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Composition of the Atmosphere from Mid-Earth Orbit (CAMEO): Observations for air quality studies

A future atmospheric composition mission concept by

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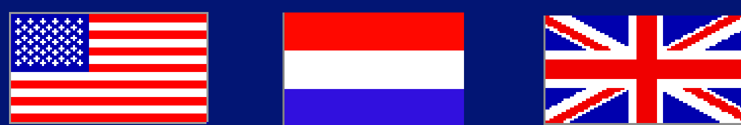

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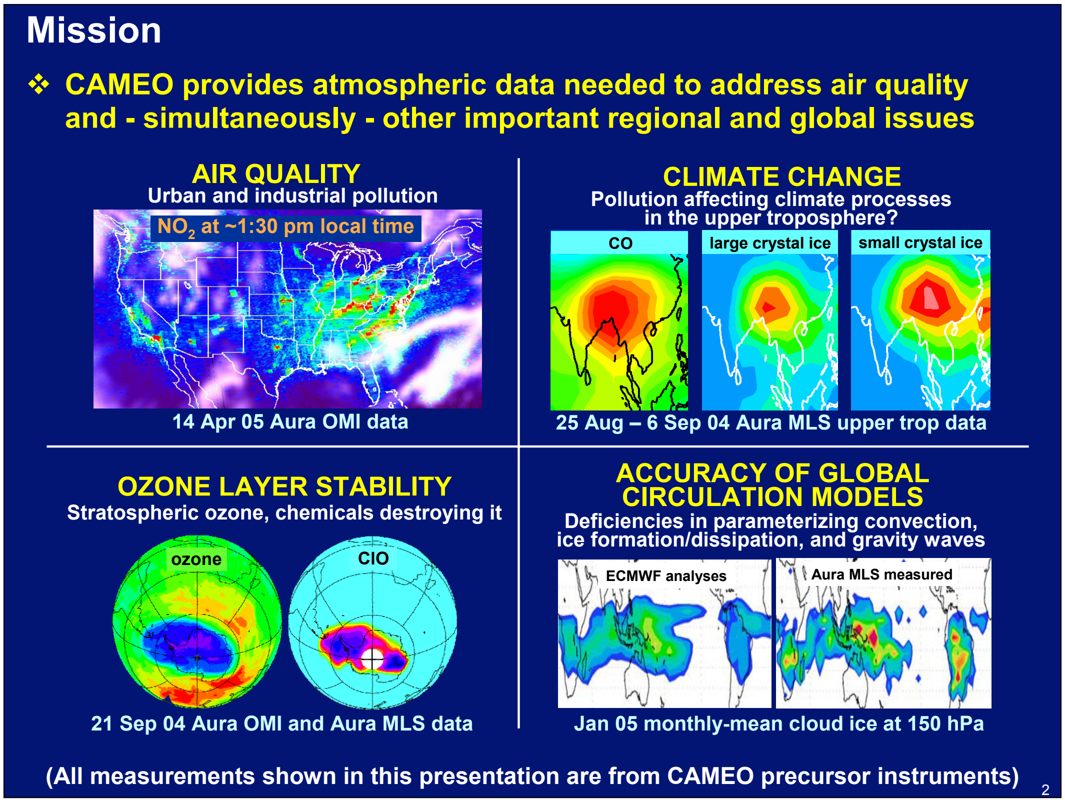
CAMEO is a mission concept developed by a team from JPL, two organizations in the Netherlands, and the UK University of Edinburgh.

Here, because of time, I can only cover CAMEO's major points

But we have three posters that give much more information. Nathaniel Livesey has posters on the overall mission and on its microwave instrument. Pieternel Levelt's poster describes the CAMEO UV/Vis/NIR/SWIR instrument



CAMEO provides data needed to address important air quality issues. In this presentation I will emphasize our air quality measurements.

But CAMEO also addresses key issues in:

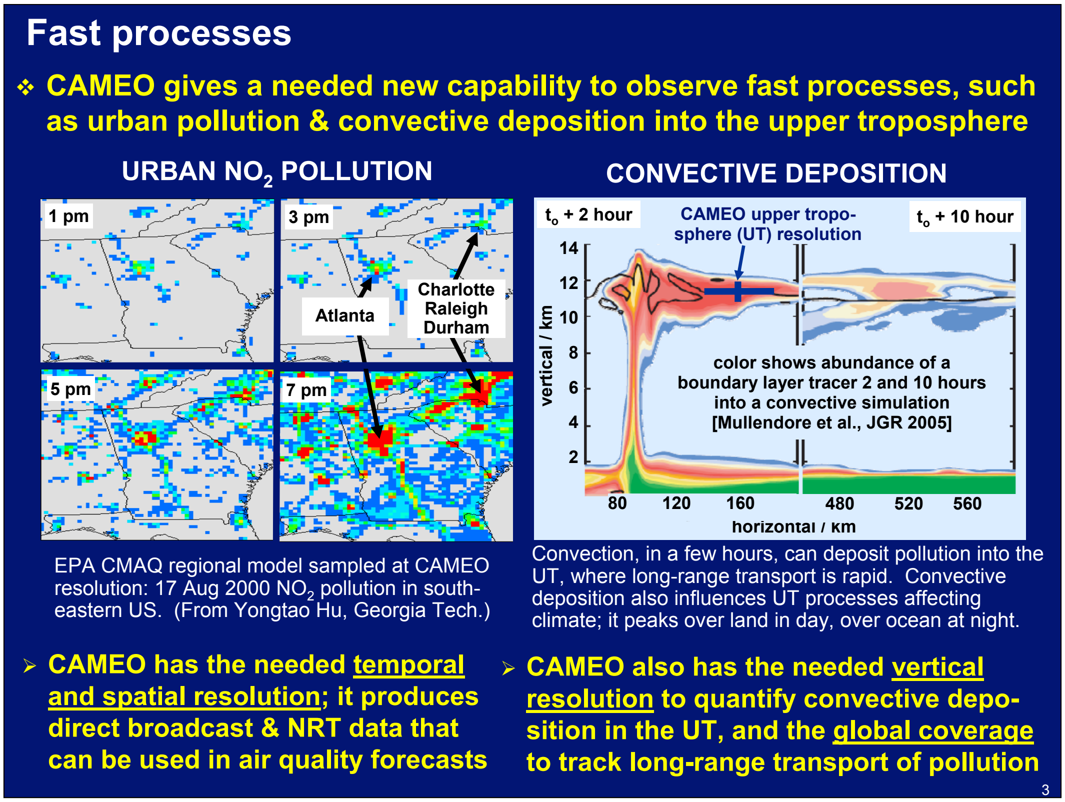
- **Climate change**, especially how change in air quality may affect climate,
- **Ozone layer stability**, and
- **The accuracy of Global Circulation Models used for weather and climate forecasts.**

Our community has already developed a tremendous capability in satellite measurements in these areas. Examples are shown in this slide.

However – as is recognized – a serious deficiency exists in the temporal resolution of these measurements: most are made only once, or at best twice, per day.

A serious deficiency also exists in the horizontal resolution of limb-sounding instruments that give the vertical resolution required for many measurements. This is especially important for tropospheric limb sounding.

CAMEO remedies both these deficiencies – and, simultaneously, gives measurements needed long-term.



Here are examples of two important processes whose measurement requires better temporal resolution than we now have.

The first, illustrated on the left, is urban pollution that – due to emissions and chemistry – can change substantially within a few hours.

This shows NO2 pollution in the southeastern US between 1 and 7 pm for a day in August 2000, from the EPA CMAQ regional model. The model has been sampled at the 2-hour temporal resolution of CAMEO, and at its 10 km spatial resolution for NO2.

Aura, for example, measures NO2 only at 1:30 pm – near 1 pm shown in upper left. But CAMEO allows us to track the temporal variation, and see the much larger abundances of NO2 occurring later in the day.

In addition to NO2, CAMEO measures several other tropospheric pollutants at this resolution. The complete suite of measurements will be given in a later slide. And, in addition to data files for research, CAMEO also produces direct-broadcast and near-real-time data that can be used in operational air quality forecasts.

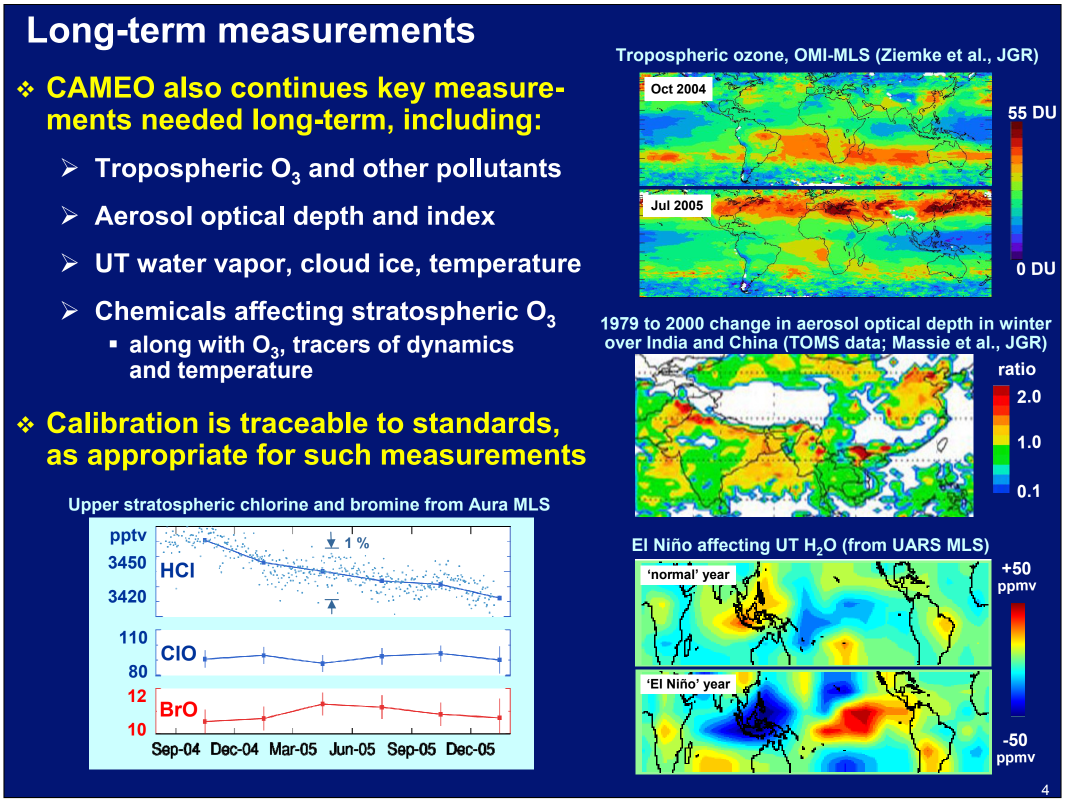
Convection (illustrated on the right) – also in a few hours – can deposit boundary layer pollution into the upper troposphere, where it is rapidly transported intercontinentally. CAMEO has the resolution to quantify this convective deposition, and does so globally.

Also, its global measurements – made multiple times per day – precisely track the long-range transport of pollution, which is – of course – an important international issue.

Convective deposition also influences upper tropospheric processes affecting climate, such as water vapor and cloud ice feedbacks, and ozone at heights where its radiative forcing is greatest Convection generally peaks over land in day and over ocean at night. Diurnal measurements, as done by CAMEO, are needed.

Now, thinking has been that a GEO or L1 orbit is needed for <u>temporal</u> resolution, while LEO is needed for <u>vertical</u> resolution to study such things as processes in the upper troposphere.

But CAMEO – with an orbit between LEO and GEO – simultaneously obtains both.



CAMEO also provides key measurements needed long-term. These include

- Tropospheric ozone and other pollutants
- Aerosol optical depth and index
- Upper tropospheric water vapor and related parameters, and
- Chemicals affecting stratospheric ozone.

Some examples are shown in this slide.

The top right, from a recent paper by Jerry Ziemke, shows the global distribution of tropospheric ozone in different months. The differences seen here are related to biomass burning, pollution events, and strat-trop exchange.

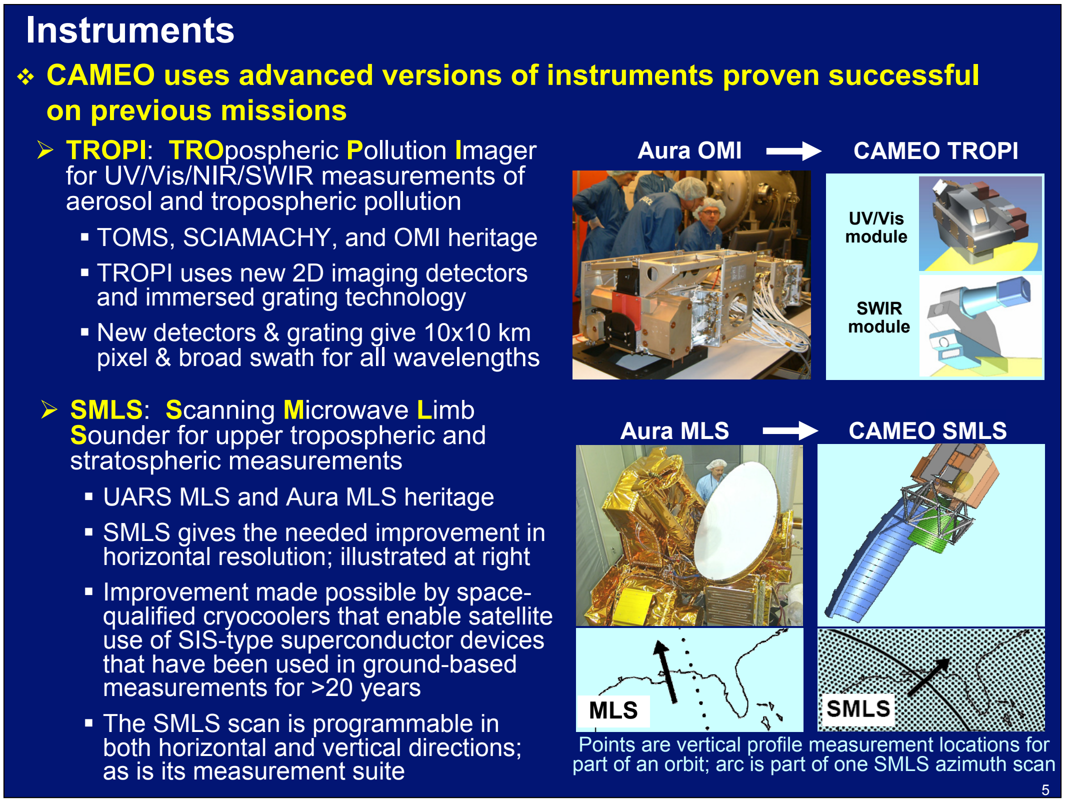
Next, from a paper by Steve Massie, shows the 1979 to 2000 change in winter aerosol over China and India. The increases seen here, up to a factor of 2, are thought caused by the growing SO2 pollution being converted to sulfate, and – over India – also due to increases in use of residential biofuel.

The bottom right shows El Nino affecting the distribution of upper tropospheric water vapor as measured by UARS MLS. Better understanding of this coupling, obtained through long-term measurements, should help improve seasonal climate forecasts.

The bottom left shows the time-series to date of Aura MLS measurements of halogen species in the upper stratosphere. HCl here is a measure of total chlorine in the stratosphere. Dots are daily global measurements; the line connects seasonal averages. The observed decrease is consistent with the rate at which anthropogenic chlorine is expected to be cleansed from the stratosphere. Although this cleasing will take more than 50 years, we can now track it with useful accuracy on a seasonal, or even shorter, basis. This provides a crucial test of whether regulations are having the desired effect.

MLS also measures ClO, the dominant reactive form of chlorine – and BrO, which is both the dominant reactive and reservoir forms of bromine.

All these measurements are needed long-term, and CAMEO will provide them.



CAMEO uses advanced versions of instruments proven successful on previous missions.

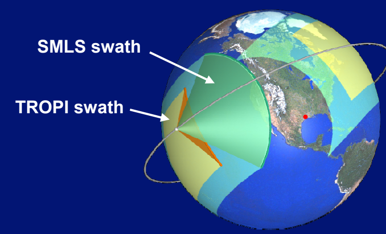
The "Tropospheric Pollution Imager" (TROPI) makes UV/Vis/NIR/SWIR measurements of aerosol and tropospheric pollutants. It has heritage from TOMS, SCIAMACHY, and OMI.

The "Scanning Microwave Limb Sounder" (SMLS) makes upper tropospheric and stratospheric measurements. It has heritage from UARS and Aura MLS.

As illustrated in the lower right, SMLS has **dramatic** improvement in horizontal resolution over Aura MLS. (Each dot here is a vertical profile.) This improvement is needed for studying upper tropospheric processes. The improvement is enabled by space-qualified cryocoolers developed for other missions. The coolers allow superconductor detectors, of the SIS-type used in ground-based measurements for more than 20 years, finally to be deployed in satellite. Such detectors give measurements in only milliseconds, allowing the vertical scan to be split into very many azimuths.

Orbit

- **CAMEO uses a new, and easily-reached, mid-Earth orbit (MEO)**
- **This orbit and the broad-swath instruments provide an unprecedented combination of temporal, vertical, and horizontal resolution and global coverage needed to:**
  - Quantify 'fast processes' that affect air quality, climate, and the accuracy of global circulation models used for weather and climate forecasts
  - Continue LEO measurements needed long-term



- **The combination of resolution and coverage cannot be obtained from a single satellite in other orbits**
  - LEO does not provide the temporal resolution and/or coverage
  - GEO does not provide the vertical resolution
  - L1 does not provide the vertical resolution or the diurnal coverage
  - L2 does not provide the horizontal resolution or the diurnal coverage
- **Following is animation showing CAMEO coverage for several orbits**
  - The red dot (at Houston, as example) facilitates seeing how measurements at a given location are made on many successive orbits – yielding temporal coverage
  - For this 16-hour example, measurements over Houston are made 8 times by SMLS and 6 times by TROPI; the measurements are spaced by ~2 hours local time

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Now let's talk about orbits.

GEO and L1, although giving good temporal resolution, do not yield the vertical resolution that is needed – for example to study upper tropospheric processes. Furthermore, L1 cannot provide any nighttime measurements, and a singel GEO satellite sees just a fraction of the globe.

LEO, on the other hand, although allowing good vertical resolution, does not give the temporal resolution we need.

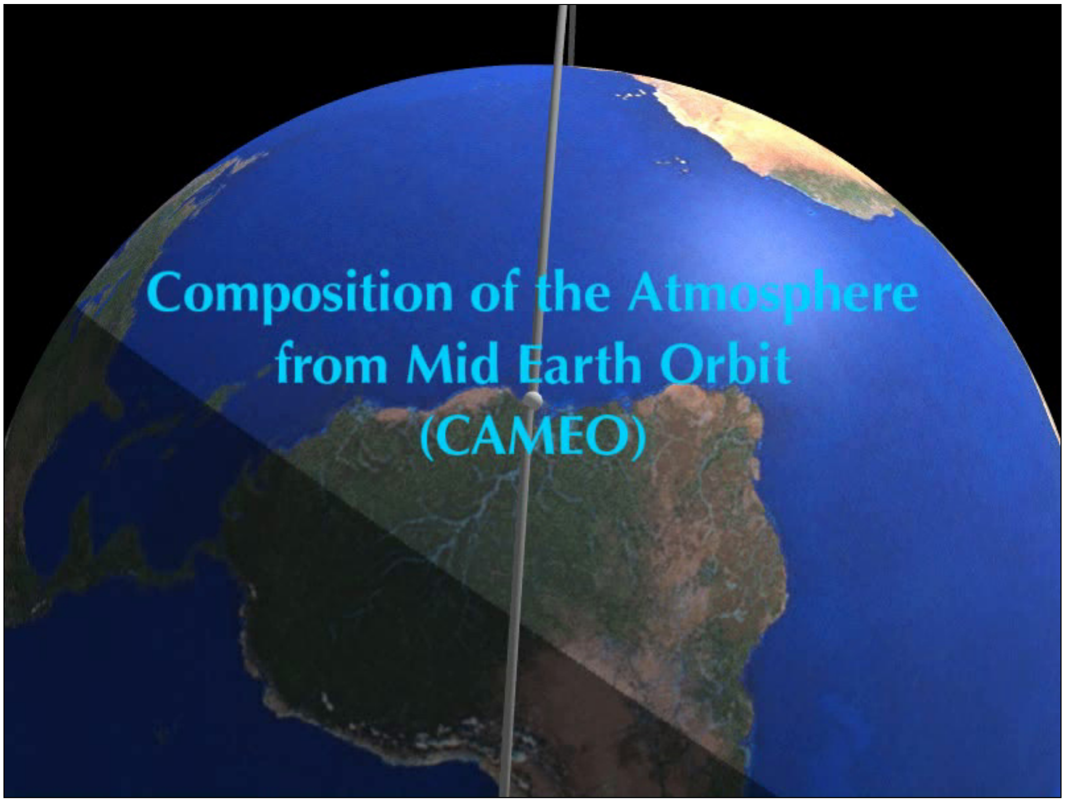
But – between LEO and GEO – a mid-Earth orbit can give the needed combination of temporal, vertical, and horizontal resolution – and global coverage.

CAMEO uses such an orbit. Let's see how it works.

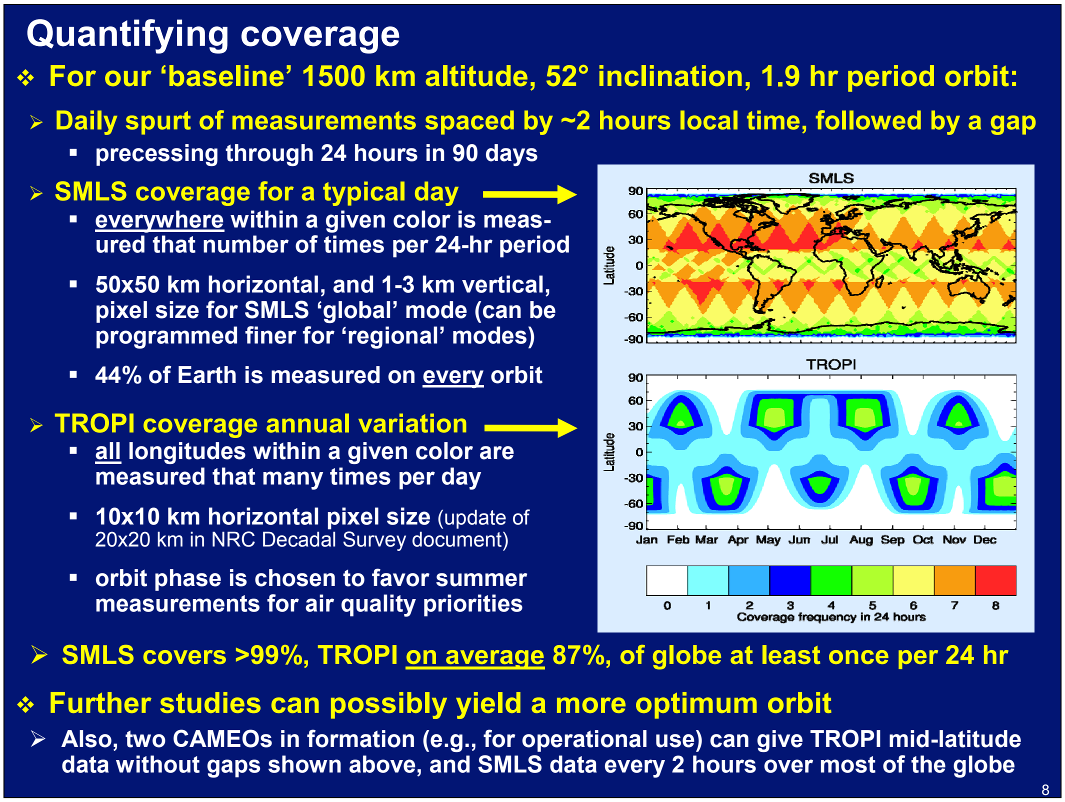
Here, in the upper right, we show the measurement swaths for our two instruments. The orbit is sufficiently high for these swaths to cover an extremely broad width on Earth. But it is sufficiently low to allow limb-sounding, with its good vertical resolution.

This is a Goldilocks "just right" obit – neither too high nor too low.

Now we'll see a movie showing how the orbit, with these instruments, yields temporal resolution.



- Here we are looking down on CAMEO from above, and will follow it around the orbit for a bit.
- The SMLS swath is added.
- We are now coming round to the day side of the orbit.
- The TROPI swath is added.
- Now we'll zoom out.
- You can see that all of Europe is covered on this single orbit.
- We are now looking from the direction of the sun, and watching Earth and CAMEO move beneath us.
- We've put this red dot at Houston as a reference. With it you can more easily see how measurements at a given location are made orbit after orbit after orbit. Local times for Houston measurements are in the upper left.
- From this, I think you can see how the measurement overlaps from successive orbits give the temporal coverage.
- For example, in the 16 hours covered by this animation, SMLS makes 8 measurements over Houston; TROPI makes 6. Measurements are spaced by 2 hours local time.

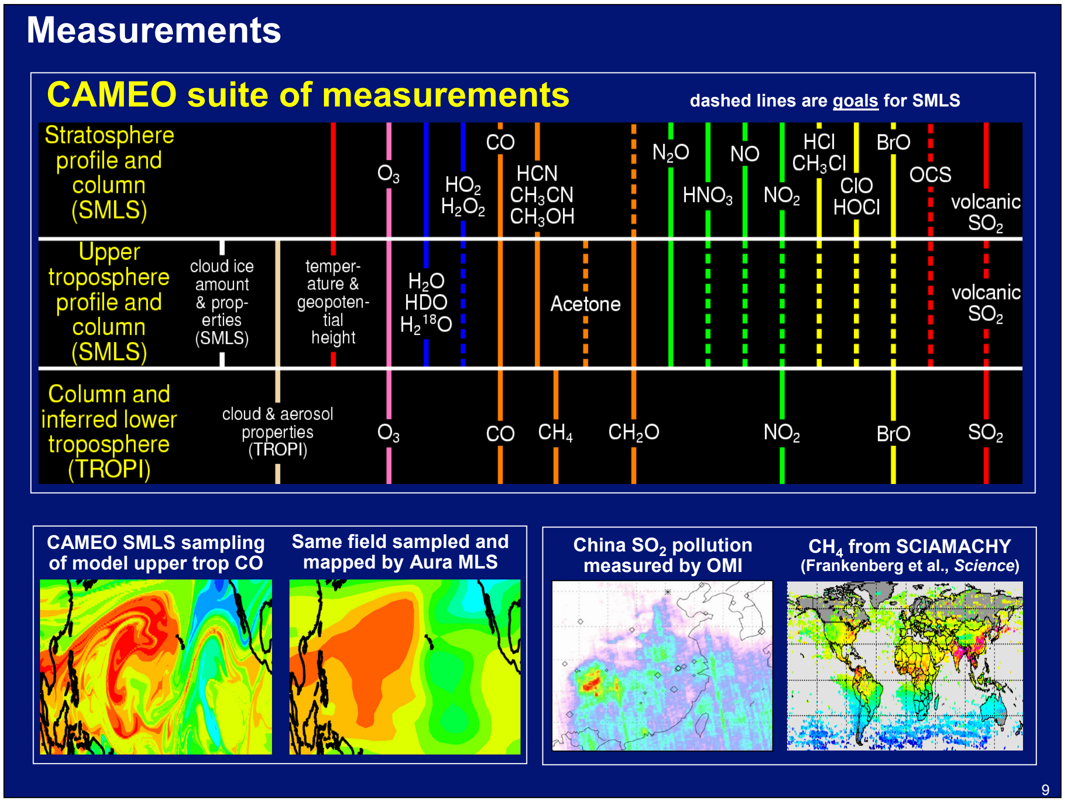


Here we quantify CAMEO's coverage for our baseline orbit.

This orbit gives a daily spurt of measurements spaced by 2 hours, followed by a gap. During every season the pattern precesses through all local times.

The top panel shows SMLS coverage for a typical day. Everywhere within a given color is measured that many times per 24-hour period. Over a broad mid-latitude range measurements are made 6 to 8 times per 24 hours; in the tropics 4 to 7 times. As on Aura, measurements are made to plus/minus 82 degrees latitude on every orbit.

The bottom panel shows the annual variation in coverage of TROPI measurements, which are made only during daylight. All longitudes within a given color are measured that number of times per day. Measurements extend to plus/minus 70 degrees latitude. Mid-latitudes are measured 4-5 times per day over month-long periods that switch between northern and southern hemispheres. The orbit phase is chosen for summer air quality priorities. For operational use, two CAMEOs in formation give measurements without the mid-latitude gaps shown here.



This shows the suite of CAMEO measurements.

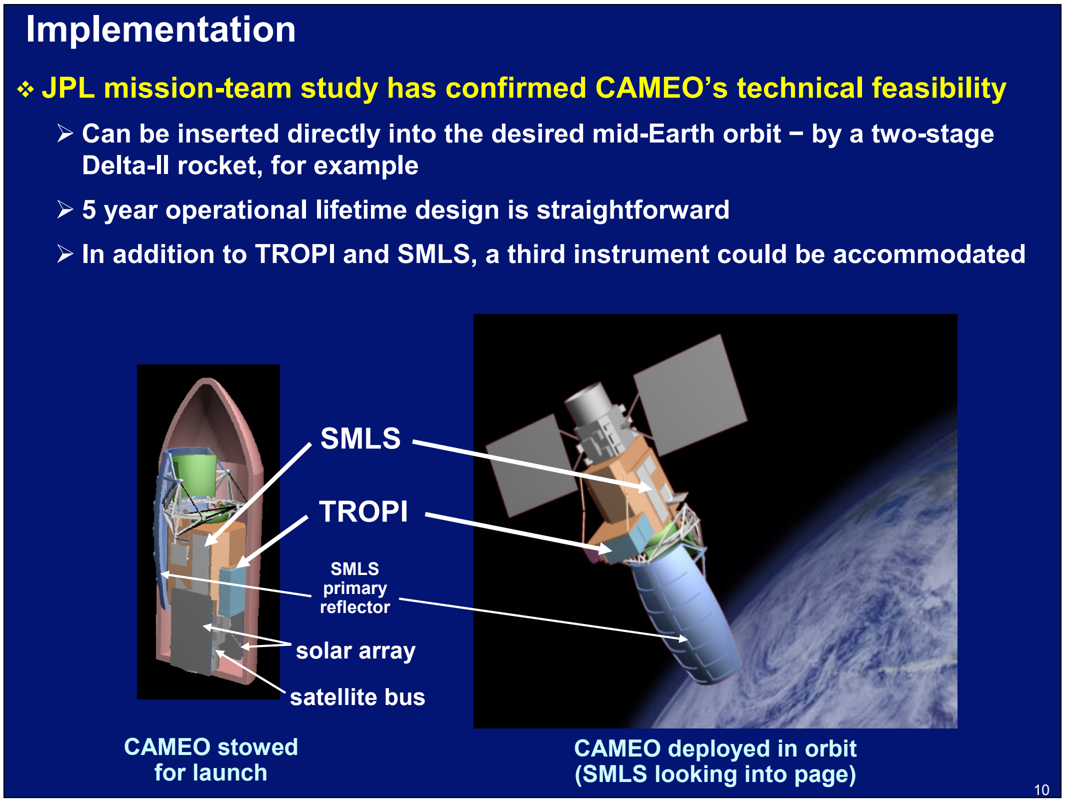
TROPI measures cloud and aerosol parameters – and total columns for ozone, CO, methane, formaldehyde, NO2, BrO and SO2. In most cases these columns are dominated by lower tropospheric abundances. Where they are not, most notably for ozone, differences with SMLS yield tropospheric values.

The SMLS upper tropospheric measurements are cloud ice amount and particle-size parameter, temperature and geopotential height, ozone, water and its isotopes, CO, HCN and related species, formaldehyde, and N2O. Additional important upper tropospheric goals are HO2, H2O2, HNO3, NO, NO2 and others. Although these are easy stratospheric measurements for SMLS, more work is needed to establish their feasibility in the upper troposphere. **An important feature of SMLS is its ability to make upper tropospheric measurements in the presence of ice clouds that prevent shorter-wavelength measurements.**

SMLS stratospheric measurements include key species in all the major chemical families affecting ozone. These give both prognostic and diagnostic information on ozone layer stability.

Importance of the SMLS horizontal resolution is shown in the lower left. We compare high-resolution model upper tropospheric CO as seen by CAMEO and by Aura. Among many features evident in CAMEO, but not Aura, is the thin filament connecting enhanced CO above the Americas to Asian CO pollution. **CAMEO gives detailed and continuous tracking of the long-range transport of pollution around the globe.**

The bottom right shows OMI measurements of SO2 pollution, and SCIAMACHY measurements of methane. TROPI will continue these important measurements with better temporal resolution.

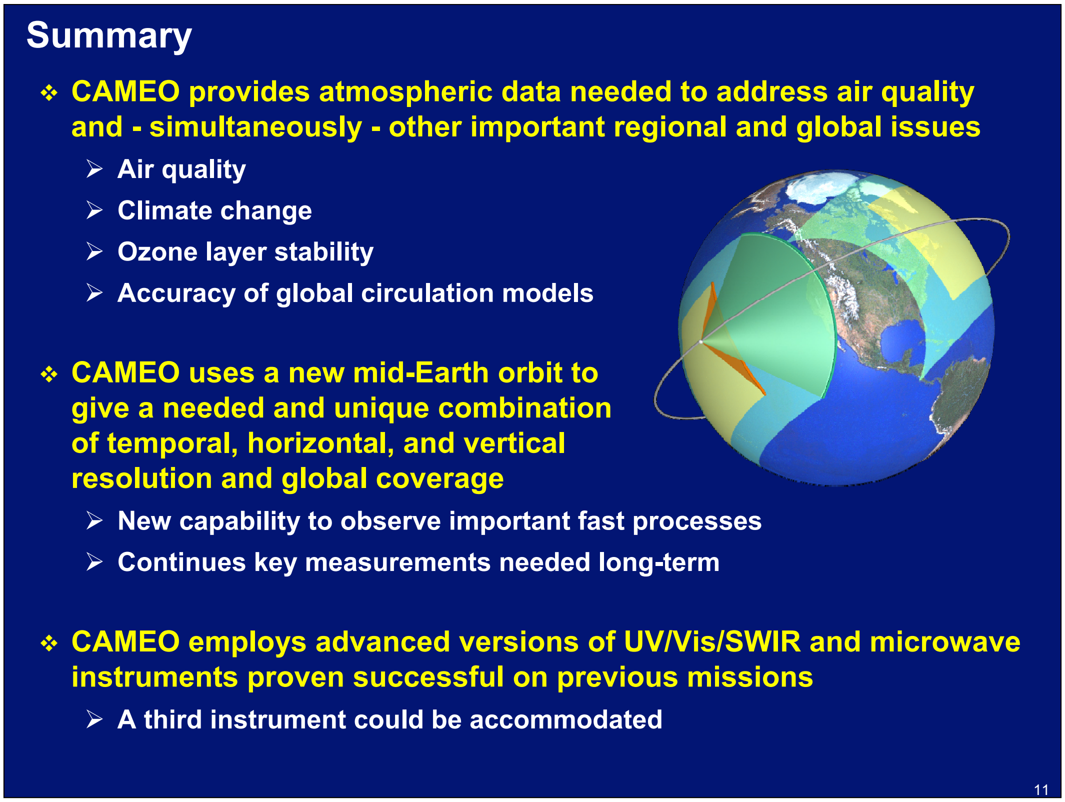


A JPL mission-team study has confirmed CAMEO’s technical feasibility.

It can be inserted directly into the desired orbit – for example by a two-stage Delta-II.

A third instrument could be accommodated.

Here we show CAMEO stowed for launch and deployed in orbit.



In summary:

- **CAMEO provides data to address important air quality issues**

  It also gives key measurements for

  - **climate change,**
  - **ozone layer stability, and**
  - **the accuracy of GCM's used in weather and climate forecasts.**

  For progress in understanding Earth's atmosphere as a whole, we believe that much is to be gained from an atmospheric composition mission that simultaneously addresses all these issues and their interactions.

- CAMEO uses a mid-Earth orbit to give the needed combination of temporal, horizontal, and vertical resolution and global coverage

- And it employs advanced versions of instruments proven successful in previous missions.

We appreciate the opportunity to present CAMEO at this Air Quality workshop.

As on previous experiments, our team welcomes the involvement of additional scientists, and – of course – any criticisms and suggestions for improvements.

Thank you.