

Advanced Remote-sensing Imaging Emission Spectrometer (ARIES): AIRS Spectral Resolution with MODIS Spatial Resolution

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Abstract—This paper describes a measurement approach and a future space based instrument concept that will provide scientist with data needed to support a wide variety of Earth System Science investigations. The measurement builds on the observations made by AIRS and MODIS and exceeds their capability with improved spatial and spectral resolution. This paper describes the expected products and the instrument concept that can meet those requirements

Keywords—Remote Sensing, Spectrometer, MODIS, AIRS

I. INTRODUCTION

The Advanced Remote-sensing Imaging Emission Spectrometer (ARIES) will measure a wide range of earth quantities fundamental to the study of global climate change. It will build upon the success of the Moderate Resolution Imaging Spectroradiometer (MODIS) and the Atmospheric Infrared Sounder (AIRS) instruments currently flying on the EOS Aqua Spacecraft. Both instruments are facility instruments for NASA providing data to thousands of scientists investigating land, ocean and atmospheric Earth System processes. ARIES will meet all the requirements of AIRS and MODIS in a single compact instrument, while providing the next-generation capability of improved spatial resolution for AIRS and improved spectral resolution for MODIS.

II. MEASUREMENT OBJECTIVES

For the AIRS products, improved spatial resolution would greatly increase the scientific utility of hyperspectral infrared observations. AIRS has proven its viability as an instrument to measure trace gases and water vapor in the atmosphere on the global scale. Higher spatial resolution will result in significantly more clear observations, reducing the deleterious effects of clouds on retrieval of atmospheric quantities. Secondly, observations of atmospheric quantities with high horizontal variability such as water vapor, and trace gas emissions from localized sources such as volcanoes and forest fires can be made with much better sensitivity and resolution. Water vapor is known to have a high degree of horizontal variability; with higher spatial resolution, and, as

the resolution of the observations improve, it is expected the accuracy will also improve. Trace gas concentrations are expected to be higher in localized regions near the sources, improving SNR of individual observations. Finally, for global studies that do not require the high spatial resolution, more observations are obtained per unit area, thereby increasing the SNR. In general, the effects of horizontal variability on the sensitivity and accuracy of products obtained from AIRS is hampered by the low spatial resolution of AIRS. Many of the retrieval issues will be resolved with high spectral observations at 1km spatial resolution.

MODIS has the advantage of high spatial resolution which aids in surface evaluation since scene variability is better characterized on the 1km scale of MODIS, however, water vapor absorption impacts the accuracy of surface products. With high spectral resolution, the surface temperature can be retrieved simultaneously with atmospheric water vapor and temperature. Although not demonstrated at this time, we believe it may be possible to retrieve the spectral signature of the emissivity across the ARIES band. A spectral emissivity will aid in radiative balance studies, retrieval of atmospheric constituents and surface infrared classification for weather forecast models. Surface reflectance can be better characterized with knowledge of the atmospheric absorption due to water vapor and aerosols.

A logical progression of the observations of AIRS and MODIS is to observe the scene with the higher spatial resolution of MODIS and the higher spectral resolution of AIRS. There are several problems that can be expected when we attempt to achieve the requirements of both systems. From a data management perspective, future instruments will produce orders of magnitude more information than MODIS and AIRS. New techniques for data filtering, data compression, and data storage will be needed in order to successfully download, store and distribute the data. Fortunately, much progress has been made in the last decade and is ongoing making the realization of such a system feasible. Additionally, instruments must be capable of acquiring high resolution

spectral and spatial information simultaneously while preserving signal-to-noise ratio, accuracy and stability.

III. MEASUREMENT PARAMETERS

ARIES will measure all geophysical parameters from MODIS and AIRS while providing enhanced resolution to improve accuracy and enable new science. We list here the main products from these two instruments; a complete listing is given the references [1, 2]

Calibrated IR Radiances: AIRS Radiances are assimilated by the NOAA/NESDIS Operational forecast system for distribution to NWP centers. ARIES will provide the same radiances at 2 km resolution rather than 13.5 km.

Land: Surface Albedo/BRDF, Snow Cover, Land Surface Temperature and Emissivity, Land Cover/Change, Vegetation Indices, Thermal Anomalies/Fire, LAI/FPAR, Net Primary Vegetation Production

Oceans: SST, Pigment Concentration, Chlorophyll Fluorescence, Photosynthetically Active Radiation, Suspended Solids, Organic Matter Conc., Ocean Primary Productivity, Coccolith Concentration, Sea Ice Cover, Phycoerythrin Concentration

Atmosphere Products: Temperature Profiles, Humidity Profiles, Total Precipitable Water, Aerosols, Fractional Cloud Cover, Cloud Top Height, Cloud Top Pressure, Cloud Mask, Polar Winds, Total Ozone, CO Profile, Tropospheric CO₂, CH₄ Profile, SO₂

IV. BENEFITS TO EARTH SCIENCE

ARIES provides a wide variety of benefits to the scientific community in key important areas. This is because of its high spectral and spatial resolution leading to numerous important products such as water vapor and trace gases to surface reflectance and emissivity.

Model Improvement: A significant contribution of ARIES to the scientific community is the high resolution water vapor observations. These will be used extensively for improvement of the most critical earth system models for climate and weather prediction including the next generation finite volume GCM's which are expected to operate on a grid scale smaller than 5km. ARIES will provide 2km cloud-cleared water vapor and temperature and infrared radiances.

Science Investigations: ARIES science investigations will build on the hundreds of investigations currently being performed by MODIS and AIRS. These include Monitoring of Earth System Resources, Land and Ocean science, Weather Prediction and Global Climate Monitoring and Prediction. ARIES will be an extremely useful system to a wide range of scientists and agencies if we extrapolate on what AIRS and MODIS have accomplished today.

Cal/Val for NPOESS: ARIES will be ideal for cross-calibrating the NPOESS CrIS and VIIRS instruments. It can simulate the bandpass of either sensor and provide the measurements at the resolution of the highest sensor. It can also be used with ERBS, CMIS, and OMPS in validation of

their major products. It builds on the AIRS instrument technology which has demonstrated better than 10 mK/year observational stability. AIRS currently cross-validates with AMSR-E, HIRS, TES, MLS, MISR, MODIS, and CERES

Atmospheric Correction: ARIES high resolution water vapor and temperature can be used for atmospheric state determination by any other instrument on the same platform or within a few hours of overpass.

V. INSTRUMENT CONCEPT

The ARIES instrument is an infrared imaging spectrometer covering the spectral range of 0.4 to 15.4 μm and is shown in Figure 1. It has 3577 spectral channels, a horizontal spatial resolution of better than 1km and scans a full swath of $\pm 55^\circ$. It has 6 wide field spectrometers, each covering a portion of the full spectral range, and using its own FPA. Table 1 gives the spectral ranges, resolution and number of channels. It includes standard infrared imaging support hardware including a 2 axis scan mirror, thermal control subsystems, and calibration targets. It is designed for low earth orbit in the range of 705.3 km to 833 km.

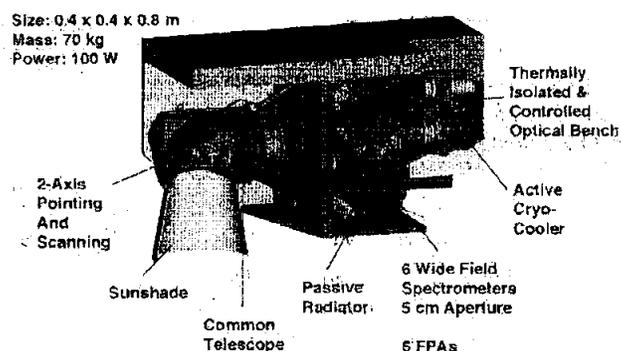


Figure 1. ARIES Instrument Concept: ARIES uses standard well established infrared technologies proven in prior flight systems.

The high spatial resolution and large number of channels lead to a very high internal data rate ($> 1\text{Gbps}$). The downlink data rate is controlled using commandable spatial and/or spectral subsetting and onboard data compression. For reference, the MODIS Aqua peak daytime data rate is 10.6 Mbps uncompressed. There are four example modes for the output data stream as shown in Table 2. Multiple modes can be output simultaneously depending spacecraft and ground system limitations, and different modes are certainly possible. All modes provide full coverage.

TABLE I. ARIES SPECTRAL RANGES AND RESOLUTION

	Vis/NIR	SWIR	MWIR1	MWIR2	LWIR	VLWIR
λ_{min} (μm)	0.40	1.22	3.57	6.20	8.70	11.24
λ_{max} (μm)	1.00	2.18	4.61	8.70	11.24	15.38
$\lambda/\Delta\lambda$	146	222	1306	1222	1302	1192
N_{chan}	256	256	670	851	710	836
IFOV (km)	0.25	0.50	1.00	1.00	1.00	1.00
SNR	70-140	50-120	0.2K	0.2K	0.2K	0.4-0.6K

TABLE II. ARIES SAMPLE OUTPUT MODES

Mode	IR (CM/IFOV)	SW (CM/IFOV)	VNIR (CM/IFOV)	Rate* (Mbps)
Full Resolution Global	3067 1 km	254 0.5 km	254 0.25 km	1006.48
AIRS-Next Global	512 2 km	n/a n/a	n/a n/a	17.77
MODIS-Like Global	16 1 km	4 0.5 km	16 0.25 & 0.5km	10.75
Research Mode $\pm 10^\circ$ Swath	512 1 km	n/a n/a	n/a n/a	11.47

*Uncompressed

VI. TECHNOLOGY READINESS

ARIES uses standard infrared technology developments proven over the last decade with additional critical components advanced in the NASA Instrument Incubator Program (IIP) and other technology development programs. The basic improvement over heritage systems such as MODIS or AIRS is the use of area array focal plane assemblies (FPAs). MODIS uses 36 arrays each 1 x 10, 20 or 40 elements. AIRS used 17 modules ranging from 1 x 93 to 1 x 191 elements. ARIES uses 1024 x 1024 element arrays on a 27 micron pitch in the IR. It aggregates 4 in the along track direction for an effective 108 micron pixel. The entrance slit to the spectrometer is 54 microns and at 27 micron pixel size, the spectral direction is Nyquist sampled. Similar FPAs have been developed by Rockwell, BAE Systems and Raytheon.

Large Format FPAs require wide field optics. JPL recognized this need and with Ball Aerospace (BATC) developed the SIRAS grating spectrometer in the NASA IIP in 2001. The development unit demonstrated a 12-15 micron bandpass with spectral resolution of 1000 and a field of view of 16.2°, and used a linear array focal plane. The SIRAS-G currently in build at BATC includes a 2 dimensional focal plane [3]. ARIES uses individual telescopes per spectrometer and a common scan mirror. This avoids the complications of beamsplitting a wide field of view and allows customizing the performance by spectral range. (e.g allows a depolarizer for the visible).

The remaining systems include a significantly smaller active cryocooler available from Raytheon, Ball Aerospace, or a number of vendors, a two axis gimbaled scan mirror, a thermal calibration blackbody, and thermal control of the optical bench for instrument stability. Electronics modules accompany each spectrometer with digital output for ease of integration and testing.

ARIES represents an opportunity to demonstrate in space advancements made in the last decade in the area of infrared technology. It does so with the commensurate low-risk of using technology that is evolutionary rather than revolutionary.

VII. INSTRUMENT PERFORMANCE

Spatial: ARIES spatial response matches that of MODIS; 1km for all IR bands, 0.5 km for SW and 0.25 km for Vis/NIR. MODIS 1 km and 500 m Vis/NIR products are made by spatial aggregation; as a result MTF will be improved for those channels. The spatial coverage matches that of MODIS, i.e $\pm 55^\circ$.

Spectral: ARIES spectral resolution and sampling match or exceed AIRS for all IR channels. ARIES has 3067 IR channels, and 256 each for the Vis/NIR and SW. MODIS bands are generated by aggregation.

Radiometric: The ARIES matches the AIRS [4] radiometric sensitivity with NEDTs ranging from 0.2 to 0.6K for a scene at 250K, and ARIES meets or exceeds all MODIS SNR and NEDT requirements [5] except bands 13 and 14 (currently) when aggregated to the MODIS spectral resolution.

VIII. CAL/VAL REQUIREMENTS

The visible and near infrared calibration of ARIES will be performed using an internal lamp for short-term and diurnal variability, combined with views of the moon and deep convective clouds for long-term trending. The Solar Diffuser approach used on MODIS is not included in the ARIES design. The infrared bands will use an internal full aperture blackbody and a space view for a two point radiometric calibration. There will be no other internal spectral calibration sources or targets.

IX. SUMMARY

The ARIES concept is designed to meet the requirements of AIRS and MODIS in a single compact instrument while offering hyperspectral capability at 1km or better spatial resolution from the Vis/NIR to VLWIR. The design offers extremely good value to the government in that it measures a wide range of products while offering the resolution to advance earth science and weather forecasting. The design uses proven technology developed on AIRS and NASA technology programs for the best calibration stability and least development risk.

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