

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

**A future atmospheric composition mission concept by**

**Joe Waters, Nathaniel Livesey, Michelle Santee, Paul Stek, Richard Cofield,  
Jonathan Jiang, Qinbin Li, Gloria Manney, William Read, Duane Waliser, Dong Wu**

NASA Jet Propulsion Laboratory, California Institute of Technology, U.S.

**Pieterernel Levelt, Hennie Kelder, Bert van den Oord, Pepijn Veefkind**

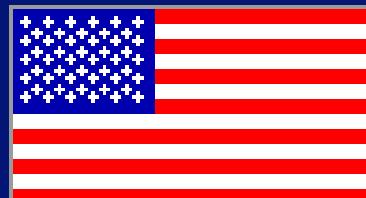
Royal Netherlands Meteorological Institute, The Netherlands

**Ilse Aben, Avri Selig**

Netherlands Institute for Space Research, The Netherlands

**Mark Filipiak**

School of Geosciences, The University of Edinburgh, U.K.

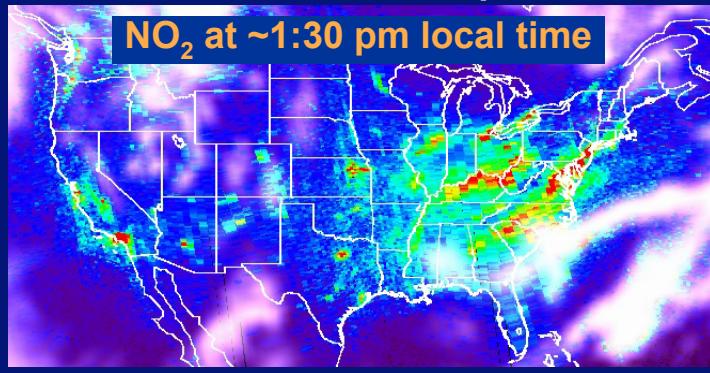


# Mission

- ❖ CAMEO provides atmospheric data needed to address air quality and - simultaneously - other important regional and global issues

## AIR QUALITY

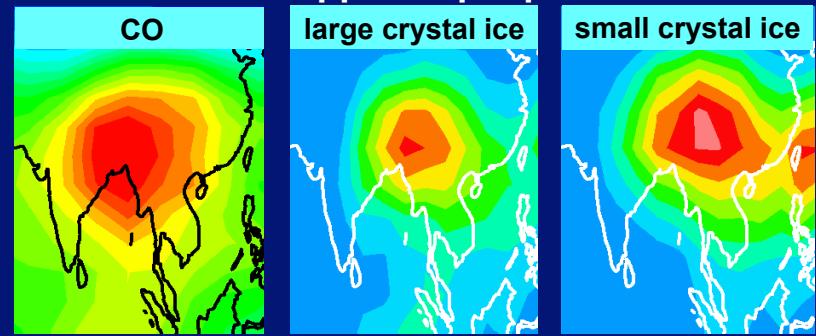
Urban and industrial pollution



14 Apr 05 Aura OMI data

## CLIMATE CHANGE

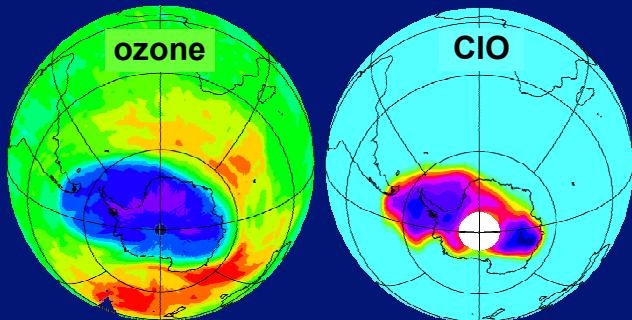
Pollution affecting climate processes in the upper troposphere?



25 Aug – 6 Sep 04 Aura MLS upper trop data

## OZONE LAYER STABILITY

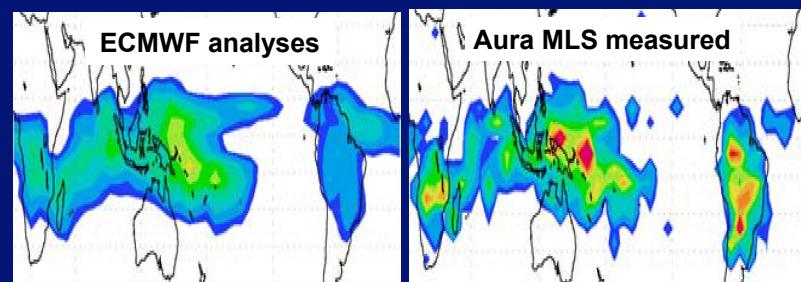
Stratospheric ozone, chemicals destroying it



21 Sep 04 Aura OMI and Aura MLS data

## ACCURACY OF GLOBAL CIRCULATION MODELS

Deficiencies in parameterizing convection, ice formation/dissipation, and gravity waves



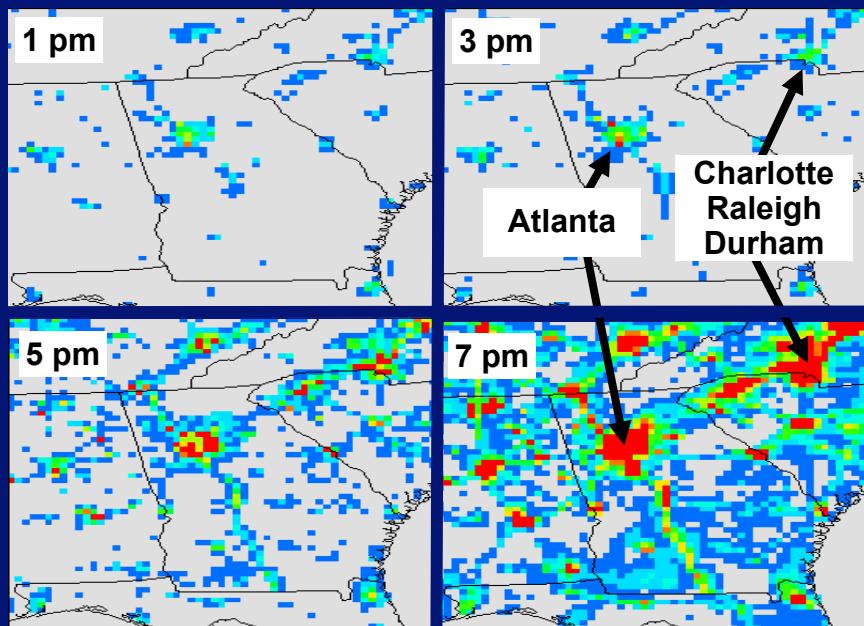
Jan 05 monthly-mean cloud ice at 150 hPa

(All measurements shown in this presentation are from CAMEO precursor instruments)

# Fast processes

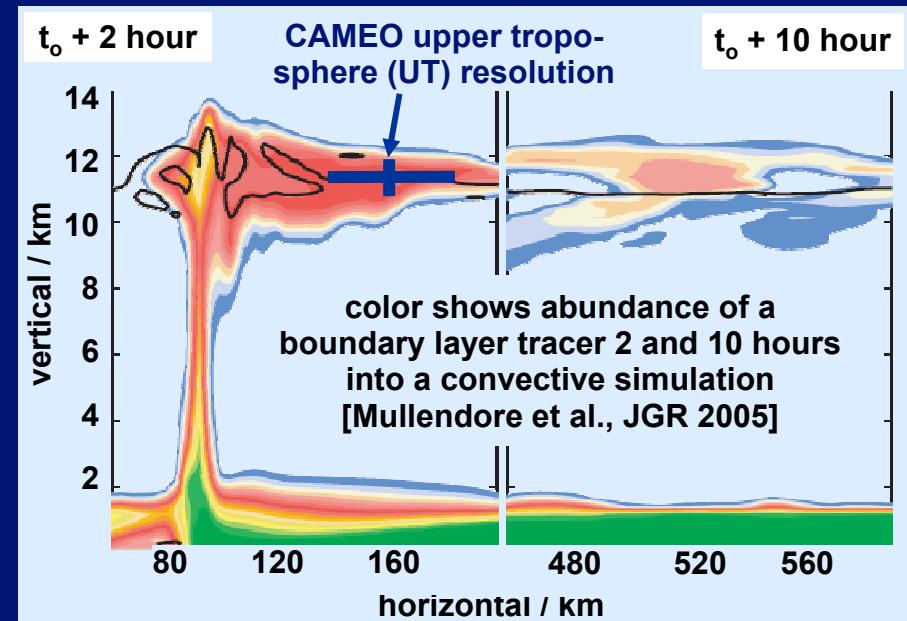
- ❖ CAMEO gives a needed new capability to observe fast processes, such as urban pollution & convective deposition into the upper troposphere

## URBAN NO<sub>2</sub> POLLUTION



EPA CMAQ regional model sampled at CAMEO resolution: 17 Aug 2000 NO<sub>2</sub> pollution in southeastern US. (From Yongtao Hu, Georgia Tech.)

## CONVECTIVE DEPOSITION



Convection, in a few hours, can deposit pollution into the UT, where long-range transport is rapid. Convective deposition also influences UT processes affecting climate; it peaks over land in day, over ocean at night.

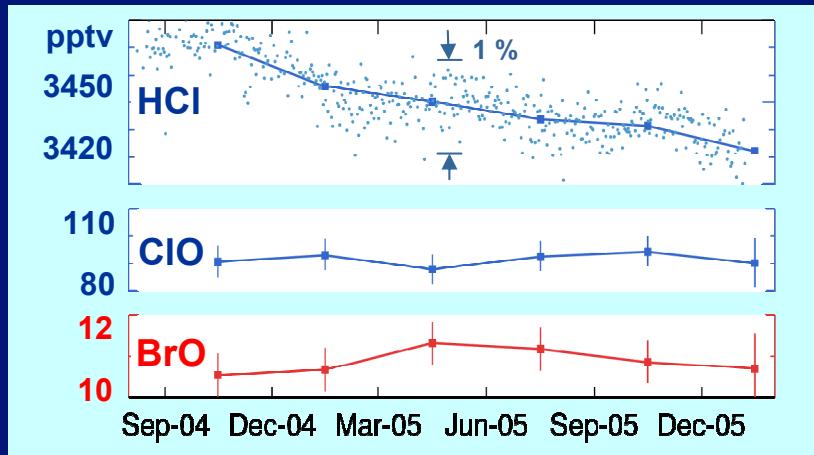
- CAMEO has the needed temporal and spatial resolution; it produces direct broadcast & NRT data that can be used in air quality forecasts

- CAMEO also has the needed vertical resolution to quantify convective deposition in the UT, and the global coverage to track long-range transport of pollution

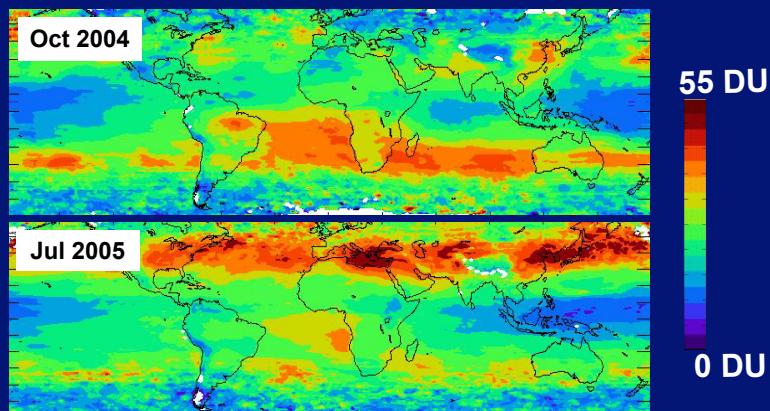
# Long-term measurements

- ❖ CAMEO also continues key measurements needed long-term, including:
  - Tropospheric O<sub>3</sub> and other pollutants
  - Aerosol optical depth and index
  - UT water vapor, cloud ice, temperature
  - Chemicals affecting stratospheric O<sub>3</sub>
    - along with O<sub>3</sub>, tracers of dynamics and temperature
- ❖ Calibration is traceable to standards, as appropriate for such measurements

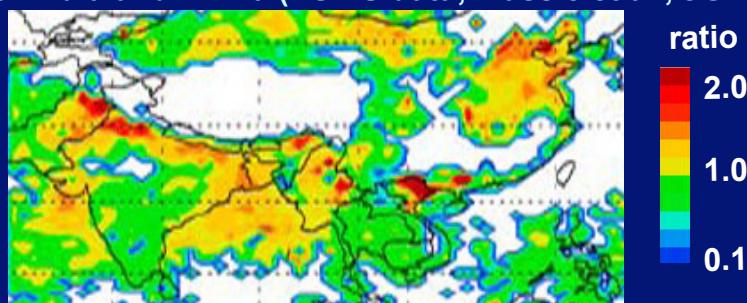
Upper stratospheric chlorine and bromine from Aura MLS



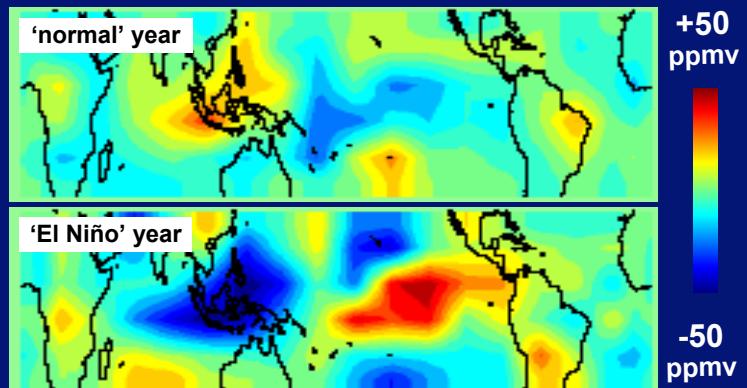
Tropospheric ozone, OMI-MLS (Ziemke et al., JGR)



1979 to 2000 change in aerosol optical depth in winter over India and China (TOMS data; Massie et al., JGR)



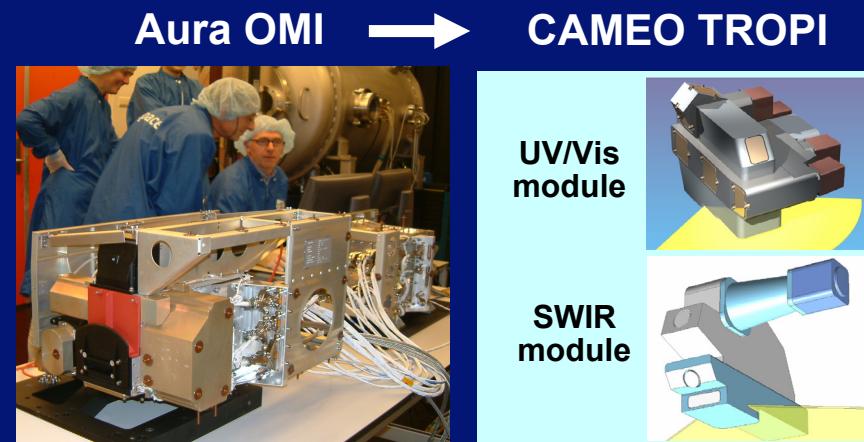
El Niño affecting UT H<sub>2</sub>O (from UARS MLS)



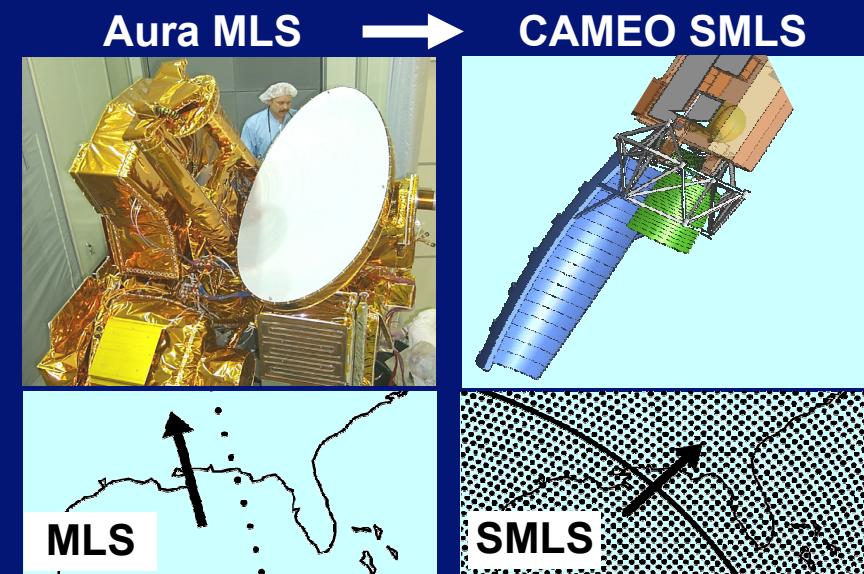
# Instruments

❖ **CAMEO uses advanced versions of instruments proven successful on previous missions**

- **TROPI:** **T**ropospheric **P**ollution **I**mager for UV/Vis/NIR/SWIR measurements of aerosol and tropospheric pollution
  - TOMS, SCIAMACHY, and OMI heritage
  - TROPI uses new 2D imaging detectors and immersed grating technology
  - New detectors & grating give 10x10 km pixel & broad swath for all wavelengths



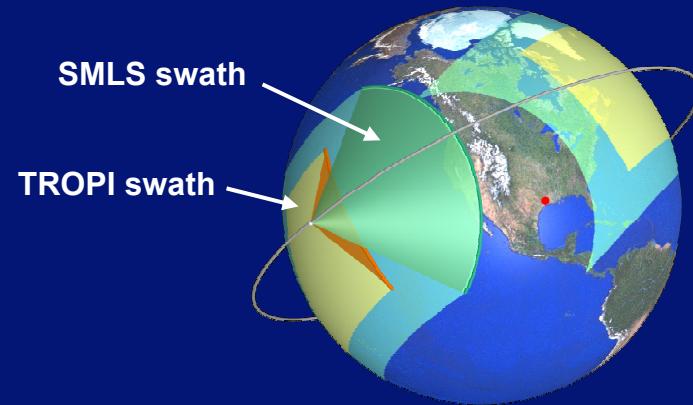
- **SMLS:** **S**canning **M**icrowave **L**imb **S**ounder for upper tropospheric and stratospheric measurements
  - UARS MLS and Aura MLS heritage
  - SMLS gives the needed improvement in horizontal resolution; illustrated at right
  - Improvement made possible by space-qualified cryocoolers that enable satellite use of SIS-type superconductor devices that have been used in ground-based measurements for >20 years
  - The SMLS scan is programmable in both horizontal and vertical directions; as is its measurement suite

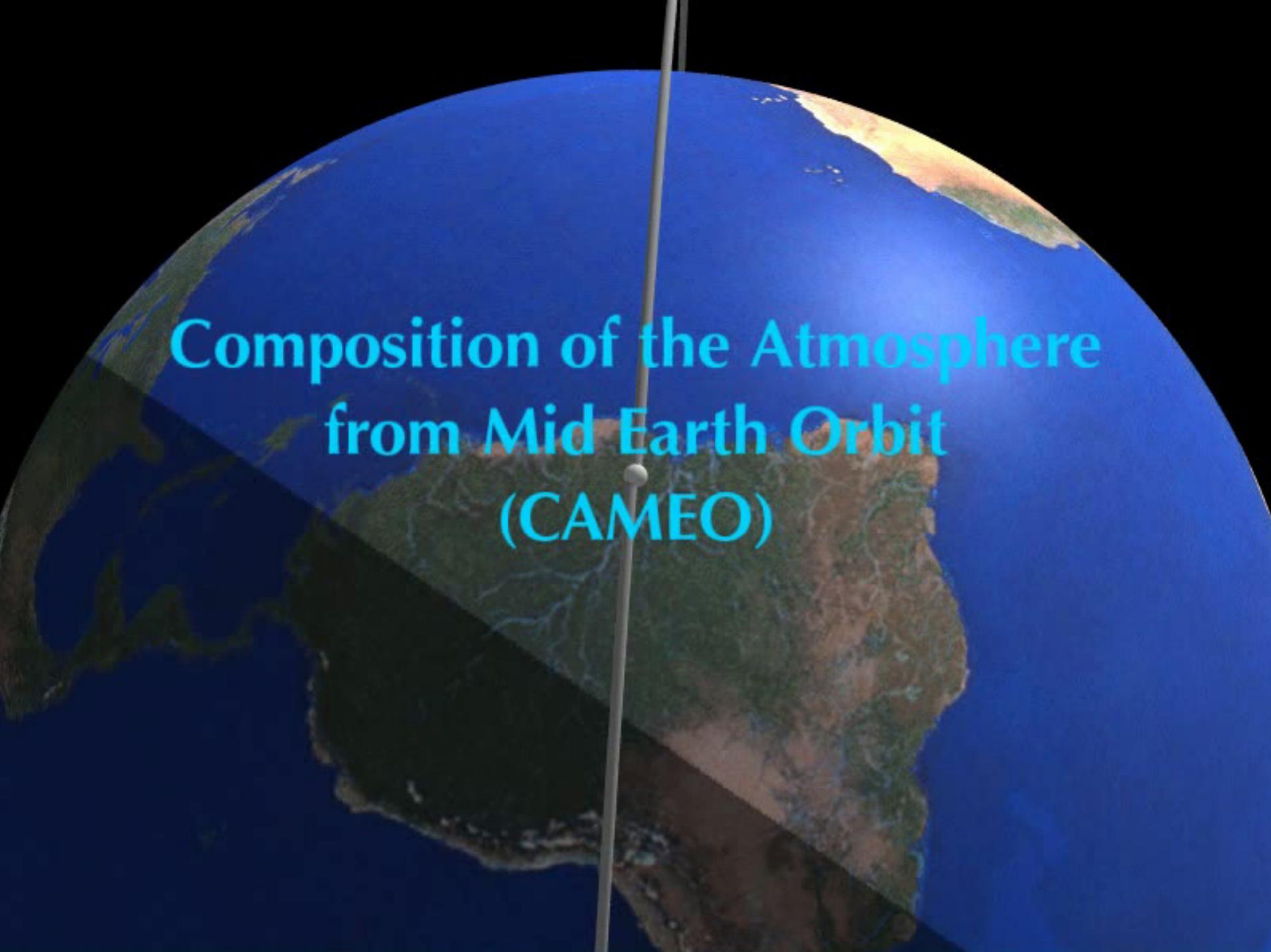


Points are vertical profile measurement locations for part of an orbit; arc is part of one SMLS azimuth scan

# 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

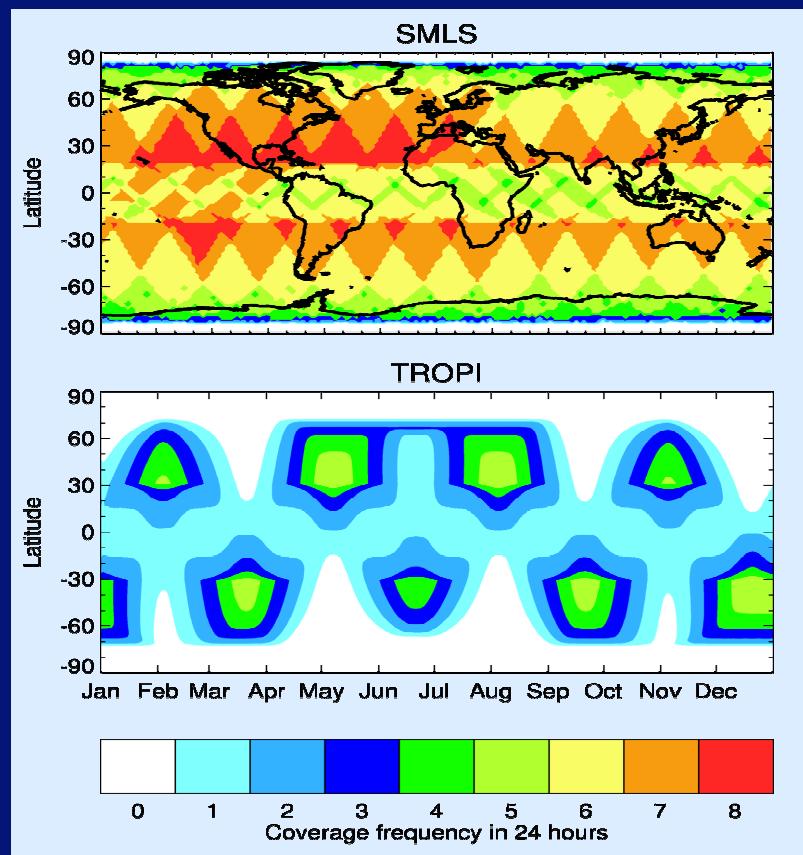




# **Composition of the Atmosphere from Mid Earth Orbit (CAMEO)**

# Quantifying coverage

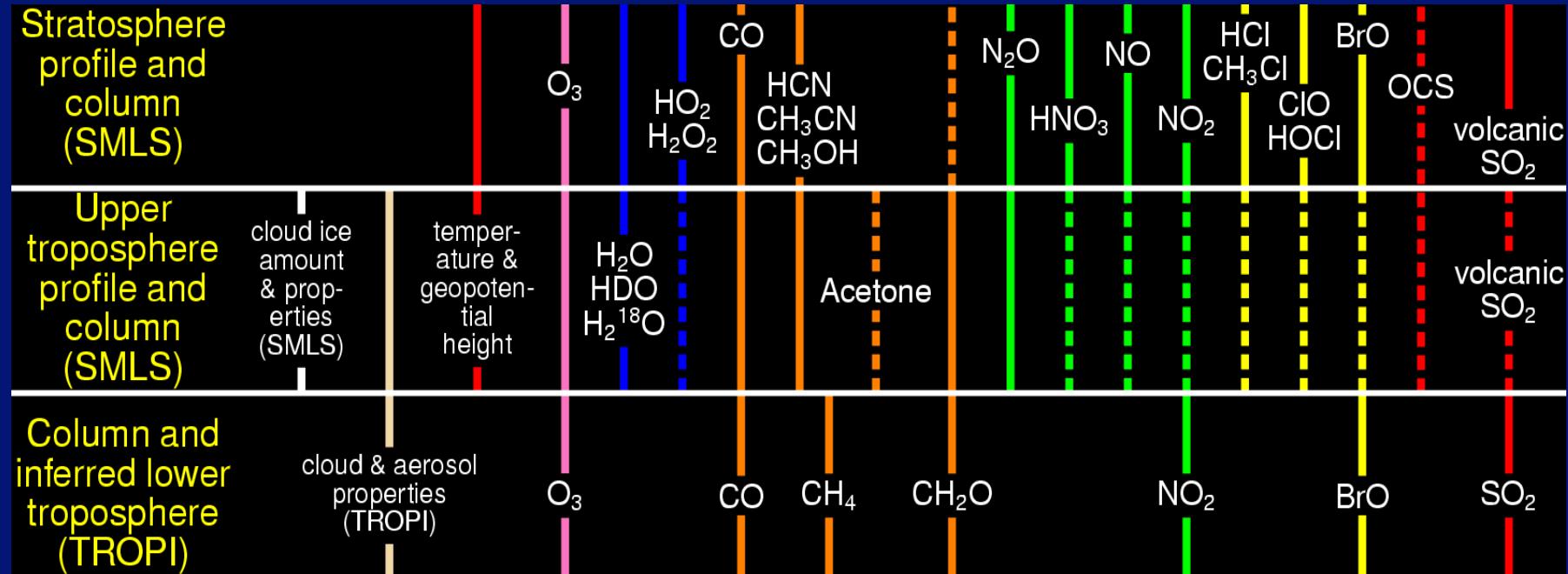
- ❖ For our ‘baseline’ 1500 km altitude, 52° inclination, 1.9 hr period orbit:
  - Daily spurt of measurements spaced by ~2 hours local time, followed by a gap
    - precessing through 24 hours in 90 days
  - SMLS coverage for a typical day →
    - everywhere within a given color is measured that number of times per 24-hr period
    - 50x50 km horizontal, and 1-3 km vertical, pixel size for SMLS ‘global’ mode (can be programmed finer for ‘regional’ modes)
    - 44% of Earth is measured on every orbit
  - TROPI coverage annual variation →
    - all longitudes within a given color are measured that many times per day
    - 10x10 km horizontal pixel size (update of 20x20 km in NRC Decadal Survey document)
    - orbit phase is chosen to favor summer measurements for air quality priorities
  - SMLS covers >99%, TROPI on average 87%, of globe at least once per 24 hr
  - ❖ Further studies can possibly yield a more optimum orbit
    - Also, two CAMEOs in formation (e.g., for operational use) can give TROPI mid-latitude data without gaps shown above, and SMLS data every 2 hours over most of the globe



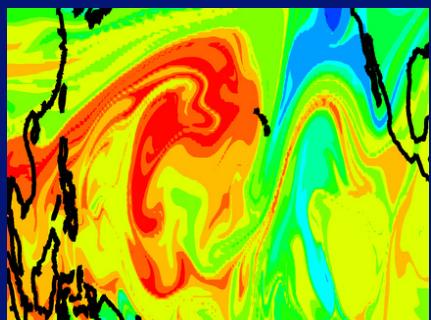
# Measurements

## CAMEO suite of measurements

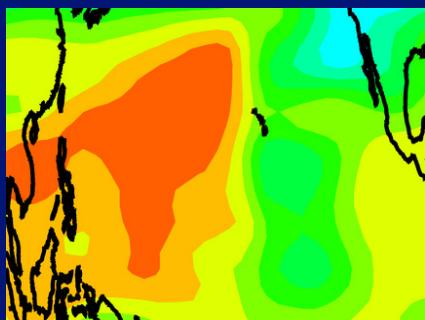
dashed lines are goals for SMLS



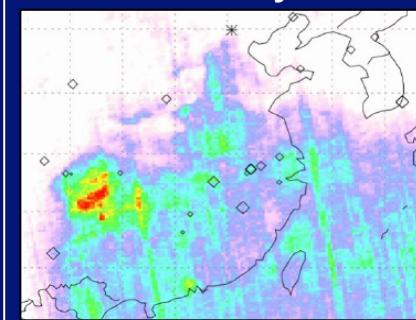
CAMEO SMLS sampling of model upper trop CO



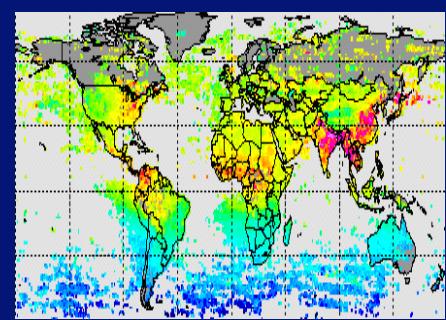
Same field sampled and mapped by Aura MLS



China SO<sub>2</sub> pollution measured by OMI

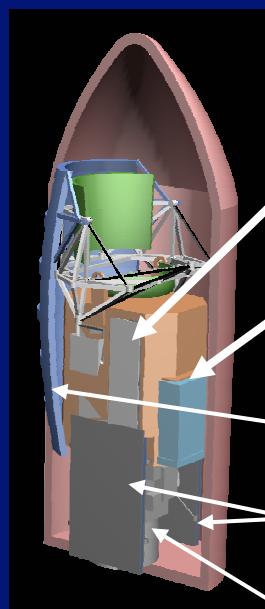


CH<sub>4</sub> from SCIAMACHY (Frankenberg et al., Science)

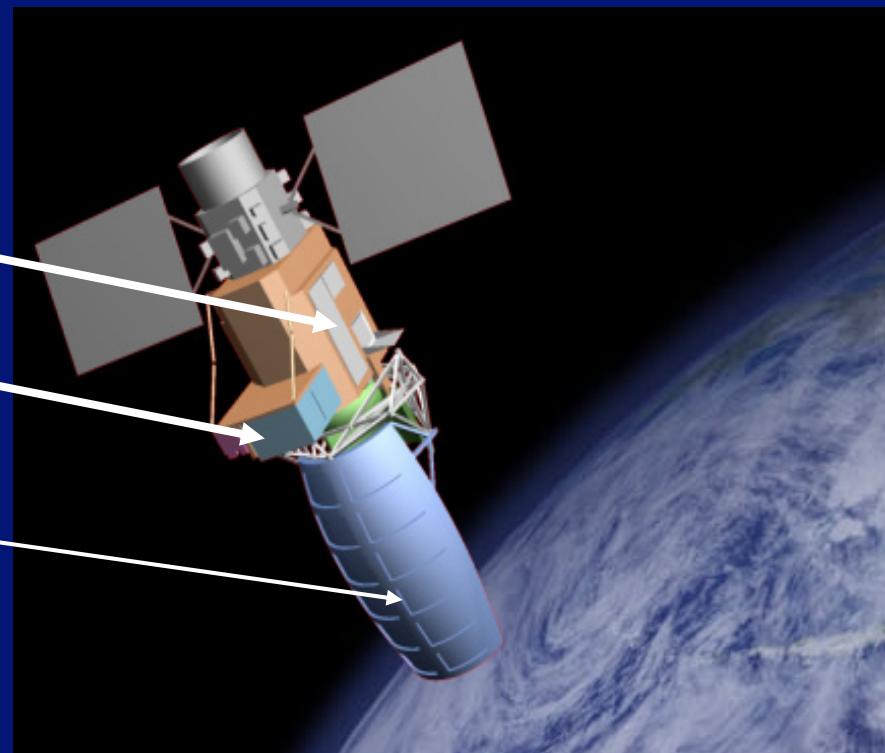


# Implementation

- ❖ JPL mission-team study has confirmed CAMEO's technical feasibility
  - Can be inserted directly into the desired mid-Earth orbit – by a two-stage Delta-II rocket, for example
  - 5 year operational lifetime design is straightforward
  - In addition to TROPI and SMLS, a third instrument could be accommodated



CAMEO stowed  
for launch



CAMEO deployed in orbit  
(SMLS looking into page)

# Summary

- ❖ CAMEO provides atmospheric data needed to address air quality and - simultaneously - other important regional and global issues
  - Air quality
  - Climate change
  - Ozone layer stability
  - Accuracy of global circulation models
- ❖ CAMEO uses a new mid-Earth orbit to give a needed and unique combination of temporal, horizontal, and vertical resolution and global coverage
  - New capability to observe important fast processes
  - Continues key measurements needed long-term
- ❖ CAMEO employs advanced versions of UV/Vis/SWIR and microwave instruments proven successful on previous missions
  - A third instrument could be accommodated

