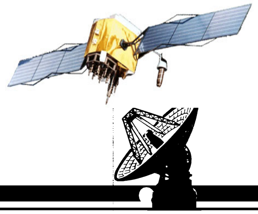
NASA Goddard Space Flight Center

Search and Rescue Mission Office



JPL 2002 AIRSAR Earth Science and Application Workshop

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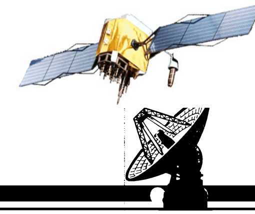
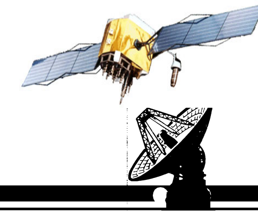
Web Page: http://poes.gsfc.nasa.gov/sar/sar.htm



Topics

- NASA's Role in Search and Rescue
- Cospas-Sarsat System
- Advanced Satellite-Aided Search & Rescue
  - *Distress Alerting Satellite System (DASS)*
- Remote Sensing Applications
  - *Search and Rescue Synthetic Aperture Radar (SAR^2) System*
- Conclusions

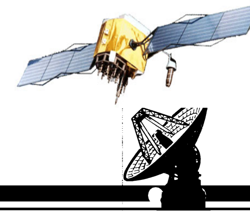


NASA's Role in Search and Rescue

U.S. Search and Rescue Responsibilities

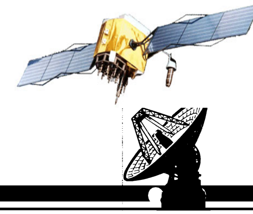
- US military + government agency SAR Responsibilities defined by:
  - National Search and Rescue Committee (Presidential cabinet level)
  - National Search and Rescue Plan
  - Interagency MOU for Cospas-Sarsat
- Civilian SAR responsibilities: (per National Search and Rescue Plan)
  - USCG performs maritime SAR + oversees U.S. national SAR policy
  - USAF coordinates rescue for CONUS SAR region + operates AFRCC
  - Civil Air Patrol + Local Governments - conduct in-land searches
- Cospas-Sarsat supports hundreds of thousands of beacons worldwide including military and NASA applications:
  - CSEL, Navy seat pack, ejection seat radios, submarine rescue buoys (sub-safe)
  - Astronaut survival
- NASA partnered with:
  - USCG, USAF (AFRCC) & CAP, DoD, NOAA, DOE, FAA, Cospas-Sarsat
- NASA responsible for SAR R&D per National SAR Plan

NASA's Role in Search and Rescue



- Goddard's Search and Rescue Mission Office continues to be the only NASA office to support the National Search and Rescue Plan

- Three R&D areas have been identified as near-term search and rescue needs
  - Improvements to the current Cospas-Sarsat distress beacons
  - GPRS - DASS: Transition of Cospas-Sarsat system to a state-of-the-art, near-instantaneous, high reliability system, with potential to significantly reduce false alarm rate
  - Remote Sensing Applications:
    - Search and Rescue Synthetic Aperture Radar ($SAR^{2)}$: An alternative radar search method for cases when Cospas-Sarsat does not detect a distress beacon
    - L-SAR: A method to locate aircraft wreckage using laser reflection to aid visual searches



Satellite-Aided Search and Rescue

- **Over 800,000 emergency beacons in use worldwide carried on aircraft, ships, and individuals - many are mandated**
- **Satellite technology for detection and location of aircraft and vessels in distress was developed by NASA in 1979 and operated by NOAA – evolved into international cooperative effort with spacecraft hardware provided by U.S., Canada, France, and Russia - called Cospas-Sarsat System**
- **Cospas-Sarsat System currently has 33 participating countries, SAR payloads on 11 satellites, a worldwide network of 45 ground terminals, and supports search and rescue agencies worldwide.**
- **Since the first launch in 1982, Cospas-Sarsat contributed to saving over *13,000* lives worldwide**

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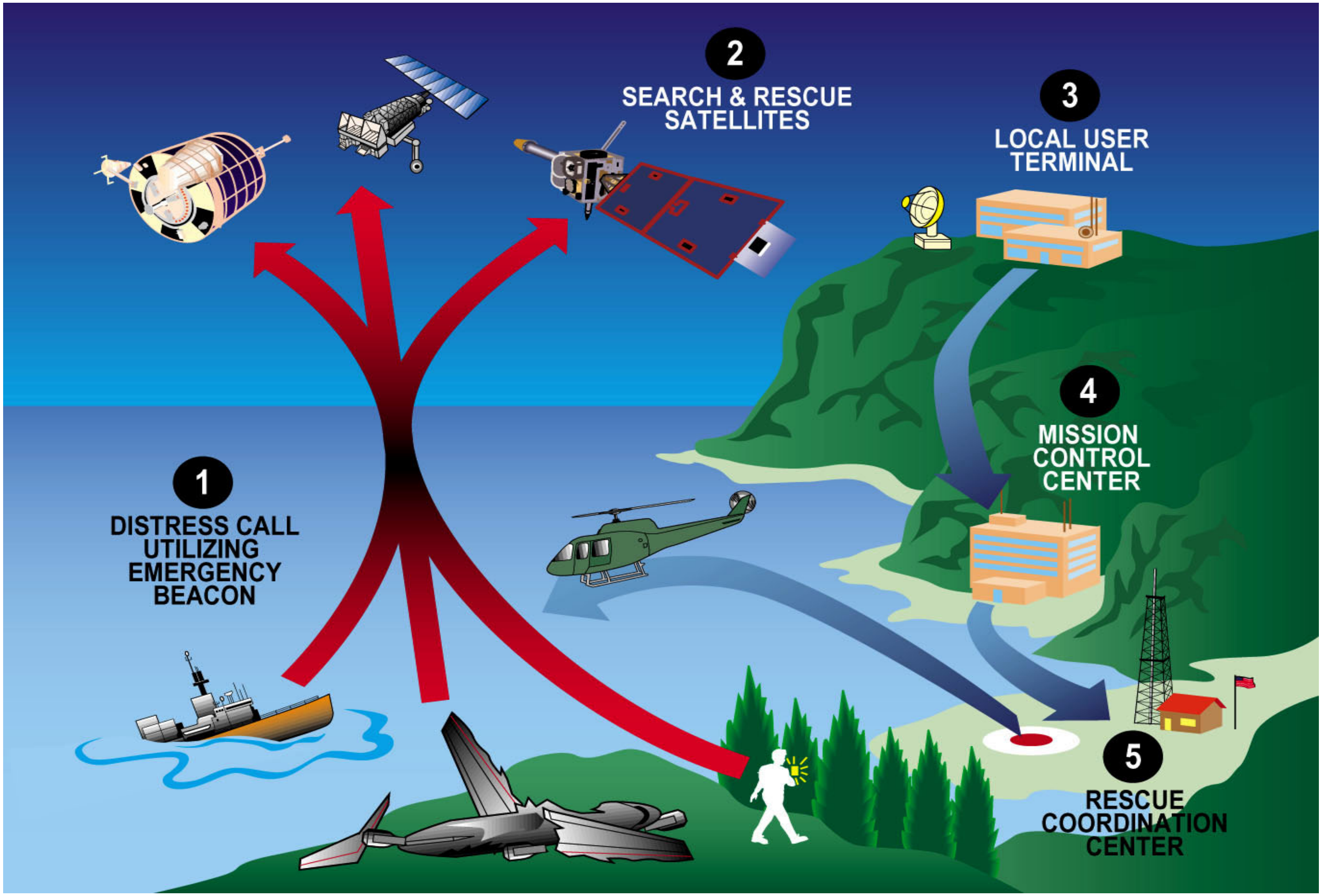
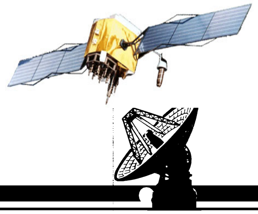
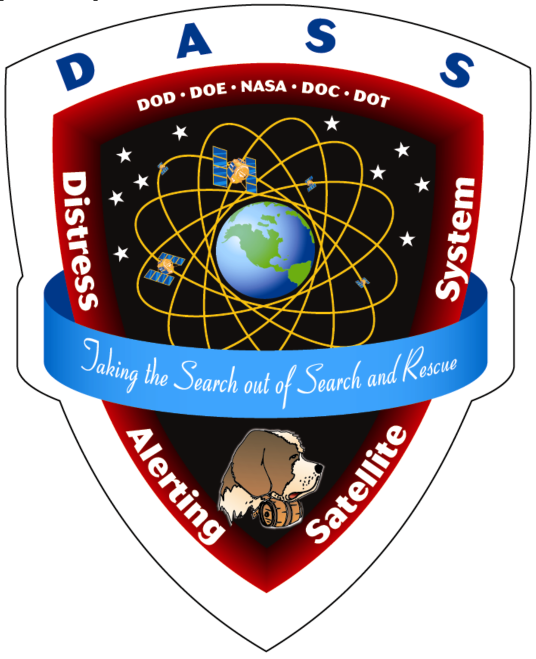
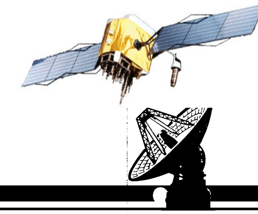
Search and Rescue Mission Office
Cospas-Sarsat System Concept





The Global Personnel Recovery System (GPRS) is a state-of-the-art, 2-way, combined Government/Military and Public 406 MHz satellite-based search and rescue system called the Distress Alerting Satellite System (DASS). The system consists of repeater equipment carried on the next generation GPS satellites (Blocks IIR, IIF, and III). This system has the potential to significantly improve search and rescue in the U.S. and worldwide by providing greatly improved timeliness, coverage, and availability. A possible 2-way capability allows mitigation of false alarms and coordination of rescue operations. The Government segment can be used by government agencies to track equipment and personnel. The majority of the cost for this new system will be borne by the Department of Defense (DoD).





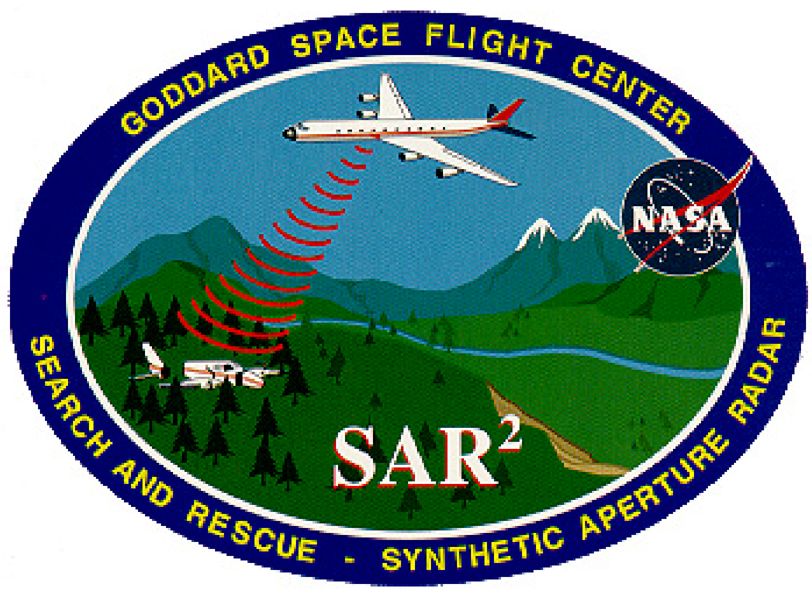
Concept

- **State-of-the-art combined military/government segment (GSAR) and public search and rescue segment, called *Distress Alerting Satellite System* (*DASS*), carried by future GPS satellites**

- ***DASS* provides:**
  - **406 MHz “bent-pipe” repeaters on future GPS satellites**
  - **Full compatibility with existing + future 406 MHz beacons**
  - **Global detection + location:**
    - **beacon without embedded GPS - greater than Cospas-Sarsat accuracy with 3 bursts or less**
    - **self-locating* beacons - GPS accuracy after single beacon burst**
  - **Support for USAF/military SAR responsibilities**
  - **Alert data downlink freely available internationally**
  - ***Possible two-way link* (<u>provided only if GSAR is flown</u>)**

*** A self-locating beacon includes GPS location data encoded in its transmission. While most present beacons do not have this capability, most future beacons are expected to have it.**

Search and Rescue Synthetic Aperture Radar (SAR^2) is a system intended to aid in finding obscured crashed aircraft in remote areas when no emergency beacon is operating. SAR^2 consists of a radar carried aboard a search aircraft, unmanned aerial vehicle (UAV), or satellite that images the ground. Post processing of radar data yields potential crash sites by eliminating clutter and known man-made features.



Visual Search Challenges

- Terrain
- Weather
- Hours of Darkness
  - Visual search limited to daylight hours
- Large Search Area
  - Emergency beacon failure
  - Intended flight plans and radar tracks not always available
  - Witness information not always reliable
- Limited Resources
- Time Factor
  - Victim survivability decreases dramatically with time
- Search and Rescue Personnel Considerations
  - Availability
  - Search hazards
  - Stress and fatigue increase human error

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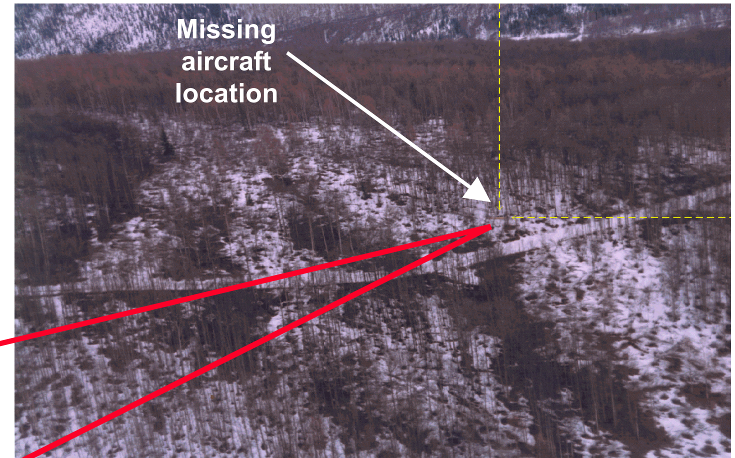
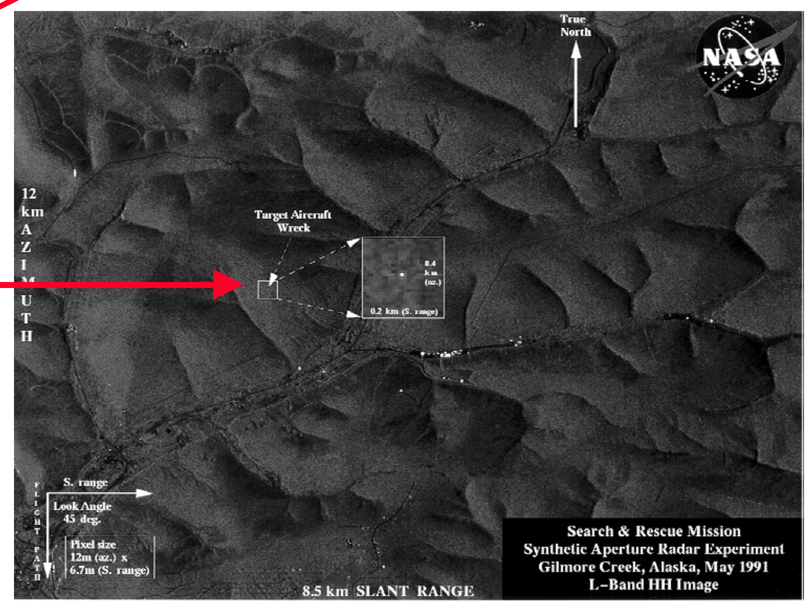
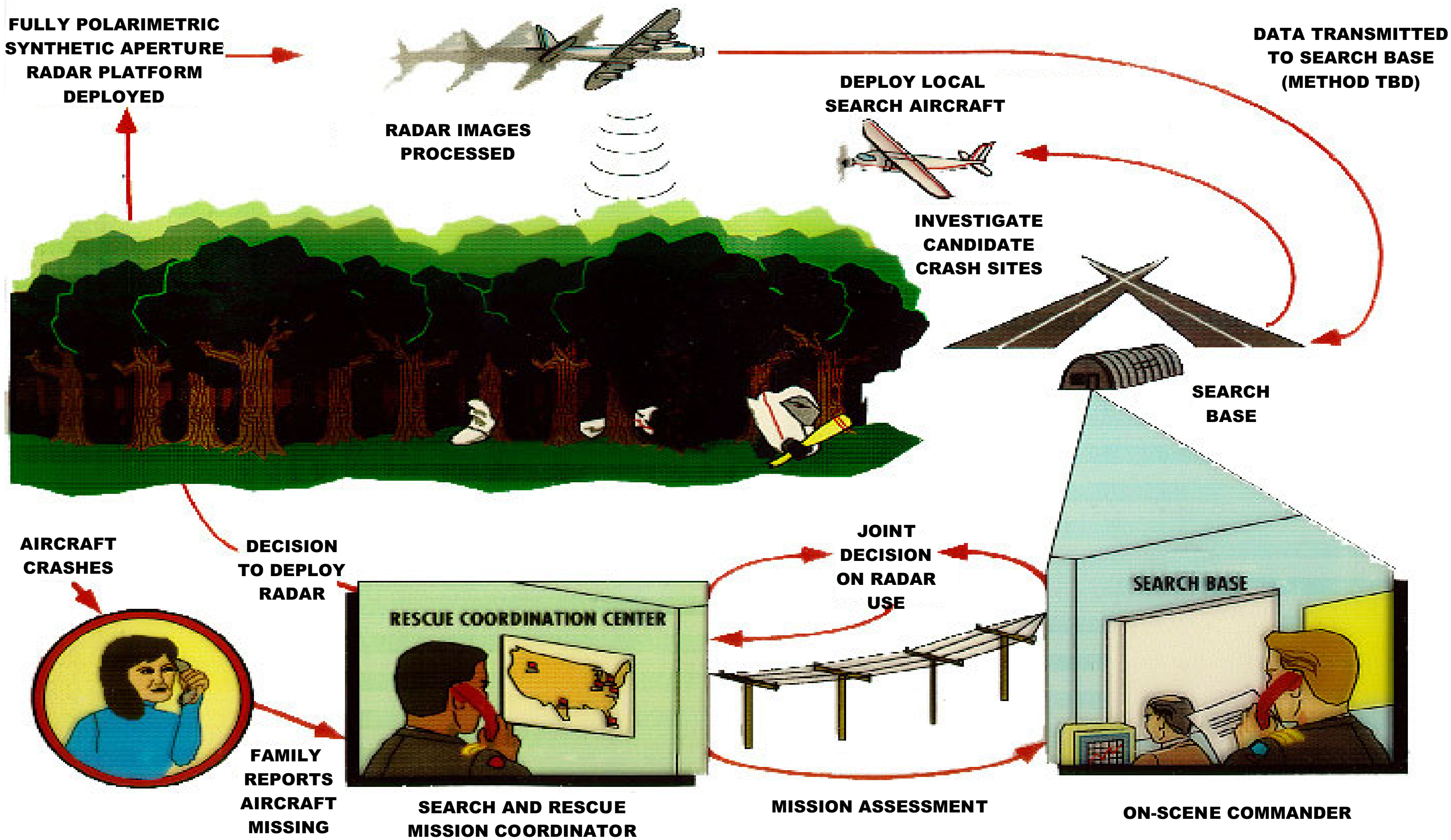
Search and Rescue Mission Office
Search for a Missing Aircraft



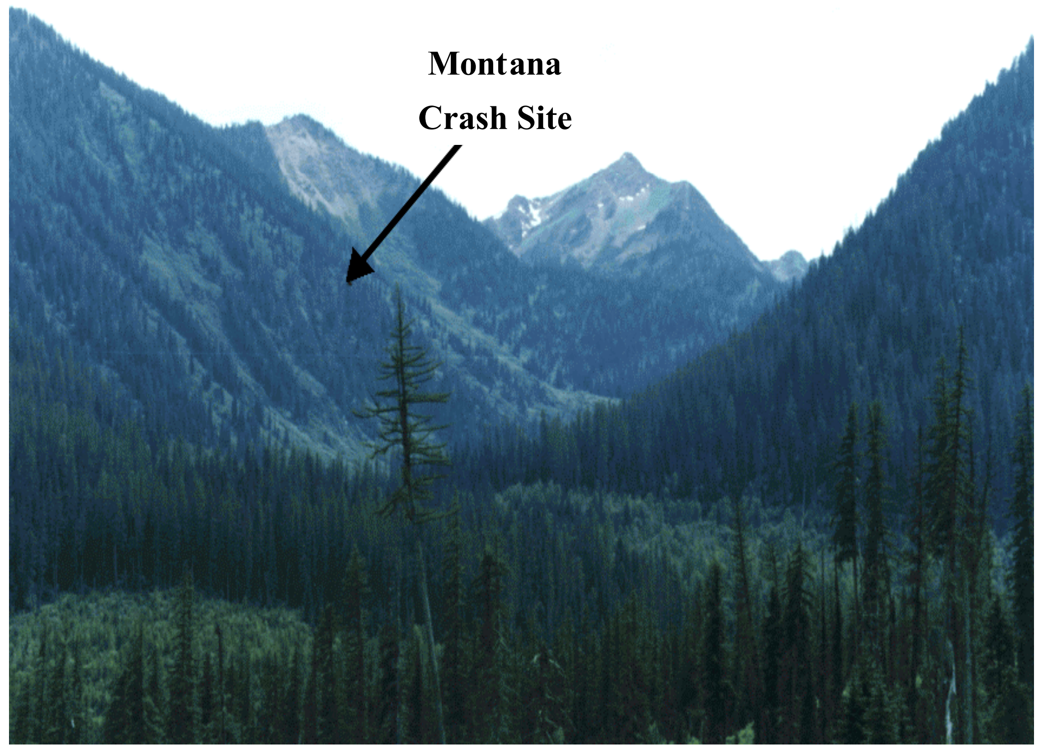


SAR² Search Scenario



Benefits:

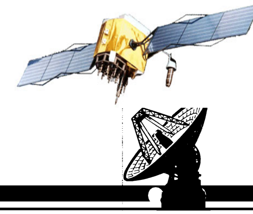
- Wide area, all weather, day/night searches of remote areas by high altitude aircraft, UAV, or satellite
- Used when emergency beacons fail to operate (over 50% fail)
- Low frequency radar penetrates foliage canopy
- Greatly improved response time in difficult searches
- Complete search area coverage without gaps
- Saves lives, reduces risks to searchers, and decreases search and rescue costs



SAR^2 Program Objectives:

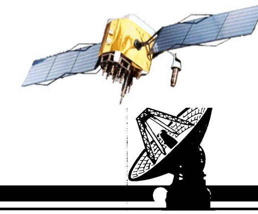
- **Phase I - R&D**
  - ✓ ***Develop necessary processing algorithms for synthetic aperture radar data***
  - ✓ ***Determine if synthetic aperture radar can locate crashed aircraft targets under foliage***
  - **Develop and automate algorithms to select candidate crash sites**
- **Phase II - Prototype field evaluation**
  - **Determine if the technique is practical for search and rescue**
    - **Develop prototype SAR^2 system**
    - **Conduct search-force exercises to develop procedures, train personnel, and improve crash site detection process**

Note: "lessons learned" from Phase II may require continued R&D



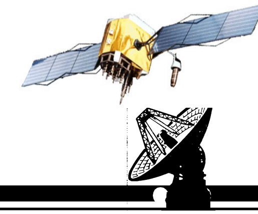
Search and Rescue Radar Field Experiments

Year	Location
1989	Duke Forest, Durham, NC & Bangor, Maine
1990	Mahantango Forest, PA & Univ. of Mich. Forest, MI
1991	Bonanza Creek & Gilmore Creek, AK
1992	Crystal Springs Reservoir, CA and Corvallis, OR
1993	Bonanza Creek and Gilmore Creek, AK
1993	Crystal Springs Reservoir, CA
1994	Half Moon Bay, Lodoga, S. Canyon & Calistoga, CA
1995	Bishop, CA
1995	Teton National Forest, WY
1996	San Francisco, CA
1998	Virginia Beach, VA
2002 (4/1/02)	San Bernardino County, CA



Instruments/Platforms Used

Platform	Frequency	Application
JPL AirSAR	C, L, P	Polarimetric detection Foliage Penetration
Navy/ERIM P-3 SAR	X, C, L, UHF	Polarimetric detection Foliage Penetration Interferometry
Sandia Twin Otter SAR	X	Interferometry Resolution Enhancement
SIR-C	L, C	Polarimetric detection from space
ERS-1, -2	C	Interferometry, CCD Resolution enhancement
Future Search & Rescue Airborne Platform	L or UHF or both	Future Operational Utility Testing



SEARCH AND RESCUE TECHNOLOGIES

SAR Data Processing

- Advanced raw data processing
  - Migration processor for UHF SAR data
- Motion compensation
- Special focusing algorithm (variant of PGA) developed by NASA
- Geo-location

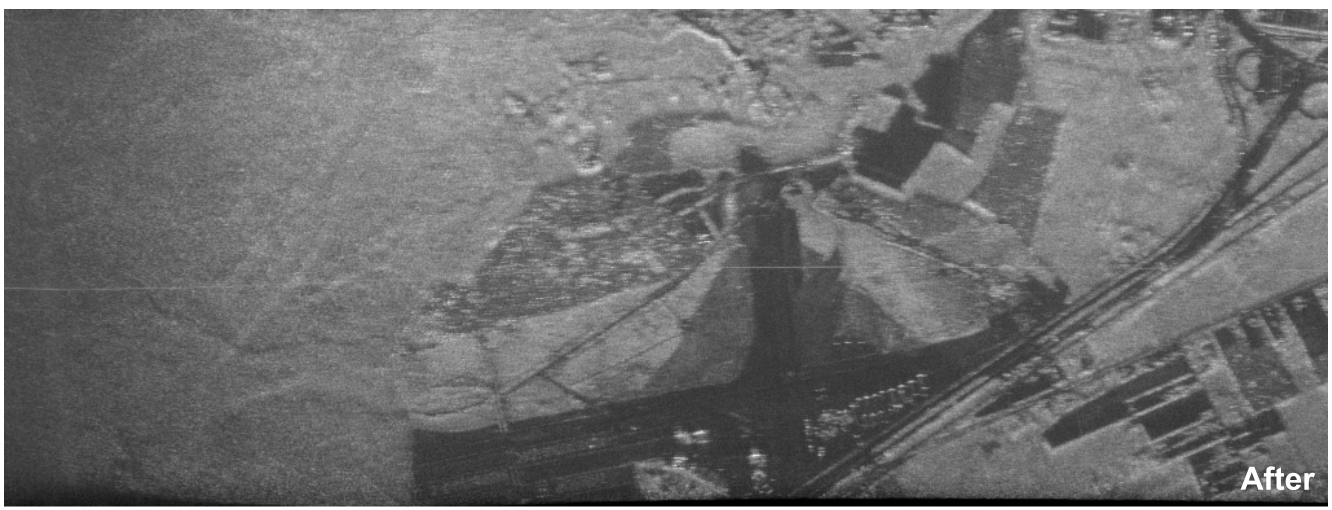
SAR Polarimetry

- Four channels: HH, HV, VH, VV collected simultaneously
- Detection of elementary shapes
- Crash site detection processing

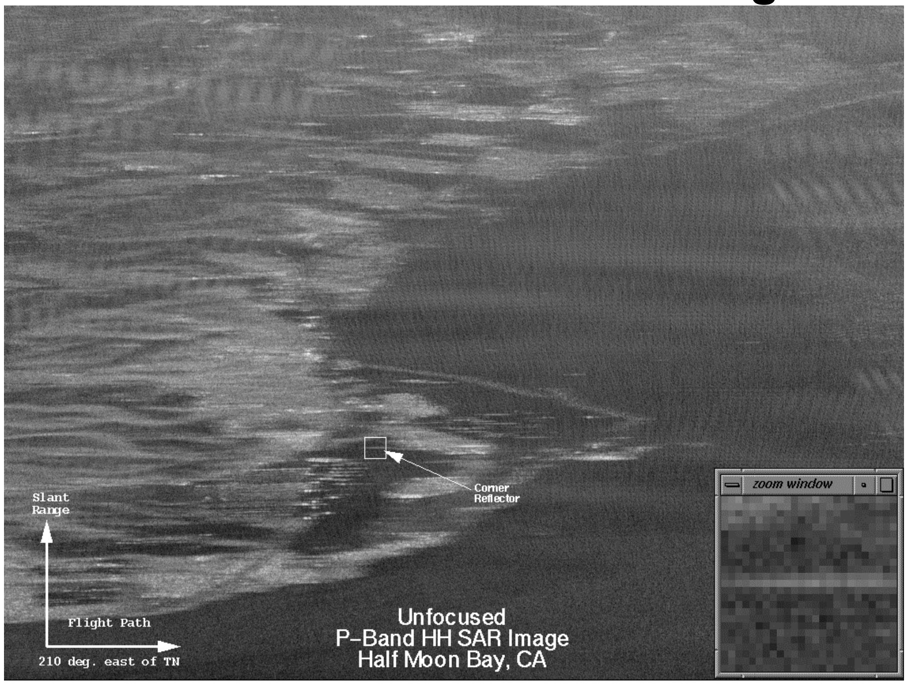
SAR Interferometry

- Digital terrain elevation map of search area
- Coherent Change Detection (CCD)

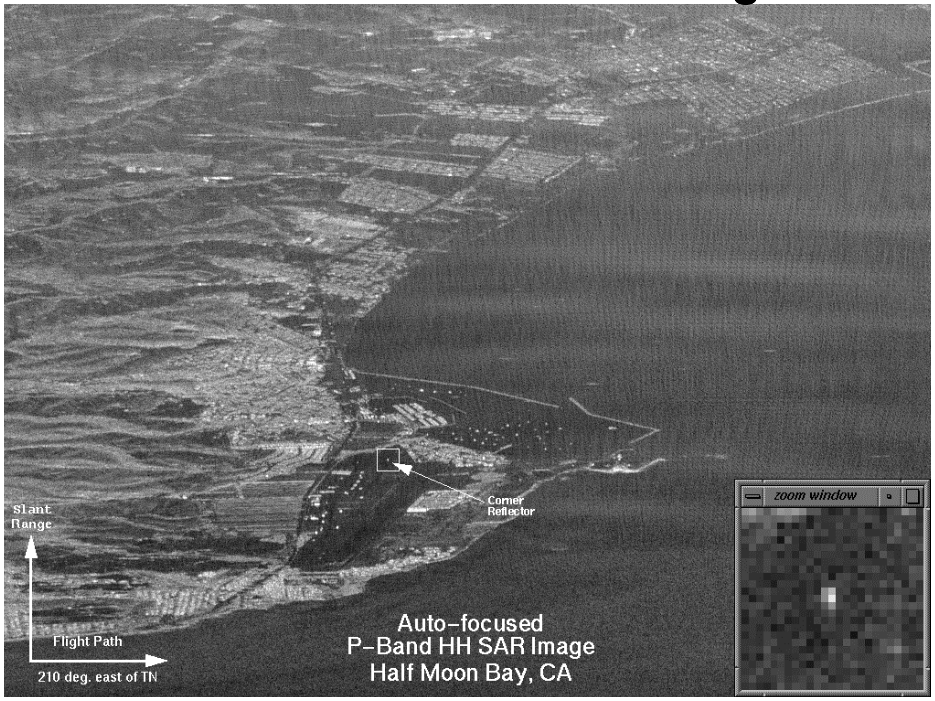
UHF Motion Compensation



Unfocused P-band SAR Image



Focused P-band SAR Image



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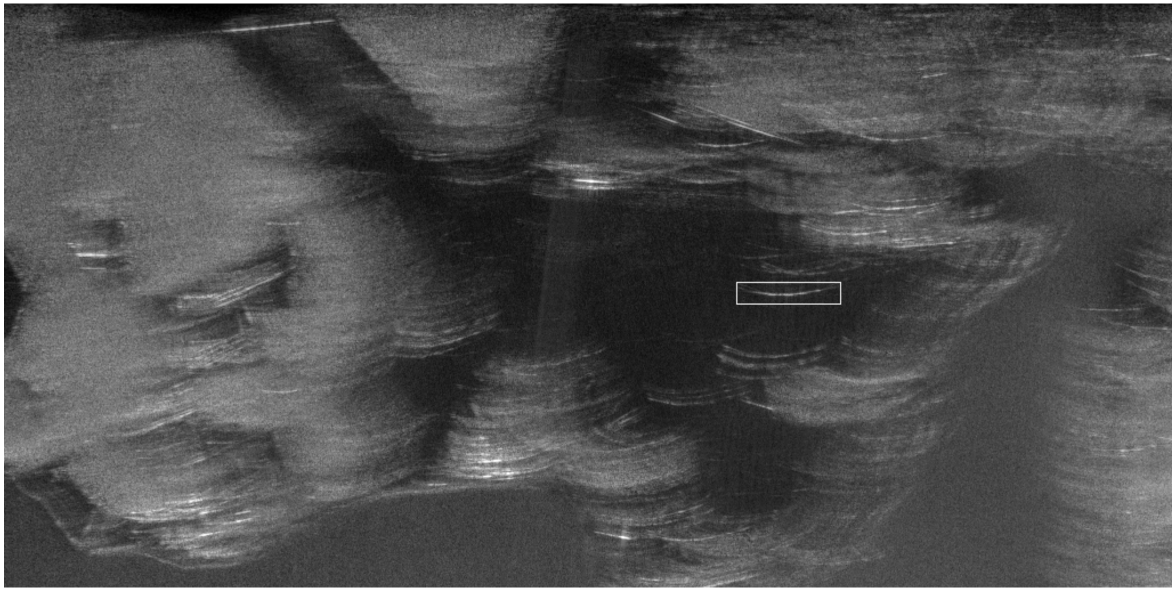
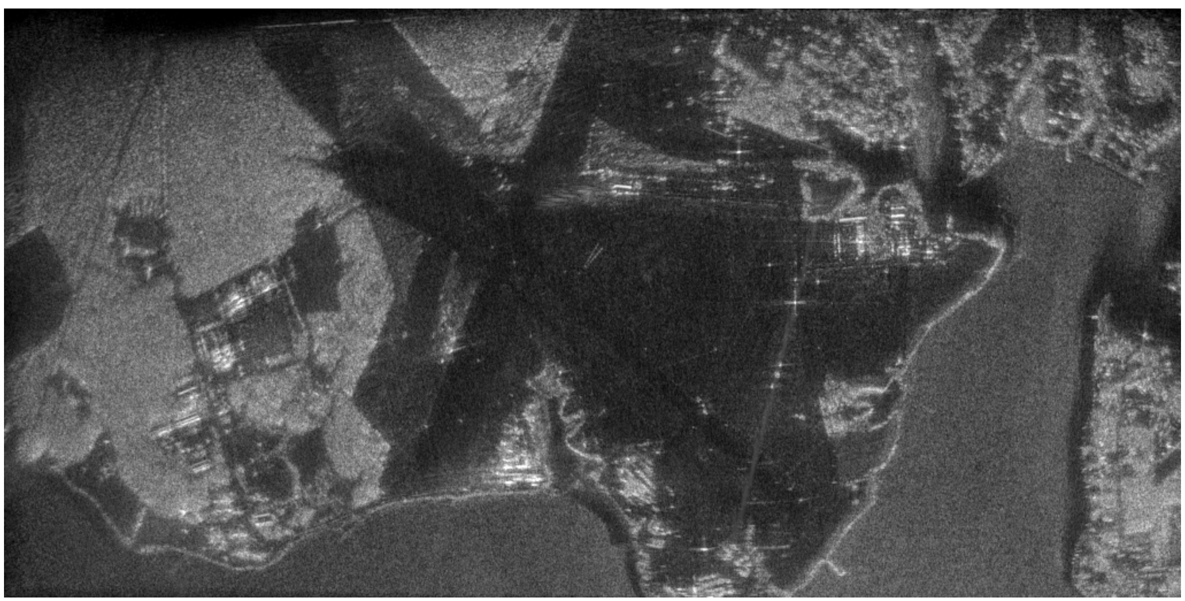
Search and Rescue Synthetic Aperture Radar



UHF SAR Image With Residual Uncompensated Motion



Autofocused UHF SAR Image

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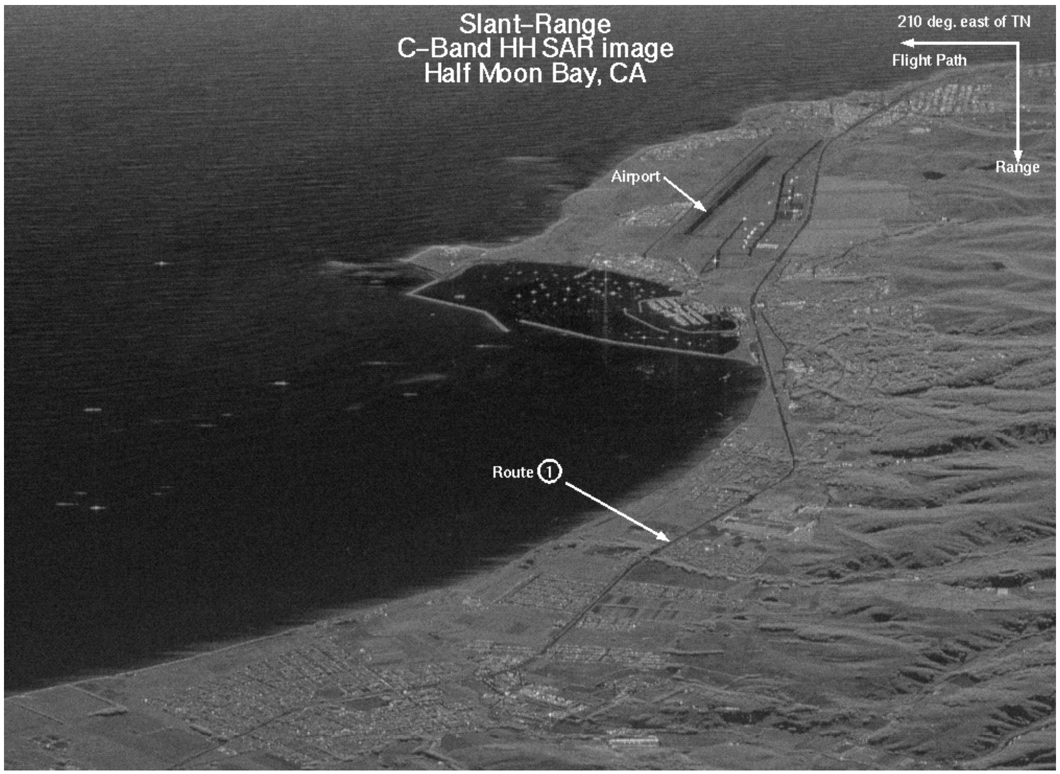
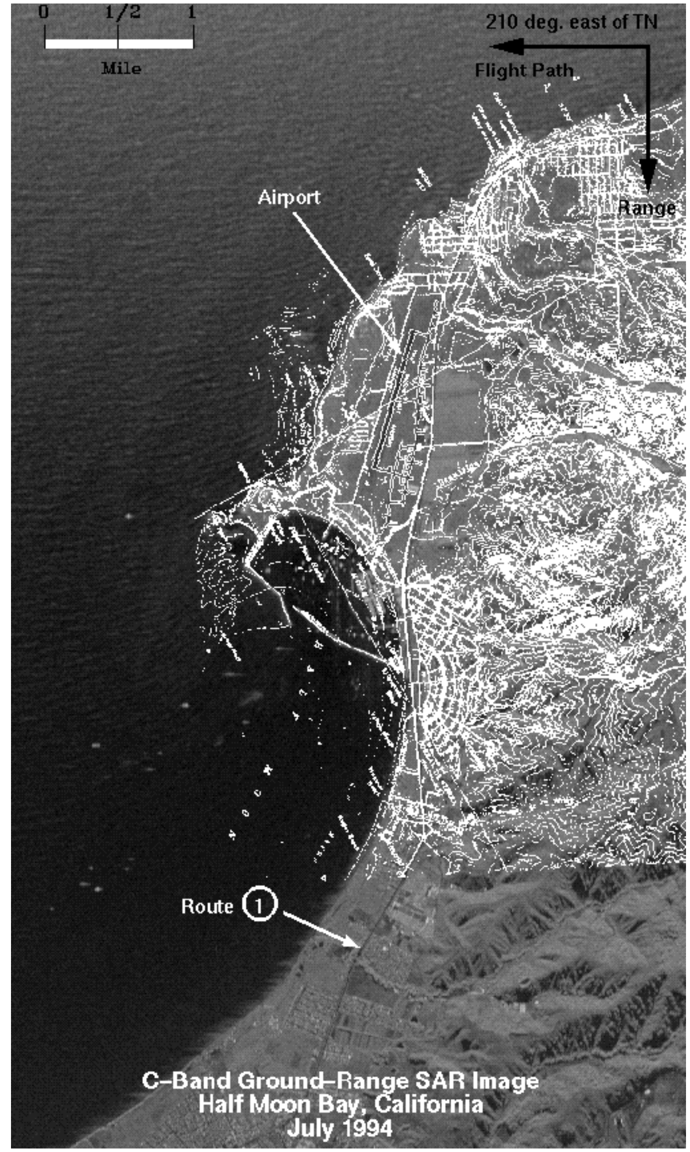
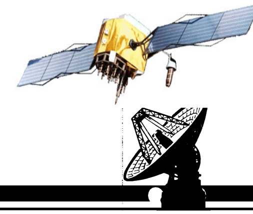
SAR image geo-rectification for accurately locating candidate crash sites.





5 March 2002



Polarimetric Shape Detection

- The electromagnetic (radar) scattering from a complex object in the field is modeled as a composite of smaller objects drawn from a set of six elementary shapes: trihedral, cylinder, dipole, dihedral, narrow diplane and quarter-wave device.

- The return from an elementary shape is completely determined by its geometric shape. Natural objects (trees, bushes, etc.) typically produce trihedral returns, whereas "man-made" objects have more structure such as right angles which give a dihedral return.

- Cameron method: the dominant elementary shape of any pixel return in the SAR image can be determined from polarimetric analysis.

Elemental Scatterers

Polarimetric Shape Detection

Trihedral
natural world

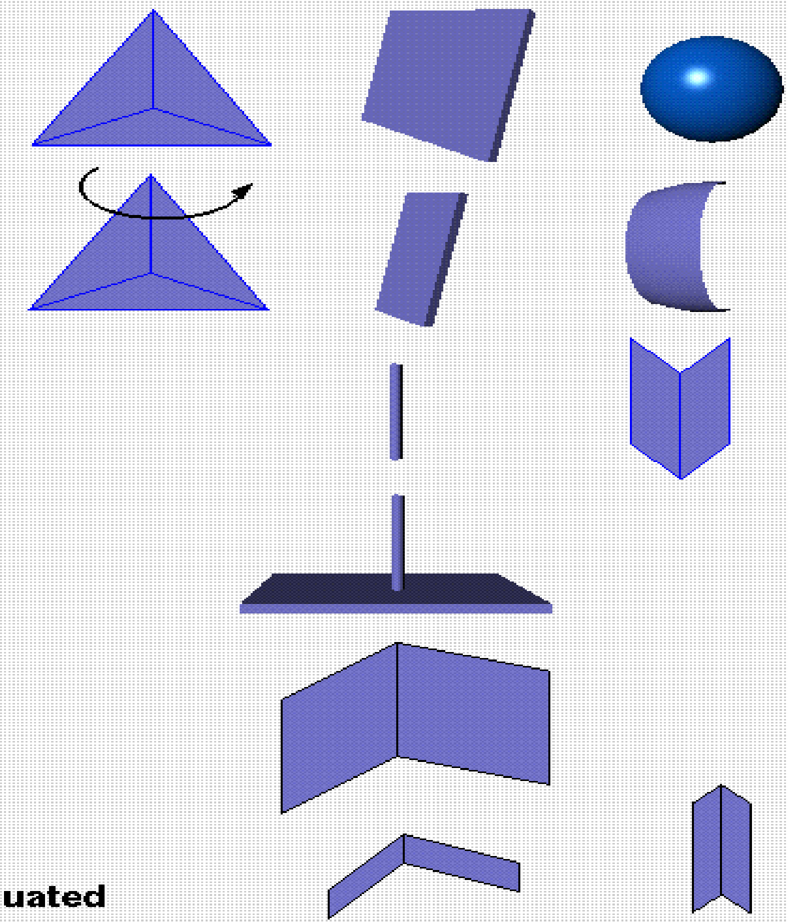
Cylinder
return weak in one direction

Dipole
no return in one direction

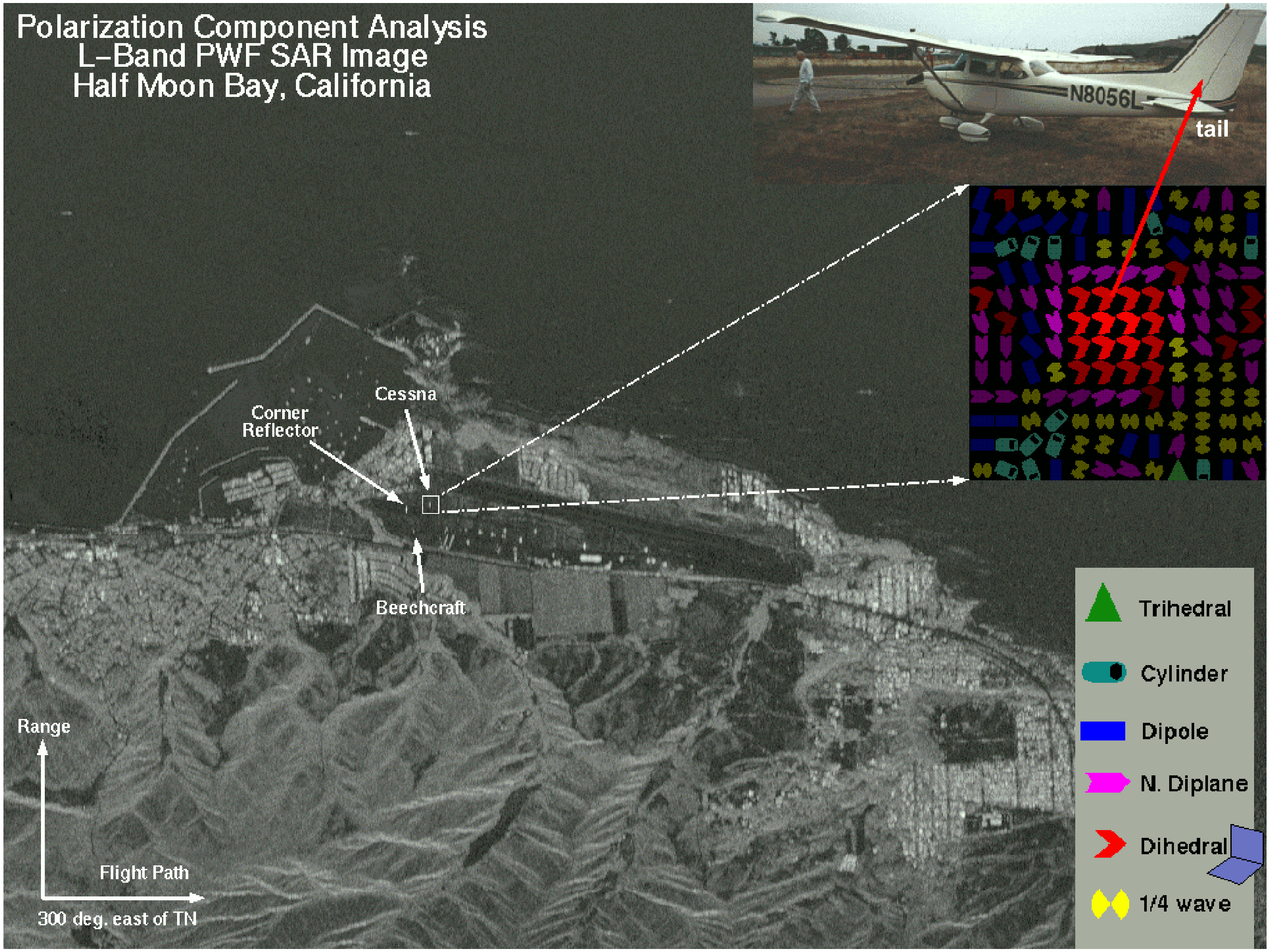
1/4 wave
second direction delayed

Dihedral

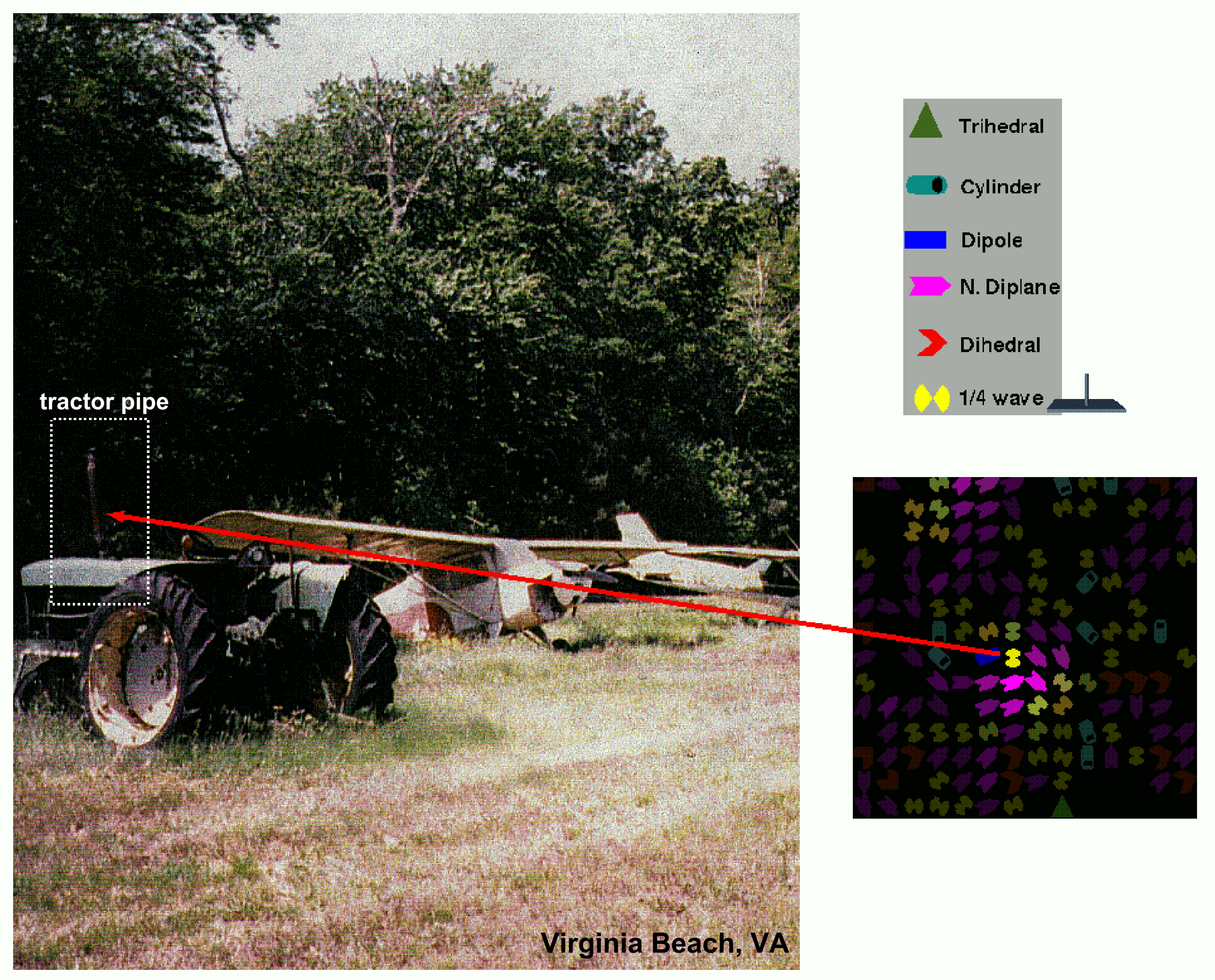
Narrow Diplane
dihedral with one direction attenuated



Search and Rescue Radar Experiment



Search and Rescue Radar Experiment



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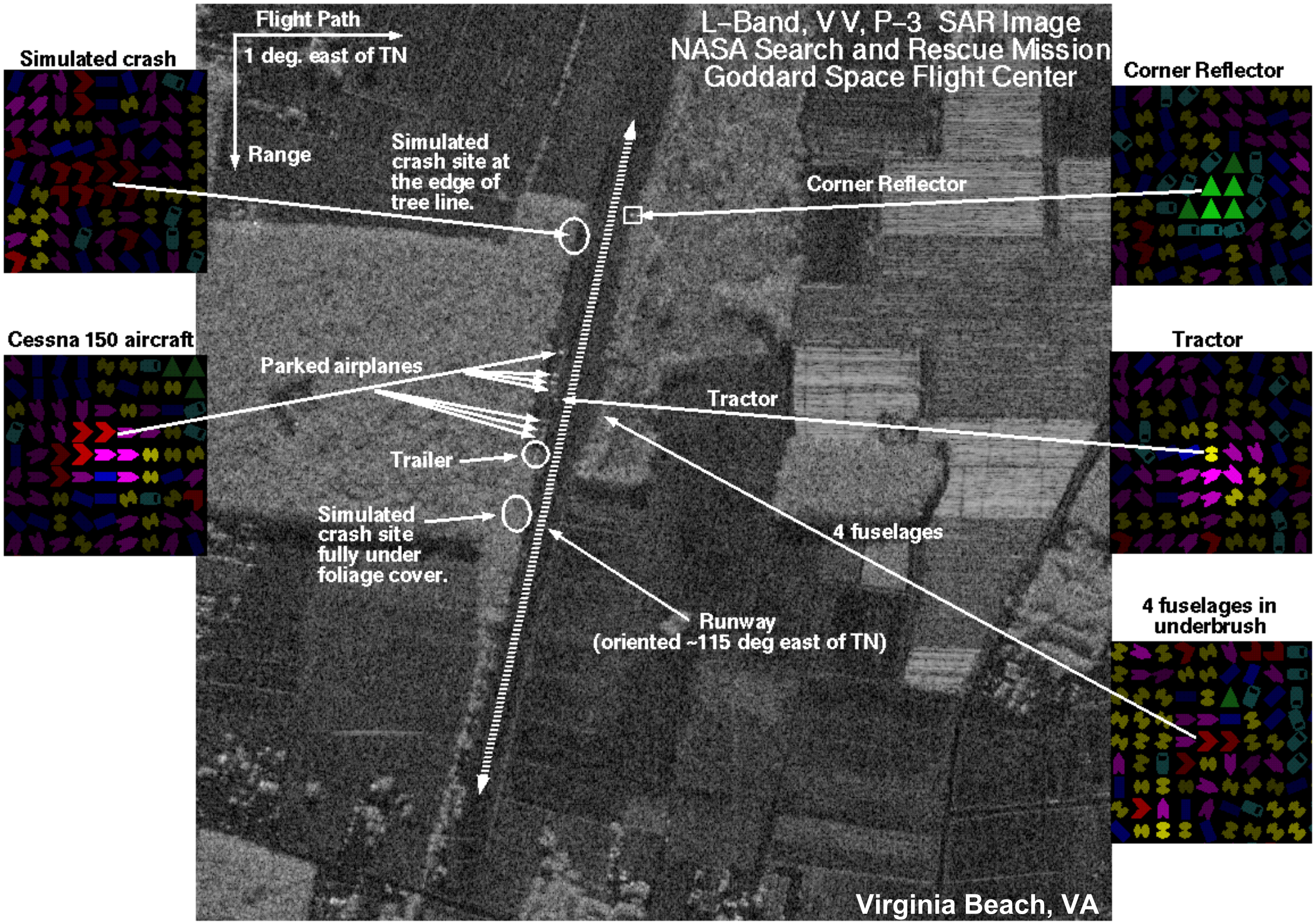
Polarimetric Classification (cont'd)

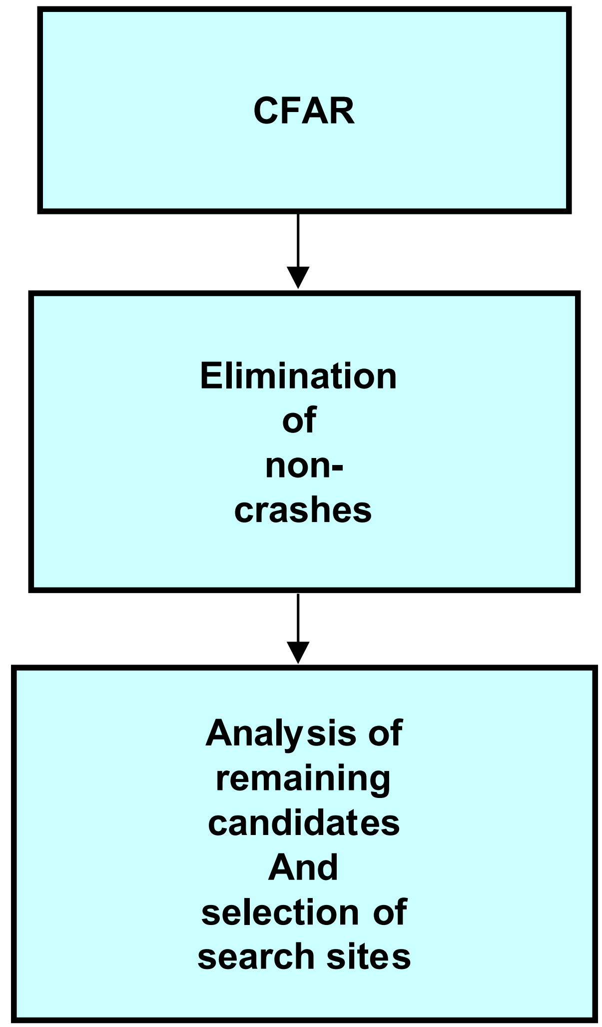


Crash Site Detection Processing:

- Initial screening - constant false alarm rate (CFAR) detector based on:
  - Polarimetric shape detection
  - Polarization whitening
  - Power of return

- Elimination of known man-made features and natural clutter:
  - Clustering at building sized scales
  - Fractal dimension
  - Clutter/target modeling

- Examination of remaining candidates by Search and Rescue operator using aids, research tools, and local knowledge.

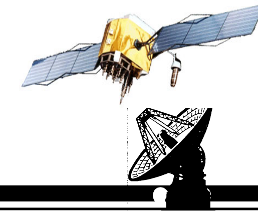


Search for a Missing Piper Malibu Aircraft

NASA/JPL AIRSAR Data Collection

Kalispell, Montana

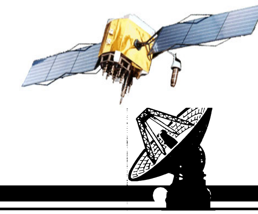
May/June 1998



Search Requests

	Date	Place	Type Aircraft	Requested by
	2001	San Bernardino, CA	Piper PA-28	CA CAP
	1999	New Hampshire	Lear Jet	Family
	1998	Kentucky - Tennessee	Army Helo	AFRCC
	1998	Bolivia, South America	Cessna 185	World Bank
	1998	Kings Canyon, California	Piper Cherokee	CA CAP
→	1998	Kalispell, Montana	Piper Malibu	Family
	1997	Colorado (A-10)	USAF A-10	AFRCC
→	1996	Big Sur, California	Cessna 152	CA CAP
→	1995	Bishop, California	Beech Debonair	CA CAP
→	1992	Mt. Islip, California	Skymaster	CA CAP

→ Search requests responded to by NASA Search and Rescue Mission



Search History and NASA Participation

- **<u>11 April 1998</u>: Piper Malibu aircraft with two persons aboard was lost off radar ~20 miles ESE of Kalispell, Montana.**

- **<u>12-26 April 1998</u>: Extensive air & ground search was conducted, with negative results. Official search was suspended on 7 May 1998.**

- **<u>7 May 1998</u>: SAR^2 search effort initiated. NASA HQ approved participation using resources from GSFC, Stennis Space Center, Jet Propulsion Laboratory (JPL) and Dryden Flight Research Center.**

- **<u>12 May 1998</u>: Data collection flights completed by NASA/JPL AIRSAR System.**

- **<u>13 May-15 June 1998</u>: GSFC Search and Rescue Mission office processed the radar data and selected 14 potential crash sites. Site locations were forwarded to the privately funded search effort.**

- **<u>15 June 1998</u>: Missing aircraft located near one of the potential sites.**

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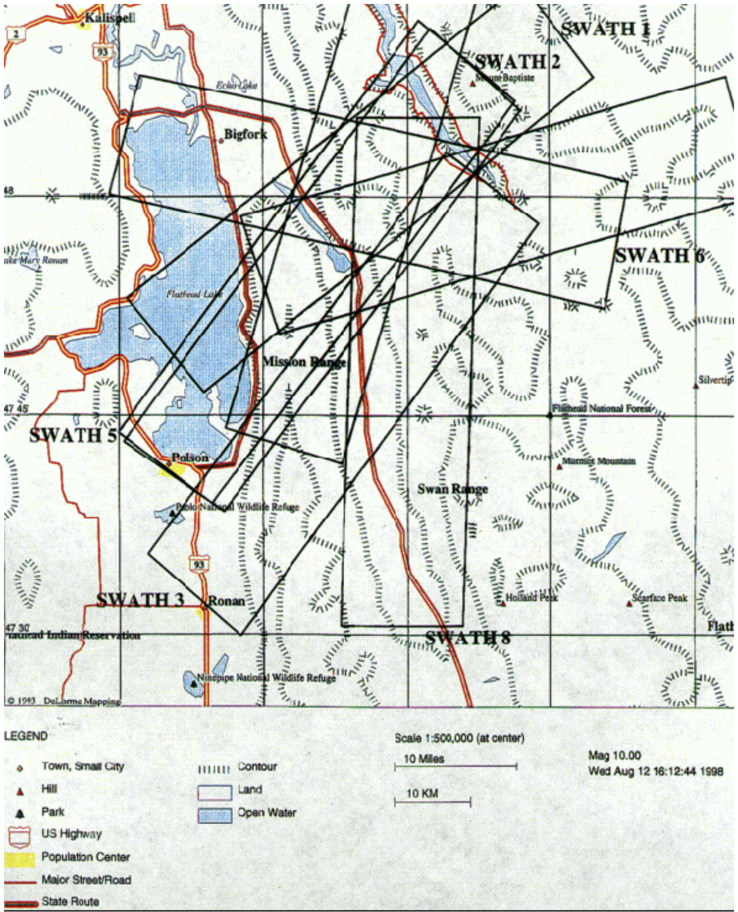
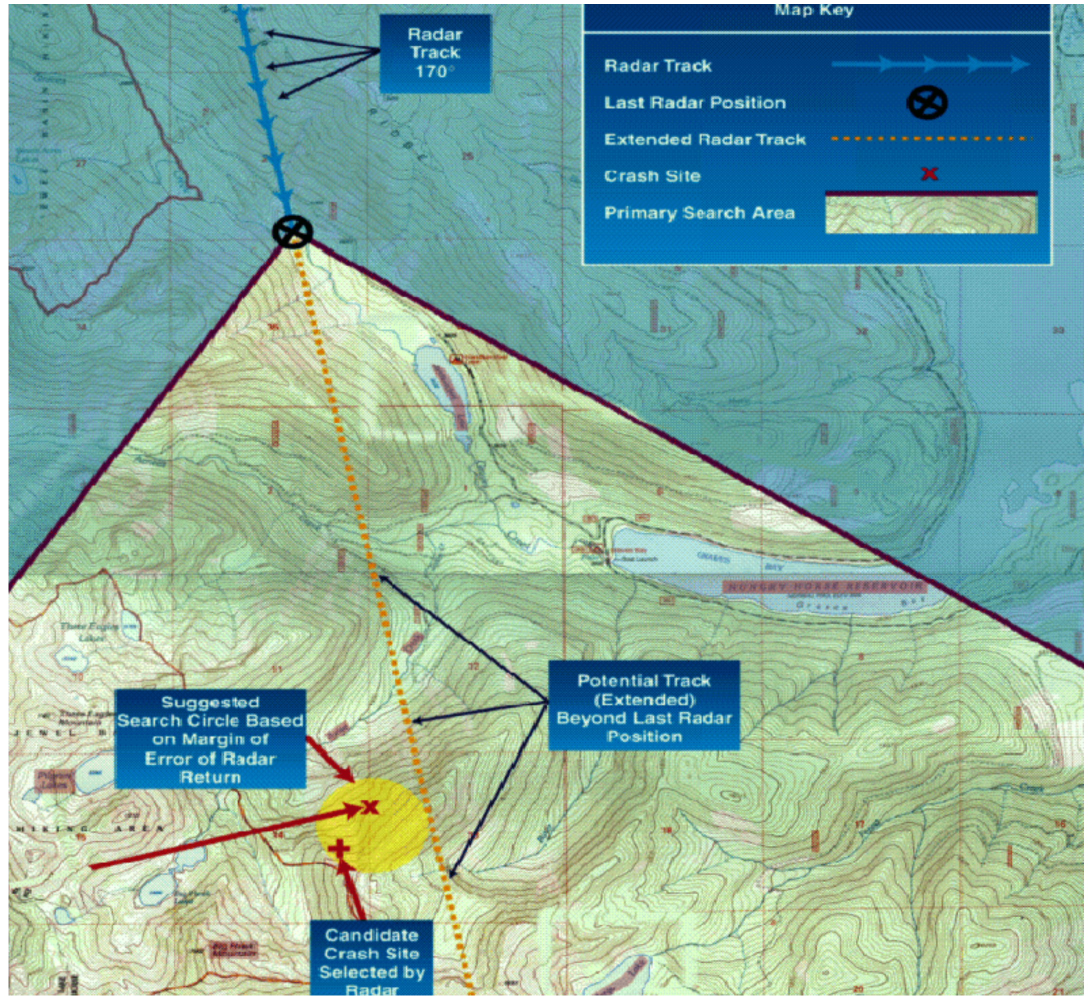
Search and Rescue Mission Office
Search and Rescue Synthetic Aperture Radar

Data Collection Flight Paths



Search area based on missing aircraft radar track and last radar position



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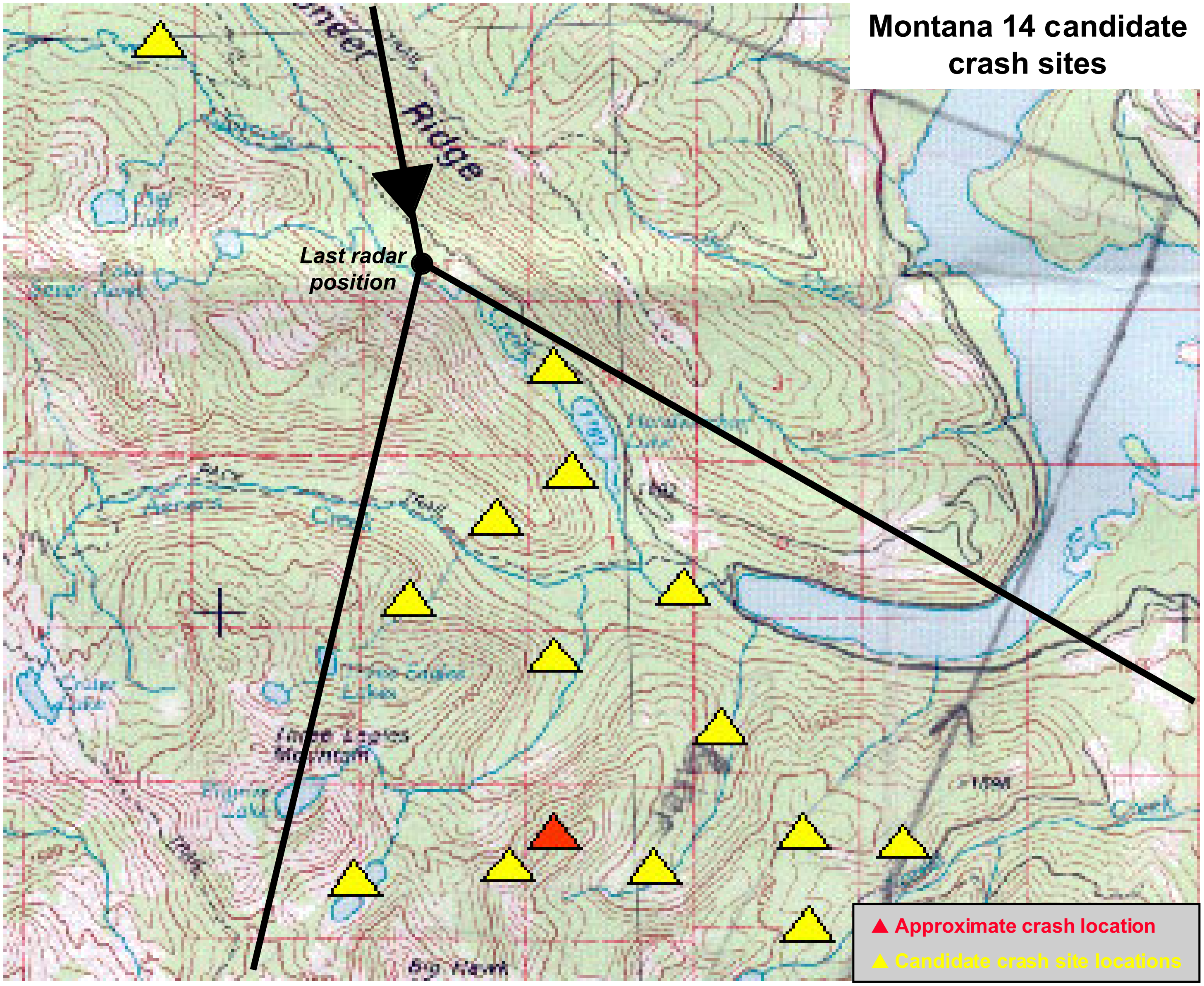
Search and Rescue Mission Office
Search and Rescue Synthetic Aperture Radar

Montana 14 candidate crash sites



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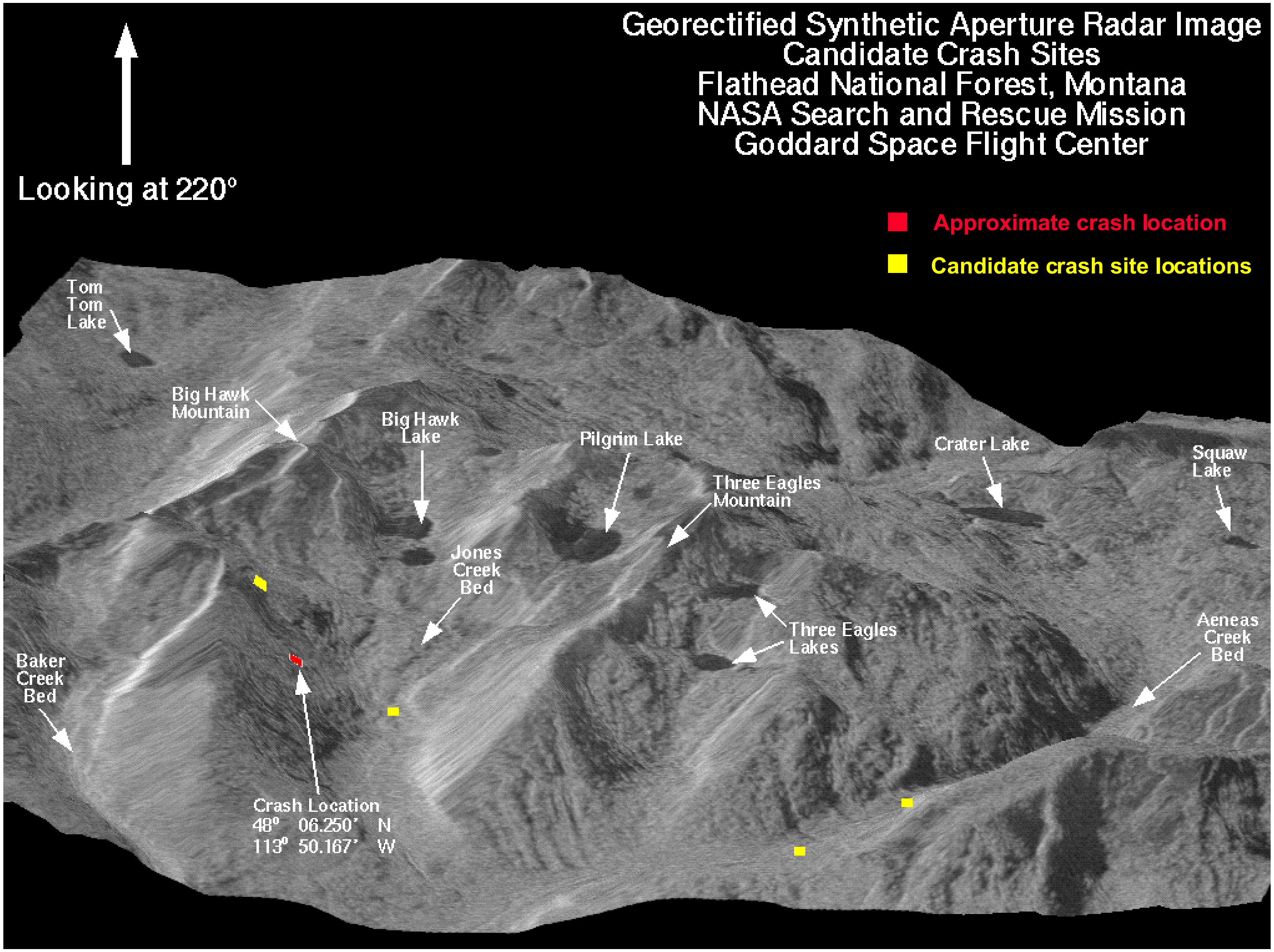
Search and Rescue Synthetic Aperture Radar



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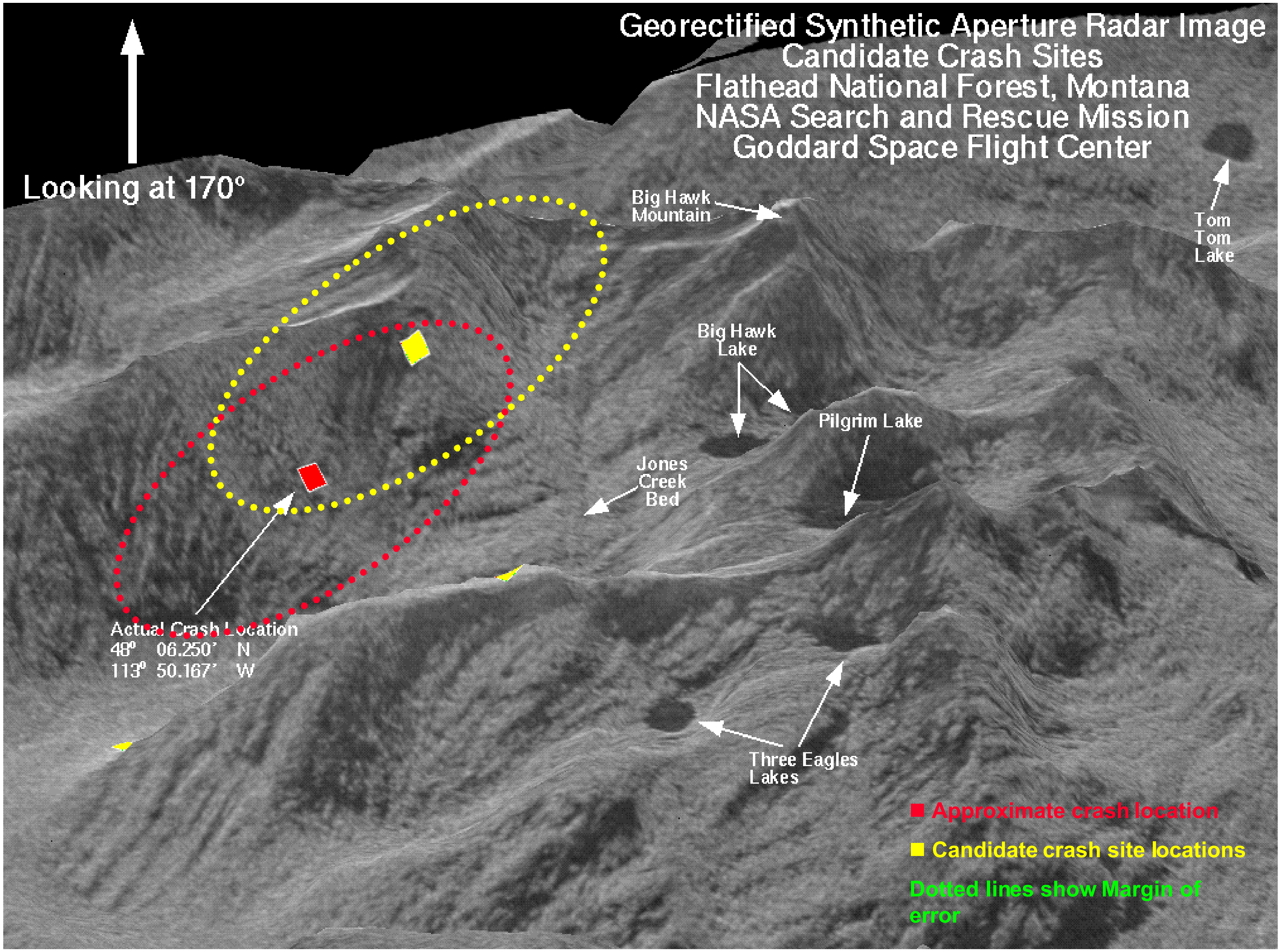
Search and Rescue Synthetic Aperture Radar



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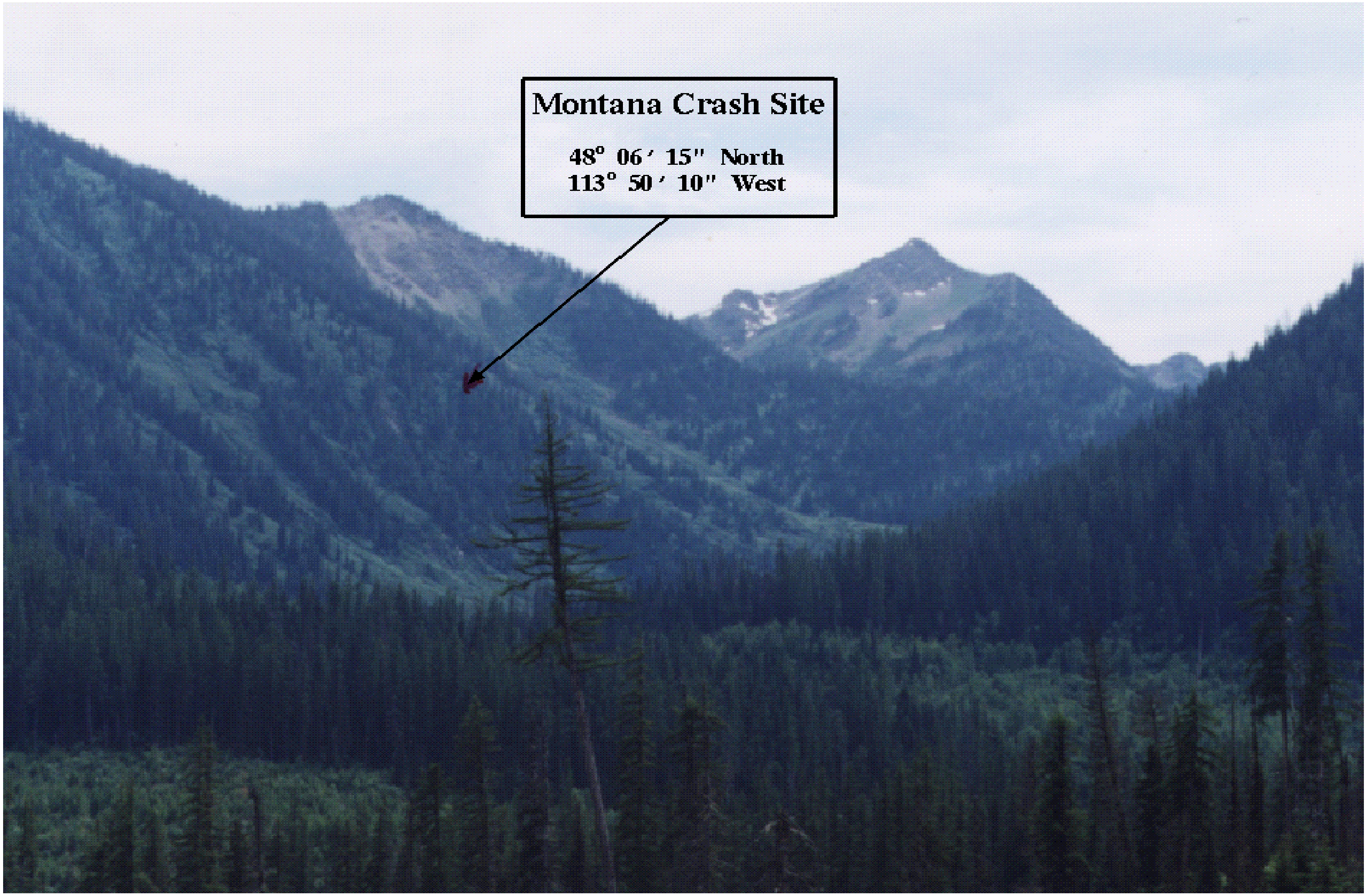


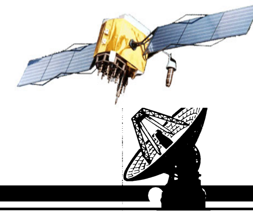
Montana crashed aircraft wreckage

Search and Rescue Mission Field Experiment

NASA/JPL AIRSAR Data Collection

Lytle Creek, San Bernardino, California

April 2002



SAR² System

Data Collection Segment

Radar

- Integrate in aircraft/UAV /spacecraft — Low risk
- Frequency selection — Some risk

Ground Processing Segment

Raw Data

Data Processing

- 4 polarimetry channels full-resolution processed and calibrated — Done - Integrate

SAR Images

Detection Processing

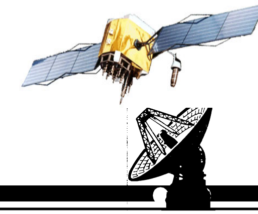
- Polarimetric processing — Done - Integrate
- Crash site detection processing produces candidate crash site list — Good Progress - Some risk.

Annotated Images

Geo-location

- Image ortho-rectification using digital terrain elevation data — Done - Integrate

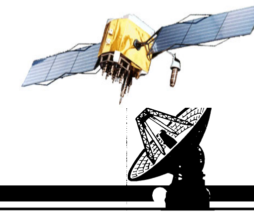
- Map coordinates for candidate crash site list
- 3-dimensional visualizations



SAR² Risk Areas and Engineering Challenges

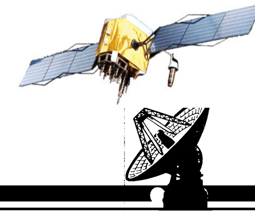
Requirements	Risks/Trades	Tasks
Detection algorithm	**Detection performance (e.g., probability of detection).** **- algorithm**	Experiment sequence Empirical statistical analysis
Small aircraft	Motion compensation - gymbal vs. fixed antenna stabilization - use of GPS or INS or both - achieving uniform v/PRF or not **Envelope** - Aircraft selection	Identify candidates
Radar system	Calibration **Selection of frequency** **- single or dual** Small aircraft integration - envelope constraints Antenna - both side looking	Radar design
Processing system - Minimize mission timeline (e.g. 8 hours)	System throughput - mission timeline vs. benefit Envelope - Process and display onboard	Ground Data Processing System design
Use by non-experts	User interface complexity - waterfall, CFAR knob, local maps/GIS	Training
FCC Permission for wideband	**Authorization**	
AFRCC Coordination		

NASA Goddard Space Flight Center
Search and Rescue Mission Office
Background



- **Joint effort of NASA and National Association for Search and Rescue (NASAR)**
  - Cooperation agreement signed on November 1, 2001by NASA Associate Administrator (Dr. Ghassem R. Asrar) and President of NASAR (Mr. Mike Tuttle)
- **Local Partner: San Bernardio County Sheriff's Department**
  - Mike Tuttle, Sheriff's Lieutenant, in charge all NASAR provided local support and coordination
- **National Telecommunications and Information Administration (NTIA) Issues**
  - Obtained approval for temporary operation of AIRSAR's P-band radar using a 40 MHz emission bandwidth (410 MHz - 450 MHz)
  - Need to coordinate with government agencies using this band

Experiment Requirements

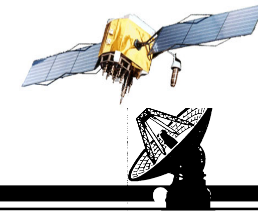


- **Frequency coverage: VHF through L-band**
  - 200 MHz - 1.3 GHz
  - Bandwidth commensurate with resolution (below)

- **Fully Polarimetric**
  - Four simultaneous channels (HH, HV, VH, VV)
  - Capable of coherent polarimetric data analysis (e.g., Cameron)

- **Experimental Geometry**
  - Swath width $\geq$ 1 km
  - Grazing angles: 10^{o} - 70^{o}
  - Image at different azimuth angles
  - Repeat-pass for change detection
    - Ability to repeat flight paths to within 10m

Experiment Requirements (continued)



- **Targets**
  - Spectrum of targets
    - 2-3 mock crashed aircraft sites
    - 8 trihedral corner reflectors (8-ft) for calibration targets
    - Existing crashed aircraft sites
  - Ground truth essential
    - Differential GPS
    - Accurate mapping and photographs of test and calibration target set ups
    - Aerial photographs essential, 6” resolution
  - Several under foliage

- **Image Quality**
  - Resolution (FWHM) $\leq$ 1.5 m X 1.5 m
  - ISLR $\leq$ -12 dB
  - PSLR $\leq$ - 20 dB

- **Sensitivity**
  - $NE\sigma_0 \leq$ -35 dB at L-band
  - $NE\sigma_0 \leq$ -40 dB at VHF
    - These numbers achieve CNR $\geq$ ~5 dB for grassy fields in cross-pol

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Test Area - San Bernardino County, California

- Highly mountainous with mean elevation of 800 meters and peaks as high as 3500 meters
- Heavy underbrush cover consisting of scrub oak and other deep-rooted plants
- Slopes of above 25^{o} with deep ravines containing 15-20 ft trees and heavy underbrush
- Good accessibility via dirt roads to set up test and calibration targets in open areas and under foliage

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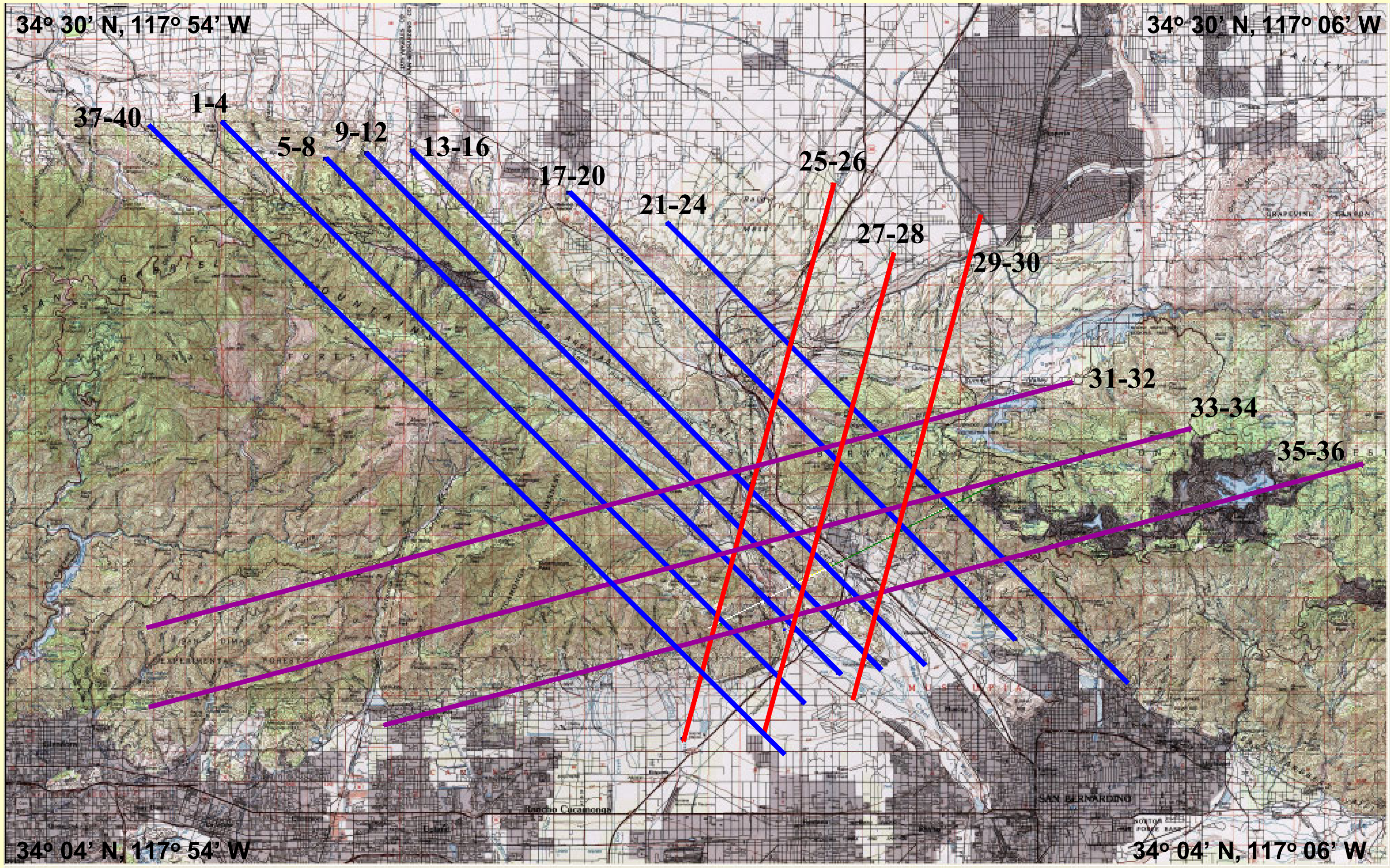
Planned AIRSAR Flight Paths

Search and Rescue Mission Experiment Flight Paths
San Bernardino, California



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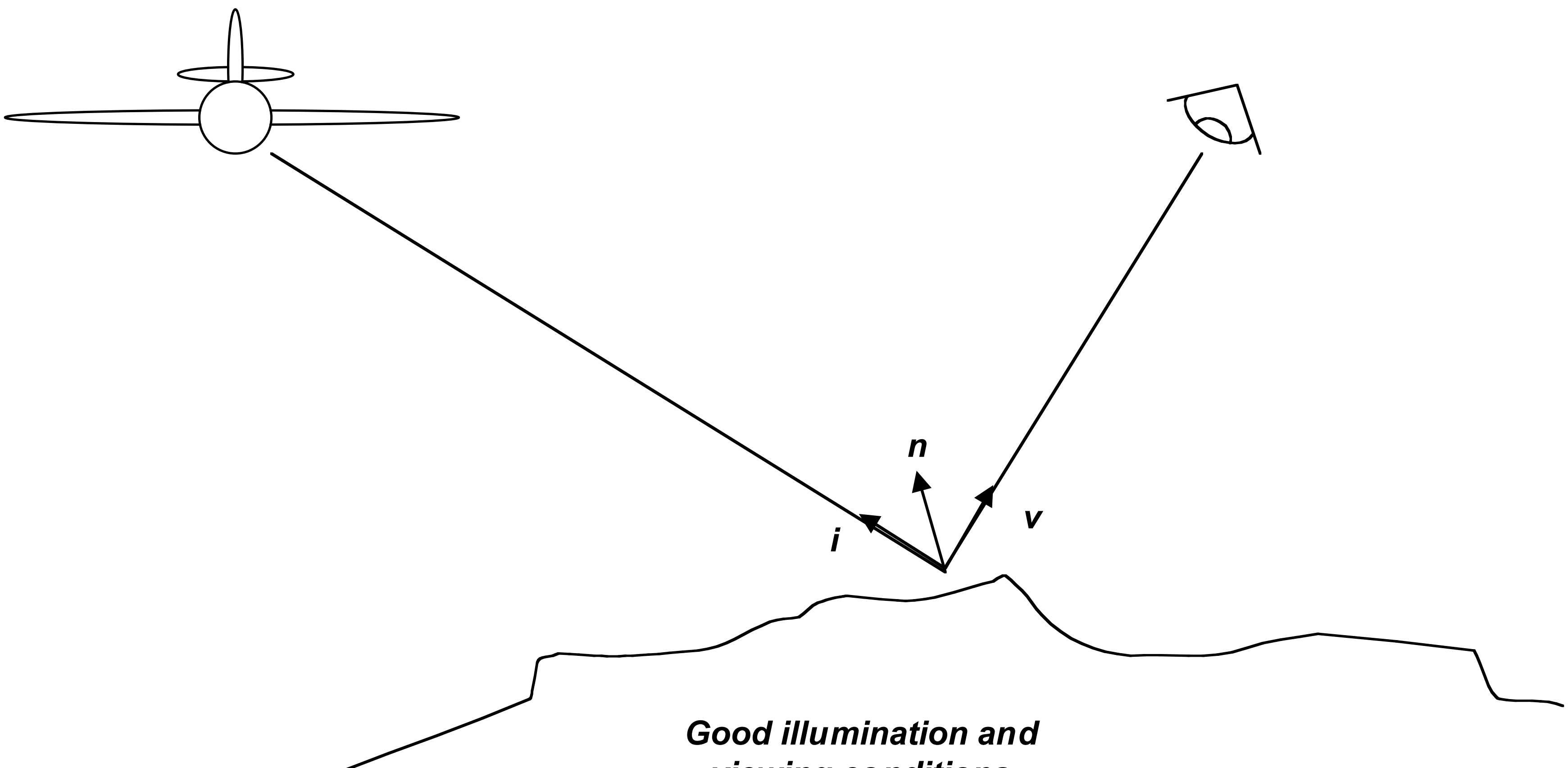
Flight Pass Planning in Rugged Terrain



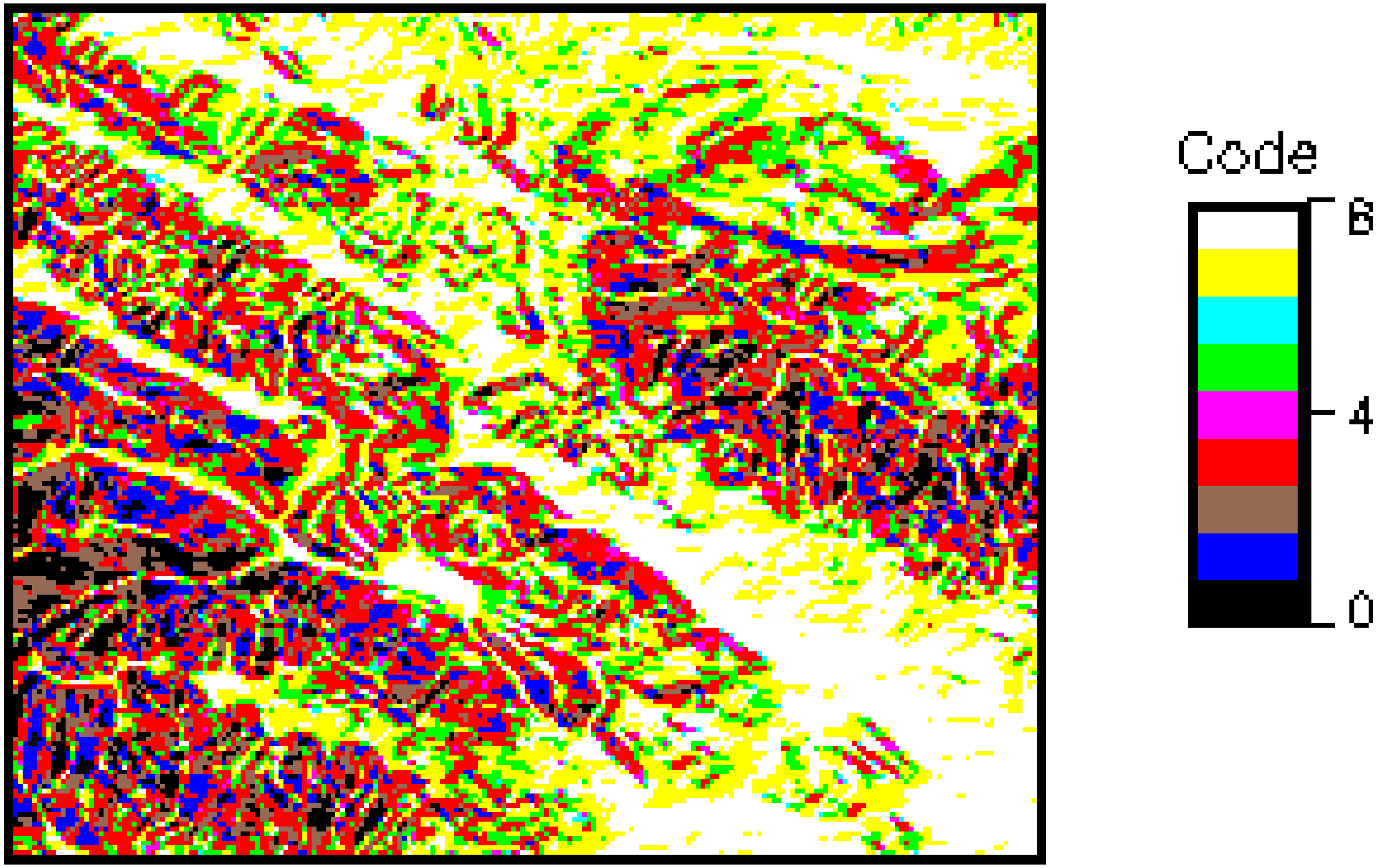
Good illumination and viewing conditions

$n \bullet I \geq 1/2$

$n \bullet v \geq 1/2$

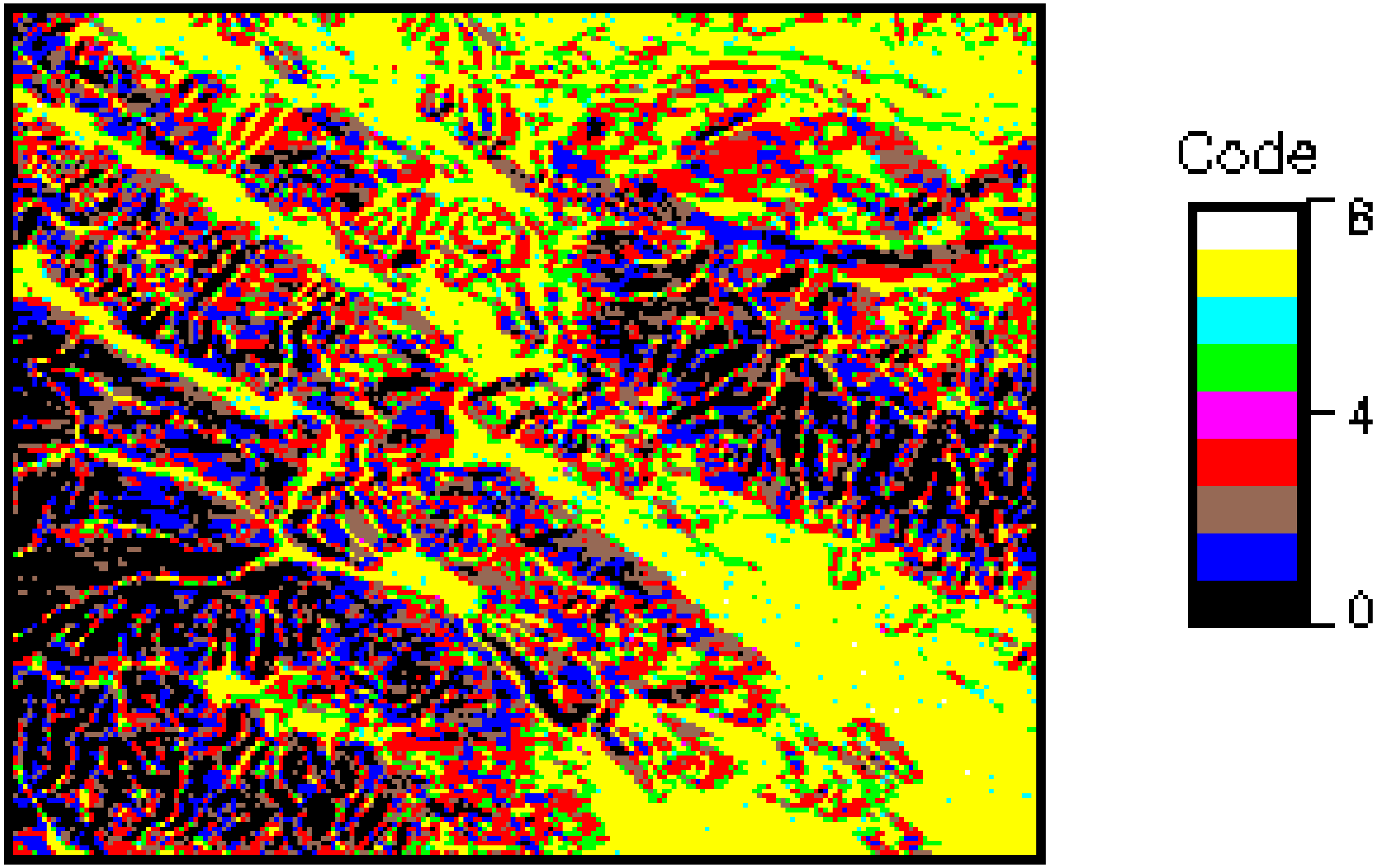
Topography of Experiment Area

Shadow Analysis



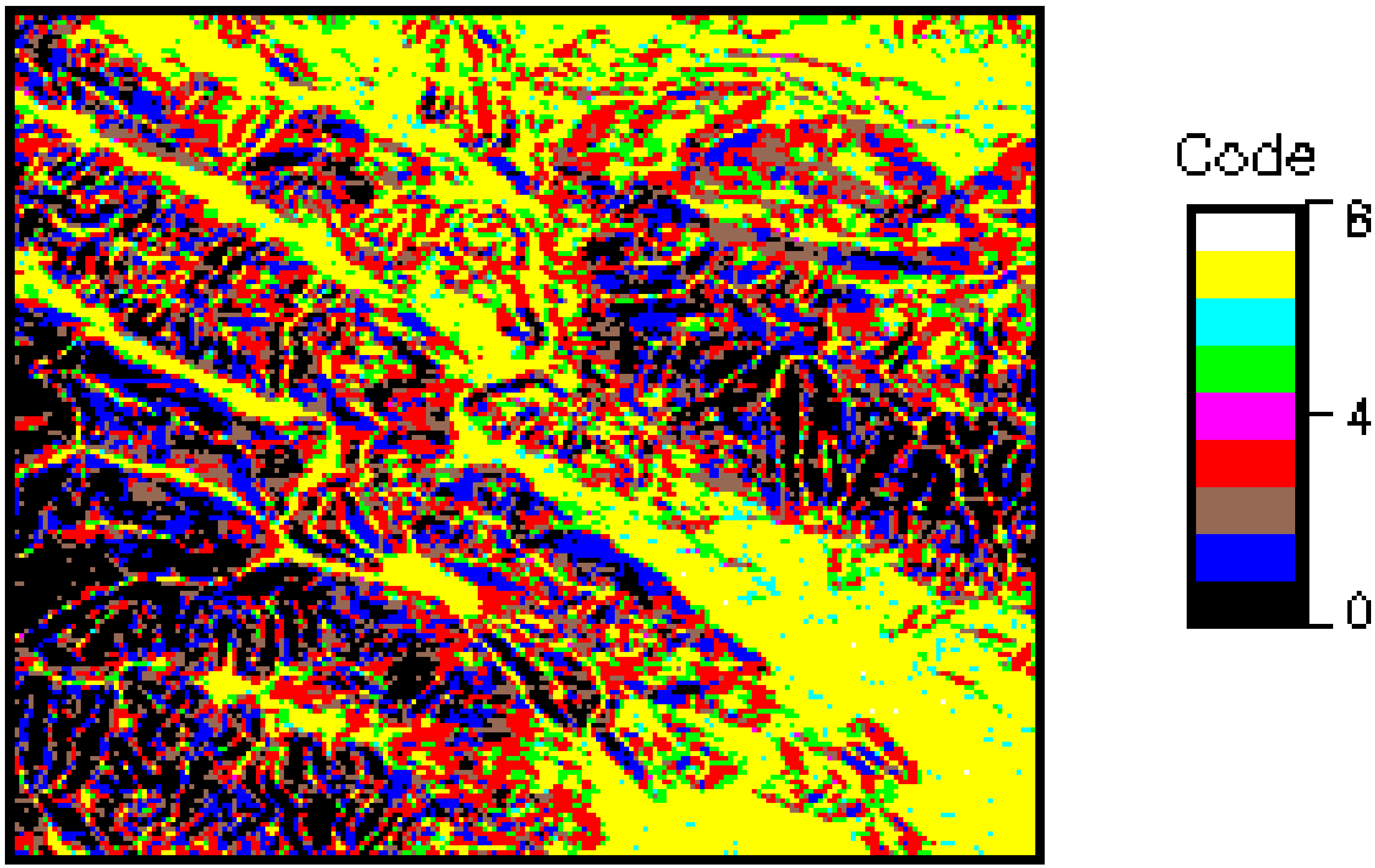
Coverage of Selected Flight Passes (***n•i*** & ***n•v*** $\geq$ 0.4)

Shadow Analysis

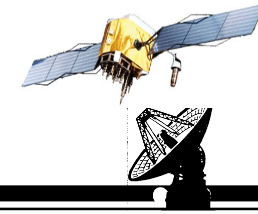


Coverage of Selected Flight Passes

Shadow Analysis



Coverage of Selected Flight Passes
(All headings rotated 30^{o})



Experiment Goals

- **Evaluate finer resolution (40 MHz) on performance of polarimetric detection techniques**
  - **Previous AirSAR tests used 20 MHz bandwidth**
- **Assess L-band vs P-band**
  - **Evaluate relative utility separately**
  - **Consider merging superior foliage penetration of P-band with better target strength and interpretability of L-Band**
- **Assess feasibility of exploiting multiple pass SAR data**
  - **Combine polarimetry with angle diversity**
- **Possibly assess utility of interferometric techniques for detection of crashed aircraft**