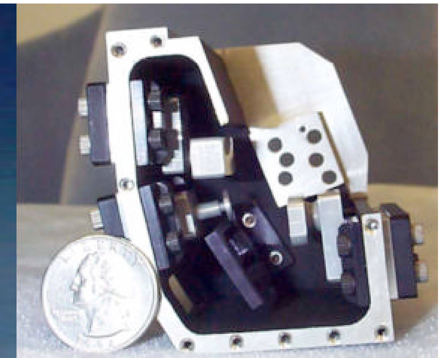
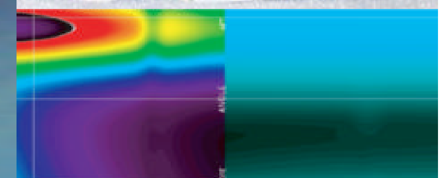
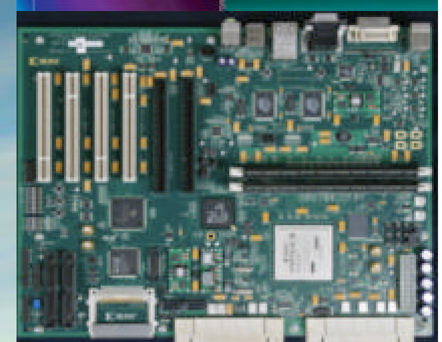
ESTO Technology Investments

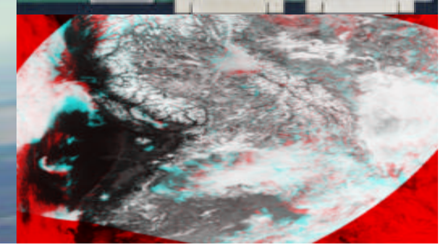
in support of the

Aerosol-Cloud-Ecosystems (ACE) Decadal Survey Mission







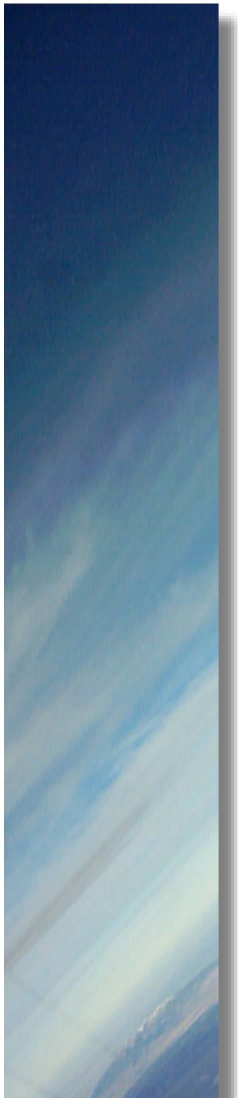


August 2009

Mission and Payload

The primary goal of the Aerosol-Cloud-Ecosystems (ACE) mission is to reduce uncertainty about climate forcing in aerosol-cloud interactions and ocean ecosystem carbon dioxide (CO2) uptake. Aerosol-cloud interaction is the largest uncertainty in current climate models. Aerosols can make clouds brighter and affect their formation. Aerosols can also affect cloud precipitation and have been linked to decreased rainfall in the Mediterranean. Results from the ACE mission would narrow the uncertainty in climate predictions and improve the capability of models to provide more precise predictions of local climate change, including changes in rainfall. ACE aerosol measurements could also be assimilated into air-quality models to improve air-quality forecasts. Ocean ecosystem measurements would provide information on uptake of CO2 by phytoplankton and improve estimates of the ocean CO2 sink. As CO2 increases, the oceans will acidify, and this will affect the whole food chain, including coral-reef formation. The ACE mission could assess changes in the productivity of pelagic fishing zones and provide for early detection of harmful algal blooms. Benefits of the mission would include enabling the development of strategies for adaptation to climate change, evaluation of the consequences of increases in greenhouse gases, enabling of improved public health through early warning of pollution events, and evaluation of effects of climate change on ocean ecosystems and food production.

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



Mission Overview

- **Mission Description**
  - Aerosol and cloud profiles for climate and water cycle; ocean color for open ocean biogeochemistry

- **Key Instruments**
  - Multi-beam cross-track dual wavelength lidar
  - Cross-track scanning cloud radar (Ka/W band)
  - Multiangle, multi-wavelength polarimeter
  - Multiband, cross-track visible-UV spectrometer

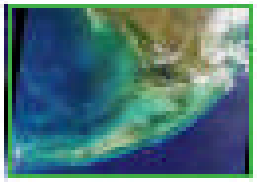
Ref: “Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond,” National Academies Press, 2007

Earth Science Technology Office

AEROSOL-CLOUD-ECOSYSTEMS (ACE)

Launch: 2013-2016 Mission Size: Large

Cloud and aerosol height

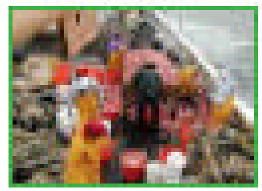


Organic material in surface ocean layers

Aerosol and cloud types and properties

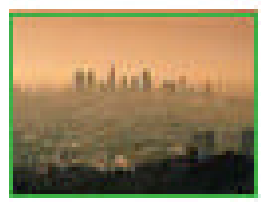
Improved climate models

Prediction of local climate change



Ocean productivity

Ocean health



Air-quality models and forecasts

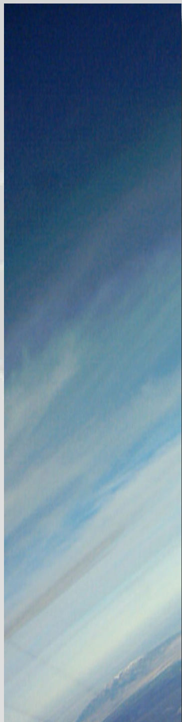
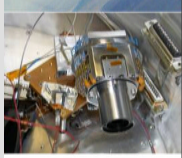
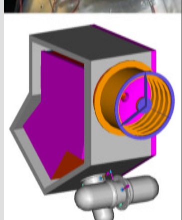
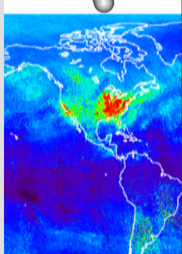
Ref: "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond," National Academies Press, 2007

ESTO Earth Science Technology Office

Sentinel Multispectral Atmospheric Composition Measurements

UV/VIS/NIR

Update 6-11-08

Missions Supported: ACE, GACM , GEO-CAPE

Measurement Approach

A multispectral spectrometer (UV/VIS/NIR) that accurately measures atmospheric composition profiles from LEO and GEO

Earth Science Technology Office (ESTO) Investments

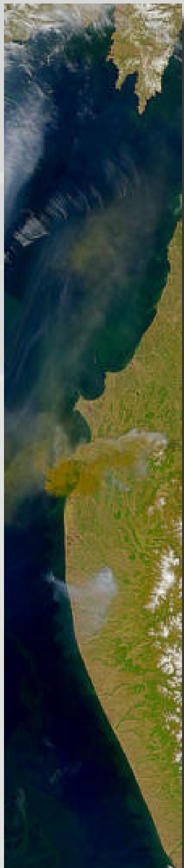
- **Development and characterization of an ocean radiometer to enable the measurement of the ocean phytoplankton species composition & uptake of CO2 by measuring ocean color in support of ACE mission (McClain/GSFC-IIP07)**
- **Develop temporal polarization scrambler into ruggedized aircraft capable unit (Illing/Ball ACT-08)**
- **Developed an engineering model Wide Field-of-View imaging spectrometer, hyperspectral imaging system providing continuous wavelength coverage from the UV to NIR with better than 1-nm spectral resolution and an instantaneous field-of-view of 1 km x 1 km at a 705-km circular orbit (R. Pollock IIP-98)**
- Demonstrated a full-scale breadboard dual spectrograph with sensitivities in the UV/VIS (310-481 nm) and the VIS/NIR (500-900 nm) for geostationary observations (S. Janz IIP-02)
- **Development and demonstration of the multi-disciplinary frameworks and observation simulations of an adaptive measurement strategy on a sensor web for rapid air quality assessment (Lee/JPL - AIST05)**
- **Development of the Adaptive Sky Cloud Science Sensor Web simulation for global atmospheric cloud monitoring (Burl/JPL - AIST05)**
- Development and demonstration of high-speed, high-dynamic range CMOS hybrid focal plane arrays (FPAs), and parallel, co-aligned optical trains for UV/V/NIR, and mid-IR bands of (PanFTS) instrument (Sander/JPL-IIP07)
- **Retirement of technology risk associated with the multi-angle, high-accuracy polarimetric spectrometer for the ACE mission for detailed measurements of atmospheric clouds and aerosol (Diner/JPL-IIP07)**

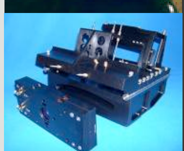
- **Bold text indicates projects directly applicable to ACE**

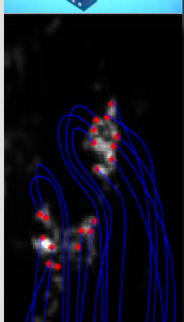
ESTO Technology Development in Support of

Next Generation Aerosol Measurements

Microwave







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Missions Supported: ACE

Measurement Approach

Ka/W-band dual-frequency Doppler radar;
High & low frequency swath radiometers*
Microwave temperature/humidity sounder*

Earth Science Technology Office (ESTO) Investments

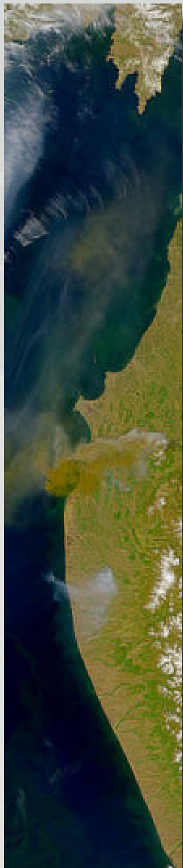
- **Develop and test a 1.5m prototype high frequency, high gain deployable reflector (Fang/JPL ACT-08)**
- **Development and airborne demonstration of a Ku/Ka-band dual frequency, Doppler, polarimetric, scanning precipitation and cloud radar for TRMM Follow-On missions (Im/JPL-IIP 98)**
- **Development and laboratory demonstration of dual-band (Ka & W) radar for cloud and precipitation measurements (Durden/JPL-IIP07)**
- **High Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP) Ku/Ka band active microwave instrument developed for flights on WB-57 and Global Hawk (Heymsfeld/GSFC-IIP04)**
- **Lab demonstration of rad-tolerant FPGA-based 4-channel radar data processor (with EDAC) and controller for adaptive rain scene targeting. This technology enables 3X increase in swath coverage and 2X data reduction (Berkun/JPL - AIST99)**
- **Lab demonstration of a breadboard single-chip, FPGA-based real-time processor for computing full Doppler spectrum of precipitation (Durden/JPL – AIST01)**
- **Development and laboratory demonstration of a prototype model of a dual frequency, wide-angle beam-pointing, membrane antenna for spaceborne rainfall measurements (Im/JPL-IIP 01)**

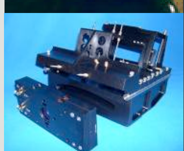
* Overguide Instrument

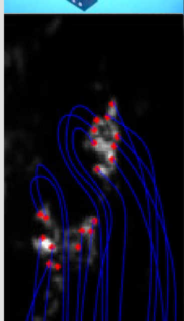
ESTO Technology Development in Support of

Next Generation Aerosol Measurements

Optical







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Missions Supported: ACE

Measurement Approach

Multi-angle multi-spectral imaging polarimeter;
Multi-wavelength high spectral resolution backscatter and extinction lidar

Earth Science Technology Office (ESTO) Investments

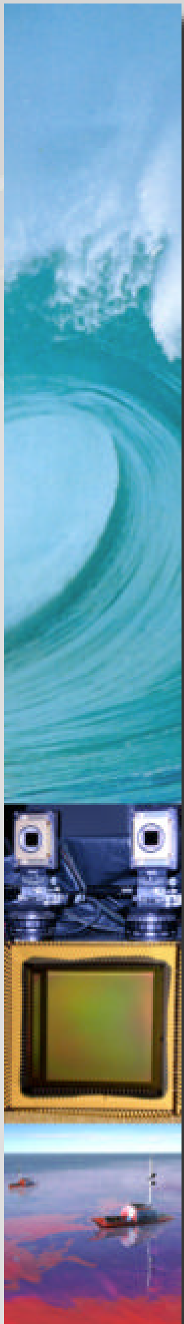
Polarimeter

- **Demonstrate on-board processing to achieve 2 orders of magnitude data rate reduction for the MSPI instrument (Pingree/JPL AIST-08)**
- **Full spectropolarimetric validation and performance enhancements for a hyperspectral polarimeter for aerosol retrievals (HYSPAR) (Jones/SBIR Phase III)**
- **Retirement of technology risk associated with the multi-angle, high-accuracy polarimetric spectrometer for the ACE mission for detailed measurements of atmospheric clouds and aerosol (Diner/JPL-IIP07)**

Lidar

- **Development of high quantum efficiency CCD detectors and readout circuitry (Hostetler/LaRC/IIP-QRS-08)**
- **Development and lab demo of a high efficiency photon counting, solid state detection system (McGill.GSFC/ACT08)**
- **Development and Demonstration of an Optical Autocovariance Direct Detection Wind Lidar (Grund/Ball-IIP07)**
- **Advancement and aircraft (UAV) demonstration of the high-energy pump laser technologies and UV conversion techniques for spaceborne ozone and aerosol lidar applications (Browell/LaRC-II P04)**
- **Develop transmitter and receiver technologies for a combined High Spectral Resolution Lidar (HSRL) and Differential Absorption Lidar (DIAL) instrument for aerosols and ozone measurements (Hostetler/LaRC-IIP 04)**
- **Development of the Adaptive Sky Cloud Science Sensor Web simulation for global atmospheric cloud monitoring (Burl/JPL-AISTQRS)**

Update 6-11-08



ESTO Technology Development in Support of

Global Ocean Carbon, Ecosystems, & Coastal Process Measurements

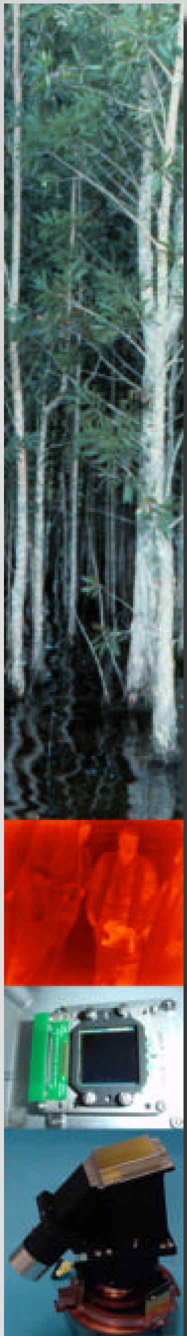
Missions Supported: ACE, GEO-CAPE

Measurement Approach

- **LEO UV-VIS spectrometer**
- GEO high resolution hyperspectral imager

Earth Science Technology Office (ESTO) Investments

- **Develop temporal polarization scrambler into ruggedized aircraft capable unit (Illing/Ball ACT-08)**
- Developed and partially demonstrated a multi-spectral imager for oceanographic imaging applications. The concept is based on implementing a surface plasmon tunable filter (SPTF) with a CMOS imager (B. Pain - ATIP-99)
- **Development of a tele-supervised adaptive ocean sensor fleet for improved in-situ study of harmful algal blooms, coastal pollutants, oil spills, and hurricane factors (Dolan - AIST-05)**
- **Development and installation of a prototype gateway between the Digital Oceanographic Data System (DODS) and Web Mapping Servers (WMS) to enable access to Earth science data (P. Cornillon - AIST-QRS-01)**
- **Development and demonstration of a low cost, reusable, autonomous ocean surface platform to collect ocean-atmosphere data and distribute it in real-time as part of a sensor web (T. Ames - AIST-QRS-01)**
- **Development and implementation of on-board data reduction and cloud detection methodologies to reduce communication bandwidth requirements (J. LeMoigne - AIST-02)**
- **Development of a spatiotemporal data mining system for tracking and modeling ocean object movement (Y. Cai - AIST-QRS-04)**
- **Design and development of an integrated satellite, underwater and ocean surface sensor network for ocean observation and modeling (P. Arabshahi – AIST-05)**
- **Development and integration of model-based control tools for mobile and stationary sensors in the New York Harbor Observation and Prediction System sensor web (A. Talukder - AIST-QRS-06)**



Update 6-11-08

ESTO Technology Development in Support of

Physiology & Functional Group Measurements

Missions Supported: ACE, HyspIRI

Measurement Approach

Polar-orbiting imaging spectrometer(s) (~350-2500 nm); Multi-Spectral imager in the Thermal IR; High spectral resolution aerosol lidar (SP) for atmospheric correction over oceans

Earth Science Technology Office (ESTO) Investments

- Developed a large format (256 X 256) array VIS-NIR blind Aluminum Gallium Nitride (AlGaN) UV imager designed for 310-365-nm operation (Mott/GSFC – ACT 02)
- **Developed ultra-narrow UV and visible interference filters that demonstrated a 100%improvement in transmission over previously available filters (Potter/Barr Associates – ACT 02)**
- **Developing an autonomous diode-pumped UV laser system for High Spectral Resolution (HSRL) Aerosol Lidar measurements. Proposed flight demonstration of autonomous joint Ozone and aerosol performance. (Hostetler/LaRC – IIP 04)**

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Polarimeter
Instrument Technologies

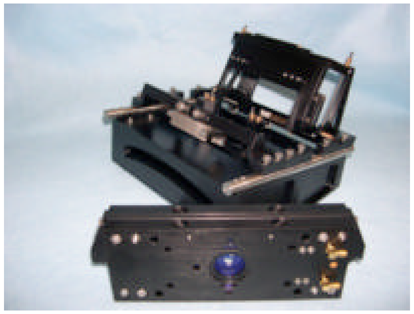
(Current and Completed ESTO Investments)

SWIR Aerosol/Cloud Polarimetric Imager

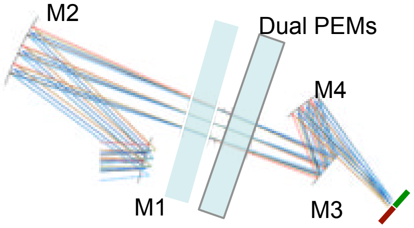
PI: David Diner, JPL

Objectives:

- Retire technology risk associated with the multi-angle, high-accuracy polarimetric spectrometer for the Aerosol-Cloud-Ecosystems (ACE) mission for detailed measurements of atmospheric clouds and aerosol
  - By extending the polarimetric imaging approach from the ultraviolet/visible/near-infrared (UV/V/NIR) band into the shortwave infrared (SWIR)
- Develop the following technologies:
  - Miniature SWIR spectropolarimetric filters in the 1595 - 2130 nm range
  - Quarter-waveplate with VIS-to-SWIR performance
  - Diattenuation compensation from UV to SWIR



Brassboard camera with dual photoelastic modulator assembly in the foreground. (This multi-angle UV/V/NIR polarimetric spectrometer has been developed through prior ESTO IIP.)



Modified camera design enabling incorporation of UV/V/NIR, and SWIR focal planes.

Approach:

- Design, fabricate, and test (a) quarter-waveplate (QWP) with visible-to-SWIR performance, (b) miniaturized filters and polarizers
- Rebalance the diattenuation compensation performance of the camera mirror coatings
- Incorporate commercial SWIR detector array
- Develop the cooling system for the laboratory SWIR focal plane and a conceptual thermal design for the satellite sensor
- Integrate and test the brassboard camera

Key Milestones:

- Upgrade laboratory Mueller Matrix Polarimeter 07/09
- Complete preparation for SWIR filter testing 09/09
- Complete QWP design 09/09
- Develop lab cooling system for SWIR detector 12/09
- Complete calibrated SWIR detector 04/10
- Complete QWP testing 07/10
- Integrated focal plane subassembly 09/10
- Integrate camera 10/10
- Complete camera system test 03/11

Co-Is/Partners:
Ab Davis, JPL; Russell Chipman, University of Arizona

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

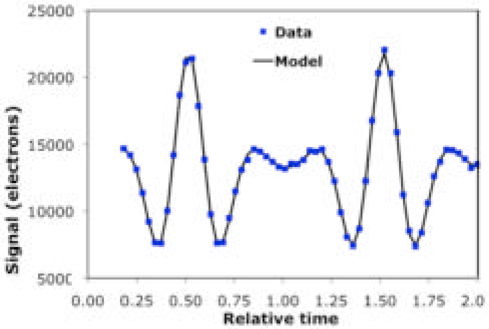
04/09

Aerosol Spectropolarimetric Camera (ASPC)

PI: David J. Diner, JPL

Objectives:

- Retire risk of key technologies for a new-generation spaceborne imager, integrating the unique strengths of multispectral, multiangle, and high-accuracy polarimetric approaches for atmospheric clouds and aerosol measurements. Technologies include:
  - A ruggedized photoelastic modulator (PEM) to extract accurate linear polarization imagery
  - Robust optics preserving radiometric and polarimetric fidelity of the measurements
  - Miniature spectropolarimetric filters
- This polarimetric spectrometer is targeted to be a primary instrument of the Aerosol-Cloud-Ecosystems (ACE) Mission



Brassboard camera (left) polarimetric results (right) from testing

Accomplishments:

- Designed and fabricated a brassboard camera, and demonstrated its functional capability for imaging polarimetry with the potential to meet 0.5% Degree of Linear Polarization (DOLP) accuracy for the Decadal Survey ACE Mission
  - Optics with high resolution over a ±31° FOV, for the 355 to 2130-nm spectral range
  - Robust mirror coatings meeting requirements for low diattenuation from 400 to 700 nm
  - Focal plane employing custom Si-CMOS detector and custom 3-channel polarimetric filter at 660 nm
- Developed a packaging design for the PEMs and demonstrated the ability to survive a protoflight 15-g rms launch environment
- Demonstrated the manufacturing technology to fabricate miniaturized 13-channel filters that meet the requirements of the imaging polarimeter in both airborne and satellite implementations
- Established design requirements for a spectropolarimetric imager based on detailed error modeling of the design concept

Co-Is/Partners: Ab Davis, JPL; Russell Chipman, University of Arizona

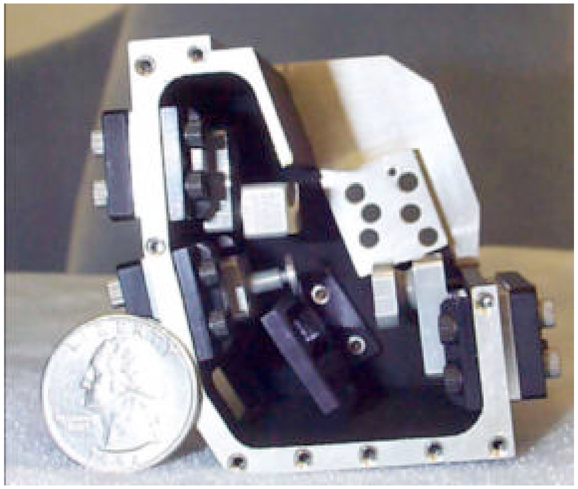
TRL_{in} = 3 **TRL_{out} = 5**

Multi-angle Imaging SpectroRadiometer 2 (MISR-2)

PI: David Diner, JPL

Objectives:

- Develop several key technologies needed for the next generation multi-angle imaging spectroradiometer to measure aerosols, clouds heights, and distribution of land surface cover. Such technologies will demonstrate:
  - A significant size and mass reduction in the optical system
  - A >50% volume reduction of the camera electronics board
  - That filters can be cut and bonded to meet the more stringent packaging requirements of 80 µm center-to-center spacings (which is a 2x reduction from the MISR dimensions)



MISR-2 Camera

Accomplishments:

- Achieved all major goals of the MISR-2 activity
- Demonstrated that all-reflective camera has adequate performance
  - The all-reflective design opens new possibilities for MISR-2 cameras in terms of both spectral range and polarization
- Developed and demonstrated the MISR-2 electronics with capability for 6 signal chains
- Achieved the targeted size, mass, volume, and cable complexity reductions
- Developed the MISR-2 Electrical Ground Support Equipment
  - It can be used during any future MISR-2 development efforts with minimal modifications
- Demonstrated that significant reductions in filter size are possible

Partners: Barr Associates, SSG Inc.

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

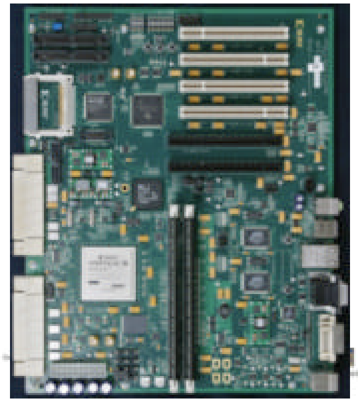
On-Board Processing to Optimize the MSPI Imaging System for ACE

PI: Paula J. Pingree, JPL

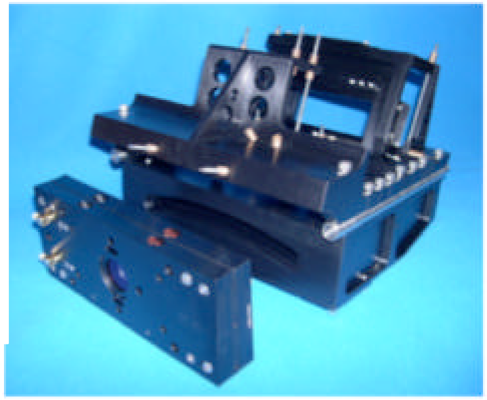
Objectives:

- Demonstrate an on-board processing (OBP) system to optimize data processing and instrument design of a Multiangle SpectroPolarimetric Imager (MSPI) for the ACE NRC Decadal Survey mission.

- Achieve a 2-orders of magnitude reduction in data rate for polarimetric data processing with improvements in the instrument digital signal processing (DSP) design train.



ML 510 Development Board



Prototype Camera Design

Approach:

- Complete design of a heritage polarimetric processing algorithm with migration & testing on the Xilinx Virtex-5 FPGA and development board.
- Integrate the on-board processor into the camera brass-board system.
- Perform FPGA design trades to optimize performance & explore how digital signal processing features can be incorporated into the design.
- Perform laboratory and airborne validation of OBP system with real-time retrieval of polarimetry data.

Co-Is/Partners: Thomas A. Werne, Dmitriy L. Bekker, Ab Davis, David Diner, and Sven Geier, JPL

Key Milestones:

Migrate/modify Virtex-4 linear least-squares processing to Virtex-5 system	09/09
Integrate FPGA development board system into MSPI camera brass-board in laboratory	06/10
Finish design trades on algorithm implementation to optimize performance	12/10
Finish design trades on other DSP train operations to simplify camera design	06/11
Test (airborne pending availability) integrated system on real-time data acquisition	02/12

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

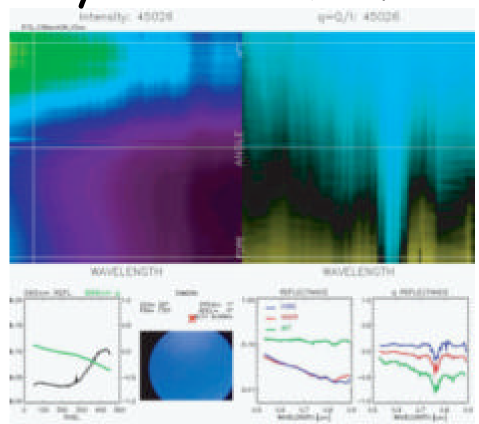
Full Spectropolarimetric validation and performance enhancements for the Hyperspectral Polarimeter for Aerosol Retrievals (HySPAR)

PI: Stephen H. Jones, Aerodyne Research, Inc.

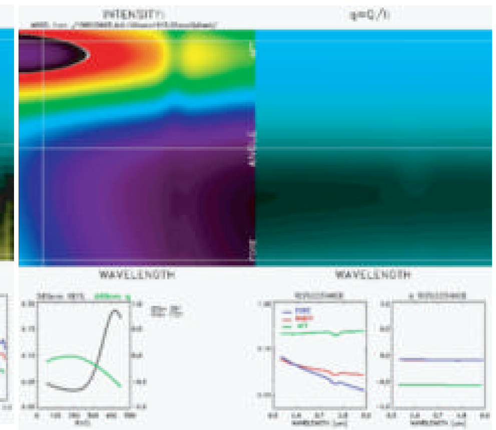
Objectives:

- Validate Level 1 data products – Stokes parameters using HyperSpectral Polarimeter for Aerosol Retrievals (HySPAR) designed and built under SBIR Phase II.
- Validate Level 2 data products – aerosol properties for uplook, downlook over water, and downlook over land.
- Demonstrate flightworthiness through a series of flights w/ LaRC's High Spectral Resolution Lidar (HSRL) and LaRC's A-band spectrometer (LAABS) sensors.

HySPAR Data Frame



Model Calculation



Accomplishments:

- Successful operation of HySPAR during all 15 Megacities Initiative: local & global research observations (MILAGRO) flights on an aircraft.
- Successful comparison of Level 1 data with the Research Scanning Polarimeter during coordinated flight.
- Learned that aircraft environment requires special algorithmic techniques to account for thermally induced sensor effects.
- Advanced the state-of-the-art in polarimetry including increased spectral resolution and addition of circular component of Stokes vector.
- Investigated successfully the combined active-passive retrieval techniques employing polarimetry and lidar.

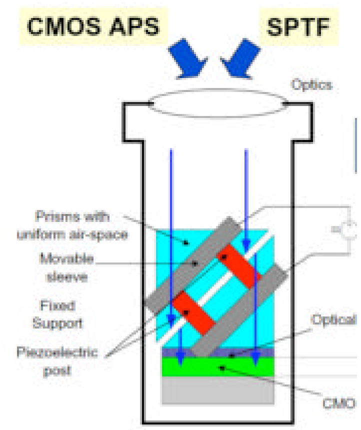
$TRL_{in} = 4$ $TRL_{out} = 6$

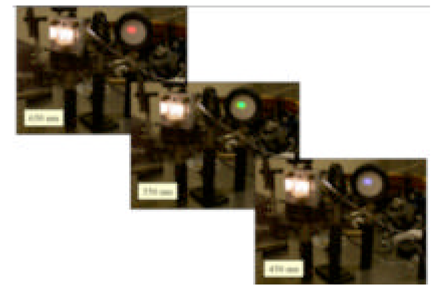
Multi-Spectral Staring CMOS Focal-plane Array for Oceanographic Imaging Applications

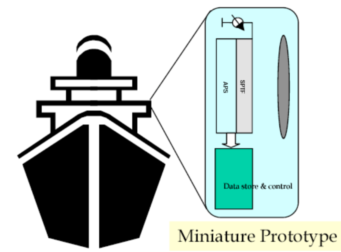
PI: Mithu Pain, JPL

Objectives:

Develop an advanced, low-cost, compact, high-resolution, staring multi-spectral digital focal-plane array (FPA) based on demonstrated CMOS Active Pixel Sensor (APS) and Surface-Plasmon-Tunable-Filter (SPTF) technologies. The instrument component will find use in Oceanography and Meteorology, atmospheric chemistry, cloud studies, aerosol studies, studies relating to vegetation recovery, volcanic ash characteristics, flood characterization, and land-cover usage and changes.







Accomplishments:

Developed a new multi-spectral imager by integrating a Surface-Plasmon-Tunable-Filter (SPTF) with a CMOS imager.

- **Unlike other spectral devices, this unit operates in a spectral-sequential manner, providing output at one wavelength over the entire field-of-view.**
- **The center-frequency (or wavelength) can be changed across the entire visible band and is tunable on-the-fly by changing the applied voltages on the SPTF.**
- **The instrument is small and compact (<100 gm, < 1inch^3) and is low-power (<100 mW) due to the use of a CMOS imager and due to the absence of any d.c. current draw by the SPTF.**

Developed a megapixel imager with superior performance compared to previous generation in terms of cross-talk, noise, linearity, and signal handling capacity.

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

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Spectrometer Instrument Technologies

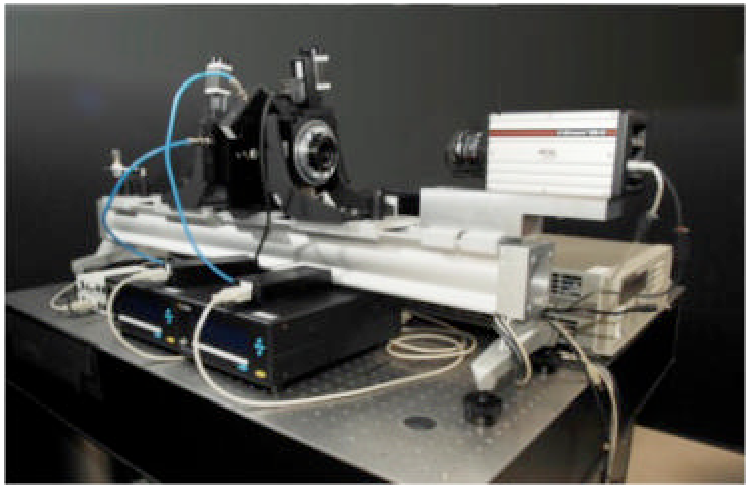
(Current and Completed ESTO Investments)

PolZero Time-Domain Polarization Scrambler

PI: Rainer Illing / Ball Aerospace

Objective

- Develop a time-domain Polarization Scrambler (PolZero) component that provides polarization sensitivity reduction without using beam replication, introducing image distortion, or requiring a specialized optical path.
- Performance goals are Mueller matrix elements $|T_{ij}|<0.01$ (normalized to $T_{00}=1$) over wide spectral, optical insertion, and aperture position range.
- Develop a ruggedized airborne prototype.
- Demonstrate PolZero performance in model spectrometer in an airborne campaign.



PolZero polarimeter testbed

Approach

- Characterize available concept demonstration unit over wide spectral, optical insertion, and aperture position range.
- Develop PolZero design from measured properties and relevant Decadal Survey mission requirements (GEO-CAPE, ACE, HyspIRI, GACM).
- Develop a ruggedized, correct form and function PolZero prototype for available spectrometer
- Demonstrate PolZero performance in lab as a stand-alone unit and a spectrometer subsystem, and in airborne operation.

CoIs/Partners: None

Key Milestones

• Complete PolZero specification	07/09
• Complete prototype fabrication	05/10
• Complete lab testing	08/10
• Complete integrated field testing	11/10

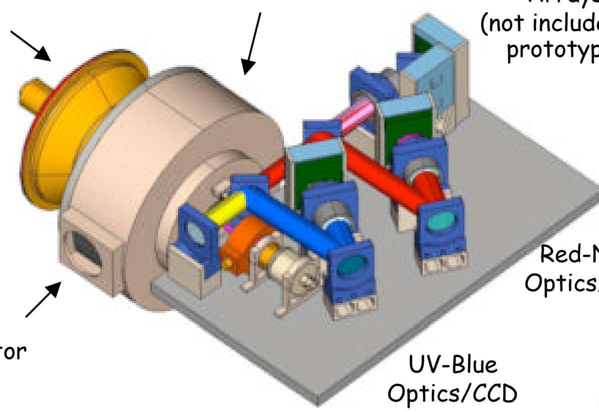
$TRL_{in} = 3$ $TRL_{current} = 3$

Ocean Radiometer for Carbon Assessment (ORCA) Prototype

PI: Charles McClain, NASA GSFC

Objectives:

- Provide information on the ocean phytoplankton species composition and uptake of CO_2 by measuring ocean color in support of the Aerosol, Cloud, and Ecosystem (ACE) mission
- Build a working prototype of ORCA including the rotating telescope and CCD focal plane arrays spanning the UV-NIR (345 nm – 865 nm)
- Develop a comprehensive set of component and system level performance specifications
- Define and test sensor calibration and characterization procedures and equipment required for the ORCA design.



Approach:

- Build a test bed version on an optical bench to refine optical layout and to test components and subsystems (e.g. polarization, point-spread functions, relative spectral response)
- Incorporate telescope scanning capability and package the system into a portable prototype
- Perform system level characterization at the National Institute of Standards and Technology (NIST)

Co-Is/Partners:

Jay Smith, Mark Wilson, Carl Kotecki, Ken Bluemenstock, Jim Butler, and Bryan Monosmith, GSFC; Mike Behrenfeld, Oregon State Univ.; Steve Brown, NIST; and Alan Holmes

Key Milestones:

- Perform optical component performance test 08/09
- Complete component testing and static optical bench configuration 11/09
- Complete initial bench testing 12/09
- Fabricate and integrate rotating telescope assembly into bench system 04/10
- Finalize prototype bench testing 07/10
- Complete portable prototype packaging and deliver to NIST for system level testing 12/10
- Complete system prototype tests at NIST 06/11
- Complete system level calibration 08/11

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

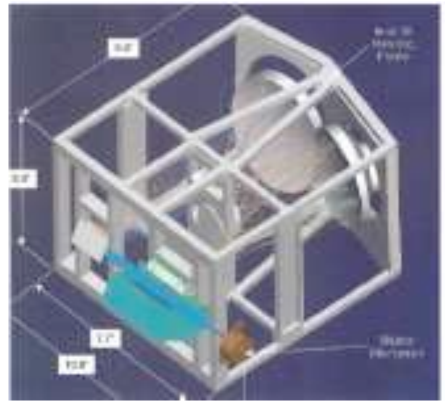
Wide Field Imaging Spectrometer (WFIS)

PI: Randy Pollock, Hamilton-Sundstrand

Objectives:

- Perform the final design iteration and test an engineering model of the WFIS to study atmospheric chemistry, clouds, and aerosols
- Build a hyperspectral instrument with limb-to-limb viewing and 1 km resolution
- Reduce size, weight, and power over similar current instruments
- Obtain airborne test data

Concept Design



Accomplishments:

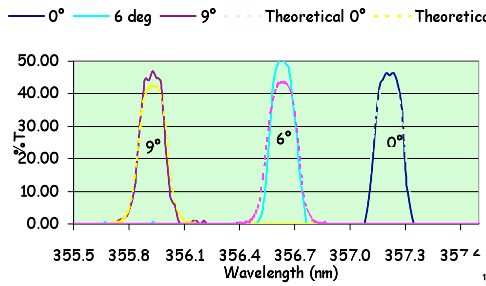
- Demonstrated optomechanical portions of WFIS in a laboratory environment.
- Completed optomechanical design to near flight standards.
  -Met materials requirement for vacuum pressure and vibration (weight ~6.8Kg, size (22x18x33cms),
- Measurements of the geometric distortion of the optical system look promising.
- Simple modifications to the present work indicate that all the performance requirements for atmospheric chemistry and clouds/aerosol science can be demonstrated with the WFIS EM.

Co-Is: Warren Wiscombe, Yoram Kaufman, Pawan Bhartia, GSFC

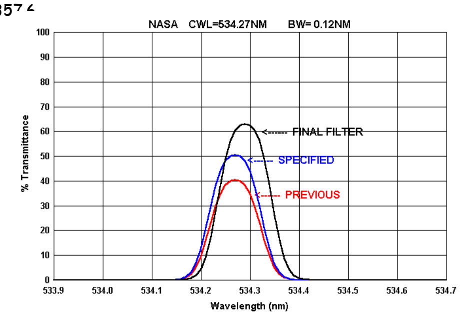
TRL_{in} = 3 TRL_{out} = 5

Advanced UV and Visible Ultra-narrow Interference Filter Technology Development

PI: John Potter, Barr Associates Inc.



Tuning performance



Transmission

Description and Objectives:

- 3 year effort to conduct research to build interference filters with up to twice the transmission of current filters while maintaining other specifications in the UV. Technology can also be applied to Vis and UV areas of the spectrum.
- Demonstrate filter performance using a Raman LIDAR.
- Transfer research result to space optics.

Co-I's: David Whiteman (NASA –Goddard SFC), Igor Veselovskii/UMBC, Ms. Rebecca Tola, Barr Associates Inc. , Martin Cardirola / Ecotronics

Accomplishments:

- **UV Band-pass filter fabrication and testing:** More than a factor of 2 improvement in transmission versus previous capability. Manufactured Angle tunable Ultra-Narrow band filter. (0-9°)
- **Impact:** Techniques and filters developed here have been used to improve upper tropospheric measurements of water vapor for Aqua satellite validation.
- **Enables:** Improvements in the transmission of these filters while maintaining other required specifications such as blocking permits higher sensitivity measurements of water vapor, temperature, ozone, etc. than is currently being accomplished by these systems with no increase in size, weight or power consumption. Only the interference filter in use would need to be changed.

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

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Radar
Instrument Technologies

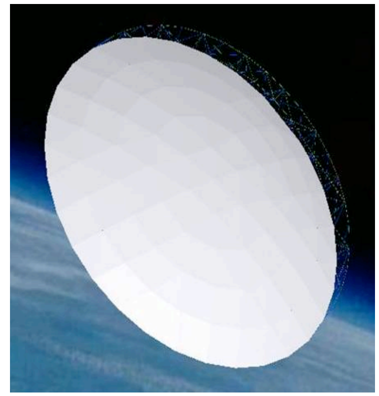
(Current and Completed ESTO Investments)

A Large High-Precision Deployable Reflector for Ka- and W-band Earth Remote Sensing

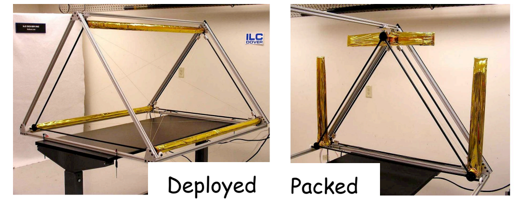
PI: Houfei Fang, JPL

Objectives:

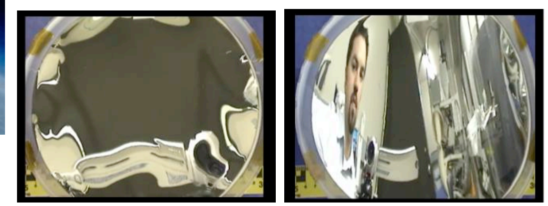
- Develop a large, high frequency and high gain deployable reflector technology to enhance the Aerosol, Clouds and Ecosystem (ACE) Mission and enable the Nexrad-In-Space (NIS) mission.
  - This will be implemented by leveraging and integrating several recently developed material technologies, including Shape Memory Polymer (SMP) material; high-precision Membrane Shell Reflector Segment (MSRS) casting process; near zero CTE (coefficient of thermal expansion) membrane Novastrat™; and Poly-Vinylidene Floride (PVDF) electro-active membrane.
- This technology offers an order of magnitude higher in precision than the currently used tensioning cable truss reflector and provides a desirable surface contour.



Architecture: a deployable SMP tetrahedral truss supports a set of MSRS to form a high definition, smooth and continuous surface



A SMP composite truss



An optical quality PVDF film deforms from a flat shape to a concave shape with the application of the voltage

Approach:

- Develop Shape Memory Polymer tetrahedral truss
- Develop Membrane Shell Reflector Segment
- Integrate a 1.5-m subscale prototype
- Conduct tests for the 1.5-m prototype
- Analytically scale-up from 1.5-m to 5-m for ACE application, and to 35-m for NIS application

Co-Is/Partners:

Simone Tanelli, Mark Thomson, JPL
James Moore, ManTech SRS Technologies
John Lin, ILC Dover

Key Milestones:

Complete structure concept	09/09
Complete MSRS design and optimization	12/09
Complete structure prototype design	06/10
Complete structure component development	12/10
Complete MSRS manufacturing technology	12/10
Complete subscale prototype integration	06/11
Complete subscale prototype testing	09/11
Complete scale-up	12/11

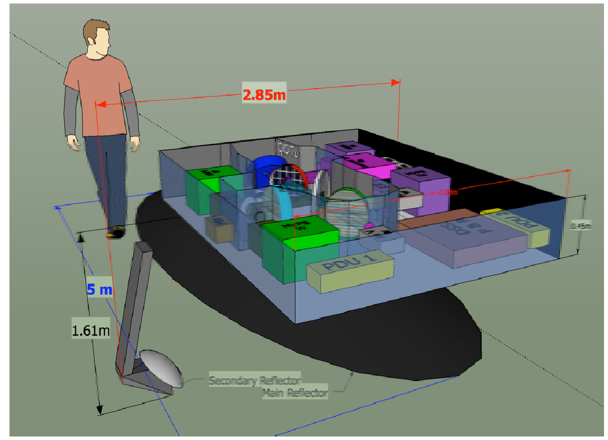
TRL_{in} = 2 $TRL_{current}$ = 2

A Multi-Parameter Atmospheric Profiling Radar for ACE (ACERAD)

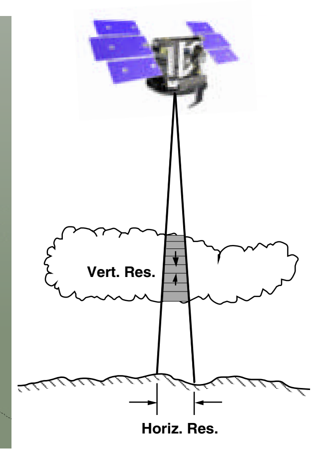
PI: Stephen L. Durden, JPL

Objectives:

- Design a dual-frequency (35/94 GHz) radar system for cloud and precipitation measurements.
  - The proposed radar would be a key element of the Aerosol-Cloud-Ecosystems (ACE) mission.
- Develop a detailed design of the antenna and radar front end for this radar.
- Verify the performance of a scaled antenna and prototype quasi-optical front end through laboratory testing.
- Study feasibility, performance, and utility of an Extremely High Frequency (EHF) channel above 200 GHz.



ACERAD radar configuration concept



ACERAD cloud measurement concept

Approach:

- Develop ACERAD requirements and perform a system level design; perform more detailed RF design and identify long-lead parts. Develop simulation of radar to verify performance.
- Design and test antenna and quasi-optical (low-loss) radar front end.
- Design and test EHF channel

Co-Is/Partners:

Simone Tanelli, Daniel Esteban Fernandez, Lorene Samoska, Raul Perez, JPL

Aluizio Prata, JPL and USC

Key Milestones:

- Complete system requirements 04/09
- Complete design of EHF source 09/09
- Complete high-level system design 11/09
- Complete Antenna/Transmission Line design 01/10
- Complete first EHF source testing 03/10
- Complete detailed Instrument design 10/10
- Complete Antenna/Transmission Line development 01/11
- Complete second EHF source testing 04/11
- Complete RF subsystem design 05/11
- Complete Subsystems testing 08/11

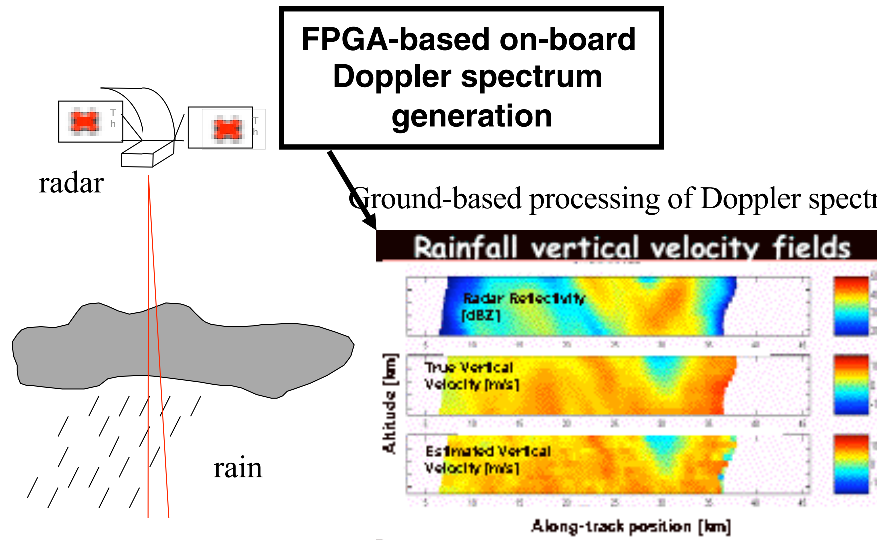
TRL_{in} = 3 $TRL_{current}$ = 3

An On-Board Processor for a Spaceborne Doppler Precipitation Radar

Stephen L. Durden, JPL

Objective:

- The objective of this work is to develop an on-board data processor that computes the Doppler spectrum of precipitation radar echoes.
- Justification: To improve latent heating measurements in future space-borne precipitation radars, we need to measure the vertical motion V of the atmosphere.
  - Accurate measurement of V from a moving satellite requires the full Doppler spectrum
  - On board FPGA-based processing substantially reduces the data volume for downlinking



Accomplishments:

- Completed high-level radar design
- Completed processor requirements
- Completed processing algorithm design; implemented bit-true FFT algorithm for simulations
- Completed Verilog coding of processor
- Generated test data using archived airborne radar data
- Lab hardware setup demonstrated for processing one coherent processing interval CPI (one block of data)
- Processor performance demonstrated using multiple CPIs of airborne radar data and 230 CPIs from model output

Co-Is: Mark Fischman (JPL), Andrew Berkun (JPL)

TRL_{out} = 5

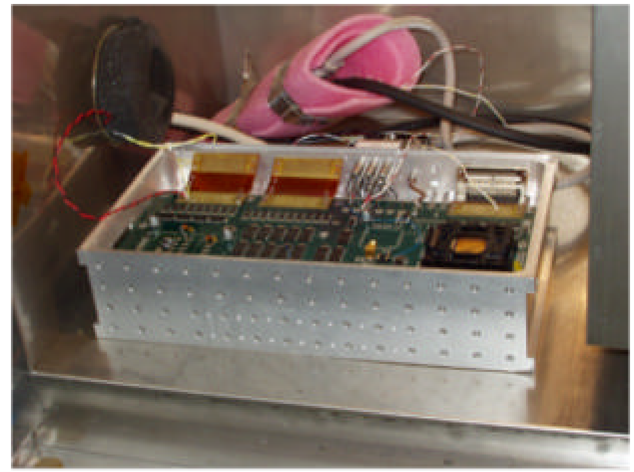
FPGA-Based On-Board Processor/Controller for Satellite-Borne Precipitation Radars

PI: Andrew Berkun, JPL

Objective:

Develop an electronics assembly suitable for earth orbit environment with the following capabilities:

- 4 channel radar data processing
- Radar and antenna timing control
- Software free operation
- Using processed radar data to target areas of rain.



Accomplishments:

Developed a 4 channel radar data processing unit that met all objectives with the following characteristics:

- 83-94% efficient timing solution
- Robust radiation upset correction approach
- Thermal design which allows operation up to 70° C
- Compatibility with normal spacecraft interfaces
- -75 dB sidelobes --> **1000x data reduction**
- Auto targeting --> **improves number of looks 6x in areas of interest**

System successfully demonstrated aboard airborne prototype deployments: CAMEX-4 (Aug-Sep 2001), AMSR-E experiment in Wakasa Bay (Jan-Feb 2003), LRR validation (May-Jun 2003).

Co-Is: Stephen Durden, Eastwood Im, Greg Sadowy, JPL

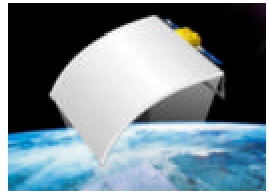
TRL_{in} = 2 **TRL_{out} = 5**

Second-Generation Precipitation Radar (PR-2) Adaptable for Multi-Mission and Multi-Orbit Applications

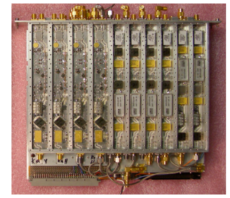
PI: Eastwood Im, JPL

Objectives:

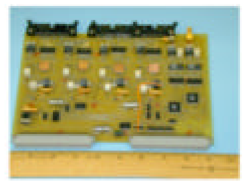
- Develop and demonstrate an advanced radar system and associated technologies to support the development the Global Precipition Mission (GPM)
  - Dual-frequency (14/35 GHz) to improve dynamic range and sensitivity on rain measurements
  - Factor of two improvement in radar resolution to reduce errors caused by rain inhomogeneity
  - Dual polarization to differentiate between liquid and frozen hydrometeors
  - Doppler capability to obtain vertical motion structure
  - Cross-track adaptive scan over ±37° to increase swath coverage



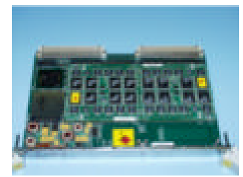
PR-2 system concept



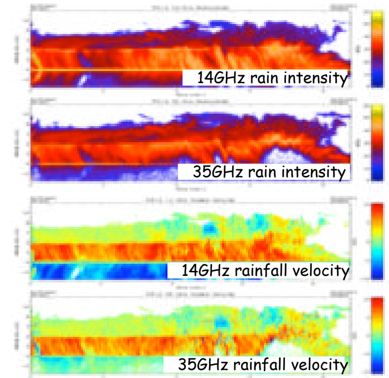
IF/LO board



ADC/AWG board



FPGA real-time processor board



Dual-frequency rain intensity and fall velocity profiles of hurricane obtained by PR-2 airborne experiment in Sep'2001

Accomplishments:

- Developed a 12-bit A-to-D Converter (ADC) and variable waveform generator (AWG) board to achieve 2x improvement in sample filtering and -60dB pulse sidelobe suppression capability
- Developed an FPGA-based real-time Doppler and adaptable scan signal processor with 40 ops/sec capability
- Developed a compact Intermediate-Frequency/Local Oscillator (IF/LO) module with 2 transmit and 4 receive channels
- Developed the conceptual design on a light-weight, wide-angular scanning, dual-frequency antenna
- Developed the spaceborne PR-2 design, and prototyped an airborne PR-2 simulator (a.k.a. APR-2)
  - Verified the all radar electronics performance through airborne testing in 2001
- APR-2 successfully acquired the first-ever measurements of simultaneous 14/35-GHz, dual-polarized rain intensity and vertical velocity profiles during the 4th Convection and Moisture Experiment (CAMEX-4) in 2001

Co-Is: S. Durden, G. Sadowy, S. Tanelli, A. Berkun, J. Huang, Z. Haddad (JPL); E. Smith (GSFC); Y. Rahmat-Samii (UCLA)

TRL_{in} = 2 **TRL_{out} = 6**

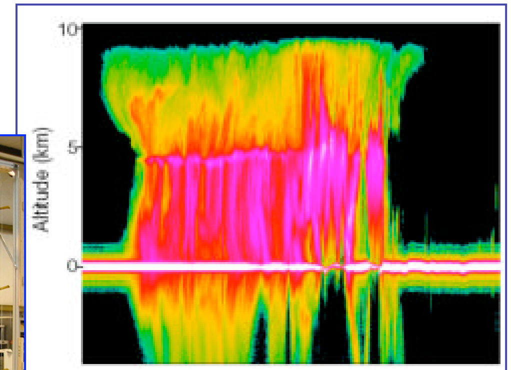
Advanced Precipitation Radar Antenna and Instrument (APRA)

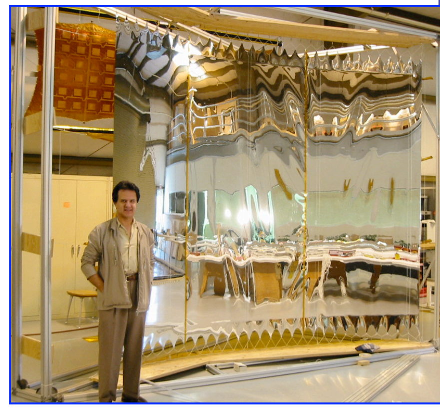
PI: Eastwood Im, JPL

Objectives:

- Develop a half-size (2.6m x 2.6m) model of a light-weight, deployable, dual frequency, wide-angle beam-pointing antenna for spaceborne rainfall measurements.
- Incorporate the antenna's physical and performance characteristics into the overall system design of the Second-Generation Precipitation Radar (PR-2).

Airborne PR-2 simulator measured detailed rain structure of Tropical Storm Chantal during CAMEX-4





The structural model of APRA half-size antenna reflector prototype

Accomplishments:

- Completed antenna electrical performance characterization, including surface ripple distortions
- Completed Ku/Ka-band array feed design, fabrication, and performance assessment
- Completed the structural modeling of the membrane surface ripples
- ILC Dover completed prototype antenna build and reflector support structure
- Completed correlation of antenna model simulation with measured results
- Feed array performance characteristics satisfactory
- Studied the space dynamics for spaceborne APRA membrane antenna

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

Ka-band Active Array for Remote Sensing of Precipitation

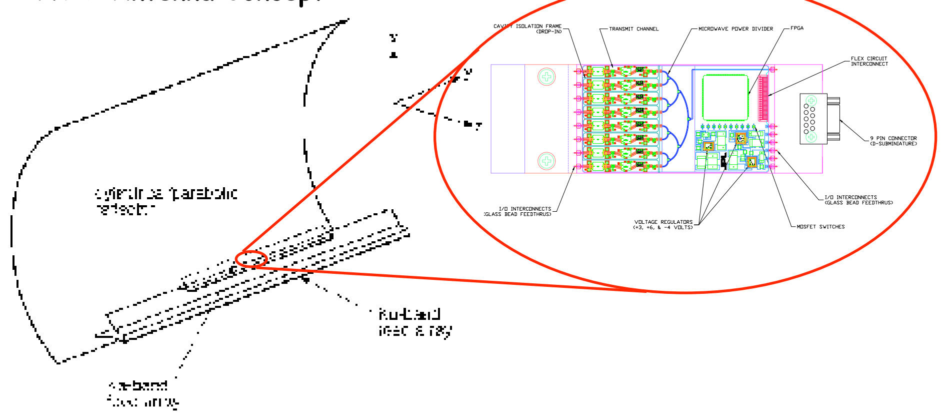
PI: Greg Sadowy, JPL

Description and Objectives:

- The PR-2 instrument will utilize two frequencies (14 and 35 GHz) and two polarizations to enable more accurate estimation of rain rates while increasing measurement swath width using adaptive scanning.
- Objective: To develop a dual-polarized electronically-scanned Ka-band (35 GHz) subarray for the PR-2 antenna.
- Development of this subarray will provide a proof-of-concept as well as a design that can easily be adapted for a future flight program.

Ka-band T/R Module 8-pack

PR-2 Antenna Concept



Accomplishments:

- Full array electromagnetic simulations complete
- Designed, fabricated and tested compact orthomode transducer
- Breadboarded and characterized MMICs
- Designed, fabricated and tested Ka-band phase shifter
- Designed and fabricated transmit and receive chain MIC (hybrid circuit) breadboards
- Designed LTCC 8-pack modules

$TRL_{in}=2$ $TRL_{out}=3$

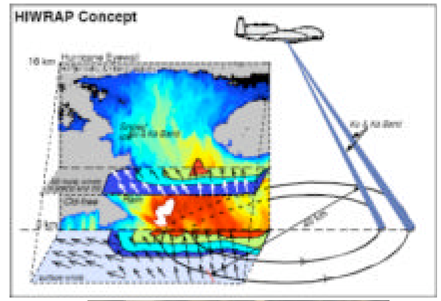
ESTO Earth Science Technology Office

High-Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP)

PI: Gerald Heymsfield, NASA GSFC

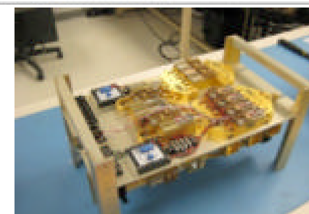
Objectives:

- Develop and validate a high-altitude UAV-based conical scan dual-frequency (Ku- and Ka-band) active microwave instrument for measuring:
  - Tropospheric winds within precipitation regions,
  - Ocean surface winds in rain-free to light rain regions
- Apply and validate the conical scanning concept of the low-altitude Imaging Wind and Rain Airborne profiler (IWRAP) for use at high-altitude
- Use solid state power amplifier design with pulse compression and FPGA technologies




Ka- & Ku-band Feed


Radome


Ka-band transceiver


HIWRAP antenna (20" dia. & 16 lbs)
In Goddard's Anechoic Chamber

Approach:

- Develop radar transceiver subsystem utilizing a solid-state power amplifier design and pulse compression techniques at Ku- and Ka-bands
- Develop digital receiver and data processing subsystem using FPGA technology
- Develop dual frequency and dual-look angle antenna subsystem
- Flight test the HIWRAP on a high-altitude aircraft

Co-Is/Partners:

James Carswell, Remote Sensing Solutions;
Lihua Li, UMBC/GEST; Dan Schaubert, Univ. of Mass.

Key Milestones:

- Design radar transceiver subsystem
- Design digital receiver subsystem
- Design antenna subsystem
- Complete flight hardware design
- Complete subsystem assembly and testing
- Complete environmental system testing
- System integration for WB-57 aircraft
- Conduct test flight demonstration aboard WB-57 aircraft
- Conduct preliminary data analysis

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

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Lidar
Instrument Technologies

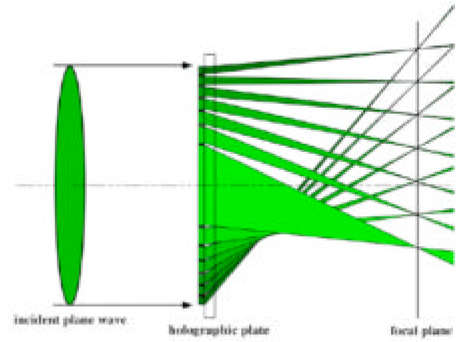
(Current and Completed ESTO Investments)

Detector Technology Development for Cloud-Aerosol Transport Lidar

PI: Matthew McGill, NASA GSFC

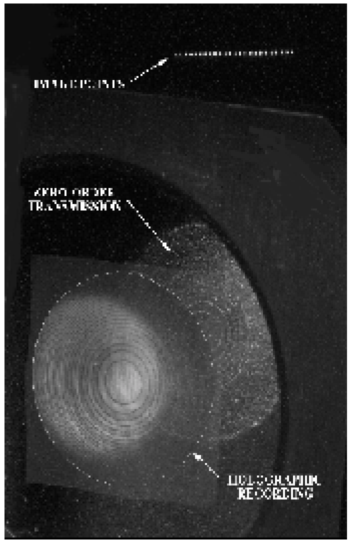
Objectives:

- Develop and demonstrate a high-efficiency, photon-counting, all-solid-state detection subsystem for use with Fabry-Perot interferometers (FPI)
  - Primary application is for use in lidar remote sensing applications, where spectral resolution is required; but can also be used in passive sensing applications
- Reduce cost and complexity of measuring Fabry-Perot interference fringes while simultaneously simplifying optical alignment and increasing detection efficiency
- Demonstrate subsystem performance in a configuration suitable for inclusion in future airborne instruments, with a long-term goal of inclusion in the ACE mission



Holographic Circle-to-Point Converter (HCPC) showing the resulting array of image points.

If the incident light contains spectral content, then the image points will contain the same spectral information.



Approach:

- Use the HCPC coupled with a linear array detector and associated detection electronics to:
  - Develop back-end electronics for detector and demonstrate proper performance
  - Demonstrate simultaneous detection on each channel with no cross-talk between channels
  - Demonstrate proper scanning of Fabry-Perot fringe pattern using laboratory lidar receiver simulator
- Leverage previous investments by SBIR and IRAD

Co-Is/Partners:
Stan Scott, Shane Wake, GSFC

Key Milestones:

• Complete preliminary design of control software and optical and electrical systems	04/09
• Demonstrate >20MHz count rate per channel in detector electronics	07/09
• Demonstrate zero optical and electrical cross-talk in subsystem	04/10
• Complete scanning of FPI fringe pattern	01/11
• Complete end-to-end functional test	01/11

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

Strategic Investments toward Lidar Detectors for ACE

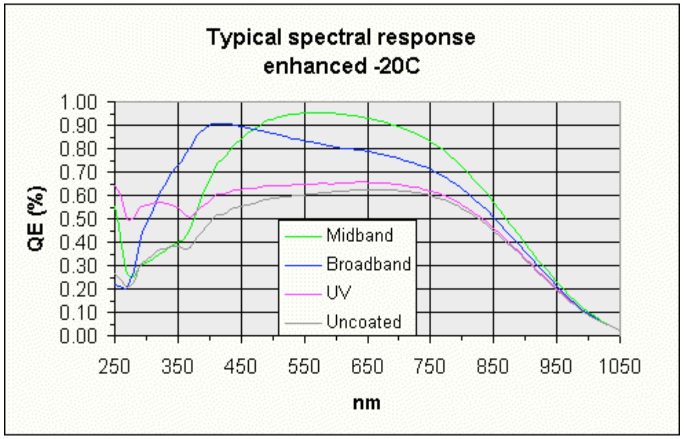
PI: Chris Hostetler, NASA LaRC

Objectives:

Develop high quantum efficiency electron-multiplying CCD detectors suitable for lidar applications in support of the Aerosols Clouds and Ecosystems (ACE) mission.

- High QE, low noise detectors are needed to reduce the size, power, and cost of the advanced aerosol/cloud lidar

- Develop the engineering heritage on devices and read out circuitry to help guide future industry partners on the development of detectors customized for the ACE lidar application.



QE of enhanced CCD detectors produced by e2V: >90% QE at both 355 and 532 nm, the most critical wavelengths for the ACE lidar. For comparison, the QE of the 532 nm PMT used on CALIPSO is ~10%.

Approach:

- Procure and characterize two state-of-the-art COTS electron-multiplying charge couple device CCD (EMCCD) cameras. Evaluate
  - QE, Gain, Noise performance
  - Speed of binning, moving, and digitizing signals
- Develop read-out integrated circuit (ROIC) for a bare COTS EMCCD detector
- Characterize EMCCD + custom ROIC combination as lidar detector
- Develop requirements for custom EMCCD+ROIC optimized for lidar detection

Co-Is/Partners:

Bill Luck, Charles Antill, NASA LaRC.

Key Milestones:

- Procure COTS EMCCD cameras and bare detector 01/09
- Complete characterization of EMCCD cameras 04/09
- Begin development of brassboard ROIC 05/09
- Complete brassboard ROIC 08/09
- Characterization of EMCCD + custom ROIC 08/09

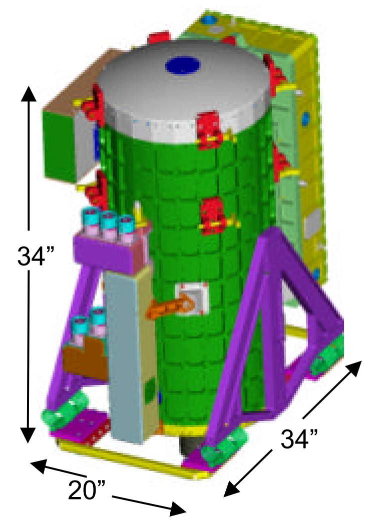
TRL_{in} = 3 $TRL_{current}$ = 3

Technology Development for a Combined HSRL and O_3 DIAL Lidar

PI: Chris A. Hostetler, NASA LaRC

Objectives:

- Develop transmitter and receiver technologies suitable for a combined High Spectral Resolution Lidar (HSRL) and Differential Absorption Lidar (DIAL) instrument to measure tropospheric aerosols and ozone.
- Enable unique and important measurements of ozone and aerosol optical & microphysical properties from space-based and advanced airborne platforms (e.g., UAVs) in support of the ACE Decadal Survey Mission.



Compact O_3 DIAL and HSRL Lidar Instrument Concept

Approach:

- Develop a diode-pumped , conductively cooled pump laser suitable for a combined DIAL and HSRL transmitter
- Develop a tunable UV Optical Parametric Oscillator (OPO) laser mated to the pump laser.
- Develop a high efficiency ozone DIAL aft optics receiver module.
- Evaluate and develop 355nm interferometric receiver breadboard for multi-wavelength HSRL measurements.
- Demonstrate a combined laser transmitter for multi-wavelength HSRL and O3 DIAL measurements

Co-Is/Partners:
Edward Browell, Johnathan Hair – NASA LaRC
Thomas McGee –NASA GSFC
Fibertek Inc, ITT Industries, Welch Mechanical Design

Key Milestones:

• Complete Ozone Receiver	05/07
• Complete Pump Laser Transmitter	09/07
• Complete Non Linear Optics (NLO) Module	12/07
• Integrate and Characterize Pump Laser and NLO	02/09
• Complete Interferometric HSRL Receiver	06/09
• Complete HSRL and Ozone System Integration	11/09
• Complete Ground and Flight Tests	12/09

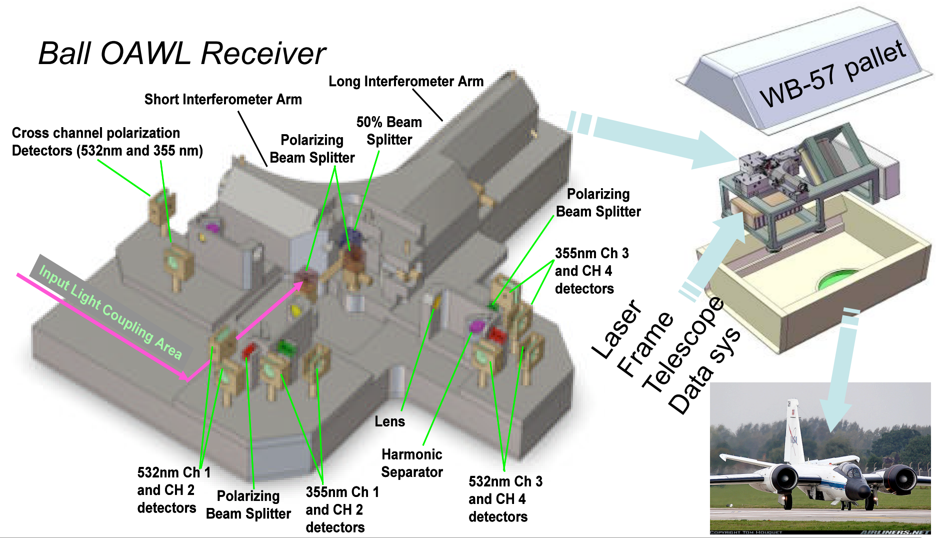
TRL_{in} = 4 $TRL_{current}$ = 4

Development and Demonstration of an Optical Autocovariance Direct Detection Wind Lidar

PI: Christian J. Grund, Ball Aerospace & Technologies Corp.

Objectives:

- Develop a complete Optical Autocovariance Wind Lidar (OAWL) transceiver for airborne testing in support of the 3D WINDS Decadal Survey Mission.
  - Validate OAWL performance by comparing WB-57 flight data with NOAA wind profilers and other corroborative measurements.
  - Verify alignment-free interferometer construction is suitable for space qualified design.
  - Validate radiometric and integrated system performance models for space-based OAWL.



Approach:

- Use science advisory board to ensure relevance.
- Test and adapt the Ball OAWL 2I receiver for aircraft operation.
- Design/fabricate a complete lidar system.
- Ground test against wind profiler and/or radiosondes and/or other ground-based Doppler Wind Lidar.
- Ruggedize system for autonomous flight.
- Flight test on WB-57.
- Corroborate against wind profilers. Validate space-based radiometric and integrated system models against test data.

Co-Is/Partners: None

Key Milestones:

- Preliminary design review 08/08
- Science advisory board established 04/09
- Receiver environmental testing 05/09
- Critical design review (system) 04/09
- System integration complete 10/09
- Ground testing complete 12/09
- Airborne mods and autonomous control 05/10
- Flight Readiness Review 09/10
- Airborne testing complete 10/10
- OAWL flight performance report 12/10
- Space-based system models validated 03/11

TRL_{In} = 3 $TRL_{current}$ = 3

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Information Systems Technologies

(Current and Completed ESTO Investments)

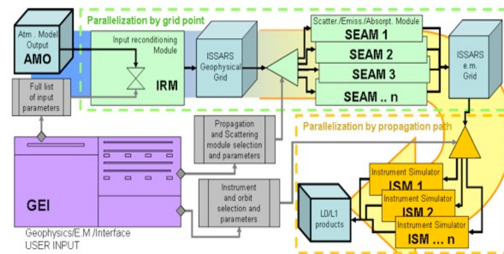
Instrument Simulator Suite for Atmospheric Remote Sensing (ISSARS)

PI: Simone Tanelli, JPL

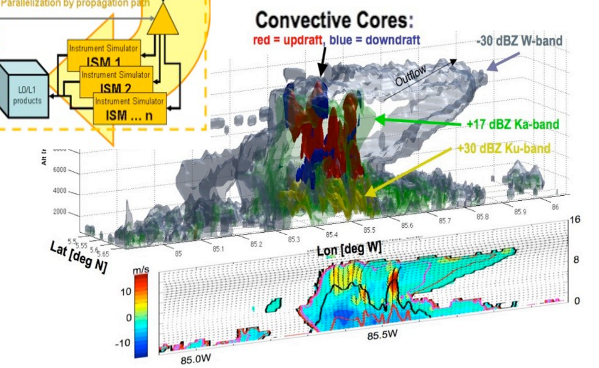
Objectives:

Develop ISSARS as a service-based tool suite that provides simulated measurements for a wide range of instruments aimed at remote sensing of the atmosphere, on missions such as ACE, GPM, A-Train, NIS and others, based on input from atmospheric models. It will enable:

- Immediate and accurate verification of the achievability of desired scientific requirements
- Efficient implementation of multi-instrument, multi-platform Observing System Simulation Experiments (OSSE's)
- Rapid integration of new models
- Efficient and accurate performance assessment of on-board or at-ground processing methods to achieve scientific requirements given available hardware and financial resources



ISSARS high-level block diagram & example of output



East Pac ITCZ: July 24, 2007 (Field Experiment: TC4, Model WRF 333m 3D-turb closure)

Approach:

- Build ISSARS with state-of-the-art IT technologies to allow easy configuration of instrument designs by a user-friendly GUI front-end.
- Develop a web-services interface for instrument models.
- Adopt a modular architecture to handle independently the geophysical, scattering, and propagation modules, consistently among all the simulated instruments.

Co-Is/Partners:

Co-Is: Peggy Li and Joseph Jacob, JPL; Chris Hostetler, LaRC; Kwo-Sen Kuo, Caelum Research Corp.; Wei-Kuo Tao and Toshihisa Matsui, GSFC.

Key Milestones:

• Infrastructure design completed	10/09
• Initial geophysics electromagnetic interface	04/10
• Input reconditioning module completed	10/10
• Integrate Scattering/Emission/Absorption module	04/11
• Complete Discrete Dipole Approximation (SEAM)	08/11
• Complete Radar/Radiometer Instrument Modules	08/11
• Complete Lidar/Polarimeter Instrument Modules	12/11
• ISSARS testing completed	02/12
• ISSARS release	04/12

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

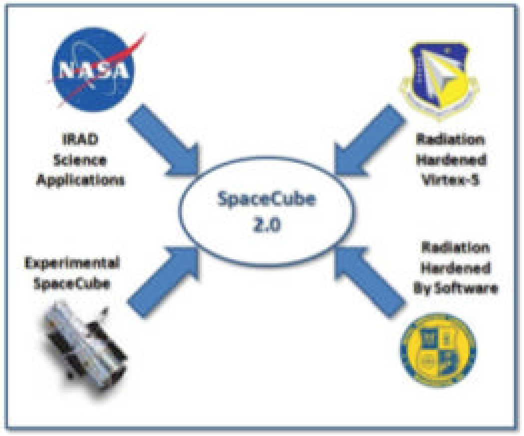
Advanced Hybrid On-Board Data Processor – Space Cube 2.0

PI: Tom Flatley NASA/GSFC

Objectives:

•Develop advanced on-board processing to meet requirements of Decadal Survey missions advanced instruments such as hyper-spectral and synthetic aperture radar (SAR) to facilitate:

- •timely conversion of ES "data" into ES "information"
- •reconfiguration or adaptation while in progress (on-the-fly)
- •detection and reaction to events
- •production of data products on-board for direct downlink, quick look, and "first responder" real-time awareness
- •sensor web multi-platform collaboration
- •on- board "lossless" data reduction by moving "ground" functions on-board
- •NASA supported missions such as ACE, DESDynI, GEO-CAPE, HyspIRI, ICESat-II, LIST, SCLP, SWOT, and 3D-Winds



Technology collaborations between NASA, Air Force Research Lab and NRL converge to produce SpaceCube 2.0

Approach:

- Design, build, and test a SpaceCube 2.0 system based on new radiation hardened Virtex-5 parts
  - V-5 devices will eliminate 95% of the mitigation issues and 100% of the "critical" upset scenarios associated with the SpaceCube 1.0 Virtex-4 parts
- Couple with "radiation hardened by software" techniques to deliver a flight-worthy system that approaches the on-orbit performance of full radiation hardened systems

Key Milestones:

- Software & breadboard design 11/09
- ETU design & software testing 12/10
- ETU testing & application integration 10/11
- System integration and test complete 03/12

Co-Is/Partners:
Gerald Heymsfield, GSFC

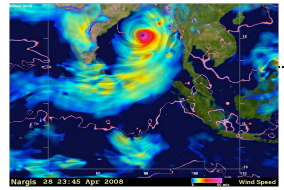
TRL_{in} = 4 $TRL_{current}$ = 4

Coupling NASA Advanced Multi-Scale Modeling and Concurrent Visualization Systems for Improving Predictions of Tropical High-Impact Weather (CAMVis)

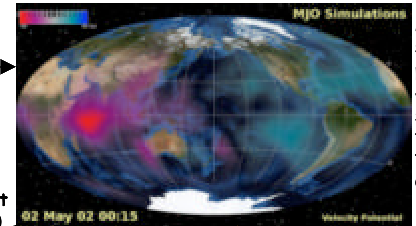
PI: Bo-Wen Shen, UMD/ESSIC

Objectives:

- Develop CAMVis weather prediction tool to improve predictions of tropical high-impact weather systems.
- The tool will seamlessly integrate NASA technologies
  - Advanced supercomputing (Pleiades)
  - Concurrent visualization (CV)
  - Multi-scale (i.e., global, meso, cloud scale) modeling system, the NASA finite-volume Multi-scale Model Framework (fvMMF)
- The goal is to improve the understanding of the roles of atmospheric moist thermodynamic processes (i.e., the changes of precipitation, temperature, and humidity) and cloud-radiation-aerosol interactions. CAMVis will support the decadal survey missions CLARREO, ACE, PATH, and 3D-Winds.

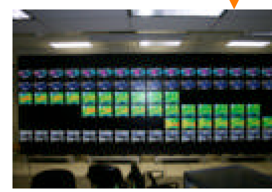


fvGCM, showing a 7-day forecast of tropical cyclone Nargis (2008) and westerly wind belt in the Indian Ocean

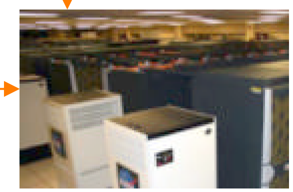


Multiscale modeling system, simulating planetary-scale Madden-Julia Oscillation. The system consists of the fvGCM and tens of thousands copies of GCEs.

GCE, simulating high-fidelity clouds motions



Concurrent visualization (CV) system on the 128-panel hyperwall-2



Pleiades supercomputer with 51,200 cores

Approach:

- Improve parallel scalability of the multi-scale modeling system to take full advantage of the next-generation peta-scale supercomputers (e.g., NASA Pleiades)
- Integrate NASA fvMMF (which includes Goddard Cloud Ensemble model (GCE) and the finite-volume General Circulation Model (fvGCM)), and the concurrent visualization (CV) system
- Significantly streamline data flow for fast post-processing and visualizations
- Conduct high-resolution numerical simulations and visualizations for high-impact tropical weather events
- Test coupled systems

Co-Is/Partners: Wei-Kuo Tao, GSFC; Bryan Green, Chris Henze, Piyush Mehrotra, ARC; Jui-Lin Li, Peggy Li, JPL; Antonio Busalacchi, UMD

Key Milestones:

- Implement/update model components and CV on Pleiades Columbia supercomputer; run benchmarks 09/09
- Improve parallel scalability of model components; Integrate the NASA fvGCM and CV; Develop super-component meta global GCE (mgGCE) 03/10
- Couple the NASA mgGCEs and CV Implement and test an I/O module 09/10
- Integrate the fvMMF (GCEs, fvGCM) and CV 03/11
- Streamline data flow for production runs 09/11
- Test CAMVis system; Produce results 03/12

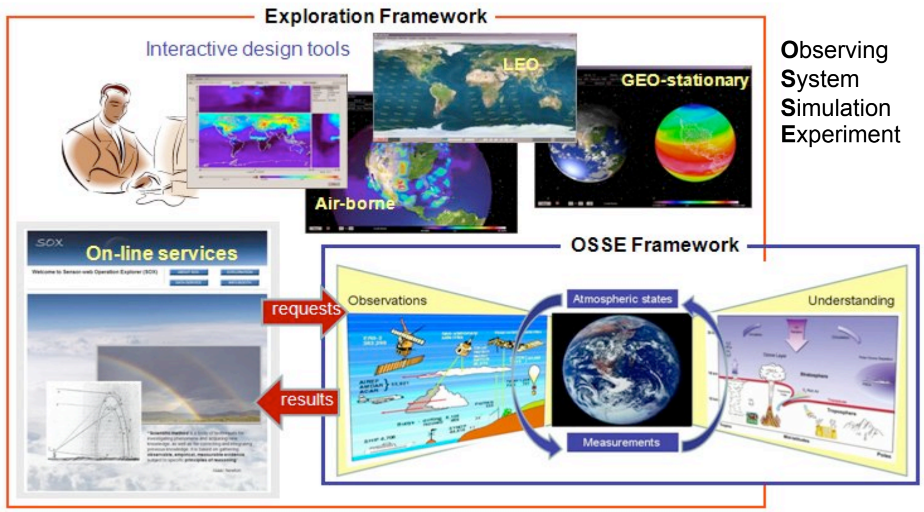
TRL_{in} = 3 $TRL_{current}$ = 3

Sensor-Web Operations Explorer (SOX)

PI: MeeMong Lee, JPL

Objectives:

- Enable adaptive measurement strategy exploration on a sensor web for rapid air quality assessment.
- Provide a comprehensive sensor-web system simulation with multiple sensors and multiple platforms.
- Provide a quantitative science return metric that can identify where and when specific measurements have the greatest impact.
- Provide a collaborative campaign planning process among distributed users.



Approach:

- Develop multi-disciplinary frameworks and link observation simulations, reference models, science retrieval and analysis algorithms, data assimilation software, forecasting code, and assessment code.
- Develop scalable system modules with asynchronous interface protocols and create a "system of systems" providing flexible system configuration and operation.

Co-Is/Partners

Charles Miller, Kevin Bowman, Richard Weidner, JPL; Adrian Sandu, Virginia Tech

Key Milestones:

- Software architecture design 03/06
- Interface definitions 02/07
- Single-platform SOX system deployment 09/07
- Air-borne sensor-web simulation 03/08
- Dual-platform campaign planner 06/08
- Dual-platform SOX service deployment 11/08
- In-situ sensor-web configuration 03/09
- Multi-platform campaign planner 06/09
- Multi-platform SOX system deployment 09/09

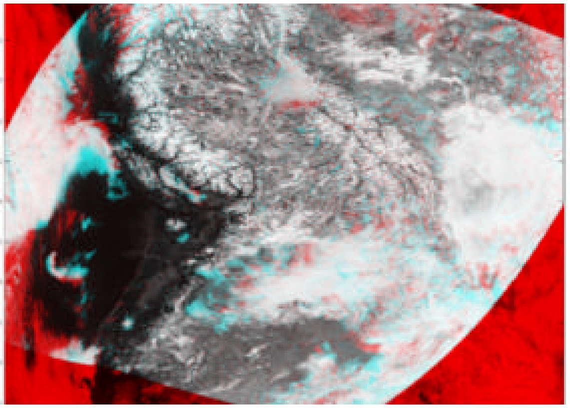
TRL_{in} = 2 $TRL_{current}$ = 4

Adaptive Sky

PI: Michael Burl, JPL

Objective:

- Enable observations from multiple sensing assets (satellites, in-situ sensors, etc.) to be dynamically combined into "sensor webs".
- Develop an efficient, trusted C-language feature correspondence toolbox that serves the sensor web community as LINPACK (LINear algebra PACKage) has served the numerical computing community.
- Demonstrate fusion of multi-instrument observations into novel data products of high scientific value.



Automatic registration between images taken 100 minutes apart with the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on Aqua (cyan) and the twin MODIS instrument on Terra (red).

Accomplishments:

- Detailed scientific use scenarios – Earth Observing System (EOS) match-ups, combining satellite and ground-based cloud imagery, volcanic plume and ash cloud monitoring, Southern California Fires, etc.
- Developed a toolbox that other sensor web projects can use to compare data
- Successful application of techniques to real data:
  - Detection and tracking of clouds in ground imagery using Maximally-stable Extremal Region (MSER) features.
  - Identification and automatic registration of A-Train and Terra coincidences.
  - Automatic stabilization of Geostationary Operational Environmental Satellite (GOES) image sequences.
- Demonstration of multi-instrument fusion within Google Earth – lidar observation of volcanic ash cloud.

CoI: Michael J. Garay (Raytheon)

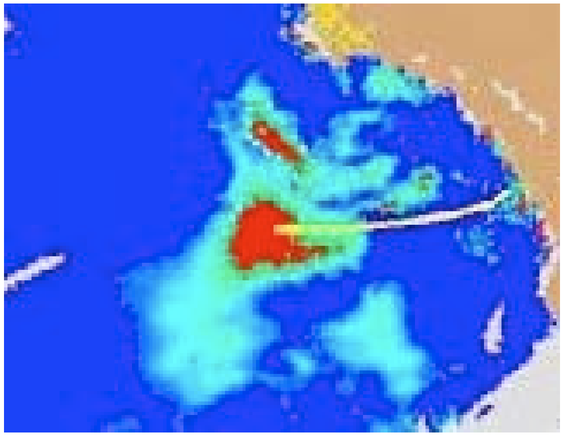
$\mathbf{TRL_{in} = 3}$ $\mathbf{TRL_{out} = 4}$

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: Richard Stumpf, NOAA

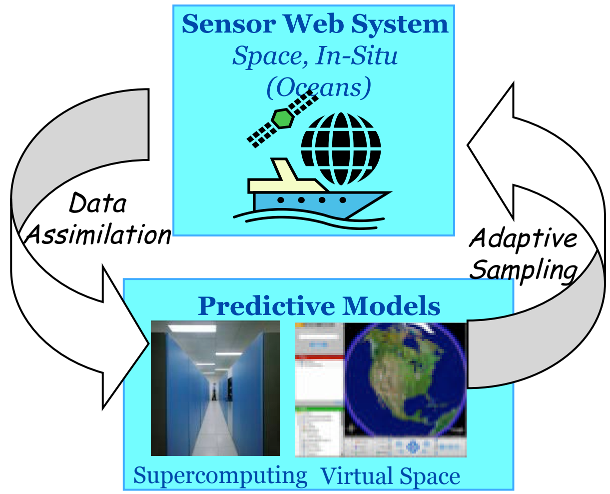
TRL_{in} = 4 **TRL_{out} = 6**

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

PI: Payman Arabshahi, University of Washington (UW)

Objectives:

- 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. Key features include
  - reconfiguration of sensor assets
  - adaptive sampling, targeted observations
  - autonomous event detection,
  - built-in navigation on mobile nodes (Seagliders),
  - high-bandwidth, high-power observation on cabled seafloor and stationary nodes.
- Perform science experiments in Puget Sound or Monterey Bay, enabled by such a network, and evolve them to growing levels of sophistication over 3 years.



Semi-closed loop dynamic smart ocean sensor web architecture

Approach:

- Develop a comprehensive acoustic sensor network architecture, engineering model, and telecom protocols, including features and evaluation performance metrics.
- Develop a full and accurate software simulation environment, incorporating network element models, and the developed protocols.
- Perform laboratory tests and ocean sensor web data collection experiments.
- Develop the interface between the ocean smart sensor web and the Regional Ocean Modeling System (ROMS) predictive model, operate it in near real-time, assimilating acoustic measurements.

Co-Is/Partners:

Andrew Gray, AGCI Inc; Yi Chao, JPL/UCLA;
Sumit Roy, UW; Bruce Howe, University of Hawaii

Key Milestones:

• Prepare satellite sensor data for Monterey Bay	03/07
• Software demonstration of 2-element network	09/07
• Architecture description document	09/07
• Test and refine the ROMS prediction	03/08
• Develop MAC and network layer protocols	05/08
• Full-scale software demonstration, modeling of network elements, and a 4-element network	07/08
• Ocean sensor web experiments at Monterey Bay	01/09
• Demonstration of first prototype of integrated satellite/acoustic sensor network	01/09
• Complete data analysis from field demonstration	08/09

$TRL_{in} = 3$ $TRL_{current} = 5$

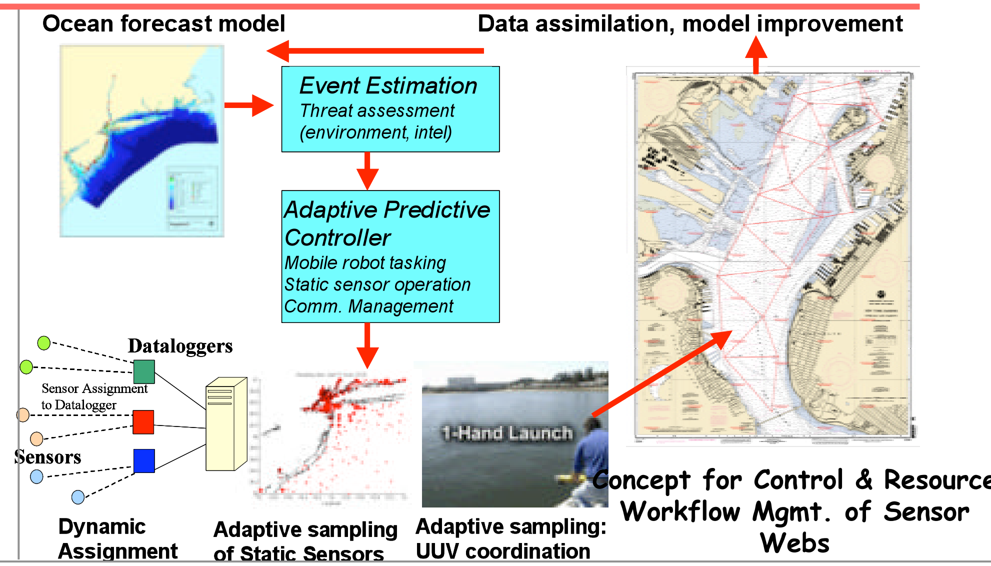
Autonomous In-situ Control and Resource Management in Distributed Heterogeneous Sensor Webs (CARDS)

PI: Ashit Talukder/Jet Propulsion Laboratory

Objective:

Design, implement and test model-based control tools in the existing New York Harbor Observation and Prediction System (NYHOPS) sensor web with the following primary task objectives:

- Adaptive in-situ control of multiple resources in heterogeneous spatially distributed sensor webs
- Model based event detection and prognosis from distributed sensor measurements
- Off-line science validation of NYHOPS sensor web operational autonomy and control with CARDS
- Adapt the sensor web to study plumes, coastal storm surges for advanced warning and improved analysis



Accomplishments:

- Developed Model Predictive Control framework to adaptively manage real-time resources of a variety of fixed & mobile assets with limited resources to increase predictive power of existing ocean model
- Reduced wireless data transmission costs by 38% using adaptive relay station assignment
- Event detection algorithm designed for unexpected freshwater flow events
- Quantified model uncertainty for use in event detection
- Controlled path of unmanned underwater vehicles so as to maximally increase the utility of their sensor measurements
- Validated above adaptive resource management solution on real coastal NYHOPS sensor web data
- Visualize sensor web data & control outputs in 3-D using Google Earth.
- Implemented Metrics to quantify performance of sensor web control technique

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

Telesupervised Adaptive Ocean Sensor Fleet

PI: John M. Dolan, Carnegie Mellon University (CMU)

Objectives:

- 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
- Establish sensor web capability combining ocean-deployed and space sensors
- Provide manageable demands on scientists for tasking, control, and monitoring

Telesupervised Adaptive Ocean Sensor Fleet investigating a Harmful Algal Bloom (simulated with water-tracing dye).

Approach:

- Telesupervise a networked fleet of NOAA surface autonomous vehicles (OASIS)
- Adaptively reposition sensor assets based on environmental sensor inputs (e.g., concentration gradients)
- Integrate complementary established and emergent technologies (System Supervision Architecture, Inference Grids, Adaptive Sensor Fleet, Instrument Remote Control, and OASIS)
- Conduct 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; John Higinbotham, Emergent Space Technologies

Key Milestones:

• Interface Definition Document	02/07
• Test components on one platform in water	05/07
• Autonomous multi-platform mapping of dye	07/07
• Science requirements for Inference Grid	02/08
• Multi-platform concentration search simulation	05/08
• HAB search in estuary for high concentration	07/08
• Moving water test plan & identify location	02/09
• Simulate test using in-situ and MODIS data	05/09
• Use MODIS data to target and reassign fleet	07/09

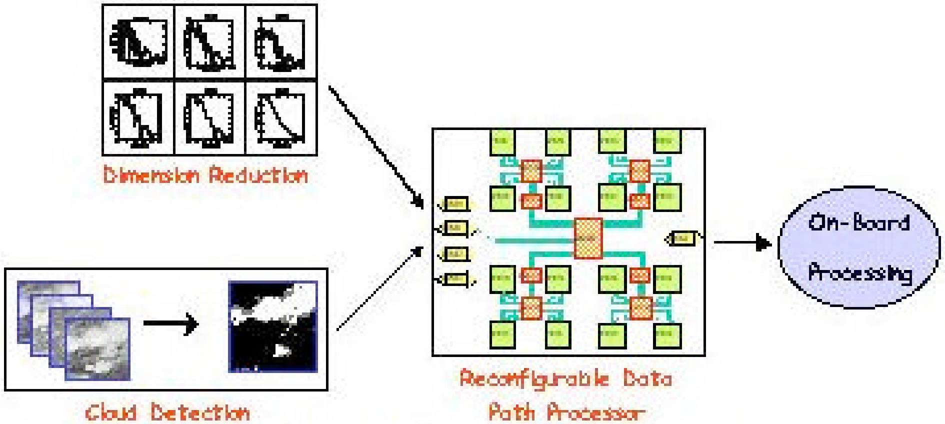
TRL_{in} = 4 $TRL_{current}$ = 6

A Reconfigurable Computing Environment for On-Board Data Reduction and Cloud Detection

PI: Jacqueline Le Moigne, GSFC

Objective:

- Investigate the use of reconfigurable computing for on-board automatic processing of remote sensing data.
- Use Reconfigurable Data Path Processor/Field Programmable Path Array (RDPP/FPPA), a radiation tolerant alternative to Field Programmable Gate Arrays, developed at NASA/Goddard and U. of Idaho as the computation engine of our study.



Reconfigurable Data Processing

Accomplishments:

- Performed Algorithms Tradeoff Studies
- Applied and Validated Dimension Reduction to Hyperspectral AIRS Data
- Designed a Flexible FPPA Reconfigurable Processing Testbed ; Designed FPPA Graphical Design Environment
- Performed Algorithm implementation study
- Developed New FPPA Technology Advances/Method &Pilot Software for Accurate Mathematical Computing on Integer Hardware
- Implemented Wavelet-Based Hyperspectral Dimension Reduction on SRC-6: 32X Speedup
- Implemented Automatic Cloud Cover Assessment (ACCA) on SRC-6: 28X Speedup and less than 1% Error Over Water
- Implemented Automatic Image Registration in SRC-6: 4X Speedup

CoIs: P.S. Yeh, J. Joiner, GSFC; W. Xia, GS&T
G. Donohoe & Team, U. Idaho; T. El-Ghazawi & team, GWU

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

ESTO Earth Science Technology Office