

Wind Imaging Spectrometer and Humidity-sounder (WISH): a Practical NPOESS P3I High-spatial Resolution Sensor

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Abstract

Tropospheric wind is a top priority NPOESS EDR that can be retrieved by tracking high spatial resolution altitude-resolved water vapor sounding features in imagery provided by a humidity imaging sounder. A Wedge-filter Imaging Spectrometer (WIS) can provide the required humidity imagery and has already been studied for application in geostationary orbit by Puschell, Huang and Woolf. The Wind Imaging Spectrometer and Humidity-sounder (WISH) described here would incorporate the same technology and could be developed in time for flight on the NPOESS C2 spacecraft. WISH would take advantage of payload capacity available for P3I demonstrations in NPOESS and would serve as a risk reduction and technology demonstration for future NOAA environmental satellite missions.

Introduction

Tropospheric wind is among the top priority NPOESS Pre-Planned Product Improvement (P3I) EDR candidates. This EDR can be retrieved by tracking high spatial resolution altitude-resolved water vapor sounding features in imagery at appropriate temporal sampling provided by a humidity imaging sounder. A Wedge-filter Imaging Spectrometer (WIS) can provide the required humidity imagery and has already been studied for application in geostationary orbit by Puschell, Huang and Woolf (2001). The geostationary WIS would use spatially variable wedge filter spectrometers to collect earth radiance with ~2 km resolution over a broad infrared (710-2900 cm⁻¹) spectral region at 1% spectral resolution. The resulting sensor is a compact, lightweight, and rugged imaging sounder with better sensitivity, spectral resolution, spatial resolution and full disk coverage time than the current multispectral GOES imager. The Wind Imaging Spectrometer and Humidity-sounder (WISH) could incorporate the same Raytheon WIS technology and is suitable for flight on the NPOESS C2 or C3 spacecraft. WISH would take advantage of the payload capacity available for P3I demonstrations in NPOESS and would serve as a risk reduction and technology demonstration for future NOAA environmental satellite missions.

Wedge imaging spectrometers

WIS technology has been developed and patented at Raytheon since 1990. As shown in Figure 1, the WIS is based on a hybridized sensor chip assembly (SCA) that combines a multi-layer “wedge” interference filter and an area detector array with a readout circuit. The “spectral” dimension is parallel to the filter taper (exaggerated in the illustration), with the thin edge transmitting the shortest wavelength. Blocking filters reduce out-of-band response across the filter. Jeter, et al (1996) built and demonstrated aircraft-based visible, near-infrared (VNIR) and short-wave infrared (SWIR) WIS sensors. Lencioni and Hearn (1996) discussed an advanced GOES imager concept that included a visible/near-infrared WIS.

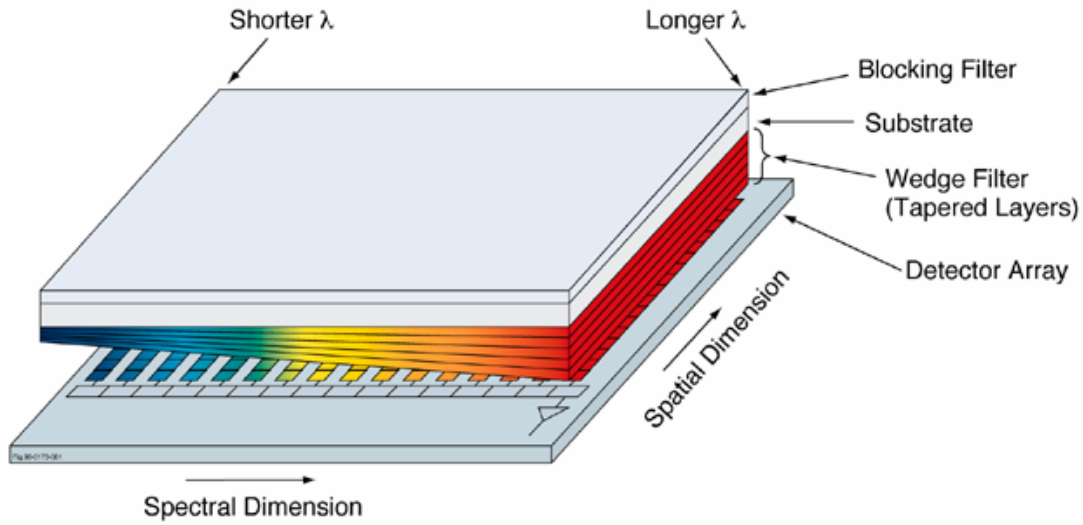


Figure 1. Wedge Imaging Spectrometer concept.

Puschell, Huang and Woolf (2001) described a Geostationary Wedge Imaging Sounder (GWIS) concept for the 3.5-14 μm spectral region.

A principal advantage of the WIS over alternative approaches is its relative simplicity, as shown in Figure 2. The WIS does not require the complex aft optics used in other spectrometers. This feature offers several benefits including a compact, easily ruggedized instrument design and an uncomplicated layout that result in minimal sensor integration and test time, thereby reducing cost and delivery time with respect to other approaches.

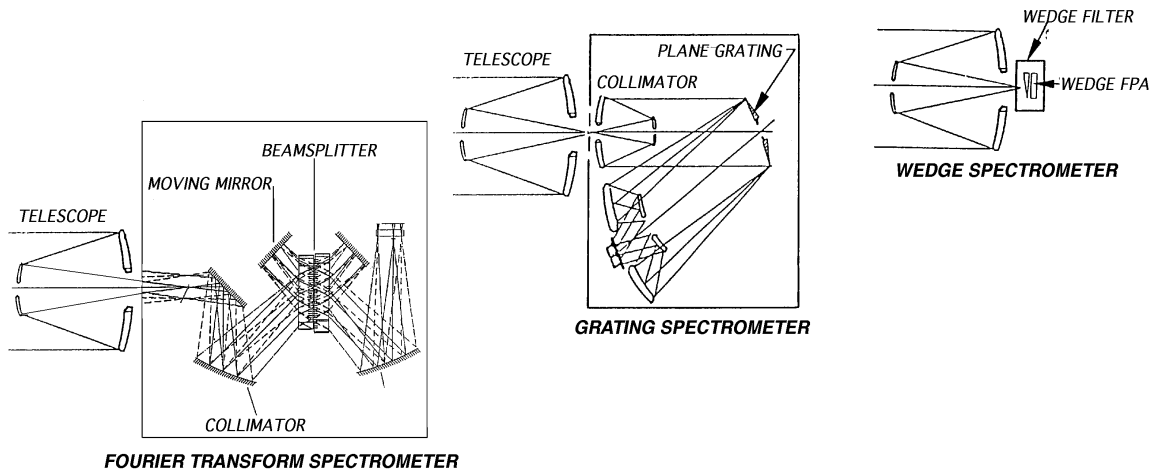


Figure 2. The Wedge Spectrometer offers a simple optical layout compared with other approaches

Long Wave Infrared (LWIR) WIS Sensor Chip Assembly

Recently, Raytheon extended WIS technology to the LWIR (8.0-11.8 μm) by building a WIS SCA using PV HgCdTe detectors (Figure 3).

This 320 (spatial dimension) by 210 (spectral dimension) SCA uses 40 μm detectors to cover the 8.0-11.8 μm spectral region with $\sim 1.5\%$ point bandwidth and optical transmittance of $\sim 80\%$ (Figure 4). The 210 spectral axis elements can be processed to provide roughly 27 non-overlapping bands or as many as 210 overlapping spectral channels. This SCA is designed for use at cryogenic operating temperatures. Therefore, it can provide the high radiometric sensitivity needed to enable its use in infrared hyperspectral imaging from space.

In addition to this LWIR SCA and the VNIR and SWIR sensors mentioned above, Raytheon has also applied wedge filter technology in the midwave infrared (MWIR) region. High performance wedge filter spectrometers can be built for wavelengths out to 14 μm and beyond and with point bandwidths substantially below 1%. This combination of performance capabilities makes WIS technology a promising candidate for space-based imaging and sounding.

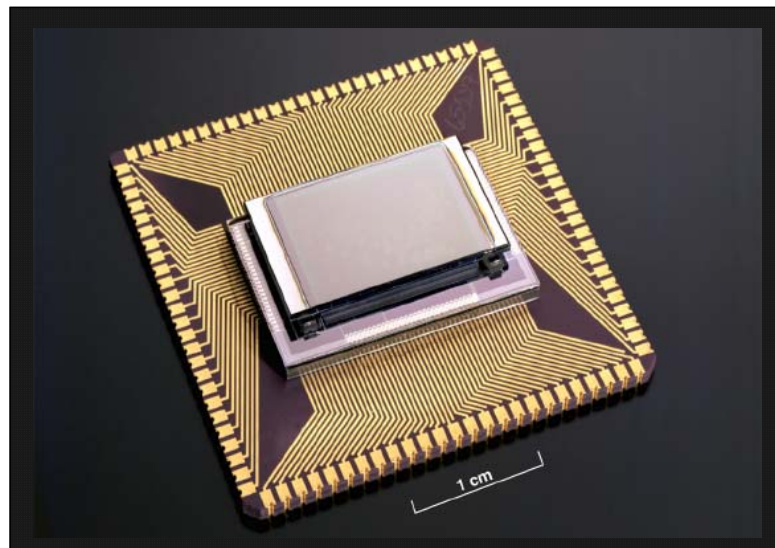


Figure 3. Hybridized WIS SCA hardware.

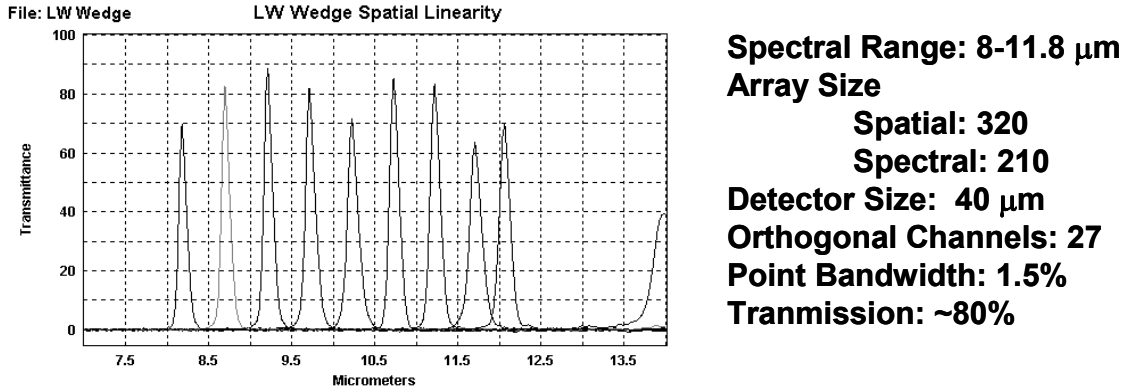


Figure 4. Characteristics of a recent Raytheon LWIR wedge filter.

Wind Imaging Spectrometer and Humidity-sounder (WISH) Concept

WISH consists of two spectrometers that provide data for retrieving wind vectors at different altitudes in the troposphere by observing Earth in the 6.7- μm water vapor band. The method for retrieving wind vectors from WISH data is described by Huang, et al. (2005). The WISH system retrieves wind vectors by analyzing movement of water vapor features between observations of the same Earth region made with the two spectrometers. As shown in Figure 5, one of the WISH spectrometers is pointed 50 deg ahead of nadir along track while the second spectrometer is pointed 50 deg aft of nadir along track. Approximate time between measurements of the same Earth region is about 5.3 min. During that time, a water vapor feature appears to move ~ 8 pixels for a 20 mph wind.

WISH measures emitted Earth radiance in 210 spectral channels that cover the 5.7 – 8.7 μm spectral region with 10 cm^{-1} spectral resolution. Spatial resolution is 290 m from the NPOESS satellite altitude of 833 km. This spatial resolution enables accurate water vapor measurements across a relatively short baseline in time. WISH uses actively cooled PV HgCdTe detector arrays to achieve radiometric sensitivity better than 0.1 K across the entire spectral region even for a 220 K scene temperature.

WISH is compatible with accommodation aboard any of the NPOESS satellite configurations, as shown by comparing preliminary WISH characteristics with a recent assessment of NPOESS system resources available for Pre-Planned Product Improvements (P3I) described by Naegeli et al. (2004). Figure 6 shows how the approximate WISH nadir deck footprint compares with deck area currently available in the NPOESS 1330 configuration. Table 1 summarizes how power, mass and data rate expected to be available for a NPOESS P3I sensor compares with preliminary WISH characteristics. Based on this initial assessment of sensor volume, mass, power and footprint size, WISH can be accommodated within any of the NPOESS configurations. However, the data rate required for continuous data collection and transmission is about 36 Mbps, which exceeds the available data rate by about a factor of ten. The simplest approach to reduce data rate for this technology risk reduction demonstration instrument is to not transmit all data to the ground, such as by selecting only part of the full swath for continuous transmission to Earth or by transmitting full swaths only from selected regions.

WISH is a low risk and relatively low cost approach for making tropospheric wind measurements. It is a relatively small, low impact instrument that is based entirely on existing technology. Additional work is needed to define better the expected absolute radiometric accuracy of WISH, to determine impact of spectral calibration and spacecraft pointing knowledge on wind vector determination and to optimize the design against a more detailed set of mission and sensor requirements.

Summary

A Wind Imaging Spectrometer and Humidity-sounder (WISH) that incorporates recent MWIR/LWIR Raytheon technology developments offers a practical, low risk approach for measuring water vapor winds using spacecraft capacity available in NPOESS. Due to its relatively high spatial resolution (290 m) compared with previous water vapor sounder concepts, WISH can measure water vapor winds accurately with only a ~5 minute measurement baseline. Additional work is needed to optimize the WISH sensor design and assess its radiometric and spectral calibration performance.

References

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Table 1. NPOESS Satellite Power/Mass/Data Rate Budget Status (July 2004) compared with preliminary WISH characteristics.

NPOESS Orbit	2130	1330	1730	WISH
P3I Sensor Power Allocation (W)	326	326	326	<75
Satellite Power Margin (W)	1,407	234	1,013	
P3I Sensor Mass Allocation (kg)	365	365	365	<80
Satellite Mass Margin (kg)	609	189	216	
P3I Data Rate 1394 (Mbps)	3.2	3.2	3.2	36 (continuous)
P3I Data Rate 1553 (Kbps)	200	200	200	

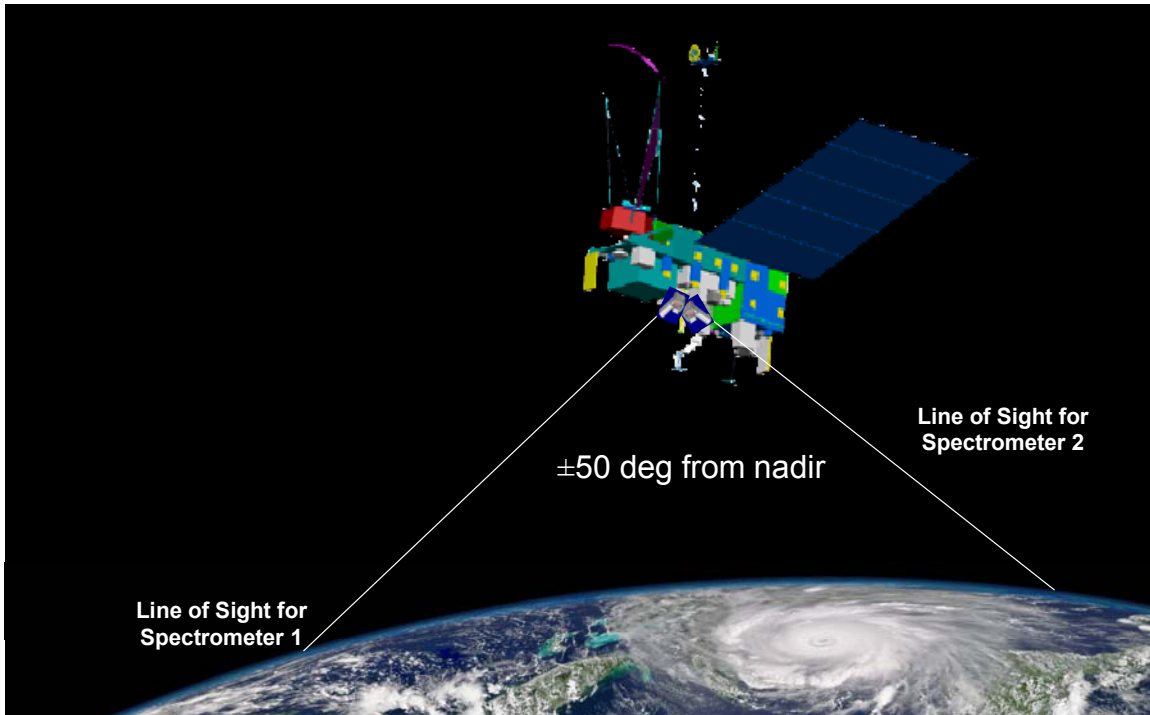


Figure 5. WISH consists of two wedge spectrometers that measure wind by observing the same Earth region twice with ~5 minute measurement separation in the 6.7 micron H₂O band from NPOESS.

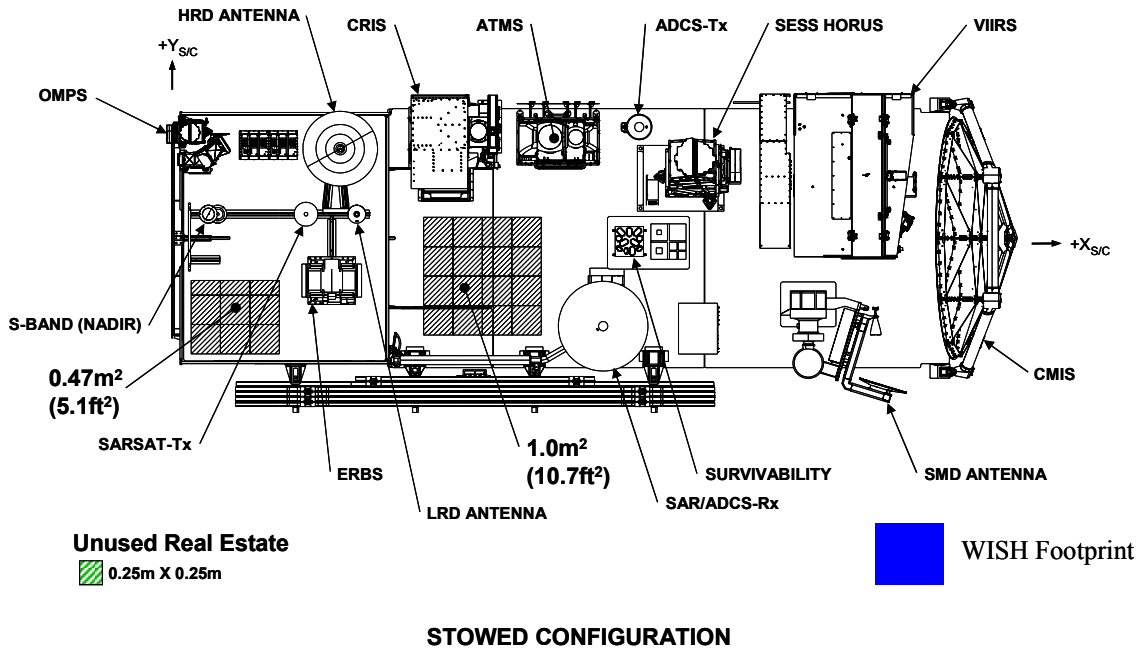


Figure 6. NPOESS 1330 satellite configuration.

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