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

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***Abstract*—This paper describes a space based instrument concept that will provide scientists with data needed to support key ongoing and future Earth System Science investigations. The measurement approach 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 the primary earth quantities fundamental to the study of global climate change including atmospheric water vapor and temperature, atmospheric composition of key gases, and land and ocean productivity. 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 MODIS and AIRS are facility instruments for NASA providing data to thousands of users 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 and spectral resolution for AIRS and improved spectral resolution for MODIS.

II. Measurement Objectives

MODIS and AIRS complement each other by providing moderate spatial resolution observations for land and oceans observations (MODIS) with high spectral resolution for atmospheric observations (AIRS). Despite their individual success, MODIS products suffer from atmospheric interference and AIRS products suffer from surface interference.

The moderate spatial resolution of MODIS (1km), combined with its global coverage makes it ideal for mapping global surface quantities, such as NDVI and ocean productivity, as well as studies of local processes such as land use, change detection and hazard identification (e.g. fire detection). The ARIES meets all the MODIS requirements, but also provides a high spectral resolution capability. This is important for improving the accuracy of the MODIS products by allowing better selection of channels to avoid atmospheric absorption lines, better characterization of aerosols, and by providing a "spectrum" that can be used to improve classification and identification. The MODIS total column water vapor will be replaced with a column profile in ARIES, currently an AIRS product but at higher spatial resolution. The MODIS land surface temperature, emissivity and sea surface temperature will greatly improve in accuracy with ARIES since better atmospheric correction is achieved.

AIRS has demonstrated it utility in forecast improvement and climate studies with its global temperature, water vapor and trace gas products [1]. Higher spatial resolution will result in significantly more clear observations, reducing the deleterious effects of clouds on retrieval of atmospheric quantities. For example, AIRS water vapor profile accuracy is currently limited to about 15% due to the high degree of variability in the large 13.5 km pixel. ARIES water vapor column accuracy is estimated to be 5% just due to more homogeneous pixels and less cloud influence. AIRS also observes mid tropospheric gases such as CO, CH_4, CO_2, O_3, and SO_2. The fundamental image resolution and contrast is expected to greatly improve at higher spatial resolution for those gases with localized sources (e.g. CO), thereby improving observational SNR. For global studies involving those gases that do not require the high spatial resolution, more observations are obtained per unit area, thereby increasing the SNR (reducing "computational error") of the measurements. Finally, ARIES has 2x higher spectral resolution at shorter wavelengths than AIRS which will improve retrieval sensitivity at lower altitudes.

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 and data storage are planned in order to successfully download, store and distribute the data. Additionally, these instruments must be capable of acquiring high resolution spectral and spatial information simultaneously, while preserving signal-to-noise ratio, accuracy and stability.

III. ARIES MEASUREMENTS

ARIES will *simultaneously* measure all geophysical parameters obtained from MODIS and AIRS while providing enhanced resolution to improve accuracy and enable new science. Required spectral ranges and resolutions are listed in Table 1. For reference, AIRS spectral resolution ranges from 2.2 cm^{-1} at 3.7 μm to 0.5 cm^{-1} at 15.4 μm

TABLE I. REQUIRED IFOV, SPECTRAL RANGES AND RESOLUTION FOR ARIES

Reflective	**IFOV (km)**	**λ_1 (μm)**	**λ_2 (μm)**	**$\Delta\lambda$ (nm)**	**N_{chan}**
Ocean, Land, Atmosphere	0.25	0.40	1.00	4.8	254
Snow/Ice, Cirrus, Albedo	0.50	1.22	2.18	3.9	254
Emissive	**IFOV (km)**	**ν_1 (cm^{-1})**	**ν_2 (cm^{-1})**	**$\Delta\nu$ (cm^{-1})**	**N_{chan}**
Temperature, CO_2, CH_4, N_2O	1.00	2100	2950	1.0	787
Water, CH_4, SO_2, HNO_3	1.00	1150	1613	0.5	999
O_3, HNO_3	1.00	880	1150	0.5	637
Temperature, CO_2	1.00	650	880	0.5	674

In the following, we list the main products from these two instruments; a complete listing is given the references [1, 2]. All are available from ARIES with improved resolution and/or accuracy.

Calibrated Radiances: Calibrated Radiances are the fundamental climate data record from which all other AIRS and MODIS products are derived. The knowledge base of how to calibrate AIRS and MODIS is still in place at NASA [3,4] and will be used in the design of ARIES to allow continuation of the AIRS/MODIS climate data record. High calibration accuracy is the fundamental requirement for ARIES that will allow it to be a standard for cross-calibrating other sensors.

Land Products: Surface Albedo/BRDF, Snow Cover, Land Surface Temperature and Emissivity, Land Cover/Change, Vegetation Indices, Thermal Anomalies/Fire, Leaf Area Index/ fraction of Photosynthetically Active Radiation (LAI/FPAR), Net Primary Vegetation Production

Ocean Products: Sea Surface Temperature (SST), Pigment Concentration, Chlorophyll Flourescence, Photosynthetically Active Radiation, Suspended Solids, Organic Matter Conc., Ocean Primary Productivity, Coccolith Concentration, Sea Ice Cover, Phycoerythrin Concentration

Atmospheric Products: Temperature Profiles, Humidity Profiles, Total Precipitable Water, Fractional Cloud Cover, Cloud Top Height, Cloud Top Pressure, Cloud Mask, Polar Winds, Total Ozone, Ozone Profile, CO Profile, Tropospheric CO_2, CH_4 Profile, Volcanic SO_2, HNO_3, N_2O.

IV. ARIES ENHANCEMENTS TO EARTH SCIENCE

As already mentioned, the numerous science investigations currently using AIRS and MODIS data are expected to improve with ARIES. Without the higher resolution observations of ARIES, it is expected that the science discovery will eventually plateau, and without the climate quality observations of AIRS and MODIS, trending of even existing parameters will not be possible.

Land Science: The hyperspectral Vis/NIR allows greatly improved classification of vegetation types and stress. In the SWIR, the hyperspectral measurements improve the classification of mineral types. Overall, hyperspectral measurements allow more channel options for science and avoidance of atmospheric absorption. NASA has demonstrated the value of hyperspectral Vis/NIR/SWIR with the 220 channels of the Hyperion instrument on EO-1.

Ocean Color Science: The improved spectral resolution of ARIES in the Vis/NIR allows more flexibility in the retrieval methods for phytoplankton pigment concentrations by selection of channels for best SNR and avoidance of atmospheric absorption lines. ARIES will use a depolarizer to avoid problems seen in MODIS with variable polarization from the scan mirror.

Atmospheric Science: ARIES will improve our understanding of processes that link water vapor, trace gases, radiation and climate in the atmosphere. A significant contribution of ARIES to the scientific community is the high resolution water vapor observations. ARIES water vapor profiles 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 5 km. Note: MODIS polar winds derived from water vapor, and AIRS water vapor channels have demonstrated forecast improvement in NCEP models. Finally, the higher spectral resolution and greater range of ARIES is in response to simulations done at JPL to assess the improvements needed in AIRS atmospheric composition products (in particular O_3, CH_4, CO, and N_2O). These include better sensitivity at lower altitudes, better vertical resolution, and what is required to offer new measurements not currently in AIRS.

Cal/Val for NPOESS: The NPOESS CrIS and VIIRS instruments are not required to make climate quality observations. ARIES builds on the AIRS instrument design and technology which has demonstrated better than 10 mK/year observational stability [1]. ARIES will provide a calibration standard for CrIS and VIIRS; 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.

V. INSTRUMENT CONCEPT

The ARIES instrument concept is an imaging spectrometer covering the spectral range of 0.4 to 15.4 µm and is shown in Figure 1. Instrument characteristics are given in Table 2. The highlight of the ARIES concept is its tremendous value. With ARIES we can acquire a wealth of science information with minimal size, mass, power, cost and risk. The ARIES is actually smaller and lighter than AIRS or MODIS and uses less power. This is due to advancements in technology developed over the last 20 years. The risk of these new technologies has been mostly retired in NASA technology development programs and the NASA Instrument Incubator (IIP) Program.

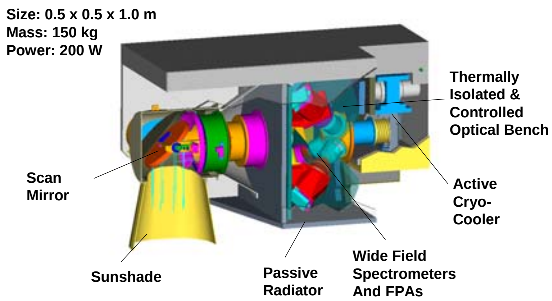

Figure 1. ARIES Instrument Concept uses proven technology and results in a compact, lightweight package.

TABLE II. ARIES INSTRUMENT PROPERTIES

Size	0.5 x 0.5 x 1.0	m^3
Mass	150	kg
Power	200	W
Data Rate	60.3	Mbps
Orbit	705.3	km
Swath (±55°)	256 x 2330	km
IFOV	0.25, 0.5, 1.0	km
Spectral Range	0.4 - 15.4	µm

The ARIES design is very similar to the AIRS and MODIS in concept, but with significant technological advancements. ARIES operates in a sun-synchronous low-earth polar orbit and scans a swath width of 256 km N/S and 2330km (±55°) in the E/W direction. This produces contiguous coverage at the equator. ARIES uses grating spectrometer technology to achieve the spectral ranges and resolution in Table 1.

The high spatial resolution and large number of channels lead to a very high internal data rate (> 1 Gbps). This is not an issue internally, as parallel processors are planned for each of the six FPAs. The downlink data rate is controlled to 60 Mbps using commandable spatial and spectral subsetting. For reference, the MODIS Aqua peak daytime data rate is 10.6 Mbps, AIRS is 1.27 Mbps, and the requirements for GOES-R is 300 Mbps. We show in Table 3 an example of how we envision data subsetting. In this example, we download all data from truly clear scenes, and scenes related to calibration which is about 2% of the total. We also download a simulated MODIS product and a simulated AIRS product, but at 5 km resolution rather than the 13.5 km resolution of the AIRS. Both the AIRS and MODIS products are downloaded 100% of the time to avoid interruption of global climate and weather data sets.

TABLE III. ARIES EXAMPLE DATA RATE

	IFOV	# Chan	Internal Rate	Duty Cycle	Net Rate
	(km)		**(Mbps)**		**(Mbps)**
Full Resolution	Full	3605	1071.8	2%	21.4
MODIS Sim	MODIS	36	10.0	100%	10.0
AIRS Global	5 km	514	27.9	100%	27.9
Overhead					1.0
Total Data Rate					**60.4**

VI. TECHNOLOGY READINESS

ARIES uses advanced infrared remote systems technology that has been vetted over the years in prior space based instruments flown by NASA and the DoD, including MODIS and AIRS.

The basic improvement over heritage systems such as MODIS or AIRS is the use of area array focal plane assemblies (FPAs). MODIS uses 36 linear arrays of dimension 1 x 10, 1 x 20 or 1 x 40 elements. AIRS used 17 modules ranging from 2 x 93 to 2 x 191 elements. The ARIES concept presented in this paper uses 256, 512 and 1024 pixels along track for the IR, SWIR and Vis/NIR respectively, and N pixels spectrally where N represents the number of spectral channels (see Table 1). The actual number of elements spectrally will depend on the final resolution and sampling required. The Vis/NIR FPAs are readily available. The frame rate for the IR is nominally 40 Hz, and the signal levels are low making the readout development quite reasonable. Materials are readily available to handle the longwave cutoff. The only issue will be the yield due to the physical size of the FPA. Several vendors have methods for improving yield in IR FPAs that should be investigated during the design phase.

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 (Figure 2). The development unit demonstrated a 12-15 micron bandpass with spectral resolution of 1000 and a field of view of 16.2°, and using a linear array focal plane. The SIRAS-G IIP currently in build at

Figure 2. SIRAS Wide Field Grating Spectrometer enables 1km hypserspectral imaging from LEO

BATC includes a 2 dimensional focal plane [5] like what is needed for ARIES. ARIES most likely will require 6 spectrometers to cover the spectral range. Spectral separation is planned in the object space to allow insertion of a depolarizer for the Vis/NIR and avoid a complex beamsplitting arrangement.

The remaining systems include a significantly smaller active cryocooler (as compared with AIRS) available from a number of vendors, a scan mirror; a thermal calibration blackbody; and thermal control of the optical bench for instrument stability. Optics and focal planes are cooled to 160K and 60K respectively using active cryogenic coolers coupled to passive radiators. Electronics modules accompany each spectrometer with digital output for ease of integration and testing.

The overall cost of ARIES is expected to be much less than AIRS and MODIS due to minimal technology development requirements.

VII. Instrument Performance

Spatial: ARIES spatial response matches that of MODIS; 1 km 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 global coverage matches that of MODIS with a ±55° scanned field of view.

Spectral: ARIES spectral resolution and sampling match or exceed AIRS for all IR channels. ARIES has almost 3000 IR chanels, and 256 each for the Vis/NIR and SW. MODIS bands are generated by aggregation; this should improve accuracy when tying the ARIES to the MODIS data record. An example is shown in Figure 3 where the Vis/NIR spectrometer synthesizes band 3 of the MODIS. The original band profile and synthesized band essentially lie on top of each other. Reproduction is better than 3% in amplitude at any point in the curve.

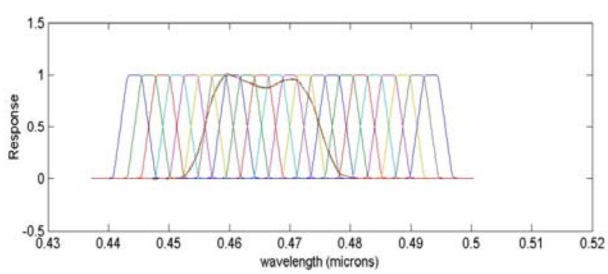

Figure 3. Example Synthesis of MODIS Band 3 using ARIES data. The trapezoidal lines are the ARIES channels. No difference can be seen between the original MODIS band 3 and the synthesized band.

Radiometric: Performance models at JPL indicate ARIES radiometric sensitivity matches the AIRS [3] with NEdTs ranging from 0.2 to 0.6K for a scene at 280K. ARIES meets or exceeds all MODIS SNR and NEdT requirements [4] 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 NASA MODIS and AIRS key facility instruments on the EOS Aqua spacecraft have made significant advancements in Earth Science and weather forecasting [4,6]. The NPOESS VIIRS and CrIS instruments have no requirements for climate quality products, and have known reductions in observational performance (fewer bands on VIIRS, and lower spectral resolution on CrIS). The ARIES instrument concept will not only assure the continued climate quality observations of MODIS and AIRS for science research, but offer hyperspectral resolution from the Vis through the LWIR at MODIS spatial resolution or better. This new capability will enable new scientific discovery by the broad community of existing users of AIRS of MODIS resulting in major contributions to Earth Science for the next decade. The instrument concept is reasonable in size, mass, power, data rate and cost, and should fit well with any mission in low earth orbit.

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