The Abdus Salam
International Centre
for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

2453-5

School on Modelling Tools and Capacity Building in Climate and Public Health

15 - 26 April 2013

Remote Sensing

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Remote Sensing

Dr. Pietro Ceccato

The International Research Institute for Climate and Society,
The Earth Institute, Columbia University

Sensing

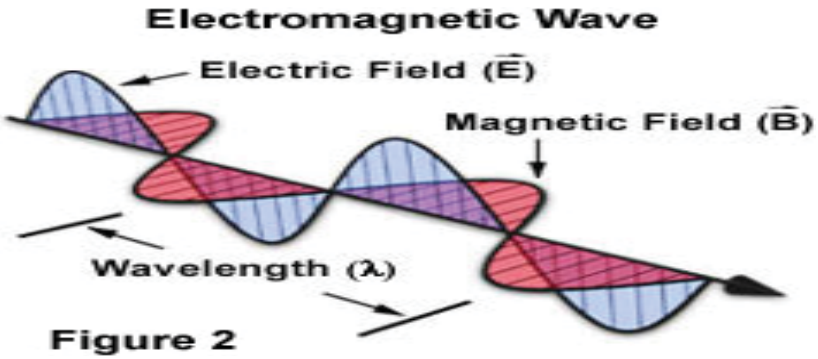
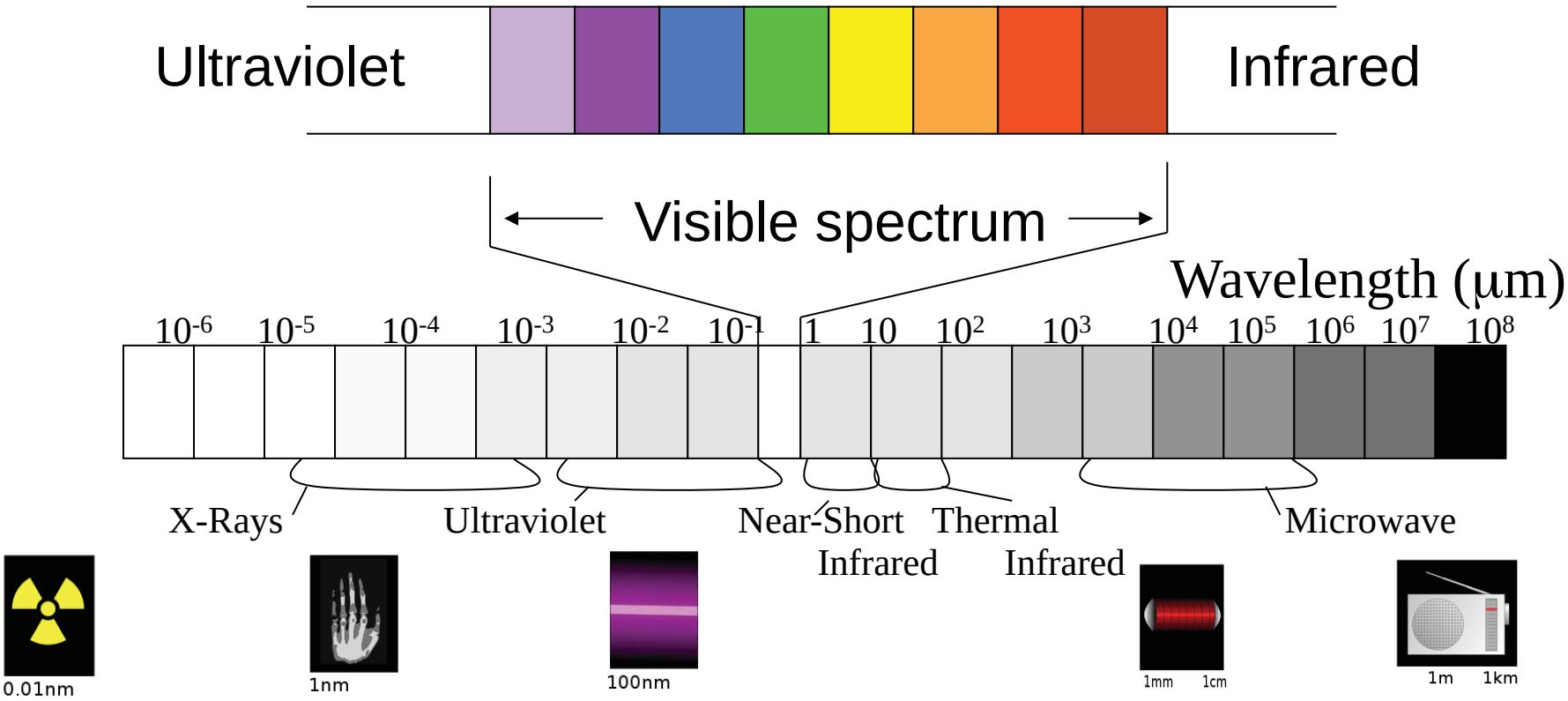
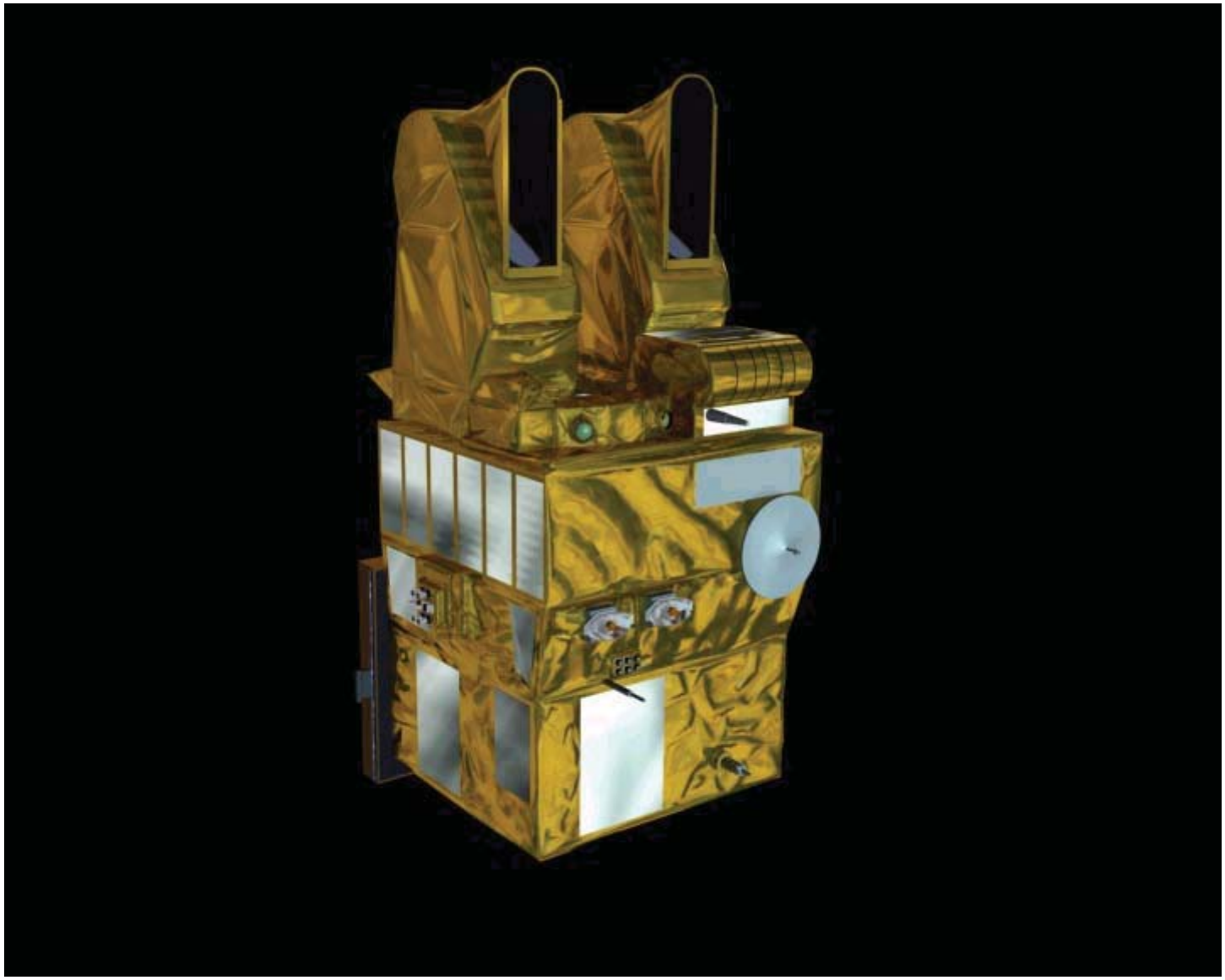


Figure 2



Sensor



An Image

An image is composed by pixels which contain values (radiance) of electromagnetic radiation

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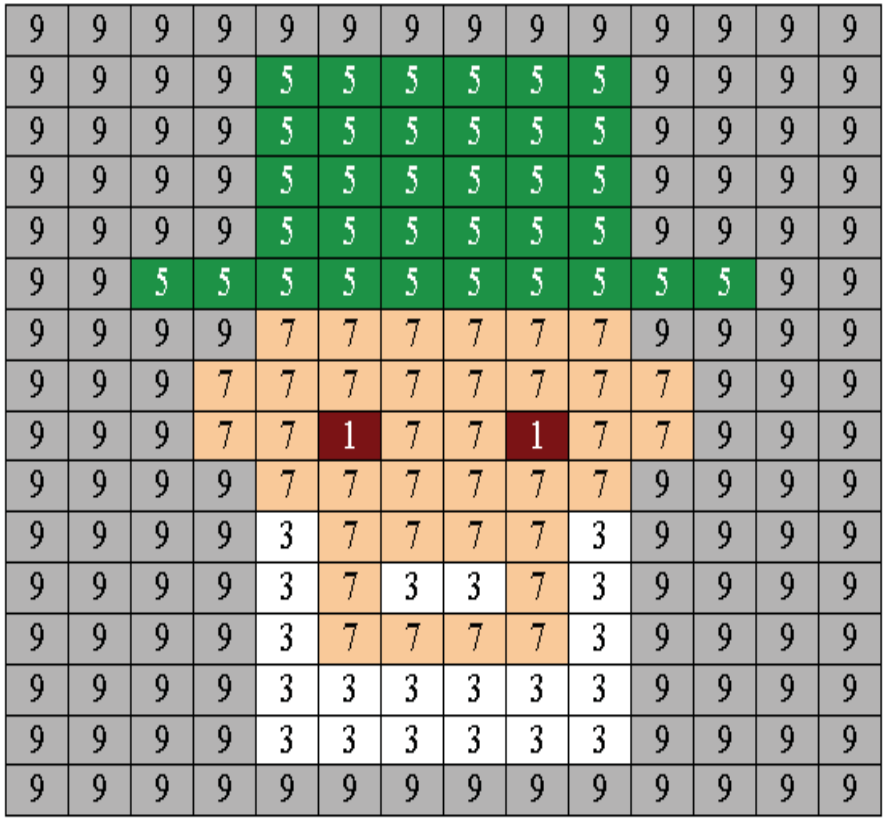

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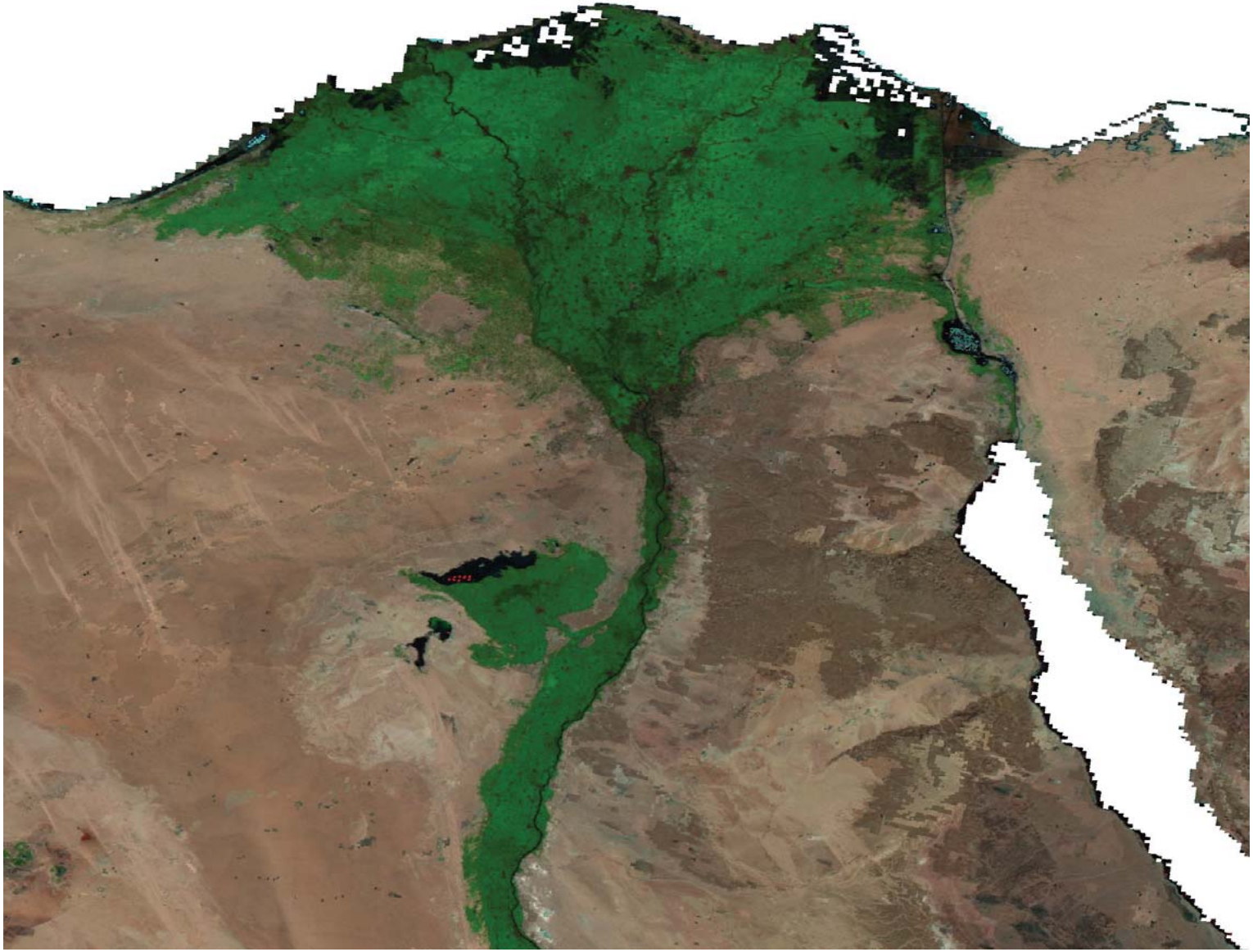
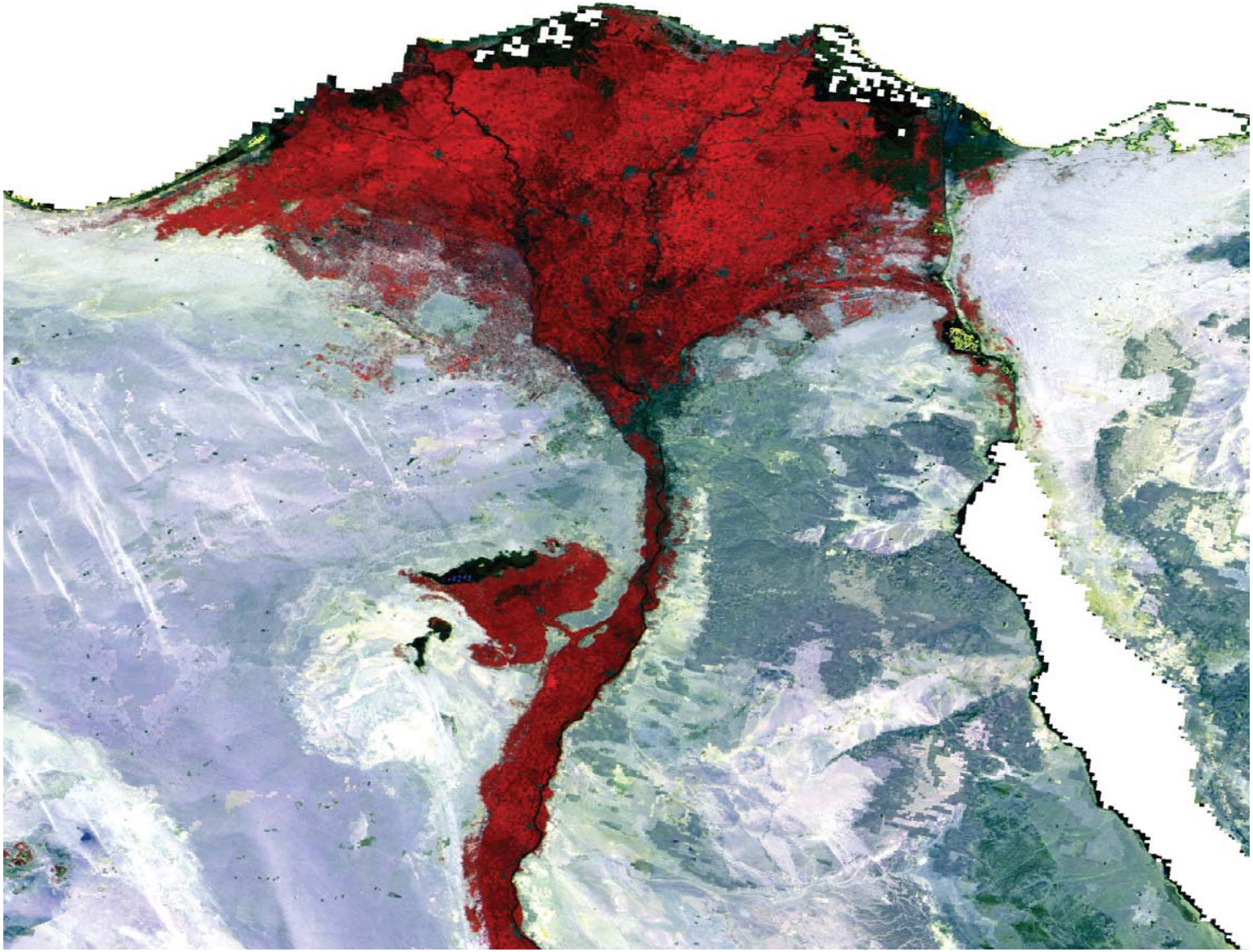
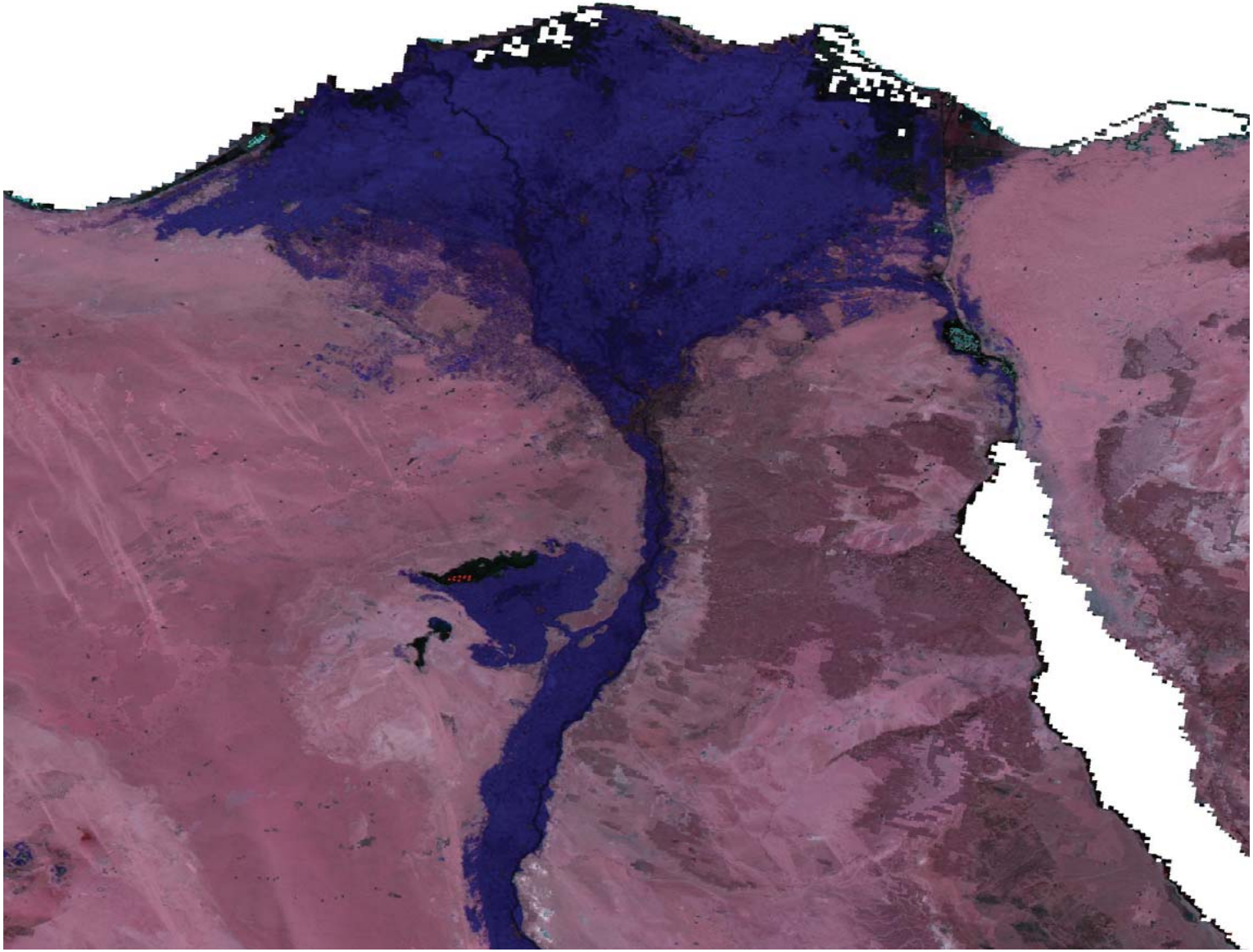


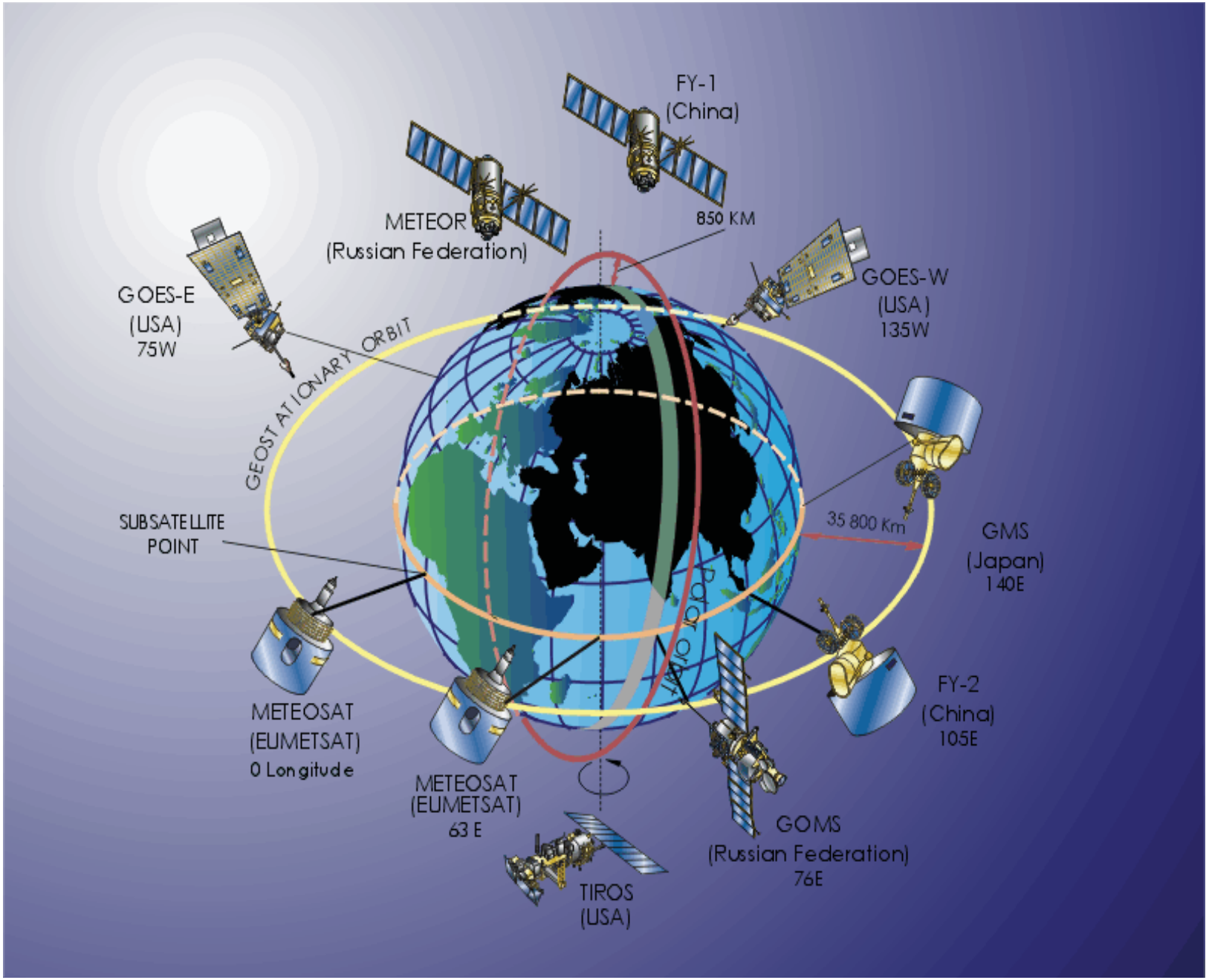




Remote

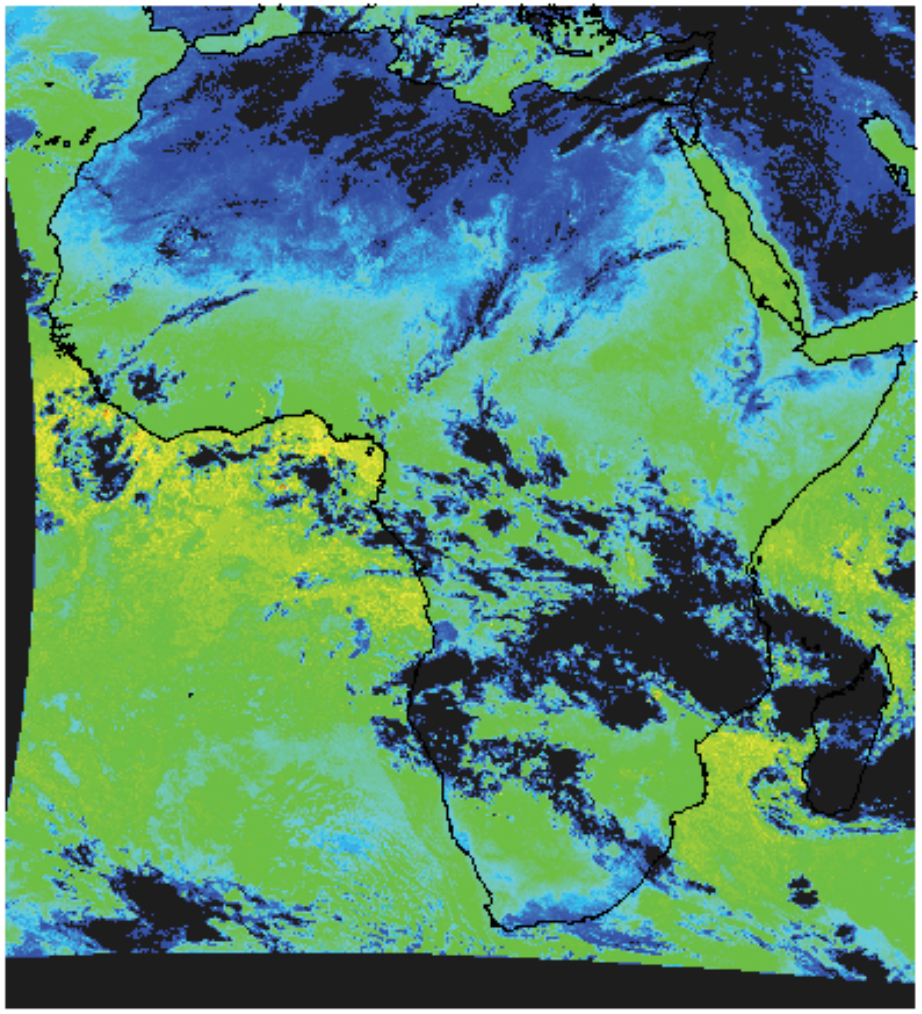
Satellites

Geostationary or Polar-Orbiting Satellites



Geostationary Satellites

- Located at about 35,800 km above the equator
- Orbit at the same speed as earth's rotation
- Repeat coverage about 15 to 30 minutes
- Cover full earth disk
- Observes events and their evolution

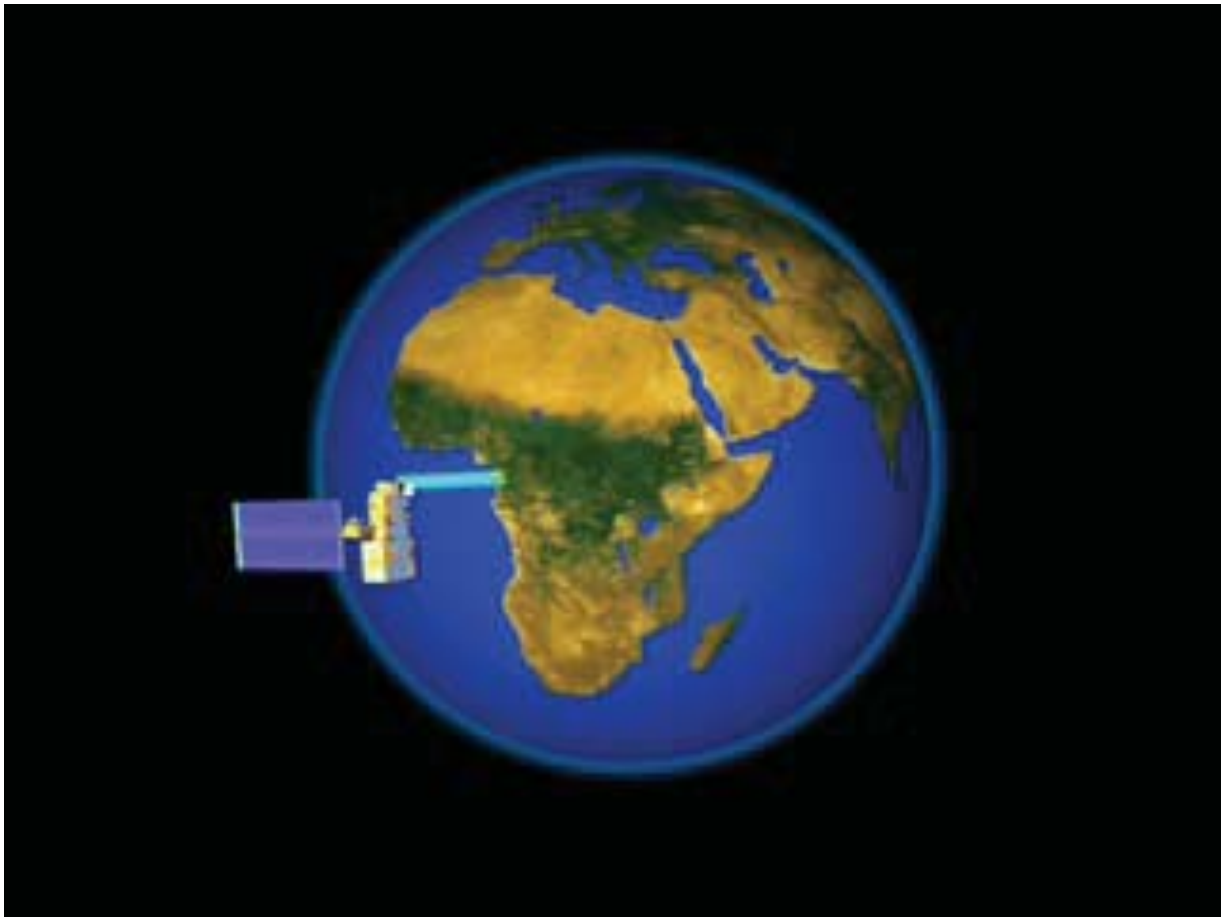


0000 1 Jan 2005

Polar-Orbiting Satellites

- 350 to 1000 km height
- Narrow spatial coverage
- Less frequent observations

http://eyes.jpl.nasa.gov/earth/



Spatial Resolution (Size of the Pixel)

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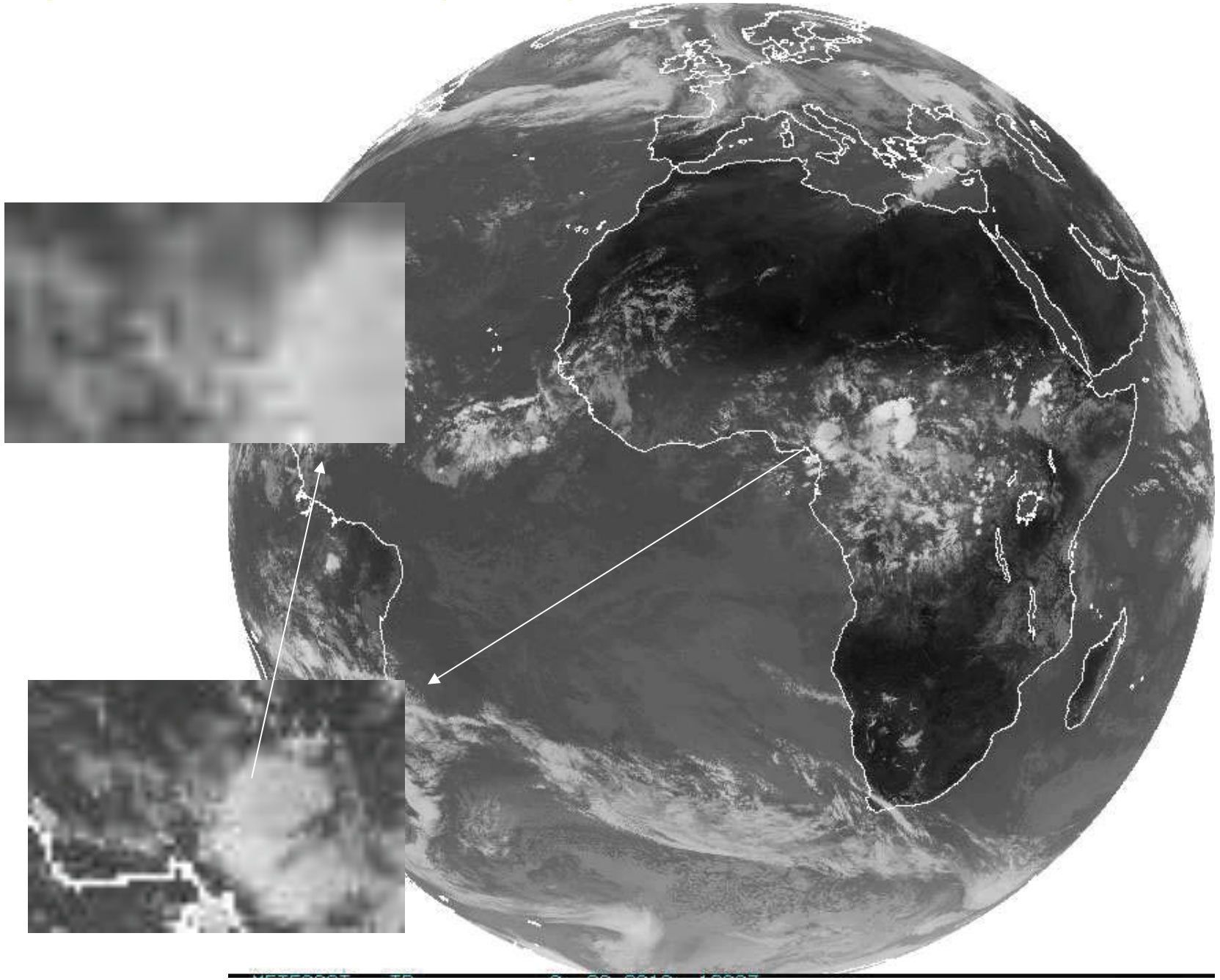
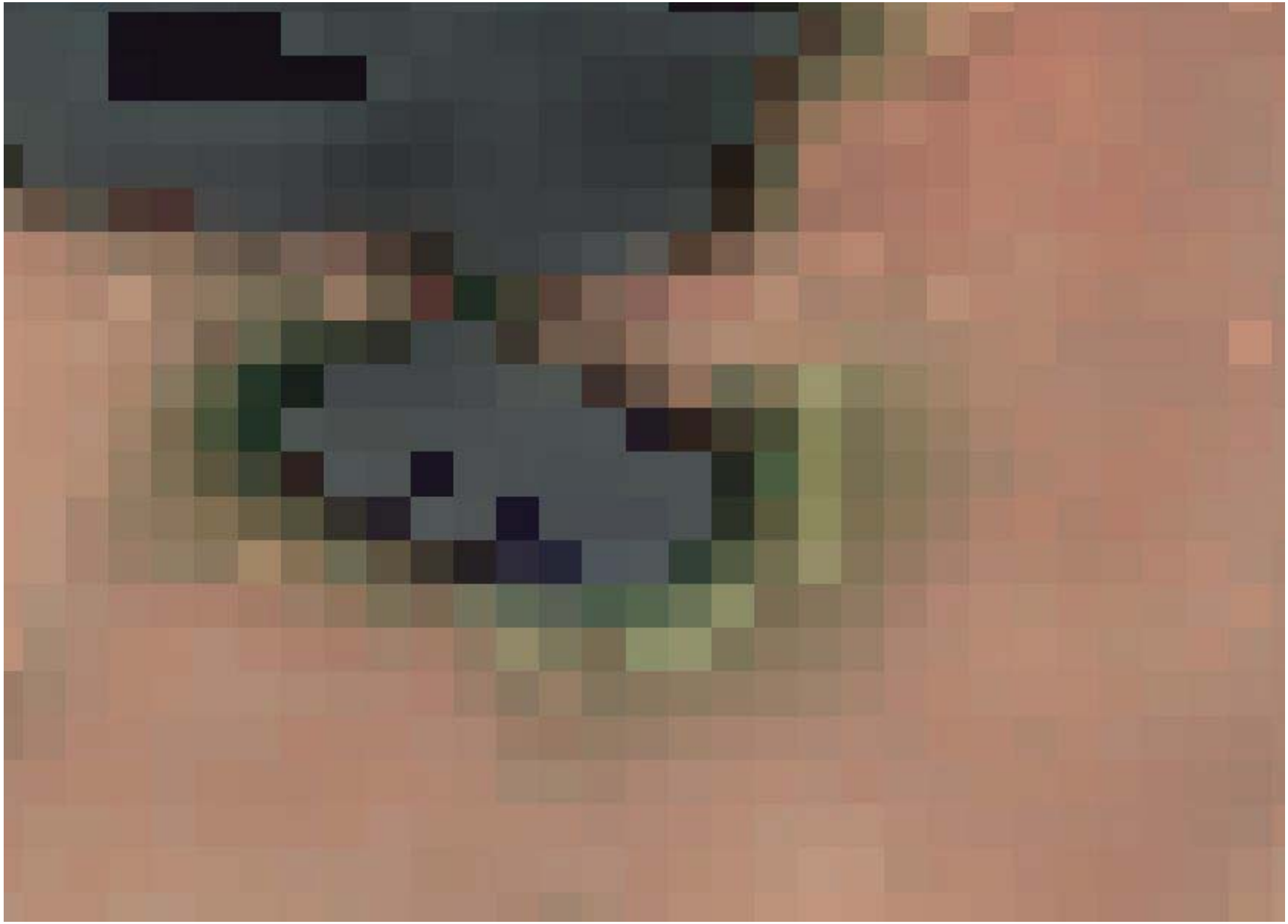
Spatial Resolution (5 Km)



Spatial Resolution (1 Km)



Spatial Resolution (30 m)

Spatial Resolution (45 cm)

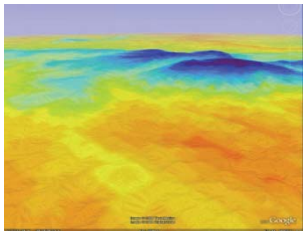
ICTP

Environmental Parameters

Precipitation

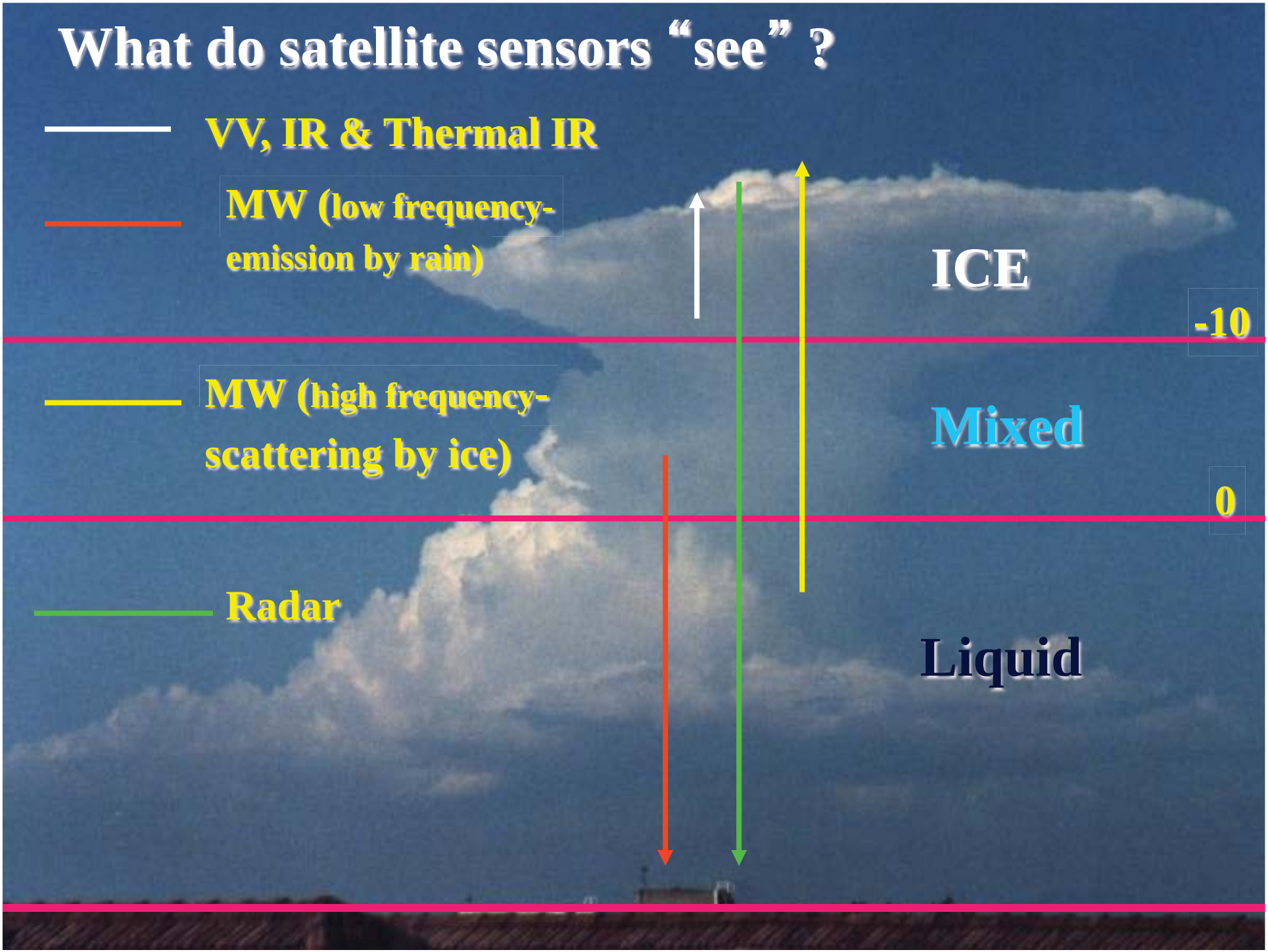
Vegetation

Temperature



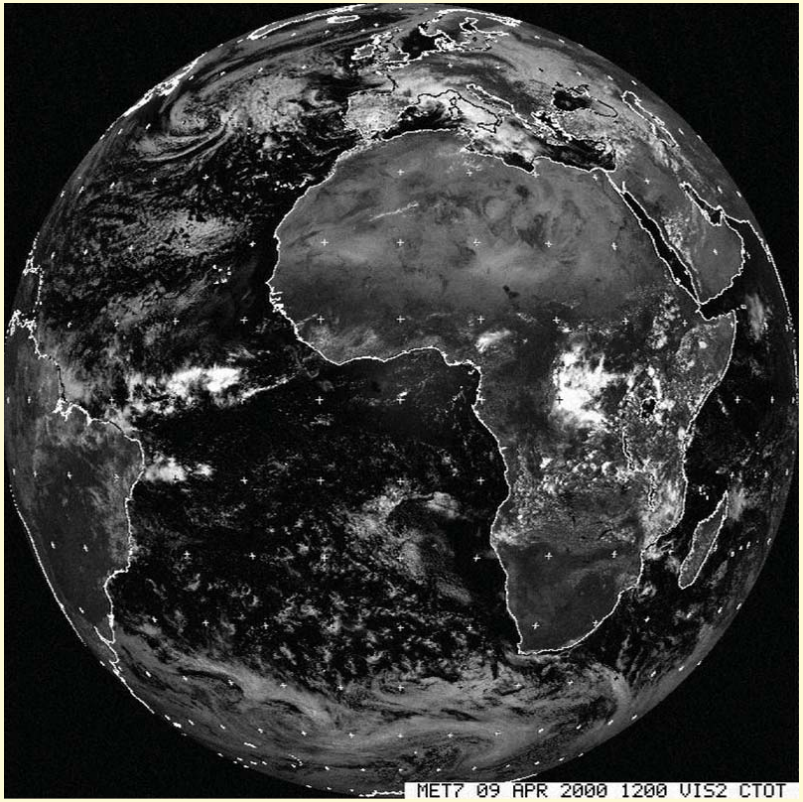
Water Bodies

Precipitation Estimation


What do satellite sensors "see" ?
VV, IR & Thermal IR
MW (low frequency-emission by rain)
MW (high frequency-scattering by ice)
Radar
ICE
-10
Mixed
0
Liquid

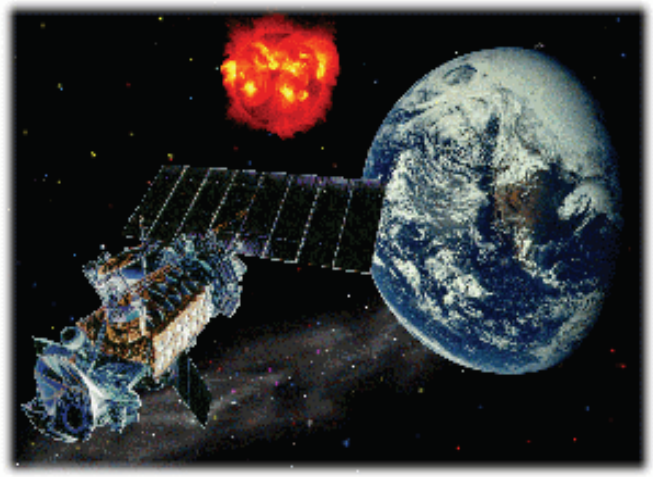
Geostationary Satellites

- Located at about 35,800 km above the equator
- Visible, NIR and Thermal Infrared
- Repeat coverage about 15 to 30 minutes
- Observes events and their evolution



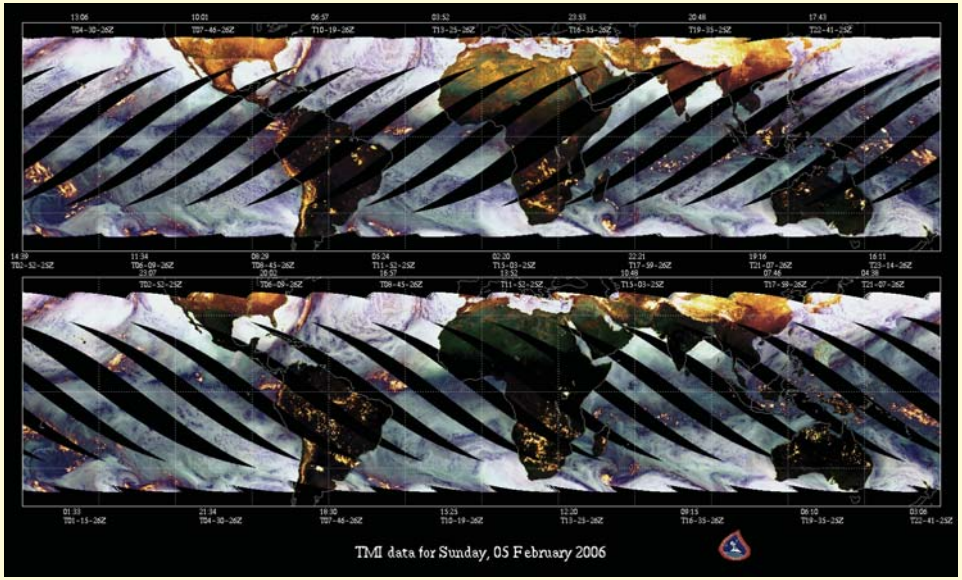
Polar-Orbiting Satellites Passive Microwave

Defense Meteorological Satellite Program (DMSP)



Special Sensor Microwave/Imager (SSM/I)

- Swath width: 1400-km
- Seven passive MW channels

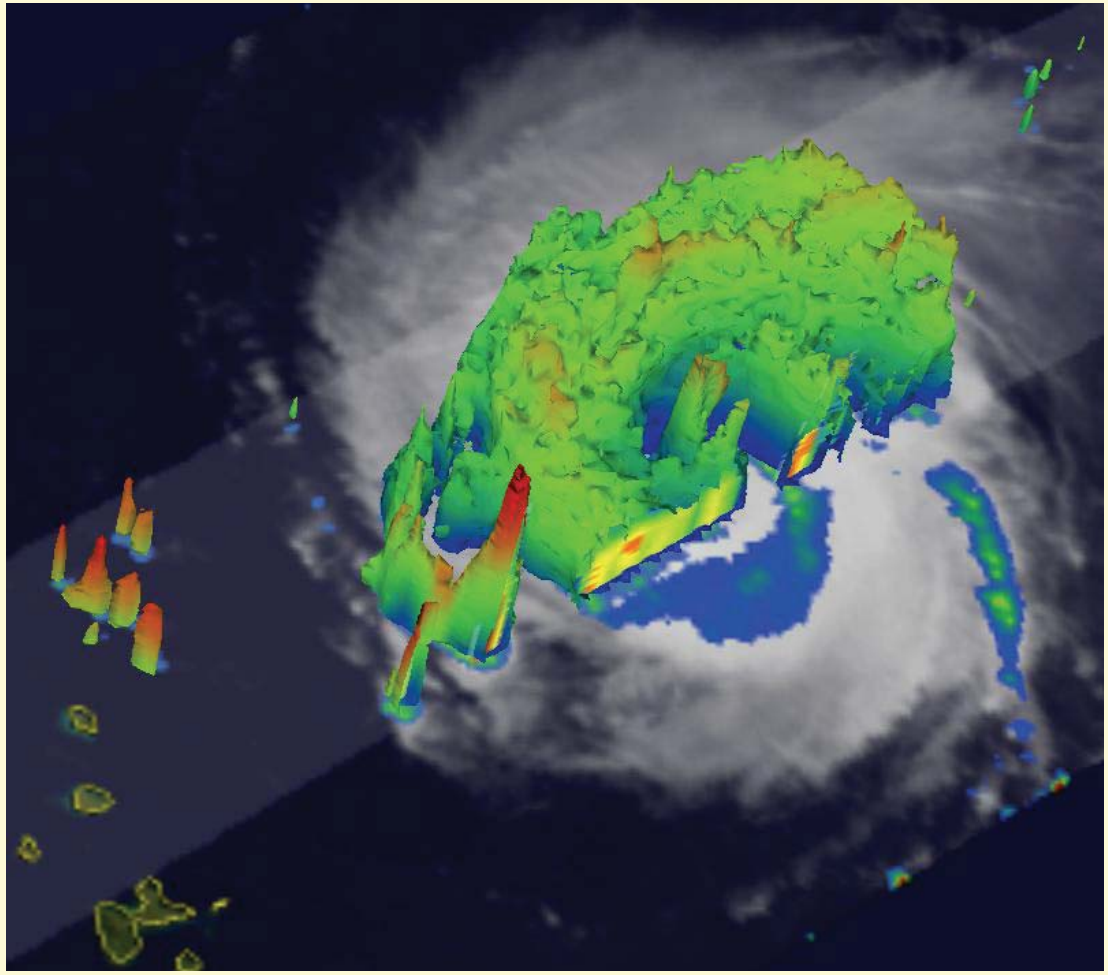


Radar and Passive Microwave on-board Satellites

Tropical Rainfall Measurement Mission (TRMM)

- **Precipitation radar (PR)**
  - **215 km Swath**
  - **250 m vertical resolution**
- **TMI**
  - **9-channel MW**
  - **760 km swath**
- **VV/IR**
- **Lightening detector**

TRMM product



Merging IR, Passive and Active Microwave

Rainfall Estimates

Combines the best features of both approaches:

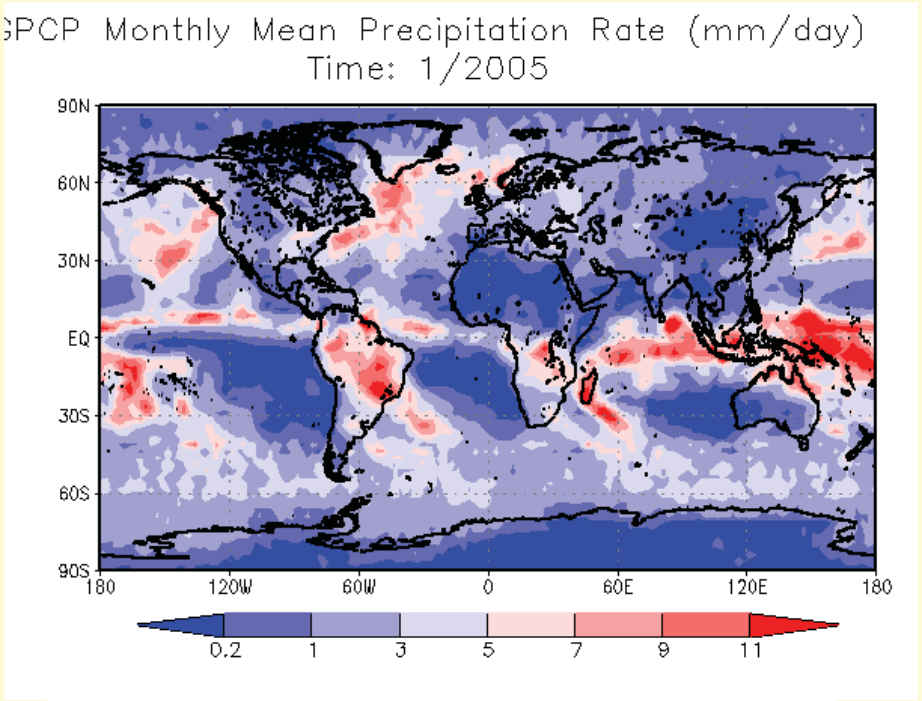
- Good *space/time resolution* of geostationary estimates
- Better *accuracy* of microwave estimates

Satellite Rainfall Estimates

Products	Time Res	Space Res	Existence	PM	Gauge
CMORPH	Daily	0.25 deg	2002-Pres	Y	N
NRL	3-hourly	0.25 deg	2003-2006	Y	N
PERSIANN	3-hourly	0.25 deg	2000-2006	Y	N
TRMM-3B42	3-hourly	0.25 deg	1998-Pres	Y	Y
TRMM-3B42RT	3-hourly	0.25 deg	2002-Pres	Y	N
CPC-RFE	Daily	0.1 deg	2001-Pres	Y	Y
CPC-ARC	Daily	0.1 deg	1995-Pres	N	Y
GPCP-1DD	Daily	1.0 deg	1996-Pres		
TAMSAT	10-daily	~0.05 deg	1996-Pres	N	N
GPCP	Monthly	2.5 deg	1979-2008	Y	Y
CMAP	Monthly	2.5 deg	1979-2010	Y	Y
TRMM-3B43	Monthly	2.5 deg	1998-Pres	Y	Y

Global Precipitation Climatology Project (GPCP)

- **Merged satellites with gauge**
- **2.5° spatial resolution**
- **monthly rain rate**
- **Also 1-degree daily(1DD)**
- **1979-2009 (monthly)**
- **1997-2009 (1DD)**

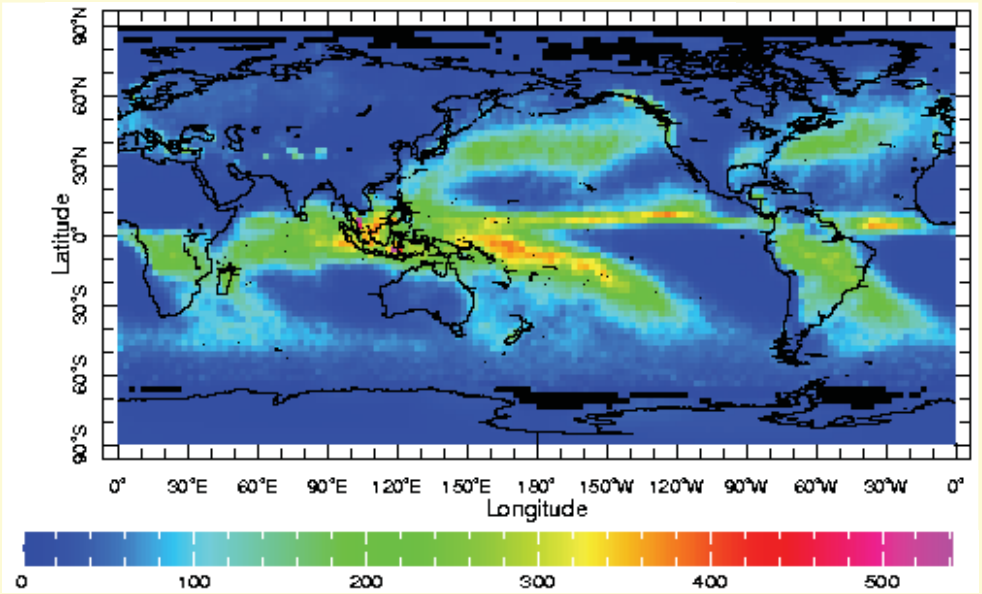


http://cics.umd.edu/~yin/GPCP/main.html

CPC-Merged Analysis of Precipitation (CMAP)

- **Merged satellites, numerical model predictions and gauge observations**
- **2.5° spatial resolution**
- **monthly total rain**
- **Also 5-day total**
- **1979-2011**

CMAP December Climatology(1979-2005)

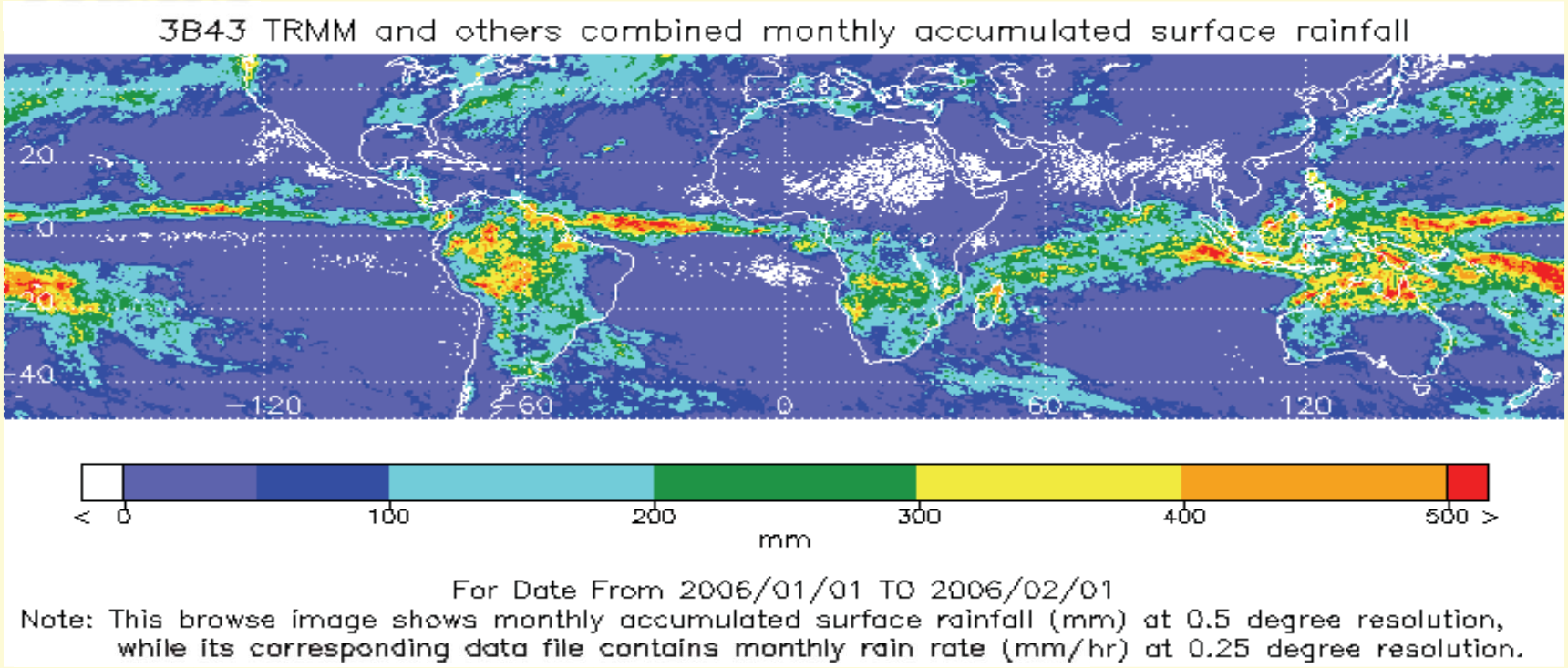


From IRI data library

http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCEP/.CPC/.Merged_Analysis/.monthly/.latest/.ver2/.prcp_est/

Satellite Products

TRMM



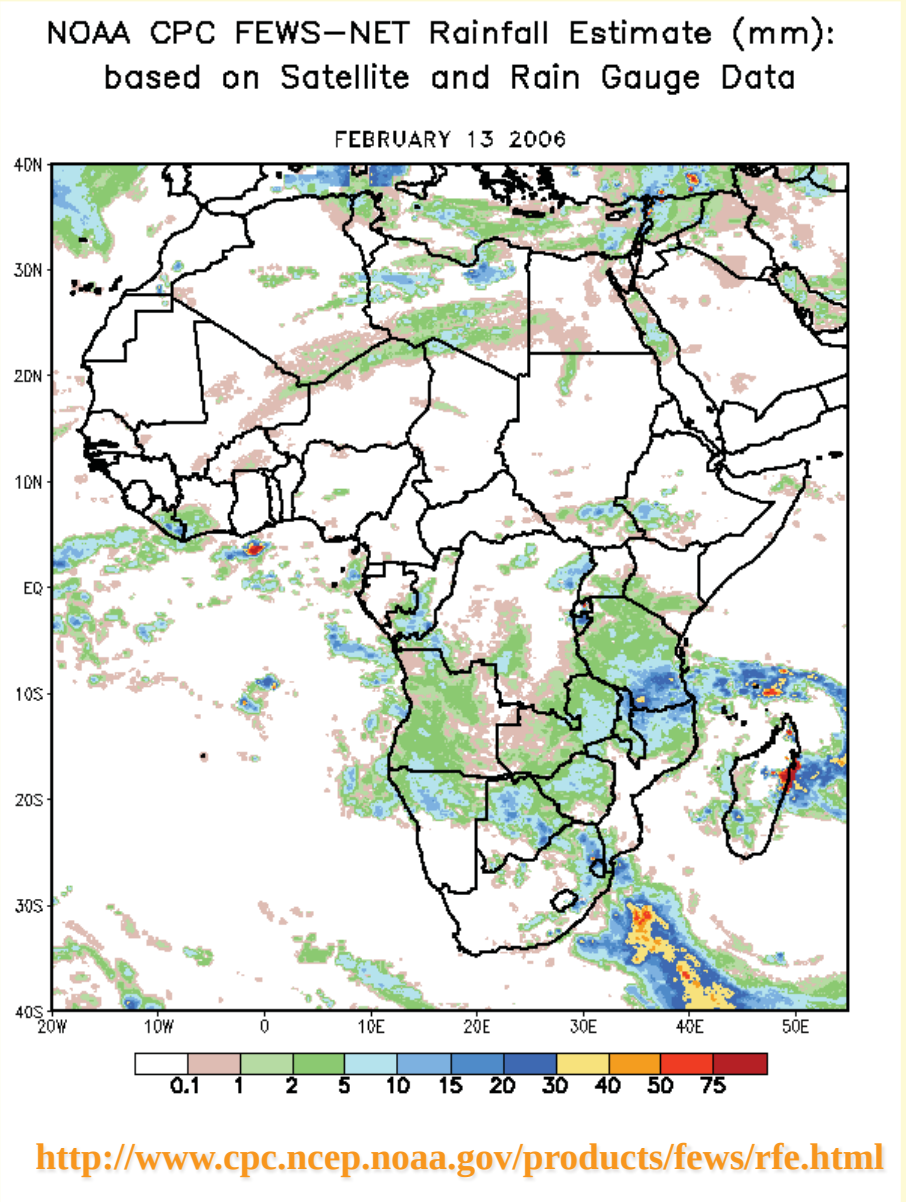
- **Active and passive microwave instruments**
- **0.25° spatial resolution**
- **monthly total rain**
- **Also 3-hourly**
- **1998-current**

http://disc.sci.gsfc.nasa.gov/data/datapool/TRMM/01_Data_Products/02_Gridded/07_Monthly_Other_Data_Source_3B_43/index.html

Satellite Products

RFE

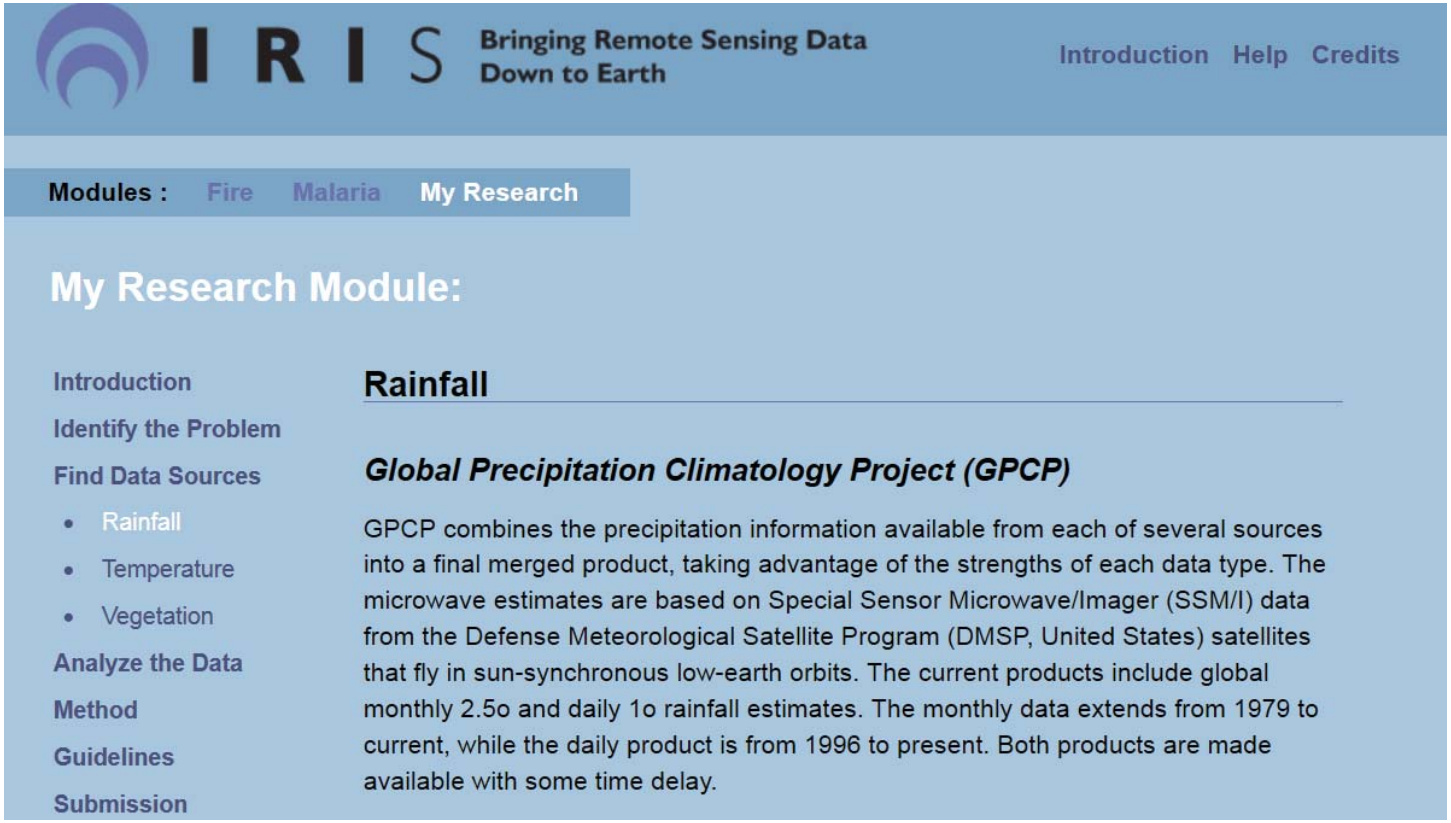
- **Merged satellites and gauge**
- **0.1° (11 km) spatial resolution**
- **Daily total rainfall**
- **RFE1: 1995-2000**
- **RFE2: 2002-current**



http://www.cpc.ncep.noaa.gov/products/fews/rfe.html

Rainfall Products available on IRIS Web Site

http://iris.ccnmtl.columbia.edu/myresearch/rainfall_2.html



Validation of Rainfall Products

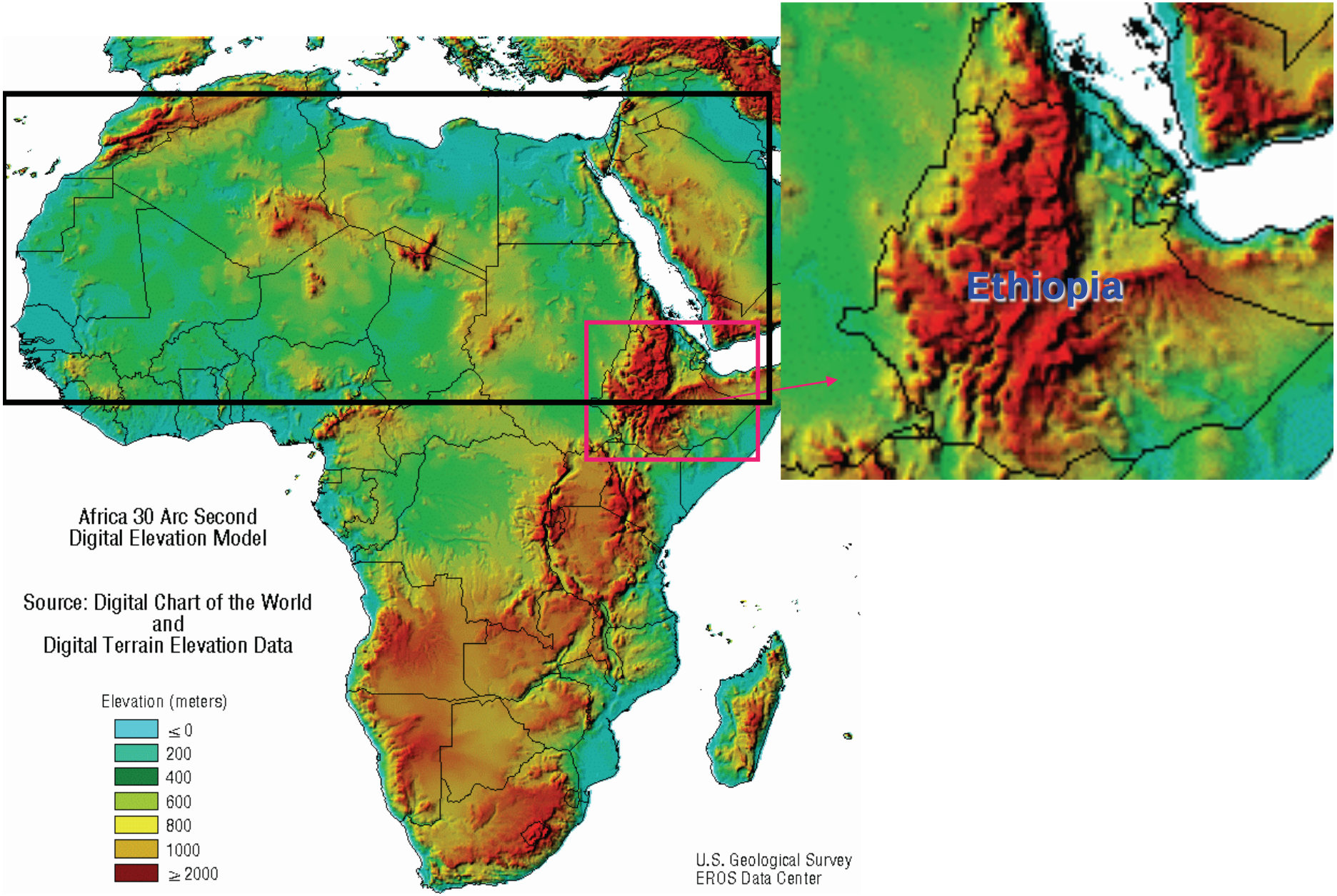
Validation:

Comparing Rainfall Estimates

with

Rain Gauge Data

Validation of Rainfall Products

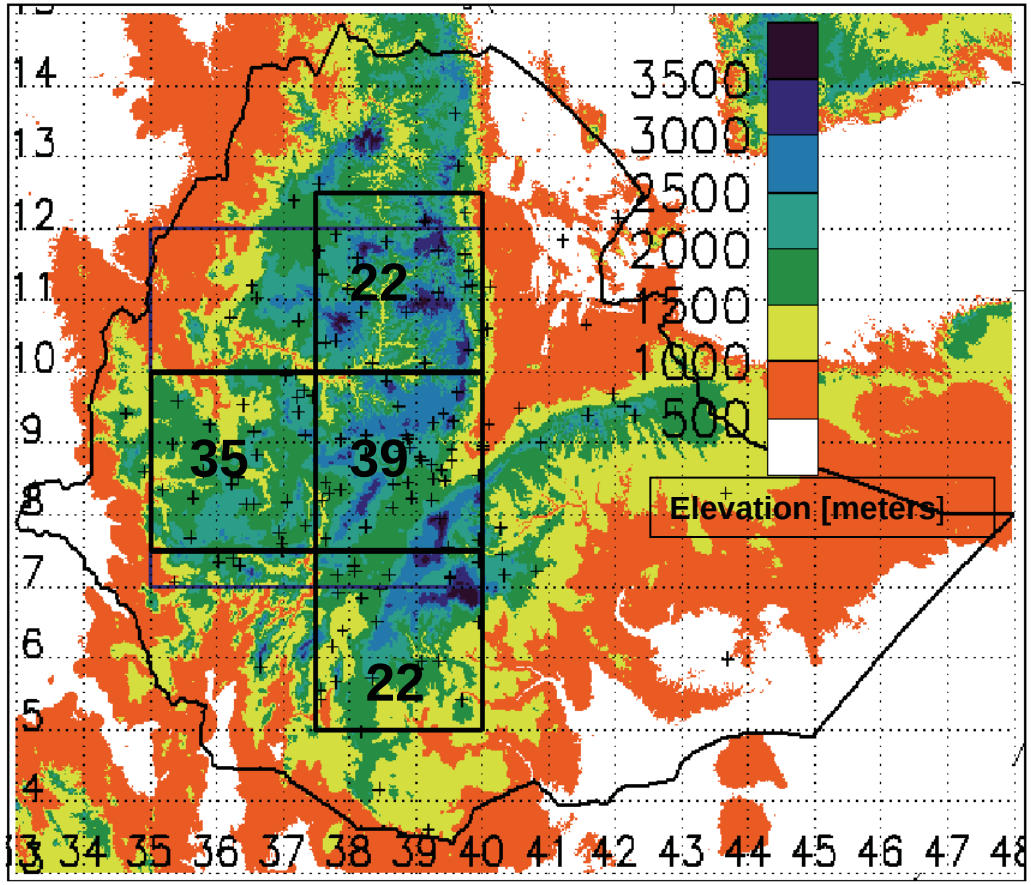


Validation of Rainfall Products

- 120 Stations used

- Gauge data gridded using Climate Aided Interpolation

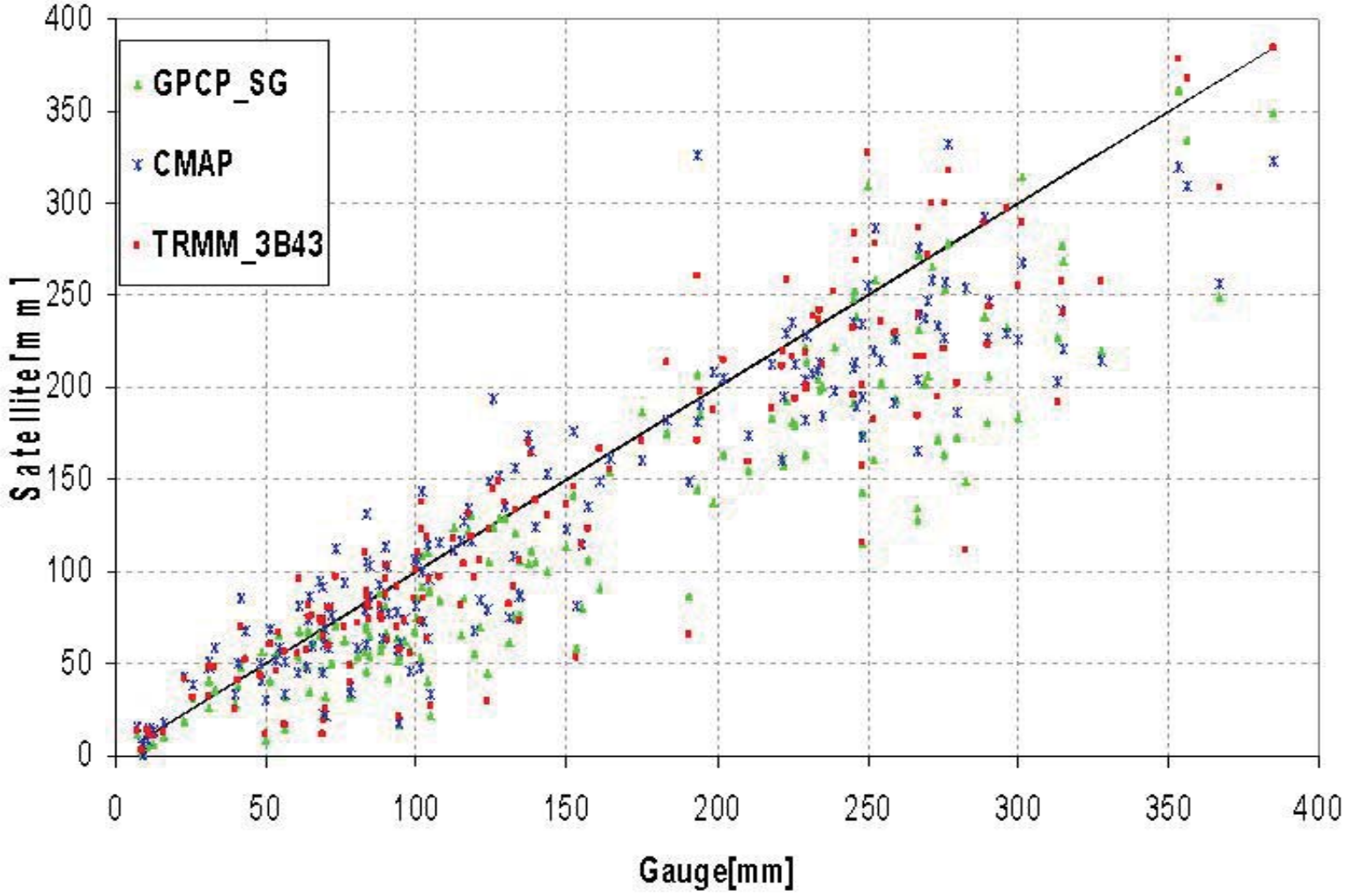
  - Kriging for interpolating the means



Topography and distribution of gauges. The four 2.5 degree boxes are used for at 2.5 degree resolution, and the number of gauges in each box is given. Stations in the larger box is used for validation at 1-degree resolution.

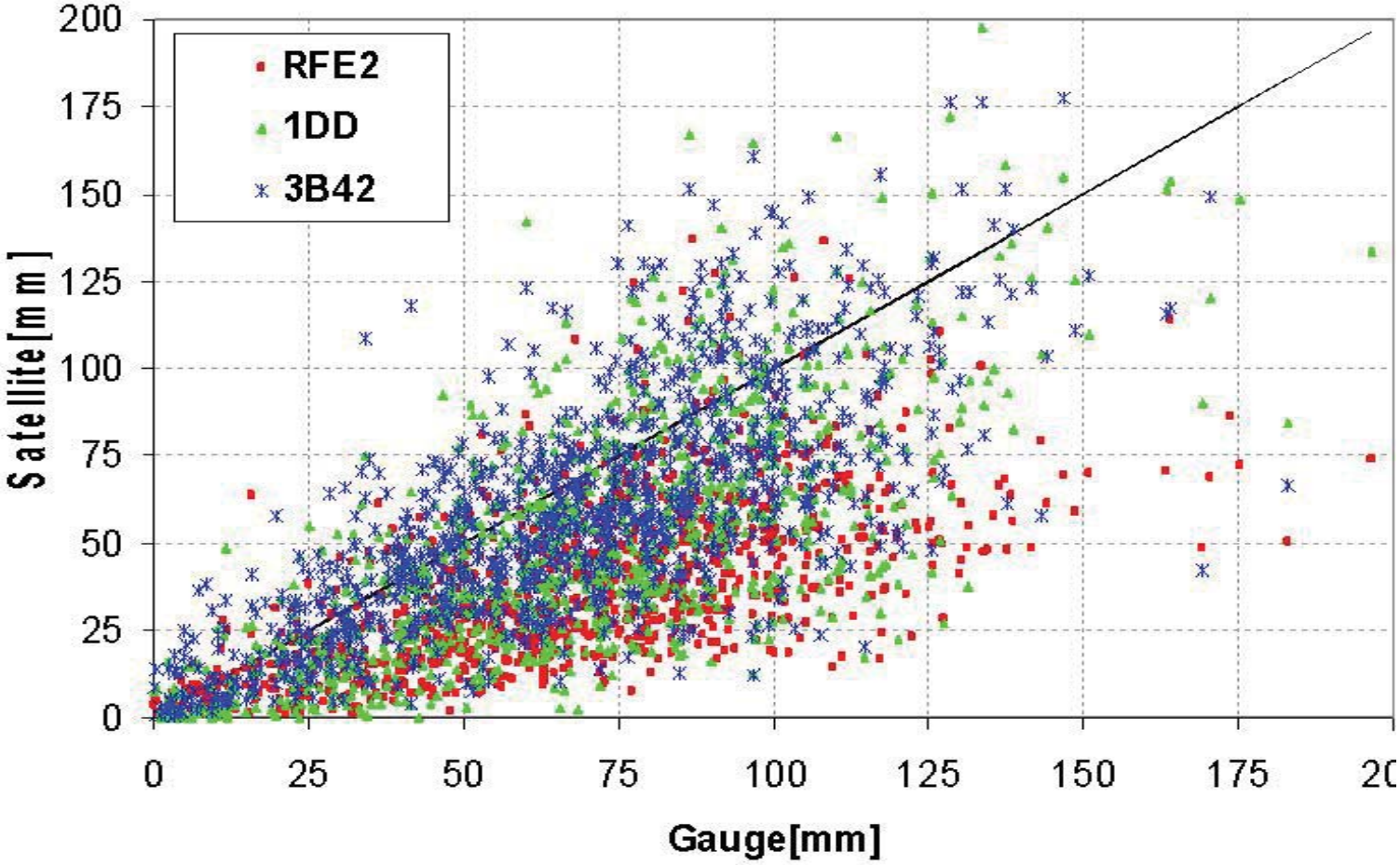
Validation of Rainfall Products

Monthly at 2.5-degree



Validation of Rainfall Products

10-day total at 1º x 1º



Comparison of CPC-RFE2, GPCP-1DD & TRMM-3B42

Validation of Rainfall Products

The following statistics were used to evaluate the accuracy of the rainfall estimate products to retrieve rainfall: coefficient of determination (R^2), mean error (ME), standard deviation (Stdv), root mean square error (RMSE), mean absolute error (MAE), and bias.

$$ME = \frac{1}{N}\sum(G-R)$$

$$RMSE = \sqrt{\frac{\sum(G-R)^2}{N}}$$

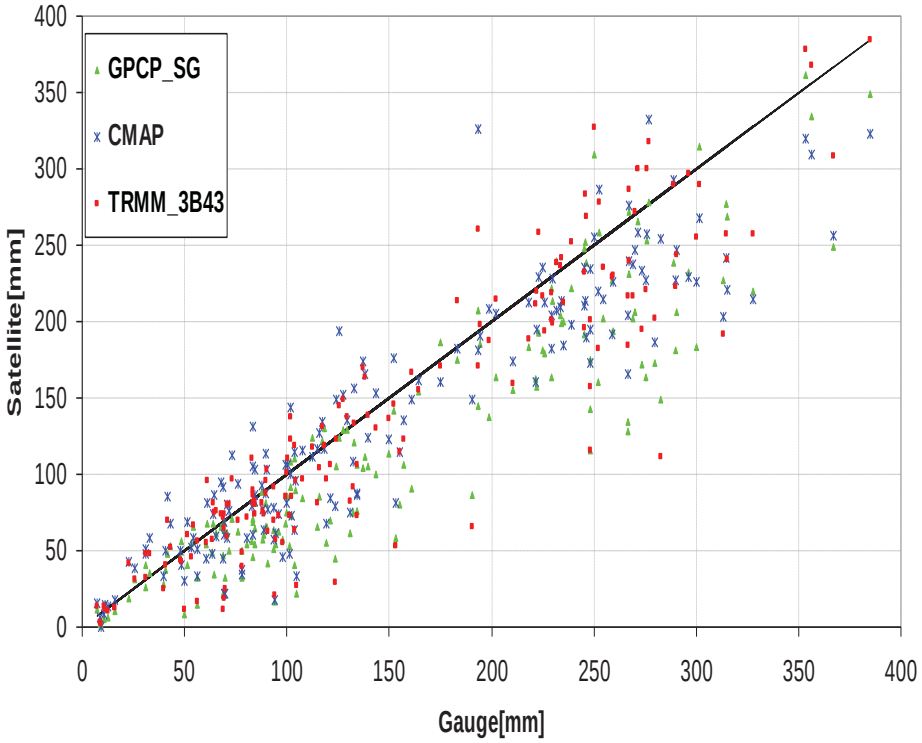
$$MAE = \frac{1}{N}\sum|(G-R)|$$

$$Bias = \frac{\sum G}{\sum R}$$

Where R = reference rain gauge observation, G = rainfall estimate product, and N = number of data pairs. ME and MAE are in mm while R^2, Stdv, RMSE and Bias are unit-less.

Validation of Rainfall Products

Monthly at 2.5-degree

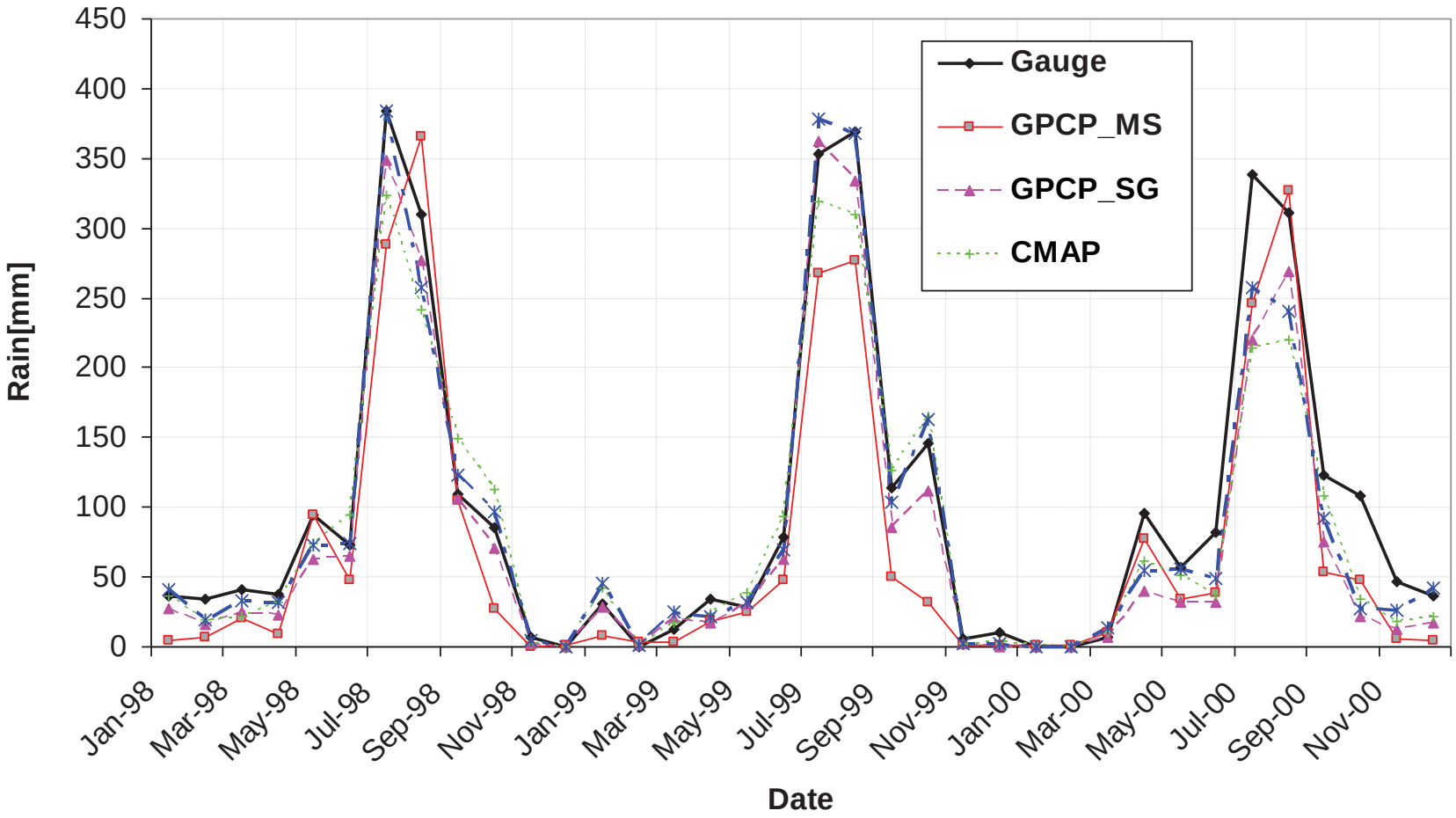


N = 360	GPCP	CMAP	3B43
CC	0.92	0.92	0.92
Bias	0.80	0.91	0.92
ME	-30	-12	-12

Data: 1998-2004

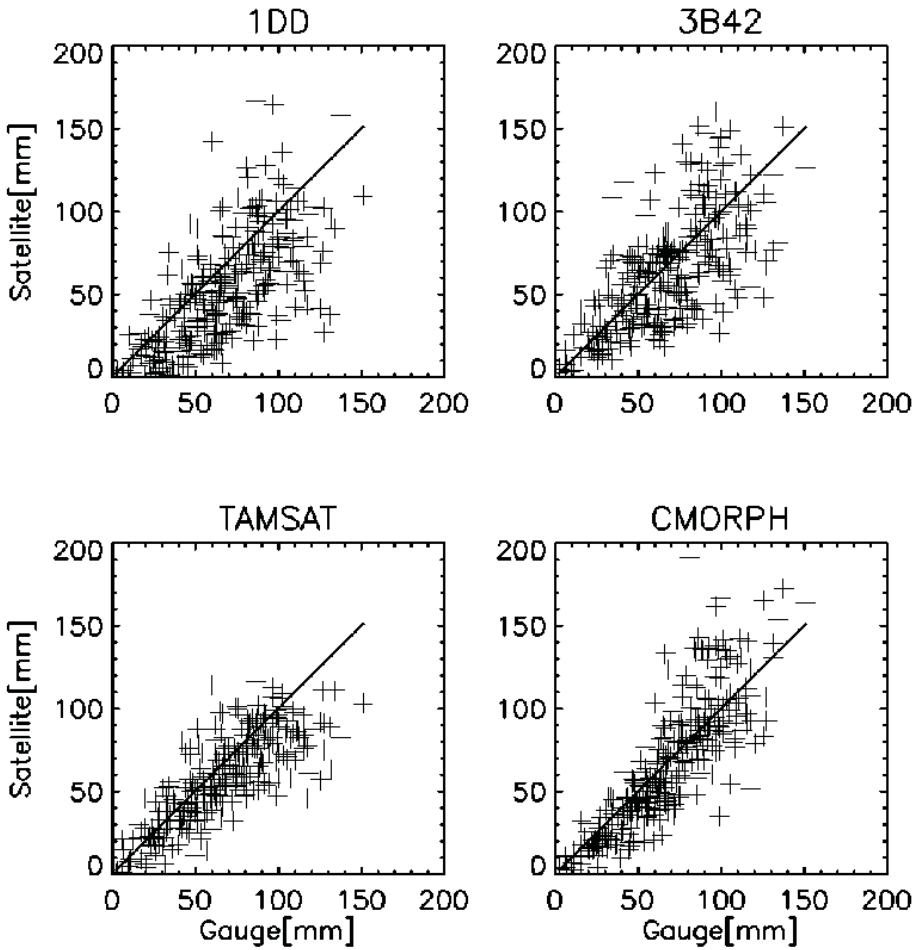
Validation of Rainfall Products

Monthly at 2.5-degree



Validation of Rainfall Products

10 Days at 1ºx1º



10-day @ 1º x 1º

N=306	1DD	3B42	TAMSAT	C M O RPH
CC	**0.68**	**0.68**	**0.79**	**0.83**
Bias	**0.77**	**0.94**	**0.86**	**0.98**
ME	**-16**	**-4**	**-9**	**-1**

Validation of Rainfall Products

Daily @ 0.25-deg	RFE	PERS	NRL	3B42	3B42RT	CMORPH
CC	0.26	0.40	0.36	0.39	0.37	0.32
Bias	0.60	1.54	0.85	0.84	0.83	0.91

10-Daily @ 1 deg	RFE	1DD	3B42T	3B42	TAMSAT	CMORPH
CC	0.66	0.71	0.72	0.72	0.79	0.83
Bias	0.55	0.72	0.95	0.87	0.93	0.98

Monthly @ 2.5-deg	GPCP	CMAP	3B43
CC	0.92	0.92	0.92
Bias	0.80	0.91	0.92

Improving Rainfall Estimates

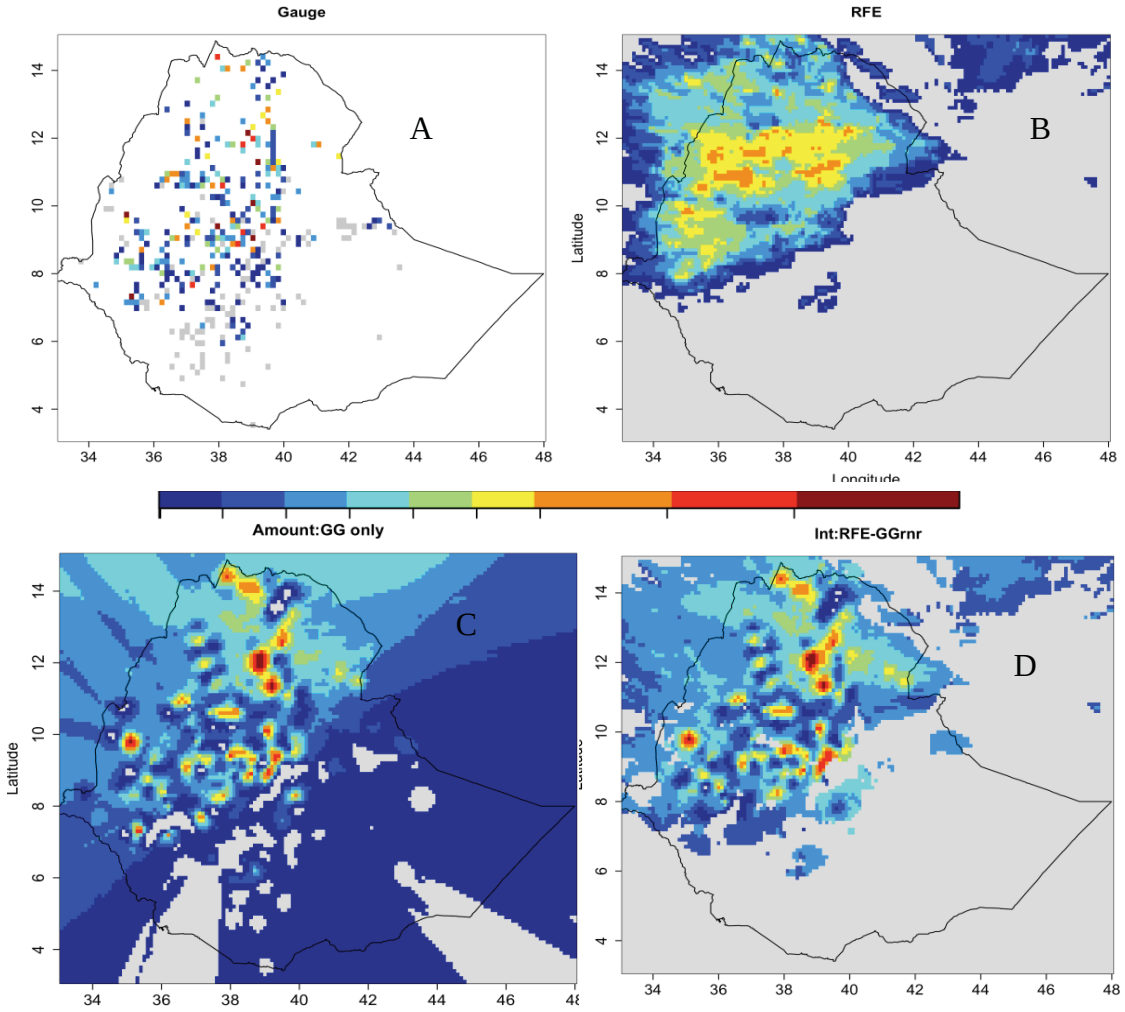
Calibration:

Integrating Rainfall Gauges

within

Rainfall Estimates Derived from Satellites

Improving Rainfall Estimates



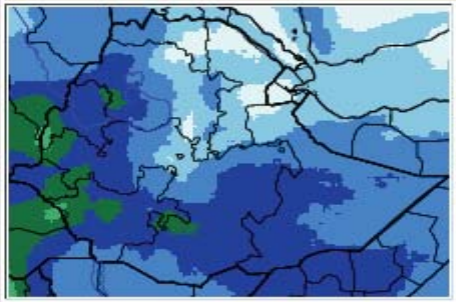
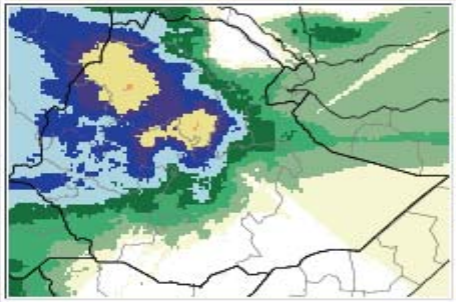
Comparison of rain gauge data (A), satellite estimates (B), gauge-only gridded products(C), and combined gauge-satellite product (D), over Ethiopia for 7 July 2003. All products have spatial resolution of 0.1º lat/long

Ethiopian Meteorology Agency

NMA ብሔራዊ ሚቲዎሮሎጂ ኤጀንሲ NATIONAL METEOROLOGY AGENCY

Climate Analyses and Applications Map Room

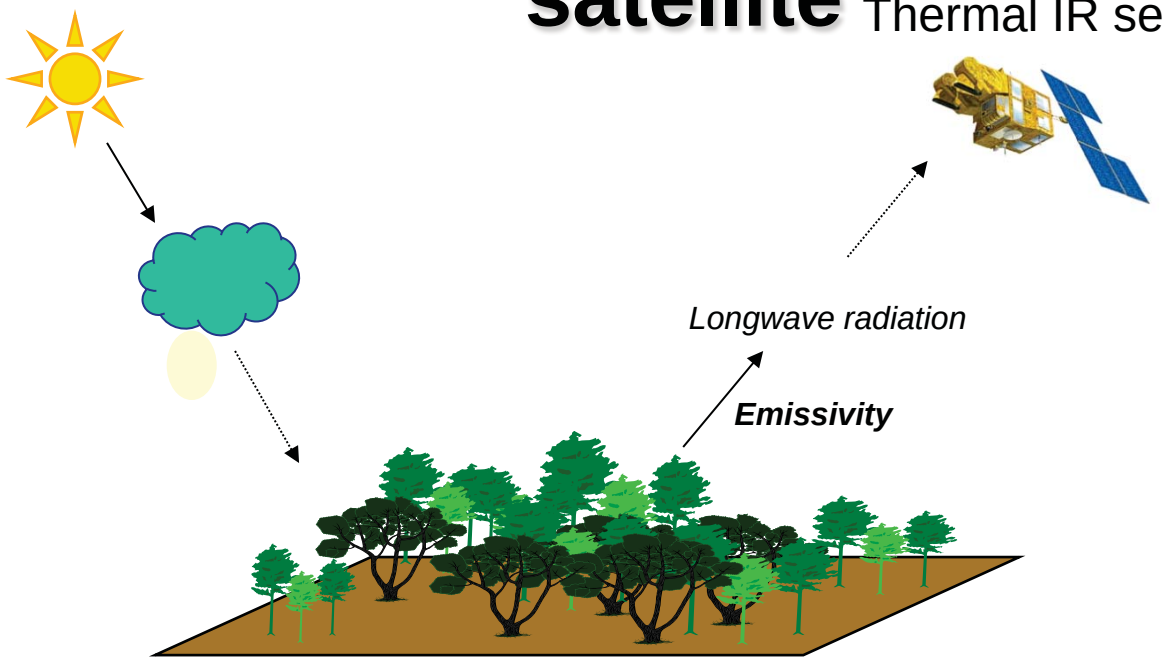
http://www.ethiomet.gov.et/

Climate Analysis	
	Rainfall and temperature time series (1983-2010) reconstructed from station observations and remote sensing proxies. This interface allows users to view rainfall, maximum and minimum temperature climatologies and anomalies.
Climate Monitoring	
	This is a rainfall-monitoring product based on dekadal rainfall. The interface allows users to view recent rainfall with a seasonal and recent historical perspective. Time series analyses of rainfall data are generated based on user-selected parameters.

IRI

Temperature

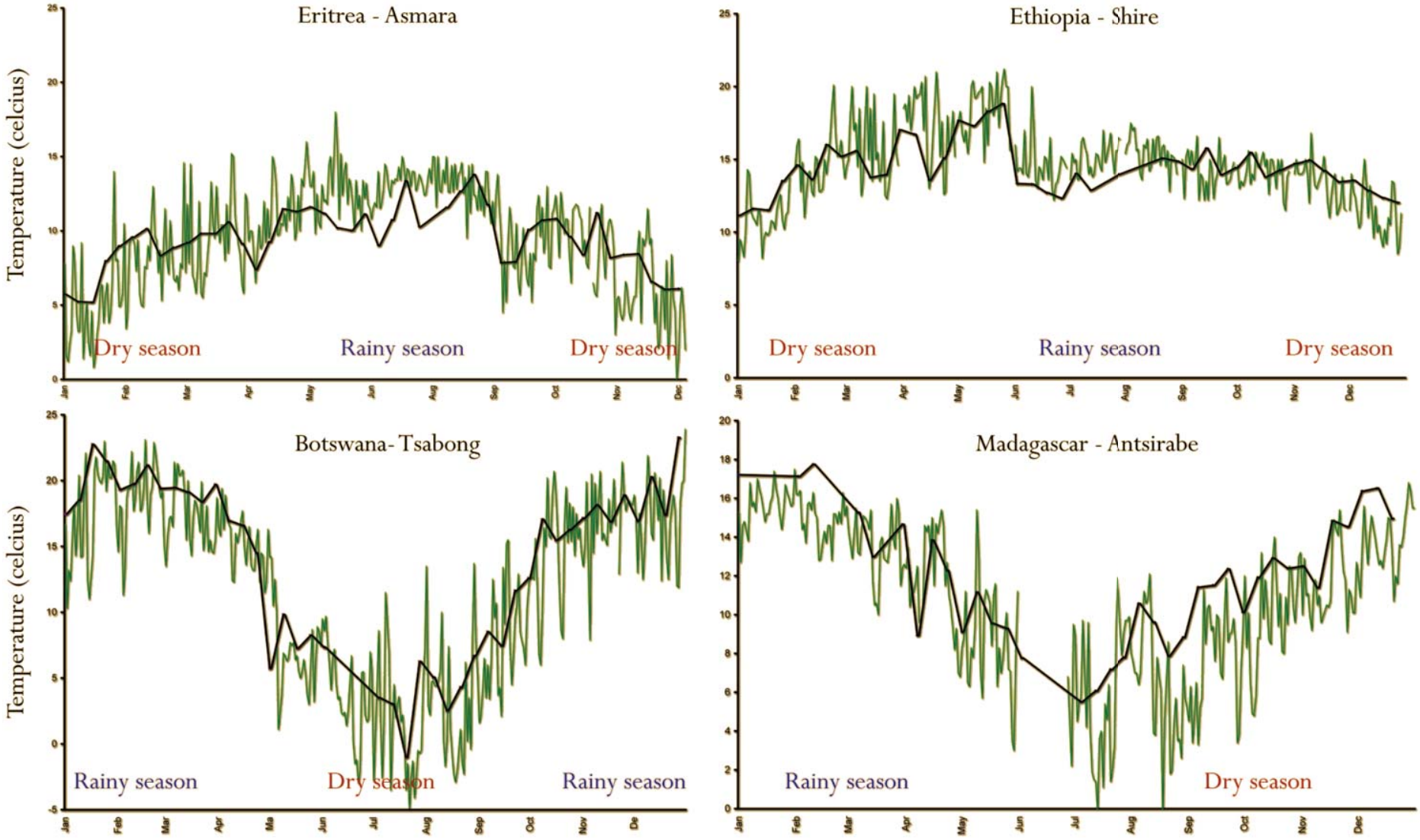
Land surface temperature retrieval from satellite Thermal IR sensors



Land surface (skin) temperature (LST) retrieval from thermal infrared sensors on board geostationary or polar orbiting satellites

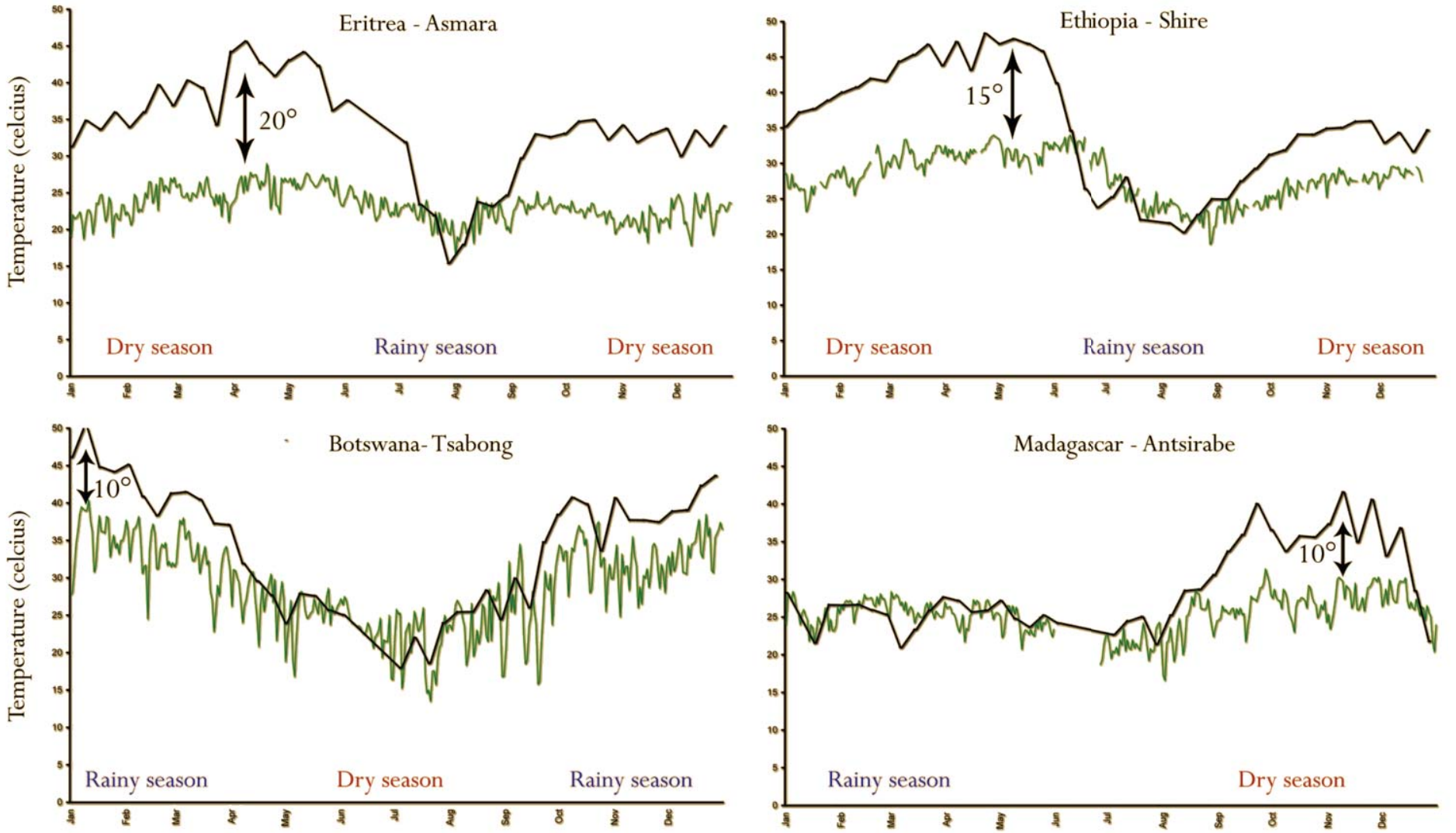
Air Temperature

Comparison between MODIS Night LST and min air T



Air Temperature

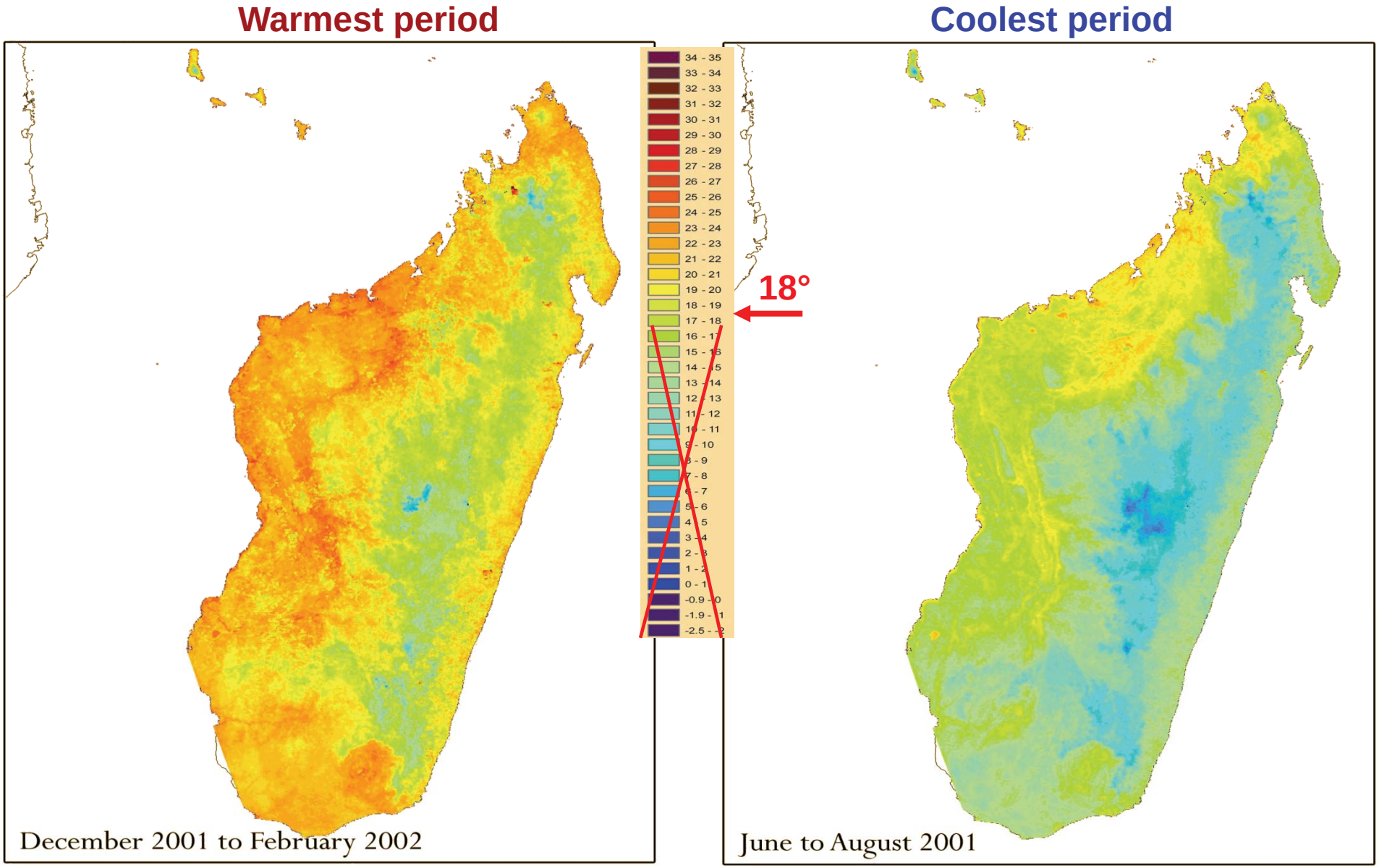
Comparison between MODIS Day LST and max air T



Profiles over the year 2001 of the land surface temperature (black line) in comparison with the minimum air temperature measured at station (green line) in 4 countri

Air Temperature

Minimum Air Temperature maps from MODIS Land Surface Temperature at night



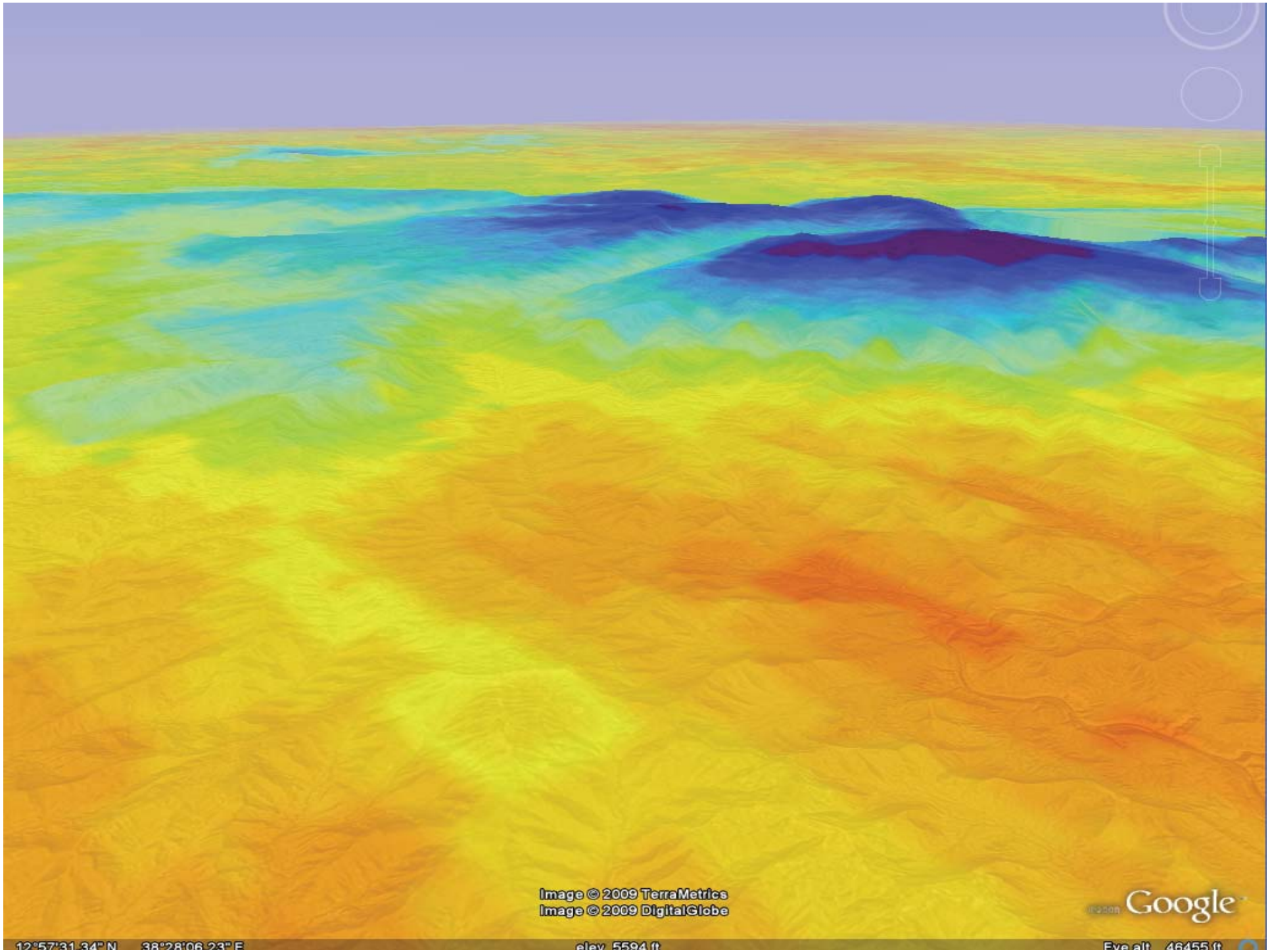
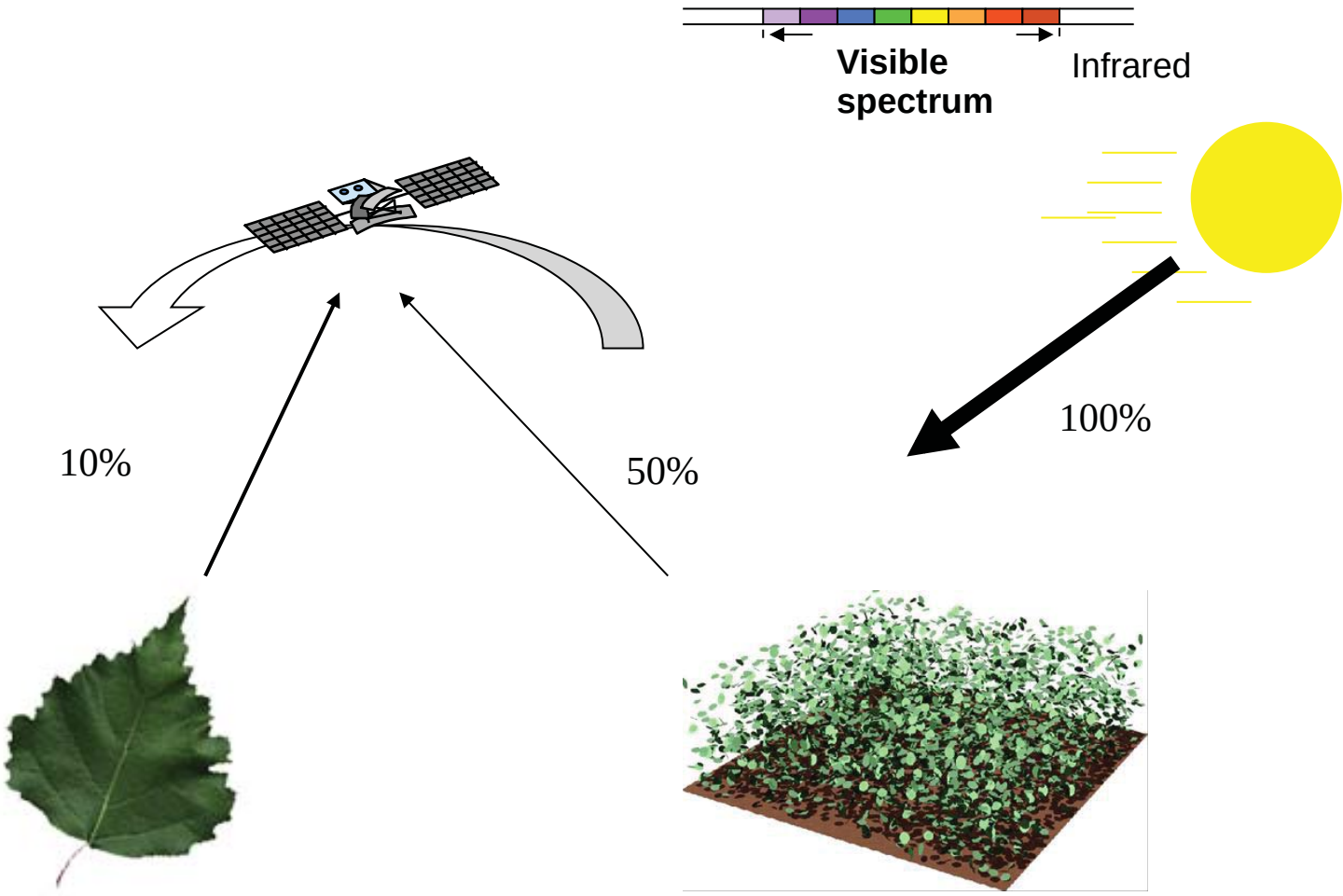


Image © 2009 TerraMetrics
Image © 2009 DigitalGlobe
Google
12°57'31.34" N 38°28'06.23" E
elev 5594 ft
Eye alt 46455 ft

Vegetation

Vegetation



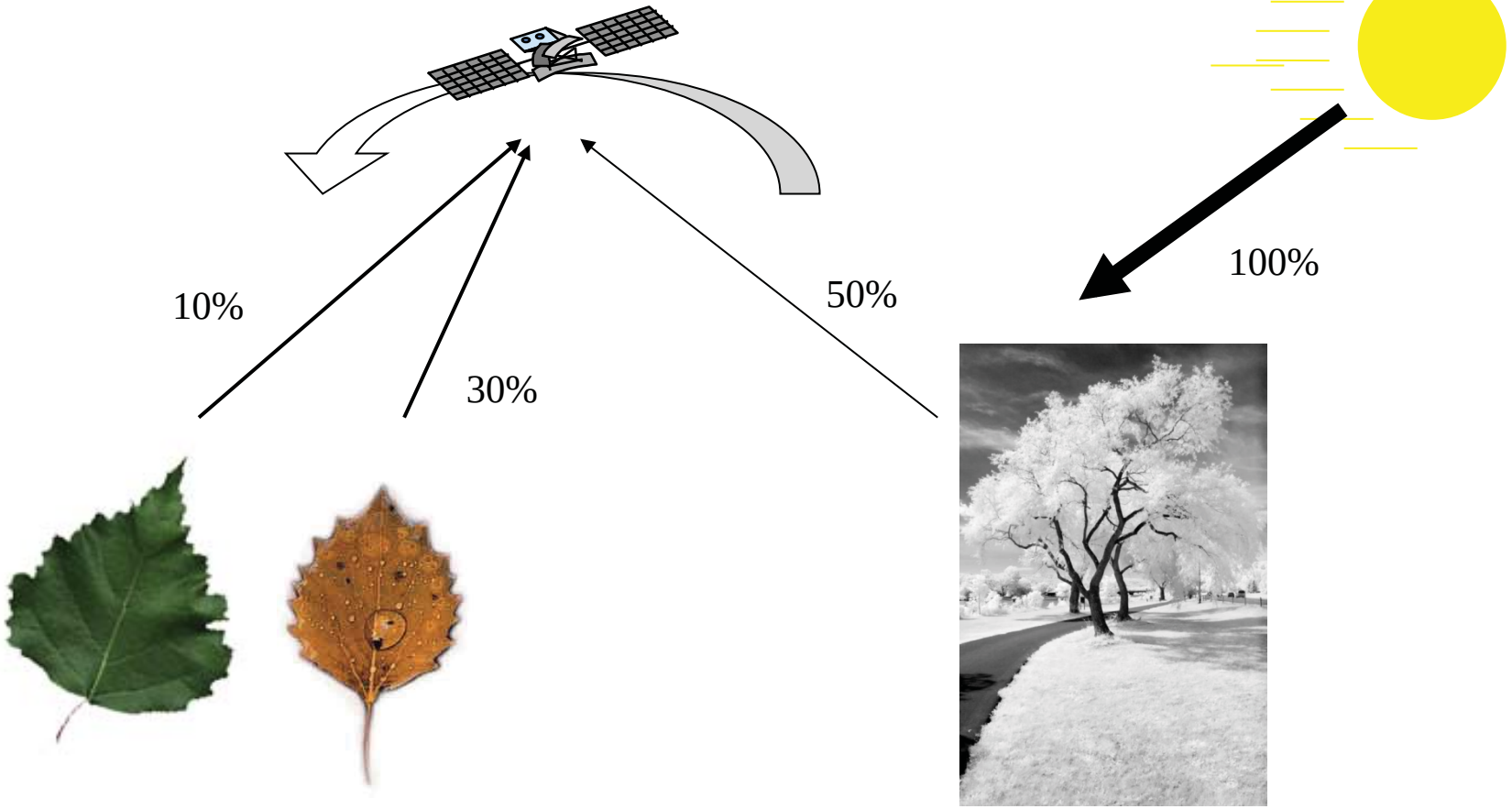
Chlorophyll absorption

Multiple-scattering at leaf level

Red Channel

Near Infrared Channel

Vegetation



Chlorophyll absorption

Multiple-scattering at leaf level

Red Channel

Near Infrared Channel

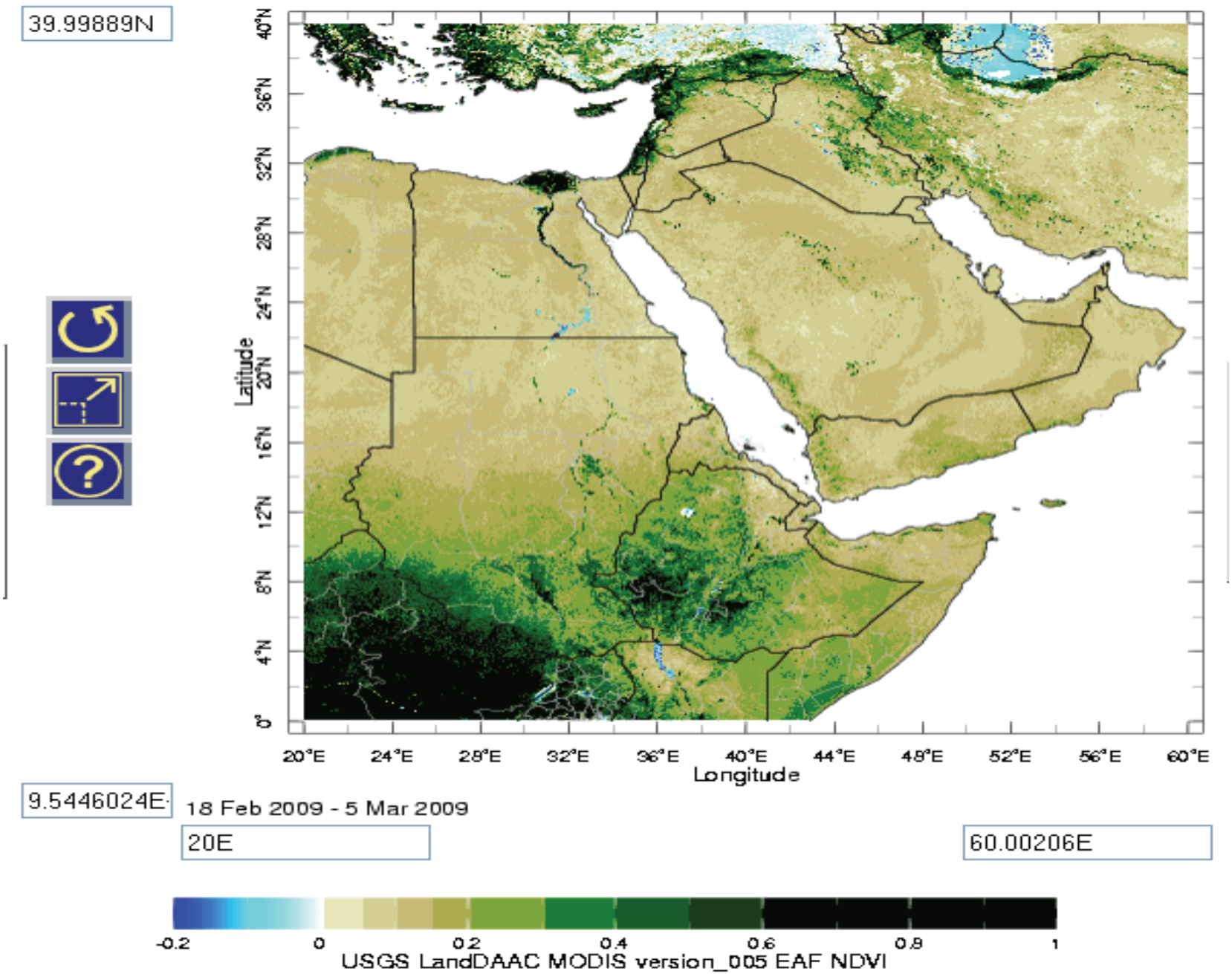
Vegetation Index: NDVI

- In the Red channel:
  Low reflectance values = Strong chlorophyll absorption = green vegetation

- In the NIR channel:
  High reflectance values = High quantity of biomass

- **Normalised Difference Vegetation Index**
  NDVI= (NIR-Red)/(NIR+Red)

Vegetation

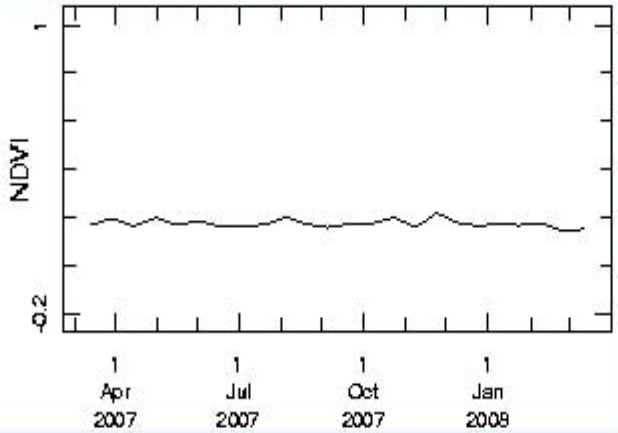

39.99889N
40°N
36°N
32°N
28°N
24°N
20°N
16°N
12°N
8°N
4°N
0°
Latitude
20°E
24°E
28°E
32°E
36°E
40°E
44°E
48°E
52°E
56°E
60°E
Longitude
9.5446024E
18 Feb 2009 - 5 Mar 2009
20E
60.00206E
-0.2
0
0.2
0.4
0.6
0.8
1
USGS LandDAAC MODIS version_005 EAF NDVI

Observations for:
38E, 3.3N
~ 11x11 km

11km | 37.96357E | 3.32904N

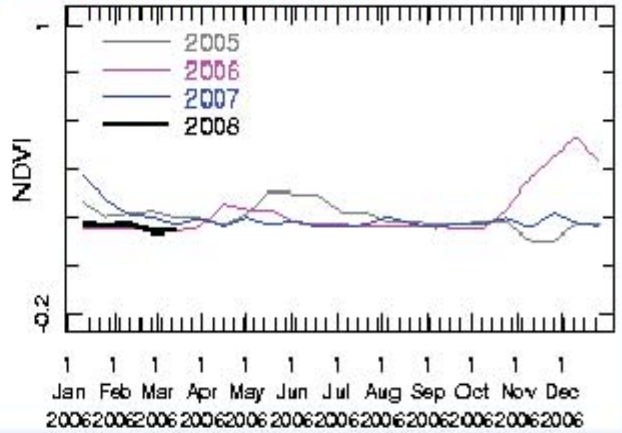
Generate new time series

a) NDVI from most recent 12-month period



Data in this graph
Data from Feb 2005 to present

b) Multi-year NDVI comparison



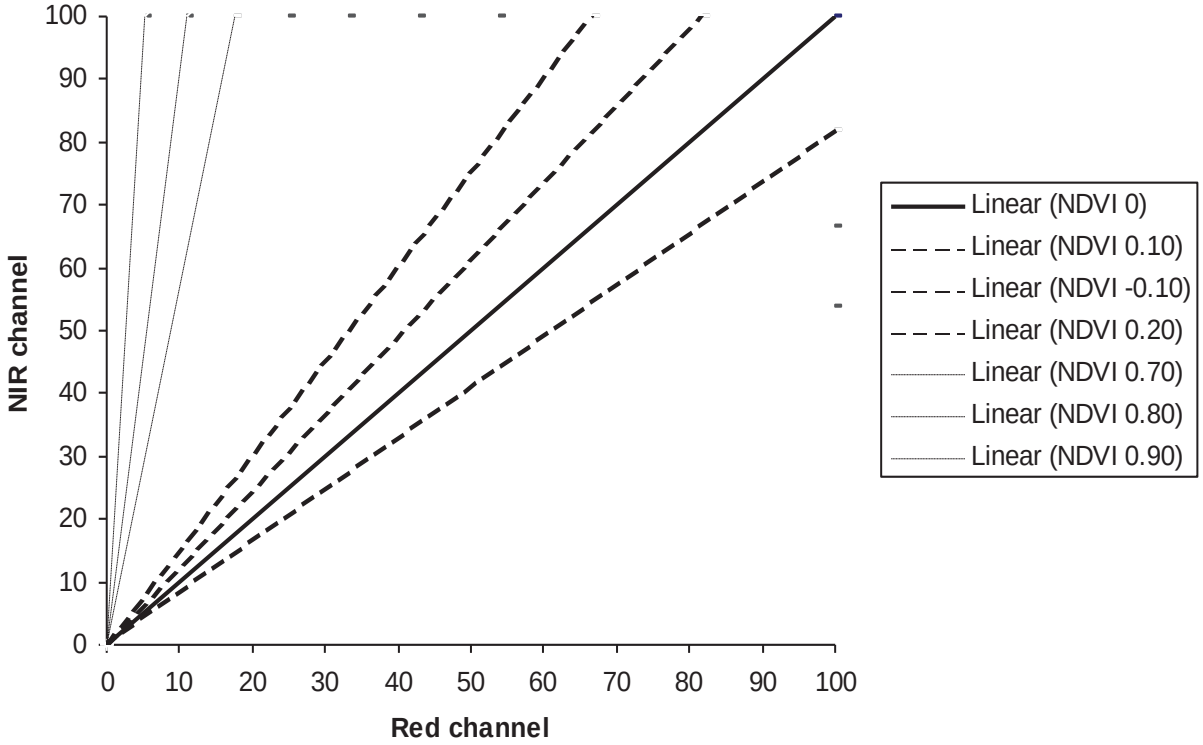
Description

a) 16-day Normalized Difference Vegetation Index (NDVI) for the selected region during the most recent 12 month period.

b) Same as (a) for the current calendar year (thick black line), as indicated by the axis labels. NDVI estimates from previous years are also shown (blue: -1 yr from present; magenta: -2 yr from present).

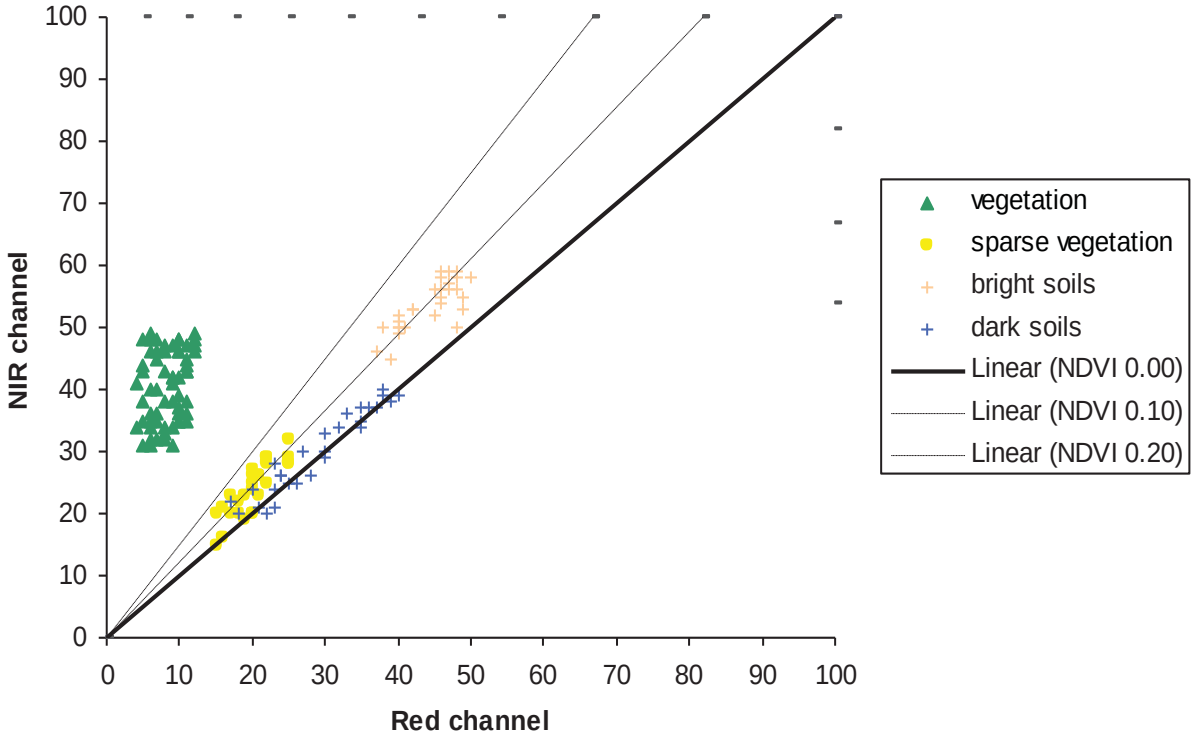
NDVI Study

(NIR-Red)/(NIR+Red)

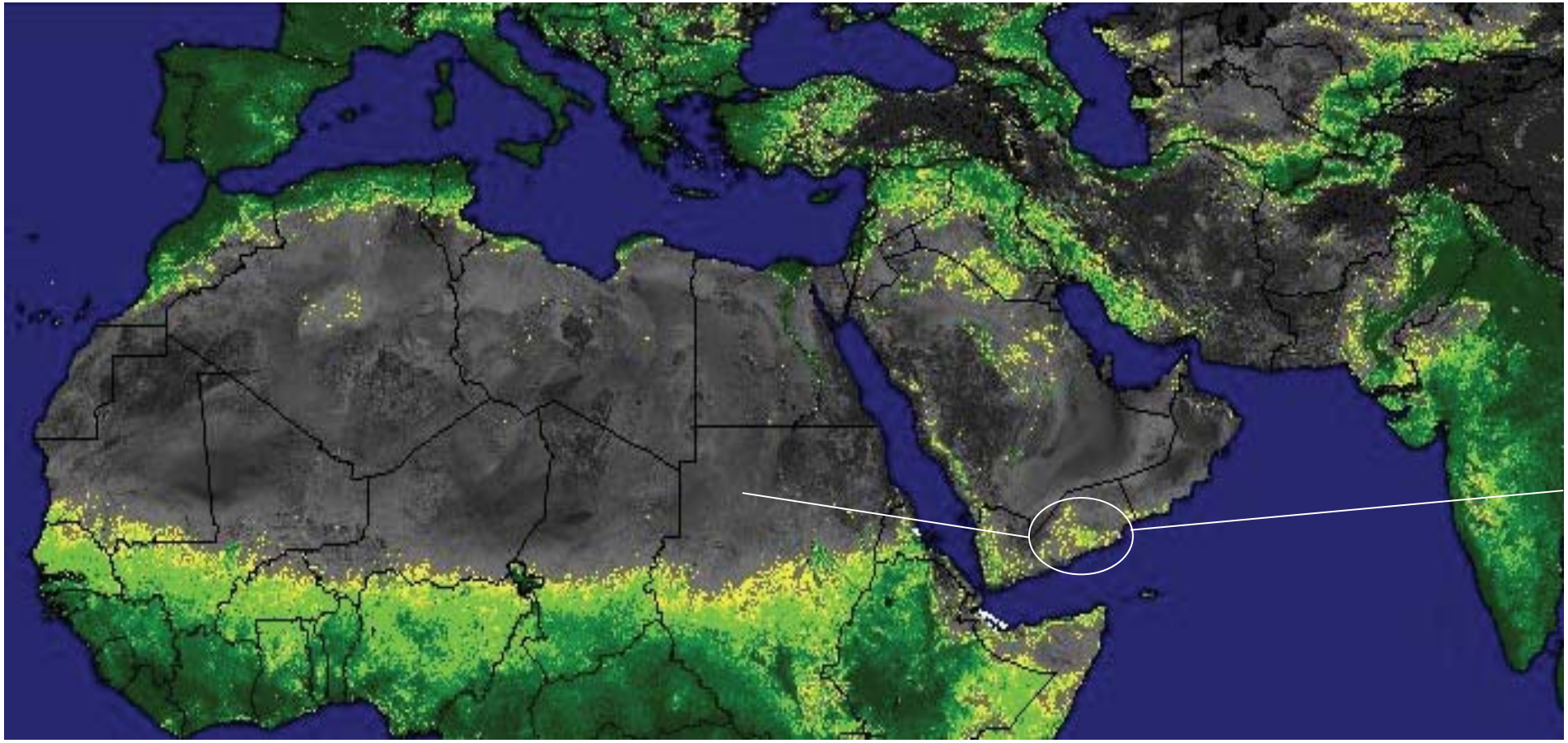


NDVI Study

(NIR-Red)/(NIR+Red)

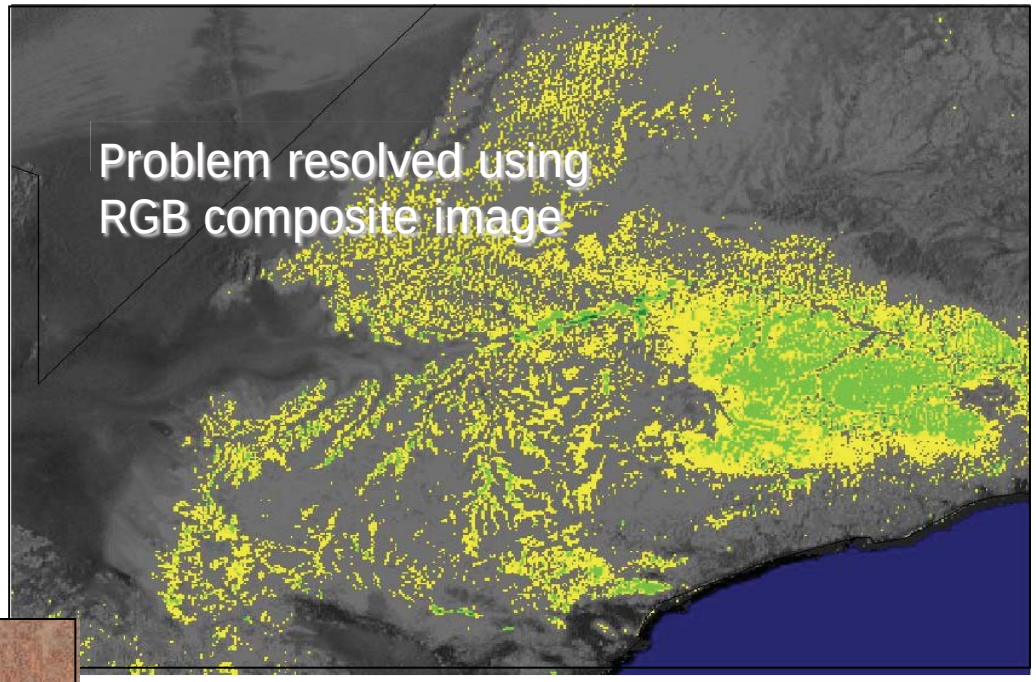


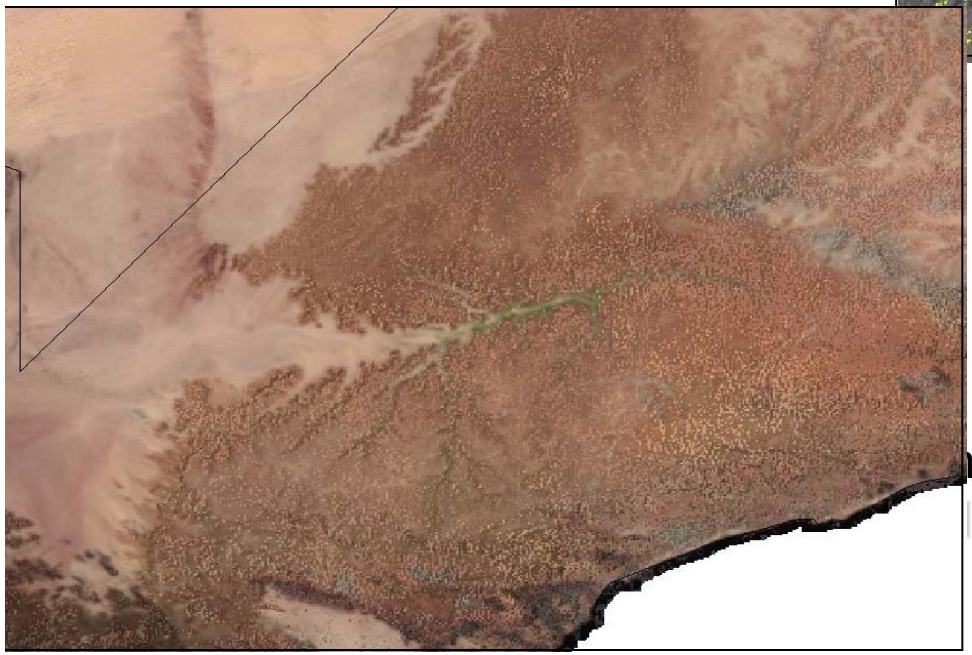
NDVI example

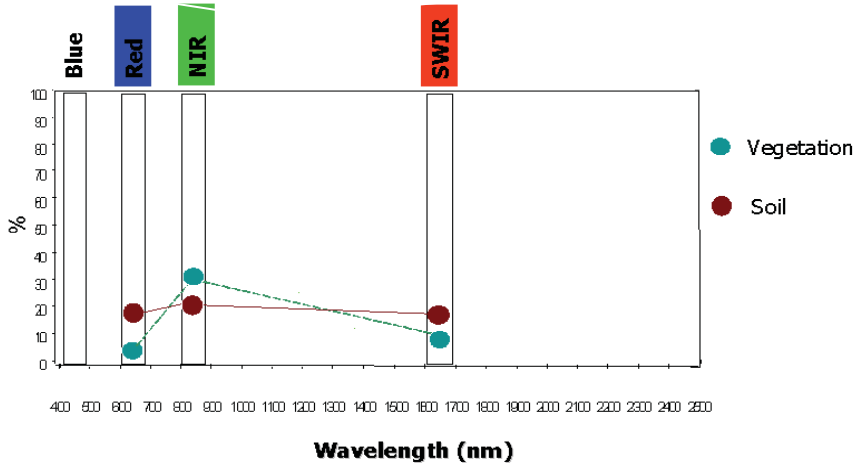


NDVI shows the presence of vegetation when there is no vegetation in the field

NDVI example



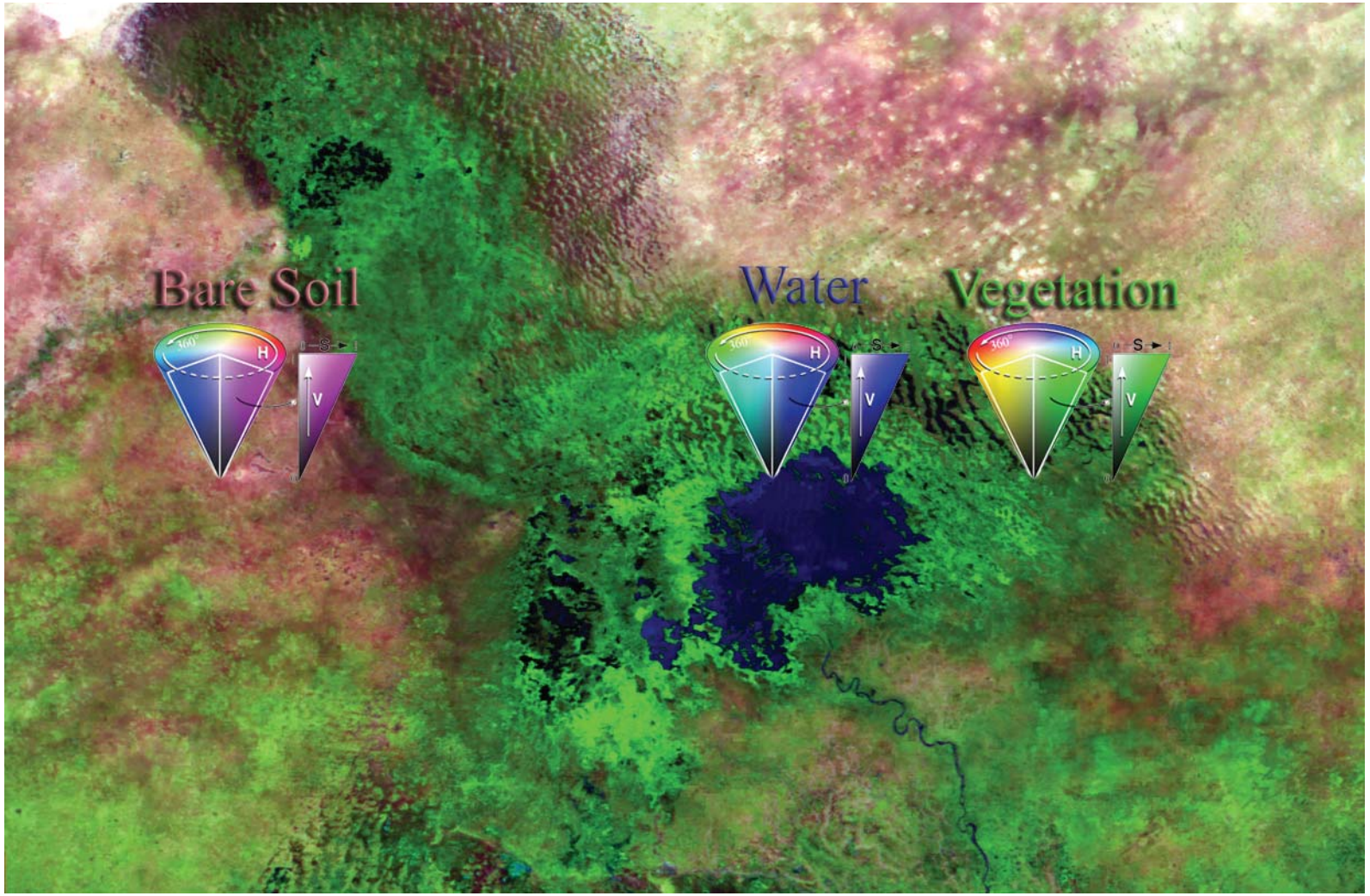




Water Bodies

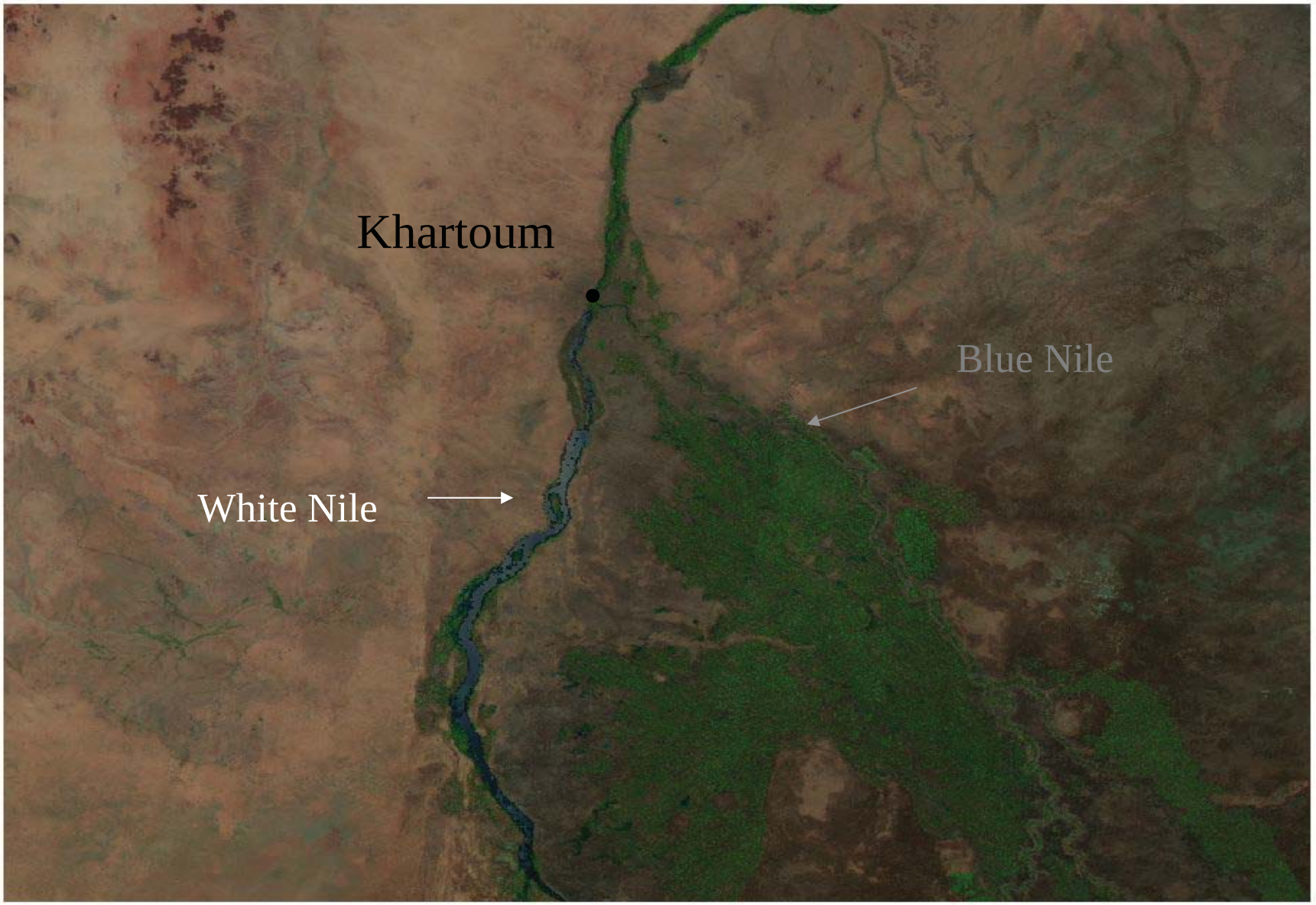
Hue as a Qualitative Index

The various land cover types have specific ranges of Hue



Temporal variations of Hue can be interpreted as a change of land cover type

Water Bodies



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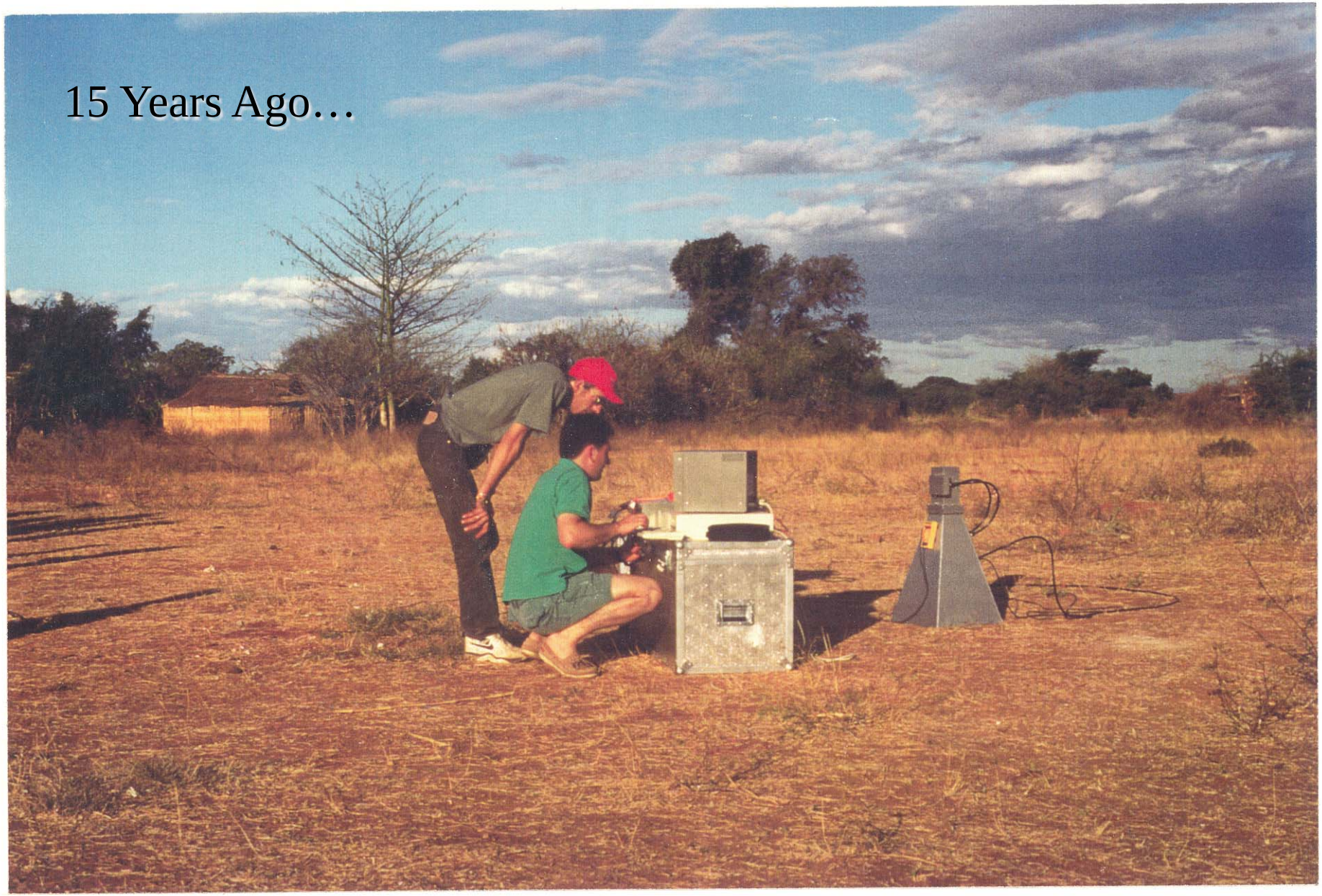

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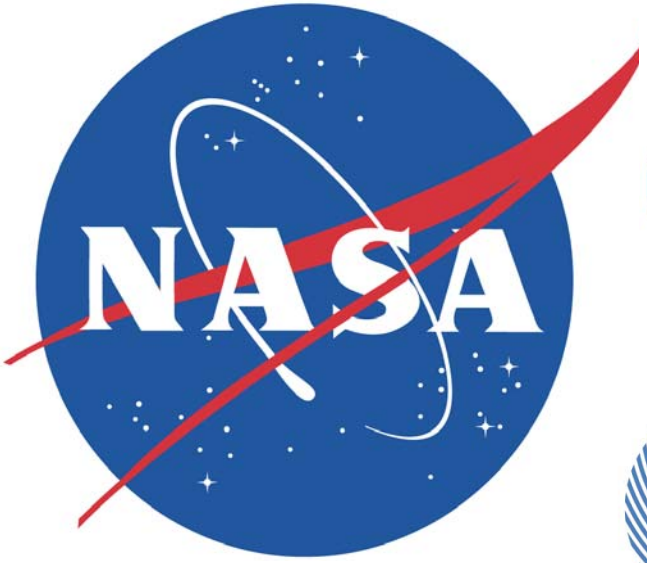
Today, Images are available via Internet ...



etc…

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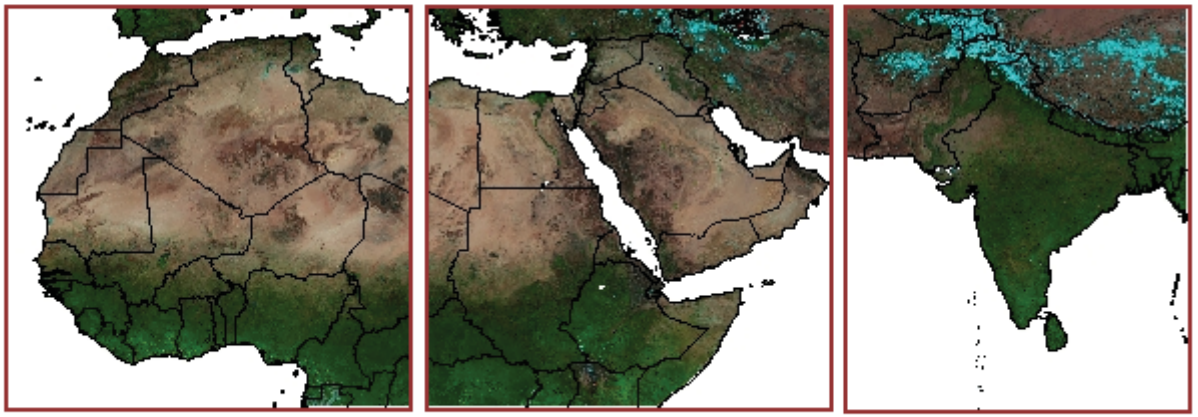

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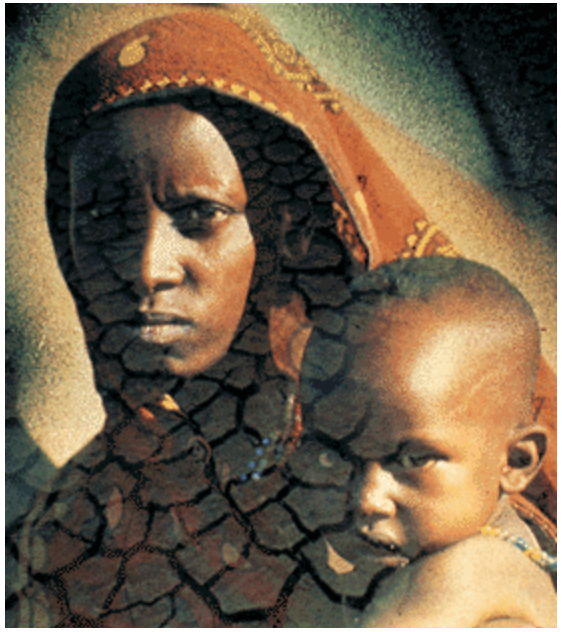
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