GEO-CAPE: Major Questions and Previous Mission Studies

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- Coastal Ocean Color Requirements
  - GEO-MDI/Integrated #5
- Boundary Layer O_3 Measurement
  - GeoMAC
- CO Instrument Implementation
- UV-Vis Performance Optimization

Observatory Concept

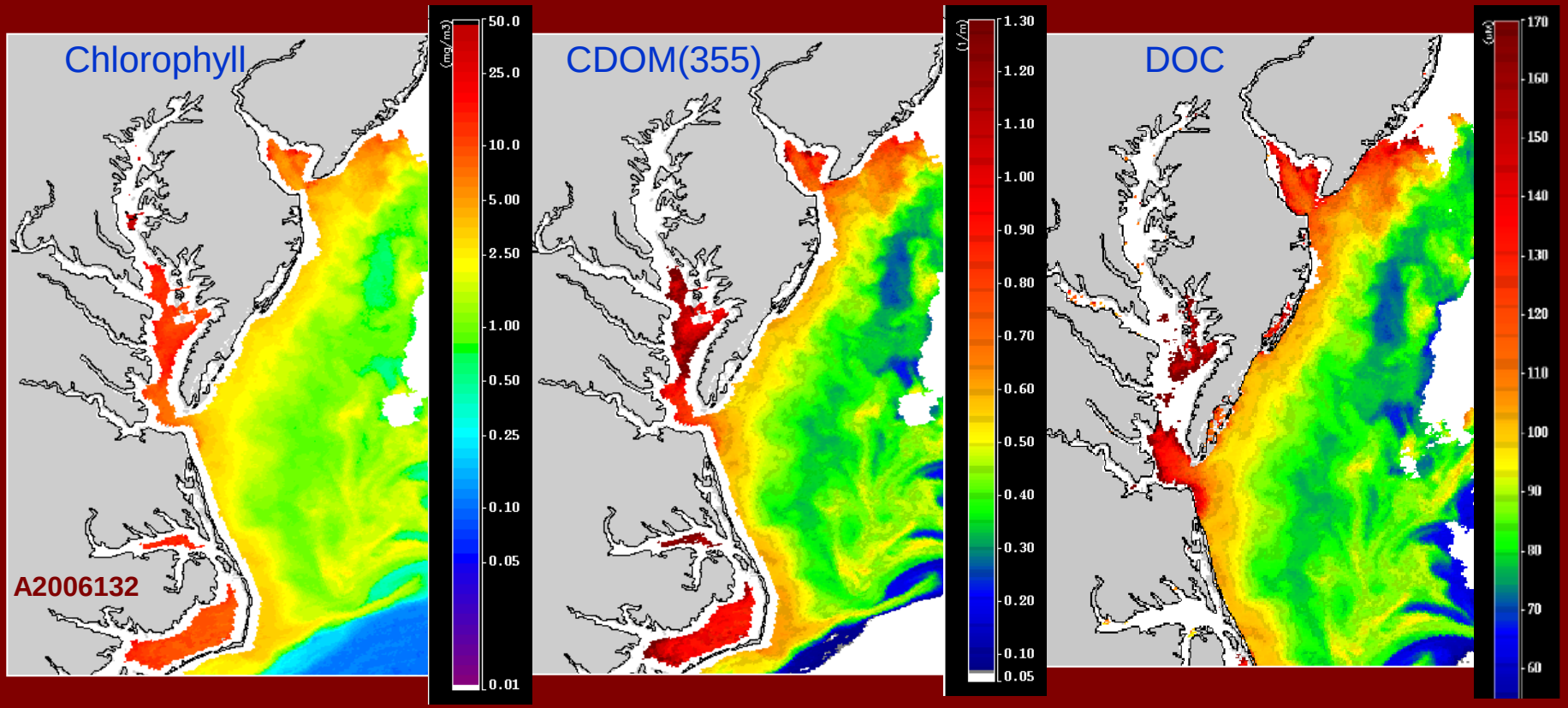
Strategic Concept: An Earth-viewing, Hubble-like programmable observatory facility.

- **Combination of medium-resolution (5 km) continental scanning instruments with high-resolution (300-m) regional viewing spectrometer.**

- Geosynchronous viewpoint provides new and unique approach to satellite remote sensing for atmospheric composition and coastal ocean properties.
  - Potential ground-breaking new science in each discipline plus synergies.
- Multi-disciplinary imager is shared resource for regular observations, special observing studies, and emergencies.
- Look at S America, consider terrestrial biosphere objectives

Ocean Ecological Products

Critical products: Primary productivity, chlorophyll, particulate organic carbon, dissolved organic carbon (DOC), colored dissolved organic matter (CDOM), fluorescence line height, calcite, phytoplankton physiology and functional type (including harmful algal blooms).



Coastal Ocean Spatial Resolution

250 x 500 km scan/15 min

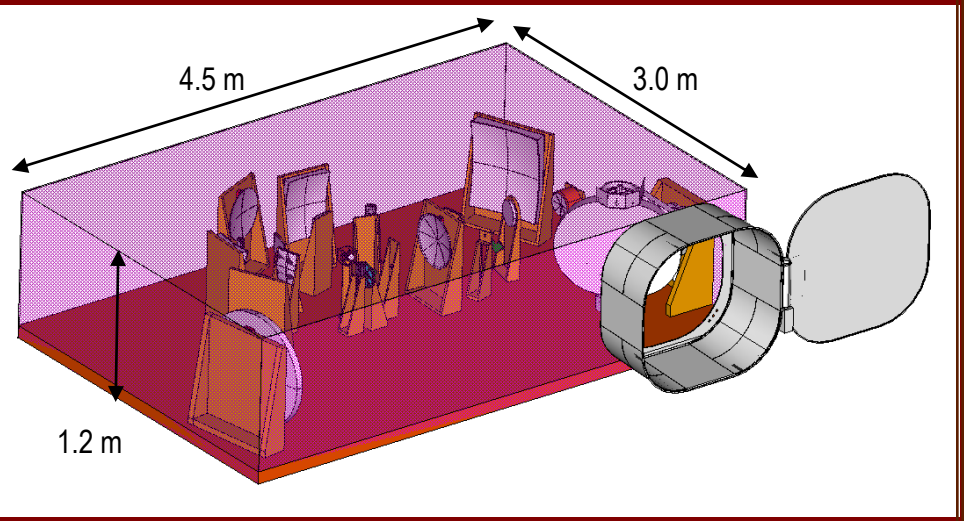
Sample coastal waters at 300-m resolution

- What field of view, with what resolution, how often, and with what spectral information?

Multi-discipline Instrument Requirements

	Coastal Ocean	Atmosphere	Biosphere
Spectral Bands (nm)	340-1100, 1240, 1640	300-480, 400-600, 2300, 4600	400-1300, 2000-2300
SNR	>1000 in UV-VIS	1000	>800
Spectral Resolution	1-5 nm	<1 nm UV 1-2 nm Vis	5-10 nm
Spatial Resolution	100-300 m	>1 km	<250 m
Temporal Resolution	3-6 / day	~ hourly	3-6 / day
Spatial Coverage	~320 km Ocean adjacent to coast; estuaries, bays, rivers, large lakes	200 km Polluted urban areas	200 km Ecosystem area
Radiometric Stability	<0.1% band-to-band 0-10 hours	<0.1% band-to-band 0-10 hours	<0.1% band-to-band 0-10 hours

Multi Discipline Imager (MDI)



Instrument Concept

- Enable scientific objectives of coastal ocean, atmosphere, and biosphere.
- Capable of pointing anywhere on visible Earth hemisphere.
- Measurement parameters adjustable: dependent on science objective.
- Employs three focal planes/bands

  Two Si: 1k (spectral) x 2k (spatial) Rockwell hybrid focal plane

  One HgCdTe: 256 x 2k Rockwell hybrid focal plane

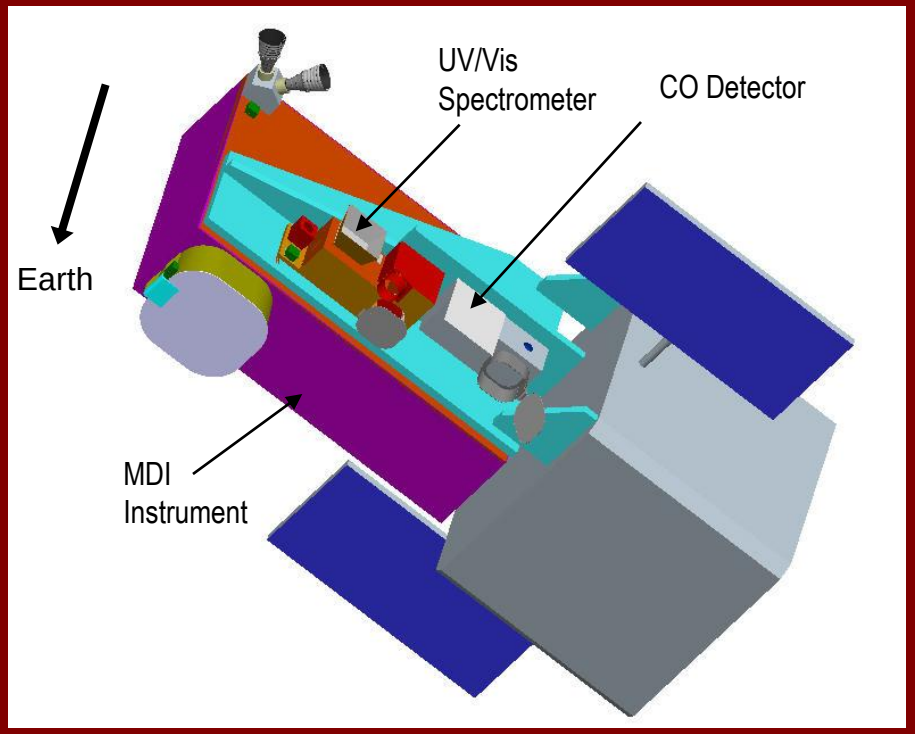
Instrument Performance Data

- Spectral Bands: 300-556, 340-1139, 1240, 1640 nm
- Spectral Resolution: 0.75 (3x sample), 0.8, 40, 40 nm
- SNR: > 1000 (bands 1, 2); > 500 (bands 3, 4)
- Spatial Resolution: 300 m pixels, Coverage: 500 km
- Temporal Resolution: < 1 hour

Technology Assessment / Development Needs

- Mirror stabilization system for image generation will require further development to meet the required precision.
- Large size drives cost, risk; need to optimize for science and feasibility.

Satellite Mission Concept



Features

- Instrument Complement: MDI Ins, UV/Vis, CO Detector
- Launch: ~FY2014
- Launch Vehicle: Atlas V 401 or Delta IV 4040-12
- Orbit Type
  - Geostationary
  - 100 Degree W Longitude
- Real-Time Science Data Downlink with Dedicated Ground Station
- Disposal into Geo + 300 km Parking Orbit

Performance Data (with margins)

- Mass: 1286 kg (payload), 4679 kg (observatory wet total)
- Power (Average): 930 W (payload), 1625 W (total)
- Data Rate: 120 Mbps (payload), 179 Mbps (total),
- Spacecraft Pointing (1 sigma): 30 arc-sec control, 4 arc-sec knowledge
- Lifetime (years): 2 (design), 5 (goal & consumables)

Technology Development Needs

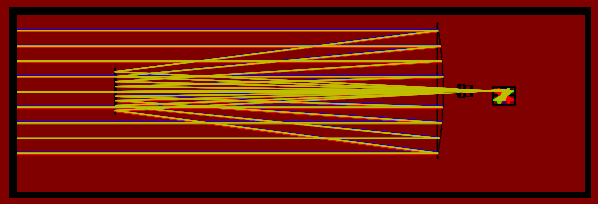
SC Bus & Launch Vehicle

- None (over 20 geostationary launches/year)

Est. Cost: $1.27B

Alternate Instrument Concepts

Coastal Ocean Carbon Observations and Applications (COCOA)



Specifications

Instrument mass: 45-60 kg
Power: ~50 W
Cost: 12-20 Million (USD RY)
Optics: F/5 Cassegrain; all beryllium optics and structure; Offner Spectrometer
Focal Plane Array: Commercial visible detector
Length: 120 cm
Primary Mirror: 70 cm diameter
Secondary Mirror: 20 cm diameter

Performance

Spatial Resolution at Nadir: 200 meter
Spectral Resolution: 5 nm between 350 and 1050 nm (140 bands)
Signal to Noise: exceeding 400 between 400 nm and 900 nm

- Performance up to requirements?

GOES-R HES Coastal Waters Threshold and Goal Requirements

Nominal Threshold Channel Center Wavelength (um)	Nominal Threshold Resolution (um)	Nominal Threshold Signal to Noise	Nominal GOAL Channel Center Wavelength (um)	Nominal GOAL Resolution (um)	Nominal Goal Signal to Noise
0.412	0.02	300 to 1 all channels	0.407 through 0.987	0.01	900 to 1 all channels
0.443	0.02		0.57	0.01	
0.477	0.02		1.38	0.03	
0.49	0.02		1.61	0.06	
0.51	0.02		2.26	0.05	
0.53	0.02		11.2	0.8	
0.55	0.02		12.3	1	
0.645	0.02	Nominal Threshold Horiz. Resolution			Nominal Goal Horiz. Resolution
0.667	0.01	300-meters all channels (at Equator)			150-meters all channels (at Equator)
0.678	0.01				
0.75	0.02				
0.763	0.02				
0.865	0.02				
0.905	0.035				

Coverage area U.S. navigable coastal waters within 400 km from shore including Great Lakes, Puerto Rico, and rivers.

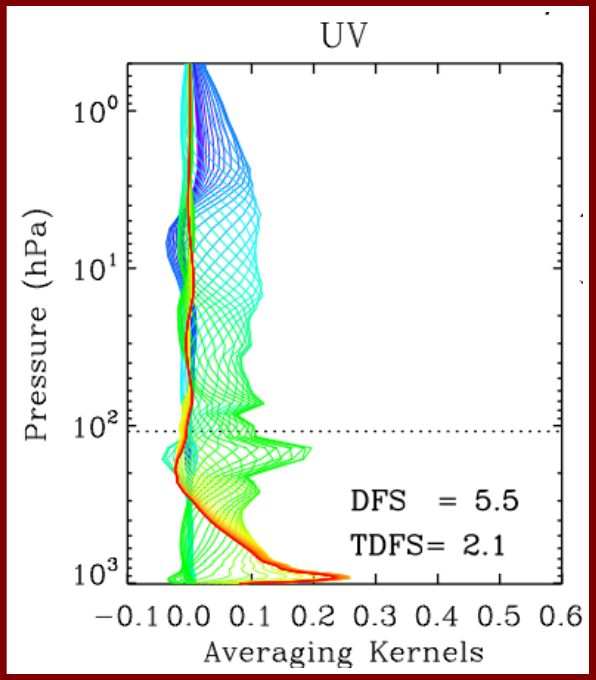
- Appears close to meeting ocean color science requirements.
  - UV bands, atmospheric correction?
- No detail available (yet) on size/mass/data rate/cost.

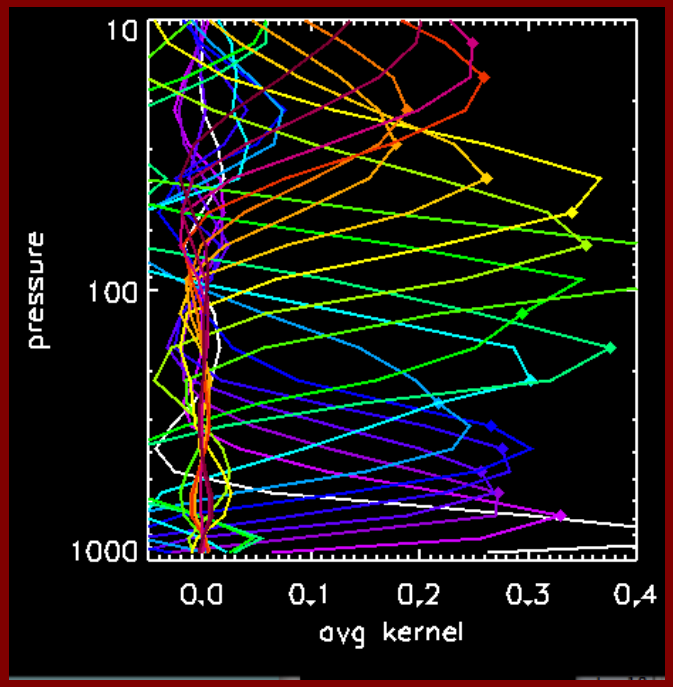
Atmospheric Boundary Layer O_3

UV

UV+TIR

UV+NIR





Can it be measured? How well? To what purpose? At what cost?

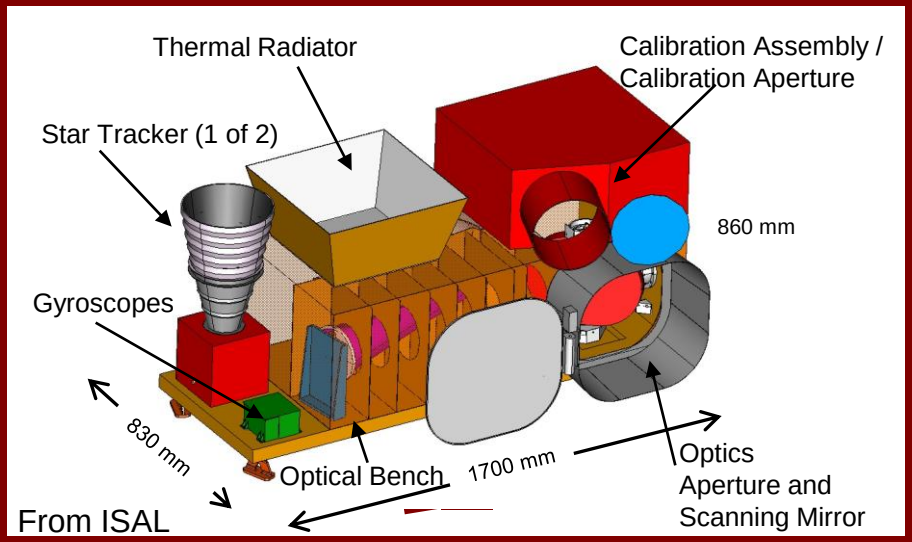
GeoMAC Measurement Requirements

Trace gas sensitivity required to meet science goals

Trace Gas	Needed mixing ratio precision	Needed accuracy	Column density capability* [molecules cm^{-2}]	Instrument Requirement [SNR]	Instrument Implementation
NO_2	0.2 ppbv	±20%	5.0×10^{14}	2000 (430 nm)	<u>UV/VIS grating spectrograph:</u> Cost effective broadband measurement at moderate spectral resolution (< 1nm). High spectral stability and throughput. Strong heritage.
HCHO	1.0 ppbv	±20%	2.5×10^{15}	1500 (350 nm)	
O_3	10 ppbv (troposphere)	±10%	1.3×10^{16}	1000 (320 nm)	
SO_2	Not applicable	±20%	2.2×10^{16}	500 (312 nm)	
CO	10 ppbv	±10%	1.0×10^{17}	2500- 9500 (2.3 μm) (scene dependent)	<u>Gas Filter Correlation Radiometer:</u> Target gases with very high sensitivity/resolution. Multi-spectral for robust retrieval and to separate PBL from free trop. Strong heritage.
CO	10 ppbv	±10%	1.0×10^{17}	700 (4.67 μm)	
Near-surface CO	10 ppbv	±10%	1.0×10^{17}	Not applicable	Inferred from multispectral analysis
Near-surface O_3	5 ppbv	±10%	1.3×10^{16}	Not applicable	Inferred from multispectral analysis

* Assumes PBL height of 1 km. Additional information on science requirements can be found at http://qp.nas.edu/QuickPlace/decadalsurvey/Main.nsf

Scanning UV/Vis Spectrometer



Measurement Concept

- Measure atmospheric pollutants O_3, aerosols, and precursors NO_2, SO_2, HCHO.
- Field of regard: Western Hemisphere with emphasis on continental United State
- Sample revisit time of 1 hour, during sun illumination.
- Mission Design Life: 2 years, goal 5 years (consumables sized for 5 years), launch Sept. 2014.

Performance Data

- Single focal plane, continuous band from 300 nm to 480 nm.
- Spectral resolution: 0.8 nm.
- Signal-to-noise ratio of 720 at 320 nm and 1500 at 430 nm.
- Typical scanned field-of-view: 8° N/S (5000 km) x 8° E/W (5000 km). Can point anywhere on visible hemisphere.
- Pointing stability maintained through active jitter compensation.
- Sample spatial resolution 1.25 km N/S x 5.0 km E/W.

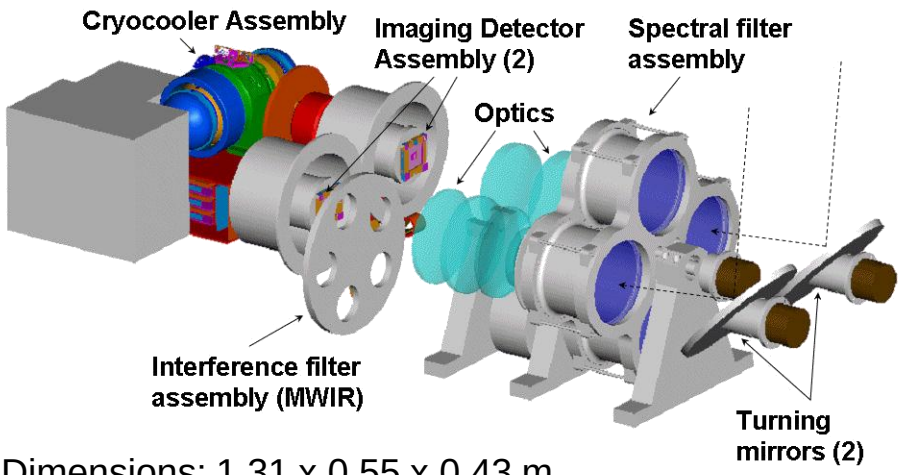
Technology Assessment / Development Needs

- Measurement demonstration and technical feasibility completed under NASA Instrument Incubator Program.
- No technical hurdles to instrument or spacecraft.
- Pointing requirements are commensurate with GOES.
- Detector optimization, single crystal silicon mirror testing, and aircraft demo recommended for technology readiness level 6.

~$84M (‘07)

Carbon Monoxide Detector

From LaRC IDC



Dimensions: 1.31 x 0.55 x 0.43 m

Measurement Concept

- Gas correlation filter radiometer measures CO in near-IR reflected sunlight and thermal IR emission.
- Spectral combination approach identifies CO boundary layer distribution from space.
- Measures CO, an atmospheric pollutant precursor of O_3 and primary indicator of combustion.
- Continue outstanding performance of MOPITT; scientific findings based on MOPITT data demonstrate the measurement maturity and technical feasibility.

Instrument Performance Data

- Detector: Use of large format 2-D arrays in space (no scanning)
- Data array: 1024 x 1024 pixels for each SWIR & MWIR
- Spatial resolution: 5 x 5 km^2; spectral resolution better than 0.1 cm^{-1} provided by gas filter.
- Each spatial pixel requires frame averages to achieve SNR.
- Onboard calibration: blackbody targets, deep space and solar views

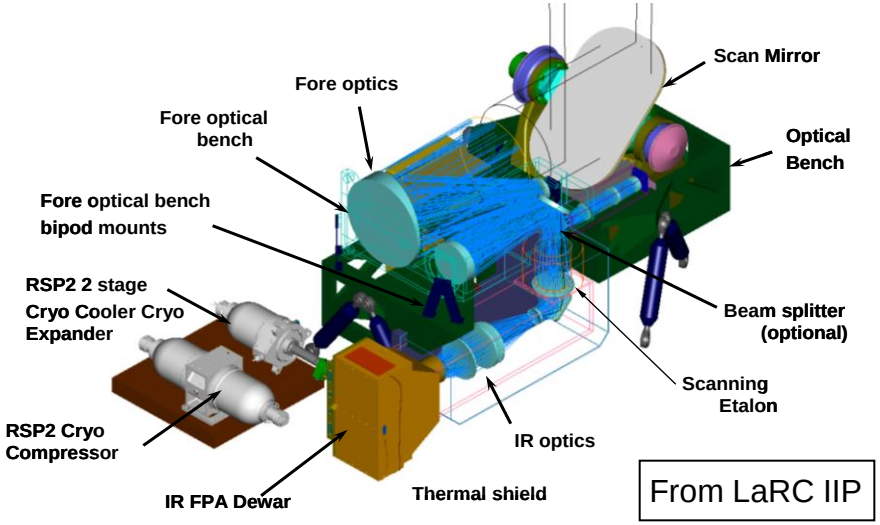
Technology Assessment / Development Needs

- Technology for this instrument is at high readiness level.
- Measurement Heritage: MOPITT, HALOE
- Beneficial investments:
  - Radiation hard high performance electronics
  - Light weight thermal control and structural materials

~$85M (‘07)

Trop O_3 Instrument

Ozone Instrument Illustration



From LaRC IIP

Ozone Instrument Concept

Measure O_3 in thermal IR (to combine with O_3 retrievals in UV and visible parts of spectrum)
Multi-spectral analysis approach estimates O_3 distribution in the middle and lower troposphere.
Double etalon Fabry-Perot Interferometer (FPI) technique
Infrared FPI spectral range: 1053.5 to 1056 cm^{-1} (~9.5 µm)
Space heritage: HRDI (12 years on orbit), TIDI on TIMED (visible, not IR).
Cooled optical cavity
Onboard calibration targets.

Ozone Instrument Performance Data

- Instrument dimensions: 1.24 m x 0.9 m x 0.9 m
- 1-hour revisit time for continental US
- Spatial Resolution 5 x 5 km^2 at center of field of regard.
- Large format 2-D array detector using one dimension in space, one in spectrum; 256 x 256 pixel array
- Spectral resolution: 0.068 cm^{-1} at 9.45 µm
- Onboard calibration: Deep groove, flat plate full aperture radiometric calibrator, star look spatial cal; CO_2 spectral cal
- Data rate 2.5 Mbps (9 Gb per data take, downlink in 60 minutes)

Technology Assessment / Development Needs

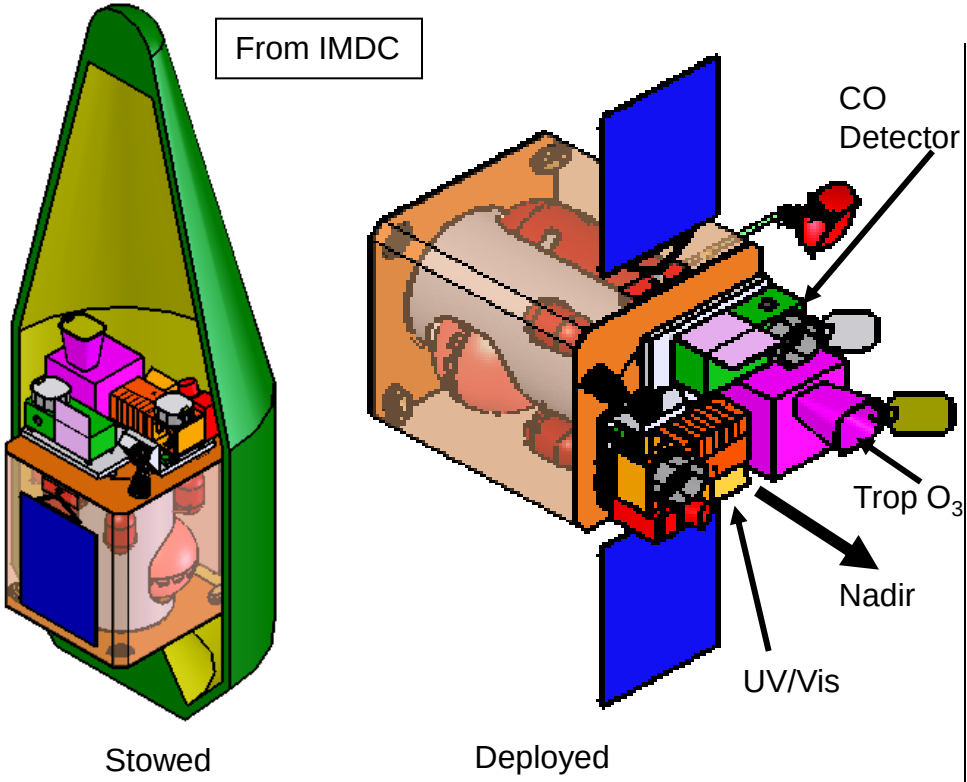
- Completed instrument incubator project (IIP) in 2006.
  - •TTSS-FPI (Tropospheric Trace Species Sensing Fabry-Perot Interferometer)
- Aircraft instrument is awaiting flights at present.
- TRL Level 6 achieved for all components: dual etalon, two stage active cooler, and spectral calibration source
- Beneficial enhancements:
  - •Engineering analysis of optics and coatings to increase transmission , decrease absorption/emission
  - •Evaluate thermal environment and trades on optics and alignment versus cryo cooling complexity, cost.

GeoMAC Instrument Summary Table

Instrument/ Specification	UV/Vis Spectrometer	CO Instrument	Trop 0_3	Totals
Spectral Coverage	300-480 nm	2.299 -2.364 μm, 3.877 - 4.728 μm	9.470 – 9.492 μm	--
Spectral Resolution	0.8 nm	0.1 cm^{-1}	resolving power: 15530	--
Spectral Sampling	4 pixels/resolution element	NA	NA	--
Spatial Coverage	$(5000\ km)^2$ steerable FOR	$(5000\ km)^2$ fixed field of regard (FOR)	$(5000\ km)^2$ steerable FOR	--
Spatial Resolution	1.25 km x 5 km (nadir)	5 km (center of FOR)	5 km (center of FOR)	--
Revisit Time	1 hour	1 hour	1 hour	--
SNR	700:1 (@320 nm) 1500:1 (@430 nm)	2500/9500 @2.3 μm 700 @ 4.67 μm	100:1	--
Data Rate* (Mb/s)	17	40	6	63
Mass* (kg)	139	113	99	351
Power* (W)	208	190	210	608

*without margin

GeoMAC Mission Concept



Features

- **Science Objectives**
  - Atmospheric Composition over North America
  - Local & Regional Atmospheric Pollutant Sources, Impacts, Variability
- **Instrument Complement:** UV/Vis, CO Detector, Trop O_3
- **Launch: ~FY2014**
- **Launch Vehicle: Atlas V 401 or Delta IV 4040-12**
- **Orbit Type**
  - Geostationary
  - 100 Degree W Longitude
- **Real-Time Science Data Downlink with Dedicated Ground Station**
- **Disposal into Geo + 300 km Parking Orbit**

Performance Data (with margins)

- **Mass (kg): 456 (payload), 3849 (observatory wet total)**
- **Power (Average W): 790 (payload), 1205 (observatory total)**
- **Data Rate (Mbps): 82 (payload orbit average), 94 (downlink)**
- **Pointing (1 sigma arc-sec): 30 (control), 4 (knowledge)**
- **Lifetime (years): 2 (design), 5 (goal & consumables)**

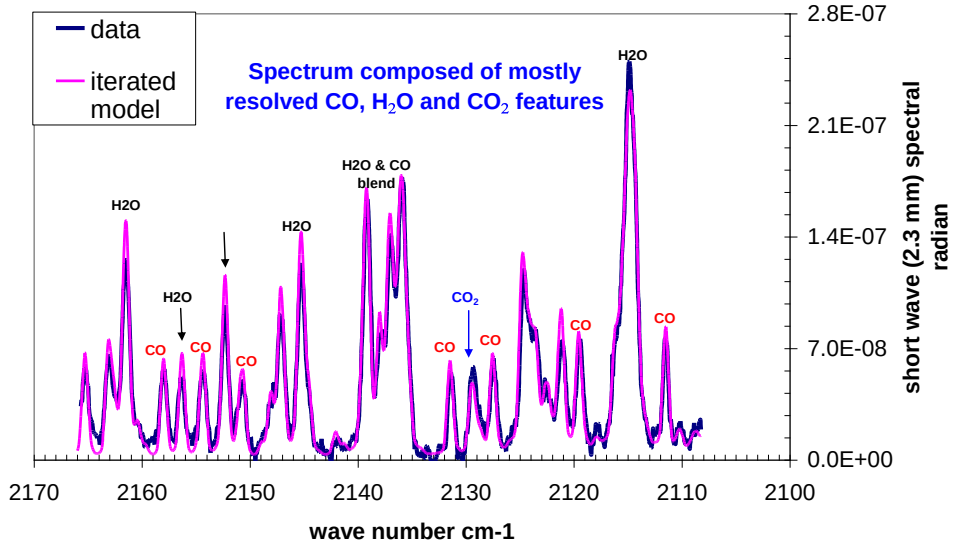
Technology Development Needs

- **SC Bus & Launch Vehicle**
  - None (over 20 geostationary launches/year)

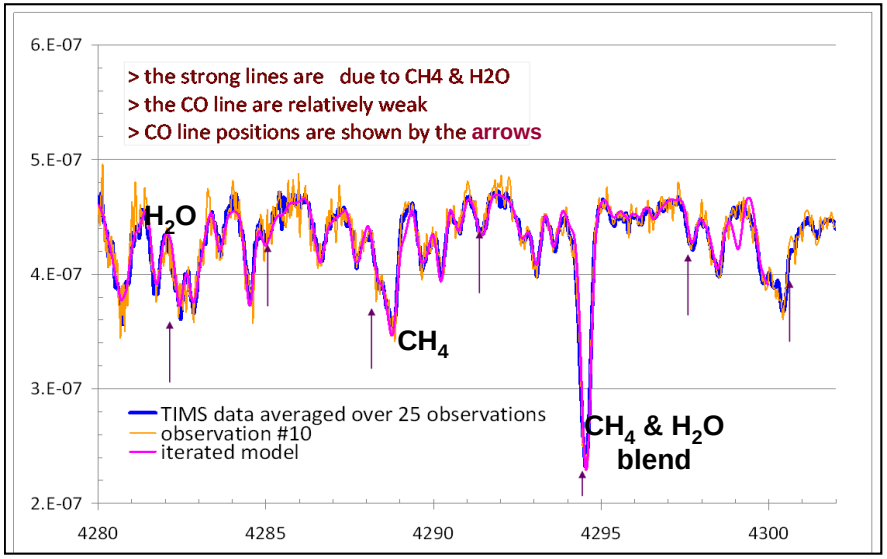
Cost Est.: $850M (‘07)

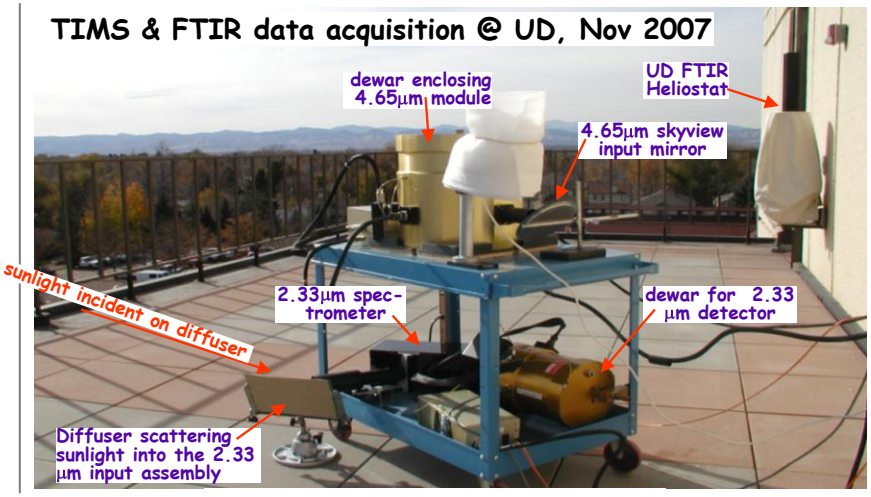
NASA Instrument Incubator Program (IIP) -Tropospheric Infrared Mapping Spectrometers (TIMS) for Globally Mapping CO Profile

mid wave (4.67 μm) uplooking atmospheric emission data



Short wave (2.3μm) solar absorption data





TIMS demonstration data scale to the GEO-CAPE CO capabilities:

- Map total column with ≤ 10% precision
- Map tropospheric vertical structure
  - The order 3 + layers profile capability
- satisfy the NRC DS GEO-CAPE mission requirements for
  - footprint ≤ 7 km x 7 km
  - areal coverage over the American continents from 45°S to 50°N
  - repeat time of once per hour
- Can accommodate added spectral regions for O_3 profile (troposphere, UTLS & layers above)
  - Also, precise lower trop H_2O profile; CH_4 total column

Outstanding Questions

1) Coastal Ocean Color Requirements: spatial, spectral, temporal
   - Compare MDI, HES, GOCI, COCOA concepts
   - OC baseline, atmospheric correction, synergistic science -> instrument study
2) Approach to boundary layer O_3 measurement: UV-Vis, UV+TIR, UV+ NIR and associated instrumentation
   - Retrieval sensitivity studies
   - Instrument and mission design studies
3) CO instrument: evaluate various techniques, added capabilities
4) UV-Vis: Optimize science performance versus instrument size/cost
5) Refine observing strategy: regular scans, special looks, drifting or repositioning GEO, …
6) Launch/Platform: hosted payloads, commercial satellites, …

Back-Up Slides Follow

Science Objectives

- **Ocean:**
  - quantify the response of marine ecosystems to short-term physical events;
  - assess the importance of high temporal variability in coupled biological-physical coastal-ecosystem models;
  - monitor biotic and abiotic material in transient surface features;
  - detect, track, and predict the location of sources of hazardous materials; and
  - detect floods from various sources, including river overflows.
- **Air-quality:**
  - satisfy basic research and operational needs related to air-quality assessment and forecasting;
  - emission of O_3 and aerosol precursors, including human and natural sources;
  - pollutant transport into, across, and out of North, Central, and South America; and
  - large puff releases from environmental disasters.
- Measurements of aerosols from the air-quality instrument can be used to correct aerosol contamination of the high-resolution coastal ocean imager.
- Compatibility with objectives of the terrestrial biophysical sciences should also be explored.

Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond
http://www.nap.edu/catalog/11820.html

Atmospheric Instrument Suite Concept

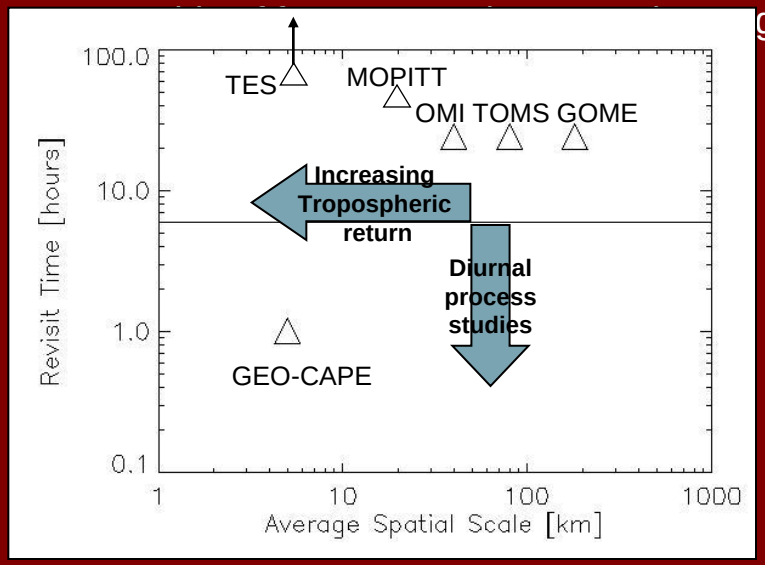
- Performance of existing instrument technologies is generally adequate for geostationary deployment.
- Adapting heritage sensor technology does not present a major hurdle.

1. UV/Vis
   - Scanning UV/Visible spectrometer (300 – 480 nm); detect total column O_3, NO_2, HCHO, SO_2, and aerosol. limited efficiency for O_3 in the boundary layer.

2. CO Detector

Gas correlation filter radiometer measuring in reflected near-IR and thermal IR emission; senses atmospheric CO total column to surface and mid- and upper-troposphere weighted; separate boundary layer from free troposphere abundance.

3. Multi-Discipline Imager
   - Very high resolution UV-Vis-NIR imaging spectrometer; resolve coastal ocean color variations; gencies and special events in oceans, atmosphere, and



- Measurements need to be made closely in time and space to enable detailed examination of transport and photochemical processes, e.g., O_3 production from CO oxidation:

$$CO + OH + O_2 \rightarrow CO_2 + HO_2$$
$$HO_2 + NO \rightarrow OH + NO_2$$
$$NO_2 + h\nu + O_2 \rightarrow NO + O_3$$

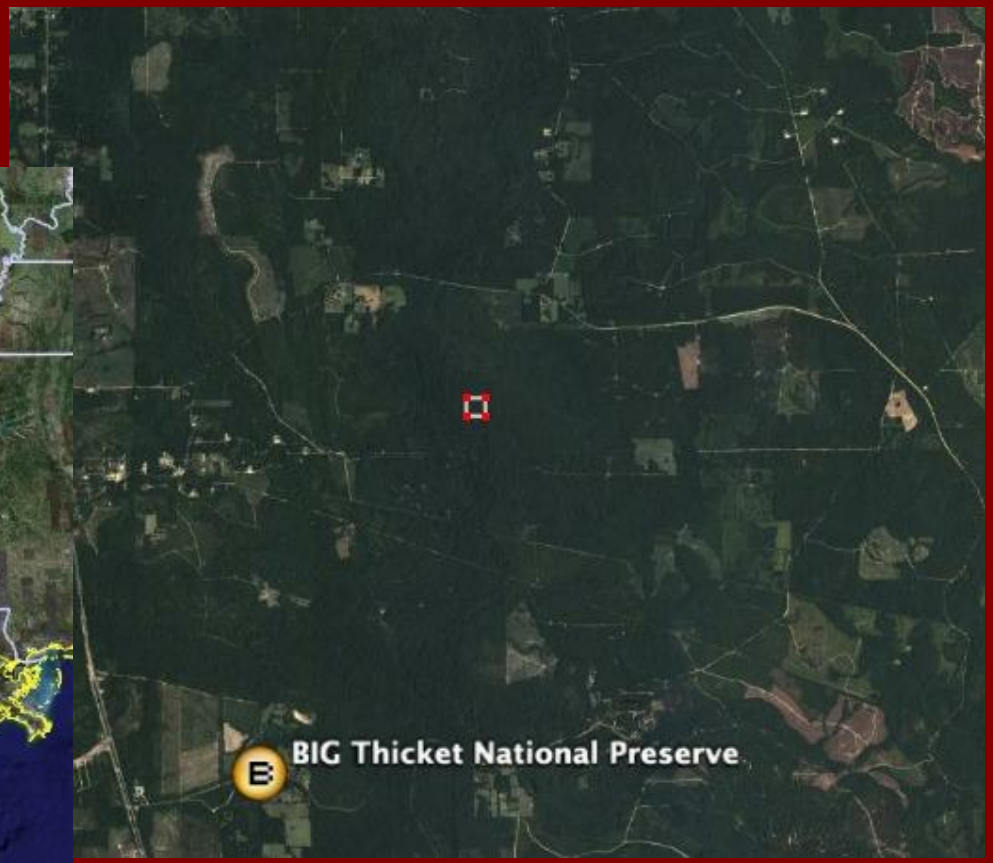
Other Considerations

- Spacecraft and launch vehicle
- Advanced technology investments
- Ground system architecture
- Mission operations
- Cal/Val requirements, Validation program
- Supporting research and analysis
- International cooperation

➢ **No show stoppers**

Terrestrial Vegetation Opportunity

Scan forest at 300-m resolution



$(250\ km)^2$ scan/15 min

GEO-CAPE Ocean DRAFT Measurement & Instrument requirements v.2.0

		Minimum	Goal
Coverage Area			
US coastal waters (US CW) (within CONUS plus Puerto Rico, US VI and Hawaii?)	CW – includes bays, estuaries, lakes and rivers within coastal coverage	*US CW 400 km wide region along the coast, Great Lakes and major rivers.	*US CW 500 km wide region along the coast, Great Lakes, and major rivers.
Open Ocean (OO)		None	±62° local zenith angle (LZA)
Regions of Special Interest (RSI)		Amazon & Orinoco River plumes, Peruvian upwelling, etc.	All other CW of North & South America ±50° latitude within 300 km from shore.
Spatial Resolution	Ground sample distance (GSD)	300 m	200 m (~100 m nadir) (1 km for OO)
Temporal Resolution	US CW (Routine)	3 scans per day (~every 3 hours)	every 0.5 hour
	OO	None	3 scans per day
	RSI	3 scans per day	every 0.5 hour
	Targeted Events	every hour	every 0.5 hour
Instrument			
Spectral range	Hyperspectral UV-VIS-NIR	350-900 nm; plus SWIR bands: 1245, 1640 and 2130 nm	340-1100 TBD; plus SWIR bands: 1245, 1640 and 2130 nm
Spectral resolution		4 to 5 nm TBD	0.75 nm (atm. NO_2 & O_2 A-band)
Signal-to-Noise Ratio (SNR)		1000:1 for 10 nm aggregate bands (380-800 nm) for ocean scenes; 10-40nm bandwidths in NIR; TBD for SWIR	1500:1 for 10 nm bands for 380-800 nm for ocean scenes (400:1 for NO_2 [$1x10^{15}$ molecules] band between 410-430 nm)
SZA		±70°	±75° (near dawn & dusk)
Avoid scanning cloudy regions		Utilize coarser GEO sensor to avoid scanning cloudy regions.	
Lunar Calibration		Full disk imaging capability to observe Moon	
Sensor radiometric accuracy		UV-VIS-NIR + SWIR 1% radiometric accuracy through mission lifetime	UV-VIS-NIR + SWIR 0.5% radiometric accuracy through mission lifetime
Pre-launch sensor characterization	Complete Pre-launch sensor characterization	Demonstrated 1 month at 0.1% radiometric stability	
Sensitivity & Saturation	Cloud radiances for stray light est.	High sensitivity but non-saturating detector array	
Measurements from other sensors	NO_2, Ozone, total water vapor, surface wind velocity, sea-level	Contemporaneous Atm. NO_2 from other G-C sensor.	

* Coverage area width includes major estuaries and rivers such as Chesapeake Bay & Lake Pontchartrain/Mississippi River delta), e.g., the Chesapeake Bay coverage region would span west to east from Washington D.C. to several hundred kilometers offshore (total width of 400 km minimum).