A Forest Fire Sensor Web Concept with UAVSAR

Yunling Lou, Steve Chien, Duane Clark, Joshua Doubleday, Ron Muellerschoen, Sassan Saatchi, Daniel Tran, Yang Zheng

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

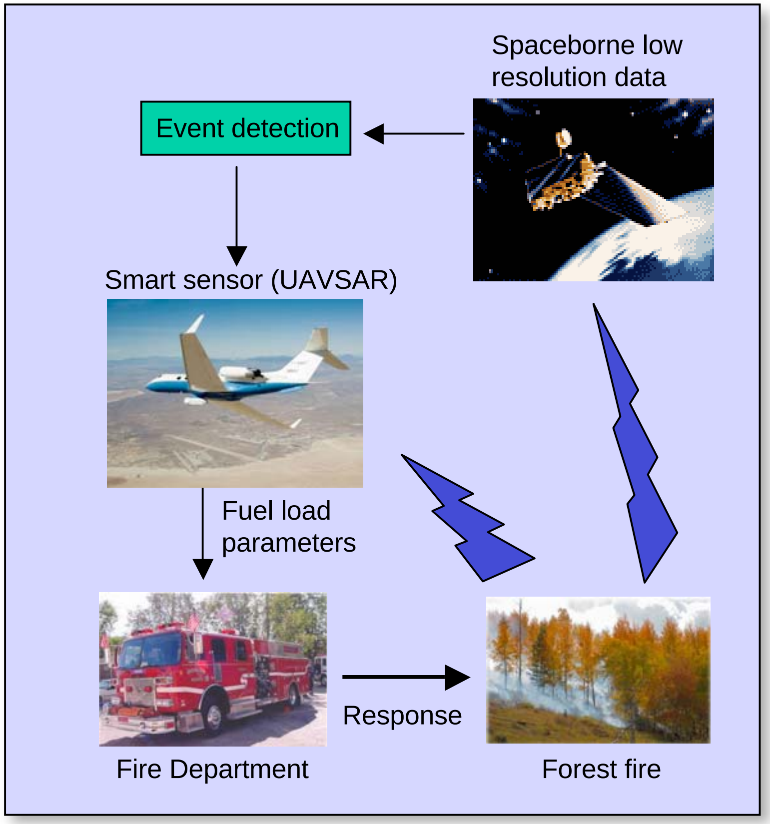
NASA Earth Science Technology Conference
24-26 June, 2008
College Park, Maryland

Agenda

- Objective
- Motivation
- Smart sensor architecture
- Overview of smart sensor development
- Current status
- Summary

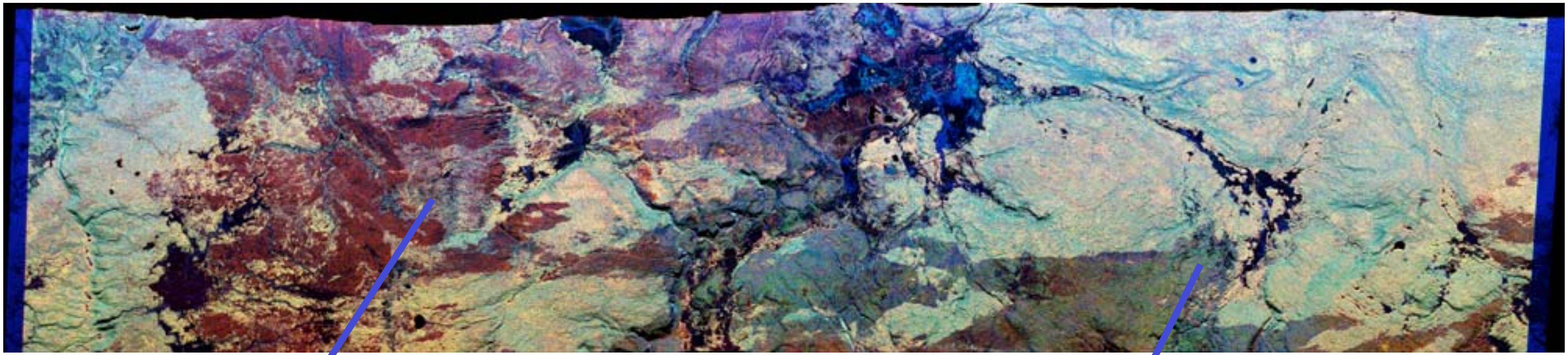
Objective

- Improve the fidelity of a previously developed AIST onboard SAR processor by including:
  - Polarimetric and interferometric calibration
  - Science algorithms for detecting and monitoring fire disturbances
  - Artificial intelligence for decision making, and onboard data acquisition replanning capability
- The product of this development is a prototype smart sensor for demonstration on NASA's UAVSAR, a compact, L-band polarimetric repeat-pass InSAR



The detection and response architecture of a forest fire sensor web

AIRSAR Data over Yellowstone National Park



R: LHH, G: LHV, B: LVV

2003 Burn

1988 Burn

Motivation for Autonomous Disturbance Detection & Monitoring System (ADDMoS) with UAVSAR

- Develop a smart sensor that combines the unique capabilities of imaging radar with high throughput onboard processing technology and onboard automated response capability that will enable us to detect/monitor disturbances due to:
  - forest fire
  - hurricane
  - volcanic eruptions (lava and lahar flows)
  - flooding
  - soil moisture
  - ground freezing and thawing
  - ship channel freezing and thawing
- The ***timeliness*** of the smart sensor output can be used for disaster management, agricultural irrigation, and transportation such as shipping
- Onboard automated response will greatly reduce the operational cost of the smart sensor by ***reducing onboard data storage and downlink data rate while maximizing science observations***
- This smart sensor technology is well suited for space flight missions and different science algorithms can be used for a variety of disturbances

Relevance of ADDMoS to Future Missions

The ADDMoS technology is directly applicable to future radar missions or mission concepts listed below:

Missions/ Concepts	Instruments	Measurements	Benefits of Onboard Processing
SMAP	L-band radar & radiometer	soil moisture and freeze/thaw	Deliver timely data products to users, maximize observations
DESDynI	L-band InSAR, laser altimeter	surface and ice sheet deformation	Reduce downlink data volume with partial onboard processing and adaptive observations
XOVWM	scatterometer	sea surface wind vectors	Deliver timely data products for weather forecasting
SWOT	Ka-band wide swath radar, C-band radar	ocean, lake and river water levels	Reduce downlink data volume
SCLP	Ku-band radar, X-band radar	snow accumulation for fresh water availability	Reduce downlink data volume, deliver timely data products to users
Europa Topomapper	Ka-band Single-Pass InSAR	topographic mapping of planetary surface	Reduce onboard data storage, reduce downlink data rate to < 670 kbps

CASPER Onboard Planner

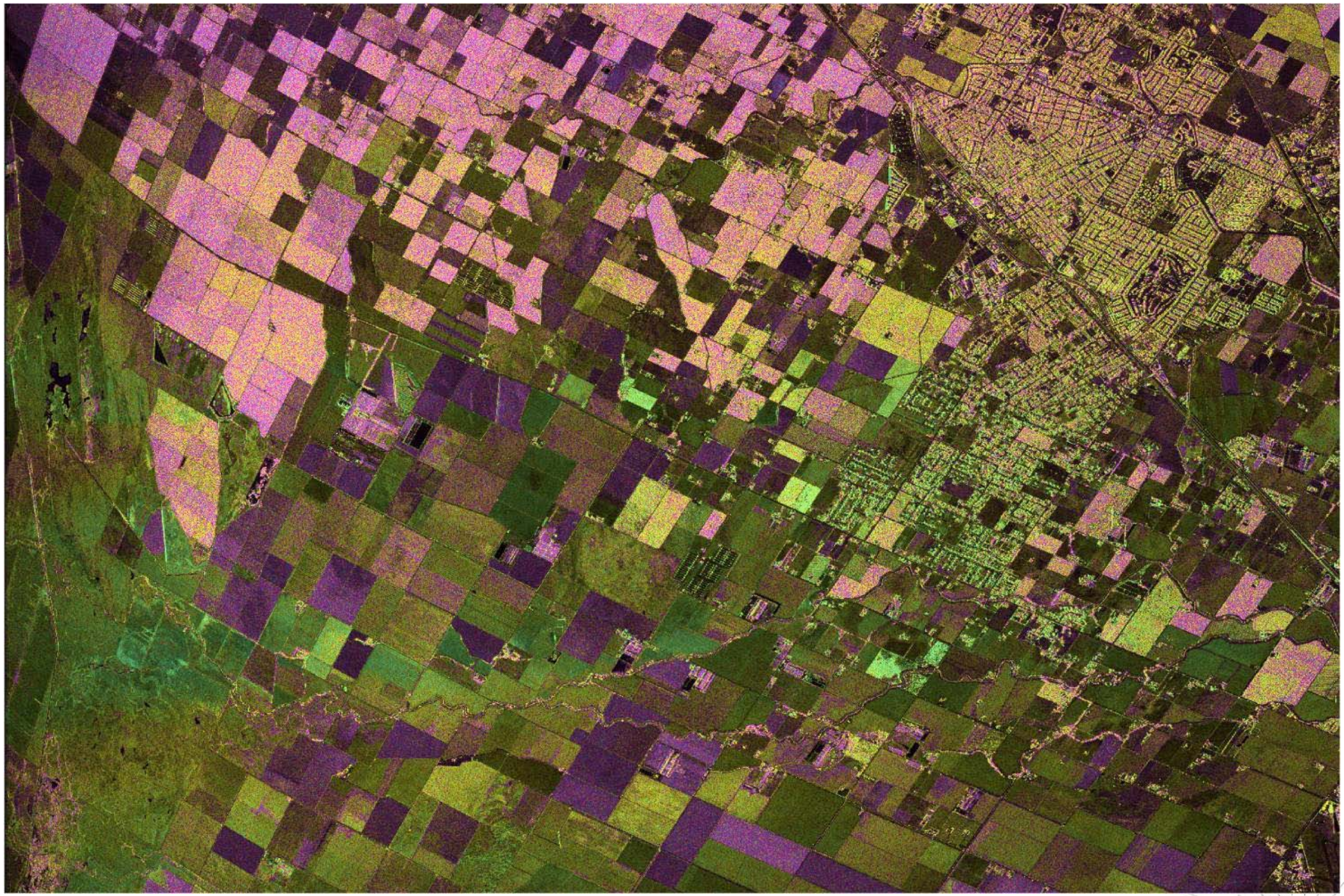
- Heritage:
  - CASPER flown on EO-1 (Earth Observation) and Three Corner Sat Missions
  - Ground use for several missions– MAMM (Modified Antarctic Mapping Mission), Orbital Express
- Approach:
  - Uses a declarative model of operations activities and required states, resources to derive plans
- For UAVSAR application, will interface with
  - Radar Operator Workstation (ROW) – CASPER will derive new flight paths based on data analysis, mission goals, GPS location information, and available resources
  - Automatic Radar Controller (ARC) – ARC will execute new flight plan from the ROW
  - Aircraft Autopilot – to allow transfer to flight system

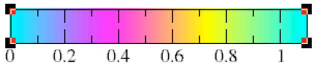
UAVSAR System Characteristics

Parameter	Value
Frequency	L-Band 1217.5 to 1297.5 MHz
Bandwidth	80/100 MHz Chirp/Noise
Resolution	1.67 m Range, 0.8 m Azimuth
Polarization	Full Quad-Polarization
ADC Bits	1 to 12 bit selectable BFPQ, 180Mhz
Waveform	Nominal Chirp/Arbitrary Waveform
Antenna Aperture	0.5 m range/1.5 azimuth (electrical)
Azimuth Steering	Greater than ±20° (±45° goal)
Transmitter Power	> 3.1 kW
Polarization Isolation	<-20 dB (<-30 dB goal)

California Central Valley Repeat Pass Coherent Change Detection

- Correlation map from a portion of two passes collected over the California Central Valley on March 24 and 31 of 2008. Note changes are highly correlated with field boundaries.





Fire Fuel Estimation over Complex Terrains

Original Parameters:

Canopy fuel weight:

The biomass of the canopy including foliage and thin branch wood. This is often computed for forest tree species using allometric equations.

Canopy bulk density:

The mass of available canopy fuel per unit canopy volume. This is an important parameter to predict both the crown fire initiation and spread.

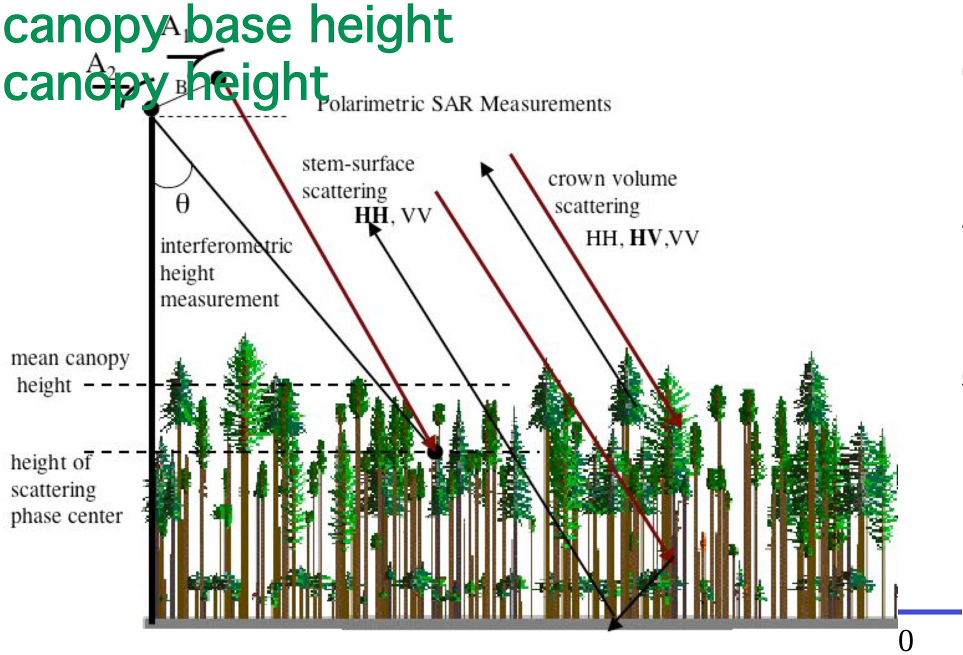
Foliage moisture content:

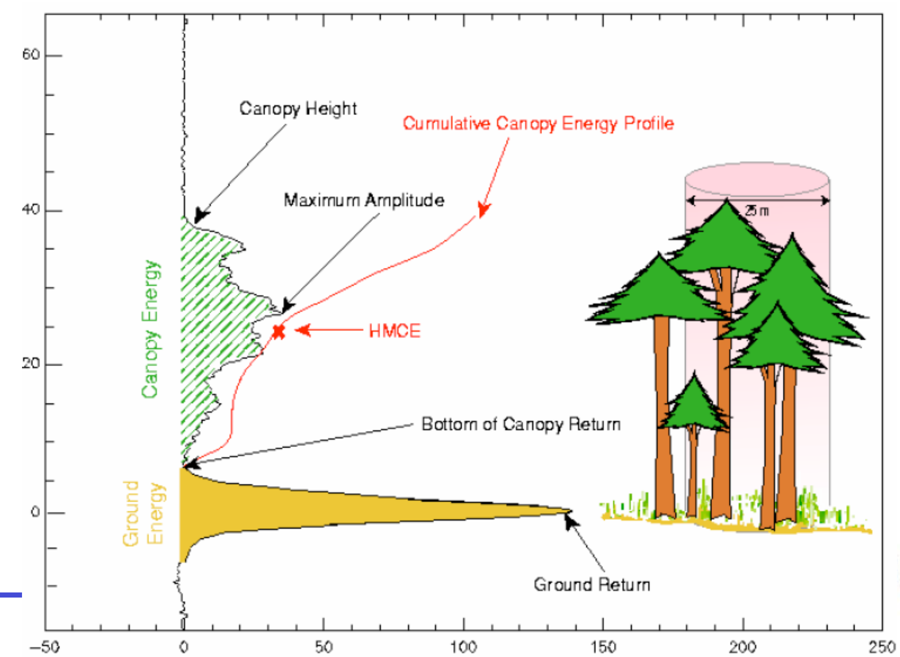
Important parameter for fire spread and initiation measured on seasonal basis.

Improvements:

canopy base height

canopy height





Sensor Web Enablement

- Open Geospatial Consortium (OGC) defines standards for interoperability between multi-assets and processing chains (workflows)
  - SAS: Sensor Alert Service informs registered parties of varying conditions on observed data
  - SOS: Sensor Observation Service provides requested observation data sets
  - SPS: Sensor Planning Service allows a workflow/user to request and execute sensor activities/observations
  - WPS: Web Processing Service provides data transformations, classifications and other processing routines on well defined sets of data
- Services can be orchestrated through Web Service workflow technologies
- EO-1, and in-situ Volcanic (Kilauea) Sulfur sensors have these services in operation

Forest Fire Sensor Web Concept

MODIS RapidFire

UAVSAR triggered on alert (SAS)

Schedule new UAVSAR data-take (UAVSAR SPS)

DEMs and historical Vegetation Maps prepared/obtained (Other OGC SOSs)

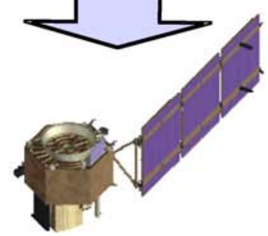
Flight Begins. Autonomy or new requests alter flight plan (SPS)

Real-time Fuel-Load Maps generated and alert sent (SAS)

Flight Ends

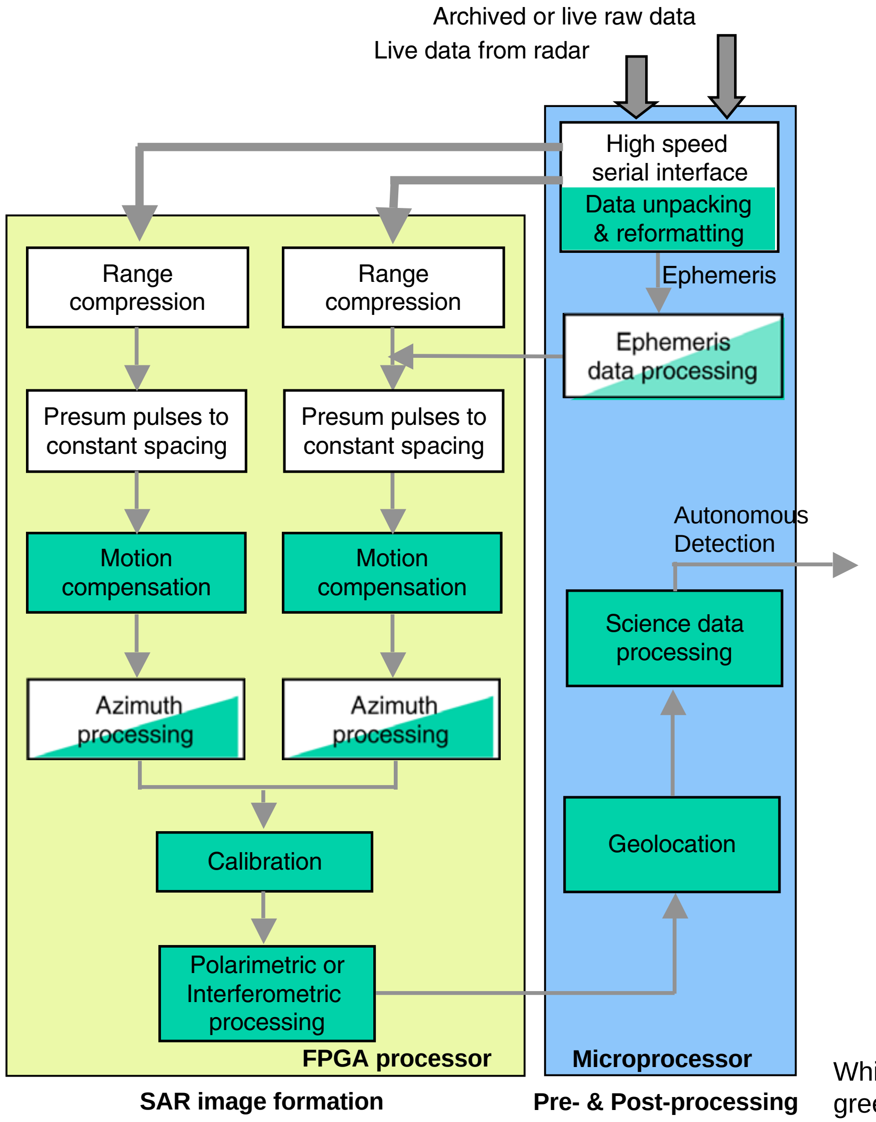
Full SAR data made available and alert sent (SOS, SAS)

UAVSAR continues to replan and track fire



Precise fire location enables autonomous response of other assets such as EO-1 to also acquire fire data

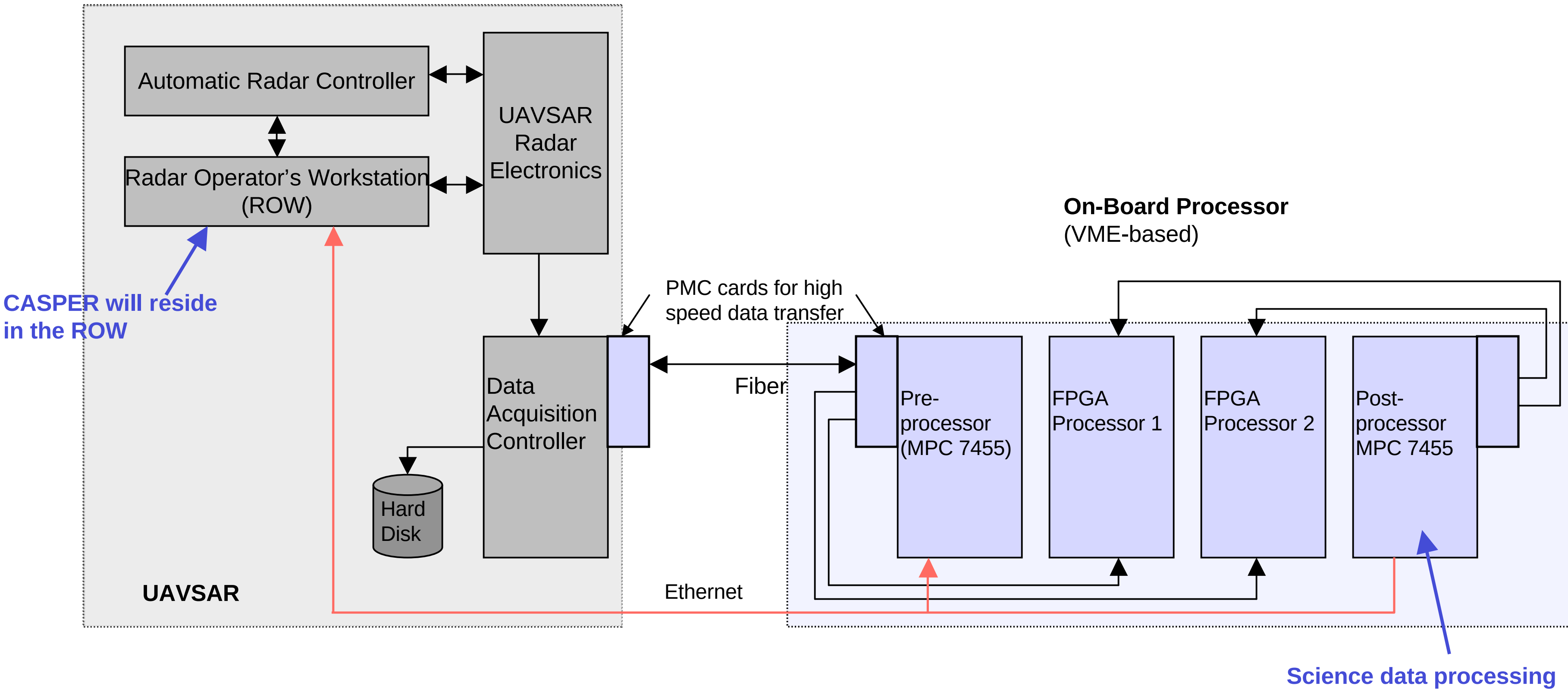
Functional View of Onboard Processor



- Range compression focuses the image in the cross track direction
- Presumming resamples the pulses to a user-specified along track location and spacing to reduce the number of pulses to process in the along track direction while reducing the noise on each pulse
- Motion compensation is the process where the radar signal data are resampled from the actual path of the antenna to an idealized path called the reference path. This process is necessary to align the phase centers of two data channels to the same reference path to ensure maximum correlation.
- Azimuth processing focuses the image in the along track direction
- Radiometric and phase calibration are necessary to generate polarimetric or interferometric science data products

White blocks are the existing capabilities and dark green blocks are the new capabilities we will develop in this task

High Level Architecture of the Smart Sensor



- Raw radar data, position and motion information (headers) flow into the On-Board Processor via the custom PCI-to-RocketIO interface (PMC cards or PCI Mezzanine Cards)
- The PMC card strips off the headers and sends them to the pre-processor while reformatting the raw data and routes them to FPGA processor 1 and FPGA processor 2 respectively
- FPGA processor 1 generates the LHH (L-band horizontal transmit horizontal receive polarizations) SAR image while FPGA processor 2 generates the LHV (L-band horizontal transmit vertical receive polarizations) SAR image
- LHH and LHV data are combined in the Post-processor to generate geo-rectified science data products
- Science data products are routed to the ROW via Ethernet
- CASPER (Continuous Activity Scheduling Planning Execution and Replanning software) takes the science data products, generates a new flight line to be merged with the current flight plan.

Overview of Smart Sensor Development (1 of 4)

SAR Onboard Processor (OBP)

- Modify the OBP hardware and software developed by our AIST-02 task to process UAVSAR data
  - Modify high speed data interface card to interface with UAVSAR's Data Acquisition Controller
  - Modify microprocessor and FPGA code to handle electronic beam steering and motion compensation
  - Calibrate gain and phase of onboard processor for dual-polarized L-band data
  - Ortho-rectify output imagery

Overview of Smart Sensor Development (2 of 4)

Onboard Autonomy Software

- Utilize CASPER (Continuous Activity Scheduling Planning Execution and Replanning software) onboard the UAVSAR as the main scheduler of data-taking activities
- Autonomous response process flow:
  - Read the current flight plan
  - Process a batch of Points-of-interest (POIs) generate by the fuel load map and weather predictions to determine the swaths for future data acquisition
  - Merge new flight plan with existing flight plan in the ROW. May require knowledge of current platform location and other platform-related constraints such as aircraft fuel, airspace clearance, pilot approval in the case of the Gulfstream-III aircraft, etc.

Overview of Smart Sensor Development (3 of 4)

Science Data Product Generation

- Modify science algorithms to work with UAVSAR data
  - Existing fuel load models require HH, HV, and VV polarization channels
  - The OBP can currently process two polarization channels in real time (HH and HV)
- Science data product generation flow:
  - Apply polarimetric calibrations to the high resolution imagery
  - Geolocate the imagery to an equi-angular surface
  - Estimate forest fuel load from the polarimetric data channels
  - Apply any ancillary data such as weather or terrain information
  - Generate points of interests (POIs) for the onboard autonomy software

Overview of Smart Sensor Development (4 of 4)

Communication Infrastructure onboard the UAVSAR:

- High rate raw data interface from the UAVSAR's data acquisition controller to the OBP
  - custom PCI-to-RocketIO interface
- Communication between CASPER and UAVSAR's Automatic Radar Controller and Radar Operator Workstation to update flight plan
  - Ethernet between the Linux laptop and single board computer
- External interface to receive Sensor Alert Service (SAS) and Sensor Observation Service (SOS) such as weather information as well as the transmission of low resolution science data products generated by the OBP to the ground-based users
  - Iridium satellite phone onboard the Gulfstream-III
  - ~2kbps data rate is sufficient for transmitting 30 - 50 m posting data and SAS to other sensors

Earth Science Technology Office

Development Status

- We are about half way through our 3-year development effort
- Development of the real-time SAR processor for UAVSAR is due to be completed by December 2008 (our focus thus far)
- Development of interface between the onboard autonomy software and UAVSAR's flight planning software is completed
  - Working on interface to the Radar Operator Workstation to update flight plan
- Forest fuel load algorithms were validated with AIRSAR data over Yellowstone
  - Need to modify algorithms to work with UAVSAR data
  - Plan to acquire UAVSAR data over California forests to validate algorithms
- Development of communication infrastructure nearly complete
  - Plan to demonstrate sensor web infrastructure with UAVSAR at the end of July
- Focus on year 3 will be:
  - Complete the real-time OBP development
  - Implement polarimetric calibration
  - Develop science data products
  - Complete software to retask UAVSAR with science triggers
  - Validate sensor web (see next page)

Sensor Web Validation Plan

We plan to validate the forest fire sensor web concept through the following steps:

- Acquire sample forestry data in Southern California with UAVSAR to validate the fidelity of the real-time SAR processor and science algorithms used for forest fuel load map generation.
- Use UAVSAR to demonstrate a closed loop smart sensor concept by retasking UAVSAR in flight based on results generated by the onboard SAR processor.
- Use UAVSAR as an element of a larger sensor web, including the EO-1 Hyperion (hyperspectral imager), IKHANA AMS (Autonomous Modular Scanner, a thermal-infrared imaging system developed at Ames), and ground weather stations to demonstrate the forest fire sensor web concept.

Summary

- Developing an autonomous disturbance detection and monitoring system with imaging radar (ADDMoS)
  - Developing high throughput onboard processing technology
  - Developing onboard automated response capability based on specific science algorithms
  - Demonstrate closed-loop autonomy with UAVSAR
  - Demonstrate smart sensor operation as an element of a sensor web (e.g. forest fire sensor web with EO-1)
- ADDMoS technology will improve timeliness of data product distribution and maximize science observations of several future radar missions
- ADDMoS technology will reduce onboard data storage and downlink data volume of future interferometric radar missions with onboard processing and autonomous targeted observations
- The framework of ADDMoS will allow UAVSAR and future radar missions to readily participate in application specific sensor webs