Minutes of the
10th Atmospheric Composition Constellation Workshop (ACC-10)
College Park, Maryland, USA
4-5 June 2014

1.0 Executive Summary

The Committee on Earth Observation Satellites (CEOS) ACC-10 was held at NOAA Center for Weather and Climate Prediction (NCWCP) in College Park, Maryland, on 4-5 June 2014. The Atmospheric Composition Constellation (ACC) is one of the seven virtual constellations that support the overall goals of the Group on Earth Observations (GEO) and provide prototype systems supporting the implementation of the Global Earth Observing System of Systems (GEOSS). The ACC's key objectives are to collect and deliver data to improve predictive capabilities for coupled changes in the ozone layer, air quality, and climate forecasting and to meet participating agency priorities that are aligned to the GEO societal benefit areas (e.g., health, climate, energy, ecosystems). ACC works to facilitate international collaboration among space agencies and establish a framework for long term coordination of CEOS's goals.

Researchers from participating CEOS agencies, related universities, and supporting organizations participated in person or by WebEx. These agencies included ADNET, Belgian Institute for Space Aeronomy, CNRS, DLR, ESA, EUMETSAT, Harvard University, JAXA, KNMI, LATMOS, NASA, NOAA, SSAI, University of Maryland, and USRA. We are grateful to Larry Flynn from NOAA for hosting the meeting at the NCWCP and to Eric Beach for providing WebEx remote access participation and handling many other logistical issues.

The Workshop addressed five principal topics: (1) the Limb Sounding Mission Gap, (2) ACC Air Quality Constellation, (3) Greenhouse Gas (GHG) ECV generation, (4) Volcanic Ash Monitoring From Space, and (5) Long-Term Total Ozone Data Set Harmonization. The workshop Agenda and participant list are attached to these minutes. The presentations can be found at http://www.ceos.org/acc.

2.0 Workshop Highlights and Recommendations

1. Limb Sounding Mission Gap

    a. Participants in the CEOS ACC-10 meeting recognize the significance of the looming gap in limb sounding data. Following the demise of the currently operating but aging instruments:

    - MLS on Aura (microwave emission),
    - SMR (microwave emission) on Odin,
    - OSIRIS (limb scatter UV-Vis-NIR) on Odin,
    - ACE-FTS (solar occultation IR) on SCISAT, and
    - ACE-MAESTRO (solar occultation UV-Vis-NIR) on SCISAT,

the only limb sounding instruments will be:

- OMPS Limb Profiler on Suomi-NPP (limb scatter UV-Vis-NIR),
- SAGE-III/ISS (solar occultation & limb scatter UV-Vis-NIR, planned for 2016),
- OMPS Limb Profiler on JPSS-2 (limb scatter UV-Vis-NIR, planned for ~2021).

Participants support efforts to raise awareness of this issue in the hope of influencing space agencies to prioritize planning for future limb sounding missions.

In particular, participants:

- Endorse and wish to contribute to the initiative taken by members of the SPARC community to draft a paper for publication, highlighting the science that will no longer be possible without limb sounding data, and the need for continued measurements from limb sounding satellites. This could also address potential future applications such as constraining estimates of stratospheric NO_2 when deriving air quality information from LEO and GEO nadir observations;

- Encourage, and possibly co-organize with SPARC, a community workshop on limb sounding continuity, possibly in conjunction with CEOS member agencies, the CEOS/CGMS Working Group on Climate, and WMO-Global Atmosphere Watch;

- Encourage the WMO-GAW task team, which will update the Integrated Global Atmospheric Chemistry Observations (IGACO) report of 2004, to interact with the SPARC paper authors in regards to limb sounding observations.

2. Total Ozone Measurement Coordination

   a. Results of recent total ozone intercomparison and validation activities were discussed. Intensive activities supported by both the ESA Ozone_cci and NASA/NOAA have enabled advances in error quantification and comparisons between multiple data sets and ground based data. Very good agreement between long term SBUV and the latest Ozone_cci total ozone data set have been found.
   b. The integration of infrared sensor data, e.g., IASI and AIRS, was discussed. Key benefits include the ability to expand measurement coverage to polar regions and fill in other missing data obtained from the UV sensors. Projects in the USA (SBUV/AIRS) and Europe (GOME/IASI) are being planned to produce such data sets.
   c. Proposals to produce a combined monthly zonal mean total ozone set and a combined gridded product were discussed, recognizing the science needs for these products. It was agreed to produce combined monthly mean data sets with a grid of 5x5 degrees (excluding data assimilation techniques).
   d. It was agreed to extend the ongoing total ozone intercomparison/combination activities to nadir profiling (to be discussed in detail at the next ACC meeting).

3. Volcanic Ash Monitoring From Space

    a. Detailed discussions of monitoring volcanic ash from space-based observations were presented. Activities in both the US and in Europe were discussed. Emerging services, such as the ESA-sponsored Support to Aviation Control Service (SACS) project continue to produce accurate notifications of detection to end-users and other stakeholders, particularly in the aviation sector.
    b. The inclusion of measurements from new sensors (e.g., OMPS and CrIS on Suomi-NPP) was welcomed.
    c. Laboratory studies of ash aerosol properties continue to improve our understanding of volcanic ash.

4. Air Quality Constellation Coordination

    a. Progress continues with implementing the recommendations enumerated in the ACC-produced position paper, *A Geostationary Satellite Constellation for Observing Global Air Quality: An International Path Forward*, released in 2011 and endorsed by the CEOS Strategic Implementation Team meeting, SIT-26.
    b. Summaries of the key missions - Europe Sentinel 4, Korea GEMS, NASA TEMPO, and Europe Sentinel 5P (LEO orbit) - were presented.
    c. The next near-term Constellation activity planned is harmonization to improve data product quality and usage. During 2013, the CEOS ACC AQ Constellation leads developed recommendations for harmonization to mutually improve data quality and facilitate widespread use of the data products. This included an Open Data Policy and common cal/val standards. The sharing of instrument requirements is taking place, which is influencing instrument specifications and which should ultimately improve harmonization of data products. Discussions on sharing L1B and L2 format specifications to easily exchange data are underway.

5. GHG ECV Generation

    a. Presentations were made that described GHG missions in formulation, development, and operation (e.g., OCO-2, GOSAT and GOSAT-2, Merlin, TanSat, IRS, and IASI-NG) were made.
    b. The recently released CEOS Carbon Task Force report, *CEOS Strategy for Carbon Observations from Space*, was summarized and there was discussion on the recommended actions relevant to ACC. It was agreed that a single “constellation” activity for forthcoming LEO and GEO constellations of GHG-measuring missions would be created and coordinated by ACC, mirroring the successful Air Quality constellation activities.
    c. It was agreed to provide a first implementation plan (list of short- and long-term actions) of the ACC-GHG Constellation activities at an upcoming CEOS SIT meeting.

6. Next Meeting

a. It was agreed by meeting attendees that the next ACC meeting should take place during the spring of 2015 at ESA/ESRIN in Frascati, Italy. A primary focus of this meeting will be to assess progress with coordination of the forthcoming Air Quality constellation.

3.0 Summary of Meeting Topics and Discussions

3.1 Introduction

Following a welcome address by local host, Larry Flynn (NOAA), Claus Zehner (ACC Co-Lead, ESA) discussed the scope of the meeting. The goals of the present meeting were:

- Address/highlight the looming limb/occultation mission gap, noting the ACC gap analysis produced during ACC-3 in Nov. 2008
- Briefly review the AQ Constellation Activities, with the intention of a more complete discussion at next year's meeting
- Follow up on the CEOS Task Force recommendations relating to ACC actions to establishing a Greenhouse Gas Constellation
- Review of ACC-coordinated volcanic ash activities
- On the second day, conduct a full-day workshop on combining USA and European long term total ozone data sets and assessing progress since last year's ACC-9 meeting.

3.2 Limb Sounding Mission Gap – Possible ACC Actions

3.2.1 Discussion on the Limb Sounding Mission Gap (Thomas Piekutowski, CSA)

Thomas noted that the upcoming gap in missions, following the "golden age" of limb sounding, has been pointed out repeatedly in recent years in such fora as:

- ACC Gap Analysis Report
- Ozone Research Managers Reports
- Limb Workshops
- Atmospheric Science Conferences
- National Science Workshops

This gap is also documented in multiple publications, including the GCOS Satellite Supplement and the CEOS Response to the GCOS Implementation Plan. It was also noted that a SPARC subgroup has started drafting a paper about what will no longer be possible without future limb sounding missions.

Thomas asked whether there is perhaps a perception problem. Is limb sounding seen as "research" rather than an "operational application". Perhaps the interest in limb sounding was a fad related to ozone loss and that there is now less interest in the era of ozone recovery.

Discussion among the group focused on efforts to increase the awareness of this issue in the community and with national satellite agencies. Proposals included the desire for meteorological satellite operators and NWP centers to encourage agencies to invest in limb sounding. International bodies such as WMO and WCRP could raise the issues with agencies. Interaction with SPARC and its white paper efforts was also encouraged.

A statement on this issue was agreed to by meeting participants and is presented in the Workshop Highlights and Recommendations section earlier in this document.

3.3 The ACC Air Quality Constellation

3.3.1 Status of ACC Air Quality Constellation Activities (Jay Al-Saadi, NASA)

Jay noted that the geostationary orbit provides "continuous" observations (many times per day) but that a single geostationary satellite can view only a portion of the globe. Several countries and space agencies are planning to launch geostationary satellites in the 2018-2019 timeframe to obtain air quality measurements. These missions share common objectives yet individually are restricted to regional relevance. Harmonization through a constellation framework will provide a global perspective otherwise impossible to achieve. Such an integrated global observing system for atmospheric composition is key to abatement strategies for air quality as laid down in various international protocols and conventions (IGACO, GEO, WMO GAW).

Summaries of the key missions - Europe Sentinel 4, Korea GEMS, NASA TEMPO, and Europe Sentinel 5P (LEO orbit) - were presented. The earlier launch date for Sentinel 5P would be in early 2016. GEMS is under development with a December 2018 launch date. Its Preliminary Design Review (PDR) took place in March 2014.TEMPO is currently in phase B with a launch date to occur no earlier than November 2018. Sentinel 4 is working towards a 2021 flight acceptance review. Its PDR has been completed.

The next Constellation activity planned is harmonization to improve data product quality and usage. During 2013, the CEOS ACC AQ Constellation leads developed recommendations for harmonization to mutually improve data quality and facilitate widespread use of the data products. This included an Open Data Policy and common cal/val standards. The sharing of instrument requirements is taking place, which is influencing instrument specifications and which should ultimately improve harmonization of data products. Discussions on sharing L1B and L2 format specifications to easily exchange data are underway.

Topics to be addressed at next year's meeting will include some of the next steps envisaged in the Geostationary Air Quality Position Paper (http://ceos.org/images/ACC/AC_Geo_Position_Paper_v4.pdf), which include algorithm and processor development, vicarious inter-calibration, and common validation activities.

3.4 Greenhouse Gas Constellation Activities

3.4.1 CEOS Carbon Task Force Report – Atmospheres Chapter (David Crisp, NASA JPL)

The GEO Carbon Strategy states: “a key reason for our lack of understanding of the global carbon cycle is the dearth of global observations,” and calls for “an increased, improved and coordinated observing system for observing the carbon cycle as a prerequisite to gaining that understanding.”

The Committee on Earth Observation Satellites (CEOS) is well positioned to meet this challenge and provide needed coordination for the space-based observations called for in the GEO Carbon Strategy.

CEOS established a Carbon Task Force (CTF) to coordinate the response from the space agencies to the GEO Carbon Strategy. Its goals were to take into account information requirements of both the UNFCCC and IPCC and consider how future satellite missions will support them, to also take account of, and be consistent with, the GCOS and GEO Implementation Plans, and to help define the next generation missions for individual agencies (provide a long-term outlook, 2013-2028). It will provide a basis for systematic observation and reporting of progress towards satisfying society’s carbon information needs

Space-based measurements of CO_2, CH_4, and other greenhouse gases will complement those from the ground based network with dramatically improved resolution and coverage. However, these measurements must have unprecedented accuracy (0.25%) to resolve the small variations in these gases associated with their sources and sinks. The world’s spacefaring nations are now implementing a range of innovative systems to address this increasingly urgent need.

David described a number of next-generation missions to remotely sense CO2, many of which are described in the following presentations. He noted that space-based remote sensing observations hold substantial promise for future long-term monitoring of greenhouse gases. These measurements will complement existing ground-based data with increased spatial coverage and sampling density. Over the next decade, a succession of missions with a range of CO_2 and CH_4 measurement capabilities will be deployed in LEO. Because there is little overlap between the missions, each one is a critical link in a chain that must be successfully deployed to ensure a continuous climate data record. Measurements from Geosynchronous orbit (GEO) would also be valuable for studying the diurnal cycles of CO_2 and CH_4. At present, there are no plans to collect precise CO_2 measurements from GEO. Much greater benefits could be realized if these missions could be coordinated (e.g., including collaborative calibration/validation activities) and their data products can be combined.

3.4.2 Plans for the IRS and Advanced IASI Missions (Rose Munro, EUMETSAT)

Rose discussed plans for the EUMETSAT Polar System – Second Generation (EPS-SG) Infrared Atmospheric Sounding (IAS) and for the Meteosat Third Generation (MTG) MTG-S1 and S2

Infrared Sounder (IRS) missions.

The IASI Next Generation instrument for EPS-SG (IASI-NG) will be jointly provided by CNES and EUMETSAT. IASI-NG will be an interferometer-type instrument with a performance improved by a factor of 4 with respect to the previous generation and will cover the spectral range 645 cm-1 (15.5 µm) and 2760 cm-1 (3.6 µm), with 4 different spectral bands/detectors, and a spectral resolution of 0.25 cm-1 sampled at 0.125 cm^{-1}. It will include a new optical concept, based on a Mertz interferometer (with self-apodization compensation) and an internal imager will allow for the very accurate co-registration with Metimage. There will be onboard spectral and radiometric calibration sources.

For MTG-S1 and S2, the IRS products will be vertical temperature and humidity profiles (L2) over the Earth disc, with 30 minutes refresh rate over Europe. They will be obtained by processing spectral (L1) data. They are obtained by processing spectral (L1) data and is designed and will be built by Kayser-Threde (Munich).

3.4.3 The NASA Orbiting Carbon Observatory – 2 (OCO-2) Mission Status (David Crisp, NASA JPL)

David noted the importance of GOSAT, the pioneer platform that monitors CO_2 from space. As a result of the failure of OCO, its science team has devoted considerable time to processing and understanding GOSAT measurements and planning for OCO-2 calibration and validation activities.

OCO-2 has three imaging grating spectrometers record reflected sunlight at high spectral resolution, with a high signal-to-noise ratio and will collect 24 soundings per second while over the sunlit hemisphere (1 million soundings per day). The spacecraft launched on 2 July 2014, a few weeks following the ACC-10 meeting, and has been inserted into the A-train.

A launch ready version of the OCO-2 retrieval algorithm has been delivered and has been tested using GOSAT data. The ACOS/GOSAT collaboration provided valuable insight and a critical validation of the OCO-2 algorithm. It is anticipated that the project could start delivering Level 1B products as early as late November 2014 and Level 2 products as early as February 2015.

3.4.4 GOSAT Results and Status of the GOSAT-2 Mission (Shuji Kawakami, JAXA)

The GOSAT satellite, launched in 2009, is equipped with the Thermal And Near-infrared Sensor for carbon Observation (TANSO). TANSO is composed of two subunits: the Fourier Transform Spectrometer (FTS) and the Cloud and Aerosol Imager (CAI). Shuji described GOSAT calibration and validation activities as well as FTS products release history.

GOSAT has demonstrated the ability of CO_2 and CH_4 observation from space with more than 5-years of global observations of XCO_2 and XCH_4. The precision of the XCO_2 retrieval is ~ 2ppm. There has been significant uncertainty reduction in global CO_2 flux estimation. Among it new findings and challenges are sun-induced chlorophyll fluorescence from highly-resolved O2A spectra, large point source detection, the challenge of missing observations in high latitudes (limited by pointing mechanism availability) and less observations in cloudy tropical forests (South-Asia, Amazon, etc.).

Through the results of the GOSAT, observation performance improvements are now better defined for use in the response to global warming. In October 2013, the manufacturer of GOSAT-2 was selected and GOSAT-2 system was defined in December 2013.In April 2014, GOSAT-2 was shifted to phase B and the launch date will be in early 2018.Around end of this decade, GHG observing satellites will work on orbit, and Shuji noted that it will be necessary to establish a platform to collaborate and provide reliable data for policy makers and other uses.

3.4.5 The Merlin Mission Status (Diego Loyola, DLR)

The MEthane Remote sensing LIdar missioN (Merlin) mission seeks a better understanding of the global methane cycle and the nature of the processes which govern the exchange of methane between biosphere and atmosphere.

Its primary objective is highly accurate space-borne measurements of the spatial and temporal variability of atmospheric CH_4 for determination of CH_4 fluxes (emissions) on the Earth surface A secondary (tentative) priority is to measure surface properties & vegetation and contribute to a cloud/aerosol data base.

For XCH_4, an Integrated-Path Differential Absorption (IPDA) Lidar in the near IR using pulsed laser transmitter and rang-gated receiver in nadir-viewing mode will be employed. For fluxes, inverse models will convert XCH_4 into CH_4 fluxes (emissions) & errors.

Development status is currently in Phase B. SRR was successfully passed in Nov. 2013. A Satellite PDR is planned for June 2015 with launch planned by end of 2019 in Kourou.

3.4.6 TanSat Mission Status (Yi Liu, CSA; presented by David Crisp)

A Chinese Carbon Dioxide Satellite (TanSat) is under development. Measurement goals for Term-1(2011-2015) include XCO_2 at 1~4 ppmv monthly at 500 x 500 km^2. For Term-2 (2013-2015), CO2 flux will relative flux error of 20% monthly at 500 x 500 km^2. Details of the carbon dioxide spectrometer were described, as well as plans for calibration and validation.

Retrieval algorithm is progressing with application of the TanSat XCO_2 retrieval algorithm to GOSAT observations (ATANGO). A special issue with papers on TanSat topics appeared this year in the *Chinese Science Bulletin* 59(14).

Three prototype spectrometers have been developed (760, 1610, 2060 nm). A large-area diffraction grating has been manufactured, but there are challenges in improving diffraction efficiency and the wave front. A prototype model and electrical interface test has been finished.

Cloud and Aerosol Polarization Imager (CAPI) is on the schedule. Launch is currently planned for June 2016.

3.4.7 Results of the ESA Workshop on Future Challenges for GHG Satellite Missions (May 8/ESTEC) (Claus Zehner, ESA)

Claus described the recent ESA workshop on Future GHG Mission Challenges. Discussions at the workshop noted that satellites cannot directly measure fluxes (noting that a combination with ground-based data is necessary). TCCON measurements are traceable and of high accuracy, and are highly sensitive to surface fluxes but are limited in coverage. Flux Towers have high spatial resolution but uneven sampling, which misses many disturbances (e.g., fires). Satellite GHGs will have a huge number of data points, but limitations on sensitivity to transport and retrieval error. It was agreed that an integrated system, which includes ground-based in situ (e.g. TCCON) networks providing global trends and calibration, complemented by satellites on coverage is needed. Aircraft measurements could provide a link between the surface and satellite data.

It was further noted that emission inventories verification from space would be politically relevant. Simple maps of CO_2 hot spots could have high political impact (but, high spatial resolution is critical). Emission reduction strategies are often planned on city scale level (70% of CO_2 emission are coming from urban areas) so there is a need for high spatial resolution satellite data. Combining GHG data with other atmospheric data (e.g. fluorescence, CO, NO_2, water vapor (moisture), and temperature will be essential to better understand processes. There is a need for improved transport models. Currently, there are model limitations for the full exploitation of a mission like CarbonSat.

Discussion focused also on a common vision to further evolve atmospheric GHG measurements from space. An ACC GHG Constellation could leverage existing activities and ongoing co-operations (e.g. IWGGMS, NASA/JAXA co-operation, GHG_cci project) with various planning and coordination activities in both the short- (~3year) and long-term (~10 year). With respect to TanSat, a question to be addressed is the optimal equator overpassing time that would best fit into such a constellation of coordinated measurements.

3.5 Volcanic Ash Monitoring From Space

3.5.1 Development of a Space-based System for Quantitative Detection and Analysis of Volcanic Clouds (Mike Pavolonis, NOAA)

Mike noted that heritage NOAA volcanic ash products are imagery based and qualitative. In preparation for GOES-R, the volcanic ash requirements were re-defined and are now quantitative (ash cloud height and mass loading).

End products include ash probability, ash top height, mass loading, effective particle radius, volcanic cloud alerts, cloud vertical growth rate anomalies, volcanic thermal anomalies.

There are multiple techniques: probabilistic cloud object based ash detection, optimal estimation retrieval of ash cloud properties (ash height, mass loading, and effective radius), multi-sensor cloud tracking to improve ash detection and cloud property retrieval.

Ash detection does not rely on robust “split-window” signature and is designed to emulate a skilled human analyst (good probability of detection, very low false alarm rate) Value added applications include plume medial axis transformation and polygon fitting.

Mike described a number of case studies that included (1) ash dominated volcanic plumes, (2) ice topped umbrella clouds, and (3) SO_2 clouds and described the challenges in their detection.

Among the key limitations noted were that volcanic ash must be the highest cloud layer; the products will be degraded if L1 sensor data is degraded; the ash cloud properties, and to a lesser extent, the ash detection results, will be more accurate if determined from a more advanced sensor (methods are being explored to address this issue); the selection criteria applied to cloud objects generally works well, but is still being refined; and low-level ash plumes that have a very similar temperature as the surface or warmer than the surface will often be missed by our ash detection algorithm at the present time.

Future plans include a transition of NOAA volcanic cloud system to NESDIS operations, a an alerting service from the “experimental” system at the UW will be made available to VAACs this summer and additional users at a later time (SCOPE-Nowcasting, CEOS DRM activities, and Satellite Proving Ground activities), participation in the SCOPE-Nowcasting inter-comparison activity, several ongoing collaborations with modeling groups, and a new GOES-R project with USGS to integrate additional satellite and non-satellite data sources (hyperspectral IR, lightning, infrasound, seismic, etc…).

3.5.2 NASA’s Near Realtime Volcanic Products from the Polar Orbiting Aura/OMI (Nick Krotkov, NASA)

Nick described a NASA Applied Sciences Program funded activity that is producing near real-time volcanic SO_2 and ash data and their integration in aviation decision support systems, e.g., Volcanic Ash Advisory Centers (VAACs), AVOs, airlines, Air Navigation services.

The key tasks are a transition from research Aura/OMI NRT SO_2 and ash data to the operational NASA-NOAA Suomi-NPP OMPS data, demonstrating improved volcanic SO_2 and ash forecasts with NASA GEOS-5 model and assimilation system, and demonstrating processing Direct Readout SO_2 and ash data in Alaska and Finland. It was noted that the Ozone Monitoring Instrument (OMI) launched in 2004 continues 30+ year climatic records of ozone and volcanic SO_2 by TOMS.

Unique discrimination of volcanic clouds is possible only with UV or Thermal IR measurements. One solution is using UV (OMI – Aerosol Index) or TIR (Aqua/AIRS) direct ash measurements (typically for 1 -2 days, however, false alarms are possible, e. g. from dust clouds). An alternative is using measurements of volcanic SO_2 gas as unique marker of dispersed volcanic clouds away from their sources. This is the most sensitive method for SO_2 reach clouds from magmatic eruptions.

Fast data delivery is key for volcanic disasters application. This is complicated in Arctic polar regions since drifting ash clouds may be missed by GEO satellites. However, Direct Readout (DR) of OMI SO_2 and AI data over North Atlantic and Europe by the Finnish Meteorological Institute (FMI) are processed within 15 minutes after the NASA Aura satellite overpass at Sodankylä ground station (http://omivfd.fmi.fi/volcanic.html).

The NASA EOS-Aura and S-NPP satellites have Direct Broadcast (DB) capability, i.e. the ability to broadcast data at the same time as it is measured. This possibility is utilized in the OMI Very Fast Delivery (VFD) Service (http://omivfd.fmi.fi) for monitoring atmospheric composition and UV-radiation in almost real time, within 20 minutes after the overpass. The service started in 2006 with UV and ozone. After the eruption of the Eyjafjallajökul the system was updated in 2010-11 with volcanic products (ash and SO_2). The OMI VFD covers presently Northern Europe and Arctic Ocean, but the coverage is restricted by the fact that the satellite has to be visible from the Sodankylä ground station in northern Finland.

3.5.3 The SACS Project (Michel van Roozendael, BIRA/IASB)

Michel described the Support to Aviation Control Service (SACS) project (http://sacs.aeronomie.be). SACS is an ESA project hosted by BIRA/IASB. The objective of SACS is (with respect to volcanic SO2 and ash) to (1) deliver in near-real time space observations, (2) provide near-real time notifications (email and web-based), and (3) to provide access to archived data. These products are useful for operational and research applications. At present, there are 215 subscribed users, including VAACs, observatories, academia, airlines, and pilots.

Multiple observations are used, including AIRS, GOME, GOME-2, OMI, and IASI. Michel provided a case study of the May 2011 Grímsvötn eruption. For the SO_2 based warning system, one e-mail is sent per 12 hours and per 30°x30° predefined region (first instrument to detect SO_2). The system is optimized to avoid false notifications (e.g., anthropogenic SO_2) with a success rate >95%. After a notification, all other warnings (confirmation during the next 12h) are available through the webpage.

A new notification system selective for the detection of ash using IASI-A, IASI-B and AIRS has been operational since October 2013. Extensive tests on historical data have been performed with no major eruptions missed. False notifications are at ~1% and misses (small puffs) <1% (but with a compromise on sensitivity).

Future improvements of SACS envisaged include (1) continuous development of the warning system, (2) improvement of the ash monitoring capability of SACS, (3) inclusion of new sensors, e.g. OMPS and CrIS onboard Suomi-NPP, and (4) near realtime retrievals of SO_2 plume height.

3.5.4 Optical, Microphysical and Compositional Properties of the Eyjafjallajökull Volcanic Ash (Adriana Rocha Lima, University of Maryland)

Adriana described her research which seeks to understand the physical mechanisms of absorption and scattering of light by different types of aerosol particles, noting that aerosol optical properties are important for both remote sensing retrievals and for atmospheric and climate models.

The approach was to measure aerosol properties in the lab, including size (r) and shape (sphere, spheroid, …) and the mass absorption efficiency (a) and retrieving the complex refractive index m = n + ik and this was done successfully for different types of aerosols.

Key conclusions were:

1. Compared to other volcanic ashes, her imaginary refractive index in UV has the same order of magnitude of previous laboratory measurements for Mount Spurr volcano (Krotkov et al., 1999).
2. However, her results have smaller imaginary refractive index than Mount St. Helens and Fuego ashes measured in the 80's (Patterson et al., 1981, 1983).
3. Differences in optical properties and in the composition were found between fine and coarse fraction of the Eyjafjallajökull volcanic ash.
4. Assuming spherical or spheroid particle shapes in calculations of the mass absorption efficiency both yield similar imaginary refractive indices for fine particles.

3.6 Long-Term Total Ozone Column (TOC) Data Sets

3.6.1 Introduction to GSICS with Emphasis on the Research Working Group UV Subgroup (Larry Flynn, NOAA)

The Global Space-based Inter-Calibration System (GSICS) mission is to assure high-quality, inter-calibrated measurements from the international constellation of operational satellites to support the GEOSS goal of increasing the accuracy and interoperability of environmental products and applications for societal benefit. http://gsics.wmo.int/.

GSICS Methods for IR/Vis/MW include (1) Simultaneous Nadir Overpass (https://gsics.nesdis.noaa.gov/wiki/GPRC/LeoLeo), (2) Double Differences (Transfer Standards) using RT Forward Models with forecasts as inputs and LEO under-flights of GEO, and (3) Targets (and distributional analysis) including deserts, ice, Moon, and deep convective clouds.

Larry described the Solar UV Measurement Project which includes a high resolution solar reference spectra (from various sources including Solstice, SIM, Kitt Peak) and instrument data bases. Using these information sources enables the comparison of spectra from different instruments and times.

Future prospects and challenges include: L1 measurements from DSCOVR (early 2016); GEO measurements from TEMPO (NASA, 2018), GEMS (KARI, 2018), and Sentinel 4 (ESA, 2019), integration of limb instruments, e.g., SAGE III/ISS (NASA, 2016). Also, how can we use the 4 billion year-old lunar diffuser?

3.6.2 Generation of a Combined (European/US) Long-Term Total Ozone Record – Introduction (P.K. Bhartia, NASA)

P.K. noted the heritage of the various US backscatter UV profiling instruments from 1970 through the present. Strengths of this record include that appears to be of high quality, despite problems with some instruments; total O_3 values are available up to 88˚ SZA; integrating kernels and algorithm error bars for monthly zonal means are provided, and that the algorithm, instrument, and validation documents have been published.

But, there are limitations which include that only nadir data are available so that less than 10% of the sunlit globe covered every day; no measurements poleward of 81˚; no data in polar night; and that local time variation reduces latitudinal coverage for some instruments.

A description of the TOMS record was also made. Strengths include full coverage of the sunlit globe every day, including the poles and that V9 provides data up to 88˚ SZA and also integrating kernels and algorithm error bars. But, data quality is not as good as SBUV, particularly for Meteor-3 and EP TOMS and there is no data in polar night.

With respect to a combined monthly zonal mean record, P.K. does not recommend adjustment of SBUV record to Dobson since the ground-based data have played an important, though indirect, role in creating the SBUV record, further adjustment will make the data worse. And, further, data quality issues mainly occur at SZA>80˚ where ground-based data are not reliable. He noted that the TOMS O_3 record is less reliable than SBUV, so there are plans to adjust it to SBUV.

Agreement between SBUV and GODFIT is very good, but further evaluation is needed at larger SZAs.

With respect to a combined gridded product, SBUV can be interpolated to create 5˚x5˚gridded monthly product with reasonable accuracy. The interpolated SBUV data can be combined with mapping instruments when such data are available. IR data can be used to fill gaps in polar night.

3.6.3 Comparison of Profile Total Ozone from SBUV (v8.6) with GOME-type and Ground-Based Total Ozone For a 16-year Period (Er-Woon Chiou, NASA)

Er-Woon used OMI, GOME, TOMs (v9), and SBUV (v8.6) data in his analysis. Monthly zonal means were extracted based on 5-deg latitudinal zones and the overall characteristics of the biases were examined using the three broad latitudinal bands: (60S-30S), (30S-30N), and (30N-60N). Comparing OMTO3 vs SBUV (v8.6) and GTO vs SBUV(v8.6) for the 3 broad latitudinal bands, the biases were as follows:

- OMI-SBUV range between -1.01% and -1.53%
- GTO-SBUV range between 0.22% and 0.58%.

while the standard deviations were

- OMI-SBUV range between 0.25% and 0.37%
- GTO-SBUV range between 0.51% and 0.68%.

In the 5-degree high latitudinal zones, GTO-SBUV biases become negative. The standard deviations become larger, particularly in the northern hemisphere (60N-65N) (increase by about a factor of 2). The negative biases for OMI-SBUV could be attributed to differences in ozone cross sections. There are no significant trends in the biases.

Comparing TOMS (v9) vs SBUV (v8.6) for the 3 broad latitudinal bands, the biases were between 1.75% and 1.95% and the standard deviations range between 0.29% and 0.63%

In the 5-degree high latitudinal zones, the standard deviations become larger (increase by about a factor of 2 in both 65S-60S and 60N-65N). And, there are no significant trends in the biases.

In summary, despite the differences in the satellite sensors and retrieval methods, GTO, OMTO3 and SBUV (v8.6) multi-year total ozone data records show very good agreement in the variability of monthly zonal means (with no significant trends in the biases).The agreement among the data records in higher latitudes is not as good, probably due to the effect of high solar zenith angle and other complicated situations.

3.6.4 Validation Results of Total Ozone Data (Arno Keppens, BIRA/IASB)

Arno described the total ozone validation activities at BIRA/IASB being performed under the ESA Ozone_cci activity. The level 2 and level 3 total ozone validation results are described fully in the presentation.

Arno also discussed the profile ozone validation round-robin. Rationale for the activity include the ACC harmonization of total ozone with agreement on validation protocol, community practices for limb/occultation ozone profile validation, and as a future step, the harmonization of nadir ozone profiles with common protocol for nadir ozone profile validation.

In summary, there is a need for common protocol with more complete approach to validation. The protocol must include guidelines on nadir profile data and associated diagnostics. Further, the protocol must include guidelines on the validation process (filtering, unit conversion, regridding, etc.). Full details may be found in the presentation.

3.6.5 Total Ozone Grid Data – Sampling Errors and Comparison of GTO-ECV 1.0 with SBUV-MOD 8.6 (Diego Loyola, DLR)

The GTO-ECV V1.0 has been generated in the framework of the ESA CCI project, gridding L3 monthly mean total ozone data with a 1x1° resolution and including the standard deviation and estimated error. GTO-ECV sampling errors were characterized using an Observing System Simulation Experiment (OSSE). Full details are available in the presentation.

For ESA CCI Phase II, Geo-statistical algorithms for optimal spatial-temporal interpolation based only on the satellite data will be developed for GOME, SCIAMACHY, and GOME-2. The CCI interpolation algorithms will be tested with SBUV in collaboration with the NASA team.

3.6.6 New Ozone results for IASI (Cathy Clerbaux, LATMOS/ULB)

Cathy described new ozone results from IASI, focusing on tropospheric chemistry, intercontinental transport, and air quality and the chemistry-climate ozone hole with detailed results available in her presentation.

Six years of data (total columns and profiles) now available, with good sensitivity in the middle troposphere, but low sensitivity towards the surface. There is a known bias in the UTLS. These measurements were operationally retrieved at LATMOS/ULB, are to be transferred at the EUMETSAT CAF (O3MSAF-CDOP2) whenever possible. These measurements are now included in CCI-O3 (phase 2). Long-term continuity (~20 years) is foreseen with IASI/MetOpC and IASI-NG (or advanced IASI) on EPS-SG.

3.6.7 Intercomparison of KNMI/NASA OMI Total Ozone Columns (Pepijn Veefkind, KNMI)

Pepijn described the CAMA toolkit used to facilitate this intercomparison activity. Key features of this tool (which is available to other researchers) are its ability to compare, correlate, and plot a large number of OMI L2 observations; correlate with any other field in the files and apply simple operations, make comparisons pixel-by-pixel, filter data for each field, and its ability to automatically produce PDF reports with large number of visualizations.

He concluded that to improve on current algorithms requires going into details using a pixel-by-pixel analysis. The CAMA tool can be used for automatically generated reports, but data should be in OMI-like format.

3.6.8 Stability of the OMI Instrument/Ozone Data (Pepijn Veefkind, KNMI)

Pepijn described the OMI instrument in detail, its CCD detectors, and the row anomaly issues. Multiple errors are caused by the row anomaly in L1B data: a multiplicative error, a wavelength shift, stray earthlight related additive error and a stray sunlight related additive error. Details of the stability analysis are available in the presentation.

He concluded that OMI is a very stable instrument, with degradation almost linear. The row anomaly affected data is flagged in the L1B product.

3.6.9 OMI Total Ozone Columns Intercomparison of Current Products (C. Lerot and M. Van Roozendael, BIRA-IASB)

There is a long history of total ozone measurements from US and EU sensors based on different algorithms/approaches. Within ACC, there's been an effort to improve the link between US and EU total ozone activities. Intercomparison of zonal mean total ozone from SBUV-type and GOME-type sensors shows an excellent agreement within 1% at low and mid-latitudes (Chiou et al., 2014; see his earlier presentation). But, there is a need for a more thorough analysis to better understand remaining differences. OMI/Aura is the ideal sensor to conduct such an analysis since all types of algorithms may be applied to its spectra. A pixel-per-pixel comparison is possible.

The OMI total ozone intercomparison was described in detail. Four different algorithms were employed (see presentation for details), using 12 days in 2006, one per month. Only common pixels are intercompared. For GODFIT-SAO comparisons, the spatial resolution of GODFIT is degraded to the SAO resolution (8 GODFIT pixels averaged for one SAO pixel).

Overall, the consistency is reasonable with mean differences less than 2% at low and mid-latitudes. There is excellent agreement between TOMSv8 and GODFIT. Good agreement is seen between SAO and GODFIT, but with a bias of about 2%. A row dependence visible in the three maps, which needs to be investigated. There are larger DOAS-GODFIT differences at high Southern latitudes.

Overall, all four products agree quite well. With respect to GODFIT, a +1% bias is visible in the OMI-TOMSv8 and OMI-DOAS product. The SAO columns are about 2% larger than GODFIT. This bias might originate from the row dependence, from differences in cross-section and also from the soft-calibration procedure applied in the SAO algorithm. The standard deviation of the differences is the smallest for SAO-GODFIT. These two algorithms are conceptually closer.

The quality flag of TOMSv8 should be used to filter out high SZA pixels, as there are meaningless O3 columns retrieved from those. Is this improved with TOMS v9? All products are characterized by a significant row dependence. Only the SAO product has limited this dependence with a soft calibration procedure of the radiances. OMI-DOAS appears to provide ozone columns too large in ozone hole conditions and also when the scene is contaminated by high clouds. Other small dependences are visible in this OMI product intercomparison (e.g. with resepec to effective temperature, cloud top pressure). It is however difficult to draw conclusions on a 'best' reference without any independent reference. Finally, the importance of validation with correlative ground data was noted.

3.6.10 Estimating Sampling Errors in SBUV Gridded Total Ozone (Stacey Frith, NASA)

The goal of the study was to construct a 5° by 5° gridded monthly mean set of total ozone observations from the TOMS and SBUV series of instruments with appropriate errors. SBUV series has best calibration, but nadir measurements sample < 10% of globe each day. Therefore, it's necessary to estimate and attempt to reduce sampling errors. TOMS Level 3 data (1° lat x 1.25° lon) were used to test SBUV sampling.

Approaches to increase sampling included (1) combining SBUV and TOMS, (2) using daily spatial interpolation to fill gaps between orbits, (3) including other instruments (IR sensors), (4) using assimilation techniques.

It was shown that using a simple interpolation scheme to fill in gaps between orbits on a daily basis notably improves SBUV sampling issues at middle and high latitudes, particularly in the Southern Hemisphere.

Sampling errors are lower in the tropical region due to reduced variability, and thus interpolation does not lead to significant improvement.

To produce high resolution gridded data we will (1) combine SBUV and V9 TOMS/OMI (adjusted to SBUV), (2) interpolate SBUV to reduce spatial errors in periods with no TOMS/OMI data, (3) apply more sophisticated spatial/temporal interpolation techniques as needed, and (4) investigate the use of IR data or assimilation to expand coverage to the poles.

3.6.11 Merging of SBUV/TOMS Ozone Data with AIRS (Gordon Labow, NASA)

Gordon described various proposed approaches to merging the SBUV/TOMS record with AIRS. AIRS/AMSU was launched on EOS Aqua on May 4, 2002. AIRS is a multi-detector array grating spectrometer. The AIRS Field of View (FOV) is 13 km x 13 km at nadir. The AIRS retrieval uses a physically based retrieval system which is independent of GCM except for surface pressure. It uses cloud cleared radiances to sequentially determine the solution for different geophysical parameters which represents what AIRS would have seen in the absence of clouds.

What can be done with these merged data? With full coverage one can fill in missing OMI, SBUV, TOMS data. Zonal means for the polar regions can be produced (yielding trends). A key issue is that validation will be very difficult in polar night (possibly using assimilation using MLS). There is still much to do before looking at ozone profiles. The AIRS group is already improving their ozone retrievals.

3.6.12 Ozone column multi-sensor reanalysis for the period 1970-2012 (MSR v2) (Ronald van de A, KNMI; presented by Claus Zehner)

The key assumption of this study is that the ground observations are on average a good approximation for the truth. The reanalysis procedure was:

- All UV-VIS satellite data (BUV, TOMS, SBUV, GOME, SCIAMACHY, OMI, GOME-2) in the period 1970-2012 is used.
- Step 1: Correct satellite data to avoid biases. The reference data that is chosen are ground data observations from reliable WOUDC stations.
- Step 2: Satellite data is assimilated in a chemical-transport model to achieve complete global and temporal coverage.

In summary, 18 total ozone data sets from BUV, TOMS, SBUV, GOME, SCIAMACHY, OMI and GOME-2 were corrected by comparison with Brewer and Dobson data (WOUDC). An improved data assimilation scheme was developed and verified by observation-minus-forecast (OmF) analysis for different years of the data record. The MSR data record was extended to the period 1970-2012 on a 1x1 degree grid (0.5 degree resolution). The BUV years are of less quality due to missing data (especially 1975-1978). OmF analysis of the MSR2 results are consistent with assumptions.

Future work will include ground observations in data assimilation of 1970-1978 (MSR version 3 within MACC III)

The Multi Sensor Re-analysis (MSR) is available at http://www.temis.nl. The MSR version 1 is published in: R.J. van der A , M.A.F. Allaart and H.J. Eskes, Multi sensor reanalysis of total ozone, *Atm. Chem. Phys.*, 2010, 10, 11277-11294.

Atmospheric Composition Constellation Meeting (ACC-10) - Agenda

June 4

09:00-09:15 Welcome – L. Flynn - NOAA
09:15-09:30 Scope/Overview of this Meeting - C. Zehner – ESA
09:30-10.30 Tour de Table on Agency/Mission Status Reports
10:30-11.00 Discussions on the Limb Sounding Mission Gap/ACC Actions necessary to raise awareness? – T. Piekutowski – CSA/All
11:00-11:30 Coffee Break
11:30-12:00 Status of ACC AQ Constellation Activities – J. Al-Saadi - NASA
12.00-12:20 CEOS Carbon Task Force Report (chapter on atmosphere) – D. Crisp - NASA
12:20-12:40 Plans for the IRS and advanced IASI missions - R. Munro - EUMETSAT
12:40-13:00 OCO Mission status - D. Crisp - NASA
13.00-14:00 Lunch Break
14:00-14:30 GOSAT 1 results and status of the GOSAT-2 missions S. Kawakami - JAXA
14:30-14:50 The Merlin Mission Status - D. Loyola - DLR
14:50-15:10 TansSat Mission status – provided by Y. Liu - CAS
15:10-15:30 Results of the ESA Workshop on Future Challenges for GHG Satellite Missions (May 08/ESTEC) – C. Zehner - ESA
15:30-16:00 Discussion on Setting up an ACC-GHG Constellation - All
16.00-16:30 Coffee Break
16.30-16:40 Overview of ongoing ESA activities, SCOPE-Nowcasting & CEOS project on volcanic emissions – C. Zehner – ESA
16.40-17:00 Development of a Space-based System for Quantitative Detection and Analysis of Volcanic Cloud - M. Pavolonis – NOAA
17:00-17:20 NASA's NRT volcanic products from the polar orbiting Aura/OMI N. Krotkov – NASA
17:20-17:40 The SACS project - M. van Roozendaehl - BIRA/IASB
17:40-18:00 Optical, microphysical and compositional properties of the Eyjafjallajokull volcanic ash - A. Rocha Lima - University of Maryland
18:00- 18:30 Discussion

June 5

09:00-09:20 GSICS Research Working Group UV Activities - L. Flynn – NOAA
09:20-09:40 Generation of a combined (European/US) long term Total Ozone Record /Introduction – PK. Bhartia – NASA
09.40–10:00 Comparison of profile total ozone from SBUV (v8.6) with GOME-type and ground-based total ozone for a 16-yr period - E. W. Chiou – NASA

10:00-10:20 Validation results of total ozone data – A. Keppens - BIRA/IASB
10:20-10:40 Importance of sampling errors when generating Level 3 data
D. Loyola - DLR
10:40-11:00 New ozone results from IASI – C. Clerbaux - LATMOS
11:00-11:30 Coffee Break
11:30-11:50 Intercomparison of KNMI/NASA OMI total ozone columns
P. Veefkind – KNMI
11:50-12:10 Stability of the OMI instrument/ozone data - P. Veefkind – KNMI
12:10-12:30 Intercomparison of GODFIT/NASA OMI total ozone columns
M. van Roozendaehl - BIRA/IASB
12:30-14:00 Lunch Break
14:00-14:20 Sampling errors in gridding SBUV data and their reduction by combining
SBUV data with mapping instruments such as OMI – S. Frith - NASA
14:20-14:40 Merging AIRS total ozone with SBUV data - G. Labow – NASA
14:40-15:00 Merging different total zone data sets using data assimilation techniques
R. van der A – KNMI
15:00-16:30 Discussion/Next Steps

CEOS ACC-10 Participants
NOAA NCWCP, 4-5 June 2014

Name	Affiliation
C. Zehner	ESA
R. Munro	EUMETSAT
T. Piekutowski	CSA
P.K. Bhartia, D. Crisp, R. McPeters, D. Haffner, K. Jucks, G. Labow, G. Taha, R. Eckman, J. Al-Saadi, A. Pszenny, E-W. Chiou, S. Frith, N. Kramarova, D. Wickland	NASA
L. Flynn, E. Beach, Q. Liu, X. Xiong, M. Pavolonis, S. Kondragunta, J. Wild	NOAA
M. Van Roozendael, A.Keppens	BIRA/IASB
S. Kawakami	JAXA
D. Loyola	DLR
R. Salawitch, A. Rocha Lima	University of Maryland
C. Clerbaux	LATMOS
P. Veefkind	KNMI
K. Chance	Harvard/SAO