NASA's Tropospheric Chemistry Program and GEO-CAPE

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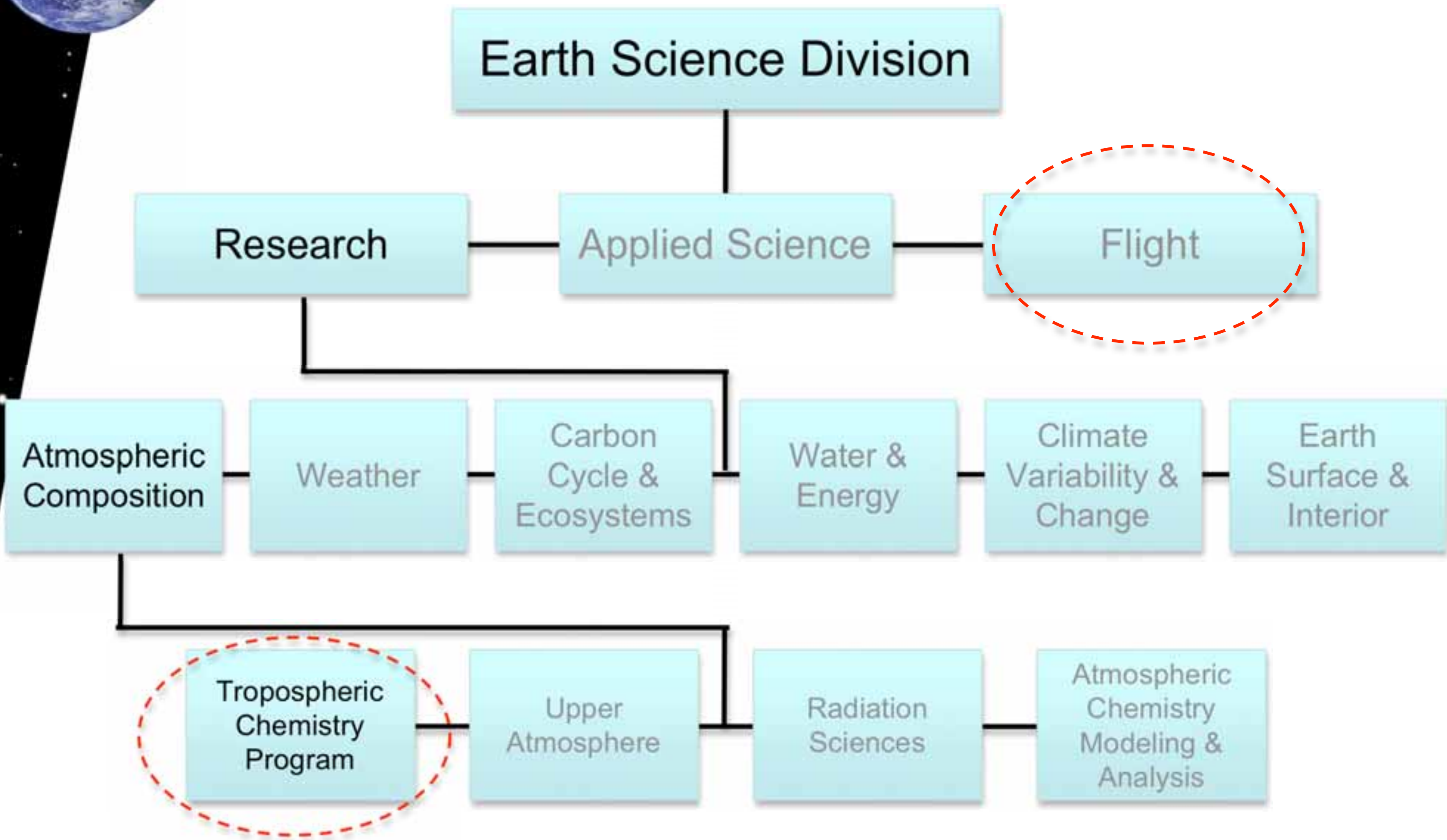
CEOS ACC Workshop on Air Quality
ESA/ESRIN, Frascati, IT
15-17 June 2009

GEOstationary Coastal ocean and Air Pollution Events

TCP within NASA Earth Science Structure

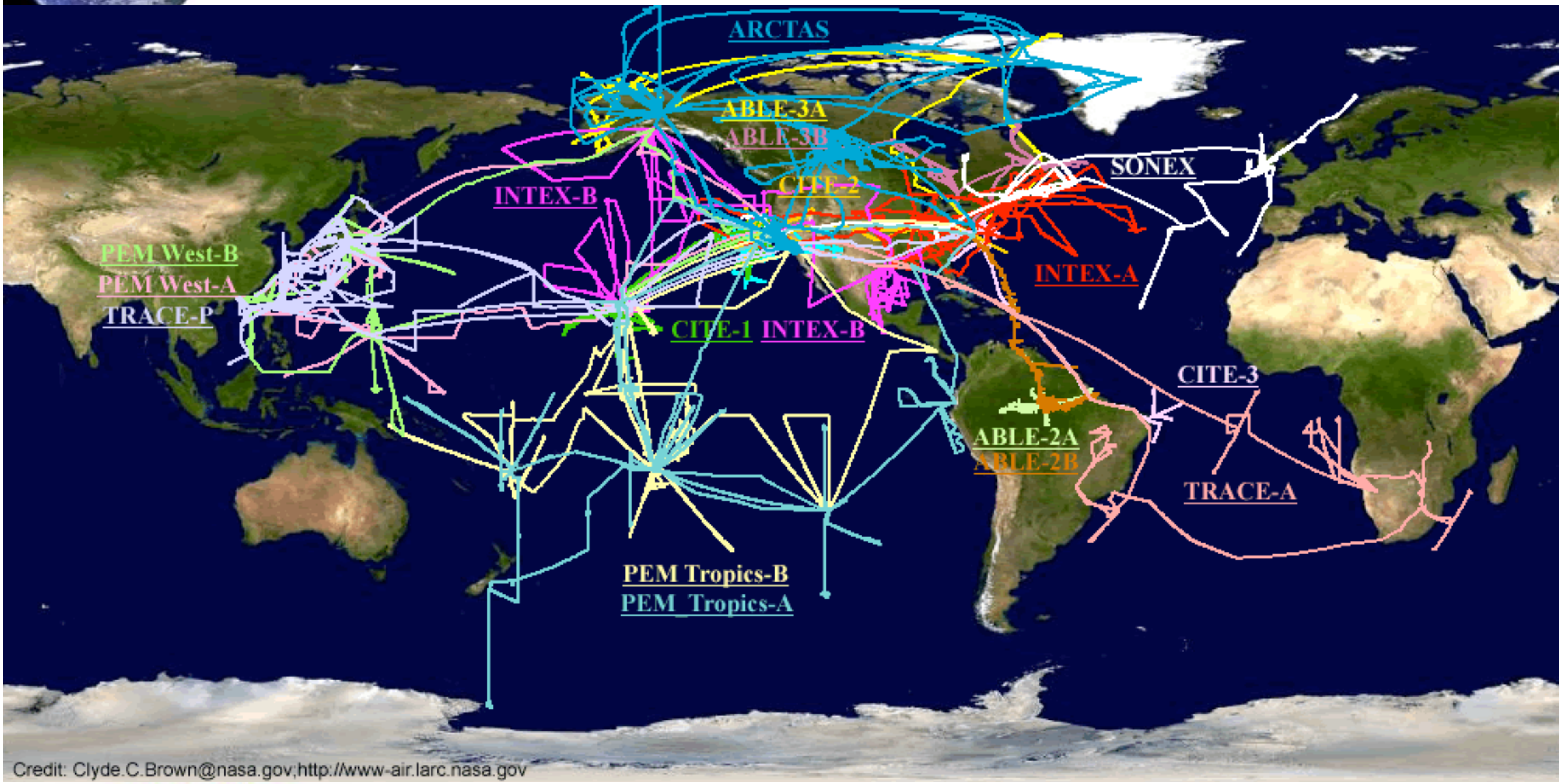
(Expanding only those branches directly in the tree)



Tropospheric Chemistry Program Profile

- Primarily supports science organized around major airborne field campaigns conducted every 2-3 years
- Most of the budget directly supports competitively selected 3-year proposals for field campaign participation and post-mission analysis
- Program budget approximately $7.1 Million/year
- For example, 2009 budget is primarily funding ARCTAS:
  - *$6.0M competed direct field mission (41 investigations)*
    - 11 NASA
    - 27 University
    - 3 Other US Federal Government
  - *$0.7M competed laboratory studies*
  - *$0.3M ongoing field mission project office support*
  - *$0.1M community support (IGAC, GRC, AAAR, …)*

NASA Airborne Tropospheric Chemistry Field Campaigns 1983-2008



1983-2001 missions conducted as the NASA Global Tropospheric Experiment project

Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS)

A NASA contribution to IPY and the international POLARCAT initiative

Conducted in spring and summer 2008 with 4 scientific themes:

1. Long-range transport of pollution to the Arctic (including arctic haze, tropospheric ozone, and persistent pollutants such as mercury)
2. Boreal forest fires (implications for atmospheric composition and climate)
3. Aerosol radiative forcing (from arctic haze, boreal fires, surface-deposited black carbon, and other perturbations)
4. Chemical processes (radical chemistry and implications for ozone, aerosols, mercury and halogens)

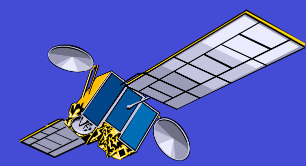
April 2008: Fairbanks and Barrow, Alaska; Thule and Iqaluit, Greenland

July 2008: Cold Lake, Alberta; Yellowknife, NW Territories; Thule

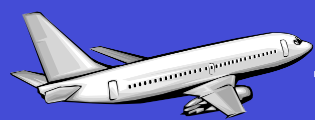
Partners: NASA, NOAA, DOE, NSF, Canada, CNRS, DLR

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

Satellite instruments: CALIOP, GOME-2, OMI, TES, MLS, SCIAMACHY, MODIS, MISR, MOPITT, AIRS, IASI



- Aerosol optical depth, properties
- H_2O, CO, methane, ozone, NO_2, HCHO, SO_2, BrO



Calibration and Validation
Retrieval development
Correlative information
Small scale structure and processes

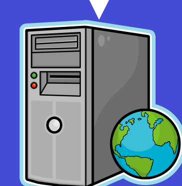
Aircraft: DC-8, P-3B, B200

- Comprehensive in situ chemical and aerosol measurements
- Active remote sensing of ozone, water vapor and aerosol optical properties
- Passive radiance measurements

Model error evaluation
Data assimilation
Diagnostic studies

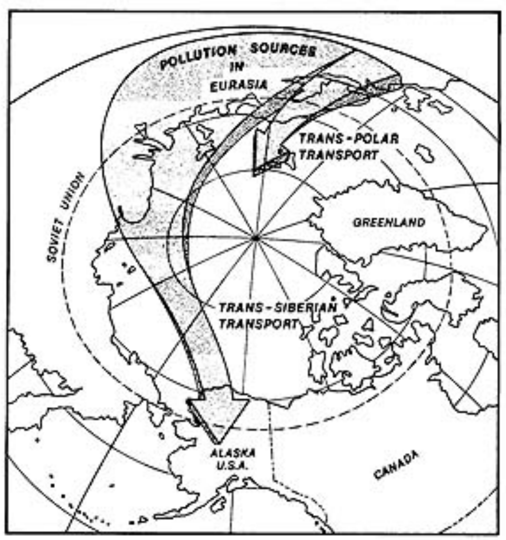
Models: CTMs, GCMs, ESMs

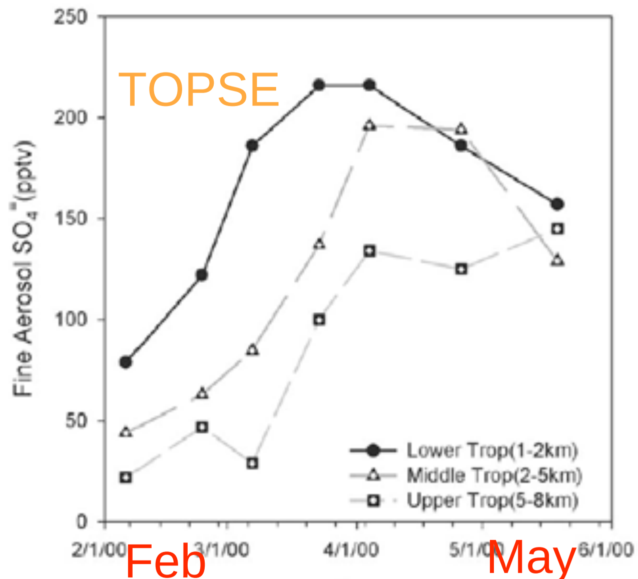
- Source-receptor relationships for pollution
- Inverse modeling for estimating emissions
- Aerosol radiative forcing
- Detailed chemical processing



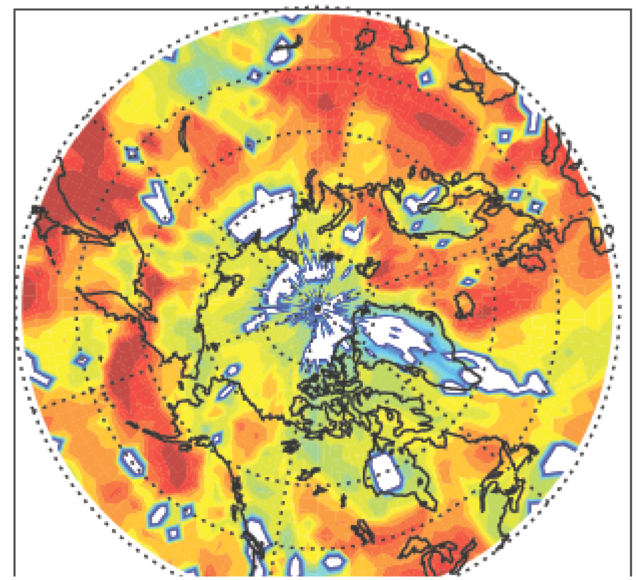
ARCTAS Science Theme 1:
Transport of mid-latitudes pollution to the Arctic

European influence | Seasonal sulfate build-up | AIRS CO column, 5 Apr 2008





Scheuer et al., 2003



Juying Warner (UMBC), Jenny Fisher (Harvard)

- What are the transport pathways for different pollutants?
- What are the contributions from different source regions, what are the source-receptor relationships?

Satellite capabilities:

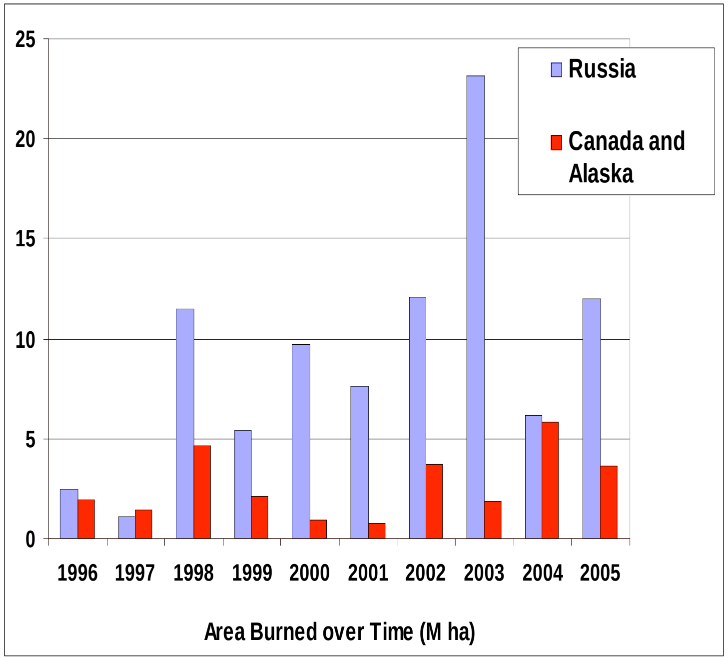
- CO (TES, AIRS, MOPITT)
- ozone (TES, OMI-MLS)
- aerosols (CALIOP, MODIS, MISR)
- methane (TES, AIRS)

Aircraft added value:

- detailed chemical composition
- tracers of sources
- vertical information

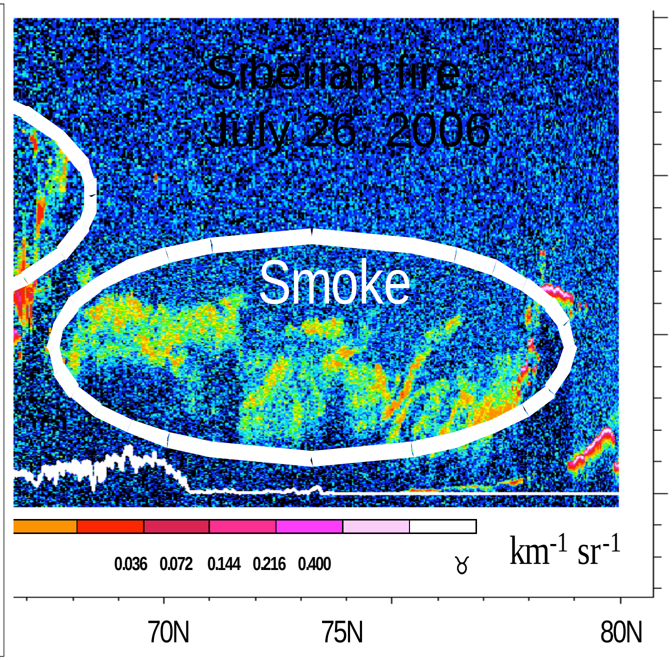
ARCTAS Science Theme 2: Boreal forest fires

Fire trend over past decade



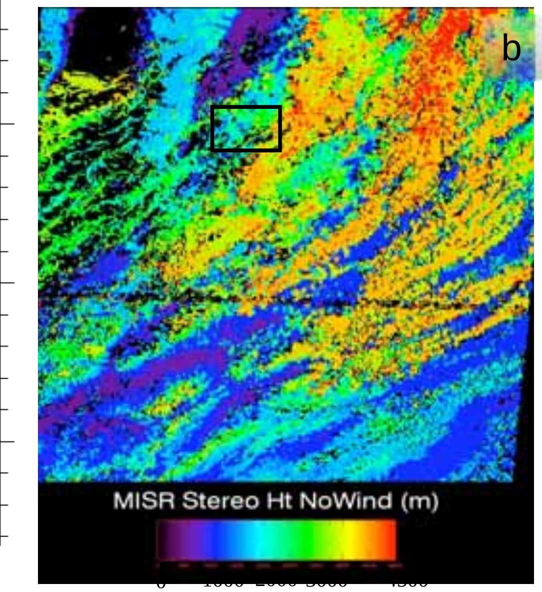
A. Soja, LaRC

CALIOP view of fire plume



C. Trepte, LaRC

MISR injection height



R. Kahn, JPL

- What are the chemical compositions & evolution of the fire plumes?
- What are their aerosol optical properties, how do these evolve?
- What are the injection heights?
- What are the implications for regional and global atmospheric composition?

Satellite capabilities:

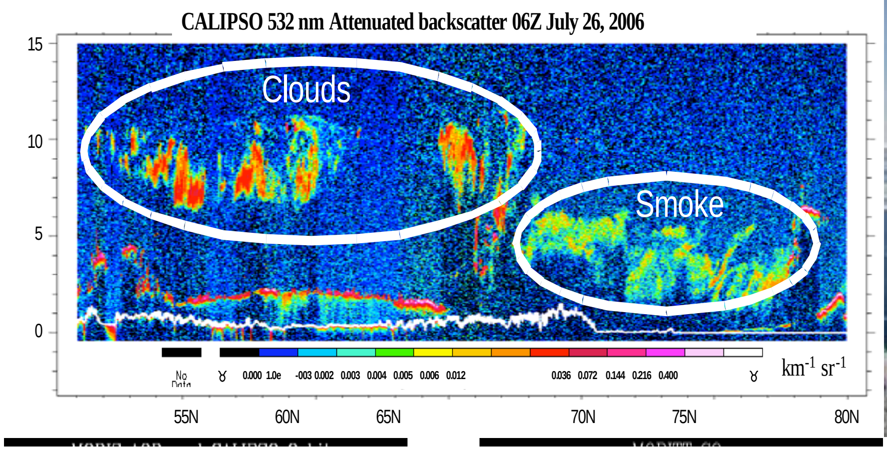
- aerosols (CALIOP, MODIS, MISR, OMI)
- CO (TES, AIRS, MOPITT, MLS)
- ozone (TES, OMI-MLS)
- methane (TES)

Aircraft added value:

- detailed chemical composition
- aerosol properties
- pyroconvective outflow

ARCTIC Science Theme 3: Aerosol radiative forcing

CALIPSO clouds and smoke



C. Trepte, LaRC

Arctic haze

MISR true-color fire plume

R. Kahn, JPL

- What is the regional radiative forcing from Arctic haze, fire plumes?
- How does this forcing evolve during plume aging?
- What are the major sources of soot to the Arctic?
- How does soot deposition affect ice albedo?

Satellite capabilities:

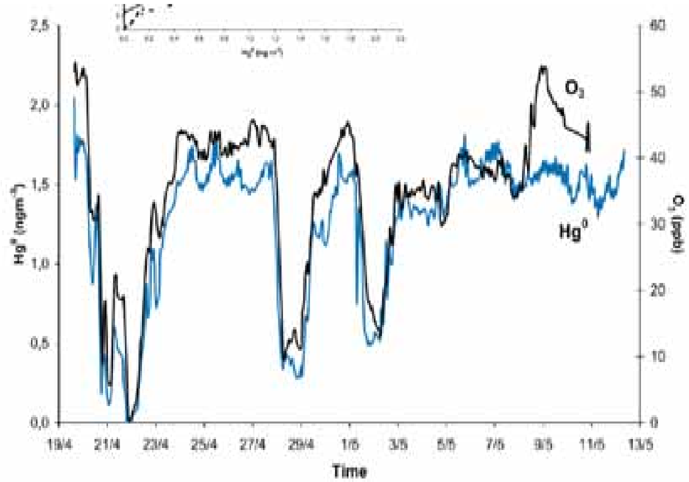
- UV/Vis/IR reflectances (Cloudsat, MODIS, MISR, OMI)
- multi-angle sensing (MISR)
- lidar (CALIOP)

Aircraft added value:

- detailed in situ aerosol characterization
- remote sensing of radiances, fluxes
- BRDFs

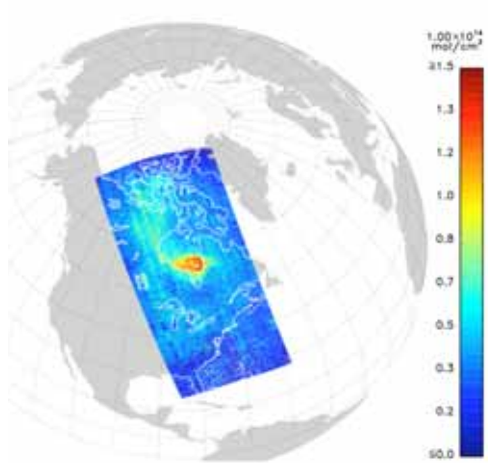
ARCTAS Science Theme 4: Chemical processes

Ozone, Hg depletion events



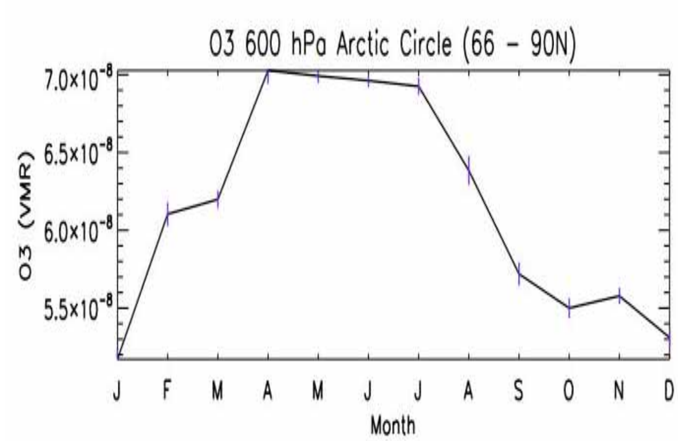
Sprovieri et al. [2005]

OMI tropospheric BrO



K. Chance, Harvard/SAO

TES tropospheric ozone



J. Worden, JPL

- What controls HO_x-NO_x chemistry in the Arctic?
- What drives halogen radical chemistry in the Arctic, what is its regional extent?
- What are the regional implications for ozone, aerosols, mercury?
- How does stratosphere-troposphere exchange affect tropospheric ozone in the Arctic?

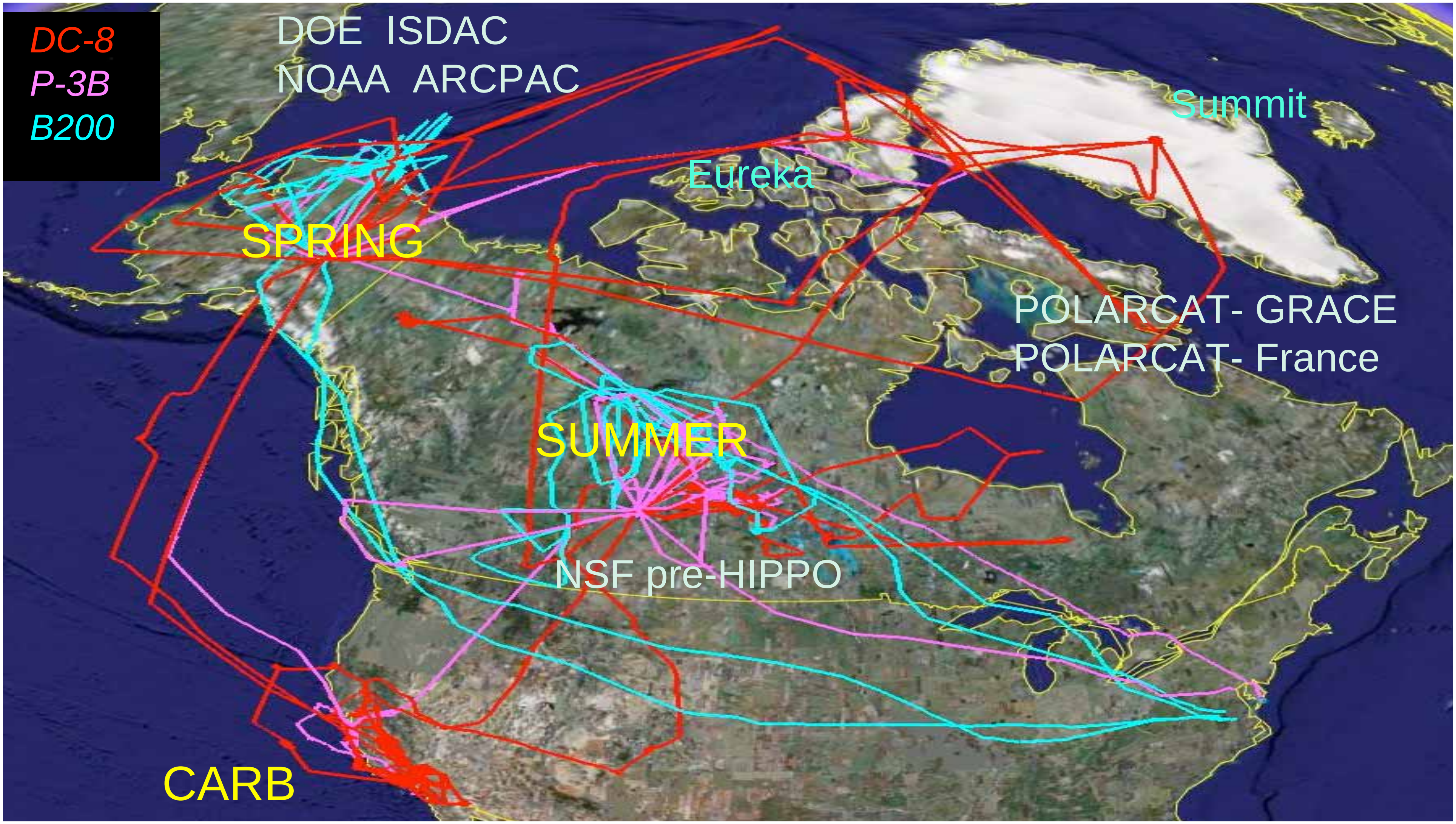
Satellite capabilities:

- Ozone (TES, OMI/MLS)
- BrO (OMI, SCIAMACHY, GOME-2)
- CO (TES, AIRS, MOPITT)

Aircraft added value:

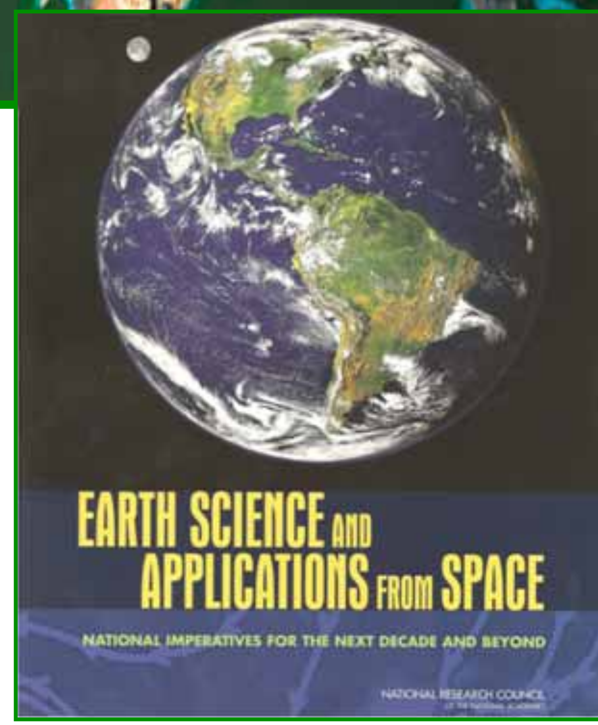
- detailed chemical characterization, constraints on photochemical models
- validation of OMI tropospheric BrO
- HO_x measurement intercomparison

	DC-8 (185 flight hours)	P-3B (158 flight hours)	B-200 (150 flight hours)
Spring (1-20 April)	9 sorties	8 sorties	27 sorties
California (18-24 July)	4 sorties	1 sortie	
Summer (26 Jun-13 July)	9 sorties	12 Sorties	21 Sorties



Part 2: The GEO-CAPE Mission

GEOstationary Coastal ocean and Air Pollution Events



The US NRC Decadal Survey

- In 2004, NASA, NOAA and USGS requested the National Research Council (NRC) form a panel to identify and prioritize the next set of observational platforms that should be launched and operated over the next decade.
  - *Strategic rather than tactical*
  - *Across all fields of Earth science*
- The Earth Science and Applications from Space Decadal Survey was released Feb 2007
  - *"Minimal but robust" Earth system science missions*
  - *Societal benefits should be a focus of all missions*
- NASA is implementing missions within 3 "Tiers" in accordance with the sequencing of the Decadal Survey.

NRC Recommended Missions - Early/Mid

Decadal Survey Mission	Mission Description	Orbit	Instruments	$ Estimate
Timeframe 2010 – 2013, Missions listed by cost				
CLARREO (NASA portion)	Solar and Earth radiation: spectrally resolved forcing and response of the climate system	LEO, Precessing	Absolute, spectrally-resolved interferometer	$200 M
SMAP	Soil moisture and freeze/thaw for weather and water cycle processes	LEO, SSO	L-band radar L-band radiometer	$300 M
ICESat-II	Ice sheet height changes for climate change diagnosis	LEO, Non-SSO	Laser altimeter	$300 M
DESDynI	Surface and ice sheet deformation for understanding natural hazards and climate; vegetation structure for ecosystem health	LEO, SSO	L-band InSAR Laser altimeter	$700 M
Timeframe: 2013 – 2016, Missions listed by cost				
HyspIRI	Land surface composition for agriculture and mineral characterization; vegetation types for ecosystem health	LEO, SSO	Hyperspectral spectrometer	$300 M
ASCENDS	Day/night, all-latitude, all-season CO_2 column integrals for climate emissions	LEO, SSO	Multifrequency laser	$400 M
SWOT	Ocean, lake, and river water levels for ocean and inland water dynamics	LEO, SSO	Ka-band wide swath radar C-band radar	$450 M
GEO-CAPE	Atmospheric gas columns for air quality forecasts; ocean color for coastal ecosystem health and climate emissions	GEO	High and low spatial resolution hyperspectral imagers	$550 M
ACE	Aerosol and cloud profiles for climate and water cycle; ocean color for open ocean biogeochemistry	LEO, SSO	Backscatter lidar Multiangle polarimeter Doppler radar	$800 M

NRC Recommended Missions - Late

Timeframe: 2016 -2020, Missions listed by cost				
LIST	Land surface topography for landslide hazards and water runoff	LEO, SSO	Laser altimeter	$300 M
PATH	High frequency, all-weather temperature and humidity soundings for weather forecasting and SST*	GEO	MW array spectrometer	$450 M
GRACE-II	High temporal resolution gravity fields for tracking large-scale water movement	LEO, SSO	Microwave or laser ranging system	$450 M
SCLP	Snow accumulation for fresh water availability	LEO, SSO	Ku and X-band radars K and Ka-band radiometers	$500 M
GACM	Ozone and related gases for intercontinental air quality and stratospheric ozone layer prediction	LEO, SSO	UV spectrometer IR spectrometer Microwave limb sounder	$600 M
3D-Winds (Demo)	Tropospheric winds for weather forecasting and pollution transport	LEO, SSO	Doppler lidar	$650 M

15

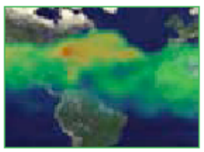
Overview of the mission from the Decadal Survey

Geosynchronous orbit with notional payload of 3 instruments:

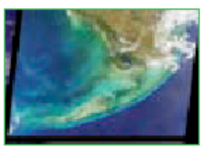
- UV-Vis-near IR wide area spectrometer, 45S to 50N, hourly (O_3, NO_2, CH_2O, SO_2, Aerosols)
- IR correlation radiometer for CO mapping
- High spatial resolution event-imaging spectrometer

GEOSTATIONARY COASTAL AND AIR POLLUTION EVENTS (GEO-CAPE)

Launch: 2013-2016   Mission Size: Medium



Identification of human versus natural sources of aerosols and ozone precursors



Dynamics of coastal ecosystems, river plumes, and tidal fronts

Observation of air pollution transport in North, Central, and South America

Prediction of track of oil spills, fires, and releases from natural disasters

Detection and tracking of waterborne hazardous materials

Coastal health

Forecasts of air quality

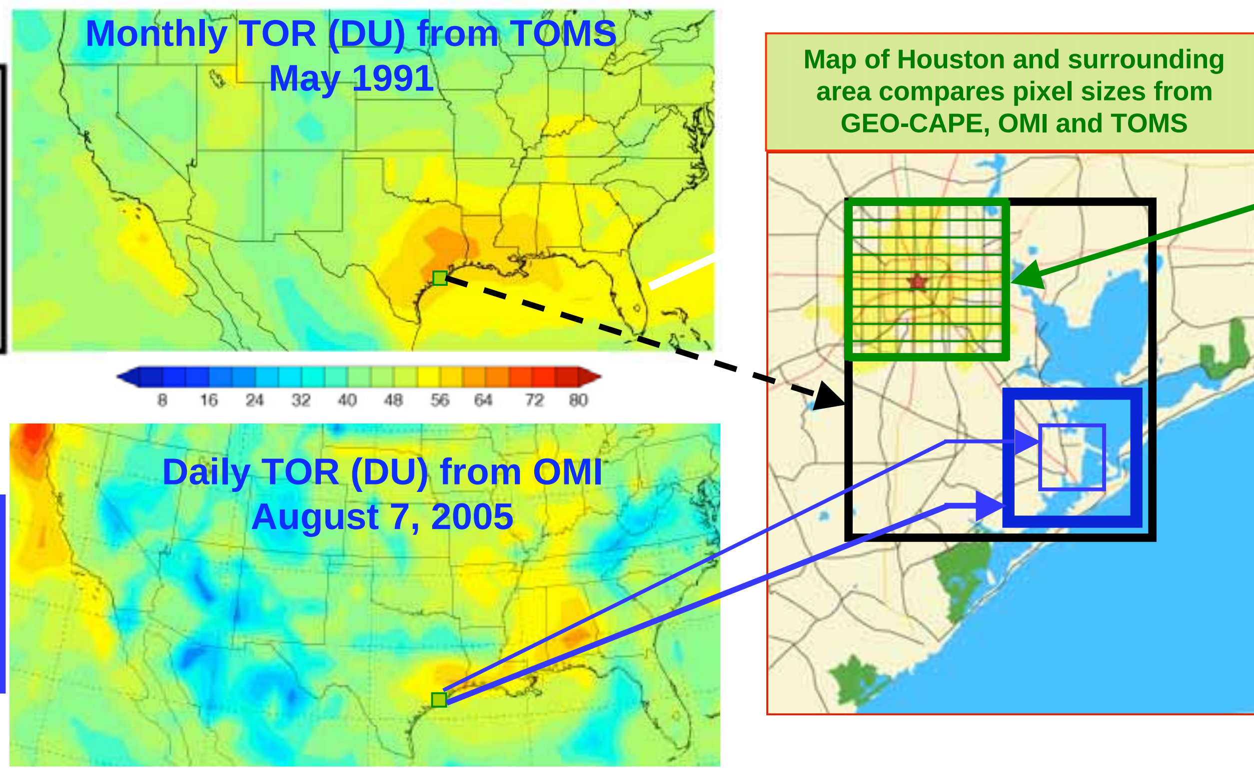
Geostationary Observations Will Provide Revolutionary Advances in Understanding Air Quality

Geostationary orbit view enables the *continuous, frequent, high spatial-resolution observations* of atmospheric composition that are required to provide the foundation for quantitatively connecting global and local scales of pollution.

Mature technology (OMI, MOPITT heritage) for O_3, NO_2, CO, SO_2, CH_2O and aerosols

TOMS (Daily)
~100 km res.
(used for monthly climatologies)

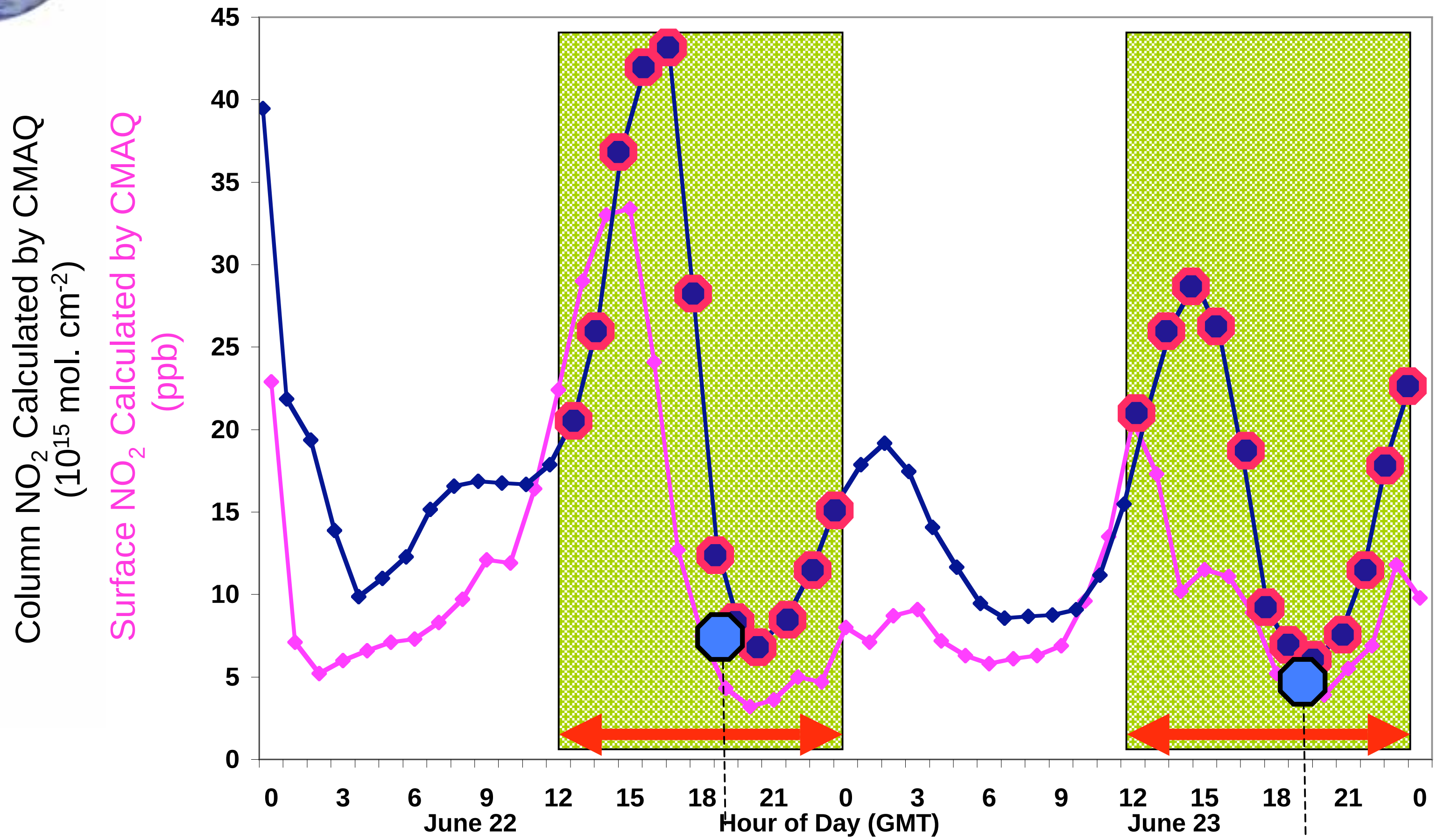
OMI (Daily)
~25-50 km res.



GEO-CAPE
(Hourly)
~5 km res.

GEO-CAPE Will Capture Diurnal Cycle of Key Trace Gases and Aerosols

Surface Concentrations and Integrated NO_2 Column Calculated by CMAQ Plotted as a Function of Hour: June 22-23, 2005



Measurements provided once per day from LEO (OMI,) provide relatively little information for examining AQ model performance

Hourly measurements possible from geostationary orbit capture daylight portion of diurnal cycle

Key Pre-Phase A Questions

- What science MUST this mission achieve?
  - *What specific measurements?*
  - *To what accuracy?*
  - *What are the required data products?*

Should be resolved ~ 12 months prior to KDP A

- What mission parameters can achieve the science?
  - *What orbit (inclination/altitude)?*
  - *Which instruments?*
  - *What is the baseline mission duration?*
- How can NASA achieve these measurements?
  - *Are there other missions required/desired to achieve the science?*
  - *Who can NASA partner with to achieve this mission?*

Should be resolved ~ 6 months prior to KDP A

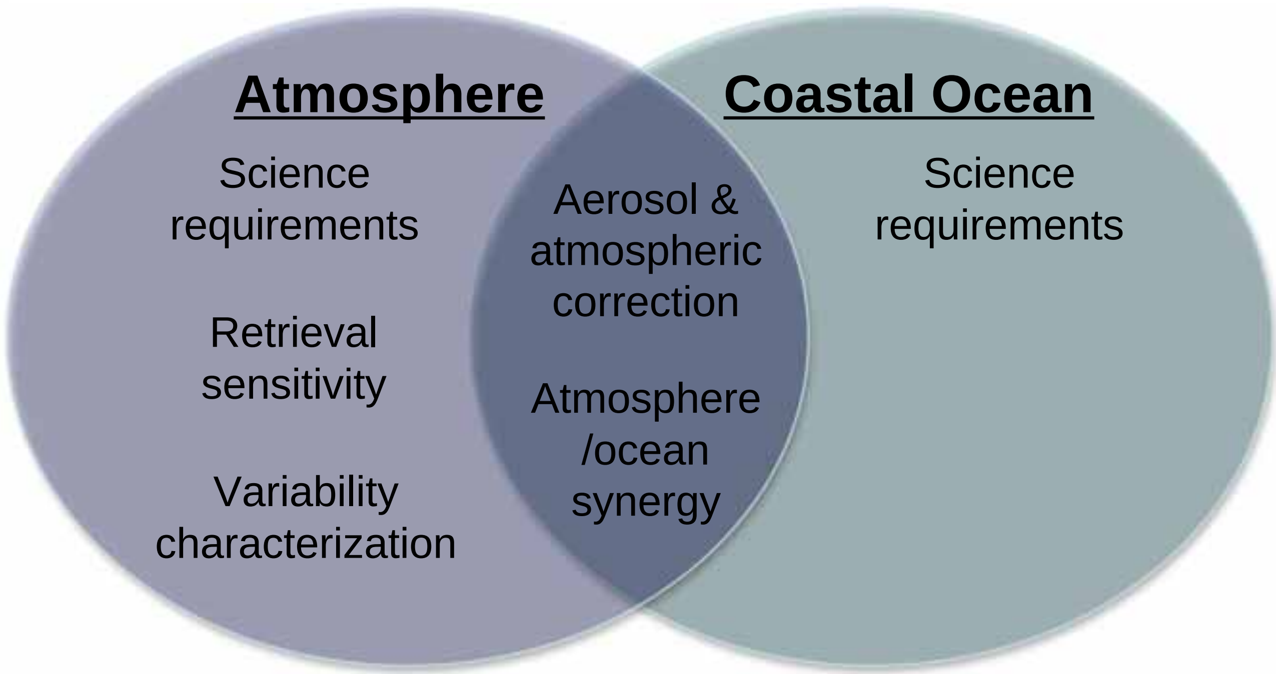
GEO-CAPE Mission Study Status

- *Science requirements*
  - Nominal baseline requirements from the NRC Decadal Survey
  - 2008 Community Workshop Report (~150 participants from AQ and OC communities) available, *http://geo-cape.larc.nasa.gov/documents.html*
  - Science Working Groups are currently refining requirements, draft due end of this year

- *Technology Readiness*
  - Measurement, instrument and retrieval requirements under preliminary definition by Science Working Group
  - Advanced instrumentation development through NASA Instrument Incubator and Advanced Component Technology programs

GEO-CAPE Science Working Group

- *Atmosphere and Coastal Ocean subgroups working on near-term priority tasks as defined by the 2008 Workshop Report ($2M FY2009)*
  - Broad but dynamic community involvement, currently includes NASA, University, NOAA, US EPA
- *Refine science, observation, and instrument requirements by end 2009*
- *Plan focused OSSE and systems engineering design studies in 2010 to enable assessment of readiness to proceed to mission formulation*



GEO-CAPE SWG subgroup focus themes (9 June 2009)

GEO-CAPE Mission Study Issues

- Vertical resolution of air quality species within the troposphere
  - *Can multi-wavelength retrievals provide increased boundary layer sensitivity?*
  - *Is BL sensitivity a science requirement?*
  - *Joint atmosphere/ocean retrievals*
- Observing strategy
  - *Combined atmosphere and ocean requirements for “fine” spatial / ”frequent” temporal resolution with large area coverage present major technological challenges*
  - *Systematic vs episodic*
- Mission cost (including launch/orbit)
  - *Advanced instrumentation concepts may offer reduced mass and improved capability, but at higher mission risk*
  - *Potential for “hosted payload” on commercial ComSat*

Instrument Incubator Program 2007 Awards vs. Decadal Survey Missions

2007 Instrument Incubator Awards versus Decadal Survey Missions	CLARREO	SMAP	ICESat-II	DESDynI	HyspIRI	ASCENDS	SWOT	GEO-CAPE	ACE	LIST	PATH	GRACE-II	SCLP	GACM	3D-Winds	CLARREO-NOAA	GPSRO	XOVWM
Abshire/GSFC - column CO2, lidar						■												
Diner/JPL - aerosols and clouds, polarimetric imager									■									
Durden/JPL - clouds and precipitation, profiling radar									■									
Folkner/JPL - time-varying gravity, laser frequency stabilization												■						
Fu/JPL - surface water and ocean topography, interferometric SAR							■											
Grund/Ball - tropospheric winds, Doppler lidar															■			
Hackwell/Aerospace - mineral and gas, TIR spectrometer					■													
Heaps/GSFC - column CO2, lidar						■												
Hook/JPL - mineral/water resources, hyperspectral TIR spectrometer					■													
Kavaya/LaRC - tropospheric winds, Doppler lidar															■			
Kopp/CU - radiation balance, UV-SWIR hyperspectral imager	■																	
Lambrigtsen/JPL - T, water vapor, precipitation; microwave sounder											■							
McClain/GSFC - ocean color, UV-SWIR radiometer									■									
Mlynczak/LaRC - radiation balance far-IR spectrometer	■																	
Neil/LaRC - boundary laser CO, gas correlation radiometer								■										
Papapolymerou/GT - snow-water equivalent, X-band phased array													■					
Revercomb/UWM - radiation balance, SI-traceable IR calibration	■																	
Sander/JPL - air pollution and coastal imaging, panchromatic FTS								■										
Stek/JPL - atmospheric composition, microwave limb sounder														■				
Weimer/Ball - vegetation canopy, steerable lidar				■														
Yu/GSFC - topography and vegetation structure, swath-mapping lidar										■								

■ IIP07 Awards

Earth Science Technology Office

Advanced Component Technology Program
2008 Awards vs. Decadal Survey Missions

2008 Advanced Component Technology Awards versus Decadal Survey Mission	CLARREO	SMAP	ICESat-II	DESDynI	HyspIRI	ASCENDS	SWOT	GEO-CAPE	ACE	LIST	PATH	GRACE-II	SCLP	GACM	3D-WINDS	CLARREO-NOAA	GPSRO	XOVWM
Dobbs/ITT - corrugated mirror telescope array for lidar			■	■		■			■	■				■	■			
Fang/JPL - large deployable reflector for Ka- and W-band									■									
Hoffman/JPL - thermal packaging for RF hybrids, radar				■			■											
Illing/Ball - polarization scrambler, spectroscopy					■			■	■					■				
Janz/GSFC - visible NIR blind GaN focal plane array, hyperspectral								■										
Krainak/GSFC - NIR optical receiver, lidar			■	■		■			■	■					■			
Marx/GSFC - hybrid doppler wind lidar transceiver															■			
McGill/GSFC - detector technology for cloud aerosol lidar									■						■			
Meehan/JPL - RF ASIC for digital beamforming, GNSS															■		■	
Mlynczak/LaRC - FIR detectors for Earth radiation	■																	
Phillips/LockMart - CO2 laser absorption spectroscopy						■												
Reising/Colo. St. Univ.- radiometer for wet-tropospheric correction							■											
Rider/JPL - analog to digital converter from UV to mid-IR					■			■	■					■				
Siqueira/Univ. Mass. - low power, high BW receiver, Ka-band							■											
Taylor/Composite Tech. Dev. - large aperture, deployable reflector		■					■				■		■					■
Thomson/JPL - deployable Ka-band reflect array							■											

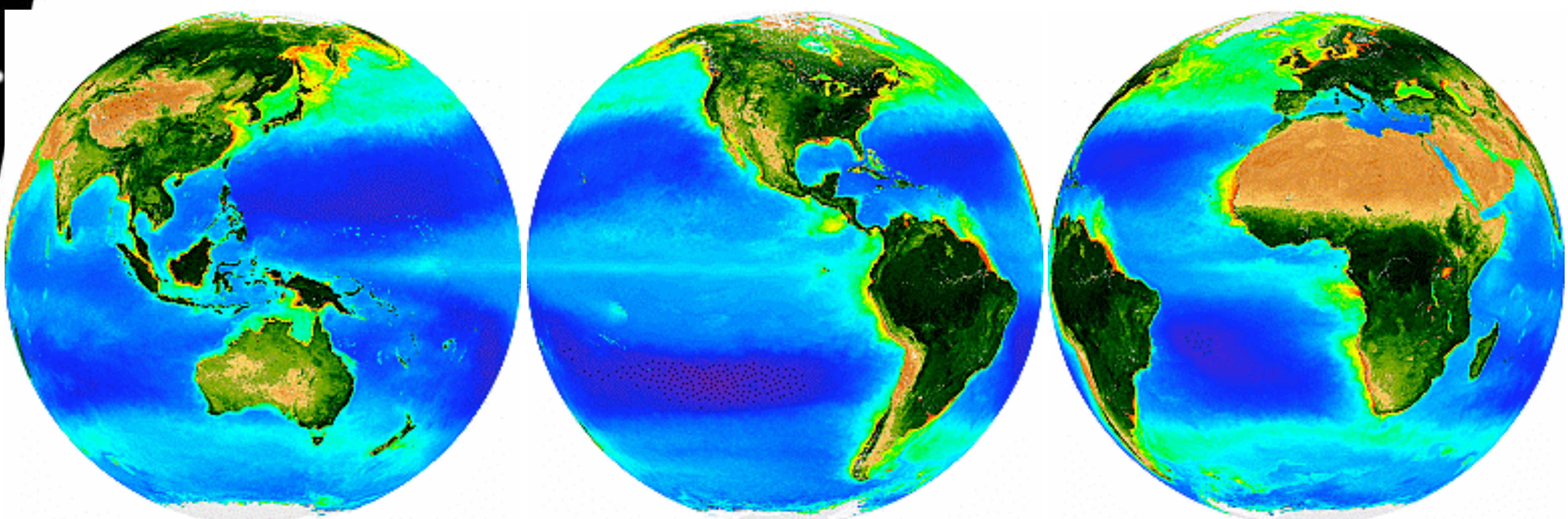
Earth Science Technology Office

Assembling a Global View: International Cooperation

Synergies with International Missions: ***Complementary Coverage***

- Current expectation: launch no earlier than 2017
- IGACO Vision of constellation of geostationary platforms
  - Korean GOCI sensor (2009): ocean color observations from GEO
  - ESA Sentinel 4: GEO Satellite for atmospheric composition
  - JAXA GEO platform for atmospheric composition
  - Korean future GEO atmospheric composition/ocean mission

Mutual participation on working groups and science teams is necessary!



Asia and Australia: JAXA, KARI

Americas: NASA

Europe and Africa: ESA

Backup Slides

GEO-CAPE Mission Study Overview (3)

Consensus of the Science Study Groups

- *UV-VIS-NIR Spectrometer Science Measurement*
  - 0.5 nm bands from 340 – 1240 nm, SNR > 1000:1
  - 7 km spatial resolution, hourly revisit
  - North & South America land and shallow water
  - Some type of Near IR observation is required for CO
  - Potential of combining thermal and mid IR with UV to get better leverage on boundary level ozone, but concept has yet to be proven

- *Event-Imaging Science Measurement*
  - 250-500 m spatial resolution, hourly revisit
  - North & South America land and shallow water

- *Mission*
  - Geostationary, high temporal frequency
  - Choice of longitude is important

Science Questions and Mission Objectives

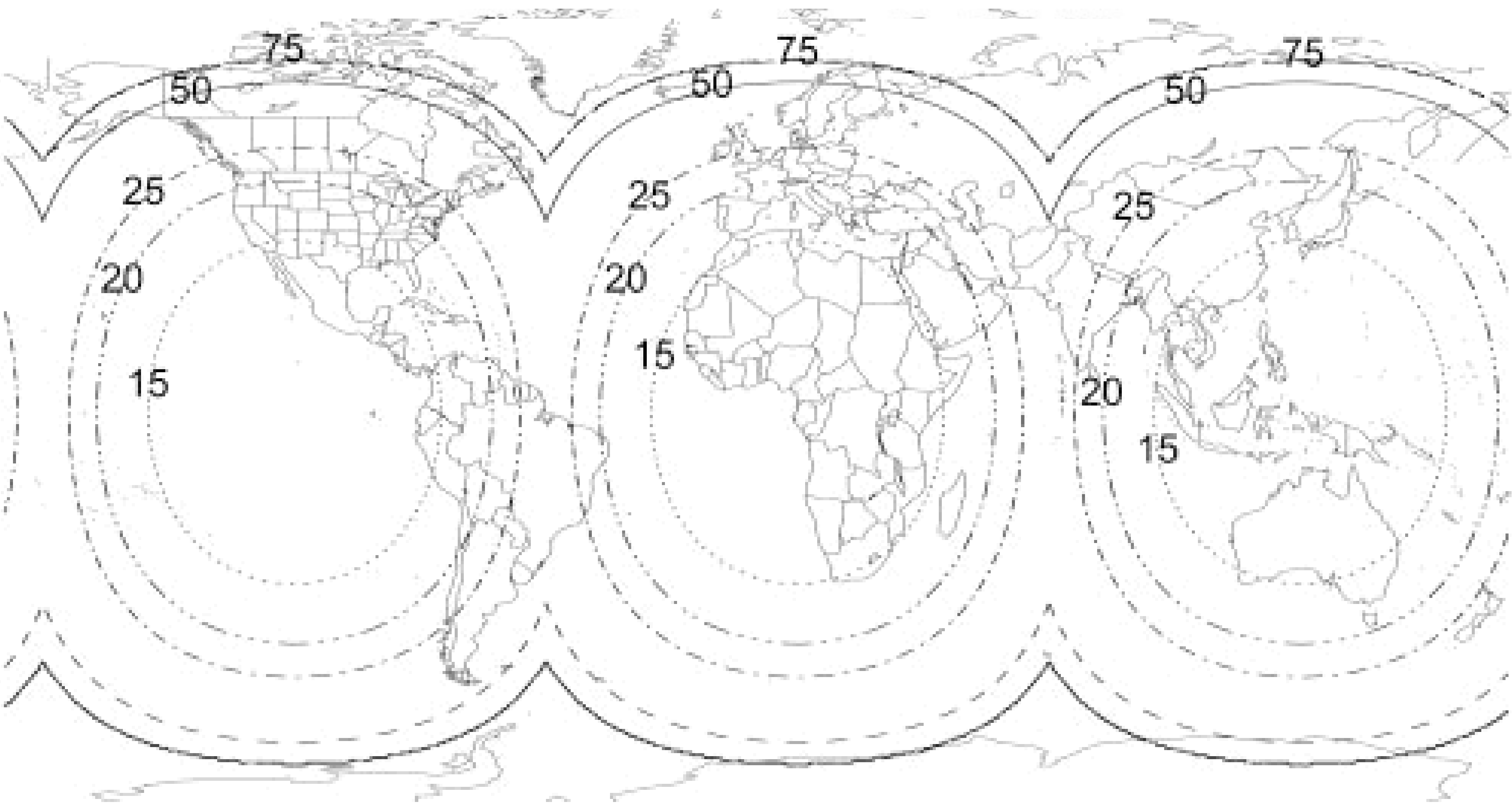
Overarching Science Question:

What are the effects of gaseous and particulate emissions on atmospheric composition, air quality, and coastal ecosystems, and how will they respond to climate change and increased human populations?

Science Questions	Mission Objectives
What are the emission patterns of the precursor chemicals for tropospheric ozone, aerosols, and air quality pollutants?	Quantify the diurnal emission patterns of ozone and aerosol precursors, and air quality pollutants over North & South America and the adjacent ocean.
What are the diurnal processes that impact the evolution of gaseous and particulate emissions through chemical formation and loss, transport, and deposition, and how are these processes impacted in a changing world?	Measure the evolution of these atmospheric constituents as they are transformed and transported throughout the day over North & South America and surrounding ocean.
What processes affect and control the biology and biogeochemistry of aquatic coastal ocean zones, and how are they modulated by natural and anthropogenic forcings?	Characterize variability in primary productivity, phytoplankton biomass, and carbon pools in the coastal ocean in conjunction with measurements of natural and anthropogenic forcings.
How do climate variability, anthropogenic activity, weather and the episodic releases from fires and volcanoes affect air quality, river discharge, water quality, and the ecology and biogeochemistry of coastal ecosystems and what are the feedbacks?	Characterize changes in the atmospheric chemistry, hydrology, and coastal ocean biogeochemistry in response to climate variability, human activity, weather events and episodic input from fires and volcanoes.

When staring nadir (directly down) at the visible Earth disk, size of footprint increases with distance from the equator.   For a 10 km footprint at equator, sizes are marked in km.

Most meteorological satellites in geo observe small patches on the face of the Earth disk rather than the viewable area in order to minimize this pixel size change.



Flight opportunities available when replacement commercial satellites are launched