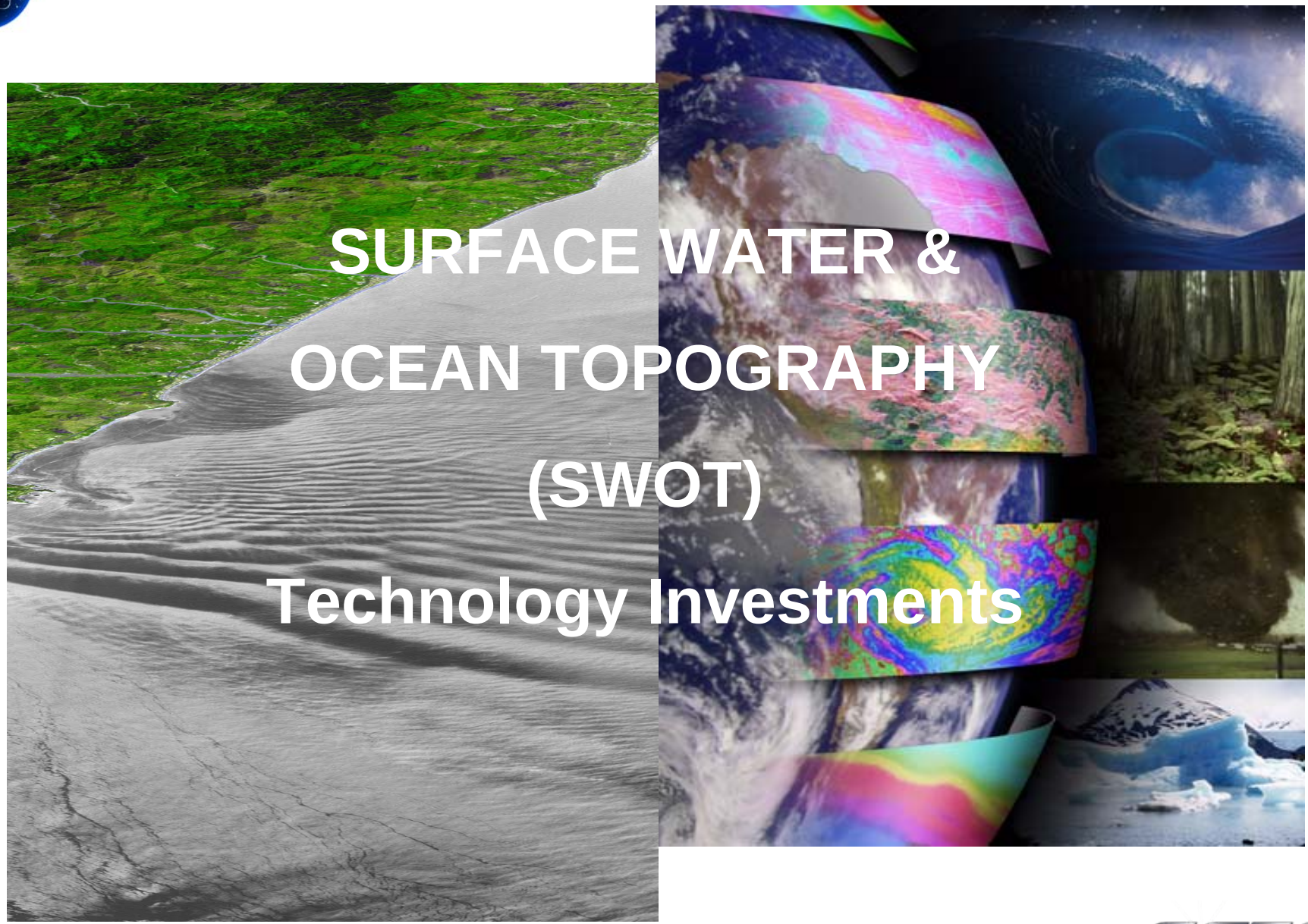

SURFACE WATER & OCEAN TOPOGRAPHY (SWOT) Technology Investments

ESTO
Earth Science Technology Office

Mission and Payload

For the Surface Water and Ocean Topography (SWOT) mission a suite of instruments will be flown on the same platform: a Ku-band near-nadir SAR interferometer; a 3-frequency microwave radiometer; a nadir-looking Ku-band radar altimeter; and a GPS receiver. The Ku-band SAR interferometer draws heavily from the heritage of the Wide Swath Ocean Altimeter (WSOA) and the Shuttle Radar Topography Mission (SRTM). The Ku-band synthetic aperture interferometer would provide vertical precision of a few centimeters over areas of less than 1 km2 with a swath of 120 km (including a nadir gap). The nadir gap would be filled with a Ku-band nadir altimeter similar to the Jason-1 altimeter, with the capability of doing synthetic aperture processing to improve the along-track spatial resolution. Because the open ocean lacks fixed elevation points, a microwave radiometer will be used to estimate the tropospheric water-vapor range delay and the GPS receiver for a precise orbit. A potential side benefit is that the GPS receiver could in principle also be used to provide radio-occultation soundings. Orbit selection is a compromise between the need for high temporal sampling for surface-water applications, near-global coverage, and the swath capabilities of the Ku-band interferometer. A swath instrument is essential for surface-water applications because a nadir instrument would miss most of even the largest global rivers and lakes. To achieve the required precision over water, a few changes will be incorporated into the SRTM design. The major one would be reduction of the maximal look angle to about 4.3°, which would reduce the outer swath error by a factor of about 14 compared with SRTM. A key aspect of the data-acquisition strategy is reduction of height noise by averaging neighboring image pixels, which requires an increase in the intrinsic range resolution of the instrument. A 200-MHz bandwidth system (0.75-m range resolution) would be used to achieve ground resolutions varying from about 10 m in the far swath to about 70 m in the near swath. A resolution of about 5 m (after onboard data reduction) in the along-track direction can be achieved with synthetic aperture processing. To achieve the required vertical and spatial resolution, SAR processing must be performed. Raw data would be stored on board (after being passed through an averaging filter) and downlinked to the ground. The data-downlink requirements (for both ocean and inland waters) can be met with eight 300-Mbps X-band stations globally.

Ref: “Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond,” National Academies Press, 2007

Mission Overview

- **Mission Description**
  - Ocean, lake, and river water levels for ocean and inland water dynamics
- **Key Instruments**
  - Ka- or Ku-band radar
  - Ku-band altimeter
  - Microwave radiometer

Ref: “Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond,” National Academies Press, 2007

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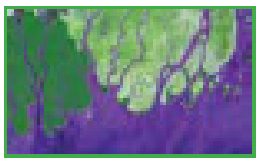
SURFACE WATER AND OCEAN TOPOGRAPHY (SWOT)

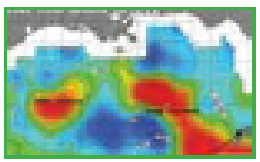
Launch: 2013-2016 Mission Size: Medium

Lake, wetland, and reservoir storage

Ocean eddies and currents

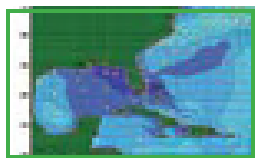


Estimates of river discharge



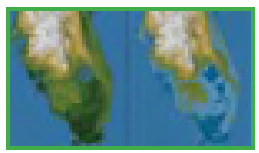
Sea-level measurements extended into coastal zones

Forecasts of floods



Marine forecasts

Identification and forecasts of inundation and malaria zones



Prediction of changes in sea level

Ref: "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond," National Academies Press, 2007

Update 9-12-08

ESTO Technology Development in Support of

Sea Surface and Terrestrial Water Level Measurements

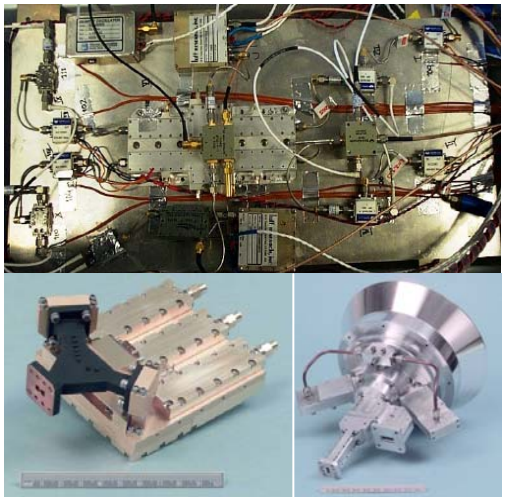
Missions Supported: SWOT

Measurement Approach

Ku- or Ka-band near-nadir synthetic aperture interferometer, Ku-band nadir altimeter, 3-frequency radiometer

Earth Science Technology Office (ESTO) Investment Highlights:

- End-to-end system design and performance analysis of a Ku-band interferometric SAR altimeter. Developed and laboratory demonstrated the prototyped critical subsystems, including chirp signal generator, FPGA-based on-board INSAR processor, dual-polarized waveguide array feeds, planar reflectarray antenna, phase-tracking receiver pair, on-board calibration unit, and the rest of the RF electronics (Fu/JPL – IIP98)
- Enhancement of key technologies (Ka-band radar interferometry antenna design, onboard interferometric SAR processor, and internally calibrated high-frequency (above 90 GHz) radiometer) required for SWOT mission (Fu/JPL - IIP07)
- Developed the system design and performance verification of the Ku- and Ka-band Dual-Down Converters (DDC's) for spaceborne interferometric radar applications (Siqueira/Univ. Mass. - ACT 05)
- Developing the system design and performance analysis of a Ka-band digitally beamformed interferometric SAR for topographic mapping of glaciers and ice sheets, and development and laboratory demonstration of the digital beamforming technologies that include lightweight radiating elements, phase-stable antenna array, digital receiver, and calibration unit (Moller/JPL – IIP04)
- Developing an autonomous disturbance monitoring system for InSAR that includes capabilities of radar calibration, hazard detection and monitoring, and artificial intelligence for decision making and onboard data acquisition replanning (Lou/JPL – AIST05)
- Developing a prototype Land Information Sensor web simulator to enable on-the-fly reconfiguration of sensors & models to improve knowledge & prediction of hydrological and land surface conditions (Houser/IGES – AIST05)
- Developed a land information system framework that assimilates geographically distributed data needed for high resolution modeling to predict water, energy and carbon cycles (Peters-Lidard/GSFC – AIST02)
- Developing a smart sensor web for ocean observations that integrates satellite surface & underwater sensors with a predictive regional ocean modeling system (Arabshahi/Univ. WA – AIST05)



Instrument Technologies

(Current and Completed ESTO Investments)

Ka-band SAR Interferometry Studies for the SWOT Mission Description

- This task is to significantly enhance the readiness level of the new technologies required for SWOT, while laying the foundations for the next-generation missions to map water elevation for studying Earth.

- The work proposed is to reduce the risk of the main technological drivers of SWOT will address the following technologies:
  - Ka-band radar interferometry antenna design
  - onboard interferometric SAR processor
  - internally calibrated high-frequency (above 90 GHz) radiometer.

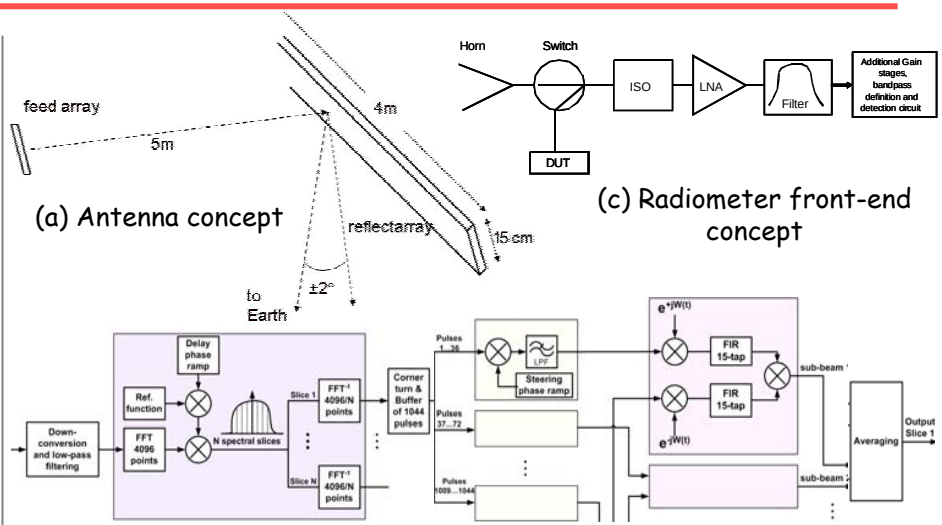
- The heritage of the radar interferometry is from the Wide-Swath Ocean Altimeter (WSOA) developed through a previous IIP-funded project under the same PI. The key personnel of the present proposal is the same as the WSOA Team. The change of Ku-band real-aperture radar for WSOA to a Ka-band SAR for SWOT will improve the spatial resolution by one to two orders of magnitude to meet the new oceanography and hydrology requirements. The first two technologies will address the challenges of the Ka-band SAR interferometry. The high-frequency radiometer will address the requirement for small-scale wet tropospheric corrections for coastal zone applications.

Ka-band SAR Interferometry Studies for the SWOT Mission

PI: Lee-Lueng Fu, JPL

Objectives:

- Design, prototype, and verify the performance of an antenna concept for the Ka-band Synthetic Aperture Radar interferometer (InSAR).
  - The proposed antenna technology is the printed reflectarray, but other options will be evaluated.
- Develop and prototype an Field-Programmable Gate Array (FPGA)-based on-board processor to decrease radar's output data rate to meet downlink capabilities.
- Develop and prototype a high-frequency (> 90 GHz) radiometer channel without external calibration (no view of hot/cold loads) to provide wet tropospheric path delay corrections to the radar measurements.



(a) Antenna concept

(c) Radiometer front-end concept

(b) On-board InSAR processor algorithm flow

Approach:

- Develop requirements and design concept, and perform analysis and trade studies for the antenna.
- Fabricate and test antenna prototype.
- Develop requirements and design for the on-board processor, and develop a software "golden model".
- Develop FPGA processor design and breadboard.
- Develop a high-frequency radiometer test-bed to assess performance of internal calibration techniques.
- Develop a radiometer breadboard and acquire roof-top sky measurements to test and verify performance.

Co-Is (JPL):

- Ernesto Rodriguez, Richard Hodges, Daniel Esteban-Fernandez, Shannon Brown, Pekka Kangaslahti

Key Milestones:

• Antenna:	
• Complete design concept analysis	01/10
• Complete prototype development	01/11
• Complete performance verification	04/11
• On-board interferometric SAR processor:	
• Complete system requirements	09/09
• Complete FPGA design	09/10
• Complete performance verification	02/11
• Radiometer:	
• Complete test-bed analysis	04/10
• Complete breadboard prototype	08/10
• Complete performance verification	02/11

$TRL_{in} = 3$

Advanced Altimeter for Oceans Studies Description

- This effort sought to develop enabling technologies for a new generation microwave radiometer system for the Jason-2 mission with significantly reduced size, mass, and power compared to previous instruments. Three key elements were identified of the radiometer system on which to concentrate the effort:
  - 1. Integrated Microwave Radiometer Module
    - Leverage monolithic microwave integrated circuit (MMIC) technology to develop a prototype radiometer design that integrates the three receiver channels into a single module. Replacing the three bulky, narrowband, waveguide ferrite Dicke switches used in previous designs with GaAs MMIC PIN diode switches enables the entire radiometer front-end to be realized in a compact planar architecture.
  - 2. Hybrid Calibration Noise Source (CALNS)
    - Develop a prototype hybrid avalanche diode noise source module that promises reduced radiometer calibration uncertainties in a compact package with integrated, ridged waveguide directional coupler. The IIP funded design improves on the JMR-1 CALNS by realizing the noise diode source in a miniaturized, microwave integrated circuit (MIC) topology and integrating this assembly with a compact, broadband ridged waveguide coupler.
  - 3. Five-frequency Feedhorn
    - Demonstrate a novel, five-frequency feedhorn design that supports both C and Ku band nadir radar altimeter channels and the three radiometer channels. This feedhorn technology enables a shared radiometer/nadir altimeter antenna option that would eliminate an entire antenna system in a future altimetry satellite.

- Onboard Processor
  - The onboard processor is needed to reduce the 131 Mbps down to the required 20kbps. This is accomplished by digital down conversion, real-time pulse compression, and interferogram formation and averaging. High density FPGAs were used to develop the prototype of the onboard process. This software was written in VHDL and is compiled into a core that can be loaded into a FPGA.

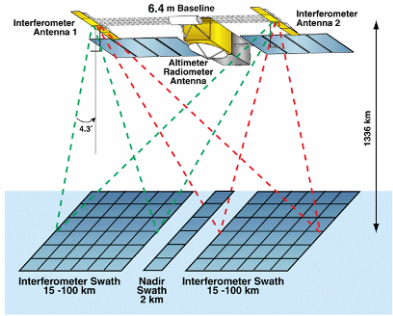
- Reflectarray Antenna
  - The interferometer utilizes two antennas separated by a baseline distance of approximately 7 m. Each antenna produces two orthogonal linearly-polarized beams. One beam is scanned +3.3° away from boresight in elevation, and the other beam is scanned -3.3°. The azimuth and elevation half-power beamwidth requirements of 0.46° and 3.8°, respectively, led to a selection of a 225 cm by 35 cm rectangular antenna aperture. A reflectarray was chosen because its lightweight flat-panel configuration enables easy deployment.

Advanced Altimeter for Oceans Studies

PI: Lee-Lueng Fu, JPL

Objectives:

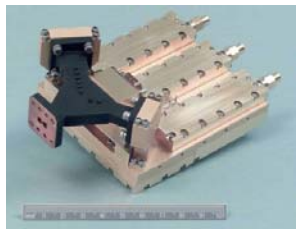
- Develop detailed instrument concept, architecture and design, and advance the associated technologies for a wide-swath ocean altimeter using the combined radar interferometry and altimetry.
- Advance the associated key technologies, including multi-frequency antenna shared by radar and radiometer, monolithic microwave integrated circuit (MMIC) based instrument electronics, field programmable gate array (FPGA) on-board processor
- Application: The significantly improved space-time sampling provided by this instrument enables global measurements of mesoscale eddies - the largest contributor to ocean kinetic energy spectrum



Wide-swath ocean altimeter concept

FPGA-based on-board processor

Ku-band dual-polarized reflectarray



Radiometer module

5-frequency feed

Accomplishments:

- Fabricated and tested a Ku-band dual-polarized reflectarray test article for the wide-swath interformetric altimetry applications
- Developed a compact radiometer brassboard using MMIC technology that integrates three receiver channels into a single module (frequencies: 18.4/21/34 GHz; power: 4 W; noise figure: 5 dB; mass: 0.5 kg; power: 4 W)
- Developed a prototype hybrid avalanche diode noise source module for reducing radiometer calibration uncertainties
- Demonstrated a five-frequency feedhorn design for both C and Ku band nadir radar altimeter channels and the three radiometer channels.
- Prototyped an FPGA on-board processor and demonstrated a data rate reduction from 130 Mbps to 20 kbps

Co-Is: Ernesto Rodriguez, JPL

TRL_{in} = 2 **TRL_{out} = 4**

Advanced Performance Ku- and Ka-band Dual-Downconverter Description

- The downconverters are constructed with a high degree of symmetry between the two channels for the purpose of forming a balance between the two interferometric signal pathways, and therefore, to maximize phase tracking as a function of temperature changes. This high degree of symmetry, and closeness of proximity of the two channels however, has the potential to increase channel cross-talk, hence a balance must be found between maintaining a thermal balance between the two channels, and maximizing the channels separation from one another

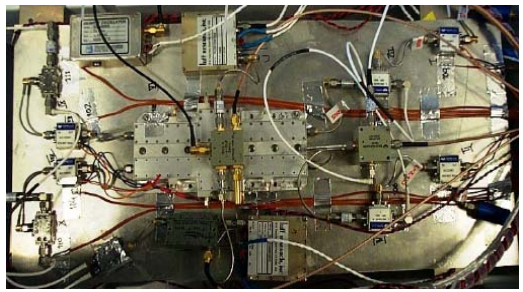
- For both frequencies, a common L-band to baseband section is used for noise bandwidth filtering and signal gain. Both the RF and IF boards contain considerable (24 channels) of audio A/D resources for collecting telemetry related to temperature and power monitoring of critical components along the signal path. This telemetry is read out via a serial port located on the back-end of the downconverter.

Advanced Performance Ku- and Ka-band Dual-Downconverter

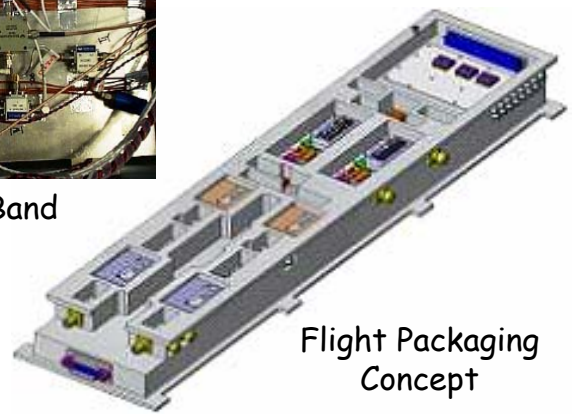
PI: Paul Siqueira, Univ. of Mass., Amherst

Objectives:

- To develop and build advanced-performance Ku- and Ka-band Dual-Down Converters (DDCs) for use in space borne interferometric radar applications.
- Characterize performance of prototypes using recently developed measurement techniques that provide high accuracy.



Two-channel Ku-Band Breadboard



Flight Packaging Concept

Approach:

- Design, build, and test a Ku-band breadboard to guide construction of the Ku-band DDC.
- Use Ku-band DDC prototyping results to guide development of Ka-band DDC.
- Build prototypes using new low-thermal expansion materials to achieve thermal stability.
- Characterize amplitude and phase stability between –10 and 50 deg C in a thermal chamber.

Co-Is:

Mr. Michael Tope, JPL

Key Milestones:

• Conduct Ku-Band DDC Design Review	01/06
• Complete Ku-Band DDC Feedthrough Test	07/06
• Complete Ku-Band Functional Testing	11/06
• Conduct Ka-Band DDC Design Review	03/07
• Complete Ku-Band Performance Report	05/07
• Complete Ka-Band DDC Feedthrough Test	09/07
• Ka-Band Functional Report	11/07
• Deliver Final Report	08/08

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

Ka-band Digitally Beamformed Radar Interferometer Description

- The technology development effort is for a novel Ka-band (35 GHz) radar that utilizes digital beamforming (DBF) over an elevation array in order to achieve significant savings in transmit power when compared with system requirements for a non-beamformed or scanned array that has the same swath illumination

- The single-pass, single platform interferometric synthetic aperture radar (InSAR) has an 8mm wavelength, which minimizes snow penetration while incurring minimal attenuation due to the atmosphere. In contrast to lidars, the instrument will be insensitive to clouds, provide significant swath-widths, cover the poles submonthly, and provide inherently variable spatial resolution: high spatial resolution for sub-meter-scale vertical precision on glaciers and coastal regions; coarse spatial resolution for decimeter accuracy on featureless ice sheet interiors.

- To date, no civilian spaceborne InSAR system has utilized Ka-band. Also, to our knowledge no digital beam forming radar has flown in space. This technology has no alternatives when high resolution and swath is required other than the use of extremely high power transmitters that are impractical from both a technological and power consumption standpoint

- The most notable challenges are the large (4x1m) Ka-band digital beam-forming antenna array, systematic calibration and data processing

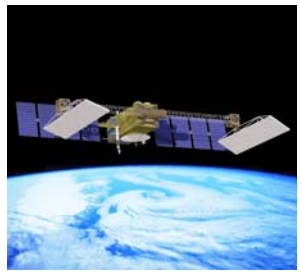
Note: This technology has generic applicability to this mission

A Ka-band Digitally Beamformed Radar Interferometer for Topographic Mapping of Glaciers and Ice Sheets

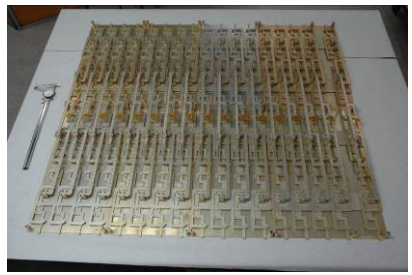
PI: Delwyn Moller, JPL

Objectives:

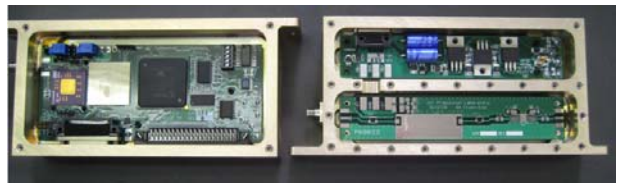
- Develop a high accuracy radar for ice topography mapping (both icesheet and glaciers) over a wide swath with sub-seasonal repeat intervals.
  - The instrument is a Ka-Band digitally-beamformed interferometric synthetic aperture radar.
  - The use of millimeter-wave signals increases accuracy, decreases mass and reduces snow penetration.
  - Elevation digital beamforming preserves swath yet maintains high antenna gain on receive.



Conceptual rendition of the deployed cross-track interferometer



Backside of Ka-Band slotted waveguide array (1 x 1.1 m)



Front and back view of digital receive element

Approach:

- A mission design and trade study will be performed to define the antenna requirements.
- Integration of the antenna from radiating elements to digitization
  - development of lightweight radiating elements
  - development of a small digital receiver
  - development of a phase-stable antenna array
- Demonstration of entire array to verify antenna, calibration and beamforming concept.

Co-Is (JPL):

- Greg Sadowy
- Eric Rignot
- Mark Zawadzki

Key Milestones:

• Completed System/Science Requirements Document	04/06
• Designed and tested Radiating Element	09/06
• Demonstrated Ka-band Down converter	01/07
• Completed Science Impact Assessment Report	03/08
• Complete L-Band Receiver fabrication	06/08
• Conduct end-to-end system demonstration at JPL antenna range facility	10/08
• Conduct science experiment on UAVSAR over Greenland	04/09

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

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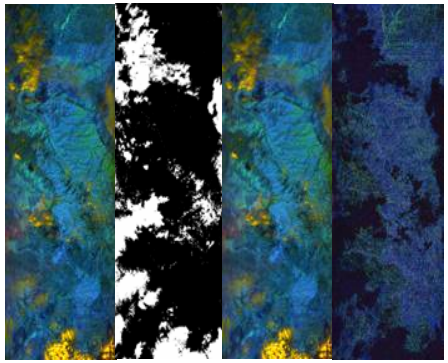
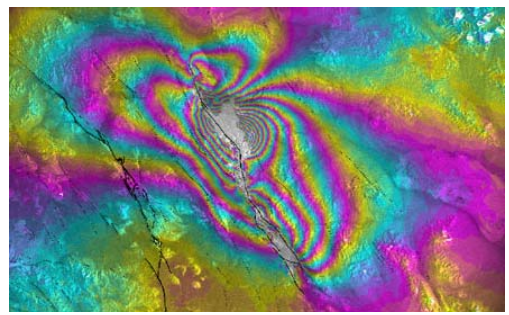


Information Systems Technologies

(Current and Completed ESTO Investments)



On-Board Processor for Direct Distribution of Change Detection Data Products Description

Build an on-board imaging radar data processor for repeat-pass change detection and hazards management

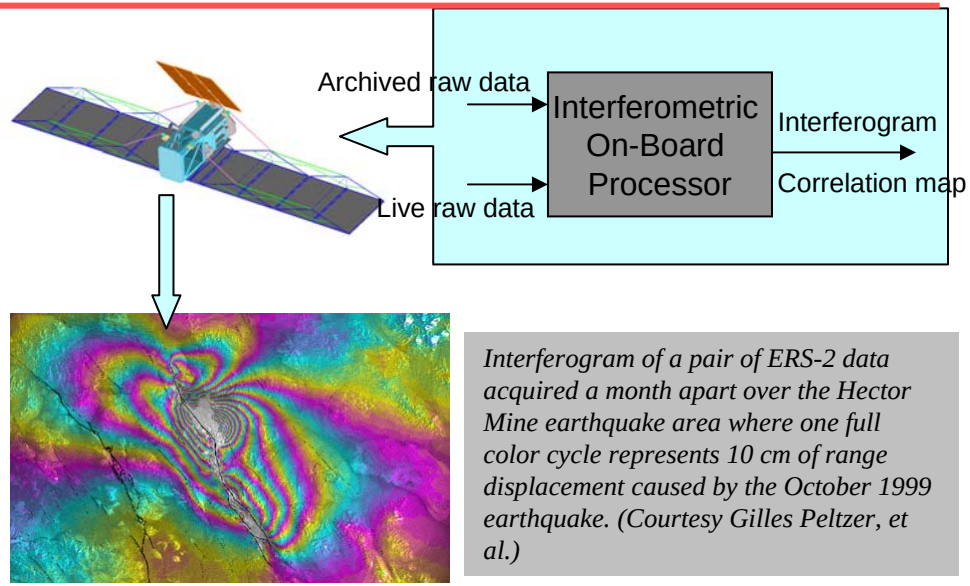
- This processor will enable the observation and use of surface deformation data over rapidly evolving natural hazards, both as an aid to scientific understanding and to provide timely data to agencies responsible for the management and mitigation of natural disasters. Many hazards occur over periods of hours to days, and need to be sampled quickly. The new technology has the potential to save many lives and millions of dollars by putting critical information in the hands of disaster management agencies in time to be of use.
- The processor architecture integrates two key technologies by combining a Field Programmable Gate Array (FPGA) front-end with a reconfigurable computing back-end. This approach capitalizes on the strengths of both technologies for the optimization of performance while maintaining flexibility where needed within the algorithmic implementation.
- A searchable on-board data archival will store the reference data sets needed for change detection processing. The benefit of this technology development is not limited to future spaceborne imaging radar missions, but will aid any NASA and commercial spaceborne mission that requires high-speed FPGAs, digital signal processors, and searchable data archival systems.

On-Board Processor for Direct Distribution of Change Detection Data Products

PI: Yunling Lou, JPL

Objective

- Build an on-board imaging radar data processor for repeat-pass change detection and hazards management (CDOP).
- Enable the observation and use of surface deformation data over rapidly evolving natural hazards, both as an aid to scientific understanding and to provide timely data to agencies responsible for the management and mitigation of natural disasters.



Interferogram of a pair of ERS-2 data acquired a month apart over the Hector Mine earthquake area where one full color cycle represents 10 cm of range displacement caused by the October 1999 earthquake. (Courtesy Gilles Peltzer, et al.)

Accomplishments:

- Developed a flexible processor architecture by integrating two key technologies: a Field Programmable Gate Array (FPGA) front-end with a microprocessor computing back-end
- Developed custom designed FPGA processor hardware for synthetic aperture radar (SAR) image formation that features a fibre-channel interface to ingest raw data at 1 Gbps and large on-board memory (> 1GB) for real-time processing
- Developed capability for real-time reconstruction of airborne platform trajectory by using a 6-state Kalman filter to ingest 3-dimensional position and velocity data
- Demonstrated dynamic Doppler parameter updating for motion compensation and azimuth compression via VME bus
- Demonstrated real-time SAR image formation with sample radar data
- Provided roadmap to leverage this technology effort toward future Earth orbiting and planetary imaging radar missions

Co-Is:

- Frank Cheng, Scott Hensley, Charles Le, Delwyn Moller, Biren Shah, Rob Muellerschoen, JPL
- Duane Clark, Leeward Engineering

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

MATLAB-Based Adaptive Computing for NASA Image Processing Applications Description

- Typical NASA applications have image processing tasks that require high performance implementations. Interest in targeting FPGAs for high performance hardware-based implementations is growing, fueled by research that shows that orders of magnitude speed-ups are possible within this domain. The major roadblock to obtaining this performance is the lack of sophisticated tools.

- This effort develops an automatic compilation system which will allow users to compile MATLAB codes directly to FPGAs. This will not only shorten development cycles enough to support new scientific investigations and the rapid prototyping of new algorithms, but it will allow the development to be performed by the scientists themselves. To aid the developer at a higher level, we will develop a suite of variable precision analysis and simulation tools.

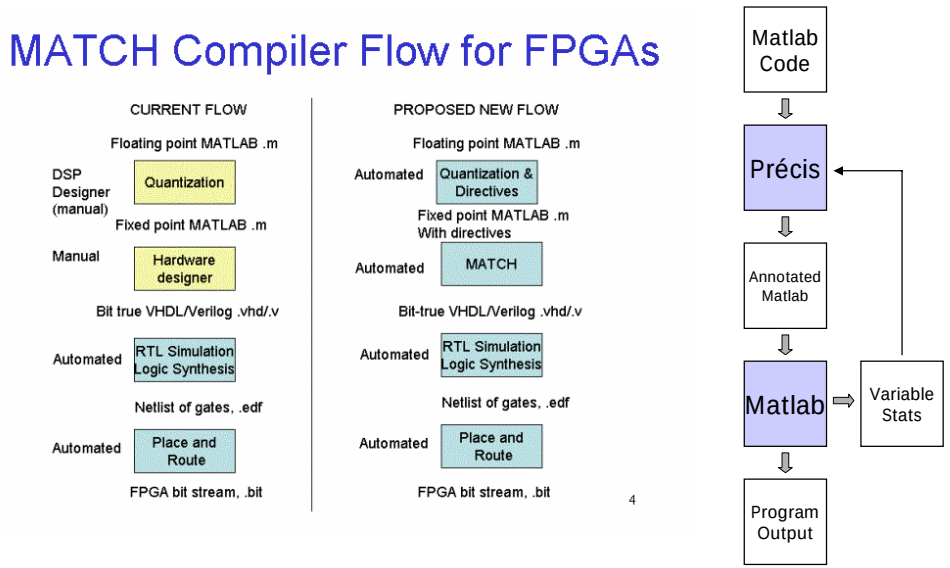
- These tools will allow the developer to interactively study the effects of bit-width variation on the implementation size, performance, and validity of their algorithms. We believe that NASA scientists can use these technologies in both ground-based and satellite-based systems, providing very high performance with a realistic programming model.

MATLAB-Based Adaptive Computing for NASA Image Processing Applications

PI: Scott Hauck, University of Washington

Objective

- Reduce code development times for adaptive applications from weeks to hours using compiler tools
- Produce efficient codes that optimize resources under performance constraints, or optimize performance under resource constraints
- Enable Adaptive (Field Programmable Gate Array (FPGA) based) Computing for NASA scientists via
  - MATLAB to FPGA Compiler (MATCH)
  - Automatic Variable Precision Support
  - Multi-spectral Image Classification Example



Accomplishments

- Reduced code development times for adaptive applications from weeks to hours using compiler tools
  - Developed compiler for automatic translation of MATLAB programs to Register Transfer Level (RTL) Very High Speed Integrated Circuit (VHSIC) Hardware Desciption \Language (VHDL) for mapping to FPGAs on reconfigurable hardware
  - Developed a set of variable precision tools to aid NASA developers in trading off quantization errors and fidelity for resources on an FPGA
  - Produced efficient codes that optimize resources under performance constraints, or optimize performance under resource constraints
- Transferred MATCH compiler technology to Accelchip, Inc. for commercialization
  - Developed an experimental prototype of the MATCH compiler on commercial FPGAs
  - Developed real-world applications to drive research on optimizations

CoIs: Prithviraj Banerjee, Northwestern University

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

Region-of-Interest Data Compression with Prioritized Buffer Management Description

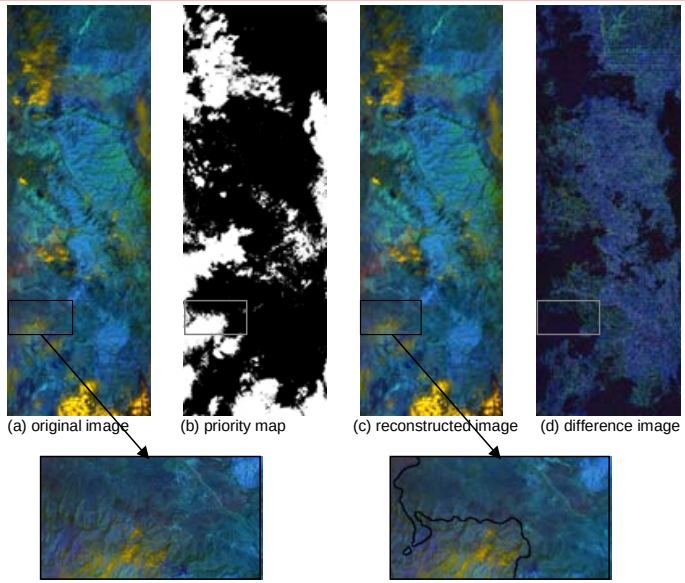
- This effort is to develop integrated data compression and buffer management algorithms to maximize the science value of data returned from spacecraft instruments. Onboard science processing algorithms that recognize scientifically relevant features in the collected data can be used to drive progressive data compression algorithms (such as wavelet compression for images). During progressive compression, the science data is parsed into hierarchical data segments that yield continual but diminishing improvement of fidelity with each segment.
- The work will develop innovative compression schemes for science-directed progressive compression that will produce data segments specially tailored to "regions of interest (ROIs)" specified by science processing modules. The prioritized buffer manager will ensure that the highest priority data segments are transmitted first, and the least valuable data segments are discarded. Our approach is to adapt existing progressive compression algorithms for amenability with identified ROIs, and to develop buffer strategies for prioritizing, storing, and delivering the most valuable compressed segments, and eventually reconstituting the original data. These algorithms will be developed subject to practical limits on the onboard computer's speed, memory, and storage. We will measure the gain in science return versus required processing speed, memory, and storage of the onboard computer.
- The work will provide a significant advance over current technology. The current state-of-the-art includes rapidly maturing progressive image compression algorithms such as Said and Pearlman's Set Partitioning In Hierarchical Trees (SPIHT), but it does not include Integrated, jointly optimized algorithms for incorporating ROI considerations across many images or different data types. This new work will provide the enabling technology to switch Earth Science's mission-planning paradigm to that of a scientist onboard the spacecraft, thus either enhancing the science value of data returned, or reducing the mass and power demands on the downlink communication link without significantly reducing the value of data returned.

Region-of-Interest Data Compression with Prioritized Buffer Management

PI: Sam Dolinar, JPL

Objectives

- Create an onboard priority-oriented data compression tool for scientists to maximize science return despite scarce downlink resources
- Obtain test images and multi-spectral datasets, and develop algorithms for assigning priorities
- Develop a Web-accessible testbed for active experimentation by scientists
- Measure the gain in science return versus the required processing speed, memory, and storage of onboard computer



Accomplishments

- Developed region-of-interest (ROI) compression algorithms and software (ROI-ICER)
- Developed prioritized buffer management algorithms and software (PBM)
- Developed classification/prioritization algorithms for specific realistic scenarios
- Developed Web-accessible testbed for the ROI-ICER & PBM software
- Performed doctoral-level research on further improvements to the algorithms for classification/prioritization, ROI compression, and prioritized buffer management, leading to four Ph.D. theses at USC
- Some "so what's" e.g.:
  - Enables efficient use of limited communication resources by allocating scarce bits to the most important sections of images (both within images and across images). See example of prioritized bit allocation in image above.

Co-Is: Matt Klimesh and Aaron Kiely at JPL, Antonio Ortega at USC, and Roberto Manduchi at UCSC

$TRL_{in} = 1$ $TRL_{out} = 3$

A Smart Sensor Web for Ocean Observation: System Design, Modeling, and Optimization

- This task is to design, develop, and test an integrated satellite and underwater acoustic communications and navigation sensor network infrastructure and a semi-closed loop dynamic sensor network for ocean observation and modeling.

- This first-of-its-kind sensor network will incorporate features such as reconfiguration of sensor assets, adaptive sampling and autonomous event detection, targeted observation, location-aware sensing, built-in navigation on Seagliders, and high-bandwidth, high-power observation on mooring systems with vertical profilers.

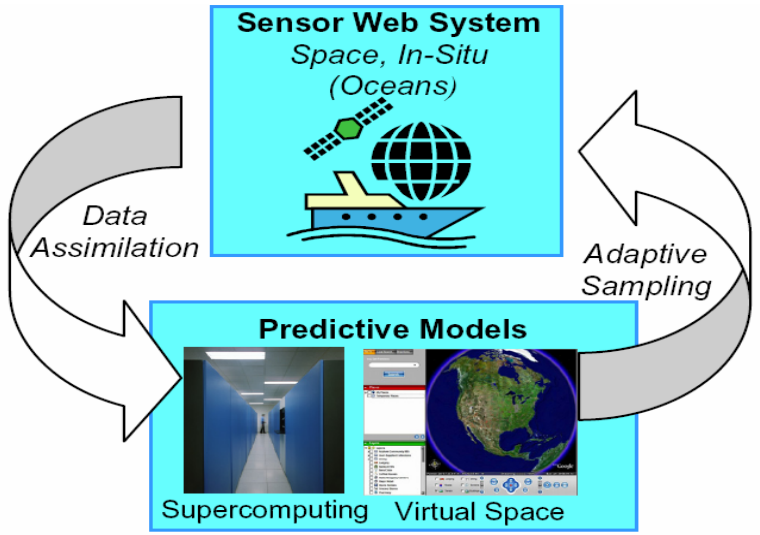
- Many challenges in communication network design for the underwater channel and data assimilation remain, which will be addressed over the next three years. The work continues efforts to provide essential infrastructure elements throughout the ocean volume – power, precise timing, communications, and navigation – necessary for any and all ocean observing efforts.

A Smart Sensor Web for Ocean Observation: System Design, Modeling, and Optimization

PI: Payman Arabshahi, University of Washington

Objective

- Design, develop, and test an integrated satellite and underwater acoustic communications and navigation sensor network infrastructure and a semi-closed loop dynamic sensor network for ocean observation and modeling.
- Perform science experiments in Monterey Bay, enabled by such a network, and evolve them to growing levels of sophistication over the period of performance (three years).



Semi-closed loop dynamic smart ocean sensor web architecture

Approach

- Develop a first-of-its-kind ad-hoc multi-hop satellite/acoustic sensor network, with features such as sensor asset reconfiguration, adaptive sampling and autonomous event detection, targeted observation, location-aware sensing, built-in navigation on mobile nodes (Seagliders), and high-bandwidth, high-power observation on cabled seafloor and moored nodes.
- Develop strong tie with NASA satellite oceanography and ocean science community to carry out new experiments which will overcome limitations in current approaches and do in-situ calibration of data gathered via remote sensing by NASA satellites.

Co-Is/Partners

- Andrew Gray / AGCI
- Yi Chao / JPL
- Sumit Roy, Bruce Howe, Warren Fox / U. Washington

Key Milestones

• Acoustic/Satellite Sensor Web	
·Baseline Network	08/07
·Enhanced Network	08/09
• Field Work at Monterey Bay	
·Deploy mooring and modems	11/07
·Complete field test with seagliders	11/08
• Data Analysis	
·Interface between sensor and Regional Ocean Modeling System (ROMS)	11/07
·Data analysis from field work	05/09

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

Land Information Sensor Web

- This project will develop a prototype Land Information Sensor Web (LISW) by integrating the Land Information System (LIS) in a sensor web framework. Through continuous automatic calibration techniques and data assimilation methods, LIS will enable on-the-fly sensor web reconfiguration to optimize the changing needs of science and solutions.

- This prototype will be based on a simulated interactive sensor web, which is then used to exercise and optimize the sensor web – modeling interfaces.

- In addition to providing critical information for sensor web design considerations, this prototype would establish legacy for operational sensor web integration with modeling systems.

- Improve rapid knowledge and prediction of land surface hydrologic conditions and hazardous extremes (e.g., surface inundation extent and change)

Land Information Sensor Web

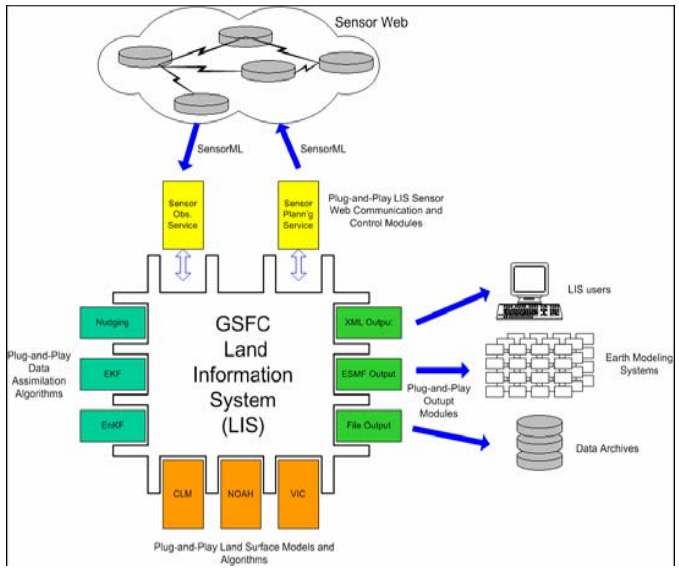
PI: Paul Houser, Institute of Global Environment and Society, Inc.

Objective

• Develop a prototype Land Information Sensor Web (LISW) by integrating the Land Information System (LIS) in a sensor web framework through continuous automatic calibration techniques and data assimilation methods

• LIS will enable on-the-fly sensor web reconfiguration to optimize the changing needs of science and solutions

• LISW will be based on a simulated interactive sensor web, which is then used to exercise and optimize the sensor web - modeling interfaces



Enabling LIS to interact with sensor webs with open protocols and web

Approach

This work will be performed in six steps:

• Establish a synthetic global land "truth"
• Establish a model of future land sensors
• Develop sensor web communication, reconfiguration and optimization
• Establish various land surface uncertainty, prediction and decision support metrics
• Exercise and evaluate the system using LISW experiments
• Design trade-offs for sensor web design

Co-Is/Partners

• James Geiger / NASA-GSFC
• Sujay Kumar, Yudong Tian / U. of Md. Baltimore Campus

Key Milestones

• Scenario development	03/2007
• Sensor simulation	09/2007
• Sensor web framework	02/2008
• Evaluation and optimization metrics	09/2008
• LISW experiments	03/2009
• Sensor web design implications	08/2009
• Collaboration, Communication & Dissemination	08/2009

TRL_{in} = 4

Coupling High-Resolution Earth System Models Using Advanced Computational Technologies

- The NASA/GSFC Land Information System (LIS; http://lis.gsfc.nasa.gov) has been successfully coupled to the Weather Research and Forecasting (WRF; http://www.wrfmodel.org) and Goddard Cumulus Ensemble (GCE; http://rsd.gsfc.nasa.gov/912/model/model.html) models using parallel techniques in a manner partially compliant with the Earth System Modeling Framework (ESMF; http://www.esmf.ucar.edu).
- LIS is a high-performance Land Data Assimilation System (LDAS). The original LIS consists of several land surface models run in an uncoupled manner (i.e. “offline”) using observationally-based precipitation, radiation and meteorological inputs, and surface parameters including Moderate Resolution Imaging Spectroradiometer (MODIS)-based Leaf Area Index (LAI).
- In this project, LIS is first executed in an uncoupled manner in order to provide soil moisture and soil temperature initial conditions for a case study period (the 2002 International H2O Project (IHOP) field program). Then, during the case study period, the land surface (LIS) and atmospheric (WRF/GCE) models are executed in a coupled manner using the ESMF infrastructure and superstructure.
- In addition to demonstrating the ESMF technologies, we also provide distributed data access, transport, translation, mining and conversion capability via the Grid Analysis and Display System/Distributed Oceanographic Data System (GrADS/DODS) server. These technologies are critical to advance ESE science and prediction goals, in which geographically distributed databases may hold petabytes of Earth system observations needed for high-resolution modeling and data assimilation to understand and predict water, energy, and carbon cycles.

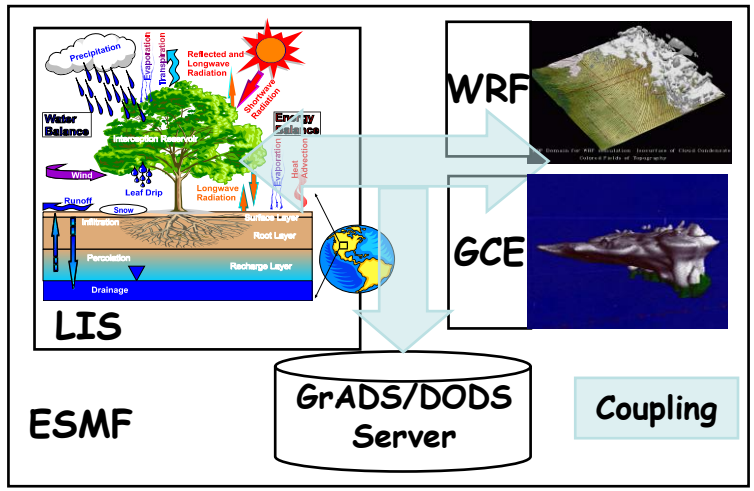
Note: This technology has generic applicability to this mission

Coupling High-Resolution Earth System Models Using Advanced Computational Technologies

PI: Christa Peters-Lidard, GSFC

Objectives

- Apply advanced computational technologies to the problem of coupling high-resolution Earth system models
- Combine the emerging technologies of the Earth System Modeling Framework (ESMF), the Land Information System (LIS) and the Grid Analysis and Display System (GrADS)/Distributed Oceanographic Data System (DODS) and couple them to the Weather Research and Forecasting (WRF) model and the Goddard Cumulus Ensemble (GCE) model to enable high-resolution modeling



Accomplishments

- Successfully coupled LIS to GCE and WRF with ESMF
- Populated LIS GrADS/DODS Server (GDS) with data for the 2002 International H2O Project (IHOP) experiment
- Completed ESMF-compliant and non ESMF-compliant coupling of LIS and WRF and LIS and GCE
- Completed IHOP synthetic and real cases with WRF and GCE that show significant impact on radiation coupling timestep, length of spin-up, type of data used in spin-up, and horizontal heterogeneity

CoI: Wei-Kuo Tao, GSFC
Paul Houser, GMU/IGES

TRL_{in} = 3 **TRL_{out} = 5**

Data Mining for Understanding the Dynamic Evolution of Land-Surface Variables

- The objective of our project is to develop data mining and knowledge discovery in databases (KDD) techniques, to facilitate analysis, visualization and modeling of land-surface variables obtained from the TERRA and AQUA platforms in support of climate and weather applications. The project is developing capacity to access very large multivariate datasets; represent heterogeneous data types; integrate multiple GIS data sets stored in many GIS file formats; analyze variable relationships and model their dependencies using cluster and grid computing; and visualize input data, as well, as extracted features, integrated data sets and data mining results.

- The large volume of data necessitates using parallelized learning algorithms to estimate the empirical models. The traditional means of estimation are examined and reconstituted in an arbitrarily parallel fashion. This allows us to spread the computational burden across as many or as few computers as are available. Our parallelized algorithms are implemented in a dataflow/workflow framework based on NCSA's Data2Knowledge tool. The platform is used for the mining of the relationship of vegetation dependencies on attributes of climate, elevation, and soil.

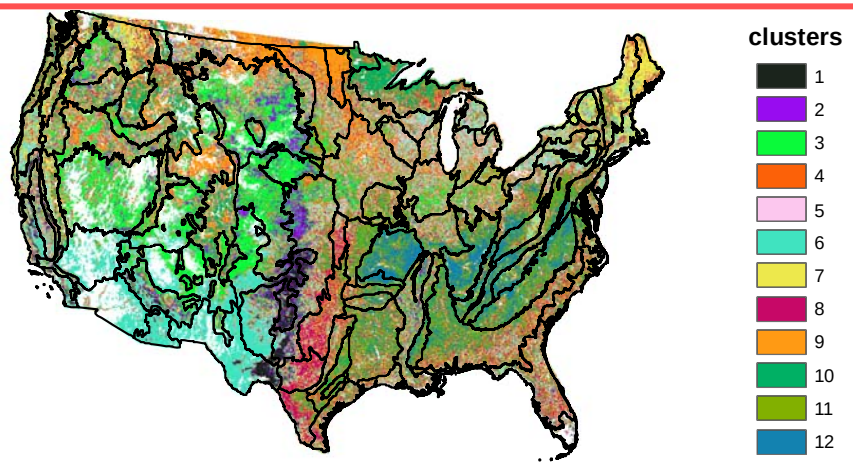
Note: This technology has generic applicability to this mission

Data Mining for Understanding the Dynamic Evolution of Land-Surface Variables: Technology Demonstration using the D2K Platform

PI: Praveen Kumar, University of Illinois

Objective

- Develop data mining techniques, using the Data to Knowledge (D2K) platform of NCSA, to facilitate analyses, visualization and modeling of terrestrial variables obtained from the TERRA and AQUA platforms, in support of scientific investigations for climate and weather applications.
    - MODIS terrestrial products to be supported include NDVI, EVI, LAI, FPAR, NPP, LST, and snow and ice cover.



Clustering analysis of MODIS Terrestrial data at 1km for May 2004. Clusters identified by different colors are overlaid with ecoregion boundaries.

Accomplishments

- Developed GeoLearn which supports processing, data mining, and visualization based on various data products
    - Terrestrial products (NDVI, EVI, LAI, FPAR, LST, Albedo, snow/ice cover (HDF-EOS files)
    - SRTM elevation
    - GIS coverage (vector and raster)
- GeoLearn provides data processing and mining support for very large data sizes (out of core processing capability)
- GeoLearn provides scientific analyses at regional and continental scales

CoI: Peter Bajcsy, NCSA, Univ. of Illinois

TRL_{in} = 4; TRL_{out} = 6

Mining Massive Earth Science Data Sets for Climate and Weather Forecast Models Description

- The sheer volume of Earth science data precludes interactive, real-time scientific exploration required to characterize and understand features that can inform and improve physical models. The traditional way to look for large scale structure in very large observational or model generated data sets is to examine maps of means and standard deviations of parameters of interest on a coarse spatio-temporal grid. This approach is popular because it is easy to implement and understand, but unfortunately, it throws away almost all of the distributional information in the data. Moreover, maps are computed for individual parameters of interest, and therefore do not retain information about relationships among two or more parameters.

- In this work, we use a modified data compression algorithm to produce multivariate distribution estimates for each grid cell. The algorithms optimally mediates between data reduction and fidelity loss using information-theoretic principles. Changes in these distribution estimates over time, space and resolution reflect large scale data structure. This is the basis for a data mining algorithm that characterizes those changes using a pseudo-metric for the distance between distributions.

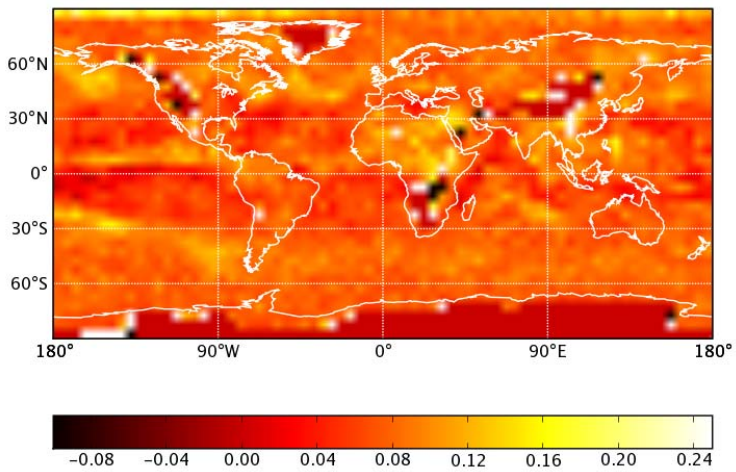
Note: This technology has generic applicability to this mission

Mining Massive Earth Science Data Sets for Climate and Weather Forecast Models

PI: Amy Braverman, Jet Propulsion Laboratory

Objectives

- Produce reduced volume, reduced complexity summary data set from very large observational and model generated data sets. Ensure summaries approximately preserve multivariate, statistical and distributional properties of the original. Users can then calculate with summaries as if using the raw data, and estimate the error incurred. Demonstrate on 3 months' data.
- Facilitate user defined custom data products through an interface with the Genesis (a JPL REASoN project for distributed computing and remote access) SciFlo analysis environment.
- Facilitate more informative comparisons of observations and model output, also via SciFlo.



Estimated correlation of AIRS atmospheric temperature and water vapor at 300 mb computed from compressed summaries.

Accomplishments

- Processed 3 months of *global, high-resolution* model output for 2 major atmospheric models (GFDL - Geophysical Fluid Dynamics Laboratory and NCAR) achieving compression ratios of about 70:1.
- Processed 3 full years of ground station data for the Atmospheric Radiation Measurement Southern Great Plains site and corresponding high-resolution model output.
- Developed and implemented algorithms for i) hierarchical summarization (summarize the summaries to coarser resolution in time and space); ii) visualization of summaries and comparison of model vs. observational summaries; iii) hypothesis testing to determine whether distributions (summaries) from model and observations differ significantly and if so why; and iv) calculation of AIRS "Level 3 Products on Demand" using the SciFlo distributed computing environment.

Co-Is

Robert Pincus and Cris Batstone, NOAA Climate Data Center;
Tim Barnett and Dave Pierce, Scripps; Brian Wilson & Eric Fetzer, JPL.

$TRL_{in} = 4$ $TRL_{out} = 6$

Telesupervised Adaptive Ocean Sensor Fleet

- A fleet of extended-deployment surface autonomous vehicles will enable in-situ study of surface and sub-surface characteristics of HABs, coastal pollutants, oil spills, and hurricane factors. To enhance the value of these assets, this task is developing a telesupervision architecture that supports adaptive reconfiguration based on environmental sensor inputs (“smart” sensing), increasing data-gathering effectiveness and science return while reducing demands on scientists for tasking, control, and monitoring.

- The system being developed allows the autonomous repositioning of smart sensors for HAB study (initially simulated with rhodamine dye) by networking a fleet of NOAA OASIS (Ocean-Atmosphere Sensor Integration System) surface autonomous vehicles. In-situ measurements intelligently modify the search for areas of high concentration. Inference Grid techniques support sensor fusion and analysis. Telesupervision supports sliding autonomy from high-level mission tasking, through vehicle and data monitoring, to teleoperation when direct human interaction is appropriate.

- Telesupervised surface autonomous vehicles are crucial to the sensor web for Earth science. This system is broadly applicable to ecological forecasting, water management, carbon management, disaster management, coastal management, homeland security, and planetary exploration.

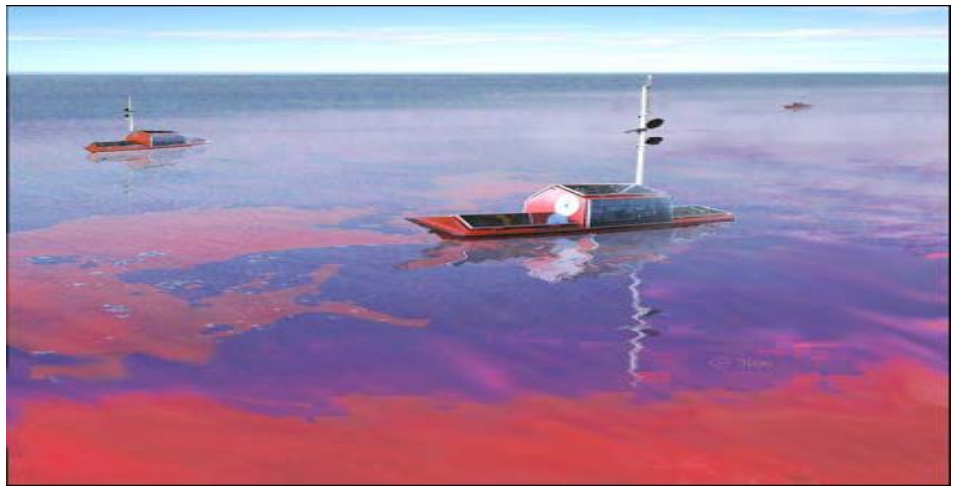
Note: This technology has generic applicability to this mission

Telesupervised Adaptive Ocean Sensor Fleet

PI: John Dolan, Carnegie Mellon University (CMU)

Objective

- Improve in-situ study of Harmful Algal Blooms (HAB), coastal pollutants, oil spills, and hurricane factors
- Expand data-gathering effectiveness and science return of existing NOAA OASIS (Ocean Atmosphere Sensor Integration System) surface vehicles
- Establishment of sensor web capability combining ocean-deployed and space sensors
- Manageable demands on scientists for tasking, control, and monitoring



Artist's conception of telesupervised sensor fleet investigating a Harmful Algal Bloom.

Approach

- Telesupervision of a networked fleet of NOAA surface autonomous vehicles (OASIS)
- Adaptive repositioning of sensor assets based on environmental sensor inputs (e.g., concentration gradients)
- Integration of complementary established and emergent technologies (System Supervision Architecture, Inference Grids, Adaptive Sensor Fleet, Instrument Remote Control, and OASIS)
- Thorough, realistic, step-by-step testing in relevant environments

Co-Is/Partners

- Jeffrey Hosler, John Moisan, Tiffany Moisan / GSFC
- Alberto Elfes / JPL
- Gregg Podnar / CMU

Key Milestones

• Interface Definition Document	02/2007
• Test components on one platform in water	05/2007
• Autonomous multi-platform mapping of dye	07/2007
• Science requirements for Inference Grid	02/2008
• Multi-platform concentration search simulation	05/2008
• HAB search in estuary for high concentration	07/2008
• Moving water test plan & identify location	02/2009
• Simulate test using in-situ and MODIS data	05/2009
• Use MODIS data to target and reassign fleet	07/2009

$TRL_{in} = 4$

Spatiotemporal Data Mining System for Tracking and Modeling Ocean Object Movement

- A Spatiotemporal Bayesian model is developed for predicting the occurrence of surface objects, such as harmful algal blooms (HAB) and river plumes in the presence of coastal areas.

- In the model, a space is divided into a set of two-dimensional lots where each lot has a set of states and historical data. The model is tested with Karenia Brevis cell counts and other data from Florida coast for 40 years.

- From computational performance tests it was found that there is a near linear relationship between the CPU time and number of data points or number of evidences. This proves that the model is 'cheap' in terms of computing resources. Further investigation includes incorporating chlorophyll anomaly data from satellite images, along with wind data and recursive learning

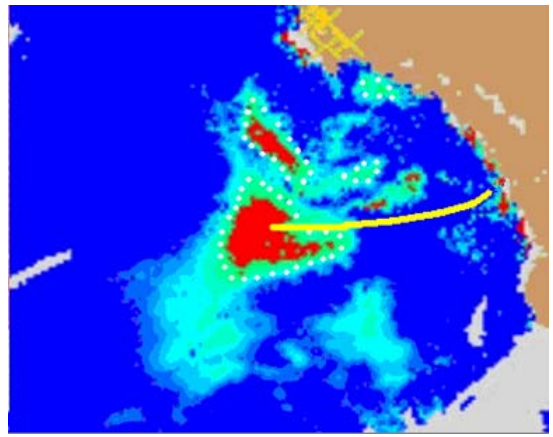
Note: This technology has generic applicability to this mission

Spatiotemporal Data Mining System for Tracking and Modeling Ocean Object Movement

PI: Yang Cai, Carnegie Mellon University

Objectives

- This project enables more efficient and less time consuming analysis of oceanographic objects, e.g. river plumes and harmful algal blooms, etc.
- To track the movement of ocean objects that have been identified
- To predict the movement of identified objects.



Tracking and prediction of harmful algae

Accomplishments

- Completed case studies for tracking the harmful algal blooms and river plumes, using SeaWiFS satellite images
- Completed the prototypes of the spatiotemporal data mining toolbox in MATLAB that can easily be used by field researchers and monitoring institutes
- Developed prototype software for object tracking that can help to monitor the harmful algae across regions and is able to automate the visual oceanography process
- Developed the prediction models that combine images and numerical data sources. Results show that the computer model can process more samples (over 2,384) than human manual process (188) with better accuracy in positive detection and positive accuracy

Co-I/Partner: Co-I, Richard Stumpf, NOAA

TRL_{in} = 4 **TRL_{out} = 6**