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The NPOESS PREPARATORY PROJECT (NPP)
A Transitional Mission from EOS to NPOESS
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INTRODUCTION:

We propose to fly up to three sensors on a small platform in the 2004 time frame as part of a transition from the EOS 1st series to the converged operational satellite series that is under development by the Integrated Program Office (IPO). Beginning in 2009, the IPO will deploy the National Polar–orbiting Operational Environmental Satellite System (NPOESS). It is designed to meet the long term measurement requirements of the Department of Defense (DOD), the National Oceanic and Atmospheric Administration (NOAA) and NASA. We propose two sensors that are precursors of planned NPOESS sensors. Both sensors have a strong heritage in the EOS 1st series.

- The Advanced Global Imager (AGI) continues many of the measurement series initiated by the Moderate Resolution Imaging Spectroradiometer (MODIS). The measurement series will be further extended by the Visible Infrared Imaging Radiometer Suite (VIIRS) in the NPOESS era.
- The Clouds and the Earth's Radiant Energy System–II (CERES-II) instrument is an improved version of the biaxial CERES instrument flown on various NASA missions in preparation for a similar instrument on NPOESS.

Space is allocated for a third sensor that would complement AGI and CERES-II either in a specific process study in support of NASA's program or as a candidate for inclusion on the NPOESS satellite.

This mission, the NPOESS Preparatory Project (NPP), is critical to the Earth Science Enterprise program in that it provides continuity of the data record initiated by MODIS and CERES. The NPP will address the science issues defined explicitly in the climate change and the terrestrial and marine ecosystems change scenarios. It also contributes to the atmospheric composition scenario and the applications scenario.

The NPP also strongly supports the NASA goal of working closely with other agencies by the provision of an early version of the next generation of the operational sensor, VIIRS. The AGI proposed here would be identical or nearly identical to the planned VIIRS. This will allow the IPO to prototype their algorithms as much as five years in advance of the operational need.

1.) SCIENTIFIC AND APPLICATIONS RATIONALE

1.1) One of the major sources of uncertainty in understanding climate and predicting future potential climate change is the role of clouds in the Earth's radiative energy balance (IPCC, 1995). Even the sign of cloud feedback in the current climate system is unknown, much less the quantitative magnitude of such feedbacks. In addition, aerosols are thought to have a potentially significant effect on the radiative energy balance, either by a direct interaction with solar radiation, or indirectly through modification of cloud properties. The EOS-AM and EOS-PM missions set for launch in 1999 and 2000 represent the first ability to quantitatively and simultaneously measure both key cloud and aerosol properties (MODIS) as well as top of the atmosphere (TOA) solar and thermal infrared radiative fluxes. When combined, these cloud, aerosol, and radiation measurements are expected to greatly improve our ability to infer the radiative energy fluxes at the top of the atmosphere, at the surface of the Earth and within the atmosphere (Wielicki et al., 1995). These MODIS and CERES measurements are expected to provide the most critical constraints for testing models of clouds and aerosols in the climate system over the next 5 to 10 years.

The MODIS and CERES EOS-AM and EOS-PM measurements are expected to be a necessary, but insufficient data set to fully resolve the climate prediction uncertainties. There are three primary reasons for this limitation:

- Inability to measure all relevant cloud and aerosol properties with passive solar and thermal infrared measurements. Missing important elements include multiple cloud layers, cloud ice water path, and aerosol single scattering albedo.

- The six-year expected lifetimes of the EOS-AM and PM missions provide a climate record that is too short to rigorously test climate model simulations. The CERES measurements in particular represent an integral energy balance constraint on the climate system. Rigorous testing of the performance of model predictions of these radiative energy fluxes, cloud properties, and aerosols requires data that include long-time scale variability of the climate system. Such variations include ENSO events every 4–6 years, unpredictable large volcanic eruptions like Pinatubo, and year-to-year climate system variability.

- Simulations have shown the need for diurnal sampling by three orbits in order to accurately determine the diurnal cycle of cloud properties and radiative fluxes (Young et al., 1998). This requirement will be met for one year (2001) assuming that EOS-PM launches on time and that TRMM achieves its full planned lifetime.

All three of these shortcomings are expected to be addressed within the context of mission plans submitted to the EOS Follow-on request for concepts. The present concept deals primarily with the critical need to extend the record established by EOS-AM and EOS-PM by transitioning most of the CERES/MODIS measurement capability to the NPOESS mission in essentially the EOS-AM orbit geometry. Other proposals will deal with obtaining the proper diurnal cycle sampling, and with improved use of active and passive sensors, to measure the missing cloud variables. Because of the greater expense of the active instruments, there will be a continued need to continue the CERES/MODIS class of measurements for clouds, aerosols, and radiative fluxes into and through the NPOESS era beginning in 2009.

1.2) The long-term data record acquired by AGI on NPP will serve the science objectives of the NASA research thrust on Land Cover and Global Productivity. The underlying science questions for which the data will be used, are embedded in developing an improved understanding of the carbon and associated biogeochemical cycles, the structure and function of global terrestrial ecosystems and their interactions with the atmosphere and hydrosphere, and developing a predictive understanding of the role of water in land-atmosphere interaction.

The importance of a MODIS-AM follow-on to the terrestrial research community lies in the continuity of the MODIS data record of critical, high quality observations such as vegetation indices, leaf area index, land cover, fire and surface temperature.

The MODIS-AGI-VIIRS instruments will provide improvements over the existing AVHRR data by increasing the multi-spectral capability and dynamic range of the measurements together with improving on-board calibration, spatial resolution, and registration accuracy. Research using AVHRR data has been used to address important global change monitoring questions, such as quantifying the interannual variability in vegetation production associated with ENSO events, identifying long-term trends in the length of growing season in northern latitudes, documenting the interannual variability in the global distribution of fires and their associated trace gas and aerosol emissions, and documenting the current distribution of global land cover. The AVHRR data are being used to provide simple parameterizations and validation of different types of models including models for operational weather forecasting, global climate models, soil vegetation atmospheric transfer (SVAT) models and vegetation production efficiency models. Continuation of a MODIS class of measurements beyond EOS–PM will provide the necessary link to and overlap with the proposed NPOESS measurements. The data will provide a continuing basis for detecting and quantifying changes in land cover characteristics at seasonal and interannual to decadal scales that is an integral part of the US and International Global Change research agenda.

1.3) The importance of AGI to the oceanographic research community is also continuity of MODIS data records for marine ecosystem dynamics and sea surface temperature (SST). Closely related in importance is that this mission will help assure fidelity in the transition of these basic Earth science measurements, and the improvements which MODIS will bring to them, to the operational NPOESS series. The NPOESS series will provide the first ocean color measurements on the operational satellites. The SST measurements are a crucial continuation of observations required to address the basic question of determining the magnitude of climate change, and developing predictive capability. The MODIS class of SST of measurements, which focus on skin brightness temperature, are important for heat budget and energy flux studies, as well as process and prediction-oriented studies and models of seasonal-interannual and decadal scale climate variability, such as ENSO and El Niño. The visible ocean measurements of MODIS extend the ocean color time series begun with SeaWiFS. This times series forms the baseline for assessing the response of marine ecosystems to climate and long term change, and for addressing questions related to carbon storage, harmful alga blooms, and the sustainability of coastal marine resources needed by humanity. In addition, these visible observations aid in improving the accuracy of aerosol retrievals over the ocean. Together, the visible and IR Ocean observations represent a distinct improvement over classical AVHRR measurements through improved spectral and radiometric sensitivity, as well as instrument calibration and characterization.

2.) MEASUREMENT APPROACH AND SPECIFIC OBJECTIVES

2.1) Measurement Approach. NPP will acquire measurements in an orbit at 833-km altitude and with a 9:30 AM equator crossing time. The crossing time and orbit altitude is chosen to match the parameters of the European METOP satellites, since they will provide the coverage required by the NPOESS. Spatial resolution will differ from the EOS AM-1 due to differences in both the orbit and the sensors. Approximately 20 spectral bands, many of which will coincide, with MODIS bands, will be used. CERES–II will carry two additional bands. Existing MODIS and CERES algorithms will be modified to account for these changes. The data products will be cross-validated with the products from EOS AM-1 to establish the necessary relationships to use the combined data sets for long term climate and ecosystem studies.

2.2) Implications for Technology Development. The interagency measurement requirements for VIIRS are for operational products, and do not include research oriented capabilities such as ocean fluorescence and high spatial resolution sounding of atmospheric properties. From the perspective of NPP, small sensors to synergistically address these measurements, either from the NPP platform or from a separate platform are prime candidates for the Instrument Incubator Program (IIP). Alternate approaches to the measurement of fire properties may also be appropriate for consideration in the IIP.

EOS AM, together with Landsat 7 offers important synergistic capabilities, especially with MISR and the Enhanced Thematic Mapper+. From the perspective of NPP, development of small sensors to synergistically address these measurements, either from the NPP platform or from a separate platform, are prime candidates for the IIP.

NPP will include the capability to directly broadcast AGI data to users via an X-band direct broadcast system. Technology development to reduce the size, mass, and power of such an X-band system would be a candidate for technology development programs. Wide-band on-board processing for compression and/or higher order product generation (such as through the use of adaptive computing systems such as reconfigurable computing) would be very useful technology developments.

Two options for improved direct broadcast capability could be developed in parallel. Experimental use of optical communications links or a Ka-band phased array to transmit stored data to selected developers of data products would permit the testing of a federated data system as envisioned in EOSDIS planning.

2.3) Metrics for judging the success of an NPP mission include:

- Successful extension of the time series of the proposed data products.
- Demonstration of agreement between AGI derived data products and VIIRS derived data products as well as between CERES/NPP and CERES/NPOESS to within the long term accuracy requirements of the agencies as documented in the 1997 IPO report "Climate Measurement Requirements for the National Polar–orbiting Operational Environmental Satellite System National Polar–orbiting Operational Environmental Satellite System (NPOESS)".
- Improvements in data product accuracies over heritage (AVHRR–MODIS–SeaWiFS and CERES) products.

3.) MISSION TYPE

We propose a systematic measurement program, based upon a single satellite mission to bridge between EOS AM-1 and the NPOESS beginning in 2009.

While NPP is proposed for a morning equatorial crossing orbit to extend the MODIS- and CERES-AM measurements, the continuity of MODIS-like and CERES-like measurements in the afternoon crossing time is also needed. An option to fly a second mission in the 2007 time frame using advanced sensors could be used to test the next generation of sensors for the second block of the NPOESS.

4.) REMOTE SENSING MEASUREMENT TECHNIQUES

The measurement principles for AGI follow directly from those developed for MODIS. Daily coverage of the entire globe allows cloud free composites to be acquired at time scales commensurate with biospheric changes. A multi-band derived cloud mask is integral to the production of all higher level products. Capability to detect thin cirrus clouds is continued. Rigorous band-to-band co-registration requirements assure that physically meaningful spectral ratios can be obtained. Spatial resolution is generally slightly better than in MODIS, permitting better studies in complex terrain such as coastal zones.

The proposed band set spans the region from .4 micrometers to 13.3 micrometers. In order to minimize the downlink data rate and focal plane complexity, the ocean and land bands in the vis/NIR are combined, utilizing the wavelength requirements and bandpass limitations of the ocean bands, but employing bi-linear gains to encompass the required dynamic range and radiometric resolution. SWIR bands at 1.24, 1.38, 1.64 and 2.1 microns support the retrieval of cloud and surface properties. In support of global land cover and atmospheric composition studies, bands at 1.24, 2.1, and 3.9 micrometers have bi-linear or tri-linear gains to enable measures of surface fire properties. Detection of thin clouds over sea ice is especially difficult due to surface inversions and low sun angle or nighttime conditions. A new spectral channel is proposed at 10. 25 μm, which has similar ice absorption properties as an existing MODIS 8.55 μm channel but with different liquid water absorption.

A band for the measurement of ozone has been eliminated. Retrievals of total atmospheric water vapor at high spatial resolution are needed for atmospheric correction in most of the algorithms; AGI will use several spectral regions for this purpose. (Fewer bands are required than were used in MODIS.) Carbon dioxide absorption bands for cloud top properties have been reduced by three. The remaining band, at 13.3 micrometers, is required for thin cirrus detection. Appendix 1 lists the set of bands being used in an AGI/VIIRS accommodation study that is currently underway. Appendix 2 lists the NPOESS Environmental Data Records (EDR's) an other MODIS-like data products to be produced.

CERES-II is an advanced version of the successful CERES instrument design. It adds two channels to the current CERES instrument; one covers 0.7-4.5um to allow separation of the solar broadband into two major components. Recent studies using Nimbus 7 ERB nonscanner broadband data have indicated substantial changes in cloud absorption between these two portions of the solar spectrum. This separation will also assist in vegetation studies, PAR estimates, and separation of the predominantly scattering processes in the atmosphere for wavelengths less than 0.7um, with the significant gas and particle absorption at wavelengths longer than 0.7um. A second new channel is the "polar window" from 17-30um. This spectral region becomes an atmospheric window at very cold temperatures and low water vapor amounts such as the polar regions, and can dominate the thermal infrared radiation budget, both because the water vapor amounts are low, as well as because at low temperature the Plank function emission peak shifts to longer wavelengths. CERES-II will include the existing 3 CERES channels to continue the critical radiation budget climatology begun with the TRMM mission. Instrument size, power, and mass will remain low at roughly 50 kg and 50W. The first CERES instrument has demonstrated unprecedented ground to orbit stability of calibration to better than 0.5%.

5. TECHNICAL CHARACTERISTICS

The AGI instrument would be developed under a joint activity between NASA and the IPO, utilizing the existing competitively selected contractors for the VIIRS instrument. The mass, power, volume and data rate constraints of the IPO will be maintained, but consideration will be given to NASA unique requirements for instrument calibration and characterization. By leveraging the existing IPO study effort, risk will be greatly reduced for a rapid development cycle. The AGI would meet the IPO requirements for imagery and environmental data records for the study of the atmosphere, ocean and land, but would not address the low light level imaging requirements. The data stream would be utilized by NASA to produce the data products specified in the attached table, and by the IPO contractor to produce prototypes of the IPO VIIRS environmental data records.

Orbital characteristics are described in section 2.1. The spacecraft is a small, three-axis stabilized spacecraft capable of accommodating the requirements of AGI and CERES-II and possibly a third sensor. Mass allocation to AGI is 132 kg, to CERES-II is 60 kg, and to a third sensor is 100 kg. Average power allocation to AGI is 100 W, to CERES-II is 60 W, and a third sensor is 100 W. Total sensor payload is therefore 292 kg, 260 W. Pixel geolocation knowledge, post-processed, is required to be 125 m (including all sources of error such as attitude knowledge, spacecraft position knowledge, and DEM), likely necessitating both star trackers and GPS. Consistent with AVHRR-POES and MODIS-EOS-AM1, direct broadcast of AGI data is required. On-board data storage is estimated to be 100 Gb, well within the range of current capability. Based on the preliminary estimates of resource requirements and system requirements, at least four spacecraft buses from the current catalog of spacecraft offered through the NASA Rapid Spacecraft Development Office (RSDO) are capable of implementing NPP. Also, based on the preliminary estimates of overall spacecraft mass and volume, the SELVS II-B launch vehicle is capable of placing NPP into the required orbit.

Appendix 1
Notional Band Set for AGI

Band # (MODIS #)	Bandwidth	Cloud Mask	Clouds, Aerosols & PW	SST & LST	Land Bio	Fire	Ocean Bio
1 (8N)	0.402 - 0.422	.	.				X
2 (9N)	0.433 - 0.453	.	.		X		X
3 (3N)(10)	0.480 - 0.500	.	X		X		X
4 (4)	0.545 - 0.565	snow	X		X		X
5 (1)	0.620 - 0.670	clouds	X		X	X	X
6 (15)	0.743 - 0.753		X				X
7 (2)	0.841 - 0.876	clouds/shadow	X		X	X	
8 (19)	0.915 - 0.965	.	X				
9 (5)	1.230 - 1.250	.	X		X		
10 (26)	1.360 - 1.390	thin cirrus	.				
11 (6)	1.628 - 1.652	snow	X		X	X	
12 (7)	2.105 - 2.155	heavy aerosol	X		X	X	
13 (20)	3.660 - 3.840	.	X	X	X		
14 (21-22)	3.929 - 3.989	clouds	.	X	X	X	
15 (27)	6.535 - 6.895	high moisture	.				
16 (29)	8.400 - 8.700	cirrus	X	X			
17 (New)	10.00 – 10.50	thin cirrus	X				
18 (31)	10.75 – 11.25	window	X	X	X	X	
19 (32)	11.75 – 12.25	low moisture	X	X	X		
20 (33)	13.19 – 13.49	.	X	X			

N means that the wavelength is New, but it fulfills the algorithmic roll of that MODIS band.
PW – Precipitable Water;
SST – Sea Surface Temperature;
LST – Land Surface Temperature;
Land Bio algorithms include: Atmospherically Corrected Imagery, BRDF/Albedo, Land Cover/Land Cover Change, Vegetation Indices, Leaf Area Index, Fraction of Absorbed Photosynthetically Active Radiation, Net Photosynthesis and Primary Productivity.
Ocean Bio algorithms include: Normalized Water Leaving Radiance, Clear Water Epsilon, Chlorophyl-1, 2 concentration, Detached Coccolith Concentration, Instantaneous Photosynthetically Active Radiation, Net and Annual Primary Productivity.

Appendix 2
AGI Data Products

AGI Data Products that Match IPO Requirements

EDR	NPOESS & AGI Parameters	MODIS	Bands	Accuracy	Cell(km)
2.3.2	Cloud cover (fraction)	MOD06	16, 18-20	<0.1	5
4.7	Cloud top height	MOD06	EDR 4.8 + Pressure Profile	0.5 km –cu, 1 km-ci	5
4.8	Cloud top pressure	MOD06	16, 18-20	50 mb	5
4.9	Cloud top temperature	MOD06	EDR 4.8+ Temp. Profile	2 - 5 K	5
4.6	Cloud optical thickness	MOD06	5,6,9,11-13,18	10%	1
4.3	Cloud effective particle size	MOD06	5,6,9,11-13,18	10%/1-3mkm	1
3.1.1	Aerosol Opt Thick (Ocean)	MOD04	4-7, 9, 11, 12	<0.05	10
	Aerosol Optical Thick (Land)	MOD04	3-5,9,12,13,18	0.05	10
3.3	Precipitable water	MOD05	18,19; 7-9	7% , 10%	1
5.2	Surface albedo	MOD43	3 - 5, 7,9,11,12	0.03	pixel
6.1#	Land surface temperature	MOD11	13,14,16-20	1 K	1 & 5
6.2	NDVI	MOD13	5, 7	0.05-0.07	.25, 25
6.3	Snow cover/depth	MOD10	4, 11,12	<10% (no depth)	0.5
6.4	Veg index/surface type	MOD12	3 - 5, 7,9,11,12	80%(17class)	1
2.3.2.	Sea ice fraction	MOD29	4, 11,12	<0.1	0.5
7.2	Fresh water ice fraction	MOD29	4, 11,12	<0.1	0.5
7.3#	Ice surface temperature	MOD29	18, 19	0.3-2.1 K	1
2.4#	Sea surface temperature	MOD28	17 -19	0.35K	1, 10
7.6#	Ocean color/chlor conc.	MOD21	1 – 6	30%	1
7.11#	Mass loading (mg/l) -conc. of suspended matter in ocean	MOD23 –25	1 - 4, 6	30%	1

Additional AGI Data Products

	Cloud phase	MOD06	5, 11, 16, 18, 19	-	5
	Aerosol size distribution over ocean	MOD04	3-5, 12, 13	coarse & accum modes	10
	Surface BRDF	MOD09	3-5, 7,9,11,12	10%	1
	Land Cover/Land Cover Change	MOD12	3-5, 7,9,11,12	-	1
	Land surface emissivity	MOD11	13, 14, 16-20	0.02	1
	Vegetation indices (SARVI)	MOD13	3-5, 7	10%	0.25 -1
	LAI and FPAR	MOD15	3-5, 7,9,11,12	10% (FPAR), 0.5 (LAI)	1
	PSN and ANPP	MOD15	3-5, 7	<25% (PSN), <35% (NPP)	1
	Fire products	MOD14	5,6, 11,12, 14, 19	15% (emitted energy)	1
	Surface PAR and IPAR (ocean)	MOD22	1, 2, 6	6%	1
	Detached coccolith concentration	MOD25	2, 4	10**10 cocol/m3	1
	ANPP (ocean)	MOD27	1 - 6	-	

Cell is the aggregate resolution of the final data product at the specified accuracy.
Pixel means that the data product is produced at multiple resolutions. (e.g. 250m, 500m & 1,000m)