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Introduction to special section on Aura Validation

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[1] Aura, the last of the large EOS observatories, was launched on 15 July 2004 and has now been operating for several years. Aura is designed to make comprehensive stratospheric, mesospheric, and tropospheric constituent measurements from its four instruments HIRDLS, MLS, OMI, and TES. All of the instruments are performing well and observations of stratospheric and tropospheric trace gases and aerosols are revolutionizing our understanding of stratospheric chemistry and transport processes, ozone depletion, air quality, and the hydrological cycle. In this special section, the instrument teams and collaborators report on the validation of the released Aura data products.

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1. Introduction

[2] EOS Aura (Latin for breeze) is an atmospheric composition mission. Aura was launched 15 July 2004 into 705 km Sun-synchronous polar orbit with a 98° inclination and a local equator-crossing time of 1344 for the ascending node. The design life is 5 years with a 6-year operational goal. Aura flies in formation in the A-Train about 15 min behind Aqua. The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) and CloudSat, launched together on 28 April 2006 [*Stephens et al.*, 2002] fly a few minutes behind Aqua. Several minutes behind CloudSat, flies the French Space Agency (CNES) Polarization and Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar (PARASOL) satellite launched in December 2004. Aura brings up the rear of the "A-Train."

[3] Figure 1 shows the Aura spacecraft and its four instruments (Table 1): the High Resolution Dynamics Limb Sounder (HIRDLS), the Microwave Limb Sounder (MLS), the Ozone Monitoring Instrument (OMI) and the Tropospheric Emission Spectrometer (TES).

2. Science Objectives of the Aura Mission

[4] The objective of the Aura mission is to address three principal science questions: Is the ozone layer changing as expected? What are the processes that control tropospheric pollutants? What are the roles of aerosols, water vapor and ozone in climate change? The strategy Aura employs in addressing these questions is to obtain a comprehensive set of chemical observations at high vertical and horizontal resolution throughout the atmosphere (Table 1). These measurements, when combined with those from field campaigns, other satellites (e.g., Aqua, CloudSat and CALIPSO), and ground-based instruments, should provide unprecedented insights into the chemical and dynamical processes associated with our atmosphere.

3. Aura Mission Design

[5] The Aura mission, including instrument overviews, is described by *Schoeberl et al.* [2006]. Aura limb instruments were designed to observe roughly along the orbit plane. MLS is on the front of the spacecraft while HIRDLS, TES and OMI are mounted on the earth-facing side. HIRDLS and TES make limb soundings observing backward while MLS observes in the forward direction. OMI and TES make nadir soundings as shown in Figure 2. The advantage of this instrument configuration is that MLS, OMI and TES observe roughly the same air masses within minutes. Although all the instruments are operating nominally, HIRDLS will only deliver data products along one scan position because of a piece of plastic that was blown on the scan mirror during launch decompression, and TES is no longer doing limb scans in order to preserve instrument life.

4. Aura Validation

[6] Well before launch, the science team developed a comprehensive validation document and plan. Aura is unique among the EOS missions in that the validation activities were designed to involve all the instruments: validation was a platform wide activity.

[7] The Aura validation program has included aircraft field campaigns, high-altitude balloon launches as well as routine ground-based and sonde measurements. Some of the more significant campaigns are given in Table 2. The first aircraft campaign, Aura Validation Experiment (AVE) Houston, took place in the fall of 2004, shortly after launch, and the most recent campaign took place in the summer of 2007. The validation comparisons discussed in this section involve only the satellite, aircraft, balloon and ground-based data taken between mid 2004–2006. Validation activities

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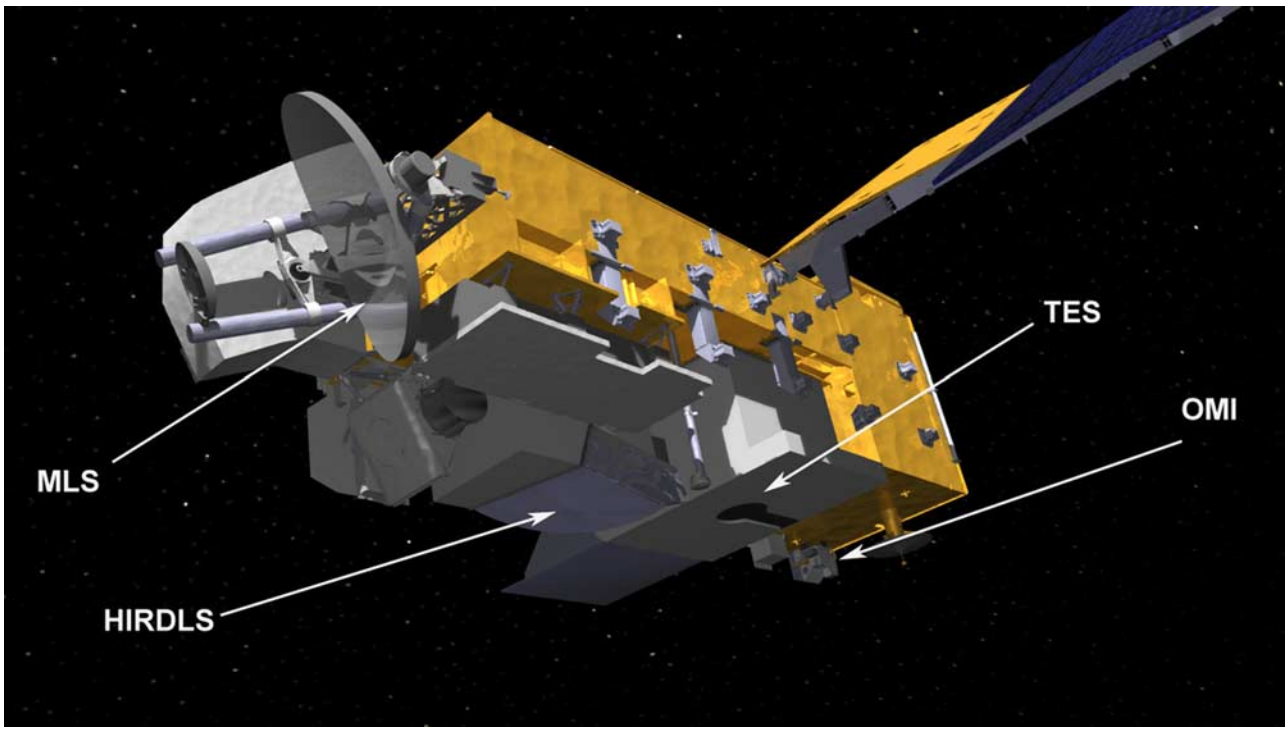

Figure 1. A sketch of the Aura spacecraft showing the location of the four instruments HIRDLS, MLS, OMI and TES [from *Schoeberl et al.*, 2004].

continue into 2007–2008. Finally, as part Aura validation activity, the Aura Project developed a data center to facilitate access to validation data and foreign data sets and to subset the Aura data products at the validation locations. The Aura Validation Data Center can be accessed at http://avdc.gsfc.nasa.gov/.

[8] Validation is an activity by which the satellite data products are compared to independent measurements and the differences are documented. It is important to recognize that a validated data product may not agree with independent measurements, although in most cases the differences will be small. Data users should always consult the validation papers and work with the instrument teams in using the data to get validation updates, avoid data misuse and to understand where differences between the satellite data and independent measurements are important.

[9] This special section contains papers describing the validation of 30 different data products from Aura, including descriptions of their accuracy, precision, and resolution, and findings from comparisons with other data sets.

[10] Table 3 gives a very brief description of the subjects of each paper in the special section. Table 3 lists the relevant

Table 1. Aura Instruments and Measurements[a]

Acronym	Name	Instrument PIs	Constituent	Instrument Description
HIRDLS	High Resolution Dynamics Limb Sounder	John Gille, National Center for Atmospheric Research and University of Colorado, and John Barnett, Oxford University	profiles of T, O_3, HNO_3, cloud top height, *H_2O, CH_4, N_2O, NO_2,, N_2O_5, CF_3Cl, CF_2Cl_2,$ClONO_2$*	limb IR filter radiometer from 6.2 μm to 17.76 μm, 1.2 km vertical resolution up to 50 km [*Gille et al.*, 2003, 2005]
MLS	Microwave Limb Sounder	Nathaniel Livesey, Jet Propulsion Laboratory	profiles of T, H_2O, O_3, ClO, BrO, HCl, OH, HO_2, HNO_3, HCN, N_2O, CO, HOCl, GPH, cloud ice	Microwave Limb Sounder, 118 GHz to 2.5 THz, 1.5–5 km vertical resolution [*Waters et al.*, 2006]
OMI	Ozone Monitoring Instrument	Pieternel Levelt, Royal Dutch Meteorological Institute, and Johanna Tamminen, Finnish Meteorological Institute	column O_3, SO_2, aerosols, NO_2, BrO, OClO, HCHO, cloud pressure, O_3 profiles, UV-B	hyperspectral nadir imager, 114° FOV, 270–500 nm, 13 × 24 km nadir footprint for all products except ozone profile [*Levelt et al.*, 2006]
TES	Tropospheric Emission Spectrometer	Reinhard Beer, Jet Propulsion Laboratory	profiles of T, O_3, NO_2, CO, HNO_3, CH_4, H_2O	limb (to 34 km) and nadir IR Fourier transform spectrometer 3.2–15.4μm, nadir footprint 5.3 × 8.5 km, limb 2.3 km [*Beer*, 2006]

[a]Italics indicate products not yet in production.

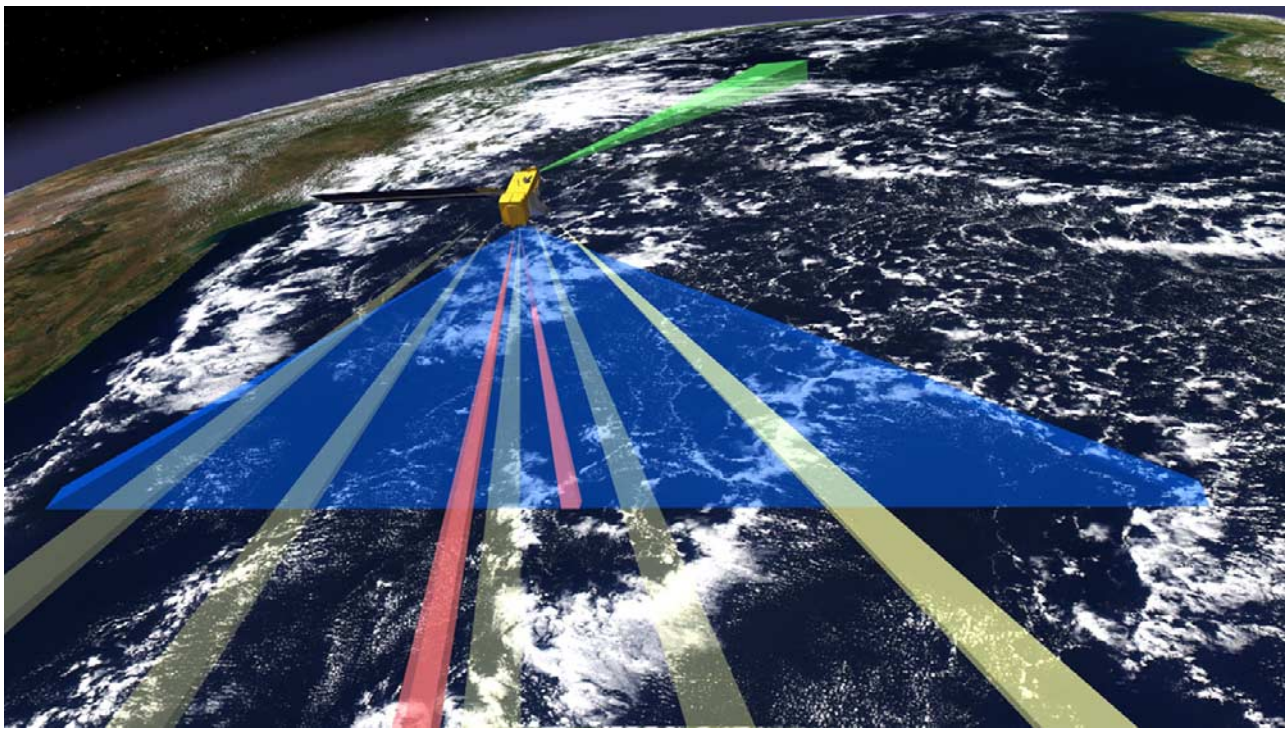

Figure 2. A view from behind Aura, looking forward. The instrument fields of view are shown as colored beams. MLS performs forward limb sounding (green). OMI nadir measurements are indicated with the blue swath. TES limb and nadir measurements are shown in pink. HIRDLS' originally planned measurements (five scan positions) are shown in yellow. TES and HIRDLS measurements are made in the antivelocity direction. Because a piece of Kapton® is blocking the HIRDLS optical system, HIRDLS is only able to make measurements in the scan position on the far right in Figure 2 [from *Schoeberl et al.*, 2004].

Table 2. Summary in Chronological Order of the Aura Validation Experiments (AVE) and Associated Aura Validation Campaigns[a]

Validation Campaign	Location	Dates	Type
Heavy Balloon	Fort Sumner, NM	17–29 Sep 2004	balloon
AVE Houston	Houston, TX	29 Oct to 12 Nov 2004	WB-57
Polar AVE	Portsmouth, NH	24 Jan to 9 Feb 2005	DC-8, ozonesondes
Heavy Balloon	Fort Sumner, NM	20 Sep to 1 Oct 2005	balloon
DANDELIONS	Europe	May–Jun 2005, Sep 2006	ozonesonde, in situ ozone, NO_2 lidar, MAX-DOAS, aerosols
Costa Rica AVE/Ticosonde	San Jose, Costa Rica	14 Jan to 9 Feb 2006	WB-57, ozonesondes, water vapor sondes
INTEX-B	Western US, Hawaii, Alaska	1 Mar to 15 May 2006	DC-8, ozonesondes
SAUNA	Sodankylä, Finland	20 Mar to 13 Apr 2006	ground-based instruments and ozonesondes
WAVES	Beltsville, MD	summer 2006, 2007	ozonesondes, water vapor lidars, aerosols
MOHAVE	Table Mountain, CA	Oct 2006–2007	water vapor lidar and water vapor sonde
Heavy Balloon	Kiruna, Sweden	24 Jan to 22 Feb 2007	balloon
TC4/Ticosonde	San Jose, Costa Rica	15 Jul to 9 Aug 2007	DC-8, WB57, ER-2, ozonesondes, water vapor sondes
Heavy Balloon	Fort Sumner, NM	22 Sep 2007	balloon
SAUNA II	Sodankylä, Finland	1 Feb to 6 Mar 2007	ground-based instruments and ozonesondes

[a]Instrumented aircraft types are high-altitude (WB-57 and ER-2) and medium-altitude (DC-8). The ER-2 was equipped with a remote sensing payload (during TC4); the WB57 was equipped with an in situ measurement payload; the DC-8 had both types.

Table 3. A Précis of Validation Special Section Papers[a]

Reference	Validation Product/Description
HIRDLS	
Gille et al. [2008][+]	overview of HIRDLS algorithms and temperature validation
Massie et al. [2007]*	measurements of PSCs and subvisible cirrus
Alexander et al. [2008]	gravity wave momentum flux estimates from HIRDLS temperatures
Nardi et al. [2008]	ozone validation
Kinnison et al. [2008]	HNO_3 validation
MLS	
Livesey et al. [2008]*	ozone and CO validation in the upper troposphere and lower stratosphere
Boyd et al. [2007]*	ozone comparisons with data from NDAAC sites
Jiang et al. [2007]*	ozone validation using sondes and lidar
Froidevaux et al. [2008a]	ozone validation in the stratosphere and mesosphere
Petropavlovskikh et al. [2008]	ozone validation using CAFS
Feng et al. [2008]	4DVAR assimilation of ozone
Krzyæcin et al. [2008]	comparison with Umkehr ozone observations
Read et al. [2007]*	H_2O validation in the UTLS
Lambert et al. [2007]*	H_2O and N_2O validation in the stratosphere and mesosphere
Vömel et al. [2007]*	validation of H_2O using water vapor sondes
Nedoluha et al. [2007]*	H_2O validation with HALOE and a millimeter-wave spectrometer
Pumphrey et al. [2007]*	CO validation in the stratosphere and mesosphere
Santee et al. [2007]*	HNO_3 validation
Santee et al. [2008]	ClO validation
Connor et al. [2007]*	ClO compared to ground-based Antarctic measurements
Pickett et al. [2008]	OH and HO_2 validation
Kovalenko et al. [2007]	BrO validation
Froidevaux et al. [2008b]	HCl validation
Lary and Aulov [2008]	HCl comparisons with ACE and HALOE HCl measurements
Wu et al. [2008]	ice water content validation
Schwartz et al. [2008]	temperature and geopotential height validation
Manney et al. [2007]	comparison of O_3, N_2O, H_2O, HNO_3 and HCl with solar occultation data
Considine et al. [2008]	comparison of MLS and HALOE data products using noncoincident Lagrangian methods
OMI	
Kroon et al. [2008a]	comparison of the OMI-TOMS and OMI-DOAS data products
McPeters et al. [2008]	validation of column ozone
Shavrina et al. [2007]*	validation of column ozone in Kiev
Kroon et al. [2008b]	ozone column compared to CAFS
Balis et al. [2007]*	ozone column, OMI TOMS and DOAS comparisons
Migliorini et al. [2008]	comparison of total column ozone with assimilation
Kramer et al. [2008]	total column ozone comparison with MAX-DOAS
Torres et al. [2007]*[+]	aerosols and surface UV validation overview
Tanskanen et al. [2007]*	erythemal radiation validation
Hassinen et al. [2008]	description of fast delivery products such as surface UV
Curier et al. [2008]	multiwavelength aerosol product
Ahn et al. [2008]	aerosol comparisons from with MODIS and MISR
Celarier et al. [2008][+]	NO_2 validation overview
Bucsela et al. [2008]	NO_2 comparison of aircraft with NRT and standard data products
Brinksma et al. [2008]	NO_2 validation using data from the DANDELIONS campaign
Boersma et al. [2008]	NO_2 OMI and SCIAMACHY comparisons
Ionov et al. [2008]	NO_2 validation from ground-based instruments
Wenig et al. [2008]	NO_2 validation from direct Sun Brewer measurements
Vasilkov et al. [2008]	Raman cloud pressure validation
Sneep et al. [2008]	cloud pressure comparison with POLDER
Stammes et al. [2008]	effective cloud fraction validation
Krotkov et al. [2008]	SO_2 validation: pollution algorithm
Yang et al. [2007a]*	SO_2 validation: volcanic algorithm
Dobber et al. [2008][+]	OMI level 1b radiance and irradiance validation
Kroon et al. [2008c]	geolocation validation
Jaross and Warner [2008]	solar radiance comparisons over Antarctica
TES	
Luo et al. [2007]*	CO validation
Lopez et al. [2008]	CO validation using AVE measurements
Eldering et al. [2008]	cloud top pressure and optical depth retrievals
Osterman et al. [2008]	validation of ozone profiles and columns
Nassar et al. [2008]	comparison of TES ozone profiles and sondes
Richards et al. [2008]	ozone profile validation using INTEX-B aircraft measurements
Shephard et al. [2008a]	water vapor validation
Shephard et al. [2008b]	radiance comparisons with S-HIS and AIRS
Combined	
Schoeberl et al. [2007]*	MLS, OMI: tropospheric ozone residual using trajectories
Yang et al. [2007b]*	MLS, OMI: tropospheric ozone residual using PV mapping
Coffey et al. [2008]	HIRDLS, MLS, TES: comparison of FTS observations of HNO_3, HCl, N_2O and H_2O with aircraft observations
Stajner et al. [2008]	OMI, MLS: OMI and MLS assimilation

[a]Overview papers are indicated by crosses. Papers published in the first group of the special section are indicated by asterisks, and papers in the second and third groups do not have asterisks.

Aura instrument and the focus of the validation or data product generation. In many cases, these papers are linked through an overview paper that is identified in Table 3. We suggest that readers consult the overview paper first and then refer to specific comparisons in the other papers. Overview papers have a cross attached to the name. An asterisk indicates that the paper is in the first publication group (about 20 papers); those papers without an asterisk are in the second and third groups. Other than the grouping by instrument and constituent, the order has no other

meaning. Papers that combine Aura instrument measurements or data products appear near the bottom of Table 3.

[11] **Acknowledgments.** The authors would like to thank the Aura PIs for helpful comments on this manuscript.

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