CrIS and IASI we used the NeDT measured on-orbit. For the 5um sounder we assumed Gaussian random noise of 0.2 K at 250K. Based on experience with AIRS and CrIS we assumed a Gaussian random error due to Radiative Transfer Model uncertainty for all cases.

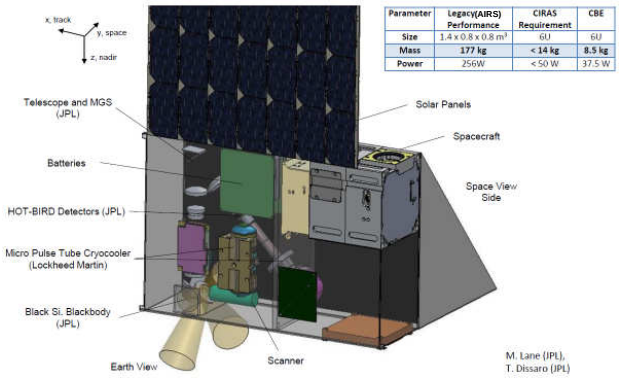


AIRS, IASI and CrIS have more DOF above 400 hPa, but above 400 hPa there is little forecast impact because of the large number of AMSU and GPS soundings.

We used a small subset of IASI data granules over ocean to estimate the retrieval performance separately for day and night data. The IASI retrieval uses the full IASI data set. The 5um sounder retrievals used the identical retrieval methodology with the 5um sounder subset of IASI data.



RMS error relative to ECMWF. IASI (black) 5um sounder (blue). Regression first guess (dashed). Day and night have similar statistics. The 5um (p) retrieval improves upon microwave from surface to 700 mb, but sticks to first guess (microwave) above that . Performance is not as good as IASI, but it does add significant information. CIRAS water vapor has similar skill as IASI from ~400 mb down to the surface. This result is robust for all systems explored.



Parameter	Legacy(AIRS) Performance	CIRAS Requirement	CBE
Size	1.4 x 0.8 x 0.8 m³	6U	6U
Mass	177 kg	< 14 kg	8.5 kg
Power	256W	< 50 W	37.5 W

CIRAS, the codename for the prototype of the 5um sounder, meets the requirements of the 5um sounder and fits into a 6 liter (6U in CUBESAT terminology) package, compared to the 800 liter envelope of CrIS. This volume difference alone results in a more than one order of magnitude cost decrease. This makes CIRAS a candidate for deployment on a CUBESAT constellation. The first CIRAS is currently funded by NASA for launch into polar orbit in late 2019.

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