Geostationary Coastal and Air Pollution Events (Geo-CAPE) Mission Requirements

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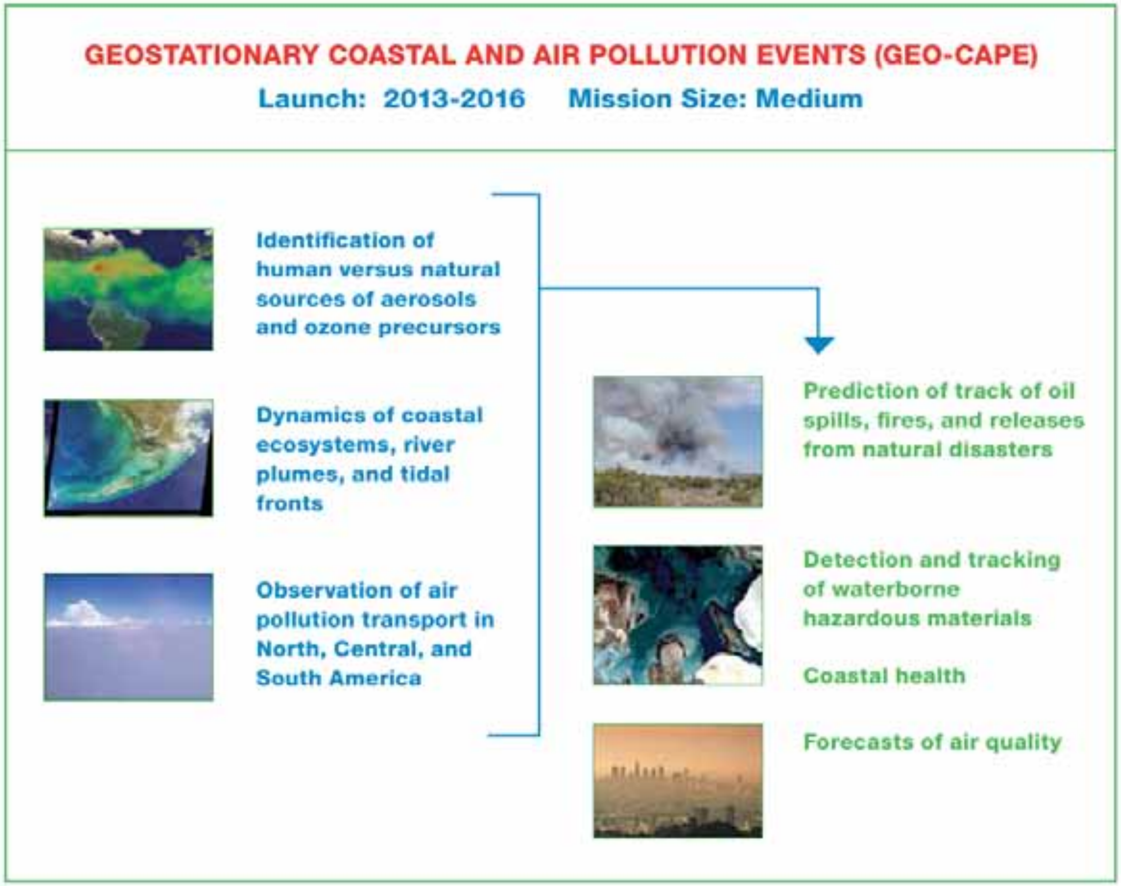
GEO-CAPE Program Scientist

GEMS Science Team Meeting
31 August 2011, Yonsei University, Seoul, Korea

2007 NRC Decadal Survey:
GEO-CAPE Mission and Notional Payload Concept



GEO-CAPE consists of three instruments in geosynchronous Earth orbit near 80°W longitude: a UV-visible-near-IR wide-area imaging spectrometer (7-km nadir pixel) capable of mapping North and South America from 45°S to 50°N at about hourly intervals, a steerable high-spatial-resolution (250m) event-imaging spectrometer with a 300-km field of view, and an IR correlation radiometer for CO mapping over a field consistent with the wide-area spectrometer.

The revolutionary advance for both disciplines is observations many times per day

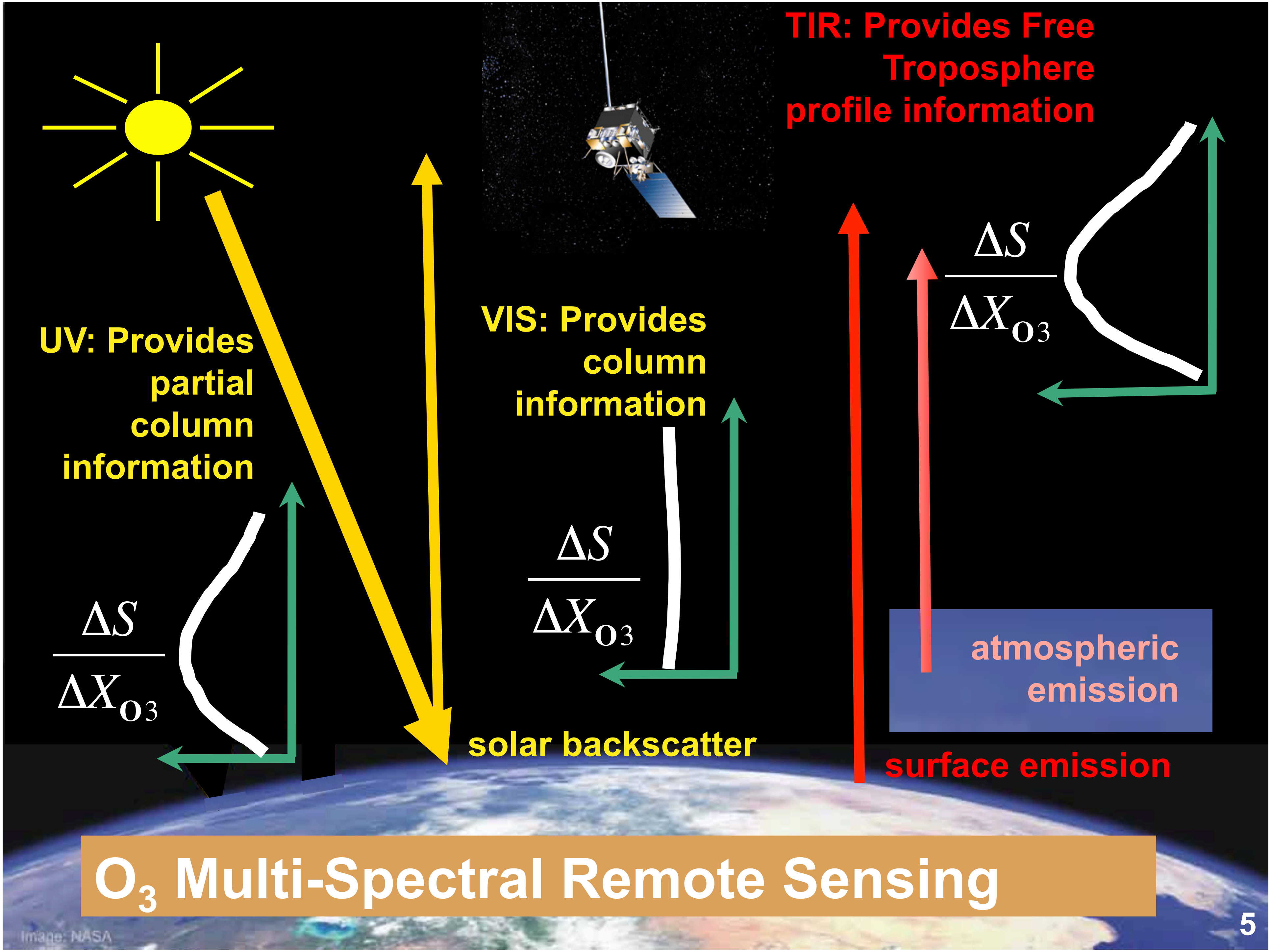
GEO-CAPE Current Status

- Challenging economic situation and budget environment
  - *GEO-CAPE not presently scheduled for launch before 2021*
  - *Working groups are developing science and applications requirements, and instrument and mission concepts, to be responsive to this situation.*
    - Compelling observations, as soon as possible, at programmatically acceptable cost and risk
- Advancement of similar missions in Europe and Asia presents opportunity to achieve common science globally through partnership
- There are no critical ***enabling*** technology needs
  - *The mission can be implemented with LEO space heritage instrumentation*
  - ***Revolution is in temporal resolution*** *– many times per day*
- There are ***enhancing*** technology developments in which NASA is investing
  - ***3 new NASA ESTO Instrument Incubator Program (IIP) selections***
    - Reduce instrument size
    - Advance instrument capabilities to enhance science return
  - *Pointing solutions for possible commercial ComSat hosting – survey study underway*
- The EV-1 DISCOVER-AQ investigation (2011-2014) will help establish how remote sensing observations many times per day will be combined with ground based measurements in integrated observing systems for Air Quality

Science Traceability Matrix: science and applications questions define measurement objectives which establish instrument requirements

Geo-CAPE Atmosphere Science Questions (Version 2010/11/15)

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


TIR: Provides Free Troposphere profile information
UV: Provides partial column information
VIS: Provides column information
ΔS / ΔX O3
ΔS / ΔX O3
ΔS / ΔX O3
atmospheric emission
solar backscatter
surface emission
O3 Multi-Spectral Remote Sensing
Image: NASA
5

GEO-CAPE Measurement Requirements: Spectral Regions and Precision
(Draft version 2011/05)

Species	Precision	Spectral region	Rationale
O_3	Stratosphere: 5% 2 km-tropopause: 15 ppb 0-2 km: 10 ppb	UV, Vis, TIR	Surface AQ, transport, climate forcing
CO	2 km – tropopause: 20 ppb 0-2 km: 20 ppb	SWIR, MWIR	CO emission, transport
Aerosol	0.05 (AOD)	Vis	Surface AQ, aerosol sources and transport, climate forcing
NO_2	1×10^{15} cm^{-2}	Vis	NO_x emissions, chem.
HCHO	1×10^{16} cm^{-2}	UV	VOC emissions, chem.
SO_2	1×10^{16} cm^{-2}	UV	SO_x emissions, chem.
CH_4	Troposphere: 20 ppb	SWIR	CH_4 emissions
NH_3	0-2 km: 2 ppb	TIR	NH_3 emissions
CHOCHO	4×10^{14} cm^{-2}	Vis	VOC emissions, chem., aerosol formation
Absorbing aerosol	0.02 (AAOD)	UV	Climate forcing
Aerosol index	0.1	UV	Aerosol events
Aerosol centroid height	1 km	Vis, NIR	Aerosol plume height, large-scale transport, AOD to PM conversion

Measurement requirements for GEO-CAPE (Draft 2011/05)

and descope options

- **Orbit centered over 100° W, observing domain north of 10° N**

- **Hourly data over land/coastlines with pixel resolution of 1x1 km^2 (aerosols) and 4x4 km^2 (gases), for SZA<70° (some species), <50° (others)**
  - co-add 1x1 km^2 pixel information spectrally (aerosols) and spatially (gases)
  descope option: degrade to 2x2 km^2 (aerosols) and 8x8 km^2 (gases)

- **Daily data over open oceans (O_3, CO, aerosol) with pixel resolution of 16x16 km^2**
  descope option: cancel data over open ocean

- **Ozone and CO: two pieces of information in troposphere including sensitivity below 2 km**

- **NO_2, HCHO, SO_2, CH_4, CHOCHO, NH_3 : columns only**
  descope options: cancel HCHO, SO_2, CH_4, CHOCHO, NH_3

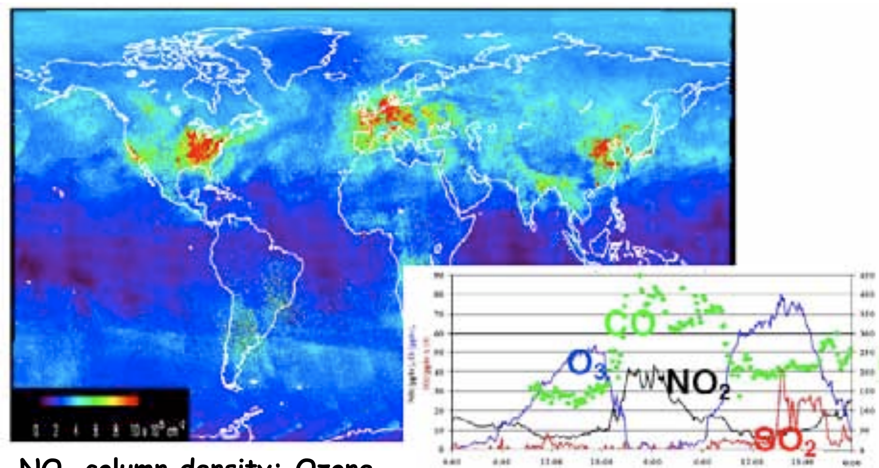
- **Aerosol optical depth (AOD), absorption (AAOD), index (AI), height (AOCH)**
  descope options: cancel AAOD, AI, AOCH

Geostationary Spectrograph (GeoSpec) for Earth and Atmospheric Science Applications

PI: Dr. Scott Janz / GSFC

Objective

- Demonstrate the feasibility of future Geostationary Earth Science missions using hyperspectral UV/VIS/NIR instrumentation.
- Geostationary orbit allows the measurement of the diurnal evolution of physical processes.
- Breadboard demonstration of a dual spectrograph instrument with UV/VIS and VIS/NIR channels using hybrid PIN/CMOS detectors.
- Target Earth Science Products: Coastal and ocean pollution events, tidal effects, origin and evolution of aerosol plumes, and trace gas measurements of O3, NO2, CH2O, and SO2.



NO_2 column density: Ozone Monitoring Instrument (OMI)

Local Time (hr)

Accomplishments:

- Completed GeoSpec instrument design and system performance studies including polarization sensitivity, spectral sampling/sensitivity trades, image quality, and detector packaging/thermal control.
- Completed design, testing, fabrication and coating of all system optics including convex holographic gratings and new technology single crystal silicon (SCS) mirrors.
- Completed design and fabrication of optical bench mechanical structure.
- Completed optical alignment and end-to-end testing of breadboard including atmospheric retrievals.
- Completed both ISAL and IMDC studies of flight instrument concept.

CoIs:

- Pennsylvania State University
- Washington State University
- Research Support Instruments/Ball Aerospace

Completed 1/07

TRL_{in} = 3 **TRL_{out}** = 4

Continued investment in instrument concepts: UV-Visible Spectrometer

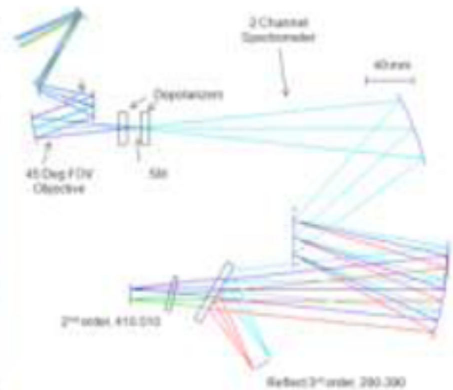
GEO-TASO: Geostationary Trace gas and Aerosol Sensor Optimization

PI: James Leitch, Ball Aerospace and Technologies Corp.

Objective

- Demonstrate a compact multi-order 2 channel spectrometer with up to 4x spectral oversampling.
- Determine optimal spectral/spatial sampling and resolution for the Geo-CAPE UV-Vis spectrometer.
- Develop a ruggedized airborne sensor to support future Geo-CAPE spectral and spatial trades and validation.
- Demonstrate needed retrieval performance under flight-like conditions.

GeoSpec IIP



Multi-order airborne spectrometer

Approach

- Derive airborne mission and sensor performance requirements.
- Design and assemble airborne sensor.
- Verify sensor performance in the laboratory including: spectral, spatial, stray light and radiometric precision and accuracy to meet limiting trace gas retrieval case (HCHO).
- Conduct two NASA DC-8 data collection flights.
- Perform retrieval analysis on airborne data to optimize Geo-CAPE spectral and spatial sampling resolution requirements.

CoIs/Partners: Scott Janz, GSFC, Kelly Chance, Xiang Liu, SAO / Jun Wang, Univ. of Nebraska, Lincoln

Key Milestones

- Mission and sensor requirements 08/11
- Sensor design and long leads on order 03/12
- Functional test (TRL 4) 10/12
- Environmental test (TRL 5) 11/12
- Performance test 08/13
- Flight data campaign (TRL 6) 11/13
- Trace gas retrievals on flight data 03/14

TRL_{in} = 3 $TRL_{current}$ = 3

ESTO Earth Science Technology Office

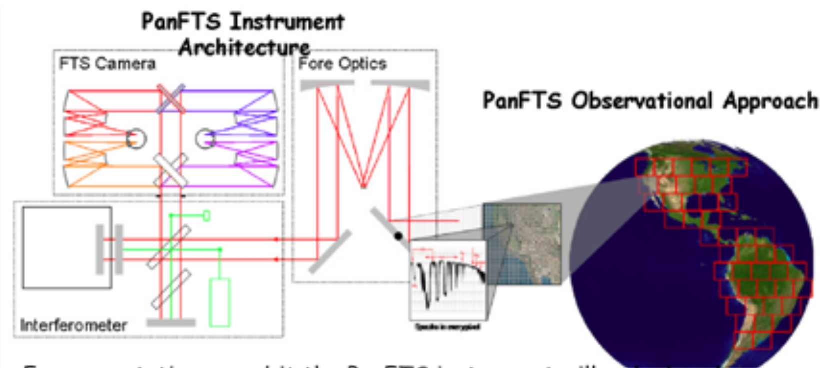
Continued investment in instrument concepts: UV-Visible through Thermal-IR Spectrometer

Panchromatic Fourier Transform Spectrometer Engineering Model (PanFTS EM) Instrument for the GEO-CAPE mission

PI: Stanley Sander, JPL

Objective

- Develop a flight-size PanFTS engineering model (EM) instrument which will reduce the risk, cost, size, volume, mass, and development time of an instrument that can make air quality and greenhouse gas measurements for the Geo-CAPE mission.
- Demonstrate two key enabling system level technologies:
  - A flight-size FTS instrument that addresses all critical scaling issues and is capable of operation over the flight instrument spectral range (0.26mm to 15mm)
  - Instrument operation in a space like thermal-vacuum environment demonstrating simultaneous UV-Vis and IR measurements under critical environmental conditions



From geostationary orbit the PanFTS instrument will make hourly measurements of atmosphere composition with wide spectral sensitivity and high resolution as well as measure important green house gases

Approach

- Develop PanFTS science and measurement requirements that support Geo-CAPE air quality and climate processes science
- Define specifications for an EM instrument design that can demonstrate the critical capabilities of a flight instrument
- Acquire and characterize EM components in lab environment and then verify in a relevant space flight operation environment (thermal-vacuum at 180 K)
- Integrate EM components and assemblies and verify in lab environment simultaneous UV-Vis and IR measurements over the flight instrument spectral range.

CoIs/Partners: J-F Blavier, K. Bowman, W. Folkner, J. Neu, D. Rider, J. Worden, JPL

Key Milestones

• PanFTS science & measurements requirements	07/11
• EM instrument design	01/11
• EM components acquired and test	07/12
• Integration and functional tests of the instrument	01/13
• Preliminary cold testing results	07/13
• Final testing	12/13

$TRL_{in} = 4$ $TRL_{current} = 4$

12/10

ESTO Earth Science Technology Office

EV-1 Airborne DISCOVER-AQ (PI Jim Crawford, NASA LaRC)
Relevance to GEO-CAPE and AQ from space

One-month campaigns over 3-4 US cities (2011-2014) will help establish how remote sensing observations many times per day will be combined with ground based measurements in integrated observing systems for Air Quality and Ocean Color.

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:

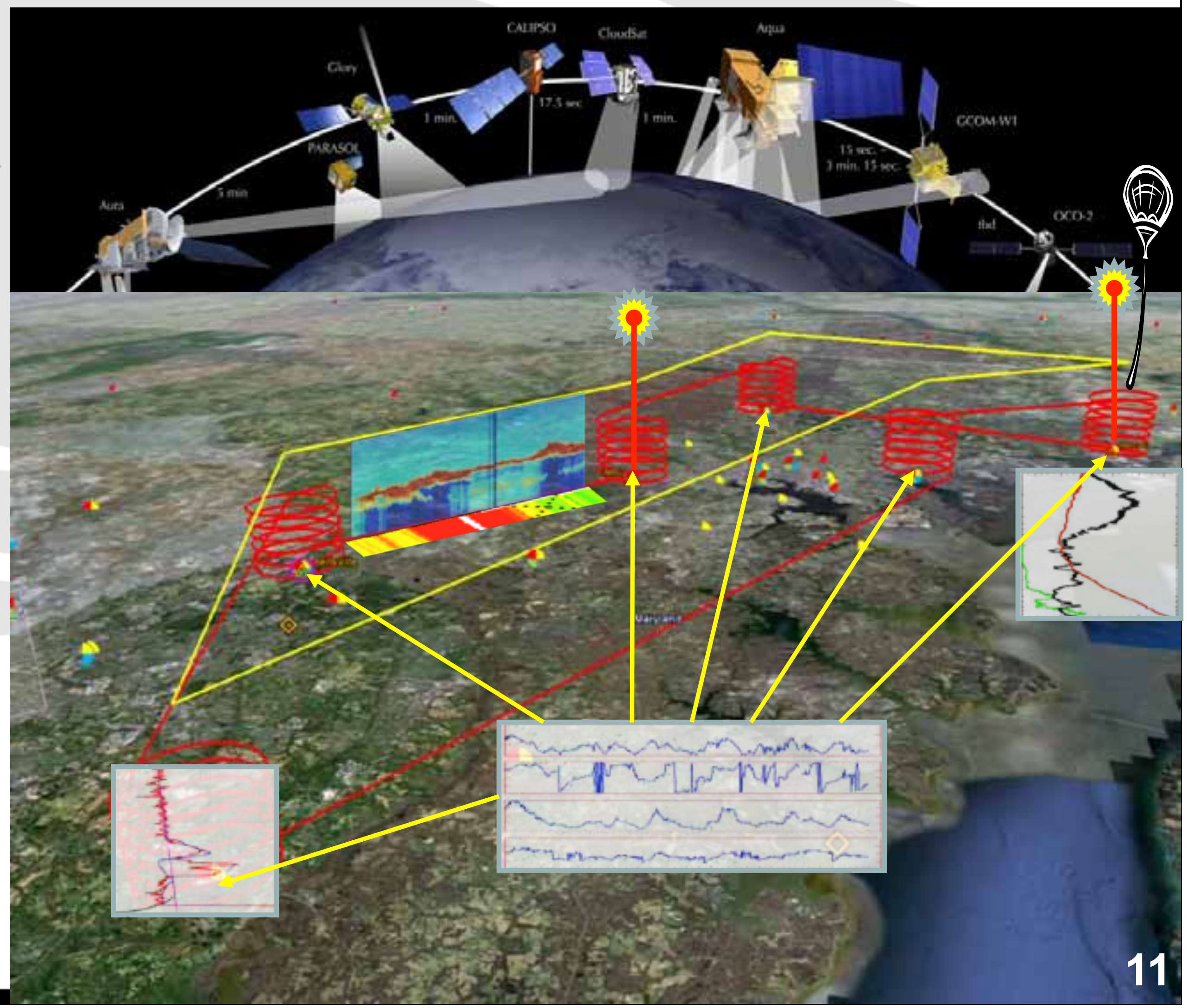
Continuous lidar mapping of aerosols with HSRL on board B-200

Continuous mapping of trace gas columns with ACAM on board B-200

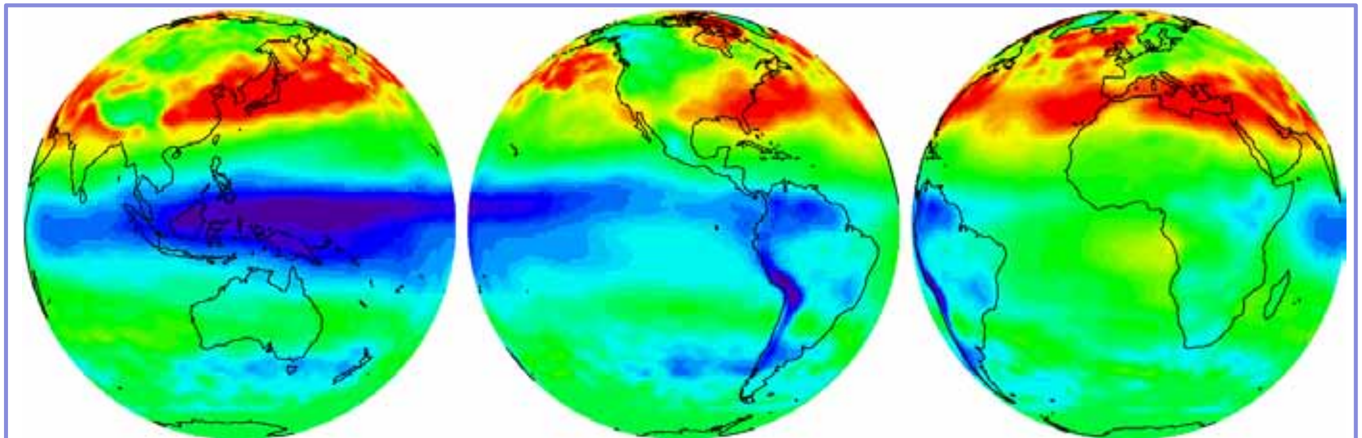
In situ profiling over surface measurement sites with P-3B

Continuous monitoring of trace gases and aerosols at surface sites to include both in situ and column-integrated quantities

Surface lidar and balloon soundings



A Geostationary Air Quality Constellation
http://www.ceos.org/images/ACC/AC_Geo_Position_Paper_v4.pdf



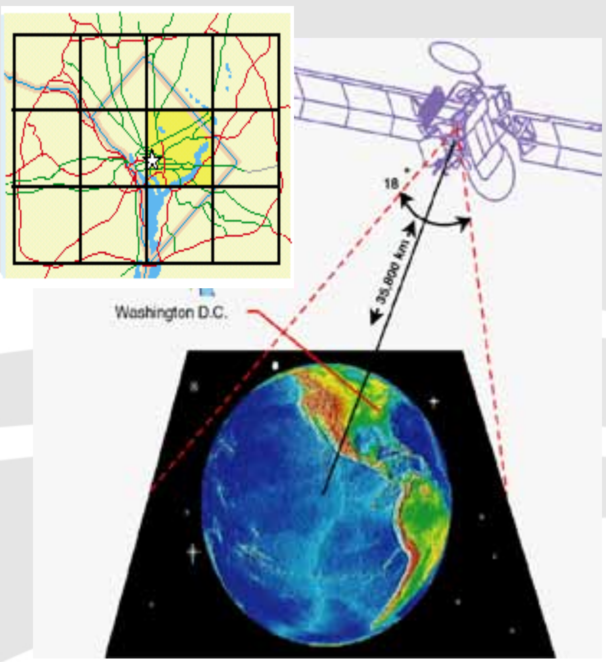
KARI/MoE GEMS
JAXA GMAP-ASIA

NASA GEO-CAPE
NOAA GOES R/S

ESA, Eumetsat
Sentinel-4 + MTG

- Several countries and space agencies are planning to launch geostationary satellites in the 2017-2022 time frame to obtain air quality measurements.
- A single geostationary satellite can view only a portion of the globe.
- These missions share fundamental common objectives yet individually are restricted to regional relevance.
  - *A constellation framework will provide a global perspective that will be otherwise impossible to achieve.*
  - *An integrated observing system for atmospheric composition is key to abatement strategies for air quality as laid down in various international protocols and conventions.*
- CEOS Atmospheric Composition Constellation (ACC) Position Paper unanimously endorsed by all CEOS parties during SIT-26 Meeting (May 2011). Now beginning to implement the near-term recommendations.

GEO-CAPE will significantly improve observational capability for Air Quality in 4 key areas:



1. High **temporal resolution** measurements to capture hourly changes in pollutant distributions due to photochemistry, emissions and meteorology
2. High **spatial resolution** measurements to access the city scale with continuous full-coverage of North America
3. Multi-spectral observations to improve knowledge of **vertical profiles** of pollutants
4. Key **contributor to an integrated observing system** in conjunction with observations from the ground-based, suborbital and satellite platforms of US and international partners

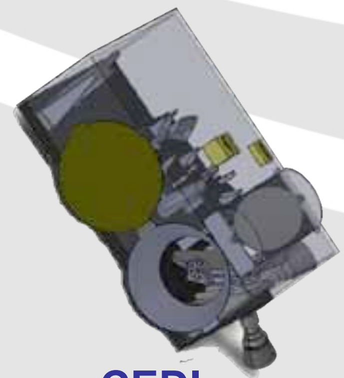
http://geo-cape.larc.nasa.gov/

Geostationary AQ mission parameters (as of 4/2011)

	Europe Sentinel 4	USA GEO-CAPE	Korea GEMS	Japan GMAP-Asia
Launch	2018	~2020	2018	~2017
Status	Industry Phase B1 started early 2010	Pre Phase-A	MP-GEOSAT funding approved 12/2010	Mission Definition Review 12/2009
Domain	Europe and surrounding	Contiguous US and surrounding	Asia-Pacific	Japan and East China (4000 km×4000 km)
Resolution	8km x 8km at 40N, revisit 1hr	8km x 8km (AOD 2km) at 40N, revisit 1hr	5km x 5km at 37N, revisit 1hr	10km (310-600 nm), revisit 1hr
Payload	UV-Vis-NIR 305-500 & 750-775 nm	UV-Vis-IR (tbc) 300-500 nm SWIR 2.3 & 4.6 μm Vis &/or TIR	UV-Vis (tbc) 300-500 nm	UV-Vis 280-600nm, TIR
Species	O3, NO2, SO2, HCHO, AAI, AOD, height-resolved aerosol	O3, NO2, SO2, HCHO, AOD, CO (CO & O3 with 2 vertical DOF)	O3, NO2, SO2, HCHO, AOD	O3, NO2, (SO2, HCHO, AOD desired)
Notes	On meteo sounding platform MTG-S and in formation with meteo imager platform MTG-I. Use MTG-S TIR (expect sensitivity to large O3 and CO events); synergy with meteo. imager w.r.t. aerosol/PM	Includes ocean color mission. In orbit with GOES-R series meteo imagers. Baseline mission to include TIR and additional species: CH4, NH3, CHOCHO, AAOD, AI, AOCH	Includes meteo and ocean color missions with meteo imager in formation. Optional accommodation for small IR instrument (CO, CO2, CH4)	Includes meteo mission. Hyperspectral TIR FTS: O3, CO, HNO3

GEO-CAPE Planning Payload

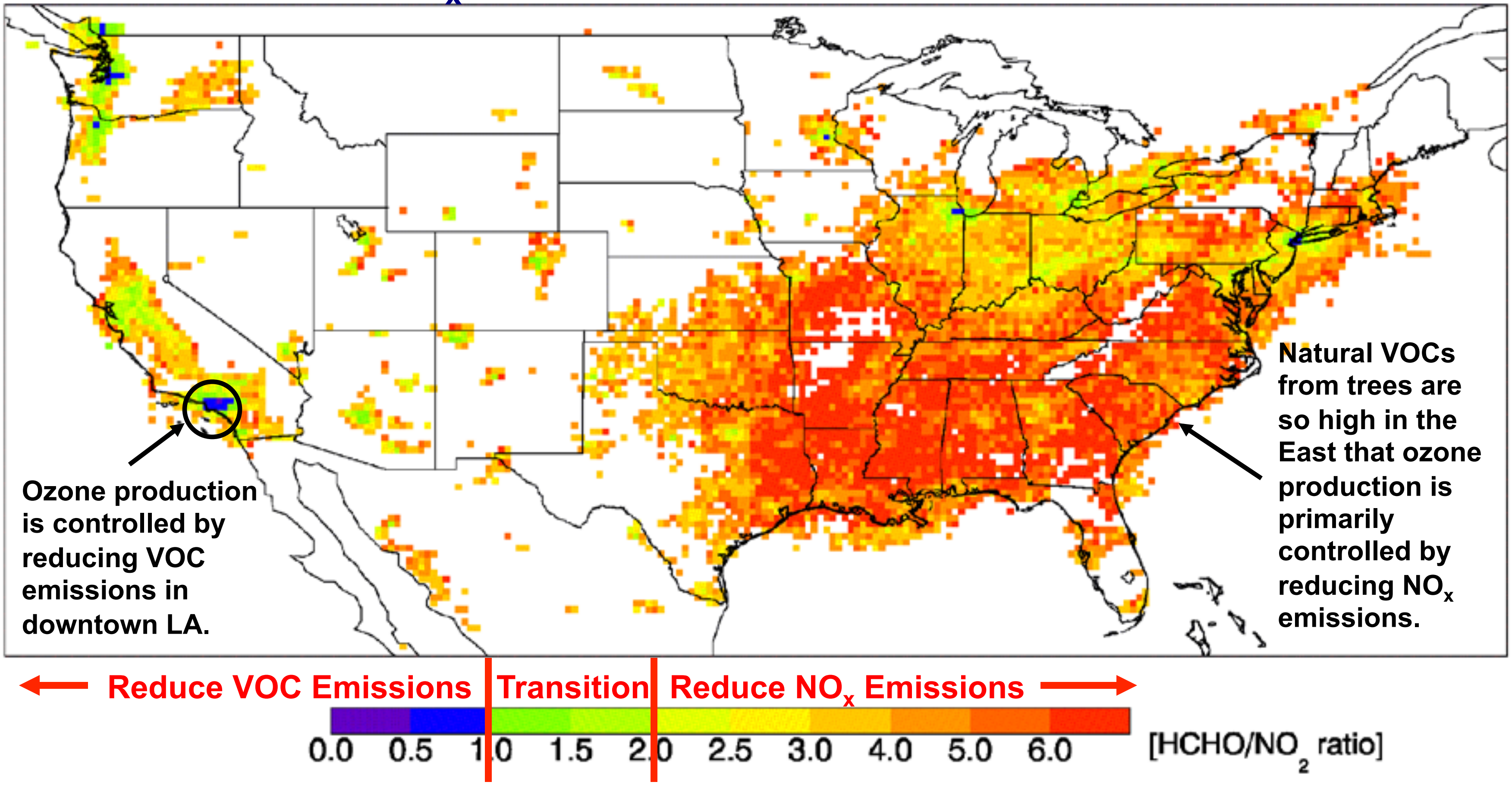
The planning payload is representative of instrumentation needed to accomplish threshold and most baseline science measurements defined in the STMs

	Small	Medium	Large
GEO-CAPE Notional Planning Payload Instrumentation	 CISR	 GEO-MAC	 CEDI
Science	Atmospheric Composition		Coastal Ecosystems
Instrument Concept	IR CO Detector	UV-Vis Spectrometer	Vis Spectrometer
Spectral Range (μm)	2.3 and 4.67	0.30 to 0.48	0.34 to 0.90 1.225 to 2.160
Size: L x W x H (m)	0.75 x 0.4 x 0.5	1.7 x 0.8 x 0.9	2.1 x 0.95 x 2.8
CBE Mass (kg)	45	140	621
CBE Power (W)	120	233	392
Data Rate (Mbps)	40	16.4	88.4
Earliest Availability	FY'16	FY'18	FY'20

GEMS and GEO-CAPE
Atmospheric Composition Co-operation

- **Joint "Technical Group on Atmospheric Composition Measurements From Geostationary Satellites" established within Earth science component of 2009 NASA and MEST *Joint Report Regarding Potential Opportunities for Enhanced Cooperation***
  - Meeting I: 13 August 2009, NASA HQ, Washington, US
    Discussed potential synergies between atmospheric composition measurements planned for the GEO-CAPE and COMS-B missions
  - Meeting II: 6 April 2010, NASA GSFC, Greenbelt, US
    Discussed NASA design studies and technical readiness of geostationary ultraviolet-visible instruments
  - Meeting III: 23-24 August 2010, Yonsei University, Seoul, ROK (with GEMS Workshop)
    Discussed technical features of the GEMS instrument and synergies with simultaneous observations being planned by other countries including USA
  - Meeting IV: 11-13 May 2011, NCAR, Boulder, CO, US (with GEO-CAPE Workshop)
    Discussed technical features of the GEO-CAPE instrument and synergies with simultaneous observations being planned by other countries including ROK
- **We should now identify any additional agreements required to mutually advance the activities defined under the The Terms of Reference (endorsed February 2010)**
  - Improve harmonization and ensure data quality of planned geostationary atmospheric composition measurements: instrument requirements, cal/val, retrievals, data products

Application of Ozone Monitoring Instrument Observations to a Space-Based Indicator of NO_x and VOC Controls on Surface Ozone Formation



The OMI formaldehyde (HCHO) to nitrogen dioxide (NO_2) ratio for August 2005. Harmful levels of surface ozone can form through a complex series of reactions involving volatile organic compounds (VOCs) and nitrogen oxides (NO_x) in the presence of sunlight. Ozone will decrease when emissions of anthropogenic VOCs are reduced when the ratio is < 1 (e.g., Los Angeles, Chicago). It will decrease when NO_x emissions are reduced when the ratio is > 2. In this way, the ratio is an air quality indicator.

Bryan Duncan & Yasuko Yoshida
The Atmospheric Chemistry and Dynamics Branch (Code 613.3), NASA Goddard Space Flight Center

Duncan et al., Atmospheric Environment, 2010