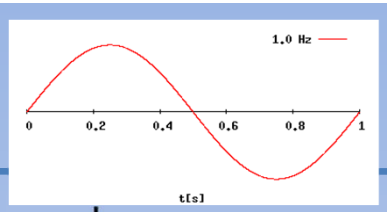
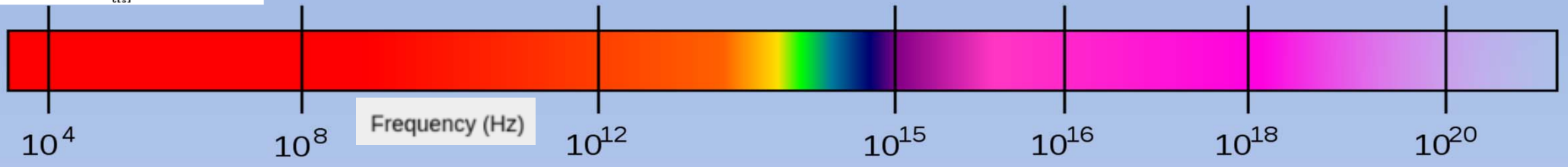
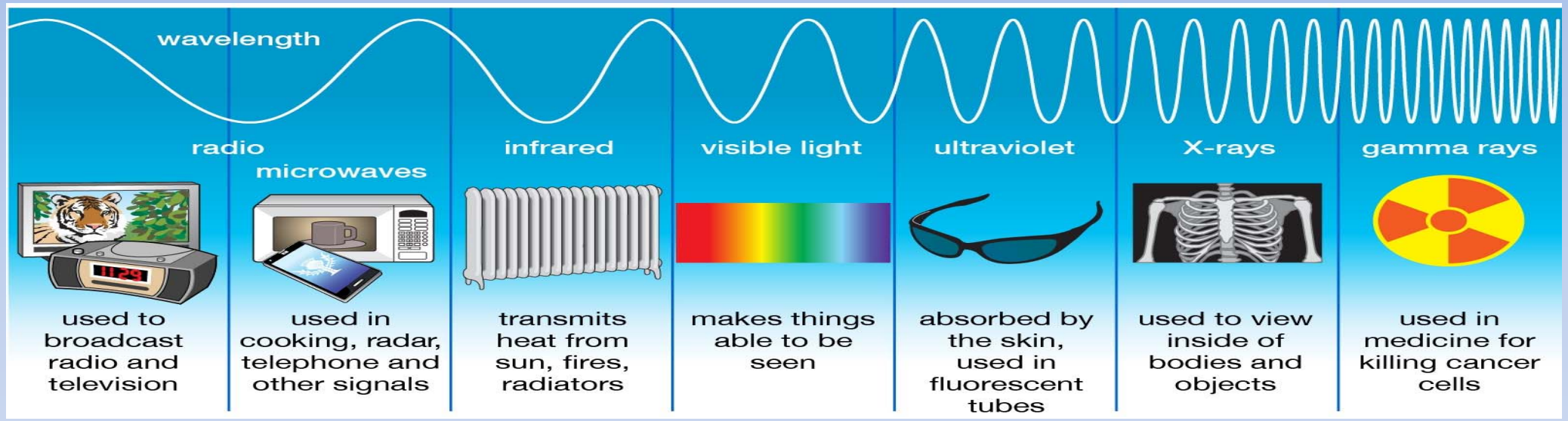
Introduction to Satellite Remote Sensing

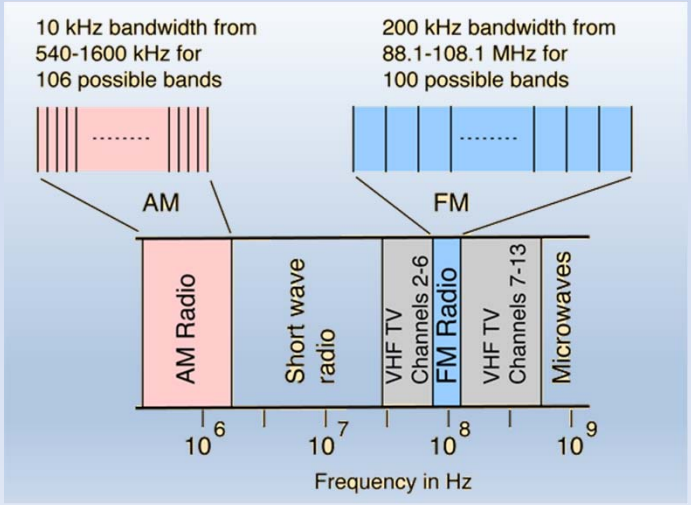
Dr. Tarendra Lakhankar

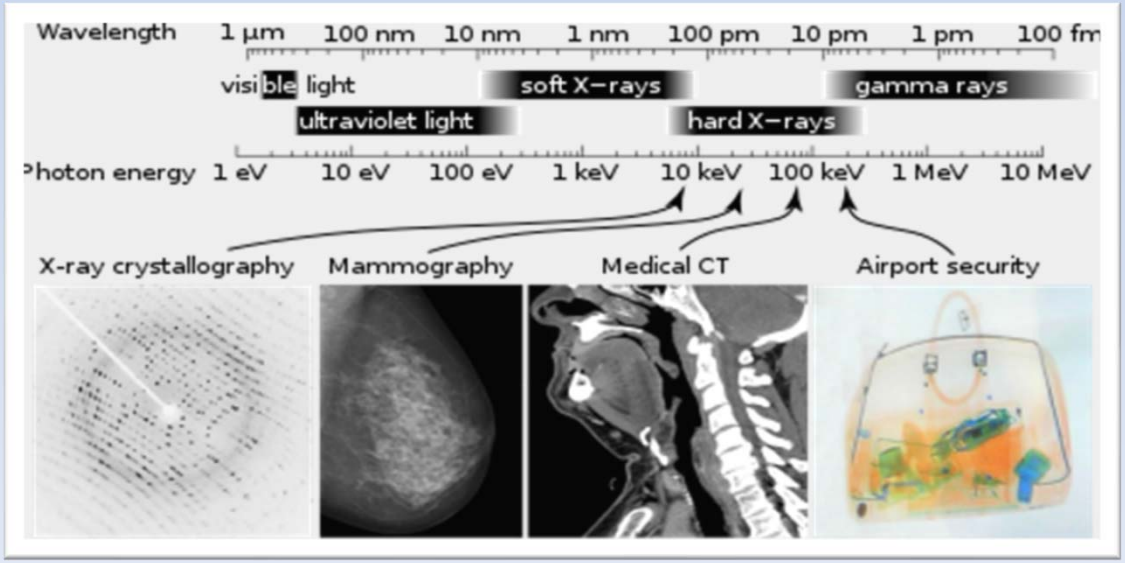


Range of Electromagnetic Spectrum

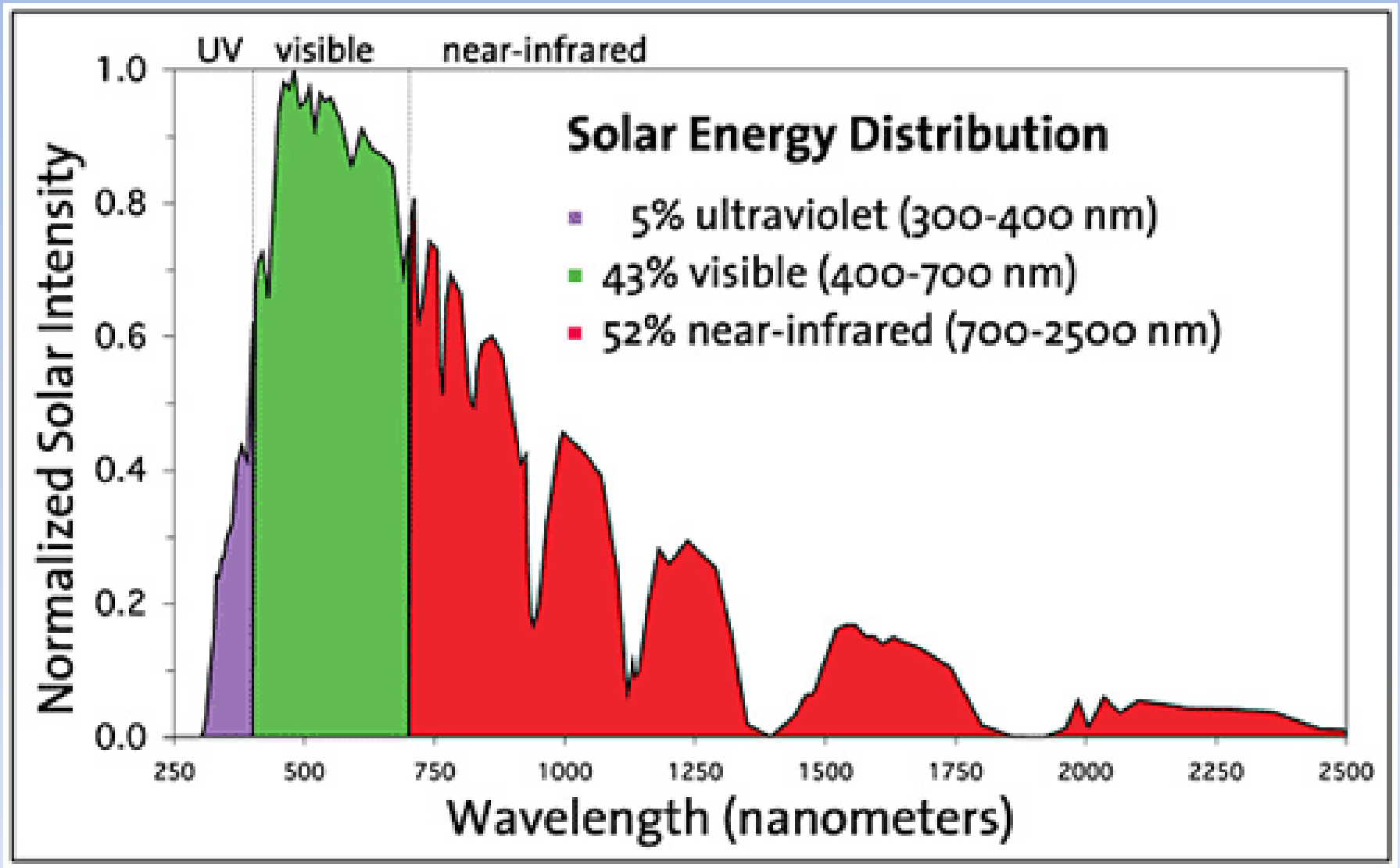




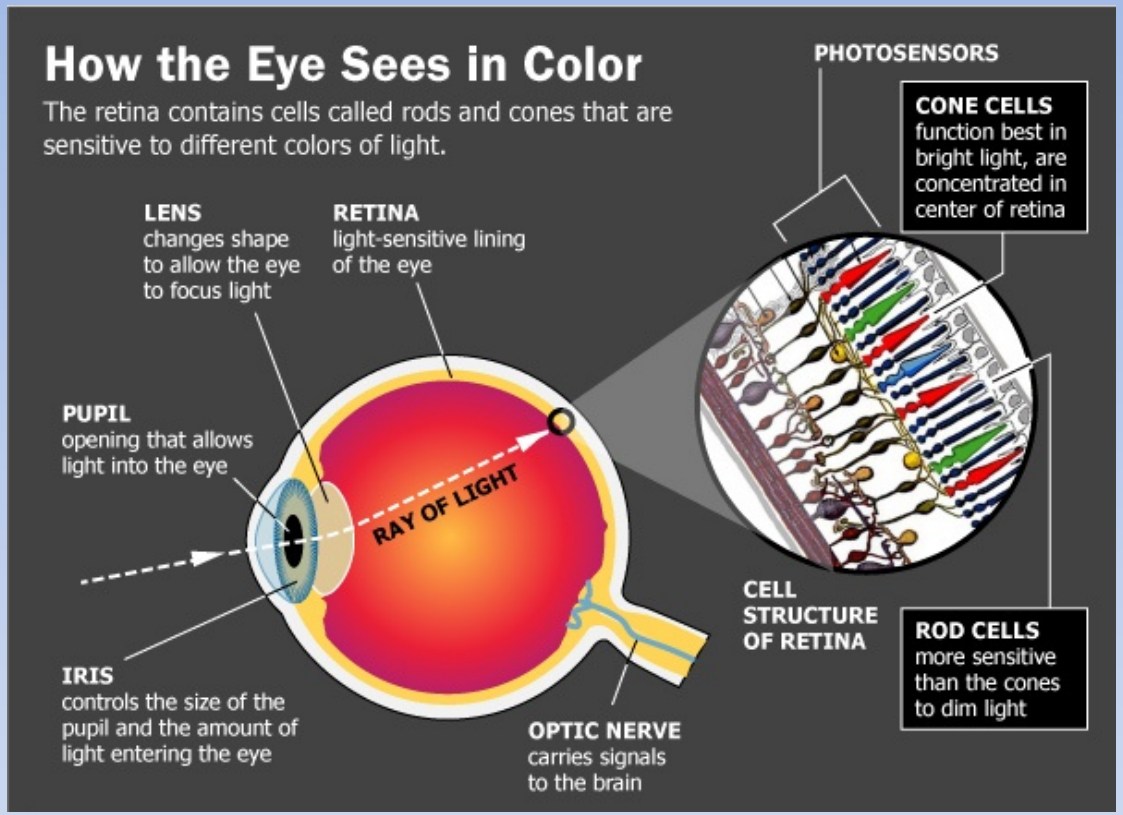


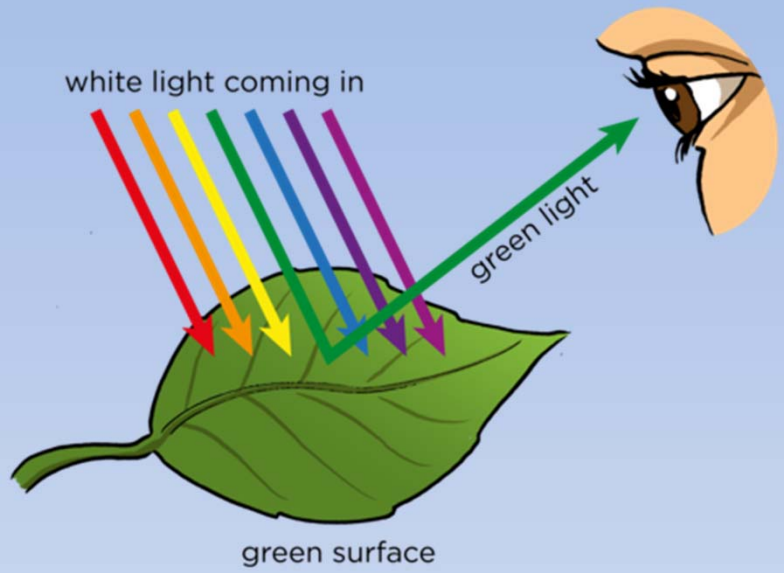


Solar Energy Distribution

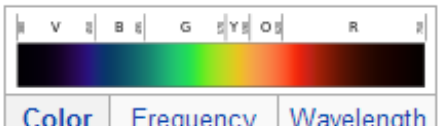


Eye vs Camera

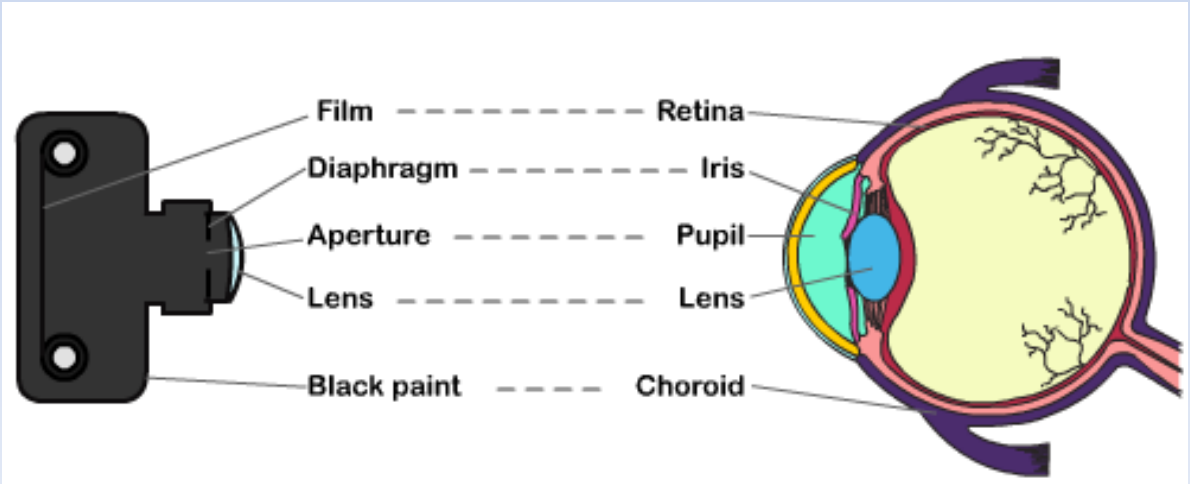




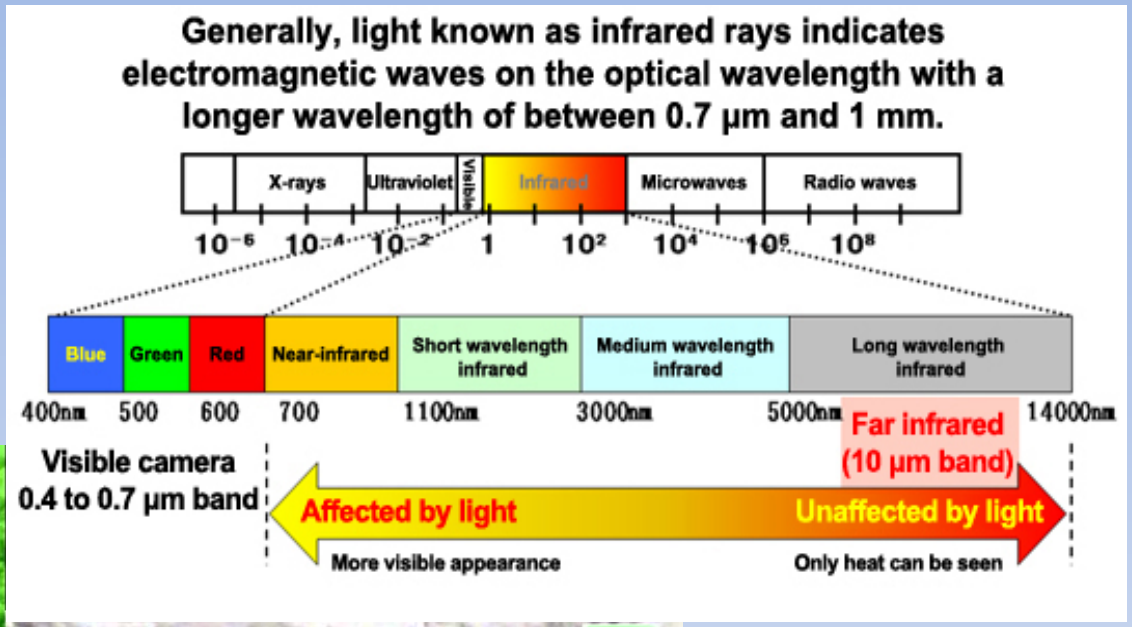
- Light energy is the only form of energy that we can see directly.

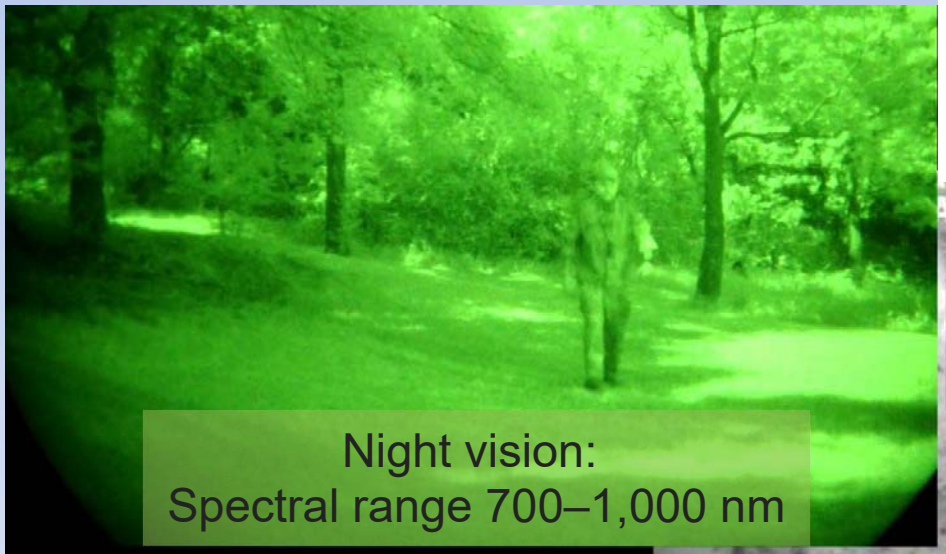


Color	Frequency	Wavelength
violet	668–789 THz	380–450 nm
blue	606–668 THz	450–495 nm
green	526–606 THz	495–570 nm
yellow	508–526 THz	570–590 nm
orange	484–508 THz	590–620 nm
red	400–484 THz	620–750 nm



Thermal vs night vision camera

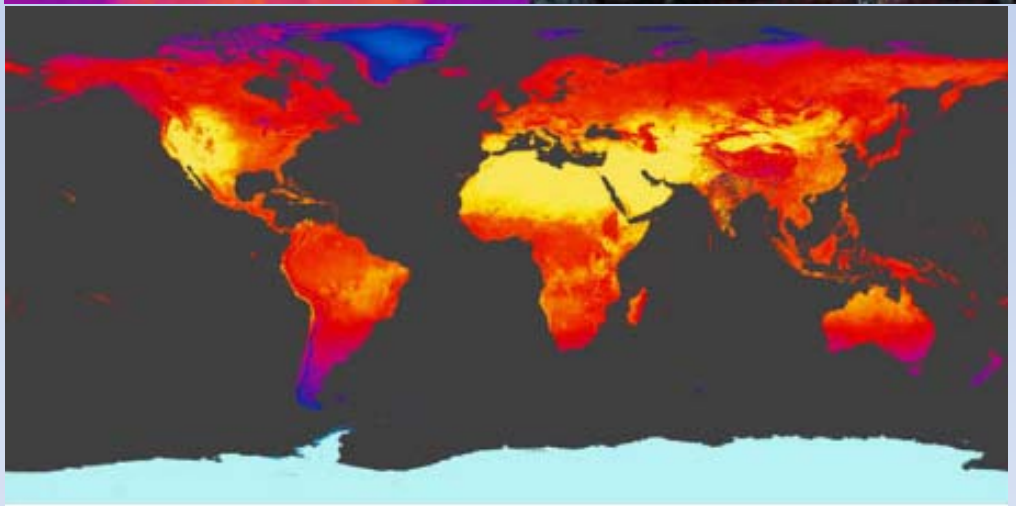


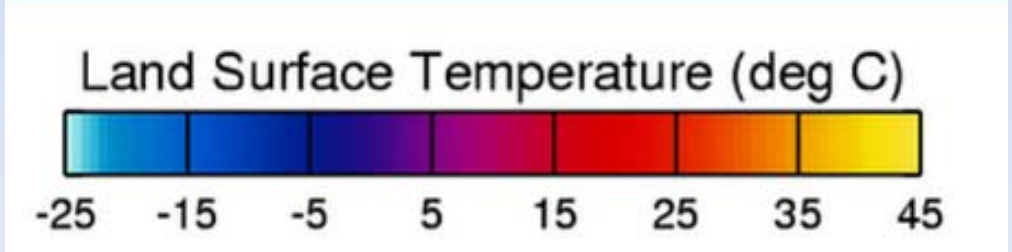


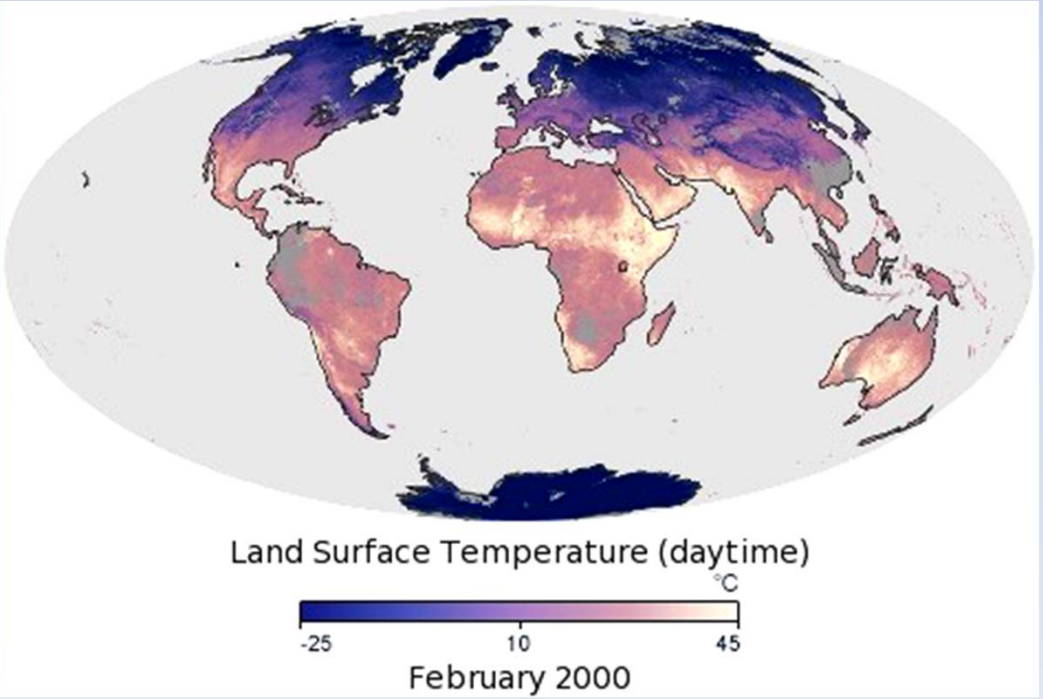
Night vision:
Spectral range 700–1,000 nm

Thermal Camera:
Spectral range 9,000–14,000 nm

Comparison of VIS and IR

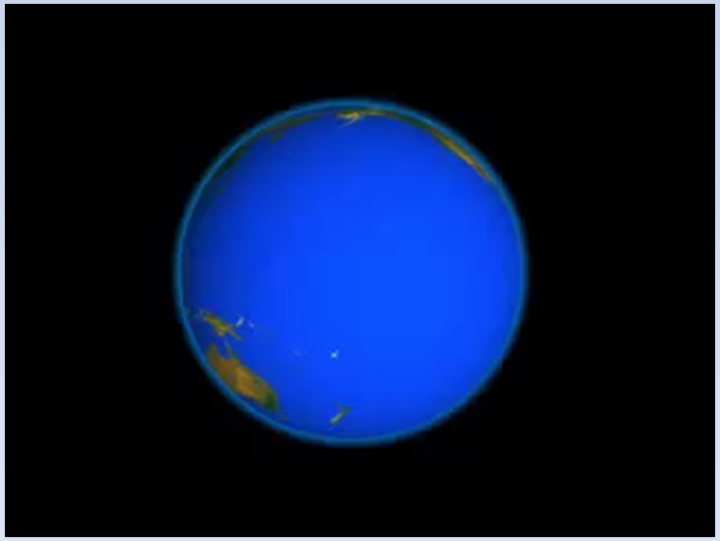


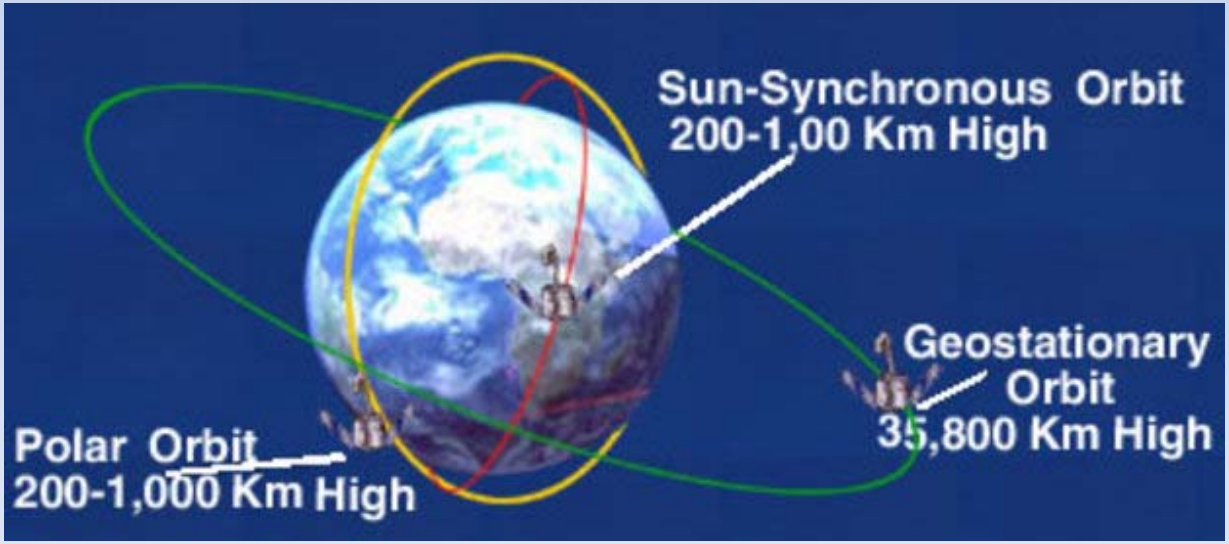




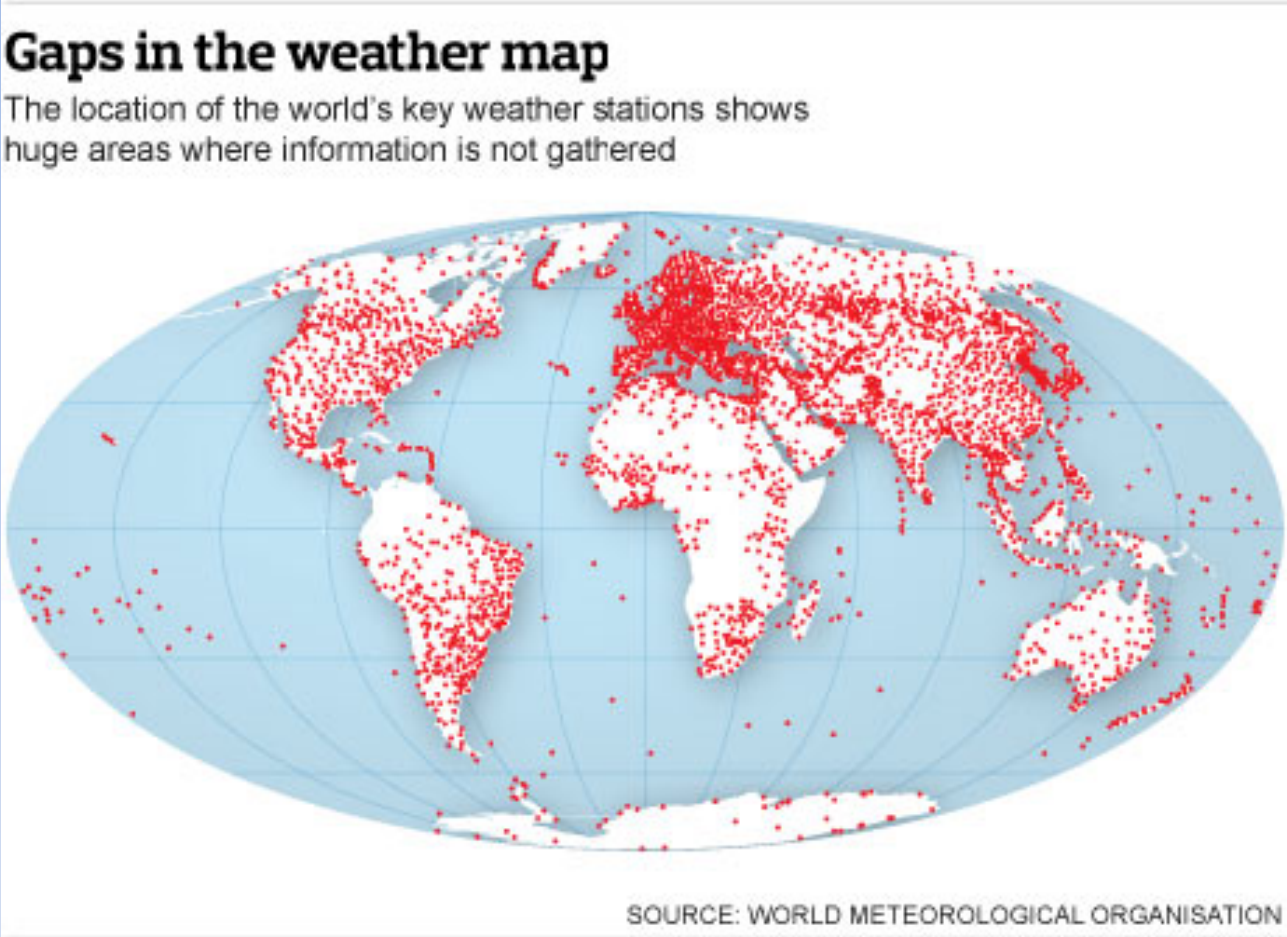
Remote Sensing

- Regular global and regional data with uniform quality
- Ability to combine satellite with other digital map layers (GIS) – cf. Google Earth
- Cost effective – many products are available.





Weather and Climate Data



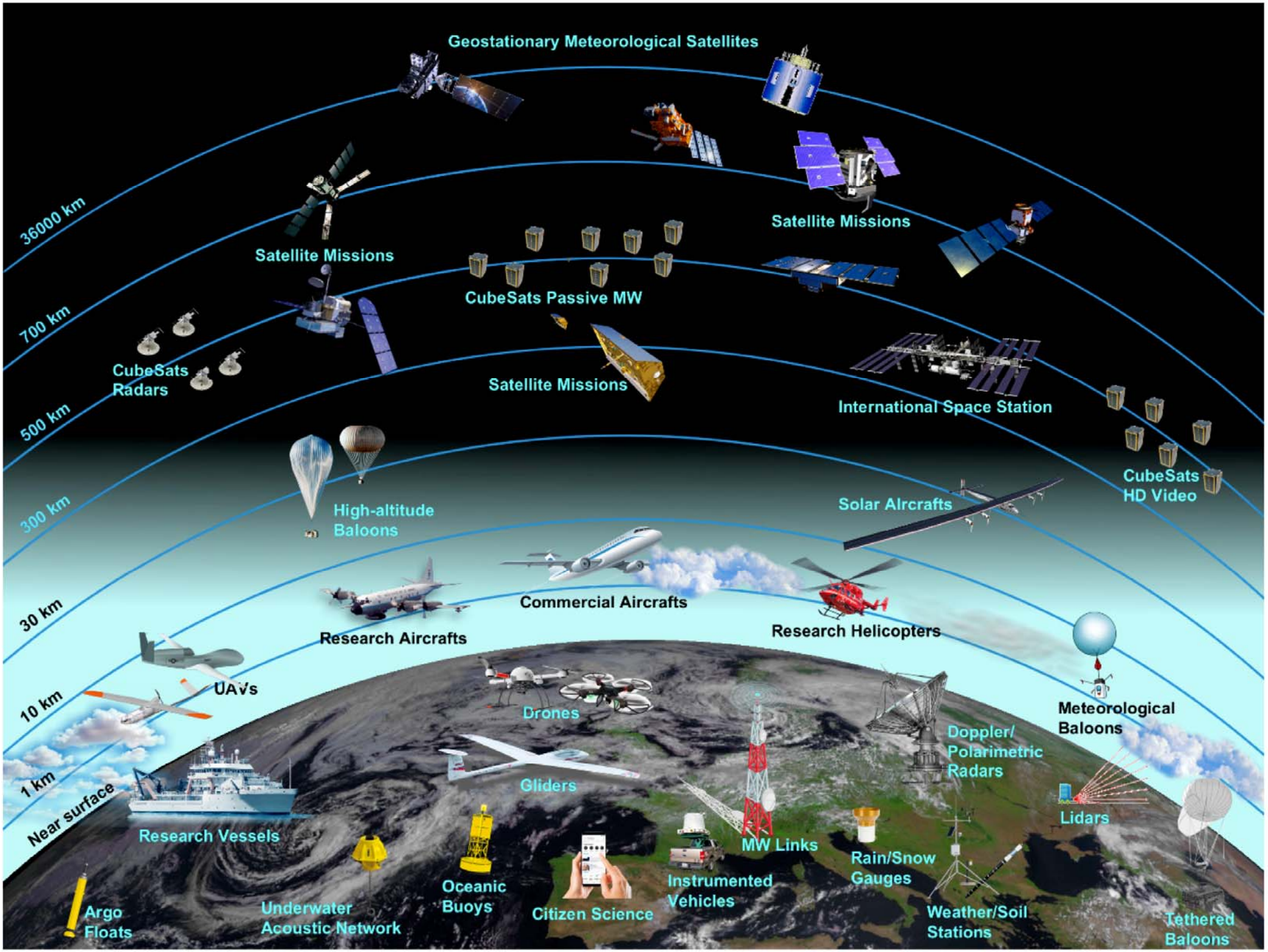
Issues:

- Delay in processing the climate data (>1-3 years)
- Spatial and temporal gaps
- Limited measurements of variables (precipitation, temperature, wind speed, river runoff)

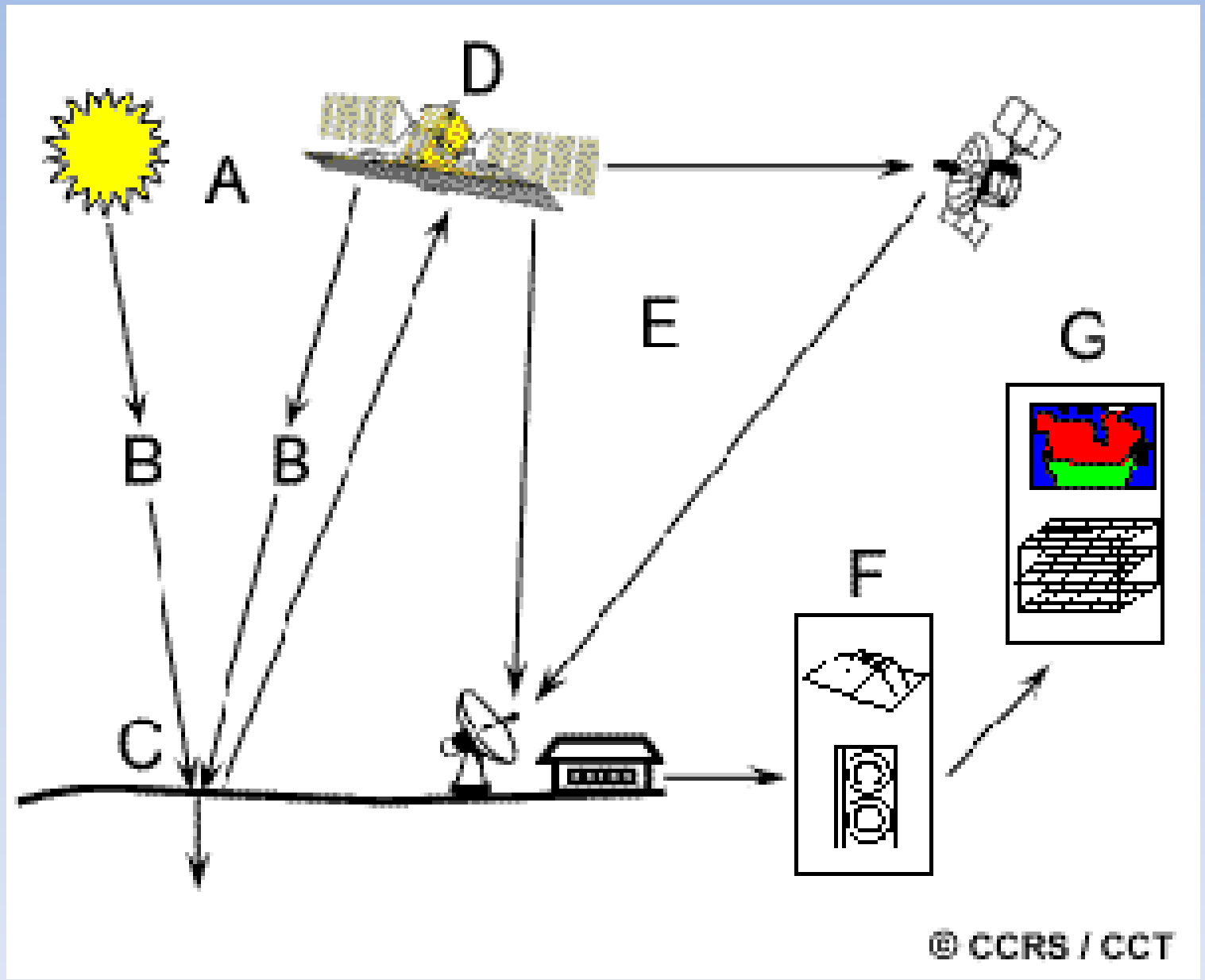
How many satellites in Space?

- Communications Satellite
- Remote Sensing Satellite
- Navigation Satellites (GPS, GNSS, Galileo, etc.)
- Geocentric Orbit type - LEO, MEO, HEO
- Geostationary Satellites (GEOs)
- Drone Satellite
- Polar Satellite
- Nano Satellites, CubeSats and SmallSats

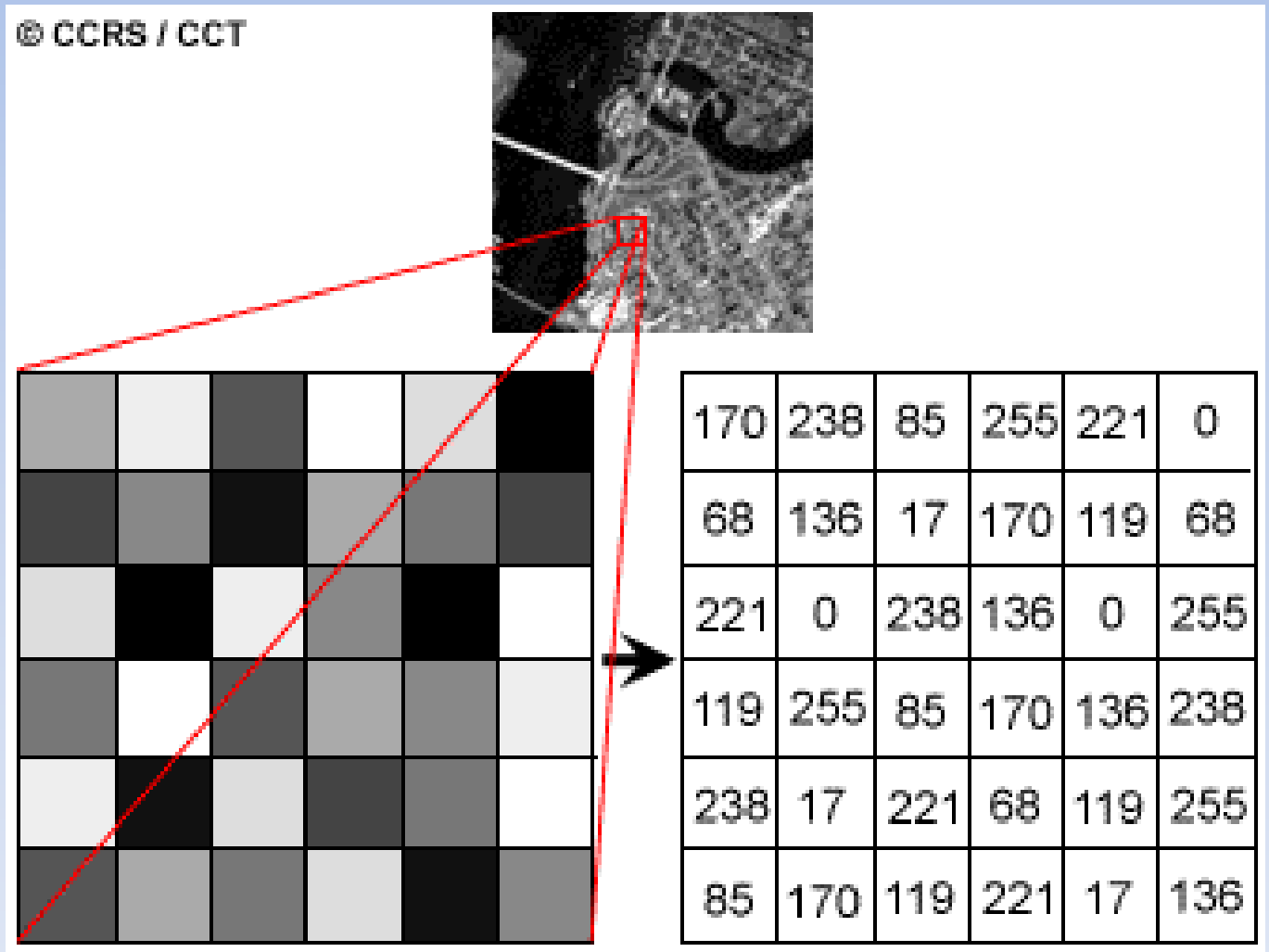
Currently there are approximately active 1,419 (4,256) artificial satellites orbiting the Earth.


Geostationary Meteorological Satellites
36000 km
Satellite Missions
Satellite Missions
700 km
CubeSats Passive MW
CubeSats
Radars
Satellite Missions
500 km
International Space Station
CubeSats
HD Video
High-altitude
Baloons
Solar Aircrafts
300 km
Commercial Aircrafts
Research Aircrafts
Research Helicopters
30 km
UAVs
10 km
Drones
Meteorological
Baloons
Doppler/
Polarimetric
Radars
1 km
Gliders
Lidars
Near surface
Research Vessels
MW Links
Rain/Snow
Gauges
Instrumented
Vehicles
Oceanic
Buoys
Citizen Science
Weather/Soil
Stations
Argo
Floats
Underwater
Acoustic Network
Tethered
Baloons

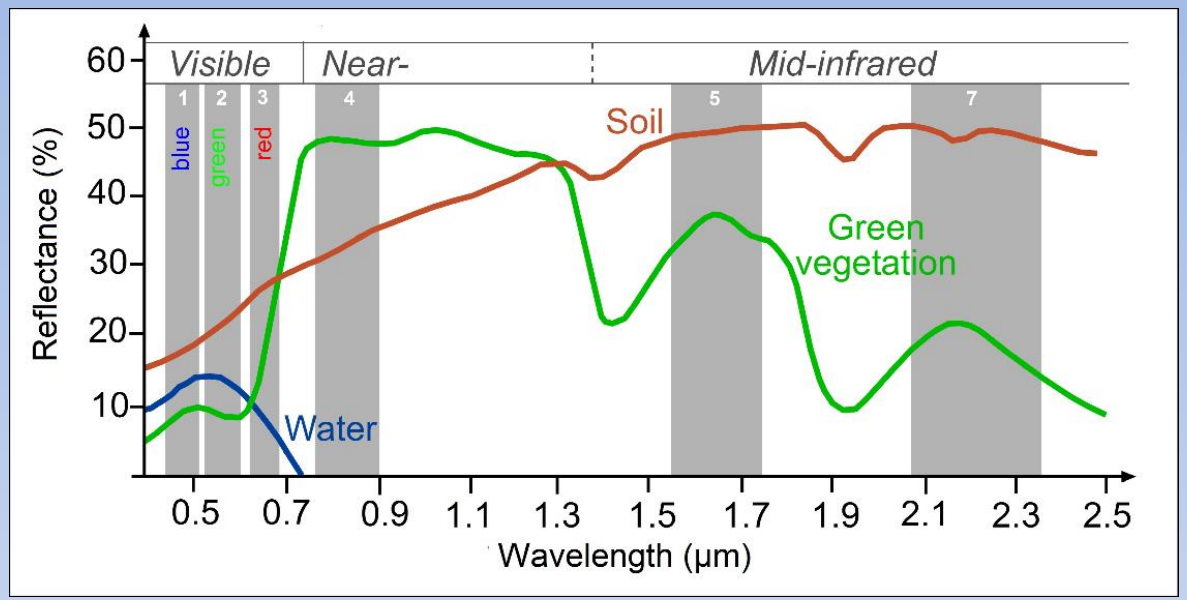
How we do Remote Sensing

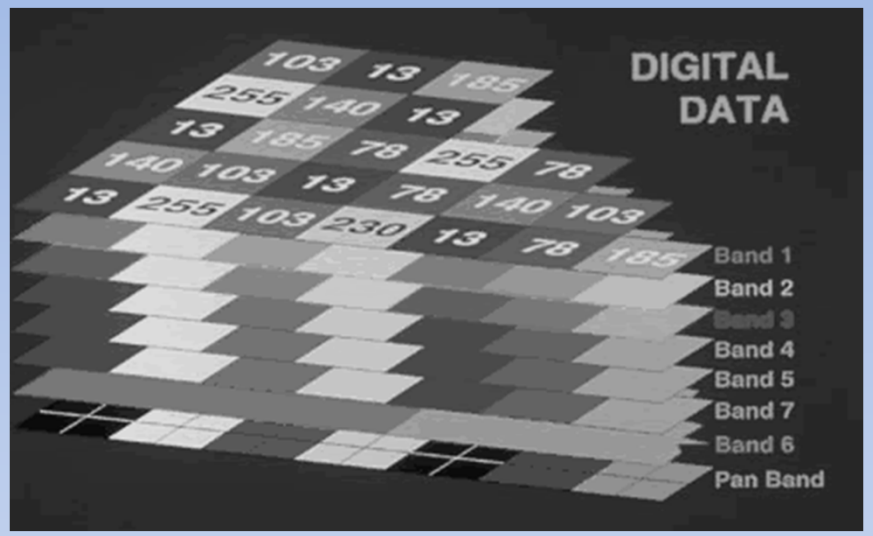


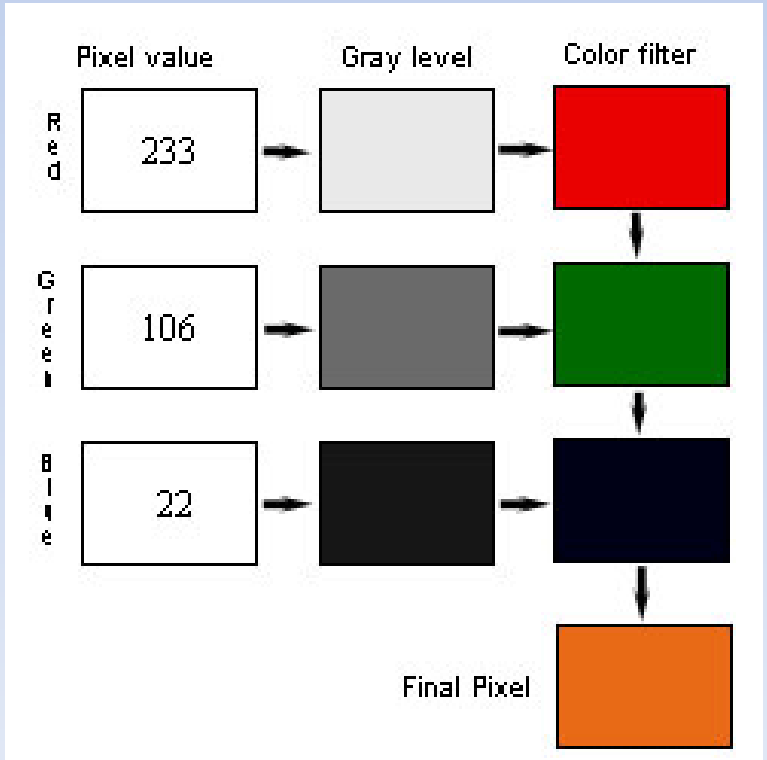
Sensors record intensity of reflected energy numerically

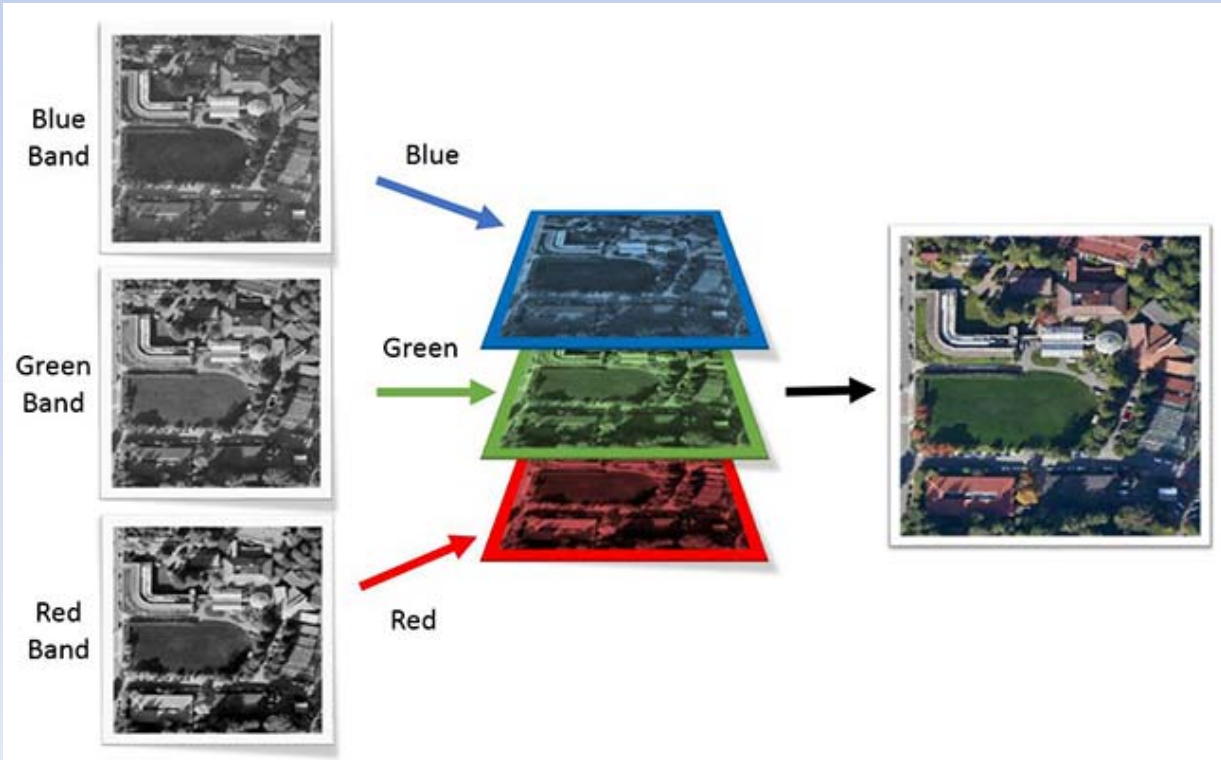


How satellite collects the data?





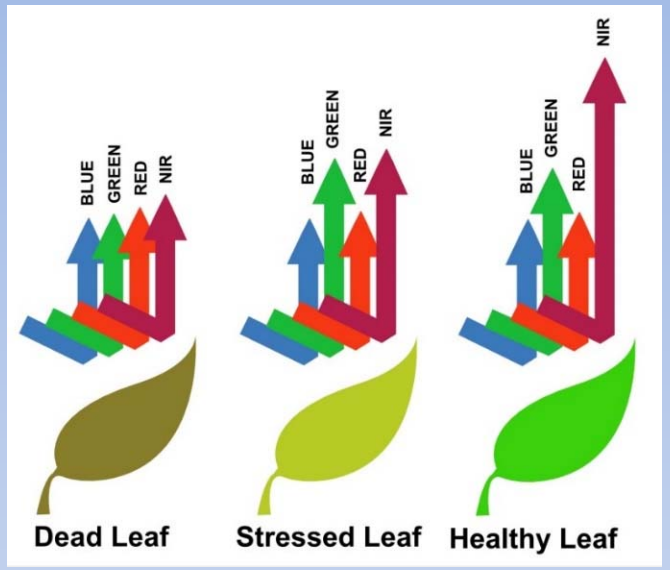


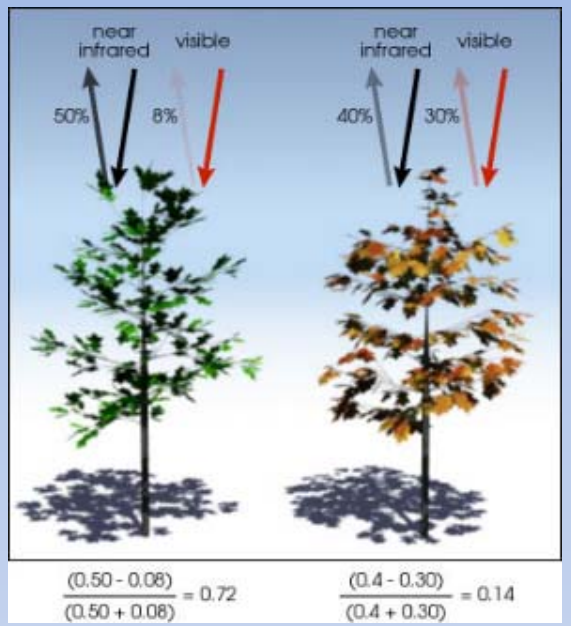


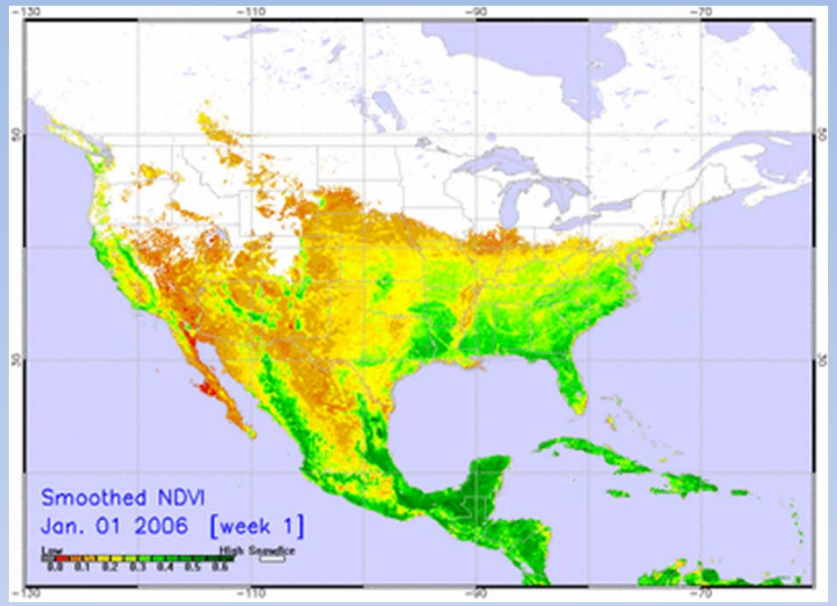
Landsat Thematic Mapper Imagery

Band	Wavelength	Useful for mapping
Band 1 – Blue	0.435 - 0.451	Coastal and aerosol studies
Band 2 – Blue	0.452 - 0.512	Bathymetric mapping, distinguishing soil from vegetation, and deciduous from coniferous vegetation
Band 3 - Green	0.533 - 0.590	Emphasizes peak vegetation, which is useful for assessing plant vigor
Band 4 - Red	0.636 - 0.673	Discriminates vegetation slopes
Band 5 - Near Infrared (NIR)	0.851 - 0.879	Emphasizes biomass content and shorelines
Band 6 - Short-wave Infrared (SWIR) 1	1.566 - 1.651	Discriminates moisture content of soil and vegetation; penetrates thin clouds
Band 7 - Short-wave Infrared (SWIR) 2	2.107 - 2.294	Improved moisture content of soil and vegetation and thin cloud penetration
Band 8 - Panchromatic	0.503 - 0.676	15 meter resolution, sharper image definition
Band 9 – Cirrus	1.363 - 1.384	Improved detection of cirrus cloud contamination
Band 10 – TIRS 1	10.60 – 11.19	100 meter resolution, thermal mapping and estimated soil moisture
Band 11 – TIRS 2	11.50 - 12.51	100 meter resolution, Improved thermal mapping and estimated soil moisture

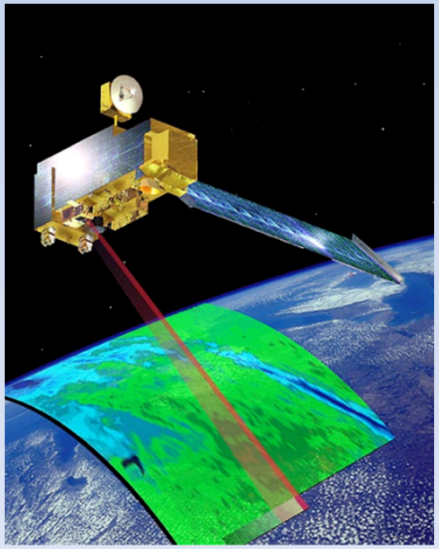
Remote Sensing of Vegetation (crop/forest)

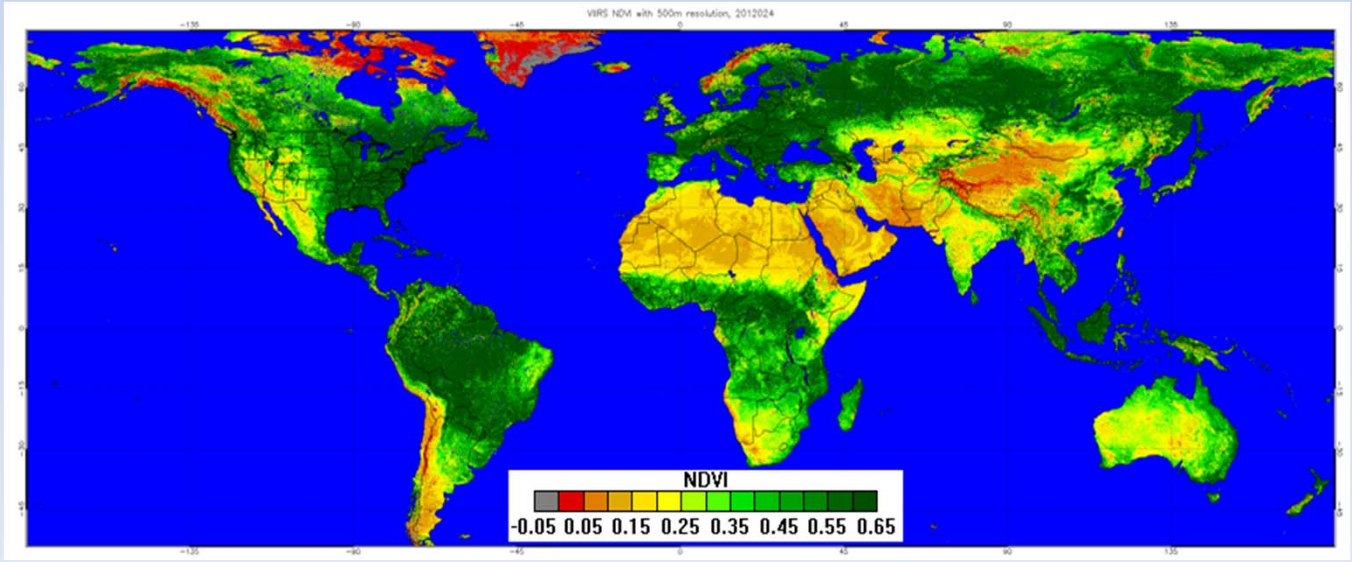




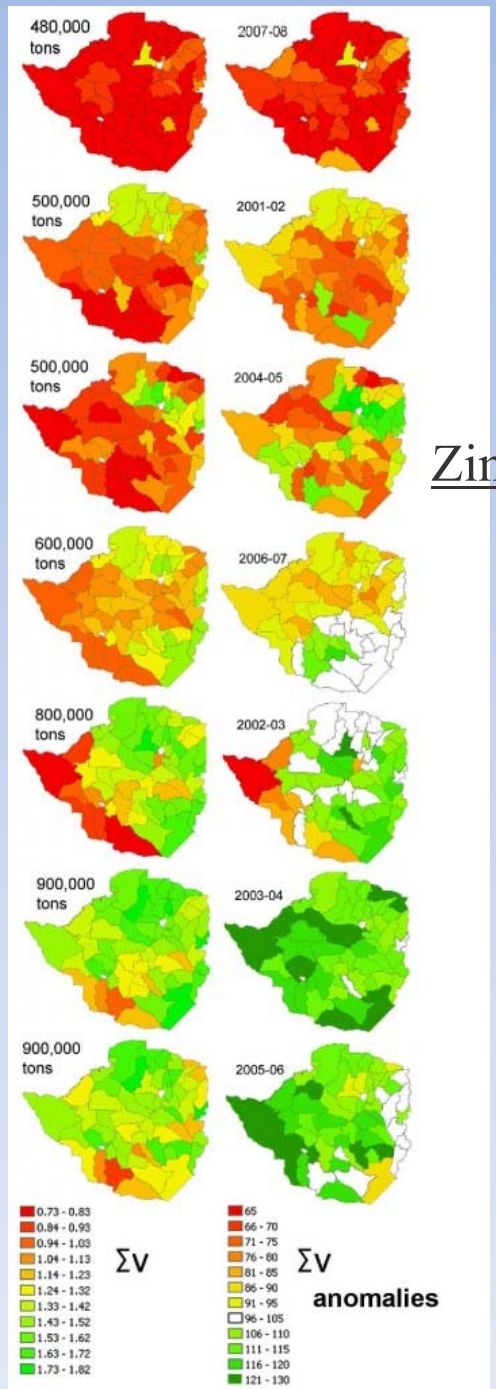


Ratios of reflectance's at different wavelengths can indicate vegetation density and health

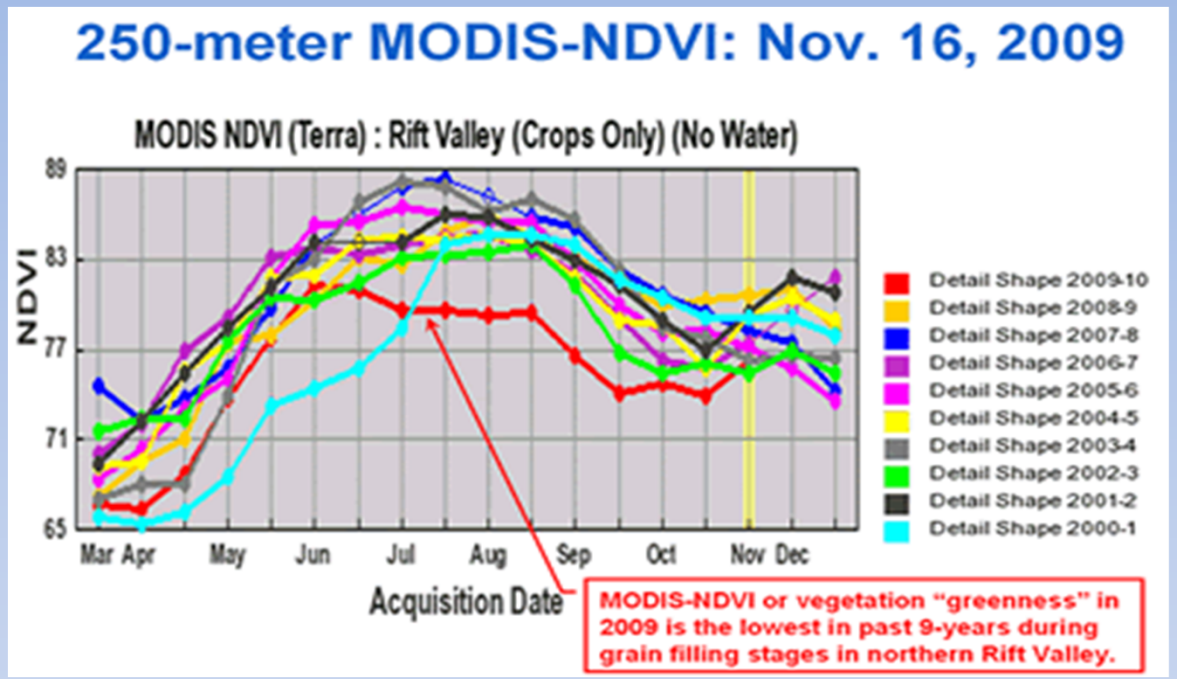




Vegetation Index (NDVI) for Food Security



Zimbabwe



Σv relies on measures of vegetation condition (NDVI) throughout the growing season to assess the likely production outcome.

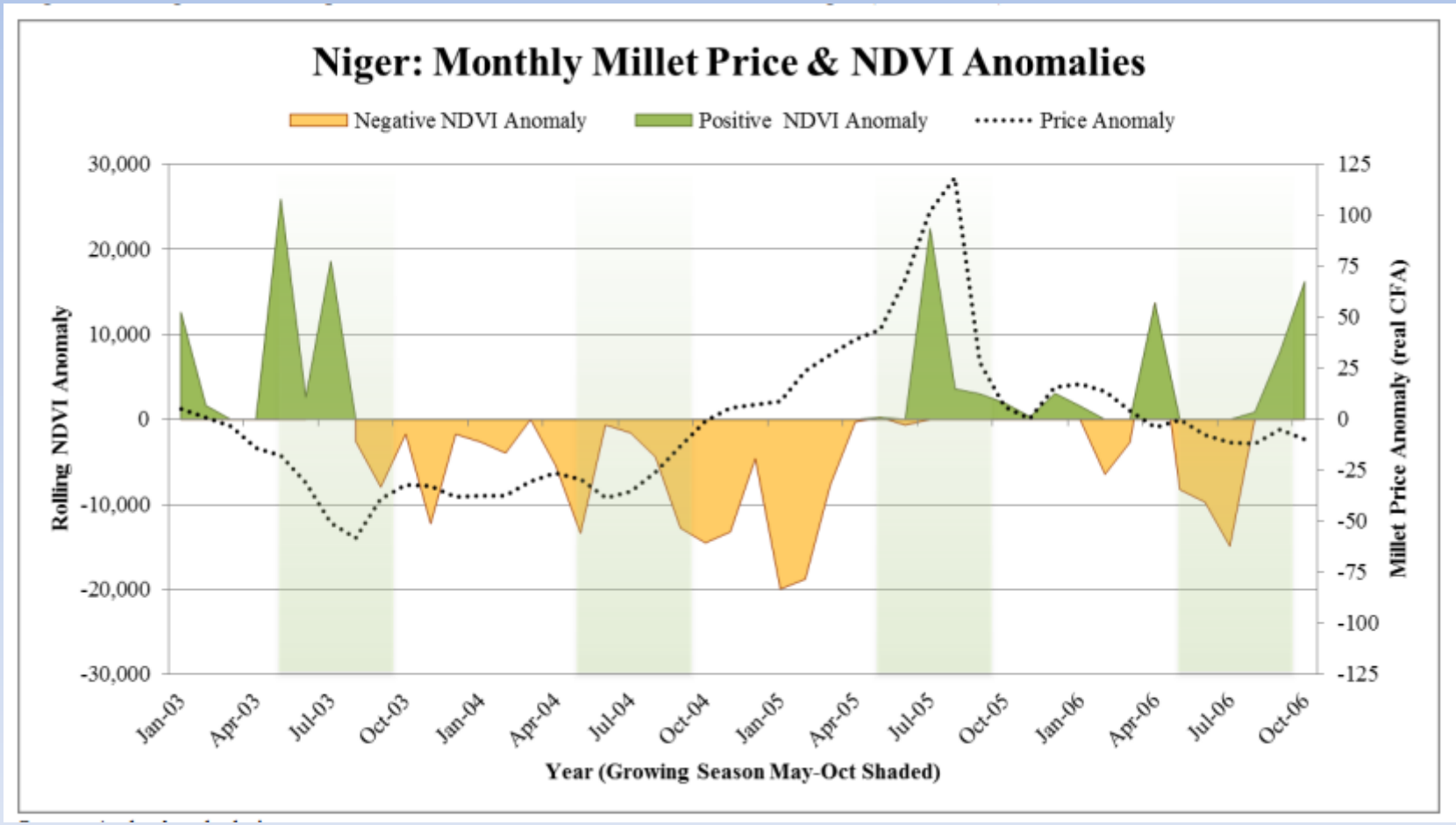
Budde et al (2010)

Year	Maximum NDVI	Yield (t/ha)
2003	0.381	2.85
2007	0.373	2.69
2005	0.364	2.51
2006	0.357	2.58
2002	0.355	2.02
2004	0.335	1.93
2000	0.320	1.12
2001	0.317	1.31
2008	0.313	1.14*

* Estimated based on regression of maximum NDVI and historical yield figures

Food price and NDVI

- Can we effectively use NDVI to analyze food Security crises?



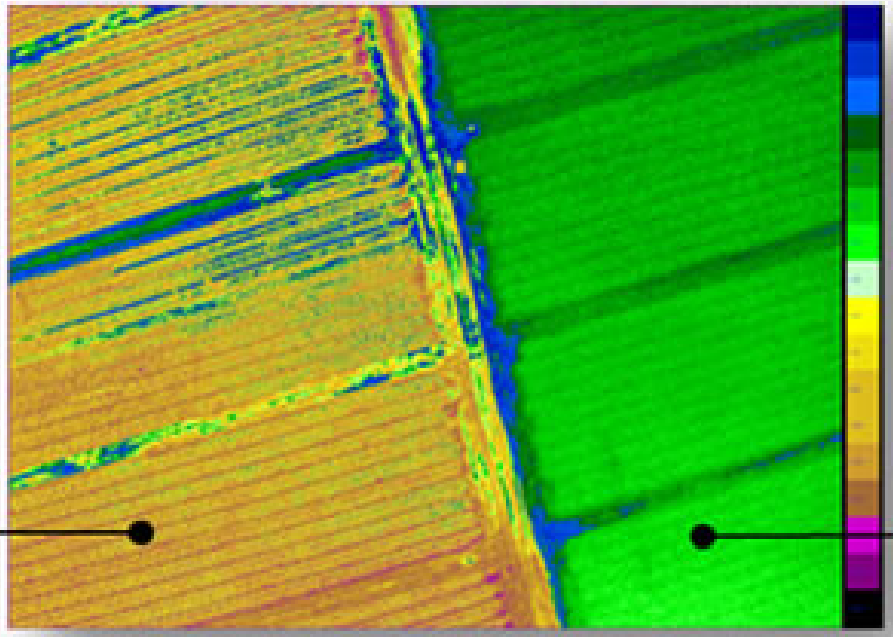
Essam (2013, PhD Thesis)

Example of vegetation mapping at high resolution

Unmanned Aerial Vehicle (UAV)

5

$$NDVI = \frac{NIR - VIS}{NIR + VIS}$$

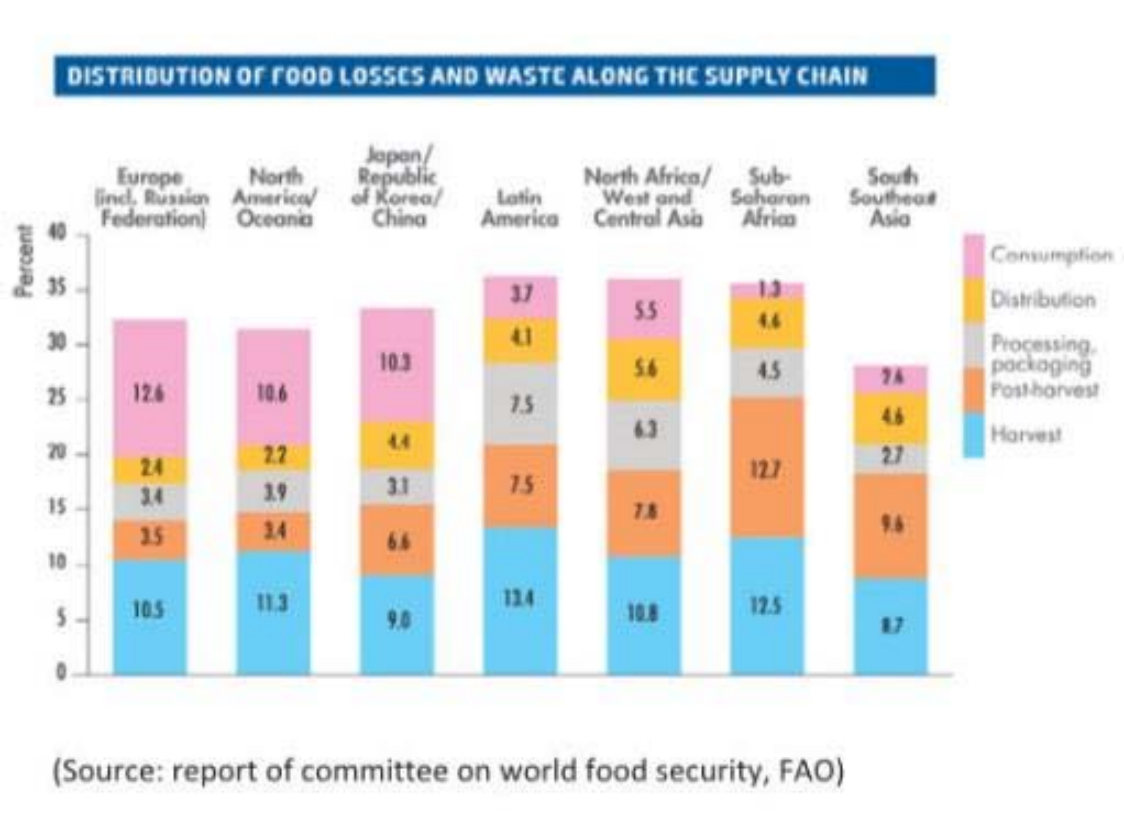


Stressed Vegetation

Healthy Vegetation

6 Aerial NDVI Image

Monitoring of Food Production

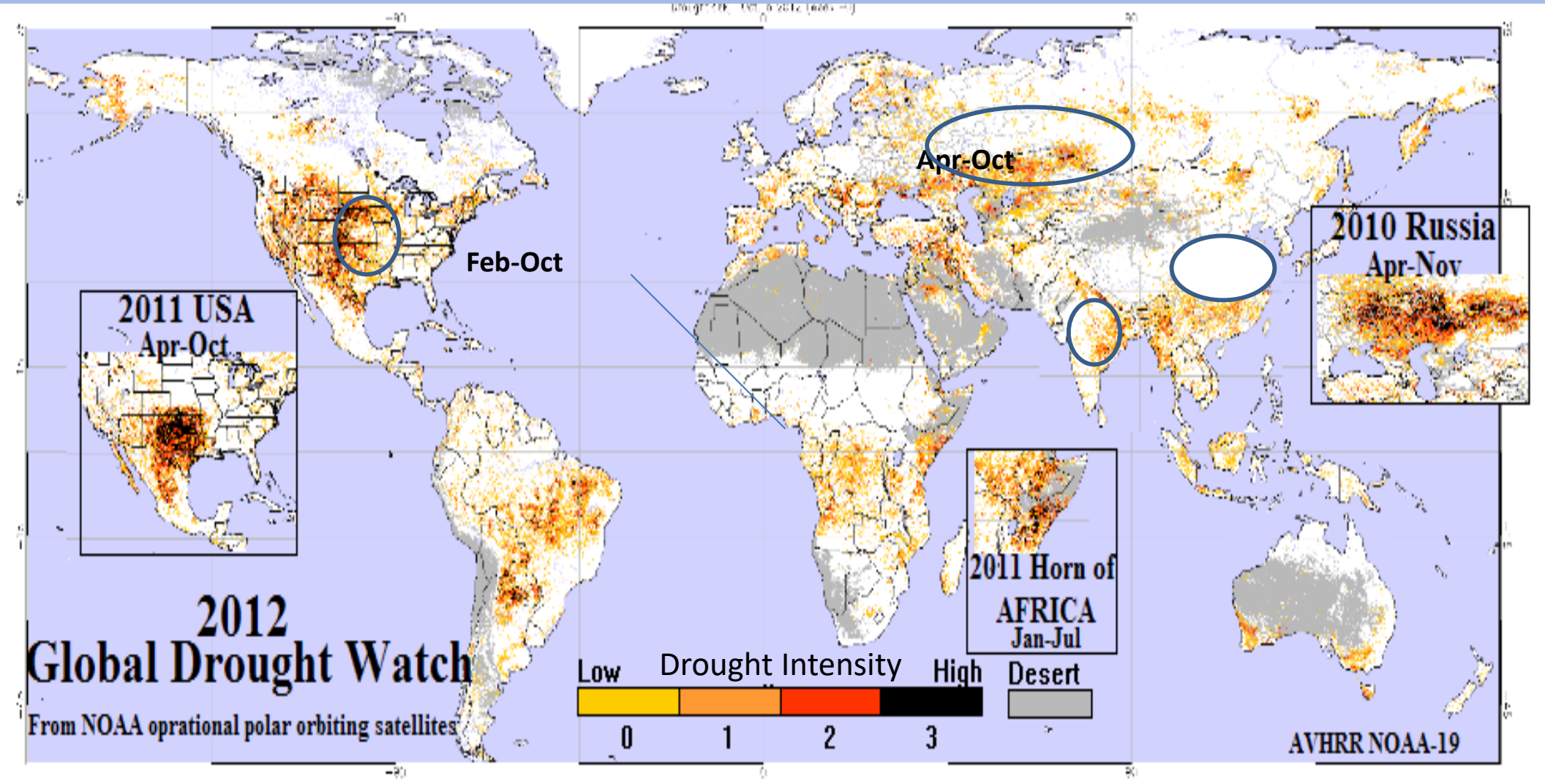


(Source: report of committee on world food security, FAO)

- Multiple handling points along with lack of quality control points from farm to consumer is the root cause of wastage.

For example: Alphonso mangoes transported in extreme summer from Konkan to Mumbai go through heat stress even in temperature-controlled trucks.

Global droughts from operational satellites



2012- Extreme drought in the USA, southern UKRAINE, northern KAZAKHSTAN,
- Severe drought in eastern INDIA, Kenya & South America

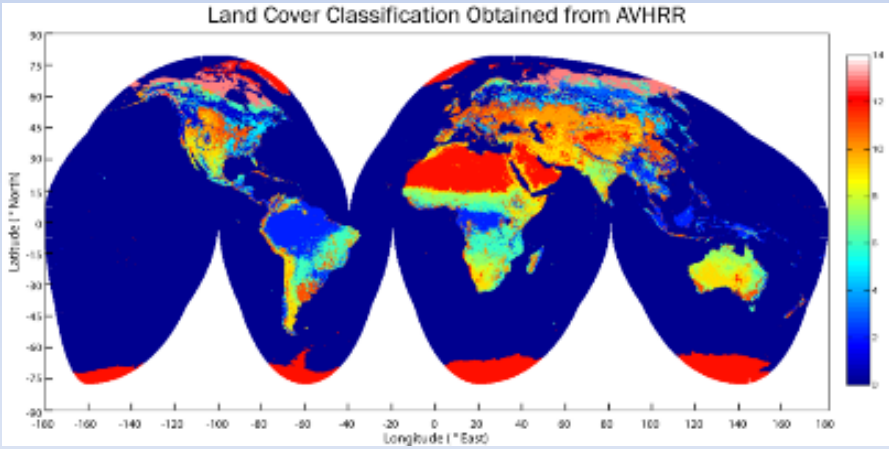
2011 – Exceptional drought in Texas (USA) and the Horn of AFRICA

2010 - Exceptional drought in RUSSIA and UKRAINE

Land Cover *(including Vegetation Type)*

- Land cover affects and is affected by global climate change in important ways. First, the interaction of land cover and the atmosphere causes a regulation of the hydrologic cycle and energy budget, which makes it necessary for weather and climate prediction.
- Land cover also plays a major role in the carbon cycle by acting as a source and a sink of carbon.
- Ongoing global land cover monitoring system integrates information from three common observational scales:
  - Moderate resolution satellite data (e.g. AVHRR, MODIS or MERIS type satellite sensor);
  - fine resolution satellite data (from Landsat and SPOT type satellite sensors); and
  - in situ observations (or very high resolution remote sensing data: IKONOS, QuickBird, aerial photo).
- Synergistic use of optical and active remote sensing (i.e., RADAR and LIDAR) data sources are improving the land cover characterization.

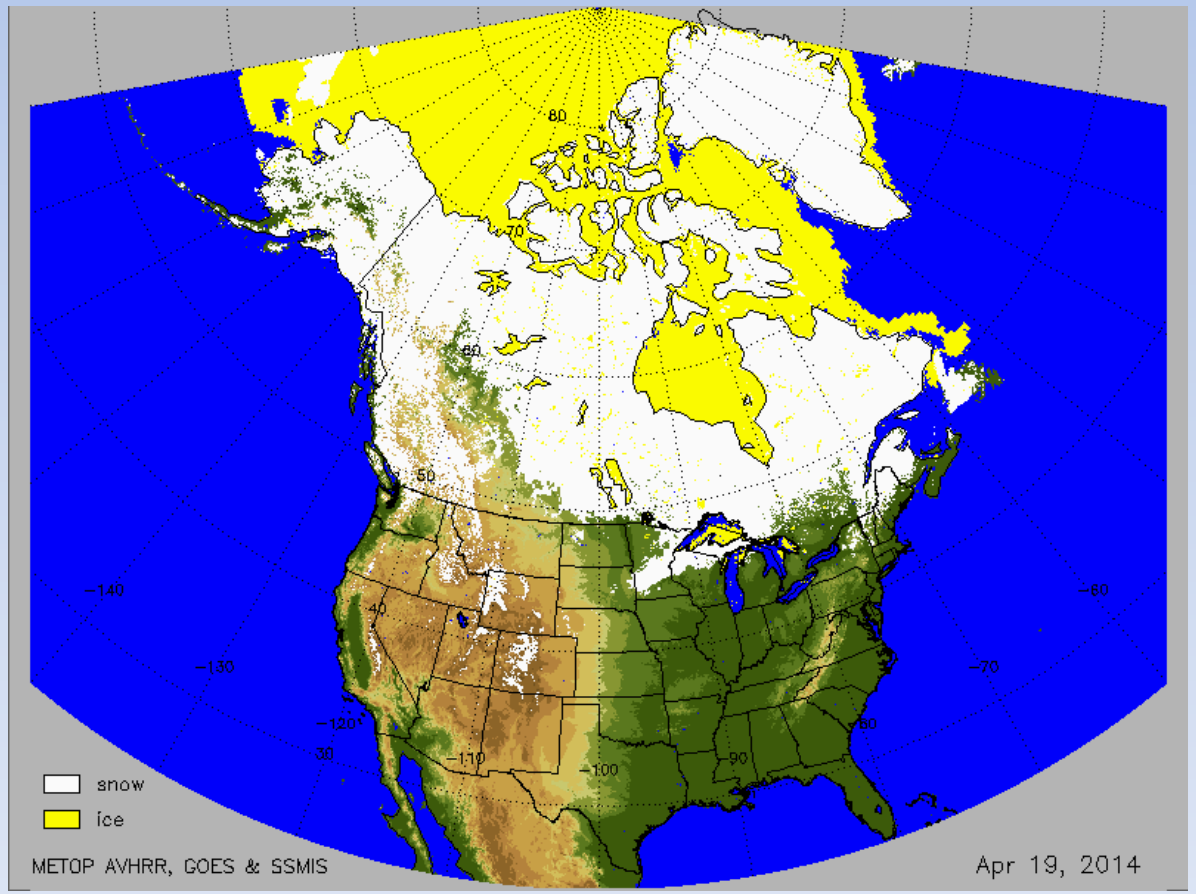
Land Cover Properties from Satellites
(European Commission Joint Research Centre, Ispra)



Value	Label
0	Water
1	Evergreen Needleleaf Forest
2	Evergreen Broadleaf Forest
3	Deciduous Needleleaf Forest
4	Deciduous Broadleaf Forest
5	Mixed Forest
6	Woodland
7	Wooded Grassland
8	Closed Shrubland
9	Open Shrubland
10	Grassland
11	Cropland
12	Bare Ground
13	Urban and Built

Automated snow mapping system

The automated snow mapping system uses synergy of observations in the visible, infrared and microwave spectral bands from operational polar orbiting and geostationary satellites to generate daily global maps of snow and ice cover.
The current version of the system incorporates data from the following satellite sensors: METOP-A AVHRR, DMSP F-16,-17 and -18 SSMIS, GOES-East and -West Imager, MSG SEVIRI

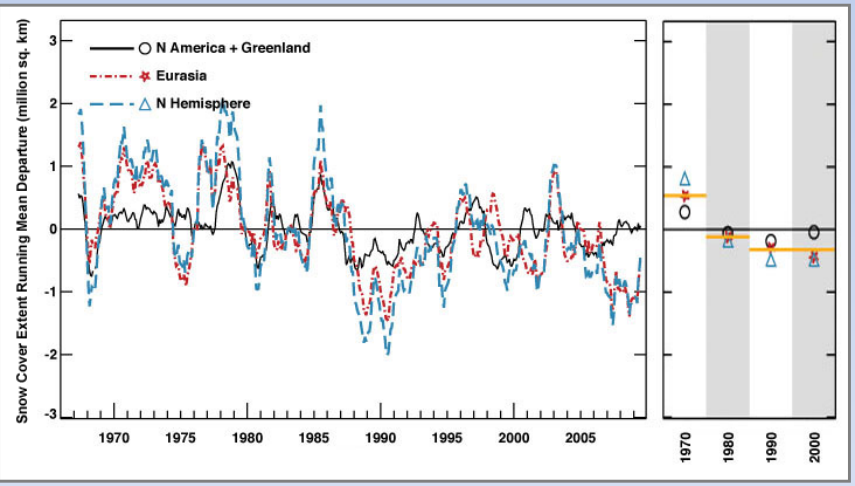


Product developed by:
Dr. Peter Romanov
(NOAA-CREST)

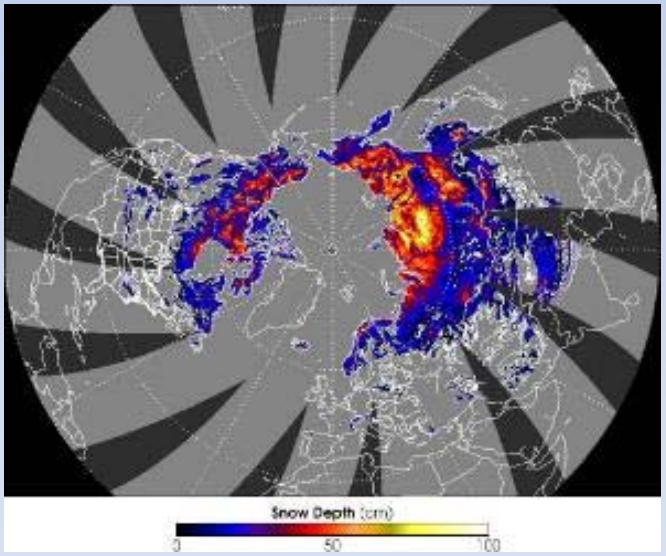
http://www.star.nesdis.noaa.gov/smcd/emb/snow/HTML/snow.htm

Snow Cover Extent

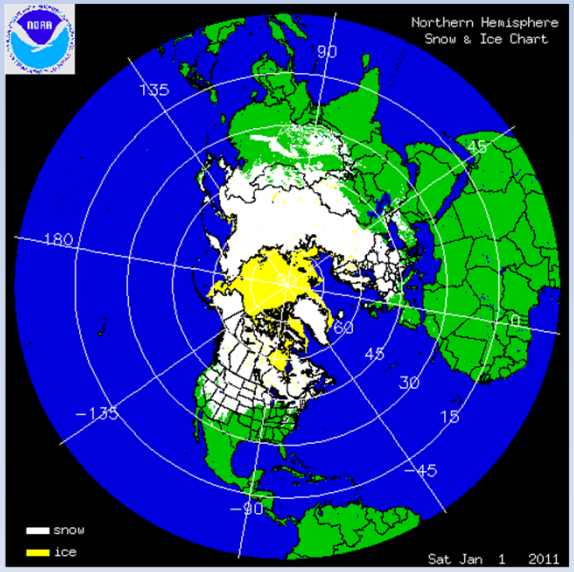
- Since 1966 NOAA has produced weekly snow extent charts for Northern Hemisphere land surfaces using visible-band satellite imagery.
- Due to the ability to penetrate most clouds, provide data during darkness, and to provide a measure of snow depth or water equivalent, passive microwave remote sensing can enhance snow measurements based on optical data alone.



Mean SCE anomalies (in million sq. km) by continent for the period of record. Decadal average departures are shown in orange. Normals based on 1971-2000. Source: State of the Climate, BAMS 2009 Vol. 91.

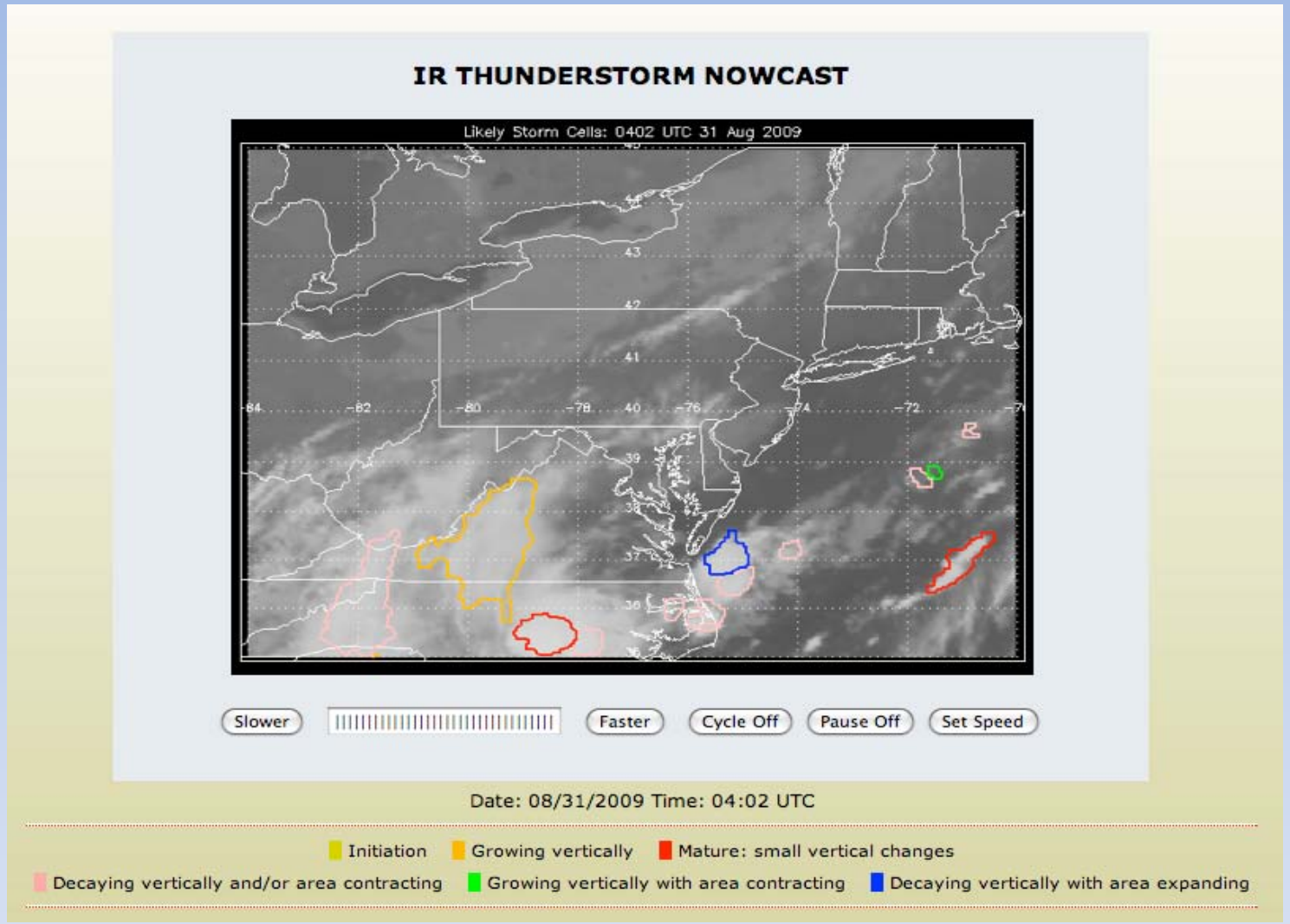


Snow depth derived from EOS (AMSR-E) on the Aqua satellite.

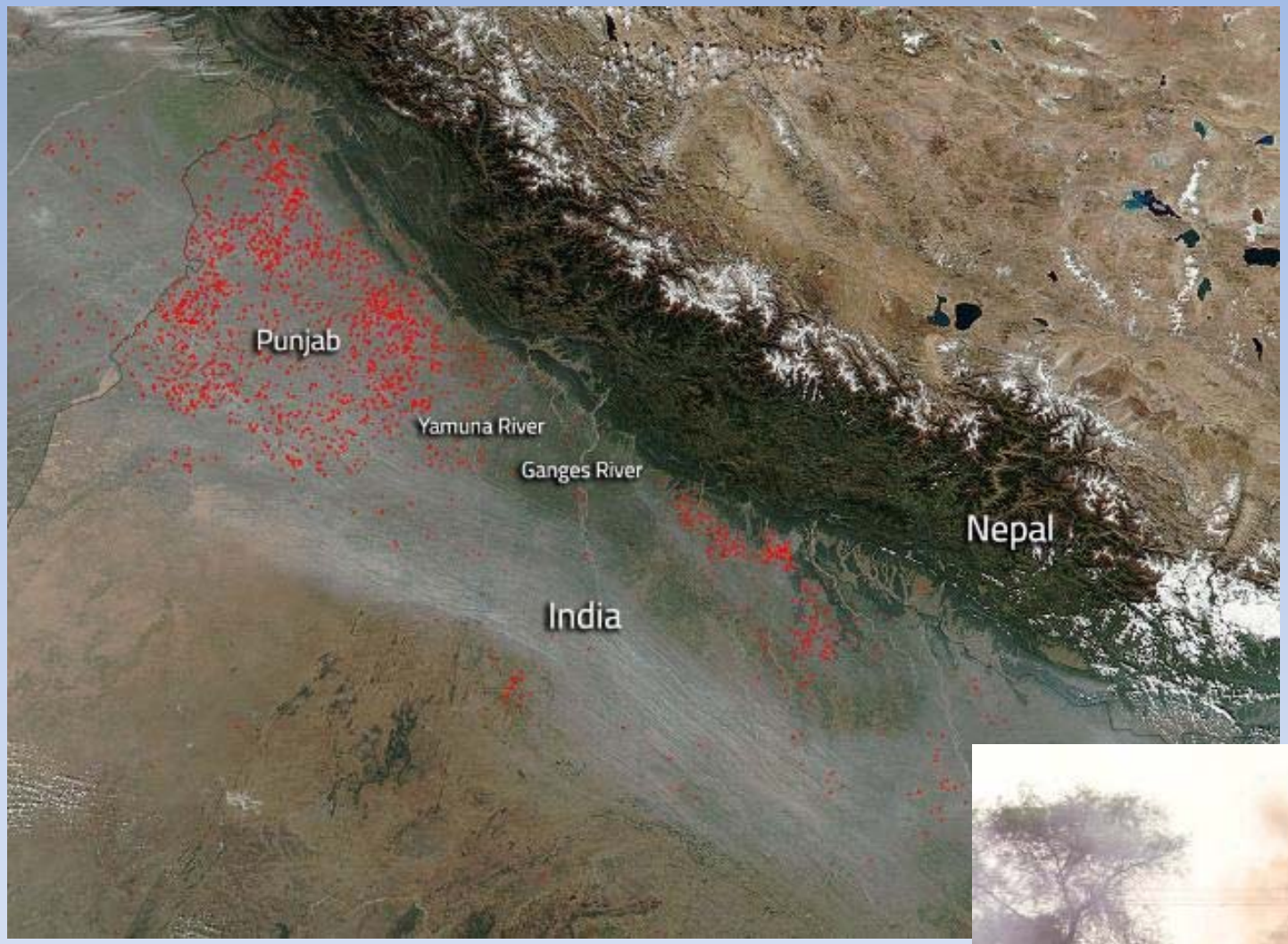


Operational products of areal extent of snow Cover by Interactive Multisensor Snow and Ice Mapping System (IMS) Daily Northern Hemisphere Snow & Ice Analysis.

NOAA-CREST Satellite Receiving Station

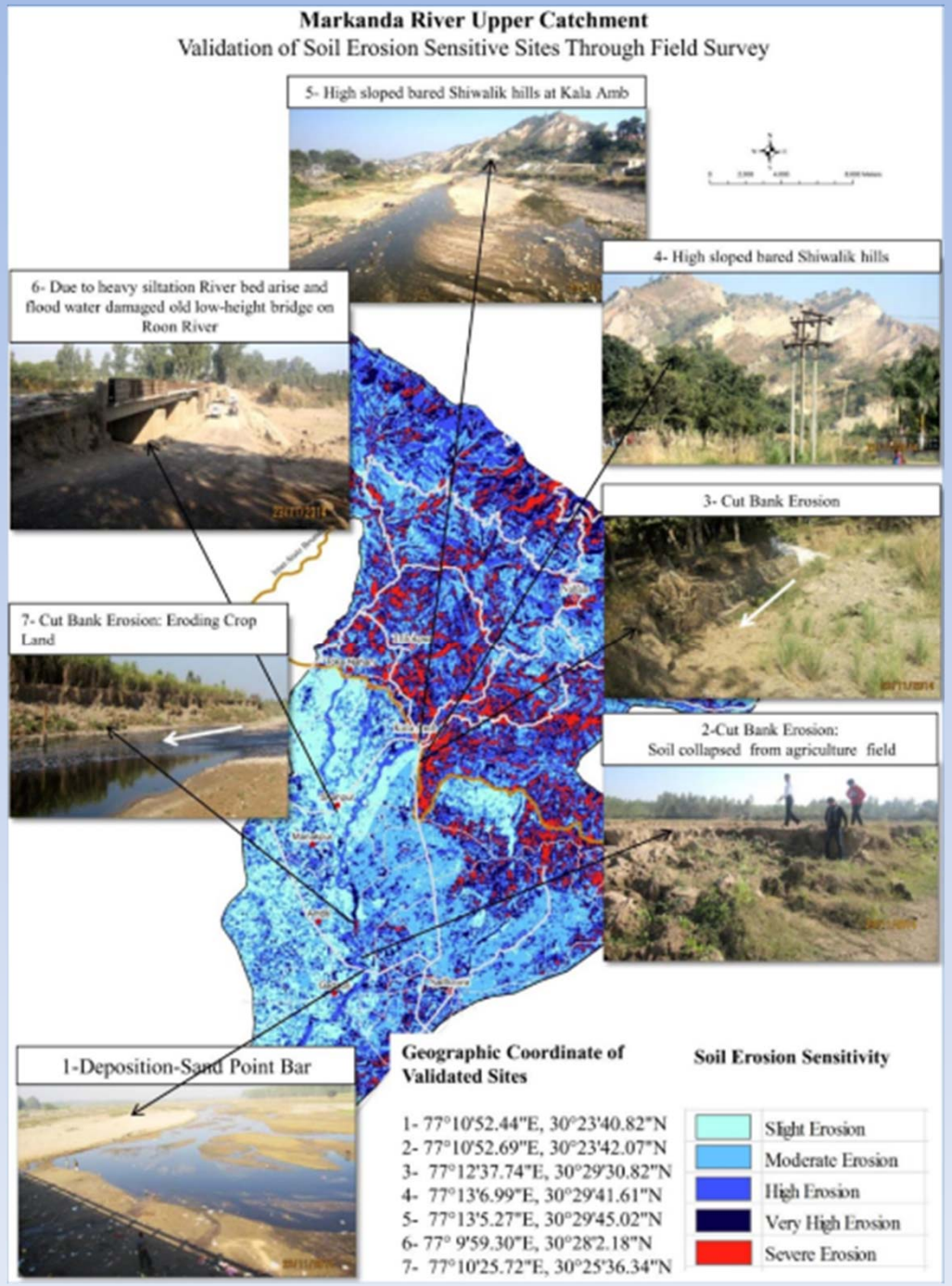


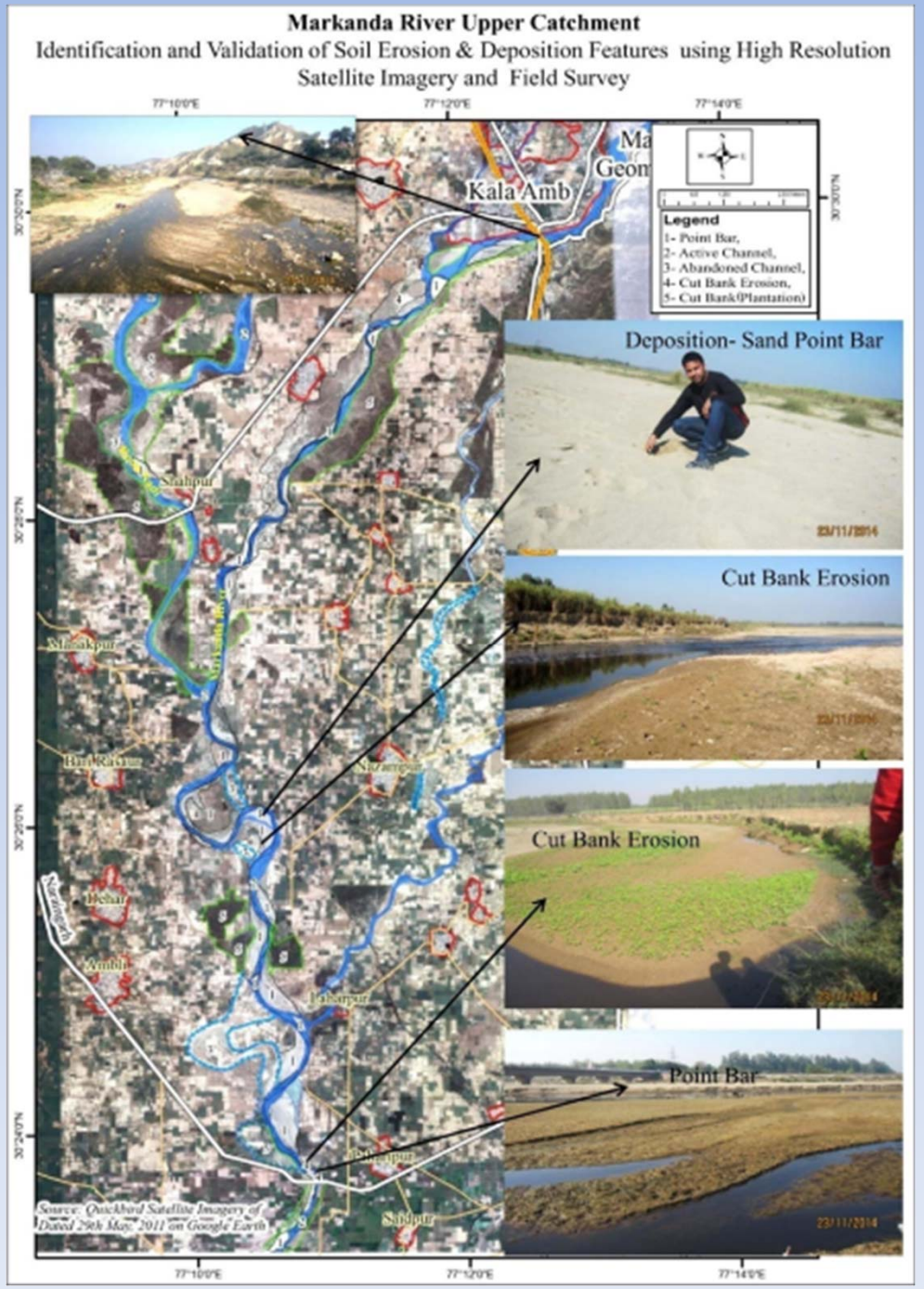
Agriculture Fire



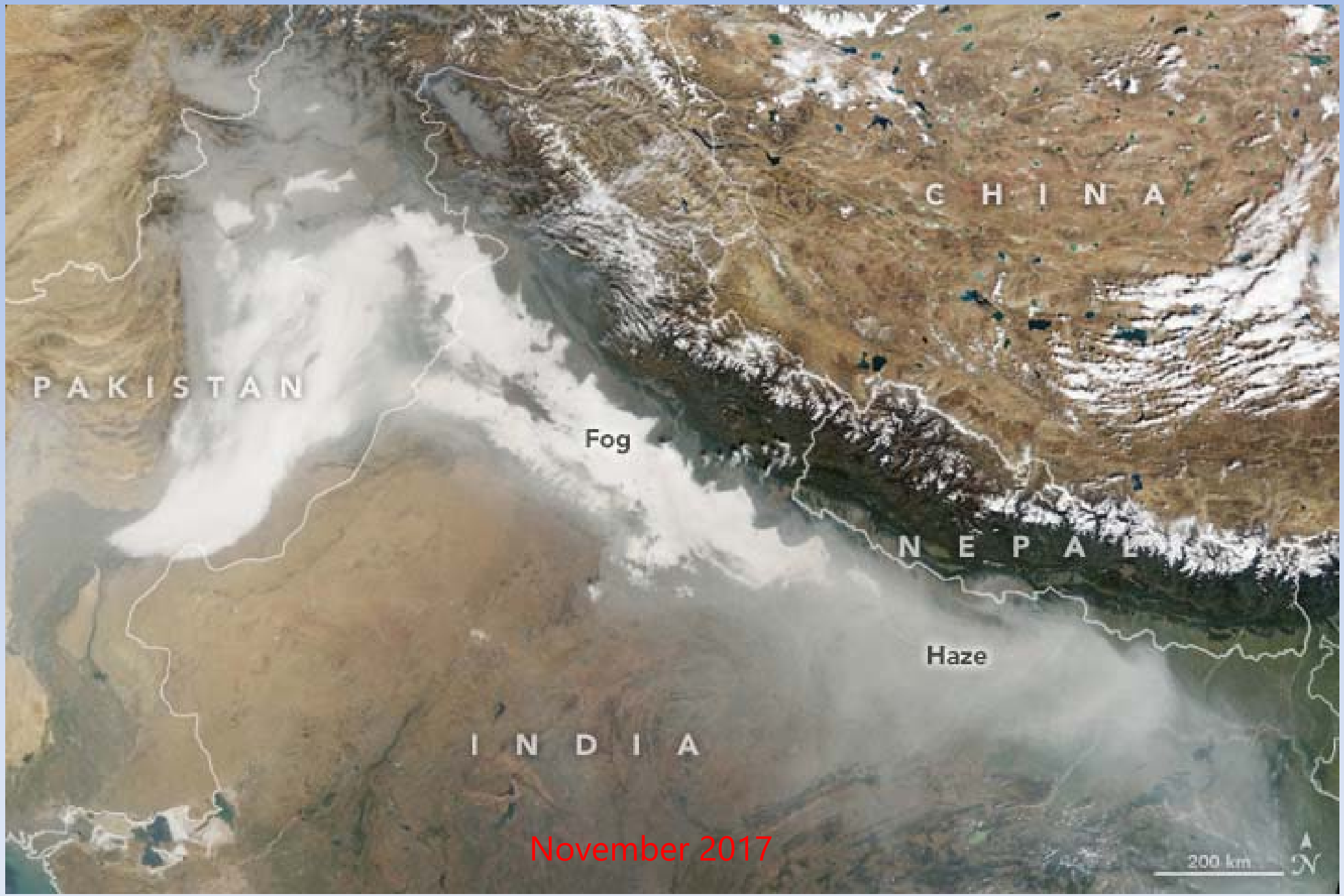
NASA's Suomi NPP Satellite Shows Agricultural Fires

Soil Erosion Mapping





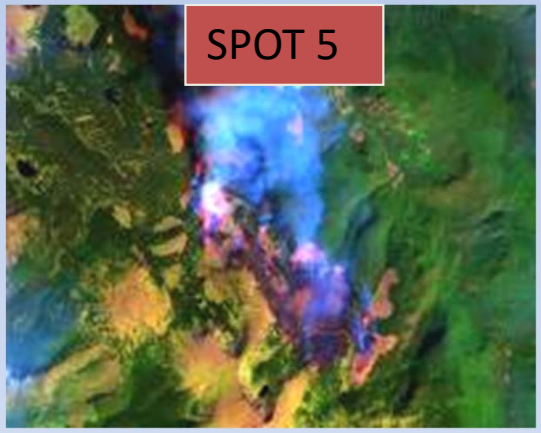
MODIS Satellite Data for Fog and Haze



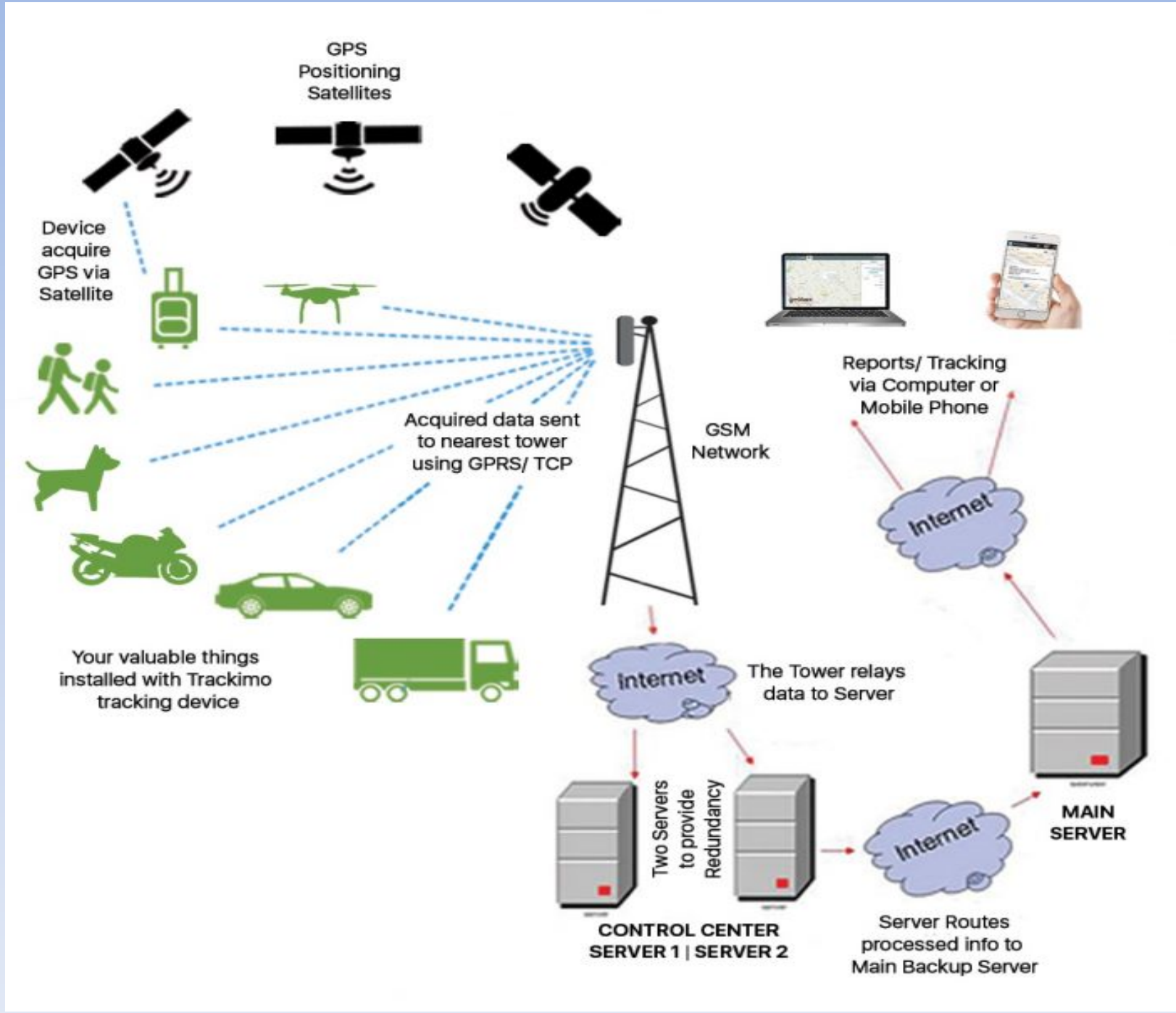
Satellite data for crop/vegetation mapping

Some satellite imagers:

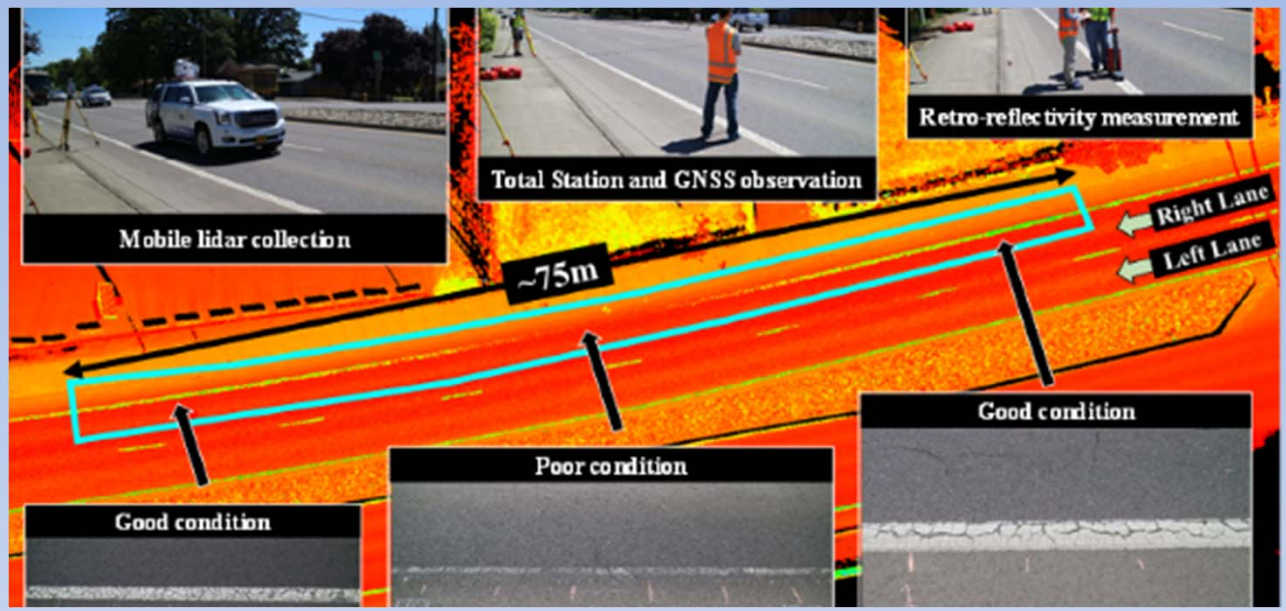
- Landsat 1-8 (1972 – now) 30m Resolution
- SPOT 1-7 (1986-now) 1.5m Resolution
- IKONOS (1999) 0.8m Resolution
- Quickbird 1-2 (2000) 0.61m Resolution
- RESOURCESAT 1-2A (2003) 5.8m Resolution
- ASTER (2000) 15m Resolution
- MODIS (2002 – now) 250m Resolution
- AVHRR (1998 – now) 1.1km Resolution



GPS and Tracking

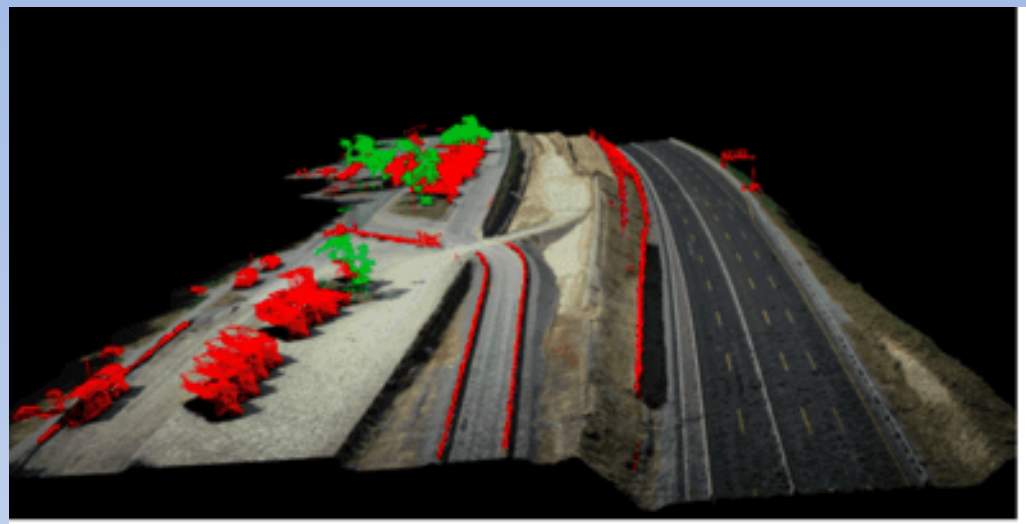


Drone for Civil Engineering

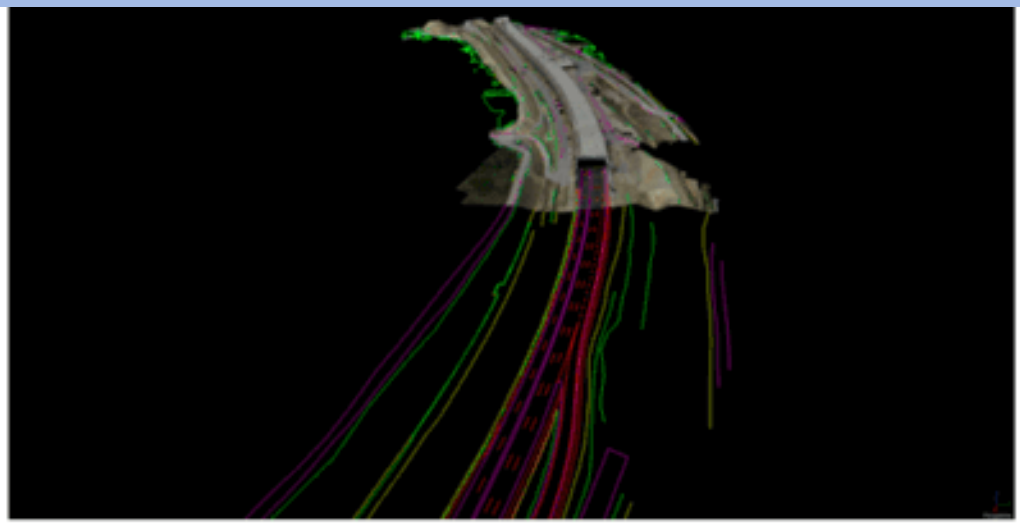


Construction Surveying
to Create Precise 3D Models

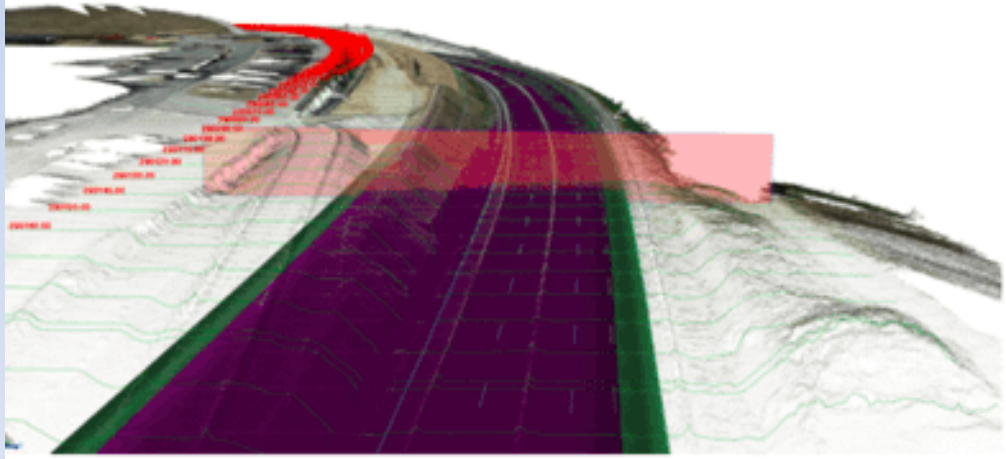
LiDAR for Digital terrain and surface modelling



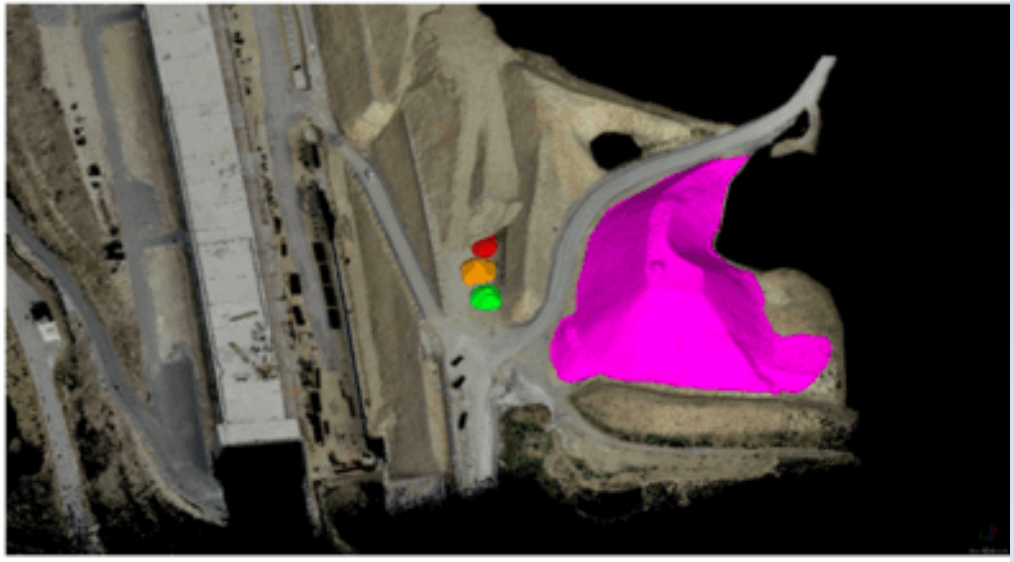
Point cloud classification



Vectorization

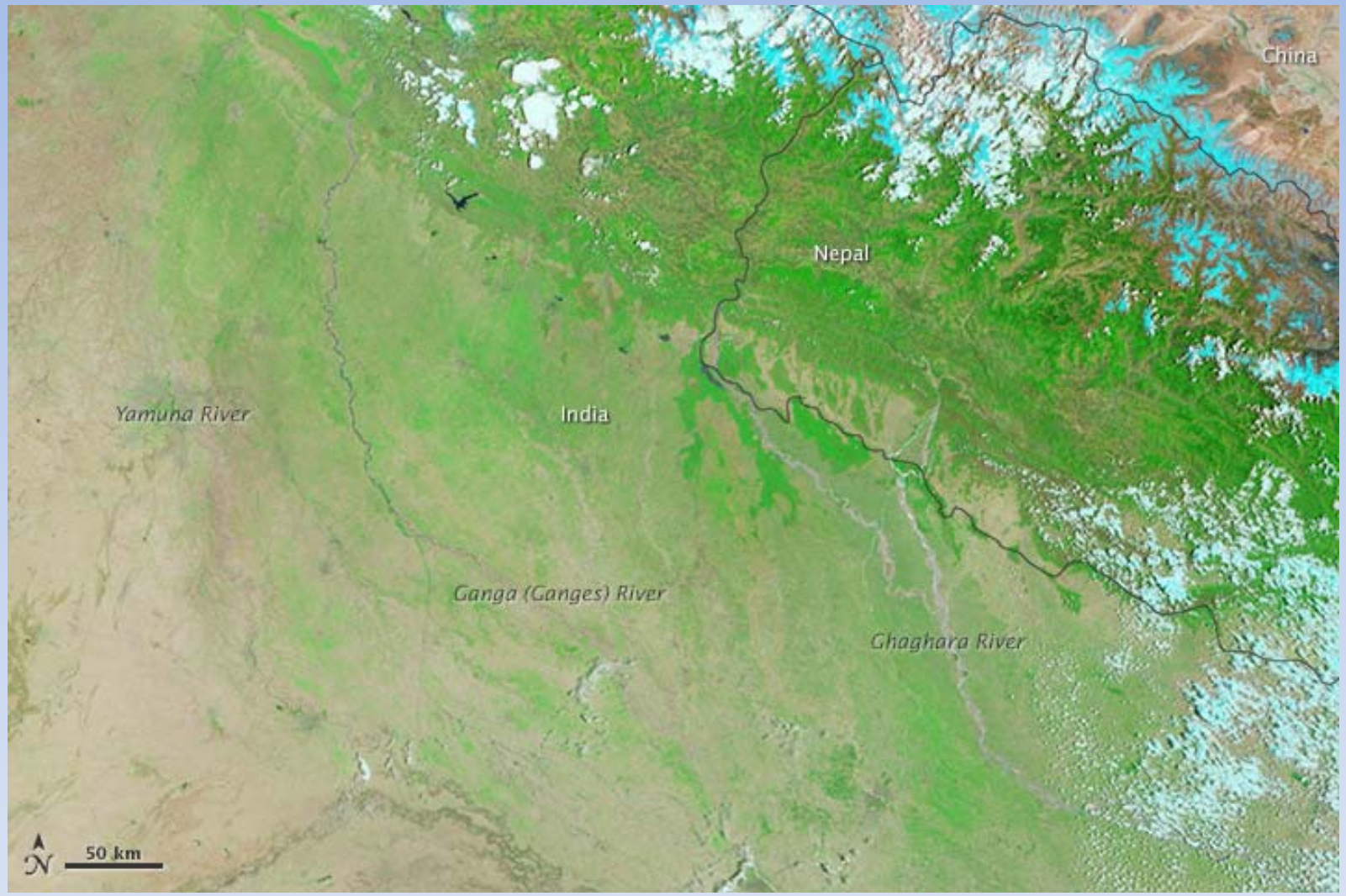


Building information modelling (BIM)



Volume and mass calculation

Snow-Melt Flood in Nepal



The Moderate Resolution Imaging Spectro-radiometer (MODIS) on NASA's Aqua satellite observed the flooding on May 30, 2013.

Snow-Melt Flood in Nepal

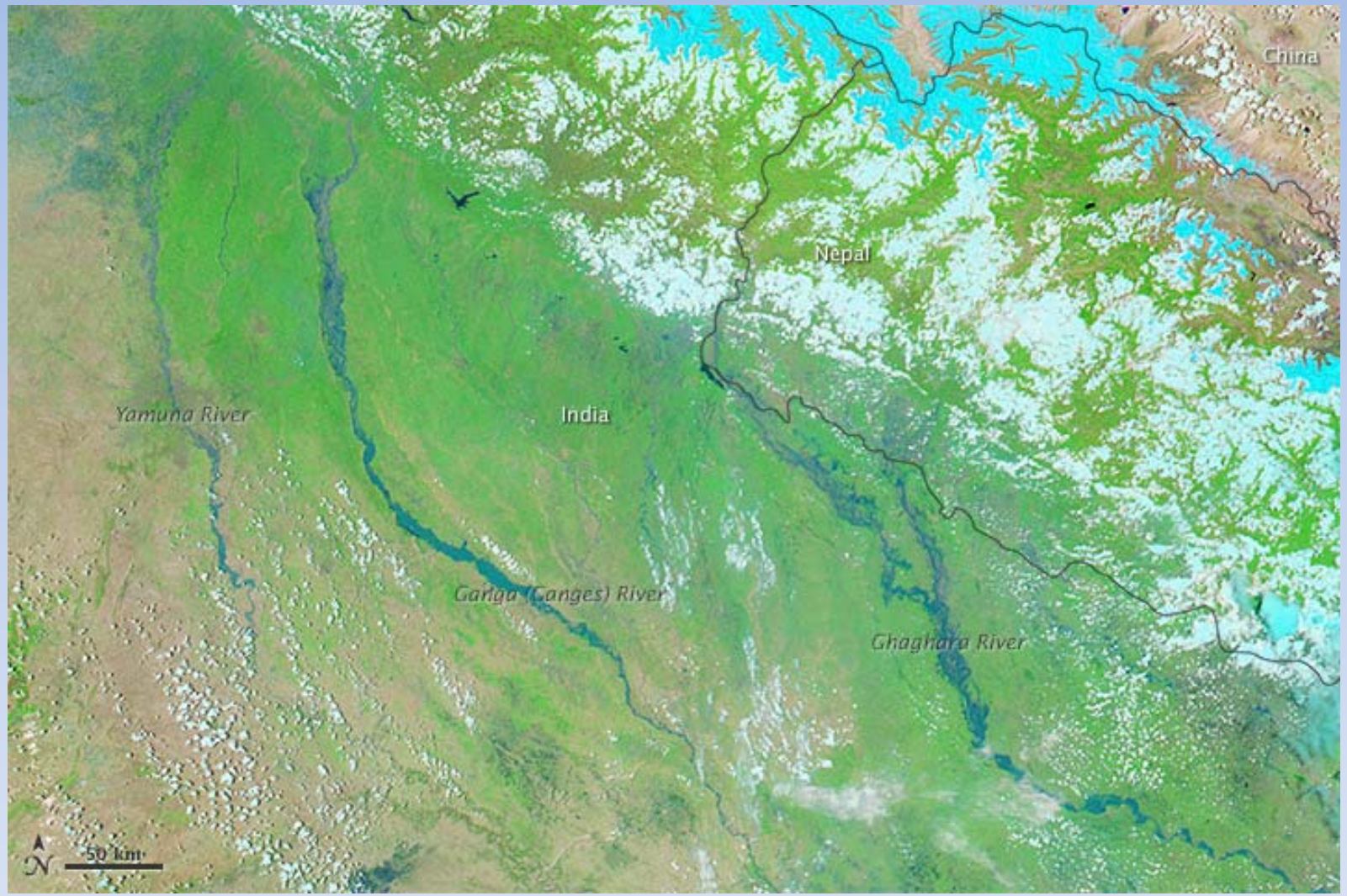
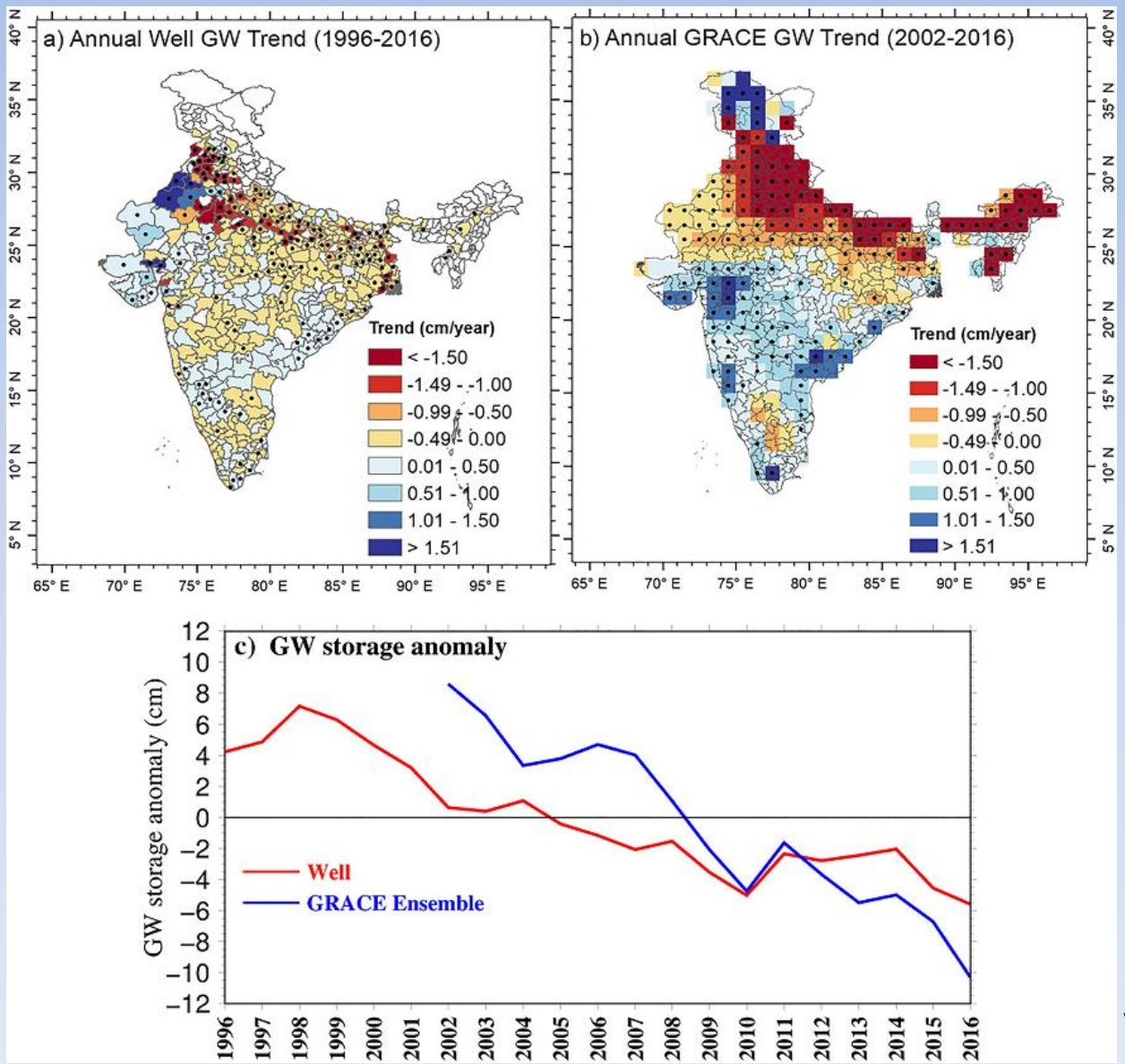


Image taken on June 21, 2013, showing flooding area

Monitoring Urban Floods Using Remote Sensing

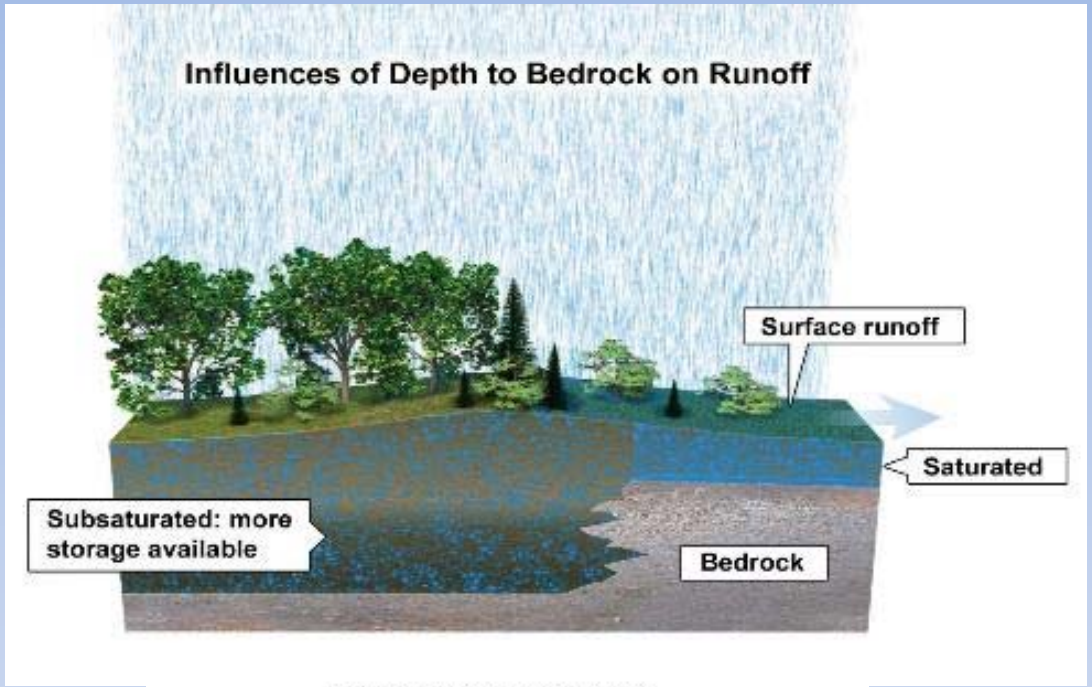
Groundwater

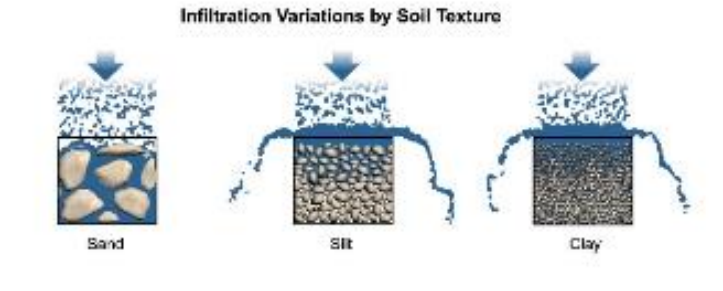
- Groundwater storage variations using the Gravity Recovery and Climate Experiment (GRACE) mission has been demonstrated by measuring subtle temporal variations in gravity.



Vimal Mishra et al 2018

Soil moisture

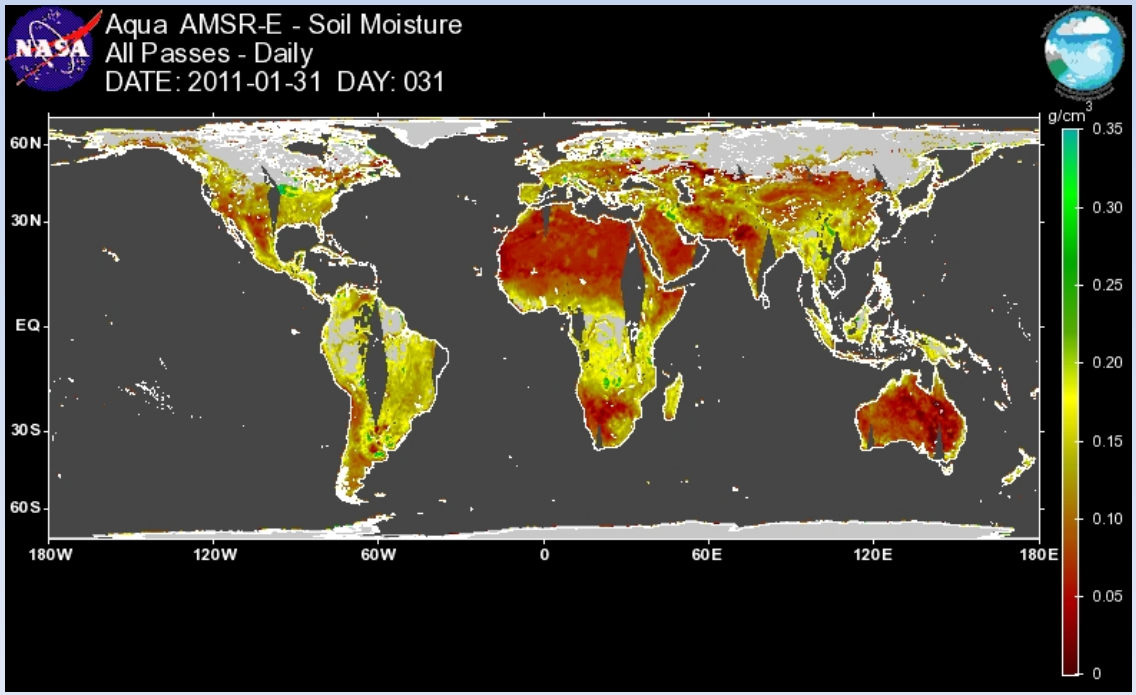


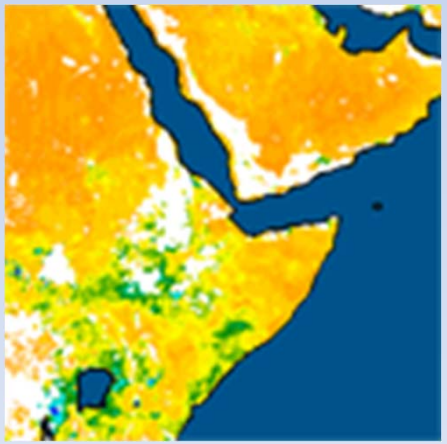


- Weather prediction modeling
- Hydrological modeling
- Flash flood warnings
- Soil erosion/ mud slide
- Improving crop yield (Irrigation scheduling)
- Optimize use of agro-chemical.

Soil Moisture

- **ERS-1 and ERS-2:** C-Band Scatterometer, ESA, 1991-2010.
- **AMSR-E:** Multi-frequency radiometer, NASA/JAXA, 2002-2011.
- **ASCAT**: C-Band Scatterometer, EUMETSAT/ESA, 2006-2020.
- **Coriolis WindSat**: Multi-frequency polarimetric radiometer, 2003-Current
- **SMOS**: L-band radiometer, ESA, 2010-Current.
- **SMAP:** L-band radiometer, NASA, Launch in 2014.





SMOS Soil moisture Map 2011. Source: ESA

What Do Satellite Sensors See?

VIS, IR & Thermal IR

MW (low frequency-emission by rain)

MW (high frequency-scattering by ice)

Radar

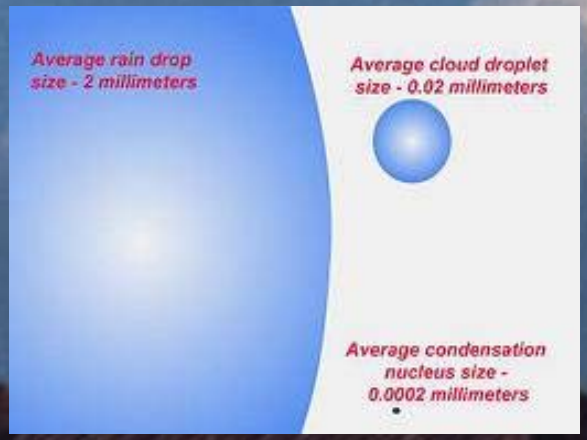
ICE

-10

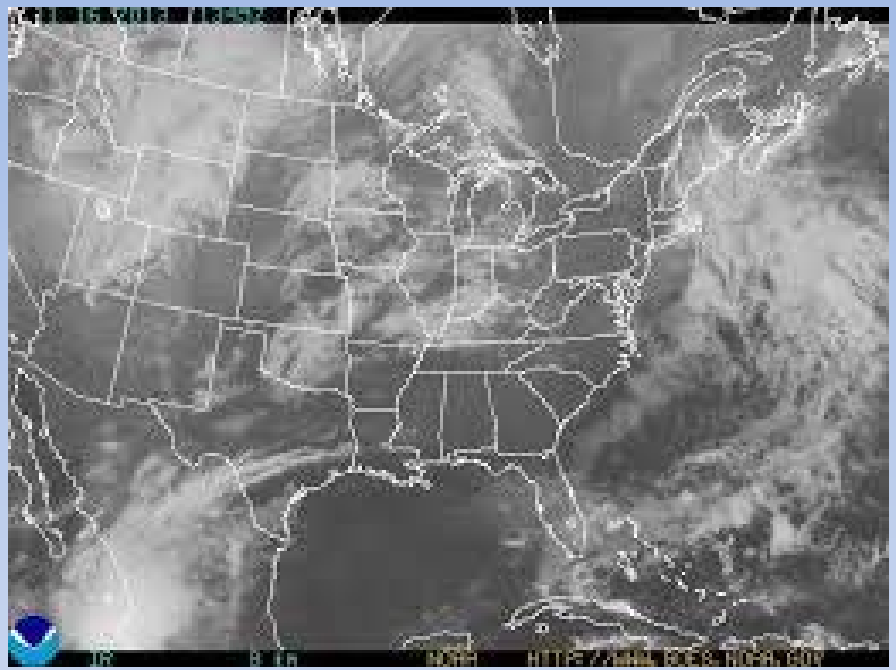
Mixed

0

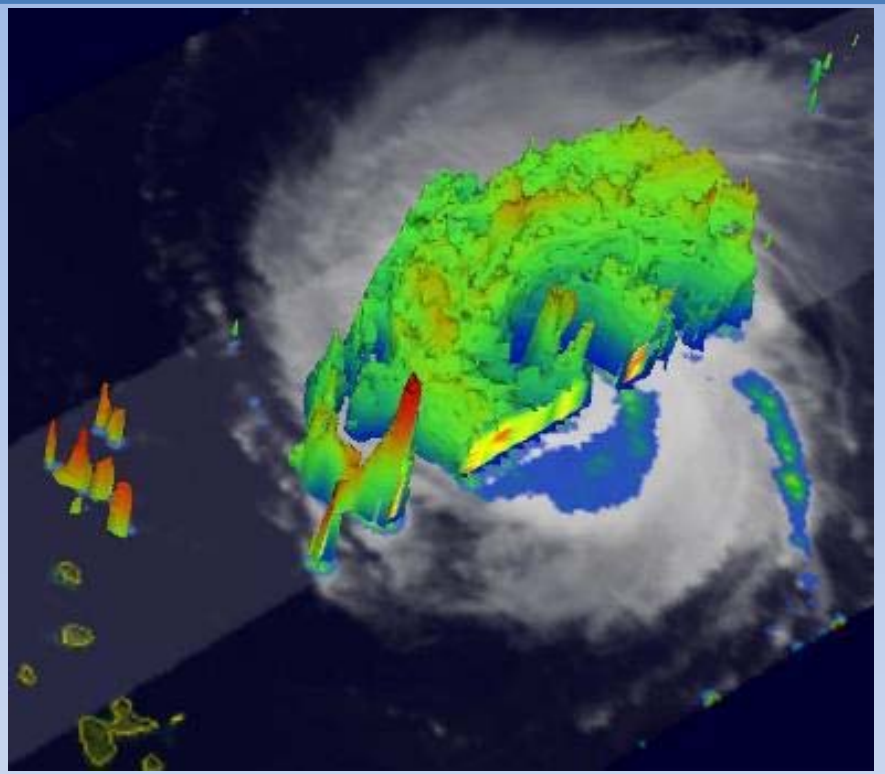
Liquid

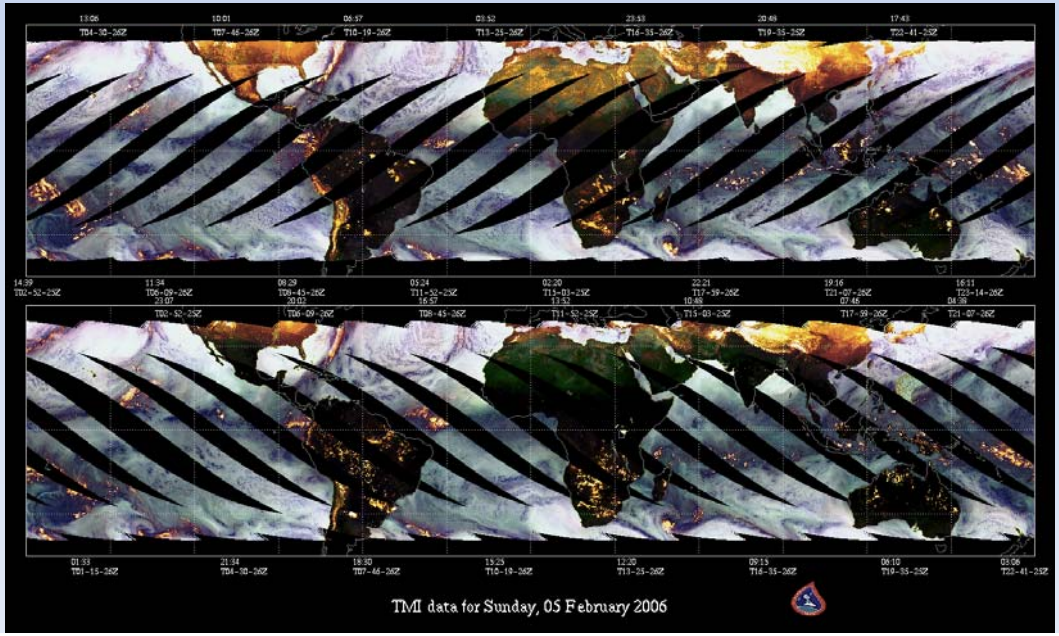


GOES, SSMI, TRMM Cloud Rainfall image



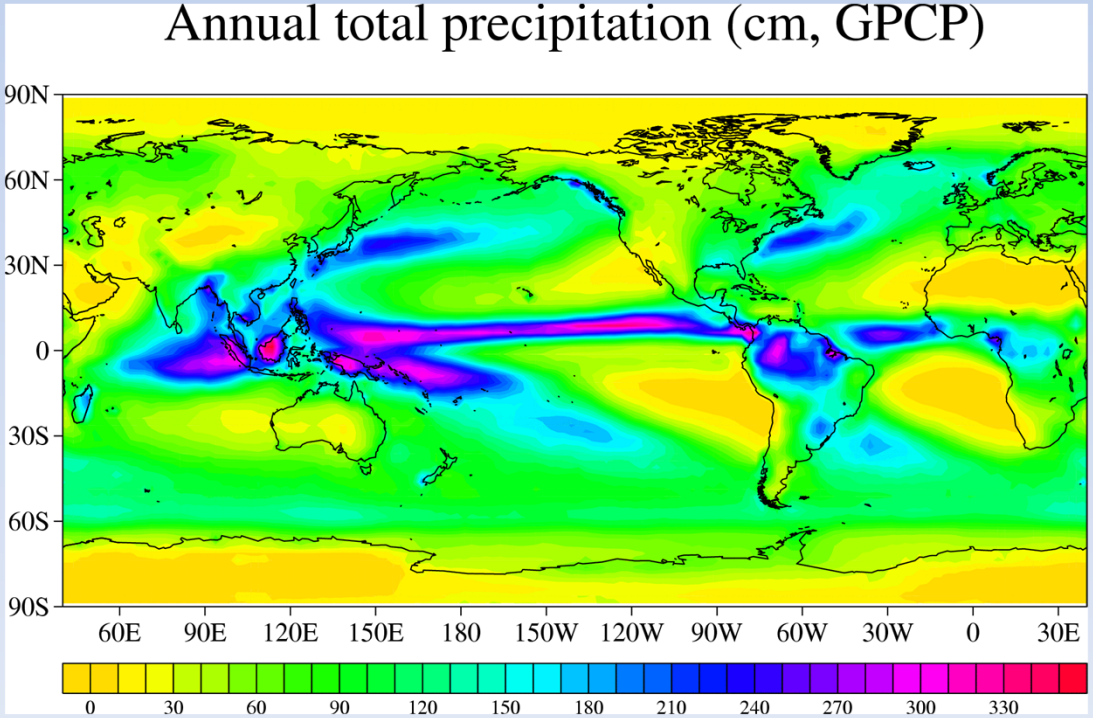
GOES VIS/IR Cloud image

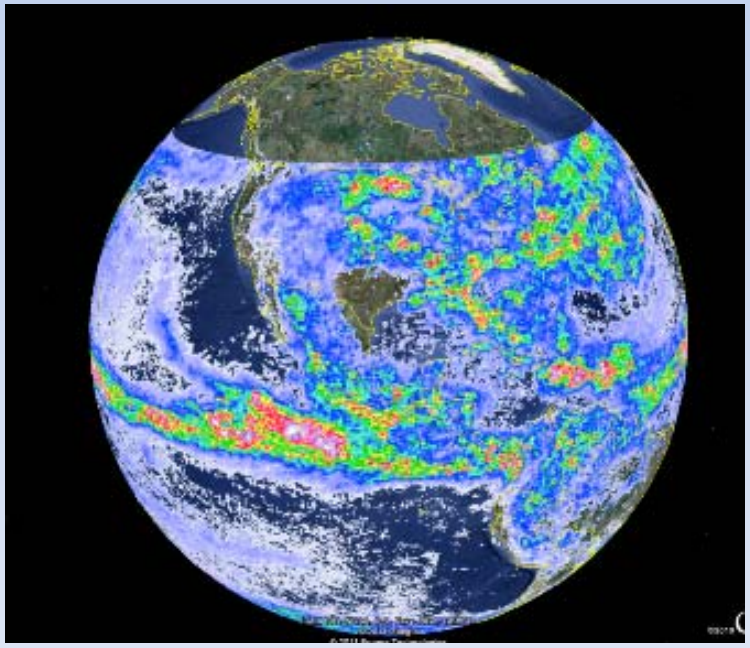




Global Precipitation Products

- Global Precipitation Climatology Project (GPCP)
  - Data from over 6,000 rain gauge stations, and satellite geostationary and low-orbit infrared, passive microwave, and sounding observations have been merged to estimate monthly rainfall on a 2.5-degree global grid from 1979 to the present.
- Tropical Rainfall Measuring Mission (TRMM)
  - TRMM consist of: Precipitation Radar (PR), TRMM Microwave Imager (TMI), Visible and InfraRed Scanner (VIRS), Cloud and Earth Radiant Energy Sensor (CERES), Lightning Imaging Sensor (LIS)
  - Produce Global (Between Latitude 35 N and 35 S) Real-Time 3-Hourly Precipitation Analysis.
- NOAA - CPC Merged Analysis of Precipitation (CMAP)
  - Monthly and pentad global gridded precipitation means. It includes a standard and enhanced version (with NCEP Reanalysis) from 1979 to near the present.

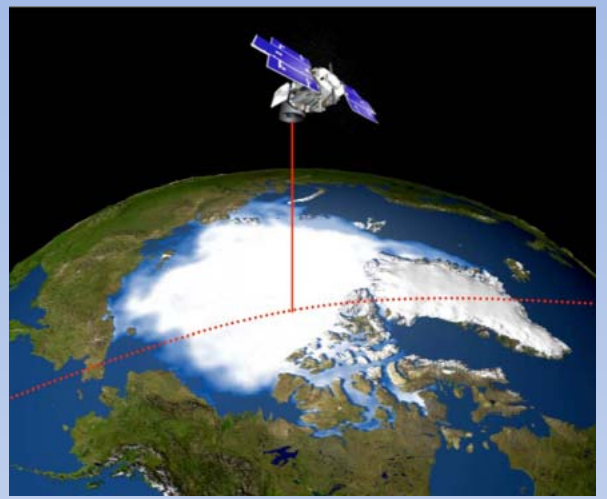




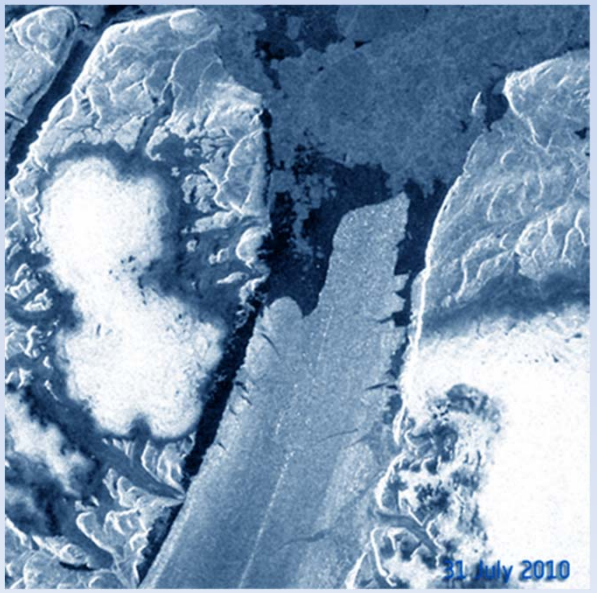
TRMM Precipitation

Glacier and Ice Caps

- Changes in glaciers provide some of the clearest evidence of climate change, constitute key variables for early-detection strategies in global climate-related observations, and have the potential to cause serious impacts on sea level, the terrestrial water cycle and societies dependent on glacier melt water.
- ICESat (Ice, Cloud,and land Elevation Satellite) is the benchmark Earth Observing System mission for measuring ice sheet mass balance.
- From 2003 to 2009, the ICESat mission provided multi-year elevation data needed to determine ice sheet mass balance.
- ICESat-2 is scheduled for launch in early 2016.
- Objective of ICESat Mission:
  - Quantifying polar ice-sheet contributions to current and recent sea-level change and the linkages to climate conditions.
  - Quantifying regional signatures of ice-sheet changes to assess mechanisms driving those changes and improve predictive ice sheet models.
  - Estimating sea-ice thickness to examine ice/ocean/atmosphere exchanges of energy, mass and moisture.



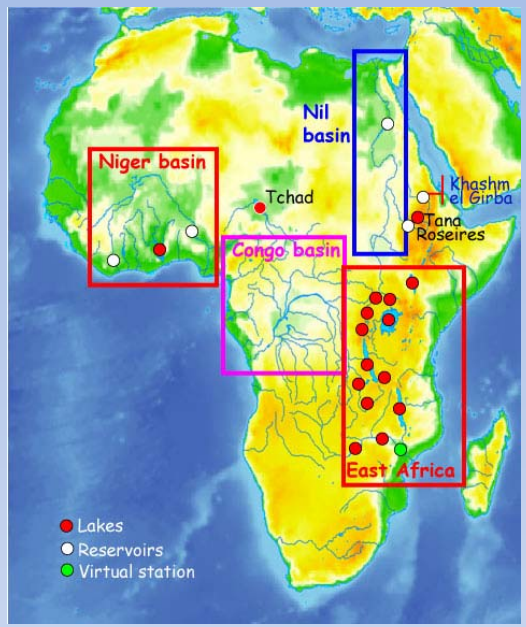
Schematic diagram of ICESat on a transect over the Arctic. ICESat uses a 1064 nm laser operating at 40 Hz to make measurements at 172-m intervals over ice, oceans, and land.

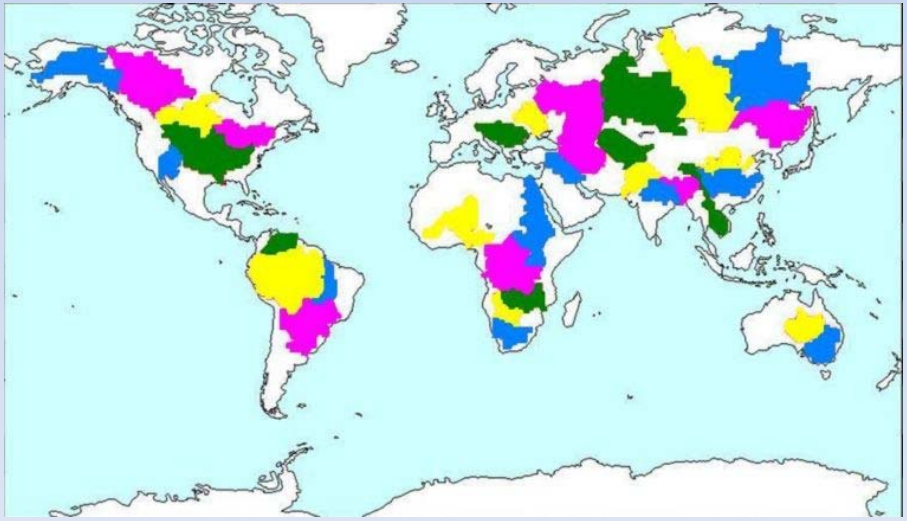


Time-series animation based on Envisat Advanced Synthetic Aperture Radar (ASAR) data from 31 July, 4 August, and 7 August 2010 showing the breaking of the Petermann glacier and the movement of the new iceberg towards Nares Strait. Credits: ESA

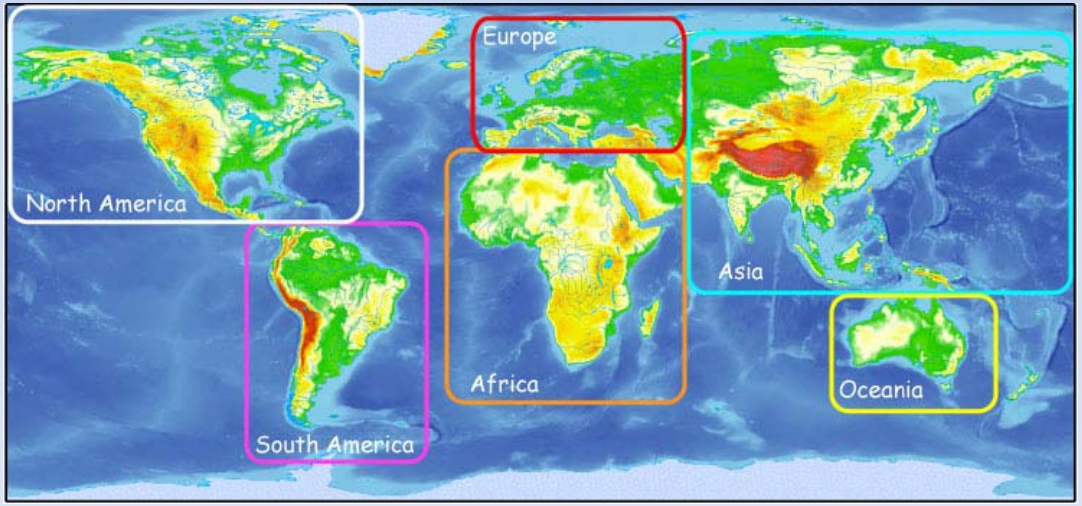
Lake Level

- Lake level is a complex index of natural water exchange within their watersheds. Therefore, long-term level fluctuations in natural (unregulated) lakes also reflect climate changes occurring in the region.
- Hydroweb provides lake level variations in time calculated from satellite radar altimetry.
- Lake Level data base contains time series over water levels of large rivers, lakes and wetlands around the world. These time series are mainly based on altimetry data from Topex/Poseidon for rivers, but ERS-1 & 2, Envisat, Jason-1 and GFO data are also used for lakes.





Continental water storage from gravimetry

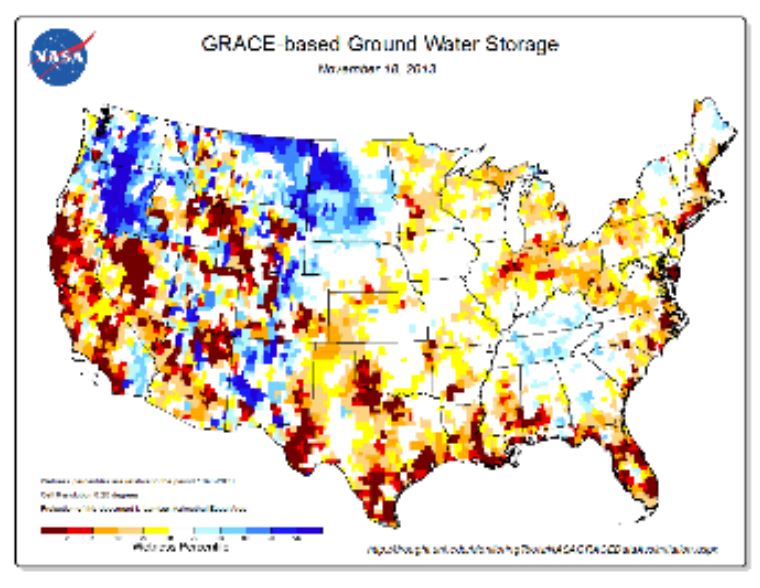


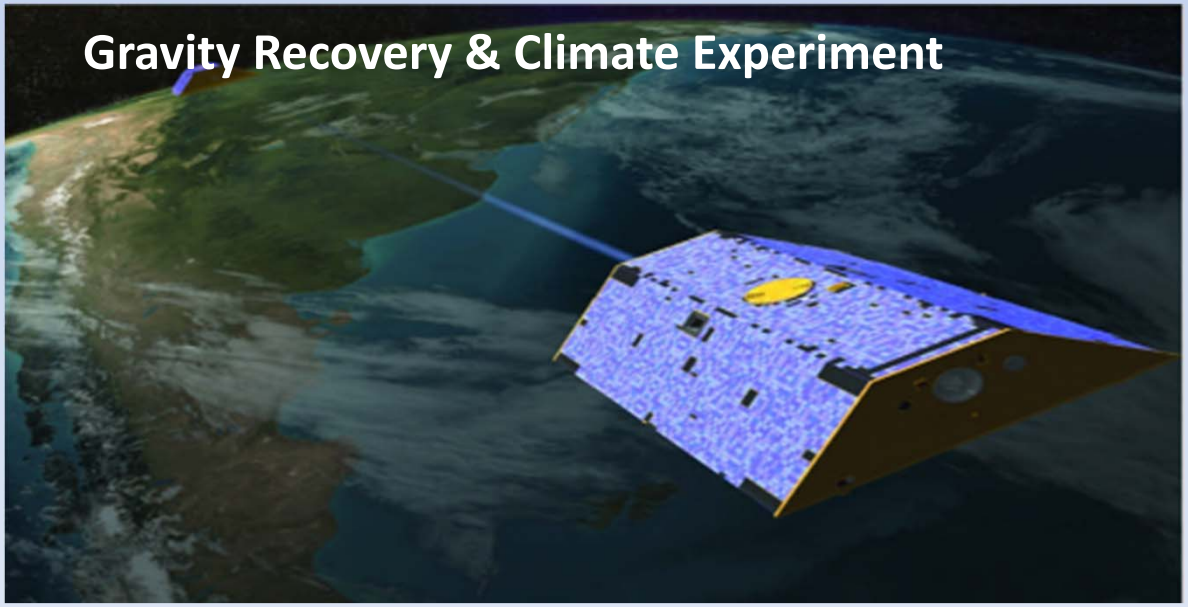
Hydrology by altimetry (Surface monitoring by satellite altimetry)

http://www.legos.obs-mip.fr/soa/hydrologie/hydroweb/index.html

Groundwater

- The feasibility of satellite observation of groundwater storage variations using the Gravity Recovery and Climate Experiment (GRACE) mission has been demonstrated by measuring subtle temporal variations in gravity.



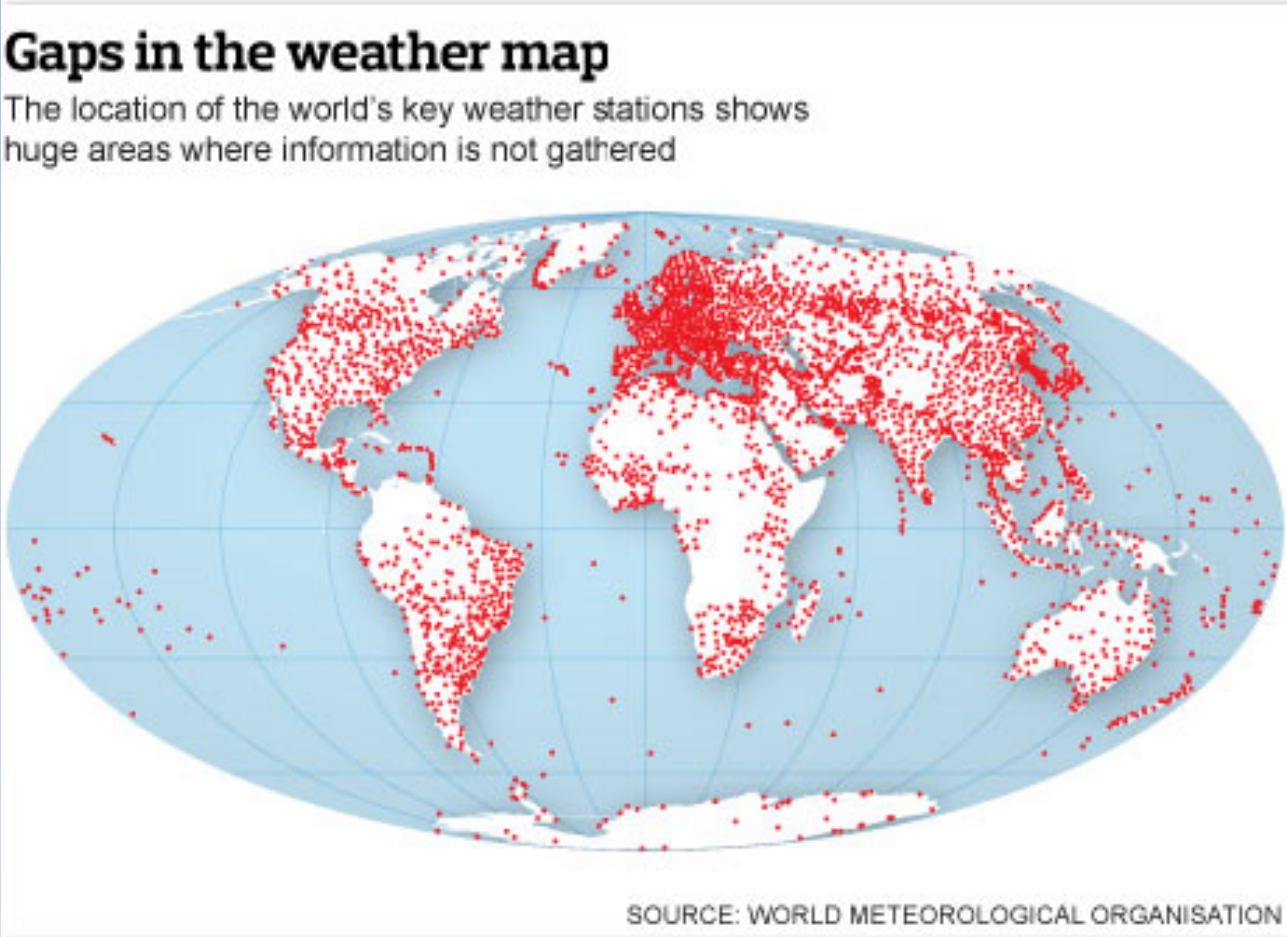


Data: Land Surface Observations and Satellites

Precipitation:	SSM/I, TRMM, AMSR-E, GOES, AVHRR, GPM
Radiation:	MODIS, GOES, AVHRR, **CLARREO**
Surface Temperature:	AVHRR, MODIS, SSM/I, GOES
Soil Moisture:	ERS-1,2, RADARSAT, SSM/I, AMSR-E, SMOS, SMAP
Groundwater:	GRACE
Snow Cover, Depth & Water:	AVHRR, MODIS, SSM/I, AMSR, GOES, **ICESat-2, DESDynI**
Streamflow:	Laser/Radar Altimeter
Vegetation:	AVHRR, Landsat TM, MODIS, GOES

Each of these satellites/sensors operates in multiple frequencies, that are used to derive one or more hydrological parameters.

Weather and Climate Data



Issues:

- Delay in processing the climate data (>1-3 years)
- Spatial and temporal gaps
- Limited measurements of variables (precipitation, temperature, wind speed, river runoff)

My research

CREST-SAFE - Snow Analysis and Field Experiment

This Field campaign setup near National Weather Service at Caribou, ME in 2010 to support NASA/NOAA's Snow Algorithms.

2010
- 37 GHz Radiometer
- 89 GHz Radiometer
- Snow Temperature Profiler

2011
- Snow Pillow (SWE)
- Rain/Snow Gauge
- Soil Moisture (2.5, 5, 10cm)
- Soil Temp (2.5, 5, 10cm)
- Network Cameras (2)

2012
- Infrared Thermometer (Skin Temperature)
- Snow Depth Sensor
- Radiation Sensors
- Wind Speed/Direction, Humidity/air temperature

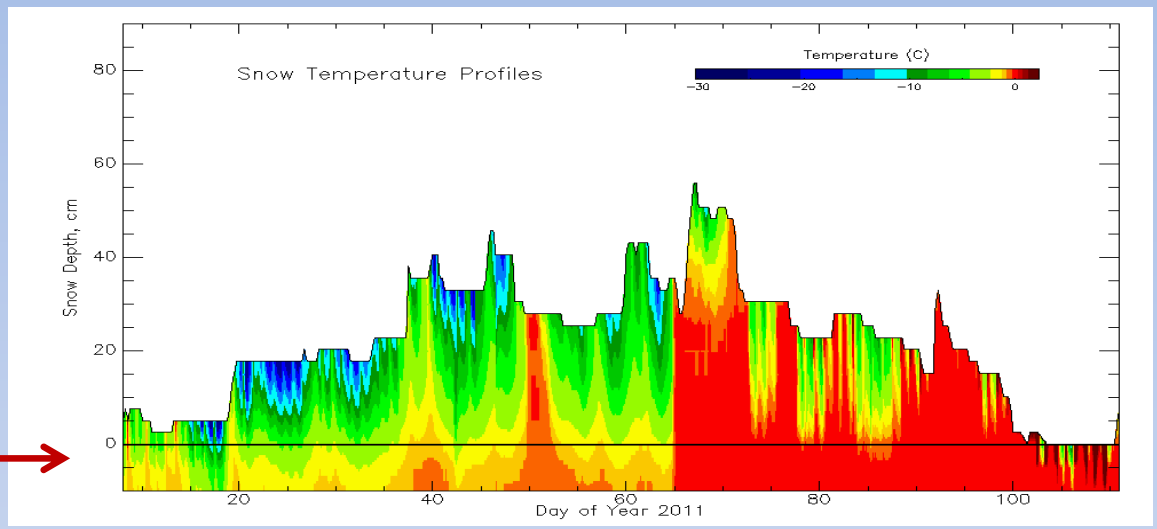
2013
- DoD / Navy Funding
- 19 and 10.65 GHz Radiometers
- CIMEL Sun Photometer

2014
- Snow Wetness profiler
- GMON3 SWE Sensor

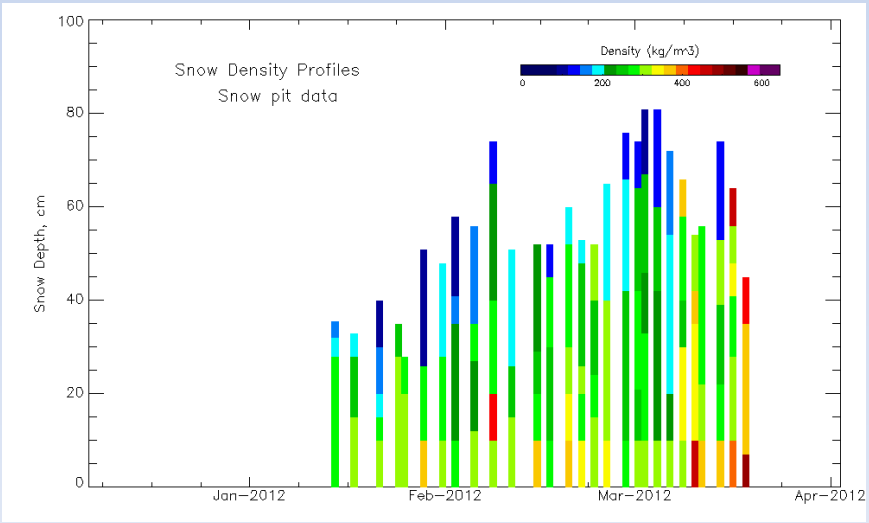
CREST-SAFE - Snow Analysis and Field Experiment

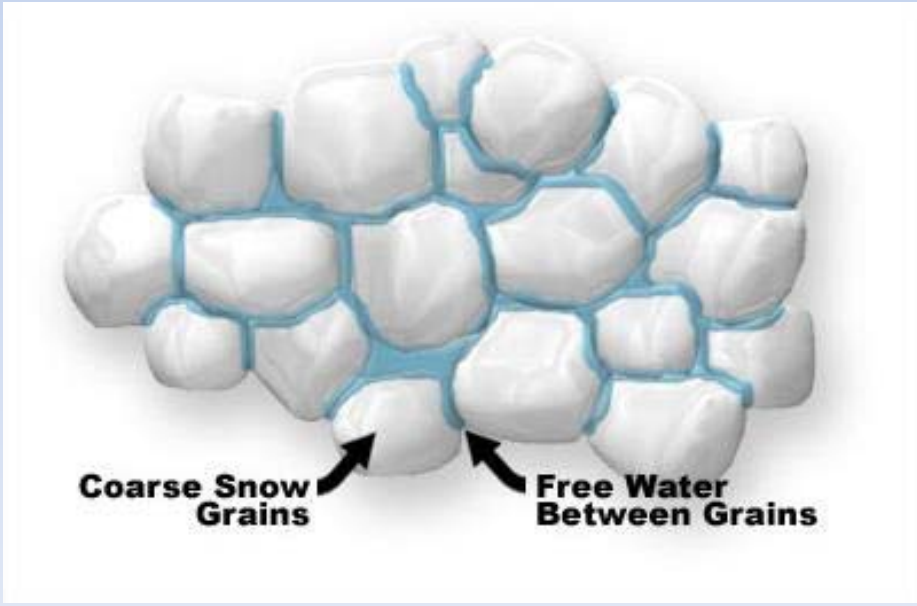
CREST-SAFE - Snow Analysis and Field Experiment

Snow temperature profiler time series



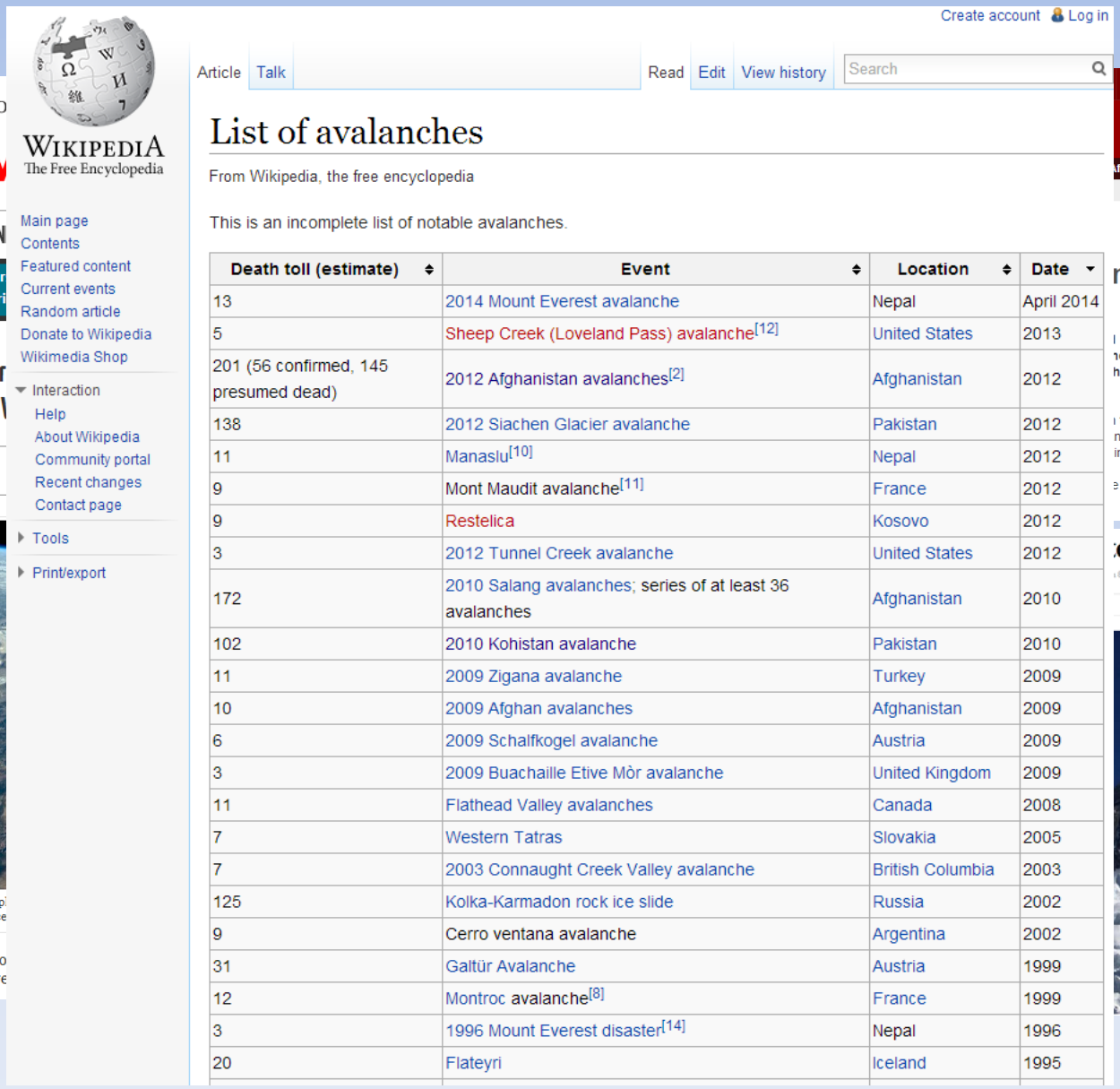
Manual Measurements:



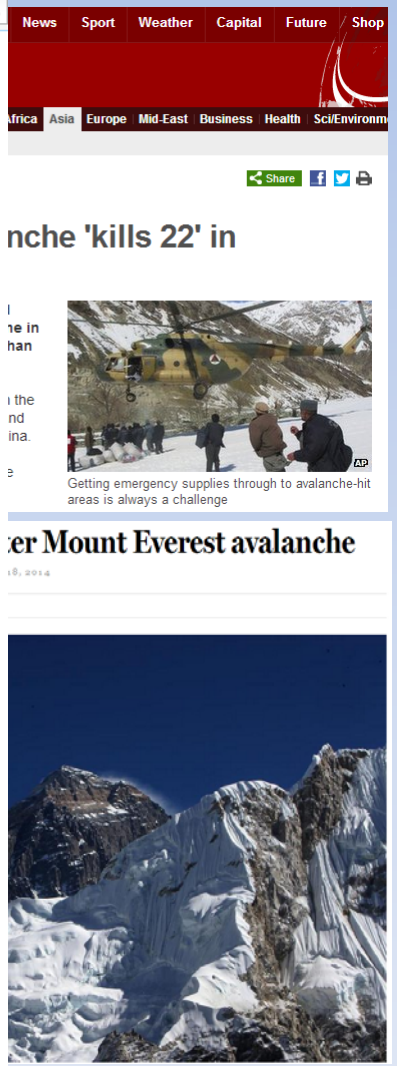


Study and monitor snow: Why?

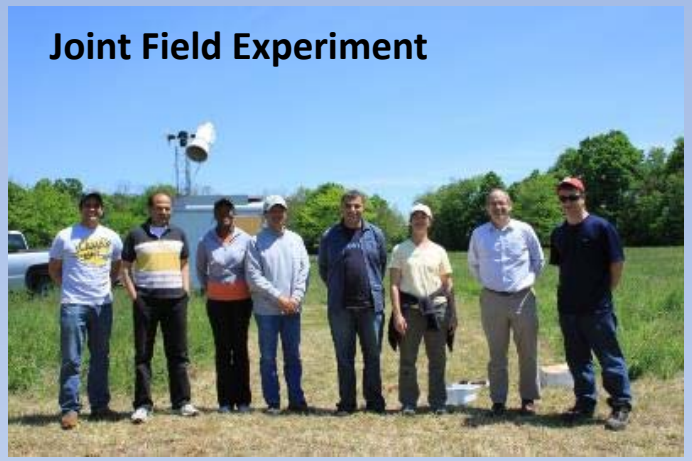
- Snow is an important factor for Transportation, Hydro-power generation, Agriculture, Wildlife, Recreation.

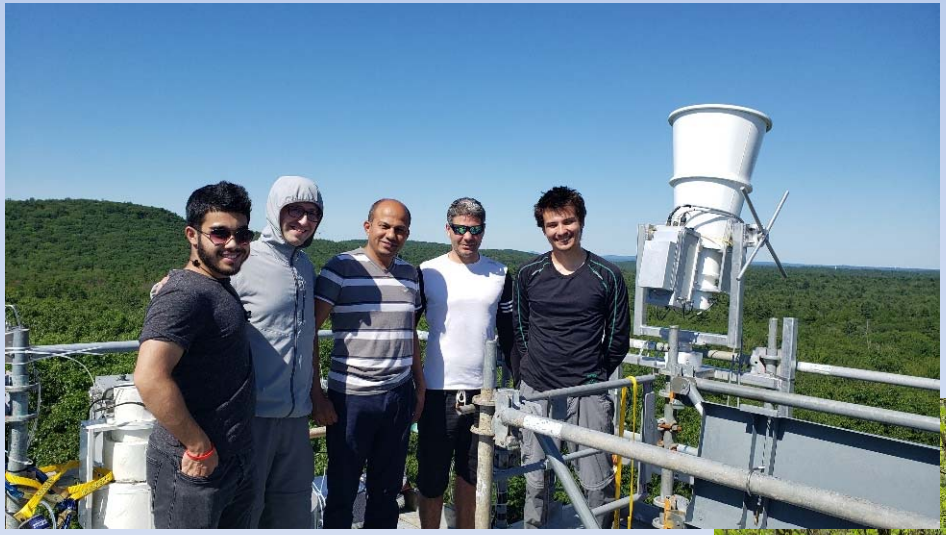


Death toll (estimate)	Event	Location	Date
13	2014 Mount Everest avalanche	Nepal	April 2014
5	Sheep Creek (Loveland Pass) avalanche[12]	United States	2013
201 (56 confirmed, 145 presumed dead)	2012 Afghanistan avalanches[2]	Afghanistan	2012
138	2012 Siachen Glacier avalanche	Pakistan	2012
11	Manaslu[10]	Nepal	2012
9	Mont Maudit avalanche[11]	France	2012
9	Restelica	Kosovo	2012
3	2012 Tunnel Creek avalanche	United States	2012
172	2010 Salang avalanches; series of at least 36 avalanches	Afghanistan	2010
102	2010 Kohistan avalanche	Pakistan	2010
11	2009 Zigana avalanche	Turkey	2009
10	2009 Afghan avalanches	Afghanistan	2009
6	2009 Schalfkogel avalanche	Austria	2009
3	2009 Buachaille Etive Mòr avalanche	United Kingdom	2009
11	Flathead Valley avalanches	Canada	2008
7	Western Tatras	Slovakia	2005
7	2003 Connaught Creek Valley avalanche	British Columbia	2003
125	Kolka-Karmadon rock ice slide	Russia	2002
9	Cerro ventana avalanche	Argentina	2002
31	Galtür Avalanche	Austria	1999
12	Montroc avalanche[8]	France	1999
3	1996 Mount Everest disaster[14]	Nepal	1996
20	Flateyri	Iceland	1995

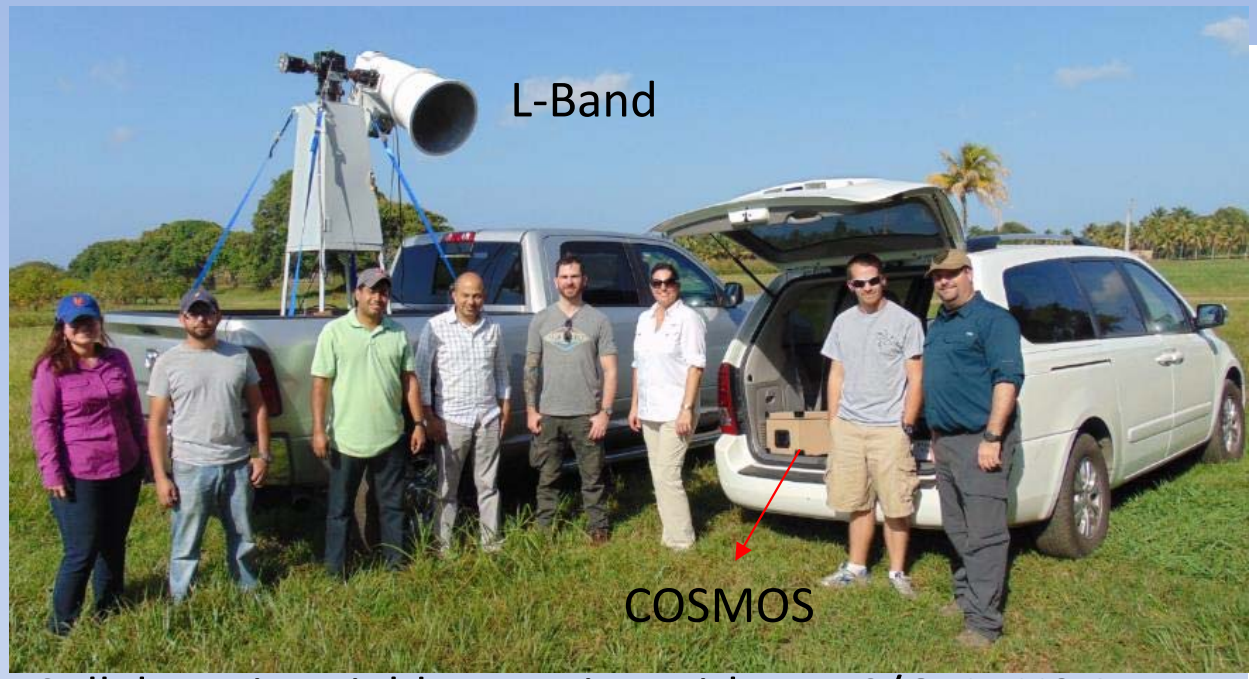


CREST-SMART - Soil Moisture Advanced Radiometric Testbed

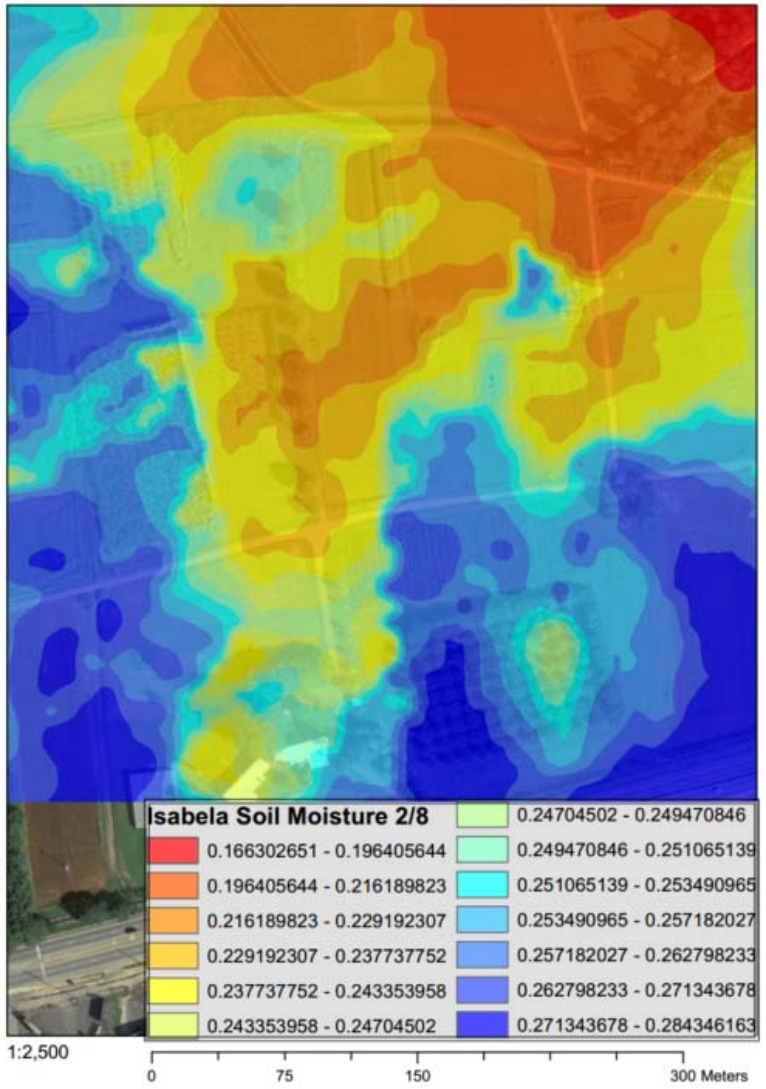




CREST-SMART - Soil Moisture Advanced Radiometric Testbed



Collaborative Field campaign with ERDC/GRL- US Army

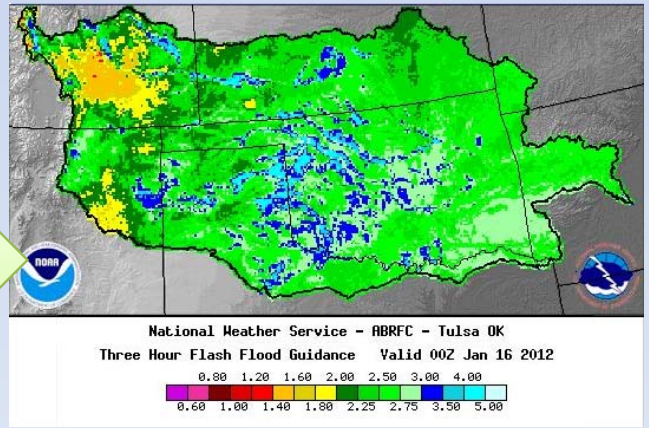


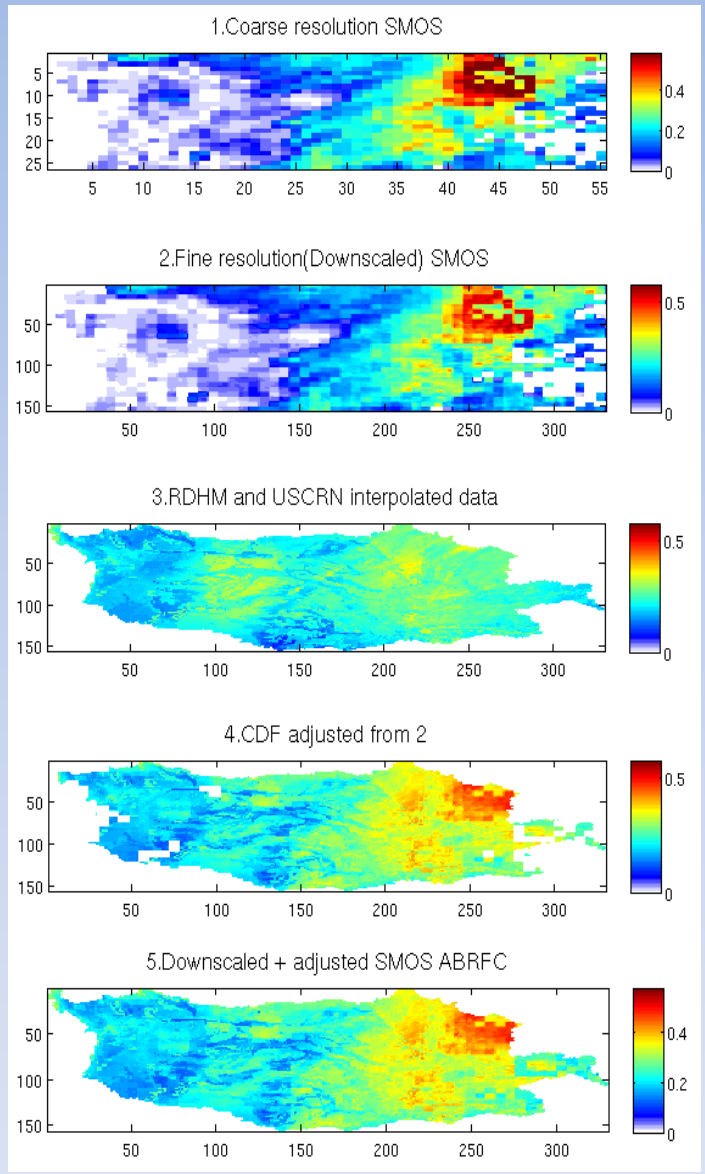
High Resolution Soil Moisture Map @ Isabela
Collaborative work with ERDC/GRL- US Army

Satellite Based Soil Moisture for Gridded Flash Flood Guidance

- The motivation of this project to **integrate remote sensing satellite based soil moisture data** in current hydrological modeling to improve NWS Gridded Flash Flood Guidance System.
- The data from Soil Moisture and Ocean Salinity (SMOS) mission is being used as a proxy to NASA's SMAP mission's soil moisture data.
- A methodology is being developed to employ the direct soil moisture data from SMOS to replace the model-calculated soil moisture state which is based on the soil water balance.
- **End Users:** River Forecasting Centers, Water Resources Managers and Public Safety Managers.

- **People involved:**
  Tarendra Lakhankar, Reza Khanbilvardi, Dugwon Seo (PhD student), Juan Mejia (MS student), Brian Cosgrove, Victor Koren, Mike Smith (NOAA/NWS/OHD), Xiwu Zhan, (NESDIS/STAR)

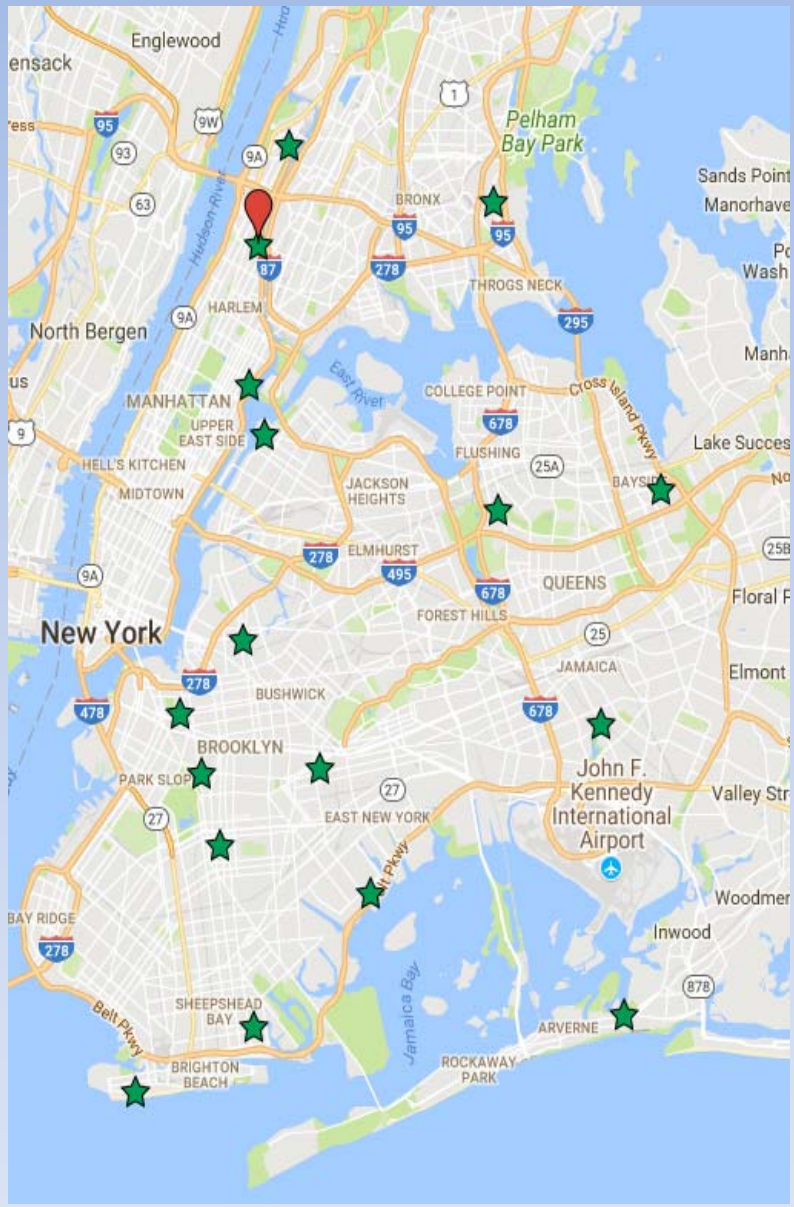




Soil moisture from SMOS to Basin scale assimilation

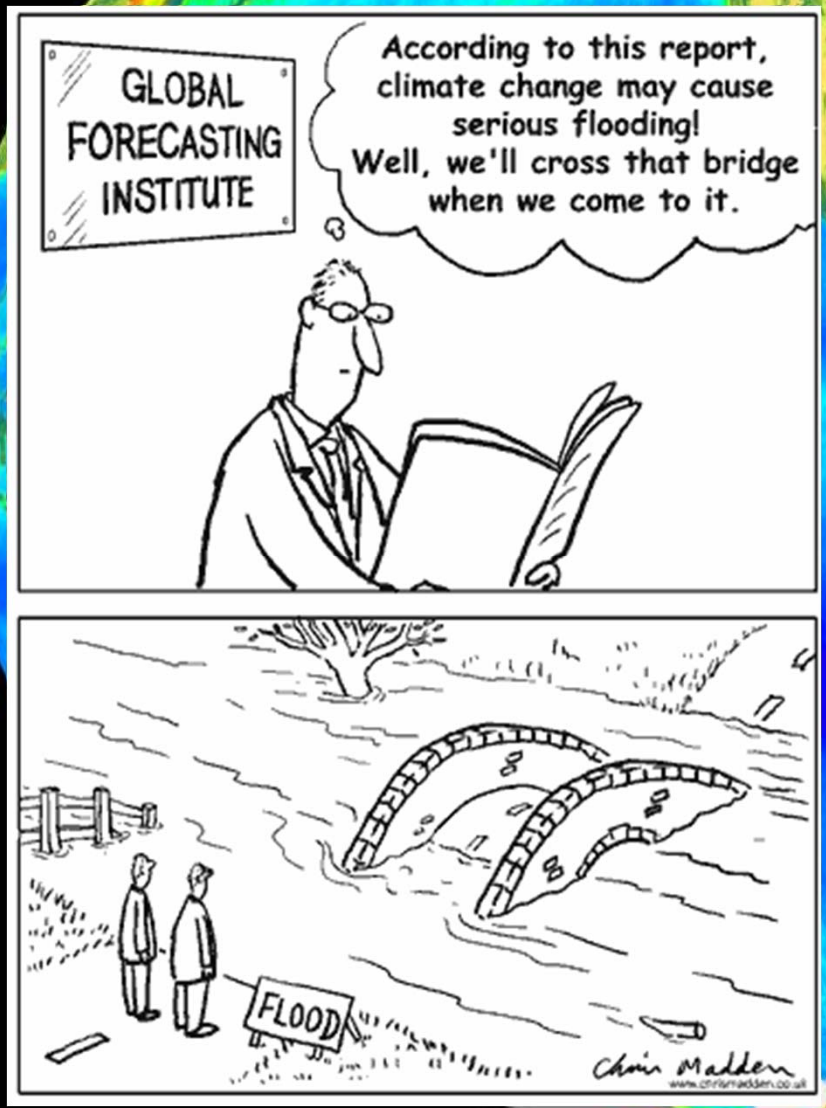
New York – Urban Hydromet Testbed

The Satellite Receiving Station



http://www.noaacrest.org/uHMT/

Questions?


GLOBAL FORECASTING INSTITUTE
According to this report, climate change may cause serious flooding! Well, we'll cross that bridge when we come to it.
FLOOD
Chris Madden


THIS IS THE SOLUTION WE'VE DEVISED FOR DEALING WITH THE FLOODING CAUSED BY CLIMATE CHANGE.
Chris Madden