Earth Observing System (EOS)
Aura Science Data Validation Needs: Update

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Main Contributors to this document:

Valuable inputs were obtained from many members of the Aura instrument science teams and those attending the various Aura Validation Working Group (AVWG) meetings. The acting representatives to the AVWG from each of the four Aura instrument teams are listed as main contributors below (in addition to the co-Chairs of the AVWG).

Lucien Froidevaux (Editor; AVWG co-Chair; AVWG MLS team representative)
Jet Propulsion Laboratory / California Institute of Technology
4800 Oak Grove Drive, Pasadena, CA 91109, USA
E-Mail: lucien@mls.jpl.nasa.gov
Phone: (+01) 818-354-8301

Anne Douglass (AVWG co-Chair; Deputy Aura Project Scientist)
NASA Goddard Space Flight Center, Code 916
Greenbelt, MD 20771 USA
E-Mail: Anne.R.Douglass@nasa.gov
Phone: (+01) 301-614-6028

Douglas Kinnison (AVWG HIRDLS team representative)
National Center for Atmospheric Research, Atmospheric Chemistry Division
P.O. Box 3000, Boulder, CO 80307, USA
E-Mail: dkin@ucar.edu
Phone: (+01) 303-497-1469

Mark Kroon (AVWG OMI team representative, The Netherlands)
KNMI (Royal Netherlands Meteorological Institute)
P.O. Box 201, De Bilt, NL-3730 AE, The Netherlands
E-Mail: Mark.Kroon@knmi.nl
Phone: (+31) 30-220-6911

Richard McPeters (AVWG OMI team representative, U.S.A.)
NASA Goddard Space Flight Center, Code 916
Greenbelt, MD 20771, USA
E-Mail: Richard.D.McPeters@nasa.gov
Phone: (+01) 301-614-6038

Stanley Sander (AVWG TES team representative)
Jet Propulsion Laboratory / California Institute of Technology
4800 Oak Grove Drive, Pasadena, CA 91109, USA
E-Mail: Stanley.P.Sander@jpl.nasa.gov
Phone: (+01) 818-354-2625

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1 Introduction

This document provides an update to the general Aura Validation Plan (2001), with further discussion of the needs and requirements for validation specifics from various platforms and over various regions and timescales. These details were arrived at following various Aura meetings from 2001 to 2004, in preparation for post-launch activities.

The 2004 NASA National Research Announcement (NRA) with a focus on Aura validation, and a European "OMI Announcement of Opportunity" (OMI AO) to further address OMI requirements should go a long way towards addressing the Aura needs, as well as strengthening the interaction among Aura and other investigators in general. The document below, despite some imperfections and inhomogeneity in writing, should provide additional useful information for those planning to respond to the above Announcements.

"Routine" measurements from satellites and ground-based networks have been covered in the Aura Validation Plan (2001). The main changes since then have been some delays in certain satellite launches (Aura included – launch now planned for June 2004), and the loss of the ADEOS II satellite, which would have provided useful validation data for Aura. Fortunately, the successful launch of SciSat with the measurements from ACE and MAESTRO and the continuing operations of SAGE II , SAGE III, POAM III, Odin, EP-TOMS, Aqua, SABER, and ENVISAT, among others, should provide a wealth of comparison/validation data for Aura investigators; expected data from CloudSat, CALIPSO, and PARASOL after 2005 will also be very useful for comparisons of aerosol and cloud-related products [see the original Aura Validation Plan for acronym explanations and other details].

In section 3, we briefly review the campaign components that are being planned for 2004 and beyond, following the outline given in the planned 2004 NASA NRA that addresses the validation needs for Aura, among other things. This, and other planned "enhancements" to routine data sets the stage for what one can expect, and helps to identify any potentially unmet needs for validation. Potential solutions to remaining issues are presented in section 3.3. Sections 4 through 7 were provided by the four Aura instrument teams, and include more specifics and details for the validation needs of each of these teams' products. It is the goal of section 3 to capture the main issues and priorities, as extracted from sections 4 through 7, but we hope that "important details" in the latter chapters are not forgotten, when the complete validation program is eventually carried out. It is also realized that complete fulfillment of the detailed needs for each of the instruments is dependent on budgetary and logistical considerations that will impose some finite limits on the validation process. The aim of the combined validation and science programs will be to optimize the gains for both validation and science, given such constraints.

There is a timely need for a response to (and review of) the NASA NRA and the European call, so that validation activities can begin shortly after Aura launch. Also, the rapid development of the Aura Validation Data Center (AVDC), now being implemented at the Goddard Space Flight Center, will be critical to the success of validation efforts. This Data Center should be a major element for facilitating the distribution of Aura validation and correlative data and for planning coordinated sub-orbital observations. The successful collection of these data and proper distribution of the data, data formats and reading programs, along with data distribution rehearsals, are now very much needed for successful post-launch operations and validation, given the preparation time (months) needed for developing validation-related software. Aura "liaisons" who have been identified as points of contact for various datasets that are deemed important for Aura validation will need to be a key part of the information transmission process regarding access to these data products, and in order to reduce duplication of effort among the various investigators participating in Aura validation.

To assist in the continuing pre-launch efforts, and now looking beyond this documentation of "needs", an "implementation document" to be used as a progress report for the Aura pre-launch activities (and beyond launch as well) will be released, for further updating from all those (mentioned above) who are expected to contribute to the making of a successful Aura validation program. Other web-based methods and interaction with the AVDC will be essential to further enhance this success in the future.

2 Campaigns in support of Aura validation

Several major field campaigns have been conceptually developed for the purposes of fulfilling many of the validations needs of Aura and other satellites while addressing outstanding questions in atmospheric science through the joint utilization of satellite and suborbital (ground-based, balloon-borne, and aircraft-borne) data. These field campaigns, Tropical Composition, Cloud and Climate Coupling (TC^4) and Intercontinental Chemical Experiment – North America (INTEX) are indicated in the timeline below. A more detailed description of the TC4 science and validation goals is presented in a "white paper" on this subject at the Aura validation website http://aura.gsfc.nasa.gov/mission/validation.html . A "white paper" on the INTEX goals can be found at http://www.espo.nasa.gov/intex-na/overview/white_paper.pdf . More frequent flights of one or more sub-orbital platforms are also envisioned to fulfill specific validation needs not explicitly addressed via these campaigns or to fill in gaps between the major campaigns. Suborbital flights between major campaigns come under the general heading of AVE (Aura Validation Experiment). In addition, we expect that the use of Uninhabited Aerial Vehicles (UAVs) will provide significant inputs to the Aura validation activities, although probably not in the early phase after Aura launch.

2.1 Time line for Aura validation / science experiments

The timeline listed below assumes proper and timely funding and operates under the assumption of an Aura launch by July 1, 2004.

2004: October - AVE from Ellington AFB or Dryden FRC. Objective: Radiance validation and in situ measurements in upper troposphere and lower stratosphere. Field deployment – two weeks. These measurements may be rescheduled depending on actual Aura launch date.

2005: January - AVE from NASA Dryden FRC. Objectives: Mid tropospheric lidar measurements of tropospheric and stratospheric ozone, aerosols and temperature across the subtropical edge and polar vortex boundaries. Field deployment – two weeks. High latitude, high resolution balloon profiles of stratospheric constituents. These measurements may be rescheduled depending on actual Aura launch date.

2005: UAV instrument development and payload construction, test flights.

2005: July – AVE/TC4 Summer, joint measurements with TCSP from San Jose, Costa Rica. Objectives: Water vapor and trace gas measurements in the tropical East Pacific near the tropopause, lidar measurements of ozone, aerosols and temperature in the troposphere and lower stratosphere. Field deployment – four weeks.

2005: September – Mid-latitude, high resolution balloon profiles of stratospheric constituents.

2006: January –AVE/TC4 Winter Southern Hemisphere, joint measurements with DoE mission in Darwin, Australia. Objectives: Water vapor and trace gas measurements in the tropical East Pacific near the tropopause. Field deployment – four weeks.

2006: January - High latitude, high resolution balloon profiles of stratospheric constituents.

2006: April – AVE/ INTEX NA-W from NASA Dryden. Objectives: Troposphere and lower stratosphere profiles and in situ measurements of tropospheric trace gases in polluted and unpolluted environments to assess inflow into the West Coast of the US. Two to three long duration North south mid-tropospheric UAV flights from Dryden FRC. Field deployment – four weeks.

2006: September- AVE from Ellington AFB or Dryden FRC. Objective: Radiance validation and in situ measurements in polluted environments throughout the troposphere and lower stratosphere. Field deployment – two weeks. Mid-latitude, high resolution balloon profiles of stratospheric constituents.

2007: January – AVE/TC4 Winter Northern Hemisphere from Guam. Objectives: Water vapor and trace gas measurements in the tropical East Pacific near the tropopause. Field deployment – four weeks.

2007: June – AVE from Ellington AFB. Radiance validation and in situ measurements in upper troposphere and lower stratosphere. May include joint flights with a UAV for mid troposphere in situ measurements. Field deployment – two weeks.

2007: October – AVE from Ellington AFB. Radiance validation and in situ measurements in upper troposphere and lower stratosphere. Mid-latitude, high resolution balloon profiles of stratospheric constituents. Field deployment – two weeks.

Moreover, ozone and water vapor sonde launches will support appropriate field campaigns and provide augmented measurements during satellite overpasses.

The Aura instrument teams expect that the above campaigns will provide validation analyses that include the following elements:

- Profiles closely coincident (within reason) with the satellite measurements.
- Range of surface types.
- Range of atmospheric conditions.
- Aircraft-based lidar profiles, in particular for O_3, aerosols, and H_2O.
- In situ measurements (and profiles) using the high altitude aircraft.
- Use of UAV(s) [e.g., for long transects]

2.2 Advantages of this schedule

- To obtain profiles that cover a range of surfaces and atmospheric conditions, fairly early in the mission (notably over ocean and land, and with flights over ARM site or site with similar measurement capabilities); this is especially useful for the nadir viewers (TES, OMI).
- To manage multiple deployments to the (data poor and scientifically interesting) tropics. However, the importance of issues such as a desire for cloud-free scenes for Aura validation will need to be kept in mind, especially earlier in the validation efforts.

We plan to make use of major field campaign data after sufficient validation has taken place that the Aura data will be available in the field with more confidence; validation efforts can then better target specific questions and be more science-oriented. The large Costa Rica campaign deployments in July 2005 will occur about a year after the planned launch of Aura (June 2004). However, we still expect that smaller efforts, even as early as October 2004 (AVE) and the polar campaign in early 2005 will generate significant returns for validation, in addition to the many more measurements from ground-based sites and other satellites.

3 Main Aura validation needs and requirements

3.1 Main priorities

There are two types of measurements needed for validation: Level-1b (radiances) and Level-2 (geophysical products). The main measurement priorities for validation of Aura products are shown in Table 3.1, with Priority 3 being the lowest.

Table 3.1 Main Measurement Priorities for Validation of Aura Products

Measurement	Priority 1	Priority 2	Priority 3
Profiles: Troposphere (and into LS)	H_2O, O_3, CO, HNO_3, NO_2, T [polluted & clean regions]	CH_4 UT/LS: N_2O, CFC-11, CFC-12, CH_3CN, HCN	UT: GPH
Profiles: Stratosphere	H_2O, O_3, N_2O, CH_4, HCl, OH, HNO_3, BrO, SO_2 [(1)], T	ClO, $ClONO_2$, CFC-11, CFC-12, HOCl, HO_2, NO, NO_2, N_2O_5, CO	CH_3CN, HCN, SO_2, GPH
Column Densities	NO_2, NO_2 (trop.), O_3 (total) O_3 (trop.), SO_2 [(1)] [polluted & clean regions]	HCHO, OClO, BrO	SO_2
Aerosols, Clouds	Clouds, Aerosols, PSCs (location, properties, statistics)		
Radiances	IR radiances (upwelling) [for TES]	IR radiances (downwelling) [for TES, in conjunction with upwelling radiances from aircraft platform] UV fluxes [for OMI]	

[(1)] Under volcanically enhanced conditions (after a major volcanic eruption).

More details about the above needs are given later. Some specific needs from various aircraft campaigns are described in section 3.2, as a result of discussions held in Houston in January 2004 (a base for the "pre-AVE" campaign). Section 3.3 summarizes some important validation needs that may not be addressed by expected campaigns and capabilities, given a detailed consideration by the four Aura instrument teams of these expected measurements. These main "remaining needs" are spelled out, along with potential solutions (that we hope will be addressed by the NASA and European Announcements in relation to Aura validation). Further details and specifics for each Aura instrument are given in the 4 subsequent sections (4 through 7).

3.2 Requirements from measurement campaigns from sub-orbital platforms

Plans for a variety of tropospheric and stratospheric measurements from sub-orbital platforms (ground-based, balloons, aircraft) after Aura launch were briefly reviewed in section 2. Some of these programs will take the form of a "mini campaign", with smaller deployments than the large, multi-platform campaigns such as INTEX from North America, or the tropical campaigns from Costa Rica or Darwin. Based on inputs from each Aura instrument team (see sections 4 through 7), the main requirements for tropical campaigns are summarized in the Tables below.

3.2.1 Tropical campaigns

Table 3.2a Main Aura requirements from tropical campaigns

Correlative Data Needs Priorities: Red = high; violet = medium; green=low	**Validation Value**	**Science Value**
- Include measurements of **UT/LS profiles (12-20 km)** ***1.*** T, O_3, H_2O, HNO_3,$CFCl_3$, HCl, N_2O, CH_4, CO, NO_2, NO, OH, BrO, clouds (type, height, coverage, composition) ***2.*** CF_2Cl_2, aerosols, HCN and CH_3CN (especially for polluted conditions) ***3.*** $ClONO_2$, HO_2, GPH	Note: Cloud size distribution useful from mm to hundreds of mm size. Total ice water content desired also [MLS]. Simultaneous H_2O and T desired (for total water and supersaturation issues)	Evaluation of TTL. Ozone balance processes in TTL, UT/LS. Strat./trop. exchange. Aerosol influences on climate (e.g., sub-visible cirrus). Better understanding of H_2O processes.
Tropospheric profiles (5-12 km) ***1.*** T, O_3, H_2O, CO, HNO_3, NO_2, NO, clouds ***2.*** CH_4, N_2O, $CFCl_3$, CF_2Cl_2 , BrO, aerosols HCN and CH_3CN (especially for polluted conditions)		Upper tropospheric chemistry. Regional and large-scale pollution issues.
Tropospheric profiles (0-5 km) ***1.*** T, O_3, H_2O, CO, NO_2, clouds ***2.*** CH_4, N_2O, $CFCl_3$, CF_2Cl_2 , BrO, aerosols		Lower tropospheric chemistry. Regional and large-scale pollution issues.

Table 3.2b Special flight characteristics and sampling requirements from tropical campaigns.

Correlative Data Needs	Validation Value
- Special flight characteristics *(not a priority list)*	
1. Include along-track data with curtain measurements (over a range close to 1000 km) if possible.	Evaluate LOS Gradients and tropospheric variability. Also useful for gravity wave validation
2. Sample horizontal gradients into subtropics	Useful for LOS gradients.
3. Several spirals for in situ profiles needed as well (preferred over "porpoise" patterns). For limb soundings, prefer vertical profiles spaced ~ every 150 km (along-track).	To obtain correlative profiles under the Aura satellite measurements.
4. Need some cloud-free regions (especially in earlier phase of validation – about 12 to 18 months after launch)	Need some clear sky conditions since clouds (thick clouds especially) will invalidate many Aura profiles below + affect column data interp.
5. Sample clean and polluted tropospheric conditions (in con- junction with Aura measurements).	For various tropospheric retrieval conditions.
6. *(TES, OMI)* Track land/sea contrast for satellite retrievals, and for different land types.	For various tropospheric retrieval conditions.
7. *(OMI)* Would like to sample high (lower tropospheric) aerosol loading conditions.	Validation of OMI aerosol products
- Sampling of regions/seasons	
A. Sample TWP in winter.	For HIRDLS, important to sample regions of low H_2O & low T; low O_3 & low T. ENSO doesn't matter as long as reach low T values.
B. Sample summer season convection	Larger H_2O & T values needed. TWP desirable (but Costa Rica adequate).

Table 3.2c Other measurements needed/requested in relation to tropical validation campaigns.

Correlative Data Needs	Validation Value
- Other correlative measurements requested ***Sondes***	
1. Coordinate additional ozone and H_2O sondes with field campaign and (for a subset) attempt good timing with Aura overpasses. ***2.*** For annual cycle coverage, start launches ~ 6 months before start of major field campaign & run for ~ 6 months thereafter).	Provides better H_2O profiling and co-validation through the TTL (and lowest H_2O values). Added value for O3 as well.
Balloons Balloon flight or flights to cover all (or most) Aura products [from ground to ~ 35 km altitude]. Explore collaborations with European balloon campaign in Brazil (Oct. 2004).	For more thorough validation of Aura strat. profiles (impact & sensitivity for lower atmospheric region), especially for Aura products with a paucity of validation data (such as radicals, $ClONO_2$, N_2O_5, CFCs).

In addition to the above prioritized specifics for tropical campaigns in support of Aura validation (and related science goals), a low altitude aircraft component is requested in order to increase the tropospheric validation and science returns. Tables 3.1 and 3.2a should be referred to for the main Aura measurements and priorities; however, complementary measurements would be invaluable for certain tropospheric science goals (e.g., in terms of characterizing atmospheric processes, chemical mechanisms and balances). To this end, a fuller payload for low altitude aircraft is suggested/requested below.

Generic request for low altitude aircraft payload
Measurements (profiles)
P/T, turbulence, winds
O_3 profile and column data
H_2O vapor
CO
HNO_3
Aerosol size distribution, composition
HCHO
N_2O, CFCs, CH_4, CH_3Br, CH_3I, and other such tracers
NO_2
NO
NO_y
PAN
HOOH
CH_3OOH (lower priority – development would be needed)

Column measurements of NO_2, HCHO, BrO

In addition, GPS downlink capabilities are needed.

Low altitude flight requirements
- Spirals that cover as large of a vertical range as possible, near Aura overpasses
- Porpoise maneuvers to provide horizontal and vertical information, near Aura overpasses
- Spiral and porpoise maneuvers must extend into the boundary layer (0 to 2 km region)

3.2.2 Mid-latitude campaigns

These campaigns include the INTEX and some AVE campaigns/flights.

The Aura requests are broadly similar to those in section 3.1.1 for the tropics. Specific requests include:

- The use of aircraft-based lidar data on ozone, aerosols, and H_2O, with along-track profiles in particular.

- Horizontal gradients are desirable (even if few/no flights into sub-tropics).

- Data on tracers (+ other chemicals) in/near tropopause folds also of interest, especially after initial validation period where stable atmospheric conditions are most desirable for proper validation of "easier" cases.

3.2.3 Polar campaigns

The Aura validation teams would very much like to obtain the following validation data in the polar regions (with Arctic data being most likely).

Balloons:

- At least 1 or 2 polar balloon launch(es) during cold polar conditions (& high ClO) with the following (daytime) measurement goals (~tropopause to 35 km).
  (1) T, O_3, H_2O, N_2O, CH_4, CO, HNO_3, NO, NO_2, HCl, ClO, $ClONO_2$, OH, CFC-11, CFC-12, BrO.
  (2) HOCl, OClO, HO_2, N_2O_5, HCHO, HCN, CH_3CN.

Aircraft:

- Mainly interested in along-track data (~ 1000 km) + several profiles for the following (daytime measurements):
  T, O_3, H_2O, N_2O, CH_4, HCl, HNO_3, CFC-11, CFC-12, ClO, PSCs, cirrus, aerosols [all coincident (as possible) with Aura overpasses]; if high altitude aircraft flights are available (up to ~20 km), $ClONO_2$, CO, NO_2, BrO and HOCl data would be useful for validation.

Column densities:

- For BrO, ground-based Differential Optical Absorption Spectroscopy (DOAS) measurements during tropospheric enhancements (late winter/spring) would benefit validation of OMI BrO polar (column) measurements. NO_2, OClO, HCHO column values are also needed.

3.2.4 Aura Validation Experiment (AVE): Focus on first 2 campaigns

In late January 2004, Aura instrument team representatives for validation met with the aircraft teams engaged in "pre-AVE" measurements out of Ellington base, near Houston, Texas. This exchange of information resulted in a summary focused on the first two AVE missions expected after Aura launch, namely the October 2004 and January 2005 campaigns. Flexibility of the AVE concept will hopefully allow for some adjustments after these two efforts, which will occur during the commissioning phase of the Aura instruments, when synergistic science goals ought to be less of a driver than after the satellite instrument teams have some good first-order validation results in hand.
Further discussions between the Aura and AVE investigators will be pursued in order to refine the campaign goals and strategies, and to benefit validation of measurements as well as common and complementary science goals.

3.2.4.1 General needs and requirements

1. Flights should be co-located (within a few km) with sub-Aura tracks and occur at times of Aura overpasses.

Notes:
a. Aircraft should be flying when Aura overpass occurs, although aircraft flight time is much longer than Aura overpass (at ~ 7 km/sec).
b. OMI provides daytime measurements only and aircraft typically provide daytime data; however, nighttime aircraft flights are very possible.

2. Stable atmospheric conditions are essential early on.
Notes:
a. Delaying the first AVE campaign much beyond October may be an issue.
b. Flying South in January is probably preferable to flying North (because of desired meteorological conditions for Aura).

3. Clear skies are a strong requirement for the early phase of validation.
Note: It is realized, however, that a completely cloud-free scene under the Aura overpass for one hundred km or more (for an along-track limb viewing averaging region) can be very difficult to come by, depending on the time and place; this is a somewhat easier requirement to satisfy for (some of) the smaller OMI or TES nadir footprints.

3.2.4.2 Instrument-specific needs

TES

1. Upwelling infrared radiance measurements (with spectral resolution of 0.5 cm^{-1} or better) over (clear-sky) ocean and the ARM Southern Great Plains Site are a high priority. Downwelling radiances from above the plane are highly desirable, but of somewhat lower priority.
Note: This need for IR radiance measurements calls for instrumentation that was not part of the "pre-AVE" payload.

2. Vertical profiles (i.e. aircraft spirals) from near the surface to above the tropopause, coincident with ground-based profile measurements of temperature, water vapor, and ozone.

OMI
Measurements over ocean and land contrasts on several flights with

1. Column ozone (above and below the aircraft).
Note: This need calls for instrumentation that was not part of the "pre-AVE" payload.

2. Aerosol optical depth (UV-VIS), size distribution, and composition, especially in the lower troposphere. This requires in-situ particle instrumentation.

3. NO_2 column and profile data, as a secondary goal (more important later on).
Note: The column could be measured with a UV-VIS instrument, and the profile requires in situ data, since there is apparently no aircraft lidar instrumentation for this.

4. Cloud height and extent.
Note: This need calls for an aerosol lidar instrument that was not part of the "pre-AVE" payload.

HIRDLS and MLS
For high altitude aircraft:

1. Along-track measurements in lower stratosphere primarily (and over clear skies) for temperature, O_3, H_2O, N_2O, CH_4, HCl, HNO_3, CFC-11, CFC-12, and $ClONO_2$.

2. Additional data in upper troposphere for the above products and for CO, as a secondary goal in the early flights (more important in January 2005).

3. Cloud and aerosol information: height, extent, properties (sub-visible cirrus information as well). Ice particle number density and size distribution (sizes from 100 µm to 1 mm), and total ice density will help interpret the cloud ice content retrievals from MLS (even if this occurs at a later stage).

For Jan. 2005 polar flights (assuming a medium altitude platform):
Lower stratospheric measurements inside the vortex and gradients across the vortex boundary for

1. High Priority: Temperature, O_3, H_2O, N_2O, CH_4, HCl, HNO_3, CFC-11, CFC-12, ClO, PSC information (extent, composition).
Notes: Higher altitude platforms are needed to get to where ClO has significant values. Remote sensing measurements are best for this. For example, lidar data could get T, O_3, and PSC information, as well as H_2O below the aircraft, and a microwave remote sensor could give O_3, N_2O, HCl, HNO_3, and ClO.

2. Lower priority: CO, BrO, HOCl, $ClONO_2$.

Besides curtain-type profiles along the sub-orbital track from lidar aircraft data, other measurements that could contribute to the above are desired (e.g., remotely sensed profiles, since in-situ data would only reach altitudes of about 14 km).

Notes:
a. Cold conditions are important for validation of certain products (e.g., H_2O, HNO_3, ClO).
b. The lower priority products would be higher priority if measured from high-altitude (20 km) aircraft in the vortex; if not, balloons and other satellites will be the main method for validation.

3.2.4.3 Flights with high validation value: Some suggested flight types

1. Mainly for limb view validation (HIRDLS, MLS, TES in limb mode)
   a. Flights along Aura sub-orbital track, with remotely-sensed profiles above and below the aircraft (“curtains”).
   b. Flights along Aura sub-orbital track, with “stair-step” (stacked) aircraft legs (~ 600 km-long initially, 300 km later on, with more steps) from top (high altitude) plane height (near 21 km) down to the tropopause (in-situ data focus).
   c. Later in the October and/or January flights (depending on satellite results), add more legs in the upper troposphere (tropical regions in particular).

2. Mainly for nadir view validation (OMI, TES in nadir mode)
    a. In situ profiles via aircraft spirals at locations along the Aura sub-orbital track; choose top and bottom heights to cover as wide a range as possible (depending on aircraft/instrument capabilities and other factors).
    b. Spirals over sites with ground-based measurements that can provide time variability information (for time periods close to the aircraft flight duration).
    c. For radiance validation, along-track data at maximum aircraft altitude.

Both (1) and (2) will provide some feeling for along-track variability of profiles (on somewhat different timescales).

3.2.4.4 Flights with high validation value: Some suggested flight locations

1. Ellington base

a. Houston area to Gulf (ocean flight), along an Aura (daytime) track.
b. Houston area to ARM Southern Great Plains site, along an Aura track.
c. Houston to Fort Sumner: A trip to “underfly” a balloon launch from Fort Sumner, New Mexico, would add value (combined datasets).

2. Dryden base

a. A flight path over Lake Tahoe would be useful for TES, given the ground-based measurement capabilities in that region.
b. The Table Mountain Facility is also a potential location of interest, given the lidar and other measurements performed on a very regular (daily) basis there (NDSC site).

3. Kiruna base

Scheduled balloon flights from this location (Esrange) provide added validation value and co-location potential.

3.2.4.5 Validation methods

The HIRDLS high resolution mode along-track (with profiles spaced roughly every 60 km) could be a useful way to “ bootstrap” and help to validate the more widely-spaced MLS profiles (once the HIRDLS profiles are deemed to be of sufficient quality); however, some 600 km-long stair-steps and/or several profiles from the lower stratosphere down to the mid-troposphere (400 o 500 hPa) would be useful early on as well.

Similarly, the TES continuous viewing mode (nadir or limb mode) may be used to obtain high resolution along-track data and enable further validation of more widely-spaced Aura measurements (from HIRDLS and MLS).

Detailed understanding of the aircraft and satellite sampling and resolution will be required for useful comparisons and validation.

3.3 Other special needs and requests

We list below, in tabular form, a number of special implementation requests or recommendations that we hope can fit within the validation program constraints, in order to boost the possibilities for validation in certain key areas where both the measurements themselves and the scientific interests are important enough to deserve special consideration. We list the parameters (measurements) desired, the region and frequency, as well as existing or assumed validation sources (refer to section 2 for campaign plans and to the 2001 Aura Validation Plan for other datasets). The rightmost columns in these Tables gives specific requests and implementation recommendations for additional validation sources of much interest and potential.

Table 3.3a Summary recommendations for validation of H_2O and O_3 profiles

Parameters Needed	Region, time, frequency	Assumed or planned relevant data	Other possible/ desirable data (solution)
H_2O: more UT/LS profiles (with better than 10% accuracy) **Cloud/cirrus** concurrent info. (e.g., opt. depth) also desired	- **Tropics:** monthly, for 1 to 2 years (& timed with Aura) - **High Latitudes:** monthly during winter/spring, for 1 to 2 years (timed with Aura) - Start in mid-2004 & during aircraft campaigns	- AVE + other campaigns (Costa Rica, Darwin, TC4) [in situ profiles, but no high-alt. lidar]. - Grnd lidars (few) - Other satellites - Radiosondes (but not useful in UT/LS)	**Added requests to fill the needs:** - **Tropics: SOWER data + timed FPH sondes** - **High Lats: TBD (sondes and/or lidars?)**
O_3: more tropospheric & LS profiles (and for polluted regions/times) **Note**: Very desirable to have concurrent H_2O and Temperature data	- Sondes timed with Aura, at least from a few sites [minimum: 2 tropical, 2 mid-lats, 1 polar] - Frequency: 1 to 2 per month	- Aircraft lidar data [along-track, 1000km] (INTEX, Costa-Rica) - In situ profiles (AVE,other campaigns) - MOZAIC - ARM, sondes [keep SHADOZ !] - Grnd lidars (few) - Other satellites	**Added requests to fill the needs:** - **Tropics: SOWER data + timed ozonesondes, mobile ground station**

Table 3.3b Summary recommendations for profile validation from balloons

Parameters Needed	Region, time, frequency	Assumed or planned relevant data	Other possible/desirable data (solution)
HIRDLS, MLS, TES, and multi-instrument profiles: **$ClONO_2$, N_2O_5, CFC11, CFC12** **OH, HO_2, BrO, HCl, ClO, HOCl, HCN, CH_3CN, SO_2 (if large volcanic plume)** **NO,** **NO_2, HNO_3, N_2O, CH_4, CO, O_3, H_2O, T** **from ~ tropopause to ~ 35 - 40 km**	**"Minimum set" of balloon-borne measurements** - **Mid-latitudes:** at least for two years in two seasons (Spring& Fall, typical, more possibly) - **Polar:** during European polar campaign (winter/spring 2005), try to obtain several balloon flights (Esrange/Kiruna is expected site) - **Tropics:** while not as easy as for mid-lats, recommend seeking collaborations, [e.g., with CNES, for Brazil launches]	- Small database from aircraft & ground for some products/altitudes - Existing intrs., at least once per year from mid-lats. (Fort Sumner as likely site) + a few polar winter flights - Lightweight FTIR first flight Fall 05 (?) (likely from Ft. Sumner) - MANTRA (Canada), for ACE valid. (Aug. 04) - Other satellites will add significant information for constituent profiles	- **Unmet needs? BrO, primarily + added balloon flights for polar, tropics** (mid-lats should be OK) - Collaborate with other balloon programs [e.g., MANTRA program in Canada, Aug. 2004, European launches planned in Brazil, Oct./Nov. 2004, in France, 2005,and in Kiruna Feb./March 2005] - Also, make use of methods such as data assimilation & trajectory analyses

Table 3.3c Summary recommendations for validation of column densities and profiles of NO_2

Parameters Needed	Region, time, frequency	Some assumed or planned relevant data	Other possible/ desirable data (solution)
Need more/ better-matched tropospheric profiles and trop. columns [boundary layer especially] **Note:** concurrent surface and aerosol/cloud information (optical depth) also desired (radiance sensitivity issues)	- Clean and especially polluted environments, with some ability to track short-term (day-to-day) changes	- RIVM lidar (development underway) - FTUV data - NDSC data (FTIR) DOAS sites data [but with some local time issues] - Airborne DOAS? - Aircraft profiles (spirals) and transects, emphasis on BL [INTEX, Costa Rica, Darwin, AVE]	**Added requests to fill the needs:** - Ensure that some campaigns include **low altitude airborne NO_2** and measurements are obtained in/across polluted regions **- Mobile ground station** setup (especially for polluted environments) - Methods such as data assimilation or trajectory analyses to reduce local time differences

Table 3.3d Summary recommendations for validation of column densities and profiles of BrO, HCHO, OClO, and SO_2

Parameters Needed	Region, time, frequency	Some assumed or planned relevant data	Other possible/desirable data (solution)
Column densities and profiles for BrO, HCHO, OClO, SO2 [for OMI, mainly]	- Various polluted and clean tropospheric environments	- Ground-based data (DOAS) exist, but fairly sparse + some local time issues) - Aircraft campaigns (DOAS) [mainly AVE, for added statistics?] - Some balloon flights (mid-lats mainly) - Other satellites	**- Mobile ground station** + DOAS for polluted, and other locations (e.g., Arctic) **- Aircraft and balloon data from other campaigns** (e.g., Europe)

Table 3.3e Summary recommendations for validation of aerosol and cloud products

Parameters Needed	Region, time, frequency	Some assumed or planned relevant data	Other possible/desirable data (solution)
- Aerosol/cloud information (size distribution, number density, composition, other properties such as ice water content) **- Improved statistical database is important** **Note:** wavelengths and particle size sensitivities vary for each instrument [e.g., want aerosol opt. depth at 340-500 nm for OMI, sub- µm particles for HIRDLS and TES, tens of µm to 1mm ice particles for MLS]	Various regions and altitudes of interest (e.g., tropospheric pollution for OMI; stratosphere and near-tropopause for HIRDLS) - At places & times close to Aura viewing locations and times, with frequency plans following AVE deployment guidelines (seasonal if possible) - Note: Importance of aerosols is much increased if large volcano erupts (and rapid response is then desired for field data)	- NDSC, ARM and Aeronet sites - Balloon in situ data (0-30 km) - Aircraft in situ (INTEX, Costa Rica, Darwin, AVE) - Aircraft campaigns with lidar(s) and in situ data (mainly AVE) - Other satellites (Calipso, CloudSat, and Parasol, although with somewhat later launches than Aura)	**- Mobile ground station**

Table 3.3f Summary recommendations for validation of tropospheric CO

Parameters needed	Region, time, frequency	Assumed or planned relevant data	Other possible/desirable data (solution)
CO: Tropospheric profiles	- Various locations (tropics & mid-latitudes especially, polluted and clean, over land and ocean)	- MOZAIC (and CARIBIC) commercial planes (~ 5-10 profiles per day, on average, 80% over NH mid-lats, 20% in tropics; 0-12 km) [but no coordination with Aura] - Aircraft campaigns (INTEX, Costa Rica, Darwin, TC4, AVE), including UAVs in the future	- Aircraft **in situ profiles** (coordinated with Aura footprints – and with some NDSC column data) [to add to low/mid-tropospheric database]

Table 3.3g Summary recommendations for validation of tropospheric HNO_3

Parameters needed	Region, time, frequency	Assumed or planned relevant data	Other possible/desirable data (solution)
HNO_3: Tropospheric profiles	- Various locations (tropics & mid-latitudes especially, polluted and clean, over land and ocean)	- No routine measurements available - Rely on aircraft campaigns (INTEX, Costa Rica, Darwin, TC4) and AVE especially for more continuous data (seasonal timescale)	- **Mainly, ensure that HNO3 is included on many of the aircraft campaigns, with measurements throughout the troposphere**

4. Specifics of HIRDLS Validation

Table 4.1. HIRDLS Correlative Measurement Priorities. All HIRDLS species are expected to be validated; however, based on limited resources available, we have listed species in the order of priority. Priorities are based on validation needs with a consideration of scientific importance.

Priority	Region	Geophysical Parameter	Comments
1	Troposphere, Z<12km	T, O_3, H_2O, HNO_3, Cirrus and PSCs;	T, O_3, H_2O, HNO_3, and Aerosols have both a high validation and science priority. Additional H_2O and O_3 sondes have been requested in the tropics throughout the T/UT/LS region. Extreme conditions needed for validation (i.e., low temperature). Measurements of tracers, e.g., $CFCl_3$ are need in regions of high gradients (UT/LS and vortex edge). High latitude polar mission(s) needed to validate T, O_3, $ClONO_2$, HNO_3, PSCs and Cirrus (again under extreme conditions and highly varying concentrations).
	UT/LS 12km<Z<20km	T, O_3, H_2O, HNO_3, $CFCl_3$, Cirrus and PSCs;	
	Stratosphere 20km<Z<50km	T, O_3, H_2O, HNO_3, $ClONO_2$, $CFCl_3$, NO_2, Aerosols	NDSC data and high altitude balloon missions (OMS type) are needed to assist in the validation of this region. Chemical data assimilation will also be used. Cross validation with other satellite instruments will be necessary (e.g., ACE, GOMOS, GPS, MIPAS, POAM III, SABER, SAGE III, SCIAMACHY, MLS, TES).
2	Troposphere, Z<12km	CH_4, N_2O, $CFCl_3$, $CFCl_3$	CH_4, N_2O, and CF_2Cl_2 are considered a high science priority (Z<20km) and correlative data is less routine for these species. These species are considered a priority 2, because vertical and horizontal gradients for these species are less severe making validation more straightforward. For Z> 20km, validation of N_2O_5, $CFCl_3$, and CF_2Cl_2 will occur primarily from balloon and satellite correlative data. These species are considered priority two based on science considerations. In addition, validation in this region will be difficult. For Z>50 km, all species of interest are given a priority of two - this is in direct response to Aura's stated science priorities.
	UT/LS 12km<Z<20km	CH_4, N_2O, NO_2, CF_2Cl_2	
	Stratosphere 20km<Z<50km	N_2O, CH_4, N_2O_5, CF_2Cl_2	
	Mesosphere Z>50km	CO_2, T, H_2O, O_3	
3	All Altitude	GPH	Will use standard meteorological analysis.

Table 4.2 Implementation Plans for HIRDLS Temperature Validation.
Relative degree of interest/usefulness: red = high; violet = medium; green = low.
NA (Not Applicable or Not Available); NN (Not Needed)

REGION	Routine	Routine+ more	High Alt Balloons	Special Grd-Based	Campaigns (major)	Other Cam-paigns	Other satellites Instruments	Unmet Needs
Trop. 0-12km	OM Radio-sonde G-vis	NN	NN	NN		NN	AIRS/AMSU GPS	None
UT/LS 12-20km	G-vis OM-data Radio-sonde	NN	NN	NN	INTEX TC4 POLAR; Need along track aircraft data (600-1000km). T and P profiles needed; plus spirals.	NN	ACE, AIRS/AMSU, Aura (MLS, TES), GPS, GOMOS, MIPAS, SABER	For Cam-paigns need along track aircraft data (600-1000 km). T and P profiles needed; plus spirals.
Strat. 20-50km	G-vis OM-data Radio-sonde	NN	NN	NN	NA	NN	ACE, AIRS, Aura (MLS, TES), GPS, GOMOS, MIPAS, SABER	None
Meso. >50km	G-vis	NN	NA	NN	NN	NN	ACE, Aura (MLS), GOMOS, MIPAS, SABER	None

Note: Table 4.2 and similar Tables in this and subsequent sections use notation as the one used in the 2001 Aura Validation Plan; in particular, the "G" routine data refer to ground-based, the "B" refers to balloon data, and "A" refers to aircraft data. Also, "OM-data" means Operational Meteorological data. Other acronyms are in common usage and have been explained in the 2001 Plan (for reference).

Table 4.3 Implementation Plans for HIRDLS H_2O Validation.

Relative degree of interest/usefulness: red = high; violet = medium; green = low.

NA (Not Applicable or Not Available); NN (Not Needed)

REGION	Routine	Routine+ more	High Altitude Balloons	Special Grd-Based	Campaigns (major)	Other Cam-paigns	Other satellites Instruments	Unmet Needs
Trop. 0-12km	MOZAIC MOZART CARIBIC G-lidar OM-data Radio-sonde	NN	NN	NA	INTEX TC4 POLAR	NN	AIRS, AMSU, AMSR, Aura(MLS,TES),GPS, MIPAS, SCIAMACHY, SSM/T2	None
UT/LS 12-20km Up to max. aircraft altitudes	H_2O Sondes (FPH)	More sondes in tropics (monthly); and at high latitudes, winter/spring.	NN	NA	INTEX TC4 POLAR; 1-2 flights along track (600-1000km); with curtain measurements and spirals	NN	Same as above + ACE, POAM III, SABER	UT/LS region will need more sondes. Lidar data not useful in LS. Campaign(s) with along track data needed.
Strat. 20-50km	H_2O Sondes (FPH) G-MW	H_2O Sondes (FPH) G-MW (good up to 35km)	NN	NA	NN	NN	ACE, AIRS, Aura(MLS,TES),GOMOS, MIPAS, ODIN, POAM III, SAGE, SABER, SCIAMACHY, UARS (HALOE)	None
Meso. >50km	NA	NA	NA	NA	NN	NN	Same as above, minus AIRS, POAM III	None

Table 4.4 Implementation Plans for HIRDLS Ozone Validation.
Relative degree of interest/usefulness: red = high; violet = medium; green = low.
NA (Not Applicable or Not Available); NN (Not Needed)

REGION	Routine	Routine+ more	High Altitude Balloons	Special Grd-Based	Campaigns (major)	Other Cam-paigns	Other satellites Instruments	Unmet Needs
Trop. 0-12km	MOZAIC MOZART CARIBIC G-vis G-lidar Sondes	NN	NN	NA	INTEX TC4	NN	Aura(MLS,TES) GOME, MIPAS, ODIN,POAM III, SABER, SAGE, SCIAMACHY	None
UT/LS 12-20km	G-vis G-lidar Sondes	More sondes, tropics (monthly). Plus additional sondes at high latitudes during POLAR.	B-remote	NA	INTEX, TC4, POLAR - Need along track aircraft data (600-1000km), with curtain measurements Spirals also useful.	NN	Same as above	For campaigns need along track aircraft data, with spirals. More sondes in tropics under extreme conditions.
Strat. 20-50km	G-vis G-MW Sondes Umkehr	NN	B-remote	NA	NA	NN	ACE, Aura (MLS,TES), GOMOS, GOME, MIPAS, ODIN,POAM III, SABER, SAGE, SCIAMACHY, UARS (HALOE)	None
Meso. >50km	G-MW	NN	NA	NA	NA	NN	Same as above	None

Table 4.5 Implementation Plans for HIRDLS HNO_3 Validation.
Relative degree of interest/usefulness: red = high; violet = medium; green = low.
NA (Not Applicable or Not Available); NN (Not Needed)

REGION	Routine	Routine+ more	High Altitude Balloons	Special Grd-Based	Campaigns (major)	Other Cam-paigns	Other satellites Instruments	Unmet Needs
Trop. 0-12km	G-IR	NN	NA	NN	INTEX, TC4, POLAR - Need along track aircraft data (600-1000km), with spirals.		NA	INTEX, TC4, POLAR - Need along track aircraft data, with spirals.
UT/LS 12-20km Up to max aircraft altitudes	G-IR	NN	B-remote Tropics and mid latitudes (seasonal for two years); Plus during POLAR campaign	NN	INTEX, TC4, POLAR - Need along track aircraft data (600-1000km), with spirals.		ACE, Aura (TES, MLS), MIPAS, ODIN	INTEX, TC4, POLAR - Need along track aircraft data, with spirals. B-remote Tropics and mid latitudes (seasonal for two years); +POLAR
Strat. 20-50km	G-IR G-MW	NN	B-remote (same as above) Plus during POLAR campaign	NN	NA	NA	Same as above	B-remote Tropics and mid latitudes (seasonal for two years); +POLAR

Table 4.6 Implementation Plans for HIRDLS $ClONO_2$ Validation.

Relative degree of interest/usefulness: red = high; violet = medium; green = low.

NA (Not Applicable or Not Available); NN (Not Needed)

REGION	Routine	Routine+ more	High Altitude Balloons	Special Grd-Based	Campaigns (major)	Other Cam-paigns	Other satellites Instruments	Unmet Needs
UT/LS 12-20km Up to max aircraft altitudes	G-IR (col)	NA	B-remote Tropics and mid latitudes (seasonal for two years); Plus during POLAR campaign	NA	POLAR - Need along track aircraft data (600-1000km), with spirals. In situ and remote meas.	NA	ACE, Aura (TES), MIPAS	High altitude Balloon and POLAR mission needed for validation.
20-50km	G-IR (col)	NA	B-remote Tropics and mid latitudes (seasonal for two years); Plus during POLAR campaign	NA	NA	NA	ACE, Aura(TES), MIPAS	High altitude Balloon needed for validation.

Table 4.7 Implementation Plans for HIRDLS N_2O_5 Validation.
Relative degree of interest/usefulness: red = high; violet = medium; green = low.
NA (Not Applicable or Not Available); NN (Not Needed)

REGION	Routine	Routine+ more	High Altitude Balloons	Special Grd-Based	Campaigns (major)	Other Cam-paigns	Other satellites Instruments	Unmet Needs
UT/LS 12-20km Up to max aircraft altitudes	G-IR (col)	NA	B-remote Tropics and mid latitudes (seasonal for two years).	NA	NA	NA	ACE, Aura (TES), MIPAS	High altitude balloon needed for validation. Chemical data assim. technique will be needed.
20-50km	G-IR (col)	NA	B-remote Tropics and mid latitudes (seasonal for two years).	NA	NA	NA	ACE, Aura (TES), MIPAS	High altitude balloon needed for validation. Chemical data assim. technique will be needed.

Table 4.8 Implementation Plans for HIRDLS NO_2 Validation.

Relative degree of interest/usefulness: red = high; violet = medium; green = low.

NA (Not Applicable or Not Available); NN (Not Needed)

REGION	Routine	Routine+ more	High Altitude Balloons	Special Grd-Based	Campaigns (major)	Other Cam-paigns	Other satellites Instruments	Unmet Needs
UT/LS 12-20km Up to max ER2 altitudes	G-IR (col)	NA	B-remote Tropics and mid latitudes (seasonal for two years). Plus during POLAR campaign	NA	INTEX, TC4, POLAR A-IR (col) A-UV/VIS (col) NOTE: it will be difficult for HIRDLS to measure NO_2 much below 20km. Column above aircraft will be useful. POLAR will need to be in Fall or late Spring (i.e., before conversion to HNO_3).	NA	NA	High altitude balloon needed for validation. . Chemical data assimilation technique will be needed. Aircraft column above. In situ meas. at upper alt range
20-50km	G-IR (col)	NA	B-remote Tropics and mid latitudes (seasonal for two years). Plus during POLAR campaign	NA	NA	NA	ACE, Aura (OMI, TES), GOME, GOMOS, MIPAS, ODIN, POAM III, SAGE, SCIAMACHY, UARS (HALOE)	High altitude balloon needed for validation. Chemical data assim. technique will be needed.

Table 4.9 Implementation Plans for HIRDLS CH_4 Validation.

Relative degree of interest/usefulness: red = high; violet = medium; green = low.

NA (Not Applicable or Not Available); NN (Not Needed)

REGION	Routine	Routine+ more	High Altitude Balloons	Special Grd-Based	Campaigns (major)	Other Cam-paigns	Other satellites Instruments	Unmet Needs
Trop. 0-12km	G-in situ G-IR(col)	NN	NA	NA	INTEX, TC4, POLAR - Need along track aircraft data (600-1000km), with spirals.	NN	NA	INTEX, TC4, POLAR - Need along track aircraft data (600-1000km), with spirals.
UT/LS 12-20km Up to max aircraft altitudes	NA	NN	B-in situ B-remote Tropics and mid latitudes (seasonal for two years). Plus during POLAR campaign	NA	INTEX, TC4, POLAR - Need along track aircraft data (600-1000km), with spirals.	NN	ACE,Aura(TES)MIPAS, SCIAMACHY, UARS (HALOE)	High altitude balloon needed for validation. Spiral and along track meas. useful for gradients.
Strat. 20-50km	NA	NA	B-in situ B-remote Tropics and mid latitudes (seasonal for two years). Plus during POLAR campaign	NA	NA	NA	Same as above	High altitude balloon needed for validation.
Meso. >50km	NA	NA	NA	NA	NA	NA	Same as above	none

Table 4.10 Implementation Plans for HIRDLS N_2O Validation.
Relative degree of interest/usefulness: red = high; violet = medium; green = low.
NA (Not Applicable or Not Available); NN (Not Needed)

REGION	Routine	Routine+ more	High Altitude Balloons	Special Grd-Based	Campaigns (major)	Other Cam-paigns	Other satellites Instruments	Unmet Needs
Trop. 0-12km	G-IR (col) G-in situ	NN	NA	NN	INTEX, TC4, POLAR - Need along track aircraft data (600-1000km), with spirals.	NN	NA	INTEX, TC4, POLAR - Need along track aircraft data (600-1000km), with spirals.
UT/LS 12-20km Up to max aircraft altitudes	NA	NN	B-in situ B-remote Tropics and mid latitudes (seasonal for two years). Plus during POLAR campaign	NN	INTEX, TC4, POLAR - Need along track aircraft data (600-1000km), with spirals.	NN	ACE, Aura (MLS), MIPAS, ODIN, SCIAMACHY	High altitude balloon needed for validation. Spiral and along track meas. useful for gradients.
Strat. 20-50km	NA	NA	B-in situ B-remote Tropics and mid latitudes (seasonal for two years). Plus during POLAR campaign	NN	NA	NA	See above	High altitude balloon needed for validation.
Meso. >50km	NA	NA	NA	NN	NA	NA	See above	none

Table 4.11 Implementation Plans for HIRDLS CFC-11, CFC-12 Validation.
Relative degree of interest/usefulness: red = high; violet = medium; green = low.
NA (Not Applicable or Not Available); NN (Not Needed)

REGION	Routine	Routine+ more	High Altitude Balloons	Special Grd-Based	Campaigns (major)	Other Cam-paigns	Other satellites Instruments	Unmet Needs
Trop. 0-12km	G-IR (col) G-in situ	NN	NA	NA	INTEX, TC4, POLAR - Need along track aircraft data (600-1000km), with spirals.	NN	NA	INTEX, TC4, POLAR - Need along track aircraft data (600-1000km), with spirals.
UT/LS 12-20km Up to max ER2 altitudes	NA	NN	B-in situ B-remote Tropics and mid latitudes (seasonal for two years). Plus during POLAR campaign	NA	INTEX, TC4, POLAR - Need along track aircraft data (600-1000km), with spirals.	NN	ACE, MIPAS	High altitude balloon needed for validation. Spiral and along track meas. useful for gradients.
Strat. 20-50km	NA	NN	B-in situ B-remote Tropics and mid latitudes (seasonal for two years). Plus during POLAR campaign	NA	NA	NA	See above	High altitude balloon needed for validation.

Table 4.12 Implementation Plans for HIRDLS Cirrus, Sulfate, STS, NAH, ICE Validation.
Relative degree of interest/usefulness: red = high; violet = medium; green = low.
NA (Not Applicable or Not Available); NN (Not Needed)

REGION	Routine	Routine+ more	High Altitude Balloons	Special Grd-Based	Campaigns (major)	Other Cam-paigns	Other satellites Instruments	Unmet Needs
Trop. 0-12km	G-lidar	B-in situ (seasonally) under volc. clean condition. Monthly if volc. enhanced.	NN	NN	INTEX, TC4, POLAR - Need along track aircraft data (600-1000km), with spirals. Info. on size distr.; extinction, and composition needed.	NN	MODIS, MISR, POLDER, CALIPSO	INTEX, TC4, POLAR - Need along track aircraft data (600-1000km), with spirals. Important to have monthly B-in situ under volc. enhanced conditions
UT/LS 12-20km Up to max aircraft altitudes	G-lidar	B-in situ (seasonally) under volc. Clean condition. Monthly if volc. enhanced	NN	NN	INTEX, TC4, POLAR - Need along track aircraft data (600-1000km), with spirals. Info. on size distr.; extinction, and composition needed.	NN	Aura (TES), CALIPSO, GOMOS, MIPAS, MODIS, POAM III, POLDER, SAGE, SCIAMACHY, UARS (HALOE)	Spiral and along track meas. useful for gradients. Important to have monthly B-in situ under volc. enhanced conditions
Strat. 20-50km	G-lidar	Same as above.	NN	NN	NN	NN	Same as above	Same as above.

Table 4.13 Implementation Plans for HIRDLS Cloud Height Validation.
Relative degree of interest/usefulness: red = high; violet = medium; green = low.
NA (Not Applicable or Not Available); NN (Not Needed)

REGION	Routine	Routine+ more	High Altitude Balloons	Special Grd-Based	Campaigns (major)	Other Cam-paigns	Other satellites Instruments	Unmet Needs
Trop. 0-12km	ARM Weather Sat. G-radar	NN	NN	NN	INTEX TC4 POLAR A-lidar	NN	AIRS, Aura (TES, OMI), ATSR-2, CloudSat., ENVISAT, CALIPSO, GOME, MODIS, ODIN	none
UT/LS 12-20km Up to max aircraft altitudes	ARM Weather Sat. G-radar	NN	NN	NN	INTEX TC4 POLAR A-lidar (MPL)	NN	Same as above, + ICESat	none

Table 4.14a Summary of Validation Needs from HIRDLS: Tropical Composition, Chemistry, and Climate Coupling (TC^4) Campaigns.

Correlative Data Needs Red = high; violet = medium; green=low	Validation Value	Science Value
- Include measurements of: T(<12km): T, O_3, H_2O, Cirrus; CH_4, N_2O, $CFCl_3$, CF_2Cl_2 UT/LS (12-20km): T, O_3, H_2O, HNO_3, Cirrus, $CFCl_3$; CH_4, N_2O, CF_2Cl_2; NO_2, $ClONO_2$, GPH		Better Understanding of H_2O processes. Evaluation of TTL; ozone balance processes in TTL, UT/LS; S/T exchange;aerosol influences on climate (e.g., sub-visible cirrus)
- Add/include along-track data (600-1000km) with curtain measurements if possible for the following: UT/LS: T, O_3, H_2O, HNO_3, Cirrus Every 150km vertical profile preferred (in 8-18km vertical range) For gravity and planetary wave validation, see AVE section.	Evaluate LOS Gradients. Also useful for gravity wave validation (1000km would be preferred with level flight conditions).	
- Sampling Region(s) / Season(s) TWP in winter. Summer season convection Sample gradient in subtropics. Cloudy regions	Regions of low H_2O and low T; low O_3 and low T. High T, higher H_2O abundances needed. Useful in evaluation of LOS gradients. Both clear sky and cloudy conditions needed.	
- Validation measurement specifics T and P profiles O_3: Lidar system; plus in situ approach. HNO_3: Dynamic range: 0.1 to 10 ppbv CH_4, N_2O, CFC11, CFC12: Rapid response needed Aerosol Size Distributions: Important to measure cirrus near the TP (<20μm). Aerosol composition: desirable (instruments may not exist, e.g., to detect organic content of aerosols in UT) Cloud height: Lidar system 3D wind and temperature	To validate the tropical cold point tropopause. To examine gradients in the UT/LS region. HIRDLS measures extinction in 4 channels. Composition affects the index of refraction. This information will increase the accuracy of the retrieval. For gravity wave validation.	
-Special Flight Characteristics Spirals for profiles (several)	Preferred over "porpoise" profiling.	
-Other Correlative Measurements Requested H_2O Sondes (see enhancement to routine) Ozone Sondes (see enhancement to routine) High Altitude Balloon data		

Table 4.14b Summary of Validation Needs from HIRDLS: POLAR Campaign(s).

Correlative Data Needs Red = high; violet = medium; green=low	Validation Value	Science Value
-Include measurements of: UT/LS (8-20km): T, O_3, H_2O, $ClONO_2$ HNO_3, PSCs, Cirrus, $CFCl_3$; CH_4, N_2O, CF_2Cl_2; NO_2		Het. Polar activation and odd-oxygen loss processes. Detailed evaluation of de-NOy and de-H_2O. Quantifying the roles of transport and mixing of ozone in the winter polar sub-vortex region
-Add/include along-track data (600-1000km) with profiles if possible for the following: LS: T, O_3, H_2O, HNO_3, CFCs, PSCs	Evaluate LOS Gradients across vortex boundaries.	
-Sampling Region(s) / Season(s) Measurement through out the Polar winter / spring. High HNO_3, H_2O, O_3, $ClONO_2$, PSCs under cold conditions (early winter, setup). Low HNO_3, $ClONO_2$ under cold conditions (mid-winter, activation). Low O_3 in spring (late winter/spring, maintenance and ozone loss).	Validate under extreme conditions. A cold NH winter/spring will meet most HIRDLS validation needs.	
- Validation measurement specifics T and P profiles O_3: Lidar system; plus in situ approach. HNO_3: Dynamic range: 0.1 to 10 ppbv $ClONO_2$: In situ and remote NO_2: In situ and remote N_2O_5: Remote CH_4, N_2O, CFC11, CFC12: Rapid response needed Aerosol Extinction: best if at HIRDLS wavelengths (4 channels) [namely at 7.06 - 7.13 μm; 8.2 – 8.33 μm; 11.96 – 12.18 μm; and 17.01 – 17.76 μm] Aerosol Size Distributions: for sulfate aerosols and PSCs Aerosol composition: especially a measurement of aerosol HNO_3/H_2O ratios	To validate under extreme polar (low T) conditions To examine gradients in the UT/LS region IR-based measurement would minimize uncertainties in Mie calculations Composition affects index of refraction	
-Special Flight Characteristics Spirals for profiles (several)	Preferred over “porpoise” profiling	
-Other Correlative Measurements Requested H_2O Sondes (see enhancement to routine data) O_3 Sondes (see enhancement to routine data) High Altitude Balloon data		

Table 4.14c Summary of Validation Needs from HIRDLS: Enhancements to Routine data.

Correlative Data Needs Red = high; violet = medium; green=low	Validation Value	Science Value
- Include measurements of: UT/LS (12-20km): O_3, H_2O, Cirrus. UT/LS (20-35km): O_3 and H_2O		Additional O_3 and H_2O sondes will augment the planned TC4 and POLAR science goals.
- Sampling Region(s) / Season(s) Tropics: Monthly frequency for both O_3 and H_2O needed. Cirrus measurements are also requested. Multiple sites throughout the Pacific preferred. Increased frequency: Balloons in the regions of (1) lowest T (TWP-most critical) and (2) largest annual cycle (Asian Monsoon – 2nd most critical). This might be done from TC4 mission base for the TWP, or a SOWER site (Indonesia for TWP). Monsoon season over South or Central Asia. Mid-latitudes NH: Additional measurements not needed. Mid-latitudes SH: Important to have a mid-latitude station (e.g., Lauder NZ) for measurements of O_3, H_2O, NO_2, and aerosols. High latitudes NH: Monthly frequency for H_2O needed (e.g., at Kiruna). This should be coordinated with a POLAR campaign. The minimum duration would be November through March. High Latitude SH: Measurement of O_3, H_2O, Temperature, and Aerosols. It would be very useful to have both lidar and sonde type measurements.	It is important to have monthly measurements at high, mid, and tropical latitudes for the first year (after activation phase). Useful to have 2 tropical annual cycles of H_2O sonde data, under extreme conditions (TWP winter), multiple sites; also QBO variation validation. Low H_2O at low temperature in TWP and high H_2O at high pressures over monsoons Current monthly measurements for H_2O sonde data should be adequate. Check possible difference in system. errors (NH vs SH). Validation under extreme conditions. Should ensure that NOAA and NDSC observations continue at SH high polar lats. (>75S).	See TC4 science plan. Investigate hemispheric asymmetries (e.g., after breakup of the SH polar vortex).
- Validation measurement specifics H_2O sondes: Frost Point, Lyman alpha, or diode laser. Note: Requested H_2O sonde launches may require additional support / training / instrument development (e.g., FP sondes like Snow White that do not need cryogens, or multiple bases for monthly launches). H_2O and O_3 lidars; O_3 sondes Information on size distributions from 10 to 500 or 1000 μm.	It is important that the accuracy (for H_2O) be 10% or less. Validation of cirrus particles.	
- Special launch Characteristics Tropics: Coordinate Ozone and H_2O sondes with TC4. Start additional launches 6-months before major field campaign, and run several months after (6 to get a full annual cycle).		
- General Comments: Assume continuation of following data 1) NDSC sites (multiple species) 2) Lauder NZ site (for O_3 sonde/lidar and NO_2 column). 3) Boulder CO site (for H_2O sonde). 4) SHADOZ sites (for O_3 sondes)		

Table 4.14d Summary of Validation Needs from HIRDLS: High Altitude Balloons.

Correlative Data Needs Red = high; violet = medium; green=low	Validation Value	Science Value
- Include measurements of: UT/LS (12-20km): T, O_3, H_2O, HNO_3, CFC11, Aerosols, CH_4, N_2O, CFC12, NO_2 S (20-35km): T, O_3, H_2O, NO_2, $ClONO_2$, HNO_3, Aerosols, N_2O_5, CFC11, CH_4, N_2O, CFC12.	In the middle stratosphere, besides cross validation from other satellite instrument (e.g., ACE, POAM III), NO_2, $ClONO_2$, HNO_3, N_2O_5 are only measured by high altitude balloon.	See HIRDLS science plan.
- Sampling Region(s) / Season(s) Mid-latitudes: Seasonal for the first two years. High-latitudes: During POLAR Campaign(s) Tropics: Seasonal for the first two years.	Validate over two years, examine drift. Validate under extreme conditions. Validate under varying QBO and tape-recorder type signals	
- Special launch Characteristics Development of smaller balloon packages would enable more frequent launches [or rely on collaborations]. For tropical conditions, a launch site in Brazil will meet HIRDLS validation needs (collaborate with European effort there).	Coordination with POLAR Campaign throughout the winter/spring season would be very valuable.	
- General Comments Data chemical assimilation approaches will be needed for species with strong diurnal variability; especially true for occultation correlative data measurements. For solar occultation measurements, sunrise conditions are preferred over sunset.	Validation of NO_2, N_2O_5, and $ClONO_2$. This is especially true for NO_2 and N_2O_5 where their distributions are much greater at SR.	

Table 4.14e Summary of Validation Needs from HIRDLS: Intercontinental Chemical Transport Experiment – North America Campaign.

Correlative Data Needs Red = high; violet = medium; green=low	Validation Value	Science Value
- Include measurements of: T (0-12km): T, O_3, H_2O, CH_4, CFC11, Cirrus, sulfate, aerosols, N_2O, HNO_3, CFC12, Cloud Top UT/LS (12-20km): T, O_3, H_2O, HNO_3, CFC11, Cirrus, sulfate aerosols, CH_4, N_2O, CFC12, NO_2, Cloud Top	Important for HIRDLS species validation in the upper troposphere.	Better understand the Ozone photochemistry in the UT. Deep convective transport of tracers in the UT region. Mixing in the UT extratropics.
- Add/include along-track data (600-1000km) with profiles if possible for the following: T/UT (5-12km): T, O_3, H_2O, HNO_3, CFCl1, Cirrus Every 150km vertical profile preferred	Evaluate LOS Gradients.	
- Special Flight Characteristics Spirals for profiles (several)	Preferred over “porpoise” profiling	
- Validation measurement specifics T and P profiles O_3: Lidar system; plus in situ approach. H_2O: Lidar system. HNO_3: Dynamic range: 0.1 to 10ppbv CH_4, N_2O, CFC11, CFC12: Rapid response needed. Aerosol Size Distributions: Important to measure cirrus near the TP (<20µm). Aerosol composition: desirable (instruments may not exist, e.g., to detect organic content of aerosols in UT) 3D wind and temperature	To validate the extratropics cold point tropopause. For tropopause region data, as well as for some information on cloud heights To examine gradients in the UT/LS region. Composition affects the index of refraction. This information will increase the accuracy of the retrieval. For gravity wave validation.	

Table 4.14f Summary of Validation Needs from HIRDLS: Aura Validation Experiment Campaigns (needs not met by planned campaigns and other data).

Correlative Data Needs Red = high; violet = medium; green=low	Validation Value	Science Value
- Needs not met by planned campaigns or other correlative data. I) Volcanic eruptions (have a plan in place).	HIRDLS is sensitive to sulfate aerosol abundance. A major eruption would significant impact HIRDLS ability to retrieve constituents in the UT/LS/S. Correlative data would be necessary to minimize aerosol interferences for retrieval algorithms.	Heterogeneous influence on UT/LS/S constituents.
II) Additional Tropical Campaign 1-2 years after TWP TC4 mission. AVE campaign to measure O_3, H_2O, T, and some tracers to target (1) anything missed by TC[4] (e.g., ENSO event) and (2) get additional information on interannual variation.	Validate ability to get an annual cycle, and to get absolute validation of trends.	Get any conditions missed due to ENSO, MJO, or QBO in tropics.
III) Mid-latitude, high altitude aircraft mission. This could be connected with INTEX in either of the planned INTEX missions (i.e., East or West). West would give more time for planning (summer 2006).	Validation of HIRDLS species in the mid-latitude UT/LS region.	Examination of S/T events, etc… Ozone photo-chemistry (UT/LS)
IV) Gravity wave validation (Rocky Mountains). HIRDLS will be sensitive to horizontal waves of 100 km (or less). The Rocky mountains are expected to be an efficient and reliable source of smaller scale GW. Aircraft flights would be needed. Aircraft data: 3D wind and temperature, T and P profiles. Measurements would be taken at cruise altitude.	Validation of small-scale waves in temperature measurements, specifically in data from special high-resolution observing modes.	Derive GW amplitude, horiz. wavelength, wave prop. direction, constraints on vert. wavelength.
V) Gravity and planetary wave validation (Equatorial sites, could be part of TC4) Aircraft data:. 3D wind and temperature, T and P profiles. Measurements would be taken at cruise altitude. Radiosondes: 4-times daily frequency or higher. High quality balloons should be used to give a consistent record well into the stratosphere, approximately 30km or higher. These should be at multiple sites in the vicinity of the aircraft flights and the total data record should extend for at least the duration of the flight campaign, and preferably longer.	These measurements at equatorial sites can also be used to observe equatorially trapped, planetary scale waves and validation of HIRDLS measurements of these waves.	Gravity wave amplitudes, frequencies, vertical & horizontal wavelengths. Horiz. structure of planetary-scale waves can also be determined from multiple well- placed launch sites

5. Specifics of MLS Validation

Table 5.1 MLS Correlative Measurement Priorities.
Measurements are listed in approximate order of decreasing priority within each category.

Priority	Geophysical Parameter	Comments
1	Upper tropospheric O_3, CO, H_2O, T	Aircraft measurements (preferably of vertical profiles) along the MLS track would be especially valuable, particularly in the tropics. Tropical data (e.g. sondes) would also be especially valuable (O_3, H_2O).
	Lower stratospheric O_3, H_2O, OH, BrO, HCl, N_2O, HNO_3 (and SO_2, if large volcano erupts into the stratosphere).	Aircraft measurements along the MLS track, vertical profiles if possible. Balloon/sonde measurements of vertical profiles.
	Upper tropospheric cloud data: number density and particle size distribution (for sizes of ~100 µm up to 1 mm), and total ice density.	Measurements for clouds above ~8 km in the tropics (along the MLS measurement track if possible).
2	Upper tropospheric HCN, CH3CN	
	Lower stratospheric ClO, HOCl, T Lower stratospheric HO_2, CO	Polar winter data needed for chlorine species. Vertical profiles needed.
	Middle/upper strat. OH, HO_2, BrO, HCl, ClO, H_2O, O_3, HNO_3, N_2O, HOCl, CO, T	Vertical profiles needed.
3	Stratospheric HCN, CH_3CN, SO_2 (if no large volcanic eruption) ,geopotential height	Vertical profiles needed.

TABLE 5.2 Implementation Plans for MLS Product Validation.

Relative degree of interest/usefulness: red = high, violet = medium, green = low.

Here, US = above ~20 km (above high alt. aircraft range); LS = trop. to ~ 20 km; UT =~ 300 to 400 hPa up to tropopause.

MLS Product & Region	Routine Correl. Data	Routine + more	High Alt. Balloon	Special Grd-based	Campaigns (major)	Other Cam-paigns	Other Satellites	Unmet Needs
Temp.	Radio-sondes, G-lidar, Oper. Met.data						Oper. Met. Data, AIRS, GPS, others	None (sufficient data, analyses, statistics).
O_3 (US)	Sondes G-lidar G-MW G-SAOZ Umkehr	More sondes (+ good timing)					SAGE UARS POAM III ODIN ENVISAT ACE Others	
O_3 (LS)	Sondes G-lidar	More sondes (+ good timing) [tropics, polar]			- TC4: With along-track data [1000 km] (profiles are best), in tropics. - POLAR		HALOE, SAGE, ACE ENVISAT, Others	Need along-track aircraft data [1000 km] (profiles are best),tropics + more sondes.
O_3 (UT)	Sondes G-lidar MOZAIC MOZART CARIBIC	- More sondes (+ good timing) [tropics,polar] - G-lidar coordi-nation (if 'routine' is not enough)			- INTEX, and TC4: With along-track data [1000km] (profiles are best), in tropics and in trop. folds.		HALOE SAGE Others	Need along-track aircraft data [1000 km] (profiles are best), in tropics, trop. folds +some more (timed) sondes (tropics) + G-lidar coordination

TABLE 5.2 (cont.) Implementation Plans for MLS Product Validation.
Relative degree of interest/usefulness: red = high, violet = medium, green = low.
Here, US = above ~20 km (above high alt. aircraft range); LS = trop. to ~ 20 km; UT =~ 300 to 400 hPa up to tropopause.

MLS Product & Region	**Routine Correl. Data**	**Routine + more**	**High Alt. Balloon**	**Special Grd-based**	**Cam-paigns (major)**	**Other Cam-paigns**	**Other Satellites**	**Unmet Needs**
H_2O (US)	G-based (MW), H_2O sondes (FPH)	More H_2O sondes [e.g., tropics, midlat, S polar]					HALOE SAGE, ACE ENVISAT, Others	Need some more H_2O sondes.
H_2O (LS)	H_2O sondes (FPH)	More H_2O sondes (+ good timing) [>1/mth; tropics?]			- TC4: With some (1-2 flights) along-track data [1000km] (profiles are best).		HALOE SAGE, ACE ENVISAT, Others	- Need more H_2O sondes (good timing) [minimum: as part of TC4] -Campaign(s) with along-track data [1000 km] (profiles are best).
H_2O (UT)	Radio-sondes, H_2O sondes (FPH), G-lidar, MOZAIC, MOZART, CARIBIC, Oper. Met. Data	- More H_2O sondes (+ good timing) [>1/mth; tropics?] - ARM (and other?) lidar data coordi-nation (if 'routine' is not enough)			- TC4 and INTEX: With some along-track data [1000km] (profiles are best).		AIRS, SAGE GPS, ENVISAT? Others?	Need more H_2O sondes (good timing) +campaign(s) with along-track data [1000 km] (profiles are best) + ARM (and other?) H_2O lidar data coordination.

TABLE 5.2 (cont.) Implementation Plans for MLS Product Validation.

Relative degree of interest/usefulness: red = high, violet = medium, green = low.

Here, US = above ~20 km (above high alt. aircraft range); LS = trop. to ~ 20 km; UT =~ 300 to 400 hPa up to tropopause.

MLS Product & Region	Routine Correl. Data	Routine +more	High Altitude Balloons	Special Grd-based	Campaigns (major)	Other Cam-paigns	Other Satellites	Unmet Needs
CO (M-T)	G-based (MW data 57N)						ODIN/SMR SCIAMACHY ACE	None
CO (US)	G-based (MWdata 57N)		NH midlats (2/yr)				ODIN/SMR SCIAMACHY ACE	None
CO (LS)			NH midlats (2/yr)		- TC4: With high altitude along-track data [1000 km], in tropics		ODIN/SMR SCIAMACHY ACE	None (other than balloon data & TC4)
CO (UT)	MOZAIC MOZART CARIBIC [good for back-ground (and other) conditions]				- TC4 and INTEX: With 100-300 hPa along-track data [1000 km] in polluted and trop. fold conditions		MOPITT	None (other than a few more campaign flights)
Cloud Ice Content (UT)	ARM cloud radar network				- INTEX: Ice particle size distr. [tropics, sub-tropics]; for clima-tology.	Clima-tology of ice particle size distri-bution	CloudSat	Climatolog yneeds hard to meet, rea-listically.
N_2O (US)	G-based (MW; 72N?, 67N, 45N?,8N?)		NH midlats, polar				SCIAMACHY, MIPAS, ACE, ODIN/SMR	None (otherwise)
N_2O (LS)			NH midlats, polar		TC4, POLAR [along-track, > 1000km]		SCIAMACHY, MIPAS, ACE, ODIN/SMR	None (otherwise)

TABLE 5.2 (cont.) Implementation Plans for MLS Product Validation.
Relative degree of interest/usefulness: red = high, violet = medium, green = low.
Here, US = above ~20 km (above high alt. aircraft range); LS = trop. to ~ 20 km; UT =~ 300 to 400 hPa up to tropopause.

MLS Product & Region	Routine Correl. Data	Routine +more	High Altitude Balloons	Special Grd-based	Campaigns (major)	Other Cam-paigns	Other Satellites	Unmet Needs
HNO_3 (US)	G-based Profiles (MW data 72N,67N, 45N, 8N)		NH polar midlats				MIPAS, ACE ODIN/SMR	None (if have POLAR & balloons)
HNO_3 (LS)			NH polar midlats		POLAR [along-track]		MIPAS, ACE ODIN/SMR	None (if have POLAR & balloons)
HCl (US)	[G-based IR, column]		NH midlats (min. 2/yr)				HALOE ACE	None (if overlap with HALOE and/or ACE)
HCl (LS)			NH midlats (min. 2/yr)		POLAR [along-track] TC4(same)		HALOE ACE	None (if overlap with HALOE and/or ACE)
OH (US)	G-based column data		midlats Fall 04, Fall 05 [from Ft.Sumner] June 05 [Fairbanks / Kiruna]?					
OH (LS)			Min. of 3 flights [same as for US]		TC4 Flights			

TABLE 5.2 (cont.) Implementation Plans for MLS Product Validation.
Relative degree of interest/usefulness: red = high, violet = medium, green = low.
Here, US = above ~20 km (above high alt. aircraft range); LS = trop. to ~ 20 km; UT =~ 300 to 400 hPa up to tropopause.

MLS Product & Region	Routine Correl. Data	Routine +more	High Altitude Balloons	Special Grd-based	Campaigns (major)	Other Cam-paigns	Other Satellites	Unmet Needs
BrO (US)	[Ground-based column]		NH midlats (2/yr min.)				[SCIAMACHY GOME, OMI, GOMOS, OSIRIS]	None (if have some balloon flights). Paucity of correl. data, but averaging required for MLS data.
BrO (LS)			NH midlats (2/yr or more)		POLAR (along-track, ~ 1000 km)			None (if have Balloons & POLAR BrO).
ClO (US)	Ground-based (MW data;79N, 45N?,20N 8N?, 78S)		NH polar vortex (late winter), midlats				ODIN/SMR	None (if have some polar data, balloons preferably). Statistics much better with other satellite(s).
ClO (LS)			NH polar vortex (late winter), midlats		POLAR (along-track, ~ 1000 km)		ODIN/SMR	Statistics and sampling issues.
HOCl (US)			NH midlats (2/yr or more)				ACE	No.Paucity of correl. data (but low priority).
HOCl (LS)			NH midlats (2/yr or more)		POLAR (could check possible enhancement)			No.Paucity of correl. data (but low priority).
HO_2 (US)	G-based (MW; 72N?)		NH midlats (2/yr or more)				ODIN/SMR?	No. Lower priority product & averaging required.
HO_2 (LS)					TC4			

TABLE 5.2 (cont.) Implementation Plans for MLS Product Validation.

Relative degree of interest/usefulness: red = high, violet = medium, green = low.

Here, US = above ~20 km (above high alt. aircraft range); LS = trop. to ~ 20 km; UT =~ 300 to 400 hPa to tropopause.

MLS Product & Region	Routine Correl. Data	Routine + more	High Altitude Balloons	Special Grd-based	Campaigns (major)	Other Cam-paigns	Other Satellites	Unmet Needs
HCN (US)	G-based (MW data; 72N, 45N?).		NH midlats				ACE	Need some correl. data (but not high priority).
HCN (LS,UT)	G-based (IR data).		NH midlats		TC4		ACE	Need some correl. data for validating enhanced values.
CH_3CN (US)			NH midlats				ACE	Need some correl. data (but not high priority).
CH_3CN (LS,UT)			NH midlats		TC4		ACE	Need some correl. data for validating enhanced values.
SO_2 [volcanic]								None, unless there is a major volcanic eruption
GPH	Oper. Met. Data						Oper. Met. Data, GPS	None

Table 5.3 Summary of Validation Needs from MLS.

CORRELATIVE DATA NEED	VALIDATION VALUE	SCIENCE VALUE (top-level)
CAMPAIGNS (non-polar) [INTEX, TC4]		
- Add/include along-track data (~1000 km) with profiles if possible [e.g., O_3, H_2O] for the following: LS O_3, H_2O (tropics) [TC4] UT O_3, H_2O (tropics) [TC4] UT CO (+ polluted conds.) [TC4, INTEX] UT CO (trop. folds) [INTEX] LS N_2O, HCl [TC4]	UT and/or LS Horizontal Gradients (O_3, H_2O,N_2O, CO)	TTL, O3 change, & climate change Trop. pollution Strat/trop exchange Transport
- Include measurements of LS OH [TC4] UT HCN, CH_3CN (polluted conds.) [INTEX 06, TC4] LS HO_2 [TC4]	LS OH UT HCN, CH_3CN enhancements HO_2 biases	
POLAR CAMPAIGN(S) - Include some (2 or more) LS flights into/ out of vortex, with the following along-track data (~1000 km): 1) N_2O, HNO_3, ClO, HCl, O_3, H_2O 2) BrO 3) HOCl	LS species in cold, po conditions (enhanced ClO), horiz. gradients	LS polar ozone chemistry, climate change issues

Table 5.3 (cont.) Summary of Validation Needs from MLS.

CORRELATIVE DATA NEED	VALIDATION VALUE	SCIENCE VALUE (top-level)
ENHANCEMENTS TO ROUTINE DATA		
- Add some "well-timed" ozonesondes (min.: 1 trop. site) for better coincidence with overpasses (over ~ 1-2 yrs).	UT/LS O_3	Climate change, Ozone change, budget, model constraints
- Develop any needed coordination with trop. O_3 lidar data providers	UT O_3	As above
- Add some "well-timed" H_2O sondes (min.: 1 tropical site, over 1-2 yrs.)	Trop. and strat. H_2O	TTL, climate & ozone change
- Develop any needed coordination with ARM (and other) trop. H_2O lidar data providers	Trop. H_2O	As above
HIGH ALT. BALLOONS (up to > 35 km)		
- **Obtain a minimum set of flights (2/yr at NH midlats for 2 years) and hopefully more than one site [e.g., potentially add Fairbanks/summer for OH, others?]** **Measurements:** 1) OH, HO_2, BrO, HCl, ClO, H_2O, O_3 2) HNO_3, N_2O, HOCl, CO, T 3) HCN, CH_3CN, SO_2	mainly for mid-upper stratospheric values	Supports various objectives (e.g., HOx, chlorine, ozone chemistry and trends)

6. Specifics of OMI Validation

6.1 Campaigns in support of Aura Validation

The international atmospheric science community organizes a variety of airborne measurement campaigns for scientific studies of the composition and physical behavior of the Earth's atmosphere [1]. In situ and remote sensing measurements are performed from aircraft and balloon platforms, sampling the atmosphere from the boundary layer and free troposphere into the tropopause and the lower stratosphere. High quality profile shape and column density information of atmospheric constituents is obtained over a number of representative locations and atmospheric conditions during these flights.

The information obtained by airborne campaigns is of high importance for satellite data validation and satellite product retrieval. Satellite data validation compares independently measured data to space based observations in order to assess the validity and accuracy of satellite data products. Airborne campaign data is highly suitable for this purpose. Measurements are taken on spatial scales much smaller than a single satellite pixel, rendering important information on the spatial variability within that satellite pixel, on time scales much longer than the satellite observation during the collocated overpass, rendering important information on the temporal variability on a regional scale. In return, the temporally collocated regional satellite observation renders information on the spatial variability beyond the reach of the airborne campaign. Satellite product retrieval benefits from comparing the result of airborne profile measurements with the profiles of atmospheric constituents as incorporated in atmospheric models. Being extracted from an ensemble of profile measurements, the model profiles are unable to capture strongly deviating situations, such as high tropospheric pollution by combustions products, aerosols and ozone in the boundary layer or the highly dynamic ozone chemistry during polar spring.

Various campaigns are in preparation at the time of writing [1]. Examples are INTEX - designed to understand the transport and transformation of gases and aerosols on transcontinental /intercontinental scales and their impact on air quality and climate - and TC4 - designed to investigate the many aspects of the chemical, dynamical, and physical processes occurring in the tropical upper troposphere and in the tropical tropopause. A summary of planned US-funded atmospheric science and validation campaigns during the time frame 2004-2007 is given in Table 6.1 below. These campaigns are all of interest to the validation of Aura satellite data products, provided that they yield columns and profiles closely coincident with the satellite measurements; cover a range of surface types and surface albedo transitions (land/sea, snow/clear); cover a range of atmospheric conditions; and cover long transects for more than one season and location.

Campaign measurements specifically in support of Aura validation are also planned under the name AVE – Aura Validation Experiment. The purpose of AVE is to supplement existing campaigns to complete the suite of measurement and to perform measurements dedicated solely to Aura validation. The January 2004 pre-AVE activity is designed to proof the concept of such a campaign that can be organized quickly and inexpensively and that returns useful information of the type necessary for Aura validation. The Pre-AVE activity offers the opportunity to create awareness amongst the aircraft experimenters and campaign planners of the correlative measurement needs of the Aura instrument validation teams and accompanying flight paths to perform such measurements.

This section serves to present the correlative data needs from campaigns, such as AVE, INTEX and TC4, for validation of the OMI instrument aboard Aura. General considerations on correlative data needs for OMI validation and necessary contributions from campaigns are presented and elaborately discussed elsewhere [2,3].

Month / Year	Acronym	Base	Country
January / 2004	pre-AVE	Ellington/Texas and Costa Rica	USA, CR
July / 2004	INTEX E	Ellington/Texas	USA
October / 2004	AVE	Ellington/Texas or Dryden/California	USA
January / 2005	AVE-polar	Kiruna	Sweden
July / 2005	TC4 summer	Costa Rica	Costa Rica
January / 2006	AVE/TC4	Darwin	Australia
April / 2006	INTEX-W + AVE	Ellington/Texas	USA
September / 2006	AVE	Costa Rica	Costa Rica
January / 2007	TC4 winter	Guam	
June / 2007	AVE (TBD)		
November / 2008	AVE (TBD)		

Table 6.1: *Atmospheric science and validation campaigns planned during the time frame 2004-2007. AVE = Aura Validation Experiment, INTEX-E = Intercontinental Chemical Transport Experiment - East (W = West), TC4 = Tropical Composition, Cloud and Climate Coupling Experiment, CAMEX = Convection And Moisture Experiment, DOE = Department of Energy, IOP = Intensive Observation Period.*

6.2 Campaign benefit for OMI validation

The EOS validation program defines validation as the process of assessing by independent means the uncertainties of the data products derived from satellite measurements, thus establishing validity and accuracy of satellite data products, to assure their quality for scientific use. The OMI validation strategy is to rely on correlative measurements based on multiple validated independent measurement techniques for this assessment. A large part of the validation will be based on enduring measurements, e.g., the ‘network data’ obtained from regular sounding stations and permanent observatories in order to capture a large number of representative locations under a large number of atmospheric conditions in the coarse of time.

Airborne campaign data supplements the available ground station ‘network data’ by performing measurements under atmospheric conditions and during flights over locations not covered by the geographically fixed ground stations. Furthermore, airborne campaigns offer the flexibility to cover events and locations of opportunity such as storm seasons, tropical cyclones, dust storms, volcanic activity, polar spring ozone chemistry, atmospheric transport of pollution and dust over the oceans, and much more. Airborne campaign measurements are taken on spatial scales much smaller than a single OMI pixel, rendering important information on the spatial variability within an OMI pixel, and on time scales much longer than the collocated OMI observation, rendering scientific information on the temporal variability in several OMI pixels. Airborne campaign measurements render column and profile information of constituents in the lower regions of the atmosphere - boundary layer and free troposphere - not covered by limb measuring satellites and integrated with the stratospheric column by column measuring satellites. In conclusion, airborne campaign data is of high interest and high importance to OMI validation.

6.3 OMI Technical Information

OMI is an advanced imaging hyperspectral instrument that will be flown as part of the EOS Aura mission and provide data on atmospheric chemistry that is highly synergistic with HIRDLS, MLS, and TES. OMI measures backscattered radiation in the UV and visible, from 270- 500 nm, with 0.5 nm resolution. OMI has an imaging swath of 114 degrees and a nadir ground pixel of 13x24 km^2 when measuring total ozone, aerosols, cloud information, and UV irradiances. Its hyperspectral capability enables measurements of trace gases such as SO_2, NO_2, HCHO, BrO, and OClO, but with a ground pixel of about 26x48 km^2 because of the higher measurement precision required.

Stratospheric ozone profiles will also be measured with this size ground pixel. OMI will obtain daily global coverage. More technical information on OMI and the scientific products of OMI retrievals can be found in the OMI-ATBD documentation [4-7].

6.4 OMI Scientific Products

Detailed information on OMI scientific products and science requirements can be found in the OMI Science Requirements Document (OSRD) [8]. The OMI products that shall be available directly after launch (L) are:

- Earth radiance and solar irradiance.
- Ozone column density (using DOAS and TOMS algorithms).
- NO_2 column density processed with simple airmass factors (unpolluted regions).

The OMI products that will be available later (> L+6) are:

- Near Real Time (NRT) and Very Fast Delivery (VFD) ozone column densities.
- Aerosol optical thickness and aerosol single scattering albedo (UVVIS).
- Cloud pressure and cloud fraction.
- Surface UV-B flux and VFD Surface UV-B flux.
- Ozone profile.
- NO_2 column density processed with airmass factors (all regions).
- Tropospheric ozone column (total column minus integrated HIRDLS stratospheric profile).
- SO_2 column.
- BrO column.
- HCHO column.
- OClO slant column (for improved comparison with ground based data).
- VFD ozone profile.
- Surface reflectance.
- Improved aerosol optical thickness and aerosol single scattering albedo (UVVIS).

6.5 OMI Correlative data needs

Specific needs for correlative data for OMI validation originates from three different aspects of the OMI project. These are (i) the OMI scientific products, (ii) the OMI retrieval algorithms and (iii) the OMI science questions. General consideration on correlative data needs are elaborately discussed elsewhere [2,3]. Here we present a selection appropriate for airborne campaigns.

6.5.1 OMI Scientific Products

6.5.1.1 Ozone (O3)

OMI's first task is to continue to monitor column ozone over the entire globe [8]. The validation of ozone column densities is therefore of highest priority. A long-standing problem in space-based remote sensing is to measure tropospheric ozone occurring under polluted conditions that is largely shielded from observation by satellite by the strongly absorbing bulk of the ozone column above the tropopause, but which does influence the total column observation. One would like to separate the variable tropospheric ozone column from the stratospheric ozone column. An airborne up- and down-looking UVVIS instrument capable of measuring the tropospheric and stratospheric column contributions separately is desired. An airborne UVVIS DOAS instrument that covers the OMI wavelength range, that can look both up and down, capable of measuring the tropospheric and stratospheric ozone column separately, and also a wide range of other OMI and Aura products, is highly desired.

One would also like to obtain the tropospheric ozone profile under polluted conditions and high aerosol loading. Therefore an aircraft lidar system that can measure ozone and aerosols is needed. The lidar should fly on the planned Aura validation/chemistry research missions (INTEX, TC4, etc.) as well as the proposed AVE missions. Finally, additional sounding of the ozone profile by means of balloon sondes in tropical regions and polluted mid-latitude regions is desired.

6.5.1.2 Nitrogen Dioxide (NO2)

Another main goal of OMI is direct monitoring of industrial pollution and biomass burning. The validation of ozone and nitrogen dioxide (NO_2) total column and tropospheric column densities - and the validation of aerosols is therefore also of high priority. The shortage of correlative nitrogen dioxide data can hopefully be relieved by campaign measurements.

Measurements are needed in the tropics, industrial and biomass burning areas where high nitrogen dioxide amounts are expected (tropics and industrial regions). NDSC-instruments do not meet this need, as they are often located at elevated or/and in relatively clean areas. With nitrogen dioxide one needs to separate the variable tropospheric column from the less variable stratospheric column. Under polluted conditions one needs to obtain the tropospheric profile shape because uncertainties in this profile introduce errors up to 50% of the total column. Profile data can be obtained with aircraft based lidars, both upwards and downwards looking, and with UVVIS (MAX or multi-axis)-DOAS instruments also upwards and downwards looking. Flights need to be carried out at the height of segmentation, close to the tropopause. A spectrally resolving sun photometer instrument can also measure nitrogen dioxide.

6.5.1.3 Aerosols

Aerosols are hard to characterize by means of optical remote sensing because one only obtains the aerosol spectral optical depth which characterizes only the total column. One would really like to know the vertical distributions of aerosol type and number density and obtain more information on the physical properties of the aerosol encountered.

Aerosol are characterized by their chemical particle composition, particle shape and size, physical structure and density of the solid material, optical refractive index, optical scattering properties, material volatility, hygroscopy and the range and distributions of all these physical properties. Important considerations for aerosols transport and transformation are their volatility (HNO_3 particles can evaporate) and their hygroscopic character. Therefore a sound aerosol aircraft or balloon-based mission should fly (spirals) while containing:

- Aerosol particle number counters: for counting number density of particles per volume.
- Aetholometers: for optical absorption spectroscopy.
- Sunphotometers: for spectrally resolved column absorption spectroscopy.
- Nephelometers: for optical scattering properties.
- Aerosol Lidar both upwards and downwards looking: for profile measurements of aerosol number density, optical scattering properties and polarization.

Optical absorption and scattering properties of aerosols should be measured and determined in the wavelength range of interest for the OMI instrument, namely 270-500 nm. Because of the optical absorption properties of the atmosphere in the deep-UV regime and the presence of aerosols mainly in the lower troposphere, a wavelength range of 340-500 nm will suffice.

Balloon based and aircraft based measurement should focus on those parts of the atmosphere where aerosols are abundant, being; close to ground level 0-500 m, the lower troposphere transporting mineral dust and pollutions 0.5-3 km; the troposphere transporting small particles over large distances 3-12 km; water and ice clouds 0-20 km.

Aerosols can often not be distinguished from thin clouds in terms of reflectivity enhancement. Aerosols and clouds both increase the air mass factor as sampled by scattered light. However, the spectral properties of aerosols and clouds are different and, depending on the wavelength of light, the air mass enhancement is different. Spectral measurements on the properties of cloud free and cloudy pixels with low and high aerosol loading will help to distinguish both extremes and provide useful data to recognize intermediate states of the atmosphere. Aerosols cannot be distinguished from surface albedo changes. Hence accurate measurements of surface albedo in UVVIS wavelength range are needed.

6.5.1.4 Clouds

Retrieval of the main level 2 products depends on cloud information, thus cloud properties must be validated carefully. Clouds will be present in many OMI pixels and simply removing cloudy pixels from the OMI data stream is a waste. Therefore a focus of attention on cloudy pixels in conjunction with planned missions that are interested in cloudy situations is necessary.

OMI determines an effective cloud top pressure and coverage, whereas tropical campaigns can determine all physical and geometrical cloud properties; cloud top, cloud base, cloud structure, cloud layering, ice water content, cloud albedo. Building up statistics with such detailed information increases the understanding of how OMI monitors cloudy conditions.

6.5.1.5 Other trace gases

For sulphur dioxide (SO_2), bromine oxide (BrO), chlorine dioxide (OClO) and formaldehyde (HCHO) there are only few opportunities to obtain correlative measurements and campaign efforts should be used to improve this. Sulphur dioxide will be observed under volcanic conditions, and in strongly polluted regions (industrial outflow plumes). Validation can greatly benefit from the flexible deployment of the AVE campaign and portable ground based and airborne MAX-DOAS systems. There is a clear need for measurements of bromine oxide on the ground, particularly on polar ice caps during the local spring period and over larger salt lakes.

Hence total and tropospheric column densities and tropospheric and stratospheric profile information for these species are most wanted - especially for formaldehyde.

6.5.2 OMI Retrieval Algorithms

General problems with trace gas retrievals are uncertainties in aerosols, clouds, ground albedo and profiles of trace gases. Aerosols will modify the path of light traveled through the atmosphere and hence modify the air mass sampled. Changes in ground albedo will strongly influence the amount of light reflected from the earth surface. Thin clouds will act as aerosols in changing the air mass factor and thick clouds will reduce the number of useful pixels. The tropospheric profile shape of several trace gases, essential for accurate column retrieval, is affected by pollution. Above all, the mentioned problems mutually influence each other and their individual influence is difficult to separate. Hence these problems require the accurate measurement of aerosols abundance and aerosols physical properties, ground albedo, cloud abundance and cloud vertical distribution, and profile shape of various atmospheric constituents such as ozone and nitrogen dioxide.

An important aspect of retrieval techniques is their sensitivity to the Airmass Factor (AMF). The AMF depends on *a priori* information. Large variations in the AMF occur during high aerosol loading in the troposphere - in smog-areas at midlatitudes and biomass burning regions in the tropics, with high cloud cover, or when there is a strong ozone concentration variation in the troposphere - which occurs in the tropics as well. Thus validation of OMI data will depend on correlative data obtained in the tropics and at mid- and high-latitudes, from ground level up to the lower stratosphere.

6.5.3 OMI Science Questions

Is the ozone layer recovering as expected? – requiring accurate global measurements of the ozone total column density and ozone profile in the upper troposphere and stratosphere, and accurate profile and column density measurements of BrO and OClO during polar vortex conditions at high latitudes. In order to understand the cause of observed ozone change it is important to distinguish the altitude at which the change is occurring.

What are the sources of aerosols and trace gases that affect global air quality and how are they transported? – requiring accurate profile measurements of tropospheric ozone, NO_2, HCHO, SO_2 and the physical properties of aerosols in the boundary layer and troposphere during long flight paths in regions of atmospheric transport of such aerosols and trace gases.

What are the roles of tropospheric ozone and aerosols in climate change? – requiring accurate column and profile measurements of ozone and aerosols throughout the atmosphere.

What are the causes of surface UVB change? – requiring accurate cloud fraction and cloud layering data, and column density and profile measurements of ozone and aerosols, throughout the atmosphere.

6.6 Campaign proposals for OMI validation

Below we list an overview of our requirements for correlative measurements to planned campaigns for the validation of OMI. Firstly we present a list of instruments that could enhance planned campaigns in order to complete the suite of measurements. Secondly, we present a list of flight path suggestions. The most innovative suggestion is to fly cross-track for studies of atmospheric variability between subsequent overpasses with the opportunity to follow a number of satellite overpasses at high latitudes.

6.6.1 Additional Instrument Suggestions

Some additional instrument suggestions are offered below, although it is understood that budgetary and time constraints will significantly limit the possibilities for new development(s) at this time.

Aircraft based UVVIS spectrometer (high priority)

- To measure UVVIS spectra with moderate spectral resolution.
- To perform simple retrievals of aerosols, clouds and columns of ozone.
- Upwards and downwards (nadir) looking instrument.
- Perform measurements at various altitudes, separating tropospheric and stratospheric part.

Aircraft based UVVIS spectrometer (high priority)

- To measure UVVIS spectra with high spectral resolution (similar to OMI).
- To perform DOAS retrievals of aerosols and clouds, and column densities of O_3, NO_2, SO_2, BrO, OClO and HCHO.
- Upwards and downwards (nadir) looking instrument.
- Perform measurements at various altitudes, separating tropospheric and stratospheric part.

Aircraft based UVVIS MAX-DOAS instrument (high priority)

- Exploit state-of-the-art DOAS technology
- To perform column retrievals of O_3, NO_2, aerosols, SO_2, BrO, OClO, HCHO.
- Multiple angles of observation offering simultaneous measurements and limited profile information.

Aircraft based O_3 Lidar (high priority)

- Curtain measurements by both downwards an upwards looking instrument.
- Resolve tropospheric and stratospheric profiles at slicing level set by altitude of flight.
- Requires flight path from boundary layer up to lower stratosphere.
- High aerosol loading and pollution conditions.

Aircraft based NO_2 Lidar (high priority)

- Curtain measurements by both upwards and downwards looking instrument.
- To resolve tropospheric and stratospheric profiles at flight altitude.
- Requires flight path from boundary layer up to lower stratosphere.
- High aerosol loading and pollution conditions.

- Ground based lidar or other profiling instruments as alternative.

Aircraft based aerosol advanced measurement package (high priority)

- Includes in-situ instruments (particle number counters, aetholometers, nephelometers) for aerosol physical properties (including optical scattering and absorption).
- Requires flight path from boundary layer up to lower stratosphere to resolve profiles.
- Includes remote sensing instruments (aerosol lidar, UVVIS DOAS, sun photometers) for aerosol optical depth and single scattering albedo, aerosol profile and column.

Aircraft based sun-photometer (high priority)

- Simple instrument measuring aerosol properties in flight with sunlight.
- Measuring solar irradiance from ground level (surface-UV) up to the aircraft ceiling.
- Requires special flight paths (spirals or porpoise) to cover sufficient range in altitude.

Aircraft based tunable diode laser (high priority)

- Curtain measurements of NO_2, O_3, and HCl both upwards and downwards.
- To resolve tropospheric and stratospheric profiles at slicing level set by altitude of flight.

6.6.2 Flight Path Suggestions

6.6.2.1 Spirals

For in situ measurements we propose to fly spirals, which cover a large vertical range to resolve tropospheric profiles, and which cover several OMI ground pixels to monitor ground pixel to ground pixel and sub ground pixel uniformity. During spiral flights we propose to cover a vertical range from 0 – 20 km with specific emphasis on the region 0 –2 km, resolving tropospheric profiles of pollution constituents such as aerosols, NO_2, SO_2, HCHO and O_3 close to ground level.

6.6.2.2 Along Track

We propose to fly paths along-track with Aura to follow, and collocate with, a column of OMI ground pixels in the very wide swath. This will provide us with information on sub-pixel and pixel to pixel variability in both space and time. When flying along track, we propose to fly near the OMI nadir position within a range of 100 km East and West of this position. This will initially limit the validation efforts to the OMI center ground pixels. Outer edge swath pixels will be treated in a later stage (read: later campaigns)

6.6.2.3 Cross Track

In tropical and mid-latitude regions of the globe, we propose to fly paths cross-track to Aura, in a westward direction, following subsequent overpasses of Aura at the same latitude, to compare east and west OMI swath ground pixels and to study variability over the 100 minutes time difference between two OMI (Aura) overpasses. Here the collocation limitation of 100 km is not applicable.

In polar and high latitude regions of the globe we propose to fly paths cross track to Aura, in a westward direction, following subsequent overpasses of Aura at the same latitude, to capture several Aura overpasses. At sufficiently high latitudes. Aura can be followed for an indefinite period of time.

6.6.3 Suggestions Overview with Accuracies and Instruments

In Table 6.2 below we present an overview of the campaign suggestions per OMI scientific products. All measurements suggested need to be performed in clean and polluted regions in view of the science goals of OMI. The accuracies mentioned originate from the OMI Science Requirements Document and represent the desired accuracy of OMI products as averaged over an ensemble of atmospheric conditions and compositions. However, we note that the planned campaigns are intended to measure under extreme atmospheric conditions. We therefore leave ample room for discussion in case the stated accuracies could not be met.

Product (What)	Accuracy (How good)	Geography (Where)	Instruments (How)	Flight Path
O_3 profile	10 % strat 30 % trop	Tropics/midlat Polluted regions Land/sea transitions Snow/clear transitions	O_3 Lidar UVVIS-DOAS	Resolve profiles from 0-20 km
O_3 column	2 %	Tropics/midlat/polar Polluted regions Land/sea transitions Snow/clear transitions	UVVIS spectrometer UVVIS DOAS	Along track Cross track
NO_2 profile	10 % strat 20 %, trop	Tropics/midlat Polluted regions Land/sea transitions Snow/clear transitions	NO_2 Lidar UVVIS -DOAS	Resolve profiles from 0-20 km
NO_2 column	10 % clean 20 % poll	Tropics/midlat Polluted regions Land/sea transitions Snow/clear transitions	UVVIS-DOAS	Along track Cross track
Aerosols AOD SSA	 30 % 0.1	Tropics/midlat Polluted regions Land/sea transitions Snow/clear transitions	particle counters aetholometers sun photometers nephelometers	Along track Cross track Resolve profiles from 0-20 km
HCHO	35 %	Tropics/midlat Polluted regions Biomass Burning	UVVIS-DOAS	Along track Resolve profiles from 0-20 km
BrO	10 %	Snow caps and salt lakes (surface sources)	UVVIS-DOAS	
SO_2	20 % or 10^{13} cm^{-2}	Polluted regions High loading (volcanic)	UVVIS-DOAS	Along track, resolve profiles from 0-20 km
Cloud fraction	0.1	Snow/clear transitions	UVVIS-DOAS	Along track Cross track
Irradiance	2 %		UVVIS spectrometer	
Radiance	2 %	Land/sea transitions Snow/clear transitions	UVVIS spectrometer	Along track

Table 6.2: *Summary of campaign recommendations for OMI validation. Column 1 lists the OMI scientific products on priority of measurement. Column 2 lists the desired accuracy of correlative measurement. Column 3 lists geophysical conditions and regions of interest. Column 4 lists suggestions of instruments to be incorporated on airborne measurement campaigns.*

The table also lists locations of geographical interest, satellite pixel collocation demands and suggested instruments. Ground albedo changes are of interest for product retrievals. There is no seasonal preference. Collocation is initially restricted to nadir ± 100 km to study OMI center swath pixels only. The full OMI swath will be validated at a later stage.

6.7 Specific needs for AVE: October 2004

Aura validation representatives have been invited to attend the Pre-AVE activities at Ellington Field, Houston, Texas, from 19-21 January of 2004. From this location, NASA-owned high altitude aircraft are operated which are capable of carrying an impressive amount of instrumentation on 5-6 hour flights up to 20 km altitude over a range of several thousand km. We strongly encourage campaign project managers to integrate UVVIS nadir column measuring equipment aboard their aircraft for measurements of column abundances of OMI satellite data products.

At the January Pre-AVE visit, the Aura validation representatives have been asked specifically to compile a wish list for the upcoming AVE activities. Below we summarize the OMI needs and rank their priority for several aspect of the project, with rank one being the highest. The correlative measurements required for a comprehensive OMI validation are ranked below in Table 6.3. Please note that all recommendations for airborne campaigns as described in section 6.6 still hold.

Rank	Product (What)	Conditions (Meteo)	Geography (Where)	Instrument (How)	Other Dta
1	O_3 column	Cloud free	- Tropics / Midlat - Clean regions - Polluted regions	UVVIS spectrometer UVVIS DOAS	Clouds Albedo Aerosol
2	O_3 column	Cloud free	- Tropics / Midlat - Clean regions - Polluted regions - GA transitions	UVVIS spectrometer UVVIS DOAS	Clouds Albedo Aerosol
3	NO_2 column	Cloud free	- Clean regions - Polluted regions	UVVIS DOAS	Clouds Albedo Aerosol
4	NO_2 column	Cloud free	- Clean regions - Polluted regions - GA transitions	UVVIS DOAS	Clouds Albedo Aerosol
5	Aerosol properties and profile	Cloud free	- Clean regions - Polluted regions	In situ aerosols suite UVVIS DOAS	
6	Aerosol properties And profile	Cloud free	- Clean regions - Polluted regions - GA transitions	In situ aerosols suite UVVIS DOAS	
7	NO_2 Profile	Cloud Free	- Tropics / Midlat - Clean regions - Polluted regions	In situ UVVIS DOAS	Aerosol
8	O_3 Profile	Cloud Free	- Tropics / Midlat - Clean regions - Polluted regions	In situ UVVIS DOAS	Aerosol
9	Aerosol optical index and Single Scattering Albedo	Cloud Free	- Tropics / Midlat - Clean regions - Polluted regions	Sunphotometer	
10	Cloud layering		- Tropics / Midlat		

Table 6.3: *Correlative measurement ranking for campaigns in support of OMI validation with rank 1 being the highest. Measurements listed are all along track and collocation is initially restricted to nadir ± 100 km to study OMI center swath pixels only. Profiles measured with in-situ instruments require spirals. There is no seasonal preference. GA-transitions indicate changes in ground albedo at land/sea and snow / clear transitions.*

OMI products

Priority 1. Ozone column
Priority 2. NO2 column
Priority 3. Aerosols optical index and Cloud fractions

Products needed for OMI retrievals

Priority 1. Aerosol physical properties and profile
Priority 2. NO2 tropospheric column and profile
Priority 3. Cloud layering, cloud albedo and cloud fraction

Science questions

Priority 1. Total ozone column over clean and polluted regions
Priority 2. Tropospheric NO2 column and aerosols profile over clean and polluted regions
Priority 3. Tropospheric ozone column over clean and polluted regions

Geographic and meteorological conditions

Priority 1. Cloud free, along track, over clean and polluted regions
Priority 2. Land-sea transitions, along track, over clean and polluted regions
Priority 3. Snow/Clear transitions, along track, over clean and polluted regions

Additional instruments (if possible within constraints)

Priority 1. UVVIS spectrometer (for high and medium altitude aircraft).
Priority 2. Aerosols lidar (for high and medium altitude aircraft), particularly for tropospheric and stratospheric profile measurements. Also capable of detecting sub-visible clouds.
Priority 3. O_3 lidar (for high and medium altitude aircraft), particularly for tropospheric and stratospheric profile measurements. Preferably under high aerosols loading (polluted conditions).
Priority 4. NO_2 lidar (for high and medium altitude aircraft), particularly for tropospheric and stratospheric profile measurements.

Considering the above priorities, the high altitude aircraft should definitely fly for OMI validation purposes during upcoming campaigns. The large suite of in-situ measurements of aerosols physical properties and abundances are most welcome for validation and retrievals and science. Profile measurements of aerosols, ozone and NO_2 are most strongly urged for. The OMI validation team strongly desires to integrate a UVVIS spectrometer performing total sky measurements aboard the high and medium altitude aircraft, primarily for measurement of total column ozone above the aircraft. After successful integration and field-testing of this system, it can be expanded to more advanced viewing geometries and employed for the retrieval of more OMI scientific products.

6.8 Affiliation Information

Mark Kroon (Dr.)
Research Scientist OMI Validation
KNMI (Royal Netherlands Meteorological Institute)
P.O. Box 201, De Bilt, NL-3730 AE, The Netherlands
T: +31-30-2206911
F: +31-30-2210407
E: mark.kroon@knmi.nl

Ellen J. Brinksma (Dr.)
Research Scientist OMI Validation
KNMI (Royal Netherlands Meteorological Institute)
P.O. Box 201, De Bilt, NL-3730 AE, The Netherlands
T: +31-30-2206749
F: +31-30-2210407
E: ellen.brinksma@knmi.nl

Richard D. McPeters (Dr.)
Principal Investigator, Earth Probe TOMS
NASA Goddard Space Flight Center
Greenbelt, MD 20771, USA
T: +01-301-614-6038
F: +01-301-614-5903
E: Richard.D.McPeters@nasa.gov

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7. Specifics of TES Validation

7.1 TES Standard Products

The TES standard data products are listed below:

Level 1B Radiances
Temperature Profile
Surface Temperature
Land Surface Emissivity
O_3
H_2O
CH_4
CO
N_2O
HNO_3

7.2 General Considerations for TES Validation Measurements

Locations

The general objective is to obtain in situ validation data over the widest possible range of conditions (source regions, outflow regions, ocean/land/ice, cloud/haze/clear).

Instruments/Aircraft

Requirements have been summarized in the Aura validation plan. Capabilities of both medium and high altitude aircraft will be required, especially for O_3, H_2O and HNO_3. Instrumentation is demanding for HNO_3 and upper tropospheric H_2O.

Congruence with Named Missions

INTEX and TC4 will not provide the full range of required measurements due to limitations in scheduling and satellite coincidences. AVE flights in Oct.04 from Ellington will be strategically very important because they will provide the first commissioning-phase trace gas data at a point when TES is likely to be ready for validation comparisons. The Jan. 05 AVE-polar flights will provide useful high latitude data, but would be optimally located at mid-latitudes, or tropics/sub-tropics to follow-on from the experience of the Oct. 04 series. The TC4 summer deployment from Costa Rica will be very useful if there are sufficient coincidences with Aura ground tracks. The Apr. 06 INTEX West and AVE series will fill in needed gaps in midlatitude validation data, but the algorithm/instrument teams would probably like to have high-latitude data in this time frame.

7.3 Level 1B Radiances

The Aura Validation Plan v1.0 discusses the general requirements for the TES Level 1B radiance end-to-end closure validation measurements.

Location(s)

Nadir radiance validation is best performed over water because of its high emissivity and spatial and spectral uniformity. Required correlative information includes water temperature, the atmospheric temperature profile and the water vapor vertical profile. Candidate sites are the Gulf of Mexico and Lake Tahoe. Another good location is the ARM-TWP site at Manus Island. While this site is well instrumented, there is very high water vapor which will complicate the retrievals and very active cloud convection which will reduce the number of coincident measurement opportunities. Next in priority are flights over instrumented land-based sites such as the ARM SGP site. Following this in priority are flights over instrumented high-latitude sites such as the ARM NSA/AAO site.

Since the TES limb view uses the same detectors as the nadir view, most of the limb radiance validation is achieved by performing nadir radiance validation. However, the differences in resolution (limb views are measured with finer spectral resolution than nadir) and the lower radiances observed in the upper atmosphere for the limb will result in lower signal levels. Hence, additional measurements are required for limb validation.

The internal consistency of TES limb radiances can be tested by adjusting the limb pointing so that detectors that nominally point near the surface are pointed at higher altitudes and comparing observed radiances with those detectors that normally point to the higher altitudes. In addition, TES plans to perform intercomparisons with Aura HIRDLS where both instruments make simultaneous measurements (both view the trailing limb) while pointing at the same tangent height.

Instrument(s)

Nadir radiance validation is best performed using high-altitude nadir-sounding instruments. A Fourier Transform Infrared Spectrometer with high spectral resolution (comparable to TES) is desirable because it permits validation measurements to be made in non-window regions as well as window regions, and will provide more information as to the primary source of the radiation (surface, molecular continua, resolved lines, etc.). For measurements over the ocean, the water temperature is needed. However, the measured temperature is seldom representative of the water radiating temperature because of the effects of clouds and solar heating. For TES validation, sonde measurements over water with simultaneous measurements of column water vapor with a microwave radiometer would be ideal. These could be accomplished using a platform such as the NOAA research vessel Ronald H. Brown. This vessel can also measure the infrared spectral radiance of the sky and the ocean surface. The vessel should be deployed in the Gulf of Mexico for these measurements.

Numerous nadir radiance validation opportunities from orbit will be available using AIRS data, since this instrument has undergone extensive validation in the past. This would be carried out starting with clear ocean scenes (viewed 15 minutes earlier by AIRS) and applying the AIRS spectral line shape to TES nadir spectra, which are measured with finer spectral resolution than AIRS. This type of comparison could be done selectively at first and eventually over many different target types with good statistics everywhere. Based on the AIRS validation experience, comparisons of measured vs. modeled radiance using accurate assimilated meteorological temperature and humidity profiles and sea surface temperatures can also provide a large statistical sample for radiance validation.

Timing

At least one summer flight and one winter flight in clear sky conditions are required. These flights must occur in the commissioning phase.

Flight Profile

Desired flight profiles are principally high altitude along-track cruises that are closely coincident with overpasses. However, coincident vertical profiles of temperature and water vapor are necessary using the same aircraft, a different aircraft or by sonde launches. High altitude measurements ($z>20$ km) are best because most of the upwelling radiance lies below the aircraft (or balloon) platform under these conditions. Radiance measurements should be made at several different altitudes in order to characterize the emission from different layers of the atmosphere.

Congruence with Named Missions

As discussed above, it is important that TES radiance validation take places in the commissioning phase. While the July, 04 INTEX and AVE flight opportunities might be suitable, it is likely that they will take place too soon after the Aura launch (TES outgassing and characterization will likely be incomplete at this stage). Therefore, the October, 2004 AVE (Ellington) and January, 05 AVE-polar missions would be best for validating TES radiances provided that the locations specified previously are traversed.

Data from the July, 2005 TC4 mission to Costa Rica and January, 2006 TC4 mission to Darwin would be desirable because they will likely traverse the Gulf of Mexico and ARM/TWP sites either on operational and/or ferry legs. However, because these missions will occur after the commissioning phase, they carry lower priority.

Target Parameter	Type of measurement	Where	When	How many	Reqmt satisfied by INTEX and/or TC4?	Other data required
Radiance	High altitude aircraft FTIR Z > 20 km	Ocean/large lake such as Gulf of Mexico, Lake Tahoe or ARM TWP site (Manus)	Commissioning	1 flight summer 1 flight winter	Not likely (see discussion)	Water temperature, water vapor profile
		Land surface such as ARM SGP site	Commissioning	1 flight summer 1 flight winter	Not likely (see discussion)	Surface temperature, emissivity, water vapor profile
		Ice/snow surface such as ARM NSA/AAO sites	Commissioning or Core	1 flight winter	No	

7.4 Trace Gases

O_3, CO, H_2O and HNO_3 have the widest dynamic ranges of the TES-measured trace gases. Algorithms need to be exercised over wide ranges in temperature profile, surface temperature and emissivity, and vertical profile variability. Analyses of the vertical profiles of retrieval error budgets for CO, O_3 and H_2O show that the best sensitivities are obtained in the southern and northern midlatitudes and tropics. Retrievals in the polar regions are considerably more challenging. The best sensitivity is obtained (generally) between 6 and 14 km for CO, 4-20 km for O_3 and 0-12 km for water vapor. The altitude range for HNO_3 (limb retrievals, mainly except in polluted locations) extends from 4-32 km.

7.4.1 Ozone (O_3)

A key requirement for the validation of TES nadir profiles of tropospheric ozone is the availability of vertically resolved measurements of spectral radiance. TES needs to retrieve tropospheric ozone through a large overburden of stratospheric ozone (90% of the total column). To show that the TES ozone algorithm correctly handles the stratospheric component, the validation program must provide measurements of the upwelling radiance in the altitude regime that is important for the TES retrievals. This is best accomplished under conditions where the stratospheric component is absent, i.e. from the boundary layer to the highest altitude attainable by instrumented aircraft (20 km). These data will be used to compare the observed pressure broadening with that predicted by the forward model. This will test both the algorithm's model of the atmospheric structure, and the accuracy of the laboratory spectroscopic data base as it concerns pressure broadening coefficients. In addition, the vertically resolved radiance data will test the ability to retrieve sharp gradients in the vertical profile near the tropopause. The radiance measurements must be complemented with a combination of ozone instruments including aircraft ozone lidar, ozonesondes and in situ measurements. The first opportunity to do this will be during INTEX in July-August, 2004.

The timing and locations for the ozone validation measurements should evolve over time as the process matures. The initial measurements (commissioning and early core validation phases) should focus on relatively simple conditions, i.e. over water under clear skies with good correlative measurement capabilities. These requirements are somewhat mutually exclusive since the sites having the best supporting measurements are all on land, e.g. the ARM Southern Great Plains site. A possible exception is a shipboard platform, based in the Gulf of Mexico, and certain aircraft platforms. As the effort evolves, increasing emphasis should be placed on overflights of land-based stations. Supporting measurements include the temperature and water vapor profiles, as well as ground-based microwave radiometer measurements of the water vapor column, as discussed below.

Where and when should these measurements be made?

In the core validation phase, emphasis should be placed on validation measurements that test the ability of TES to retrieve large spatial gradients under varying conditions of land surface type and spatial ozone gradients. Ozone sondes and aircraft campaigns will be key here. The sondes will provide good statistics, while the campaigns will provide simultaneous measurements of ozone, H_2O, and CO. Aircraft lidar measurements will be particularly useful for showing horizontal and vertical gradients along the orbit track, albeit on a different temporal scale from the satellite overpass. The measurements that will be carried out by INTEX East would be ideal here, because the North American outflow region will have large gradients and will involve both land and sea surfaces. However, this phase of INTEX will take place before the Aura core validation phase begins so it is important to obtain similar measurements at a more suitable time.

Ozonesondes will play a key role in TES validation. Based on a poll of stations by J. Logan, data should be available within a week of acquisition for 15 mid-high latitude stations and 5 tropical stations, with a further 7 extra-tropical stations providing data within a few days to a month of acquisition. Timed overpasses will be essential in the tropics, as discussed in the Aura Validation Plan v1.0. This should not be a problem for the SHADOZ tropical stations and the mid-latitude stations with U.S. funding [S. Oltmans, pers. comm.], where weekly measurements are made. Some timed overpasses at high latitude stations will also be required. Either lidar measurements of tropospheric ozone, or the launch of 3 sondes within a few hours, will be required to examine tropospheric ozone variability at a few selected mid- and low- latitude sites. The sondes also offer the opportunity for long-term validation of TES measurements.

We estimate that at least 6-12 profiles per year **under cloud-free coincident conditions in each latitude band** will be needed for initial comparisons. This implies a much larger number of total launches to achieve the stated number of useful profiles. Measurements should be made throughout the mission with a similar frequency

Summary of what, where, when for ozone

Target Parameter	Type of measurement	Where	When	How many	Reqmt satisfied by INTEX and/or TC4?	Other data required
Ozone	Aircraft *in situ* profiles	Coincident with TES ground tracks. Initially over the ocean but later over land. Tropics, mid-latitudes, polar	Commissioning phase, initially, continuing through core phase.	At least 4-6 cloud-free profiles for each set of conditions	For some conditions, possibly, but highly unlikely for all desired conditions	Temperature profile, water vapor profile
	Aircraft lidar profiles	Coincident with TES ground tracks. Initially over the ocean but later over land. Tropics, mid-latitudes, polar	Commissioning phase, initially, continuing through core phase	At least 4-6 cloud-free profiles for each set of conditions	For some conditions, possibly, but highly unlikely for all desired conditions	Temperature profile, water vapor profile
	Balloon sondes	Initially at CMDL sites, e.g. Samoa, Hawaii, Boulder, Galapagos, Ascension Is. Later at high latitudes, e.g Goose Bay, Resolute Alert	Launches timed with Aura overpasses	At least 6-12 profiles per year **under cloud-free coincident conditions in each latitude band** for initial comparisons. Measurements should be made throughout the mission with a similar frequency.	N/A	Profiles of temperature and water vapor.

7.4.2 Carbon Monoxide (CO)

Validation of CO measurements from TES requires CO profiles throughout the troposphere and into the lower stratosphere. Such measurements should be obtained on both the AVE missions and the large-scale campaigns, in order to cover a range of concentrations, profile shapes, land cover types, and clear/hazy, cloudy conditions.

Although it is still in the commissioning phase, INTEX-NA (July 04) should provide an opportunity to obtain data over polluted continental regions and in outflow regions, as well as cleaner air over the ocean. AVE (Oct. 04) will provide an opportunity to fly south into tropical air with flights down to Costa Rica, as well as north over the U.S. Both July and October are near the seasonal minimum for CO in the northern hemisphere. CO should be lower in the tropics in October than over the U.S. in July, but there may be pollution from biomass burning in Sept/Oct. in the region that could be sampled from Costa Rica. The first opportunity to sample nearer the seasonal maximum may be in Jan. 05, with AVE transit flights; these would give an opportunity to sample profiles with very high concentrations of CO in the boundary layer. The early AVE campaigns are essential for CO validation, as the first major tropical campaign is well over a year after launch

Validation is required when CO is at its lowest, 45-60 ppb, values found in the remote southern hemisphere, 20-90 S, in January-June. Prior data (e.g., PEM-Tropics B) indicate that there is not a large vertical gradient in CO at this time. Such low CO may be encountered on flights out of Darwin, Australia, in January, 2006. Earlier measurements from a Pacific Island or from S. Australia, as were done for MOPITT validation would be useful for validating TES under conditions of low CO. Those flights reached only 7-8 km, but it would be ideal to have some profile measurements throughout the troposphere.

Solar absorption measurements of CO are made at several NDSC sites, and these also present useful validation opportunities for TES.

Summary of what, where, when for CO

Target Parameter	Type of measurement	Where	When	How many	Reqmt satisfied by INTEX and/or TC4?	Other data required
CO	Aircraft *in situ* profiles (priority 1)	N.H. continental outflow	Winter/spring	6-12 profiles over ocean, land	INTEX-East OK but probably too early for Aura	T, H_2O profiles
	Aircraft *in situ* profiles (priority 1)	tropical biomass burning events	Local spring	6-12 profiles over ocean, land	TC4, but July 05 is not optimal	same
	Aircraft *in situ* profiles (priority 2)	Seasonal minimum (NH and SH)	Summer	6-12 profiles over ocean, land	No	same
	Column abundance (coarse profile)	NDSC sites	continuous	Continuous	No	same

7.4.3 Water Vapor

Validation of TES measurements of tropospheric water vapor is important not only because of the importance of these measurements for climate and atmospheric dynamics studies, but because water vapor interferes with retrievals of other standard products such as temperature, ozone and methane. The interference problem is most important for retrievals in the lower troposphere and in the infrared window regions. Water vapor validation by a number of different approaches (ground-based, balloon-based and in situ) will therefore be required, especially in the Aura commissioning phase and to a lesser extent in the core phase.

The ARM program has expended considerable effort in the validation of its own water vapor sensors, which include balloon sondes (Vaisala RS-90) for profile measurements, ground-based microwave radiometers (MWR) for measurements of the vapor and liquid total column abundance and the ground-based Raman lidar for vertical profile measurements. Several intensive intercomparisons of these instruments have been undertaken for this purpose. This work has shown that the Vaisala water vapor sondes exhibit a dry bias up to 5% relative humidity in the lower and middle troposphere, as well as sonde to sonde variability as large as 5%. The sonde profiles can be corrected using the highly accurate (and precise) column measurements from the MWR when concurrent data from these instruments are available. However, MWR instruments are available mainly at the ARM sites. Upper tropospheric water vapor measurements from the sondes cannot be corrected using this method because of the small contribution from this region to the column abundance. Water vapor profiles in the upper troposphere are best obtained using the ground-based Raman lidar systems available at the ARM sites and a few other locations, aircraft Raman lidar and *in situ* measurements, and balloons with research-grade instrumentation.

Summary of what, where, when for H_2O vapor

Target Parameter	Type of measurement	Where	When	How many	Reqmt satisfied by INTEX and/or TC4?	Other data required
H_2O	Balloon sondes	ARM sites (SGP, TWP, NSA/AAO) Gulf of Mexico (Ron Brown)	Continuous	6-12 profiles from each site/year	No	Temperature profile, column water vapor abundance (MWR)
	Aircraft *in situ*	Mid-latitude, sub-tropical	Continuous	6-12 profiles/year	INTEX-East (probably too early for Aura) TC4 satisfactory but probably too few profiles	Temperature profile
	Ground-based Raman Lidar	ARM sites, some NDSC sites	Continuous	6-12 profiles/year	No	Temperature profile

7.4.4 Nitric Acid (HNO_3)

Measurements from aircraft measurement programs such as GTE have provided a preliminary climatology of HNO_3 in certain regions of the free troposphere. Mixing ratios vary widely by region, altitude and season depending on the origin and age of the air mass (stratosphere, urban plume, polluted continental outflow, clean continental/marine) and typically range from 30 pptv in unpolluted air to several ppbv in polluted air masses.

TES measurements of HNO_3 will be obtained primarily from limb measurements except under highly polluted conditions when nadir retrievals will be obtained. Detection limits for HNO_3 from a single orbit in limb mode will be 100 pptv or less in the free troposphere. The sensitivity in the boundary layer will be considerably lower. Aircraft instrumentation for HNO_3 measurements that are compatible with these detection limits include mist chambers, filter packs and chemical ionization mass spectrometers (CIMS). These instruments have already been deployed and intercompared to a limited extent. Further intercomparisons would be highly desirable prior to deployment on validation campaigns such as AVE. Measurements from remote sensing balloons (solar occultation, thermal emission) will be helpful in extending the measurement range into the middle stratosphere (35 km and below).

Summary of what, where, when for HNO_3

Target Parameter	Type of measurement	Where	When	How many	Reqmt satisfied by INTEX and/or TC4?	Other data required
HNO_3	Aircraft *in situ*	Mid-latitude, sub-tropical	Core validation phase continuing through end of mission	6-12 profiles/year	INTEX-East (probably too early for Aura) TC4 and INTEX-W satisfactory but probably too few profiles	Temperature profile
	Balloon remote sensing	Mid-latitude	Core validation	Minimum of 4 profiles	No	Temperature profile, NO, NO_2, H_2O vapor
	Ground-based FTIR	NDSC sites	Continuous	Frequent (weekly)	No	Temperature profile