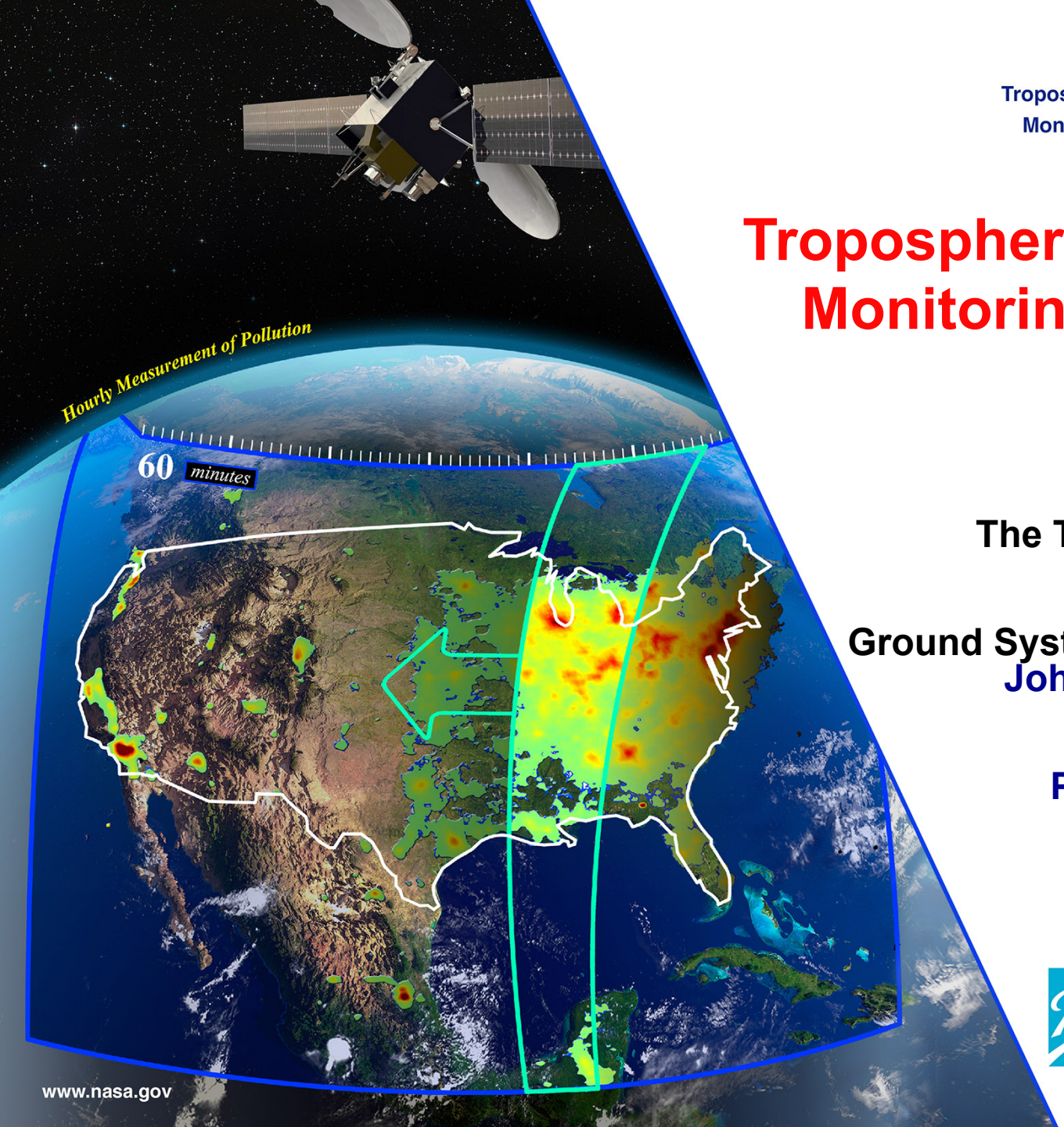


Tropospheric Emissions: Monitoring of Pollution (TEMPO)

Ewan O'Sullivan

The TEMPO Team at SAO:
P.I. Kelly Chance
Deputy P.I. Xiong Liu
Ground Systems: Raid Suleiman, John Houck, John Davis
Science: C. Nowlan, G. Gonzalez-Abad, P. Zoogman, H. Wang, et al.

SAO HEAD lunch talk
17 February 2016

Ball

Smithsonian

NASA

TEMPO overview:
hourly air pollution monitoring from geostationary orbit

UV+Visible imaging grating spectrometer with slit scanning E-W across Greater North America (GNA) once/hour

- Maps O_3, NO_2, formaldehyde column densities, profiles O_3 from ground level to stratosphere, at ~2.5x5km resolution (+ potentially SO_2, aerosols, BrO, glyoxal, water vapour, etc.)

PI: Kelly Chance (SAO)

- Main science algorithm developers at SAO
- Instrument operations and data pipeline will be at SAO

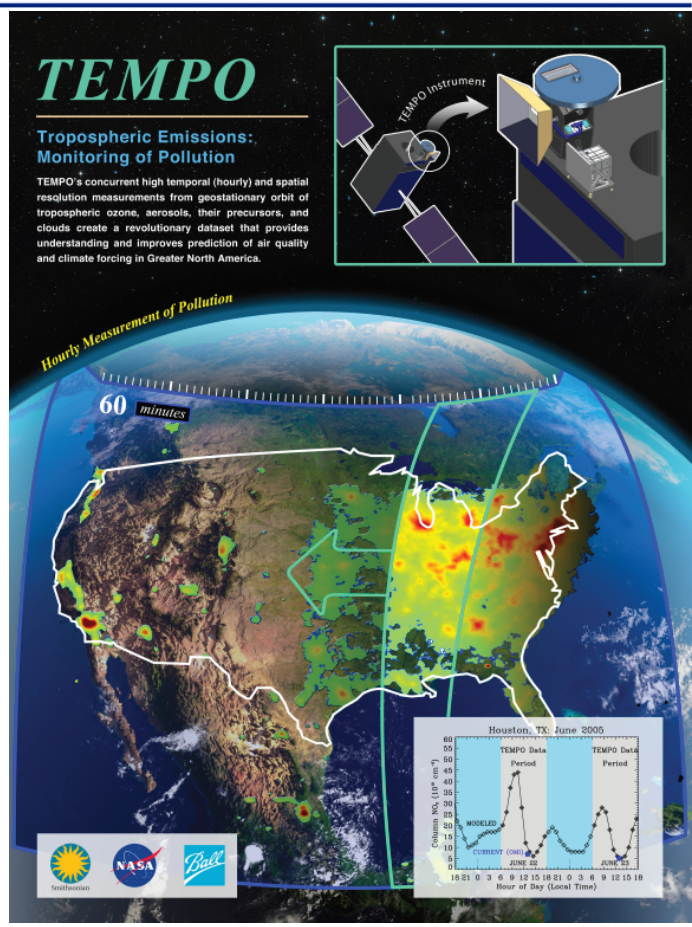
Instrument development: Ball Aerospace

Project management: NASA LaRC

Other institutions: NASA GSFC, NOAA, EPA, NCAR, Harvard, UC Berkeley, St. Louis U, U Alabama Huntsville, UMBC, U Nebraska, RT Solutions, Carr Astronautics

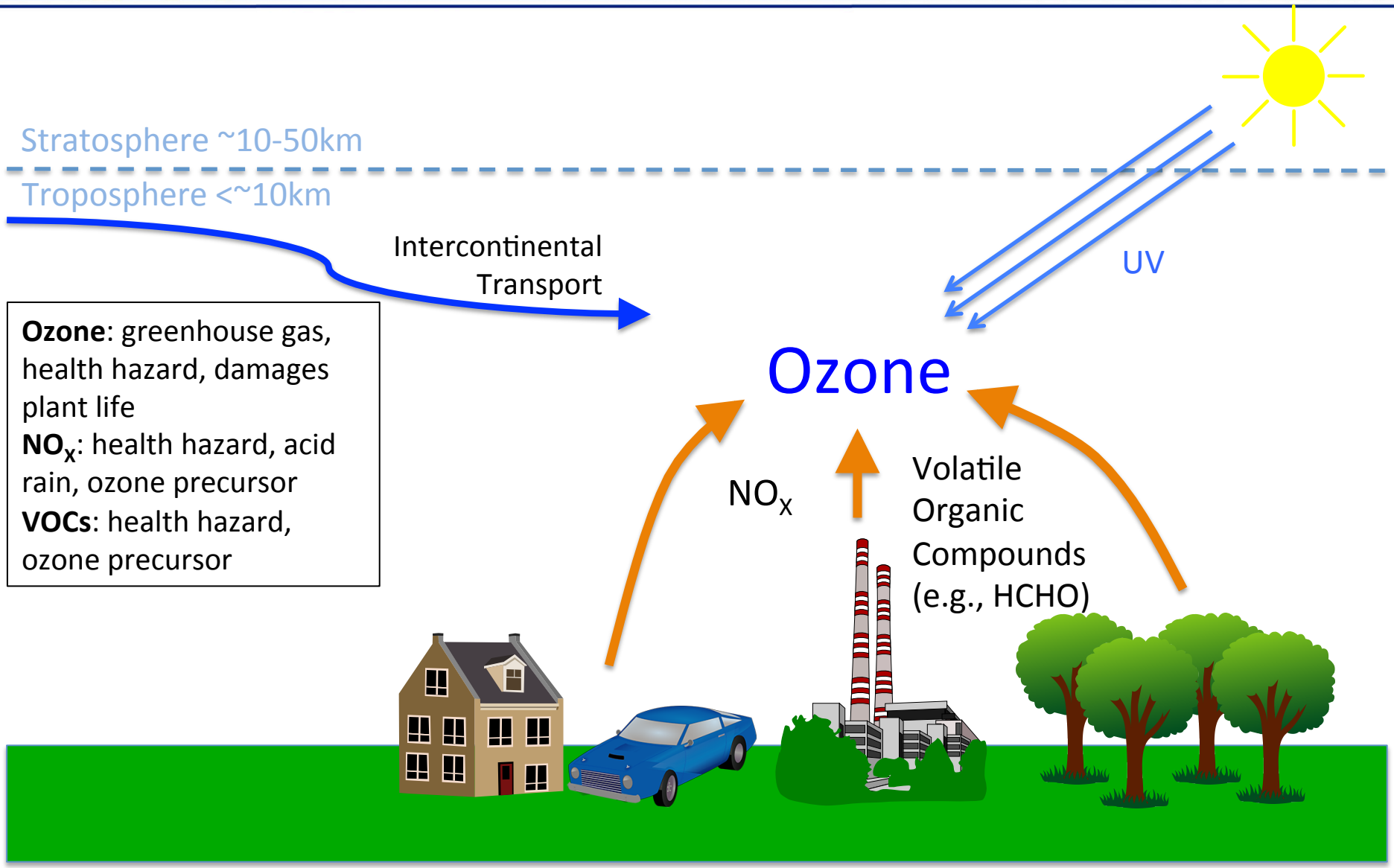
Cost-capped mission: $93.2M

Expected launch: 2019 – 2021



- **First atmospheric chemistry mission in GEO**
- **First of NASA's Earth Venture Instruments**
  - Hosted on a commercial communications satellite
- **Temporal resolution improved from daily to hourly scans**
- **Spatial resolution improved by factor 30: map pollution on sub-urban scales**
- **First orbital monitoring of ground-level (0-2km) ozone**

Atmospheric chemistry 101

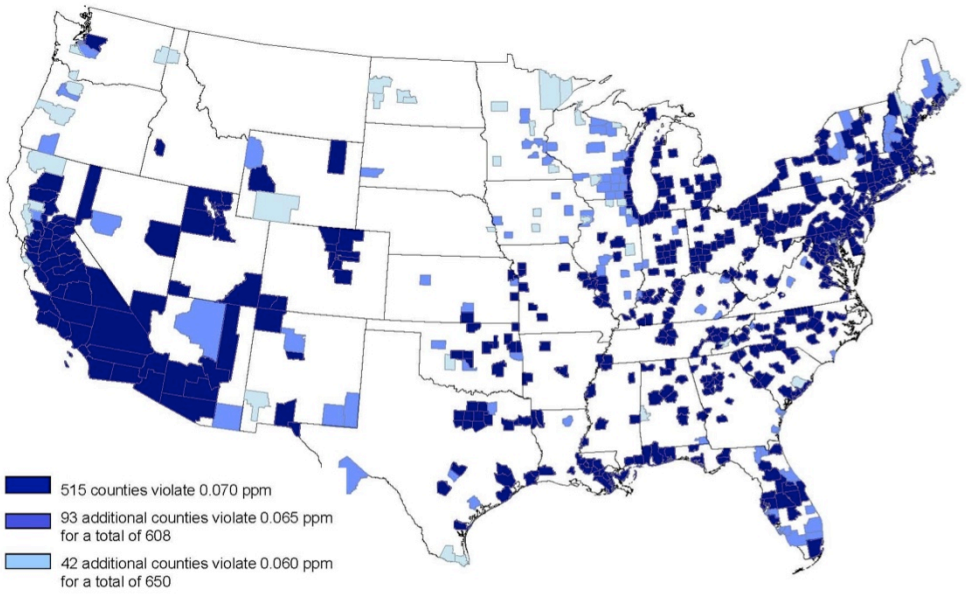


Ozone: greenhouse gas, health hazard, damages plant life
NO_X: health hazard, acid rain, ozone precursor
VOCs: health hazard, ozone precursor

TEMPO science overview

Counties Violating Ground-level Ozone Standards

(Based on 2006 – 2008 Air Quality Data)
EPA will not designate areas as nonattainment on these data, but likely on 2008 – 2010 data which are expected to show improved air quality.



Notes:
1. No monitored counties outside the continental U.S. violate.
2. EPA is proposing to determine compliance with a revised primary ozone standard by rounding the 3-year average to three decimal places.

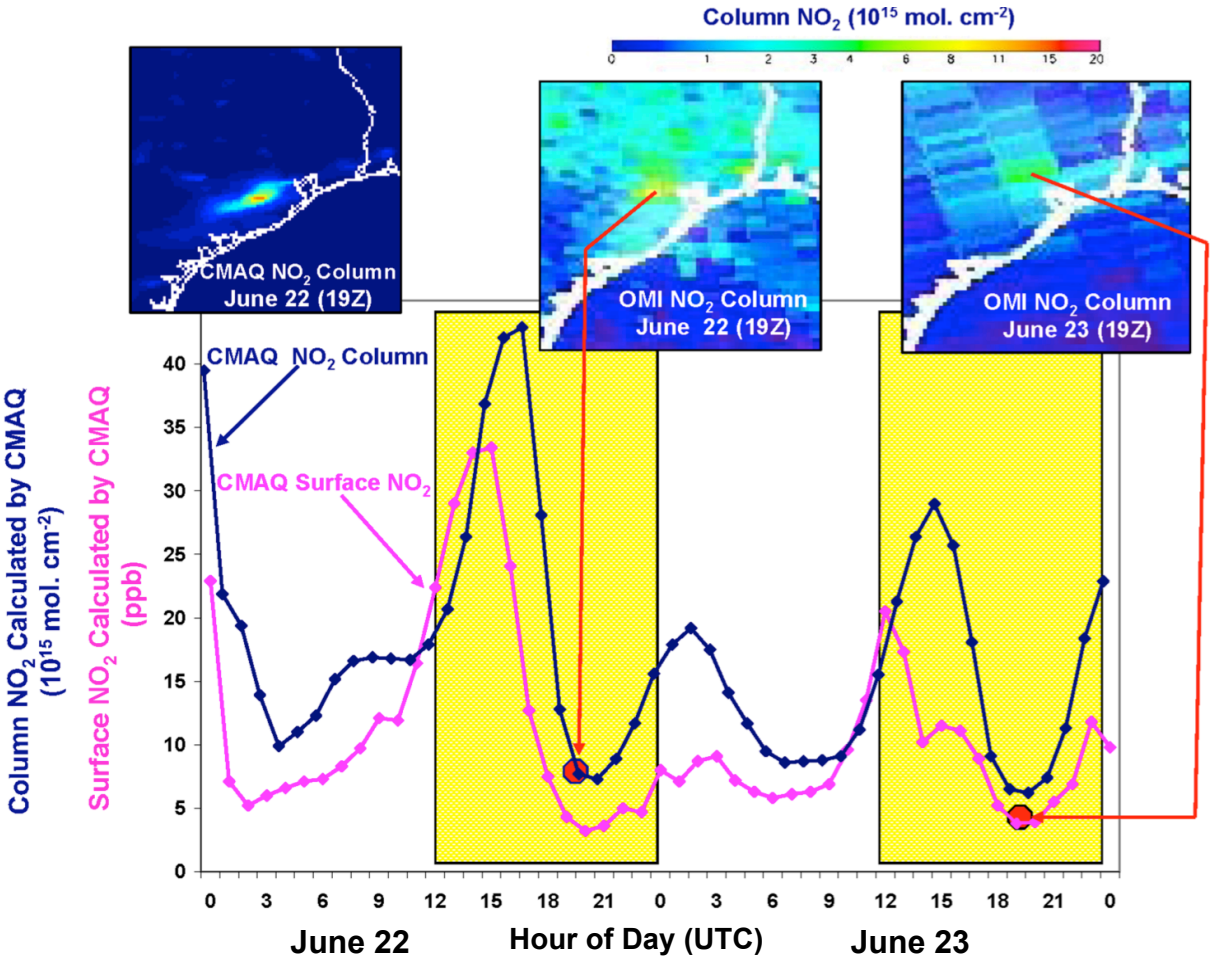
TEMPO Science Questions

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?

1. How can observations from space improve air quality forecasts and assessments?
2. How does intercontinental transport affect air quality?
3. How do episodic events, such as wild fires, dust outbreaks, and volcanic eruptions, affect atmospheric composition and air quality?

Why geostationary? Temporal resolution

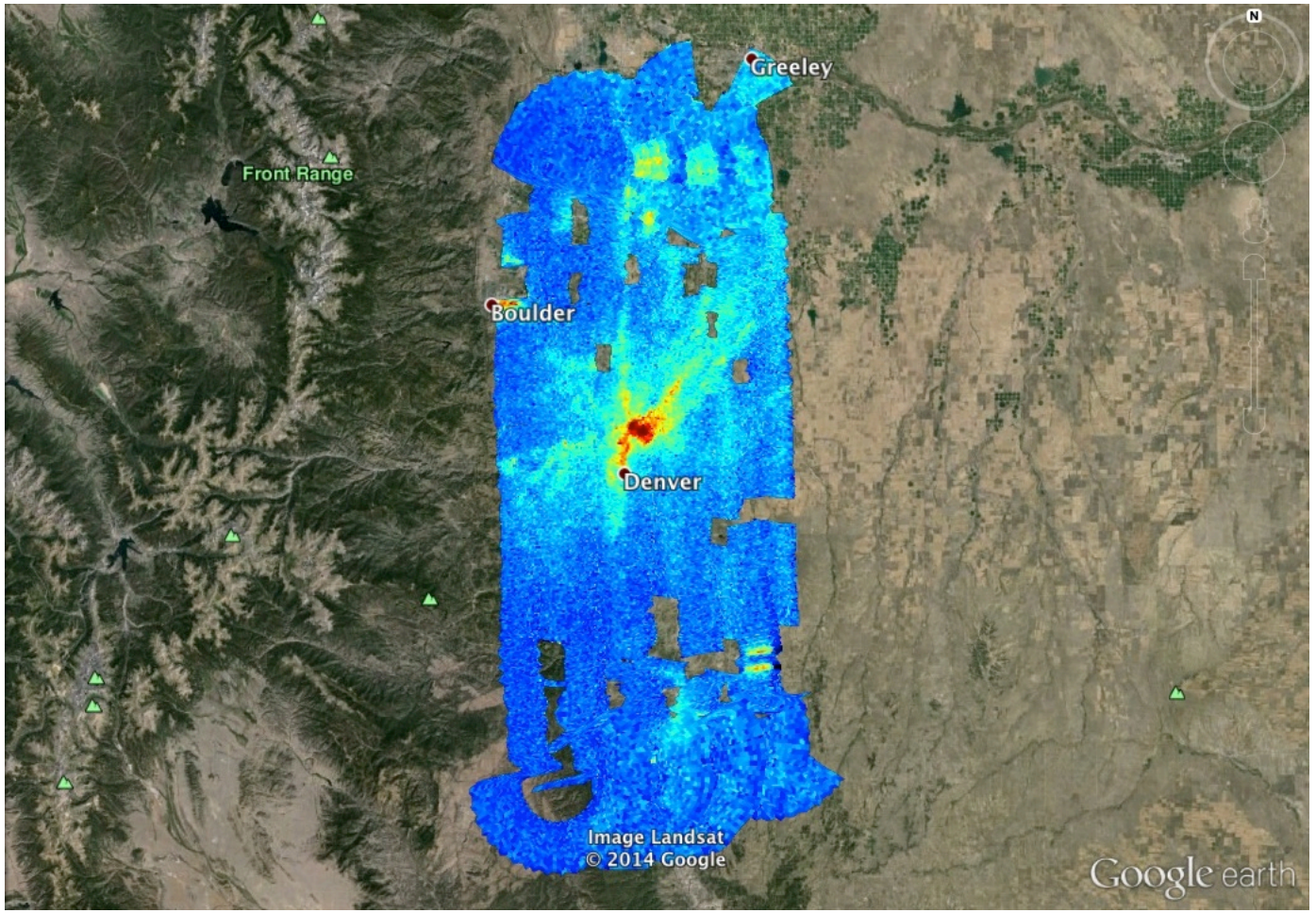
Previous missions in polar low-earth orbits: only one measurement/day per location

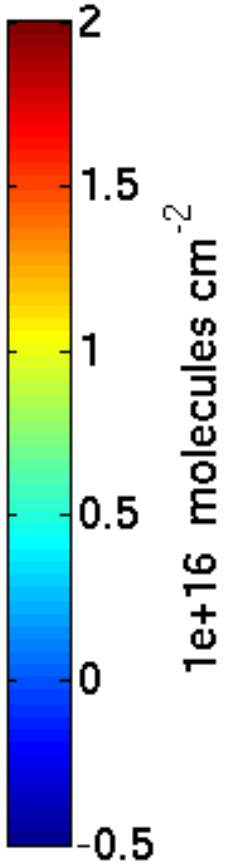


Hourly NO_2 surface concentration and integrated column calculated by CMAQ air quality model: Houston, TX, June 22-23, 2005

TEMPO measurements will capture the diurnal cycle of pollutant emissions

GeoTASO NO_2 Slant Column, 02 August 2014 Morning





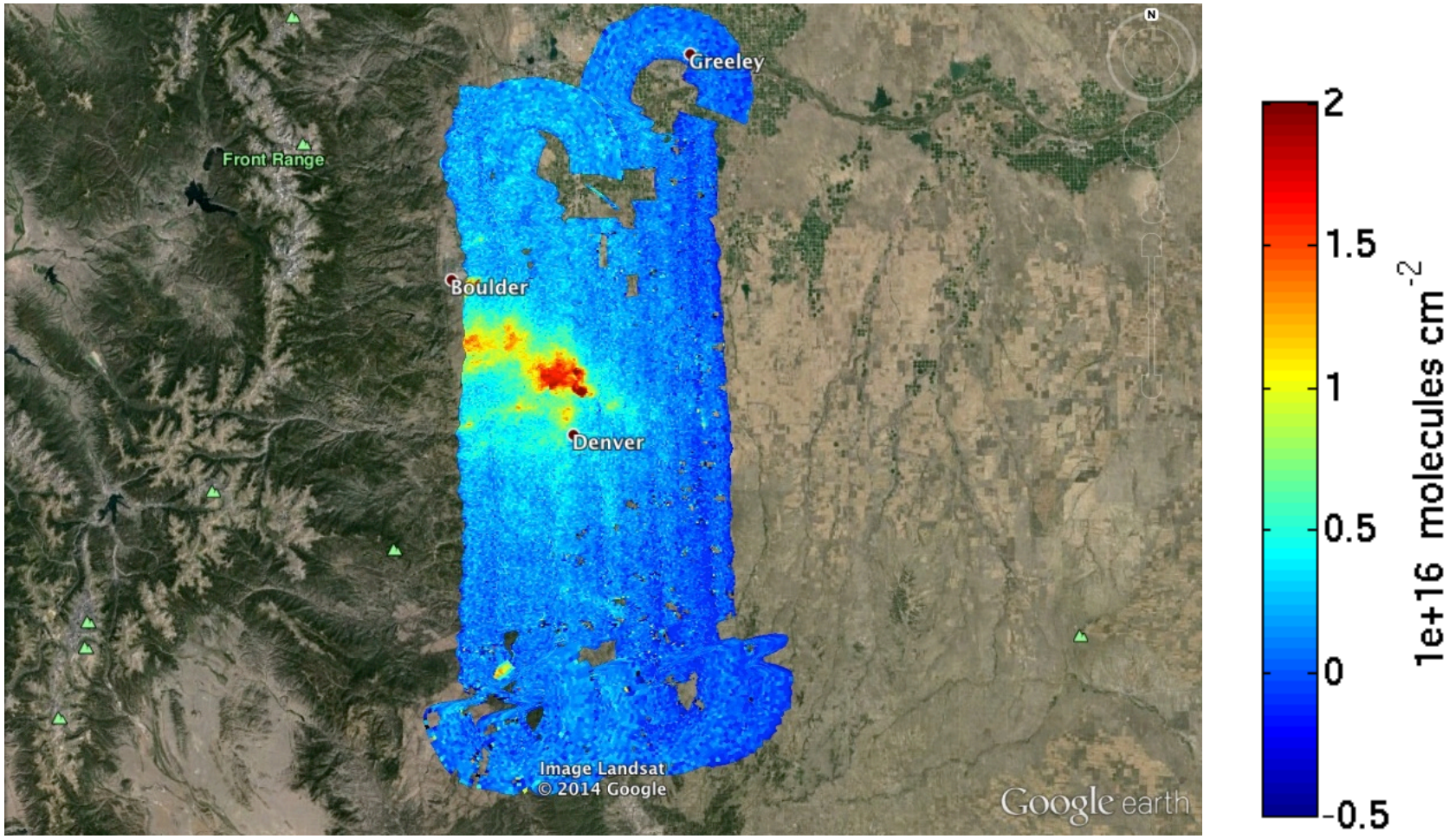
Co-added to approx. 500m x 450m

Morning vs. Afternoon

Preliminary data, C. Nowlan, SAO

TEMPO measurements will capture the diurnal cycle of pollutant emissions

GeoTASO NO_2 Slant Column, 02 August 2014 Afternoon



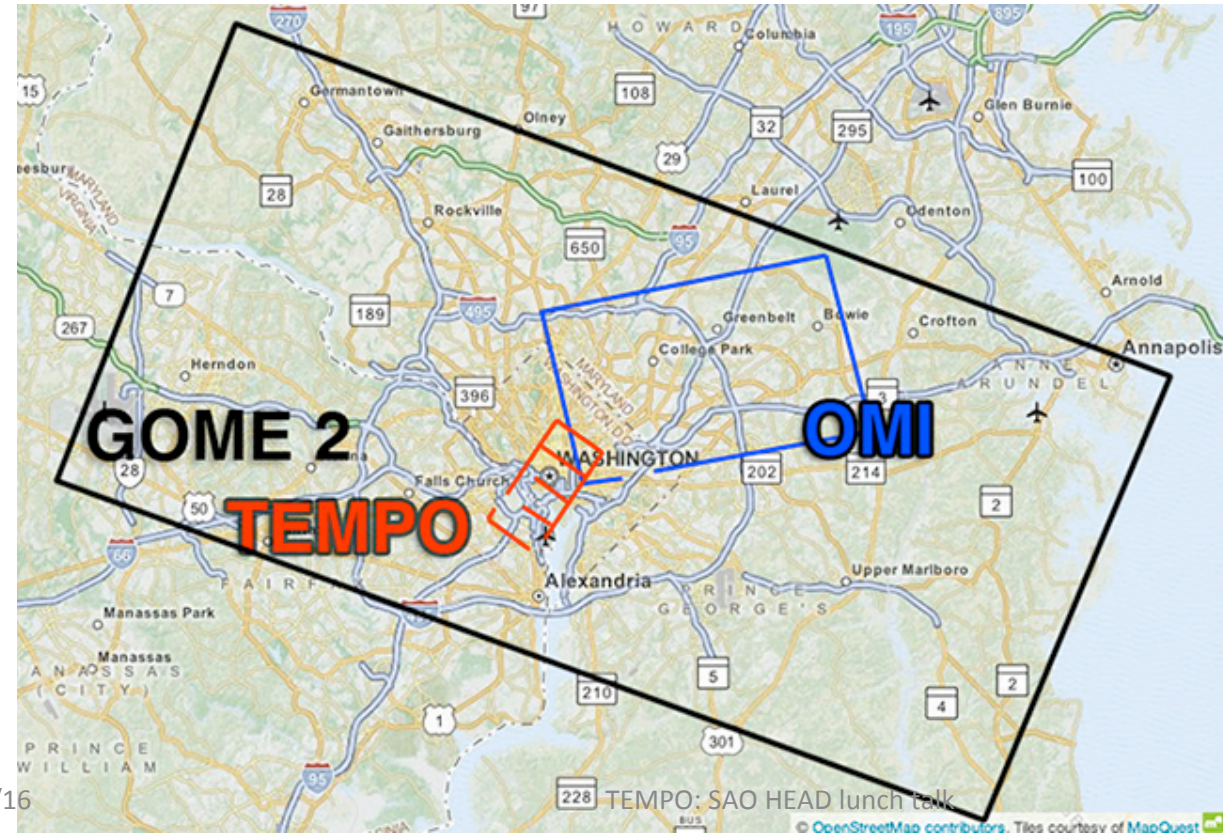
Co-added to approx. 500m x 450m

Morning vs. Afternoon

Preliminary data, C. Nowlan, SAO

Spatial resolution

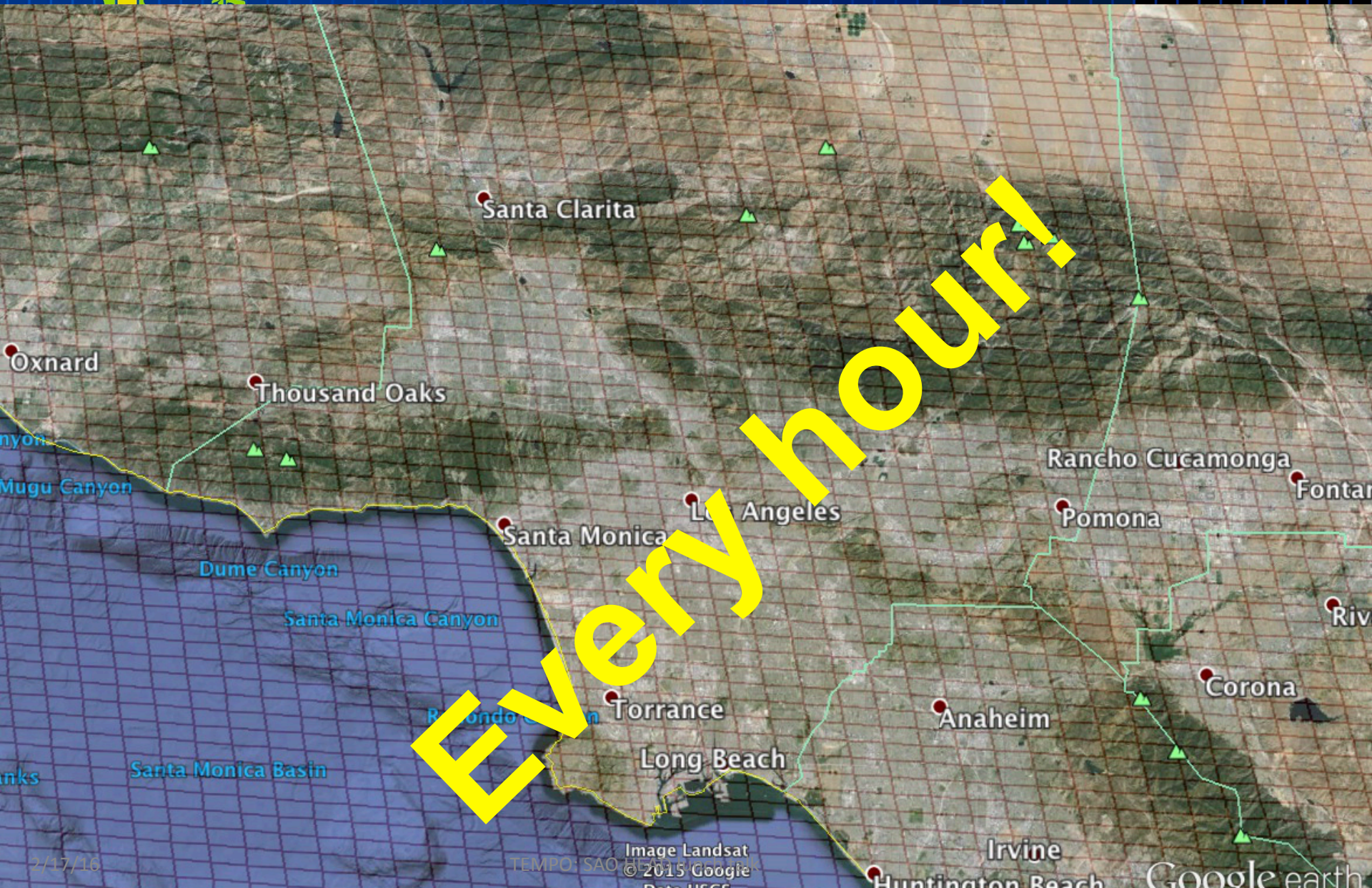
- **Spatial resolution: allow tracking pollution at sub-urban scale**
  - **GEO at 100°W: 2.1 km N/S × 4.7 km E/W=9.8 km^2 (native) at center of FOR (36.5°N, 100°W)**
  - **Full resolution for NO_2, HCHO, total O_3 products**
  - **Co-add 4 N/S pixels for O_3 profile product: 8.4 km N/S × 4.7 km E/W**



~ 1/300 of GOME-2

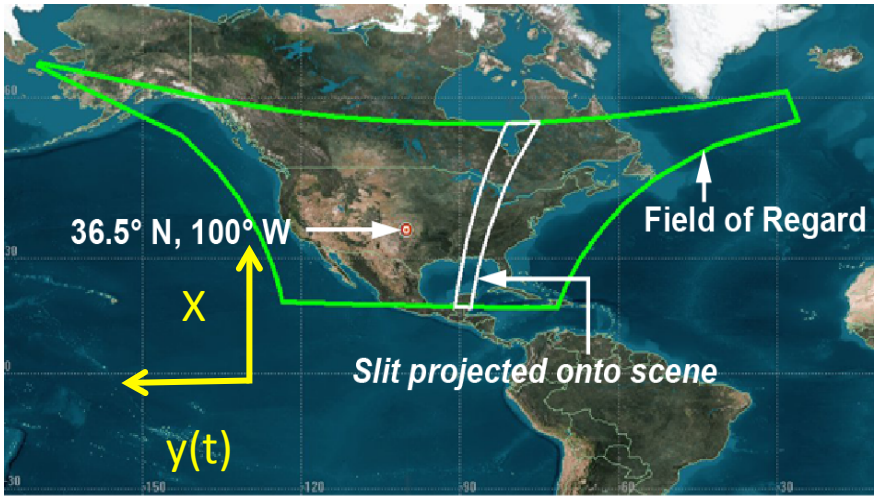
~ 1/30 of OMI

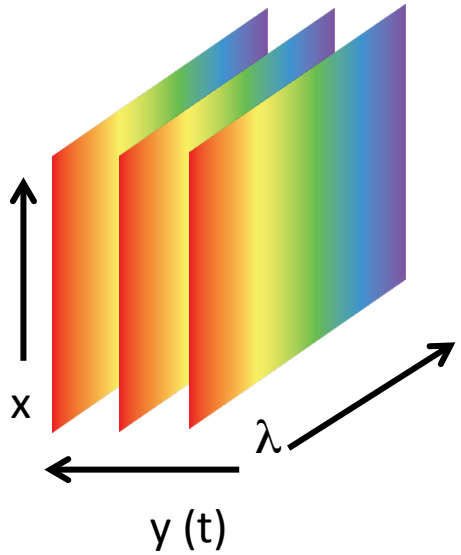
Los Angeles Coverage



TEMPO instrument concept

- Imaging grating spectrometer measuring solar backscattered Earth radiance
  - Spectral range: UV+Vis, 290-490 + 540-740 nm
  - Spectral resolution: 0.6 nm FWHM, 0.2 nm sampling
  - Two 2k x 1k CCDs in common focal plane
- Host satellite in Geostationary orbit, at 80°-115° W
  - Field of Regard: Greater North America (GNA)
    Mexico City/Yucatan to Canadian tar/oil sands, Atlantic to Pacific
  - Instrument slit aligned N/S
  - Scan mirror sweeps slit across the Field of Regard (FOR) in the E/W direction in one hour





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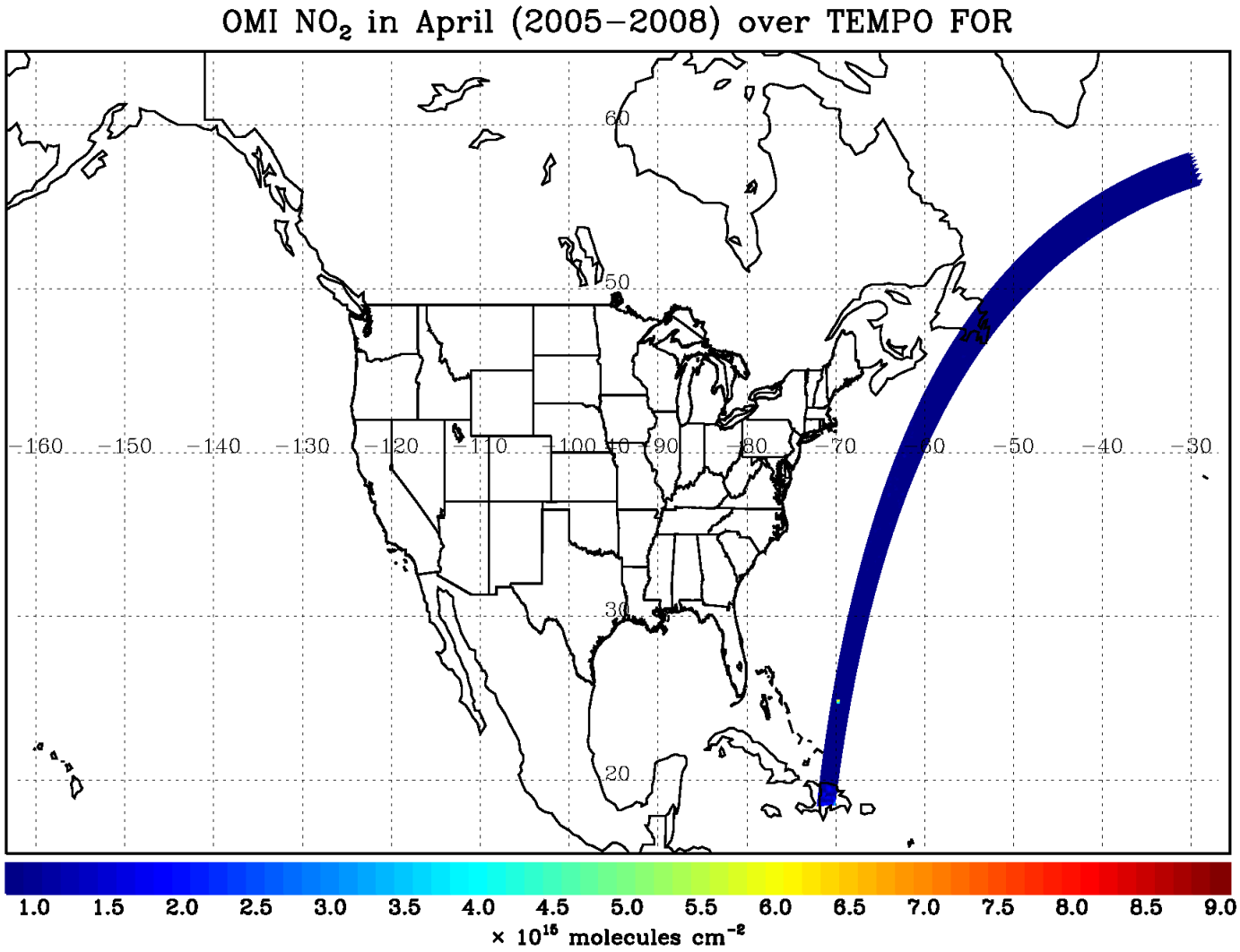
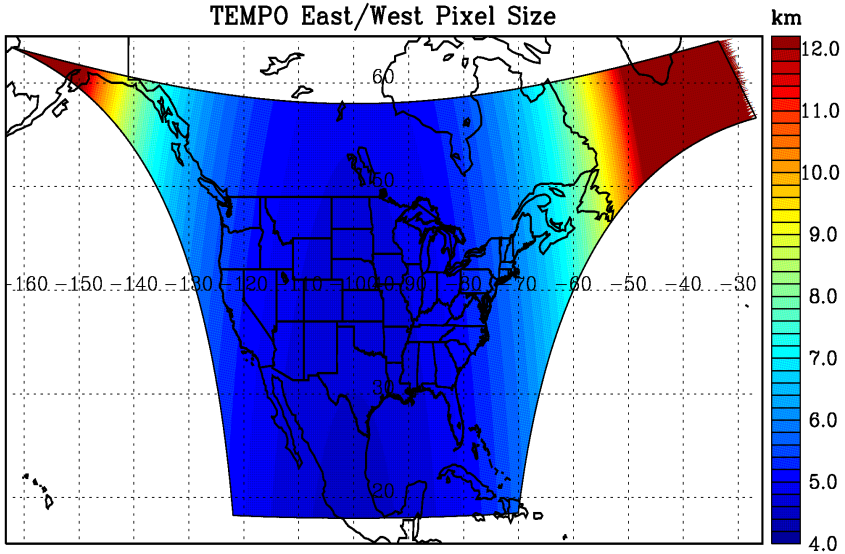
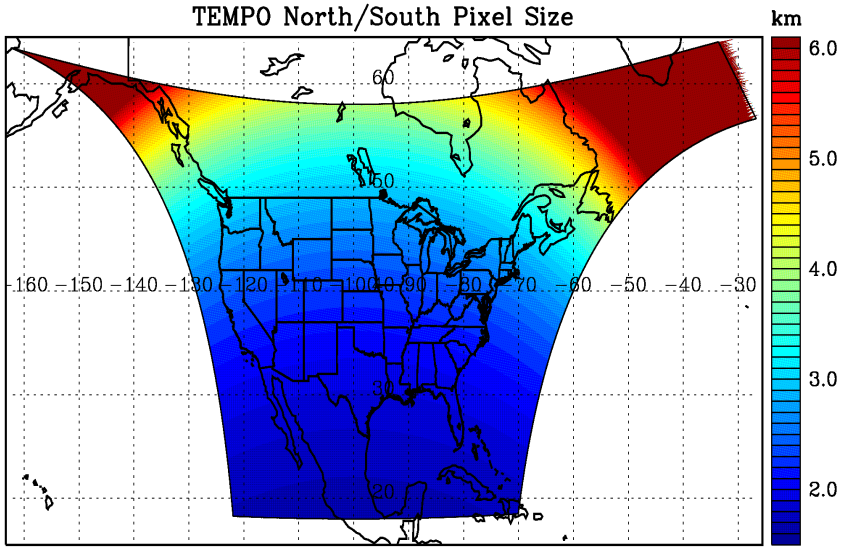
TEMPO hourly NO_2 sweep



- ~ 1282 steps/hr
- ~ 2.5 M pixels/hr
- Date rate: ~31.2 Mbs
- Data volume ~20x that of OMI

TEMPO footprint (GEO @100° W)



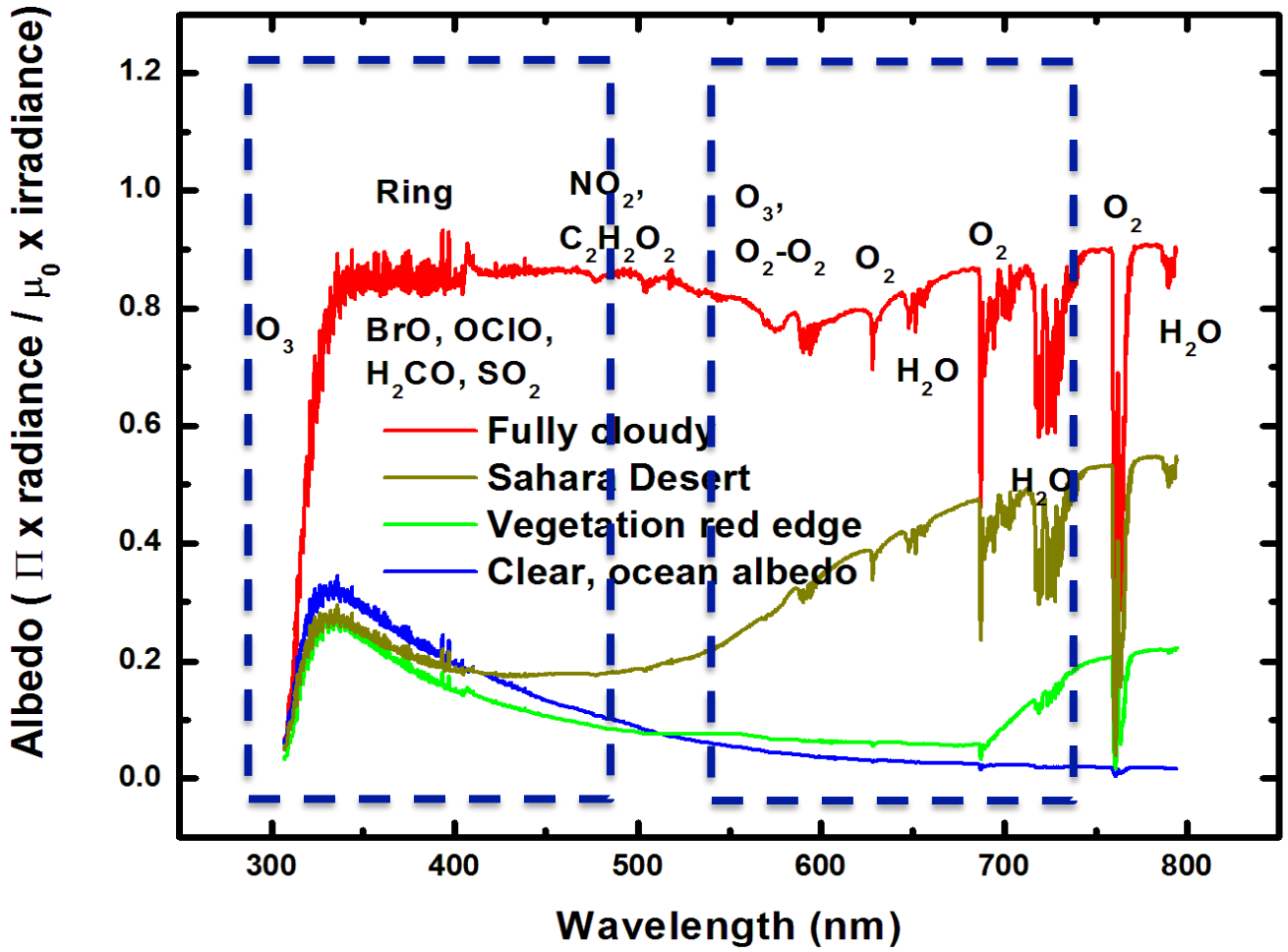


Location	N/S (km)	E/W (km)	GSA (km^2)
36.5°N, 100°W	2.11	4.65	9.8
Washington, DC	2.37	5.36	11.9
Seattle	2.99	5.46	14.9
Los Angeles	2.09	5.04	10.2
Boston	2.71	5.90	14.1
Miami	1.83	5.04	9.0
Mexico City	1.65	4.54	7.5
Canadian tar sands	3.94	5.05	19.2

Assumes 2000 N/S pixels

For GEO at 80°W, pixel size at 36.5°N, 100°W is 2.2 km × 5.2 km=11.4 km^2.

Typical TEMPO-range spectra (from ESA GOME-1)



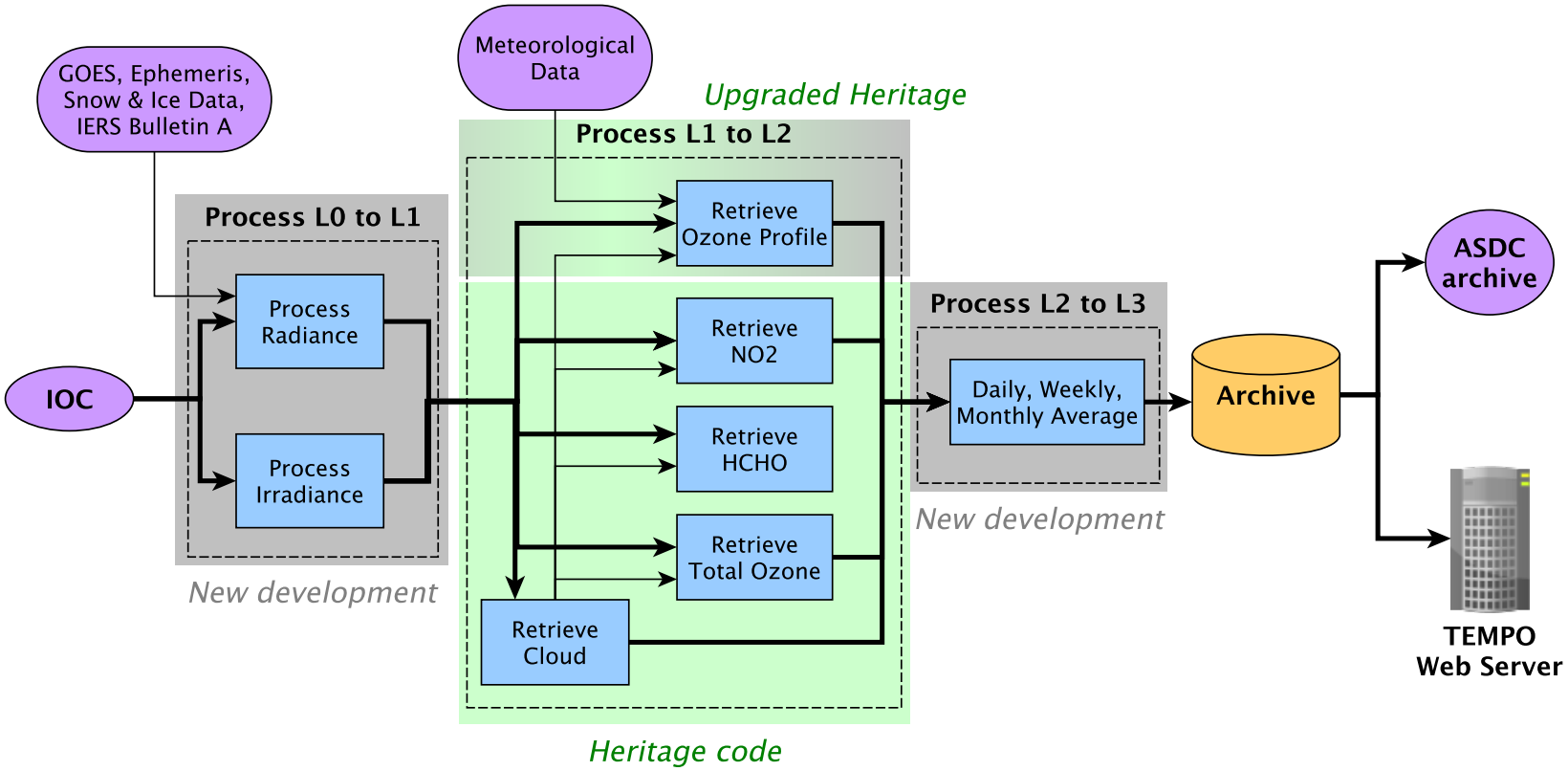
Compared to OMI and Korean/GEMS, adding the visible improves lower tropospheric O_3 retrieval sensitivity. It also enhances cloud/aerosol retrieval sensitivity and allows vegetation measurements.

Activities at SAO

- **PI and deputy PI**
- **Science algorithm development**
  - Long heritage of algorithm development for previous missions (GOME, SCHIAMACHY, OMI)
  - Improvements to trace gas algorithm
    - Separate tropospheric / stratospheric NO_2
    - Additional gases (SO_2, BrO, Glyoxal, water vapour, etc.)
  - Ongoing work to upgrade Ozone profile algorithm to use visible channel, measure ozone columns in boundary layer (0-2 km).
- **Ground systems – Instrument Operations Center**
  - Will likely be located below Phillips!
  - Staffed ~9-5, 5 days/week – autonomous operations a priority.
  - Mission planning (Scan optimization, special observations)
  - Commanding (2-week command loads uploaded once/week)
  - Instrument health & status monitoring
  - Initial telemetry processing to level 0 (cleaned & time ordered)

Data Processing Pipeline

- Science Data Processing Center located at SAO
- Process level 0 data to higher level products
- **~2.5 million 2000-element spectra per hour = ~270GB of telemetry per day**
- **Pipeline requires ~550 2.8GHz cores, 2GB/core RAM**
- Main science codes written in Fortran90



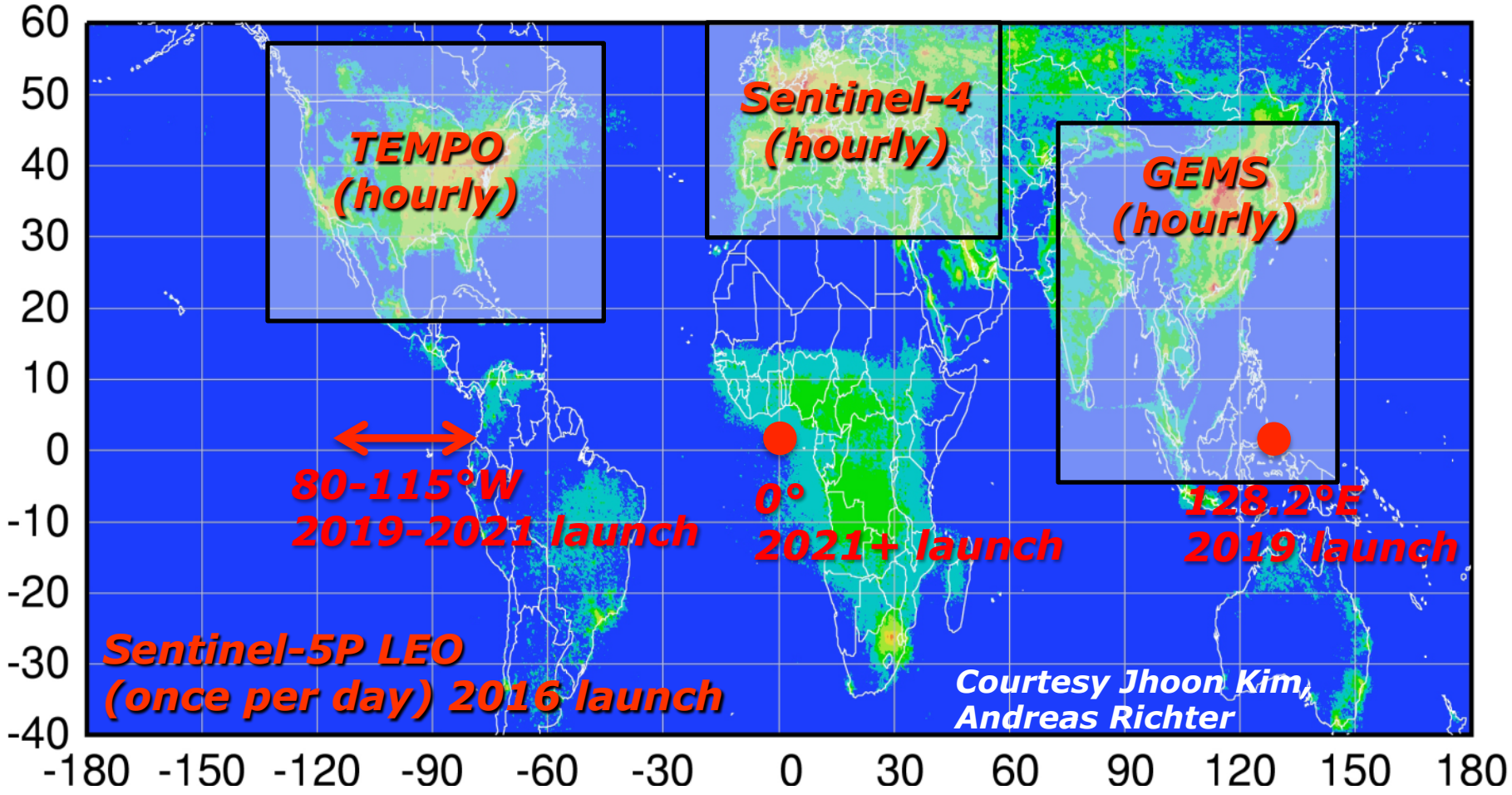
Archive & data access

- **Archive**
  - Archive growth **~1TB/day**
  - >750TB for 29-month nominal mission
  - Currently planning to use NetApp for reliability
  - Off-site archive at NASA's Atmospheric Sciences Data Center (at LaRC)
  - File format is HDF5/netCDF4
    - supports high dimensionality (we have 3, 4 and 5D arrays in our data)
    - long heritage in earth observation / geographic data fields
    - simple directory-tree file structure = easy to work with
- **Data access**
  - Many users require processed data – few have the resources to process large volumes of level 1 data (spectra) through their own algorithms
  - 30 days worth of data available via mission website at SAO
  - ASDC will provide a full publicly accessible mission archive
  - Access via EPA Remote Sensing Information Gateway (RSIG), enables subsetting, visualization, comparison with other datasets, with minimal data transfer

TEMPO status/schedule

- **Currently on-schedule and on-budget**
  - Selected November 2012
  - Preliminary Design Review in July 2014
  - Converted instrument to firm fixed price in March 2015
  - Now in Phase C: Passed KDP-C in April 2015
  - Instrument passed Critical Design Review (CDR) in June 2015
- **Ground Systems CDR in May 2016**
  - IOC/SDPC testing complete in Dec. 2017
  - Ground systems ready 6 months before Launch
- **Instrument delivery in May 2017**
- **Satellite host selection probably in 2017**
  - operating longitude and launch date are not known until after host selection
- **Launch after 11/2018, could be as late as 2021**

Global pollution monitoring constellation



Policy-relevant science and environmental services enabled by common observations

- Improved emissions, at common confidence levels, over industrialized Northern Hemisphere
- Improved air quality forecasts and assimilation systems
- Improved assessment, e.g., observations to support United Nations Convention on Long Range Transboundary Air Pollution

The end!

BACKUP