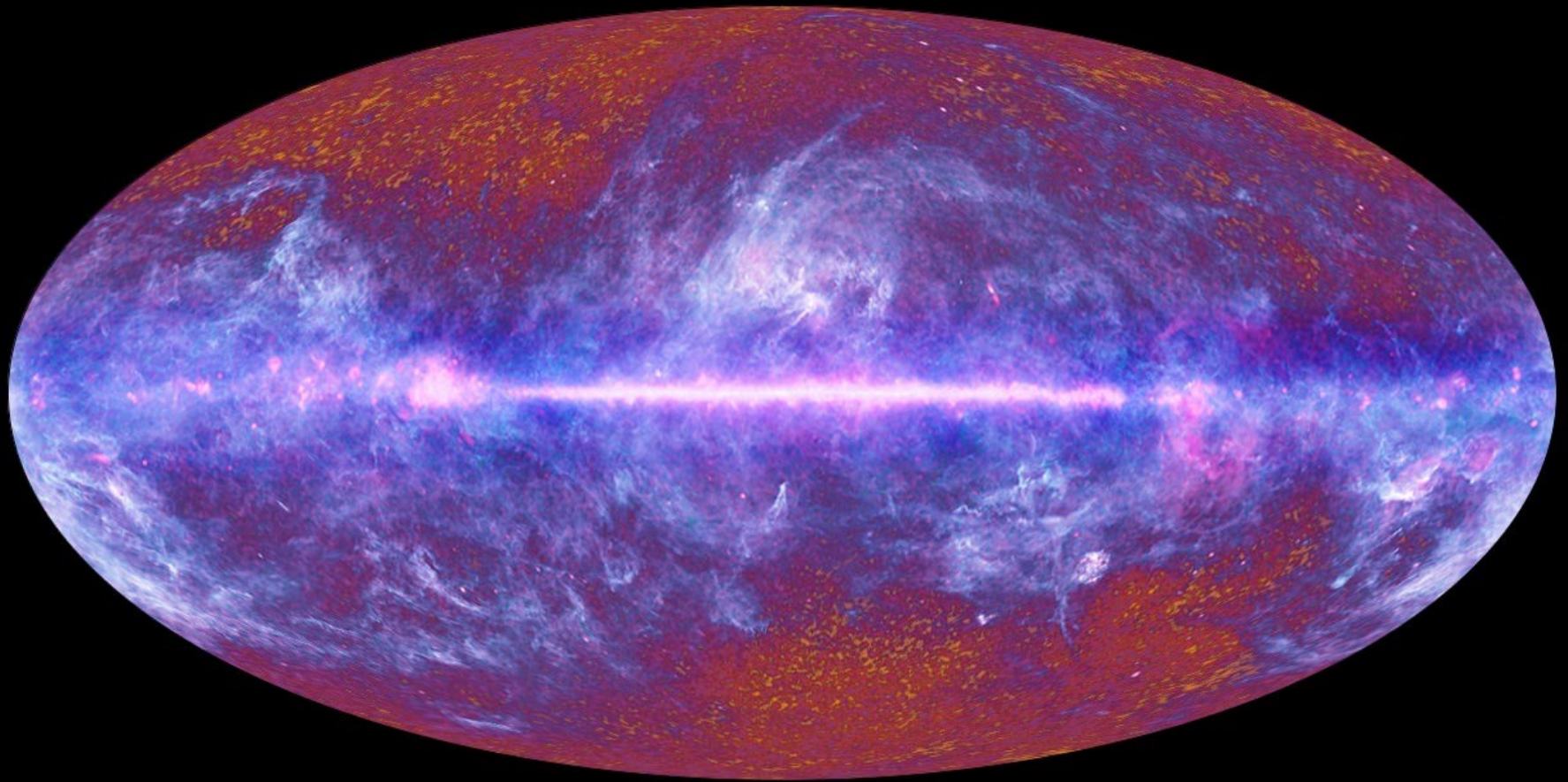
Aalto University
School of Electrical
Engineering

E4230
Microwave EO Instrumetation

2021

Jaan Praks



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Electromagnetic radiation

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Electromagnetic waves -- gathering information about the world

Electromagnetic radiation is convenient for information transfer because:

EM radiation travels at speed of light,
the fastest possible speed

EM radiation travels along a straight line

EM radiation does not need medium to travel

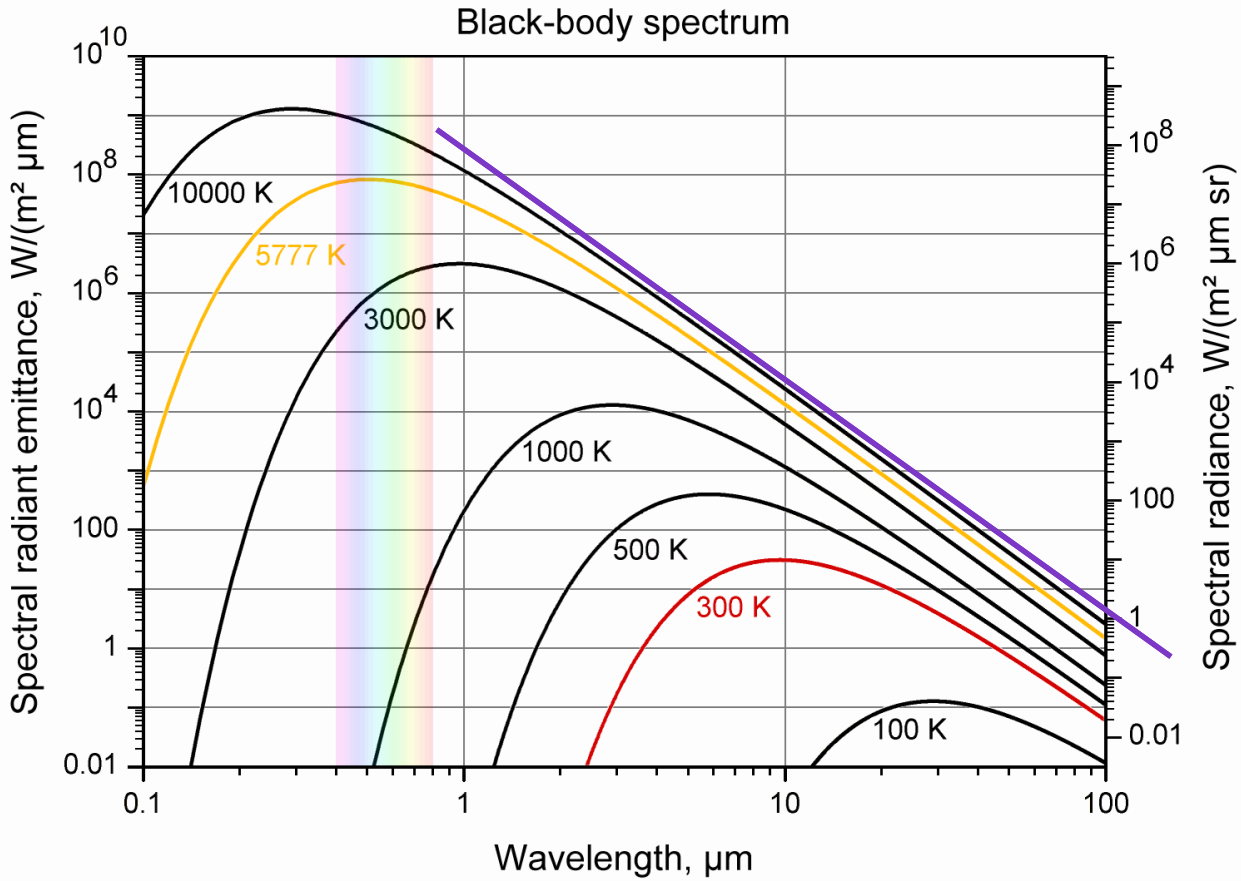
EM radiation interacts with matter

EM radiation wavelength allows to interact with targets of various size

EM radiation is everywhere, because every body in the universe radiates EM energy

Plank's Law

$$B_f = \frac{2hf^3}{c^2} \frac{1}{e^{\frac{hf}{kT}} - 1}$$

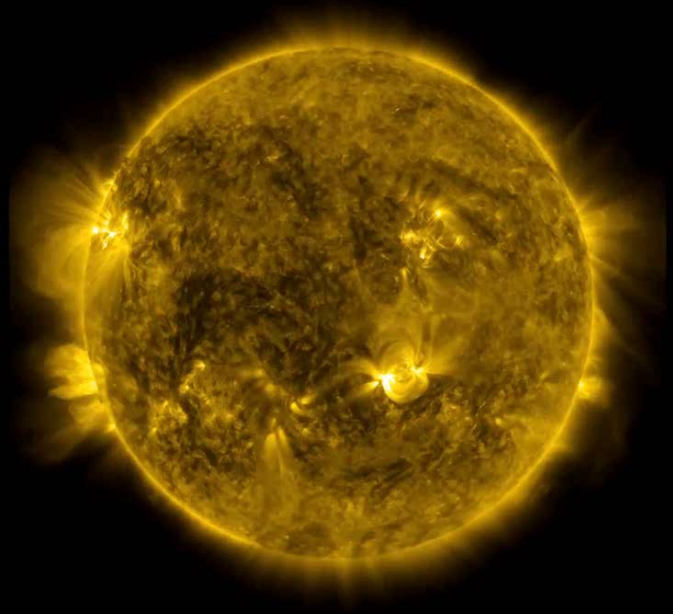


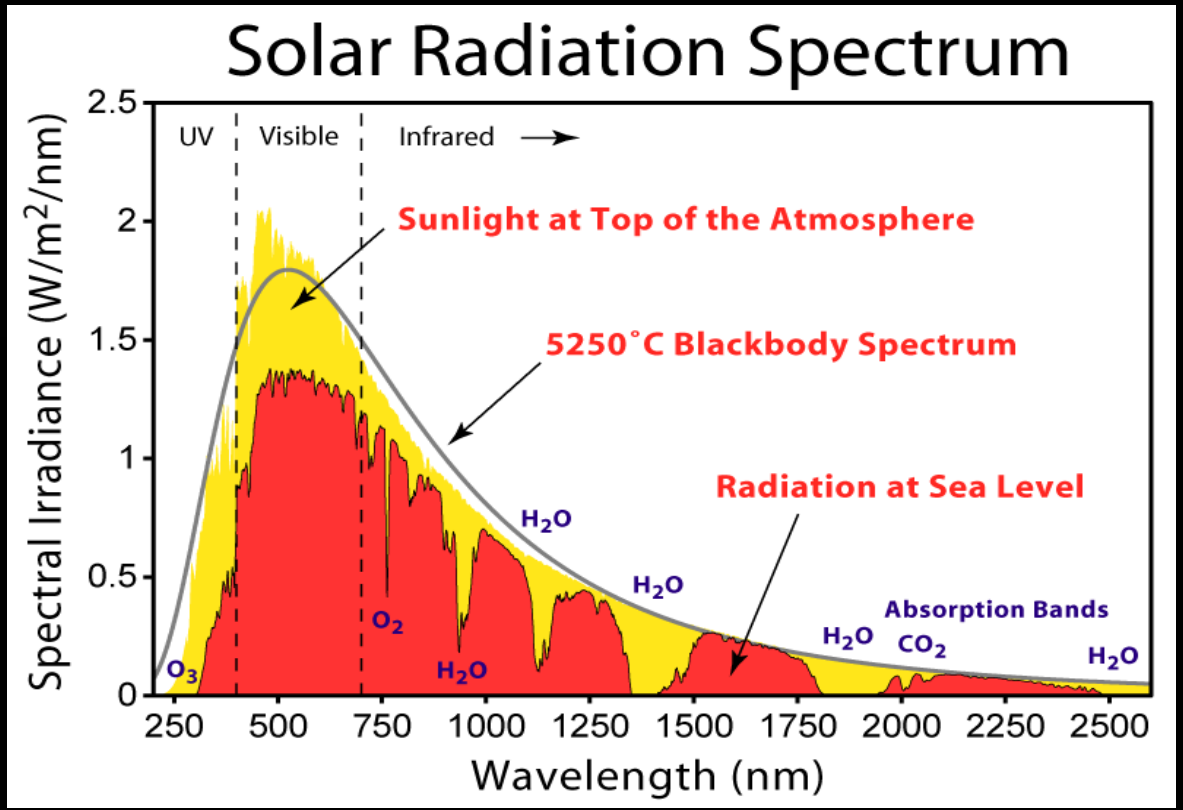
Rayleigh-Jeans law

$$B_f = \frac{2kT}{\lambda^2}$$

Low-frequency approximation for Planck's law, when

$$hf << kT$$




Solar Radiation Spectrum
Spectral Irradiance (W/m²/nm)
2.5
2
1.5
1
0.5
0
UV
Visible
Infrared
Sunlight at Top of the Atmosphere
5250˚C Blackbody Spectrum
Radiation at Sea Level
H2O
H2O
H2O
O2
O3
H2O
CO2
H2O
Absorption Bands
250
500
750
1000
1250
1500
1750
2000
2250
2500
Wavelength (nm)

Earth system

Atmosphere

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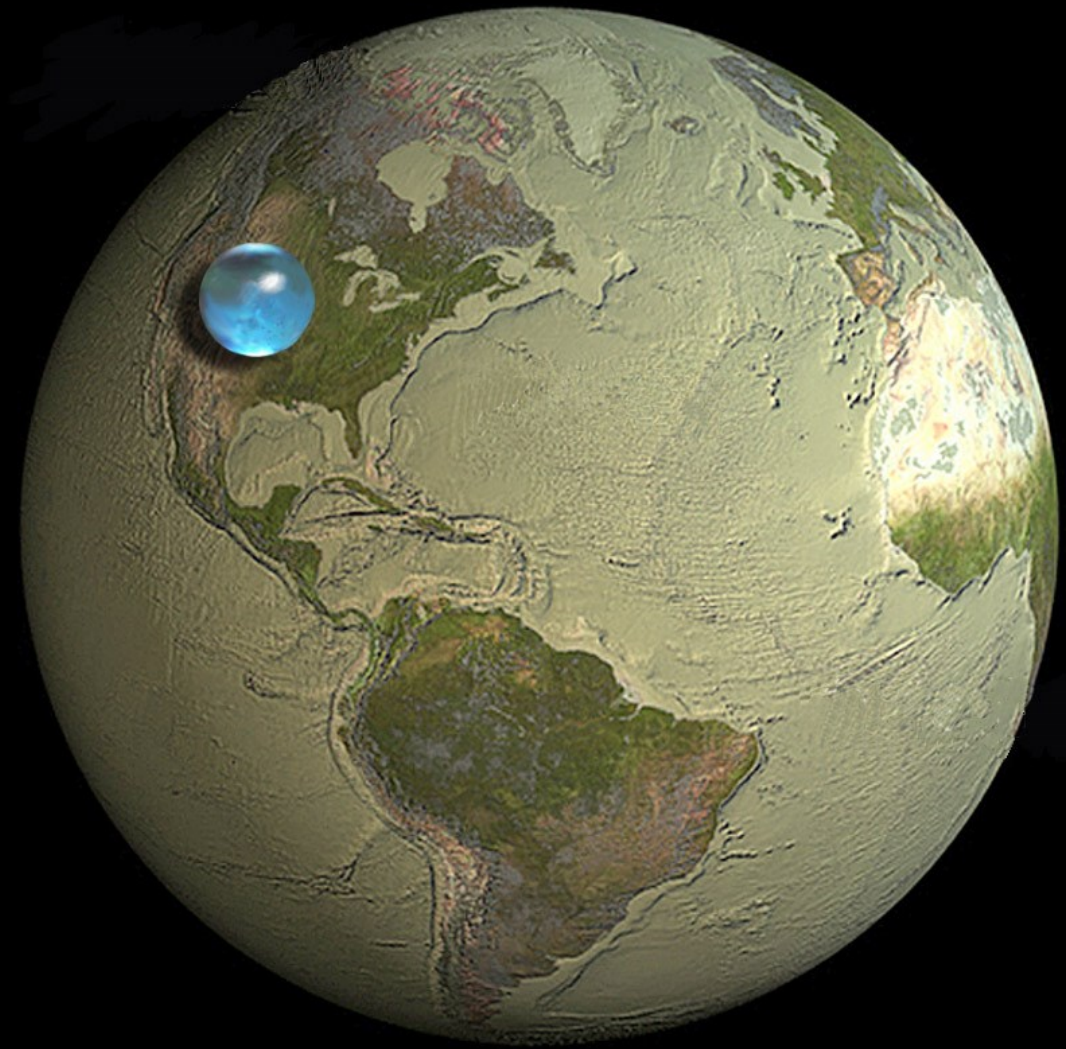
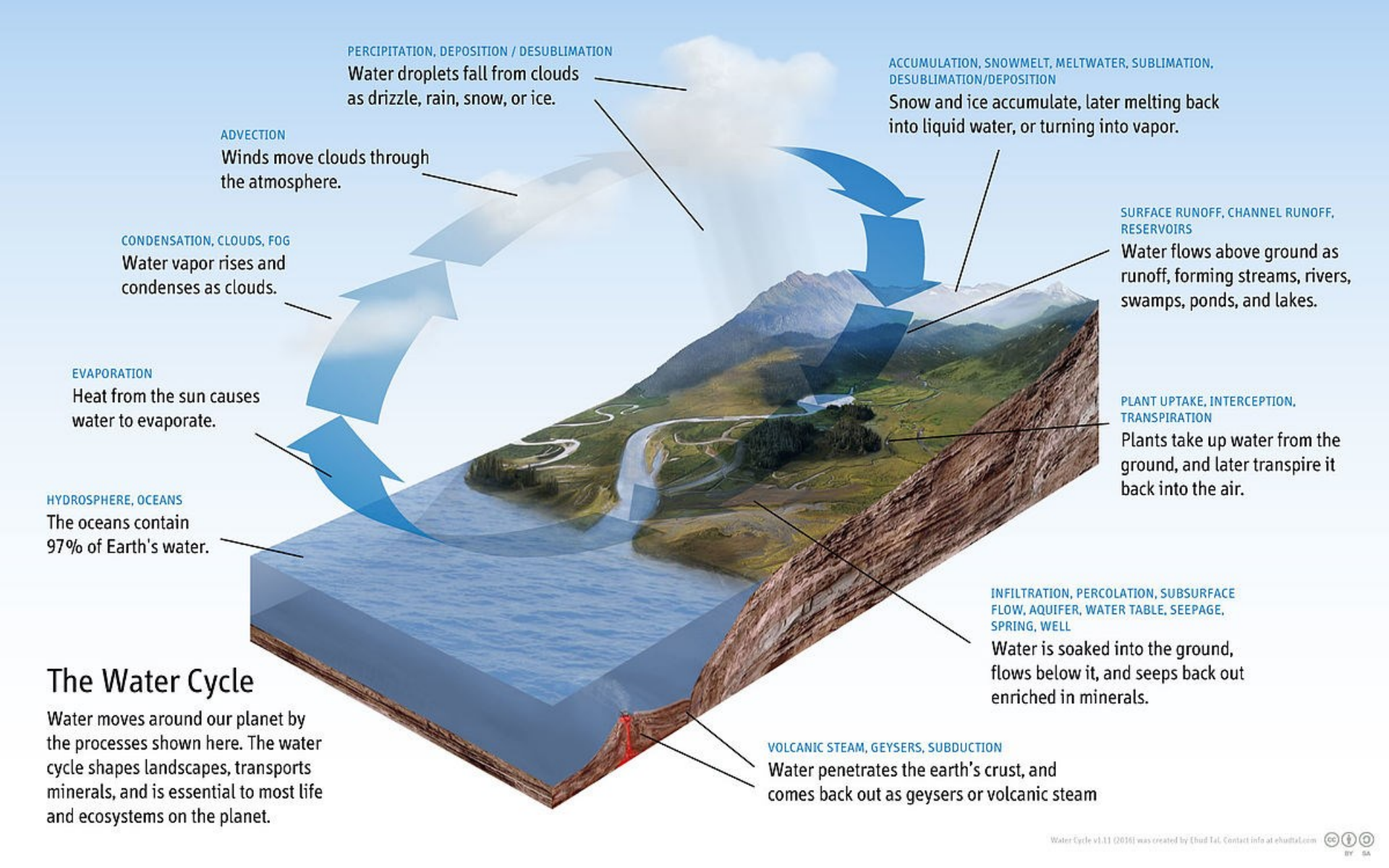
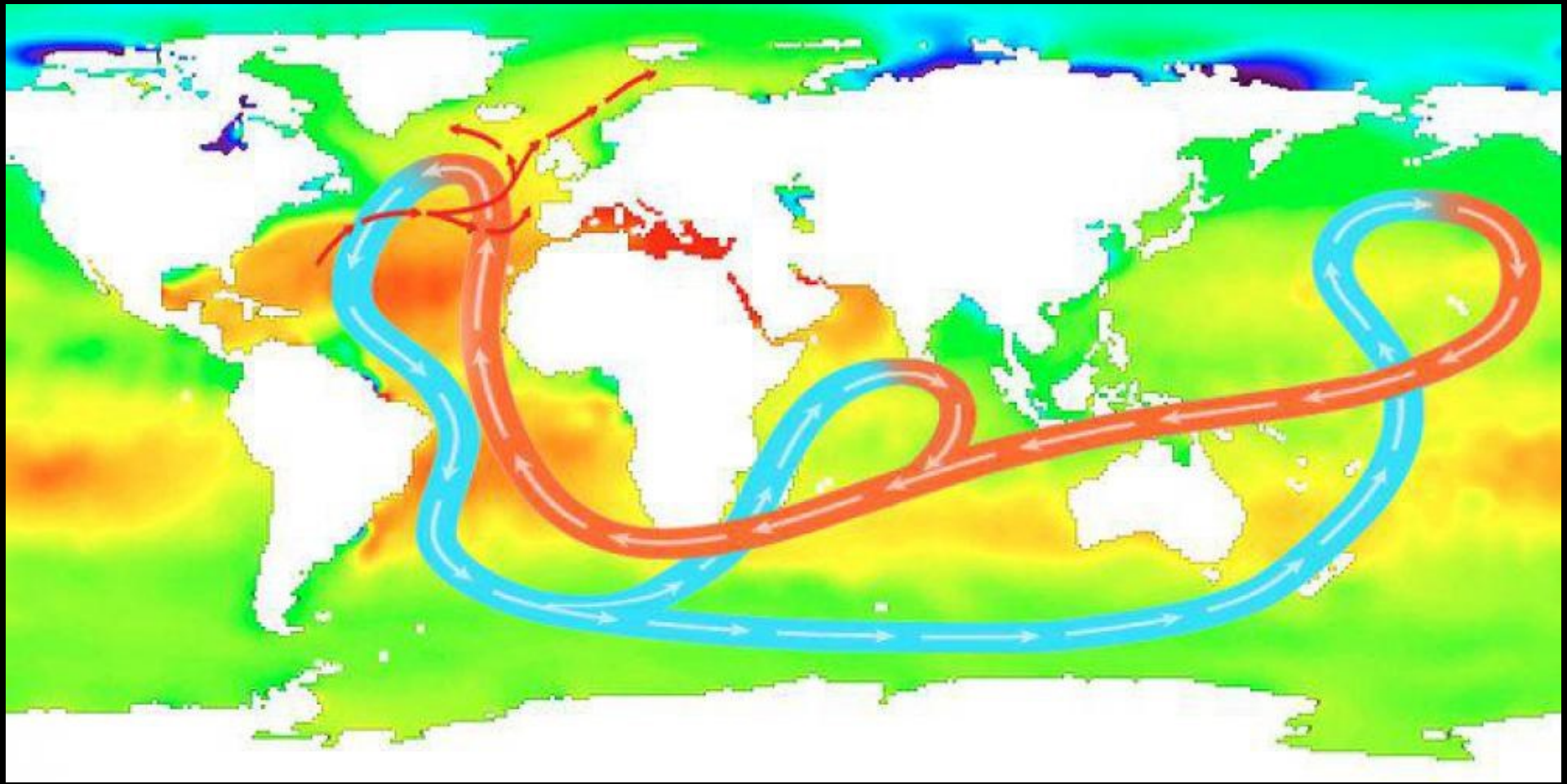
Ocean



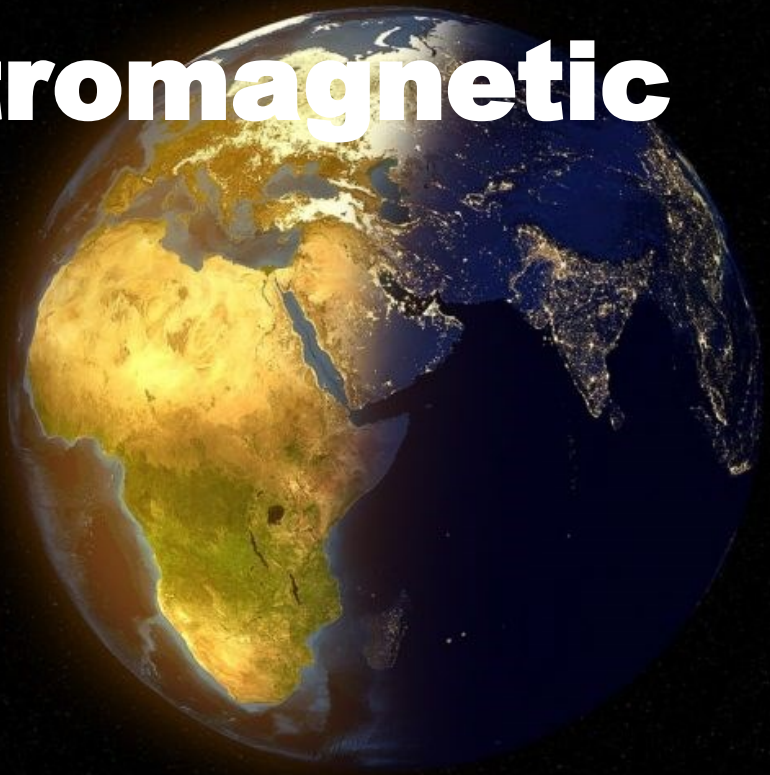


The Water Cycle

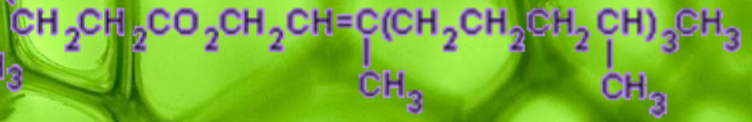
Water moves around our planet by the processes shown here. The water cycle shapes landscapes, transports minerals, and is essential to most life and ecosystems on the planet.

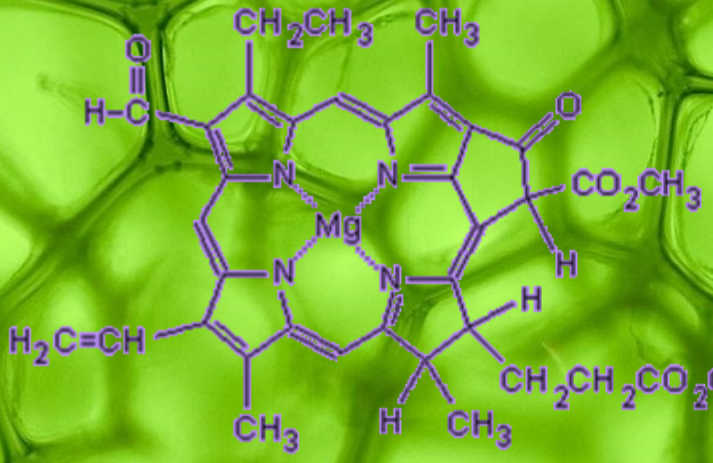


Life and electromagnetic energy

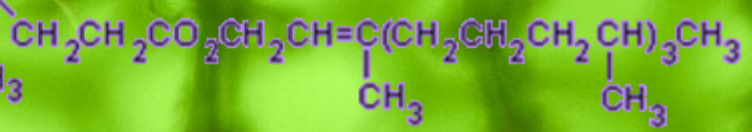


Chlorophyll a

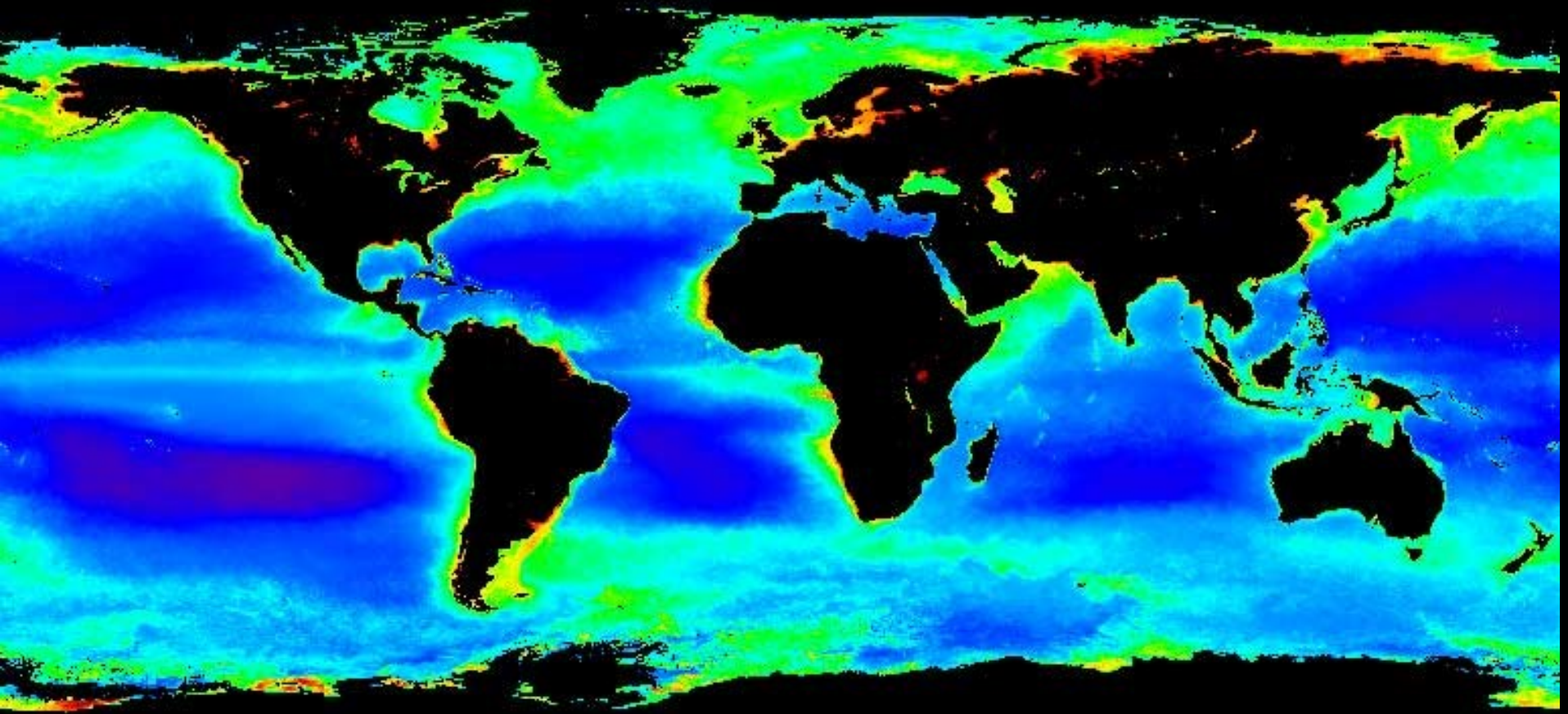


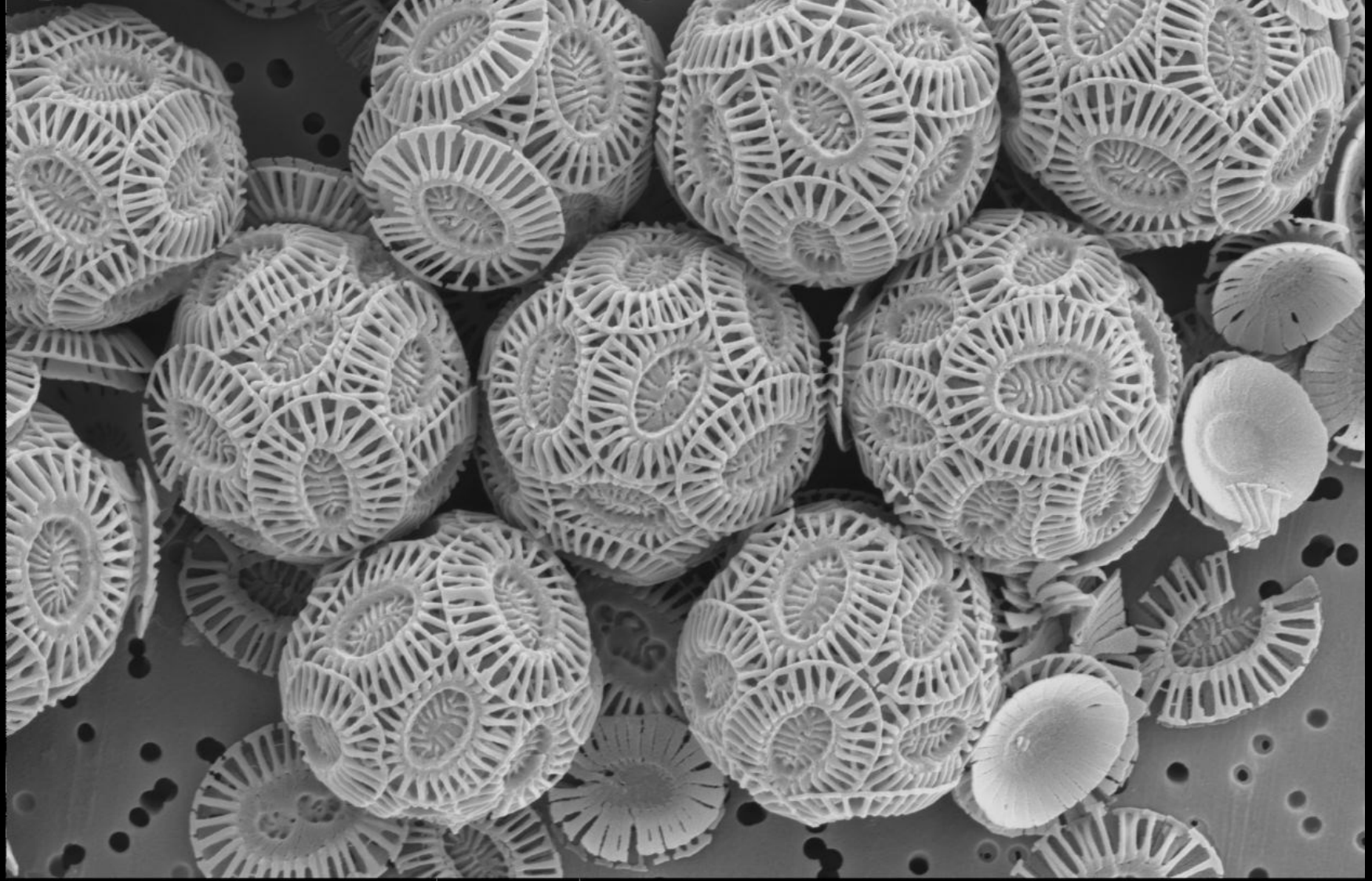


Chlorophyll b

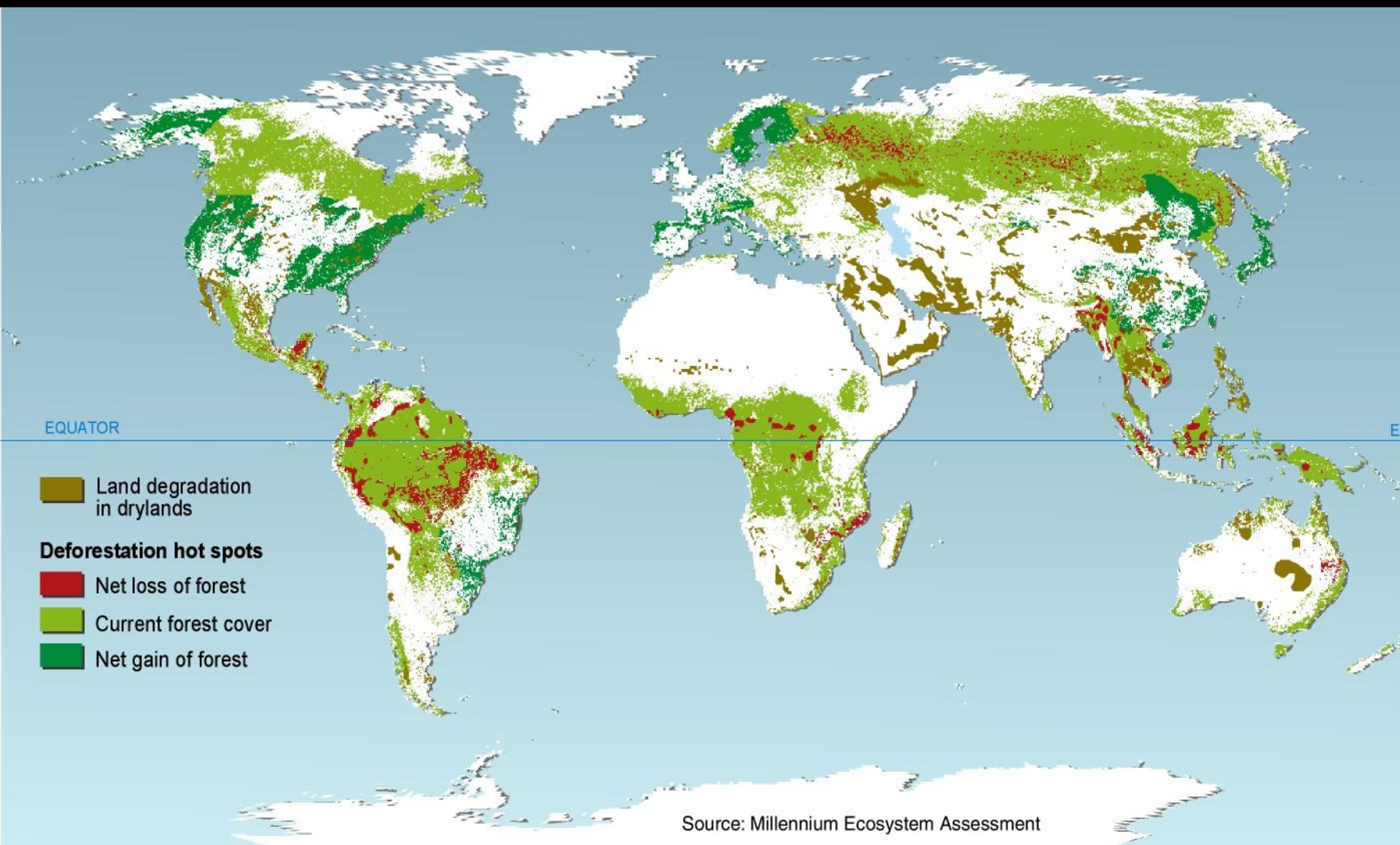


Global Zooplankton




Acc.V Spot Magn Det WD
5.00 kV 3.0 6500x SE 10.0
2 µm
JRY 218


pixabay


EQUATOR
Land degradation in drylands
Deforestation hot spots
Net loss of forest
Current forest cover
Net gain of forest
Source: Millennium Ecosystem Assessment

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Take a break

Remote sensing

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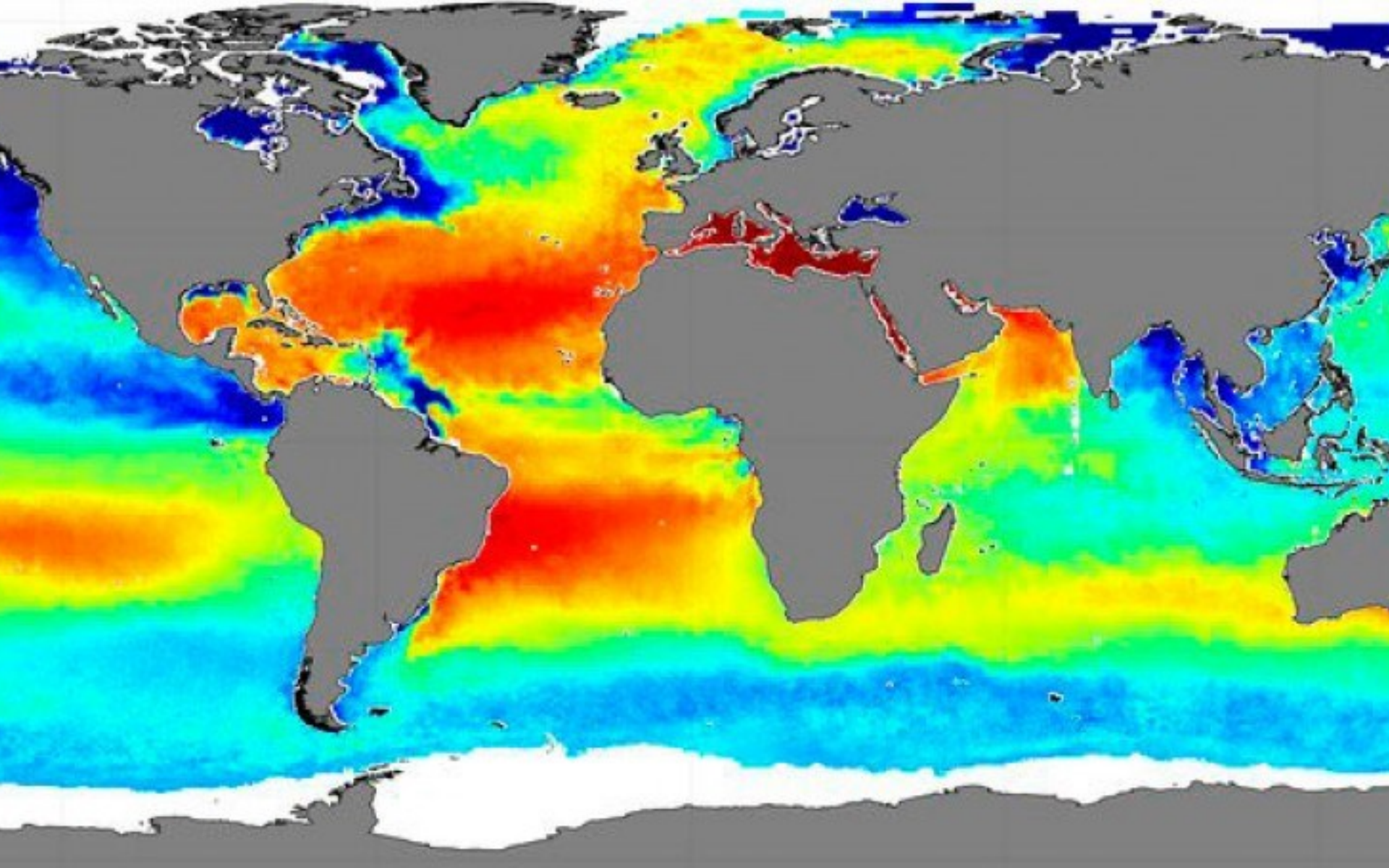
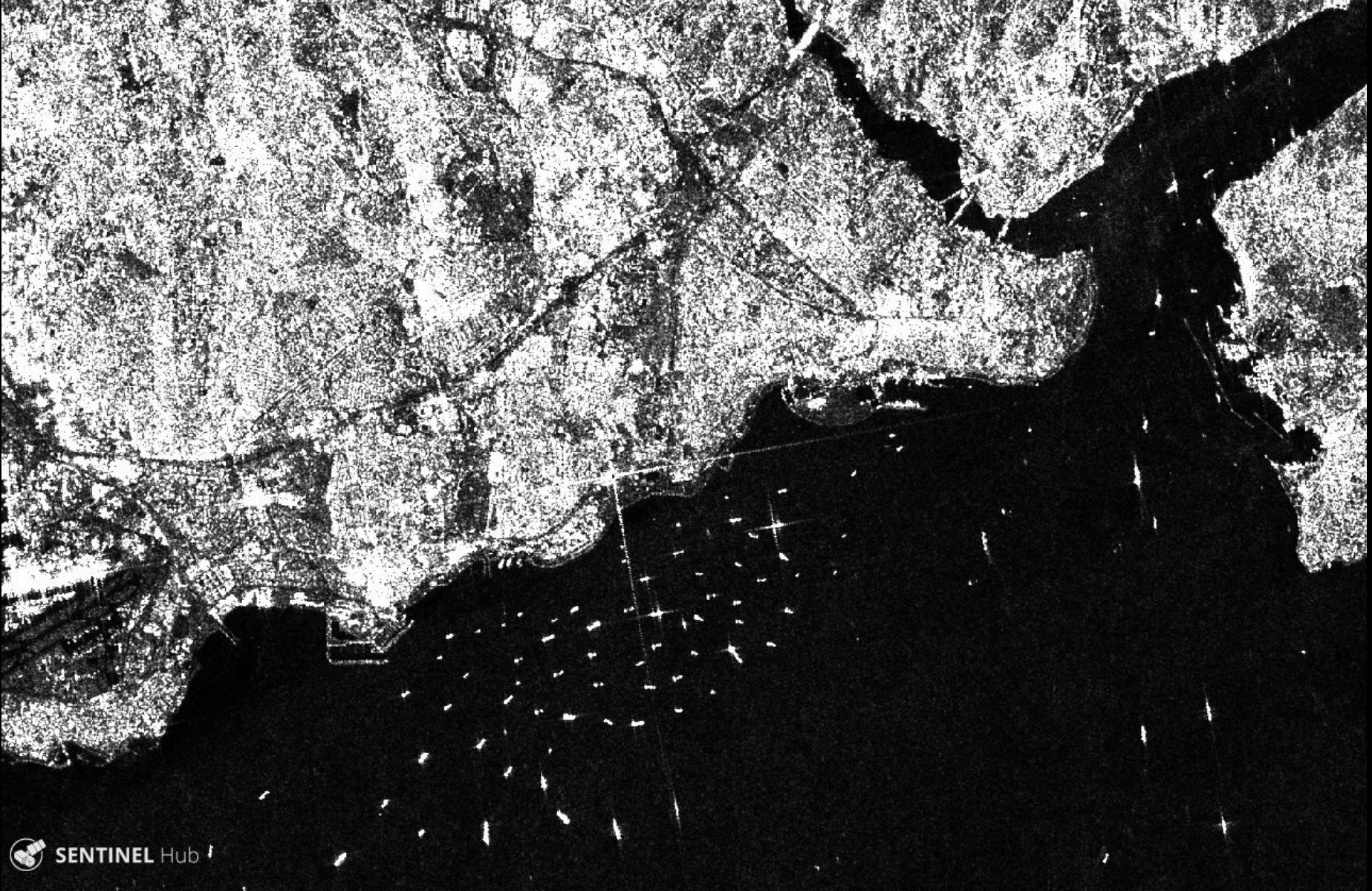
Definition of Remeote Sensing

Remote sensing is the small or large-scale acquisition of information of an object or phenomenon, by the use of either recording or real-time sensing device(s) that are wireless, or not in physical or intimate contact with the object (such as by way of aircraft, spacecraft, satellite, buoy, or ship).

In practice, remote sensing is the stand-off collection through the use of a variety of devices for gathering information on a given object or area. Thus, Earth observation or weather satellite collection platforms, ocean and atmospheric observing weather buoy platforms, the monitoring of a parolee via an ultrasound identification system, Magnetic Resonance Imaging (MRI), Positron Emission Tomography (PET), X-radiation (X-RAY) and space probes are all examples of remote sensing. In modern usage, the term generally refers to the use of imaging sensor technologies including: instruments found in aircraft and spacecraft as well as those used in electrophysiology, and is distinct from other imaging-related fields such as medical imaging.




SENTINEL Hub

Remote Sensing Instruments

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RS instruments

Active Sensors

Laser altimeter—An instrument that uses a lidar to measure the height of the platform (spacecraft or aircraft) above the surface.

Lidar—A light detection and ranging sensor that uses a laser (light amplification by stimulated emission of radiation) radar to transmit a light pulse and a receiver with sensitive detectors to measure the backscattered or reflected light.

Radar—An active radio detection and ranging sensor that provides its own source of electromagnetic energy. An active radar sensor, whether airborne or spaceborne, emits microwave radiation in a series of pulses from an antenna. When the energy reaches the target, some of the energy is reflected back toward the sensor. This backscattered microwave radiation is detected, measured, and timed.

Ranging Instrument—A device that measures the distance between the instrument and a target object. Radars and altimeters work by determining the time a transmitted pulse (microwaves or light) takes to reflect from a target and return to the instrument.

Scatterometer—A high-frequency microwave radar designed specifically to measure backscattered radiation. Over ocean surfaces, measurements of backscattered radiation in the microwave spectral region can be used to derive maps of surface wind speed and direction.

Sounder—An instrument that measures vertical distribution of precipitation and other atmospheric characteristics such as temperature, humidity, and cloud composition.

Passive Sensors

Hyperspectral radiometer—An advanced multispectral sensor that detects hundreds of very narrow spectral bands throughout the visible, near-infrared, and mid-infrared portions of the electromagnetic spectrum. This sensor's very high spectral resolution facilitates fine discrimination between different targets based on their spectral response in each of the narrow bands.

Imaging radiometer—A radiometer that has a scanning capability to provide a two-dimensional array of pixels from which an image may be produced. Scanning can be performed mechanically or electronically by using an array of detectors.

Radiometer—An instrument that quantitatively measures the intensity of electromagnetic radiation in some bands within the spectrum. Usually, a radiometer is further identified by the portion of the spectrum it covers; for example, visible, infrared, or microwave.

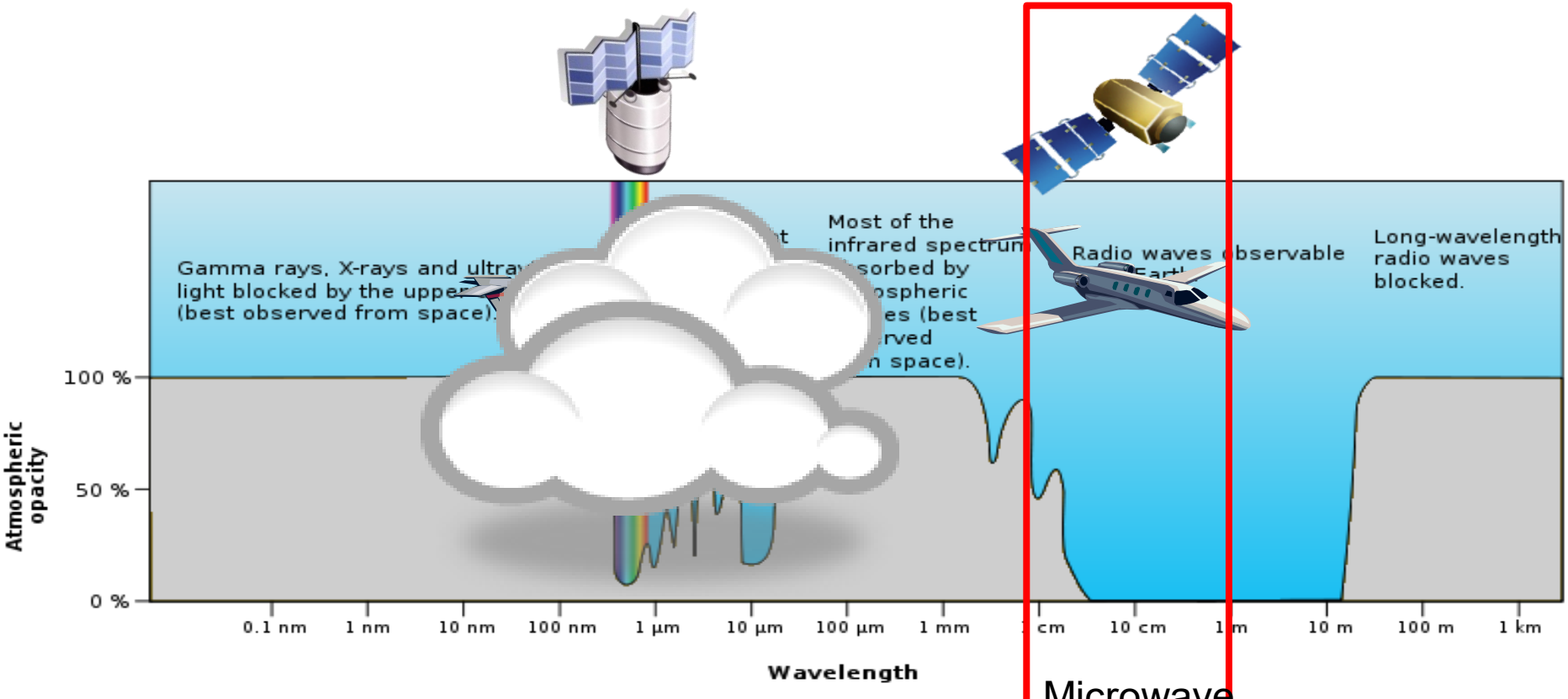
Sounder—An instrument that measures vertical distributions of atmospheric parameters such as temperature, pressure, and composition from multispectral information.

Spectrometer—A device that is designed to detect, measure, and analyze the spectral content of incident electromagnetic radiation. Conventional imaging spectrometers use gratings or prisms to disperse the radiation for spectral discrimination.

Spectroradiometer—A radiometer that measures the intensity of radiation in multiple wavelength bands (i.e., multispectral). Many times the bands are of high-spectral resolution, designed for remotely sensing specific geophysical parameters

https://earthdata.nasa.gov/learn/remote-sensors

Atmospheric attenuation



Microwave
remote sensing

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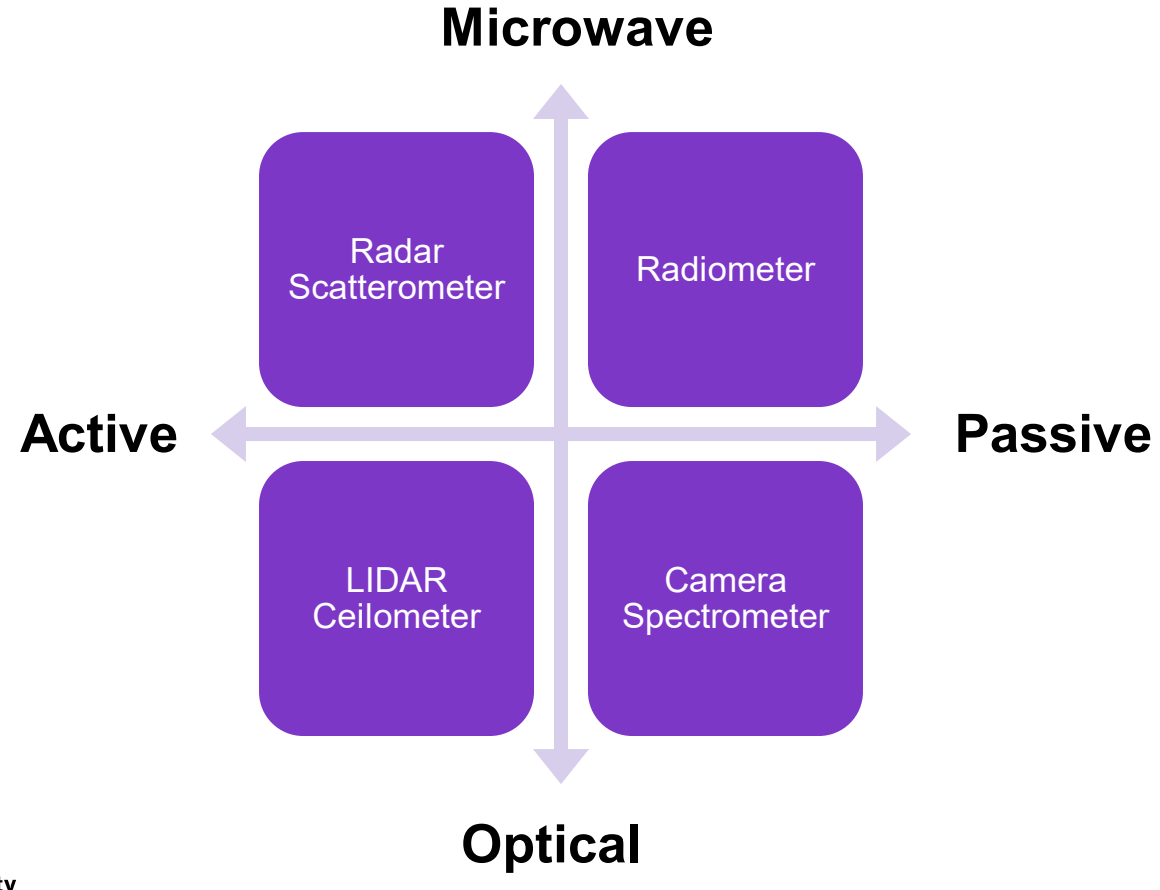
Instrument classification



Satellite as a measurement platform

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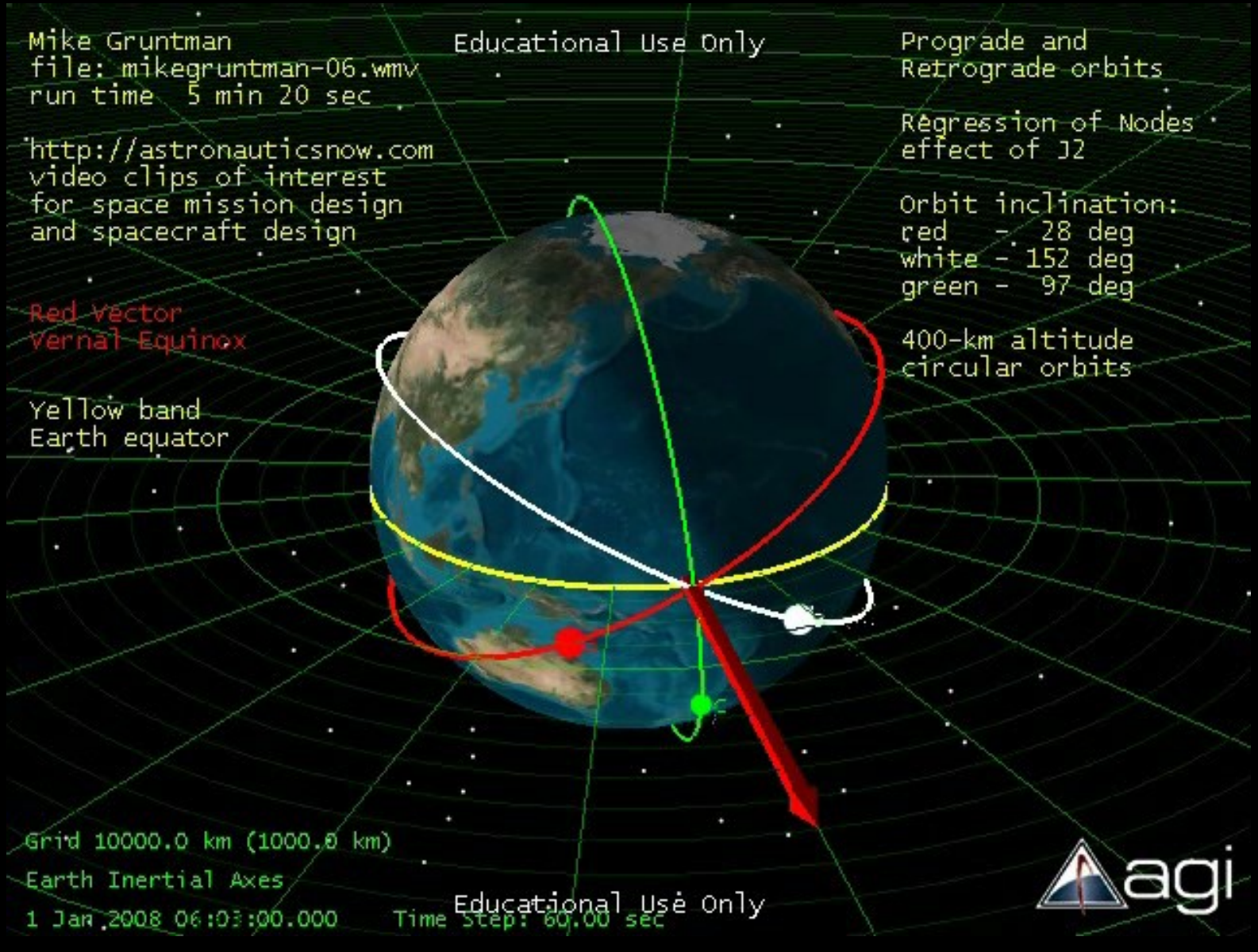
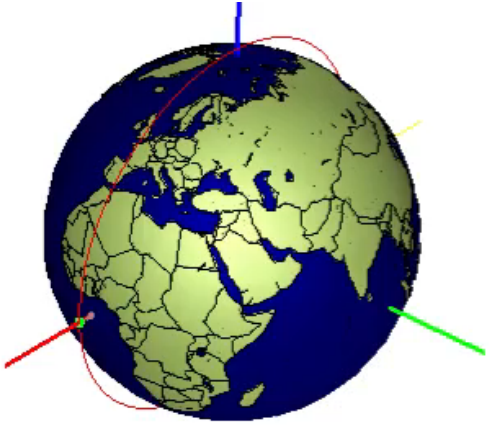
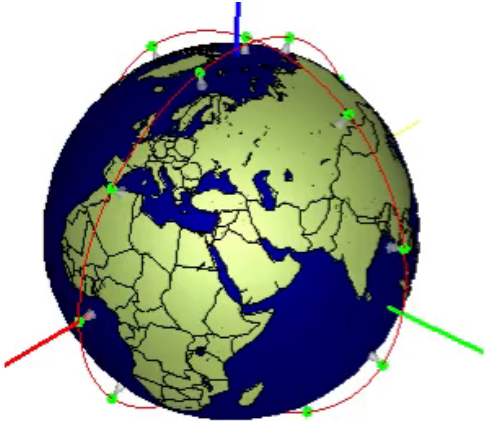
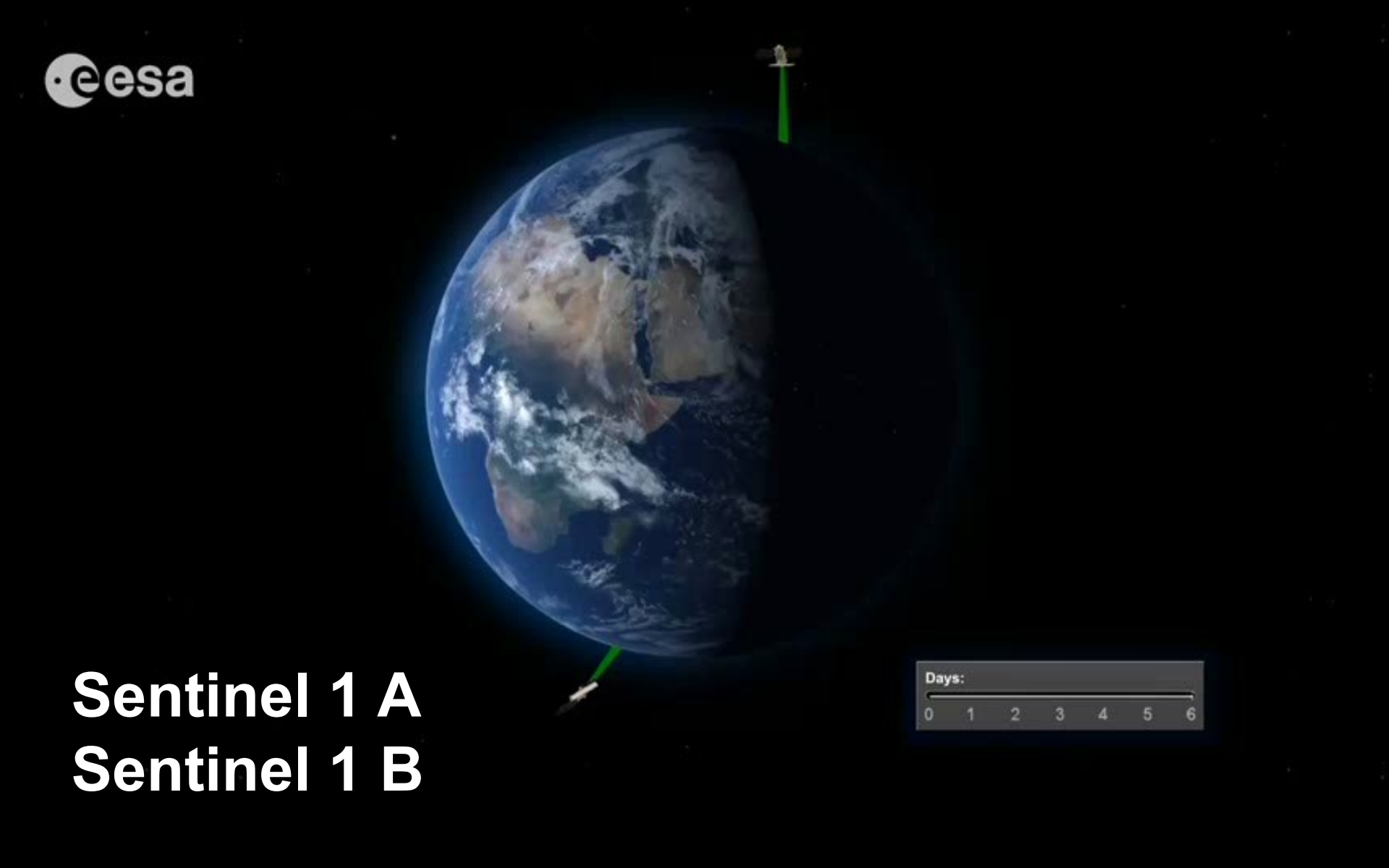

Mike Gruntman
file: mikegruntman-06.wmv
run time 5 min 20 sec
http://astronauticsnow.com
video clips of interest
for space mission design
and spacecraft design
Red Vector
Vernal Equinox
Yellow band
Earth equator
Educational Use Only
Prograde and
Retrograde orbits
Regression of Nodes
effect of J2
Orbit inclination:
red - 28 deg
white - 152 deg
green - 97 deg
400-km altitude
circular orbits
Grid 10000.0 km (1000.0 km)
Earth Inertial Axes
1 Jan 2008 06:03:00.000
Time Step: 60.00 sec
Educational Use Only
agi

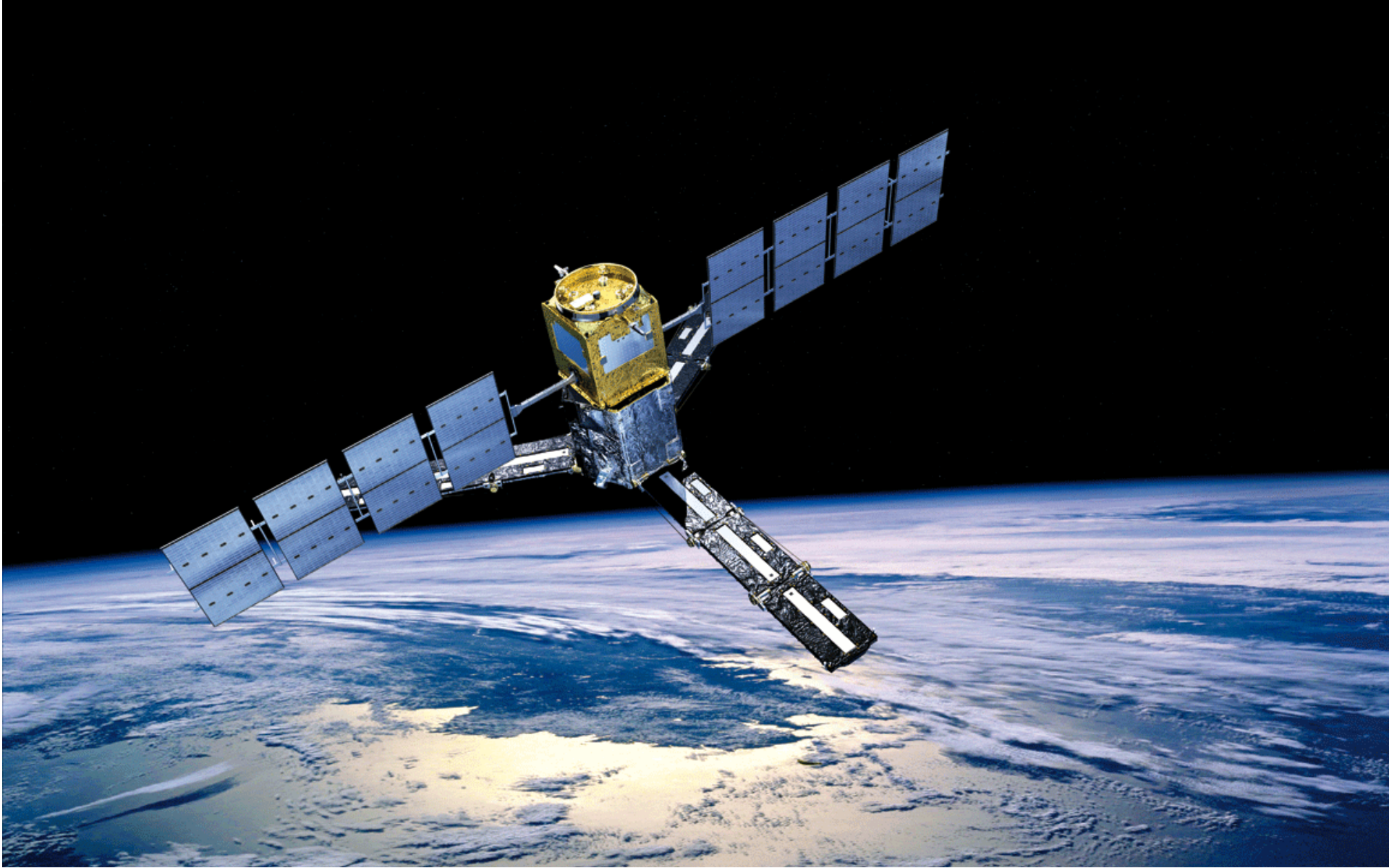
One satellite is good



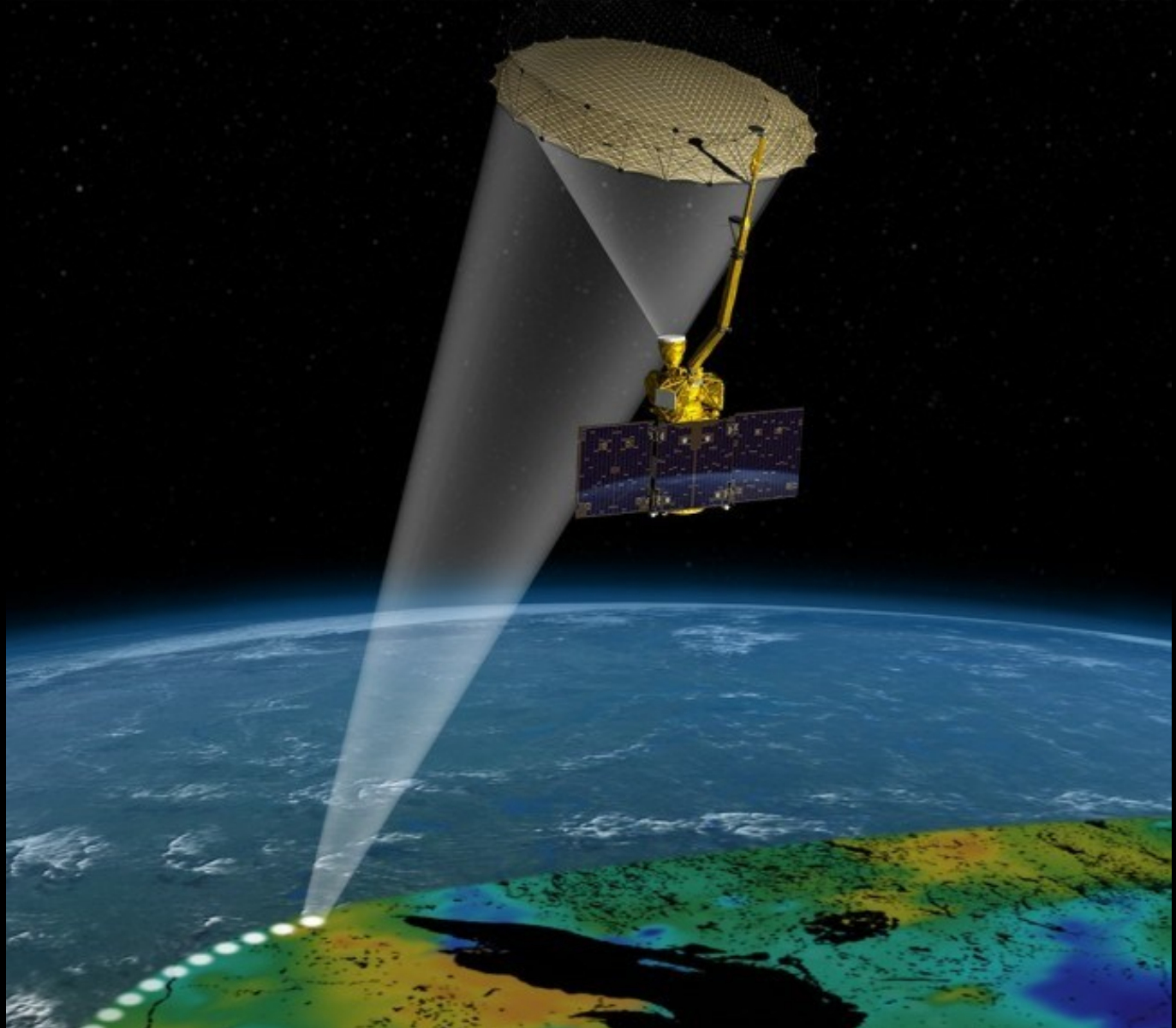
Many satellites are better

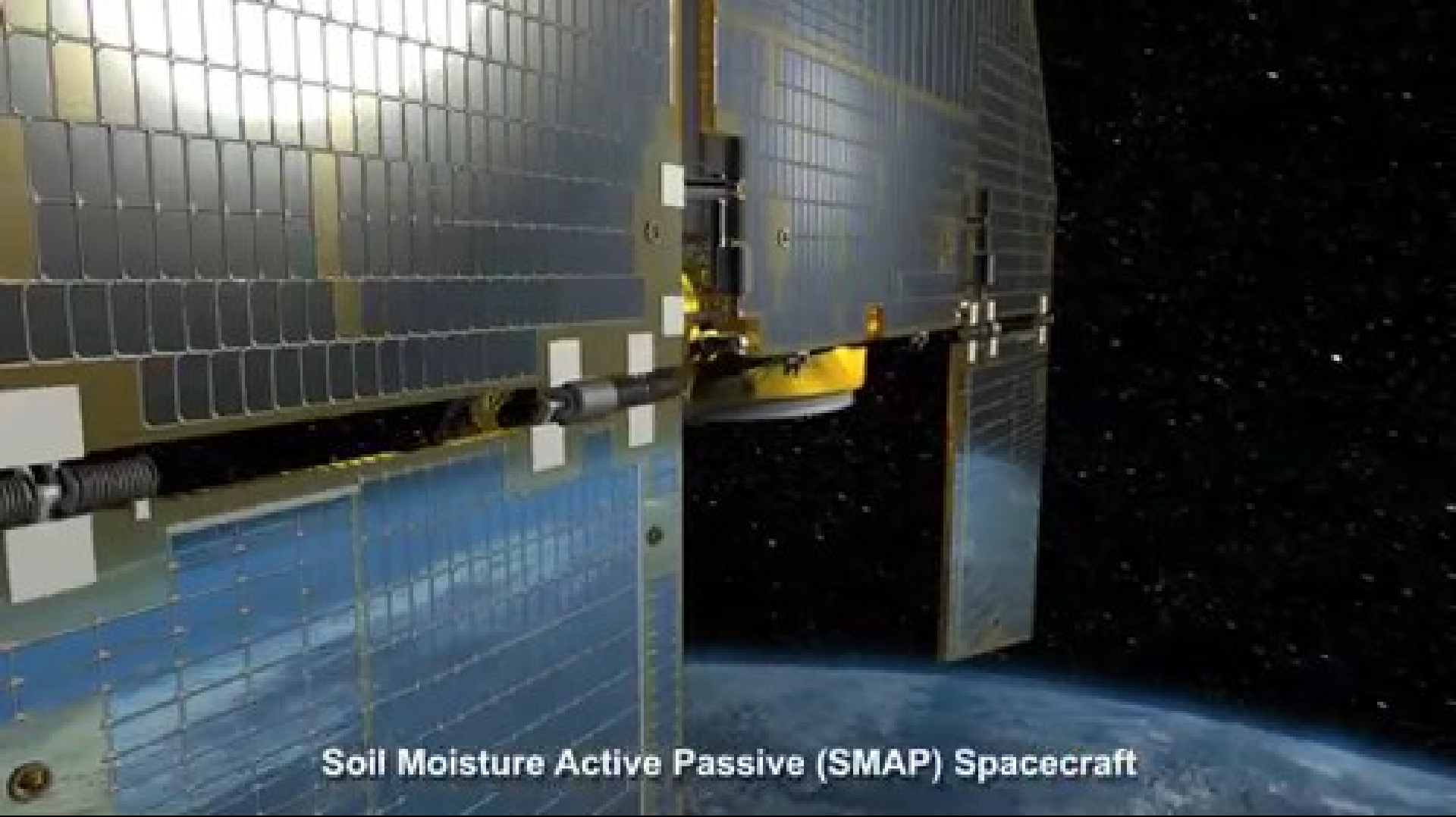


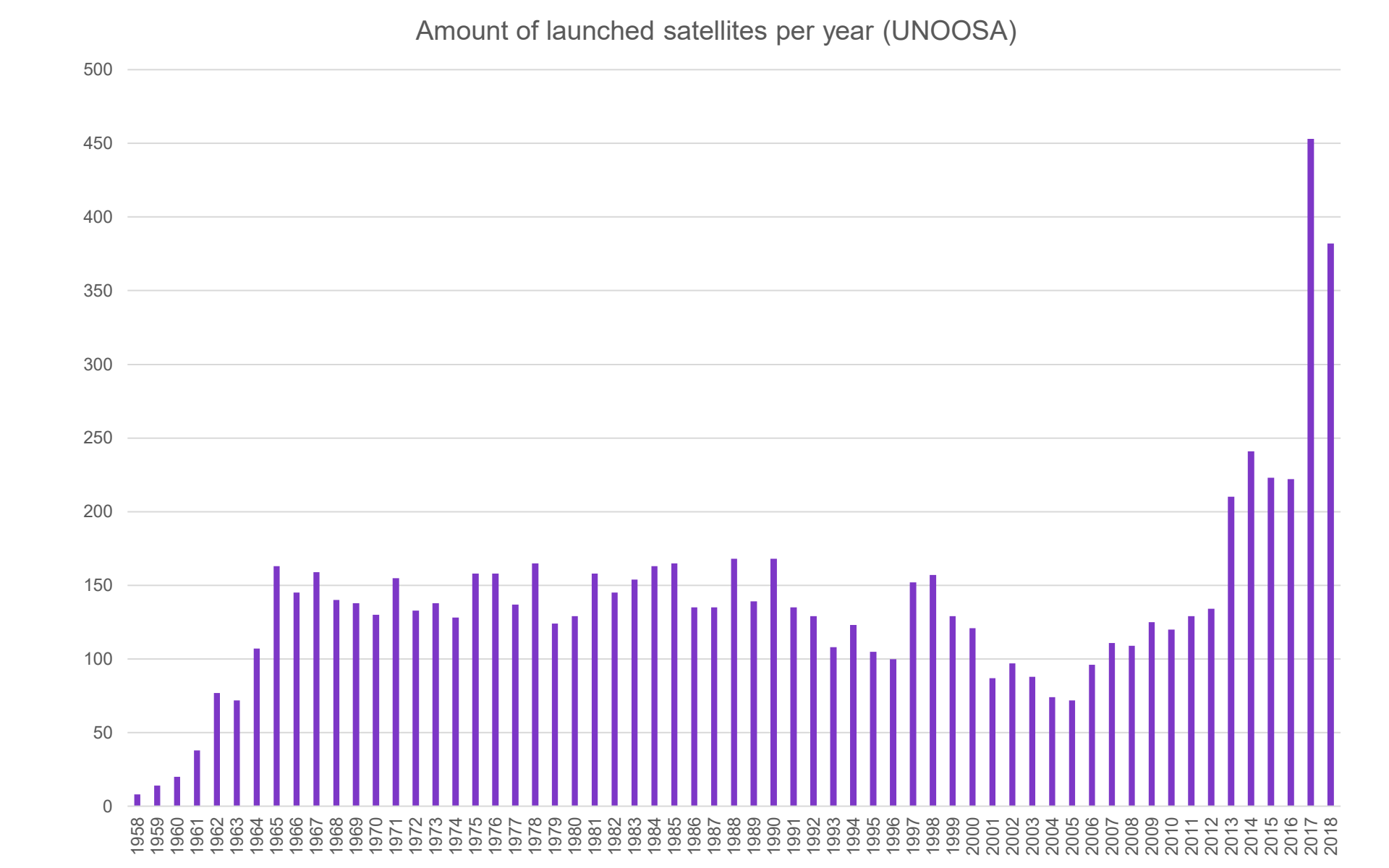

esa
Days:
0 1 2 3 4 5 6
Sentinel 1 A
Sentinel 1 B




esa
EADS
CASA ESPAC




Soil Moisture Active Passive (SMAP) Spacecraft


Amount of launched satellites per year (UNOOSA)
500
450
400
350
300
250
200
150
100
50
0
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
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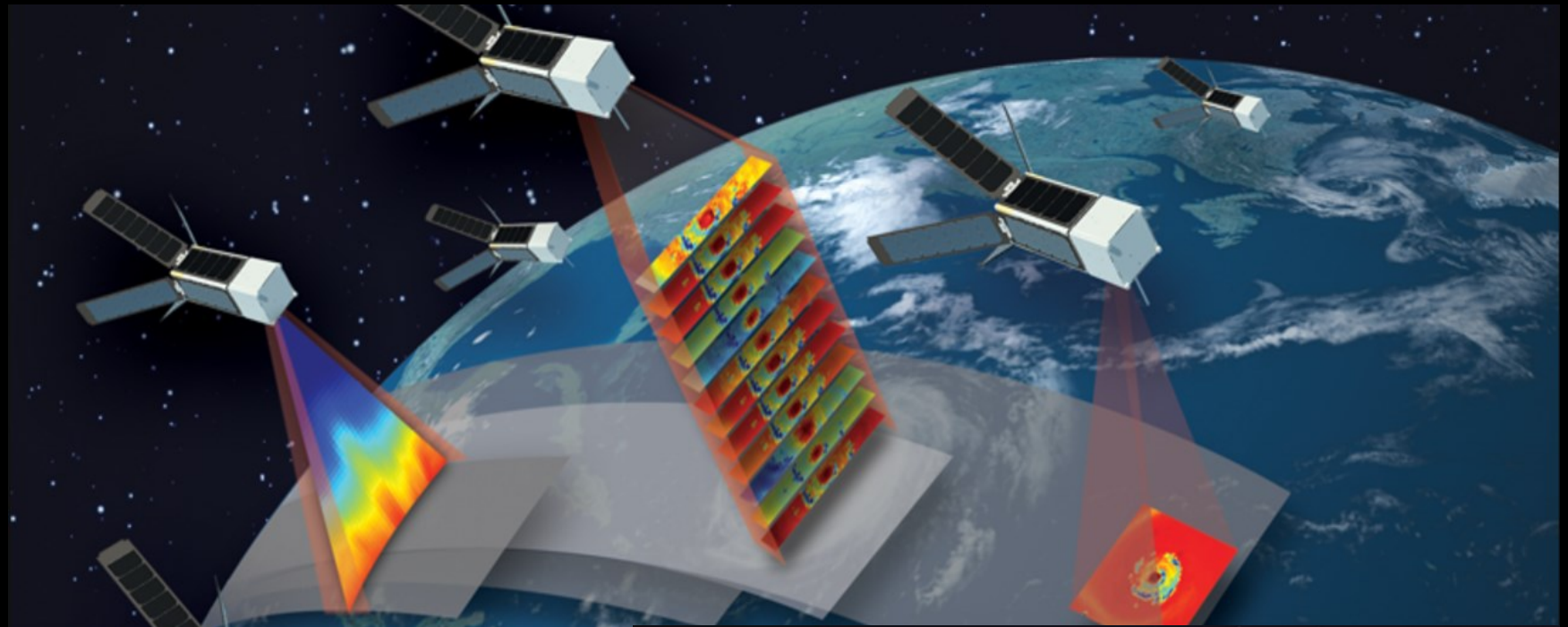
2014
2015
2016
2017
2018


planet.

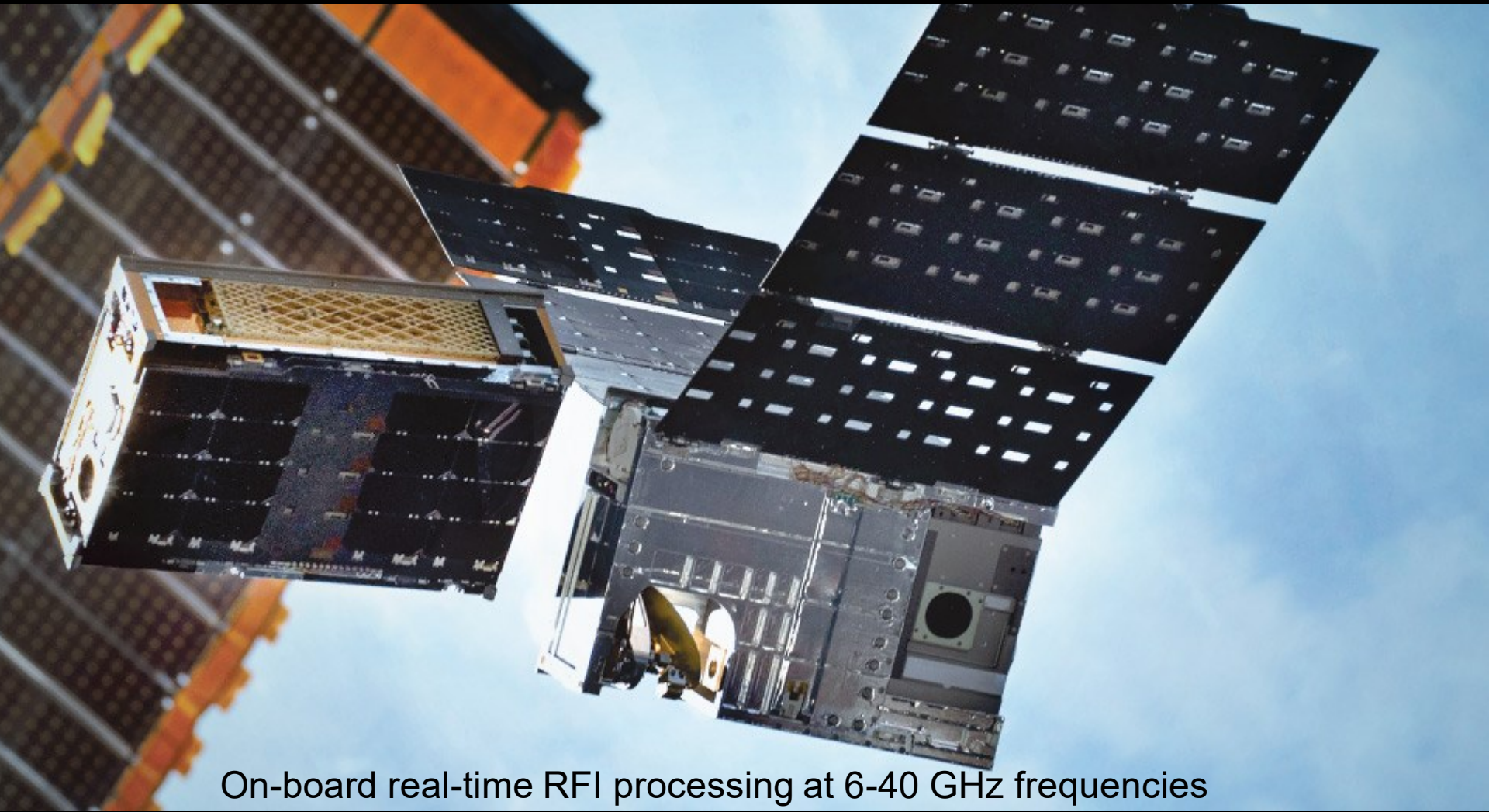


Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats

MIT Lincoln Laboratory (proposing organization)

William J. Blackwell, Principal Investigator. Scott Braun (NASA GSFC), Project Scientist

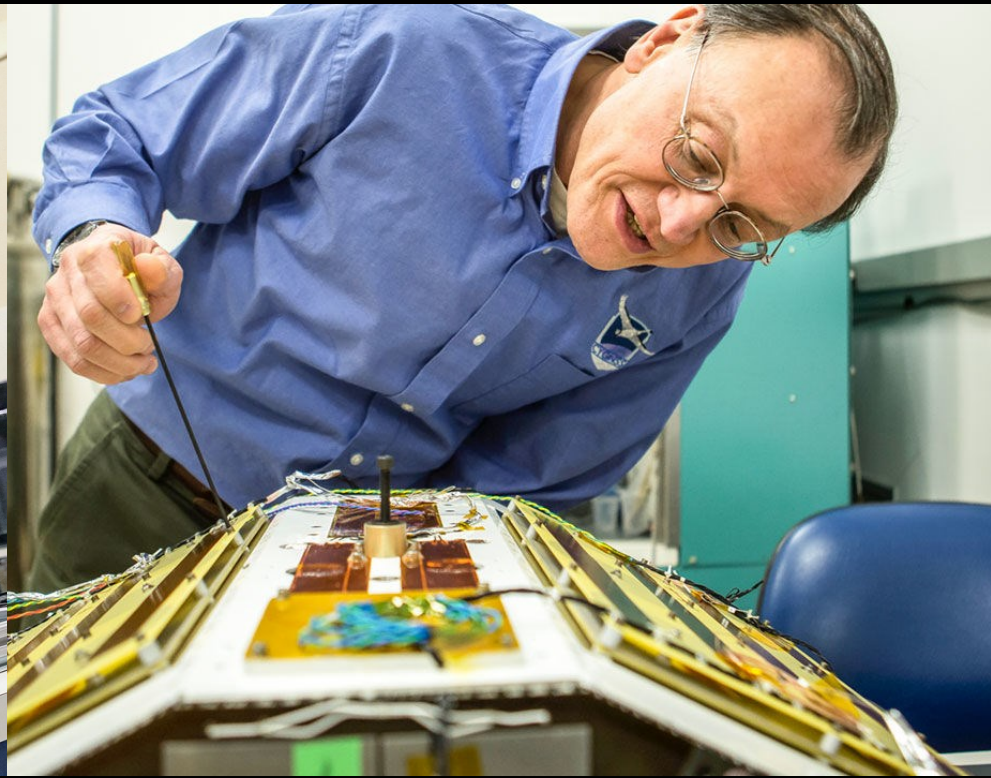
A constellation of identical 3U CubeSats provide sounding (left CubeSat has a temperature profile of a simulated Tropical Cyclone (TC) from a numerical weather prediction (NWP) model) and 12-channel radiometric imagery (center CubeSat has simulated radiances from NWP model and radiative transfer model and the near right CubeSat has a single-channel radiance image of a TC) with a median revisit rate approaching 30 minutes to meet most PATH requirements.



On-board real-time RFI processing at 6-40 GHz frequencies


THE OHIO STATE
UNIVERSITY


+X
-Y



ICEYE


USA
JAPAN
SOUTH KOREA
INDIA
CHINA
FRANCE
RUSSIA
NOAA
EUMETSAT
EUROPEAN COMMISSION
NATIONAL SPACE ORGANIZATION (NSPO)
EUROPEAN SPACE AGENCY
DSCOVR
COMS
FY-2
SOHO
ACE
HIMAWARI-8
FY-2
INSAT-3D
ELECTRO-L
KALPANA
METEOSAT-7
METEOSAT-10
NOAA-15/18/19
GPM
SENTINEL-1
SENTINEL-2
SENTINEL-3
JASON -2/3
GCOM
FY-3
METOP
METEOR
DMSP-F14-18
COSMIC
SUOMI NPP
A-TRAIN CONSTELLATION
GOES - WEST
GOES - 14
GOES - EAST
140.7° E
128.2° E
105° E
90° E
86.5° E
82° E
78° E
74° E
57° E
180° W
135° W
105° W
90° W
75° W
0°
GEOSTATIONARY ORBIT
NEAR-POLAR ORBIT
LAGRANGE POINT 1

Advantages and disadvantages of Remote Sensing

+ *Monitoring of spatially or temporally varying large-scale phenomena is possible*
+ *Acquision of up to global data sets within a few days*
+ *Avoid expensive and time-consuming collection of in-situ data*
+ *Can provide information on phenomena earlier unreachable*

- *Developing and operating satellites and sensors is very expensive*
- *Intensive work is required in order to develop reliable data interpretation methods; otherwise accuracy of remotely sensed characteristics may not be good*

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Take a break

Measurement problem for Remote Sensing

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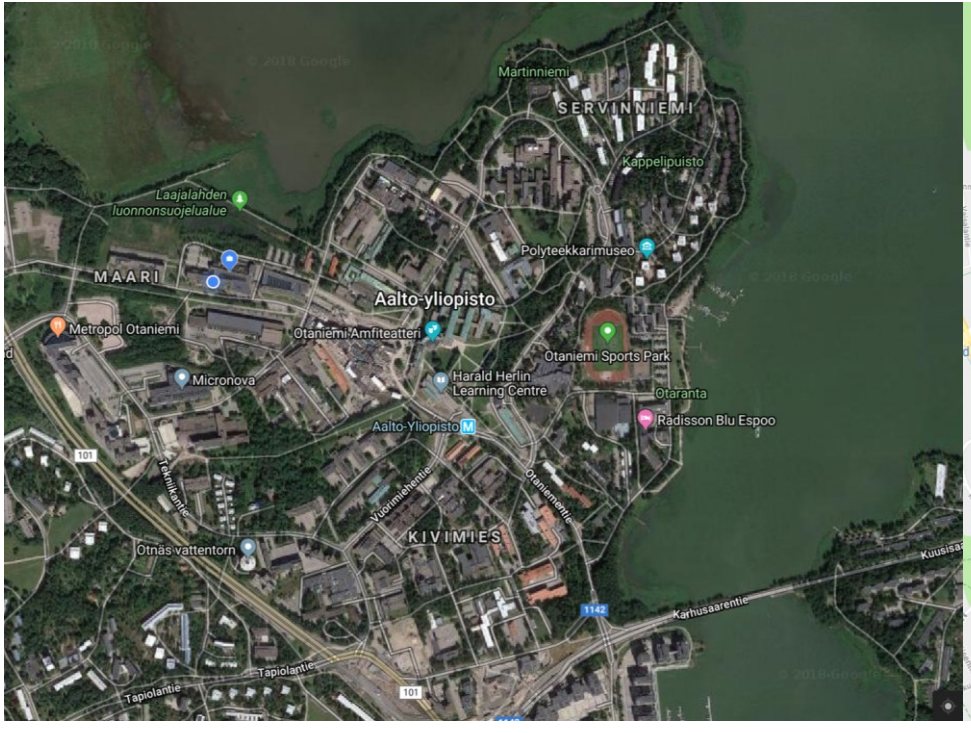
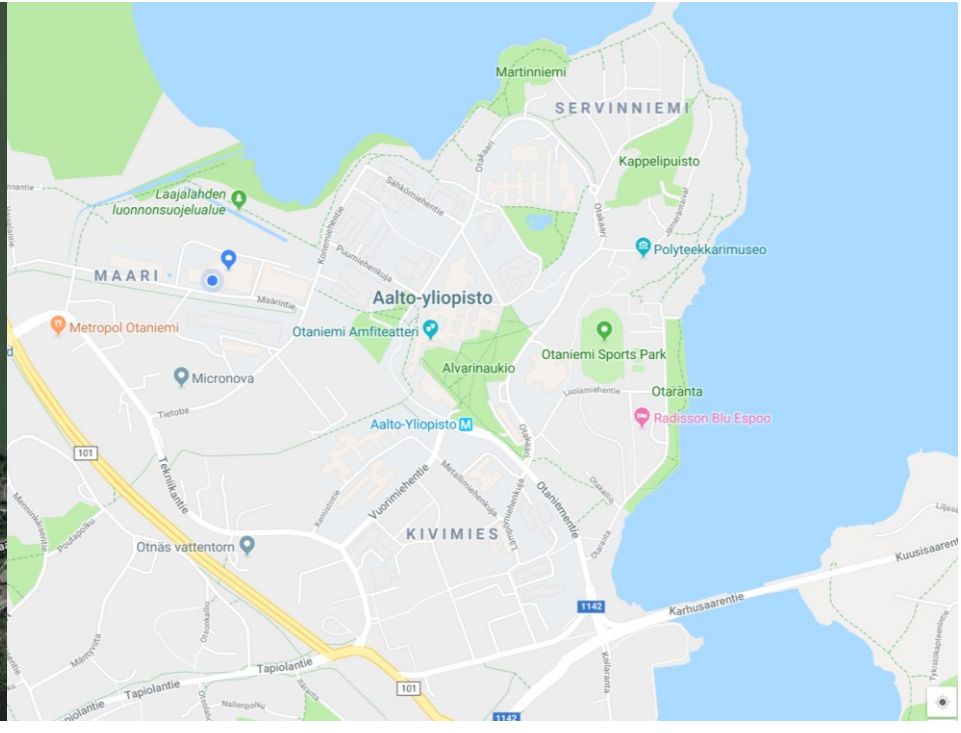
Measurement vs product





Remote sensing central problem

Measurement (spatial distribution of)

- Intensity
- Emissivity
- Reflectivity
- Transmissivity
- Absorption
- Frequency shift
- Time delay
- Spectral distribution

Needed parameter (spatial distribution of)

Forest age

Biomass

Snow depth

Wind speed

Ocean surface temperature

Soil moisture

Glacier volume

Glacier speed

Remote sensing instrument rarely measures the parameter we really need

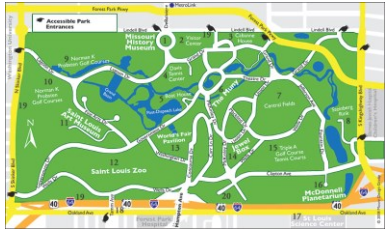
Measurement

Conditions on the ground

MODEL

Desired parameter

Ancillary data



Models

- **Empirical models**
  - based entirely on empirically found relationship between measured and desired parameters, regression models, nearest neighbour
- **Semiempirical models**
  - based approximately on known physical relationship between measured and desired parameter, however the model is calibrated with empirical parameters
- **Theoretical models**
  - Model is founded entirely on physical theory explaining the measuremed parameter and desired parameter relationship.

Microwaves

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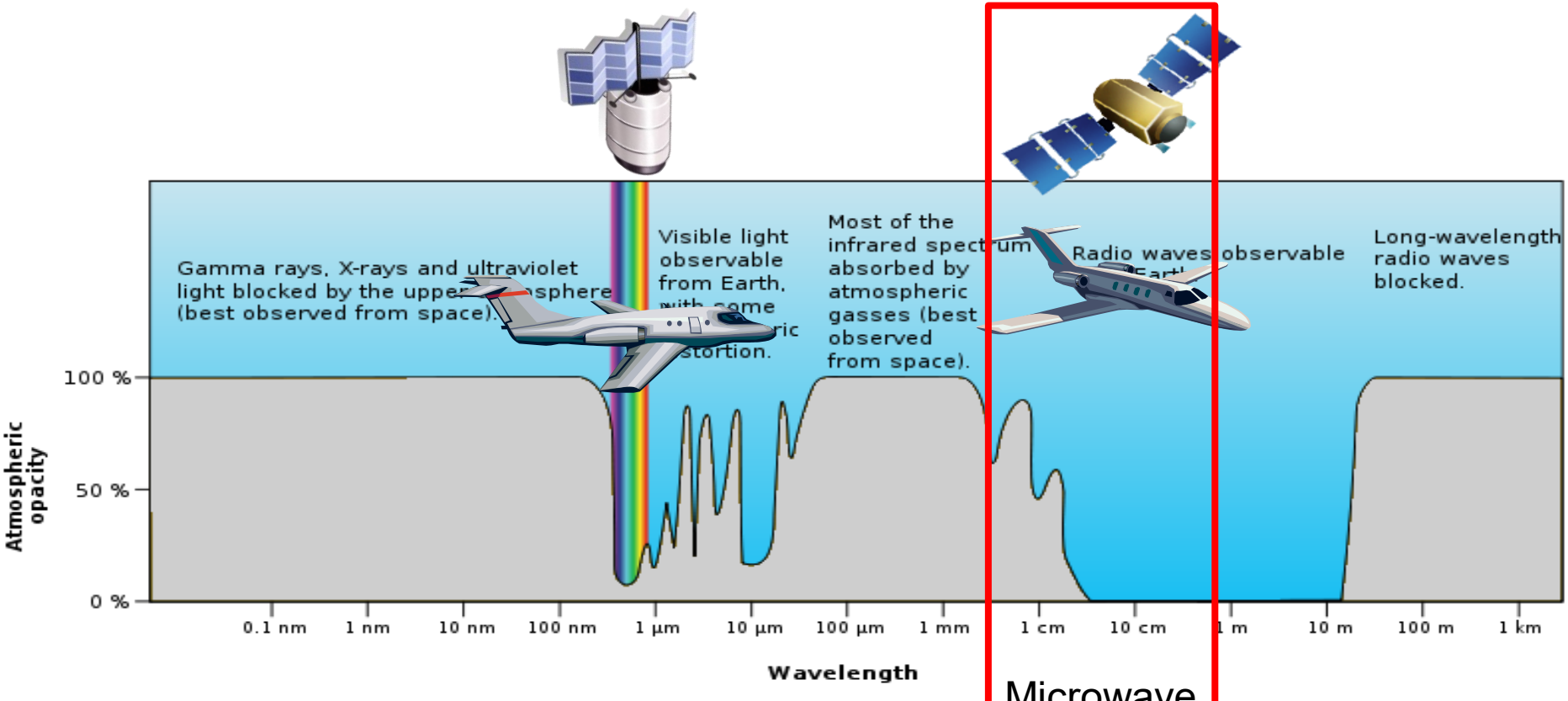
Atmospheric attenuation



Microwave remote sensing

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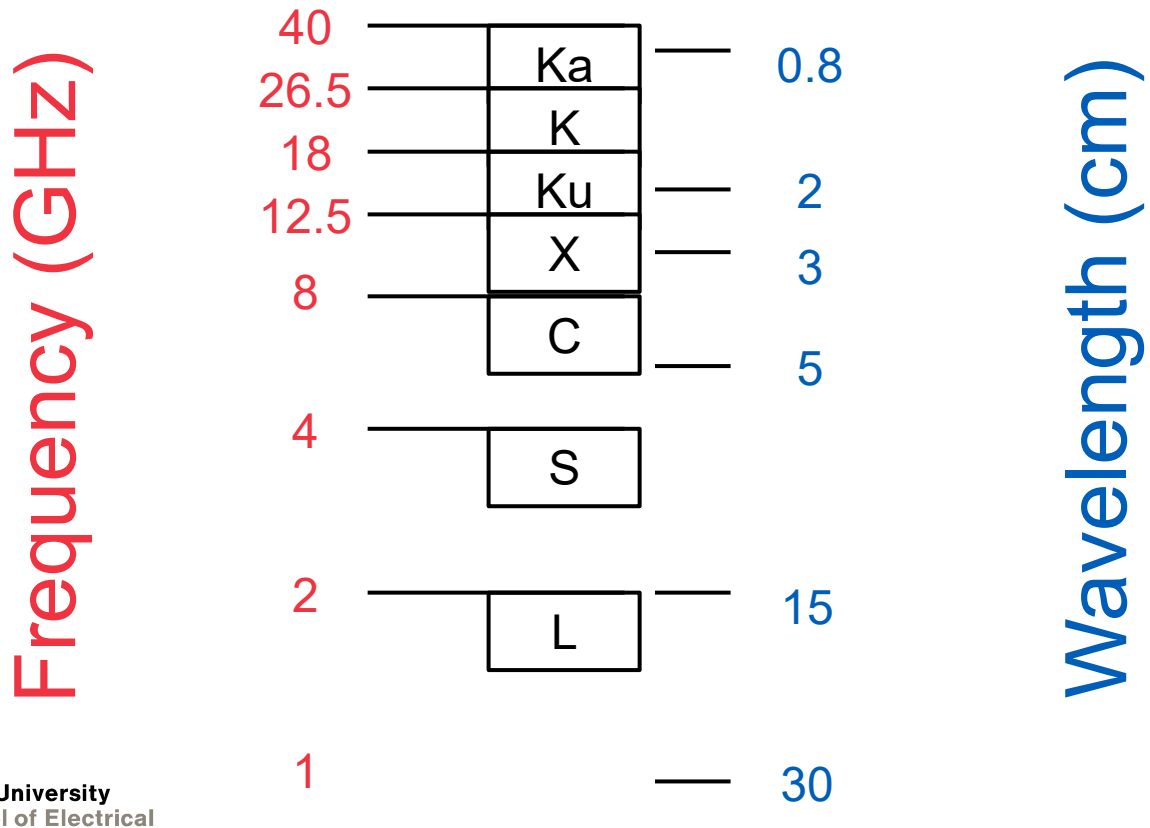
Microwave remote sensing bands



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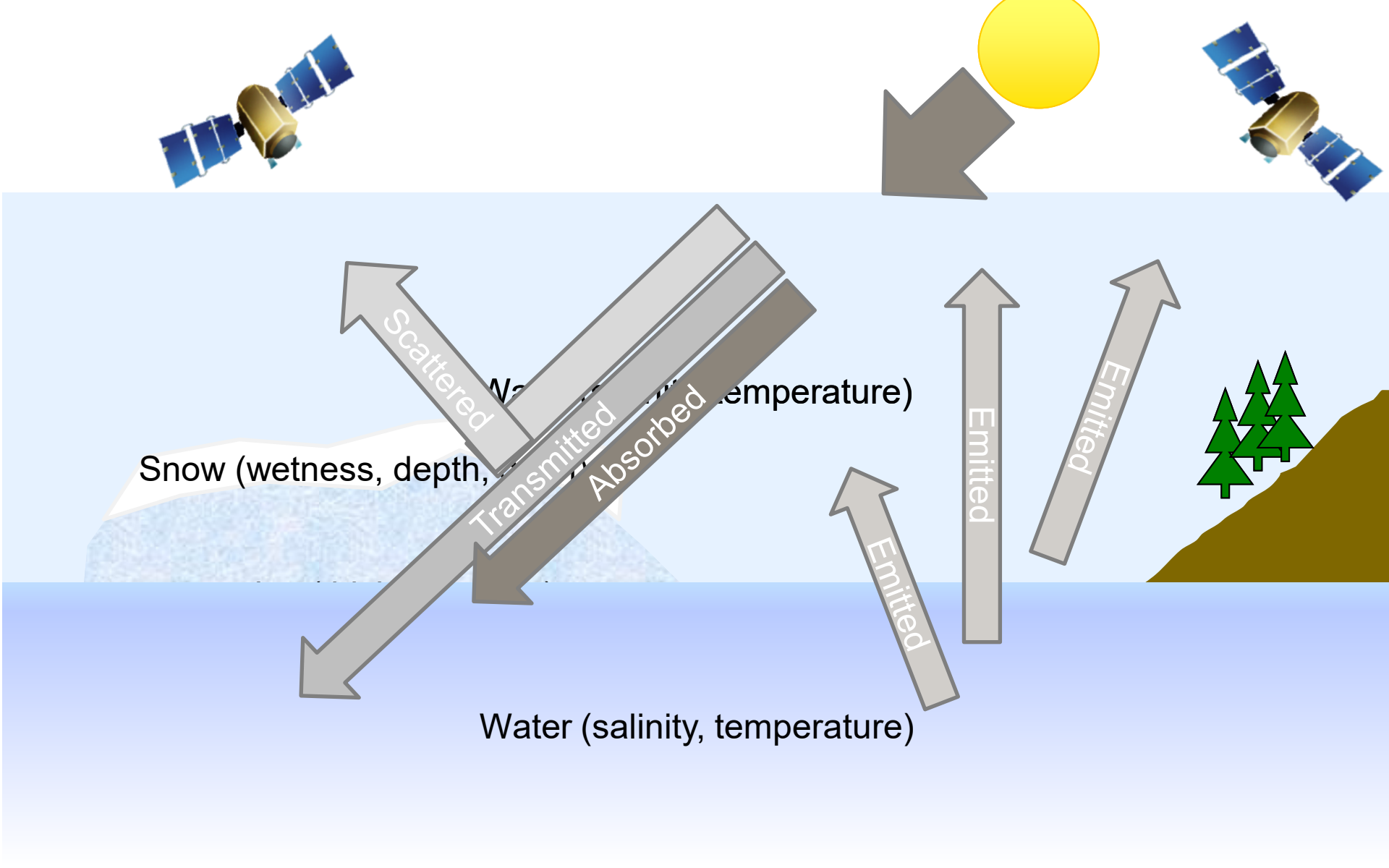
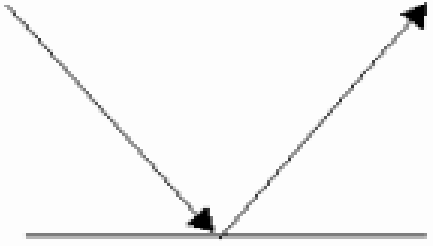
What can we see with microwaves?

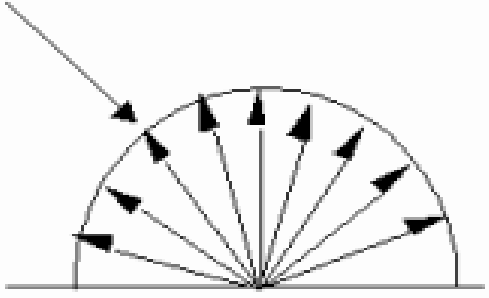

Scattered
Transmitted
Absorbed
Emitted
Emitted
Emitted
Snow (wetness, depth,
emperature)
Water (salinity, temperature)

Emission: All substances at finite temperatures radiate EM energy	**Radiometers**
Absorption: Energy into heat	**Radiometers**
Scattering: Energy to other directions due to particles in the propagation path	**Scatterometers** **Radars**

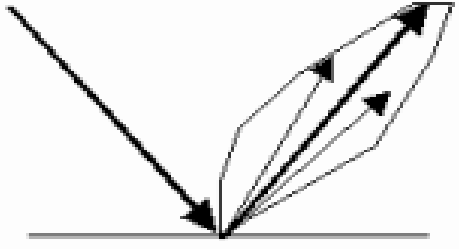
Types of Reflection



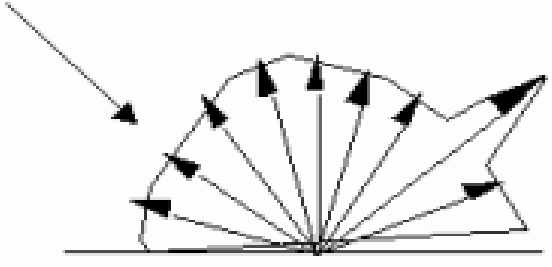
Specular reflector (mirror)



diffuse reflector (lambertian)



Nearly Specular reflector (water)



nearly diffuse reflector

Relative permittivity of liquid water

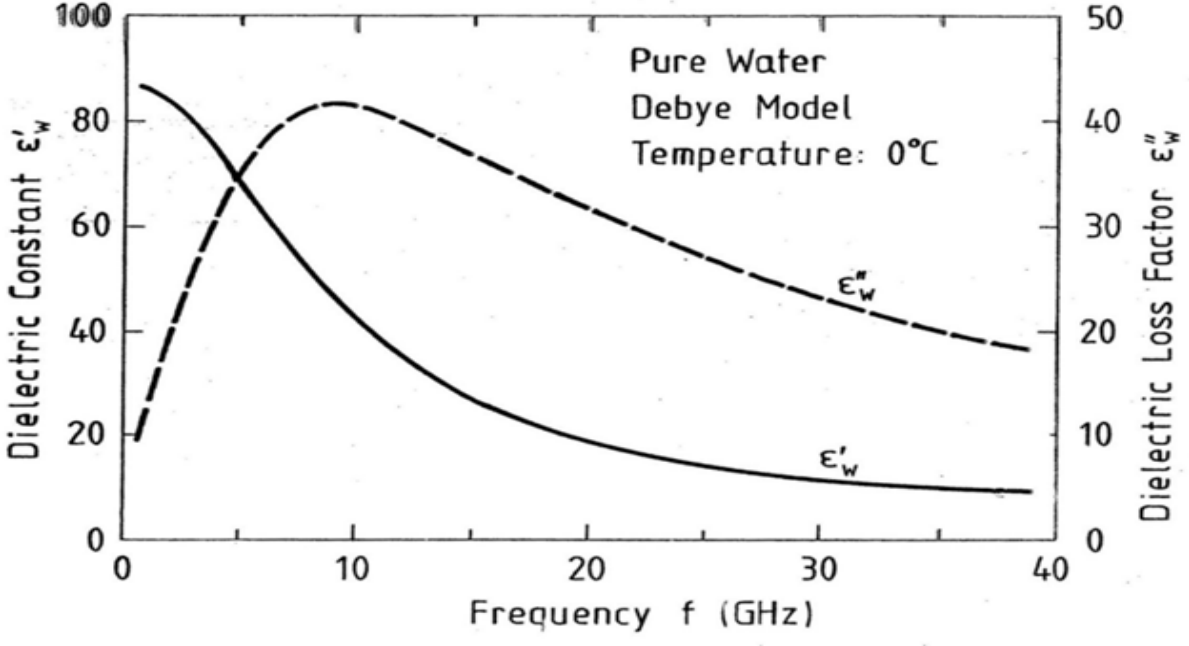
Liquid water is high contrast material compared to most natural media

$$\varepsilon = \varepsilon' - j\,\varepsilon''$$

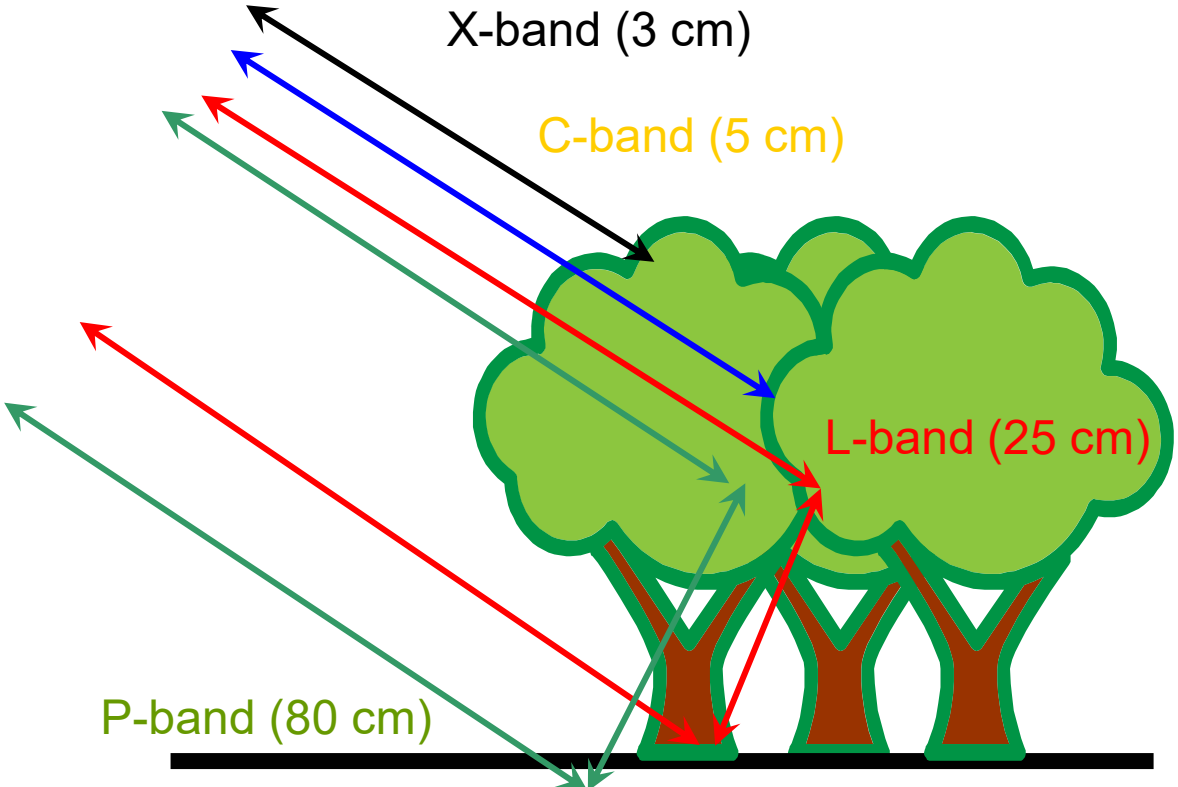
ε(temp)

ε(salinity)

ε(freezing, thaw)



Penetration depth of different microwave wavelenghts into forest



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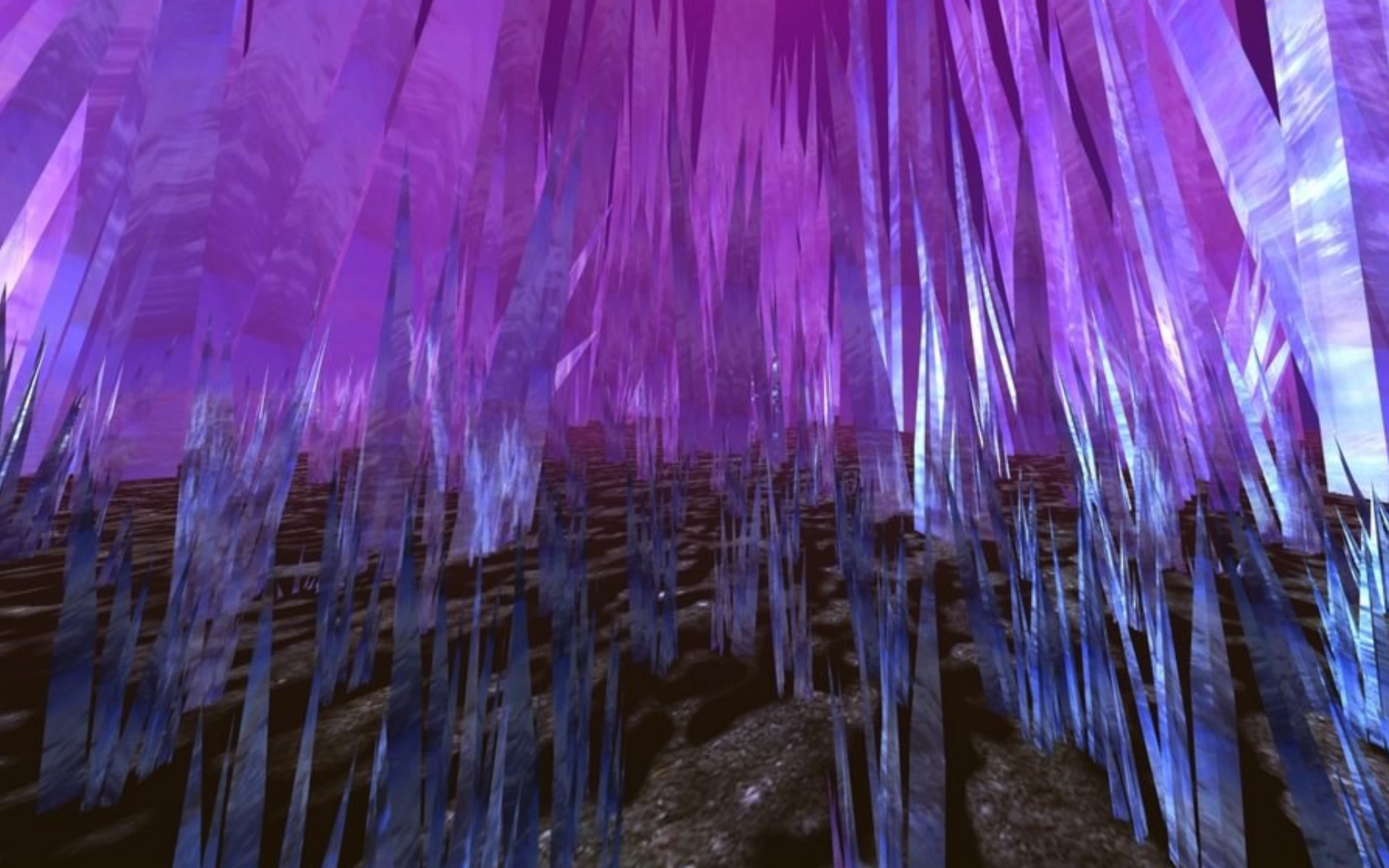

Microwave Remote Sensing Applications Areas

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Engineering

Polar Remote Sensing

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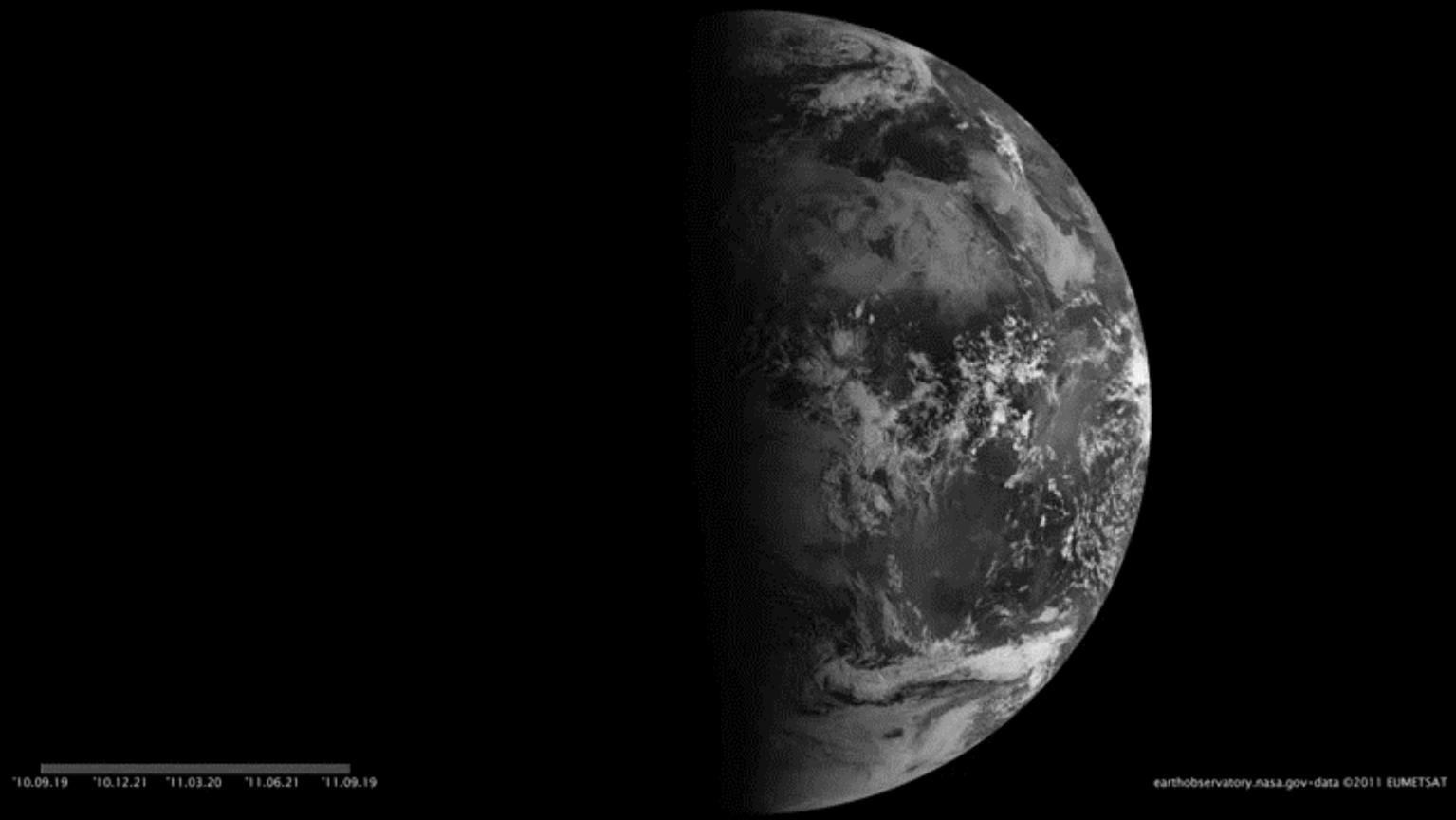
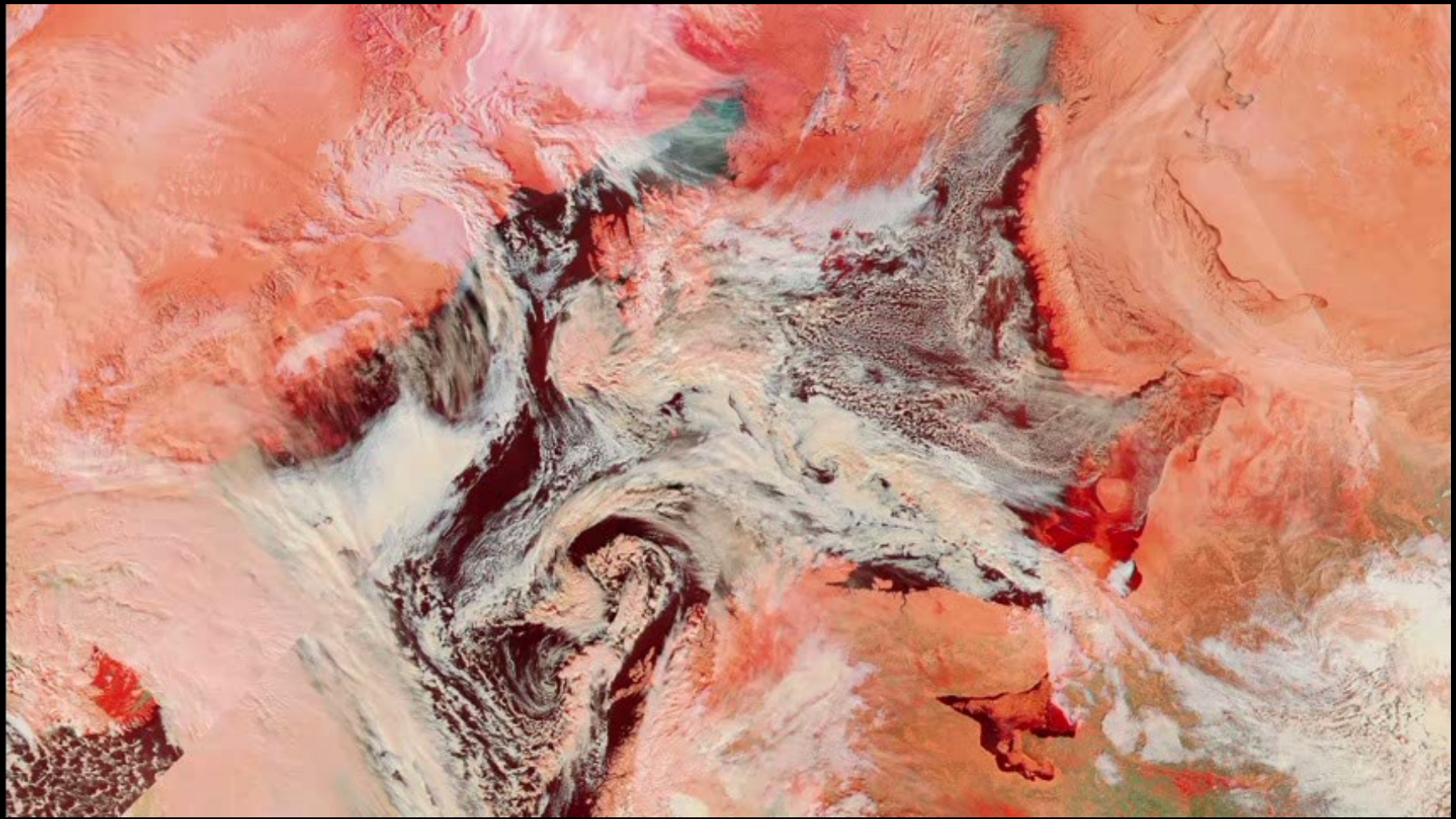
Engineering

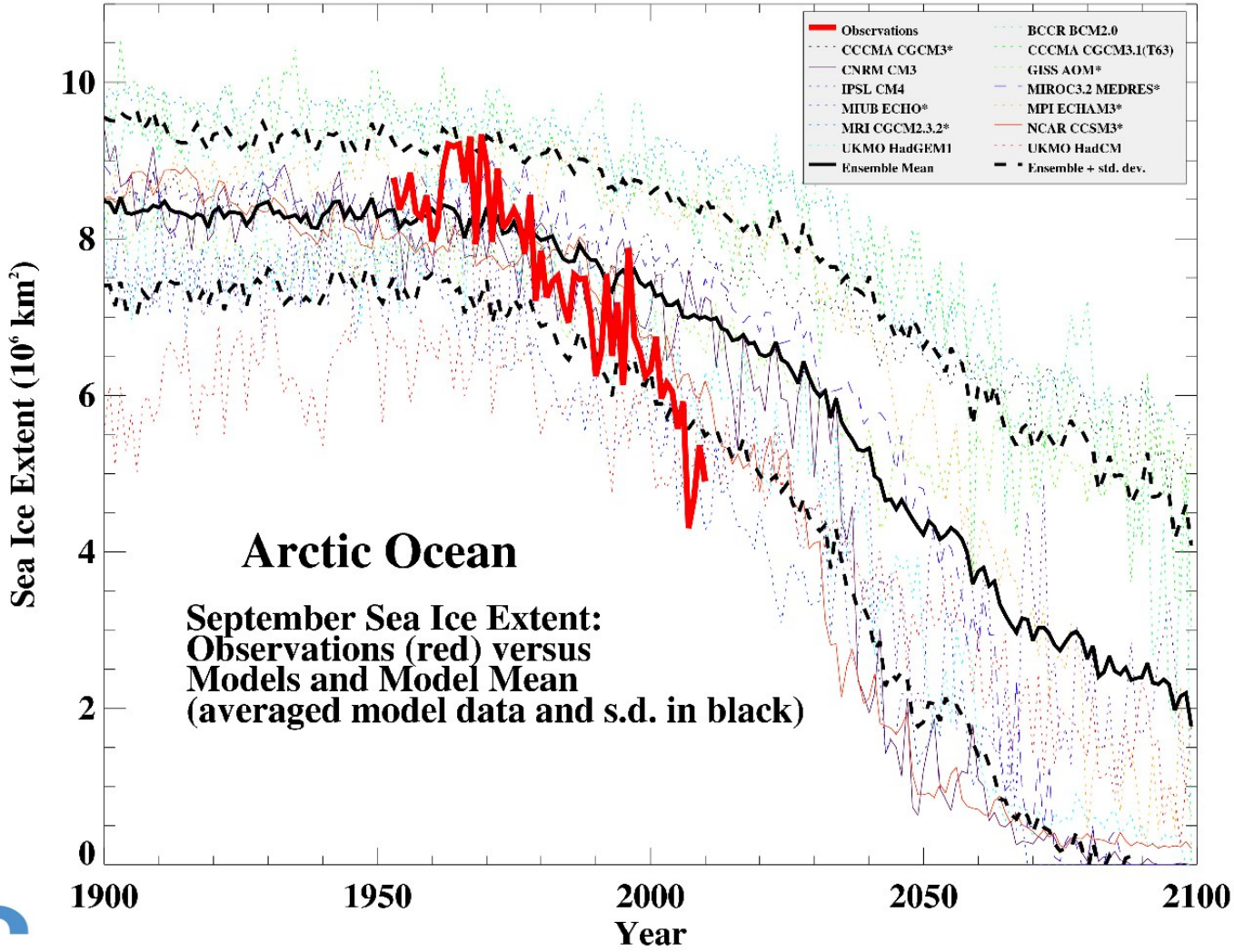
North is dark…



….and cloudy



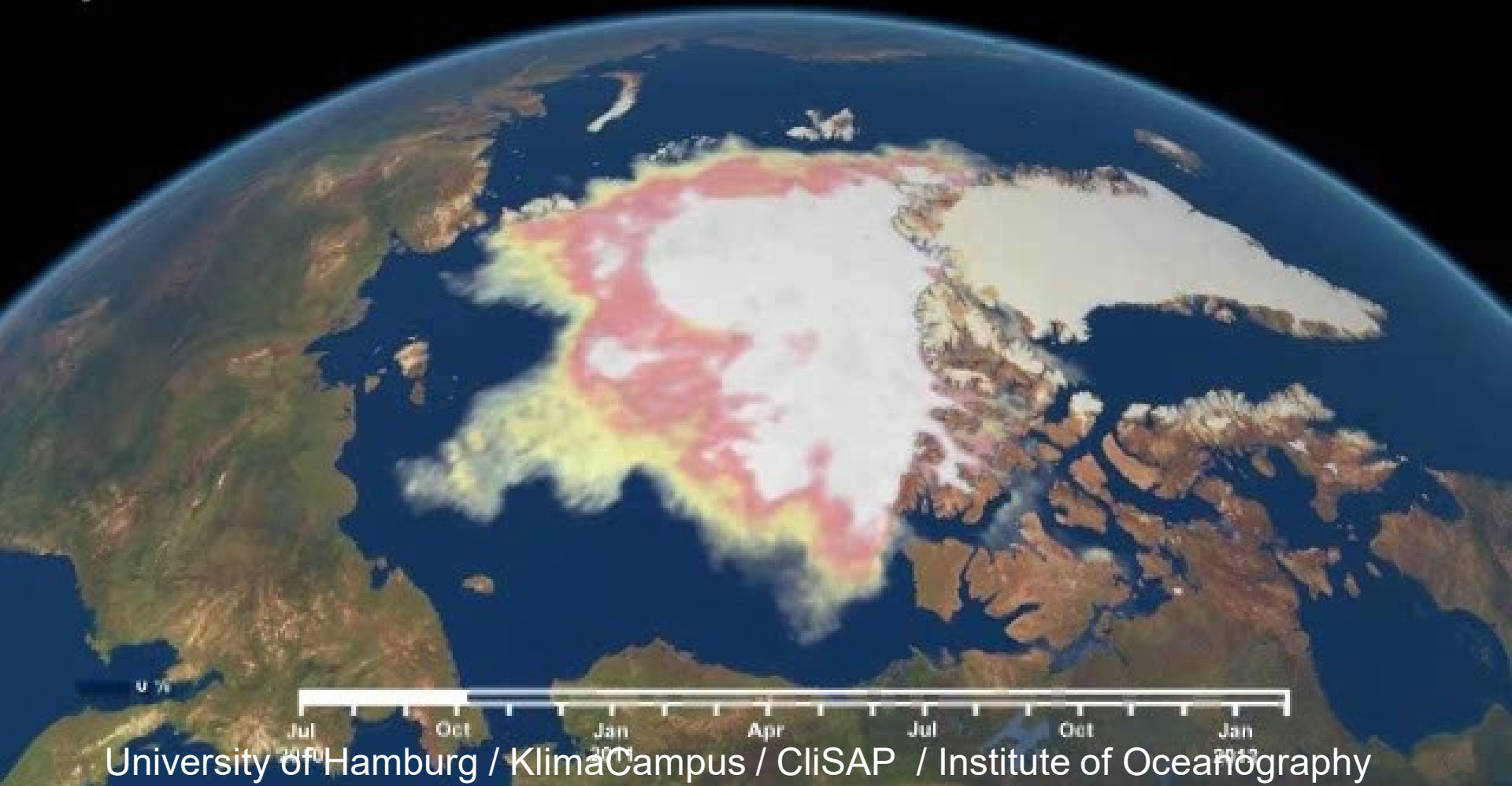
MODIS Arctic time lapse (Pekka Laurila)



IPCC
INTERGOVERNMENTAL PANEL ON
climate change

Environmental change

The sea ice thickness from SMOS



University of Hamburg / KlimaCampus / CliSAP / Institute of Oceanography

SAR in lake ice classification

SAR interferometry in height detection


esa
Jakobshavn Glacier flow
07-2017

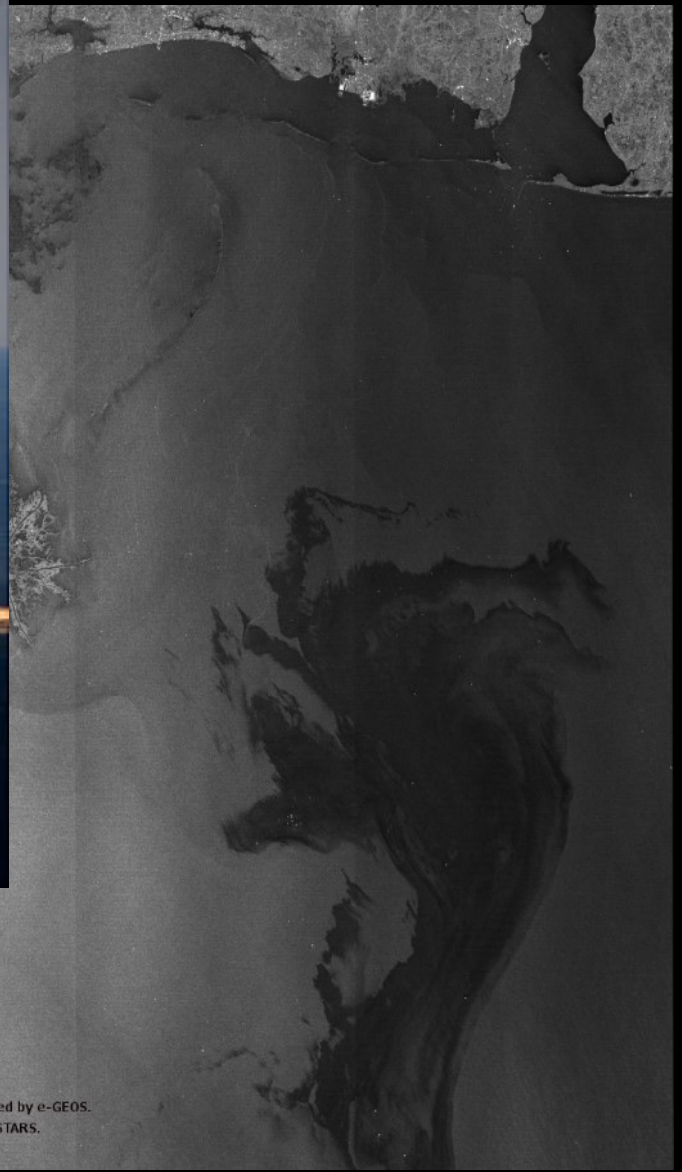
Disasters and bad weather

Aalto University
School of Electrical
Engineering


Florida
Grand Bahama
Great Abaco


Crystal Inn
SPEED LIMIT 35


Bahamas
Road network data © OpenStreetMap contributors
ICEYE



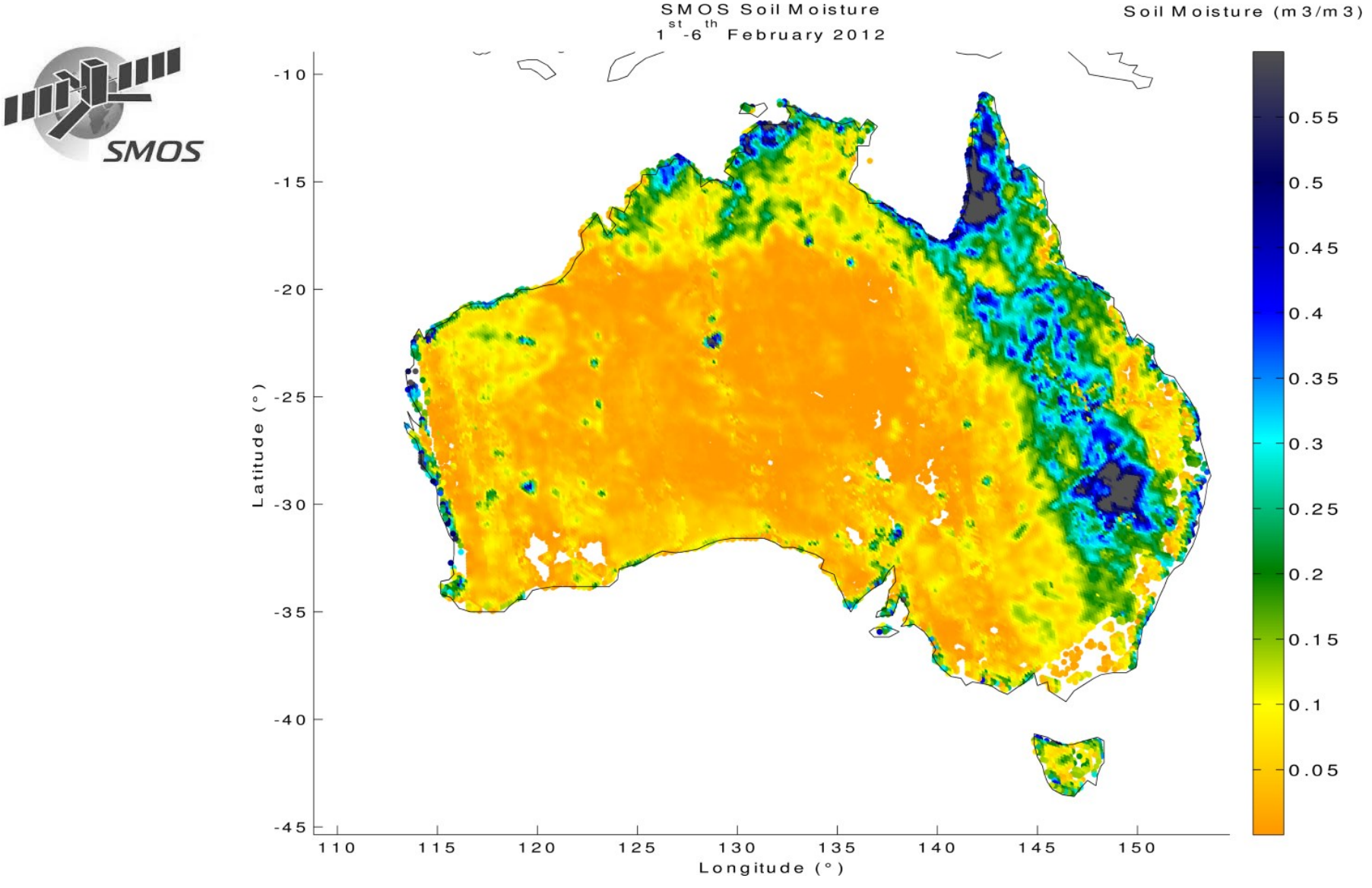
CSTARS

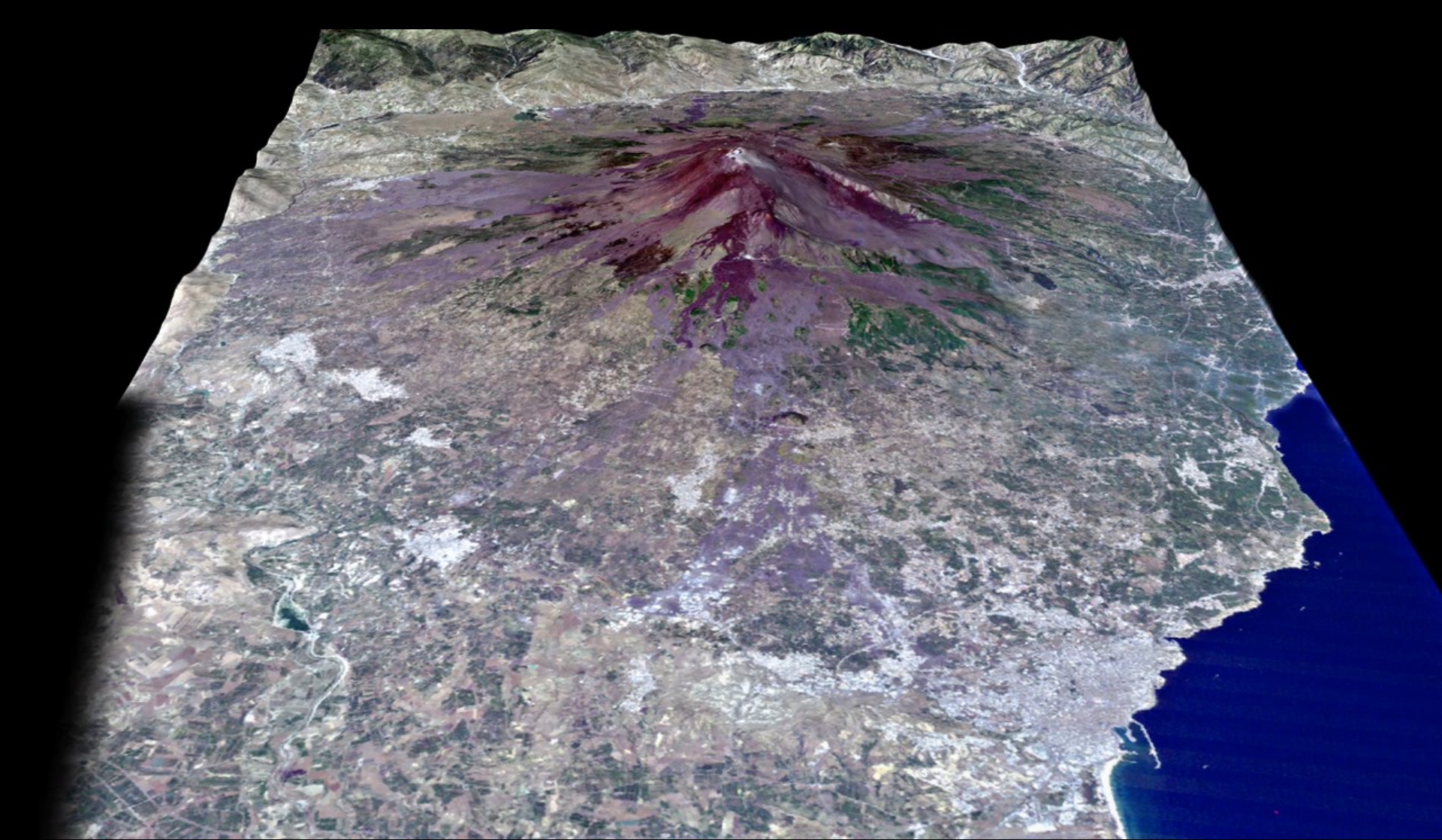
e-geos

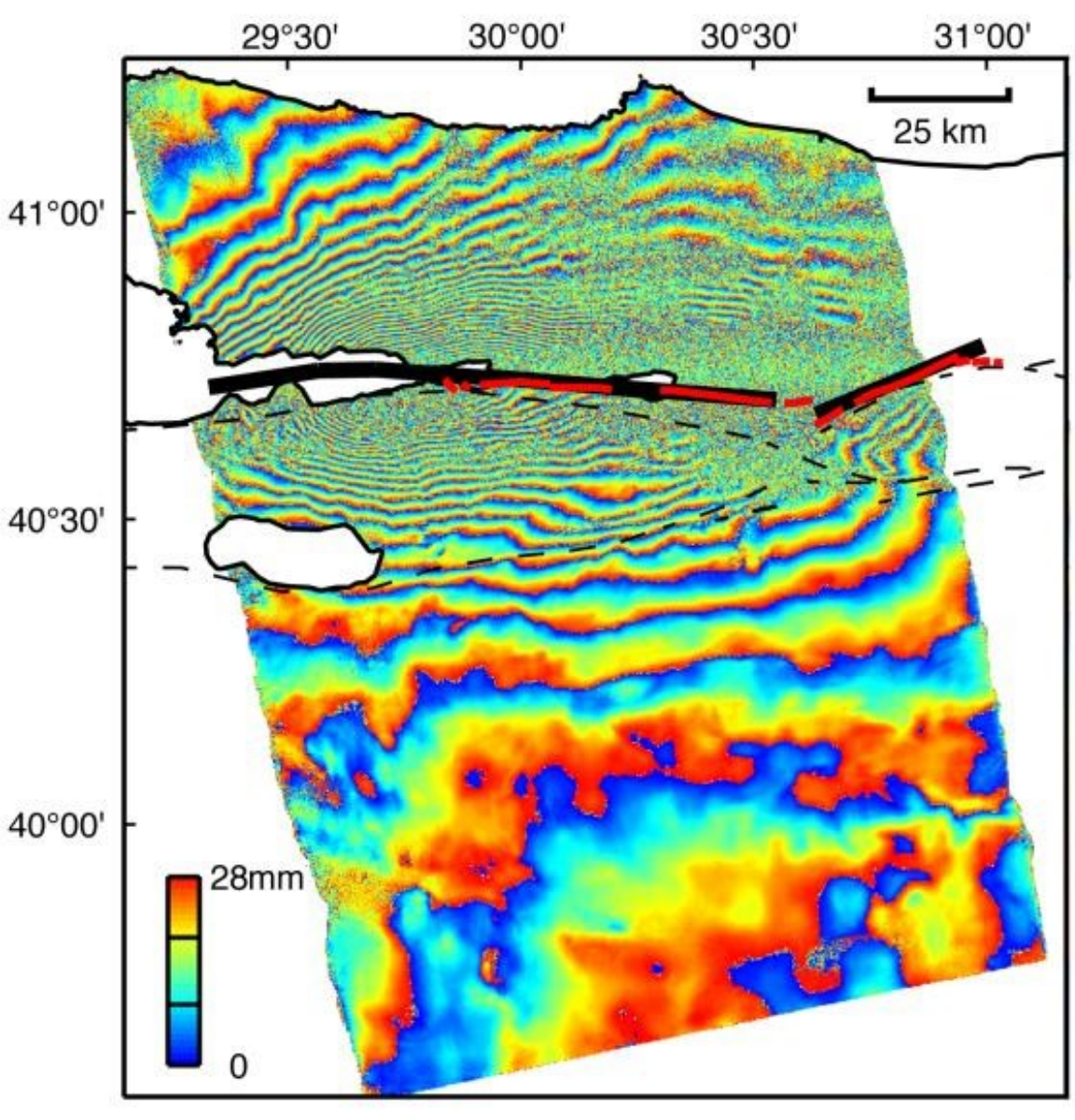
UNA SOCIETÀ ASI/TELESPAZIO

COSMO-SkyMed © ASI, distributed by e-GEOS.
Downlinked and processed by CSTARS.


esa


SMOS
SMOS Soil Moisture
1st-6th February 2012
Soil Moisture (m3/m3)
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
Latitude (°)
-10
-15
-20
-25
-30
-35
-40
-45
Longitude (°)
110
115
120
125
130
135
140
145
150




29°30'
30°00'
30°30'
31°00'
25 km
41°00'
40°30'
40°00'
28mm
0

Forest Biomass

Surveillance and tracking

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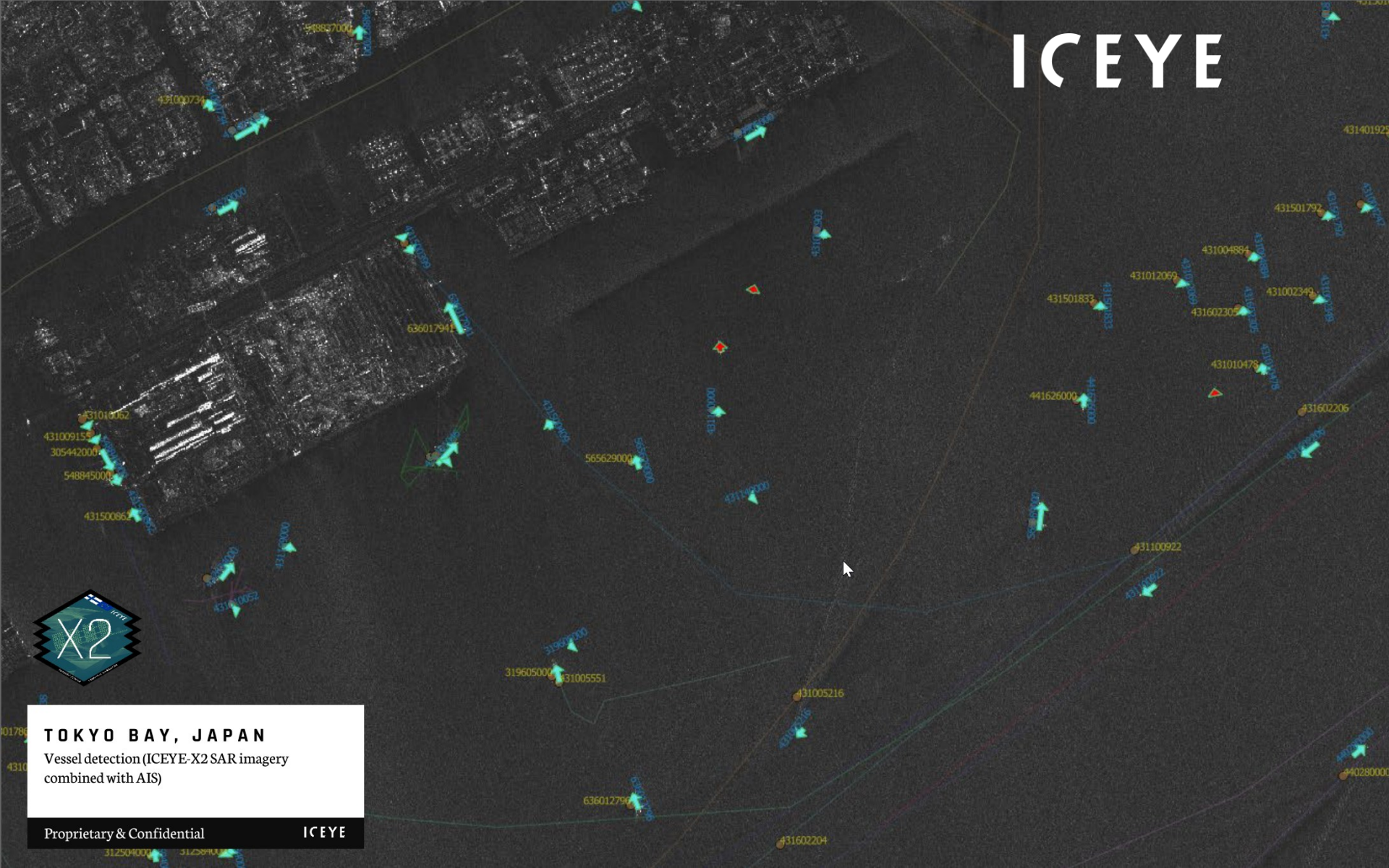
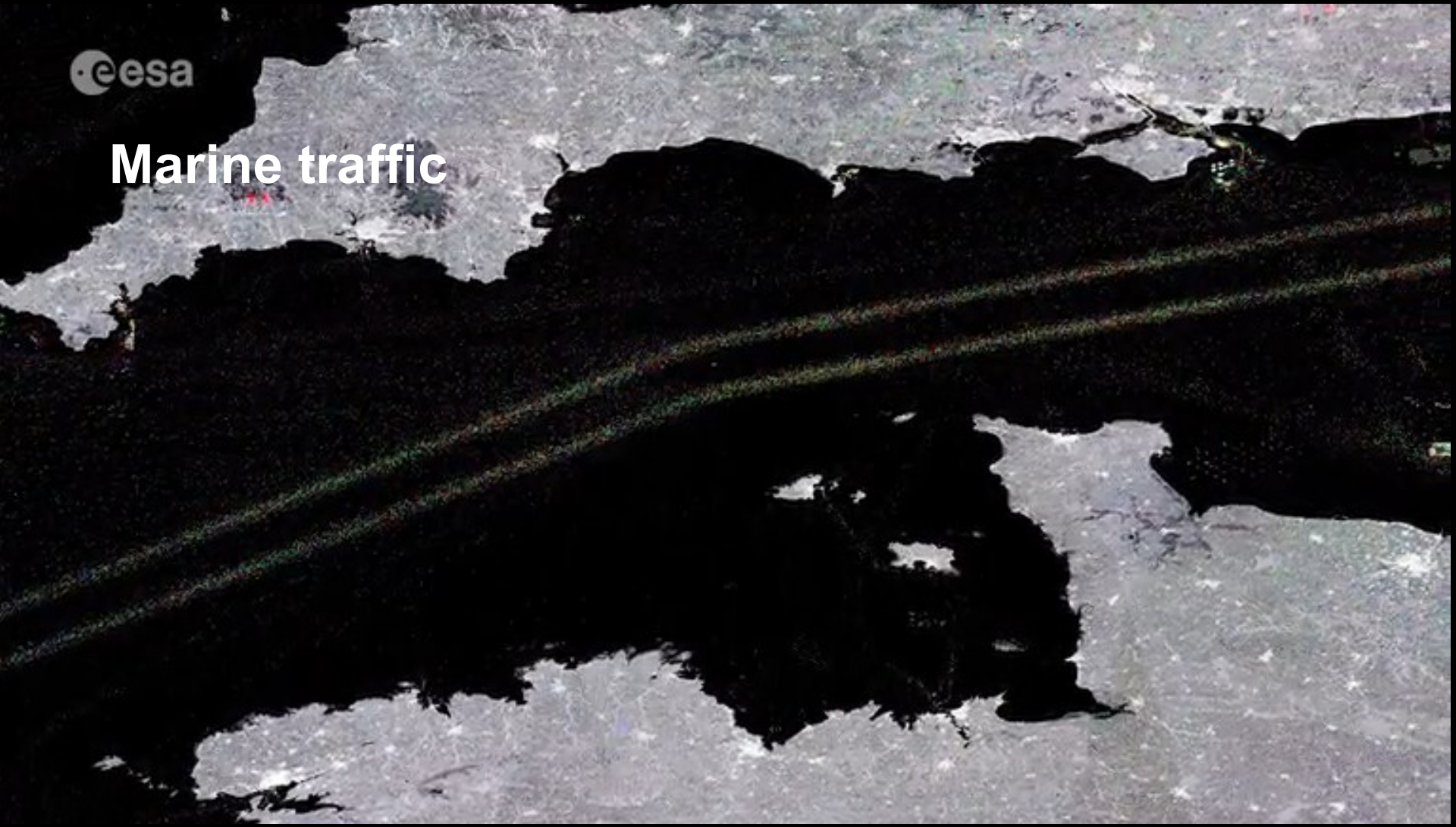
School of Electrical
Engineering

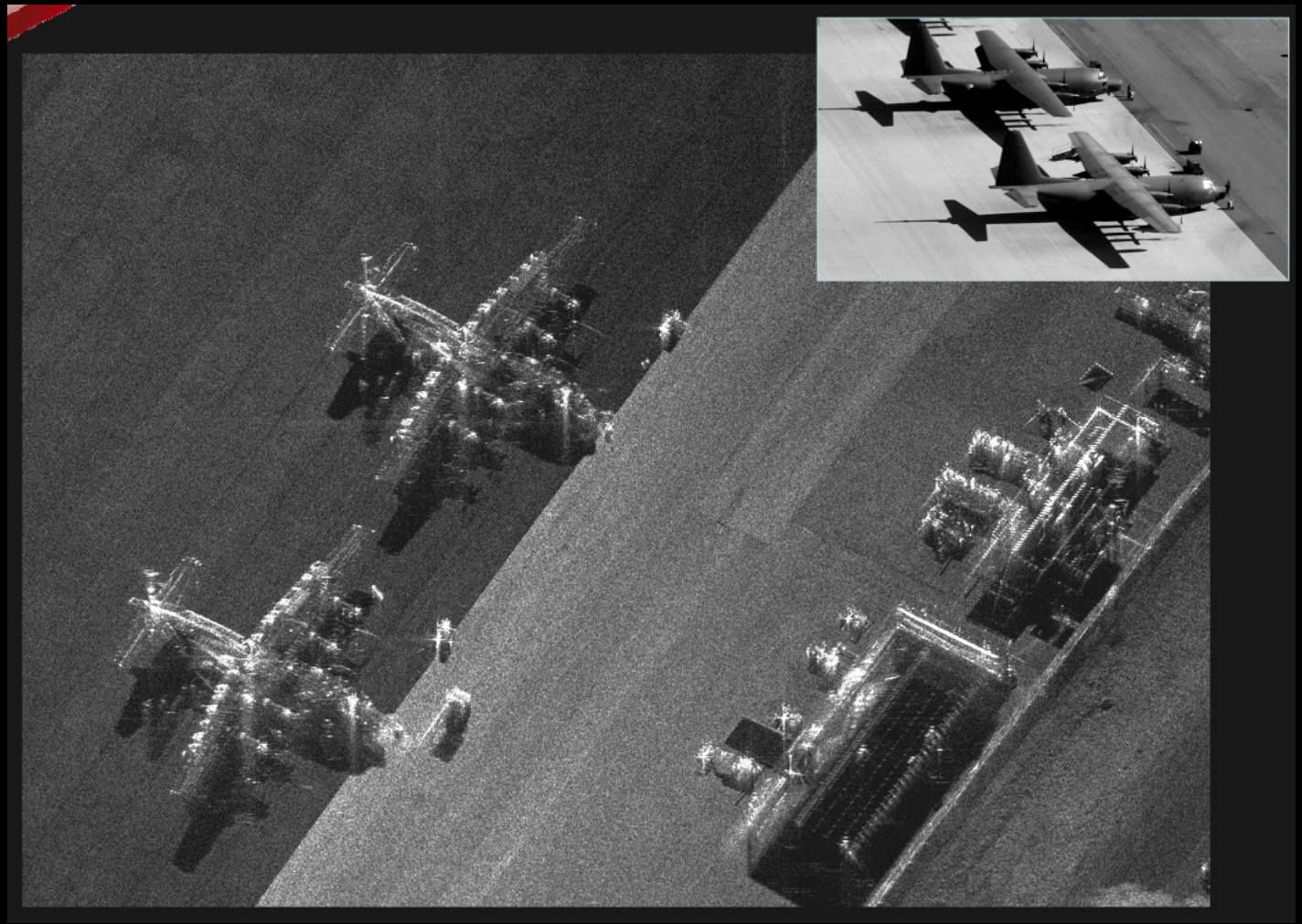

ICEYE
X2
TOKYO BAY, JAPAN
Vessel detection (ICEYE-X2 SAR imagery combined with AIS)
Proprietary & Confidential
ICEYE

Marine traffic

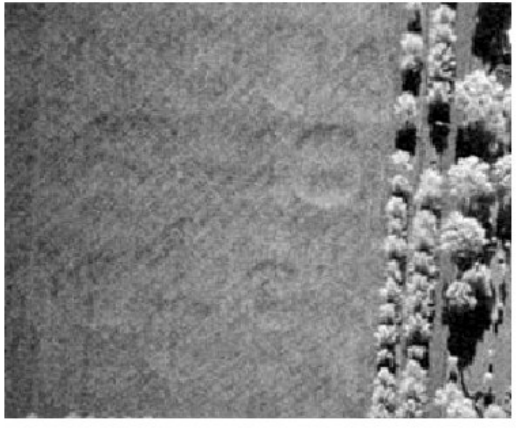



U.S.ARMY
AERONAUTICAL SYSTEMS

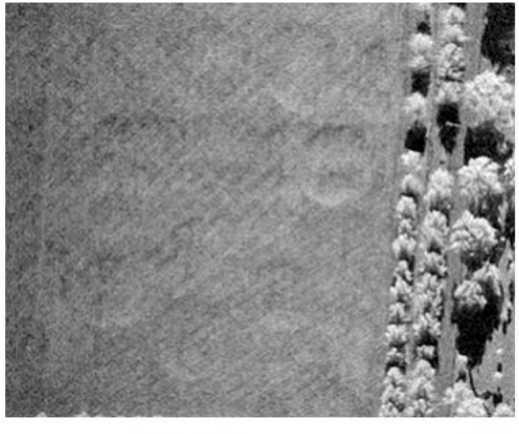
Military



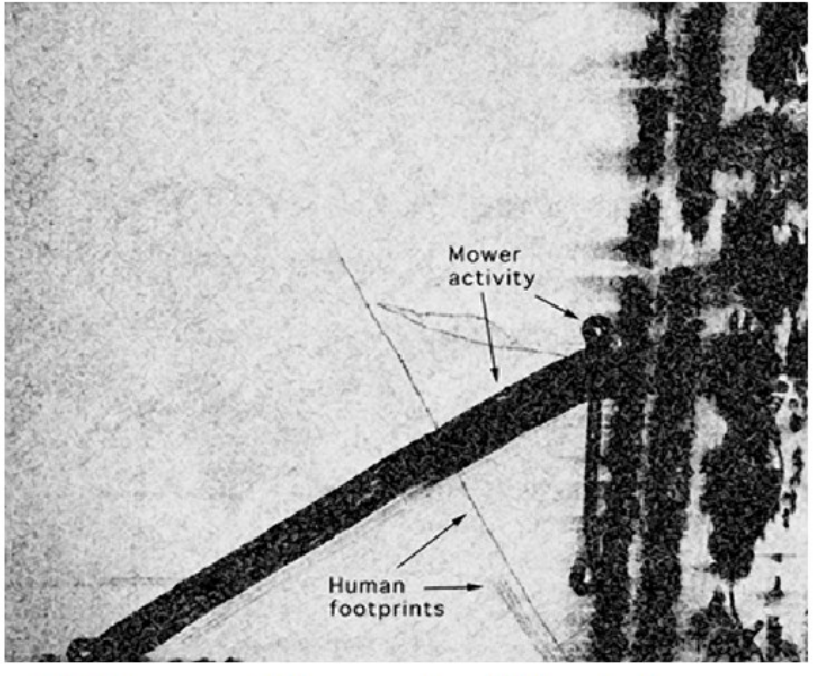
Coherent Change Detection - CCD



Reference SAR Image: Grassy Field



Current SAR Image: Grassy Field



CCD Image – Changes denoted by dark areas

Weather

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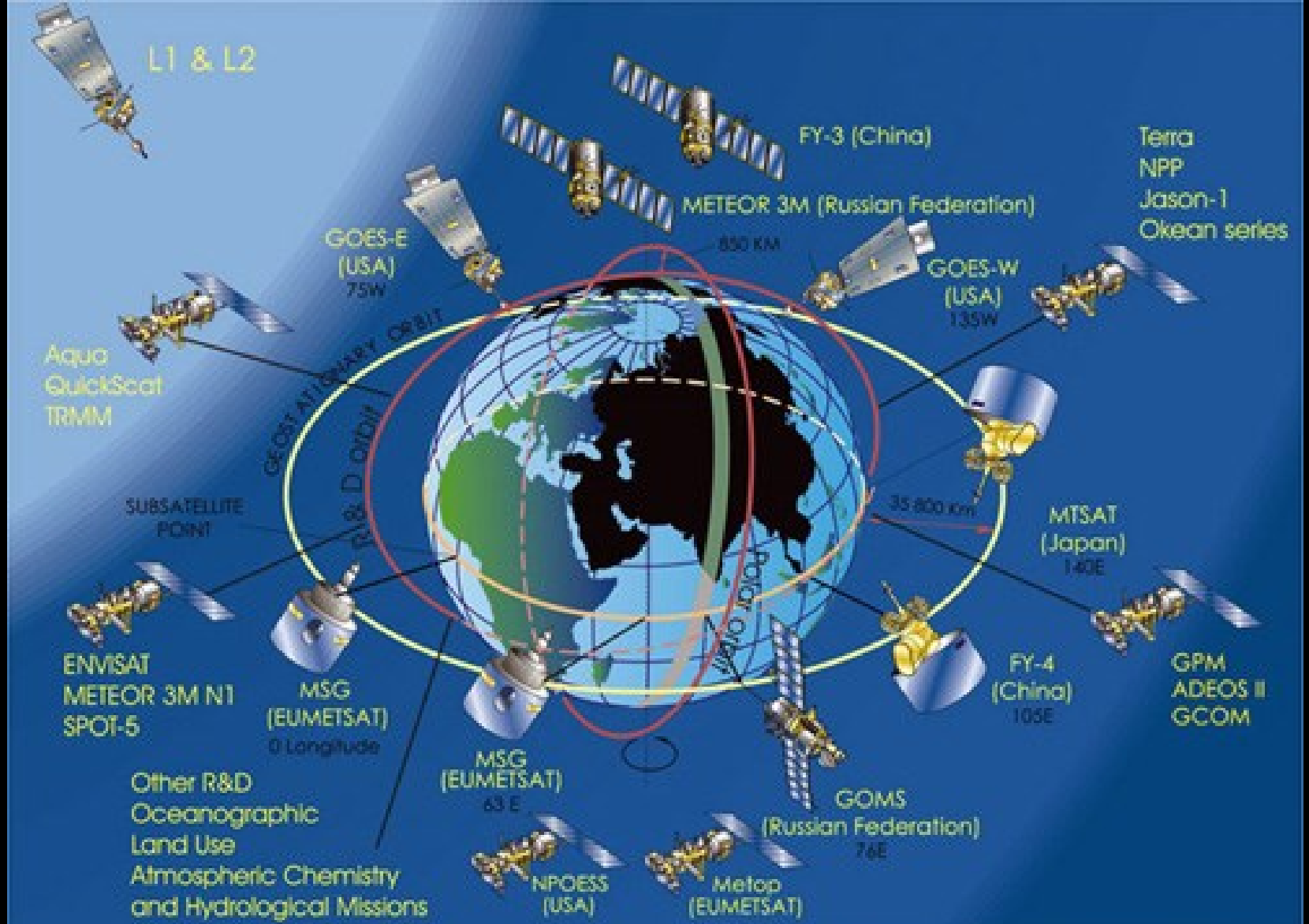
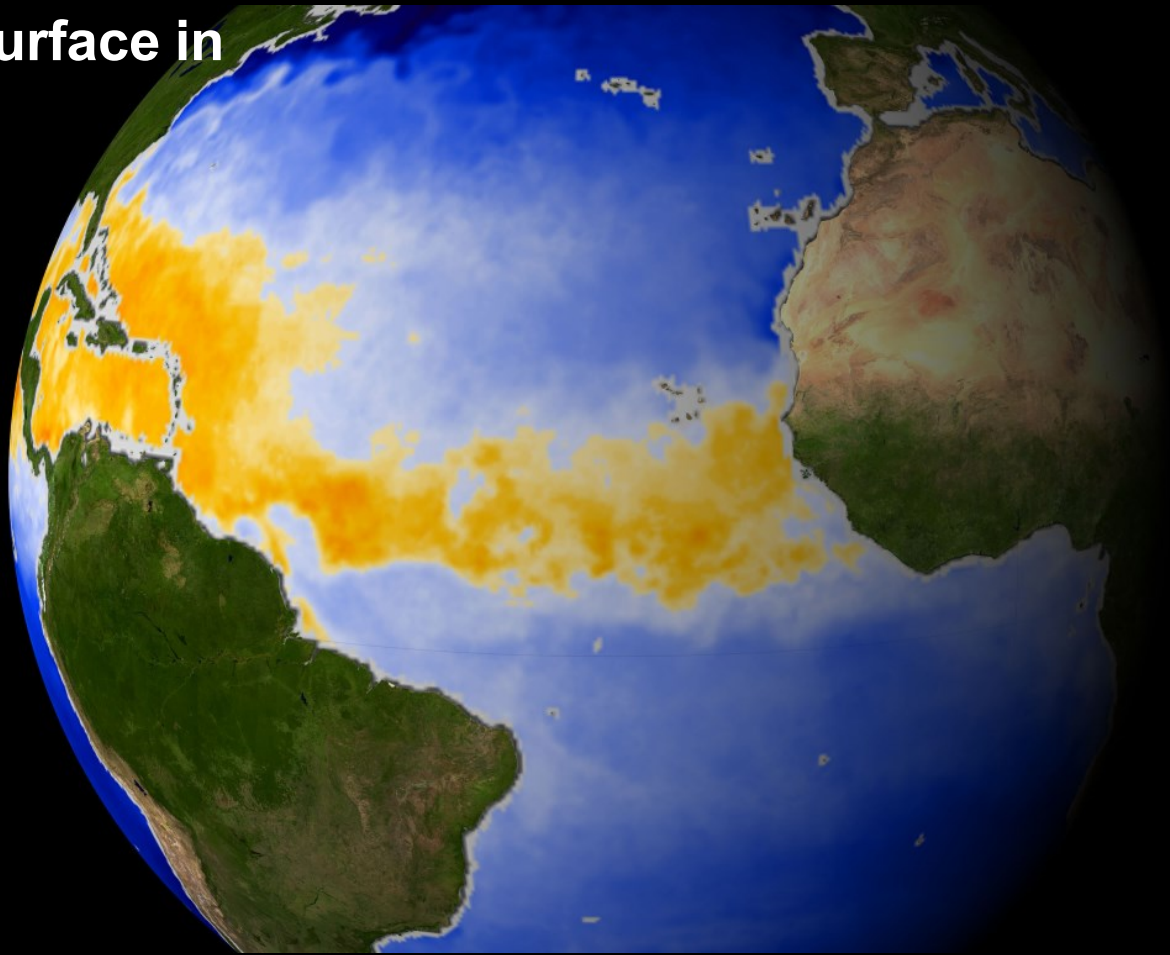
Engineering

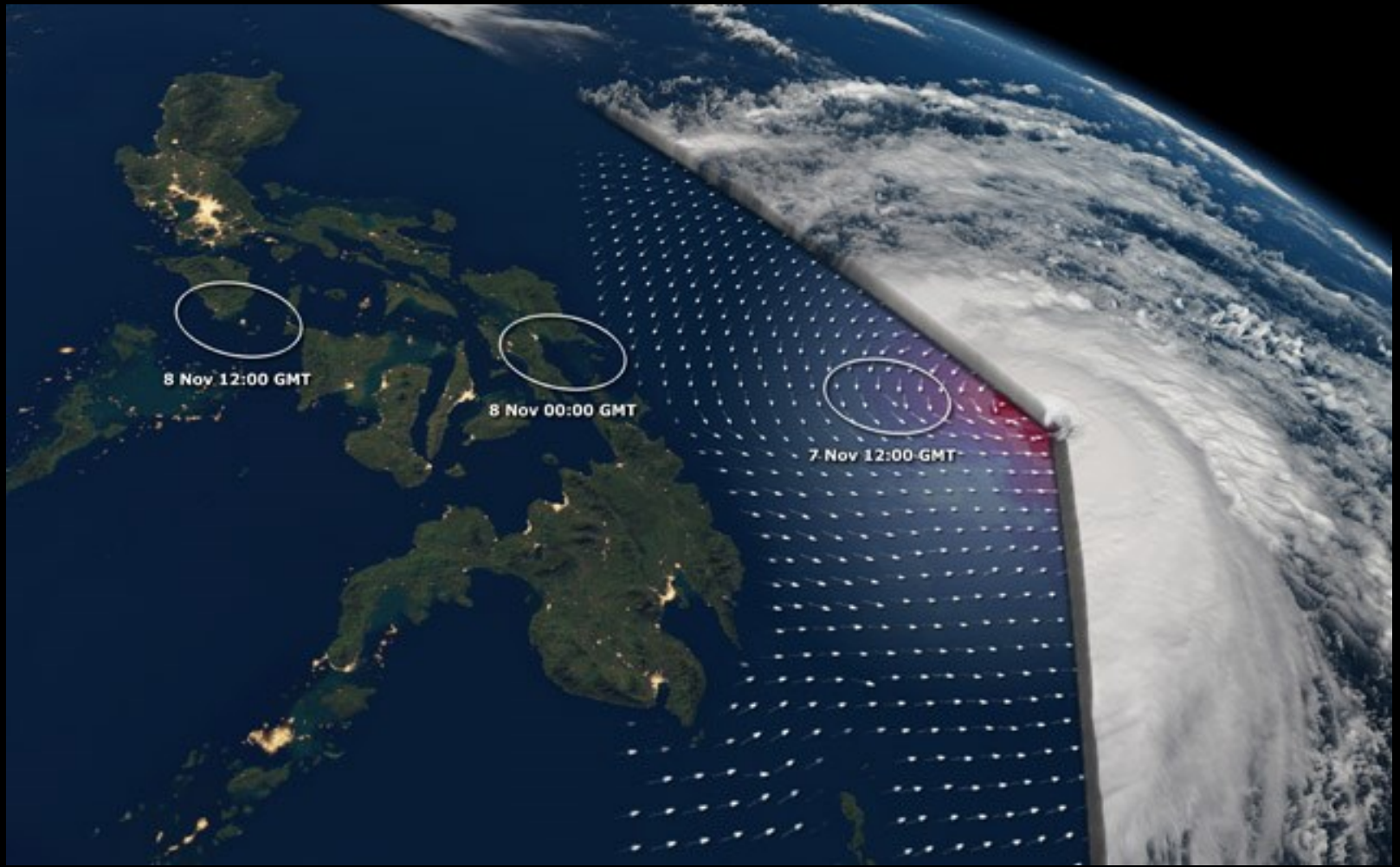

L1 & L2
FY-3 (China)
METEOR 3M (Russian Federation)
850 KM
Terra
NPP
Jason-1
Okean series
GOES-E
(USA)
75W
GOES-W
(USA)
135W
Aqua
QuickScat
TRMM
GEOSTATIONARY ORBIT
R & D orbit
SUBSATELLITE
POINT
35 800 km
MTSAT
(Japan)
140E
ENVISAT
METEOR 3M N1
SPOT-5
MSG
(EUMETSAT)
0 Longitude
FY-4
(China)
105E
GPM
ADEOS II
GCOM
MSG
(EUMETSAT)
63 E
GOMS
(Russian Federation)
76E
Other R&D
Oceanographic
Land Use
Atmospheric Chemistry
and Hydrological Missions
NPOESS
(USA)
Metop
(EUMETSAT)

Temperature of Sea Surface in May 2003

Derived from AMSR-E Microwave Radiometer Data

Image: Ochre corresponds to a temperature of 28° C, which allows formation of hurricanes





Oceansat-2, India

Space Research

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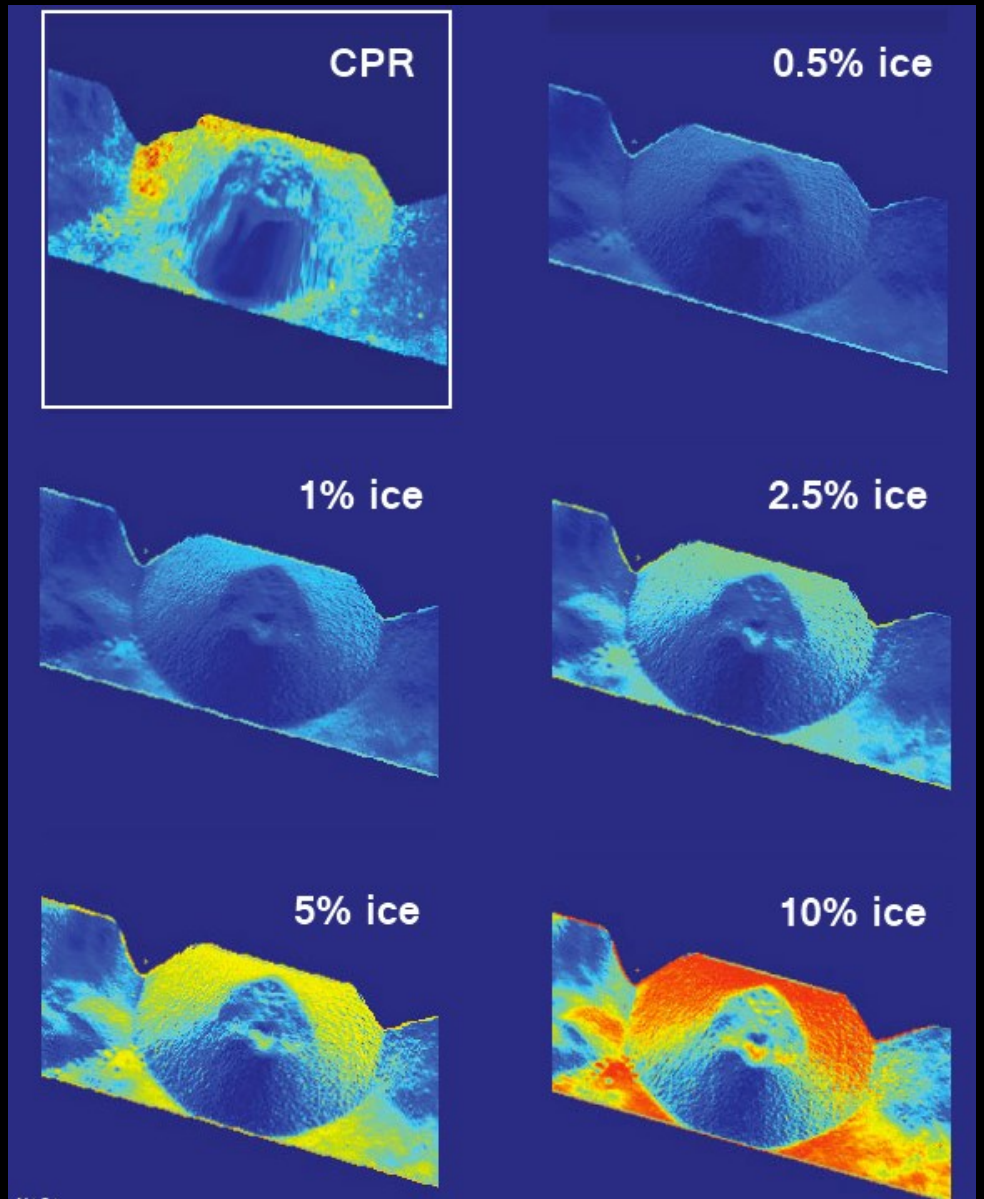
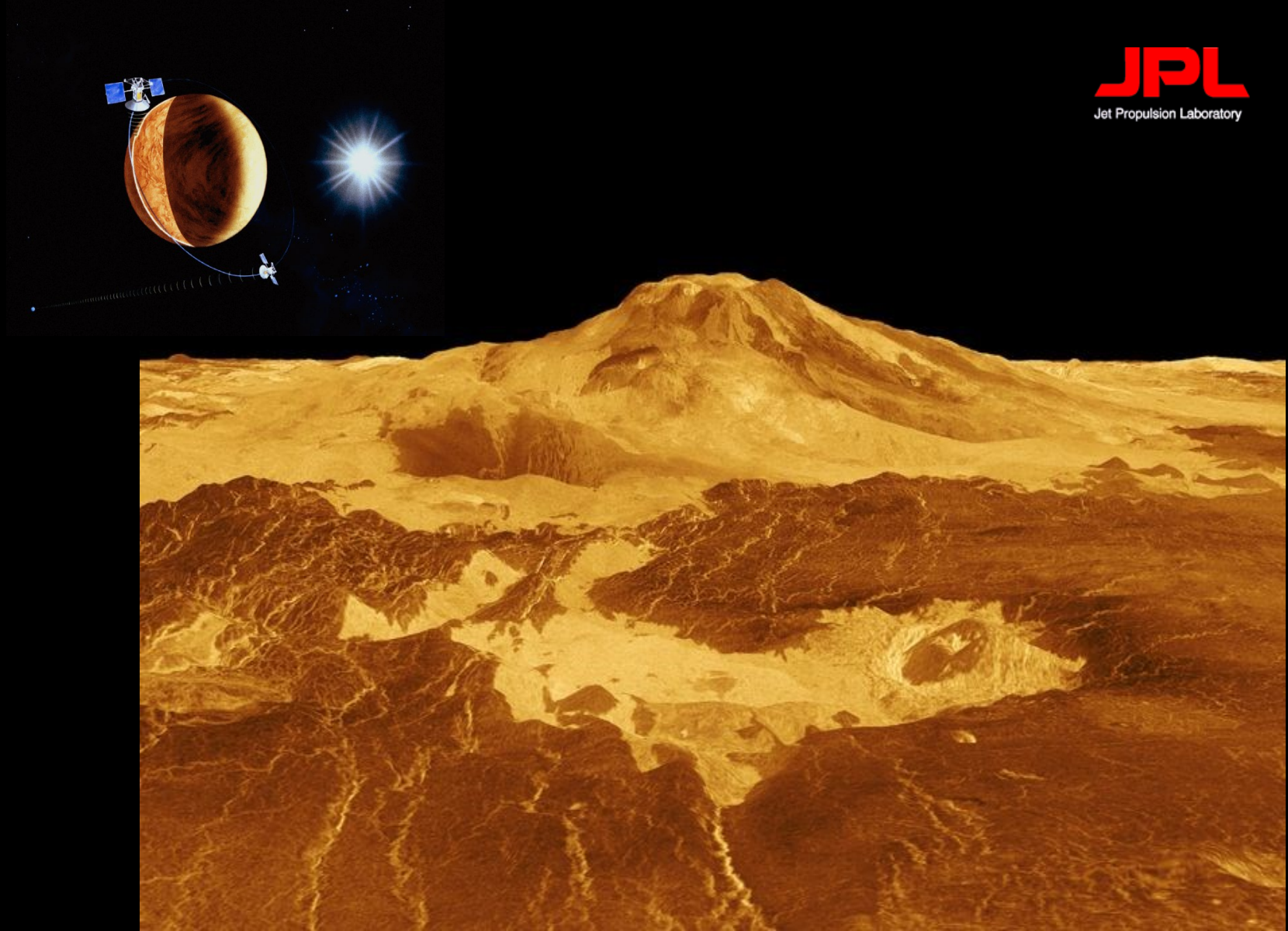
Engineering


Chandrayaan-1
Lunar
Reconnaissance
Orbiter (LRO)
Coordinated, bistatic
imaging in S-band, to be
compatible with the
Chandrayaan-1 and LRO
spacecraft, can
unambiguously resolve
ice deposits on the Moon


CPR
0.5% ice
1% ice
2.5% ice
5% ice
10% ice


JPL
Jet Propulsion Laboratory

Microwave RS science

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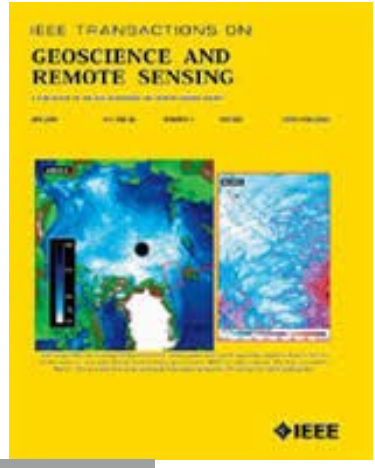
Engineering

Scientific journals

- **IEEE Transactions on Geoscience and Remote Sensing (IEEE = Institute of Electrical and Electronics Engineers, Inc.)**
- IEEE Journal of IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing
- IEEE Geoscience and Remote Sensing Letters (short articles)
- Remote Sensing of Environment (U.S.)
- MDPI Remote Sensing — Open Access Journal
- Photogrammetric Engineering and Remote Sensing (American Society for Photogrammetry and Remote Sensing)
- International Journal of Remote Sensing (U.K. Remote Sensing and Photogrammetry Society)



Remote Sensing Organizations

- IEEE Geoscience and Remote Sensing Society (GRSS): www.grss-ieee.org
- International Union of Radio Science (URSI): www.ursi.org
- Commission F: Wave Propagation and Remote Sensing
- European Association of Remote Sensing Laboratories (EARSeL): www.earsel.org
- Remote Sensing and Photogrammetry Society RSPSoc, UK): rspsoc.org
- Asian Association of Remote Sensing: www.a-a-r-s.org
- Indian Society of Remote Sensing: www.isrsindia.in
- African Association of Remote Sensing: africanremotesensing.org
- Sociedad Latinoamericana de Perception Remota y Sistemas de Information Espacial (SELPER): selper.org

POLinSAR workshop 2013

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Career in Microwave EO

Aalto University
School of Electrical
Engineering

Aalto alumni in MW EO

Space Agencies

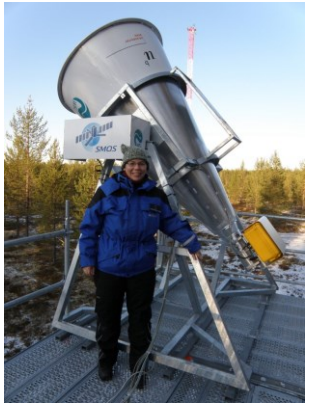
- ESA
- NASA

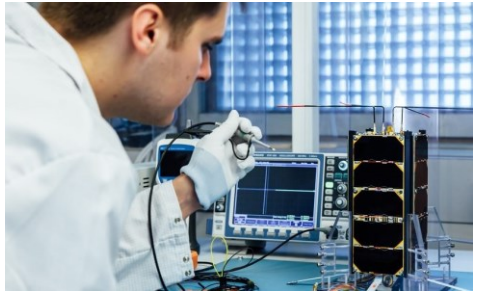
Meteorological Organizations

- NOAA
- EUMETSAT
- Finnish Meteorological Institute

Private Companies

- ICEYE
- Reaktor Space Lab





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HUTRAD crew starting airborne measurement campaign 2012

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Collecting calibration data for TerraSAR-X satellite

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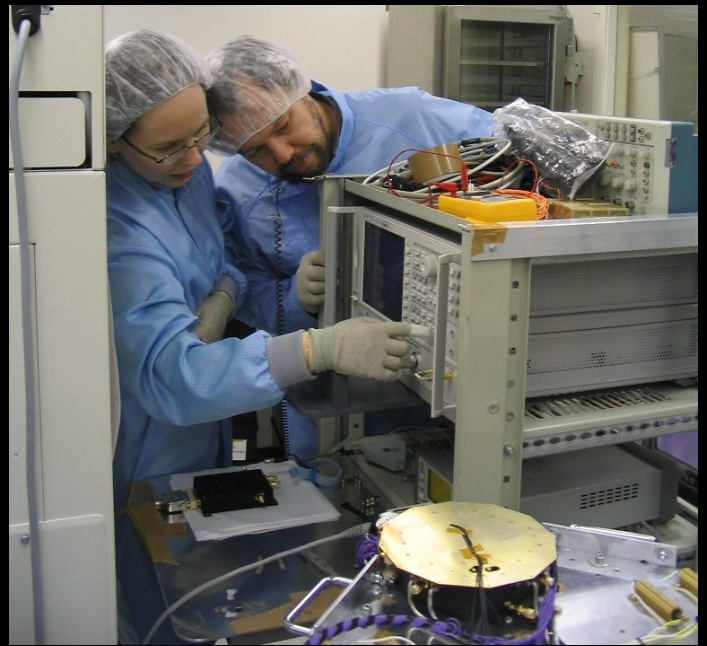
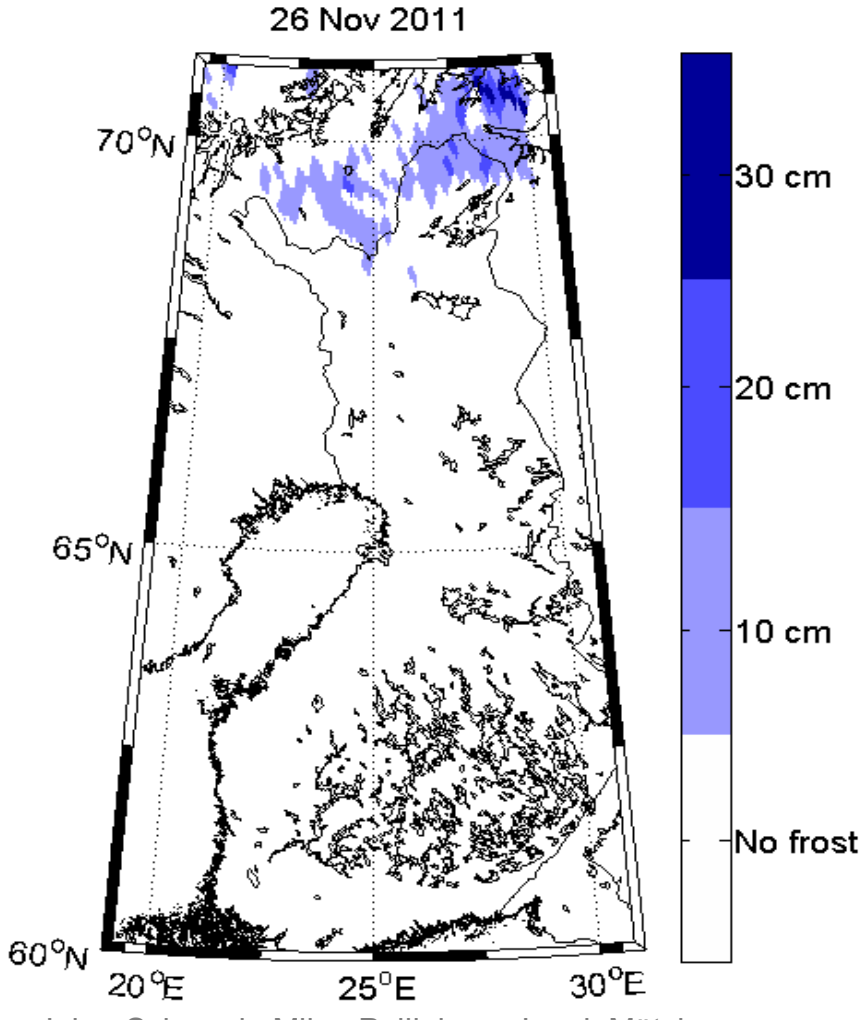
Engineering



ESA SMOS satellite calibration system qualification in Finland

Freezing Soil map by SMOS

Tower measurements in Sodanlkylä



Aalto University
School of Electrical Engineering

Rautiainen, Kimmo; Lemmetyinen, Juha; Schwank, Mike; Pulliainen, Jouni; Mätzler, Christian; Kontu, Anna; Wiesmann, Andreas, "An Innovative Application for SMOS: Characterization of Seasonal Soil Freezing" EGU General Assembly 2013, held 7-12 April, 2013 in Vienna, Austria.

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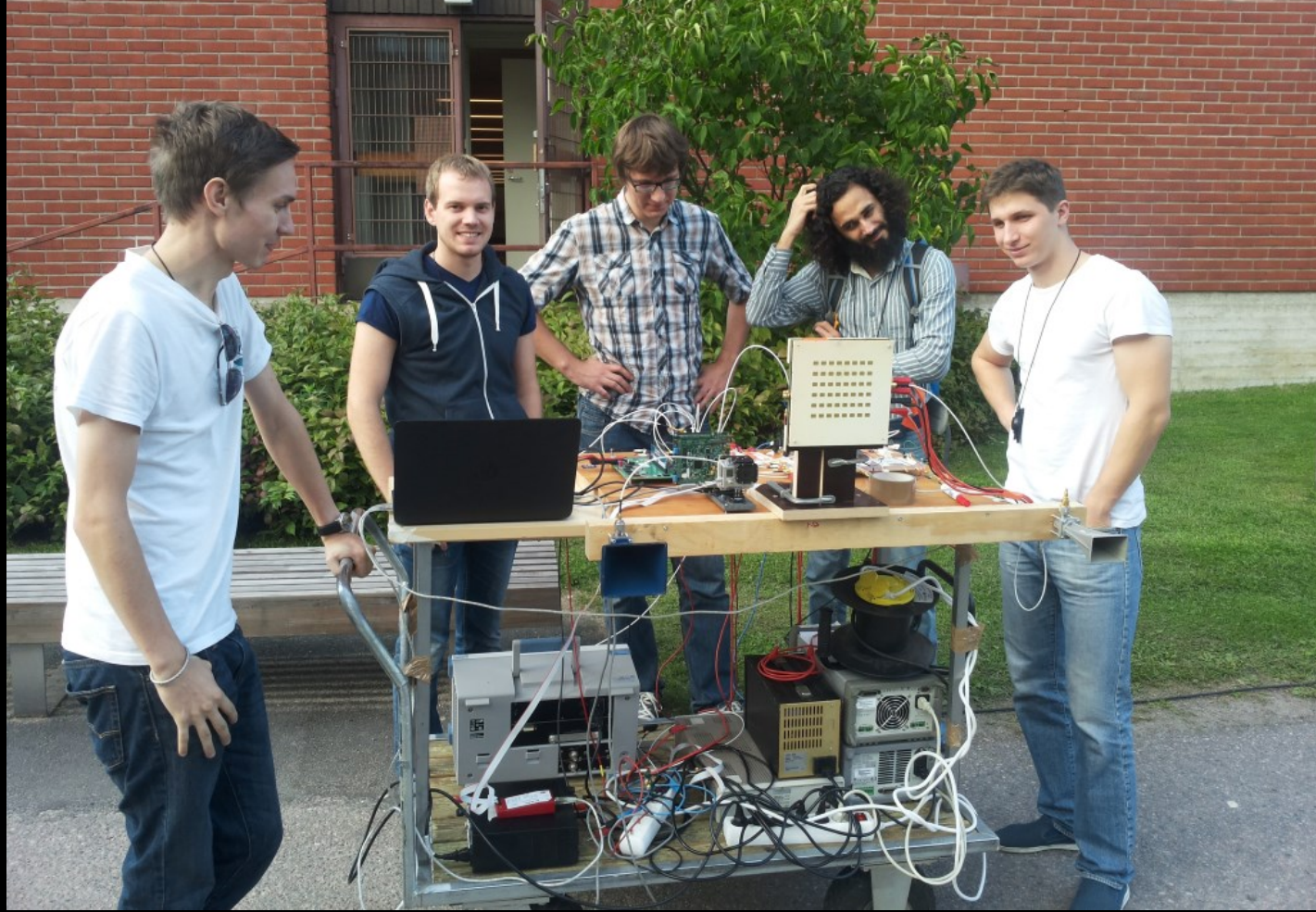
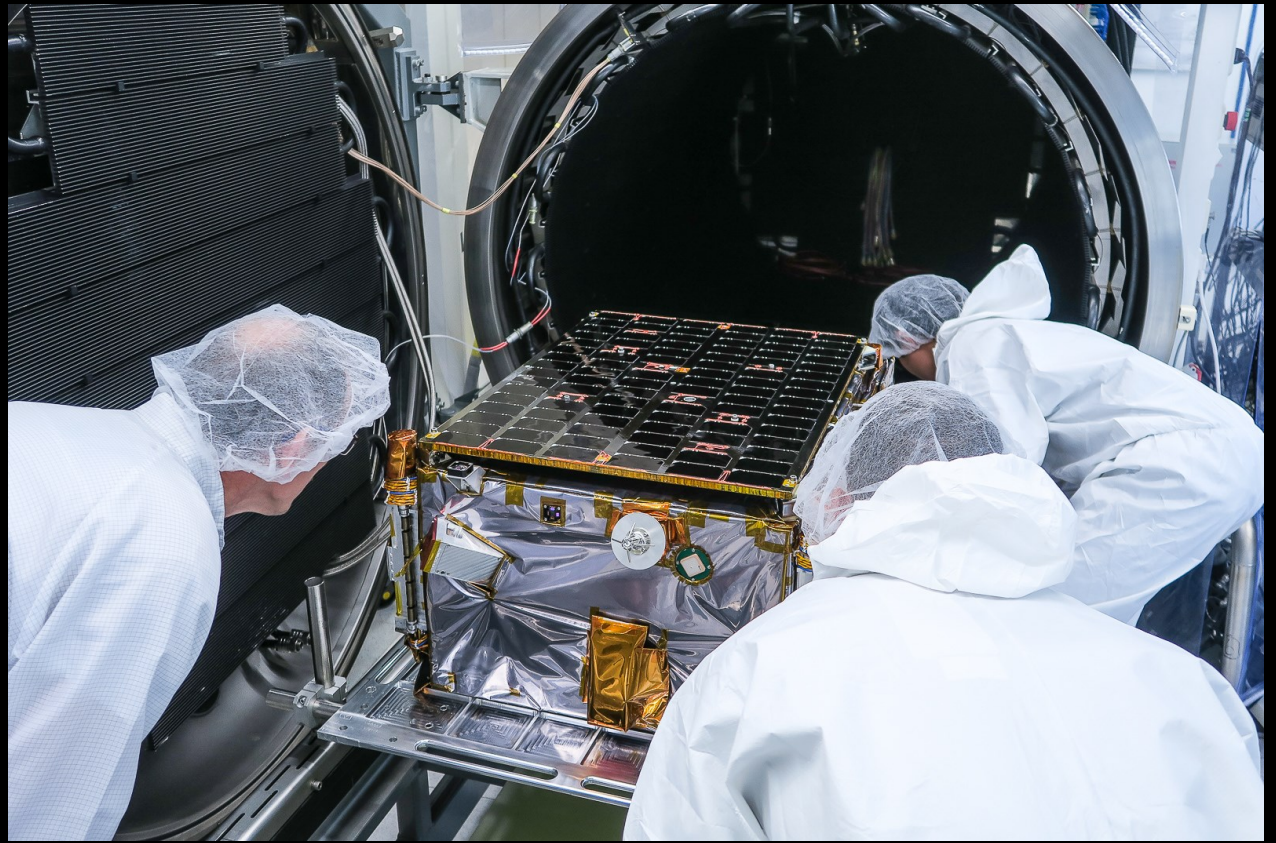
Engineering



Aalto ICEYE team
with the first X-band SAR prototype 2014

Aalto University
School of Electrical
Engineering



ICEYE X1 satellite thermal vacuum tests in Germany 2017

Now ICEYE is one of the biggest space companies in Finland

Remote Sensing and Space-Related Sites

- European Space Agency (ESA): http://www.esa.int
- European Weather Satellite Organization (EUMETSAT): www.eumetsat.int
- European Commission Joint Research Centre (JRC): ec.europa.eu/dgs/jrc
- National Aeronautics and Space Administration (NASA): www.nasa.gov
- Jet Propulsion Laboratory (JPL): www.jpl.nasa.gov
- National Oceanic and Atmospheric Administration (NOAA): www.noaa.gov
- Japanese Space Agency (NASDA): www.jaxa.jp/index_e.html
- Russian Space Research Institute (IKI): www.iki.rssi.ru/eng
- Indian Space Research Organisation (ISRO): www.isro.org
- Aalto University Department of Radio Science and Engineering: radio.aalto.fi

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Engineering

E4230

Microwave EO Instrumetation

Take a break