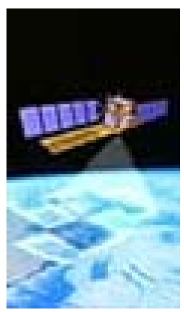
WMO/ITU Seminar
Use of Radio Spectrum for Meteorology

Earth Exploration-Satellite Service (EESS)- Active Spaceborne Remote Sensing and Operations

Radarsat



JASON

Seawinds

TRMM

Cloudsat

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Charles Wende (USA)

WMO, Geneva, Switzerland

16-18 September 2009

Active Sensor Definition

Active Sensor:

an instrument which obtains information by the transmission and reception of radio waves.

Active Sensor Types

- SYNTHETIC APERTURE RADARS – Cross-track looking sensors (one side only) which collect phase and delay time of coherent radar echoes; typical products include radar images and topographical maps of the Earth's surface.
- ALTIMETERS – Downward looking sensors measuring the precise echo delay time to extract the precise altitude of the ocean's surface.
- SCATTEROMETERS - Sensors looking at various aspects to the sides of the nadir track, measuring the return echo power variation with aspect angle to determine wind direction and speed on the ocean surface or return echo on the land surface.
- PRECIPITATION RADARS – Cross-track looking sensors measuring the radar echo returned from rainfall to determine the rainfall rate.
- CLOUD PROFILE RADARS – Downward-looking sensors measuring the radar echo returned from clouds to determine cloud reflectivity profile.

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Active Sensor Types

Frequency	Bandwidth	Missions Carrying Spaceborne Active Sensors				
Band (GHz)	MHz	SAR	Altimeter	Scatterometer	Precip. Radar	Cloud Radar
0.432-0.438	6	(SAR-P)				
1.215-1.3	85	[SIR-C], [JERS-1], ALOS, ERS-2, SMOS, (AQUARIUS), (DesDyni), (SMAP)				
3.1-3.3	200	ALMAZ	(RA2)			
5.25-5.57	320	[SIR-C], [SRTM], RADARSATs, ERSs, ENVISAT, (Sentinal-1)	TOPEX, JASONs	[ADEOS], ERS-2, MetOp		
8.55-8.65	100					
9.5-9.8	300	[X-SAR] [SRTM], COSMO-SkyMed, TerraSAR-X, (TanDEM-X)				
9.975-10.025	50					
13.25-13.75	500		TOPEX, JASONs, ERSs, ENVISAT, (RA-2)	[ADEOS], QuikSCAT, ENVISAT	TRMM, (GPM)	
17.2-17.3	100					
20.05-24.25	200					
33.5.5-36.0	500		(Altika-SARAL)		(GPM)	
78-79	1000					
94-94.1	100					CloudSAT, (EarthCARE)
133.5-1342.0	500					
237.9-238.0	100					

Notes: “[...]” are past missions, “(...)” are future missions.

Synthetic Aperture Radars (SARs)

- Provide radar images and by combining 2 images:
  - from different orbits →topographical maps of the Earth's surface, or
  - taken at different times →maps indicating ground movement ~ centimeters (Interferometric SAR, or InSAR)

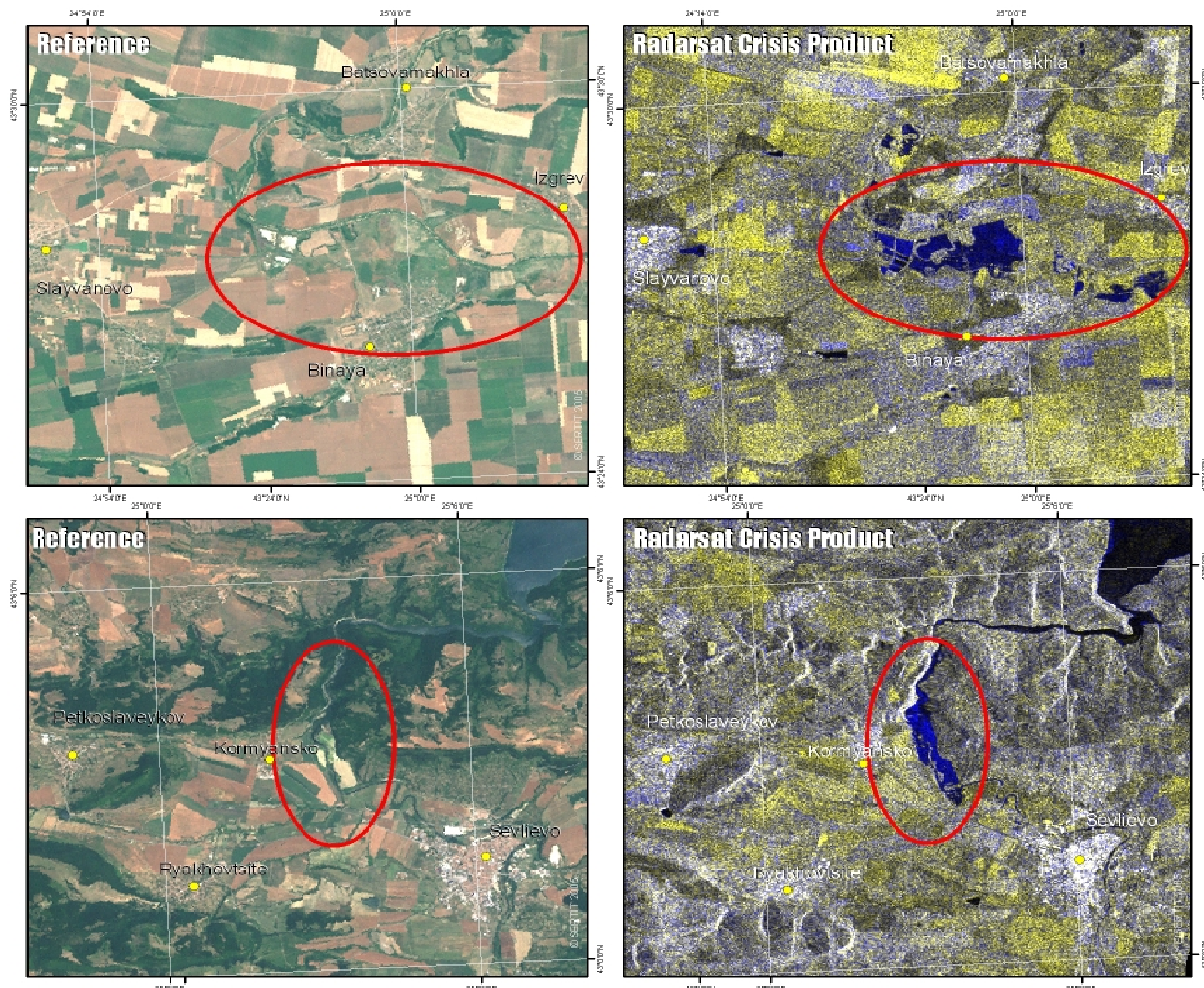
- RF center frequency depends on the Earth's interaction with the EM field
  - lower frequencies (< 2 GHz) penetrate vegetation and reflect off the ground
  - higher frequencies reflect off water (rain, vegetation, etc.)

- RF bandwidth affects the resolution of the image pixels

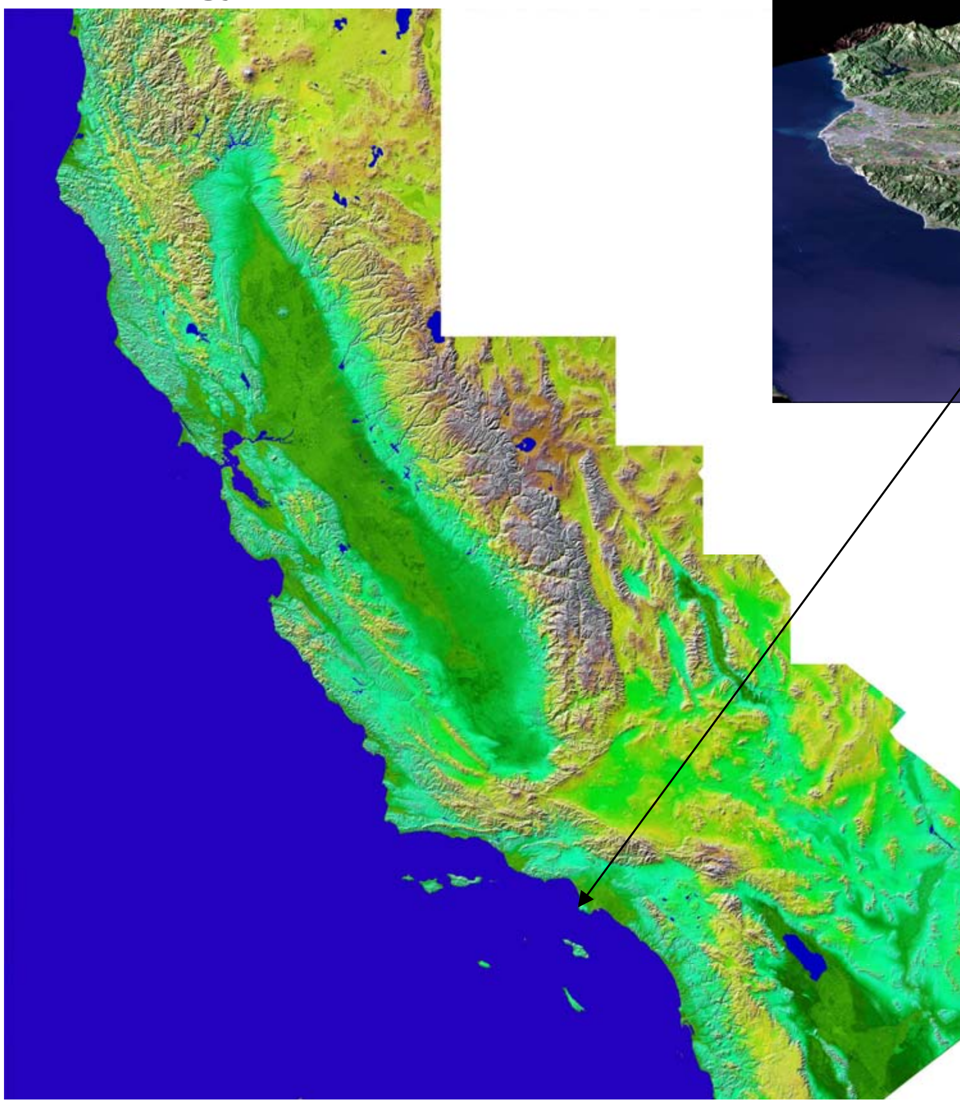
- Allowable image pixel quality degradation determines allowable interference level

SARs (cont.)

The Radarsat image (right) shows two flooded areas in north central Bulgaria in early June 2005 with respect to the reference Landsat image (left).



SARs (cont.)



Los Angeles - SRTM
with Landsat Overlay

California-Height as color

SRTM DEM's

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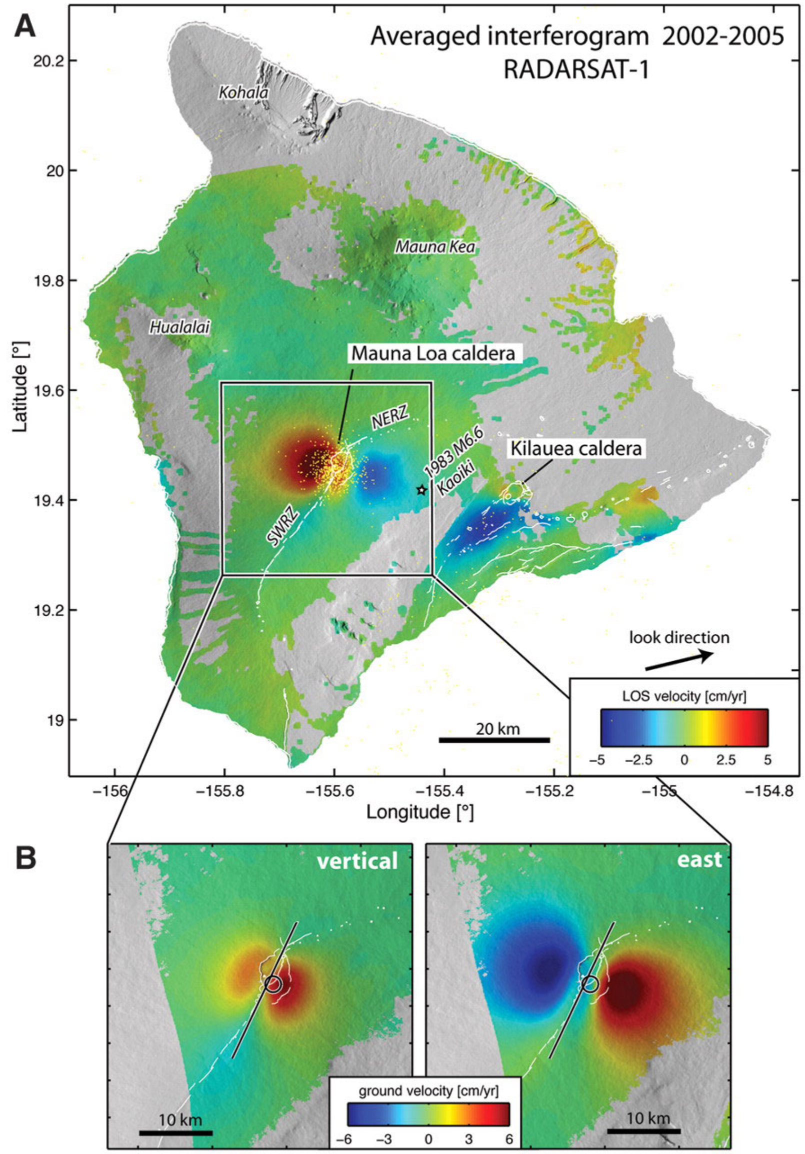
SARs (cont.)

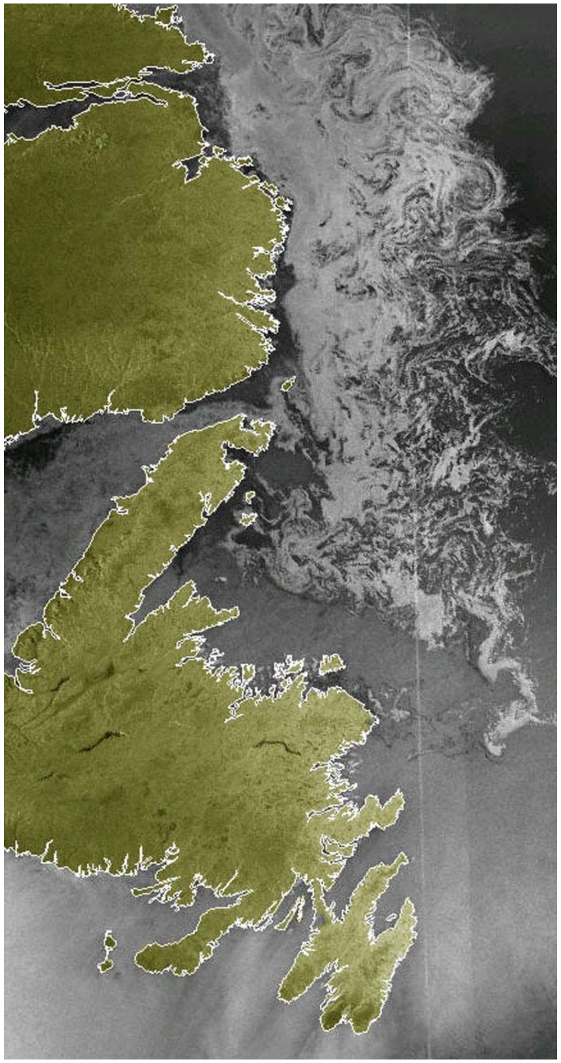
InSAR Image of the Mauna Loa Caldera in Hawaii

Ground motion indicates Dangerous underground volcanic activity



SARs (cont.)

RADARSAT-1 viewing
Ice off Newfoundland
And Labrador, Canada



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Altimeters

- Provide altitude of the Earth's ocean surface
- RF center frequency depends on the ocean surface interaction with the EM field
- Dual frequency operation allows ionospheric delay compensation
- JASON-1 uses frequencies around 13.6 GHz and 5.3 GHz
- Allowable height accuracy degradation determines the allowable interference level

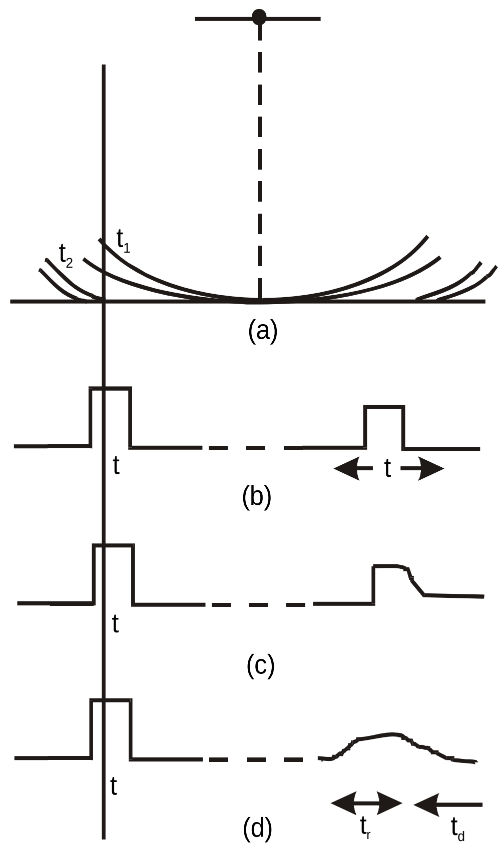

Illustration of Altimeter Return

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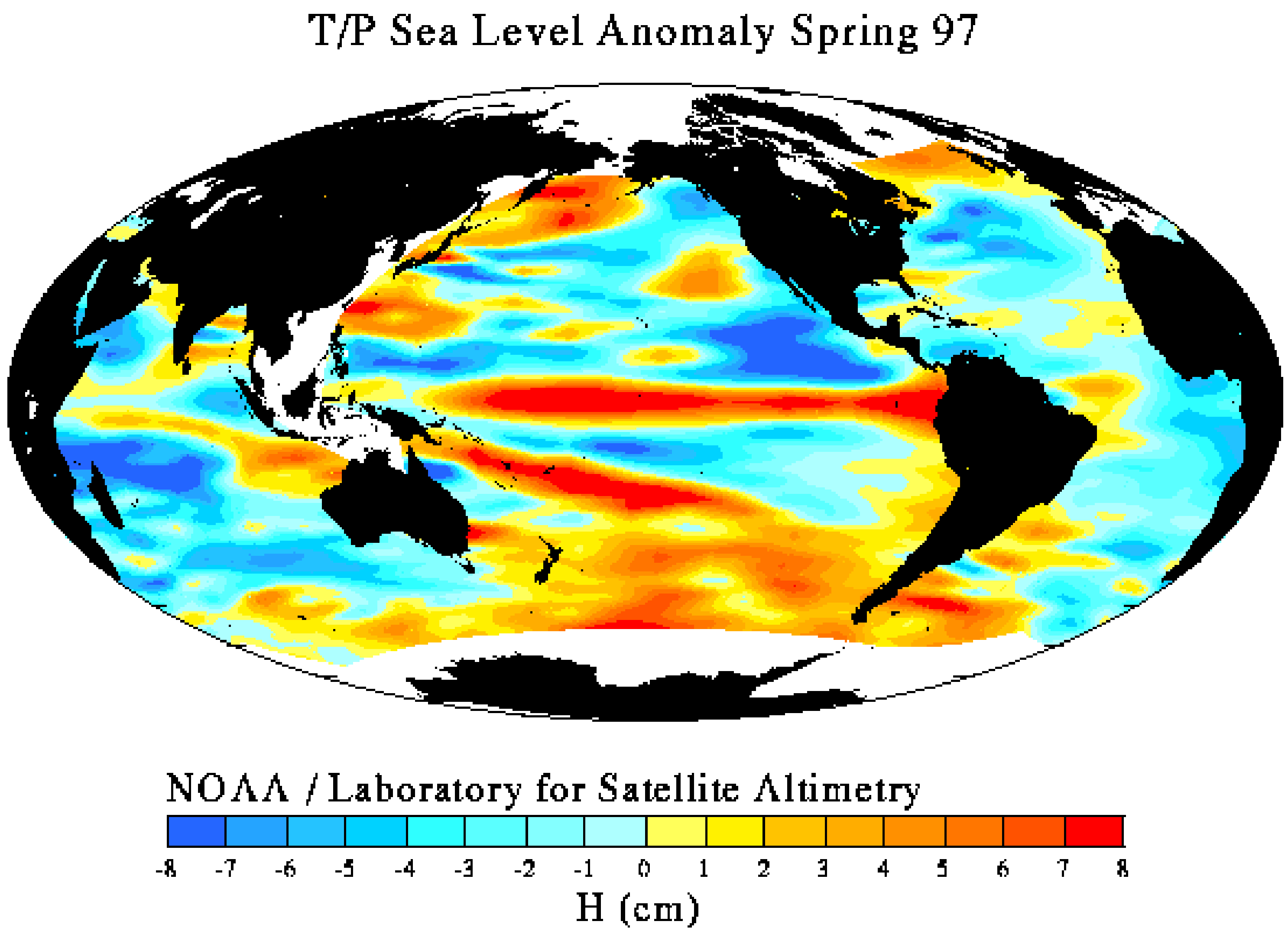
Altimeters (cont.)



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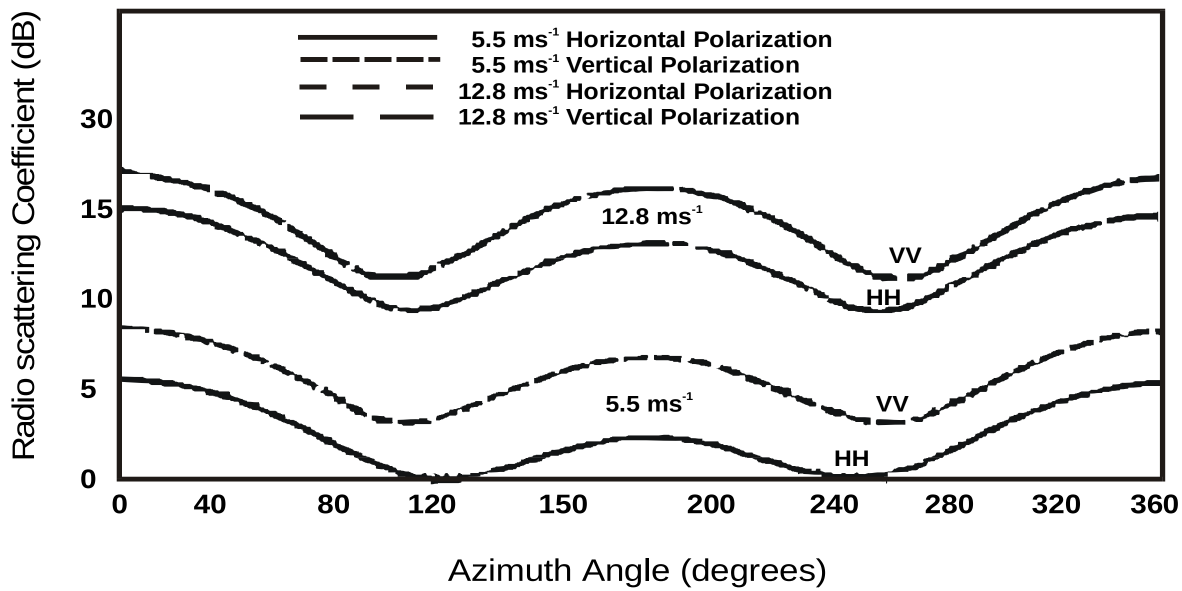
Scatterometers

- Provide the wind direction and speed over the ocean surface
- RF center frequency depends on the ocean surface interaction with the EM field and its variation over aspect angle
- Narrow RF signal bandwidth provides the needed measurement cell resolution
- Allowable wind speed accuracy degradation determines the allowable interference level

Variation of Backscatter with Aspect Angle



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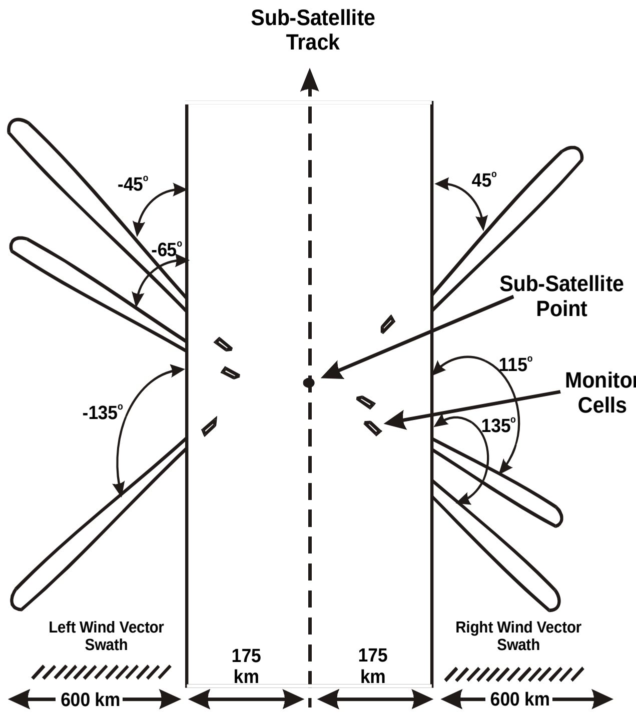
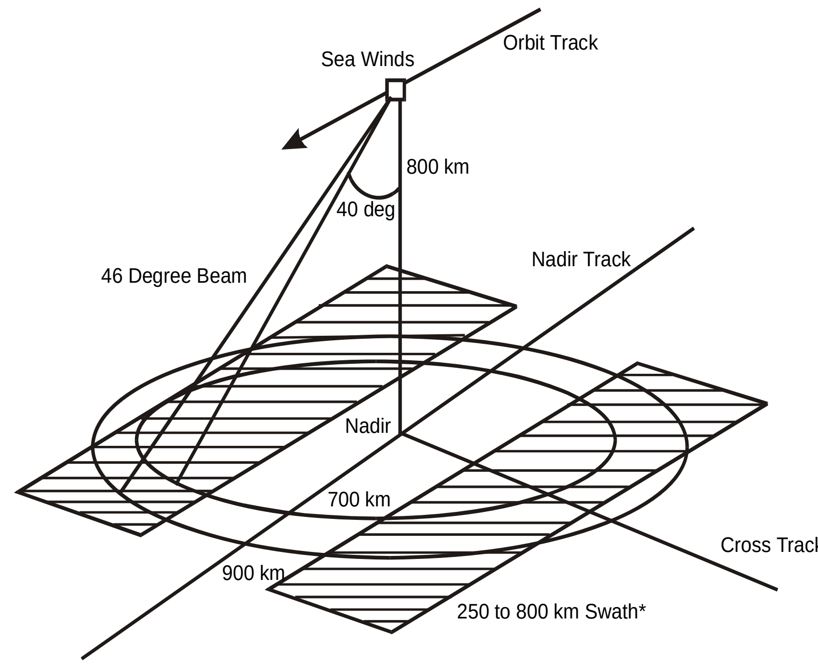
Ocean scatterometers



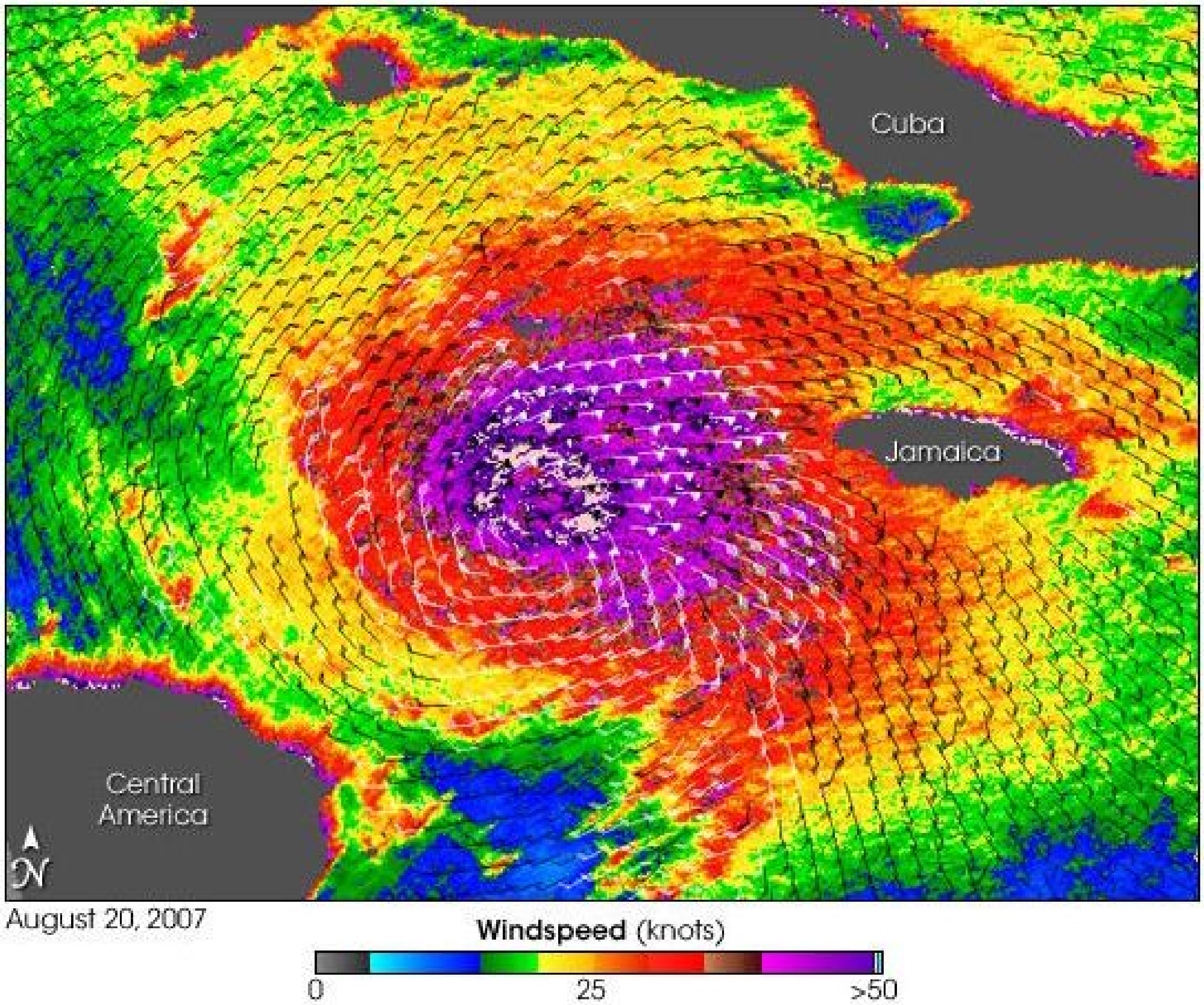
NSCAT illuminated the Earth's surface at several different fixed aspect angles



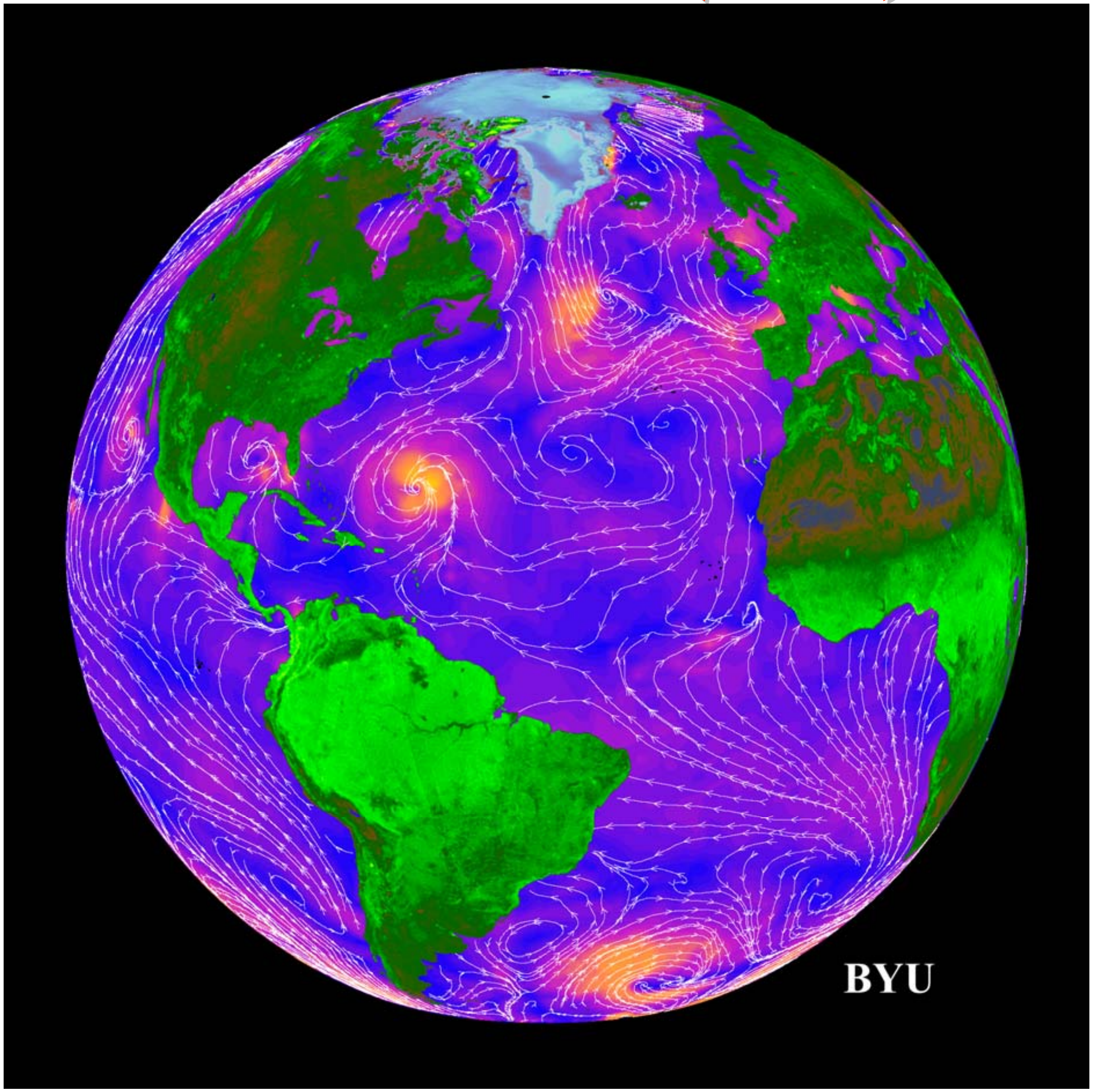
SEAWINDS scanning pencil beam illuminates scans at two different look angles from nadir, and scans 360 degrees about nadir in azimuth

Scatterometers (contd)

QuikSCAT Image of Hurricane Dean in the Gulf of Mexico, August 20, 2007



Scatterometers (cont.)



Polar-orbiting scatterometers observe ocean over the entire world.

SeaWINDS on QuikSCAT provided these data.

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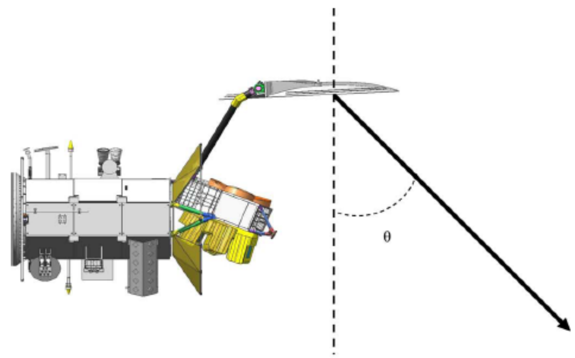
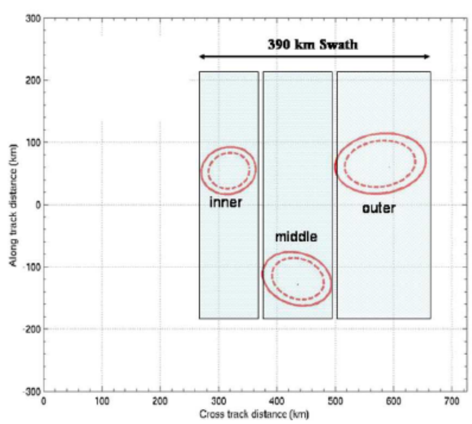
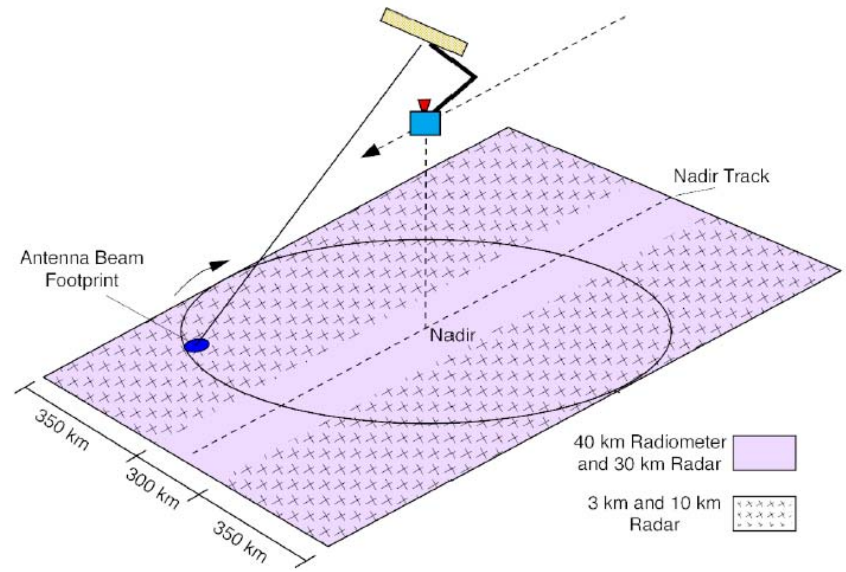
Land scatterometers



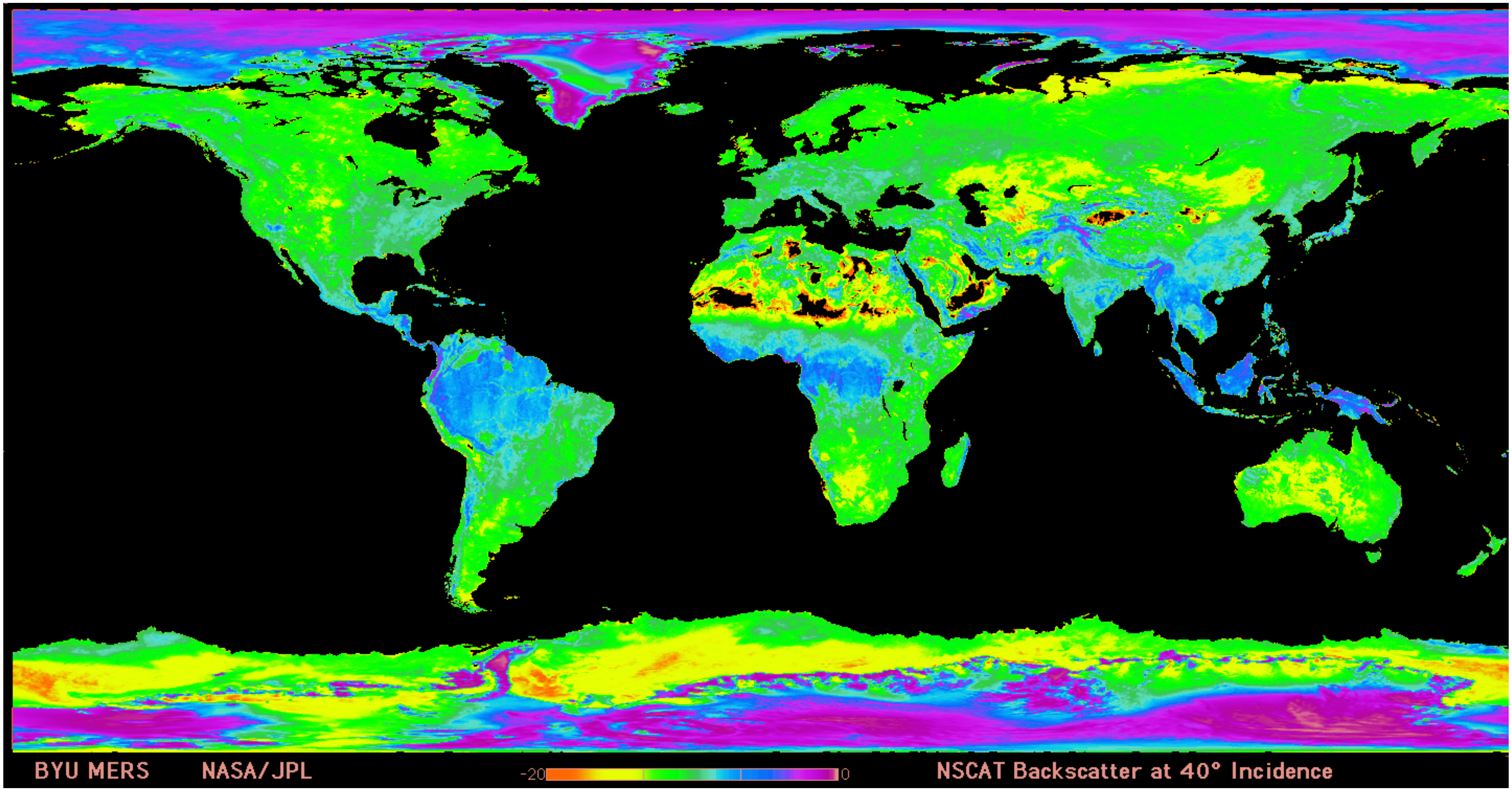


Aquarius scatterometer will illuminate the Earth's surface at several different fixed aspect/nadir angle combinations



SMAP scatterometer scanning pencil beam illuminates scans at fixed look angle from nadir, and scans 360 degrees about nadir in azimuth

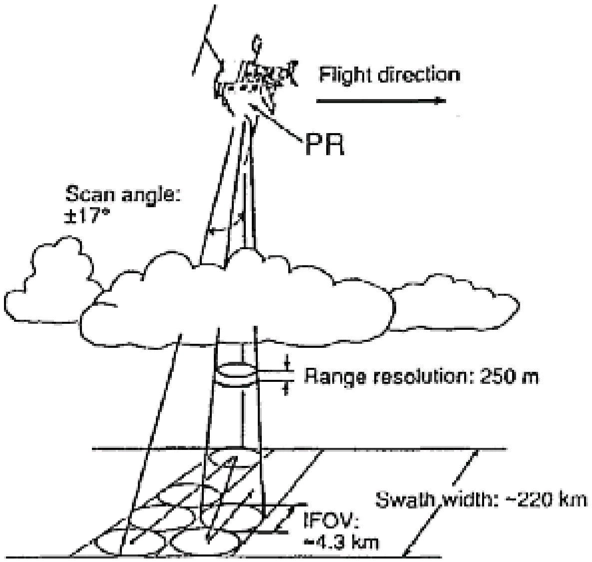
Scatterometers (cont.)



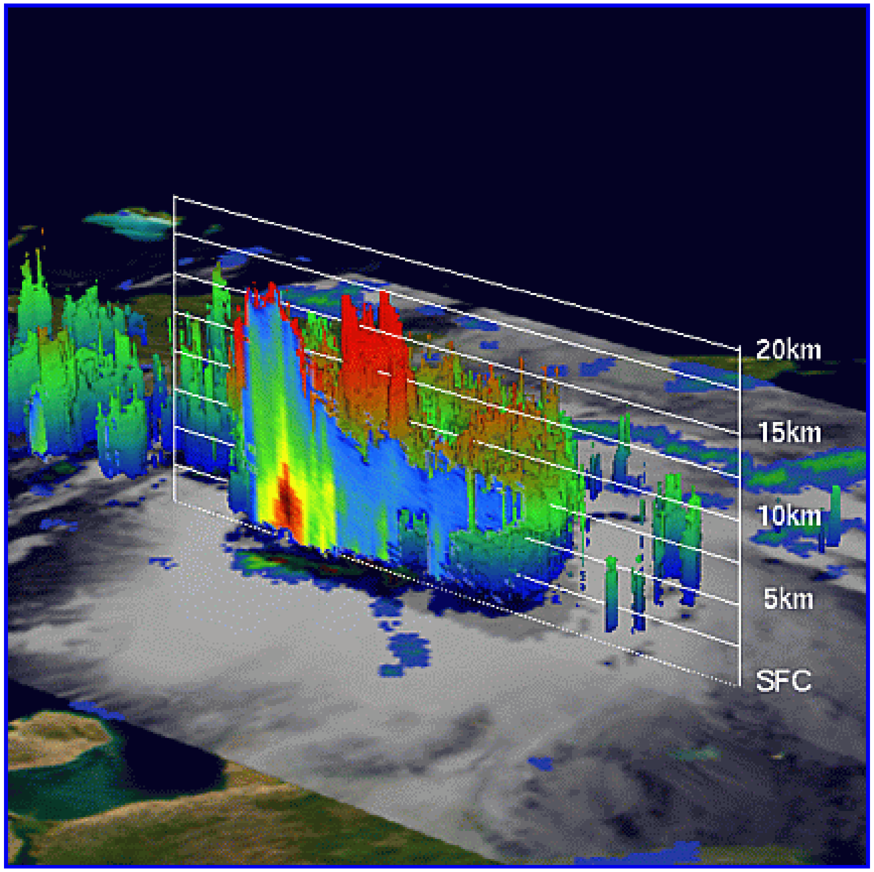
Scatterometer looking at land – wet areas (blue) reflect back signals.

Precipitation Radars

- Provide precipitation rate over the Earth’s surface, typically concentrating on rainfall in the tropics
- RF center frequency depends on the precipitation interaction with the EM field
- Narrow RF signal bandwidth provides the needed measurement cell resolution
- Tropical Rainfall Measurement Mission (TRMM) uses only 0.6 MHz RF bandwidth
- Allowable minimum precipitation reflectivity degradation determines the allowable interference level



Precip. Radars (cont.)

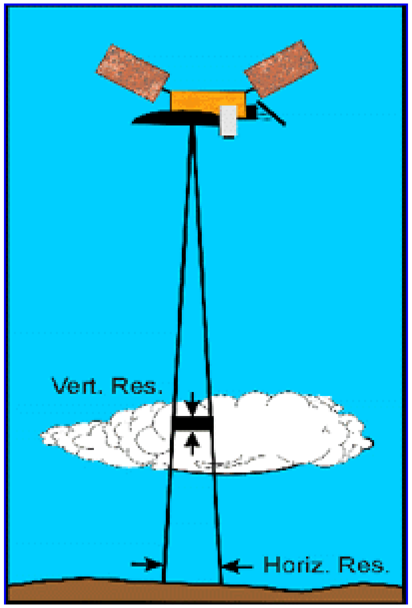


ERNESTO BECOMES THE FIRST ATLANTIC HURRICANE OF THE SEASON

The TRMM image shows the precipitation profile of the hurricane Ernesto on 26 August, 2006, revealing several deep convective towers (shown in red) that top out over 15km.

Cloud Profile Radars

- Provide three dimension profile of cloud reflectivity over the Earth's surface
- RF center frequency depends on the ocean surface interaction with the EM field and its variation over aspect angle
- Antennas with very low sidelobes so as to isolate the cloud return from the higher surface return illuminated by the sidelobes
- Narrow RF signal bandwidth provides the needed measurement cell resolution
- Allowable reflectivity accuracy degradation determines the allowable interference level



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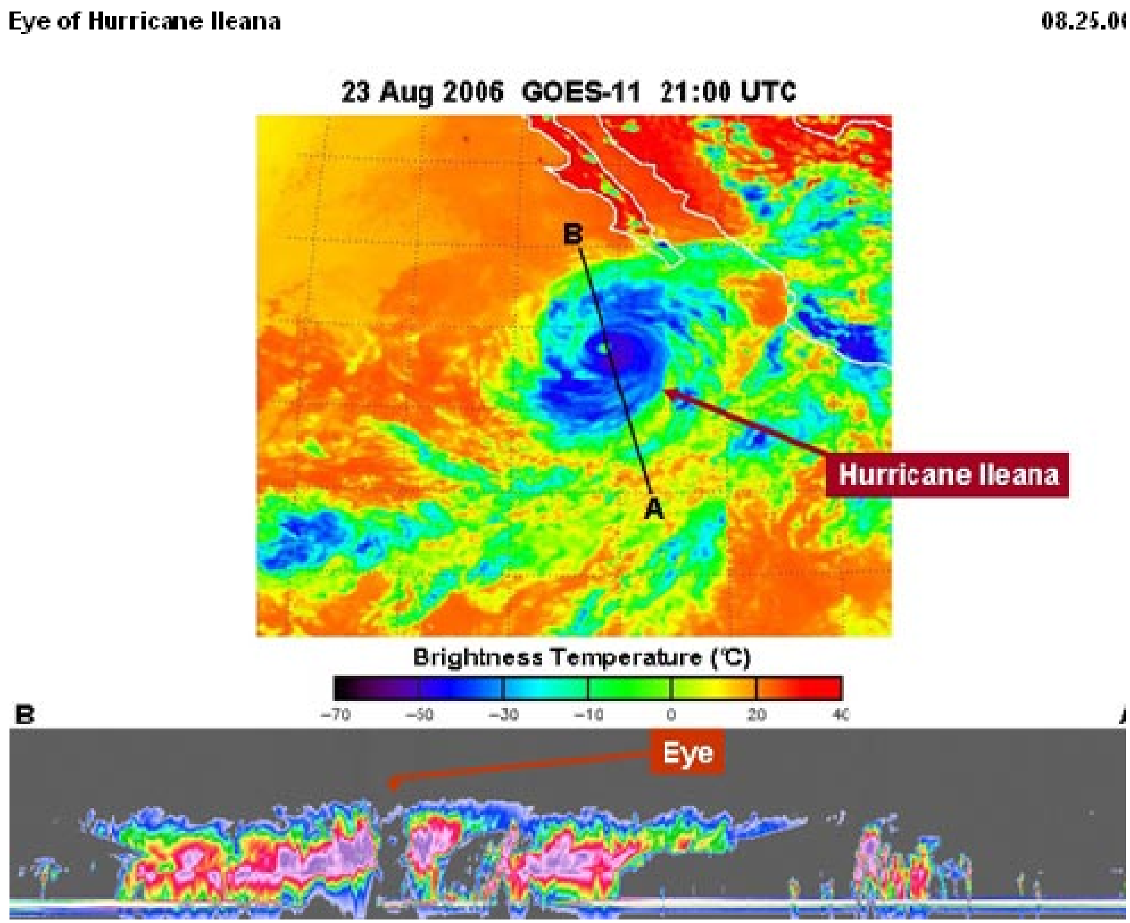
Cloud Profilers (cont.)

NOAA’s GOES (top) showed Hurricane Ileana on Aug 23, 2006.

CloudSat's Cloud Profiling Radar produced profiles of Ileana's clouds (bottom).



You have seen a variety of data products

today's instruments can produce.

Many* are available in a timely manner.

Use them to your country's advantage.

* some instruments are being demonstrated
and are not in operational use.

And you can help -

Remind your administration that these useful instruments operate in allocated frequency bands and are given protection from interference.

ANNEX

Additional details about the technques

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Active Sensor Characteristics

Characteristics	Sensor Types				
	SAR	Altimeter	Scatterometer	Precipitation Radar	Cloud Radar
Viewing Geometry	Side-looking @20-55 deg off nadir	Nadir-looking	(1) Three/six fan beams in azimuth (2) One/two conical scanning beams	Nadir-looking	Nadir-looking
Footprint/ Dynamics	(1) Fixed to one side (2) ScanSAR	Fixed at nadir	(1) Fixed in azimuth (2) Scanning	Scanning across nadir track	Fixed at nadir
Antenna Beam	Fan beam	Pencil beam	(1) Fan beams (2) Pencil beams	Pencil beam	Pencil beam
Radiated Peak Power	1500-8000 W	20 W	100-5000 W	600 W	1000-1500 W
Waveform	Linear FM pulses	Linear FM pulses	Interrupted CW, Short Pulses, or linear FM pulses	Short pulses	Short pulses
Spectrum Width	20-450 MHz	320 MHz	5- 80 kHz, 1-4 MHz	0.6 MHz	300 kHz
Duty Factor	1-5 %	46 %	10-31 %	2 %	1-14 %
Service Area	Land/coastal/ Ocean	Ocean/Ice	Ocean/Ice/Land	Land/Ocean	Land/Ocean

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Repeat Cycles, Swath Width and Orbital Characteristics for EESS (active)

Table of Orbital Characteristics of Active Spaceborne Sensors

Sensors	Repeat Cycle (days)	Altitude (km)	Swath Width (km)	Inclination (deg)
SARs RadarSAT-1/2 PALSAR ERS-1/2 JERS-1/2 ALMAZ ASAR TerraSAR-L/X	 16/24 46 3,35,168/35 44/35 3 35 18	 790 692 785 580 300 800 514	 500 max 70 102.5 100 45 406 max 200 max/ 100	 98.5 98.2 98.5 98.0 73 98.55 97.4
Altimeters JASON-1/2 RA2 Topex/Poseidon	 10 35 10	 1336 780 1336	 26 16-20 75	 66 98.5 66
Scatterometers SeaWinds ERS-1/2 NSCAT ASCAT RA-2	 2 35 41 29 35	 803 780 800 835 800	 1800 500 1400 360 100	 98.2 98.5 98.6 98.7 98.55
Precipitation Radars TRMM GPM DPR	 49 0.125 (3 hrs for core & 8-10 LEOs)	 350 400	 220 125-245	 35 66
Cloud Radar Cloudsat	 16	 705	 1-2	 98.2

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Active Sensors Applications by Sensor Type

Active Sensor Type	Active Sensor Applications
SARS	SARs can provide knowledge of deep and undercanopy soil moisture which is critical for several Earth science disciplines and public welfare and policy making processes. These applications include, but are not limited to: long-term weather forecasts, studying the long- and short-term climate variations through quantifying elements of the energy and water cycle, for Carbon cycle science studies, and for studies and management of underground water resources and aquifers.
Atimeters	The data obtained by radar altimeters will be used to study ocean dynamics and their effects on climatology and meteorology. Dual frequency altimeters also operate at 5.3 GHz to provide data to compensate for uncertainties in height measurements caused by ionospheric effects on the 13.5 GHz measurement. The radar altimeter will provide precise measurements of the distance from the satellite to the Earth’s surface and also of the power and the shape of the returned echoes from ocean, ice and land surfaces, eventually allowing us to improve our knowledge of climatology and environmental change detection.
Scatterometers	Ocean scatterometers will measure surface wind speeds and directions over at least 90% of the oceans every two days in all weather and cloud conditions. Winds are a critical factor in determining regional weather patterns and global climate. Land scatterometers will measure surface echo returns to augment passive measurements of soil moisture and sea salinity. Scatterometers will play a key role in scientists efforts to understand and predict complex global weather patterns and climate systems.
Precipitation Radars	One precipitation radar is the first space mission dedicated to measuring tropical and subtropical rainfall using several microwave and visible/infrared sensors. Major objectives of the PR are 1) to provide a 3-dimensional rainfall structure, 2) to achieve quantitative rainfall measurement over land as well as over ocean, and 3) to improve the accuracy of a microwave imager measurement by providing the rain structure information.
Cloud Profiling Radars	The cloud profiling radar has been widely recognized as a key sensor to measure global distribution of clouds, which is a critical issue in understanding the cloud role in earth’s radiation budget and thereby predicting the global warming. The objective of spaceborne CPR is to measure global three –dimensional cloud distribution. The clouds which always cover about half area of the whole earth surface, play a significant and complicated role in the earth’s radiation budget. Especially, the vertical structure of clouds is a critical parameter to decide whether clouds contribute to warming or cooling of the atmosphere.