NASA GEO-CAPE

Geostationary Coastal and Air Pollution Events

Workshop Report

August 18-20, 2008
Chapel Hill, North Carolina

GEO-CAPE Mission
NASA Workshop Report

Preface

In 2004, NASA, NOAA and the U.S. Geological Survey (USGS) requested that the National Research Council (NRC) form a panel to identify and prioritize the observational platforms that should be launched and operated over the next decade. In addition to providing information solely for the purpose of addressing scientific questions, the NRC took the approach that increasing the societal benefits of Earth science research should likewise be high on the priority list of federal science agencies and policymakers, who have long believed that the role of scientific research is not only to expand our knowledge but also to improve the lives of Americans.

The resulting NRC study, known as the *Earth Science Decadal Survey* (NRC, 2007), recommended 17 missions to be launched in three time phases. Among these was a mission dedicated to the measurement of tropospheric trace gases and coastal ocean color from a geostationary spacecraft to be launched in the second phase (2013-2016). The Geostationary Coastal and Air Pollution Events (GEO-CAPE) mission fits into the vision of providing societal benefits while also advancing the scientific understanding of processes that act on short time scales and relatively small spatial scales over a spatial domain of thousands of kilometers. The NRC also called for a low-earth orbit mission (Aerosol-Cloud-Ecosystems, ACE) in the 2013-2016 timeframe for global measurements of aerosols, clouds, and ocean color, and another satellite similar to Aura to be launched again in the 2020 timeframe (Global Atmospheric Composition Mission, GACM). Also planned for the second tier of missions is HyspIRI (Hyperspectral Infrared Imager), which complements GEO-CAPE with even better spatial resolution from a low-earth orbit.

This report documents a NASA-sponsored three-day workshop held in Chapel Hill, North Carolina, in August 2008 to refine the scientific goals, objectives, and requirements of the GEO-CAPE mission and to identify priority near-term investments needed to further mature the concept towards readiness for a Phase A mission start. GEO-CAPE workshop discussions and findings are presented following a brief background on the decadal survey, its process, and the GEO-CAPE mission recommendation.

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Executive Summary

This report documents a NASA-sponsored workshop to refine the scientific goals, objectives, and requirements of the Geostationary Coastal and Air Pollution Events (GEO-CAPE) mission and to identify priority near-term investments. Participants from the atmospheric composition and ocean color science communities articulated mission science questions and science objectives for each discipline, defined observations for these objectives, began to define measurement requirements for observations needed, and discussed potential synergies between different disciplines. The participants generated a set of science questions (Table 1) to guide the objectives of the mission and several categories of recommendations for near-term studies (Section 7).

Geostationary observations will provide distinct benefits to studies of both ocean science and atmospheric composition. The coastal ocean is an important component of the global ocean carbon cycle, and the geostationary perspective is needed to address science questions in this productive and dynamic region, where spatial and temporal scales of variability are smaller than those currently observed. Hourly observations would provide the basis for understanding the processes that affect the ecology and biogeochemistry of coastal ecosystems and would assist in resolving current uncertainty as to whether coastal regions are an overall net source or sink for atmospheric CO_2 on an annual basis. High temporal sampling and high spatial resolution will also help reduce the influence of clouds, which greatly limits the number of images available from low earth orbit (LEO) sensors. Furthermore, the spatial and temporal scales of GEO-CAPE measurements will be appropriate to constrain the next generation of coastal ocean ecological and biogeochemical models. The limited spectral measurements from the current NASA suite of ocean color sensors are inadequate for addressing the science questions articulated in Table 1, and an advanced multi-spectral or hyperspectral ocean color satellite sensor will provide the means to extend nascent capabilities to retrieve phytoplankton functional types, particle sizes and growth rates in coastal waters.

The biggest limitation to wider use of current tropospheric composition satellite observations in air quality applications and tropospheric process characterization relates to issues of temporal, spatial, and vertical resolution. Tropospheric measurements with high temporal frequency, as are possible from geostationary orbit, will revolutionize our understanding of the rapid and complex processes that transform and transport air pollutants and precursors. This information is critical for both air quality and climate policy. Measurements from LEO satellites cannot track the variability of the sources throughout the course of the day, the chemical evolution of secondary products, and the subsequent transport of these gases and aerosols. For O_3 and CO, differentiating upper and lower tropospheric concentrations will enable a much better understanding of the contributions from distant and local sources. However, the participants recognized the inherent challenge of achieving vertical resolution from nadir viewing and recommended an immediate goal of finding the best possible solution to this problem before defining

the instrumentation for the mission. With respect to aerosol observations, GEO-CAPE spectral coverage should also provide the capability to determine aerosol optical depth, size distribution and aerosol absorption from a set of sensors at fine spatial resolution and unprecedented temporal resolution, taking full advantage of state-of-the-art retrieval capabilities.

Having the ability to observe the atmosphere and coastal ocean together provides additional opportunities to exploit potential synergies that relate atmospheric transport to coastal regions, where trace gas and aerosol deposition impact the nutrient cycles of the organisms that live in the near-coastal waters and, while still in the atmosphere, interfere with the spaceborne measurements of coastal ecosystems. Gases and aerosols emitted from the ocean are known to influence the air quality in coastal regions. The synergistic science to be derived from having coincident, high resolution atmospheric and coastal ocean observations will be explored in future studies. The workshop also recognized that the GEO-CAPE mission would provide a valuable contribution to the Decadal Survey's overarching theme that future space missions should yield new information that benefits society; these potential benefits are articulated in Chapter 6.

1. Introduction

The NASA Geostationary Coastal and Air Pollution Events (GEO-CAPE) mission is recommended for launch in the second phase of missions (2013-2016) by the 2007 NRC *Earth Science Decadal Survey*. The mission's purpose is to identify human versus natural sources of aerosols and ozone precursors, track air pollution transport, and to understand the the short-term dynamics of coastal ecosystems in response to riverine and atmospheric inputs and external forcings from episodic events such as storms or ENSO. GEO-CAPE will provide important high-temporal-resolution information on coastal ocean regions to study the impact of climate change and human activity on this poorly observed yet important component of the Earth's biosphere. Near hourly observations throughout each day from GEO-CAPE's geostationary perspective will allow for adequate temporal monitoring of population exposure and the ability to relate pollutant concentrations to their sources or transport, thereby providing data to improve air quality forecasts and coastal zone management decisions.

NASA held a three-day workshop in August 2008 to refine the scientific goals, objectives, and requirements of the GEO-CAPE mission and to identify priority near-term investments needed to further mature the concept towards readiness for a Phase A mission start. The workshop brought together two science communities that had not previously considered in detail how best to design a mission that would mutually advance each discipline’s science objectives. Thus, a substantial portion of the workshop focused on defining the science questions and measurement objectives of such a mission.

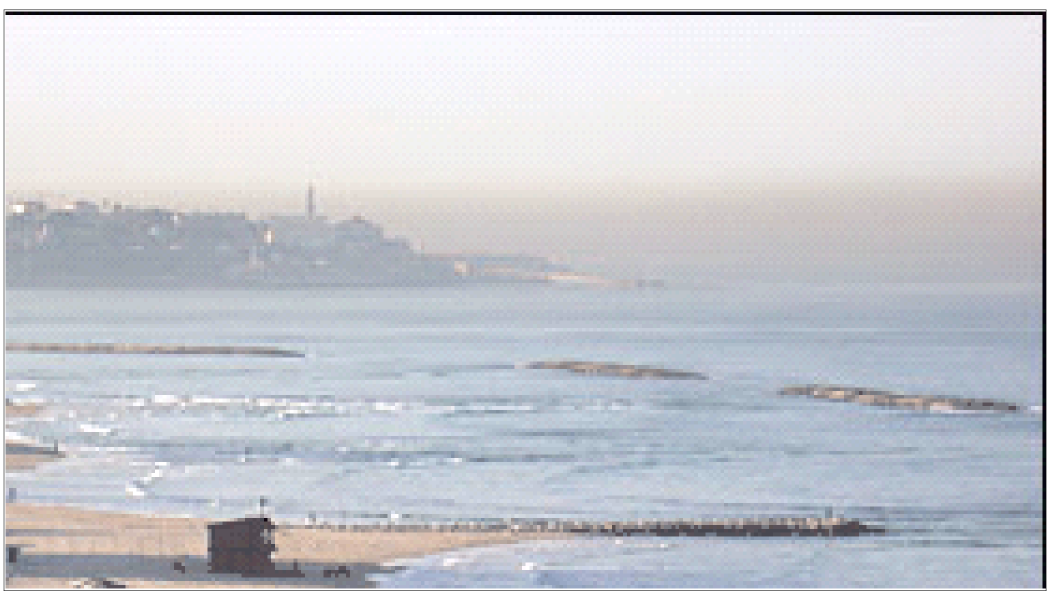

Figure 1. From a geostationary vantage point, GEO-CAPE will provide a unique capability to understand the formation and transport of regionally produced trace gases and aerosols, coastal ecosystem processes, and how anthropogenic and natural processes impact the interaction between air pollution and coastal biology.

1.1 The Decadal Survey

The National Research Council's decadal survey, *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond,* was released in 2007 as the culmination of a two-year study commissioned by NASA, NOAA, and USGS to provide consensus recommendations to guide the agencies' space-based Earth observation programs in the coming decade.

As described in the decadal survey report, the committee was organized into seven thematic panels and an executive committee. Community input was solicited via a Request for Information, and over 100 mission concepts were submitted by the community for consideration. The thematic panels evaluated submitted concepts based on eight prioritization criteria which were used to generate each panel's priority list:

1. Contribution to the most important scientific questions facing Earth sciences today (scientific merit, discovery, exploration)
2. Contribution to applications and policy making (societal benefits)
3. Contribution to long-term observational record of the Earth
4. Ability to complement other observational systems, including national and international plans
5. Affordability (cost considerations, either total costs for mission or costs per year)
6. Degree of readiness (technical, resources, people)
7. Risk mitigation and strategic redundancy (backup of other critical systems)
8. Significant contribution to more than one thematic application or scientific discipline

The panels then worked together to merge, combine, and condense the list of priorities into what is considered a "minimal yet robust" observing strategy. Ultimately, the report recommended a set of 17 missions in three time phases to achieve the needed observations while providing for both scientific advancement and societal benefit.

Several of the community submissions to the Decadal Survey articulated the need for high-temporal-resolution measurements to advance science in relation to air quality and coastal ecosystems. This resulted in the recommendation of the GEO-CAPE for the second deployment phase, identified in the report as 2013-2017. This ambitious schedule is critically dependent on the influx of additional funding, another key recommendation of the NRC. The panel proposed that the GEO-CAPE mission consist of three instruments in geosynchronous orbit: an ultraviolet-visible-near-infrared (UV-VIS-NIR) wide-area imaging spectrometer (7-km nadir pixel), a pointable high-spatial resolution (250-m nadir pixel) imaging spectrometer with a 300 km field of view, and an IR correlation radiometer for mapping carbon monoxide (CO) over an area consistent with the wide-area imaging spectrometer.

1.2 GEO-CAPE Workshop

The workshop was held August 18-20, 2008 in Chapel Hill, North Carolina and was open to all interested parties. The agenda consisted of a blend of plenary presentations, poster sessions, and interactive breakout sessions (see Appendix A). Approximately 150 participants from the air quality and ocean color science communities attended (Appendix B), including several invitees who presented plenary lectures on key science topics and other points to consider in the formation of the mission. In addition, some 40 posters were presented. Many of the talks and poster presentations can be found at the GEO-CAPE website: http://geo-cape.larc.nasa.gov/events-18AUG2008workshop-PosterTitles.html. All workshop participants were encouraged to discuss and refine the mission science goals with an emphasis on how the measurement needs of these two communities could be considered synergistically to define a better set of observations than would otherwise be achieved from two independent missions.

Presentations on the first day focused on providing background information on the relevant issues of the two distinct fields of atmospheric composition and ocean biogeochemistry and the rationale behind the NRC's recommendation that both of these disciplines be investigated from space using the same platform. In the afternoon, the two discipline groups held separate breakout sessions with the following charge:

1. Articulate mission science questions and science objectives for each discipline
2. Define observations/measurements for these objectives
3. Begin to define measurement requirements for observations needed
4. Begin to outline potential synergies between different disciplines

On the morning of the second day, a series of talks described similar efforts put forth by other space agencies and how the GEO-CAPE mission would complement future satellites, both those being planned by NASA, as well as foreign initiatives. In addition, a presentation was given summarizing a Headquarters-sponsored mission concept study with nominal instruments that would, in general terms, be capable of attaining a notional set of GEO-CAPE science objectives. The workshop then concentrated on more specific topics, including a discussion of the observational techniques that could be used to address the measurement requirements. This series of talks also highlighted the balance between complex science goals and practical implementation that minimizes complexity.

For the remainder of the workshop, participants were challenged to provide a concise set of science questions that would guide the objectives of the mission in the near-term before defining which instruments and observing strategies could best be developed to make GEO-CAPE a reality. These questions and objectives are presented in Table 1 and are the synthesis of much of the discussion that took place during the last day and a half of the workshop. A draft Traceability Matrix, extending the science questions to measurement and instrument requirements, is provided in Appendix C. It should be noted, however, that the Workshop did not rigorously discuss this Traceability Matrix due to lack of time, and Appendix C must be viewed only as an initial set of information that will be refined in subsequent workshops and meetings.

The overarching science question is "What natural and anthropogenic processes affect and control atmospheric composition, air quality, water quality, and coastal ecosystems, and how will they respond to climate change?" The mission would focus on the dynamic processes that require high frequency observations from geostationary orbit. By developing an understanding the processes this will inform models used both for short-term forecasts (e.g., air quality) as well as climate change forecasts.

The remainder of this report is organized as follows: Sections 2-4 present perspectives from the two disciplines separately. Section 2 contains science background, issues and accomplishments. Section 3 presents the mission science questions and science objectives that were defined in the breakout sessions, and section 4 presents the measurement concepts and requirements to achieve these objectives. Section 5 then turns to the issue of synergy with sections on synergy between the two GEO-CAPE disciplines, as well as synergy with other satellite missions. Section 6 discusses the societal benefits of the GEO-CAPE mission, and section 7 presents a set of recommended short term studies.

Table 1. Overarching Science Question: What natural and anthropogenic processes affect and control atmospheric composition, air quality, water quality, and coastal ecosystems, and how will they respond to climate change?

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 America and distinguish natural and anthropogenic contributions.
How do the distributions of gaseous pollutants and particulate matter evolve throughout the course of the day and what are the chemical, transport, mixing, and deposition mechanisms that determine these distributions?	Measure the diurnal evolution of atmospheric constituents as they are transformed and transported throughout the day over the continent and the surrounding ocean.
What processes affect and control the biology and biogeochemistry of aquatic coastal zones, and how are they modulated by natural and anthropogenic forcing?	Characterize variability in primary productivity, phytoplankton biomass, and carbon pools in the coastal ocean in conjunction with measurements of natural and anthropogenic forcing.
How do weather and the episodic releases from fires, dust storms 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 weather events and episodic input.

2.1 Atmospheric Composition

From an atmospheric chemistry perspective, the key measurable species in the troposphere is ozone (O_3) since it is the dominant reactive precursor that determines the abundance of the hydroxyl radical (OH) in the troposphere. If ozone's global distribution and the evolution of that distribution are understood, then many of the important questions about atmospheric chemistry can be answered, including the synergy between climate change and atmospheric composition. The primary challenge lies in the fact that O_3 is both a natural and a man-made component of the lower atmosphere (as opposed to the stratosphere, where ozone is produced only naturally). The two major sources of tropospheric O_3 are its transport from the huge stratospheric reservoir and its *in situ* photochemical production from the release of anthropogenic and biogenic precursors that are oxidized in the atmosphere to eventually become ozone. In turn, most of these trace gases are initially oxidized by OH. Thus, if the distribution of O_3 is well known, then we improve our knowledge of the oxidizing capacity (i.e., the abundance of OH) of the atmosphere as well as the global extent of air pollution. These are two of the "grand challenges" put forth in the integrated global observations strategy for atmospheric composition (Barrie et al., 2004). Global observations of trace gases using low-Earth orbiting (LEO) satellites have already provided the community with a unique set of observations. By being able to measure several important precursors to O_3 formation, as well as O_3 itself, it is clear that *in situ* production is an important, and possibly dominant, source of tropospheric O_3. However, the processes by which formation occurs are still not completely understood. Measurements from a geostationary platform would provide the temporal and spatial resolution to better quantify the mechanisms by which ozone is formed on regional scales before becoming a component of the global system.

Three critically important precursor trace gases that are key for ozone formation are CO, a class of gases known as volatile organic carbon (VOC) species, and nitrogen oxides (NO_x), which are mostly the sum of nitrogen oxide (NO) and nitrogen dioxide (NO_2). Formaldehyde (HCHO, a surrogate for VOC), CO, O_3, and NO_2 can now be measured from instruments currently flying on LEO satellites.

An example of the shortcoming associated with a lack of being able to obtain temporally resolved features is shown in Figure 2, which summarizes model results and measurements obtained during an Aura validation campaign June 22-23, 2005. The two OMI NO_2 column measurements over Houston are depicted by the red circles on the plot and were made at ~1900 GMT on each day; the distribution at the time of the measurement for the two days is shown in the center and right panels above the plots. The left top panel shows the NO_2 column distribution calculated with the Community Multi-scale Air Quality (CMAQ) model (Byun et al., 1999). On the hourly plot, there are two sets of calculated quantities: surface NO_2 concentration (magenta) and integrated tropospheric NO_2 (dark blue), the latter being what is measured by OMI. Because its distribution is dominated by local sources, the NO_2 observed by the satellite is closely linked to its concentration at the surface and the diurnal behavior of these quantities is also closely linked. If an instrument with spectral resolution comparable to that of OMI were in geostationary orbit, hourly observations of the type indicated by the blue diamonds during daylight hours (yellow shading) would be possible. Thus, an instrument using today's measurement capability that "stares" at a region throughout the course of the day would capture the most significant part of the diurnal variability that is totally missed by the low-earth orbiting Aura platform, which finds NO_2 values of 8 and 4 x 10^{15} molec. cm^{-2}, for June 22 and 23, respectively.

With the exception of CO, each of these trace species also plays an important role in the generation of aerosol particles. Sulfur dioxide (SO_2), another key component to aerosol formation, can also be measured from satellites. Thus, the simultaneous measurement of each of these species provides valuable insight into the global cycles of both tropospheric ozone and aerosols and their regional evolution as they become intertwined with the global aspects of their budgets. Furthermore, as these gases and aerosols are transported to coastal regions, they impact the nutrient cycles of the organisms that live in the near-coastal waters and, while still in the atmosphere, interfere with the spaceborne measurements of coastal ecosystems.

The question of measuring boundary-layer concentrations of various trace gases and aerosols was a key aspect of much of the discussion during the workshop. Some of this discussion will be highlighted in the "Measurement Concepts" section of this report.

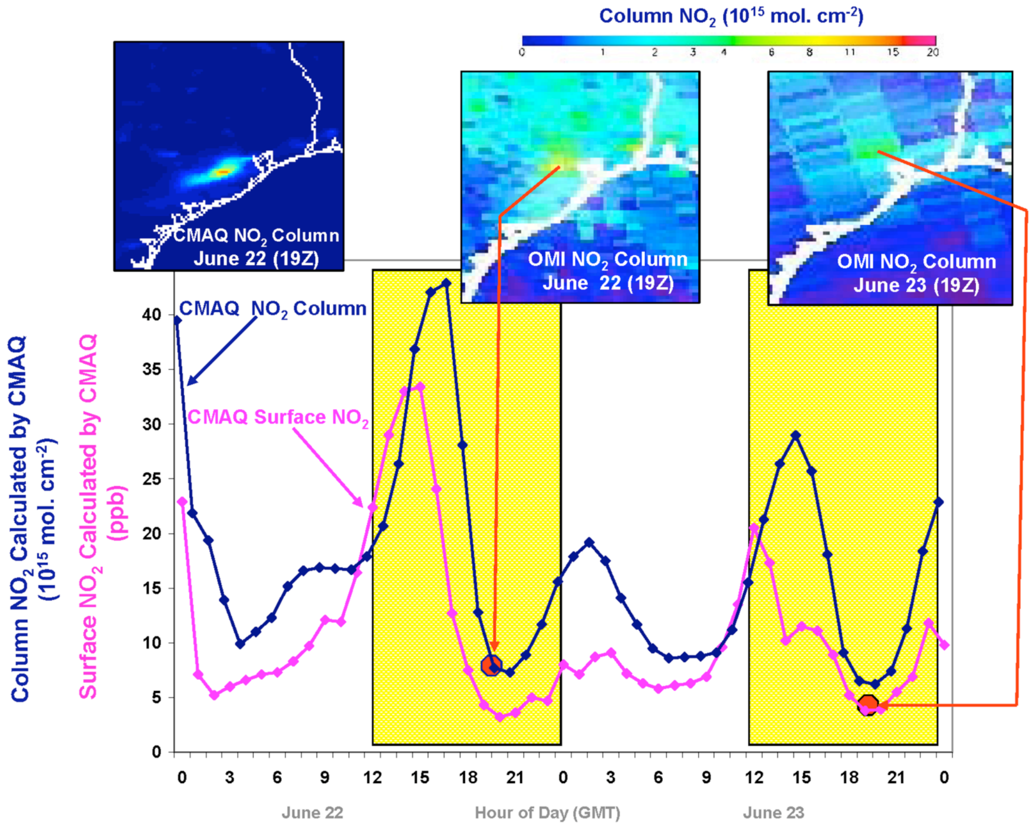

Figure 2. Two OMI NO_2 column measurements over Houston are depicted by the red circles at the time of the measurement (~1900 GMT) on June 22 and 23, 2005. The three depictions at the top portion of the figure are NO_2 column distributions: The left panel is calculated using CMAQ with a 12-km resolution; the other two panels are from OMI for the two respective days and all three depictions use the color scale above them. The diurnal calculations shown by the curves are the NO_2 surface concentrations (magenta) and the NO_2 columns (dark blue) calculated by the CMAQ model for Houston and are plotted hourly over this 2-day period. The yellow shading indicates daylight hours and illustrates when data using the solar backscattered technique (as used by OMI) could be obtained from a geostationary orbit (from Fishman et al, 2008).

2.2 Coastal Ocean Ecosystems and Biogeochemistry

Remote sensing of marine ecosystems and biogeochemical processes relies on the ability of sensors to measure subtle variations in ocean color and to differentiate this signal from variability in the overlying atmosphere. The color of the ocean, where it is sufficiently deep and far from land, is determined almost exclusively by microalgae known as phytoplankton ("phyto" = plant, "plankton" = floating). Phytoplankton contain chlorophyll *a* and other pigments that absorb light in certain bands and thus affect the emerging water-leaving radiance in those bands. In addition, phytoplankton and microbial processing of organic matter produce a form of dissolved organic carbon that also absorbs light and affects the water color. This "colored dissolved organic matter" (CDOM) absorbs in the UV, violet and blue end of the spectrum, whereas chlorophyll absorbs in the blue and red regions.

The most commonly derived product from ocean color is the upper-ocean chlorophyll concentration, which has been a measure of phytoplankton biomass long before satellites were used to study the ocean. The chlorophyll concentration is used primarily in two types of models. In one application, it is used to estimate primary productivity (or the rate of photosynthetic carbon fixation, units of mg C m^{-2} d^{-1}) in an effort to understand the role of ocean biology in the global carbon cycle (Behrenfeld et al. 2006, 2001; Antoine and Morel, 1996; Longhurst et al. 1995). Primary productivity algorithms use chlorophyll, photosynthetic available radiation (PAR), and sea surface temperature – all of which can be remotely sensed. The other application is in ecosystem models that are used to study the interaction between phytoplankton (P), zooplankton (Z), and nutrients (N). The use of satellite-derived chlorophyll in these NPZ models is often as a means of validating model predictions of P (Friedrichs et al. 2007; Fujii et al. 2007; Liu and Woods, 2004; Arrigo et al. 2003). The models predict the response of phytoplankton to physical and chemical forcing that operate on a wide range of time scales (from sub-diurnal to seasonal and longer). For satellite data to be used as input to the models, the spatial and temporal scales of the satellite data need to be comparable. Currently coastal models are run with < 1 min to 30 min time steps and 300 m to 4 km spatial bins to resolve the physical dynamics and complexity of the coastal ocean (Hofmann et al. 2008; Bissett et al. 2004). Thus, GEO-CAPE will provide critical information to constrain the next generation of coastal ocean models.

Today's operational chlorophyll algorithms use a blue-to-green ratio of water-leaving radiances in a statistical relationship derived from ~3000 surface measurements. This simple relationship is based on the so-called 'bio-optical assumption,' which assumes that all optically active constituents co-vary with chlorophyll in a globally consistent manner. It is acknowledged that the 'bio-optical assumption' is not universally valid, particularly in the coastal ocean where the ocean is influenced by the continental shelves and interaction with the land. The coastal ocean, extending some 200-300 km offshore and including the Great Lakes, is much more optically complex than the deep open ocean. In addition to phytoplankton pigments and co-varying CDOM, a dynamic mixture of materials derived from the land also influences the water color. These include terrigeneous CDOM, detritus (decaying particles), and suspended sediments. Algorithms for optically complex coastal waters are being developed to solve this multivariate problem (e.g., see IOCCG, 2006).

Some of the light absorbed by the phytoplankton is re-emitted by the chlorophyll-a pigment as a red fluorescence. The Moderate Resolution Imaging Spectroradiometer (MODIS) has three bands, one on the fluorescence peak (band 14 at 678 nm) and two on either side (at 667 and 748 nm) for measuring this fluorescence. The chlorophyll fluorescence is an especially valuable measurement for coastal waters because it is less affected by the high CDOM due to runoff from land that is found in many coastal areas. Thus, future sensors imaging the coastal zone should have sufficient spectral resolution to resolve the chlorophyll fluorescence peak and other variability related to the optical complexity of these waters. An advanced multi-spectral or hyperspectral ocean-color satellite sensor will provide the means to extend nascent capabilities to retrieve phytoplankton functional types, particle sizes, and growth rates in coastal waters (Westberry et al. 2008).

3. Science Enabled by Measurements from Geostationary Orbit

3.1 Atmospheric Composition

The biggest limitation to wider use of current tropospheric composition satellite observations in air quality applications and tropospheric process characterization relates to issues of temporal, spatial, and vertical resolution. Measurement resolution is dictated by a combination of basic physics, signal sensitivities, required sensor integration times, and orbital coverage. The issue of vertical resolution specific to trace gases and aerosols within the troposphere would face similar challenges for an instrument whether in low-earth or geostationary orbit. Issues related to temporal and spatial resolution, however, can be addressed from a geostationary orbit. The ability to “stare” from geostationary earth orbit (GEO) should provide improved integration times for weaker spectral signals and improve characterization of surface parameters. Current horizontal resolution from LEO is unable to resolve city-scale processes and match the resolutions of the next-generation regional models. Measurement with a horizontal resolution of better than 10 km (and preferably 2-5 km) will be required. Horizontal homogeneity of the viewing scene in terms of surface reflectivity (or emissivity) and cloud cover, is also important for the quality of satellite nadir retrievals. A smaller pixel also improves the chances of finding cloud-free scenes. At the same time, the horizontal domain must be at least on a continental scale to capture regional pollution episodes, and the combined requirement for high horizontal resolution and large area coverage presents major technological challenges.

Tropospheric measurements with a temporal frequency of one hour or less from geostationary orbit will revolutionize our understanding of the rapid and complex processes that transform and transport air pollutants and precursors. This information is critical for both air quality and climate policy. Most important emission sources are inherently variable on diurnal time scales (mobile sources, fires, vegetation, soil, lightning) and as such difficult to properly observe. The measurements of GEO-CAPE will be critical in characterizing in detail and drastically reducing the uncertainty on estimates of the emissions of NO_x, CO, isoprene and other VOCs (through HCHO), aerosols, and SO_2, which are presently uncertain to about +/- 50 percent or more. Chemical evolution and aerosol formation in the emission plumes takes place on hourly time scales, and understanding this processing is essential in terms of the implications for air quality and climate forcing. For ozone and CO, differentiating upper and lower tropospheric concentrations will further enable separation of distant and local sources.

Geostationary observation of atmospheric composition will also provide unique information to better quantify the sources of chemical agents of climate change, particularly those involving natural processes that may be affected by human activity (forcings) or respond to climate change (feedbacks). Measurements from GEO-CAPE will greatly improve our ability to characterize radiative forcing and climate feedbacks involving continental sources, and thus improve model projections of future regional and global climate change. Multi-angle observation of aerosols over the course of the day from geostationary orbit will provide important new information on aerosol properties could be used to improve climate models. Measurements from LEO satellites cannot track the variability of the sources throughout the course of the day, the chemical evolution of secondary products, and the subsequent transport of these gases and aerosols. Many of these sources are episodic or have strong temporal variations on hourly time scales, making them difficult to observe from either *in situ* platforms or polar-orbiting satellites. Specific sources include:

1. **Biomass burning**. Open fires emit large amounts of aerosols, as well as carbon gases and nitrogen oxides that go on to produce ozone. Fire activity varies greatly with time of day. There is large uncertainty regarding source magnitudes and how they relate to the type of biomass burned and to the burn conditions. Fires may represent a major climate forcing or feedback agent, but even the sign of the effect remains uncertain.
2. **Lightning**. Nitrogen oxides emitted from lightning are a major natural source of ozone in the middle/upper troposphere, where ozone is a strong greenhouse gas. This could represent a significant feedback to climate change. Current estimates of the global lightning source vary by about a factor of four, and there is very little understanding of how NO_x emission depends on lightning type and intensity. Lightning is episodic and associated with convective clouds, so that continuous geostationary observation is of particular advantage.
3. **Biogenic VOCs**. VOCs emitted by vegetation are a major source of organic aerosols and ozone, and this could represent an important feedback to climate change. Emissions have a strong diurnal dependence and vary with vegetation type and environmental conditions in a way that is presently poorly understood.
4. **Dust events**. Dust is the largest component of the global atmospheric aerosol, and can act as either a climate forcing (e.g., agricultural erosion) or feedback. Dust emission is episodic and is extremely sensitive to wind speed and other environmental parameters, in a manner that is poorly represented in models. Again, continuous observation offers the only means to properly characterize this source.

5. **Surface carbon fluxes**. CO_2 and methane observations from space have the potential to greatly improve our understanding of surface fluxes of these gases through inverse analyses. A recognized limitation of existing and planned polar-orbiting instruments is their inability to observe the diurnal variability of CO_2 uptake by vegetation or the episodic character of methane emission. Geostationary observations can effectively address this limitation.

The currently planned GEO-CAPE observation capabilities for aerosols, O_3, CO, NO_2, CH_4 and HCHO will powerfully address issues (1)-(4). Beyond the value of continuous observation from geostationary orbit, the multi-angle sensing of aerosols inherent in a geostationary platform has the potential to provide new constraints for describing aerosol optical properties and radiative forcing in models. Addressing issue (5) will require additional CO_2 and methane sensing channels in the solar and thermal IR. The feasibility of this addition will need to be determined as part of the GEO-CAPE design phase.

GEO-CAPE will provide a key data set for assimilation into and the development of nowcast and forecast models of air quality and climate forcing, and in this capacity it will contribute to the operational programs of the Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA). This is discussed in more detail in section 6 which focuses on Societal Benefits. In addition, an improved understanding of the tropospheric pollutant processes will improve predictions of the impacts of climate change on air pollution when climate models process representations are verified.

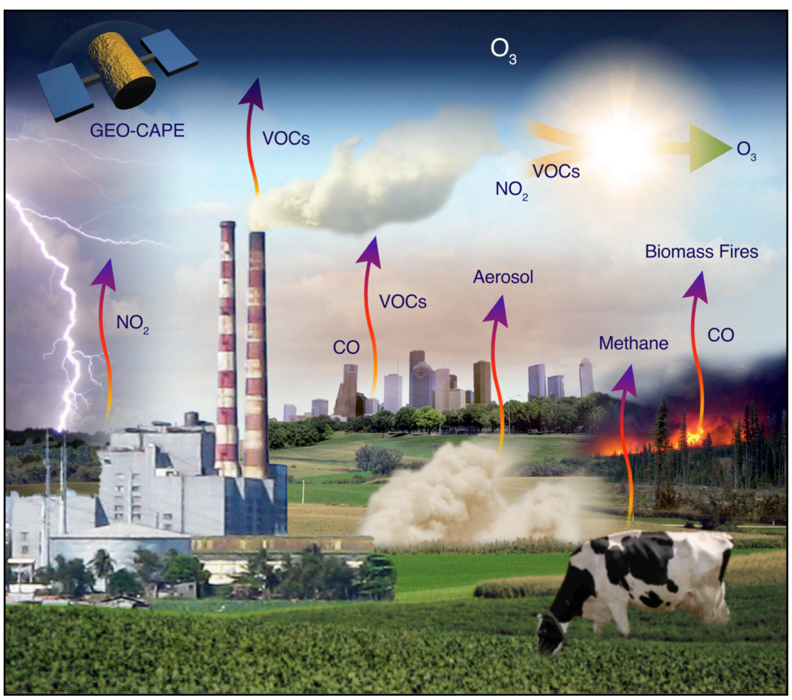

Figure 3. Application of GEO-CAPE to observe chemical agents of climate change.

3.2 Coastal Ocean Biology and Biogeochemistry

The geostationary perspective is needed to address science questions in the productive and dynamic coastal ocean, where spatial and temporal scales of variability are much smaller compared with the open ocean. High frequency (hourly), synoptic observations would provide the basis for understanding the processes that affect the ecology and biogeochemistry of coastal ecosystems. Semi-diurnal and diurnal tides play an important role in shallow near-shore regions and off-shore banks where tidal mixing stirs up bottom sediments, nutrients, and pollutants. Other coastal processes include wind-driven upwelling, atmospheric deposition, input from rivers (in particular during episodes of high discharge and coastal flooding), and the timing and fate of algal blooms that are stimulated by these forcings. Biological processes such as cell division and grazing have diel cycles that require high-frequency observations. Sea breezes introduce diel variability as on- and off-shore winds modulate the aerosols over the ocean. High temporal sampling will also help alleviate the large impact of clouds that greatly limits the number of images available from LEO sensors. The higher spatial resolution proposed for the GEO-CAPE high-spatial-resolution imaging spectrometer (250 m) will also help by reducing subpixel cloud contamination compared to the typical ~1 km pixel resolution available from current LEO ocean color sensors.

Specific science questions that can be addressed with the GEO-CAPE mission are as follows:

1. How are coastal algal blooms impacted by climate or environmental variability and change? What are the consequences of these impacts for fisheries, biodiversity, the ocean's biological pump, carbon fluxes, the extent of oxygen minimum zones, and for ecosystem health?

The drivers of coastal blooms change from region to region. The major drivers are upwelling, mixing, runoff, and atmospheric deposition. These processes will be studied intensively in regions were each driver is dominant in order to generate predictions of how they will change over time. These processes have been studied before but not at the resolution provided by GEO-CAPE. Along the west coast certain regions tend to have more intense and larger blooms relative to others (i.e. San Francisco/Monterey Bay versus Point Sur), why is this? How does a river-driven system compare to one only a few kilometers away that is not?

2. How and how fast do (harmful) algal blooms, oil spills, pollutants and other elements that could be detrimental to ecosystems disperse in the coastal ocean?

Tidal and wind driven currents typically exceed 2 knots such that features of interest can move 70 km in the 24 hours between observations made with a LEO ocean color imager. Models of coastal ocean dynamics used to track plankton blooms require <30 min time steps and 300 m to 4 km spatial resolution to resolve the coastal physics which are driving these changes. Hourly data from GEO-CAPE will make it possible to validate the biological dynamics within these models and advance our understanding of phytoplankton dynamics in the coastal ocean.

3. What is the role of continental margins in the global cycles of carbon and nitrogen (including global primary productivity)? What are the sources/pathways, forms, and fates of carbon and nitrogen to rivers, estuaries, and continental shelves? What is the contribution of terrigenous organic matter exported to the coastal ocean and to the open ocean?

The coastal ocean is an important component of the global ocean carbon cycle. Although the coastal zone is less than 10% of the surface area of the global ocean, 25-50% of the global marine photosynthesis occurs in the coastal ocean (Muller-Karger, 2001). Carbon fixed through photosynthesis in the coastal ocean is strongly influenced by complex physical and biological controls on nutrient supply and light availability. The air-sea exchange of carbon dioxide depends on both physical transport processes in the atmosphere and ocean as well biological uptake. The riverine carbon flux from land to ocean is significant; in the coastal ocean of the United States, it is 10-30% of the land-atmosphere carbon flux (Pacala, 2001). Estimates of the export of carbon to the deep ocean and sediments in the coastal zone range from 30% (Karl et al., 1996) to 80% (Walsh, 1991) of the global value. Carbon exchange between the continental margin and the deep-sea (including land-to-ocean transport of carbon) is poorly understood because it is often small and when larger, takes place episodically. The uncertainty associated with these and other estimates are large, indicating our lack of understanding and knowledge. As a result, key questions still remain as to whether coastal regions are an overall net source or sink for atmospheric CO_2 on an annual basis (Borges et al. 2005; Cai et al. 2006).

The best property for delineating a river plume is salinity. Ocean surface salinity will be measured by the Aquarius mission that is expected to fly in 2010, but it will only have a ~100 km spatial resolution. However, the spatial extent of a river plume can usually be detected by its color contrast with the receiving ocean waters. A robust river-specific relationship between CDOM (derivable from ocean color) and salinity has been demonstrated and holds promise for mapping river plumes (Salisbury et al. 2001; 2004).

Focused field expeditions and process studies along U.S. continental margins, as well as off the Amazon and Orinoco River plumes, conducted in conjunction with with a GEO ocean color sensor, will help elucidate the role of continental margins and the fate of terrigeneous and autochthonous production (mineralization, burial, and export to the open ocean). The sources and pathways to be studied include atmospheric wet/dry deposition, groundwater, agricultural runoff, forest/grassland/wetland vegetation decomposition, and air-sea exchange.

4. Measurement Concepts and Requirements

A considerable portion of the workshop was devoted to current and future measurement capabilities for spaceborne instruments. The discussion in this section is divided into various measurement techniques categorized by spectral ranges for both atmospheric composition and ocean color measurements.

4.1 Measurements of the troposphere

The recent advances in tropospheric remote sensing from LEO instruments such as the Measurement of Pollution in the Troposphere (MOPITT), the Global Ozone Monitoring Experiment (GOME), MODIS, Multiangle Imaging Spectroradiometer (MISR), Scanning Imaging Absorption Spectrometer for Atmospheric Chartography (SCIAMACHY), OMI, and the Tropospheric Emission Spectrometer (TES) have demonstrated the value of using satellites for both scientific studies and environmental applications. Although satellite remote sensing of the troposphere is a relatively new capability, great strides forward have been made in the last ten years or so. The current satellite data can best be used to characterize aerosol and ozone precursor sources, transport, and variability on continental and global scales

The useful trace gas spectral signatures (UV-A to microwave) are limited. The detection of a particular pollutant or process also often depends on the concentration perturbation that is produced relative to background levels, which in turn may depend on pollutant lifetime and transport. Remote sensing issues associated with the retrieval dependence on prior assumptions and climatologies, and the availability of required retrieval ancillary data (cloud, aerosol, scene characterization, temperature profile and contaminating signals), are particularly problematic for tropospheric measurements. There is also a strong need for observations of physical climate and land surface variables to improve emission inventory estimates and better forecast the development of pollution episodes. Important physical variables in this regard include the depth of the boundary layer (accessible by lidar aerosol observations), surface roughness, soil moisture, land cover, and winds.

Top-priority air quality (AQ) measurements from space with demonstrated capability include tropospheric O_3, CO, NO_2, HCHO, SO_2, and aerosols. Retrieval capability is being explored for NH_3, important in aerosol formation, aerosol composition and size distribution, and gas-phase species H_2O_2, PAN, HNO_3, HNO_4, acetylene, HCN, glyoxal, and formic acid. Retrieval of tropospheric ozone in the extratropics remains sensitive to information on the tropopause location and on near-surface concentration.

As part of the workshop, we reviewed the existing measurement capabilities and grouped them by spectral regions (UV, VIS and IR). The following sections contain specific measurement concepts for the various spectral regions.

4.1.1 UV/VIS Capabilities for Atmospheric Composition

Several tropospheric O_3 precursor trace gases and O_3 itself can be observed in the UV-VIS part of the spectrum (Figure 4), These measurements rely on observations of solar radiation backscattered from the atmosphere and Earth's surface and are possible during daytime. Since a number of these species have appreciable stratospheric column burdens, a significant challenge lies in isolating a tropospheric signal from these total column measurements. This is especially true in the case of O_3 where the tropospheric column of particular interest for AQ studies represents only about 10% of the total.

There is a near three decade heritage of backscatter ultraviolet (BUV) measurements used to derive atmospheric ozone. The original instruments (BUV, SBUV and TOMS) used finite spectral bands to derive O_3, SO_2 and aerosol information. A new generation of spectrometers began in the 1990s which provided continuous spectra in the near UV and VIS portions of the spectrum. These data are used to generate O_3, NO_2, HCHO, SO_2, and glyoxl (CHOCHO) column amounts using differential absorption spectroscopic techniques. Improved aerosol characteristics are also being derived from this new data. Because of the improved spatial resolution and higher precision measurements, several efforts underway to also derive tropospheric ozone.

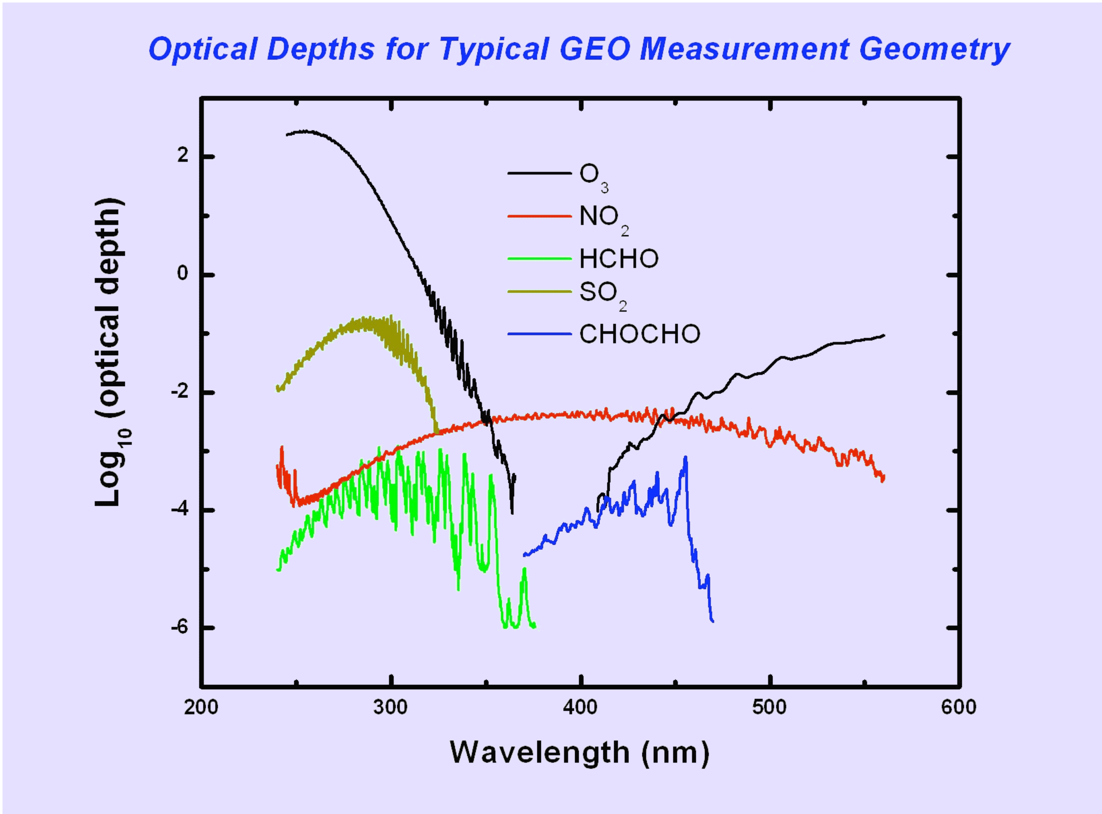

Figure 4. Optical thicknesses for absorption by pollutant gases for typical geostationary measurement geometry. SO_2 is calculated for a concentration typical of volcanic eruptions, while the other gases are calculated for conditions of moderate atmospheric pollution. Nitrogen dioxide (NO_2) serves as the proxy for odd-nitrogen pollution, while formaldehyde (HCHO) and glyoxal (CHOCHO) are indicators for volatile organic compounds released from both pollution and natural sources (Figure courtesy of Kelly Chance).

The pervasive question about how to isolate a tropospheric partial column from these total column measurements has been investigated using direct analysis of the spectral signatures and by using "residual" techniques that subtract a stratospheric component from the total column measurement with the aid of other measurement or model information. This methodology has been utilized to derive global distributions of tropospheric O_3 and NO_2. Additionally, the vertical sensitivity of the backscattered radiances has to be fully characterized when deriving vertical column amounts from the slant column measurements and when accounting for problems that arise due to interferences from clouds, aerosols, Rayleigh scattering, and surface reflectivity uncertainties. These issues can significantly reduce measurement sensitivity to the planetary boundary layer (PBL).

Satellite measurements of backscattered radiances in the UV-VIS from a geostationary orbit would significantly contribute to improving the knowledge on aerosol amounts and types. This information is not only necessary for direct application in AQ and climate analysis but also to account for the possible interference effect of aerosols in the retrieval of concentrations of trace gases, and for the required atmospheric correction in the retrieval of ocean color products.

4.1.2 IR Capabilities for Atmospheric Composition

The thermal infrared (TIR) part of the spectrum contains useful spectral signatures of O_3 and CO amongst other gases. Satellite instruments make day and night retrievals of these species using radiation that is sensitive to the emission from the Earth's surface and to absorption and emission from the atmosphere. Because these latter processes depend on the vertical profiles of pressure, temperature, and concentration of the target gas itself, it is possible to derive some vertical profile information from nadir measurements. The generally low thermal contrast between the surface and near-surface atmosphere limits the measurement sensitivity to the PBL, and characterization of the surface and cloud cover are both important for good retrievals. There are also spectral signatures of CO and O_3 in the near-IR (NIR), in addition to features for the CO_2 and CH_4 greenhouse gases. At these wavelengths, measurements primarily make use of backscattered solar radiation. Although characterization of the surface reflection is again important for good retrievals, total column retrievals are almost uniformly sensitive to the atmospheric gas profile, including the PBL.

The first TIR technique used to measure a trace gas from space, gas filter correlation radiometry (GFCR), provides high effective spectral resolution, discrimination of the spectral signatures of interest and good signal-to-noise. GFCR was the basis of the Measurement of Air Pollution from Space (MAPS) instrument that measured column CO and flew on several space shuttle flights in the 1980s and 1990s. The technique is also used for retrieval of CO tropospheric profiles by the MOPITT instrument on the Terra satellite launched in 1999. Because these retrievals rely on thermal contrast between the surface and atmosphere, the measurement is primarily sensitive to two broad layers of CO in the lower and upper free troposphere, and PBL CO is not entirely measured. Since its launch, MOPITT has since been joined by several other satellite instruments with capability to measure free troposphere CO. CO retrievals using the NIR spectral band have been demonstrated by SCIAMACHY instrument and recently by MOPITT.

The TES Fourier transform TIR spectrometer was launched in 2004 aboard the Aura satellite. In addition to measurements of CO and other species of interest for atmospheric composition studies, TES makes the key measurement of tropospheric O_3. Sounding tropospheric ozone directly in the infrared requires spectral resolution on the order of 0.1 cm^{-1} or better and signal-to-noise characteristics of at least several hundred. Sensitivity to the lower layers of the atmosphere is again primarily influenced by thermal contrast and also ozone amount. Comparisons of TES measurements to sondes and analysis of degrees of freedom of signal illustrate that TES has sufficient resolution to differentiate the upper and lower troposphere. Regular CO measurements are now underway with AIRS and IASI.

Robust techniques for the retrieval of aerosol optical depth and information on particle size distribution have been developed and are applied routinely to observations by the MODIS and MISR sensors. In addition, new retrieval approaches that make use of observations in the near-UV and blue spectral regions have been developed over the last ten years. Near-UV observations from the TOMS and OMI sensors have been successfully used for the retrieval of aerosol absorption (Torres et al., 2005). Observations at near UV (Torres et al, 2007) and blue (Hsu et al, 2004) spectral regions are also suitable for the retrieval of aerosol optical depths over land areas including arid and semi-arid regions of the world, where traditional single-view visible-near IR methods do not work. The proposed GEO-CAPE spectral coverage would, for the first time, offer the capability to simultaneously measure aerosol optical depth, size distribution, and aerosol absorption from a set of sensors at fine spatial resolution and unprecedented temporal resolution, taking full advantage of state-of-the-art retrieval capabilities. The availability of UV channels will allow the identification and characterization of organic aerosols that have a unique spectral signature in the UV and are not easy to differentiate from other aerosol types with visible-only observations. Observation of the diurnal cycle of the different processes of aerosol injection and transport will provide new, important information for the understanding of AQ and climate science issues. As with aerosol retrieval from LEO sensors, the accuracy of retrieved information is closely related to the pixel size of the observations since sub-pixel cloud contamination is the largest source of uncertainty. Thus, spatial resolution is of the utmost priority for accurate results. Although such resolution on the order of 1 km or less is preferable, studies should be conducted to see how much information can be obtained from measurements with lower resolution.

4.1.3 Multispectral Approaches to Lowermost Troposphere Measurements

The ability to retrieve trace gas concentrations in the planetary boundary layer (PBL) is important for the characterization of pollutant sources. In addition to source determination, a measure of PBL concentration in conjunction with free troposphere profile information allows local production to be separated from transported pollution. However, these retrievals are challenging; spectral signatures from the UV to NIR are subject to interferences from clouds, aerosols, and air scattering, and to surface reflectivity uncertainties. In the TIR, the general lack of temperature contrast between the atmosphere and surface limits PBL retrieval capability. Multispectral observations may provide information from which average PBL concentrations might be inferred for some species, with CO and O_3 being the best candidate species at present.

In the case of CO, a retrieval isolating the PBL will require a multispectral NIR+TIR retrieval. Examination of measurement sensitivity as characterized by the weighting functions shows that these measurements are complementary. Conceptually, the TIR measurements are used to retrieve a free-tropospheric profile and the associated partial column that is then subtracted from the NIR-retrieved total column to leave the lowermost troposphere partial column. The TIR measurement provides the “big picture” and captures the long-range transport which is primarily a feature associated with the free troposphere and can be better captured with a measurement every 24 hours. The NIR measurement is needed to observe source regions and provide increased sensitivity to the PBL. It is important to note that although the NIR measurement has sensitivity to the

PBL, it cannot isolate the PBL in terms of providing a trace gas concentration. This is particularly important in the case of CO since the PBL and free troposphere partial columns are often of comparable magnitude due to the medium lifetime and the importance of transported CO. With sufficient instrument spectral resolution and noise characterization, experience with MOPITT measurements suggests that up to three independent profile layers should be possible in the combined NIR+TIR retrieval. These would separately characterize the PBL and the lower and upper free troposphere.

Two recent studies suggest that combined wavelengths (e.g. TES + OMI) could provide improved sensitivity to boundary layer ozone. Worden et al (2007) described simulations of TES and OMI radiances, and applied a linearized retrieval to characterize the sensitivity and error. This was performed for a set of profiles that had varying ozone, surface characteristics, and atmospheric temperatures. Landgraf and Hasekamp (2007) performed a similar analysis, where in which they used instrument characteristics of GOME-2 and OMI for the UV/vis, and a TES-like design in the thermal infrared.

New instrument concepts incorporating wavelengths across the ultraviolet, visible, and infrared spectrums could provide the observations for multispectral retrievals. Alternatively, retrievals could combine information from several instruments each focused on different parts of the spectrum. Definition of the underlying measurement requirements for accessing some trace gas concentration information in the lowermost troposphere is one of the priority study areas identified at the GEO-CAPE workshop.

4.2 Measurements of the Coastal Ocean

Measurement requirements for coastal-water imaging are based on experience with three current ocean color sensors, the U.S MODIS and Sea-viewing Wide Field-of-view Sensor (SeaWiFS) instruments, and the European Medium Resolution Imaging Spectrometer (MERIS) instrument. Participants in the ocean breakout session focused on the advantages of a GEO mission as compared with today's ocean color sensors onboard polar-orbiting satellites. A fundamental problem for observing the coastal ocean is that polar-orbiting satellites can acquire data only once per day at best. In practice, viewing opportunities are much less frequent due to clouds. Even a constellation of LEO satellites cannot provide the hourly observations needed to observe variability in the coastal ocean. It is the high temporal variability that motivates a GEO mission with hourly measurements and spatial scales of a few hundred meters rather than the daily revisit and the 1-km or larger spatial sampling suitable for the open ocean. Furthermore, having multiple viewing opportunities throughout the day can mitigate the cloud problem since clouds move throughout the day. Comprehensive pre-flight and on-orbit calibration and validation programs, together with supporting research and analysis, are essential for mission success.

Better spatial resolution (250-350 m) compared with today's ocean color imagers (1 km of MODIS and SeaWiFS) is needed to resolve tidal fronts, river plumes, and phytoplankton patches in the coastal ocean. The spatial resolution of 250-350 m also makes it possible to sample much closer to the coast and into the bays and estuaries where the resolutions of today's ocean color sensors are too coarse. It can also be applied to assess water quality in certain large bays and estuaries.

Two sets of measurement requirements were discussed at the workshop. The first is NOAA's operational requirements as developed by the Coastal Ocean Applications Science Team (COAST http://cioss.coas.oregonstate.edu/CIOSS/coast.html) led by Curtiss Davis and further modified and adopted by NOAA's National Ocean Service. The second is a more advanced set of requirements as defined by NASA's 2006 Advance Plan for the Ocean Biology and Biogeochemistry (OBB) Program that represent highly advantageous goals to enable further technological development (http://oceancolor.gsfc.nasa.gov). An instrument meeting all of the NASA OBB requirements would meet or exceed the NOAA operational requirements satisfying operational as well as scientific needs.

4.2.1 NASA's Ocean Biology and Biogeochemistry Advanced Plan for Geostationary

NASA's OBB Advanced Plan describes the mission science and a preliminary set of instrument requirements for a geostationary hyperspectral imaging radiometer to study coastal ocean processes. The considerations for ocean color retrievals in coastal waters entails significant improvements in current ocean color sensor capabilities, which include: high frequency sampling each day, higher spatial and spectral resolution, broad spectral coverage including UV-VIS-NIR and SWIR bands, high SNR and dynamic range, cloud avoidance, etc. The spatial resolution of ~300 m or better is essential for sampling complex coastal environments and is a major improvement over the 1 km resolution typical of polar orbiting ocean color sensors. The other key requirement is to observe U.S. coastal waters (excluding Alaska which is not visible form geostationary orbit) several times per day with selected regions viewed more frequently for events, such as harmful algal blooms or oil spills. This will greatly improve our sampling in the highly dynamic coastal ocean compared to polar orbiting ocean color sensors that typically sample the same area once every two days.

4.2.2 Instrument Design Issues for Ocean Color

There has been a long-standing debate within the ocean color community as to whether one needs hyperspectral vs. multispectral measurements. "Hyperspectral" refers to full spectral coverage without the gaps between spectral bands in a multi-spectral sensor. It often implies relatively high spectral resolution (e.g., 350-1050 nm coverage with 5 nm resolution as proposed in the COCOA White Paper submitted to the Decadal Survey) .

Hyperspectral imaging with 10 nm or better spectral sampling has proven to be essential when imaging optically shallow waters where reflectance from the bottom adds to the complexity (Lee and Carder, 2002). In addition, the bottom reflectance greatly increases the water leaving radiance compared to optically thick waters and therefore requires greater dynamic range. However when the bottom is not imaged, the MERIS band set has proven to be as good as the 10 nm hyperspectral data for water column properties. For example, the 620 nm channel on MERIS has proven useful for mapping suspended sediments and a 705 nm channel for detecting phytoplankton blooms. Although hyperspectral imaging is not required, following the MERIS design, the instrument could be a hyperspectral imager with order 1-nm spectral resolution and the ocean channels binned on the spacecraft. To resolve 1-nm ocean features requires 0.3-nm Nyquist sampling. There are a number of advantages to this approach, particularly if 1-nm resolution is needed for the atmospheric measurements. One key advantage is that the binned channels have a Gaussian (or better) shape, and we do not have to deal with filter stray light issues or the possibility of the filters aging in space. A design study is needed to decide between a filter spectrometer (filter wheel or other design) and an imaging spectrometer design.

The limited spectral measurements from the current NASA suite of ocean color sensors are inadequate for addressing the science questions articulated in Table 1. Future sensors will need to expand the spectral range and resolution of radiometers used for measuring ocean color. Expansion into the MIR range will improve atmospheric corrections in coastal areas and the UV range will help distinguish CDOM from phytoplankton pigment absorption. Higher spectral resolution will provide details of fluorescence peaks for chlorophyll and other pigments. Fluorescence bands on the NASA MODIS sensors now provide some advantage for discriminating phytoplankton blooms from other colored phenomena, such as river plumes, and in combination with measurements in the near ultraviolet (360 – 400 nm) may provide better descriptions of in-water constituents than currently available through traditional blue-green visible bands. These new developments further emphasize the importance of expanding observations in spectral range and resolution for applications in optically complex coastal waters.

Future ocean remote sensing missions must address atmospheric correction issues associated with absorbing aerosols, improve the separation of optically active in-water constituents, enable a broad-scale characterization of unique ecosystem conditions (e.g., separating iron- and nitrogen-limited waters), and provide appropriate space and time scale observations for interdisciplinary approaches to quantify elemental fluxes at the land-ocean interface (NASA OBB Advanced Plan, 2006, http://oceancolor.gsfc.nasa.gov).

4.3 Mission Design Studies

A mission design study for a concept conforming to the GEO-CAPE mission as outlined in the NAS Decadal Survey was completed under NASA HQ support at the Goddard Instrument Synthesis and Analysis Laboratory and Integrated Mission Design Center (see "An Advanced Earth Science Mission Concept Study: Geostationary Multi-discipline Observatory" posted on the GEO-CAPE website under Review Documents). The study guidance was to combine instrumentation for atmospheric composition and ocean color to enable coastal ocean science and enhance atmospheric science. Terrestrial biosphere science, which was not explicitly regarded in the NAS document, was also considered in the design study. The instrumentation concept was a combination of medium-resolution (5 km) continental-scanning instruments, primarily for atmospheric composition, with a higher resolution (300-m) regional-viewing spectrometer driven by the coastal ocean science requirements. The higher spatial resolution instrument was envisioned as a programmable geosynchronous multi-disciplinary observatory, which would be a shared resource for regular observations, special observing studies, and emergencies. Precursor designs were found in ESEI, COCOA, GEOCarb documents. The instrument suite would meet or exceed discipline science measurement requirements to produce potential ground-breaking new science in each discipline plus synergies.

The instrument suite used in the study was 1) a scanning UV/Visible spectrometer (300 – 480 nm) to detect total column O_3, NO_2, HCHO, SO_2, and aerosol; 2) a gas correlation filter radiometer measuring reflected near-IR and thermal IR emission to sense atmospheric CO total column to surface, and mid- and upper-troposphere weighted capable of separating boundary layer from free troposphere abundance; 3) a scanning, high resolution multi discipline imaging spectrometer to measure ecosystem-scale fields of interest using three focal planes in the UV, Visible, and Near-Infrared. This instrument complement corresponds closely to those proposed for GEO-CAPE.

The mission implementation requires a single satellite in geostationary Earth orbit (GEO) that will accommodate the mass, power, volume, and data requirements of the instrument suite. A 100° West Longitude GEO orbit was specified, launching in 2014. The mission would have a two-year operating lifetime design (single string with selective redundancy) and consumables for a five-year lifetime goal to detect interannual variability. In addition to providing archived data for scientific research, the mission would also produce direct broadcast and near-real-time data with a dedicated ground station for operational applications, such as air quality forecasting. Propellant was specified for station keeping and maneuvering to parking orbit at the end of mission (~300 km above GEO altitude). An Atlas V 401 or Delta IV 4040-12 launch vehicle would accommodate the spacecraft and payload. No particular technology development needs were identified for the spacecraft bus and launch vehicle as over 20 GEO launches/year are performed worldwide. Spacecraft pointing requirements, ground system architecture, and mission operations were examined, and no “show-stoppers” were found. In addition to the space instrument segment of the mission, a vigorous program of calibration (pre-flight and on-orbit), validation, and supporting research and analysis is required for success. International cooperation is highly desirable.

Several open questions remain: Can the mission be made more affordable? We need to iterate science requirements versus instrument performance/size. Do the instruments have to fly together or can some of them be flown as hosted payloads on commercial communication satellites? Can other instrument concepts fulfill measurement requirements and what is the cost, benefit, and risk assessment? What is the priority and feasibility of boundary layer O_3 measurement? Community input, observing system simulation, and demonstration measurements from airborne platforms are recommended to answer these questions. Finally, the option to reposition the GEO longitude to view other parts of the Earth is conceivable, but further mission design study would be needed to determine drift rates, fuel load, and ground communication requirements.

To achieve the stated goal of a quantitative assessment of GEO-CAPE's readiness to proceed to Phase A, including a mission concept of operations, concerted instrument and mission engineering design studies will be needed. The science definition studies discussed above will lead to more precise mission and instrument requirements, which will be input to these design studies.

5. Synergies

5.1 Interdisciplinary Synergies within the GEO-CAPE Mission

The importance of knowing atmospheric composition for observing ocean color is what motivated the NRC to recommend combining two geostationary mission concepts into one, the GEO-CAPE mission. This is because over the ocean, reflectance from the atmosphere dominates the top-of-atmosphere signal in the UV-visible part of the spectrum and must be subtracted before the ocean color signal can be analyzed.

The process of estimating and removing the atmospheric signal, so-called "atmospheric correction," involves two components. The component due to scattering by gas molecules (or Rayleigh scattering) is estimated based on the path lengths involved (sun to surface to satellite), surface pressure, and absorbing gases in certain bands (e.g., O_3, NO_2). Scattering and absorption by aerosols presents a more challenging component to estimate. Aerosol scattering is addressed by assuming that the water is black (totally absorbing) in the near- and middle infrared bands. Thus, any signal detected in those bands is attributed to atmospheric scattering, and after subtracting the Rayleigh signal, what remains is the aerosol scattering component. With two or more bands in the NIR or MIR, the spectral slope (Ångström parameter) of the aerosol scattering function is estimated, and aerosol scattering is then extrapolated to shorter wavelengths. More recent techniques employ aerosol scattering models for different types of aerosols (marine, continental, etc.) and water vapor amounts. The presence of absorbing aerosols adds a complication that is not resolved as of yet in ocean color algorithms and is expected to be especially critical in coastal areas. Ideally, one should know the scattering and absorption properties of the aerosols present and their vertical profile.

Coastal aerosol mixtures are more complex than simple marine aerosols, and this has implications both for the radiant energy incident on the surface (i.e., photosynthetic available radiation for primary productivity) as well as the atmospheric correction algorithms. The capability of measuring aerosol absorption from space using near UV observations has been demonstrated by the TOMS and OMI sensors. Thus, extending the spectral coverage of an ocean color sensor to the near UV enhances the accuracy of retrieved parameters as the aerosol absorption effects can be accounted for in a more direct way.

Information about atmospheric constituents is also important for understanding variability in the coastal ocean. Air pollution carried offshore often contains nutrients, such as nitrogen, that are known to stimulate phytoplankton growth (figure 5). The GEO perspective will allow differentiation of such aeolian inputs from those resulting from upwelling, runoff, sewage, and other sources.

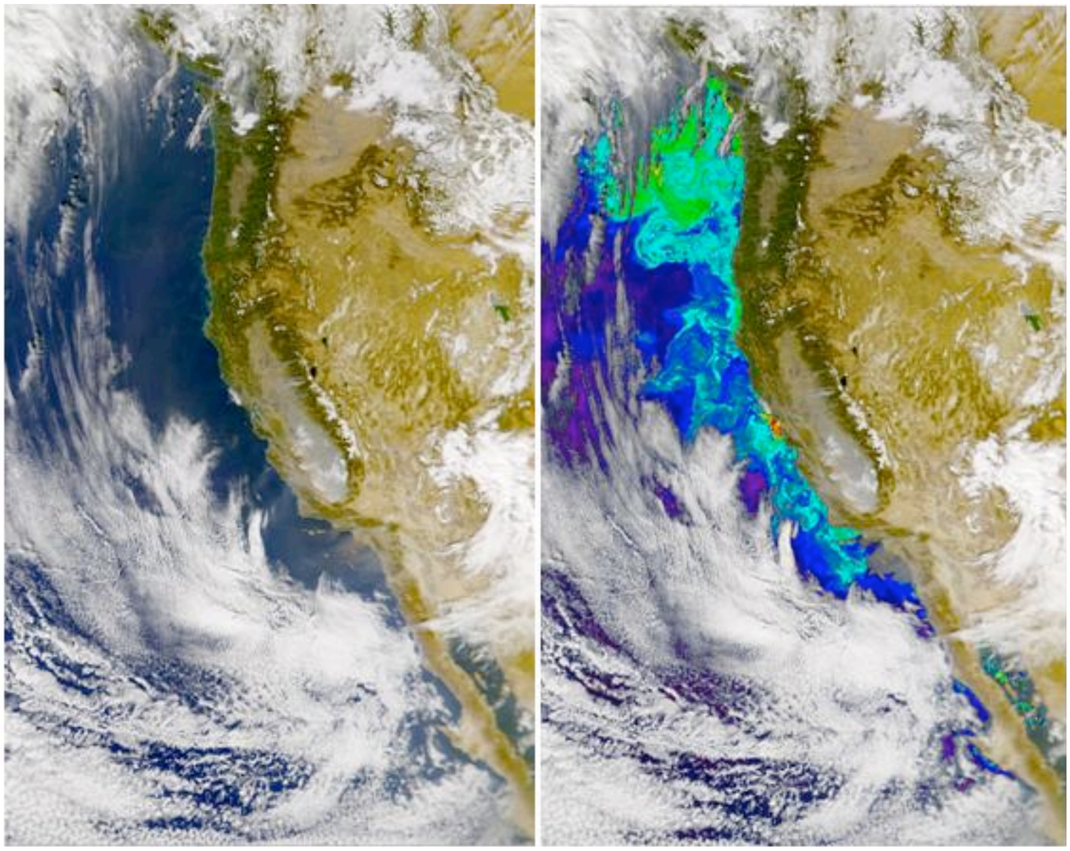

Figure 5. Strong seasonal Santa Ana winds off Southern California transport nutrient-laden dust and air pollutants from inland deserts into coastal zones as shown in this SeaWiFS image from 25 November 2002. These winds impact primary productivity (potentially through both chemical and physical forcing). A true-color composite is shown on the left and the derived chlorophyll on the right.

5.2 Synergies with Current and Future Earth-observing Missions

While the above considerations favor a platform in GEO for air quality and coastal purposes, continued global observational capability from LEO will be required and is complimentary, as well as being essential for observing intercontinental transport and providing boundary conditions for the GEO field of regard. In these cases, improved coverage is more important than high horizontal and/or temporal measurement resolution, especially over oceans where the surface is relatively uniform and trace gas distributions change on transport time-scales of several days. In such cases, daily observations should be sufficient. After delivery of emissions to the free troposphere through frontal lifting and convection, long-range transport often takes place in thin layers that retain their integrity over intercontinental scales. Continued limb observations from LEO provides the needed vertical resolution to characterize such layers in cloud-free regions, although limb measurements are typically limited to altitudes above 6-8 km and much of the intercontinental transport of pollution takes place at lower altitudes. To maintain the LEO observational capability, the NRC called for a low-earth orbit mission (Aerosol-Cloud-Ecosystems, ACE) in the 2013-2016 timeframe for global measurements of aerosols, clouds, and ocean color, and another satellite similar to Aura to be launched in the third tier timeframe (Global Atmospheric Composition Mission, GACM). Also planned for the second tier of missions is HyspIRI (Hyperspectral Infrared Imager) that complements GEO-CAPE with high spatial resolution global coverage.

5.3 GEO-CAPE International Participation and Contribution

- **GEO/GEOSS**

The Group on Earth Observations (GEO) coordinates an international effort to build a Global Earth Observation System of Systems (GEOSS). This emerging infrastructure will employ existing and future environmental global monitoring systems from ground, oceans, aircraft, and space. These systems will be interconnected through a growing array of capabilities for monitoring and forecasting changes in the global environment. This “system of systems” supports policymakers, resource managers, researchers, and decision-makers through a coherent system of data distribution facilities.

GEO is organized to address nine societal benefit areas (SBAs) with corresponding GEOSS themes: Disasters, Health, Energy, Climate, Water, Ecosystems, Agriculture, Biodiversity, and Weather. GEO-CAPE with its multi-spectral instruments, high spatial resolution, and unique ability for near continuous observations will make tangible contributions to at least the first eight of these SBAs and possibly even to Weather as described throughout this report. GEO-CAPE is committed to contributing to GEO by making its data interoperable with GEO standards and its data distribution system in addition to complying with its data-sharing principles:
http://www.earthobservations.org/geoss_dsp.shtml

To make significant advances in local-scale atmospheric composition studies and to aid AQ characterization for assessments, forecasting, and regulation to support air program management and public health advisories, a scientific and observing framework will be required that is analogous to that currently used for weather forecasting. As part of GEOSS, a similar capability for AQ constituents will be required for AQ characterization and “chemical weather” forecasting. The Boulder Air Quality Remote Sensing From Space workshop in February 2006 (Edwards, 2006) identified four principal areas in which satellite observations are crucial for future AQ basic research and operational needs: (1) AQ characterization for retrospective assessments, air program management and forecasting to support public health advisories; (2) quantification of emissions of ozone and aerosol precursors; (3) long-range transport of pollutants extending from regional to global scales; and (4) large puff releases from environmental disasters.

A major contribution to the GEOSS will be the U.S. Integrated Ocean Observing System (IOOS) as part of the Global Ocean Observing System. Planning for IOOS has been underway for at least a decade. In 1998, the National Ocean Research Leadership Council was requested by Congress to provide a plan "to achieve a truly integrated ocean observing system." Subsequent studies led to the establishment in 2000 of the interagency planning office known as Ocean.US "to develop a national capability for integrating and sustaining ocean observations and predictions." The establishment of an integrated ocean observing system received further impetus by recommendations of the Pew Oceans Commission in 2003 and the U.S. Commission on Ocean Policy in 2004. In response to these recommendations, the President's Ocean Action Plan called for the implementation of the IOOS and charged the newly formed Joint Subcommittee on Ocean Science and Technology to develop a "strategy for integration and possible convergence of existing and future requisite coastal observing systems of the IOOS."

Creation of GEOSS as a system of systems requires integration not only across observing systems but also across the research enterprise that will both formulate the needs for these measurements and use them to advance understanding and prediction. While the value of an integrated Earth observing system is unquestionable, the fundamental pragmatic challenge is to bring into being the "system of systems" that produces needed measurement and prediction services. As in building any complex system, there is one well-recognized successful strategy: (a) build component subsystems that can be assembled into larger systems, while (b) ensuring that efforts are directed at the end objective, and not on individual elements as ends in themselves. GEO-CAPE as well as other satellite missions will be components of GEOSS.

- **CEOS**

The Committee for Earth Observing Satellites (CEOS) encompasses the world's government agencies responsible for civil Earth Observation (EO) satellite programs, along with agencies that receive and process data acquired remotely from space http://www.ceos.org/. CEOS is committed to providing the space component of GEOSS as described above by means of its space assets and data distribution systems. Participating agencies strive to address critical scientific and operational questions and to plan satellite missions in a coordinated way to add value to data over the data being used separately. In order to achieve this goal and identify emerging data gaps, CEOS has established the concept of Virtual Constellations for GEO, whereby a number of satellite instruments and their observations, when coordinated and combined, will result in enhanced data applicable for science and applications. CEOS has established six constellations covering the land, precipitation, oceans, and the atmosphere.

The constellations most relevant to GEO-CAPE are the Atmospheric Composition (ACC) and the Ocean Color Radiometry (OCR-VC) Virtual Constellations (*websites available soon*). The ACC objective is to collect and deliver data to improve predictive capabilities for coupled changes in the Ozone Layer, Air Quality, and Climate Forcing associated with changes in the environment. ACC is conducting four pilot projects which demonstrate synergy by using data from multiple platforms which will provide added value to science and application users. The OCR-VC will provide calibrated ocean-color radiances (OCR) at key wavelength bands. Ocean color radiance is the wavelength-dependent solar energy reflected by the sea surface. These water-leaving radiances contain latent information on the optical constituents of the sea water, in particular the pigments (primarily chlorophyll-a) contained in the phytoplankton. The OCR-VC will collect, re-process and merge data from multiple US and international satellites for a consistent, calibrated time series required for multiple ocean color products.

Both constellations will make use of existing satellites as well as those planned by the international community. A data base describing these missions can be found at: http://database.eohandbook.com/ GEO-CAPE will be highly complementary to any of those missions measuring ocean color and atmosphere composition and are discussed below.

- **International Partners**

A review of existing and planned missions shows the following complementary opportunities, in both GEO and LEO orbits that may occur in the GEO-CAPE timeframe. A representative from Eumetsat attended the Workshop and described the up-coming Sentinel 4 and 5 missions, which are described below.

The European Union (EU) will be launching their Sentinel 4 mission on a Eumetsat platform (MTG) in a GEO located over 0 degrees longitude in the 2017 timeframe. Present plans show a suite of UV, VIS and IR sounders similar to those proposed for GEO-CAPE except they will not have the sub-km spatial resolution needed for coastal ocean color. China will launch their FY4 mission located over -105 degrees longitude where the O series may carry trace gas measurements in the 2020 timeframe. GEO-CAPE, combined with these two missions, could potentially observe nearly the entire globe and monitor long range transport of plumes in less than hourly intervals. GEO missions measuring atmosphere composition and ocean color will also be highly complementary with LEO missions carrying similar instruments. The Sentinel 5 mission in LEO planned by the EU in the 2022 time frame will likely fly in a morning orbit carrying UV, VIS, and IR instruments for atmospheric composition much like Sentinel 4 and GEO-CAPE. The NASA GACM, in LEO, will be much like Sentinel-5 and should be launched into an afternoon orbit. In addition to being complementary these two missions would provide excellent cross calibration and validation.

For Ocean Color the EU will be launching the Sentinel 3 series in LEO starting in about 2012 with VIS and thermal IR sensors. Three missions will be launched in 2 year intervals into morning orbits which will minimize sea glint and cloud cover. JAXA is planning a Global Change Observation Mission (GCOM) series of three satellites starting in 2014. GCOM-C will carry the second generation Global Imager (SGLI) which will have a 250 m spatial resolution (500 m for thermal infrared) and polarization/along-track slant view channels (red and near-infrared), which will improve coastal ocean, land, and aerosol observations.

The first geostationary ocean color sensor will be the Korean Geostationary Ocean Color Imager (GOCI) to be launched on the Communication Ocean and Meteorological Satellite (COMS) in late 2009. GOCI is a filter wheel design imager with eight ocean color channels similar to the MODIS ocean channel set and a high SNR suitable for ocean imaging. It will sample the area around Korea at 300 m horizontal resolution. GOCI will be an excellent first test to evaluate the feasibility and utility of ocean color imaging from GEO.

For both atmospheric composition and ocean color, these missions will afford many opportunities for collaboration across international space agencies and the science and applications communities. These would include pre-launch calibrations, post launch validation, algorithm development, and data distribution. This collaboration will result in unprecedented data sets for climate and environmental research as well as application for societal benefits.

6. Societal Benefits of GEO-CAPE

The use of Earth science data for applications will first require gaining an understanding how research-level data can be used for public decision making (NRC, 2007). Extracting societal benefit from space-borne measurements necessitates, as an equally important second step, the development of a strong link between the measurements and decision makers who will use such measurements. Applications development places new responsibilities on research agencies to balance applications demands with scientific priorities and the character of missions may change in significant ways if societal needs are given equal priority with scientific needs. As this new paradigm evolves, the numbers of published papers, scientific citation indices, and professional acclamation from scientific peers, will not be enough to evaluate the success of the missions that have been recommended. The degree to which human welfare has been improved and the effectiveness of protecting property and saving lives will become equally important criteria for a successful Earth science and observations program.

6.1 Societal benefits – Air Quality perspective

Observations in the broadest sense are used to characterize and explain current and changing environmental states and provide a basis for:

1. Associating human health and environmental welfare effects with air quality, which is the basis for developing U.S. National Ambient Air Quality Standards
2. Determining an area’s compliance with standards
3. Developing emission reduction strategies by supporting source apportionment studies, air quality model evaluation and assessment
4. Assessing progress in response to implemented emission strategies
5. Forecasting air quality to inform public of adverse air pollution exposures

6. Elucidating atmospheric processes to improve air quality modeling systems

The following emerging challenges in air quality management are influenced by an assortment of factors requiring a more comprehensive and well integrated assessment basis:

- ***Multiple pollutants*** – commonality and co-dependencies of sources, fate and transformation processes and effects shared by several air quality species, particularly the air quality criteria pollutants
- ***Multiple media*** – direct and reciprocal influences across atmosphere, terrestrial and aquatic systems (e.g., atmospheric deposition of excess acids, nutrients, persistent bioaccumulative and toxic chemicals (PBTs); re-emission of deposited mercury and persistent organic compounds (POPs), meteorological and air chemistry influences on biogenic emissions).
- ***Multiple spatial scales*** – increasing contribution of continental scale transport to regional and urban air quality; heightened concern of complex chemistry and transport near source/roadway environments
- ***Climate-air quality*** - accounting for the bi-directional impacts between air quality and climate change. The air quality impacts being induced by both chemical and physical processes modified by climate change as well as climate mitigation strategies focused primarily on climate forcing gases that modify other air quality emissions.

Threaded throughout these emerging challenges is the basic role of observations in accountability analyses that attempt to assess progress of air quality management policies and regulations. Observation strategies should enable detection of atmospheric chemistry changes brought about by new technologies and new fuels driven by policies and regulations addressing air quality or climate improvements.

These emerging air quality issues will benefit from a geosynchronous satellite air quality mission. In a very broad sense, enhanced spatial and temporal air quality characterizations benefit all of the general needs listed above for the air quality research and management community – the inference here that greater temporal (and spatial) resolution from geostationary orbits is intuitively beneficial. While true, the real payoff from a geosynchronous mission will be the added insight into atmospheric processes where formative events are masked or simply missed with limited time slices provided by polar orbiting platforms. Given the variety and importance of linkages across pollutants, time and space regimes and surface – atmospheric systems, there is a basic need for constant improvement in parameterizing the physical and chemical processes underlying pollutant production, transformation, fate and removal.

The complexity and diversity of air quality issues requires complementary use of deterministic models and observations. The model-observation system interface ranges from using observations as a model evaluation tool, to various levels of assimilation ranging from inverse construction of emissions inputs, post processing operations to improve spatial/temporal concentration patterns (model-observation fusion) to more dynamic assimilation of observations used in meteorological modeling. The major contribution of GEOCAPE will reside in improvements to the model evaluation process that benefits from both the added constraints in time and total atmospheric column loadings, which leads to improved model input fields (e.g., inverse emission inputs) and atmospheric process parameterizations.

6.2 Societal benefits – Coastal ecosystems perspective

Coastal ecosystems are one of the most important ecosystems on the planet for a multitude of reasons. Humans exploit the high productivity of the coastal ocean; over half of the global fish harvest is from coastal waters, and in many countries, fish are the main source of animal protein. It is no mystery, therefore, that countries such as Japan, Korea, India, and China have considered ocean color remote sensing as a high priority.

In the U.S., NOAA's National Marine Fisheries Service (NMFS) is charged with regulating fisheries. To date, they have regulated fisheries on a species by species basis, basically looking at the catch statistics and health of particular species. However, NMFS has now been charged with moving to "ecosystem-based management" of fisheries. To this end, NMFS managers are being trained in the use of satellite data as one tool for understanding coastal ecosystems and predicting the health of fish populations.

Another group in NOAA is using ocean color remote sensing data to assess the distribution and extent of Harmful Algal Blooms (HABs). They are providing data to managers who confirm the nature of the bloom with *in situ* measurements and then take appropriate management actions including closing shellfish beds to harvesting and closing beaches. Others are assessing the dynamics of river plumes, evaluating water clarity, impacts of changes in discharge, sediment, nutrient and carbon input/delivery to the coastal waters with a changing landscape and land-use, as well as a host of other applications. All of these applications would benefit greatly by more frequent data at higher resolution such as that available from GEO-CAPE.

Other societal benefits include the ability to track oil spills and pollutants entering the ocean, to observe the effects of storms on coastal flooding and shoreline erosion, and in general, to monitor natural and anthropogenic forces acting at the land-ocean interface. "Climate change combined with continuing growth of populations in coastal areas creates an imperative to monitor changes in the coastal ocean." (NRC, 2007). Observations provided by the GEO-CAPE mission will allow the development of capabilities for modeling ecological and biogeochemical processes.

7. Recommendations for Near-Term Studies

7.1 Generation of datasets for analysis

a. Develop a regional-scale synthetic dataset that can be used by the community to develop Observing System Simulation Experiments (OSSEs) specifically for evaluating what can be measured from geostationary orbit using measurement capabilities from existing LEO instruments as well as new instruments that are currently in development stage.
b. Conduct a study to statistically characterize spatial and temporal variability of the targeted atmospheric constituents over relevant ranges of scales to quantify observing requirements.
c. Use coastal ecosystem models to demonstrate how a geostationary sensor can contribute to understanding coastal ocean biology and biogeochemistry. Demonstrate how sub-diurnal (hourly) data can be used to quantify rates of biological and physical processes, and how high temporal resolution is needed to understand and predict longer-term variability and change.
d. Pursue the development of GEO-CAPE airborne satellite-simulator instruments in a stepwise approach with the objective of performing a science demonstration using airborne data for algorithm testing and refinement, uncertainty analysis, and model comparisons. Specifically, a CO instrument should fly with UV/Vis if possible and similarly for other candidate instruments when available.
e. Conduct coordinated ship and aircraft campaigns to refine the mission science questions and establish measurement, mission, and instrument requirements for the coastal ocean science. These campaigns should acquire data at high temporal, spatial and spectral resolution to characterize the variability observed from GEO, and to determine the necessary time-space sampling scales to capture the variability of coastal ocean physical, biological and geochemical processes.

7. 2 Measurement strategies and algorithm development

a. Conduct a study to determine how well PBL O_3 might be measured from space and the sensitivity of the surface ozone concentration to the concentrations at different altitudes. Investigate a wide range of combinations of bands (e.g., UV/Vis with 9.6 μm, and other IR bands) to see which methods provide the best sensitivity to O_3 in the lowermost troposphere.
b. Determine the instrument parameters in the various spectral regions that will be necessary to measure atmospheric constituents with enough accuracy to be useful for scientific studies. Results from this analysis will lead to viable trade studies that can be conducted once the mission objectives are defined.
c. Evaluate the utility of hyperspectral versus multi-spectral radiometric measurements and the spectral resolution required to derive measurements of interest for coastal ocean science.
d. Develop improved atmospheric correction algorithms for ocean color based on the improved temporal and spatial resolution data from GEO along with expanded spectral coverage in the UV, MIR and SWIR. Investigate the advantage of

resolving the synoptic movement of air masses on and off shore towards improved atmospheric correction algorithms.

e. Connect ongoing ocean color retrieval development with framework used in atmospheric retrieval – stretch goal of retrieving ocean and atmosphere jointly if it is warranted.
f. Use imagery from the Korean Geostationary Ocean Color Imager (GOCI), when it becomes available in late 2009, to assess the feasibility and utility of ocean color imaging from GEO. Analysis should include direct comparisons with MODIS and MERIS data to assess radiometric accuracy, pointing stability, and other considerations. Analysis should also focus on evaluating the advantages of high frequency sampling from GEO.

7.3 Observing strategy

a. Determine the advantages and disadvantages of developing an observing strategy that continually "stares" at large portions of the planet versus a capability that observes only a portion of the hemisphere at one particular time and then focuses on another region at a different time.
b. Determine observing requirements for identification of sources including lightning, transport resulting from stratosphere-troposphere exchange and processes such as wet removal of aerosols and other trace constituents
c. Investigate strategies for deciding where high-frequency (hourly) observations of the coastal ocean can be made. One strategy is to use the synoptic weather maps derived from GOES to locate the areas that are cloud free and then sample continuously throughout the day. Simulations can be conducted and different strategies evaluated using existing GOES data. Demonstrate how the GEO perspective enables more observations because clouds move throughout the day.

7.4 Mission Requirements

a. Determine measurement sensitivity requirements for NO_2, HCHO, SO_2, CO, and CHOCHO to quantify sources.
b. Conduct initial inverse modeling studies to see how accurately emissions can be determined and what the minimum source strength of emissions is to be detectable.
c. Determine what atmosphere-coastal ocean synergistic science is possible with the event imaging, high-resolution instrument and what are the measurement requirements?

7.5 Access to space

a. Conduct accommodation studies for planned GOES platforms.
b. Pursue the hosted-payload concept aboard communication satellites to see if a more affordable method for getting an instrument payload into geosynchronous orbit can be achieved.

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Appendix A.

GEO-CAPE Workshop
University of North Carolina -Chapel Hill
18 -20 August 2008

DAY 1, Morning

08:00-08:30	Registration		
08:30-08:40	Welcome	Ken Jucks/Paula Bontempi	NASA HQ
08:40-08:50	Mission Directive	Steve Volz	NASA HQ
08:50-09:20	Atmospheric Composition from the Geo Perspective	Jack Fishman	NASA LaRC
09:20-09:50	Ocean Biogeochemistry from the Geo Perspective	Francisco Chavez	MBARI
09:50-10:50	Break		
	What's in the Decadal Survey?		
10:20-10:50	Air Quality/Atmospheric Composition	Daniel Jacob	Harvard
10:50-11:20	Ocean Biology/Biogeochemistry	Janet Campbell	UNH
11:20-11:40	Application perspective from EPA	Pai-Yei Whung	EPA
11:40-12:00	Application perspective from NASA	Lawrence Friedl	NASA HQ
12:00-13:15	Lunch Break		

Day 1, Afternoon

13:15-13:30 Change to breakout groups, outline of breakout activity, grouping, objectives Kawa/Fishman/Campbell

13:30-15:30 **Breakout session I (by discipline)**
Articulate mission science questions and science objectives for each discipline.
Define observations/measurements (i.e., what needs to be measured) for those objectives
Begin to define measurement requirements for observations needed
Begin to outline potential synergies between different disciplines.
Open question

15:30-16:00 **Break**

16:00-17:30 **Plenary joint session: report of breakout session I and discussion**
Begin to identify interlocking and interdependent mission objectives and requirements

Early Evening: **Poster and side discussions**

<u>Day 2, Morning</u>

Synergies: Decadal Survey Missions, International Linkages/Partnerships, Cross-Disciplinary

08:30-09:30	**Presentations on ESA Sentinel Series and others**		
	Sentinel 3 – Ocean Observations	Samantha Lavender	ARGANS Ltd./Univ. Of Plymouth
	Sentinels 4&5, Geosynchronous Air Quality Observations & LEO observations	Rose Munro	Eumetsat
	Experience from SCIAMACHY and proposed GEOSCIA	Heinrich Bovensmann	Bremen
09:30-10:00	**Synergies with the related DS missions**		
	ACE	Schoeberl/McClain	GSFC
	GACM	Nathaniel Livesey	JPL
10:00-10:30	**Break**		
10:30-11:30	**Overarching talks on perspective from applications perspective**		
	EPA Air Quality perspective	Rob Pinder	EPA
	NOAA Air Quality perspective	Mitch Goldberg	NOAA
	NOAA Ocean perspective	Paul DiGiacomo	NOAA/NESDIS
11:30-12:00	**Reviews of previous NASA mission architecture studies**	Randy Kawa	GSFC
12:00-13:15	**Lunch**		

<u>Day 2, Afternoon</u>

13:15-13:45	**Retrievals and Synergies** <u>Overview talks by David Edwards (atmospheric) and Chuck McClain (ocean)</u>		
13:45-16:30	**Potential measurements options for this mission (15 minute talks)** What is measurable by what remote sensing techniques?		
	a) Boundary layer O3 measurements in the UV/Vis	PK Bhartia	GSFC
	b) O3 measurements in thermal IR (e.g., TES, AIRS)	Annmarie Eldering	JPL
	c) NO2 and CH2O measurements in the UV/Vis	Kelly Chance	SAO
	d) CO measurements in NIR and emission bands	David Edwards	NCAR
	e) Aerosol measurements (UV, vis, NIR)	Omar Torres	Hampton
	Break		
	f) Ocean biological properties	Ru Morrison	UNH
	g) Ocean biochemical properties	Carlos Del Castillo	APL
	h) atm correction, ocean color	Zia Ahmed	GSFC
	i) land sea surface	Joe Salisbury	UNH
16:30-17:30	**Discussion Session II (cross-discipline): Retrievals and Synergies** Goal: redefine disciplinary Observations and Measurement Requirements and determine Mission Requirements (e.g. spatial coverage, frequency). Goal: Ocean/Atm synergy discussion: Regional aerosols, NOx, ozone and the possible aerial transport of nutrients to the coastal ocean are some topics of interest.		

<u>Early Evening:</u> **Posters and side discussions**

Day 3, Morning

08:30-10:30	**Discussion III: Summary and Next Steps** Instrument requirements Traceability matrix Prioritizing future studies, both modeling and technology Technology gaps	Session will open with recap of days 1 and 2
10:30-11:15	**Break**	
11:15-11:45	Outline presentations of recap of Discussion II and start of workshop report	
11:45-12:00	Closing by Ken and Paula	

Appendix B: List of Participants

Ahmad	Ziauddin	Science and Data Systems, Inc.
Ahn	Myung-Hwan	George Washington University
Al-Saadi	Jassim A.	NASA Langley Research Center
Arellano	Avelino	National Center for Atmospheric Research
Arunachalam	Sarav	University of North Carolina, Chapel Hill
Baize	Rosemary R.	NASA Langley Research Center
Baldauf	Richard	Environmental Protection Agency
Beer	Reinhard	Jet Propulsion Laboratory
Benjey	William G.	Environmental Protection Agency
Bhartia	Pawan K.	NASA Goddard Space Flight Center
Bhave	Prakash	Environmental Protection Agency
Bontempi	Paula S.	NASA Headquarters
Bovensmann	Heinrich	University of Bremen
Byun	Daewon	University of Houston
Cageao	Richard P.	NASA Langley Research Center
Campbell	Janet W.	University of New Hampshire
Case	Kelley E.	Jet Propulsion Laboratory
Chance	Kelly V.	Harvard-Smithsonian Center for Astrophysics
Chatfield	Robert B.	NASA Ames Research Center
Chavez	Francisco P.	Monterey Bay Aquarium Research Institute
Chin	Mian	NASA Goddard Space Flight Center
Ching	Jason	Environmental Protection Agency
Cohen	Ronald C.	University of California, Berkeley
Considine	David B.	NASA Headquarters
Crawford	James H.	NASA Langley Research Center
Davis	Curtiss O.	Oregon State University
Davis	E. Ann	National Institute of Environmental Health Sciences
Del Castillo	Carlos E.	The Johns Hopkins University/APL
DiGiacomo	Paul M.	NOAA Science Center
Dobber	Marcel	Royal Netherlands Meteorological Institute
Doddridge	Bruce G.	NASA Langley Research Center
Duncan	Bryan N.	UMBC GEST
Edwards	David P.	National Center for Atmospheric Research
Eldering	Annmarie	Jet Propulsion Laboratory
Falke	Stefan R.	Washington University in St. Louis/Northrop Grumman
Fishman	Jack	NASA Langley Research Center
Friedl	Lawrence A.	NASA Headquarters
Gao	Yuan	Rutgers University
Gazarik	Michael J.	NASA Langley Research Center
Gleason	James F.	NASA Goddard Space Flight Center
Gordley	Larry L.	GATS, Inc.
Hanna	Adel F.	University of North Carolina, Chapel Hill
Heikes	Brian G.	University of Rhode Island
Hilsenrath	Ernest	NASA Headquarters/University of Maryland
Jacob	Daniel J.	Harvard University
Johnson	Mary M.	Environmental Protection Agency
Joiner	Joanna J.	NASA Goddard Space Flight Center

Jucks	Kenneth W.	NASA Headquarters/SAO
Kawa	Stephan R.	NASA Goddard Space Flight Center
Keith	Kim	Science Systems and Applications, Inc.
Key	Richard	Jet Propulsion Laboratory
Keyes	Jennifer P.	NASA Langley Research Center
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Kim	Jhoon	Yonsei University
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Appendix C – Draft Traceability Matrix

Science Questions	Mission Objectives	Measurement Requirements	Mission Requirements	Instrument Requirements	Mission Concept
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 America and distinguish natural and anthropogenic contributions.	O_3, NO_2, HCHO, CO partial columns; O_3 and CO with sensitivity in the planetary boundary layer (PBL); aerosol optical depth	Coverage of North and South America and adjacent ocean at spatial scales of 10 km or better. Simultaneous constituent measurements Hourly or more frequent daytime coverage; nighttime sampling for CO	High-precision radiometer/spectrometer with sufficient SNR. 0.5 nm spectral resolution in the UV-VIS-NIR Thermal IR radiometer for CO and O_3 measurements (is this redundant with first requirement?)	Instruments in geostationary orbit continuously observe populous N & S America coast-to-coast; and upwind and downwind of continent. UV/Visible spectrometer measures O_3, NO_2, HCHO, SO_2, and aerosol column density; plus CO, O_3 detectors for BL and free troposphere
How do the distribu-tions of pollutants and particulates evolve throughout the course of the day and what are the chemi-cal, transport, mixing, and deposition mechanisms that determine these distributions?	Measure the diurnal evolution of atmospheric constituents as they are transformed and transported throughout the day over the continent and the surrounding ocean				
What processes affect and control the biology and biogeochemistry of aquatic coastal zones, and how are they modulated by natural and anthropogenic forcing?	Characterize variability in primary productivity, phytoplankton biomass, and carbon pools in the coastal ocean in conjunction with measurements of natural and anthropogenic forcing.	Multi-spectral UV-VIS water leaving radiances; column O_3, NO_2 and other absorbing trace gases and NIR-SWIR radiances for atmospheric corrections.	Observe dynamic coastal regions during cloud-free viewing opportunities. Measure variability at hourly temporal resolution and spatial scales of ~ 250-500m. Monitor instrument stability and adjust calibration with solar, lunar, and surface observations.	High-precision radiometer with SNR>1000:1 (340-1000nm) ~1 nm resolution in the UV-VIS-NIR; SWIR bands: 1240, 1640 and 2130 nm for atmos. corrections Radiometric stability of <0.1% band-to-band, polarization of <1% below 700nm;	Advanced ocean color remote sensing from geostationary orbit provides the temporal resolution needed to resolve variability in biology and biogeochemistry driven by multiple processes in coastal ocean (tides, winds, upwellings, and input from rivers and atmosphere).

Science Questions	Mission Objectives	Measurement Requirements	Mission Requirements	Instrument Requirements	Mission Concept
How do weather, and the episodic releases from fires, dust storms, 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 weather events, and episodic input.	All of above atmospheric and oceanic measurements	Continuous daytime coverage; ability to focus on regions affected by episodic weather events or input from fires or volcanoes.	Same as above plus the ability to point or stare at focus areas of interest for extended periods of time.	Atmosphere and ocean observations from geostationary orbit provide the temporal resolution needed to capture responses to storms and other episodic events.