# The Role of Emerging Technologies in Imagery for Disaster Monitoring and Disaster Relief Assistance

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**Abstract:** Emerging technologies enable new concepts in low-cost Earth observing constellations. In this paper we posit an architecture that addresses a largely unmet need for real-time disaster monitoring and disaster relief assistance. A satellite based system capable of being controlled from, and downlinking data to, a relatively primitive ground site would be invaluable for focusing disaster relief efforts. In this concept, real-time continuous high resolution imagery from a system capable of selecting wavelength bands for specific needs would be implemented. The system is comprised of elements at geosynchronous and L1 altitudes. From geosynchronous altitude, focused high-value imagery is provided by steerable cameras with a 250 m resolution. At L1, full disk imagery provides context for mesoscale high resolution imagery.

**Zusammenfassung:** *Fernerkundungstechnologien für den Katastrophenschutz*. Neue vielversprechende Technologien ermöglichen neue Konzepte für Erderkundungs-Konstellationen im Niedrigkostenbereich. In diesem Beitrag stellen wir eine Architektur vor, die auf das bislang nicht erreichte Ziel einer Realzeitüberwachung von Katastrophen und auf die Unterstützung bei deren Eindämmung abzielt. Ein satellitengestütztes System, das in der Lage ist, von einer relativ einfachen Bodenstation aus kontrolliert zu werden und über diese den Datentransfer zu realisieren, wäre für den gezielten Einsatz von Gegenmaßnahmen im Katastrophenfall von unschätzbarem Wert. Mit diesem Konzept würden kontinuierlich hochauflösende Echtzeit-Bildaufnahmen mit einem System realisiert, mit dem die Wellenlängen entsprechend den spezifischen Anforderungen ausgewählt werden können. Das System besteht aus Elementen in erdsynchroner und L1-Höhe. Aus erdsynchroner Höhe werden punktuell hochwertige Bilder durch eine steuerbare Kamera mit einer Auflösung von 250 m geliefert. Aus der vollflächigen Erdabbildung aus L1-Höhe wird der Kontext für mittlere Auflösungen gewonnen.

## 1 Introduction

The **G**lobal **O**bservations and **A**lerts from **L**1 and **G**eosynchronous **O**rbit (GOAL&GO) concept is proposed as an example of what will soon be practical through the use of new technologies under development for spaceflight implementation. The architecture we discuss here will provide real-time weather and disaster monitoring information directly to users.

The GOAL&GO measurement concept provides for continuous mapping (5 km × 5 km) of ozone, aerosols, and clouds from L1 (VISHNU) while the entire Earth is accessible for surveillance for disaster monitoring and land-use assessment by an IR/Visible sensor (SHIVA) with 250 m × 250 m resolution from geosynchronous orbit. The complete constellation would consist of the VISHNU instrument at L1 and three (or more) SHIVA instruments in geosynchronous orbit. The instrument packages would be designed to produce as little impact as possible upon the spacecraft that provides systems support, thus enabling accommodation of GOAL&GO on existing platforms.

The **S**upporting **H**igh-resolution **IR V**isible **A**pplications (SHIVA) instrument is a narrow field of view (1.5°) system with a

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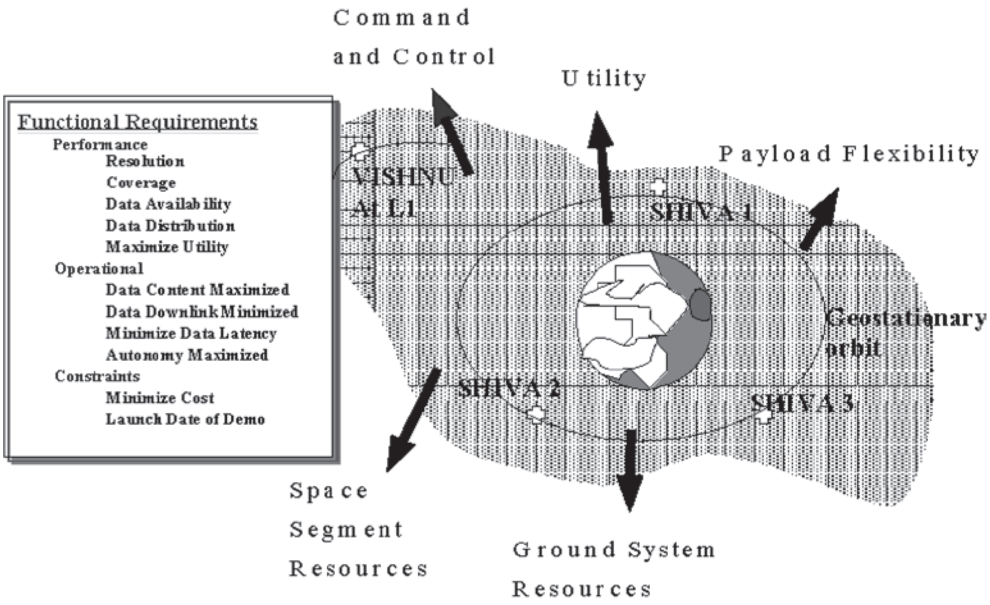


**Fig. 1:** Mission Concept. GOAL&GO applies new technologies to the functional requirements of a basic research mission with demonstrable utility to the public. GOAL&GO incorporates appropriate new technology in a system design that maximizes the return from a high data volume imaging mission while minimizing costs. The design areas are indicated in the figure as those drivers lying outside the GOAL&GO constellation. The SHIVA and VISHNU sensors share many of the same system and design elements.

large field of regard (20°) within which SHIVA obtains Earth imagery at 250 m resolution, day and night, for hazard and disaster monitoring and warning, and basic science measurements. New technologies for precisely pointing an optical system over large angular excursions make this system possible. Three SHIVA sensors could image most of the Earth from geostationary orbit: continuously observing a particular region anywhere in the world, patrolling a region, or exploring the connection between the small scale behavior of the atmosphere and biosphere (250 m pixels) to that of the global system as imaged by VISHNU. Because SHIVA is pointable and has relatively high spatial resolution for a science mission, it can be operated as a virtual companion to other Earth observing missions when they are within its field of regard. This can greatly enhance the science or commercial data return.

At L1, the **V**isible/IR/UV **I**maging **Sy**stem **H**ardware for **N**ew **U**ses (VISHNU) is a compact multispectral imager which will deliver, through the use of imbedded image compression software, full disk sun-illuminated imagery of the Earth in real-time at selected wavelengths designed to map ozone, clouds, and aerosols. VISHNU has significantly enhanced capabilities beyond the planned TRIANA mission, will be ready to be online at the end of the TRIANA mission life and provide enhanced, lower cost services with greater science content.

## 2 Overview of the Mission Concept

The GOAL&GO mission consists of two kinds of imagers. The L1 component (VISHNU) is directed toward addressing current open scientific questions and providing large-scale contextual measurements whereas the geostationary components

(SHIVA) perform two functions: (1) focused investigations of regional problems and (2) hazard assessment and information dissemination.

Our design study shows that a Cassegrain telescope meets the requirements of small field-of-view (FOV), wide spectral range, and long focal length. The 0.5° FOV is imaged on a 4096 × 4096 CCD (14 micron pixel size). For an f/10 system this gives an aperture of 64 cm. With the small FOV, image quality will be acceptable without the use of additional image flattening optics. The optical path allows for the introduction of a beam splitter which feeds two cameras. One uses an LCTF for band selection (a separate path and mechanism may be required if the wavelength coverage of the filter system needs to be handled by two LCTF) while the second uses a conventional filter assembly with narrow band-pass filters (temperature controlled) optimized for specific tasks. The optical paths are arranged so as to place the detector assemblies for optimal coupling to the cold plate. This all-reflection design can be used by SHIVA, too.

The SHIVA instrument flies on a platform in geostationary orbit and images an area of about 1000 km × 1000 km at 250 m pixel size. For SHIVA we add a cooled InSb array behind a filter wheel. This second camera is used to detect and map high altitude cirrus clouds, fires, and burn scars. The SHIVA instrument will implement high-displacement piezoelectric actuators to point the imager's FOV, as commanded, anywhere on the Earth's disk (or slightly off for characterization). We anticipate the need to move the entire telescope rather than just the mirror in order to improve off-axis rejection performance; this requires us to keep the telescope's acceptance angle at 1.5°. SHIVA uses a dedicated telemetry dowlink antenna that can be pointed. This system, nominally operating at S band (1 Mbps at 2.2 GHz with a transmitter power of 20 W), would have a 1000 km coverage diameter for a 0.5 meter ground station antenna diameter. The receiver could, then, be either inside or outside of the SHIVA FOV and would be designed to be transportable. During disaster support operations the transmitter could be directed to cover the imaged area for disaster recovery or assessment efforts or a site outside the affected area which was still able to receive the SHIVA telemetry. SHIVA enable a hazard "pager" utility for use by people in remote locations.

## 3 Measurement Requirements

GOAL&GO uses a LCTF for band selection to obtain space and time resolved spectral images of atmospheric pollution and tracers (e. g. ozone, aerosols, sulfate pollution, volcanic ash, and SO2), water vapor, vegetation, surface albedo, and ocean color. These measurements do not require either high spectral resolution (the 5 nm achievable with current LCTF technology is adequate) or contiguous wavelength coverage (i. e. spectra). Some measurements do require higher spectral resolution (or detectors sensitive to longer wavelengths) and those, consistent with the GOAL&GO vision, are accommodated in a second camera on VISHNU (or SHIVA), respectively. The science is mature as are the algorithms for the production of data products and/or onboard feature extraction.

VISHNU and SHIVA are complementary aspects of an investigation of the global biogeochemical cycle. In the list that follows, VISHNU provides the global context for the smaller scale observations of SHIVA and can be used to determine where to point SHIVA. Existing algorithms, developed for the TOMS and AVHRR flight programs as well as the MODIS development program, provide the means to confidently make the step from a measurement to a useable product. The majority of these algorithms are quite simple. SHIVA's 1000 km × 1000 km sample size provides super-regional data at extraordinary spatial and temporal resolution. The ability to point accurately means that SHIVA's FOV can "fly along" with other platforms as they make an underflight. (Note that the slew rates are very modest – about 0.2°/minute peak rate!). For the complete GOAL&GO system, SHIVA could be cued using VISHNU data.

SHIVA's second camera is optimized for fire detection. Wildfires are an important hazard: SHIVA will provide direct broadcast of the location and extent of these fires in real-time. SHIVA will enable the "tactical" use of real-time satellite remote sensing data by local emergency personnel. SHIVA will improve our understanding of the intensity and location of wildfires and our ability to model their development and assess the risk of occurrence by coupling observations of the fires to local cloud cover, land use, land cover (NDVI), soil moisture and rainfall history.

SHIVA will document trends in landcover, biodiversity, and global primary production by monitoring biomass burning. Agricultural burn-off alters land cover and the rate of evaporation and run-off. CO, $CH_4$, NMHCs, and NO are produced by biomass burning and lead to the photochemical production of ozone in the troposphere. $CH_3Cl$, and $CH_3Br$ are produced during biomass burning and thus lead to the addition of free radicals in the stratosphere that lead to the catalytic destruction of ozone. Burning alters the biogeochemical cycling of NO, $N_2O$, $CO_2$, CO, and $CH_4$ from the soil to the atmosphere. We do not have a full description of the extent of biomass burning and both MODIS and AVHRR have too low a spatial resolution ($1000\,m \times 1000\,m$) and too low a saturation temperature (500 K and 320 K) to be able to accurately map the extent of small cool fires or large hot ones. Wildfires and agricultural burn-off leave fire scars that alter the land albedo and affect the local radiation budget. Most agricultural burn-off scars in developing countries are too small to be detected by MODIS and AVHRR and the burn-off rates are under-reported if reported at all. SHIVA will be able to image these scars and map their location and time evolution.

SHIVA will be able to examine the regional consequences of short-term climate variability by providing unique data on droughts, severe storms, and flooding. SHIVA, by providing land cover information along with water and snow cover information, will enable users to combine these data with topography, soil moisture and rainfall history information from other sensors to improve the accuracy of local and regional flood forecasts.

SHIVA will be able to study global urbanization by imaging the location of artificial illumination at night. The data can be used to define the extent of human interaction with biomass burning as well as a measure of the evolving hazard from uncontrolled fires. This is especially important for developing nations that lack much of the infrastructure we take for granted in the United States. The extent and location of urban development is required to fully assess effects on climate and the source of pollutants as well as worldwide or local food security. Food security issues can also be addressed by combining vegetation stress signature data from the dayside with nightside urbanization images. The diurnal cycle of lighting is also an indicator of economic growth and activity.

## 4 Enabling Technologies and their Application to GOAL&GO

A mission such as GOAL&GO, while possible, is not practical given current technologies. New technologies are under development for implementation on space missions. These applicable new technologies have been identified and are summarized in Tab. 1 along with their impacts.

## 5 Summary

GOAL&GO is a breakthrough application of technologies to solve a real and evolving problem: as the human race expands and its material infrastructure increases the impact of changes in the global biogeochemical cycle have increased dramatically. The technologies required to get warning and assessment information to the people who need it, in a timely and useable fashion, are revolutionary. No current sensor provides realtime warning of fires and ash plumes or severe storms or the spatial and temporal resolution required to study the evolution of

**Tab. 1:** Application of Key New Technologies to GOAL&GO.

| System Driver | Enabling Technology to be Used | Impact |
|---|---|---|
| Realtime hazard monitoring and detection | Science Feature Extraction | Enables scene selection for cueing of SHIVA by VISHNU (or other means) and adjustment of SHIVA FOV |
| Scene selection and real-time hazard warning | Onboard Engineering Data Summarization and Beacon (hazard "pager") | Reduces requirement for data review by indicating when hazard has been detected – designed for s/c could be applied to data stream |
| Capture and use of custom data sets by remote user | Science from a Laptop | Enables remote users to configure SHIVA and collect data over their site |
| Coordination with EOS/ESSP missions | Virtual Platform | Enhanced science synergy by adding to effective instrument complement of existing platforms by simultaneous sampling of the common volume |
| Pointing of the SHIVA system | High-Displacement Piezoelectric Actuators | Allows improved performance by enabling pointing of FOV over large angular range |
| Stability of fast high angular resolution optics | Silicon Carbide Mirrors and Structures | Improves performance of backend of system and enables ground resolution requirements to be met |
| Data rate reduction | High Performance Data Compression (HPDC) | Reduces downlink requirements enabling lower transmitter power and/or receiver dish diameter |
| Spacecraft stability – Jitter requirement reduction | High Precision Pointing and Stabilization of Mirrors | Allows use on off-the-shelf spacecraft |
| Large aperture precision mirror | Deployable Mirror | Reduces package size while meeting science driver for resolution and collecting area |
| Communications from HEO while minimizing package size | Deployable Reflectarray Antenna | Enables implementation on a wider range of buses and potentially decreases requirements on ground segment |
| On-board image processing | Spaceborne Fiber Optic Data Bus (SFODB) | Transports large amounts of data for image processing in space |
| Low temperature IR focal planes | Low T Long-life Cryocoolers | Provides cooling for SHIVA fire detection array |
| Selectable bandpass for imager | Liquid Crystal Tunable Filter | Provides science flexibility and meets SNR requirements for images while reducing jitter spec by allowing longer effective integration period than spectrographs or other scanning or rastering systems |
| Imaging of thermal radiation | Large Format SWIR/MWIR InSb arrays | Enables fire detection mission for SHIVA with accurate cloud removal |

these phenomena on a global basis. These key capabilities could be demonstrated by the flight of SHIVA on a mission of opportunity. Commercial or international cooperative ventures could provide the funding for the implementation of the full-up system.

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