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Use of Radio Spectrum for Meteorology

Active Sensing Developments of the Past Decade and Future Challenges

Synthetic Aperture Radars

Radarsat

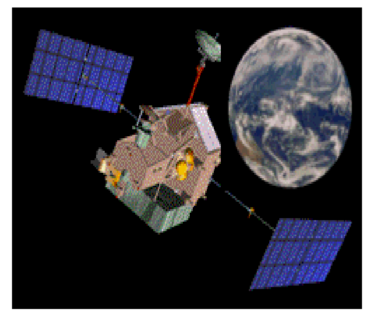
Altimeters

JASON

Scatterometers

ASCAT

Precipitation Radars



TRMM

Cloud Profile Radars

Cloudsat

Bryan HUNEYCUTT (NASA)

WMO/ITU, Geneva, Switzerland

23-24 October 2017

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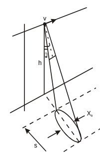
Active Sensor Definition and Types

Definition

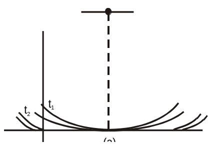
ACTIVE SENSOR: An instrument which obtains information by the transmission and reception of radio waves

Types

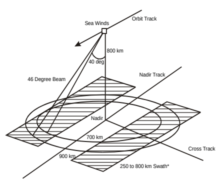
- SYNTHETIC APERTURE RADARS - Sensors looking to one side of nadir track, collecting phase and time history of coherent radar echo from which typically can be produced a radar image or topographical map of the Earth surface



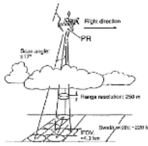
- ALTIMETERS - Sensors looking at nadir, measuring the precise time between a transmit event and receive event to extract the precise altitude of ocean surface



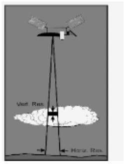
- SCATTEROMETERS - Sensors looking at various aspects to the sides of the nadir track, using the measurement of the return echo power variation with aspect angle to determine wind direction and speed on Earth ocean surface or return echo on Earth land surface



- PRECIPITATION RADARS - Sensors scanning perpendicular to nadir track, measuring the radar echo from rainfall to determine the rainfall rate over Earth surface, usually concentrating on the tropics



- CLOUD PROFILE RADARS - Sensors looking at nadir, measuring the radar echo return from clouds, to determine cloud reflectivity profile over Earth surface



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Active Sensor Missions

Frequency	Bandwidth	Missions Carrying Spaceborne Active Sensors				
Band (GHz)	MHz	SAR	Altimeter	Scatterometer	Precipitation Radar	Cloud Profile Radar
0.432-0.438	6	(BIOMASS)				
1.215-1.3	85	[SIR-C], [JERS-1], [ERS-2], ALOS-2, (NISAR), (SAOCOMs)		[AQUARIUS], [SMAP]		
3.1-3.3	200	[ALMAZ], HJ-1C, (NovaSAR), (NISAR)	[ENVISAT RA2]			
5.25-5.57	320	[SIR-C], [SRTM], [ERSs], [ENVISAT ASAR], RADARSATs, Sentinal-1 CSAR, (RISAT-1)	[TOPEX], JASONs, Sentinel-3 SRAL, HY-2A, (Sentinel-6 POSEIDON-4)	[ADEOS], [ERS-2], MetOp ASCAT		
8.55-8.65	100					
9.2-10.4	1200	[X-SAR], [SRTM], COSMO-SkyMed, TerraSAR-X, TanDEM-X, TecSAR, KOMPSAT-5 COSI, Meteor-M SAR (SAR on SCLP), CSG-1/2), (PazSAR-X)				
13.25-13.75	500		[TOPEX] ,[ERSs], [ENVISAT RA-2], JASONs, HY-2A, Sentinel-3 SRAL, Cryosat-2 SIRAL, (Sentinel-6 POSEIDON-4)	[ADEOS], [QuikSCAT SeaWinds], [ENVISAT], [OCEANSAT-2], HY-2A, FY-3E, Meteor-M SCAT, ScatSAT OSCAT	TRMM, GPM DPR, (CPM PMR), (CPM PMR2)	
17.2-17.3	100	(SAR on SCLP)				
24.05-24.25	200					
33.5-36.0	500	(SIGNAL)	Altika-SARAL, (SWOT)		GPM DPR, (Doppler Radar on ACE), (CPM PMR), (CPM PMR2)	
78-79	1000					
94.0-94.1	100					CloudSAT, (EarthCARE), (ACE)
133.5-134.0	500					
237.9-238.0	100					

Notes: “[…]” indicate past missions, “(…)” indicate future missions; current missions have no brackets or parentheses

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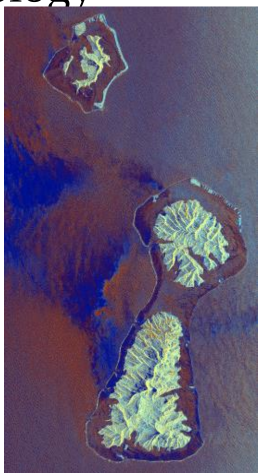
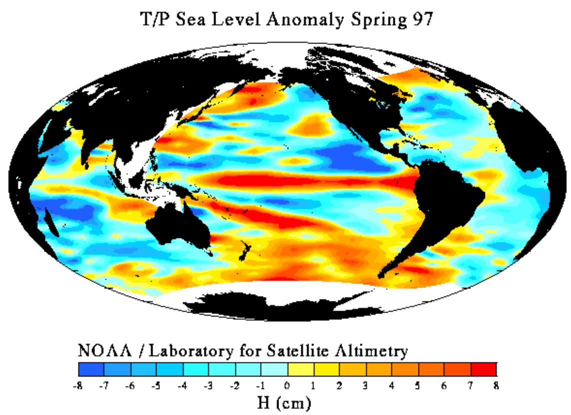
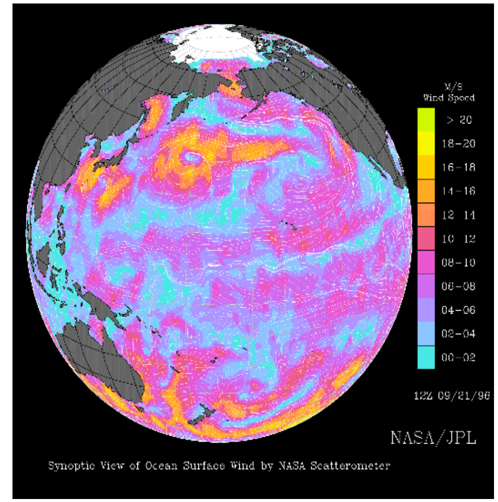
Active Sensor Product Examples



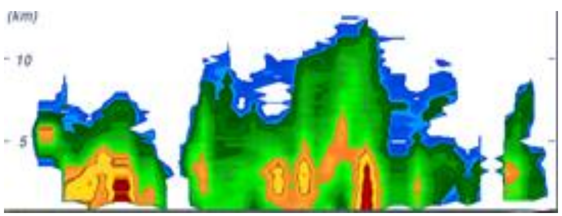
SAR-Radar Image
Bora Bora, French
Polynesia



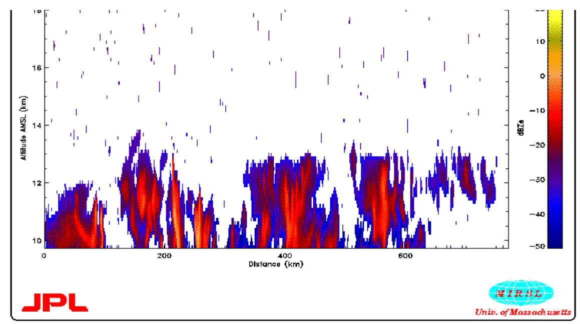
Altimeter-Sea Level



Scatterometer-Wind Speeds



Precipitation Radar-
Rain Rates



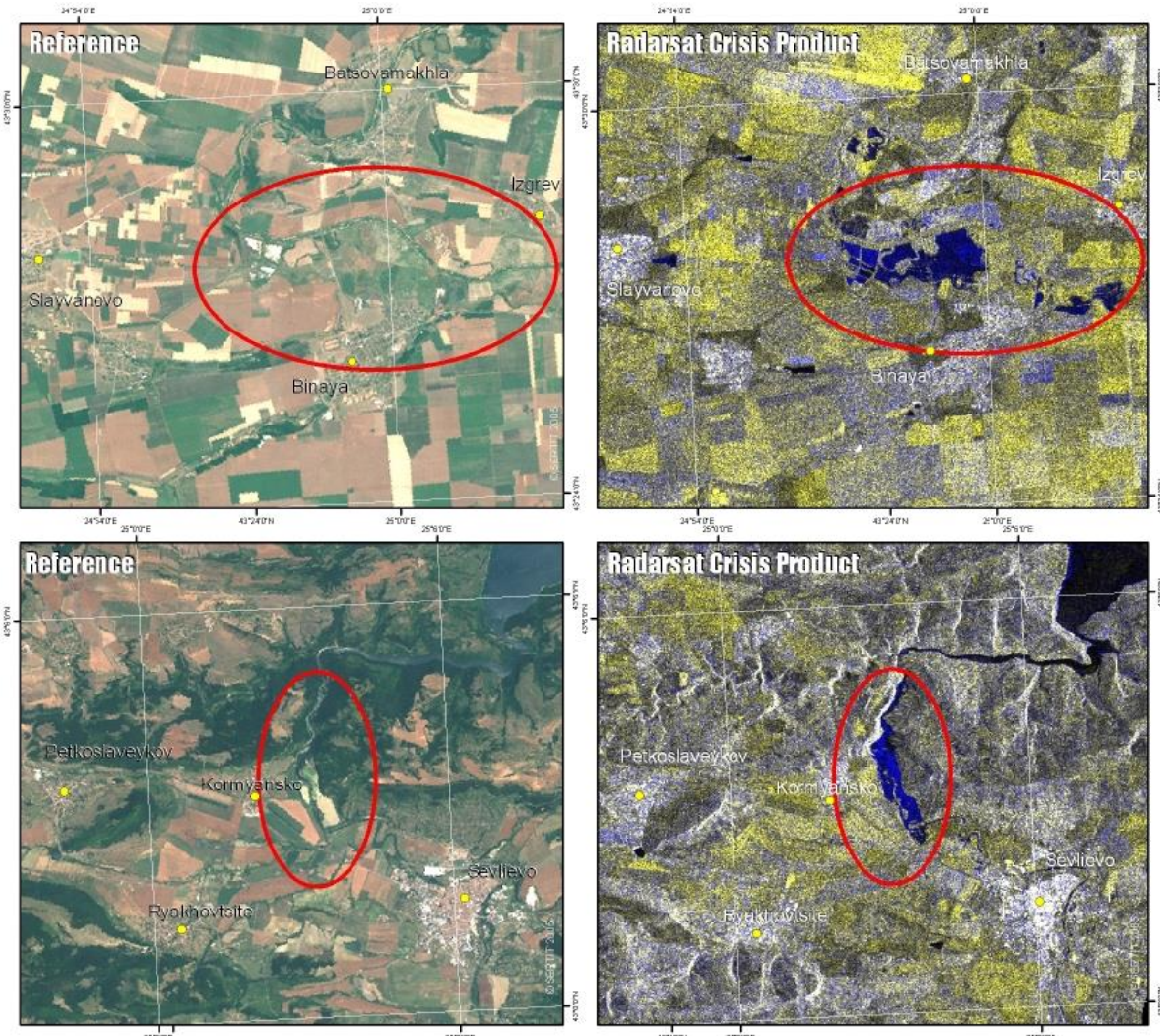
Cloud Radar-Cloud
Reflectivity Profile

Synthetic Aperture Radars (SARs)

- Provide radar images and topographical/movement maps of the Earth's surface
  - From different orbits topographical maps of the Earth's surface, or
  - Taken from different times maps indicating ground movement (centimeters)
  - (Interferometric SAR or InSAR)
- RF center frequency depends on the Earth's surface interaction with the EM field
  - Lower frequencies (<2 GHz) penetrate vegetation and reflect off the ground
  - Higher frequencies reflect of water (rain, vegetation, etc.)
- RF bandwidth affects the resolution of the image pixels
- ALOS-2 PALSAR-2 uses up to 84 MHz of RF bandwidth for fine resolution
- Allowable image pixel quality degradation determines allowable interference level

SARs (contd)

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



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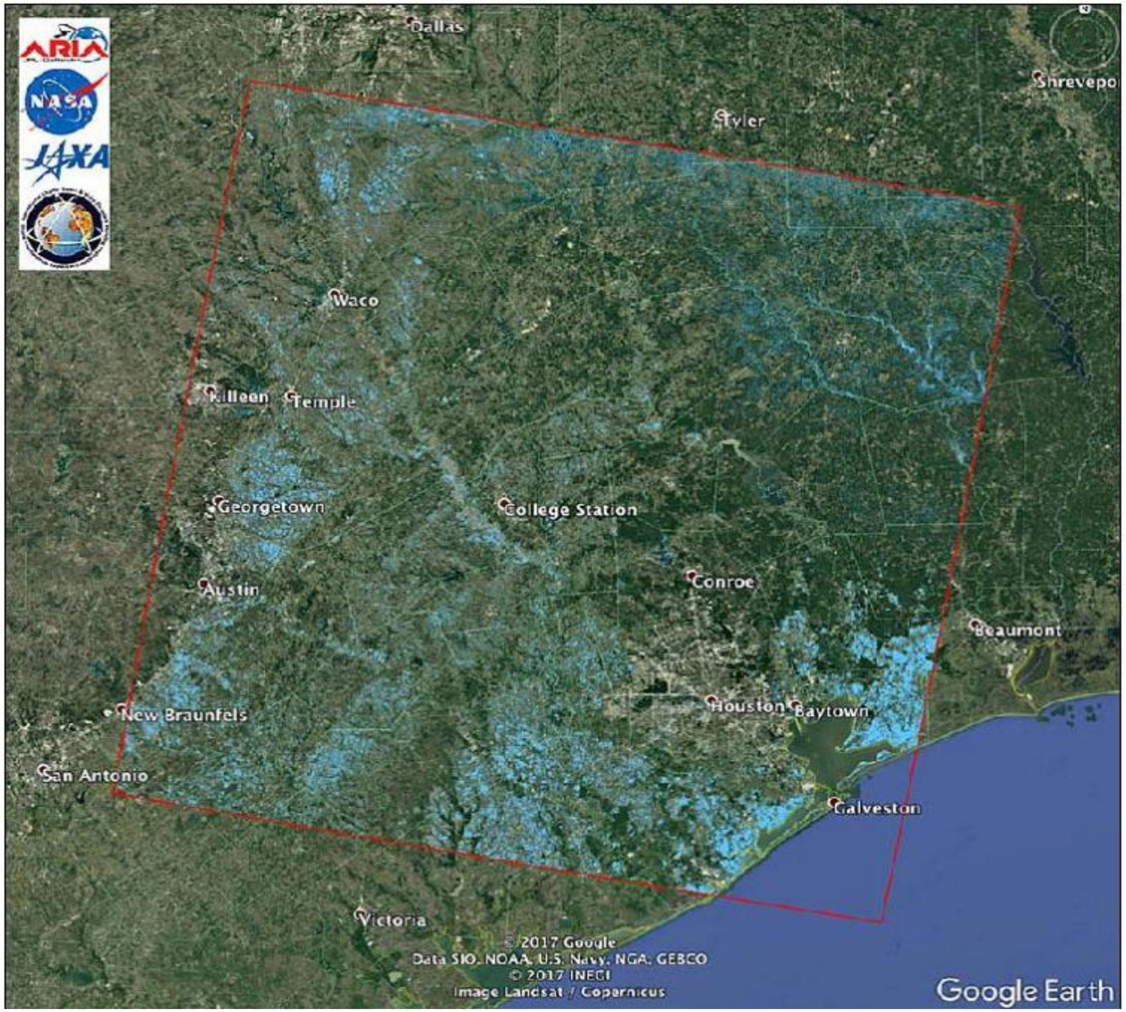
SARs (contd)

The ALOS-2 PalSAR-2 image (right) shows a Flood Proxy Map of Southeast Texas flooded from Hurricane Harvey (light blue) derived from radar images before and after landfall on August 25, 2017.



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-2/3 uses frequencies around 13.6 GHz and 5.3 GHz
- Allowable height accuracy degradation determines the allowable interference level

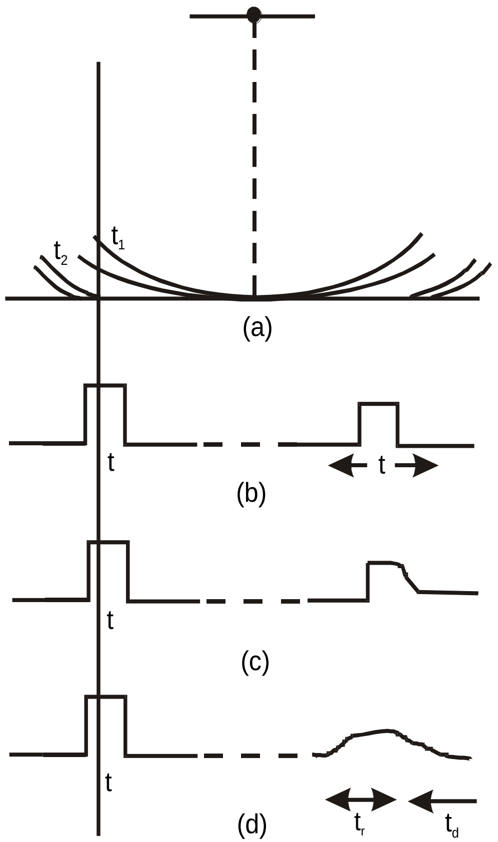


Illustration of Altimeter Return

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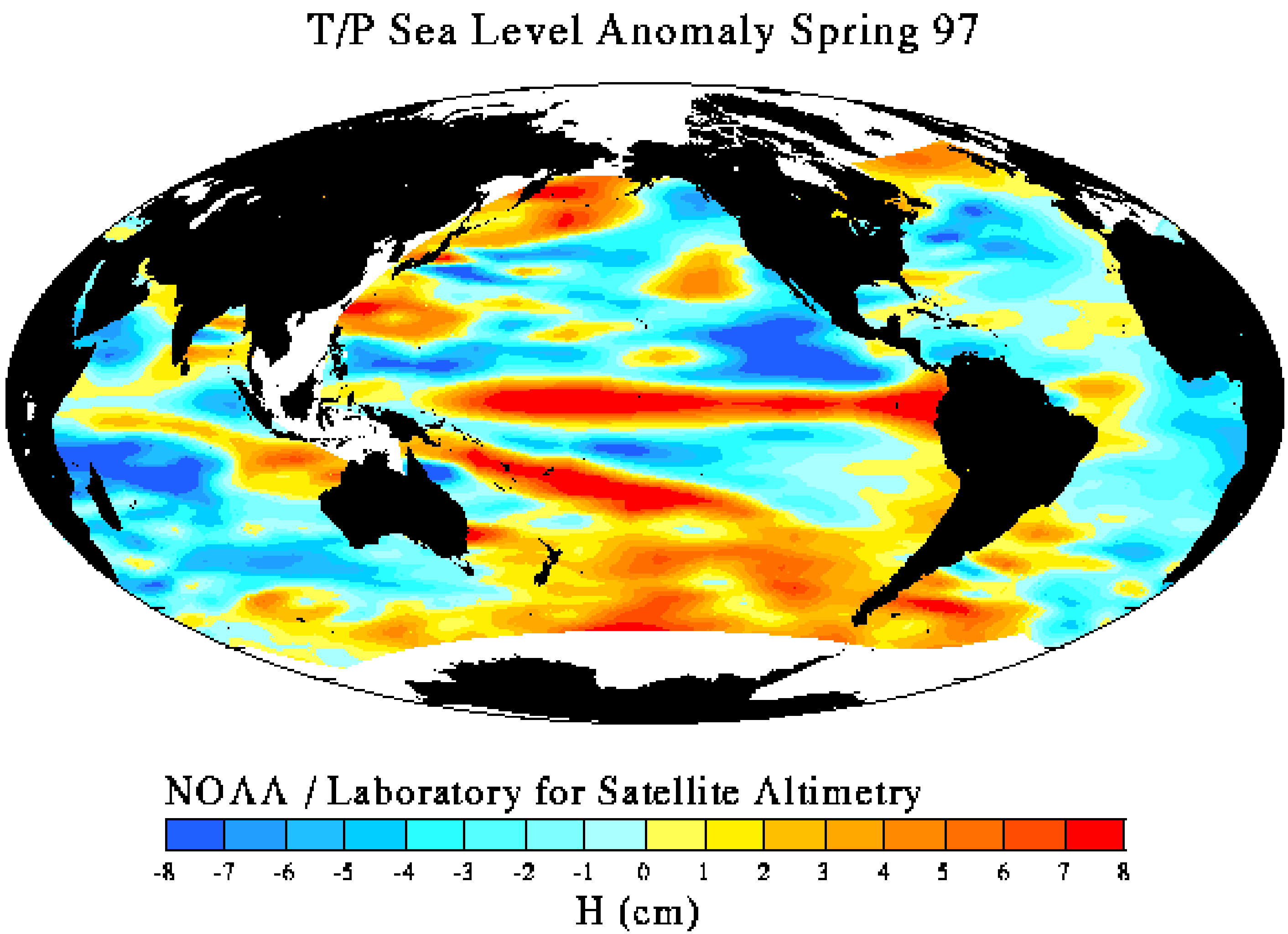
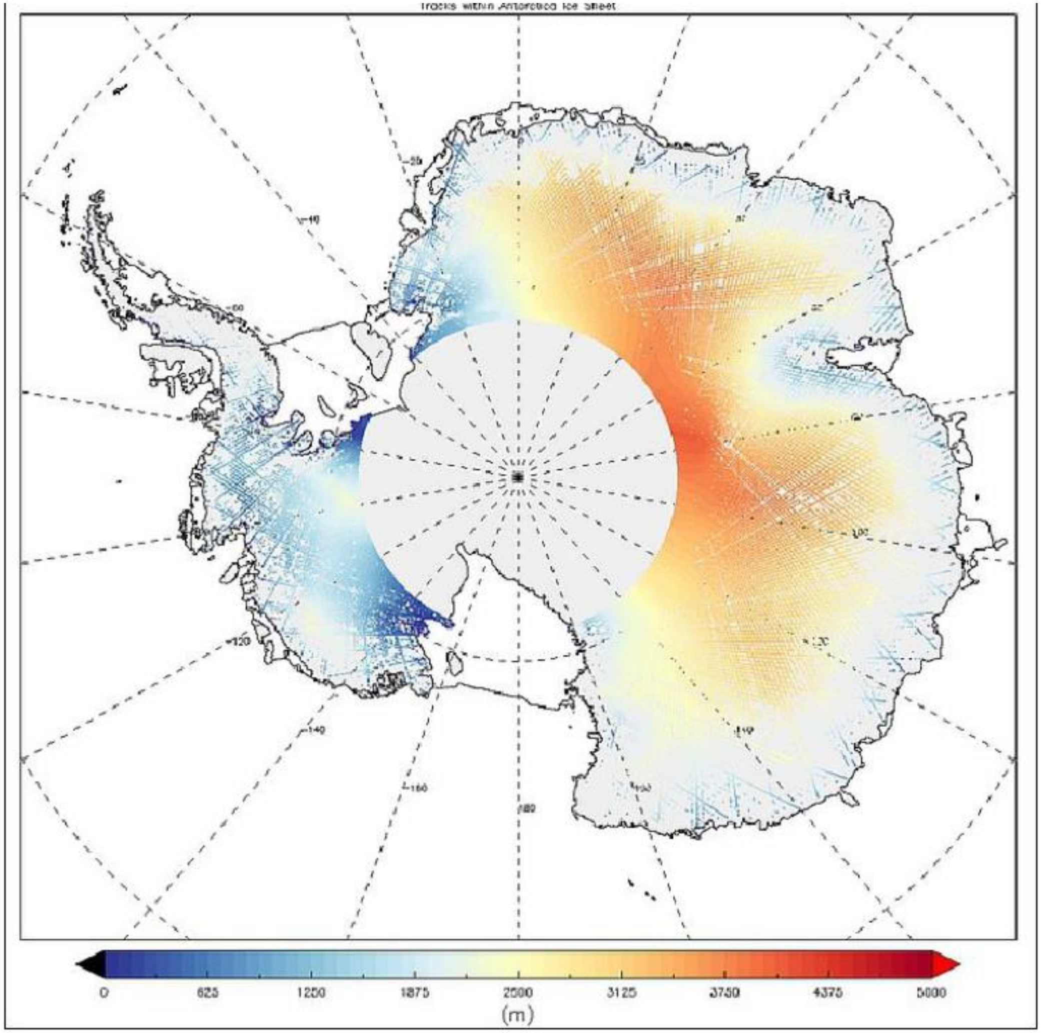
Altimeters (contd)



Altimeters (contd)

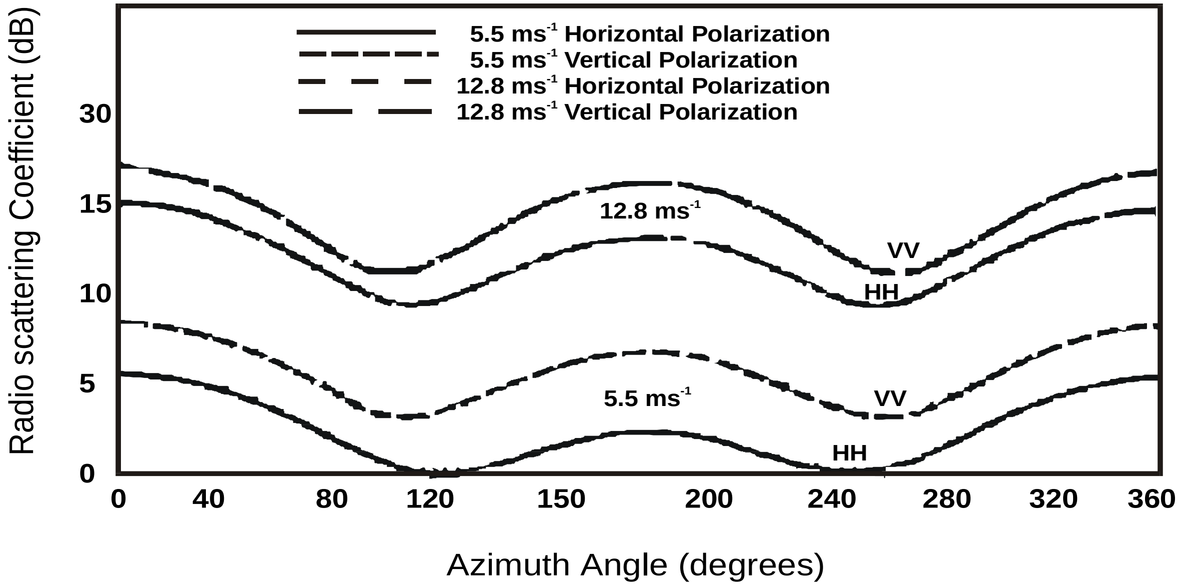
The SRAL (SAR Radar Altimeter) of the Sentinel-3A spacecraft measured the height of the Antarctic ice sheet (2016)



Scatterometers

- Provide the wind direction and speed over the Earth's 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
- Oceansat-2 scatterometer uses only 0.4 MHz RF bandwidth
- Allowable wind speed accuracy degradation determines the allowable interference level

Variation of Backscatter with Aspect Angle



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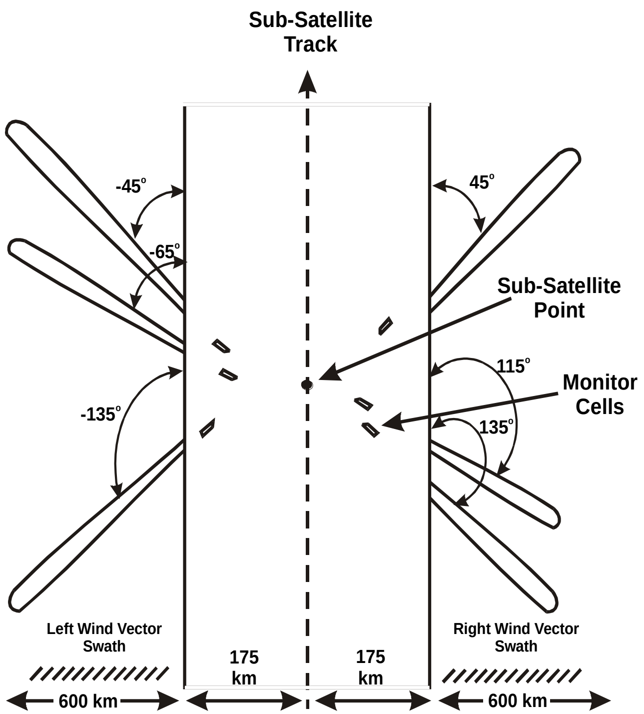
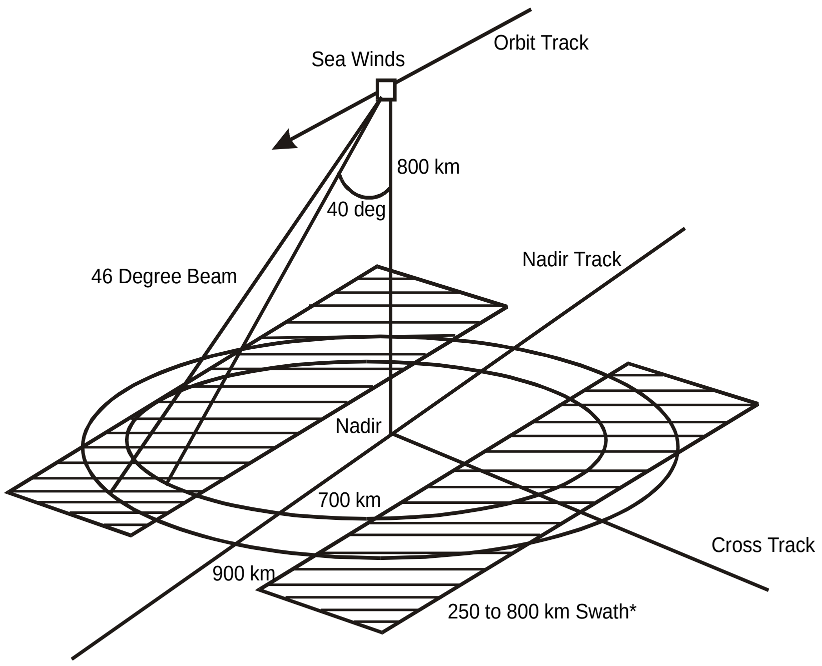
Ocean scatterometers



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

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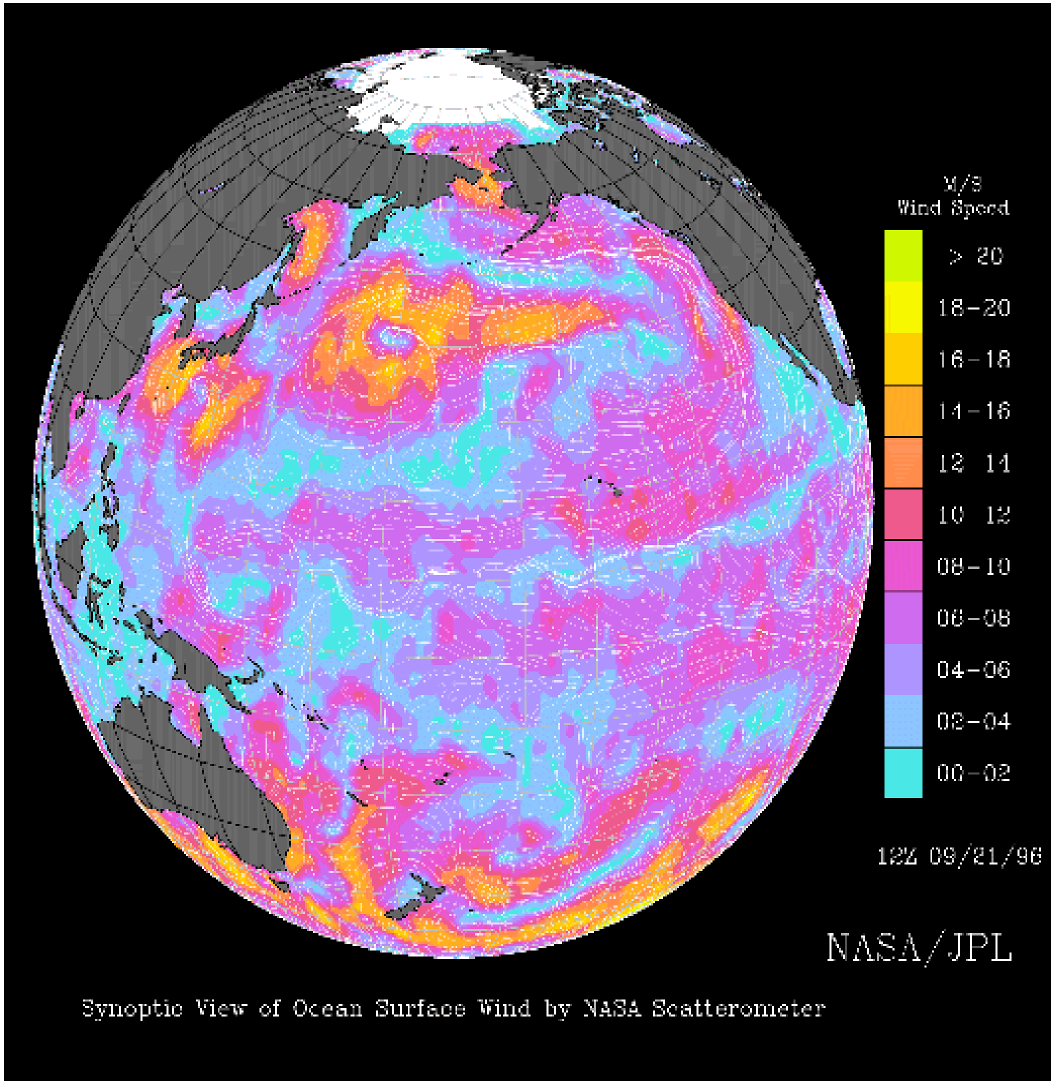
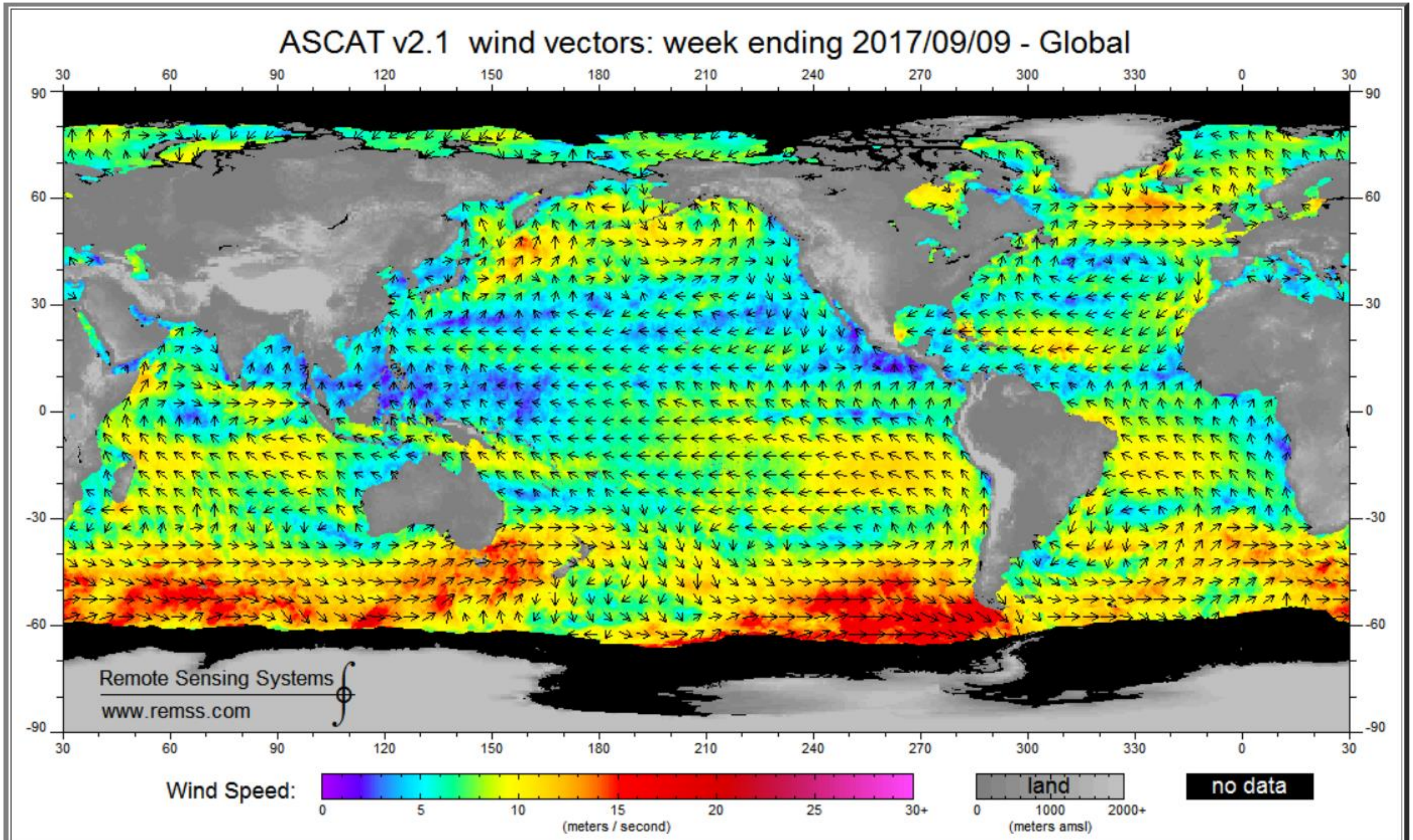
Ocean scatterometers (contd)



Ocean scatterometers (contd)



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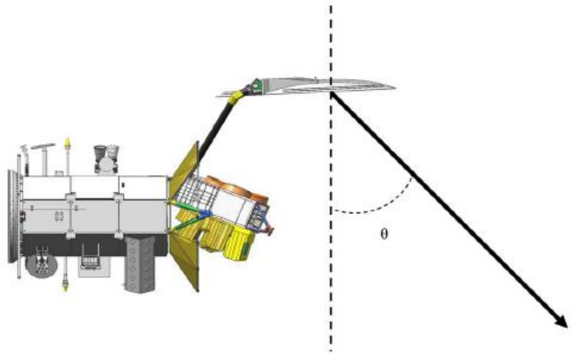
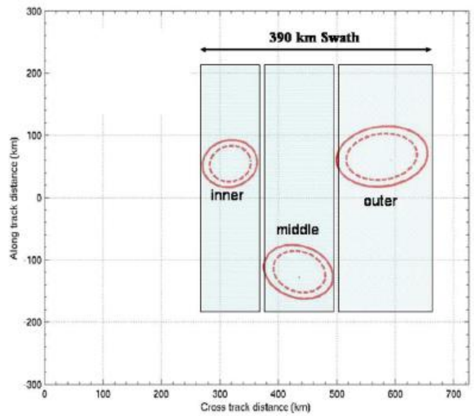
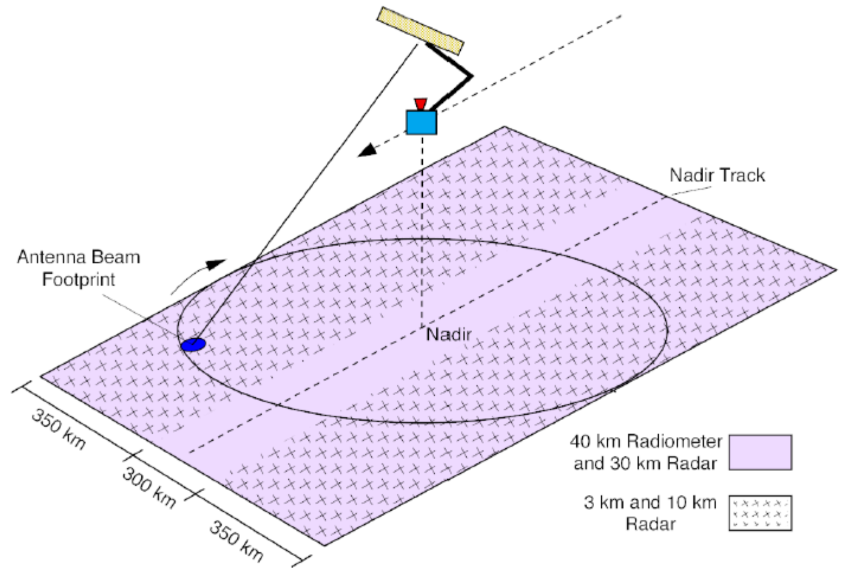
Land scatterometers



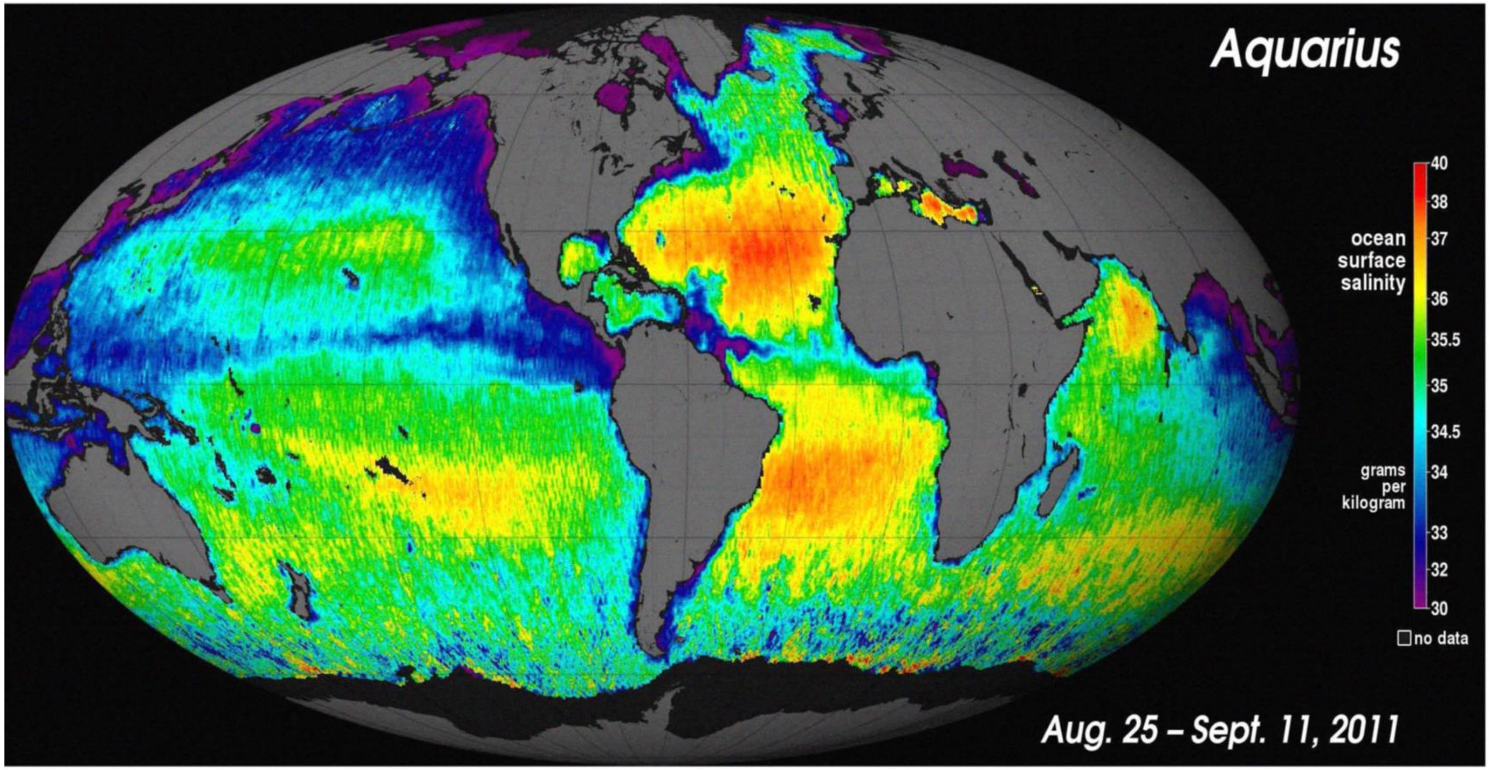


Aquarius scatterometer illuminated the Earth’s surface at several different fixed aspect/nadir angle combinations



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

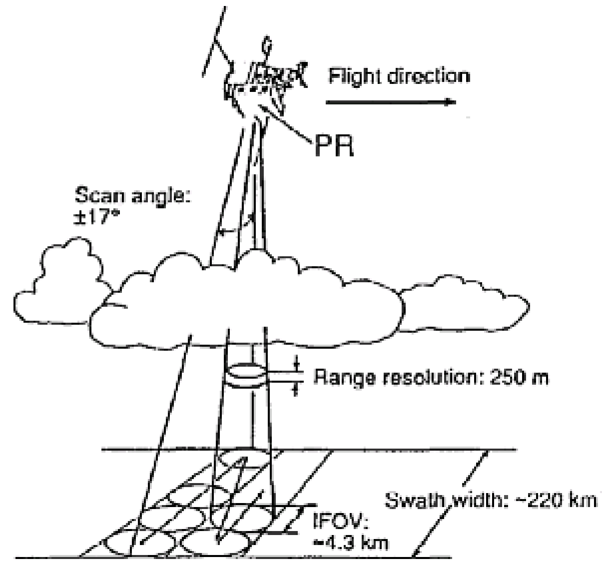
Land scatterometers (contd)



Aquarius scatterometer illuminated the Earth's surface at several different fixed aspect/nadir angle combinations; scatterometer returns used to refine radiometer measurement of ocean surface salinity

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



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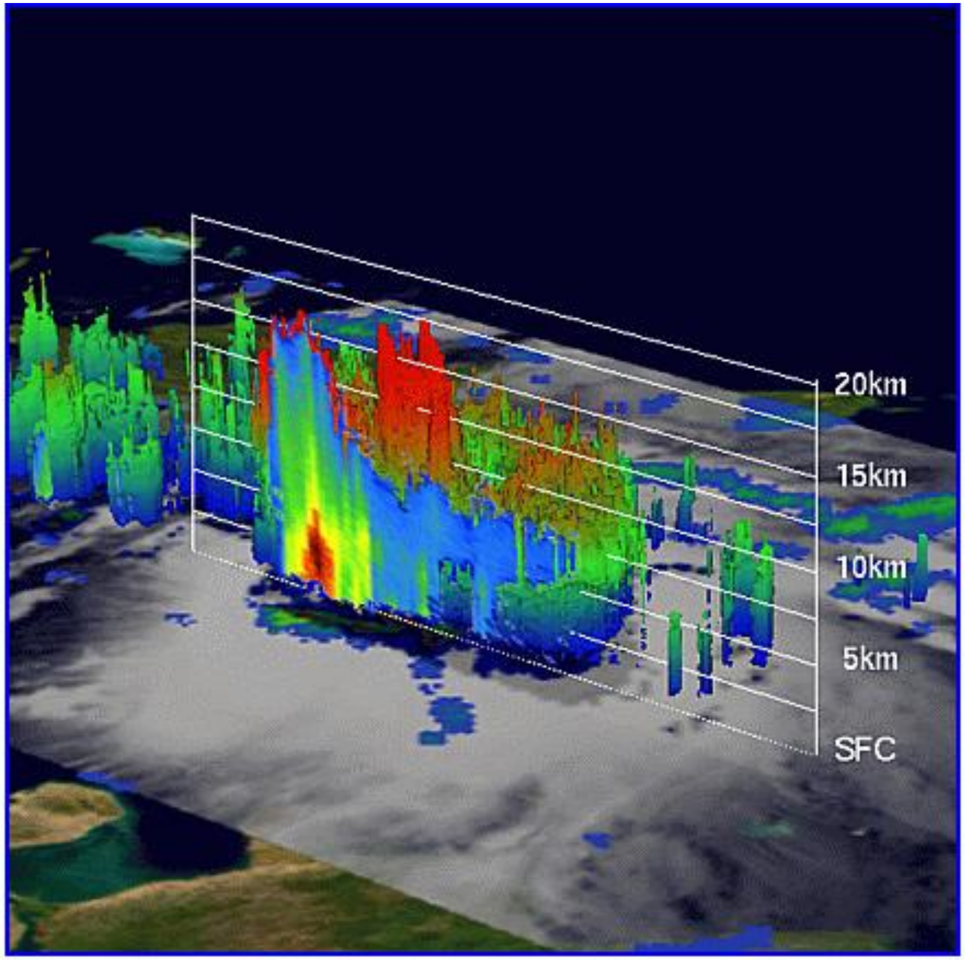
Precipitation Radars (contd)

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



ERNESTO BECOMES THE FIRST ATLANTIC HURRICANE OF THE SEASON

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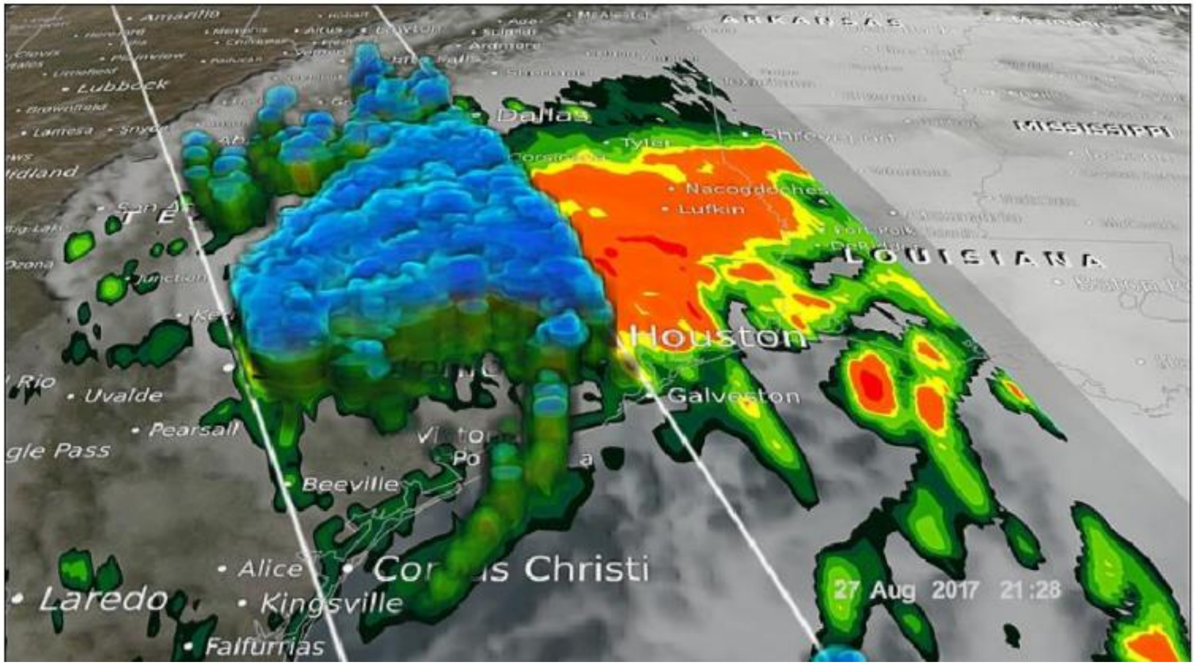
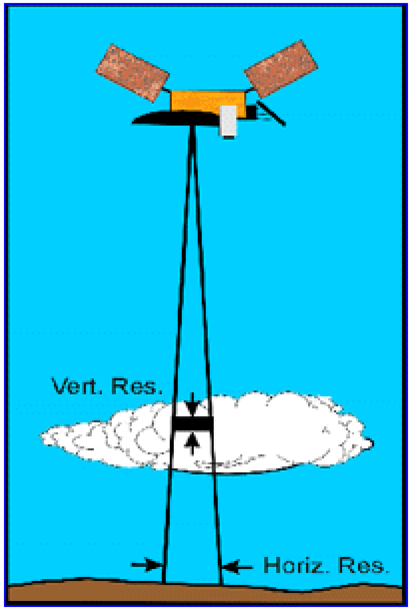
Precipitation Radars (contd)

The GPM DPR image shows the precipitation profile of the hurricane Harvey on 27 August, 2017. The image shows the rain rates from the GPM's GMI (outer swath) and the GPM DPR (inner swath) overlaid on enhanced IR data from NOAA's GOES East satellite.



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
- Cloudsat cloud profile radar (CPR) uses only 0.3 MHz RF bandwidth
- Allowable reflectivity accuracy degradation determines the allowable interference level



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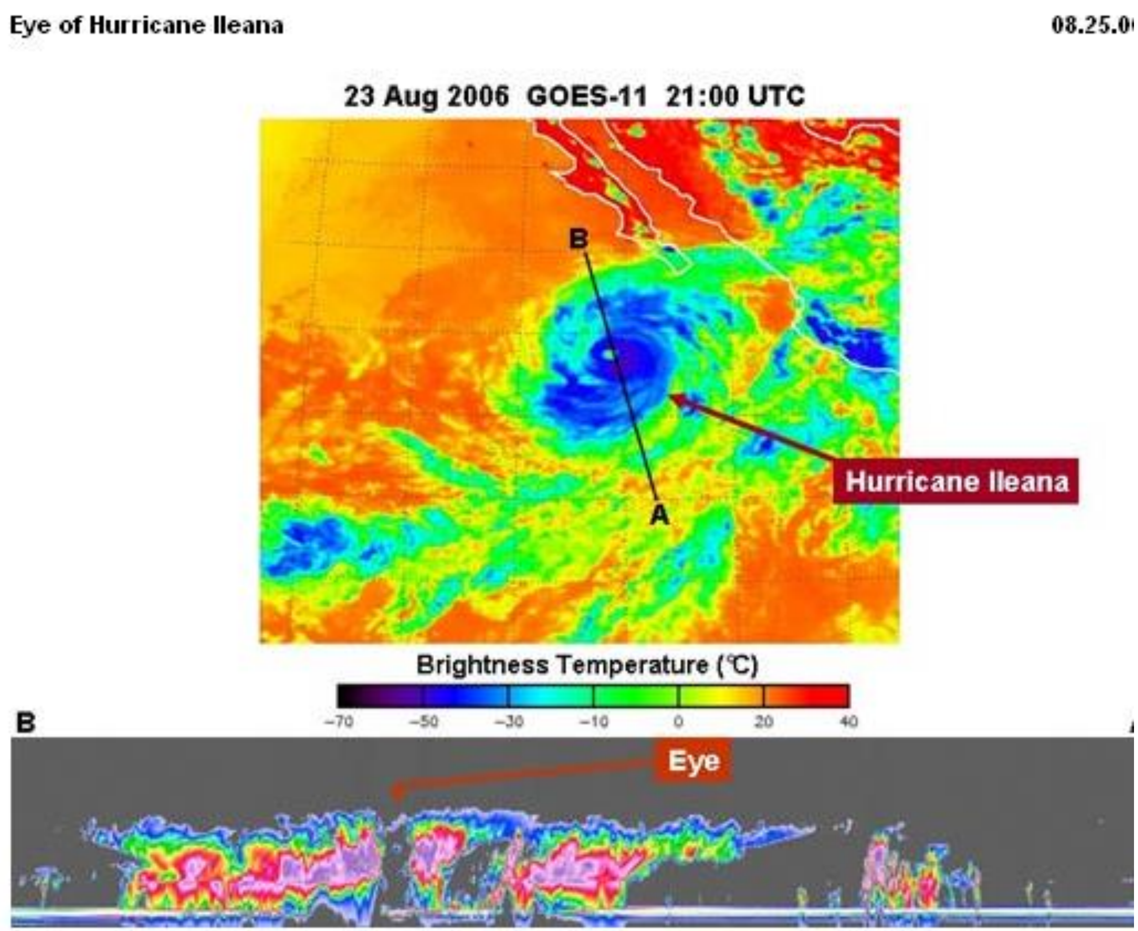
Cloud Profile Radars (contd)

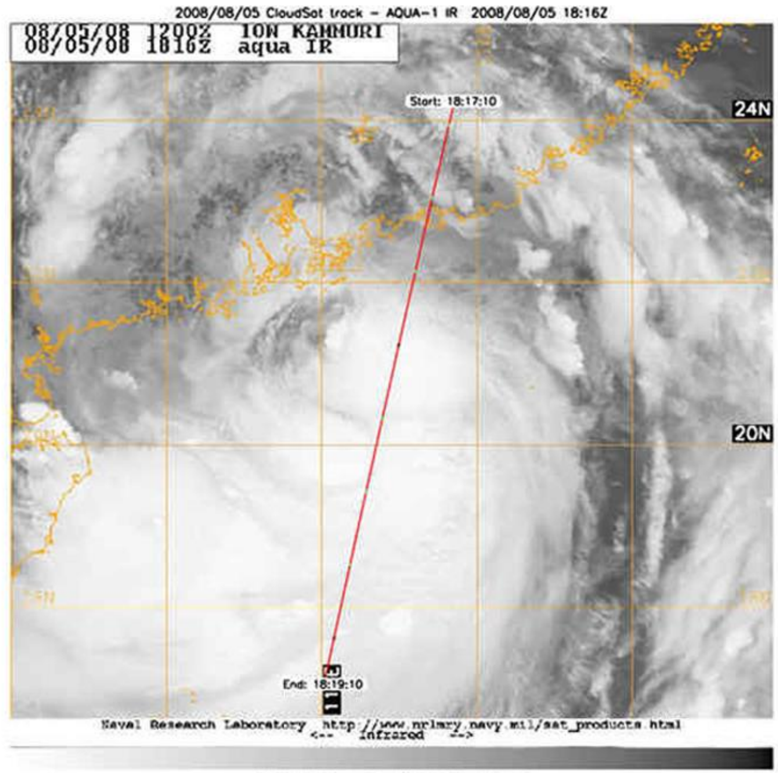
NOAA's GOES (top) showed Hurricane Ileana on Aug 23, 2006.



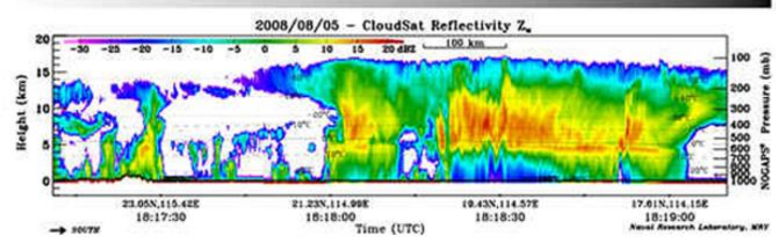
CloudSat's Cloud Profiling Radar produced profiles of Ileana's clouds (bottom).

Cloud Profile Radars (contd)

NASA's Aqua (top) showed Severe Tropical Storm Kammuri along the south coast of China on Aug 5, 2017.



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



Future Challenges

- Radar sounder at 40 – 50 MHz studied as potential new (sixth) active sensor type and potential new allocation to EESS (active)
- Biomass SAR at 432-438 MHz limited to operating beyond line-of-sight of space-object-tracking radars; secondary allocation to EESS (active)
- SARs and scatterometers in 1215-1300 MHz band must show compatibility with RNSS receivers and ARSRs through extensive tests/analyses; need survivability analysis of scatterometers with high powered terrestrial space tracking radar
- SARs at 3.1-3.3 GHz have secondary allocation in EESS (active) and must be analyzed to show compatibility with other services in band
- SARs/altimeters in 5250-5570 MHz band already share lower part of the band with RLANs and continue to analyze compatibility with RLANs in other parts of the band
- SARs at 9.2-10.4 GHz have 1.2 GHz of spectrum allocated for fine resolution operations in EESS (active) with analysis of sharing band with other services
- Altimeters/InSARs at 35.5-36.0 GHz must show that pfd <-73.3 dB (W/m^2) for angles greater than 0.8 deg from the beam center; need survivability analysis with high powered terrestrial space tracking radar
- Cloud profile radars at 94.0-94.1GHz at potential risk from out-of-band RFI from Railway Radiocommunication Systems between Train and Trackside (RSTT) stations and in-band RFI from Foreign Object Debris (FOD) detection systems at airports

Annex

Additional details about the techniques

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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	20-1200 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

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