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Research Article

Microwave Remote Sensing of Earth

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Abstract

The Microwave Remote Sensing of Earth was initiated by Russian Space Agency (ROSCOSMOS) by launching COSMOS 243 Satellite in Year 1968. This was followed by launching of Nimbua 5 by NASA in 1972. India was THIRD Country that launched Bhaskara 1 in 1979 that was launched by ISRO Carrying Microwave Radiometer SAMIR and BHASKAR2 was launched in1981 that also carried Microwave Radiometer SAMIR. European Remote Sensing Satellite 1 of ESA was launched in 1989. The Japanese Earth Resources Satellite 1(JERS-1) of JAXA was launched in 1990. The Radarsat-1 of Canadian Space Agency (CSA) was launched in 1990. The Jasan-1 of French space Agency CNES and American space Agency NASA was launched in 2001. The Fengyun-3 of Chinese National Space Agency CNSA was launched in 2008.

Till Now Sixty Seven Satellites Carrying Active and Passive Microwave Sensors have been used to Provide the information for Studying the Surface as well as upto certain depth of earth depending on frequency that has been used for Study. The different parameters like Salinity, Wind speed over Oceans, also have been Obtained including the direction of wind.The Atmosphere above earth has also been studied using Microwave remote sensing (MRS) that includes the water-vapour, Liquid water and different gases in the Atmosphere. The SNOW studies have been made using Microwave remote Sensing (MRS) that includes extent of SNOW, depth of SNOW and melting of SNOW in mountains.

Keywords: Microwave Remote Sensing; Microwave Remote Sensors; Radiometer; Synthetic Aperture Radar; Real Aperture Radar; Altimeter; Scatterometer; Dielectric Properties; Brightness Temperature

Abbreviations

Roscosmos: Roscosmos State Corporation for Space Activities NASA: National Aeronautics and Space Administration JPL: Jet propulsion Laboratory; ISRO: Indian Space Research Organisation; ESA: European Space Agency JAXA: Japan Aerospace Exploration Agency CNES: Centre National d Etudes Spatiales CSA: Canadian Space Agency CNSA: China National Space Administration. SAR: Synthetic Aperture Radar GPR: Ground Penetrating Radar.

Introduction

The Microwave Portion of the Radio Spectrum has humber of Applications, that includes Communication, Remote Sensing, Industrial and Medical etc. In case of Microwave Remote Sensing (MRS)One can study the physical and electrical properties of the material without coming in contact of the material. The microwave Remote Sensing (MRS) is used for study of Planets and Earth [1-3].

In case of Earth one is able to study Various aspects of Earth that includes Land, Oceans, Snow in mountains and Study Atmosphere. The Microwaves can penetrate the Surface upto certain depth depending on the Frequency and the electrical property of the Material. Thus the Microwave Remote Sensing is used for determination of Soil Moisture, the height of vegetation on Land. On ocean the microwave Remote sensing gives the Salinity, Wind Velocity and Direction. In the Mountains the Microwave Remote Sensing Provides information about Extent of Snow, Depth of SNOW and Melting of SNOW. The presence of water rapour, liquid water and different gases in Atmosphere can be determined by using Microwave Remote Sensing (MRS).

Thus by MRS the amount of water vapour present in Atmosphere which gives indication of rain and during rainy Season one can get information about the presence of liquid water in clouds. Thus by using Microwave Remote Sensing (MRS) one can study the Land, Mountains, Oceans and Atmosphere and for studying all these aspects over Earth One will need the sensors, and platforms [1-3].

Sensors and platforms [1-3]

These sensors are

Passive Sensors both Imaging Microwave Radiometers and Non Imaging Microwave Radiometers these Microwave Radiometers are available for Microwave Remote Sensing in Following configuration [1] they are

- Total Power Radiometer
- Dicke Radiometer
- Noise Injection Radiometer.

Then we have

Active Sensors, in this category we have also Imaging Active Sensor and Non Imaging Active Sensor. The Imaging Active Sensors are

- Real Aperture Side Looking Radar.
- Synthetic Aperture Radar

The Non Imaging Active Sensors are

- Scatterometer
- Altimeter.

These Sensors both Passive and Active are used on different platforms Namely:- Ground Based, Airborne (Drone and Aircraft) and Space borne (Satellites).

One can use these platforms for getting information that will have Ground based, Airborne and space born Sensors like Microwave Radiometers, Real Aperture and Synthetic Aperture Radars, Scatterometers and Altimeters. One has to also Collect Ground Truth data for comparison and then one can have Airborne and Space borne Campaigns for the Applications of microwave Remote Sensing to study Earth. Thus for getting these data one can use different platforms along with passive and Active microwave Sensors. These platforms will include ground based platform, Airborne platform, and space borne platform. The sensors to be mounted on these platforms will include imaging and Non imaging microwave Radiometers (passive Sensors) and imaging and Non imaging Radars (Active Sensors). Along with the data obtained from different Sensors from different platforms the ground truth has to be collected and that is used during analyzing the data obtained from different campaigns for different applications to study Earth that will include Land, ocean mountains and Atmosphere.

Exploration of earth

The word Earth is a Germanic word which means 'the ground'. The planet of humans, Earth, is the third planet from the Sun and fifth largest planet of the solar system [4]. The optical image of Earth is given in figure 1 and the physical properties of Earth [4] are given in table 1. In 1968, Cosmos 243 was the first satellite that carried Microwave Sensor to map the Earth [5]. The exploration of Earth through microwaves includes mapping of Land, Ocean, Mountains and Atmosphere. Table 2 gives the chronological list of satellite missions carrying Microwave Sensors launched for microwave remote sensing of Land, Ocean, Mountains and Atmosphere.

Figure 1: Optical image of the Earth. (Image Credit: NASA/JPL).

Parameter	Value
Moons	1
Diameter	12,756 km
Mass	5.974x 1027 g
Mean Density	5.52 g/cm3
Rotation Period	23.9345 hours
Escape velocity	11.2 km/second
Mean distance from Sun	1.000 au
Obliquity	23.45°
Orbital Eccentricity	0.017
Orbital Inclination	0.00°
Temperature	–89.2 degrees Celsius to +58 degrees Celsius
Atmosphere	78 percent nitrogen, 21 percent oxygen, and 1 percent other gases such as argon, carbon dioxide, and neon

Table 1: Physical Parameters of Earth [4].

Land applications of microwave remote sensing

Due to the dielectric properties of natural earth materials like soil, water and snow, the microwaves are sensitive to them [1]. Because of the unique properties of Microwaves, they are used to study the different land-based applications like Soil Moisture estimation, crop identification, flood mapping, snow studies, geology, forestry, urban-land use and hydrocarbons etc. [1]. In this section one satellite is taken for each application related to Microwave Remote Sensing of Land. For the soil moisture estimation, the data of Microwave Imaging Radiometer using Aperture Synthesis (MIRAS) onboard SMOS (Soil Moisture Ocean Salinity) Satellite of European Space Agency (ESA) has been used. Figure 2 is showing the photographs of SMOS (Soil Moisture Ocean Salinity) satellite and Microwave Imaging Radiometer using Aperture Synthesis (MIRAS) onboard SMOS (Soil Moisture Ocean Salinity) Satellite [7]. The estimation of soil moisture helps in the prediction of Monsoon and climate monitoring. Figure 3 is showing the soil moisture map of Indian land generated by using the data of

S. No.	Year	Mission	Sensor	Wavelength/FREQ.	Purpose
1	1968	Cosmos 243	Radiometer	8.6, 3.4, 1.35 0.81 cm	Atmospheric Water vapour, ice cover, Sea surface temperature.
2	1972	Nimbus-5	ESMR NEMS Radiometer	1.55, 1.35, 0.96, 0.56, 0.55, 0.51 cm	Rain rate sea ice concentration Atmospheric temperature profile, water vapour and liquid water content in atmosphere.
3	1973	Skylab	S-193 Scatterometer Radiometer Altimeter S-194 Radiometer	2.15 cm	Simultaneous measurement of earth surface, soil moisture, ocean winds and rain rate.
4	1975	Nimbus -6	ESMR SCAMS	0.81 cm 1.35, 0.95, 0.58, 0.56, 0.54 cm	Same as ESMR of Nimbus-5 Same as NEMS of Nimbus-5
5	1978	Seasat	SAR Scatterometer Altimeter SMMR	23 cm 2.15 cm 2.22 cm 4.54, 2.8, 1.66, 1.42, 0.81 cm	Sea, land surface imaging, sea surface, wind speed and direction Sea surface topograph, sea surface temperature, wind speed water vapour/liquid water.
6	1978	Nimbus -7	SMMR	as above	Same as Seasat SMMR
7	1979	Bhaskara -1	SAMIR	1.55, 1.35 cm	Seasurface wind speed atmospheric water vapour.
8	1981	Shuttle STS-2	SIR-A SAR	23 cm	Geological mapping

9	1981	Bhaskara-2	SAMIR	1.55, 1.35, 0.97 cm	Sea surface wind speed atmospheric water vapour/ liquid water content.
10	1984	Shuttle STS-17	SIR-B SAR	23 cm	Land and ocean surface studies.
11	1988	Shuttle	SIR –C SAR	LCN bands	Mapping of the earth
12	1989	ERS- 1	SAR, Scatt Altimeter	c-band Ku-band	Oceanographic parameters
13	1990	JERS	SAR	L-band	Ocean
14	1990	Radarsat	SAR	C-band	Sea ice/ocean
15	1990	TOPEX	Altimeter	Ku- band	Ocean topography
16	1990	NSCAT	Scatterometer Altimeter	Ku- band	Globe ocean, wind field monitoring
17	1990	Shuttle	SIR-D SAR	LCX K-band	Mapping of the earth
18	1990	MOS 1-B	MSR	23.8GHz (32km) 31.4GHz(23km) 5.320km	Ocean Atmosphere
19	1991	ERS-1 and ERS-2	ESCAT	5.3GHz	Ocean wind surface speed and direction, ocean wave length and direction, and high-resolution radar-mapping of land, ocean, ice, and coastal zones
20	1991	NOAA-12	MSU	50-58GHz R-105km S-2348	Metrology
21	1991	UARS	MLS	63, 183, 205 GHz R-V-4km R-H – 400km	Atmosphere Chem Minor const
22	1992	JERS-1	SAR	L- 0.275GHz	Ocean
23	1992	OceanSat-1	MSMR	6.6, 10.65 ,18 and 21GHZ	Atmospheric Prediction , Sea State Monitoring , Monitoring of Antarctic Sea
24	1994	NOAA-14	MSU	Same as NOAA-12	Metrological Climate
25	1995	ERS-2	Same ERS-1		Ocean Atmosphere

26	1997	TRMM	TRMM-PR	13.796 GHz, 13.802 GHz	Determining rainfall in the tropics and subtropics of the Earth through the use of a precipitation radar and radiometer
27	1998	NOAA-KLMN	MHS	89 GHz, 157 GHz, 183.3 GHz (2), 190.3 GHz	Humidity and (a) liquid water in clouds (cloud liquid water content) and (b) graupel and large water droplets in precipitating clouds (qualitative estimate of precipitation rate)
28	1999	QuickSCAT	SeaWinds Scatterometer	13.4 GHz	To acquire accurate, high-resolution, global measurements of sea-surface wind vectors in 1 to 2 day repeat cycles and fast delivery of its data
29	1999	SSM/I	DMSP Block 5D-3 Satellite Series	19.35 GHz (2), 22.24 GHz, 37 GHz (2), 85 GHz (2)	Provides low-resolution-temporal/high-resolution-spatial sounding of the atmosphere and surface. Measures sea surface winds, rain rates, cloud water, precipitation, soil moisture, ice edge, and ice chronological age.
30	2001	NASA/CNES JASON-1, -2 (OSTM)	SSALT (Sea Surface Altimeter)	5.3 GHz and 13.575 GHz	Measurements of ocean surface height
31	2001	CNES/NASA JASON-1, -2 (OSTM)	JASON/Advanced Microwave Radiometer	18.7 GHz 23.8 GHz and 34 GHz	[sea surface winds], [water vapor], [non-raining clouds]
32	2002	SMEX02 6.92Ghz, 10.65Ghz, 18.7Ghz, 23.8Ghz	ESTAR	1.413 GHz	Soil moisture algorithm performance; verifying soil moisture estimation accuracy; investigating the effects of vegetation, surface temperature, topography, and soil texture on soil moisture accuracy;
33	2002	AMSR-E	Microwave Radiometer	6.925,10.65,18.7, 23.836.5, 89 Ghz 36.5Ghz	Sea surface temperature (SST), wind speed, atmospheric water vapor, cloud water, and rain rate.
34	2003	NASA/NRL/ NOAA Coriolis Satellite	WindSat Radiometer	6.8 GHz, 10.7 GHz, 18.7 GHz, 23.8 GHz, and 37 GHz	Operational verification of spaceborne multichannel polarimetric radiometry as a means to measure the ocean surface wind vector (speed and direction)
35	2005	EnviSat	ASAR	5.331 GHz	Ocean waves, sea ice extent and motion, snow and ice extent, surface topography, land surface properties, Earth's biomass (especially deforestation in equatorial zones), surface soil moisture and wetland extent.
36	2005	ESA's CryoSat	SIRAL	13.575 GHz	Determine variations in the thickness of Arctic sea ice and elevation changes of ice sheets, ice caps and glaciers that ring the Arctic Ocean (continental ice sheets).
37	2006	ALOS-1	ALOS-1 PALSAR	1270 MHz	Day-and-night and all-weather land observation.
38	2006	NASA/CSA Cloudsat	Cloud Profiling Radar	94.05 GHz	The objective of CPR is to provide information on the vertical structure of all cloud systems.
39	2006	MetOp	ASCAT	5.225 GHz	Wind velocity over the world's oceans using radar.
40	2007	TerraSAR-X	TerraSAR-X	9.65 GHz	Hydrology, geology, climatology, oceanography, environmental and disaster monitoring, and cartography (DEM generation)

41	2007	COSMO-SkyMed	X-BandSAR	9.6 GHz	Hydrology, geology, climatology, oceanography, environmental and disaster monitoring
42	2008	FengYun-3	MicroWave Humidity Sounder	150 GHz, 183.3 GHz	Observes the atmospheric humidity profile, water vapor, rainfall, cloud liquid water, etc. Measures humidity (water) profile of the atmosphere with low temporal resolution and high spatial resolution.
43	2008	FengYun-3	MWRI	10.65 GHz, 18.7 GHz, 23.8 GHz, 36.5 GHz, 89 GHz, and 150 GHz	Observes rainfall, soil moisture, cloud liquid water, sea surface parameters. Measures atmospheric and surface water with low temporal resolution and high spatial resolution.
44	2008	FengYun-3	MWTS	50.3 GHz, 53.6 GHz, 55 GHz, and 57 GHz	Provides atmospheric temperature profile, rainfall, cloud liquid water, surface parameters, etc. Measures temperature profile of the atmosphere with low temporal resolution and high spatial resolution.
45	2008	ISA	TecSAR	9.6GHz	High-resolution SAR imagery, day and night, in all weather conditions
46	2009	SMOS	MIRAS	1.4–1.427 GHz	Soil moisture and sea surface salinity
47	2009	METEOR-M and M1	MTVZA-GY	10.6 GHz, 18.7 GHz, 23.8 GHz, 31.5 GHz, 36.5 GHz, 42 GHz, 48 GHz, 52.8 GHz, 55 GHz, 57 GHz, 91.65 GHz, 92 GHz, and 183 GHz	Monitors ocean and land surfaces as well as global atmospheric temperature and water vapor profiles, and obtains sea surface wind profiles
48	2009	Oceansat-2	OSCAT	13.5156 GHz	Oceanographic measurements
49	2010	TanDEM-X	TerraSAR-X	9.65 GHz	This mission flies near TerraSAR-X to perform interferometric SAR (InSAR) observations
50	2011	HY2A	Altimeter and Scatterometer	5.25 GHz, 13.58 GHz [altimeter]; 13.2555 GHz [scatterometer]	All weather observations, marine wind setup (wind vector), marine surface height, and SST (Sea Surface Temperature), along with aero-marine forecasts
51	2011	Aquarius/ SAC-D	Integrated L-band radiometers and scatterometer	1.42 GHz (Radiometer); 1.26 GHz (Scatterometer)	Measures the microwave brightness temperatures of the ocean surface, which are sensitive to salinity and surface roughness.
52	2011	(SNPP) mission	ATMS	23.8 GHz, 31.4 GHz, 50.3 GHz, 51.8-55.5 GHz (6), 57.3 GHz (6), 89 GHz, 166.3 GHz, and 183.3 GHz (6)	Global atmospheric temperature, moisture, and pressure profiles
53	2011	SAC-D Satellite	Microwave Radiometer	23.8 GHz and 36.5 GHz	Winds, rainfall, water vapor, and sea ice.
54	2011	MeghaT-ropiques	Radiometer	18.7GHz, 23.8GHz, 36.5GHz, 89GHz and 157GHz	Atmospheric water cycle, All-weather capability
55	2012	RISAT-1	SAR	5.35GHz	Imaging of the surface features.

56	2013	KOMPSAT-5	SAR	9.66 GHz	High resolution SAR imagery
57	2013	SARAL	Altimeter, Radiometer	35.75 GHz , 23.8 GHz and 37 GHz	Operational oceanography, Coastal altimetry Continental waters, Inland ice sheet monitoring, Light rainfall and clouds climatology, Mean sea level, Sea state observation and forecasting Geodesic reference system determination
58	2014	ALOS-2 PALSAR-2	SAR	1236.5/1257.5/ 1278.5 MHz (selectable)	Day-and-night and all-weather land observation.
59	2014	Sentinel-1A	SAR	5.405 GHz	Monitoring of Forest, agriculture, sea-ice, oil spil, sea vessel and climate monitoring
60	2014	Sentinel-1B	SAR	5.405 GHz	Monitoring of Forest, agriculture, sea-ice, oil spil, sea vessel and climate monitoring
61	2014	GPM	Microwave Imager	10.7 GHz, 18.7 GHz, 23.8 GHz, 36.5 GHz, 89 GHz, 165.5 GHz, and 183 GHz	rainfall over the Earth, water content
62	2015	SMAP	Microwave Radar and Radiometer	1.4 (Radiometer)and 1.22-1.30(Radar)	Hydrological Hazards Applications: Drought and Flood, Ecosystem Services Applications, Agricultural Productivity
63	2016	SCATSAT-1	Scatterometer	13.515 GHz (Ku-band)	Day and Night weather forecasting
64	2018	Sentinel-3	SRAL MWR	Ku/C Band 23.8/36.5GHz	Mapping of Sea surface topography, Sea Surface Temperature
65	2019	RISAT-2B	Radar	X-Band	Agriculture, forestry, disaster management
66	2019	RISAT-2BR1	Radar	X-Band	Agriculture, forestry, disaster management
67	2020	EOS- 02 (RISAT-2BR2)	Radar	X-Band	Agriculture, forestry, disaster management

Table 2: Chronological listing of satellite missions carrying microwave sensors launched for microwave remote sensing of Land, Ocean Mountains and Atmosphere [5].

Microwave Imaging Radiometer using Aperture Synthesis (MIRAS) onboard SMOS satellite [8].

Radarsat-1 satellite had been launched by Canadian Space Agency (CSA) carrying C-Band Synthetic Aperture Radar (SAR). The photograph of Radarsat-1 satellite describing the placement of C-Band Synthetic Aperture Radar (SAR) [10] is shown in figure 4. For the crop identification purposes C-Band SAR data is appropriate. Figure 5 shows the mapping of Rice crop using Radarsat-1 C-Band SAR [10].

Radar Imaging Satellite (RISAT-1) had been launched by Indian Space Research Organisation (ISRO) that carried Synthetic Aper-

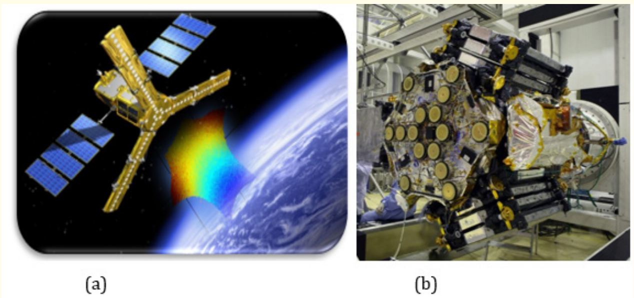

Figure 2: The photographs of (a) SMOS (Soil Moisture Ocean Salinity) satellite and (b) Microwave Imaging Radiometer using Aperture Synthesis (MIRAS) onboard SMOS (Soil Moisture Ocean Salinity) Satellite [7].

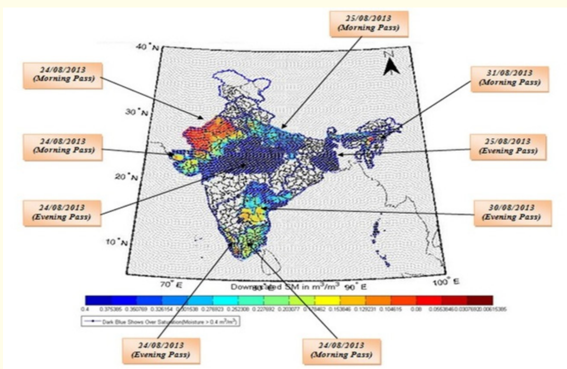

Figure 3: Higher Resolution Soil Moisture Map generated over 9 States of INDIA (August, 2013) [8].

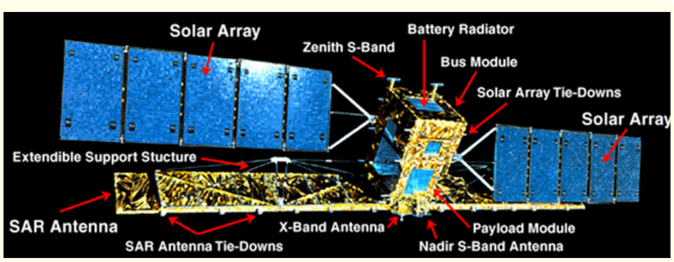

Figure 4: The photograph of Radarsat-1 satellite describing the placement of C-Band Synthetic Aperture Radar (SAR) [10].

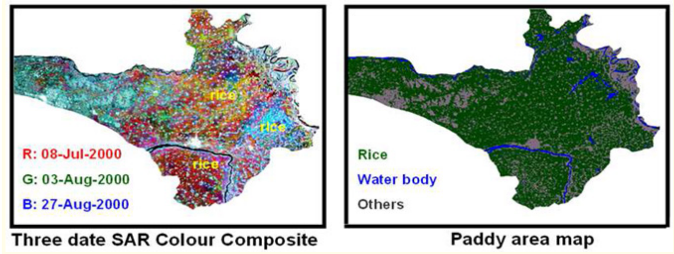

Figure 5: Paddy crop mapping using multi-temporal RADARSAT SAR data [10].

ture Radar (SAR) in 2012. Figure 6 is showing the image of Radar Imaging Satellite (RISAT-1) [11]. Similar to the Crop identification, for the mapping of forest cover C-Band SAR data gives the accurate results. Data of Estimation of forest above ground biomass over Gujarat state of India using ISRO's RISAT- C Band (5.350 GHz) SAR data [11] is shown in figure 7.

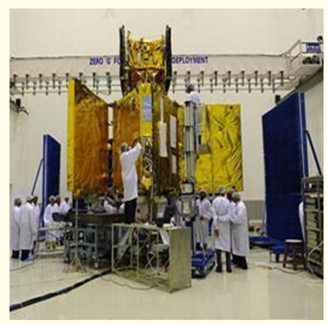

Figure 6: The original image of Radar Imaging Satellite (RISAT-1) [11].

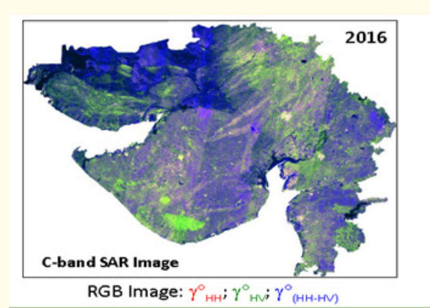

Figure 7: Estimation of forest above ground biomass over Gujarat state of India using ISRO's RISAT- C Band (5.350 GHz) SAR data [11].

RADARSAT-2 was launched by Canadian Space Agency (CSA) in 2007 having C-Band (5.405GHz) Synthetic Aperture Radar (SAR). The photograph of RADARSAT-2 satellite [9] is shown in figure 8. High Resolution Mapping of Flood in the Medinapur district of West Bengal, India was done by using Radarsat-2 C-Band (5.405GHz) SAR data [9] is shown in figure 9.

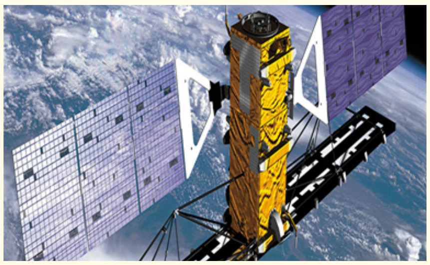

Figure 8: The photograph of RADARSAT-2 satellite [9].

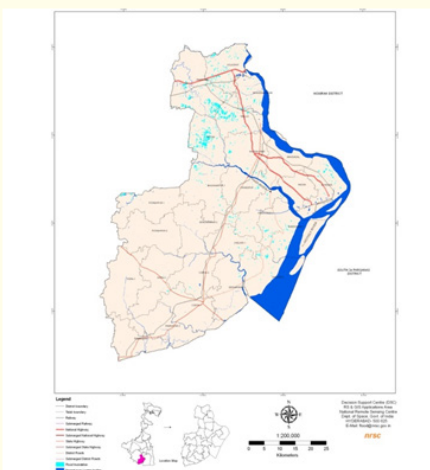

Figure 9: Flood inundated areas in East Medinapur district of West Bengal, India. The data is obtained from Radarsat [9] on 02nd July 2011.

Oceansat-1 had been launched by Indian Space Research Organisation (ISRO) in 1999 which carried Multi - frequency Scanning Microwave Radiometer (MSMR). The photograph of Oceansat-1 satellite along with Multi - frequency Scanning Microwave Radiometer (MSMR) [11] is shown in figure 10. For the estimation of snow depth at Himalayan regions, Chang's algorithm was used. Figure 11 is showing the results obtained for depth of snow of Himalayan region using [12] Multi - frequency Scanning Microwave Radiometer (MSMR) [at 6.6GHz] onboard Oceansat-1.

Figure 10: The photograph of Oceansat-1 satellite along with Multi - frequency Scanning Microwave Radiometer (MSMR) [11].

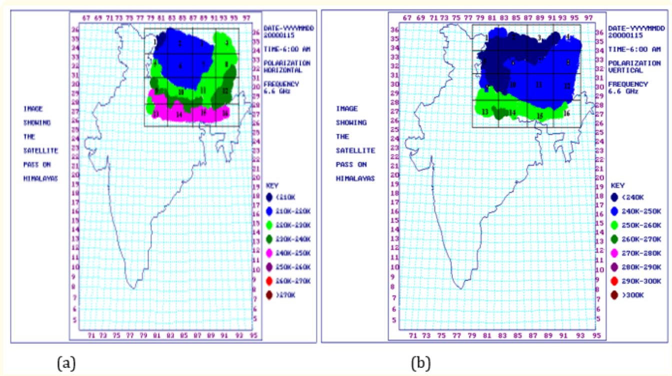

Figure 11: Depth of SNOW in Himalayan Region Images obtained for the data values taken at horizontal polarization (a) and vertical polarization (b) at frequency 6.6GHz [12].

European Remote Sensing Satellite-1 (ERS-1) was launched by European Space Agency in 1991 which carried C-Band Synthetic Aperture Radar. The photograph of European Remote Sensing Satellite-1 (ERS-1) satellite representing the placement of different Microwave Instruments [5] is shown in figure 12. The study of hydrocarbon like petroleum and natural gas have been done by using SAR. Detection of oil-slick over La Goleta oil seep, Santa Barbara Channel, California using ERS-1 Radar data of C-Band [15] is shown in figure 13.

Sentinel-1 is the European Radar Observatory system launched by European Space Agency (ESA) in 2012 carried C-band Synthetic Aperture Radar (SAR). The photographs of Sentinel-1 satellite and

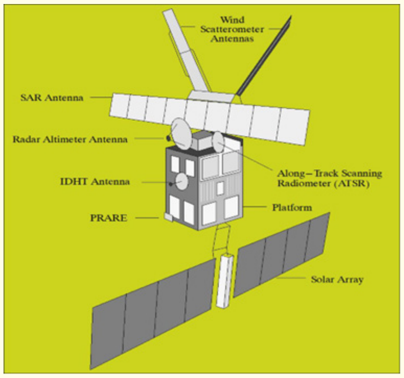

Figure 12: The photograph of European Remote Sensing Satellite-1 (ERS-1) satellite depicting onboard the placement of different Microwave Instruments [5].

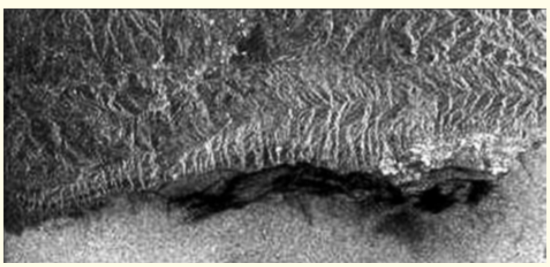

Figure 13: Radar-detected oil slick over La Goleta oil seep, Santa Barbara Channel, California, ERS-1 image quick-look, ESA Web Catalogue [15].

electronic system of C-band Synthetic Aperture Radar (SAR) [5] are shown in figure 14. Figure 15 is showing the landslide monitoring by Sentinel-1A SLC SAR (C-Band) launched by European Space Agency (ESA) [14].

Oceanographic applications of microwave remote sensing

Oceanographic studies are of prime importance for global climate change issues, fisheries, aquaculture conservation, mineral resources exploitation, marine pollution, meteorological prediction etc. [17]. The parameters that could be studied for oceans using microwave remote sensing are Sea-State measurement, sea surface salinity, topography in shallow sea, wind speed over sea, ocean circulation, significant wave height, oil pollution, sea surface

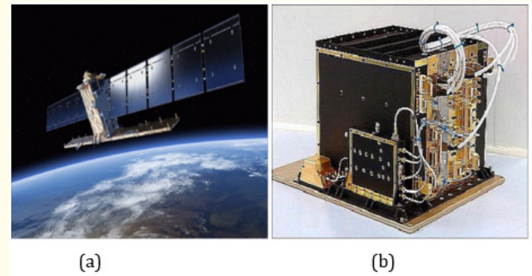

Figure 14: The photographs of (a) Sentinel-1 satellite and (b) electronic system of C-band Synthetic Aperture Radar (SAR) [5].

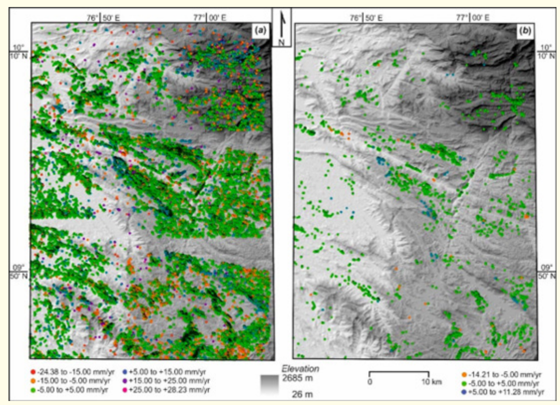

Figure 15: PSI results using the Sentinel-1A SLC SAR image (Background image is Shuttle Radar Topographic Mission (SRTM) elevation map draped over hill shade) (a) Both positive and negative VLoS values; (b) Persistent Scatter (PS) points that have greater than 95-percentile coherence [14].

temperature [1]. At ICRS, scientist have measured the sea surface salinity using brightness temperature (T_B) data obtained from MIRAS instrument onboard SMOS satellite of European Space Agency (ESA). Figure 16 represents the graph between sea surface salinity versus dielectric constant [16].

In 1979, Indian Space Research Organisation (ISRO) launched its first Earth Observation Satellite Bhaskara-1 which carried three channel Satellite Microwave Radiometer-I (SAMIR-I). After that in 1981, Bhaskara-2 had been launched which also carried three channel Satellite Microwave Radiometer-II (SAMIR-II) [17]. The

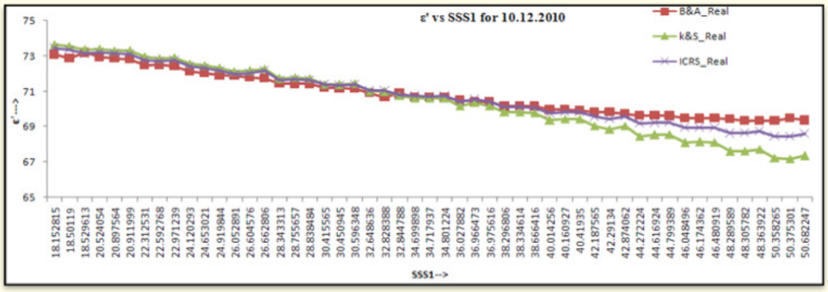

Figure 16: Real Part of complex DC vs. sea surface salinity measured [16] on 10.12.2010.

photographs of Bhaskara satellite and Satellite Microwave Radiometer (SAMIR) [1] are shown in figure 17. The wind speed over sea can be determined at frequency range of 19.35GHz and 19.22GHz. surface wind speed over sea surface obtained from the data of SAMIR payload at 19.35GHz and 19.22GHz onboard Bhaskara-1 and Bhaskara-2 Satellite respectively of ISRO [18]. is shown in figure 18.

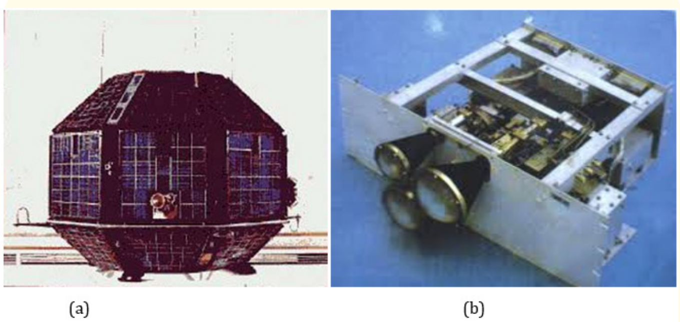

Figure 17: The photographs of (a) Bhaskara satellite and (b) Satellite Microwave Radiometer (SAMIR) [1].

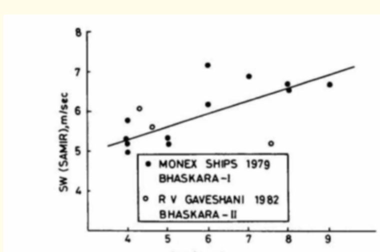

Figure 18: Comparison of Sea Surface Wind Speed (SW) derived from SAMIR data (19.22GHz) of Bhasakara-1 and 19.35GHz of Bhasakara-2 with in-situ ship data [18].

Detection of oil spill which causes the pollution and is hazardous to marine life is also very important [1]. Defence Meteorological Satellite Program (DMSP) satellite had been launched by National Aeronautics Space Administration (NASA) to do the oceanographic studies which carried a Special Sensor Microwave Imager (SSM/I) [5] shown in figure 19. The study of oil spill in the regions of Bombay high area in Open Arabian Sea using the brightness temperature data of Special Sensor Microwave Imager (SSM/I) onboard DMSP satellite at 19.35GHz [19] is shown in figure 20.

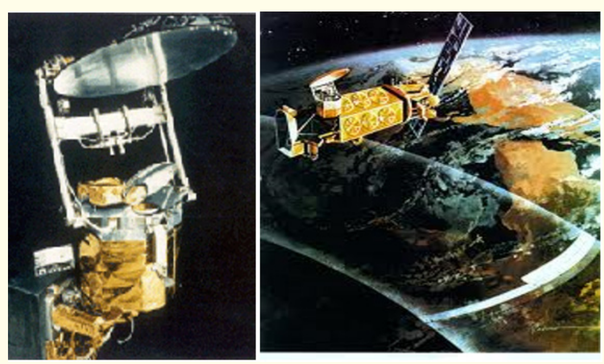

Figure 19: Image of Defence Meteorological Satellite Program (DMSP) satellite carrying Special Sensor Microwave Imager (SSM/I) [5].

Sea Surface Temperature is the important parameter for climate and weather predictions. National Aeronautics Space Administration (NASA) and Japanese Space Exploration Agency (JAXA) jointly launched Aqua satellite in 2002 which carried Advanced Microwave Scanning Radiometer- Earth (AMSR-E).

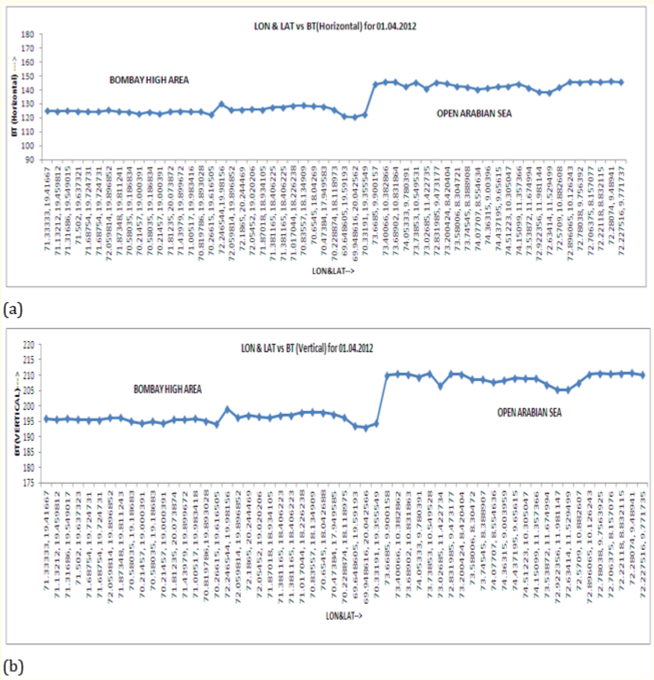

Figure 20: Illustrates the variation of Horizontal Brightness Temperature (a) and Vertical Brightness temperature (b) with respect to longitude and Latitude obtained from SSM/I data at 19.35 GHz [19].

Figure 21 is showing the images of Aqua satellite and Microwave Scanning Radiometer- Earth (AMSR-E) [5]. Figure 22 is showing the measured sea surface temperature by Advanced Microwave Scanning Radiometer- Earth (AMSR-E) onboard Aqua satellite at 7GHz and 11GHz [20].

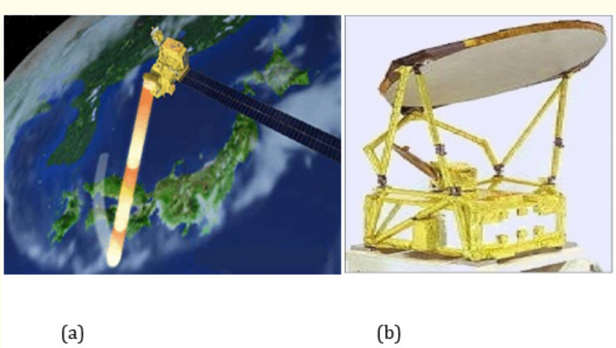

Figure 21: The photographs of (a) Aqua satellite and (b) Microwave Scanning Radiometer- Earth (AMSR-E) [5].

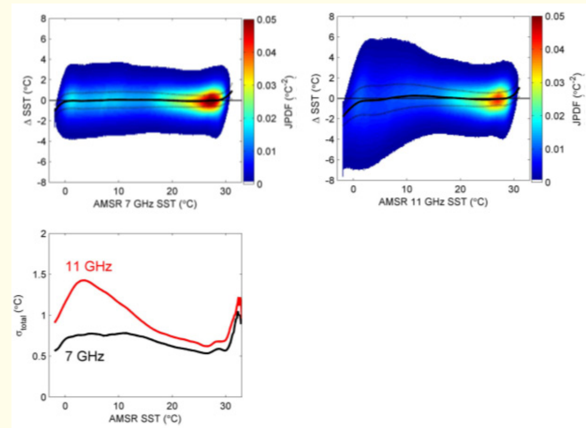

Figure 22: AMSR-E minus Reynolds SST ΔSST as a function of AMSR-E(a) 7 GHz SSTs and (b) 11 GHz SSTs and (c) the standard deviation of ΔSST as a function of AMSR-E SST [22].

Underwater topography provides useful information related to safe navigation, offshore fisheries and aquaculture, tide and biodiversity etc. Radarsat-2 satellite of Canadian Space Agency (CSA) having C-Band data of Synthetic Aperture Radar (SAR) had been launched in the year 2007. The image of Radarsat-2 satellite is shown [9] in figure 23. Figure 24 is showing the 3D view of underwater topography of coastal areas by using the fully polarimetric C-Band data of Synthetic Aperture Radar (SAR) [21] onboard Radarsat-2.

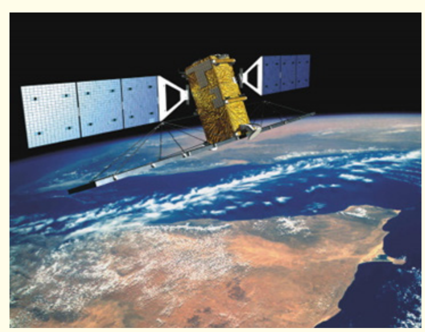

Figure 23: The image of Radarsat-2 satellite [9].

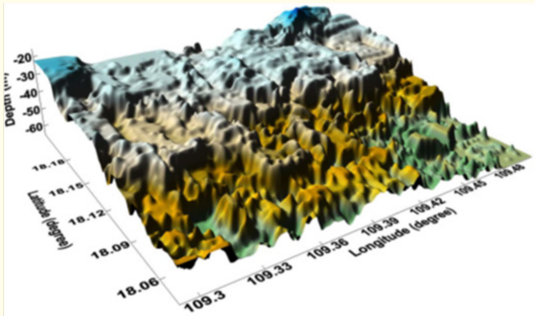

Figure 24: Three-dimensional of underwater topography with resolution of 150 m by 150 m. The estimated water depths where absolute error of the estimated depth is more than 10m are replaced with the value from the nearest location of the ENC [21].

Atmospheric applications of microwave remote sensing

Application of Microwave remote Sensing in atmospheric area is included under a high priority. In this area the applications like profiling the moisture and temperature in the atmosphere which is essential for delineating mesoscale climatic system [1]. The study of minor constituents present in the atmosphere is considered important for stratospheric research. The parameters like water vapour present in the atmosphere, Liquid water content in the clouds that will be studied are useful for Monsoon studies, monsoon temperature profile and atmospheric minor constituents [1]. The study of water vapour present in the atmosphere and cloud liquid water had been done using SAMIR payload onboard Bhaskara- 1 and Bhaskara- 2 launched by Indian Space Research Organisation (ISRO) [22] which is shown in figure 25.

Microwave Analysis and Detection of Rain and Atmosphere Systems (MADRAS) and Sounder for Atmospheric Profiling of Humidity in the Inter-tropical Regions (SAPHIR) onboard Megha-Tropiques satellite of Indian Space Research Organisation (ISRO) are 5 frequency channel Radiometer and Sounder respectively [17]. The photograph of Megha - Tropiques, MADRAS instrument and SAPHIR instrument are shown [17] in figure 26. The data obtained from Microwave Analysis and Detection of Rain and Atmosphere Systems (MADRAS) of oceanic rain rate and Humidity profile data obtained from Sounder for Atmospheric Profiling of Humidity in the Inter-tropical Regions (SAPHIR) instrument are shown in figure 27 (a) and (b) respectively [20].

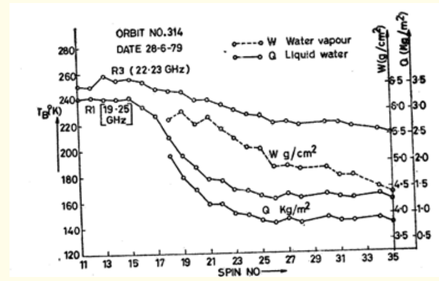

Figure 25: Water vapour and liquid water as determined from Satellite Microwave Radiometer (SAMIR) onboard Bhaskara on 28 June 1979 [22].

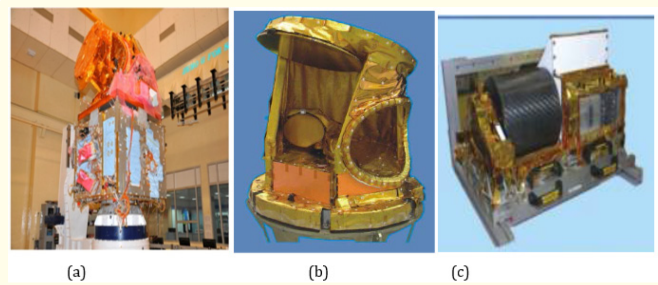

Figure 26: The photograph of (a) Megha - Tropiques, (b) MADRAS instrument and (c) SAPHIR instrument [17].

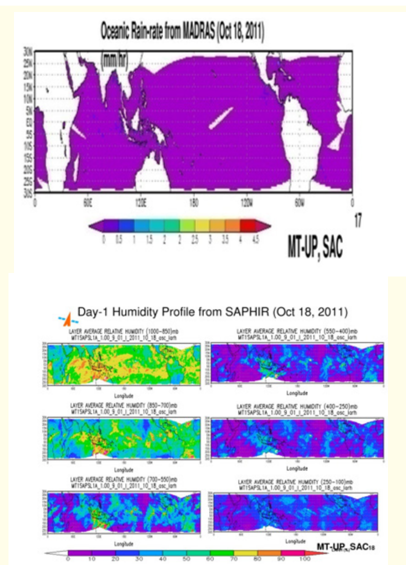

Figure 27: The data obtained from (a) Microwave Analysis and Detection of Rain and Atmosphere Systems (MADRAS) of oceanic rain rate and (b) Humidity profile data obtained from Sounder for Atmospheric Profiling of Humidity in the Inter-tropical Regions (SAPHIR) instrument [17].

Conclusion

Microwave Remote Sensing of Earth is being widely done by using C-band Synthetic Aperture Radar (SAR)data which is an Active Microwave Sansor gives the information that includes crop identification, disaster monitoring Forestry and geological Studies, hydro carbons, under water topography etc. The Satellites that have C-band Synthetic Aperture Radar onboard are Radarsat-1, ERS-1. Radarsat-2 and RISAT-1 and the Results of these satellite Sensors have been utilised and presented in this paper. The Passive Microwave sensor Radiometer provides soil moisture, sea Surface Salinity at 1.4GHZ, wind velocity and Direction over sea surface at 19.22GHZ and 19.35GHZ, Sea ice extent, snow extent, glaciers and depth of snow at 5.331GHZ 6.6GHZ, 13.575GHZ, 23.8GHZ and 36.5GHZ. Liquid water content in clouds at 31.6GHZ, water vapour at 22.235GHZ and 183.0GHZ, rain rate and Humidity at 36.5 and 183.0GHZ. respectively. The satellites which are mentioned in this paper having Microwave Radiometer on board are Bhaskara-1 BHASKARA-2 DMSP, OCEANSAT-, Aqua SMOS MEGA TROPIQUES.

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