Sensors in the space

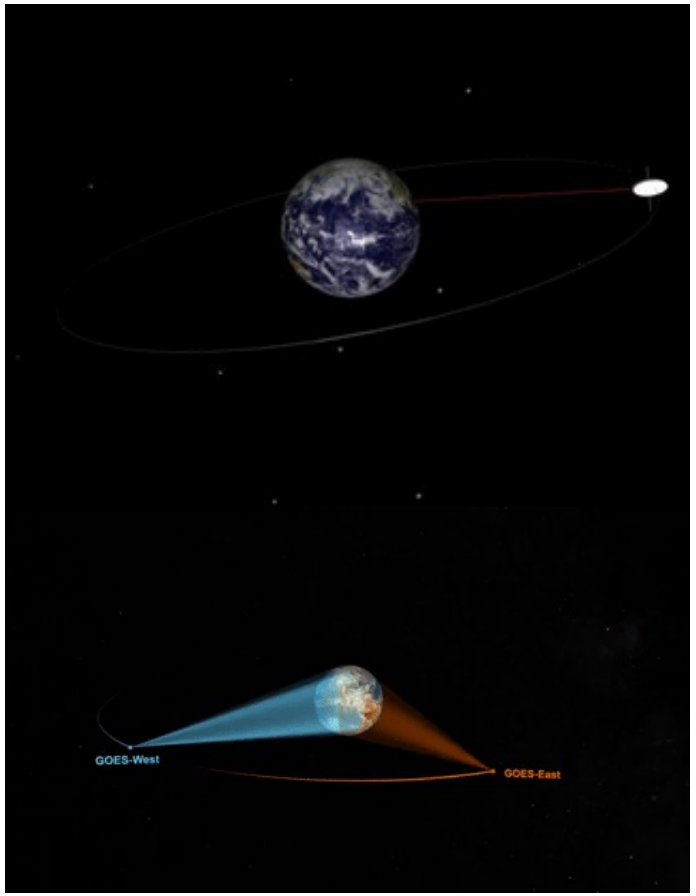
SATELLITES

DIFFERENT PATHS – DIFFERENT CAPABILITIES

- Geostationary (GEO)
- Medium Earth Orbit (MEO)
- Low Earth Orbit (LEO)
- Specialized orbits
  - Sun synchronous
  - Highly elliptical

GEO

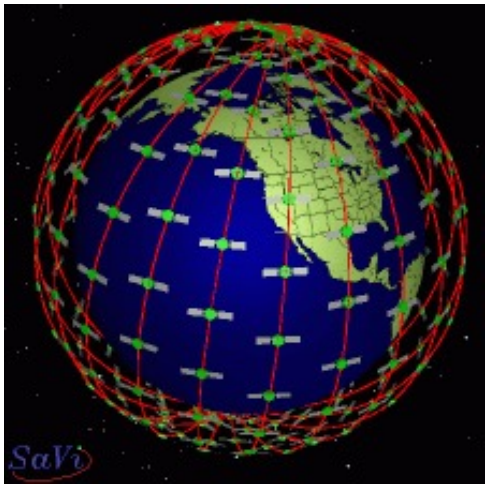
- 36k km orbit
  - Constantly over one longitude
  - Travel about 3 km/s to maintain orbit
  - Low resolution/signal strength due to large distances
- High FOV
  - 3 GEO satellites – cover entire earth
  - Can't monitor around polar regions
  - Operation has to be around equatorial plane
- Ideal for continuous monitoring
  - Weather
  - War



GEO APPLICATIONS

- Meteorological satellites
  - Satellites to track hurricanes, thunderstorms, wildfires
  - Full image (3000x3000 km) in 41 seconds stored to disk every 5-15 mins
  - Further sped up in rapid scan mode during extreme events
- Communications
  - Television, satellite radio, internet
  - Solar flares, space weather monitoring

LEO



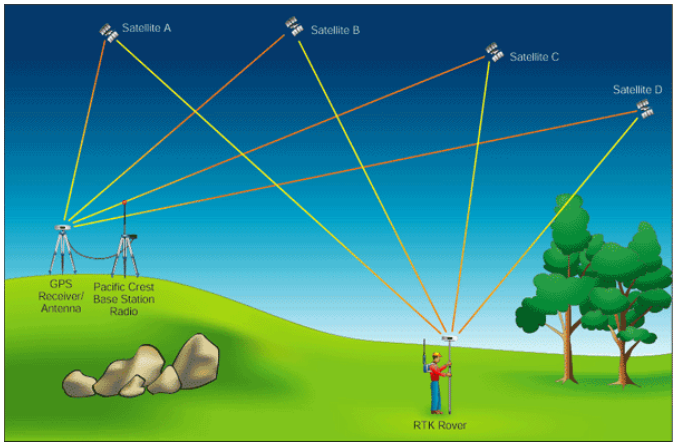
- 180 km (just above atmosphere) to 2000 km
- Most satellites – 800 km altitude
  - Starlink – 540-550 km
  - 15-16 orbits a day (at 7.8 km/s)
  - High spatial resolution and link speed
  - Constellations required for global coverage
  - Sun-synchronous orbits – same time every day
    - Great for monitoring urban growth, seasonal vegetation, ice cover

LEO APPLICATIONS

- Majority of scientific earth observation
  - Terra/Aqua (weather and climate)
  - Sentinel
  - Imaging fleets (Maxar, Planet, Pixxel)
  - Landsat (sun synchronous) – why?
- Most common usage – deforestation trends (caused 80% drop in Brazil in 2000s with satellite based monitoring and enforcement)
- Disaster response
  - Earthquakes, Tsunamis, Floods

MEO

- 2000 km to 35786 km orbit. Typically around 20000 km.
- Navigation satellites – GPS, GLONASS, Galileo
  - ~ 2 orbits a day
  - ~9000 km radius on earth
  - Covers entire earth in 24-32 satellites



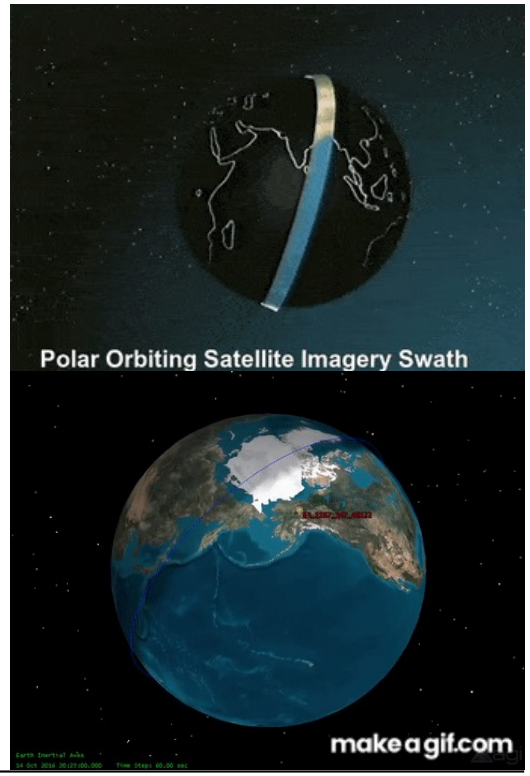
MEO APPLICATIONS

- Positioning services
- Atomic clocks and broadcast L-band radio
- COSMIC mission to observation temp/humidity through light grazing effect between satellites
- Surface winds and roughness through reflections off the ocean

POLAR AND SUN-SYNCHRONOUS ORBITS

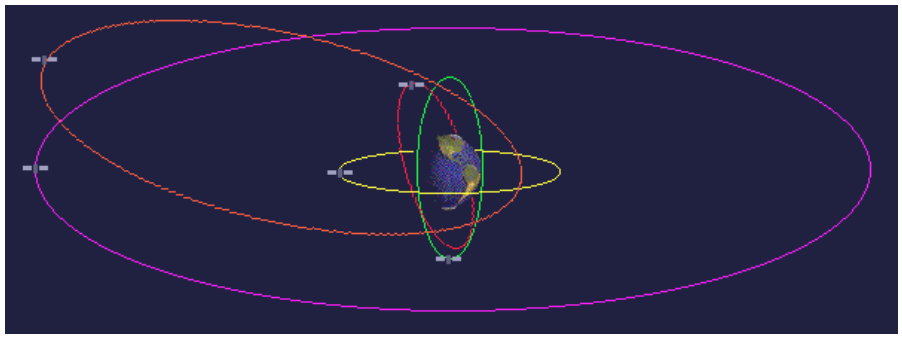
- Global coverage through slice by slice monitoring
  - NASA's Terra/Aqua/EU – METSAT are in polar orbits
- Local solar time of the overhead pass is the same everyday
  - Consistent lighting
  - Uniform shadows
  - Change detection applications
  - Weather monitoring and damage assessments
- Examples: Sentinel 2, Landsat

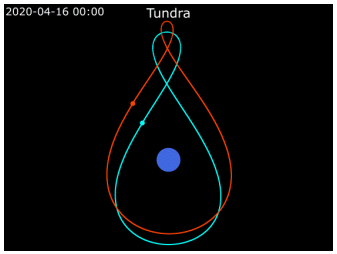
- Limitations
  - Real-time sensing (done through GEO)



HIGHLY ELLIPTICAL ORBITS

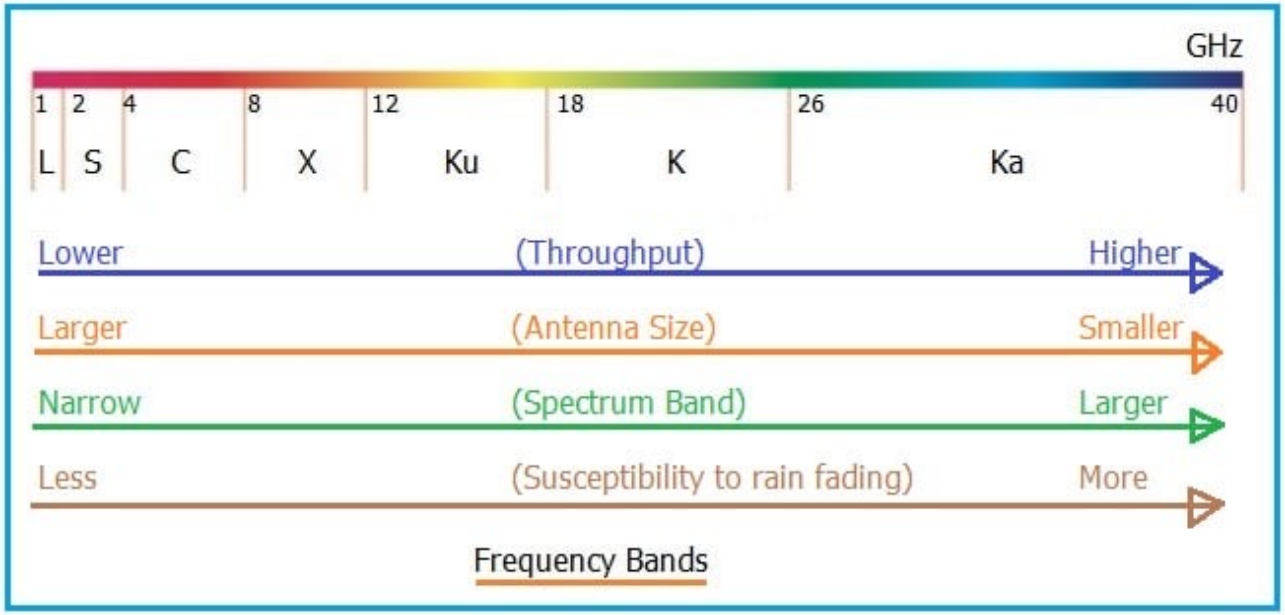
- Satellites and radio in high latitudes
- Continuous arctic weather observations
- Fills the niche for prolonged coverage of high-latitude regions





THE BANDS

SUMMARY


GHz
1
2
4
8
12
18
26
40
L
S
C
X
Ku
K
Ka
Lower
(Throughput)
Higher
Larger
(Antenna Size)
Smaller
Narrow
(Spectrum Band)
Larger
Less
(Susceptibility to rain fading)
More
Frequency Bands

L-BAND

- ‘L’ongest wavelength used in WW-II
- Penetrates through vegetation and water
- Most used for GPS/GNSS navigation signals and satellite mobile comms (high reliability comms)
- Earth observation
  - SAR for forestry, biomass and soil moisture sensing
  - Measures soil moisture and ocean salinity (SMAP mission)

S-BAND

- ISS (International Space Station) communications
- Correct ionosphere delay in radar altimeters (altitude measurement)

C-BAND

- The compromise band
- TV/International communication links
- Less attenuated than Ku band
- Sentinel 1C, Canada's RADARSAT
  - Penetrates through cloud and moderate vegetation
  - Disaster mapping, sea ice monitoring, agriculture

X-BAND

- The secret band
- Used heavily by military and government
- High resolution SAR band
  - Urban mapping, tactical military reconnaissance
  - No penetration of foliage or soil

KU-BAND

- K-under band
- Avoids the water vapor absorption line at 22 GHz
- Used for satellite TV broadcasting and broadband (DISH TV)
  - Rain attenuation
- Scatterometers measure ocean winds
  - Sensitivity to capillary waves on ocean surface caused through wind

K/KA-BAND

- K – Kurz (short) microwaves
- Increasingly important for high speed satellite communication
  - HD video/high speed internet
  - Highly susceptible to rain fade
  - Cloud penetration and altimetry (sea surface height)
  - Would be the one enabling high resolution high data rate sensors

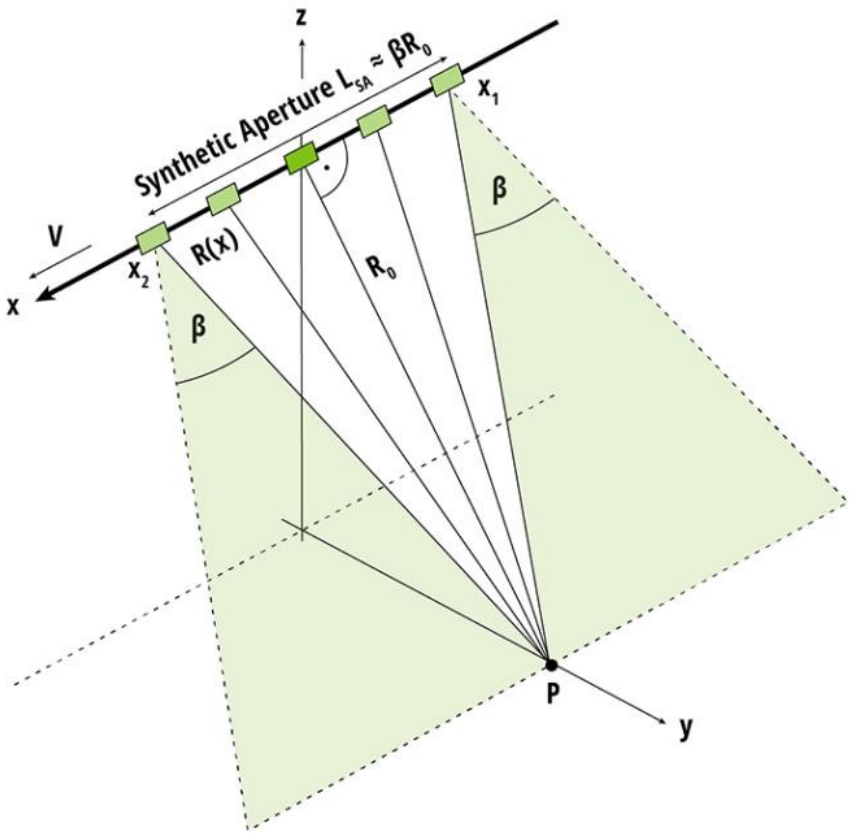
THE TRADEOFF

- Spatial resolution
- Penetration

- X, Ku – finer resolution, very affected with rain/foliage
- L – low resolution, high penetration through forest canopies or dry soil

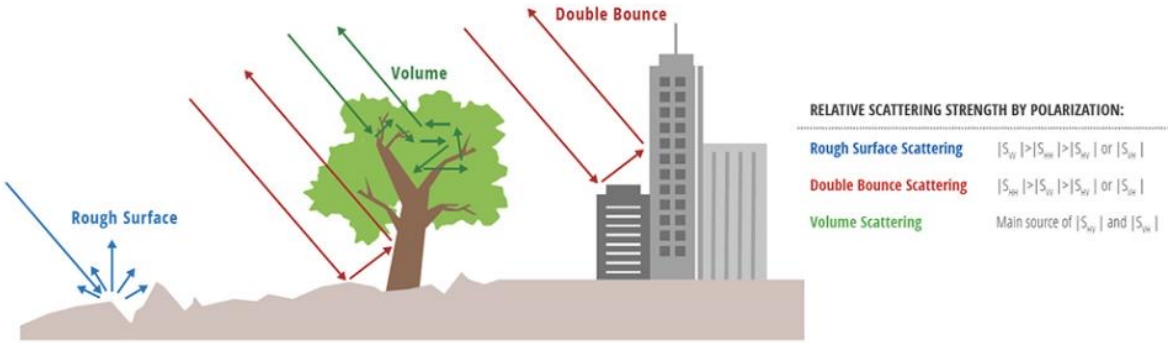
SYNTHETIC APERTURE RADAR

- Antenna Size simulated through motion of satellite
- Constructive/destructive interference for beam steering



Source: https://www.earthdata.nasa.gov/learn/earth-observation-data-basics/sar

POLARISATION



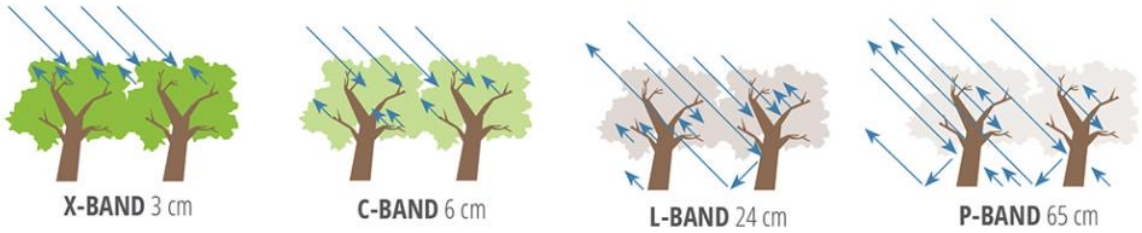
- V – Vertical, H – horizontal
- Signals emitted in vertical and received in horizontal – VH. Similarly HH, VV
- Rough surfaces – VV scattering (polarization doesn't change)
- Volume scattering – gets reflected multiple times
  - leaves and branches of forest canopy (cross-polarized data like VH/HV)
- Double bounce scattering – HH
  - Buildings, tree trunks or inundated vegetation

SOME EXAMPLE APPLICATIONS

WITH L-BAND

FORESTRY

- L-band backscatter shown to correlate with forest structural parameters, e.g., forest height and above-ground biomass
  - JAXA's global forest/non-forest maps
  - Global Mangrove watch
  - Advanced models are required for very dense canopies
- L-band combined with LiDAR/optical data is showing promise for improved forest parameter estimation



AGRICULTURE AND SOIL MOISTURE (L-BAND)

- Surface moisture with moderate vegetation
  - SMOS (Soil Moisture and Ocean Salinity)
  - SMAP (Soil Moisture Active passive)
- Can sense sub-surface moisture
  - Drought, irrigation measurements
  - Crop structure

DISASTER MANAGEMENT

- Inundation under foliage
  - Ground deformation after earthquakes
  - Movement of Amazon forest floodplain
  - earthquake uplift in forested Papua New Guinea

URBAN INFRASTRUCTURE

- Interferometric SAR can monitor ground subsidence
  - Cities built on soft soil (e.g., Jakarta and Mexico sinking)
- C and X band are generally preferred for urban detail while L-band provides a stable long-term signal (sun-synchronous polar orbit)

WITH C-BAND

C se Compromise

AGRICULTURAL MONITORING

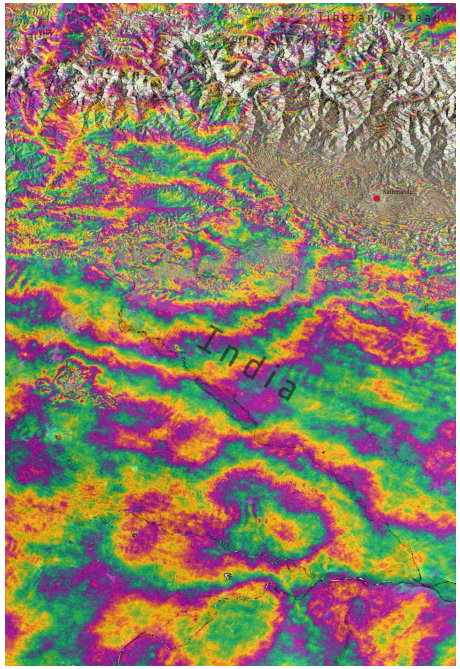
- "workhorse" for agricultural monitoring
  - Crop classification and growth monitoring
  - Unique backscatter during different phases of growth, e.g., paddy
  - Leaf area index and fractional vegetation cover

FORESTRY AND LAND COVER

- Strong volume scattering from dense forests
  - Good effectiveness in forest clearing alert
  - Logging activities
- Sensitive to freeze and thaw cycling
- Indicating forest phenology, e.g., leaf-on vs leaf-off conditions
- Change detection and mapping

DISASTER MANAGEMENT

- Flood mapping (good water/land distinguishability)
  - Copernicus emergency management service (EMS)
- Even cm of motion can be detected as fringes in the image
- For example, in 2015 Nepal Earthquake, bulls eye pattern fringes were seen indicating some uplifted and some subsided area over 120x100 km



URBAN INFRASTRUCTURE

- Still can't detect individual buildings
- Successful applications
  - Classifying land use
  - Subsidence or Uplift of built structures (mm precision)
    - Regional urban deformation surveys
- Examples:
  - Naples ground study to determine risks from underwater acquifer changes
  - Jingjin high-speed railway track assessment
  - Highway, Rail corridor, Bridges Structural integrity

TRANSPORT APPLICATIONS

- Maritime surveillance
  - Metal hull reflections
  - For example, Illegal maritime activity detection
- Mapping flood damage to roads and bridges post disaster

X-BAND

The secret sauce

REMINDER

- High spatial resolution
  - 1-3 m resolution
- Easily attenuated by rain
- Low penetration into ground/foliage
- Primarily senses the top of the surface

- Early application
  - Fire control and targeting (hence the X)

URBAN PLANNING AND INFRA

- Can detect smaller structures – individual buildings, bridges, vehicles
- A variant called Tomographic SAR could even separate scattering from different floors of buildings and reconstruct building façades in 3D
- InSAR: infrastructure stability
  - Bridges, dams, roads, railways, and buildings
  - Thermal expansion/contraction
- Beijing's Tongzhou district:
  - 8 TerraSAR-X images from 2012–2013 were used to detect where new buildings were constructed or old ones demolished, via a temporal change detection algorithm.

Wang, Shihong, Jiayi Guo, Yueting Zhang, Yuxin Hu, Chibiao Ding, and Yirong Wu. "TomoSAR 3D reconstruction for buildings using very few tracks of observation: A conditional generative adversarial network approach." *Remote Sensing* 13, no. 24 (2021): 5055.

FORESTRY

- Provides complementary fine-level detail to low-resolution data
  - It can reach the ground

AGRICULTURE

- Specialty crops, e.g.,
  - Detecting grain heads

DISASTER MANAGEMENT

- Building collapse detection
- Forecasting landslides through detection of minute changes
- Military detailed terrain maps

TRANSPORT

- Characterize a ship and its features
  - Ship’s wake, bow and stern shapes
  - Velocity estimation
  - 95% AP+ in ship detection

KU-BAND

WEATHER RADAR

- Ocean observations/Scatterometry
  - Meterological radars and altimeters
    - Raindrops and ocean waves (2 cm wavelength)
  - QuickSCAT satellite for ocean measurements since 1999
  - India – OceanSAT
- Precipitation radar
  - 3D rain profiling (even within clouds)
  - To be corrected for signal transmission losses
- Image SAR and Altimetry
  - Sea level measurements