Air Pollution Investigation Constellation

COMMUNITY WORKSHOP ON AIR QUALITY REMOTE SENSING FROM SPACE:
DEFINING AN OPTIMUM OBSERVING STRATEGY

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California Institute of Technology

The ‘clean slate’ approach

- Science question and measurement requirements
- Potential instrumentation to meet requirements
- Assembling a mission
- Constellation considerations

The message

- The range of species involved will require a set of instruments.
- The set of measurement techniques are not compatible with only one orbit.
- Must truly sample the troposphere, not only infer concentrations - high spectral resolution is required.
- Extensive analysis with assimilation systems is important to evaluating mission designs.

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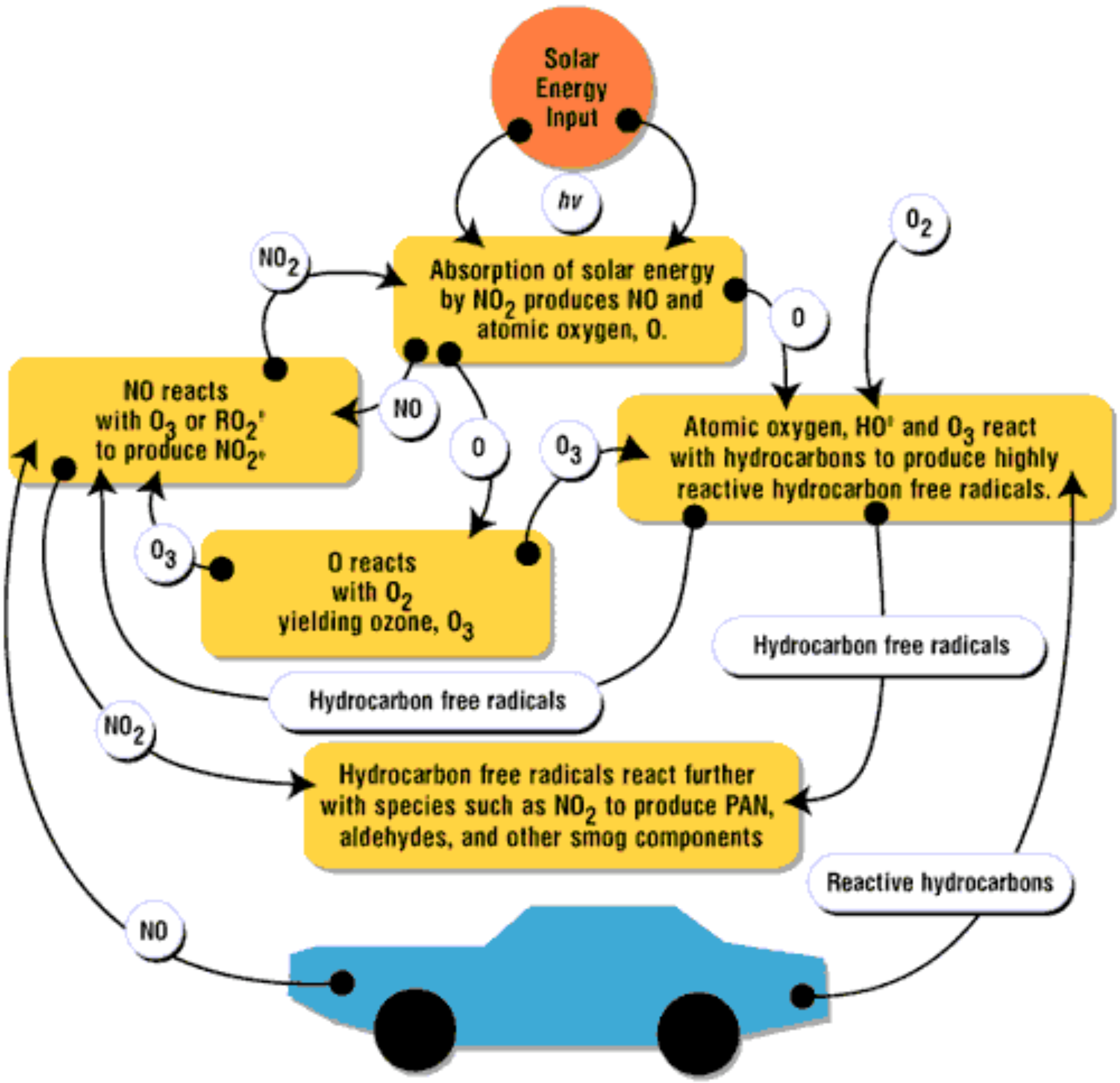
The Approach: Science Question to Mission Concept

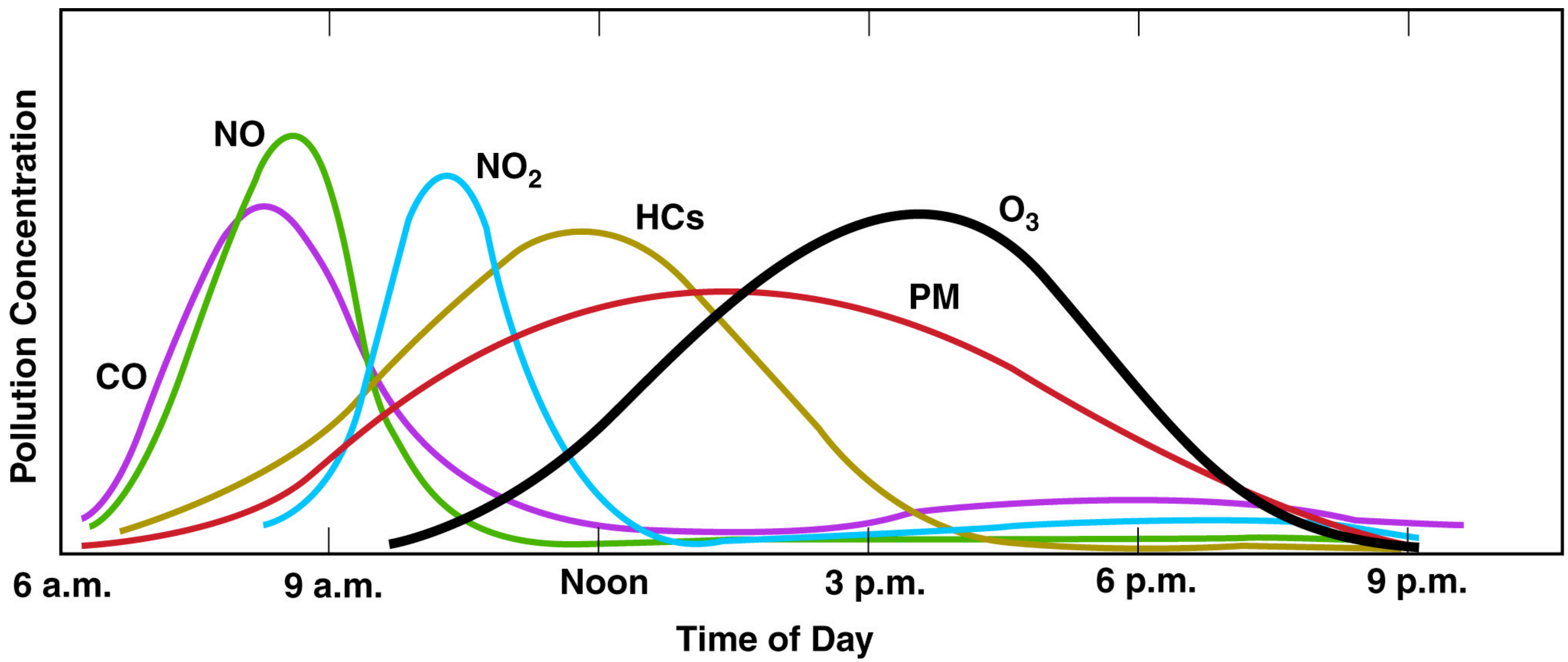
1. Define the science challenges and objectives
2. Define the species we need to measure
3. Define the resolution, accuracy and precision required
4. Define the wavelength required to measure these species
5. Define the instrument types
6. Define the optimum orbit and mission concept

Many chemical families involved



from
http://mtsu32.mtsu.edu:11233/Smog-Atm1.htm

Temporal Variability of Ozone and its Precursors Will Require Multiple Measurements per Day



- Colored lines are species required to create ozone
- Ozone precursors and ozone itself peak at different times of the day
- Need hourly measurements, multiple times of day.
- GEO and possibly MEO can achieve the required temporal resolution

Adapted from "Earth Under Siege", R.Turco

Science Requirements: AQ Emissions

Science Challenge:

Quantify the long range transport of pollutants and their effects on air quality and ecosystems. Determine the effects of changing climate on global and regional air quality.

Science Question A:

Quantify the subregional emissions of precursors of smog and particulate matter over the globe

Science Question B:

<u>Measurement Requirements</u>

Gaseous:
 NOx: NO and/or NO_2
 HCs:
Anthropogenic: CO, CH_4
Biogenic: C_5H_8 (isoprene), CH_4
Particulates:
 silicate dust, SO_2 (gas) and/or sulfate aerosol, black carbon, sea salt

RED: Top Priority
BLUE: Desired

- Daily to weekly for 1 to 2 years.
- Horizontal scale of 5 to 20km
- Vertical resolution sufficient for columns for long lived species and resolve the boundary layer for shorter lived species.
- Some diurnal information is needed for modeling.

Measurement and Vista selection

Science Requirements:
AQ Long Range Transport

Science Challenge:

Quantify the long range transport of pollutants and their effects on air quality and ecosystems. Determine the effects of changing climate on global and regional air quality.

Science Question A:

Science Question B:

Quantify the effects of transformation processes (transport, reaction, deposition) over long ranges on regional air quality

Measurement Requirements

Gaseous:

HOx: H_2O, OH and/or HO_2, H_2O_2. O_3

NOx: NO and/or NO_2, HNO_3, PNA

HCs:

Anthropogenic: CO, CH_4, PAN, ROOH, RNO_3, $RONO_2$, H_2CO, CH_3CHO, C_2H_2, C_2H_4, CH_3OH, acetone, C_3H_6,

Biogenic: C_5H_8, CH_4, terpenoids

Particulates: Surface area

RED: Top Priority
BLUE: Desired

There are two approaches that are needed

A. Daily to weekly observations on 20-50km scale with a column weighted towards in the boundary layer to provide a global understanding.

B. Multiple measurements per day with 2 to 3 layers in the troposphere to study the transformation processes. This will be linked with suborbital.

Measurement and Vista selection

Measurement Technique Selection : AQ Emissions

Family:molecule		U	I	μ
NO_x: NO	1		L	L(s)
NO_x: NO_2	1	N-col	L	L(s)
HCs: CO	1	N-col	N	L
HCs: CH_4	1	N-col	N	
HCs: C_5H_8	1			
dust	1	N		
Black carbon	2	N		
Sea salt	2			
SO_x: SO2	1	N	volc	volc
Sulfate aerosol	1	NL	volc	

U - uv/vis/NIR	N - nadir
I - mid-IR	L - limb
μ - microwave	(s) - strat

- Spatial and temporal requirements
  - Vertically integrated columns, horizontal scales of 5-20km
  - Daily to weekly measurements
- Column measurements of most priority 1 molecules can be achieved with reflected UV/Vis/NIR (ultraviolet/visible/near-infrared)
- Aerosol measurements improved by polarization
- Global characterization can be achieved with reflected UV/Vis/NIR in LEO, MEO, GEO
- Multiangle aerosol measurements: angular repeat requirement optimized in orbits lower than 1400km.

Measurement Technique Selection : AQ Long Range Transport

Family:molecule		U	I	μ
O_3	1	N-col	N	
HO_x: H_2O	1		N	N
HO_x: OH/HO_2	1	>50 km		
HO_x: H_2O_2	2			
NO_x: PNA	1			
NO_x: NO/NO_2	1	N-col		
NO_x: HNO_3	1			
HCs: CO	1	N-col	N	
HCs: CH_4	1	N-col	N	
HCs: C_2H_2	3			
HCs: PAN	1			
HCs: C_5H_8	1			
HCs: CH_2O	2	N		
Particulate surface area	1	N		

- Spatial and temporal requirements:
  - 2-3 layers in troposphere
  - 20-50 km horizontal scales
  - Hourly to daily
- Few priority 1 species can be measured as required with nadir view

U - uv/vis/NIR	N - nadir
I - mid-IR	L - limb
μ - microwave	

Limb Viewing Enables Measurements of More High Priority Species:

AQ Long Range Transport

Family:molecule		U	I	μ
O_3	1	L	OLN	L
HO_x: H_2O	1	L	OLN	LN
HO_x: OH/HO_2	1	>50 km		L
HO_x: H_2O_2	2		O	L(s)
NO_x: PNA	1		O	
NO_x: NO/NO_2	1	L-NO_2	O	L
NO_x: HNO_3	1		OL	L(s)
HCs: CO	1	N	OLN	L
HCs: CH_4	1	N	OLN	
HCs: C_2H_2	3		O	
HCs: PAN	1		O	
HCs: C_5H_8	1			
HCs: CH_2O	2	N		L
Particulate surface area	1	N		

- Limb geometry gives high sensitivity at the expense of horizontal resolution (~200 km)
- Majority of measurement requirements could be met by either solar occultation (demonstrated by ATMOS) or limb IR thermal emission (TES/MIPAS capabilities are being assessed.)
- Limb microwave measurements detect a species in each chemical family with multiple global measurements

U - uv/vis/NIR	N - nadir
I - mid-IR	L - limb
μ - microwave	L(s) - strat
	O - occultation

Blue - in development

Orbit Selection:
AQ Long Range Transport

- Geostationary and MEO orbits allow for observation of diurnal changes in air pollutants.
- Next generation SMLS designed to obtain multiple profiles per day, reaching down to 6-8 km.
- Nadir infrared sounding provides small horizontal footprints and required vertical resolution for O_3 and CO. Can be used in a variety of orbits.
- Multiangle measurements must sample range of scattering angles, restricting orbit height.
- Solar occultation durations shorten in higher orbits. Small organics can be measured with a IR solar occultation with larger horizontal scales. Measures at sunrise/sunset.
- Some molecules can only be measured *in situ*.

This points to a two or three satellite mission design.

Air Quality Constellation (GEO version)

Orbit	Air quality
Leo	• IR solar occultation (organics) • Multiangle polarization imager (aerosols)
Meo	UV/Vis/NIR spectrometer (columns of gases from emissions globally) *could be in GEO
Geo	FTIR spectrometer – vertical profiles of pollutants

- IR solar occultation - 800-2400 cm^{-1} with spectral resolution of 0.02cm^{-1} in LEO (small organics)
- Multiangle polarization imager - 340-2100 nm at < 700km (aerosol characteristics)
- Reflected uv/vis/IR in MEO or GEO (global sampling of emissions)
- FTIR spectrometer in GEO with spectral resolution better than 0.5 cm^{-1} (time evolution of pollutants)
- In-situ sampling of isoprene

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Air Quality Constellation (MEO version)

Orbit	Air quality
Leo	• IR solar occultation (organics) • Multiangle polarization imager (aerosols)
Meo	• Scanning MLS (profiles of large number of trace species) • UV/Vis/NIR/IR spectrometer (columns and profiles of trace gases)

- Multiangle polarization imager - 340-2100 nm < 1400km (aerosols)
- Scanning MLS in MEO for multiple measurements per day of photochemical species
- Reflected uv/vis/NIR in MEO
- IR in MEO for day and night ozone and some vertical information
- Retain solar occultation for small organic molecules
- Isoprene would need to be measured in-situ.

CAMEO + AEGIS as possible solution

- CAMEO (Joe Waters at 13:45).
- Scanning MLS + TROPI (follow-on to OMI)
- 1500km orbit provides multiple measurements per day at many locations
- Variant adds IR spectrometer

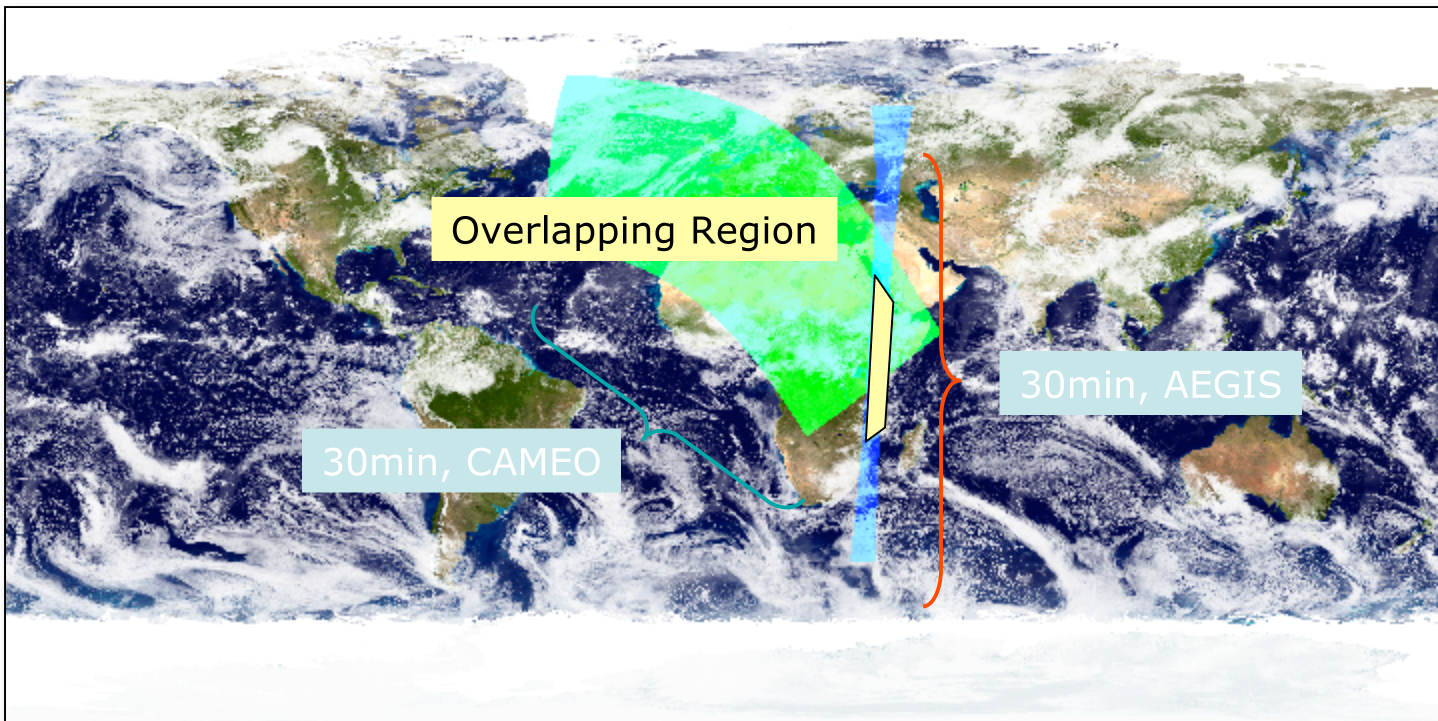
- AEGIS (Dave Diner at 15:15)
- Multiangle spectropolarimetric imager (and high spectral resolution lidar)
- Meets MEO version except IR solar occultation not included in this candidate constellation

Constellations in different orbits - sampling overlap

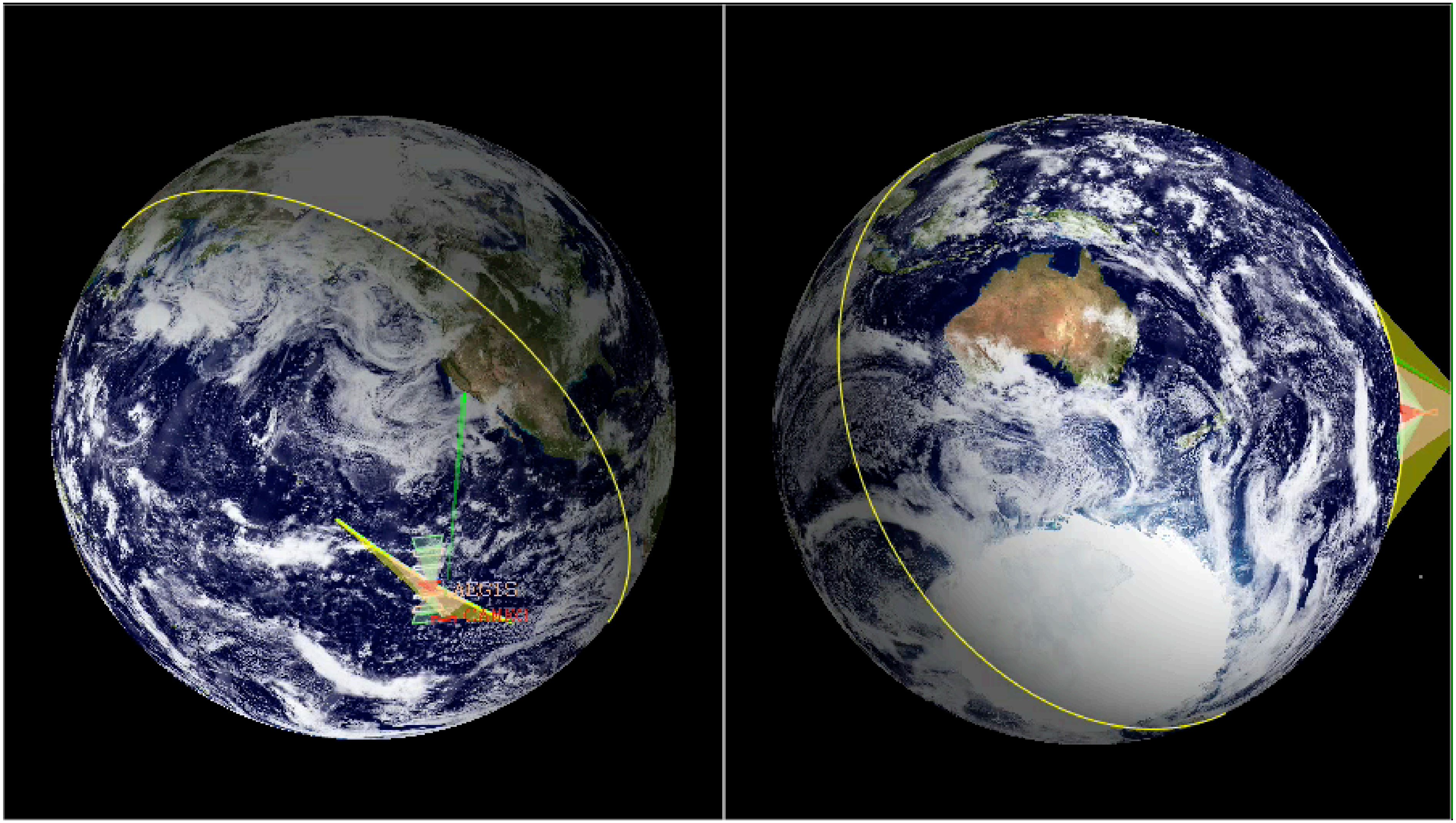
- Not like the ‘A-train’ - two very different orbits due to measurement requirements
- Data assimilation needed to account for transport/photochemistry and effectively use non-simultaneous measurements

Visualizing the Instrument Swaths

- The diagram below demonstrates the relative size of the AEGIS and CAMEO swath
- The blue and green region represents 30 min. swath track



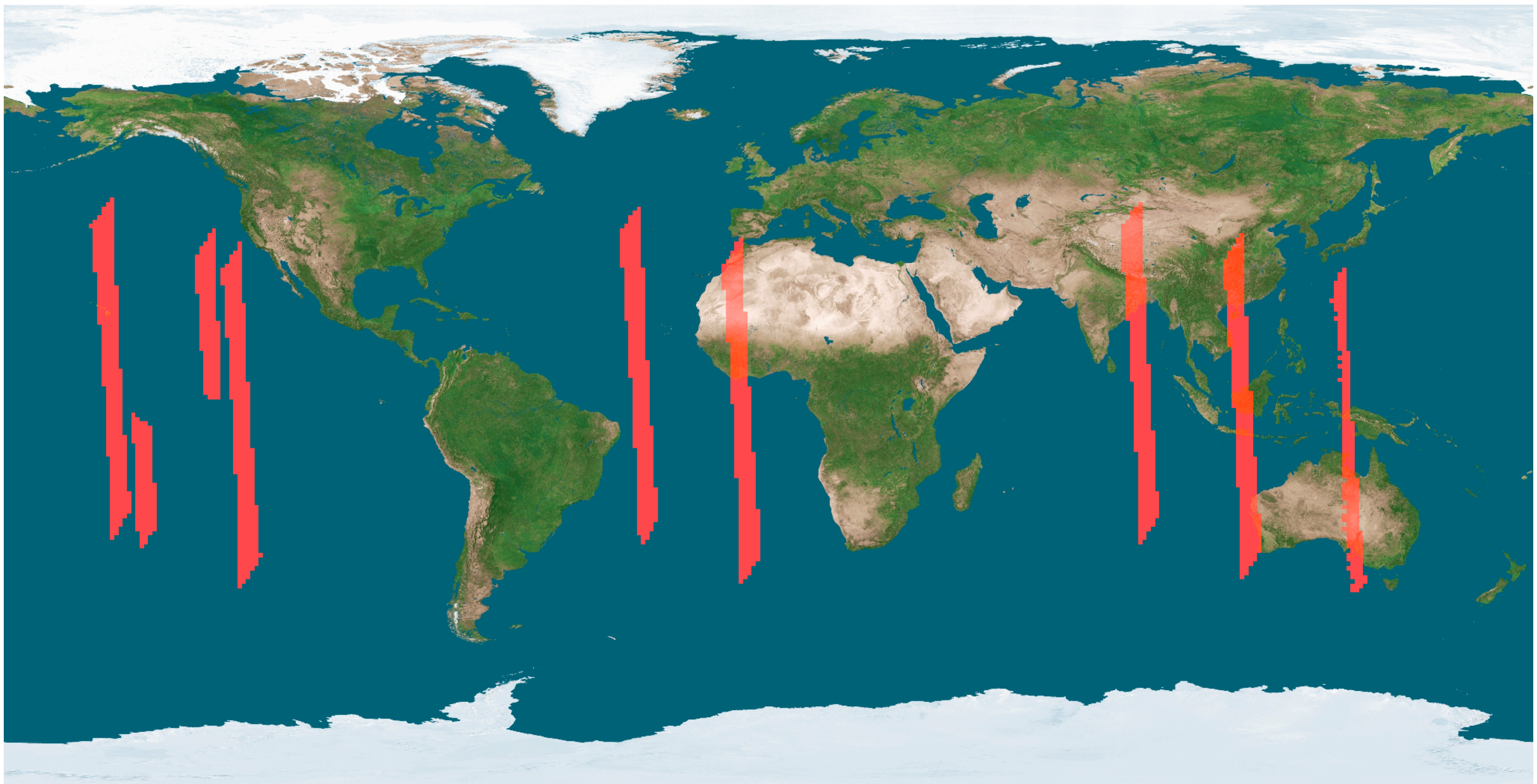
The orbits and sampling



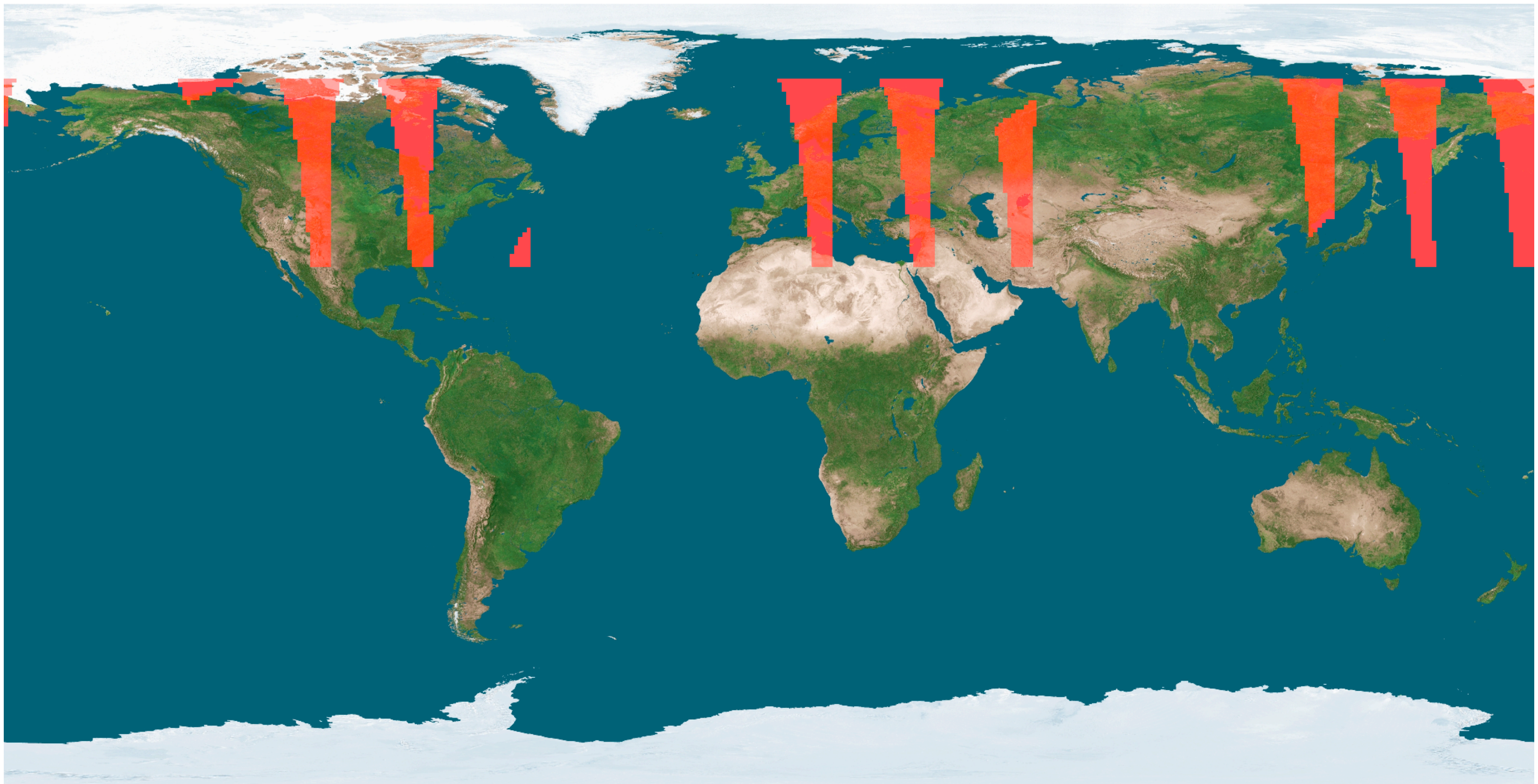
Overlapping Coverage Analysis

- Assumptions:
  - Analysis conducted over 25.1 hours, roughly 13 CAMEO orbits, and 16 AEGIS orbits
  - Relative to AEGIS, the CAMEO orbit plane rotates 360° in 123 days.
  - A maximum delay of 30min. was considered the criteria for overlap

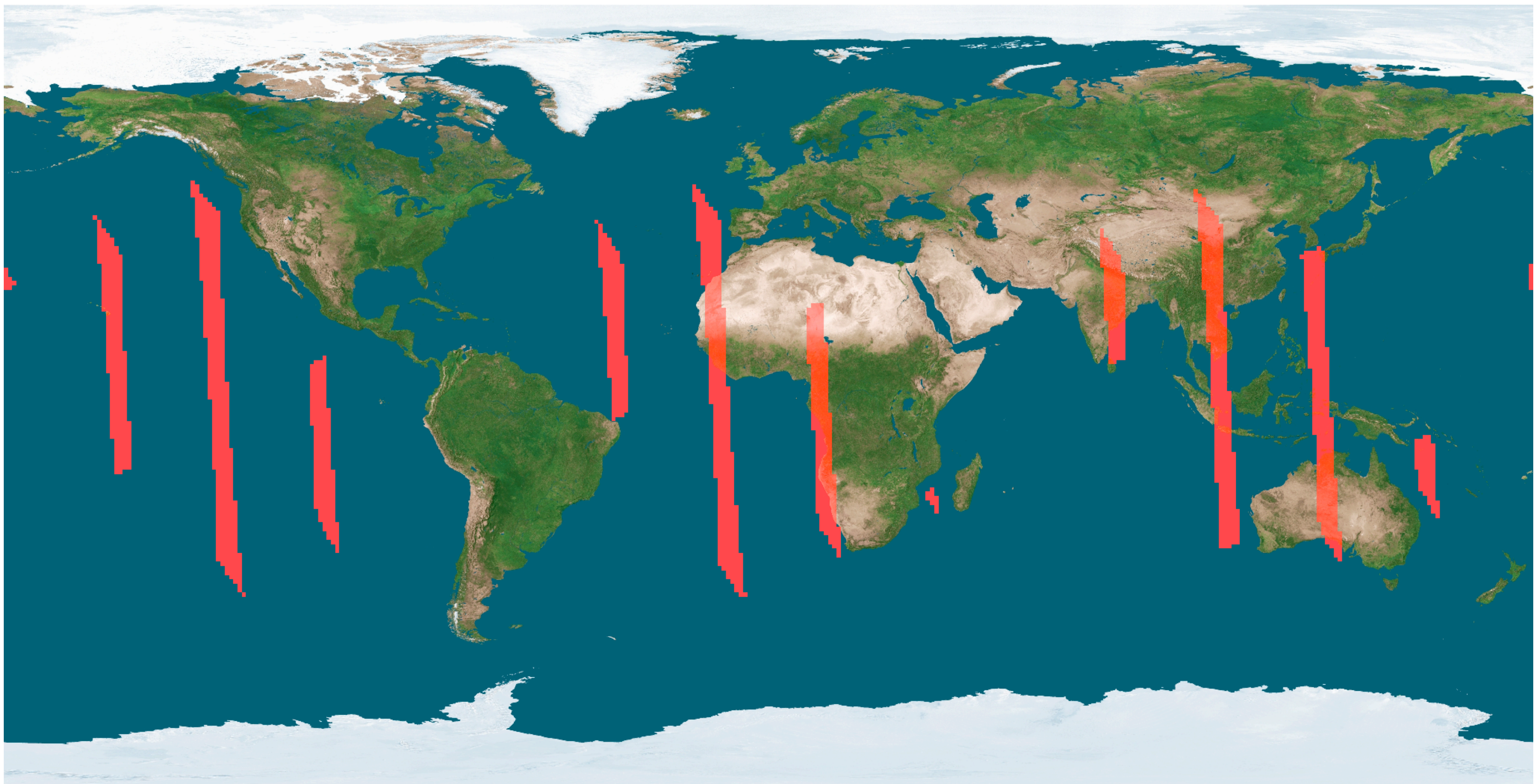
CAMEO AEGIS Overlap Analysis: Day 1



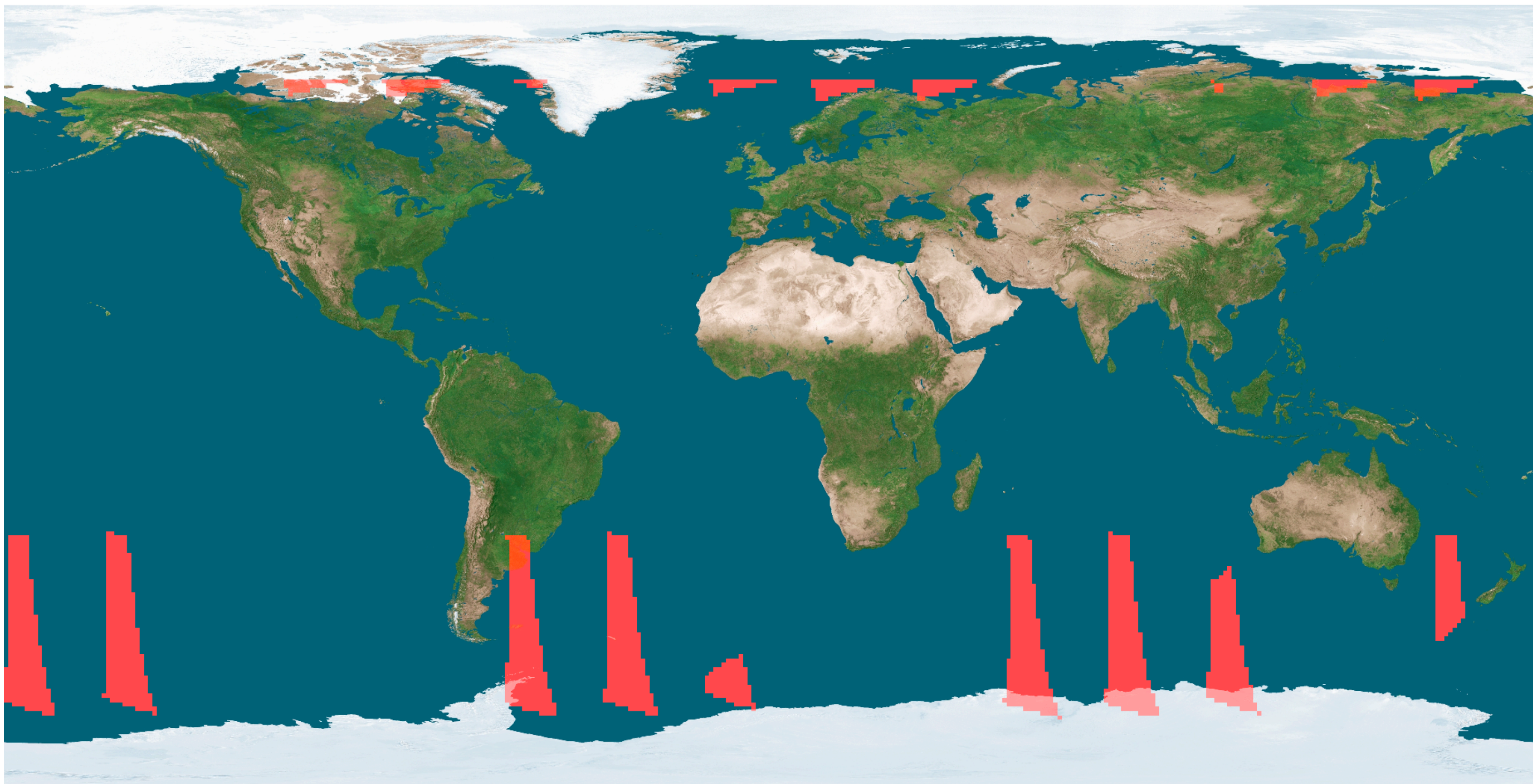
CAMEO AEGIS Overlap Analysis: Day 30



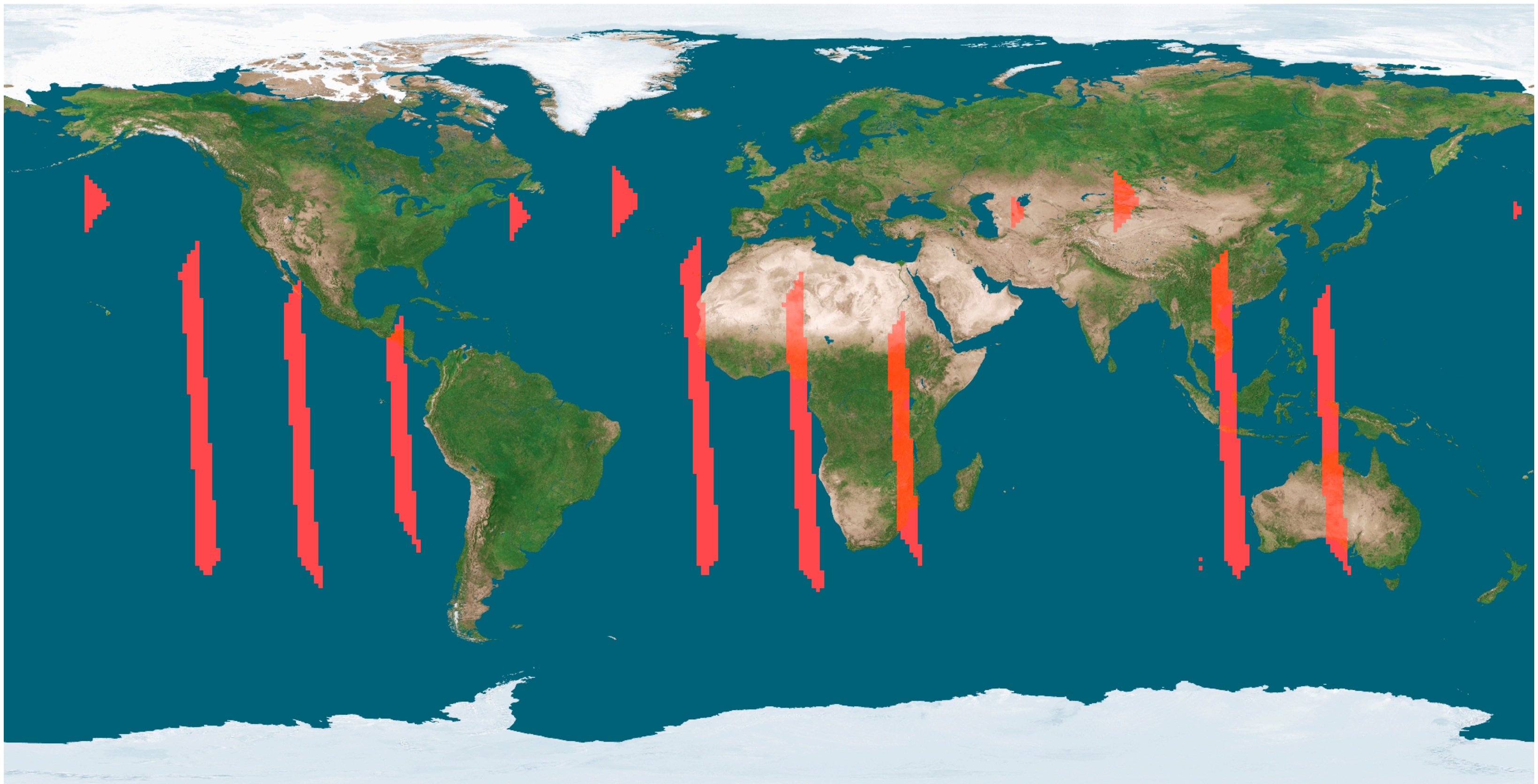
CAMEO AEGIS Overlap Analysis: Day 60



CAMEO AEGIS Overlap Analysis: Day 90



CAMEO AEGIS Overlap Analysis: Day 120



Outstanding issues

- Do all required species get measured, and are horizontal, vertical, and temporal sampling requirements met?
  - Using limb for many trace species - will limit tropospheric sampling
- How do we maximize sensitivity to trace gases in the boundary layer?
  - high spectral resolution in IR measurements
  - joint UV/Vis and IR retrievals
  - Off-nadir measurements to increase path

The message

- The range of species involved will require a set of instruments.
- Variety of measurement techniques are not compatible with only one orbit.
- Must truly sample the troposphere, not only infer concentrations - high spectral resolution is required for O_3.
- Extensive analysis with assimilation systems is important to evaluating mission designs.
- Analysis approach is general, and can be applied to other science problems.