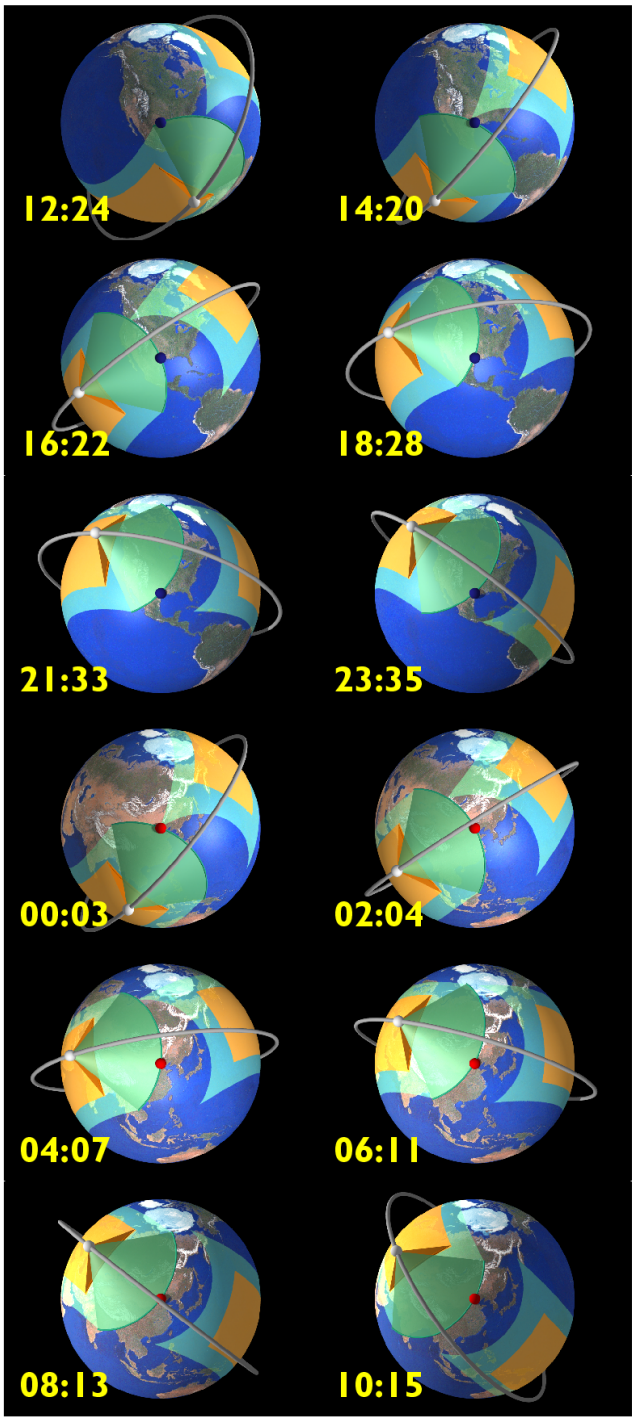
Composition of the Atmosphere from Mid-Earth Orbit (CAMEO)



CAMEO is a future mission concept submitted May 2005 to the U.S. National Research Council Decadal Survey on *Earth Science and Applications from Space.*

This update of CAMEO merges the Atmospheric Remote-sensing and Imaging Emission Spectrometer (ARIES) concept also submitted May 2005 to the Decadal Survey.

by

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updated summary

CAMEO's overlapping coverage on successive orbits gives an unprecedented combination of temporal, vertical, and horizontal resolution, and global coverage needed for progress in atmospheric science and applications. Orange shows the ARIES and TROPI instrument swaths; teal blue shows the SMLS instrument swath. Yellow numbers are universal times of successive measurements over Houston (blue dot) and Beijing (red dot) for this simulated ~24-hour measurement period. Note that the illustration switches from western hemisphere to eastern hemisphere views at 00:03 UT.

Composition of the Atmosphere from Mid-Earth Orbit (CAMEO)

Human activities are changing atmospheric composition in ways that can adversely affect life on Earth. Unhealthful urban pollution episodes are common and increasing pollution, especially from China and India, can affect global air quality and, possibly, the atmosphere's ability to cleanse itself. Increasing greenhouse gases and aerosols, and pollution lofted into the upper troposphere, can affect climate. Stratospheric chlorine loading is now more than 5× the natural amount, with the potential for more severe ozone depletion before chlorine decreases to near-natural abundances in ~50 years.

Crucial policy decisions related to atmospheric composition – involving balances between economic and environmental concerns – must be made, but obtaining the necessary consensus is politically difficult. Existing regulations on ozone depleting substances demonstrate that consensus on such issues can be obtained if sufficiently-complete scientific information is produced and clearly explained. This requires global measurements of atmospheric composition.

CAMEO gives global composition measurements needed to enable informed policy decisions related to air quality and climate change. For example, it quantifies episodic emissions of pollution worldwide and tracks pollution transport across national boundaries and around the globe – essential to supporting international policy to improve and protect regional and global air quality. It globally measures the diurnal cycle of convective deposition of water vapor and pollution into the upper troposphere – essential for quantifying water vapor feedback and pollution effects on climate.

CAMEO remedies measurement deficiencies, especially in temporal resolution, that have inhibited progress in science and applications directly linked to societal needs and benefits by providing:

a) a greatly-improved combination of temporal and spatial resolution for key air quality, climate change, and hydrological cycle measurements needed simultaneously with global coverage,[♦]
b) new upper tropospheric measurements needed to quantify how changes in air quality may affect climate,
c) measurements of cloud ice and water vapor with temporal, vertical and horizontal resolution needed to improve understanding of the hydrological cycle[*] and the accuracy of GCMs used for weather and climate prediction,[†] and
d) post-Aura measurements needed to develop an operational forecast model to predict changes in UV dosage in the coming decades, and for warning of changes in ozone layer stability well before they are evident in ozone itself.[‡]

CAMEO − a logical follow-on to Aura − uses a mid-Earth orbit, new for composition measurements, and advanced technology in three proven instrument types:

(1) **ARIES**, the **A**tmospheric **R**emote-sensing and **I**maging **E**mission **S**pectrometer, an advanced version of AIRS on Aqua, measures infrared thermal emission from 3.5 to 15μm wavelengths. Major improvements of ARIES are (a) 1×1 km horizontal resolution (15× improvement over AIRS) and (b) improved spectral resolution. Both are needed for middle and lower tropospheric composition measurements;

(2) **SMLS**, the **S**canning **M**icrowave **L**imb **S**ounder, an advanced version of MLS on Aura, measures millimeter and submillimeter emission in two broad spectral bands centered at 240 and 640 GHz. Major improvements of SMLS are (a) simultaneously scanning the limb in both horizontal and vertical directions to provide 50×50 km horizontal resolution (50× improvement in cross-track resolution, 3× in along-track, over Aura MLS) and 1-2 km vertical resolution needed for upper tropospheric measurements and (b) in-orbit programmability for rapid response to changing priorities;

(3) **TROPI**, the **TRO**pospheric **P**ollution **I**mager, an advanced version of OMI on Aura with long heritage from SCIAMACHY and TOMS, measures reflected/backscattered solar radiation in UV, visible, and near/shortwave infrared. Major improvements are (a) bands in the near and short-wavelength infrared to give CO and CH_4 in the boundary layer and (b) new detectors/gratings that give the OMI-demonstrated 10×10 km resolution from CAMEO's orbit. Additional studies will determine if better than 10 km resolution is feasible and cost-effective.

These broad-swath instruments having multiple successive orbit overlaps (see cover figure) provide an unprecedented combination of temporal/spatial resolution and global coverage needed to quantify fast processes that affect air quality and climate, and improve models used for weather/climate predictions. Figure 1 quantifies the temporal/global coverage. Launch vehicles used for polar sun-synchronous low-Earth orbit can insert CAMEO directly into the desired orbit.

Figure 2 shows the suite of CAMEO measurements. Figure 3 shows example results from precursor instruments.

NOAA's Satellite Meteorology and Climatology Division has encouraged NASA to develop the CAMEO capability for NOAA's operational use of CAMEO data. With TROPI being developed by the Netherlands and with strong UK participation, CAMEO implements the international cooperation advocated by the July 2003 Earth Observation Summit.

Additional information is in the CAMEO and ARIES documents submitted May 2005 to the NRC Decadal Survey.

[♦] CAMEO provides the mid-Earth orbit mission capability identified by the Decadal Survey Health and Human Security 'Respiratory and cardiovascular disease' subpanel as a priority 'bridge' linking air quality and other panel topics.

[*] CAMEO provides most, if not all, of the atmospheric information identified as a focus of the Decadal Survey Water Resources and Global Hydrological Cycle panel.

[†] CAMEO provides the needed 'ConTSat' (Convective transport of trace species, heat and momentum) mission limb scanning capability identified by the Decadal Survey Panel on Climate Variability and Change.

[‡] CAMEO provides measurements of all the chemical species identified by the Decadal Survey Health and Human Security Panel as needed for the 'UV exposure and skin cancer' issue, except OH (for which HO_2 is a proxy) and IO.

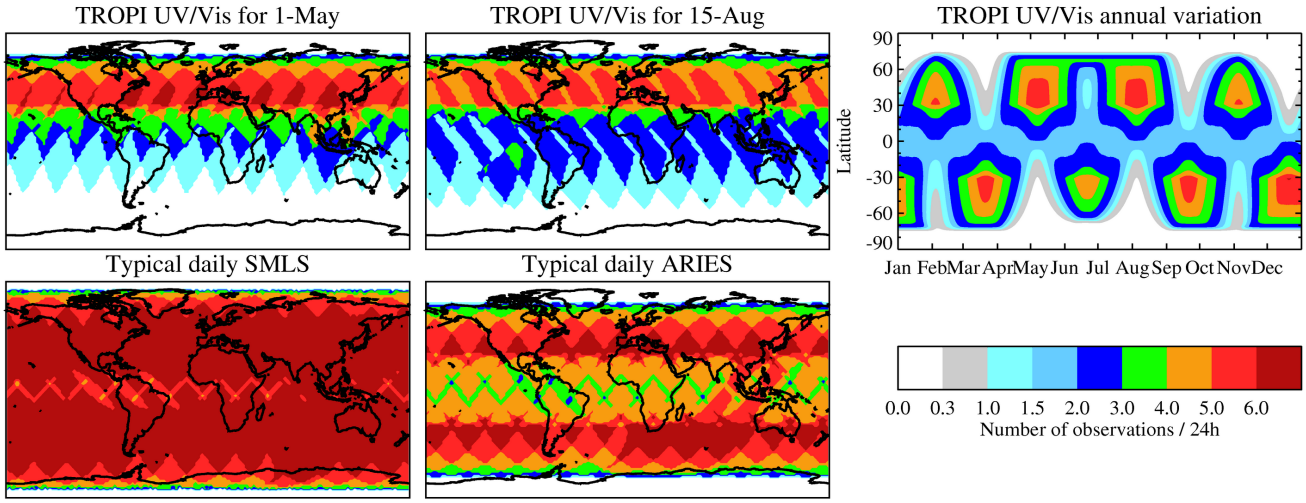


Fig. 1. Temporal and global coverage of CAMEO measurements. Everywhere within a given color is measured that number of times per 24-hour period. Measurements are made in 'spurts' of ~2 hour intervals (approximately the orbit period) followed by a gap of several hours. During every season the temporal measurement pattern precesses through all local times. SMLS and ARIES measurements (thermal emission) have a frequency pattern that is nearly constant throughout the year and is shown in the bottom panels. The TROPI measurements (reflected and backscattered sunlight) have a frequency pattern that varies annually as shown in the upper rightmost panel: mid-latitudes are measured 4-5 times per day over month-long periods that switch between northern and southern hemispheres (for operational use, two CAMEOs flying in formation will fill in the mid-latitude gaps shown here). The top left and top center panels show the TROPI measurement frequency in May (peak time of Asian pollution transport to America) and August (peak time of urban pollution in the U.S. and Europe). These plots are for the 1500 km, 52° inclination baseline orbit for CAMEO, with the orbit phase chosen for summer air quality measurement priorities.

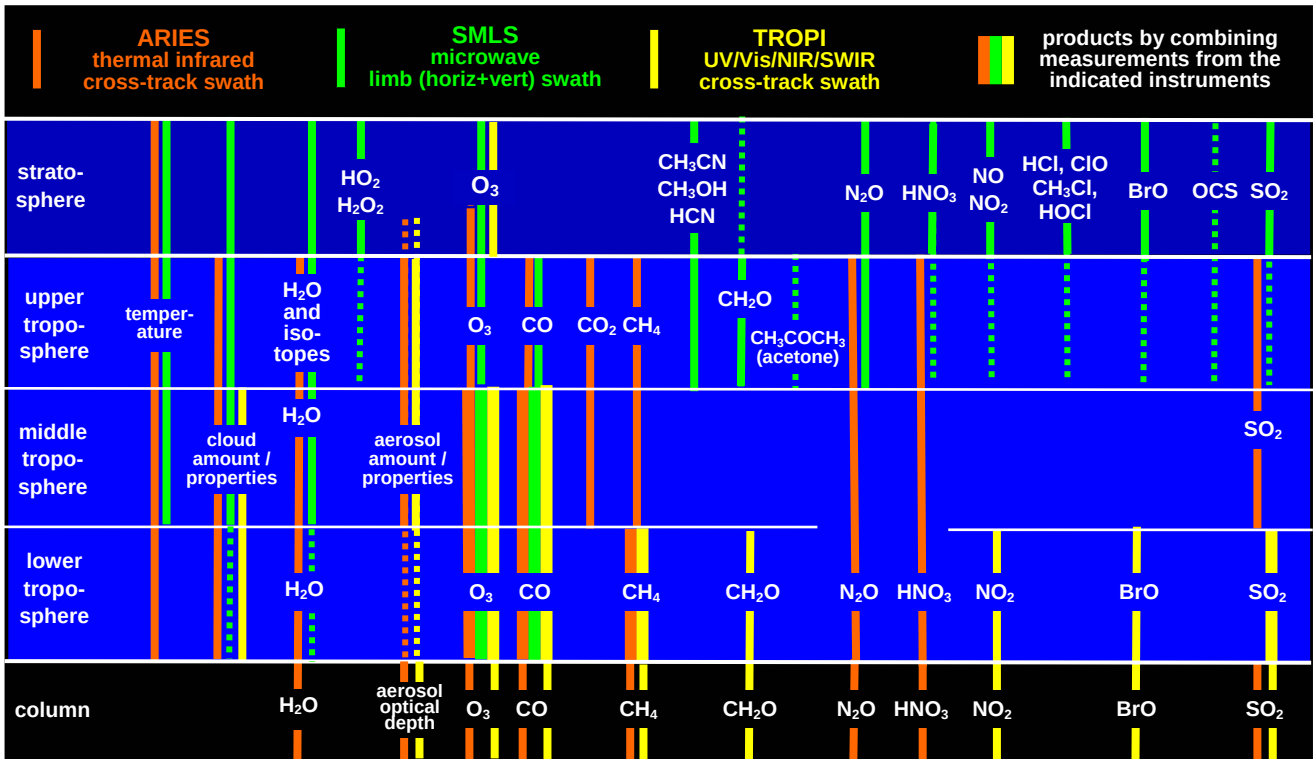
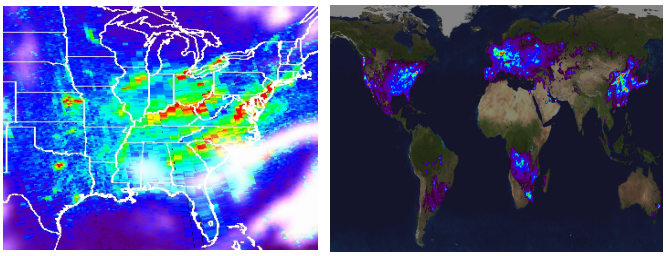
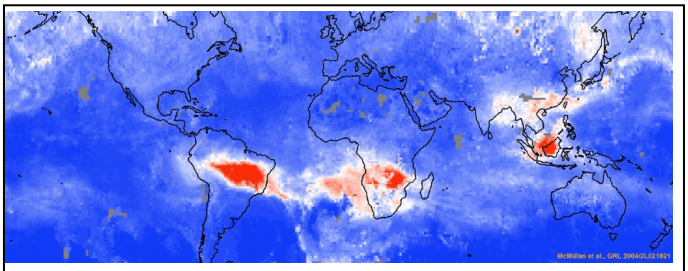


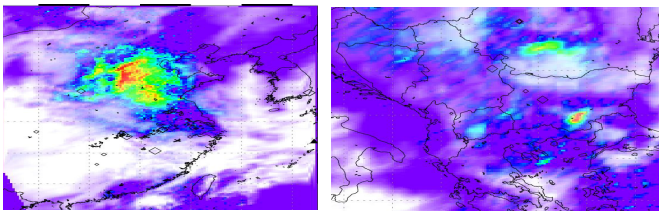
Fig 2. CAMEO atmospheric measurements (dashed lines are goals). Data from instruments are combined to obtain lower tropospheric measurements. With CO and O_3, for example, SMLS gives well-defined columns for the upper troposphere and above, yielding a constraint for ARIES and TROPI retrievals that sharpens their vertical resolution. The different ARIES/TROPI middle and lower troposphere sensitivities then yield lower tropospheric CO and O_3 abundances. The break in the horizontal line separating middle and lower troposphere for N_2O and HNO_3 indicates that only a column for the combined middle and lower troposphere is obtained for these species. SMLS measurements of HO_2, O_3, HCN, NO, NO_2, HCl, BrO, and perhaps others, extend into the mesosphere.



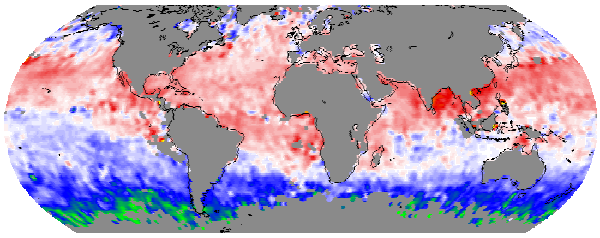
(a) Enhanced tropospheric NO_2 over the eastern U.S. on 15 Apr 2005 (left), and over the entire globe for the month of August 2005 (OMI data).



(b) Mid-troposphere CO pollution on 22-23 Sep 2002 associated with urban/industrial pollution in southern Asia – and with biomass burning in South America, Indonesia and Africa (AIRS data).

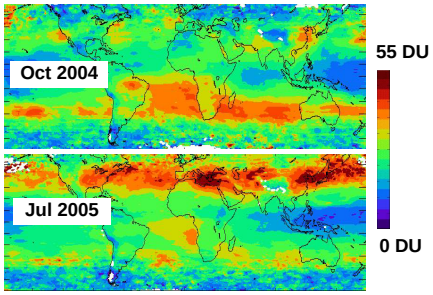


(c) Boundary-layer anthropogenic SO_2 over eastern China on 24 Dec 2004 (left) and over southeastern Europe (mainly over Romania and Bulgaria) on 9 Feb 2005 (OMI data).

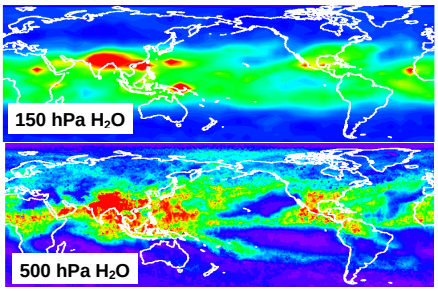


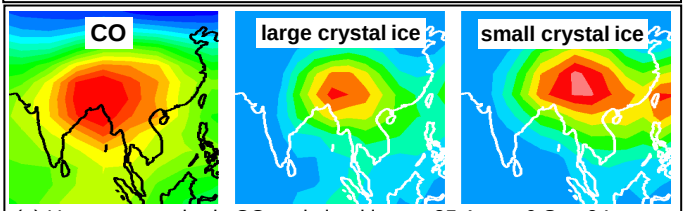
(d) Mid-troposphere CH_4 for Oct 2003, plotted as a difference from the U.S. Standard Profile; green is -8%, red is +5% (AIRS data).

(e) Total tropospheric ozone (OMI-MLS data). The differences between Oct 04 and Jul 05 can be related to biomass burning, pollution events, and stratosphere-troposphere exchange [Ziemke et al., 2006].

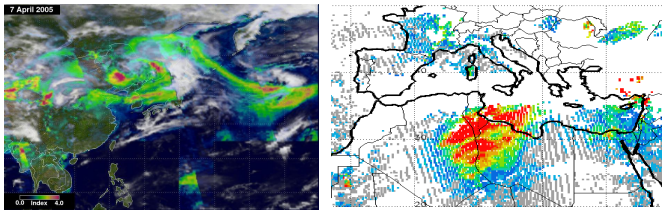


(f) 14-20 Aug 2005 tropospheric H_2O at 150 hPa (top) from MLS and at 500 hPa from AIRS (bottom). Red indicates 25 ppmv in the 150 hPa MLS image, and 2500 ppmv in the 500 hPa AIRS image.

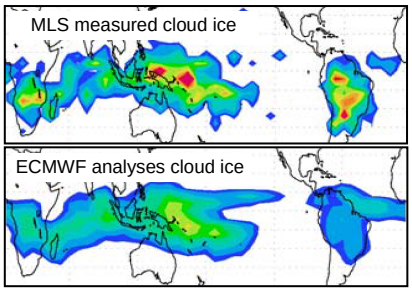




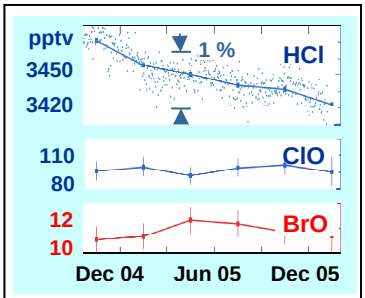
(g) Upper tropospheric CO and cloud ice on 25 Aug – 6 Sep 04 [MLS]. The enhanced CO over south Asia is traced to surface pollution lofted into the upper troposphere [Q.B. Li et al., GRL 2005]. MLS 240 and 640 GHz measurements allow separation of clouds into those with characteristic particle size larger or smaller than ~30 µm.



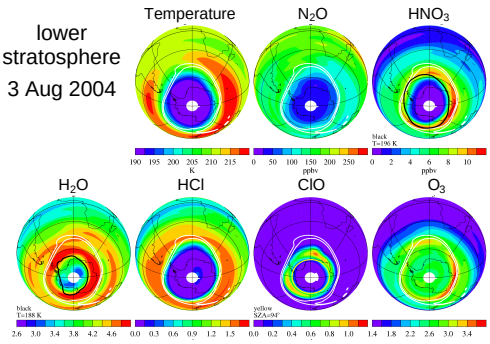
(h) **Left:** Mapped aerosol above clouds over Asia; color is OMI aerosol index and gray scale is OMI reflectivity (OMI data, 7 Apr 05). **Right**: Distinguishing between absorbing and non-absorbing aerosol in dust storm over the Sahara (OMI aerosol optical depth, 1 Mar 05).



(i) Jan 2005 upper troposphere ice water content from MLS and ECMWF analyses [J.L. Li et al., GRL, 2005]. The MLS data are being used to improve ECMWF parameterizations, but with severe temporal and spatial resolution limitations.



(j) Time-series of chlorine and bromine in the upper stratosphere [from MLS]. HCl decrease is consistent with the rate at which anthropogenic chlorine is expected to be cleansed from the stratosphere.



(k) Polar processes affecting ozone [Santee et al., GRL 2005, MLS data]. These measurements are crucial to understand how climate change may affect ozone recovery, especially important for the Arctic.

Fig. 3. Some results from precursor instruments. CAMEO employs a mid-Earth orbit and new technology in instrument types proved extremely successful in previous missions to give needed improvements in temporal and spatial resolution of global atmospheric composition measurements, while continuing essential long-term datasets not otherwise currently planned.