Solutions Network Formulation Report

Aerosol Polarimetry Sensor Measurements of Diffuse-to-Global Irradiance Ratio for Improved Forecasting of Plant Productivity and Health

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1. Candidate Solution Constituents

a. Title: Aerosol Polarimetry Sensor Measurements of Diffuse-to-Global Irradiance Ratio for Improved Forecasting of Plant Productivity and Health

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c. Identified Partners: U.S. Department of Agriculture's ARS (Agricultural Research Service), North Carolina State University, Purdue Climate Change Research Center, Cooperative Institute for Research in the Atmosphere at Colorado State University

d. Specific DST/DSS: ARS Plant Science Research Unit's Ecological, Physiological, and Genetic Aspects of Global Climate Change Impacts in Field Crop Systems

e. Alignment with National Application: Agricultural Efficiency, Air Quality

f. NASA Research Results – Table 1:

Missions	Sensors/Models	Data Product
• Glory • NPP[1]	• APS[2] • VIIRS[3]	• Aerosol optical thickness (APS) • Aerosol particle size distribution (APS) • Aerosol particle refractive index, single-scattering albedo, and shape (APS) • Fraction of fine mode aerosol (APS data combined with VIIRS data)
GSFC[4]	OMI[5] radiative transfer model	Diffuse-to-global irradiance ratio
GSFC/University of Maryland	6S[6]	Diffuse-to-global irradiance ratio

[1]NPP: NPOESS Preparatory Project; [2]APS: Aerosol Polarimetry Sensor; [3]VIIRS: Visible/Infrared Imager/Radiometer Suite; [4]GSFC: Goddard Space Flight Center; [5]OMI: Ozone Monitoring Instrument; [6]6S: Second Simulation of the Satellite Signal in the Solar Spectrum

g. Benefit to Society: Improved monitoring and forecasting of crop productivity and health

2. Abstract

Studies have shown that vegetation is directly sensitive to changes in the diffuse-to-global irradiance ratio and that increased percentage of diffuse irradiation can accelerate photosynthesis. Therefore, measurements of diffuse versus global irradiance could be useful for monitoring crop productivity and overall vegetative health as they relate to the total amount of particulates in the air that result from natural disasters or anthropogenic (manmade) causes. While the components of solar irradiance are measured by satellite and surface sensors and calculated with atmospheric models, disagreement exists between the results, creating a need for more accurate and comprehensive retrievals of atmospheric aerosol parameters. Two satellite sensors—APS and VIIRS—show promise for retrieving aerosol properties at an

unprecedented level of accuracy. APS is expected to be launched in December 2008. The planned launch date for VIIRS onboard NPP is September 2009. Identified partners include the USDA's ARS, North Carolina State University, Purdue Climate Change Research Center, and the Cooperative Institute for Research in the Atmosphere at Colorado State University. Although at present no formal DSSs (decision support systems) require accurate values of diffuse-to-global irradiance, this parameter is sufficiently important that models are being developed that will incorporate these measurements. This candidate solution is aligned with the Agricultural Efficiency and Air Quality National Applications.

3. Detailed Description of Candidate Solution

a. Purpose/Scope

Studies have shown that vegetation is directly sensitive to changes in the diffuse fraction of irradiance and that increasing the ratio of diffuse irradiance to global irradiance can accelerate photosynthesis (Roderick et al., 2001). This accelerated photosynthesis is thought to be due to a reduction in the number of shaded patches on leaves. Shaded patches would normally occur in bright light but are absent in more diffuse light (Niyogi et al., 2004). The amount and type of irradiance can vary enormously over time and space, and aerosol loading has been identified as a major contributor to increased diffuse irradiance (Kim et al., 2005; Kaufman et al., 2002). The components of irradiance can be retrieved from measurements by satellite sensors and surface instrument networks and can be calculated with atmospheric models (Cavazzoni, 2006; Rivington, et al. 2002). However, significant disagreements have been observed between the satellite values, surface values, and model results (Kim et al., 2005; Matsui et al., 2004). Because of these disagreements and the sparse distribution of surface sensors, more accurate satellite-based measurements of atmospheric aerosol properties are needed from which the diffuse fraction of irradiance can be retrieved. Satellite observations from APS/VIIRS could be used to collect accurate data on atmospheric particulates and on diffuse versus global irradiance. These values could be invaluable for predicting vegetative health/recovery following a natural disaster, such as a volcanic eruption (Robock, 2005) or a forest fire (Kanniah et al., 2006).

b. Identified Partners

The ARS (Agricultural Research Service) is the USDA's (U.S. Department of Agriculture's) chief scientific research agency. The Plant Science Research Unit of the ARS, based at North Carolina State University in Raleigh, NC, conducts research to determine how atmospheric contaminants and climate change affect plant growth, development, and yield (ARS, 2007a). Another identified partner is the Purdue Climate Change Research Center (PCCRC, 2004), which is conducting research on how changes in aerosols, stratospheric ozone, and clouds affect the distribution of ultraviolet radiation reaching plants. Also included is the Cooperative Institute for Research in the Atmosphere, located at Colorado State University (CIRA, 2007), which conducts research on climate, applications of satellite observations, air quality, and visibility.

While no formal DSSs currently require accurate values of diffuse-to-global irradiance ratio, this parameter is sufficiently important that models are being developed that will use these measurements. The USDA ARS Ecological, Physiological, and Genetic Aspects of Global Climate Change Impacts in Field Crop Systems project is performing research and assessments that focus primarily on ozone but also focus on diffuse irradiation effects on crop productivity (ARS, 2007b). In the context of the Applied Sciences Program, DSTs (decision support tools) include assessments that serve policy and management decisions.

c. NASA Earth-science Research Results

The planned launch date for APS on the Glory platform is 2008. Glory will join the "A-train" 5 minutes behind Aura and will be in front of PARASOL (Polarization & Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar). The orbit will be 705 km sun-synchronous, 98.2^o inclination, with an ascending node mean local time crossing of 1:35 p.m. to 1:50 p.m. The design life of the Glory mission is 3 years with a 5-year goal.

VIIRS will be onboard the NPP, which is scheduled to launch in September 2009. VIIRS is a multispectral imager with spectral bands similar to MODIS (the Moderate Resolution Imaging Spectroradiometer).

Smoke and dust particles scatter and absorb sunlight, thereby increasing the diffuse component of irradiance but reducing the global irradiance. Sulfate aerosols, however, tend to scatter but not absorb sunlight, increasing the diffuse component while reducing the global irradiance much less than smoke or dust (Kanniah et al., 2006). The type of irradiance can significantly affect the rate of photosynthesis. Direct irradiation has a maximum value above which the rate of photosynthesis does not increase because the chemical process becomes saturated. However, increasing the diffuse component eliminates shadows on the leaves, thereby increasing the rate of photosynthesis (Niyogi et al., 2004).

Direct and diffuse irradiance values have been derived from GOES (Geostationary Operational Environmental Satellite) and compared with surface measurements from the ARM (Atmospheric Radiation Measurement) network (Perez et al., 2001). Measurements have also been made from MODIS and compared with the AERONET (Aerosol Robotic Network) and IMPROVE (Interagency Monitoring of Protected Visual Environments) sensor networks (Matsui et al., 2004).

However, imagery at high latitudes from geostationary satellites such as GOES can be distorted or unavailable, while data obtained from polar-orbiting satellites varies seasonally because of the large range of day length and is limited by the number of satellites available (Wetzel and Slusser, 2003). Disagreements have been identified between satellite measurements and ground measurements of aerosol properties. One source of inaccuracy in satellite aerosol retrieval methods is that methods using a single directional reflectance measurement are sensitive only to the product of the aerosol phase function and the aerosol optical thickness (Leroy et al., 1997), hence assumptions are required to retrieve the aerosol properties. Multi-angle polarized radiance measurements, such as those that will be acquired by APS, contain enough information to unambiguously retrieve the aerosol properties (Russell et al., 2003).

d. NASA Earth Science Models

Radiative transfer models supported by NASA that could be used to calculate diffuse-to-global irradiance ratio include the OMI radiative transfer model (Stammes, 2002) and the 6S (Vermote et al., 1997).

e. Proposed Configuration's Measurements and Models

APS is unique because it will perform multispectral radiance measurements at multiple viewing angles and polarizations over a wider spectral range than any similar sensors. Measurements will include scene radiance in orthogonal polarizations (Stokes parameters I, Q, and U) simultaneously in 9 spectral bands between 0.41 and 2.25 μm, over a large range of along-track viewing angles with the sensor scanning field-of-view ±60º about nadir. These measurements will be used to determine aerosol optical thickness, particle size (radius and variance), refractive index, single-scattering albedo, and shape (sphericity), as well as cloud particle size distribution. Aerosol mass loading can be retrieved from the optical thickness and size distribution. The aerosol refractive index, single scattering albedo, and shape can be used to determine the aerosol composition, from which the source may be identified. Measurements with an airborne instrument almost identical to APS, the Research Scanning Polarimeter, have shown great promise for retrieving aerosol parameters with a high level of accuracy (Russell et al., 2003).

VIIRS will have multichannel imaging capabilities to support the acquisition of high-resolution atmospheric imagery for retrieval of aerosol properties. VIIRS data will be combined with APS data to retrieve the fraction of fine mode aerosol.

The aerosol data products from APS and VIIRS will be input to a radiative transfer model such as the OMI model (Stammes, 2002) or 6S (Vermote et al., 1997). The radiative transfer model will calculate diffuse-to-global irradiance ratio, which will then be incorporated into the USDA ARS photosynthesis assessment (DST) to determine the impact of global climate change (expressed in terms of diffuse/global irradiance ratio change) in field crop systems.

4. Programmatic and Societal Benefits

Plant productivity has been observed to increase as the ratio of diffuse to global irradiance is raised by sunlight scattering from aerosol particles. Atmospheric aerosol loading is highly variable over time and space and can be elevated by natural events, such as volcanic eruptions, forest fires, and dust storms, and by anthropogenic activities. If accurate measurements of atmospheric aerosols can be acquired on a regular basis, our ability to forecast diffuse-to-global irradiance ratio and hence to predict plant productivity and health will be improved. This candidate solution benefits the Agricultural Efficiency and Air Quality National Applications.

5. References

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