Solutions Network Formulation Report

Use of AIRS, OMI, MLS, and TES Data in Assessing Forest Ecosystem Exposure to Ozone

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1. Candidate Solution Constituents

a. Title: Use of AIRS, OMI, MLS, and TES Data in Assessing Forest Ecosystem Exposure to Ozone

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c. Identified Partners: USDA FS (U.S. Department of Agriculture Forest Service), Pacific Southwest Research Station, and the NPS (National Park Service)

d. Specific DST/DSS: The Ozone Calculator used by the USDA FS and by the NPS to augment understanding of vulnerability, threat, and impact of chronic or episodic elevated ozone exposure to susceptible coniferous forests in the Pacific Southwest region of the United States

e. Alignment with National Applications: 1) Carbon Management, 2) Ecological Forecasting, and 3) Air Quality

f. NASA Research Results – Table 1:

Mission	Sensors/Models	Data Product
Aqua	AIRS (Atmospheric Infrared Sounder)	Time-dependent regional measurements of atmospheric ozone concentrations
Aura	OMI (Ozone Monitoring Instrument) MLS (Microwave Limb Sounder) TES (Tropospheric Emission Spectrometer)	Time-dependent regional measurements of atmospheric ozone concentrations

g. Benefit to Society: Improved USDA FS and NPS ability to monitor, promote, and maintain healthy forests by monitoring forest exposure to abnormally high tropospheric ozone levels

2. Abstract

Ground-level ozone at high levels poses health threats to exposed flora and fauna, including negative impacts to human health. While concern is common regarding depletion of ozone in the stratosphere, portions of the urban and rural United States periodically have high ambient levels of tropospheric ozone on the ground. Ozone pollution can cause a variety of impacts to susceptible vegetation (e.g., Ponderosa and Jeffrey pine species in the southwestern United States), such as stunted growth, alteration of growth form, needle or leaf chlorosis, and impaired ability to withstand drought-induced water stress. In addition, Southern Californian forests with high ozone exposures have been recently subject to multiyear droughts that have led to extensive forest overstory mortality from insect outbreaks and increased incidence of wildfires. Residual forests in these impacted areas may be more vulnerable to high ozone exposures and to other forest threats than ever before.

NASA sensors collect a wealth of atmospheric data that have been used recently for mapping and monitoring regional tropospheric ozone levels. AIRS (Atmospheric Infrared Sounder), OMI (Ozone Monitoring Instrument), MLS (Microwave Limb Sounder), and TES (Tropospheric Emission Spectrometer) data could be used to assess forest ecosystem exposure to ozone. Such NASA data hold promise for providing better or at least complementary synoptic information on ground-level ozone levels that Federal agency partners can use to assess forest health trends and to mitigate the threats as needed in

compliance with Federal laws and mandates. NASA data products on ozone concentrations may be able to aid applications of DSTs (decision support tools) adopted by the USDA FS (U.S. Department of Agriculture Forest Service) and by the NPS (National Park Service), such as the Ozone Calculator, in which ground ozone estimates are employed to assess ozone impacts to forested vegetation.

3. Detailed Description of Candidate Solution

a. Purpose/Scope

AIRS, OMI, MLS, and TES data have potential for estimating tropospheric (i.e., ground level) ozone across broad regions to assist the USDA FS and the NPS personnel responsible for forest health monitoring and management. NASA satellite data products provide synoptic estimates of tropospheric ozone that could help USDA FS and NPS end users to assess modeled output of ground ozone concentrations based on in-situ data. In doing so, anomalies of low and high ozone levels could be identified for further study, and forest ozone health problems could be mitigated or monitored further as warranted. Ozone data contributions from NASA assets may aid the USDA FS and the NPS in complying with the Healthy Forest Restoration Act of 2003 (U.S. Congress, 2003) and Clean Air Act of 1990 (U,S, Congress, 1990). NASA satellite ozone data might also be used in conjunction with the Ozone Calculator developed by the USDA FS for assessing ozone damage impacts to exposed forests (USDA FS, 2005).

b. Identified Partners

The main partner identified for the proposed candidate solution is the USDA FS in the southwestern United States. USDA FS personnel working at the Pacific Southwest Research Station in California and at nearby National Forests have been monitoring forest ozone levels and impacts for years because ground ozone levels have frequently exceeded U.S. Environmental Protection Agency standards. A second Federal agency partner is the NPS, which includes managers, vegetation experts, and air quality specialists responsible for national parks and monuments in the southwestern United States.

Federal agencies, such as the USDA FS and the NPS, need synoptic information on ground-level ozone levels to complement regional models of site-specific ozone concentrations and to assess negative impacts to vegetation from ozone exposure. These agencies have in-situ monitoring networks spread across the United States in general and especially in areas subject to seasonally frequent high exposures of ozone. The NPS (2004) provides a detailed description on its efforts to monitor ground-level ozone within National Park lands. In most cases, in-situ data collection occurs in one place per park. In terms of vegetation management, land management agencies like the USDA FS and the NPS need to monitor forest health variables on a regular basis. The USDA FS performs this monitoring nationally via its Forest Inventory and Analysis (USDA FS, 2006c), Forest Health Monitoring (USDA FS, 2006b), and Air Monitoring (USDA FS, 2006a) National Programs, whereas the NPS does so via its Inventory and Monitoring Program (NPS, 2006) and Air Research Division (NPS, 2007).

Users of the Ozone Calculator appear to need more in-situ data and synoptic data on ground ozone concentrations within forested areas. The USDA FS and the NPS make use of the Ozone Calculator DST in assessing vegetation impacts due to exposure to elevated ground-ozone levels, especially in regions having documented air pollution problems or having high air quality standards (e.g., wilderness areas).

Potential end users of NASA ozone data include USDA FS and NPS researchers who assess forest health impacts due to tropospheric ozone exposure. For example, Nancy Grulke of the USDA FS has been studying effects of forest ozone exposures to vulnerable tree species, such as Jeffrey and Ponderosa pine, using a network of observational sites located across a gradient of ozone exposures (e.g., Grulke, 2003). Her study areas on this topic include Southern California, which has a history of seasonally high exposures of ozone in National Forest lands adjacent to Los Angeles. Grulke et al. (2006) reported that forest exposure to high ozone levels can increase individual tree susceptibility to drought, insect attack, and wildfire. During the multiyear drought of 1999–2003, the Southern California region experienced extensive bark beetle outbreaks and wildfires that resulted in unprecedented extensive mortality of coniferous forests (Minnich, in press). The area is still subject to periodic exposures to high ozone levels from pollution and from wildfires, and forest recovery is being monitored with ozone impacts in mind.

c. NASA Earth-science Research Results

Much published literature is now available on the estimation of tropospheric ozone levels from NASA satellite sensor data products, including work by Jing et al. (2006) and Ziemke et al. (2006) that used Aura OMI and MLS Earth observation satellite data for estimating tropospheric ozone concentrations. Schoeberl et al. (2004) discuss the use of Aura OMI, MLS, and TES for estimating atmospheric ozone parameters. Kelly (2006) reported that Aura has sufficient fuel to collect data at least until 2014 and as long as 2016.

Aura was deployed in 2004 and includes 3 sensors (OMI, MLS, and TES) that are used in measuring and assessing amounts and fluxes of atmospheric ozone, including ozone concentrations in the troposphere and stratosphere. The OMI is used for generating high–resolution, global-scaled ozone maps and vertical profiles of ozone concentrations. The TES makes direct measurements of tropospheric ozone, including ozone levels in the lower troposphere. MLS provides vertical profiles of ozone concentrations, including measurements of ozone in the upper troposphere. TES tropospheric ozone measurements are being augmented by combined use of MLS and OMI in which MLS stratospheric ozone is subtracted from the OMI column ozone (Zeimke et al., 2006).The OMI makes similar measurements to TOMS, although is more spatially resolute. It is unclear what spatial resolution is desirable for USDA FS and NPS needs, although it is expected that coarse synoptic data on tropospheric ozone concentrations would be a valuable addition to the currently available in-situ point measurements and the interpolated, (i.e., krigged) modeled regional surfaces of ozone concentration based on such point measurements.

Launched in May 2002 onboard the Aqua satellite, AIRS includes an ozone channel used to produce vertical profile measurements of atmospheric ozone concentrations. Such data products can be further processed to quantify ozone concentrations in the mid troposphere as well as stratospheric/ tropospheric exchanges of ozone. Such information may be useful for USDA FS and NPS needs, although more work is needed to draw conclusions. Although originally designed for a 6-year life expectancy, Aqua is now projected to last at least 8 to 10 years from present, given available fuels and satellite condition (Guit, 2006). Table 2 provides general specifications for OMI, MLS, TES, and AIRS ozone products.

The MODIS atmospheric product known as MOD07 also includes estimates of atmospheric ozone concentrations (Seemann et al., 2003). In the future, NPOESS (National Polar-orbiting Operational Environmental Satellite System) and NPP (NPOESS Preparatory Project) will include the OMPS (Ozone Mapping and Profiler Suite) sensor that will replace the TOMS (Total Ozone Mapping Spectrometer) and the National Oceanic and Atmospheric Administration SBUV/2 (Solar Backscatter Ultraviolet Spectrometer/2). NPP is due to launch in either fall of 2009 (NASA, 2006) or early in 2010 (Stockton and Ryan, 2006).

Table 2. General specifications for atmospheric ozone products from OMI, MLS, TES, and AIRS ozone products.

	OMI OMTO3: Total Ozone	**OMI: Ozone Profile**	**ML2O3: Ozone (O3) Mixing Ratio**	**TES TL2O3N: O3 Nadir**	**AIRS Ozone Product**
Instrument Type	Hyperspectral pushbroom imager	Hyperspectral pushbroom imager	Microwave radiometer	High-resolution IR Fourier transform spectrometer	Grating multispectral atmospheric IR sounder
Number of Bands for Instrument	0.270–0.314 µm; 0.306–0.380 µm; 0.350–0.500 µm	0.270–0.314 µm; 0.306–0.380 µm; 0.350–0.500 µm	Microwave; 118, 190, 240, 640, and 2,500 GHz	Four wavelength regions of 3.2–15.4 µm, tunable to high resolution bands of interest	2,378 from 3.7–15.4 µm; 4 visible/NIR channels from 0.4–1 µm
Intrinsic Horizontal Resolution	13 x 24 km	13 x 48 km	500 km (horizontal)	5.3 x 8.5 km (horizontal)	40.6 km (horizontal)
Intrinsic Vertical Resolution	6 km	6 km	3 km	2–6 km	Upper Vertical Profile (in terms of pressure): surface to 0.016 Mb
Swath	2,600 km	2,600 km	2.5–62.5 km limb to limb	5.3 x 8.5 km	99° (=1650 km)
Orbit Repeat Time	Daily global coverage	Daily global coverage	2 days	Global every 2 days	2/day
Design Life (Minimum)	5 years	5 years	3 years	3 years	6 years
Product Coverage	Global	Global	Global	Global	Global
Accuracy	3%	10%	5–10%	3%	10%

d. Proposed Configuration's Measurements and Models

The candidate solution would be evaluated using available NASA ozone data products from AIRS, OMI, TES, and MLS sensors, limiting this accrual to data collected over areas of interest in the southwestern United States where USDA FS researchers are performing forest ozone monitoring, damage assessment, mitigation, and modeling.

Such a study would allow end-users to apply and assess NASA tropospheric ozone data in regards to applications of the Ozone Calculator, a DST developed by the USDA FS and used by both the USDA FS and the NPS. The Ozone Calculator has been used to assess forest biomass loss due to ozone-induced damage. As part of the USDA FS Natural Resource Information System, the Ozone Calculator allows end users to calculate ozone levels on an hourly basis based on contiguous multi-date time series of in-situ zone measurements. The Ozone Calculator currently employs inputs on ground ozone concentrations from in-situ data and from krigged surface imagery interpolated from sporadic points of in-situ data. Auxiliary to this DST is a Web-based GIS (geographic information system) interface that allows end users to query in-situ ozone network sites for downloading data to use with the Ozone Calculator. End users within the USDA FS and the NPS can download the in-situ ozone data as well as interpolated regional geospatial models of ozone concentrations. The NASA satellite-based ozone data would be used to compare against the in-situ hourly ozone data and the regional modeling output. Ozone concentration data currently used with the Ozone Calculator is in a GIS ready format, which would facilitate comparison to geospatial ozone products derived from NASA science data.

4. Programmatic and Societal Benefits

Synoptic broad regional estimates of tropospheric ozone concentrations from NASA science data should be useful for USDA FS and NPS forest researchers and managers assessing, monitoring, modeling, and mitigating impacts from ozone induced forest damage. Such information would complement or augment in-situ and modeling inputs on ground ozone concentrations to the Ozone Calculator. The proposed solution should be a valuable alternative for providing ground ozone estimates when the in-situ based systems are inoperable, such as when severe storms or other natural disasters hit. Consequently, the proposed solution has potential for aiding users of the USDA FS Ozone Calculator DST. It also has potential for aiding work being performed by the USDA FS and NASA on development of forest health related early warning systems. Such systems are important for ecological forecasting and land resource management needed for maintaining sustainable healthy forests. The candidate solution also has potential for aiding carbon sequestration estimation and management applications. NASA tropospheric ozone data inputs to the Ozone Calculator may be useful for assessing forest ozone damage impacts on forested carbon stocks. This candidate solution aligns with the Carbon Management, Ecological Forecasting, and Air Quality National Applications.

5. References

Grulke, N.E., 2003. The physiological basis of ozone injury assessment in Sierran conifers. Section I, Chapter 2 in *Ozone Air Pollution in the Sierra Nevada: Distribution and Effects on Forests (Developments in Environmental Science)* (A. Bytnerowicz, M.J. Arbaugh, and R. Alonso, eds.), Elsevier Science Ltd., Kidlington, Oxford, pp. 55–82.

Grulke, N.E., R.A. Minnoch, T. Paine, A. Dunn, and D. Chavez, 2006. Air pollution increases forest susceptibility to wildfires in southern California. In *Proceedings of IUFRO 7.01 Symposium: Forest Fires and Air Pollution Issues*, 11 September 2006, Riverside, California, http://www.fs.fed.us/psw/iufro/abstracts/FireSymposiumAbstracts.pdf (accessed January 28, 2007).

Guit, B., 2006. *EOS AQUA – Mission Operations Status, 2006 AQUA Briefing*. Presentation to NASA Headquarters, 7 August 2006, http://aqua.nasa.gov/doc/presentations/7_Guit_MissionOps.ppt (accessed January 28, 2007).

Jing, P., D. Cunnold, Y. Choi, and Y. Wang, 2006. Summertime tropospheric ozone columns from Aura OMI/MLS measurements versus regional model results over the United States. *Geophysical Research Letters* vol. 33, L17817, doi:10.1029/20067GL026473.

Kelly, A., 2006. *EOS Aura Mission Operations Working Group (MOWG) Report*. Presentation at Aura Science Team Meeting, 11–15 September 2006, Boulder, Colorado.

Minnich, R.A., in press. Southern California coniferous forest. Chapter 18 in *Terrestrial Vegetation of California*, 3rd edition (M.G. Barbour, T. Keeler-Wolf, and A.S. Schoenherr, eds.), University of California Press, (Scheduled publication date: spring 2007), pre-publication proof available on-line at http://www.earthscience.ucr.edu/people/minnich/minnich_chapter_18.pdf (accessed January 29, 2007).

NASA [National Aeronautics and Space Administration], 2006. *NPOESS Preparatory Project (NPP).* http://science.hq.nasa.gov/missions/satellite_58.htm (accessed January 30, 2007).

NPS [National Park Service], 2004. *Ozone Monitoring Protocol, Guidance on Selecting and Conducting Ozone Monitoring.* National Park Service, Research and Monitoring Branch, Air Resources Division, Denver, Colorado, Report No. NPS D1654, 24 p.

NPS, 2006. *Inventory and Monitoring Program*. http://science.nature.nps.gov/im/index.cfm (accessed January 28, 2007).

NPS, 2007. *Air Quality Monitoring & Access to Data.* http://www2.nature.nps.gov/air/ (cache of web site viewed at: http://72.14.209.104/search?q=cache:unBQPdN9dVkJ:www2.nature.nps.gov/air/+NPS+Air+Resources+Division&hl=en&gl=us&ct=clnk&cd=1 (assessed on January 28, 2007).

Schoeberl, M.R., A.R. Douglass, E. Hilsenrath, P.K. Bhartia, J. Barnett, J. Gille, R. Beer, M. Gunson, J. Waters, P.F. Levelt, and P. DeCola, 2004. Earth Observing System missions benefit atmospheric research. *Earth Observing System, Transactions American Geophysical Union*, 85(18): 177–184.

Seemann, S.W, J. Li, W.P. Penzel, and L.E. Gumley, 2003. Operational retrieval of atmospheric temperature, moisture, and ozone from MODIS infrared radiances. *Journal of Applied Meteorology* 42: 1072–1091.

Stockman, D., and D. Ryan, 2006. NPOESS: The restructured program. Presentation at *Polar Max 2006*, 24–26 October, Silver Spring, MD, http://www.ipo.noaa.gov/polarmax/2006/day03/4.1PolarMaxNPOESSStockton-Ryan--withDWSfinaledits-FINAL.ppt (accessed January 30, 2007).

U.S. Congress, 1990. *Clean Air Act Amendments of 1990*. P.L. 101-549, November 15, 1990. http://www.epa.gov/air/caa/ (accessed January 28, 2007).

U.S. Congress, 2003. *Healthy Forests and Restoration Act of 2003*. P.L. 108-148, December 2, 2003. http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=108_cong_bills&docid=f:h1904enr.txt.pdf (accessed on January 28, 2007).

USDA FS [U.S. Department of Agriculture Forest Service], 2005. *Air Resources Management*. http://webcam.srs.fs.fed.us/why_monitor.htm (accessed February 1, 2007).

USDA FS, 2006a. *National Air Resource Management*. http://www.fs.fed.us/air/index.htm (accessed February 5, 2007).

USDA FS, 2006b. *National Forest Health Monitoring Program.* http://fhm.fs.fed.us/ (accessed January 28, 2007).

USDA FS, 2006c. *Forest Inventory and Analysis National Program.* http://fia.fs.fed.us/ (accessed January 28, 2007).

Ziemke, J.R., S. Chandra, B.N. Duncan, L. Froidevaux, P.K. Bhartia, P.F. Levelt, and J.W. Waters, 2006. Tropospheric ozone determined from Aura OMI and MLS: Evaluation of measurements and comparison with the Global Modeling Initiative's Chemical Transport Model. *Journal of Geophysical Research* 111, D19303, doi:10.1029/2006JD007089.