



NASA's Role in Tropospheric Chemistry

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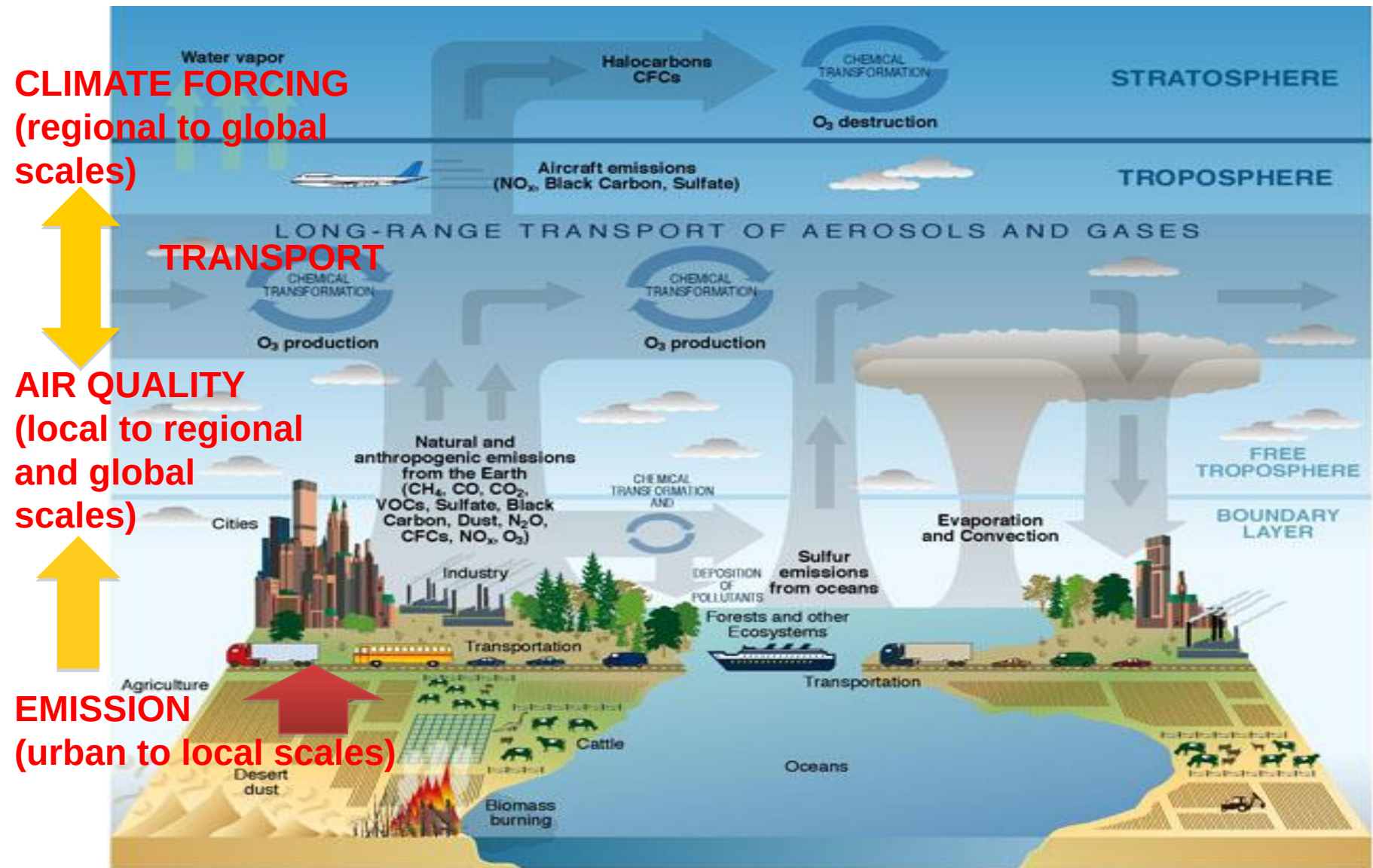
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Student Airborne Research Program. June, 2019

- ◆ *Atmospheric Composition and Tropospheric Chemistry*
- ◆ *Observing Air Quality From Space*
- ◆ *NASA Tropospheric Chemistry Airborne Field Campaigns*
- ◆ *Some Recent and Current Suborbital Campaigns*
 - *EVS-2 ATom: Atmospheric Tomography Experiment*
 - *EVS-2 NAAMES: North Atlantic Marine Ecosystems*
 - *EVS-3 ACTIVATE Aerosol-Cloud Interaction*
 - *EVS-1 DISCOVER-AQ: US Tropospheric Air Quality*
- ◆ *Future Mission:*
 - *EVI-1 TEMPO - Air Quality From Geo & Chemical Weather*
- ◆ *Summary*

Time/Space Scales of Atmospheric Composition: Emission, Transformation, Transport, Removal



Credit: CCSP Strategic Plan (illustrated by P. Rekacewicz)

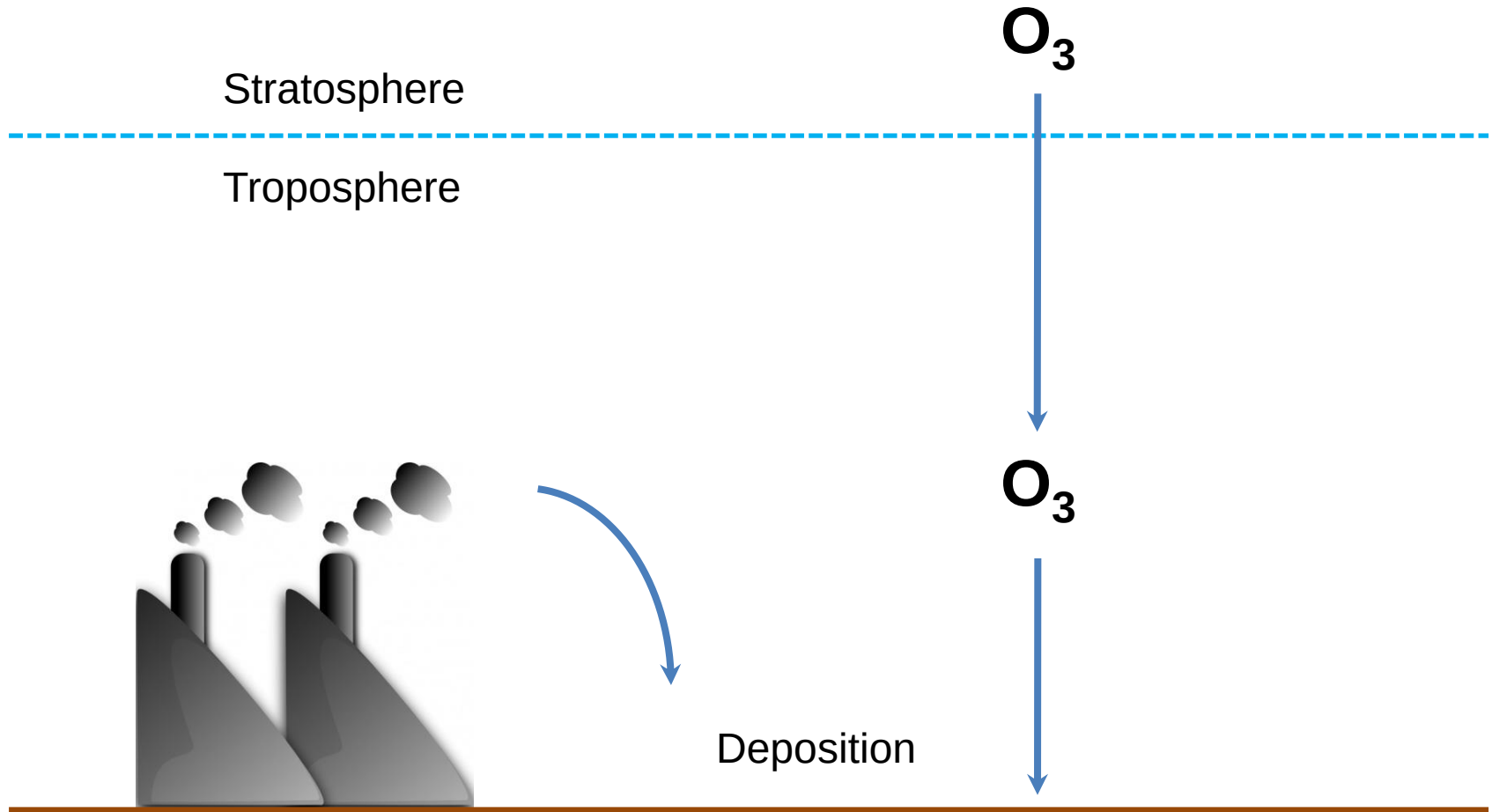
Tropospheric Ozone (O₃) Significance



- ◆ **Environmentally Important:** Ozone is a pollutant adversely impacting atmospheric chemistry, climate, health and agriculture
- ◆ **Chemically Important:** Ozone initiates oxidation cycles responsible for removing most polluting gases from the atmosphere. These oxidation cycles also influence ozone itself
- ◆ Ozone is a key constituent in **photochemical smog**, and high near-surface ozone has profound effects on vegetation, human health and habitability
- ◆ **Climatically Important:** Ozone influences climate directly as a greenhouse gas and is most important in the upper troposphere where temperatures are cold. Ozone exerts an indirect influence through the oxidation of other greenhouse gases
- ◆ NOT to be confused with stratospheric ozone. Same molecule. Very different chemistry and effects!

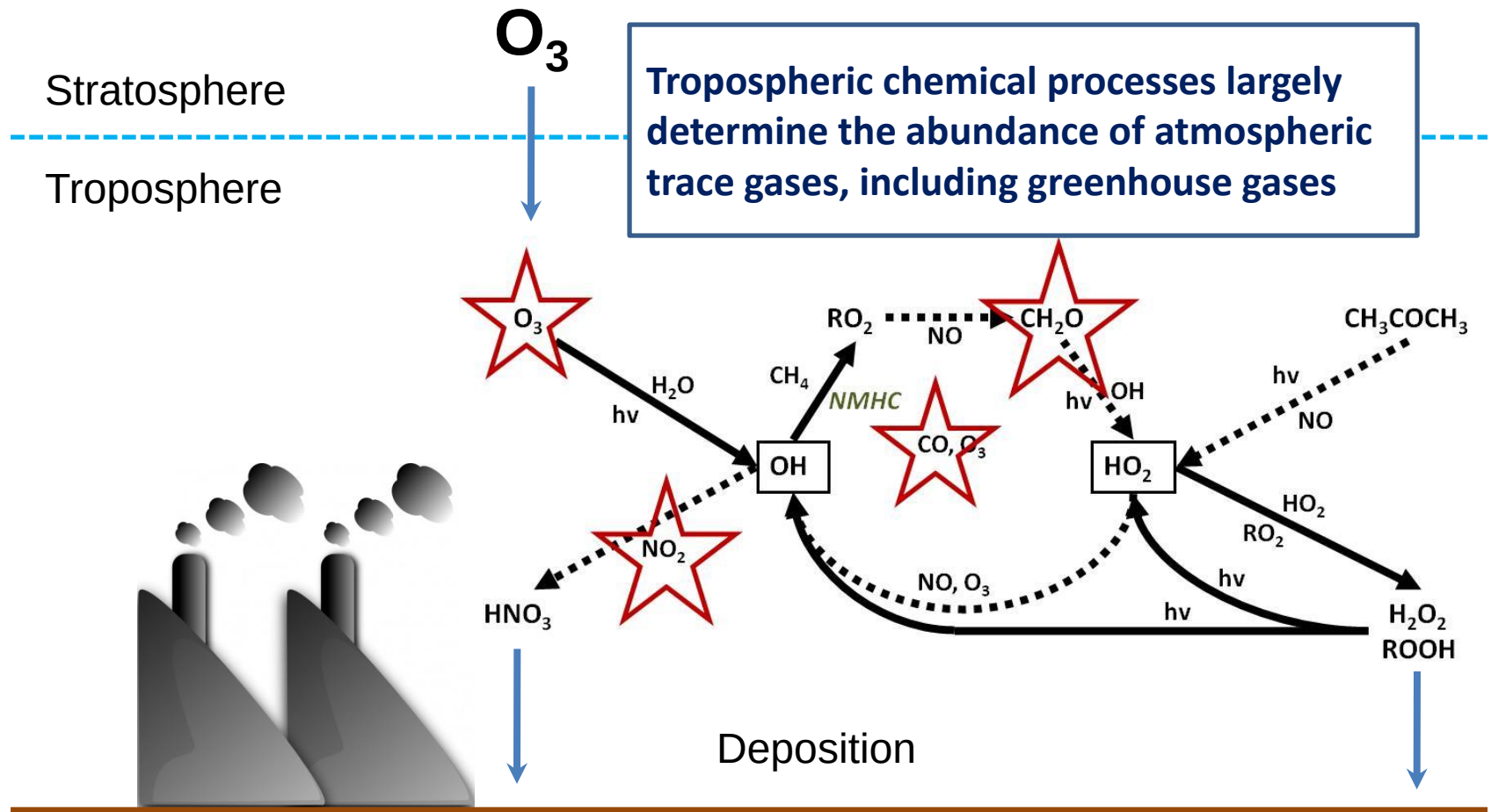
Background

Tropospheric Ozone Chemistry before 1970



Background

Tropospheric Ozone Chemistry after 1970

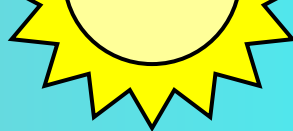


H. Levy II (1971, 1972); Chameides and Walker (1973)

Atmospheric Aerosols Significance



- ◆ **Environmentally Important:** Aerosols play diverse and key roles in climate, adversely impact health, reduce visibility, and acidify precipitation
- ◆ **Chemically Important:** Aerosols are critical in atmospheric removal processes
- ◆ **Climatically Important:** Aerosols influence Earth's energy balance directly through the scattering and absorption of radiation as well as indirectly through modification of clouds (e.g., distribution and optical properties)
- ◆ Chemistry, hygroscopicity and morphology are critical determinants of atmospheric aerosol properties

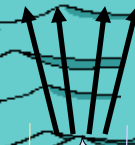
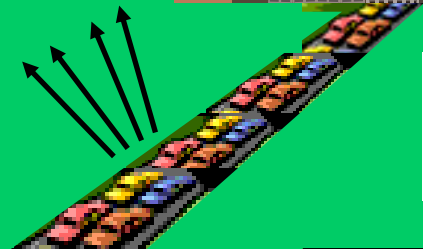
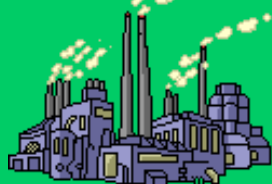
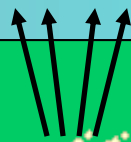
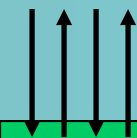
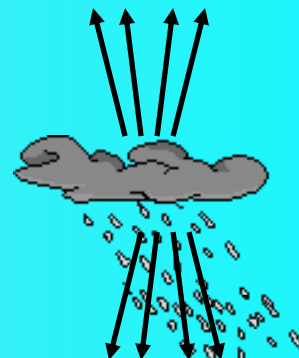


Emission ———> Transformation/Oxidation ———> Removal

(**NO_x**, **CO**, Hydrocarbons,
Aerosol, **SO₂**, **NH₃**,
VOC, glyoxal)

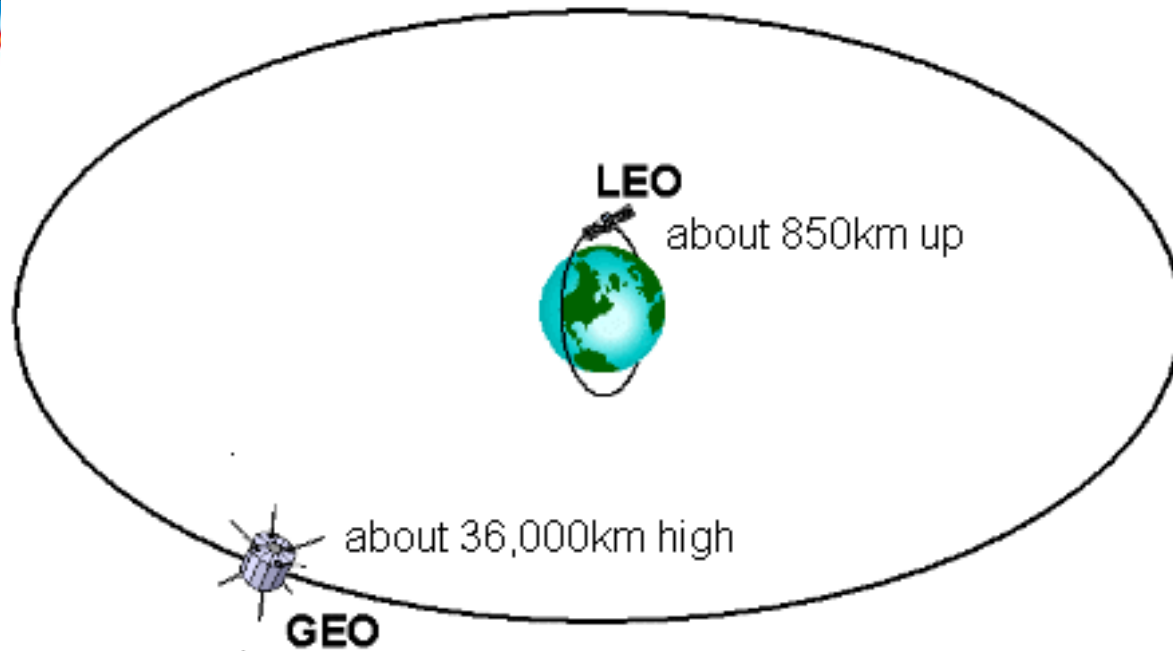
(**O₃**, OH, **CH₂O**, HO₂, RO₂,
Aerosol, **BrO**, glyoxal)

(**HNO₃**, H₂O₂, ROOH,
Aerosol),



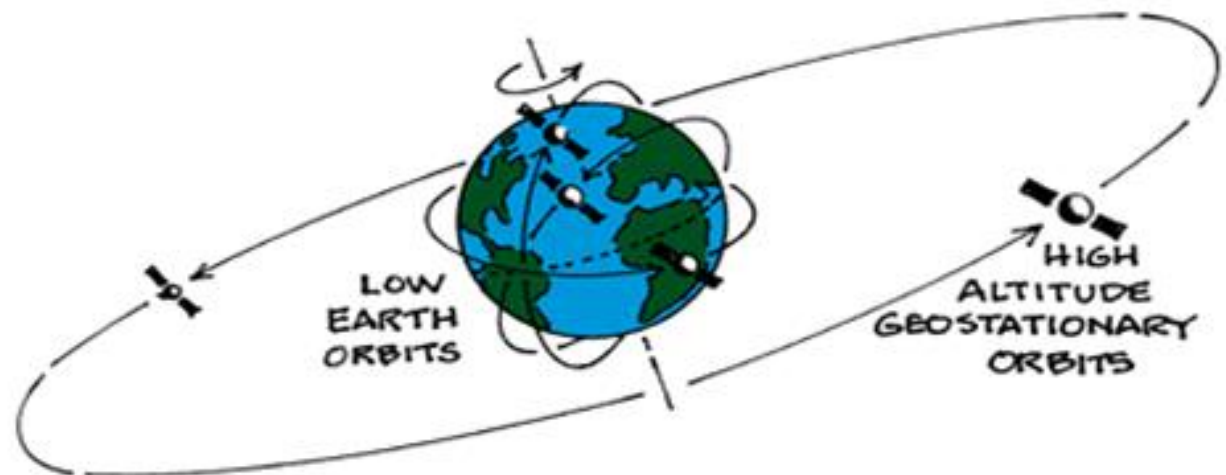
Observed from space
routinely or **developmentally**

Satellite Orbits Used for Earth Observations



Low Earth Orbit (LEO)
Global Coverage
Brief Viewing Time
Relatively Close

Geostationary (GEO)
Hemispheric Coverage
Continuous Stare
Far Away



LEO Satellite Observations Relevant to Tropospheric Chemistry

A legacy of the Earth Observing System (EOS) vision

Ozone (O_3): Aura-OMI, Aura-MLS, Aura-TES, Suomi NPP-OMPS, Suomi NPP-CrIS

Carbon Monoxide (CO): Terra-MOPITT, Aqua-AIRS, Aura-TES

Nitrogen Dioxide (NO_2): Aura-OMI

Formaldehyde (CH_2O): Aura-OMI

Aerosol: Terra-MODIS and MISR, Aqua-MODIS, Aura-OMI, CALIPSO, Suomi NPP-VIIRS

Global observations approximately once per day

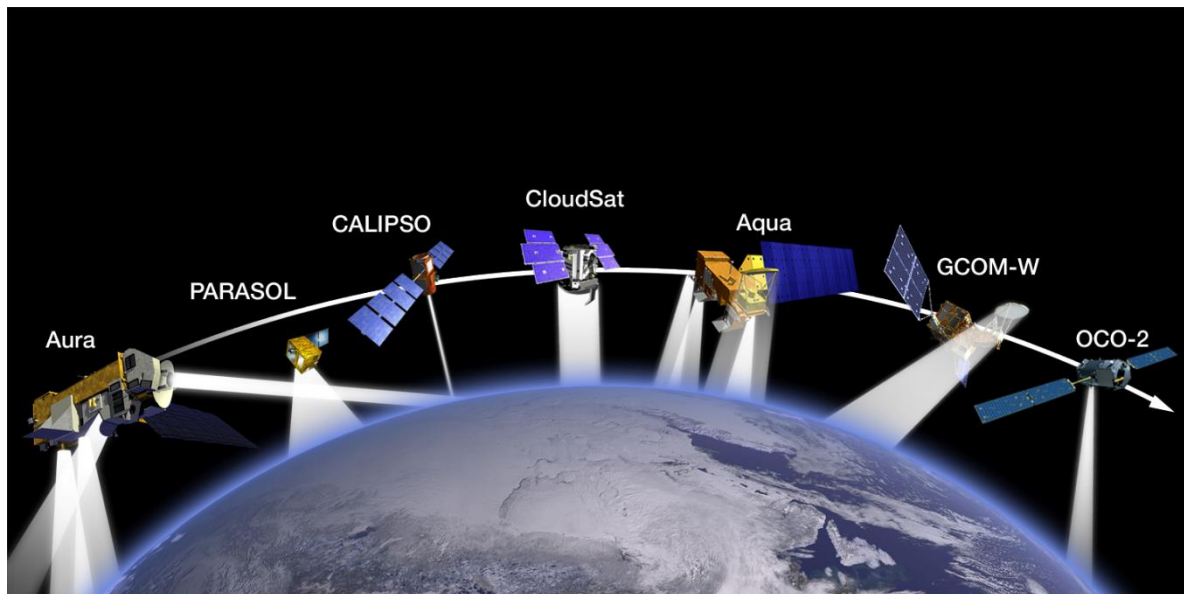
Launch dates: Terra 1999, Aqua 2002, Aura 2004, CALIPSO 2006, Suomi NPP 2011, OCO-2 2014



Terra



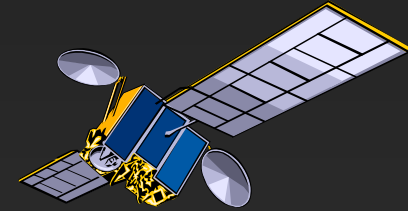
Suomi NPP



Airborne Field Campaign Strategy: Maximize the value of satellite data for improving models of atmospheric composition and climate

Satellite/Instruments:

MLS, CALIPSO, MODIS, MISR, OMI, MOPITT, AIRS, VIIRS, CrIS,...



Aircraft:

DC-8, P-3B, C-130, ER-2, Global Hawk, B-200/UC-12,...



Ground-Based Networks:

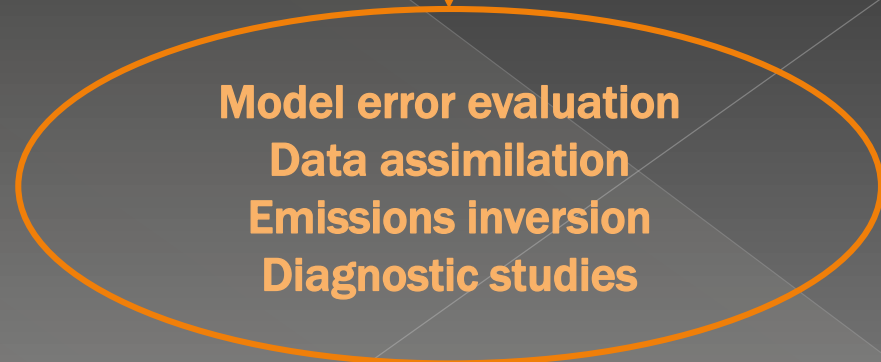
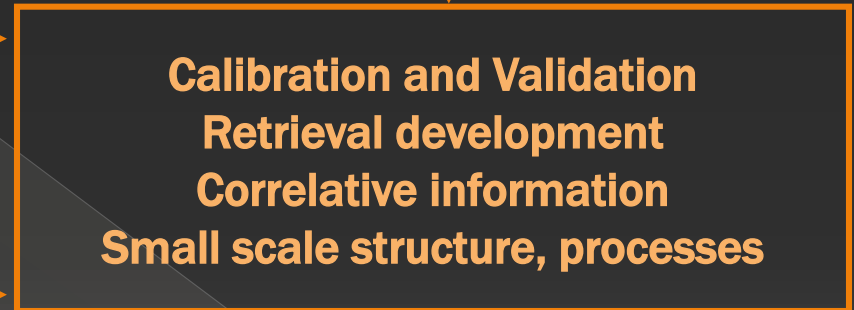
AERONET, MPLNET, SHADOZ, AQS, Pandora, TOLNet,...



Global and Regional Models:

GCMs CTMs

- Understanding
- Attribution
- Prediction



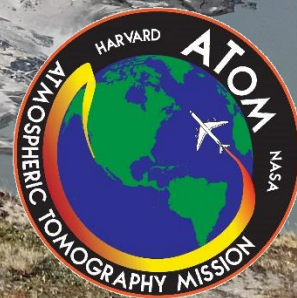
- ◆ Most effective way to obtain wide-ranging yet detailed atmospheric surveys: **“Discovery”**
- ◆ Comprehensive investigations of specific atmospheric processes: **“Understanding”**
 - *Wide range of measurements for atmospheric parameters and trace species in gas and particulate phase critical to our understanding of air quality and climate change related issues*
 - *High spatial (Horizontal: 0.2 – 12 km; Vertical: 10 – 300 m) and temporal (1 s – minutes) resolutions*
- ◆ Validate and provide context for longer term satellite and ground observations: **“Monitoring”**
- ◆ Evaluate and improve models: **“Prediction”**
 - *Wish to avoid “... getting the right answer for the wrong reason.”*

ATom: Atmospheric Tomography Experiment

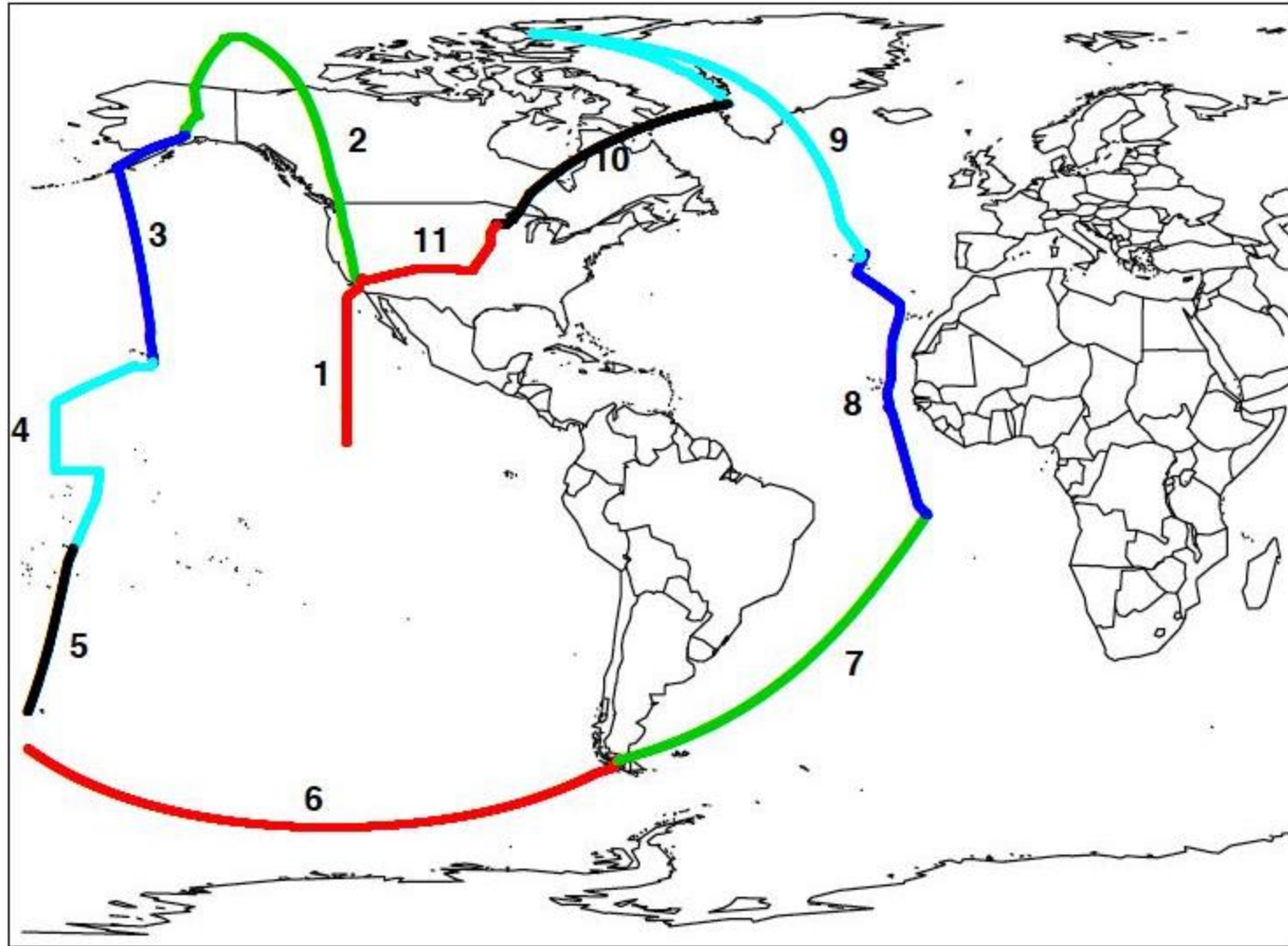
- What are the chemical processes that control distribution and abundance of O_3 and CH_4 ?
- How is global-scale atmospheric chemical reactivity affected by anthropogenic emissions?
- How can we improve chemistry-climate simulations of these processes?



Kangerlussuaq, Greenland
August 2016



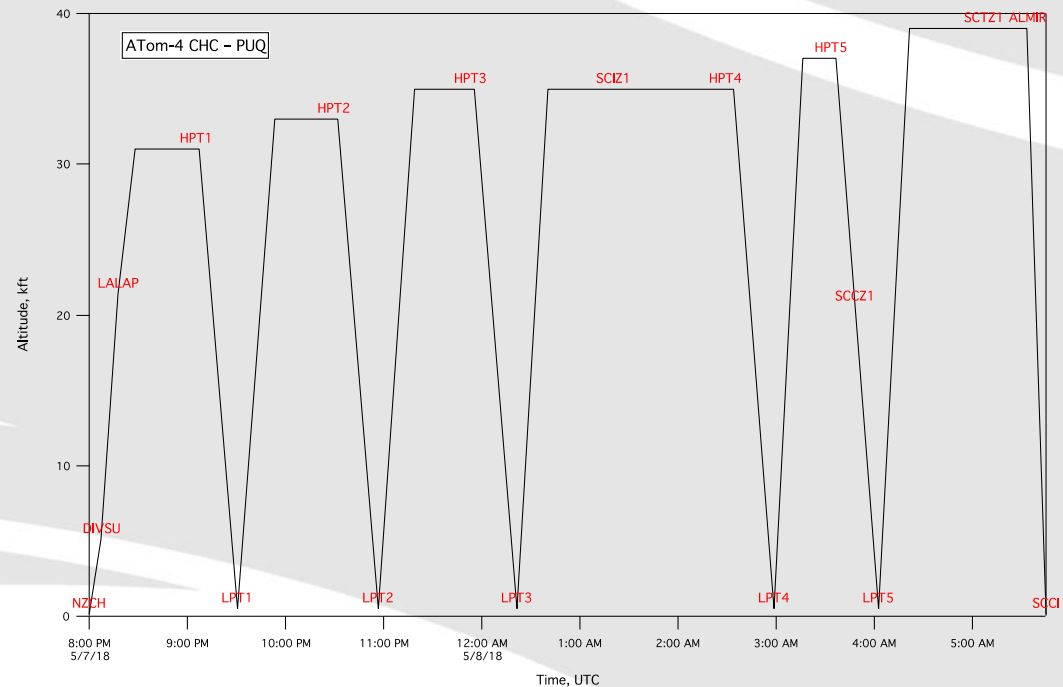
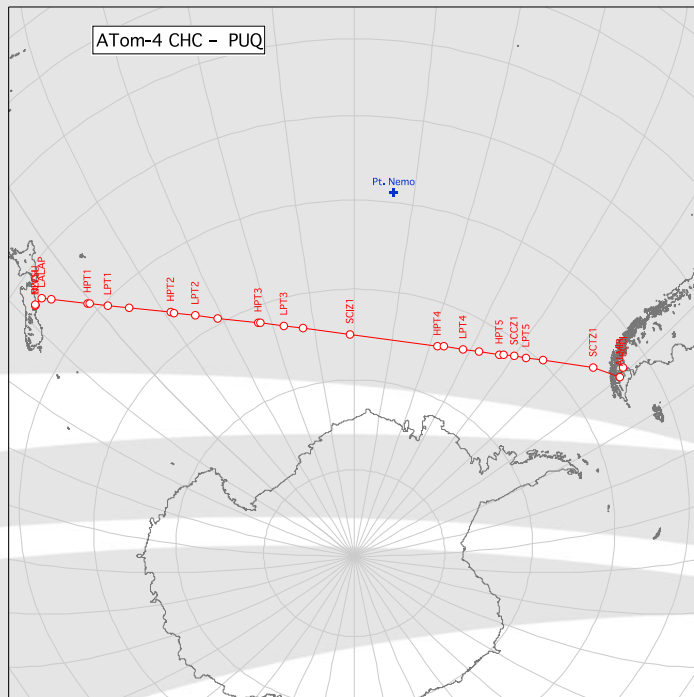
ATom-1 Flight Tracks (ATom-2,3,4 similar)



Example ATom flight plan and profile



ATom-4 flight from Christchurch, NZ to Punta Arenas, Chile



High leg altitudes and durations adjusted to achieve overall flight objectives, guided by ATC.
Low altitudes typically 5 min at 500' ASL, conditions permitting.

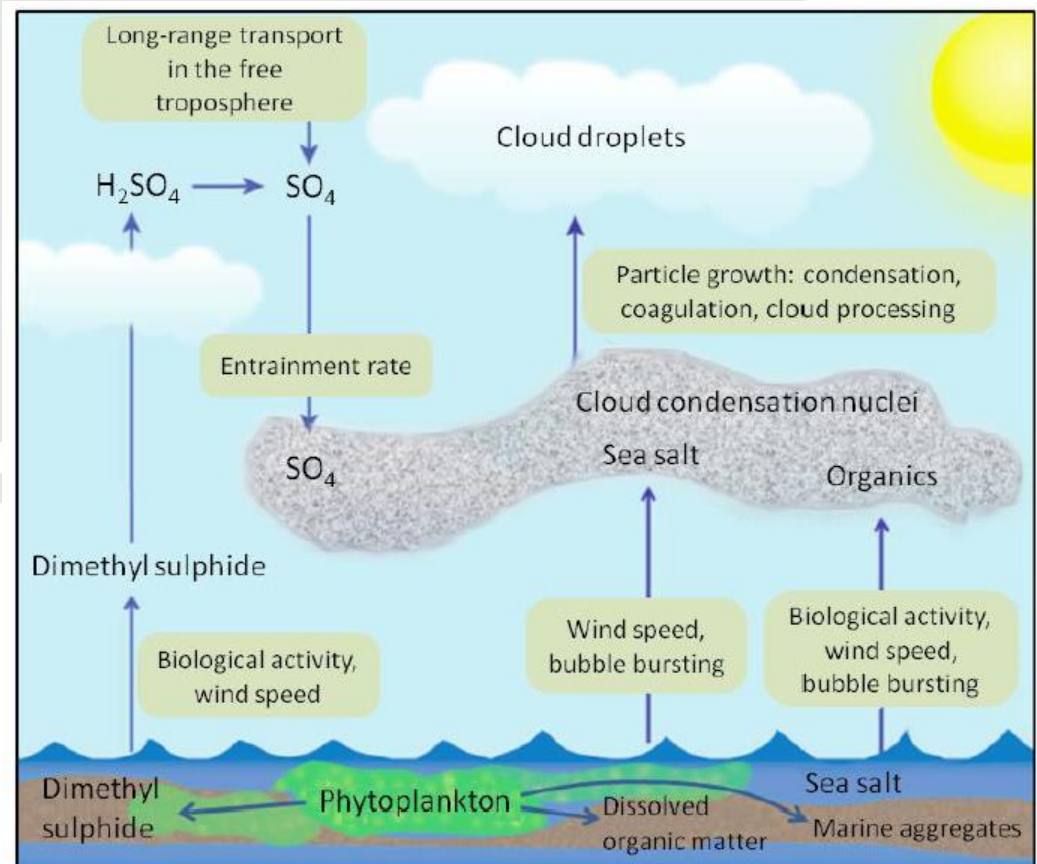
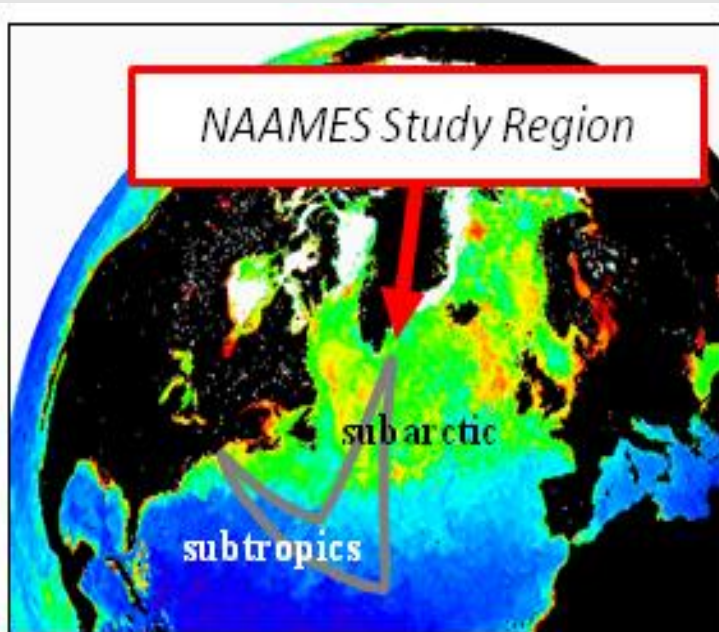
It's rough duty, but someone has to do it!



EVS-2 North Atlantic Aerosols and Marine Ecosystems Study (NAAMES)



- ◆ Determine the primary phases of the **North Atlantic plankton annual cycle**
- ◆ Resolve how these **ocean ecosystem changes influence aerosols and clouds**



NAAMES Combines Ship, Airborne and Satellite Observations to Study the Ocean-Atmosphere



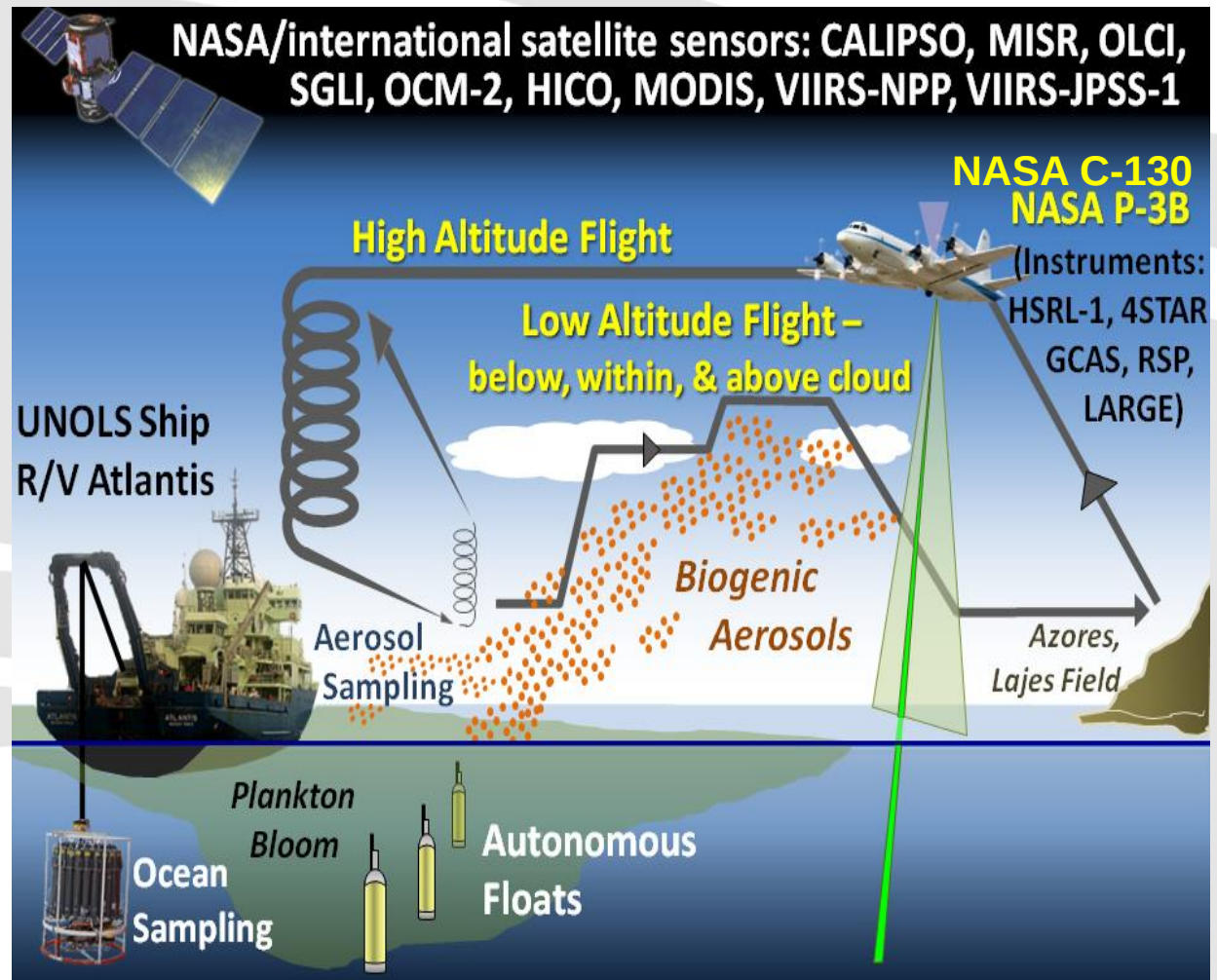
- 4 campaigns, seasonally spaced
- 26-day ship deployments
- 19-day aircraft deployments
- 6 flights over ship per deployment



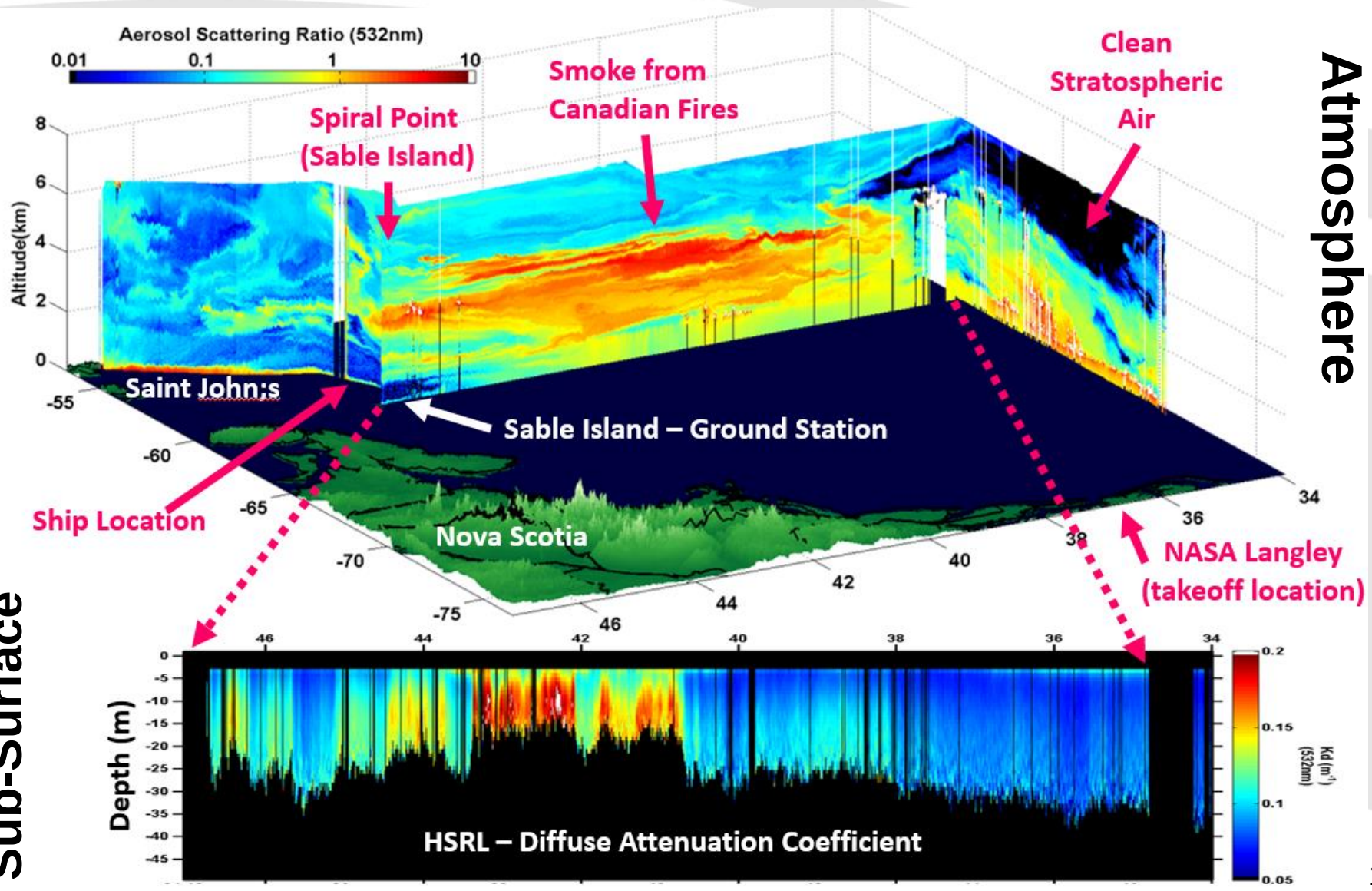
C-130



UNOLS Research Vessel



Atmosphere



Sub-Surface



Langley Research Center
Venture Class

ACTIVATE

Aerosol Cloud meTeorology Interactions oVer the western ATlantic Experiment (ACTIVATE)

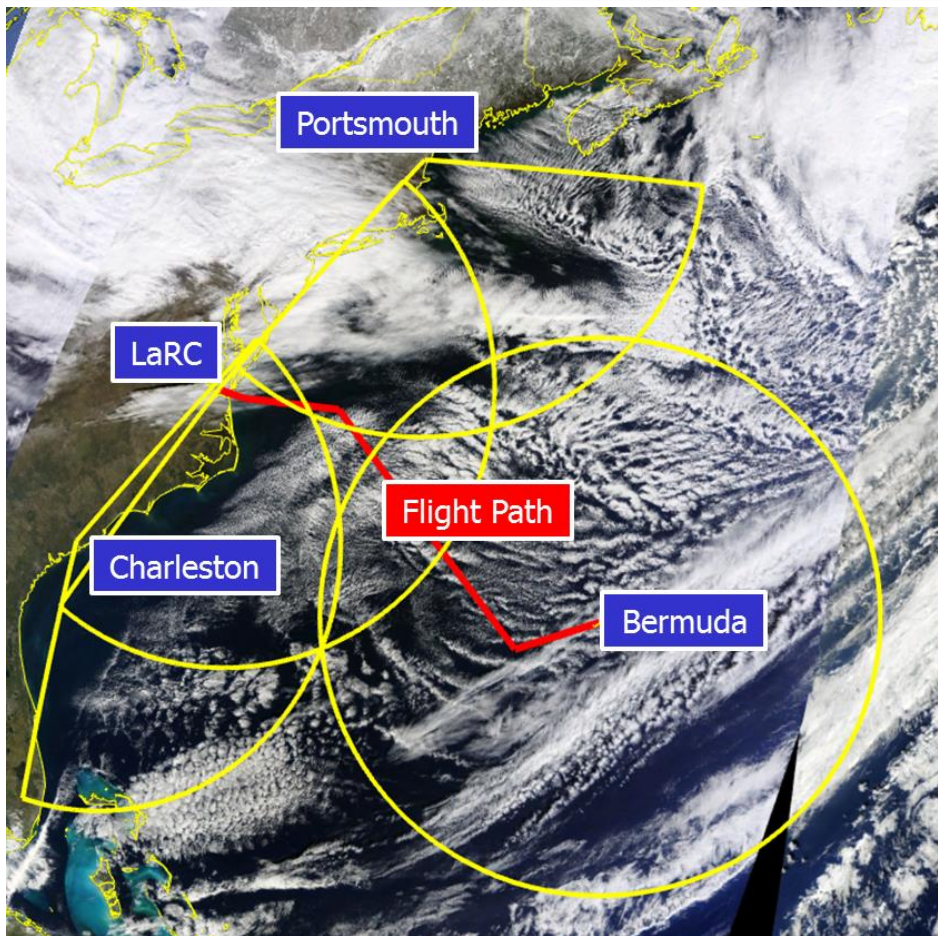
Earth Venture Suborbital-3 (EVS-3)

Slides courtesy of the ACTIVATE Science Team





Cloud-Aerosol Experimental Overview



Why such high uncertainty?
Complexity of clouds and difficulty in untangling influences from aerosols and meteorology.

Why ACTIVATE?
Will quantify relationships between aerosols, clouds, and meteorology with a new experimental approach.

Goal: A statistically robust dataset collected through six deployments over three years: 1200 hours, 300 flights (combined for two planes)



Platforms

Langley King Air - B200



High-Altitude Remote Sensing

Range: 1,500 km

Altitude: 9 km

Airspeed: 120 m/s

Duration: ~4 hours

Low-Altitude In-situ

Range: 3,000 km

Altitudes: 0.15 - 3 km

Airspeed: 100-130 m/s

Duration: ~4 hours

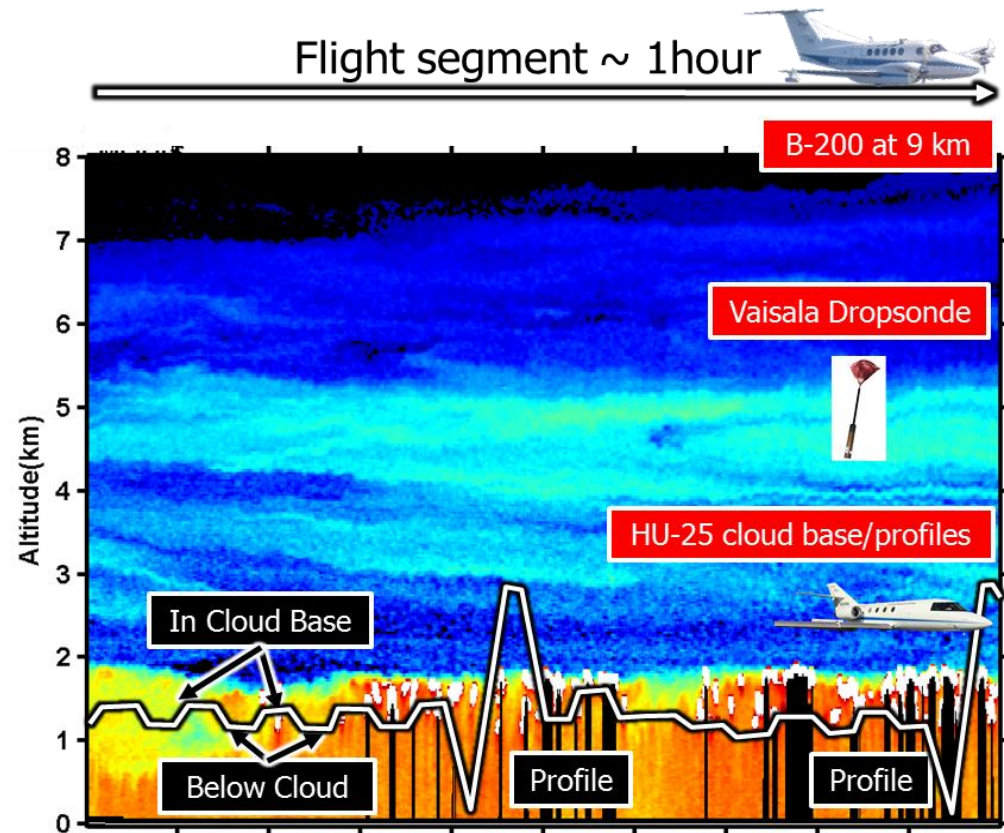
Langley HU-25 Falcon





Science/Investigation Overview

- Stacked two-aircraft flights over the western North Atlantic Ocean.
 - *NASA LaRC HU-25 Falcon & B-200 King Air*
- B-200 hosts the remote sensors and dropsondes
 - HSRL-2 Lidar (*LaRC*)
 - RSP Polarimeter (*GISS*).
 - Dropsondes (*LaRC*) - first time on B-200
 - PAMR Microwave radiometer (*U. of Miami*) – new technology
- HU-25 hosts the in-situ instruments
 - LARGE (*LaRC*) aerosol optical and microphysics
 - LARGE (*LaRC*) cloud probes and cloud water collection*
 - DLH (*LaRC*) water vapor
 - TAMMS (*LaRC*) winds



*Note: DLR (German Aerospace Center) is contributing cloud probes



Improving the View of Atmospheric Composition & Air Quality From Space



Somewhat closer to:
Measuring everything, everywhere, all the time

The Problem



Near-surface pollution is one of the most challenging problems for Earth observations from space...

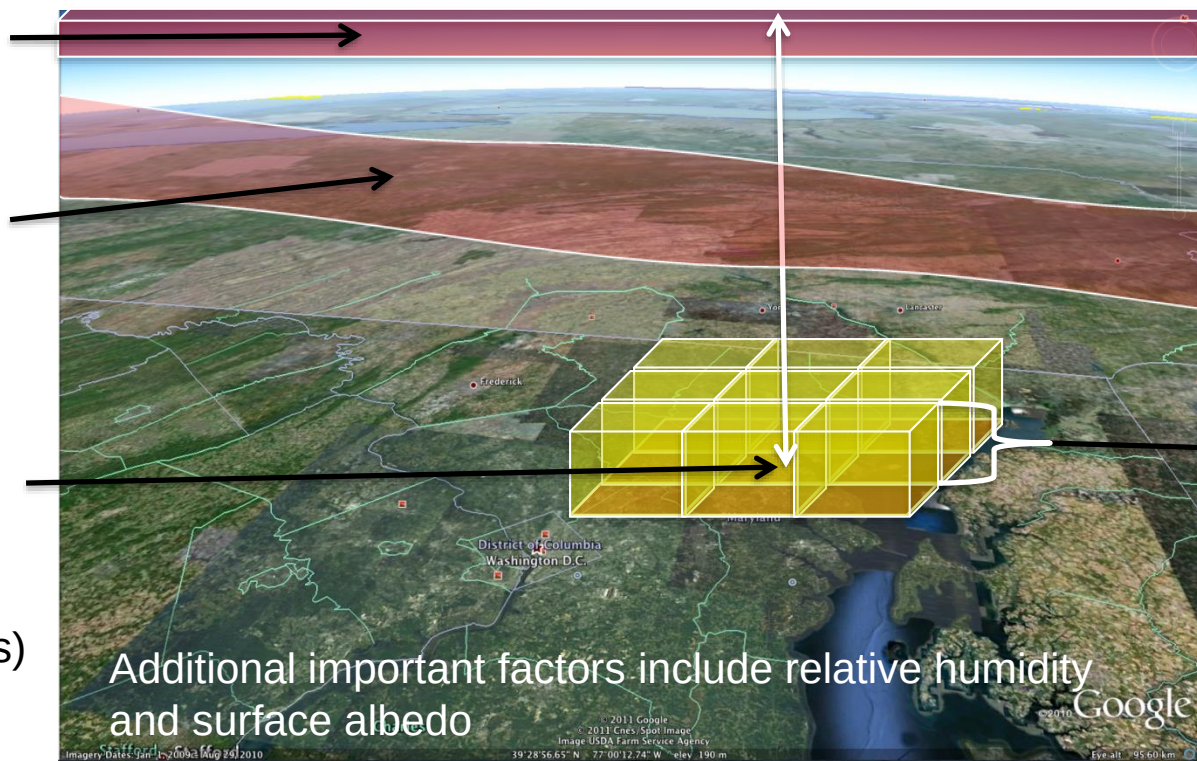
Near-surface information must be inferred from column-integrated quantities obtained by passive remote sensing from downward-looking satellite instruments

Some constituents have large relative concentrations in the stratosphere and/or free troposphere (e.g., O_3 and NO_2) making it difficult to distinguish the near-surface contribution to the total column

Stratospheric Burden

Long-range transport of pollution aloft

From space, the size of the measurement pixel matters (as does grid size for models)



Boundary layer depth influences the volume over which surface pollution is mixed

It also matters how well the pollution is mixed

Deriving Information on Surface Conditions from Column and VERTically Resolved Observations Relevant to Air Quality

A NASA Earth Venture campaign intended to **improve the interpretation of current and future satellite observations** to diagnose near-surface conditions relating to air quality

Objectives:

1. **Relate column observations to surface** conditions for aerosols and key trace gases O_3 , NO_2 , and CH_2O
2. Characterize differences in **diurnal variation** of surface and column observations for key trace gases and aerosols
3. Examine **horizontal scales of variability** affecting satellites and model calculations

Deployments and key collaborators

Maryland, July 2011 (EPA, MDE, UMd, UMBC, Howard U.)
California, January 2013 (EPA, CARB, UC-Davis&Irvine)
Texas, September 2013 (EPA, TCEQ, U. of Houston)
Colorado, Summer 2014 (EPA, NSF, NOAA, CDPHE)



Deployment Strategy



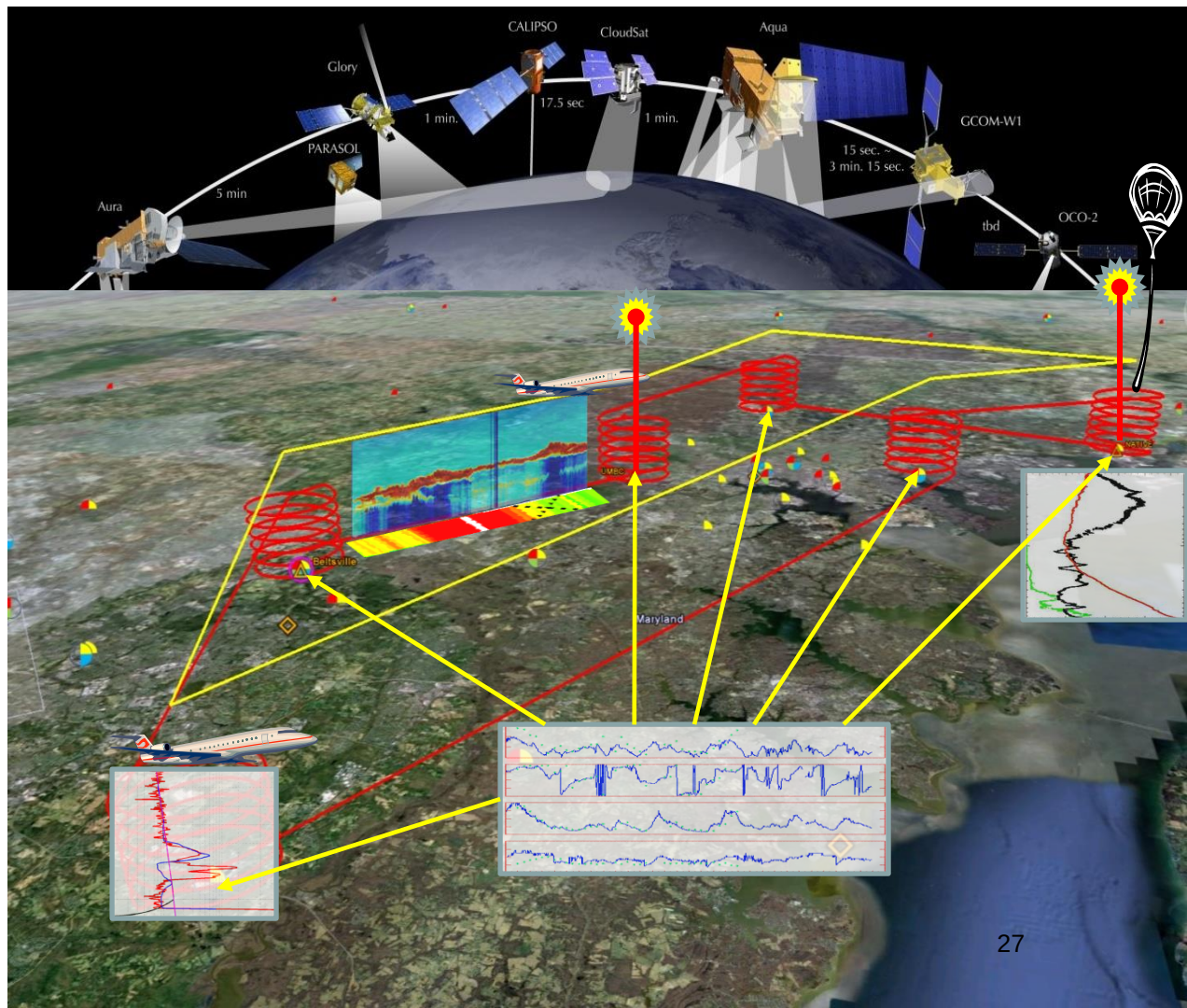
Systematic and concurrent observation of column-integrated, surface, and vertically-resolved distributions of aerosols and trace gases relevant to air quality as they evolve throughout the day. EXAMPLE: Baltimore-Washington Corridor

Three major observational components:

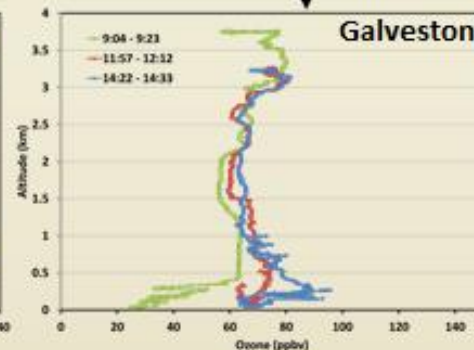
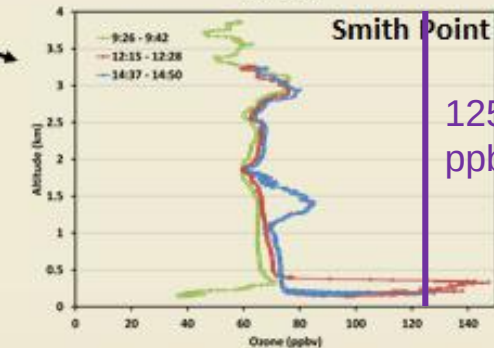
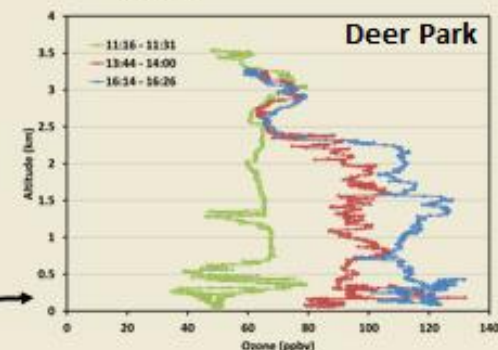
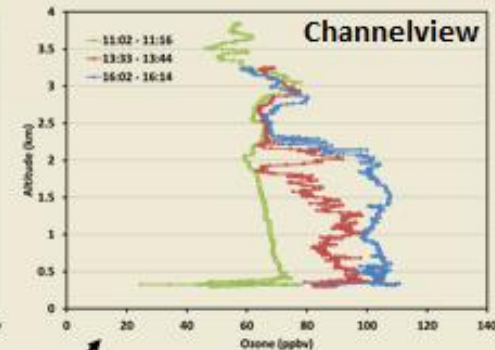
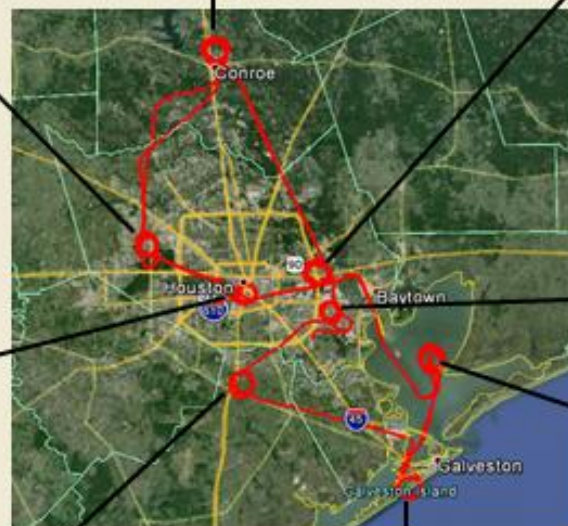
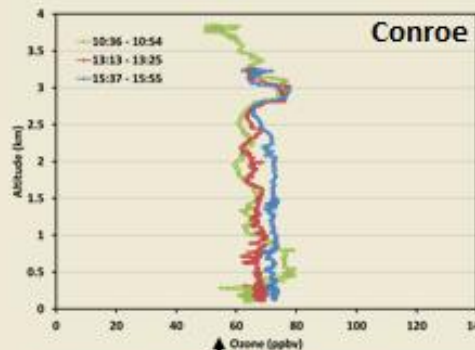
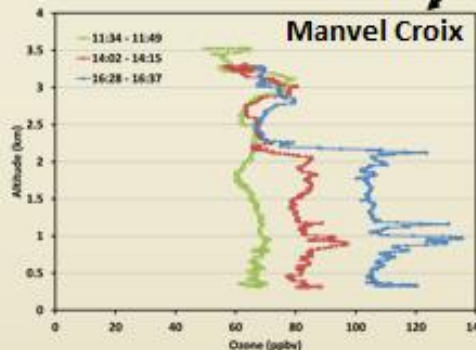
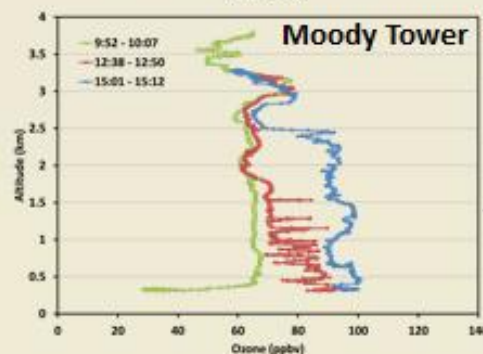
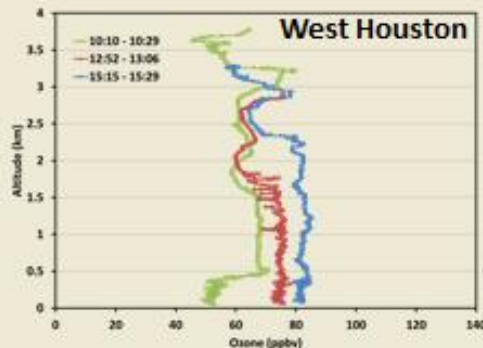
NASA King Air (Remote sensing)
Continuous column mapping of aerosol “curtains” with HSRL and trace gas columns with ACAM

NASA P-3B (in situ meas.)
In situ “spiral” profiling of aerosols and trace gases over surface measurement sites

Ground sites
In situ trace gases and aerosols
Remote sensing of trace gas and aerosol columns
Ozonesondes
Tethered balloons
Aerosol lidar observations



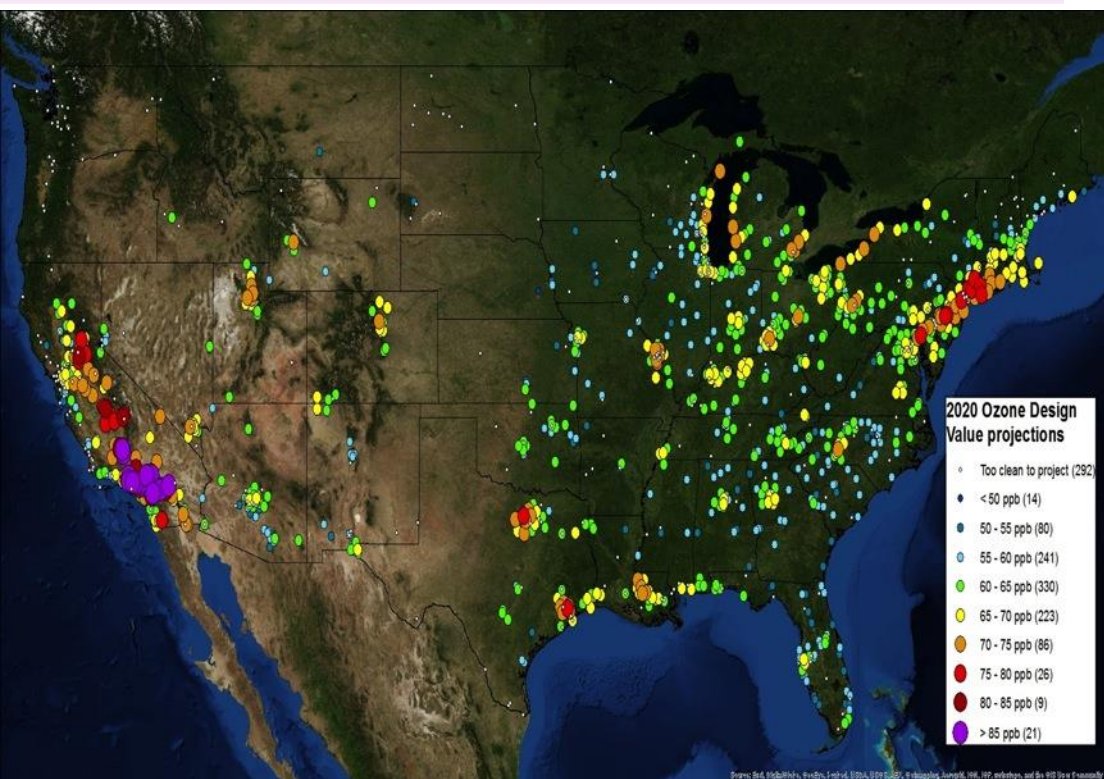
x: Ozone, O_3 (0-140 ppbv)
y: Altitude (0-4 km)



125
ppbv

- US air quality standards continue to become more stringent to better protect human health
- New and transient pollution sources (e.g., vehicular traffic, oil & gas development, trans-boundary pollution) are growing in importance yet are very difficult to monitor from ground networks
- Many areas that are not currently monitored are expected to violate proposed ozone standards
- TEMPO measurements will provide data to help solve this national challenge

US EPA Ozone 8-hour Design Projections to 2020

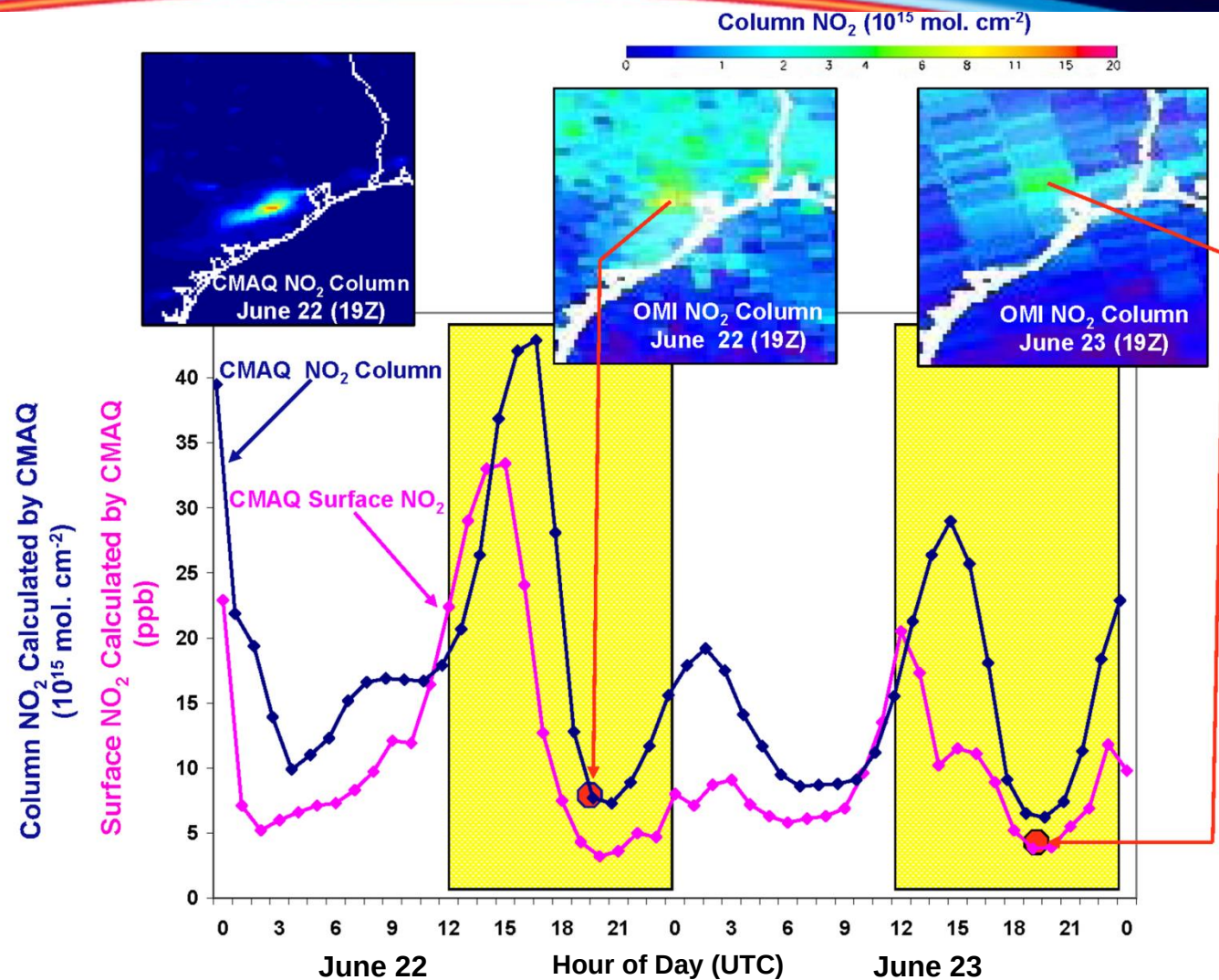


TEMPO Science Questions

1. What are the temporal and spatial variations of **emissions** of gases and aerosols important for air quality and climate?
2. How do physical, chemical, and dynamical **processes** determine tropospheric composition and air quality over scales ranging from urban to continental, diurnally to seasonally?
3. How does air pollution drive **climate** forcing and how does climate change affect **air quality** on a continental scale?
4. How can observations from space improve air quality **forecasts and assessments**?
5. How does **intercontinental transport** affect air quality?
6. How do **episodic events**, such as wild fires, dust outbreaks, and volcanic eruptions, affect atmospheric composition and air quality?

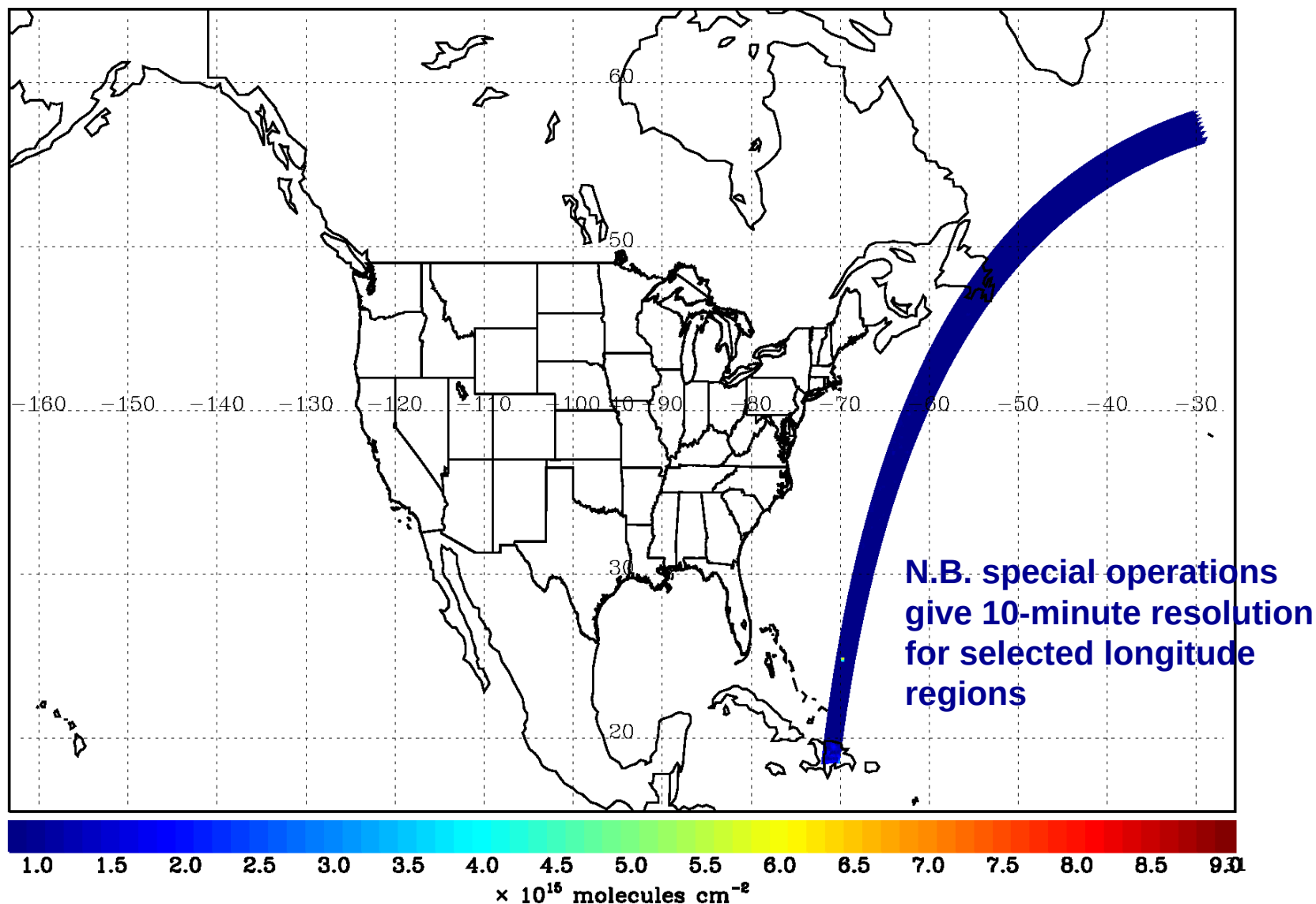
Why Geostationary? High temporal and spatial resolution

OMI accurately detects column NO_2 - once per day and with varying horizontal resolution



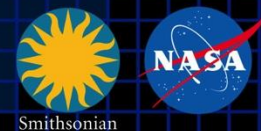
LEO observations provide limited information on rapidly varying emissions, chemistry, & transport

GEO will provide observations at temporal and spatial scales highly relevant to air quality processes

OMI NO₂ in April (2005–2008) over TEMPO FOR



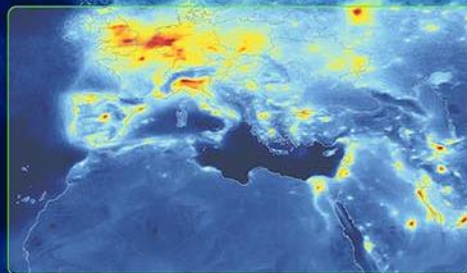
TEMPO is a component of the CEOS Atmospheric Composition Virtual Constellation for Air Quality



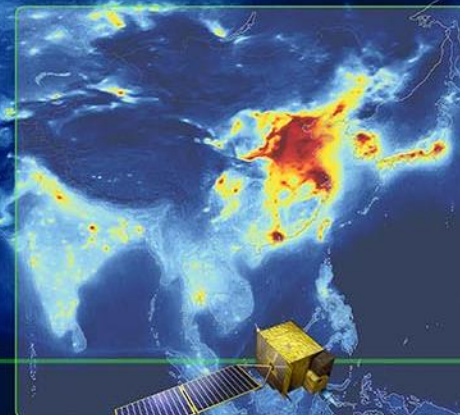
TEMPO (hourly)
Tropospheric Emissions:
Monitoring of Pollution



Sentinel-4 (hourly)



GEMS (hourly)
Geostationary Environmental
Monitoring Spectrometer



Equator

Sentinel-5P (once per day)



GaoFen-5 (once per day)



- ◆ *Air Quality and Climate Change are different manifestations of the same issue with respect to human impacts (i.e., resource management & energy consumption), albeit at different temporal and spatial scales*
- ◆ *Air Quality is fundamentally a surface concern, however it requires an understanding of the full atmosphere. Observing near-surface pollution from space is very challenging*
- ◆ *NASA airborne and satellite observations are critical to all aspects of Air Quality and Climate research including emissions, transformation (photochemical and micro-physical), transport and deposition*
- ◆ *Airborne “calibration/validation” campaigns along with integrated modeling and simulation evaluate and place satellite data in a broader context*
- ◆ *Geostationary observations of atmospheric composition, including air quality and “chemical weather,” promise unprecedented temporal resolution – but also present challenges*

Thanks for listening!

***Hope you have a truly stimulating
and enjoyable experience at
SARP this summer***



Tuesday June 19, 7 PM Hilton Garden Inn