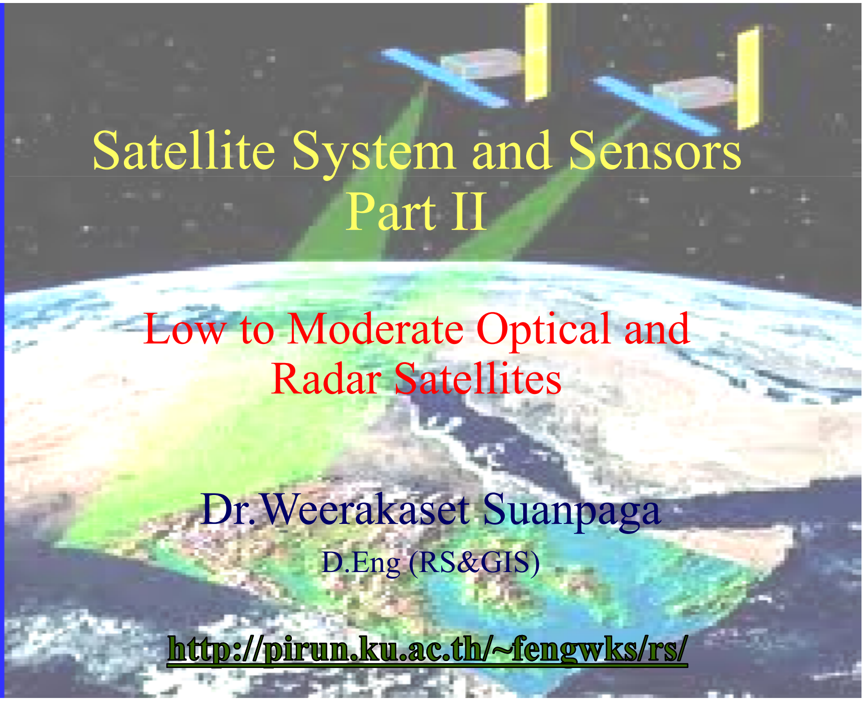


Satellite System and Sensors Part II

Low to Moderate Optical and Radar Satellites

Dr.Weerakaset Suanpaga
D.Eng (RS&GIS)

http://pirun.ku.ac.th/~fengwks/rs/

1

Low to Moderate Resolution Optical Satellites

Low to Moderate resolution satellite data with their resolution of 250 to 1km is important to regional to global scale environmental monitoring.

The advantage of these data are their frequent observation which covers the whole globe within one day. Some satellites have morning and afternoon satellites which gives us twice a day observation.

In spite of its low spatial resolution, its high multi-temporal capability, high-sensitivity sensors, multi-spectral capability provide us with excellent data and application opportunity.

Also, recent effort to provide the data in systematic way such as distribution on internet, producing value added data has been enhancing its usability.

2

Advantage

- High Multi-Temporal
- Global Coverage
- Multi-Spectral Information
- Cloud Free Products
- Free Data, Free Software
- Series of algorithm for estimating
- environmental physical parameter.
- Local Receiving is feasible
  - Free for receiving
  - S band – X band
  - 100,000 US$-500,000US$
- Hyper-Spectral Information e.g. 36 ch.
- Improved Resolution to 250m-500m
- Value Added Data Product, e.g. MODIS
- Network Data Distribution, AIT, UT, NASA
- Near Real time Monitoring, several hrs.

Advantage of High-Reso data from previous Lecture

High-Resolution
- Easy for interpretation

Good products line
- Systematic
- High-Precision

Good search/ordering system
- Commercial Distributor

Easy Handling
- Common formats
- Supported by various software
- Good combination with 1/100,00 –1/50,000 maps
- Plenty of Application examples Improved resolution

Multi-Spectral

3

Limitation

- Spatial Resolution
- Geo-location
- Data Handling
  - Format: Local format
  - Not enough Support from commercial software
  - Projection
  - 10bits data
- Difficulty in implementing local processing
- system
- Off-Nadir Observation
  - Strong Effect of Bi-directional Reflectance
  - BRDF

Limitation of High-Reso data from previous Lecture

Re-Visit Time
- 2 – 18 days

Cloud Cover
- Project planning

Spectral Information
- Panchromatic to several bands only

S/N
- Normally 6-8 bits

Geo-location
- Distortion by topographic effect (edge, highmountains)
- Off-Nadir Observation

Coverage Several 10km – 180km

Cost
- Usually not free
- Sometimes expensive
- Super-high reso: Expensive

Satellite Geometry Model: sometimes not open

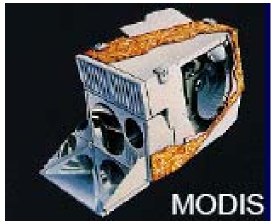
4

Application Field
Low-Moderate Resolution Optical RS

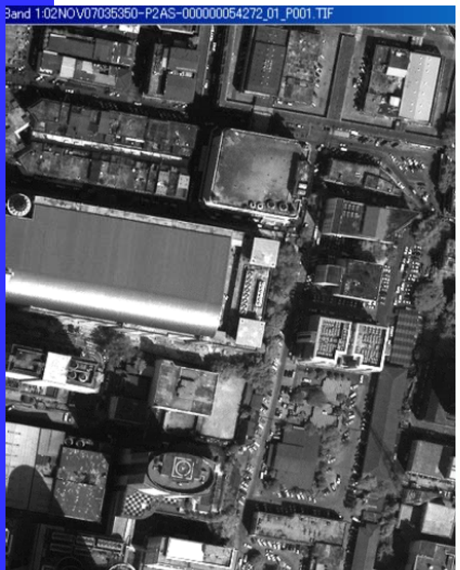
- Science
  - Oceanography
  - Atmosphere Study
- Environment
  - Vegetation Monitoring
  - CO_2 fixation
  - Urban Environment (Urban Heat Environment)
- Natural Resource
  - Land use / Land cover (1:1mil)
  - Fisheries, SST, chl-a, Red-tide
  - Agriculture Near Real Time Monitoring (Growth Monitoring,
- Yield, Water Stress…)
  - Water Resources
- Disaster
  - Flood, Forest Fire, Volcano

Various Low-Resolution and Radar Satellites

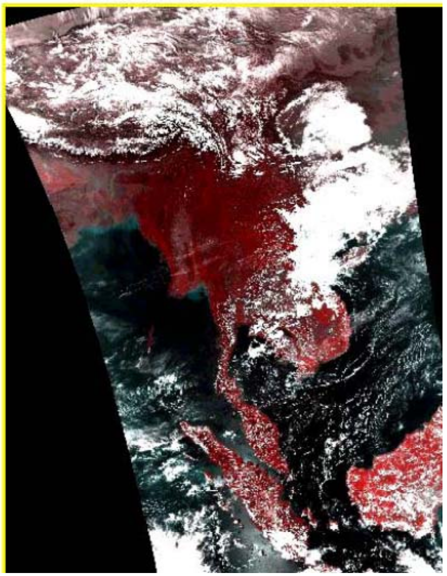
- MODIS
- NOAA
- SPOT IV
- ERS
- RADARSAT



High-Reso Satellite
Quick Bird 0.62m



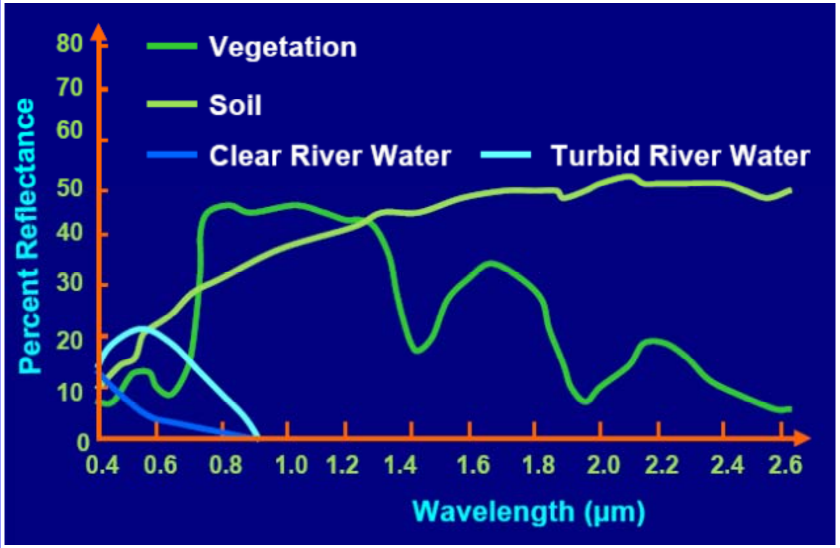
Low-Reso, High-Temporal
NOAA/AVHRR 1 km



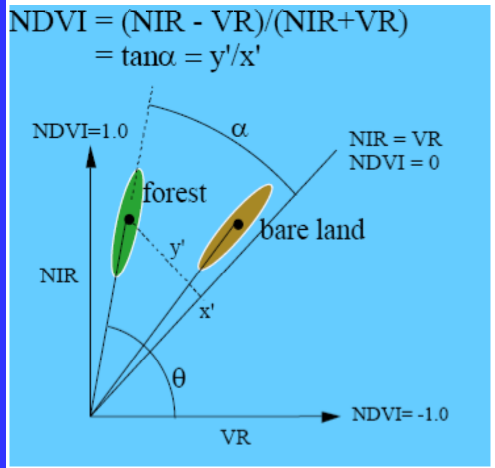
Trade-off in Performance

- Spatial Resolution (1 observation unit on ground surface)
  - 30 m - 250km - 1km
- Temporal Resolution
  - 16 days - 1day
- Spectral Resolution
  - 7 channel vs 36 channel
- Observation Extent
  - 185 km vs 2,300km
- S/N
  - 8bits vs 10bits
- cost
  - 1 scene 800US$ vs Free (Broadcast)

Spectral Reflectance

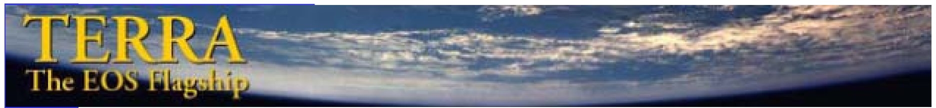


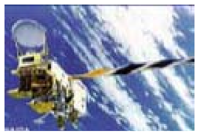
NDVI: Normalized Differential Vegetation Index



$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} \cos\pi/4 & \sin\pi/4 \\ -\sin\pi/4 & \cos\pi/4 \end{pmatrix} \begin{pmatrix} VR \\ NIR \end{pmatrix}$$

$$\tan\alpha = \frac{y'}{x'} = \frac{NIR - VR}{NIR + VR}$$





- EOS (Earth Observing System) - A Project by NASA 15 years earth observation for Environmental Problems With International Collaboration; Japan, Canada, …
- Series of Afternoon and Morning Satellites
  EOS-AM1, EOS-PM1, EOS-AM2, EOS-PM2
- TERRA (EOS-AM1)
  Successfully launched on December 18, 1999
  Activated for science operations on Feb. 24, 2000
  Followed by AQUA(EOS-PM1) in 2002

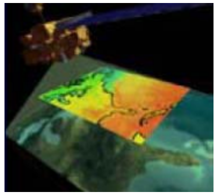
5 Instruments on TERRA

- **MODIS (Moderate-resolution Imaging Spectroradiometer : USA）**
- **ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer : Japan)**
- **CERES (Clouds and the Earth's Radiant Energy System: USA)**
- **MISR (Multi-angle Imaging Spectro-Radiometer: USA)**
- **MOPITT (Measurements of Pollution in the Troposphere: Canada)**

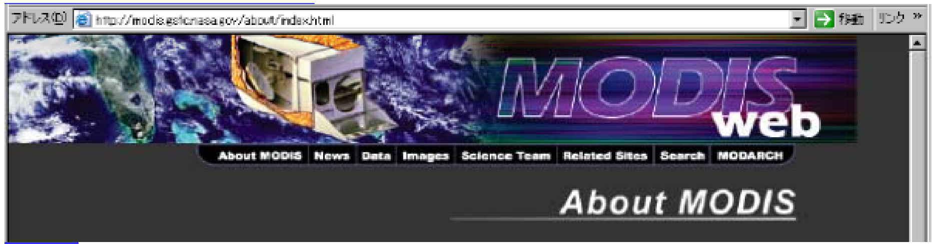
MODIS
(Moderate Resolution Imaging Spectroradiometer)

- Moderate Resolution
  250m Resolution
- Hyper Spectral
  36 discrete spectral bands.
- High Multi-Temporal
  Sees every point on our world every 1-2 days

250m (bands 1-2)
500m (bands 3-7)
1000m (bands 8-36)

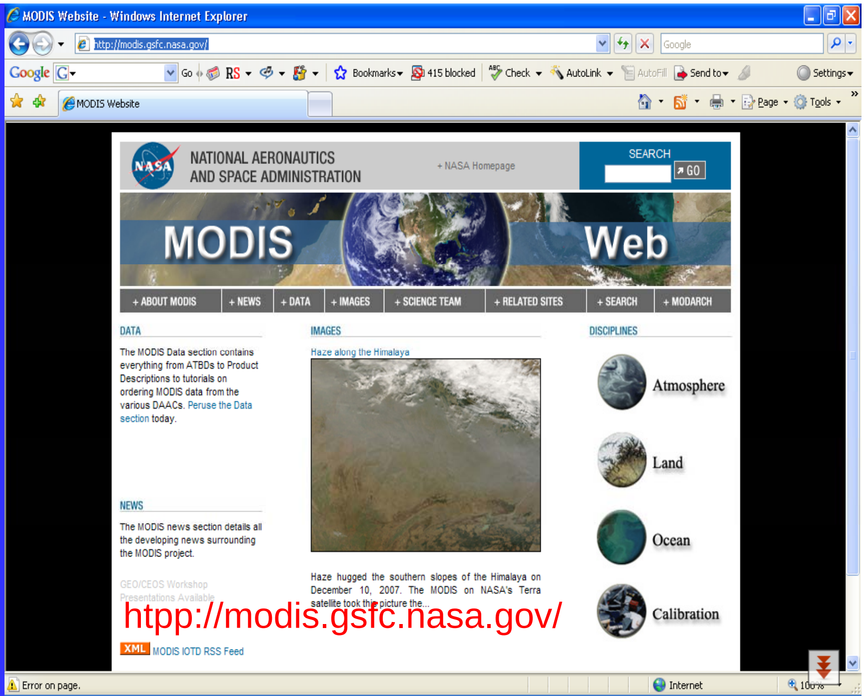


- Successor of Very Popular NOAA/AVHRR
  NOAA/AVHRR: 1km - 5 Channels – Morning and Afternoon
- MODIS is ideal for Global – Regional Environment Monitoring by improving capability of NOAA/AVHRR



MODIS (or Moderate Resolution Imaging Spectroradiometer) is a key instrument aboard the **Terra (EOS AM)** and **Aqua (EOS PM)** satellites. Terra's orbit around the Earth is timed so that it passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon. Terra MODIS and Aqua MODIS are viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands, or groups of wavelengths (see MODIS Technical Specifications). These data will improve our understanding of global dynamics and processes occurring on the land, in the oceans, and in the lower atmosphere. MODIS is playing a vital role in the development of validated, global, interactive Earth system models able to predict global change accurately enough to assist policy makers in making sound decisions concerning the protection of our environment.

http://modis.gsfc.nasa.gov/



htpp://modis.gsfc.nasa.gov/

MODIS Technical Specifications

- Orbit: 705 km, 10:30 a.m. descending node (Terra) or 1:30 pm ascending node (Aqua), sun-synchronous, near-polar, circular
- Scan Rate: 20.3 rpm, cross track
- Swath: 2330 km (cross track) by 10 km (along track at nadir)
- Telescope: 17.78 cm diam. off-axis, afocal (collimated)
- Size: 1.0 x 1.6 x 1.0 m
- Weight: 228.7 kg
- Power: 162.5 W (single orbit average)
- Data Rate: 10.6 Mbps (peak daytime); 6.1 Mbps (orbital average)
- Quantization: 12 bits
- Spatial Resolution:
  - 250 m (bands 1-2)
  - 500 m (bands 3-7)
  - 1000 m (bands 8-36)
- Design Life: 6 years

Primary Use	Band	Bandwidth	Spectral Radiance	Required SNR
Land/Cloud/Aerosols Boundaries	1	620 - 670	21.8	128
	2	841 - 876	24.7	201
Land/Cloud/Aerosols Properties	3	459 - 479	35.3	243
	4	545 - 565	29.0	228
	5	1230 - 1250	5.4	74
	6	1628 - 1652	7.3	275
	7	2105 - 2155	1.0	110
Ocean Color/ Phytoplankton/ Biogeochemistry	8	405 - 420	44.9	880
	9	438 - 448	41.9	838
	10	483 - 493	32.1	802
	11	526 - 536	27.9	754
Note:	12	546 - 556	21.0	750
Bands 1 to 19 are in nm.	13	662 - 672	9.5	910
	14	673 - 683	8.7	1087
	15	743 - 753	10.2	586
	16	862 - 877	6.2	516
Atmospheric Water Vapor	17	890 - 920	10.0	167
	18	931 - 941	3.6	57
	19	915 - 965	15.0	250

Primary Use	Band	Bandwidth	Spectral Radiance	Required NE[delta]T(K)
Surface/Cloud Temperature	20	3.660 - 3.840	0.45(300K)	0.05
	21	3.929 - 3.989	2.38(335K)	2.00
	22	3.929 - 3.989	0.67(300K)	0.07
	23	4.020 - 4.080	0.79(300K)	0.07
Atmospheric Temperature	24	4.433 - 4.498	0.17(250K)	0.25
	25	4.482 - 4.549	0.59(275K)	0.25
Cirrus Clouds Water Vapor	26	1.360 - 1.390	6.00	150(SNR)
	27	6.535 - 6.895	1.16(240K)	0.25
	28	7.175 - 7.475	2.18(250K)	0.25
Cloud Properties	29	8.400 - 8.700	9.58(300K)	0.05
Ozone	30	9.580 - 9.880	3.69(250K)	0.25
Surface/Cloud Temperature	31	10.780 - 11.280	9.55(300K)	0.05
	32	11.770 - 12.270	8.94(300K)	0.05
Cloud Top Altitude	33	13.185 - 13.485	4.52(260K)	0.25
	34	13.485 - 13.785	3.76(250K)	0.25
Note: Bands 20 to 36 are in µm.	35	13.785 - 14.085	3.11(240K)	0.25
	36	14.085 - 14.385	2.08(220K)	0.35

MODIS Standard Products

There are 44 products, Some are validated, some are not validated.

- *Data Products*
  - There are 44 standard MODIS data products that scientists are using to study global change. These products are being used by scientists from a variety of disciplines, including oceanography, biology,and atmospheric science. This section details each product individually, introducing you to the products, explaining the science behind them, and alerting you to known areas of concern with the data products. Also documented is each of the product's latest availability information. To view specific info on a product, select it from the menu below.
- Calibration 3
  - (Radiance Counts, Calibrated Geolocated Radiances, Geolocation Data set)
- Atmosphere 6
  - (Aerosol, Water Vapor, Cloud, Profiles, Gridded Info, Cloud Mask)
- Land 10
  - (Reflectance, Temp and Emissivity, Land Cover and change, NDVI, Thermal, LAI, Evapo, NPP, Reflectance, Vegetaion Cover Conversion)
- Cryosphere 2
  - (Snow Cover, Sea Ice Cover)
- Ocean 15
  - (Water Leaving Rad, Pigment Concen. Chl-Fluorescence, Chl-a, PAR, SS, Organic Matter, Coccolith, Ocean Water Attenuation, Ocean Primary Prod., SST, Phycoerythrin Cocent., Total Absorption Coeff., Ocean Aerosol, Clear Water Eps.)

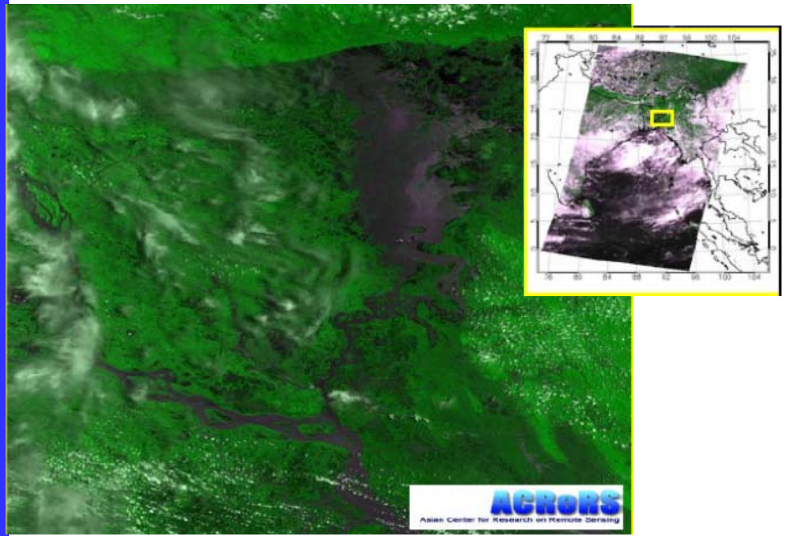
MODIS Standard Products & its level

- Beta Products
  - Beta Products are minimally validated, early release products that enable users to gain familiarity with data formats and parameters. Product is probably not appropriate as the basis for quantitative scientific publications.
- Provisional Products
  - Provisional Products are partially validated and improvements are continuing. Provisional products are viewed as early science validated products and useful for exploratory and process scientific studies. Quality may not be optimal since validation and quality assurance are ongoing. Users are expected to review products quality summaries before publication of results.
- Validated Products

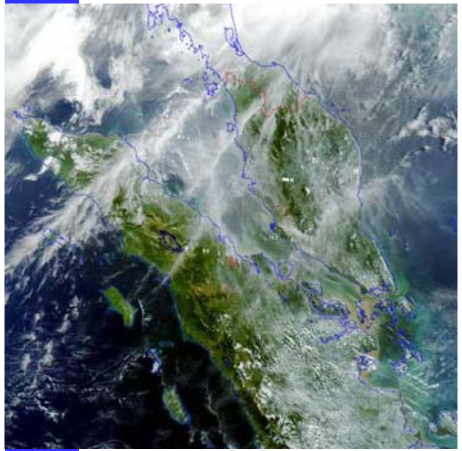
  Validated Products have well defined uncertainties. These are high quality products suitable for longer term or systematic scientific studies and publication. There may be later I improved versions. Users are expected to review products quality summaries before publication of results.

  - **Stage 1 Validation:** Product accuracy has been estimated using a small number of independent measurements obtained from selected locations and time periods and ground-truth/field program efforts.
  - **Stage 2 Validation:** Product accuracy has been assessed over a widely distributed set of locations and time periods via several ground-truth and validation efforts.
  - **Stage 3 Validation:** Product accuracy has been assessed and the uncertainties in the product well established via independent measurements in a systematic and statistically robust way representing global conditions.

MODIS for Flood Monitoring



MODIS for Forest Fire Monitoring



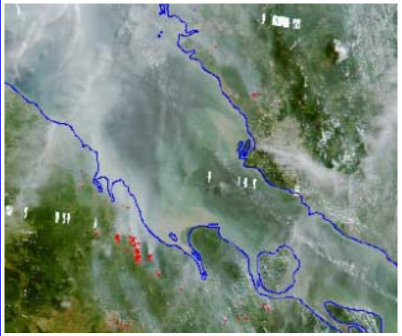
MODIS hotspot image on 7 Sep 2001. Riau Province, Sumatra

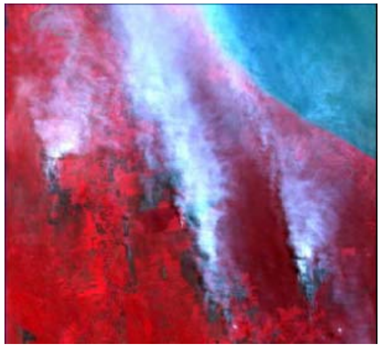
- **MODIS has 16 thermal bands and is well suited for hotspots detection.**
- **Band 21 and band 31, which have wavelengths of 3.959nm and 11.03 nm respectively, are used to determine hotpots. The criteria are:**

  BT21>360K or
  BT21>360K and BT21-T31>20K

- **Once a pixel is found to be hotspot, it will be marked in red on the georectified MODIS image**

MODIS for Forest Fire Monitoring





- Zoom-in of Riau Province, Sumatra image in 1-km resolution
- The fires captured by SPOT1 on the same day

For details visit: http://www.crisp.nus.edu.sg/~research/#current

http://www.noaa.gov/

NOAA AVHRR
(Advanced Very High Resolution Radiometer)

	Band	Wavelength (µm)	Applications
Visible	1	0.58-0.68	cloud, snow and ice monitoring
Near IR	2	0.725-1.10	water, vegetation and agriculture surveys
Short Wave IR	3 A	1.58-1.64	snow, ice and cloud discrimination
Medium Wave IR	3B	3.55-3.93	sea surface temperature, volcano, forest fire activity
Thermal IR	4	10.3-11.3	sea surface temperature, soil moisture
Thermal IR	5	11.3-12.5	sea surface temperature, soil moisture

AVHRR is primarily used for **vegetation studies** -the study and monitoring of drought conditions.

http://www.crisp.nus.edu.sg/~research/tutorial/noaa.htm

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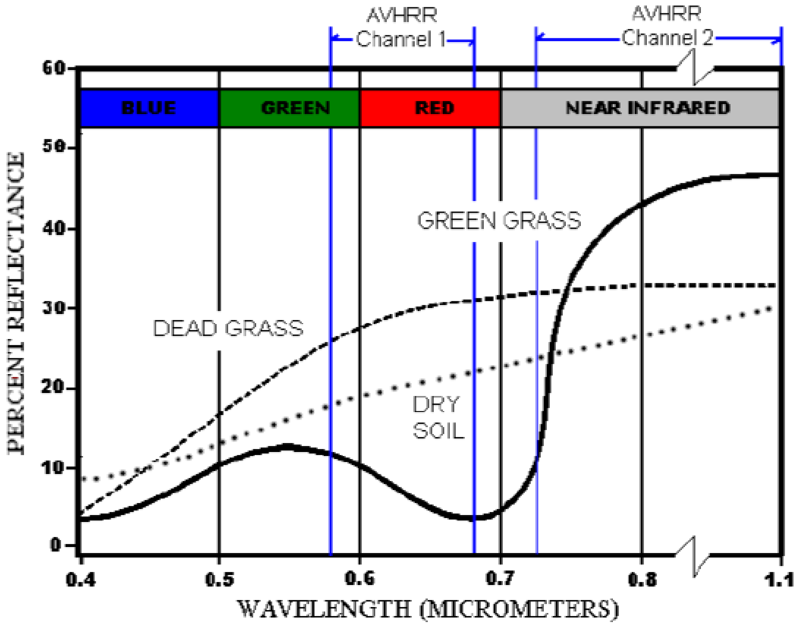

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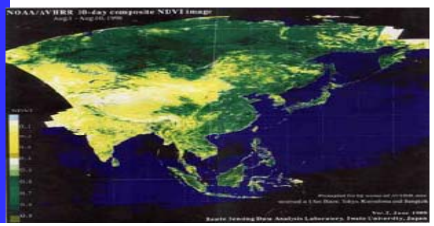
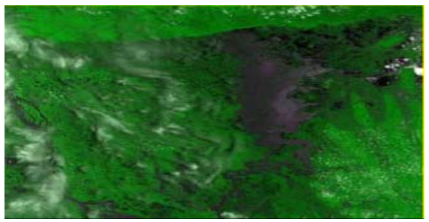
AIT NOAA/AVHRR - MODIS/TERRA Reception, Archiving and Distribution

- NOAA/AVHRR Since 15 November 1997
- • TERRA/MODIS Since 25 May 2001
- • Archiving all of the received data
- • Produce 10days and Monthly NDVI
- • Network Data Distribution over Internet for
- Near Real Time Environment Monitoring





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Cloud Free Composite

- To produce cloud free images
- Overlay certain period of images
- Detect Cloud Free Pixels
- Select pixels which has not been influenced by clouds among the candidates in the same location
- Criteria
  - Maximum NDVI
  - Scan Angle
- Popular period
  - 10days, 30 days

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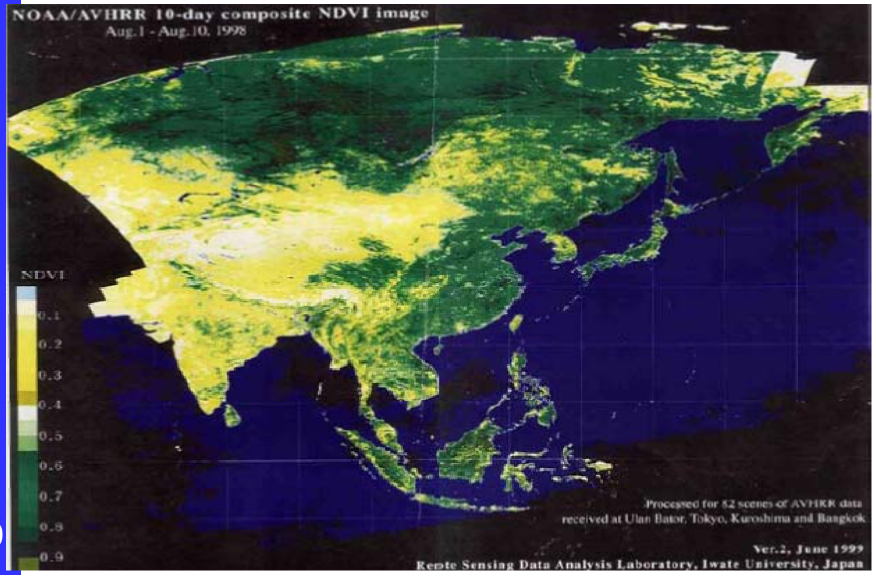
NDVI 10-days Composite
Bangkok(AIT), Ulaanbaatar, Tokyo, Kuroshima



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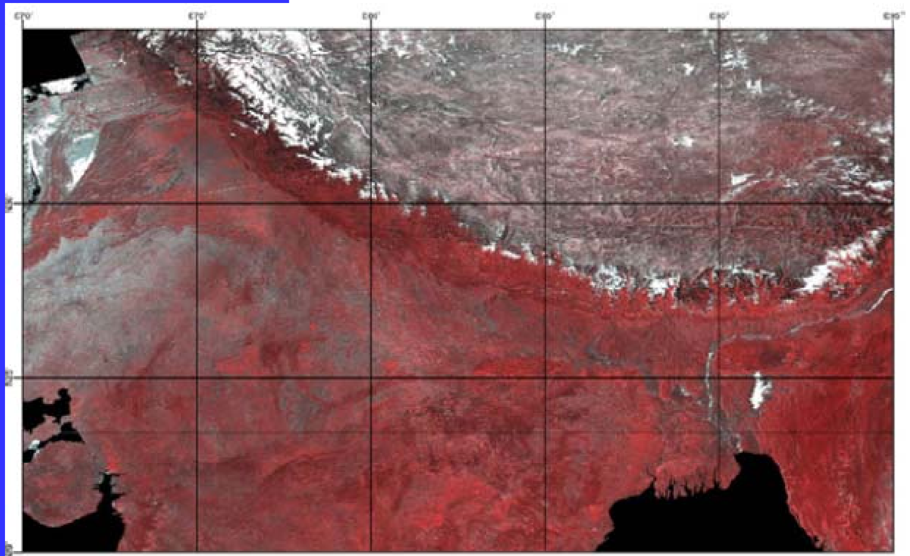
Global Mapping Project - Ganges River Basin

- Create database covering all the land area on the earth's surface with uniform accuracy and specifications in order to contribute in formulating regional level policies and planning/regional level strategies to resolve environmental problems such as
  - •soil erosion/land slide hazard
  - •food security
  - •desertification etc.,
- In this course, Ganges river basin area which covers 35degree N to 20 degree N and 70 degree E to 95 degree E, is being mapped using
  - •NOAA AVHRR data
  - •Elevation data
  - •Precipitation data
  - •Temperature data

30



Monthly Composite of NOAA AVHRR-October 1998

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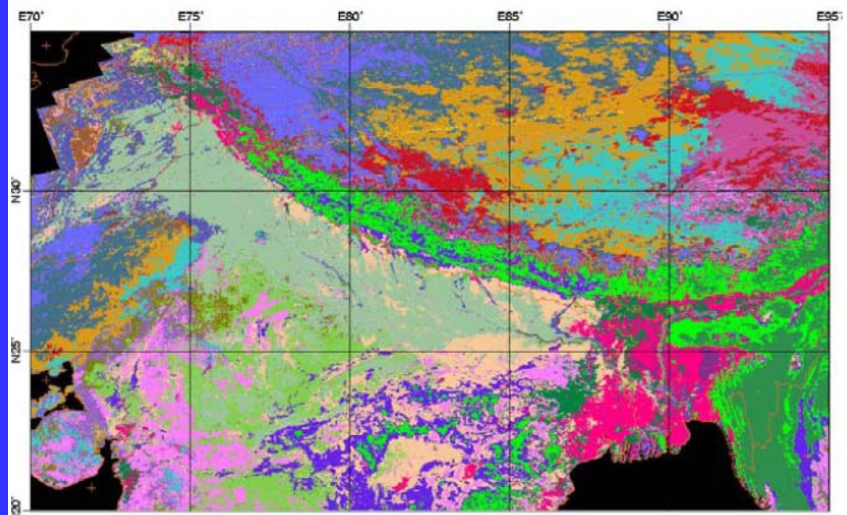
Unsupervised Classification of Multi-Temporal NDVI Results



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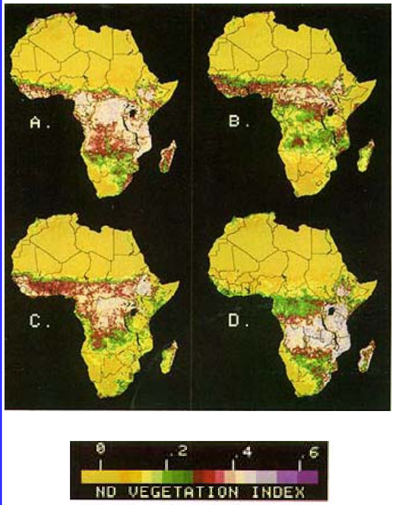

Vegetation Index

The ratio of TM Band 4 to Band 3 or AVHRR Bands 2 to 1 is a simple approximation of the Vegetation Index (VI).

Left image: **Use AVHRR to observe seasonal changes in biomass ("green wave") over all of Africa**

A. April 12-May 2, 1982; B. July 5-25, 1982; C. Sept. 27-Oct. 17, 1982; D. Dec. 20, 1982-Jan. 9, 1983.

http://rst.gsfc.nasa.gov/Sect3/Sect3_4.html

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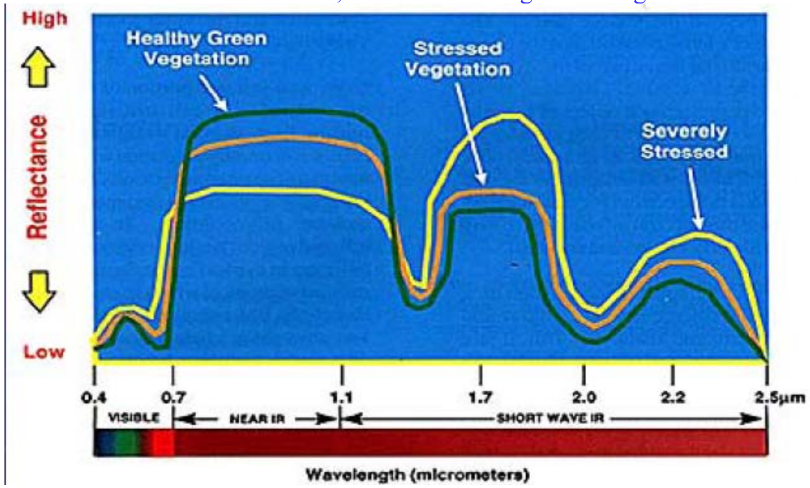
Crop Stress

- is indicated by progressive decrease in Near-IR reflectance but a reversal in Short-Wave IR reflectance, as shown in this general diagram:



http://rst.gsfc.nasa.gov/Sect3/Sect3_1.html

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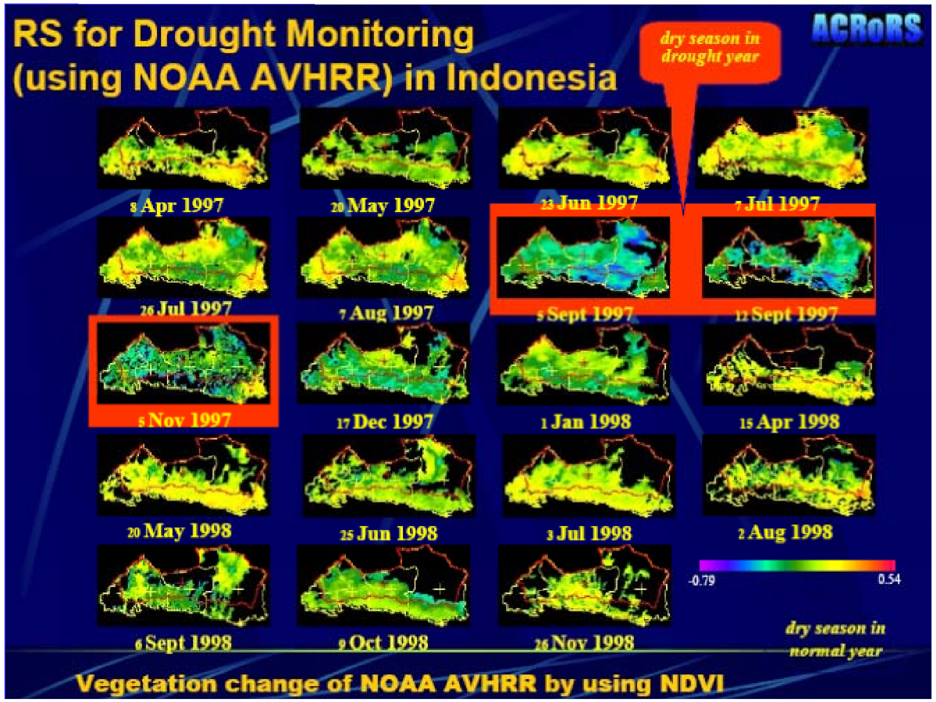

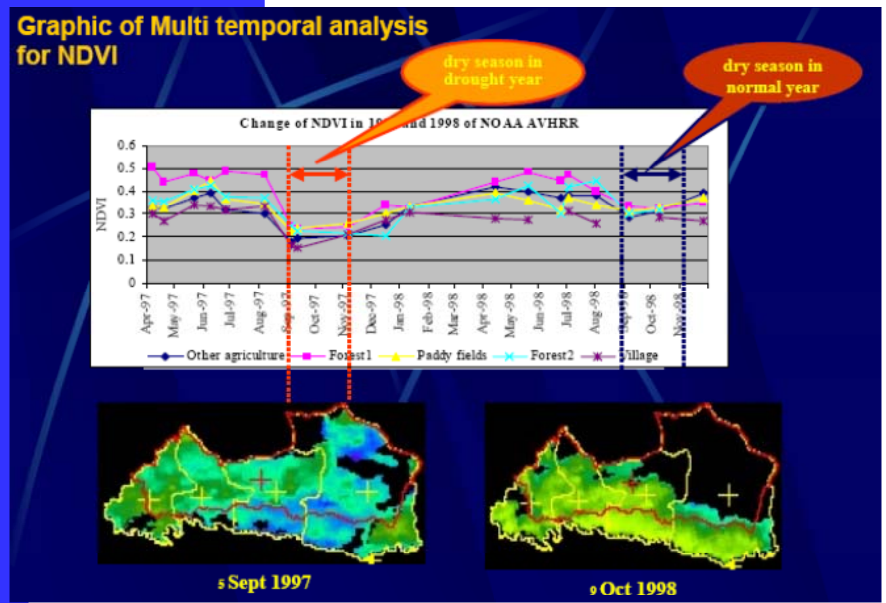

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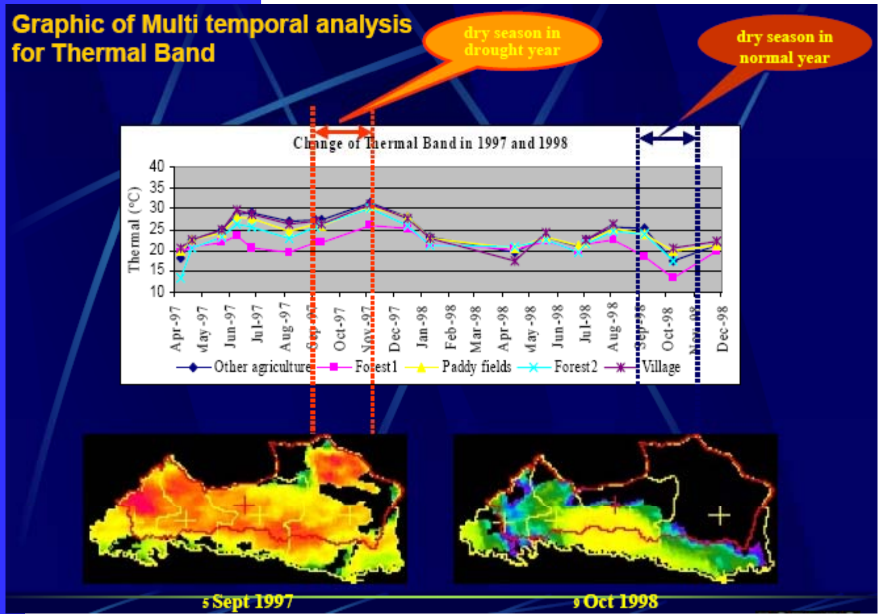
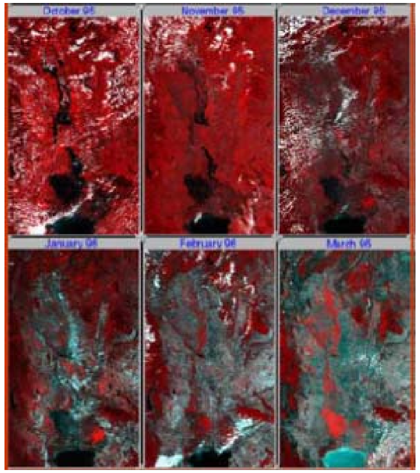


Flood Monitoring using NOAA



Flood Monitoring in Thailand using NOAA AVHRR Satellite Image

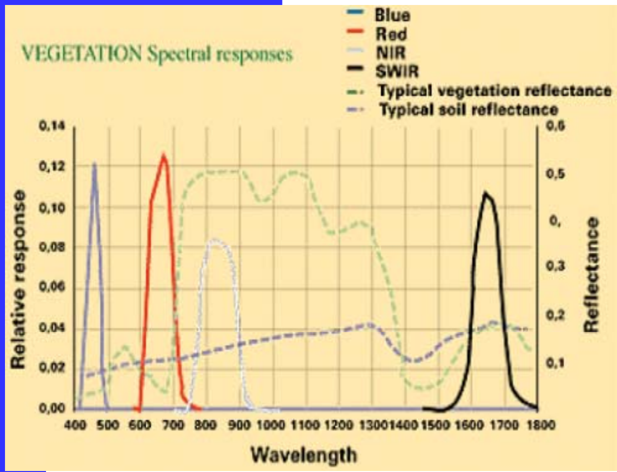
NOAA AVHRR and DEM

Flight Simulation Background for Greenmap

Spot 4-VEGETATION

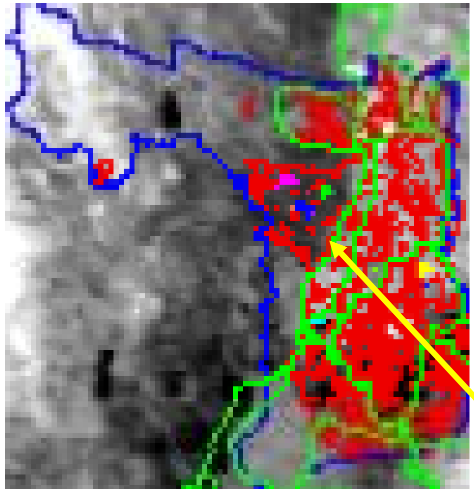
- The VEGETATION instrument on Spot 4 features a widefield-of-view radiometric imaging instrument operating in four spectral bands (blue, red, near-and short-wave infrared) at a resolution of 1 kilometer; a solid-state onboard recorder able to store 90 minutes of data; image telemetry systems and a computer to manage the instrument's work plan. A dedicated onboard calibration device also monitors radiometric performance of the cameras.
- With a swath width of 2,250 kilometres, the VEGETATION instrument covers almost all of the globe's land masses while orbiting the Earth 14 times a day. Only a few zones near the equator are covered every day. Areas above 35° latitude are seen at least once daily.

http://www.spotimage.fr/home/system/introsat/payload/vegetati/vegetati.htm



- **Spectral bands**
  - Blue: 0.43 to 0.47 µm
  - Red: 0.61 to 0.68 µ m
  - Near-infrared: 0.78 to 0.89 µ m
  - Short-wave infrared: 1.58 to 1.75 µm

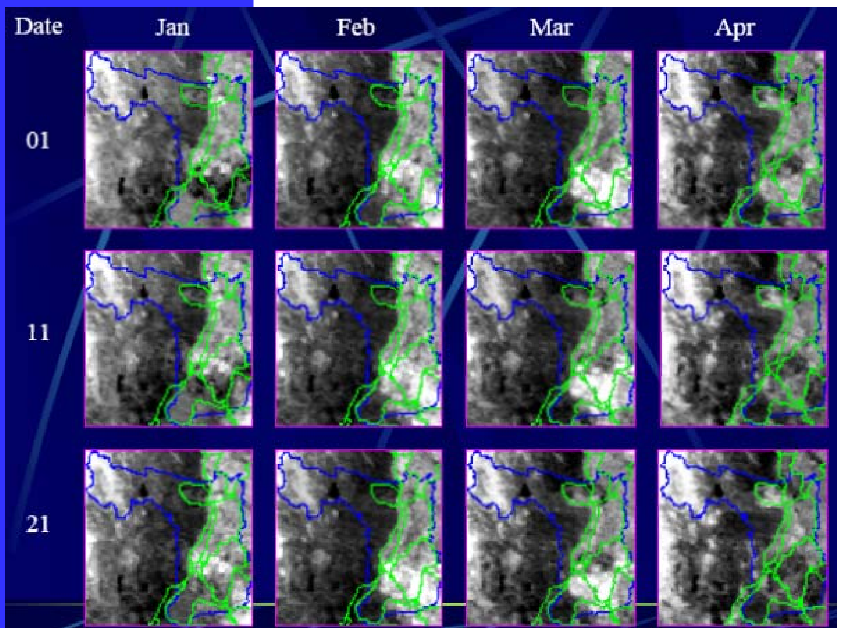
SPOT VI 2001: Suphanburi

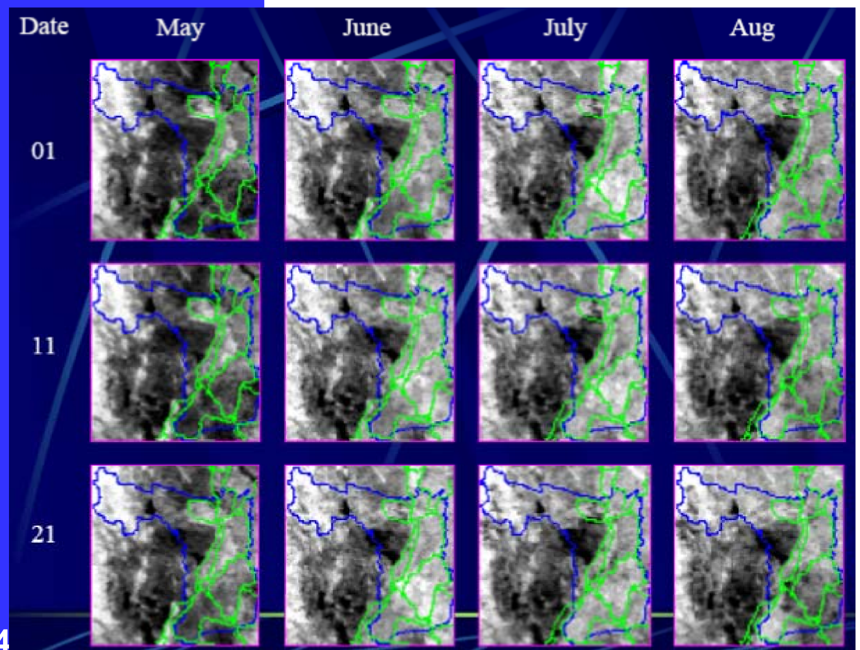


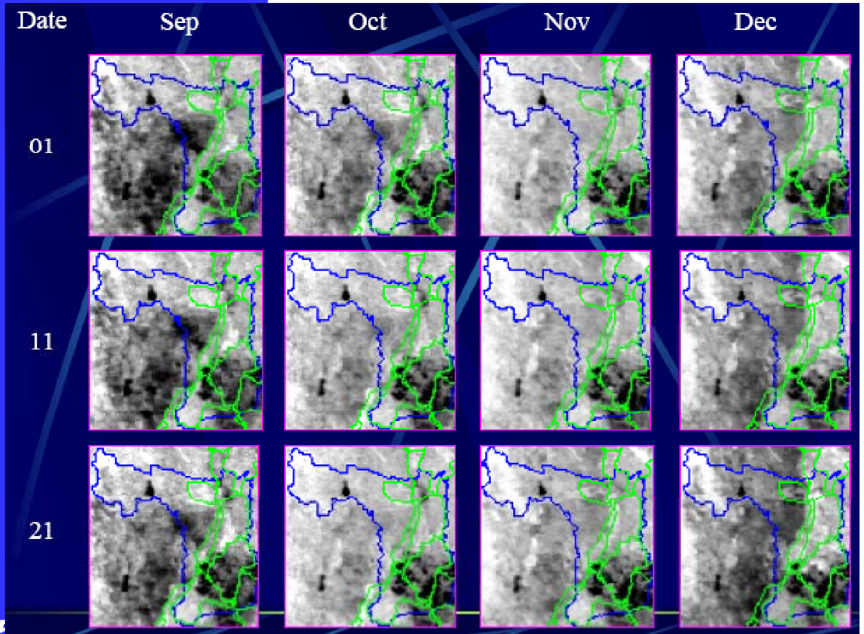
Vector descriptions:

Blue = Suphanburi bnd
Red = Rice field
Green = Irrigated area

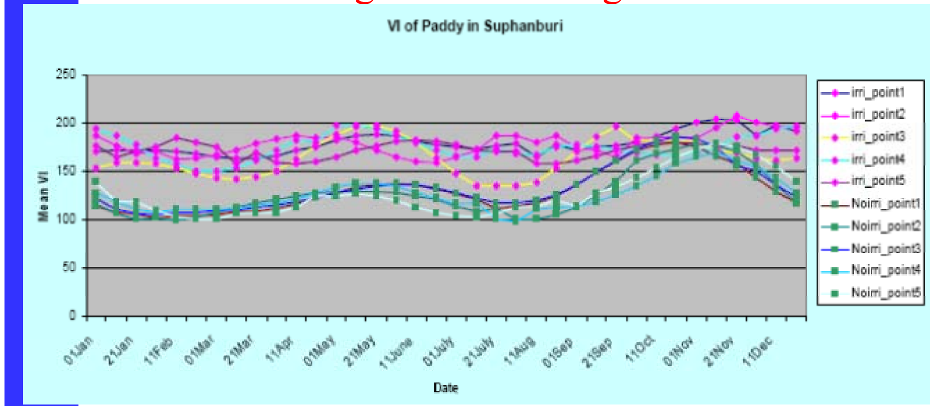
ROIs were located both in and out irrigated area, based on SPOT VI





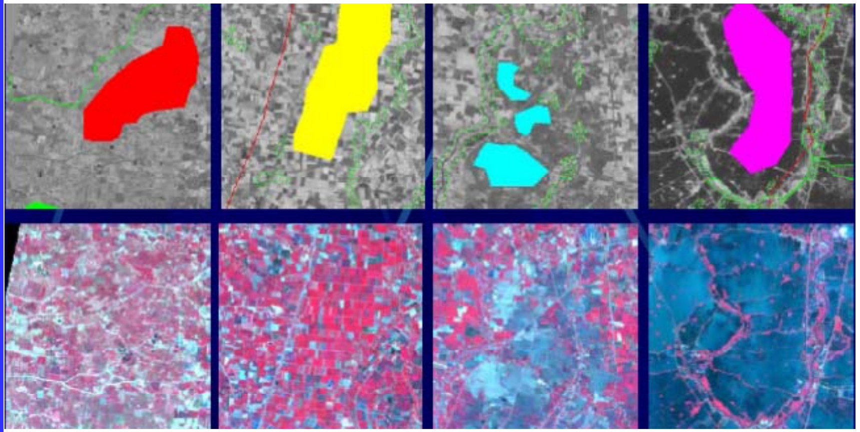


Fluctuation: SPOT VI
Irrigated: Non-Irrigated



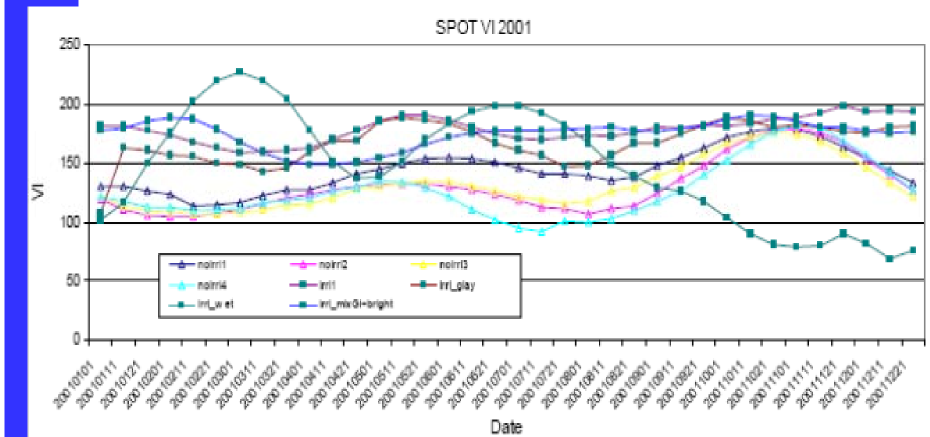
rition	Jan	Feb	Mar	Apr	May	Jun	Jul.	Aug	Sep	Oct	Nov	Dec
ndar orthern				←	- -	- -	- -	→	←	- -	- -	→

ROIs were located both in and out irrigated area, based on LS7



Non-irrigated Irrigated Irrigated Irrigated

SPOT VI 2001
At Various Agriculture(Paddy) Practice



Use area ROIs from Landsat7 to calculate VI mean in SPOT VI

Several Points when Using Multi-temporal VI

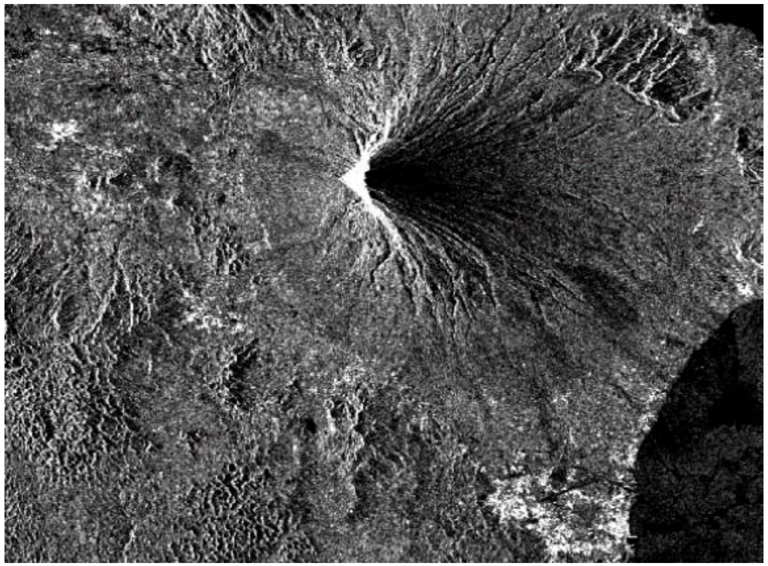
- Geo-location
  - Composite Method
  - Water Body
- Effect of Cloud
  - LMF (Local Maximum Fitting) and etc
  - Temporal interpolation
- Effect of Scan Angle
  - Especially rainy season

RADAR Remote Sensing

Remote sensing using active microwave

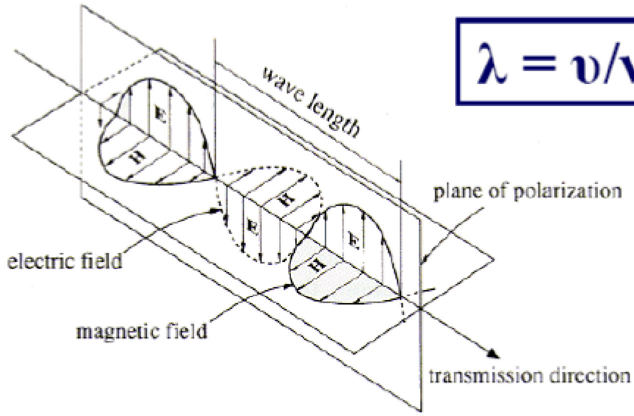
- **All-weather capability: Microwave penetrates clouds**
- **Construction of short-interval time series through**
- **cloud cover**
  - **crop-growth cycle**
- **Roughness**
  - **Land cover, Flood, Oil spill**
- **Moisture**
  - **soil moisture**
- **Structure**
  - **vegetation height, Biomass**
- **Multi-Polization**
- **Interferometry: Phase analysis: Topographic**

SAR image of Mt. Mayon in Philippines (20 May 1996)



Electromagnetic radiation

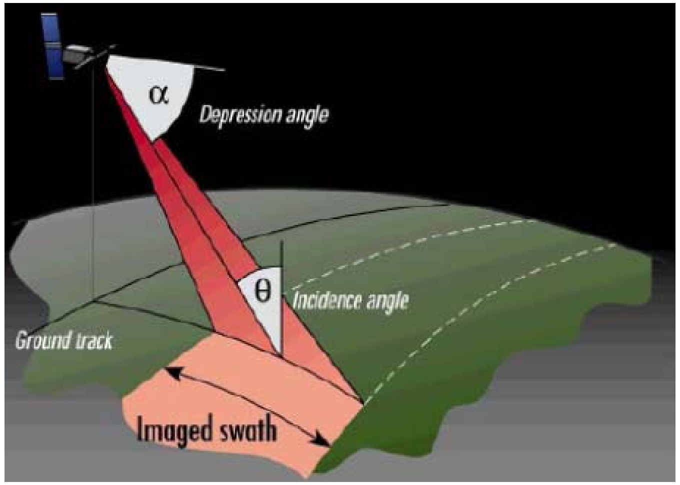
wavelength λ , frequency ν and the velocity υ have the following relation.



$$\lambda = \upsilon/\nu$$

Note: Electro-magnetic radiation has the characteristics of both wave motion and particle motion.

Basic Geometry



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RADAR Back Scatter

- Surface Back Scatter
  - Roughness
- Volume Scatter and Target's Structure
  - Volume, Structure
- Dielectric Property
  - Moisture
- Polarization
- Distance

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Surface Scattering

Rayleigh Criterion : if $\Delta h < \lambda / 8 \cos \theta$, the surface is smooth
Fraunhofer Criterion : if $\Delta h < \lambda / 32 \cos \theta$, then the surface is smooth

where Δh : standard deviation of surface roughness
λ : wavelength
θ : incident angle

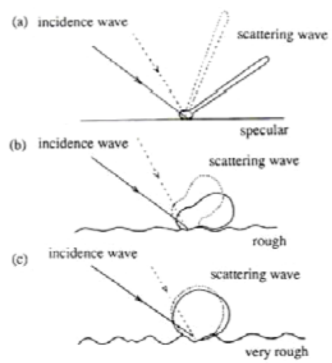
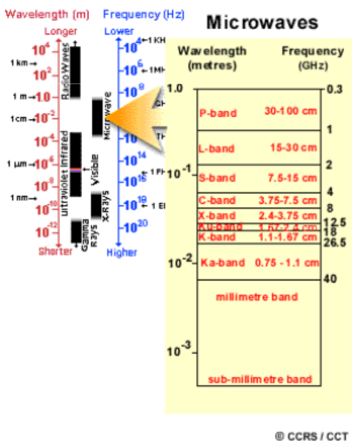


Figure 3.4.1 Surface scattering pattern with different surface roughness



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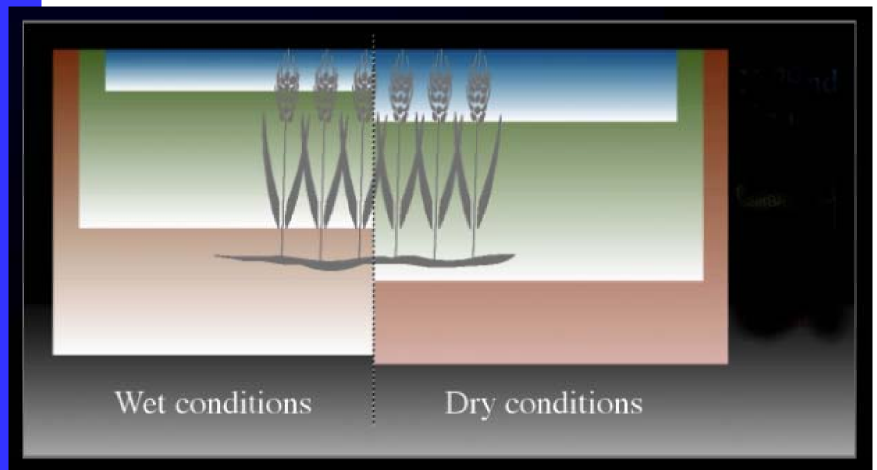
Penetration into volume: *agriculture*



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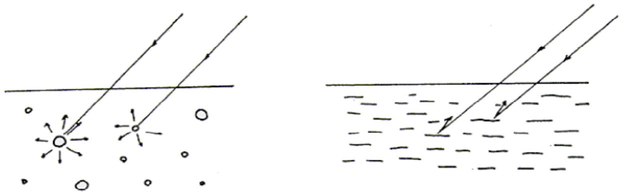
Scattering by Volume & Structure



(a)scattering by widely distributed particles (b)scattering in uneven quality media

Figure 3.5.1 Schematic model of volume scattering

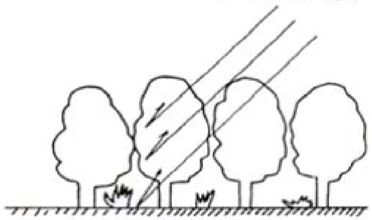
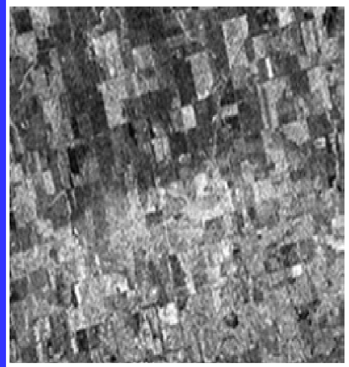


Figure 3.5.4 Schematic model in the case of forest; volume scattering by leaves and branches as well as surface scattering by crown of trees

Dielectric Constant

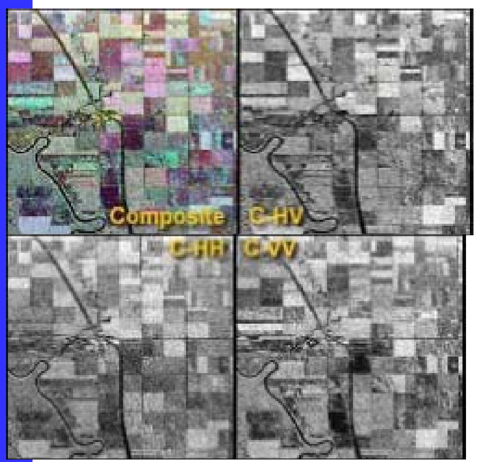
- High Dielectric C.(Wet) : High Backscatter

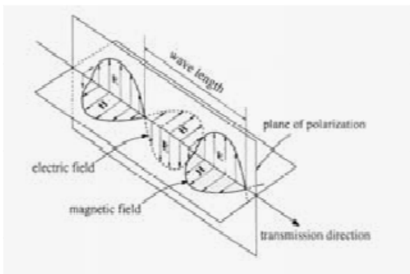


European Space Agency (ESA) ERS-1 satellite. This synoptic image of an area near Melfort, Saskatchewan details the effects of a localized precipitation event on the microwave backscatter recorded by the sensor. Areas where precipitation has recently occurred can be seen as a bright tone (bottom half) and those areas unaffected by the event generally appear darker (upper half). This is a result of the complex dielectric constant which is a measure of the electrical properties of surface materials. The dielectric property of a material influences its ability to absorb microwave energy, and therefore critically affects the scattering of microwave energy.
The magnitude of the radar backscatter is proportional to the dielectric constant of the surface. For dry, naturally occurring materials, this is in the range of 3 - 8 , and may reach values as high as 80 for wet surfaces. Therefore the amount of moisture in the surface material directly affects the amount of backscattering. For example, the lower the dielectric constant, the more incident energy is absorbed, the darker the object will be on the imag

http://www.ccrs.nrcan.gc.ca/ccrs/learn/tutorials/fundam/chapter5/chapter5_14_e.html

Multi-Polarization Observation





http://www.ccrs.nrcan.gc.ca/ccrs/learn/tutorials/fundam/chapter3/chapter3_2_e.html

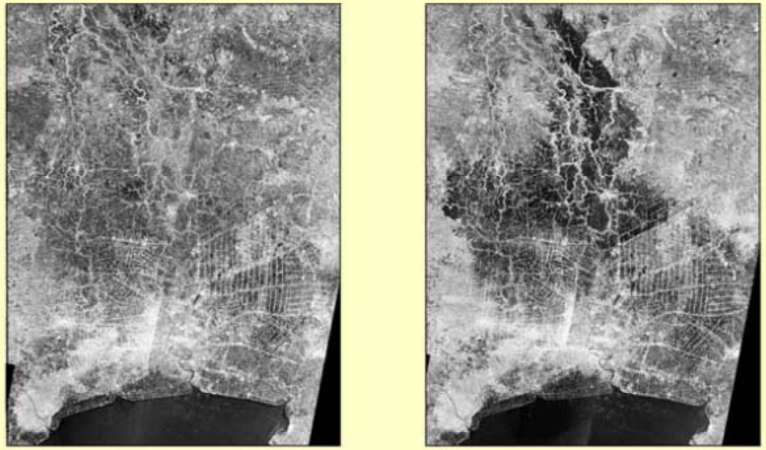
Application Field of SAR

- Agriculture (Growth Monitoring)
  - Soil Moisture, Crop Calendar, Short interval Monitoring
- Forestry (Clear cutting, Structure…)
- Water Resources (snow)
- Land use/cover change
- Oil Spill, Ice Berg
- Ocean (Wind speed, Wave)
- Flood Monitoring (Flood extent, real time)
- Earthquake (Land deformation, Building structure change)
- Volcano monitoring
  - Deformation, Deposit, Erosion, Mud-flow
  - Height information
- Topographic Mapping (global, local)

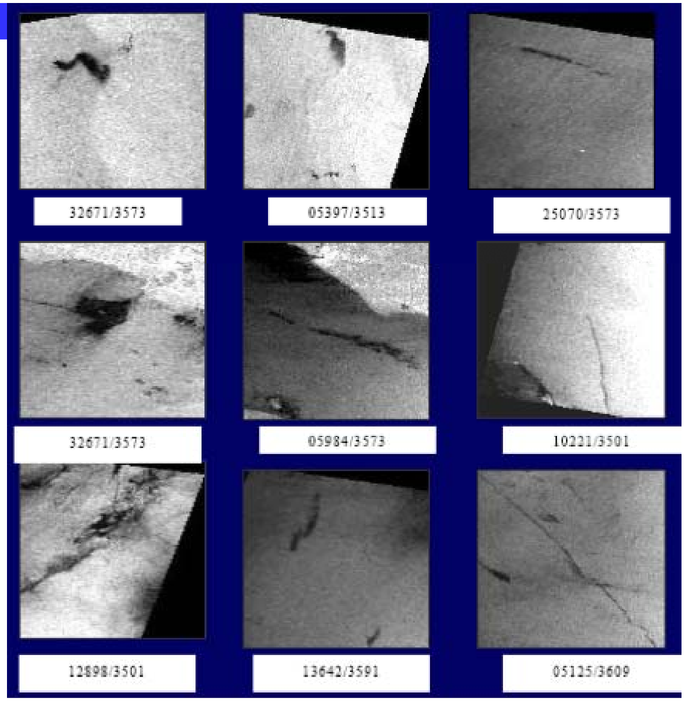
Flood Monitoring using JERS SAR
12 Scenes Mosaic

JERS-SAR Data

Dry Season (May, 1995) **Wet Season (Nov, 1995)**



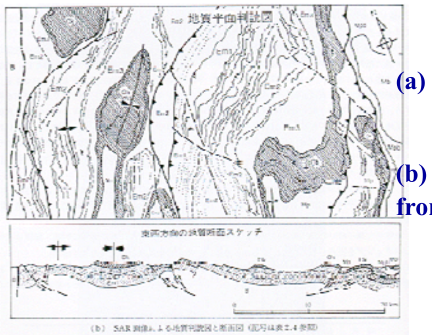
Oil Slick Detection using ERS SAR Quick Look Image (Shafa)



Tropical Rain forest

- **Geology**

Developing geological map at Kutei Basin, Karimantan, Indonesia.One of the most biggest oil production area in SE Asia.

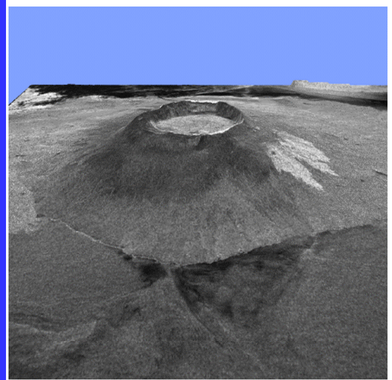


(a) JERS- SAR image for geological application

(b) Result of Geological interpretation from the image

DEM Model

<Area> Galapagos Islands

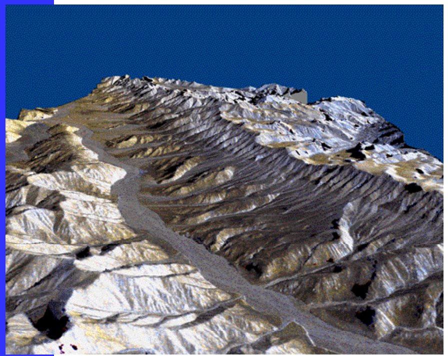


This is a three-dimensional view of Isabela, one of the Galapagos Islands located off the western coast of Ecuador, South America. This view was constructed by overlaying a Spaceborne Imaging Radar-C/X-band Synthetic Aperture Radar (SIR-C/X-SAR) image on a digital elevation map produced by TOPSAR, a prototype airborne interferometric radar which produces simultaneous image and elevation data.

Spaceborne Imaging Radar-C/X-band Synthetic Aperture Radar (SIR-C/X-SAR), TOPSAR,

DEM Model 2

<Area> Valley, China & Tibet

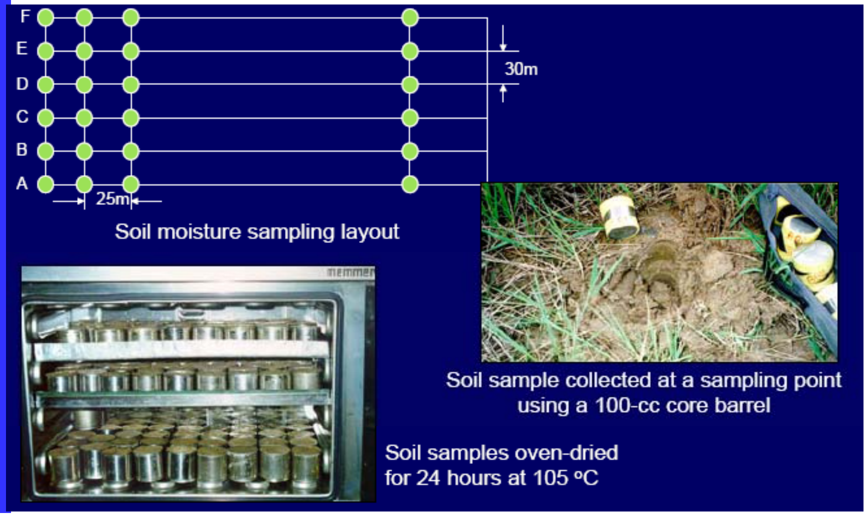


This three-dimensional perspective of Valley in the northern Tibetan Plateau of western China was created by combining two spaceborne radar images using a technique known as interferometry. Visualizations like this are helpful to scientists because they reveal where the slopes of the valley are cut by erosion, as well as the accumulations of gravel deposits at the base of the mountains.

Spaceborne Imaging Radar-C/X-band Synthetic Aperture Radar (SIR-C/X-SAR), TOPSAR,

Quantitative Soil Moisture Measurement Using ERS-2 C-band SAR data in Sukhothai

- Satellite Synchronized Field Survey -



Surface roughness measurement

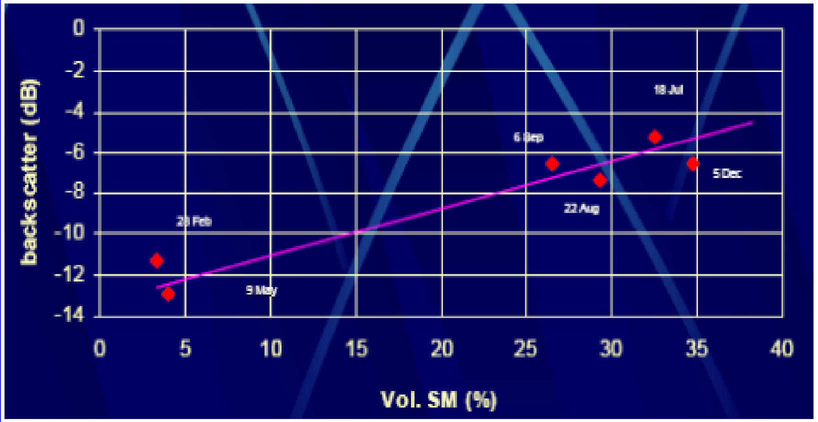
- **A roughness board of 130x45-cm size was used to measure surface roughness.**
  - **First measurement was done during the fallow period (9 May 1998) when the paddy fields**
- **are assumed to have the smallest root mean square height deviation.**
  - **Second measurement was made during the start of land preparation (6 July 1998) when**
- **the paddy fields would have their maximum height deviation from the mean.**

σ = { 1/ (*N*-1) [Σ (zi)2 - *N*(z)2] }1/2

Where:

z = (1/ *N*) Σ zi

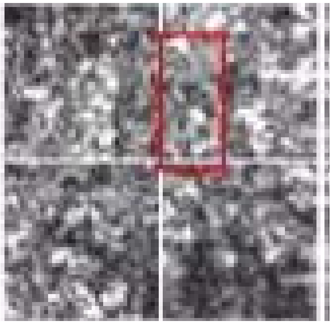
Soil moisture & radar backscatter

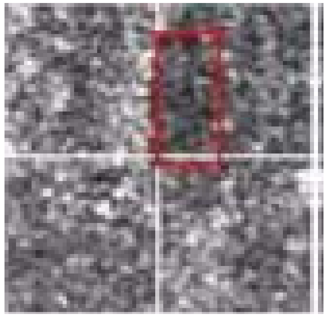


Radar backscatter plotted against volumetric soil moisture:

SMvol = 5σo + 63.75 (R2 = 0.91)

Paddy fields at various observation dates





6 Sep 97 ERS-2 SAR scene
SMVol = 26.55
Plant height = 24.87 cm
Wet biomass = 95.2 g/sq.m

28 Feb 98 ERS-2 SAR scene
SMVol = 3.94
Plant height = 0 cm
Wet biomass = 0 g/sq.

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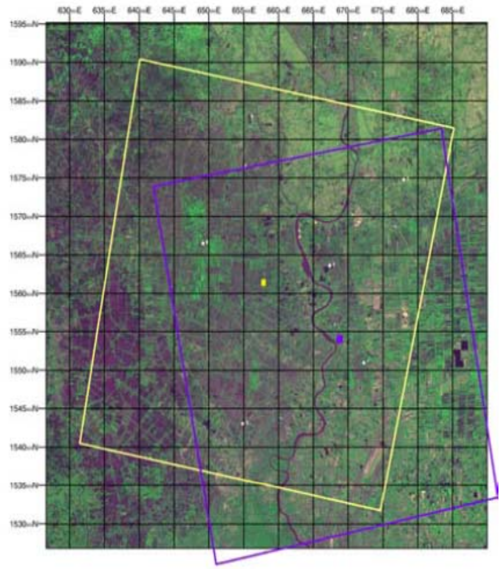
Rice Growth Monitoring Using Near Real Time RADARSAT Fine Beam SAR Data **in Pathumthani**

Deployment sites of
corner reflectors, plotted
On ADEOS AVNIR image
Canada – Japan – Thailand
Within 8 hrs after reception



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Field locations of reflectors and corresponding views in the image

(11a) Station No. 1
Reflector: 8.53 dB
Background: -21.22 dB

(11b) Station No. 2
Reflector: 9.89 dB
Background: -2.19 dB

(11c) Station No. 3
Reflector: 9.48 dB
Background: -3.14 dB

(11d) Station No. 4
Reflector: 9.21 dB
Background: -5.08 dB

for geometric correction of RADARSAT image

For Better Overlay of Radar Image and Field Survey Result

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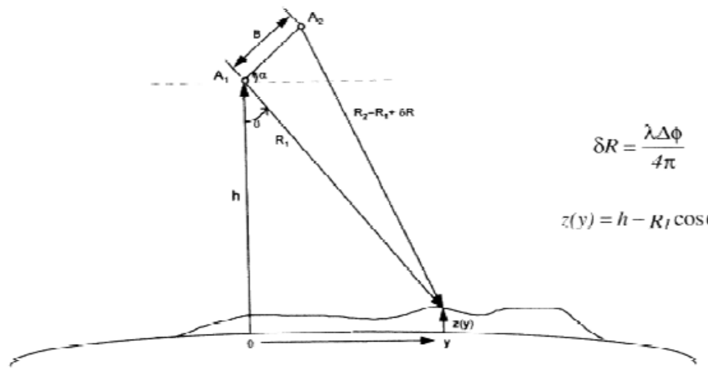
Geometry of Interferometric SAR



$$\delta R = \frac{\lambda \Delta\phi}{4\pi}$$

$$z(y) = h - R_1 \cos\theta$$

Imaging geometry for repeat-pass interferometric SAR. Antenna A_1 and antenna A_2 both transmit and receive pulses

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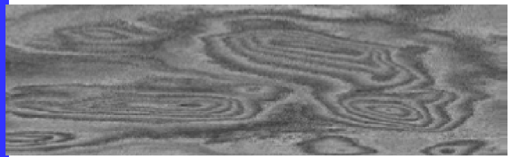
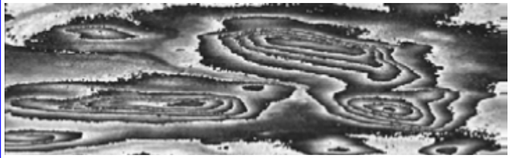
http://www.geo.unizh.ch/rsl/fringe96/papers/herland/

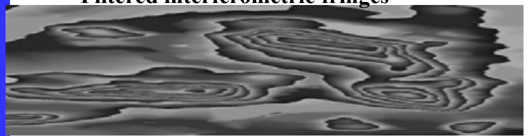
Processing chain for generation of interferometric fringes and coherence



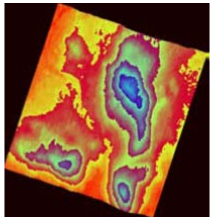
Example of interferometric fringes with average coherence 0.5



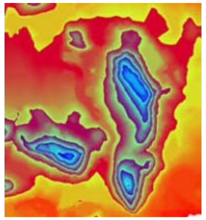
Filtered interferometric fringes



Synthetic interferometric fringes

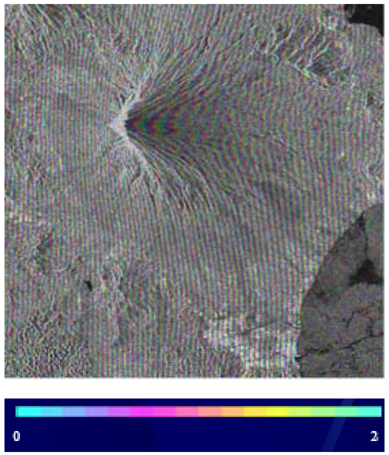


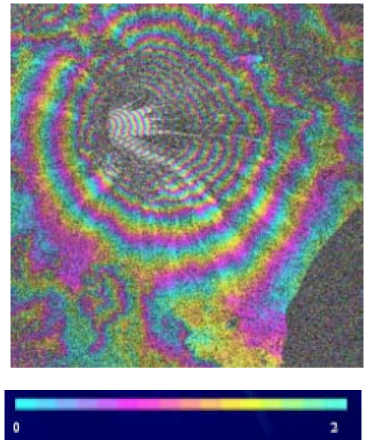
Rectified height model



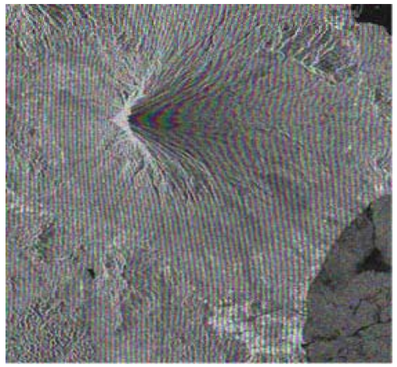
Existing height model

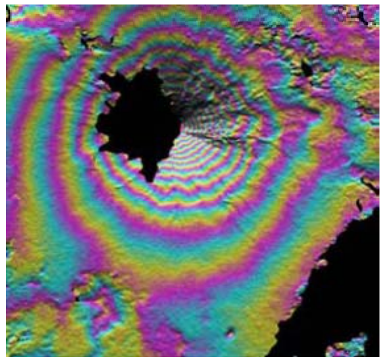
Example, Mapping Mayon Volcano, Albay, Philippines



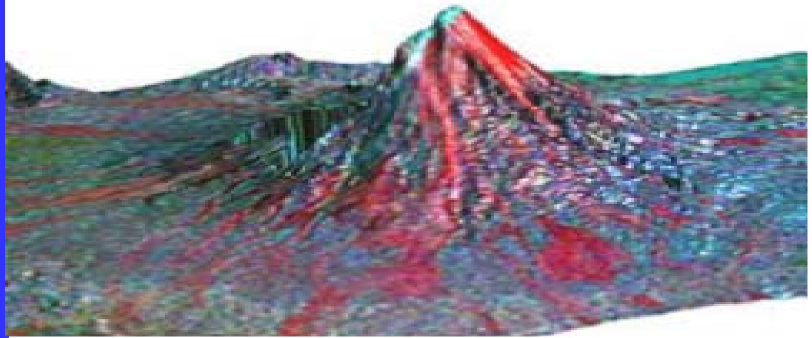


Interferogram 1996 **Flattened Interferogram 1996**





Phase unwrapped image 1996 **INSAR DEM with 160-meter cycle**



3D image view using INSAR DEM

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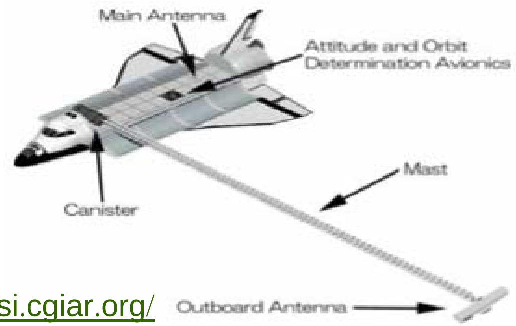
The Shuttle Radar Topography Mission (SRTM) is to map the world in three dimensions.

Using the Spaceborne Imaging Radar (SIR-C) and X-Band Synthetic Aperture Radar (X-SAR) hardware that flew twice on Space Shuttle Endeavour in 1994, SRTM will collect the following in a single 11-day shuttle flight:



http://srtm.csi.cgiar.org/

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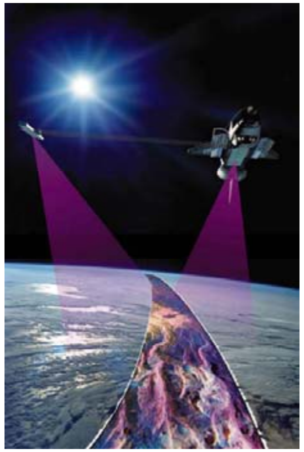
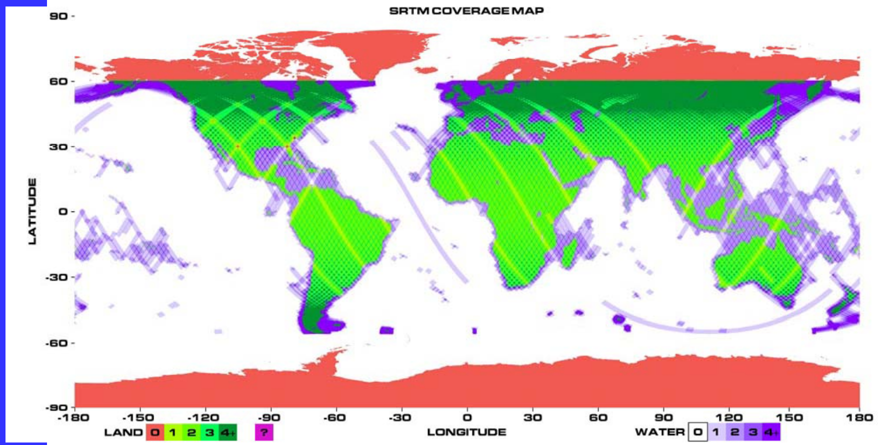
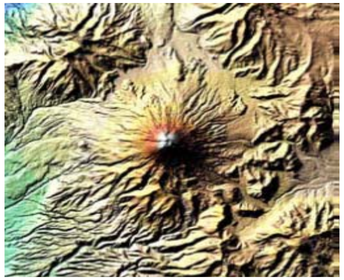
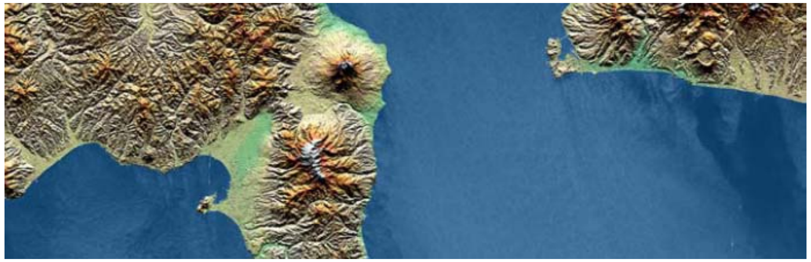




Improvement of DEM 30arcsec -> 1 arcsec





END

Thank you for Attention