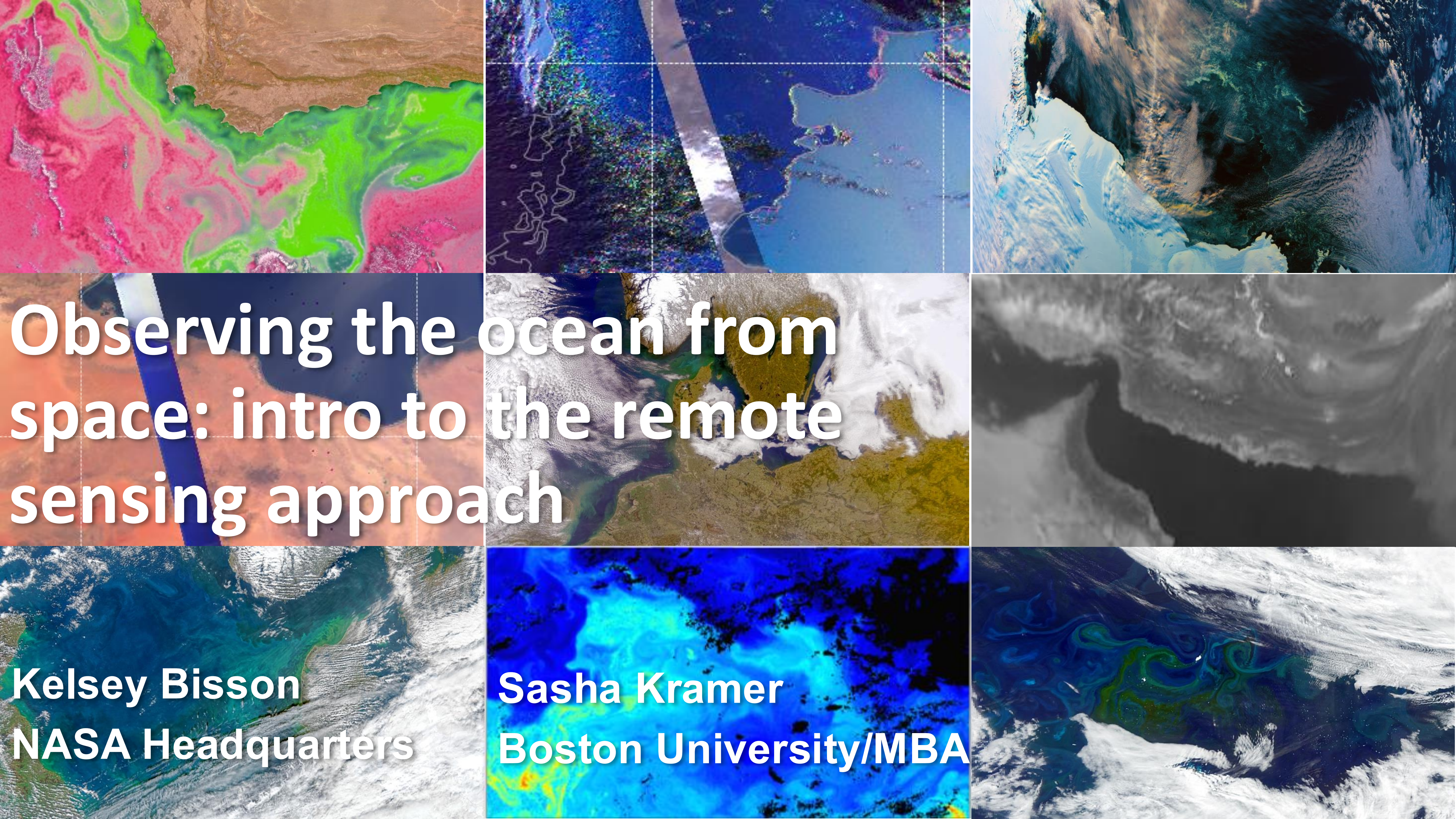


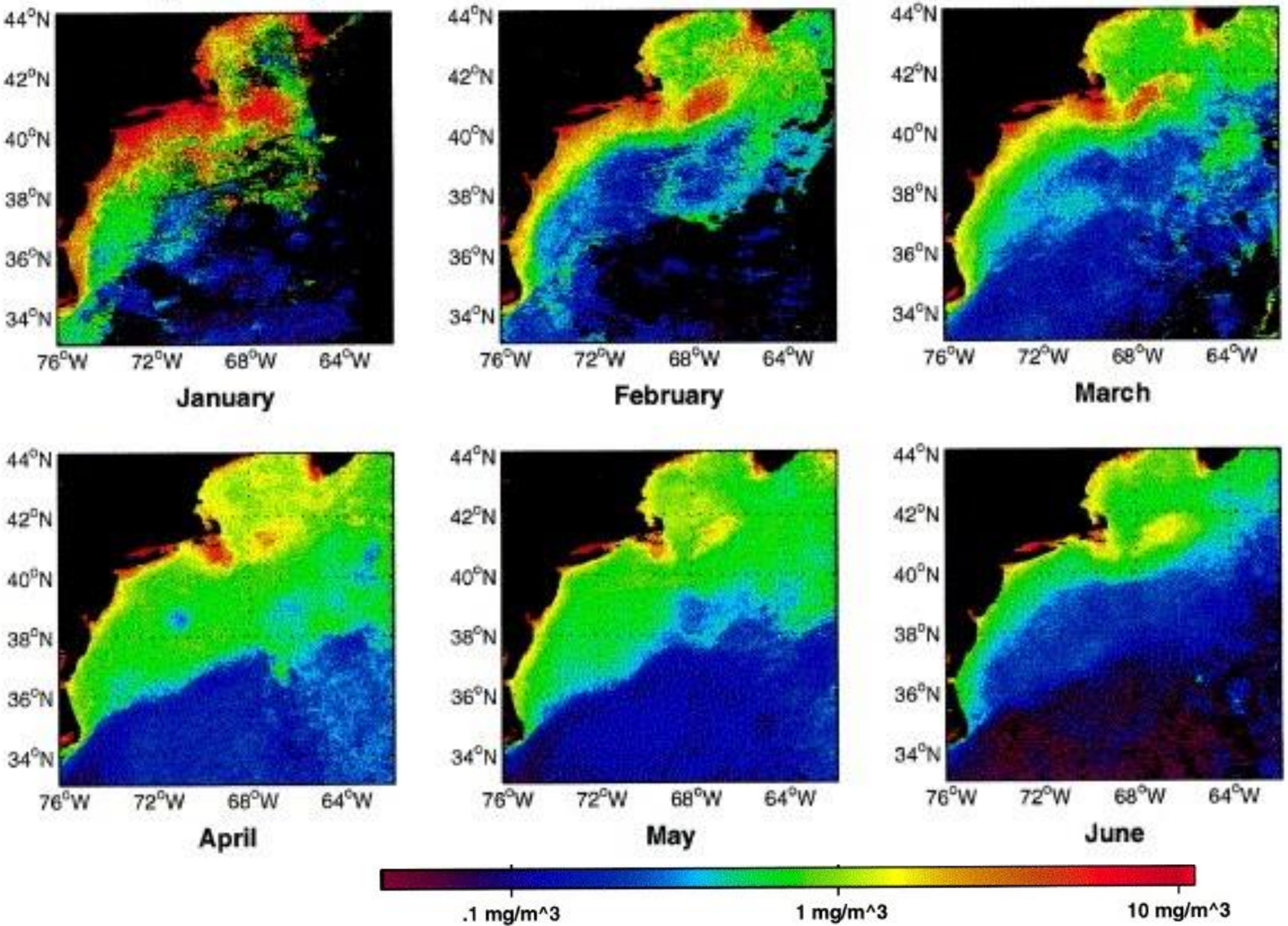
Observing the ocean from space: intro to the remote sensing approach

Kelsey Bisson
NASA Headquarters

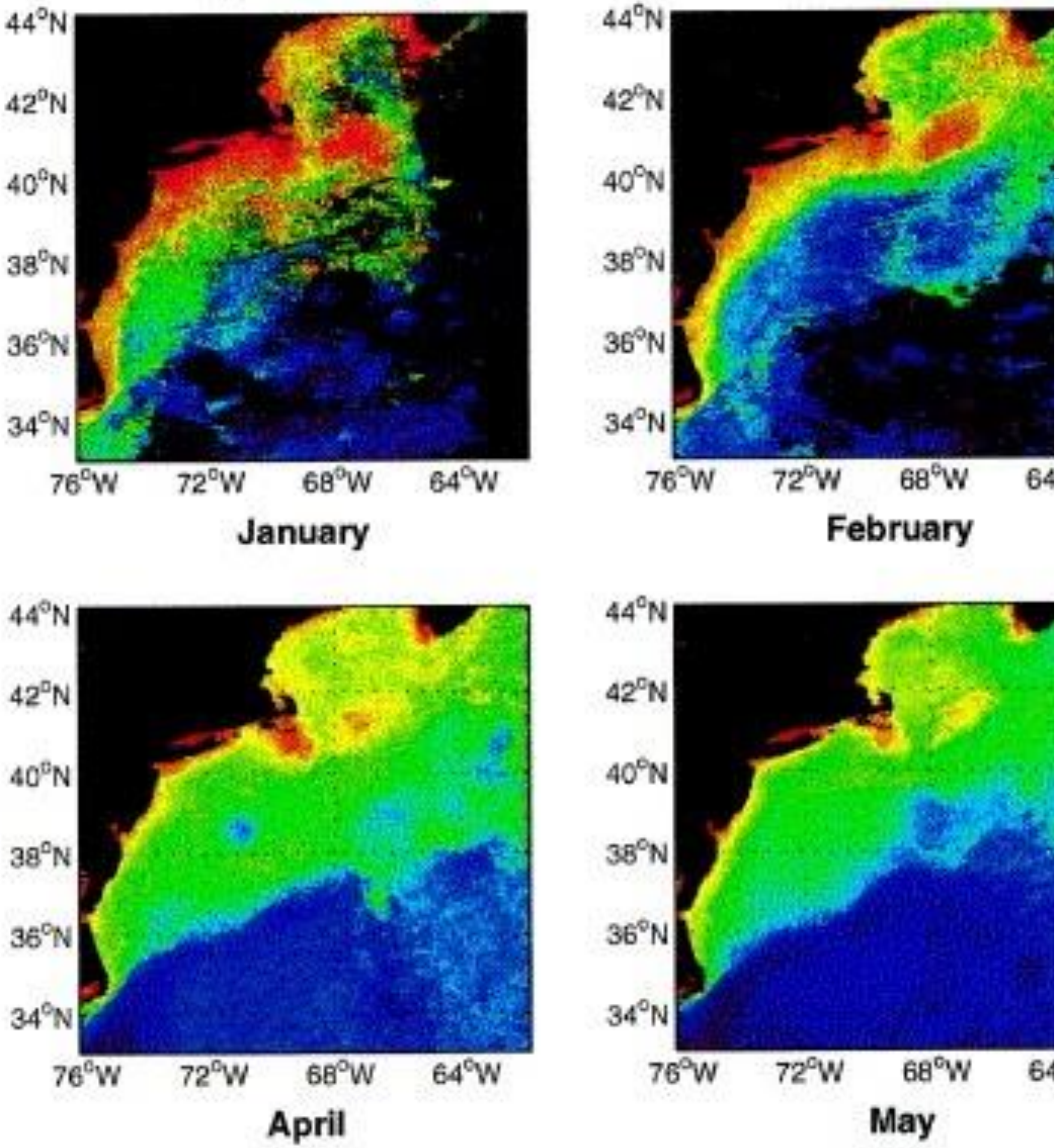
Sasha Kramer
Boston University/MBA

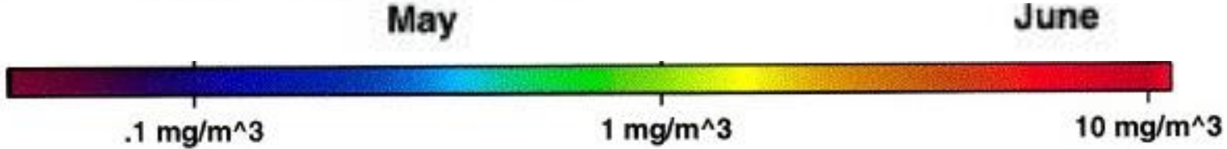
Photo by Bill Anders

CZCS composites (November 1978 – June 1986)



CZCS composites (November 1978 – June 1986)





Bloom

Song by Radiohead · 2011

Overview Lyrics

Lyrics

Open your mouth wide
A universal sigh

And while the ocean blooms
It's what keeps me alive

So why does it still hurt?

Don't blow your mind with whys

I'm moving out of orbit
(Turning in somersaults)
Turning in somersaults
(A giant turtle's eyes)
A giant turtle's eyes
(As jellyfish float by)
As jellyfish float by

Source: Musixmatch

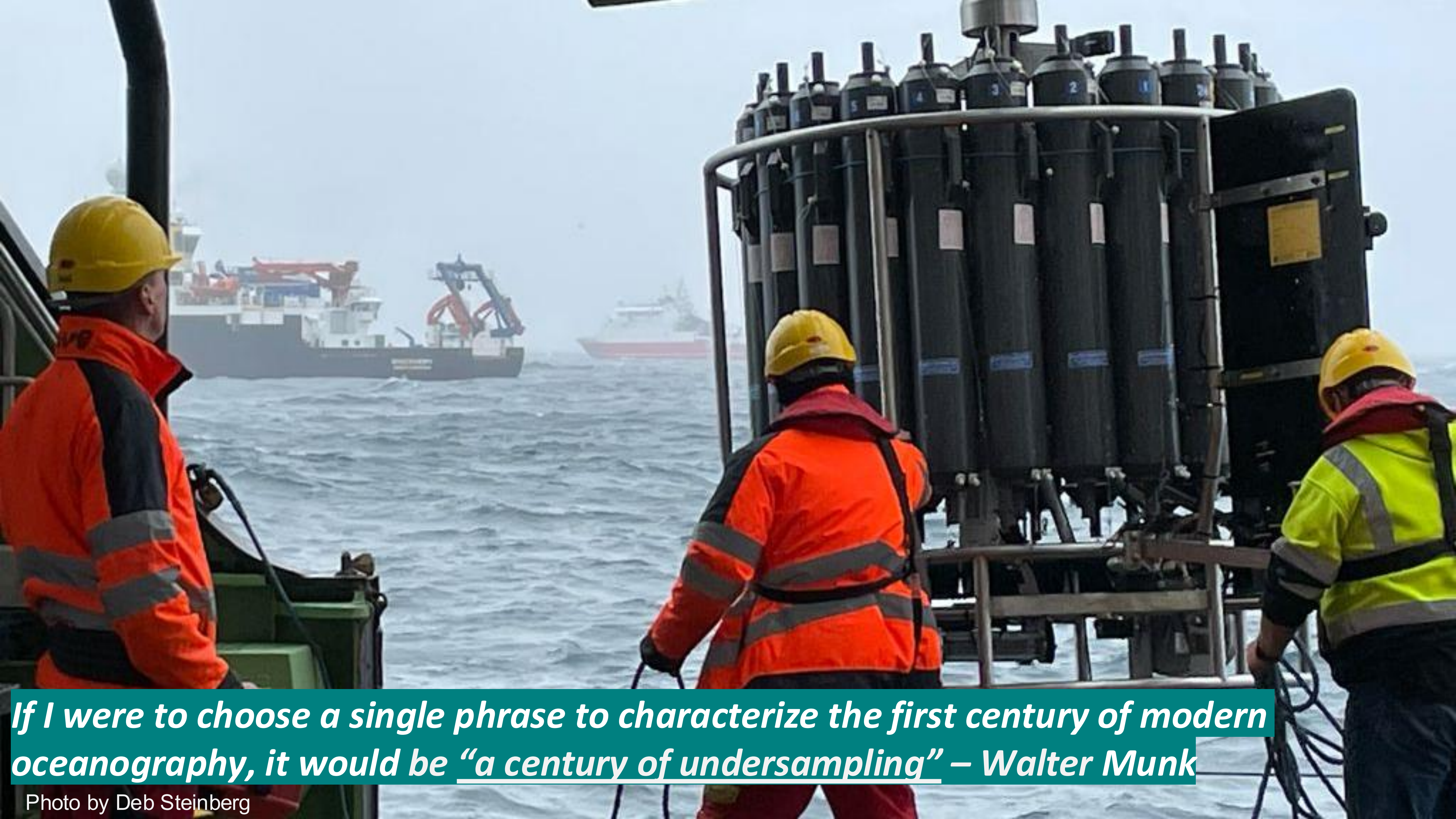
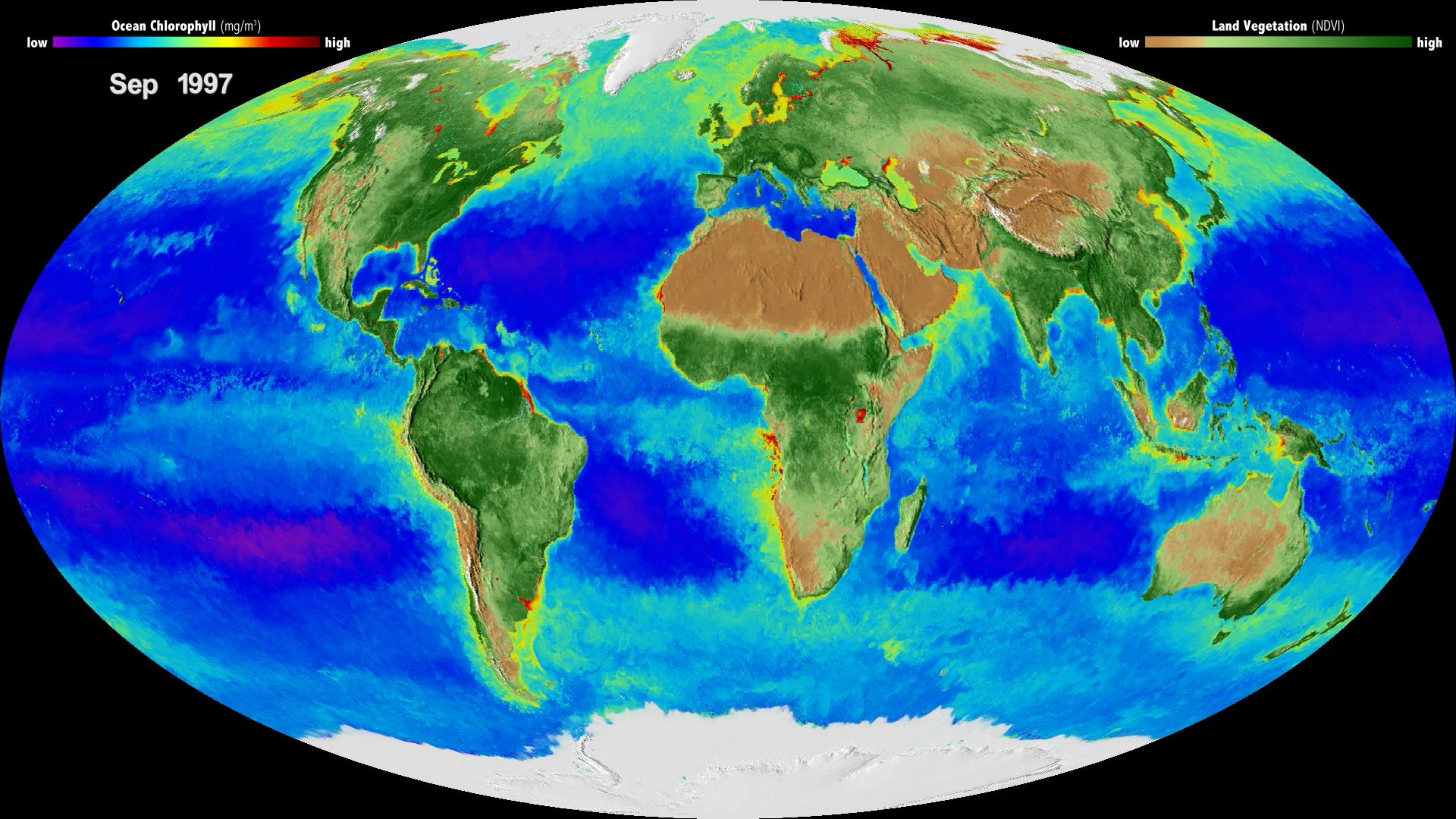
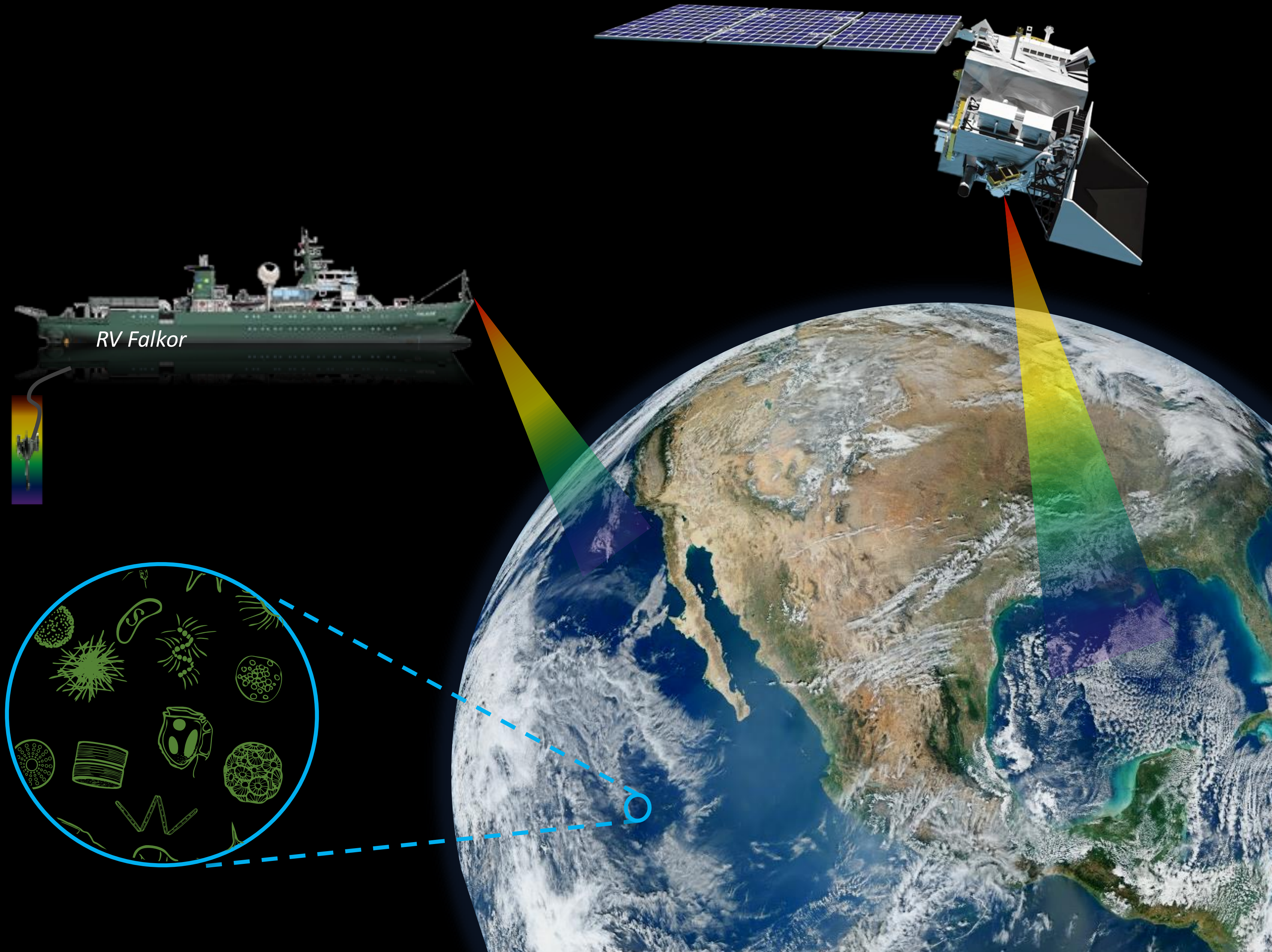


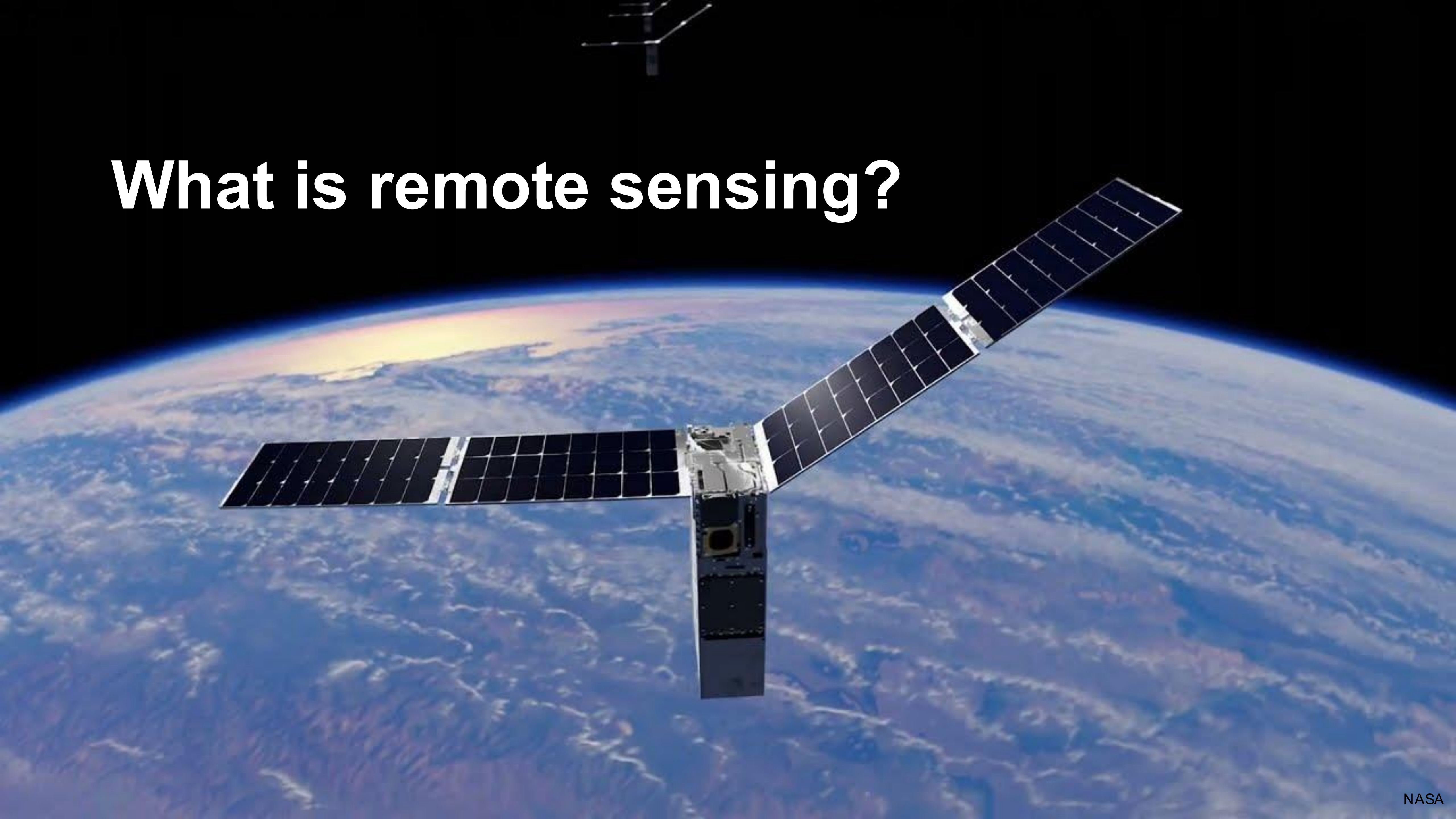
Photo by Deb Steinberg


Ocean Chlorophyll (mg/m³)
low
high
Land Vegetation (NDVI)
low
high
Sep 1997

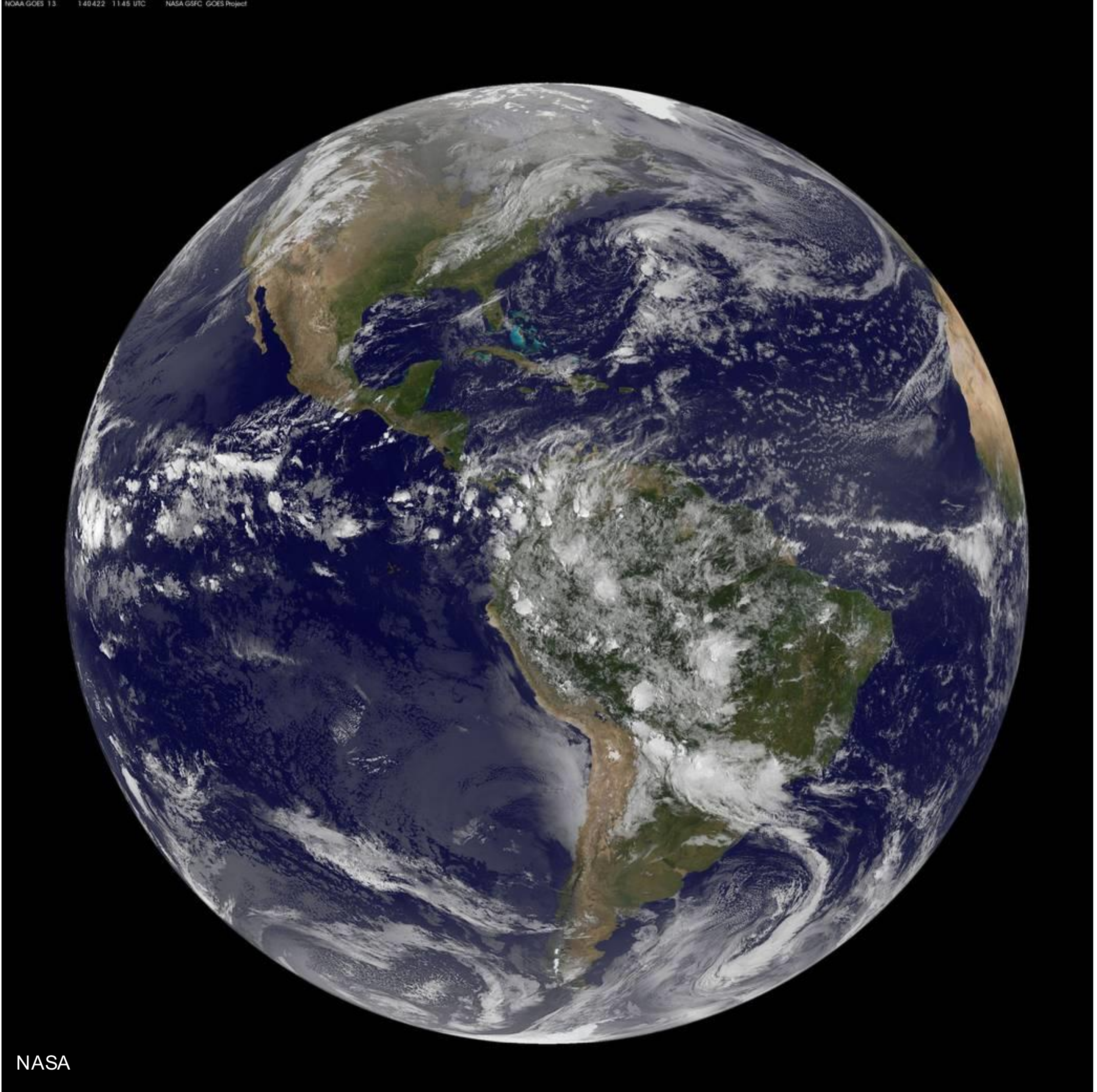
why satellites?



What is remote sensing?



NASA



NASA

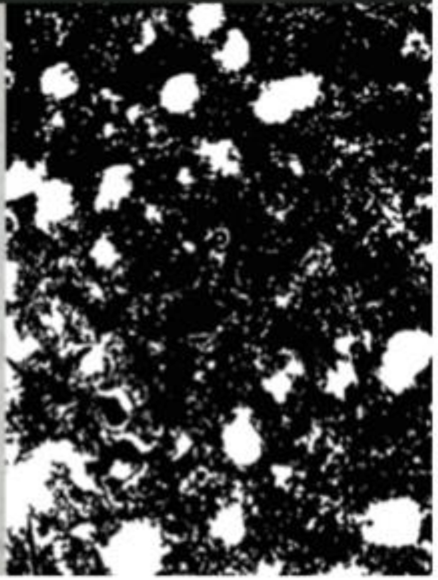
Remote sensing: "the acquiring of information from a distance."

Remote sensing: “the scanning of the Earth by a satellite or high-flying aircraft in order to obtain information about it.”

What is remote sensing?

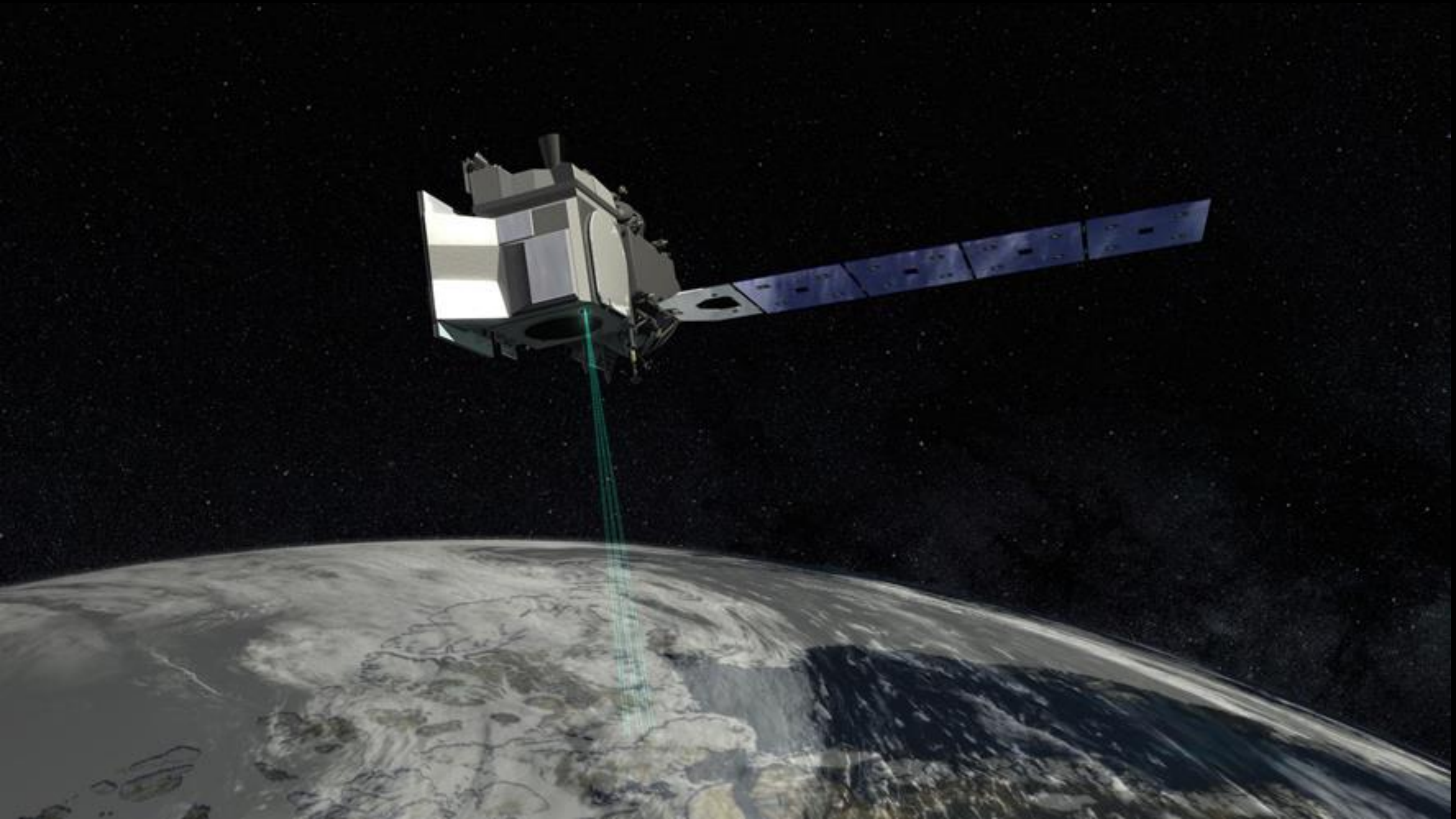
…as simple as an iphone on a fishing pole

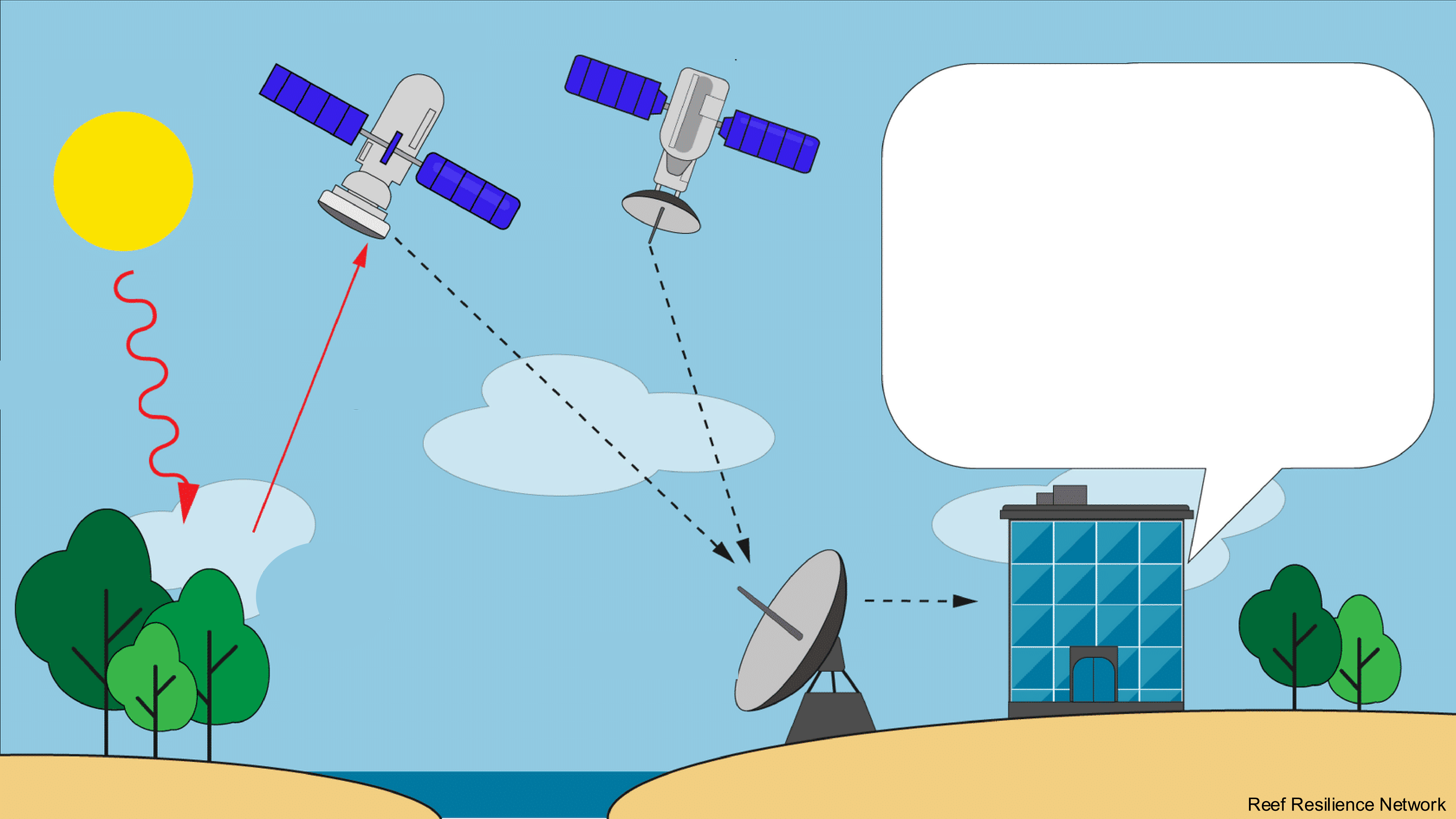
Ocean optics side project 2015, 'Landsat 10'

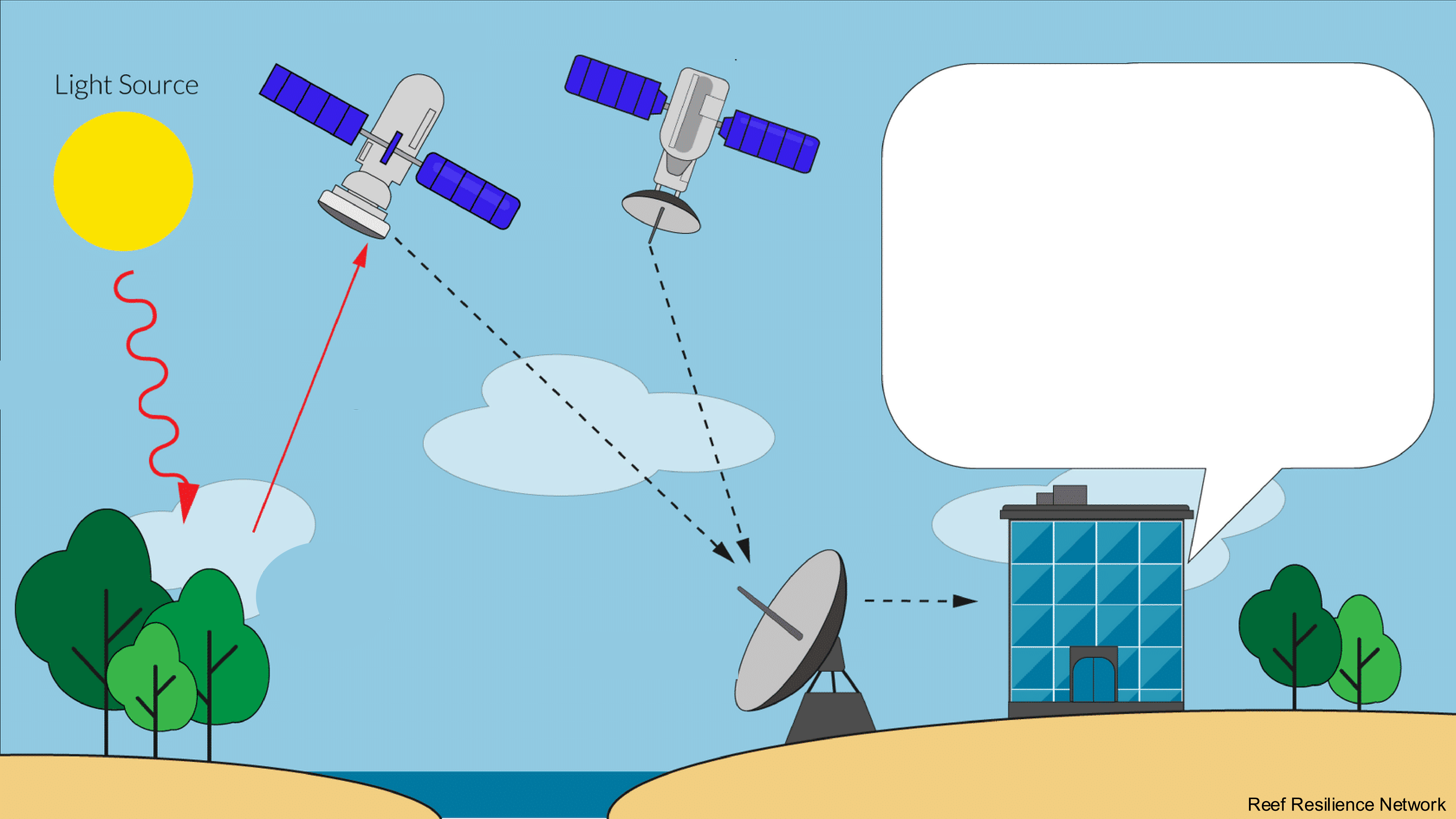


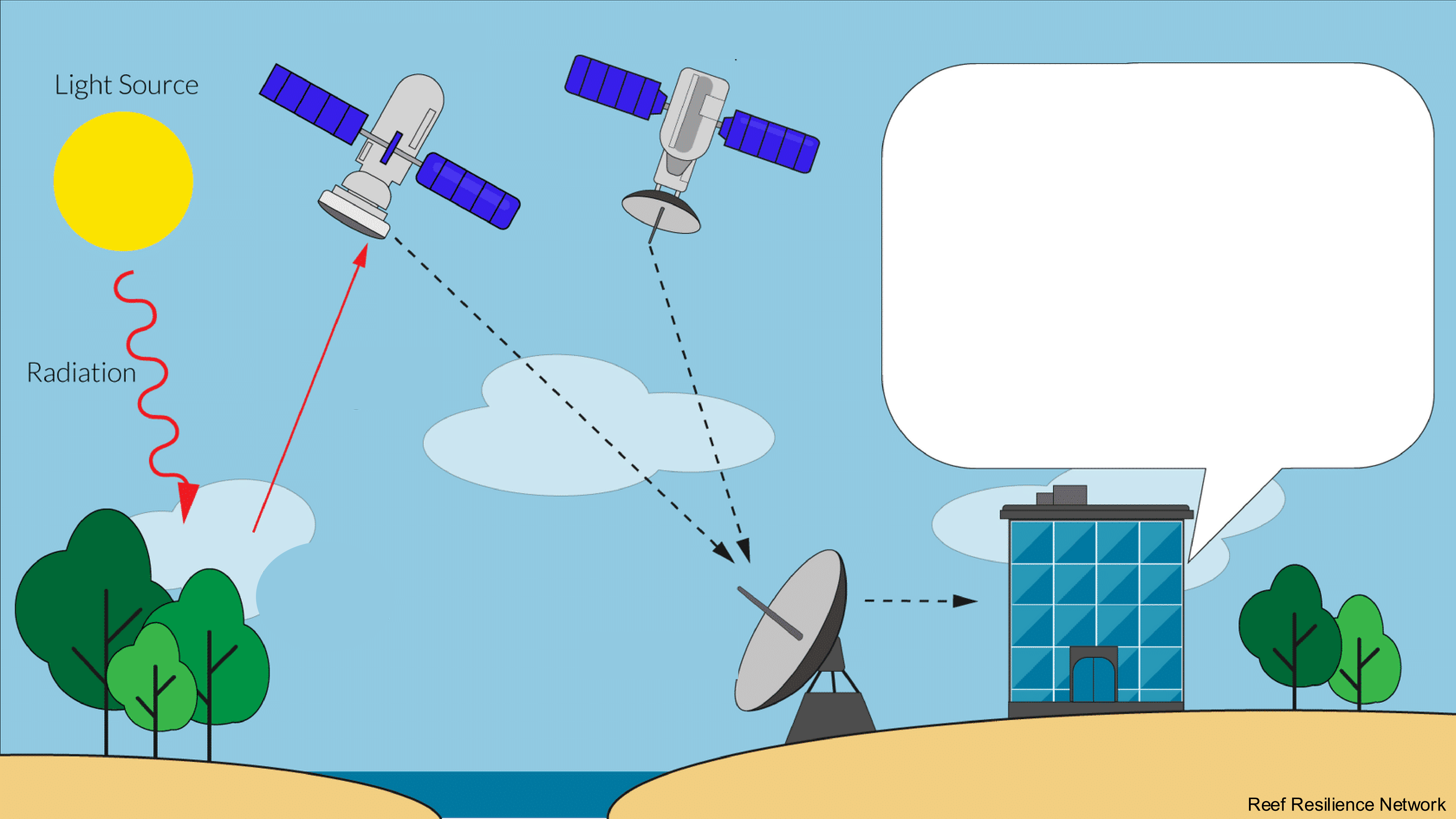
What is remote sensing?

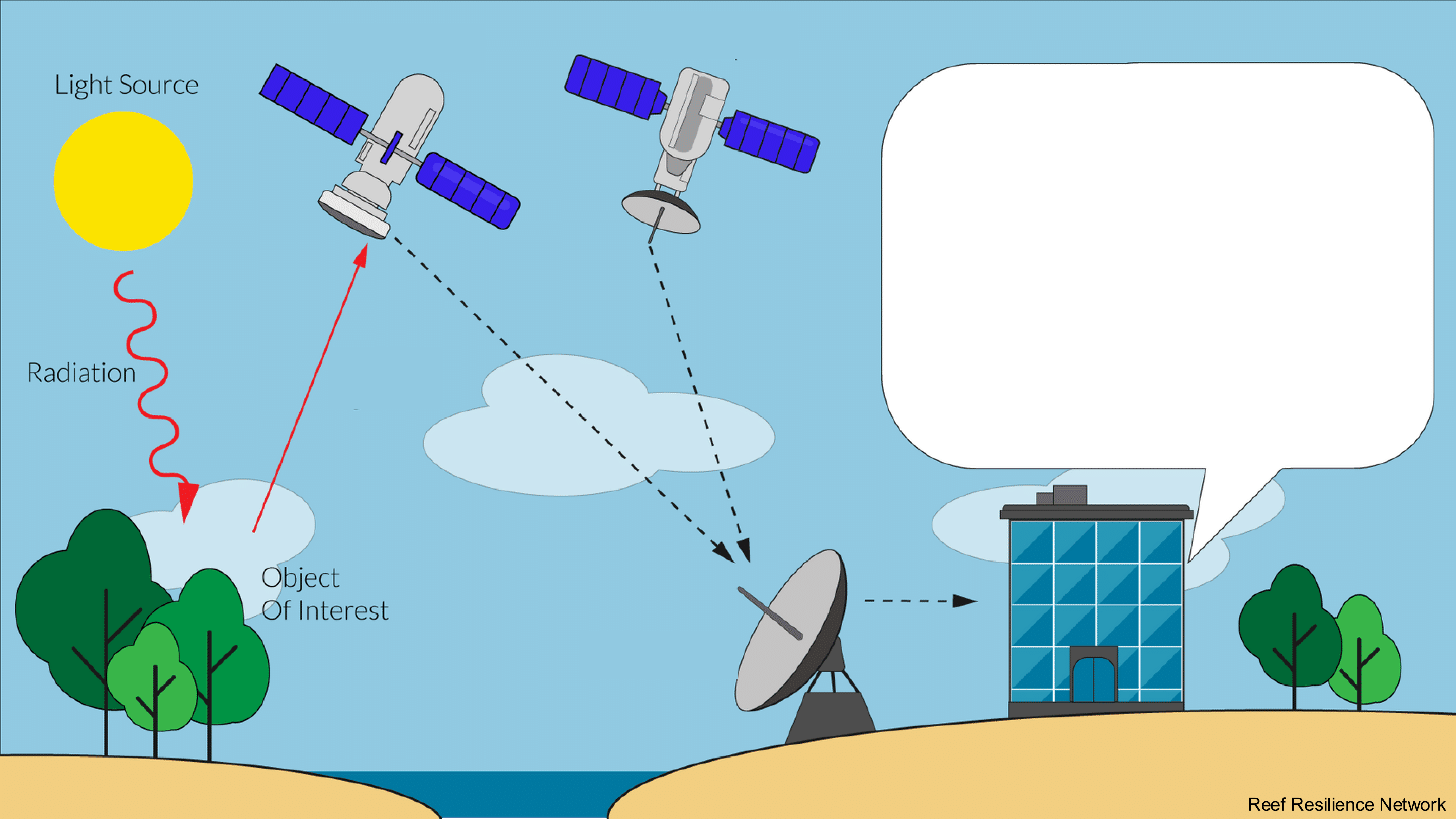
as complex as a billion dollar mission with over a decade of planning



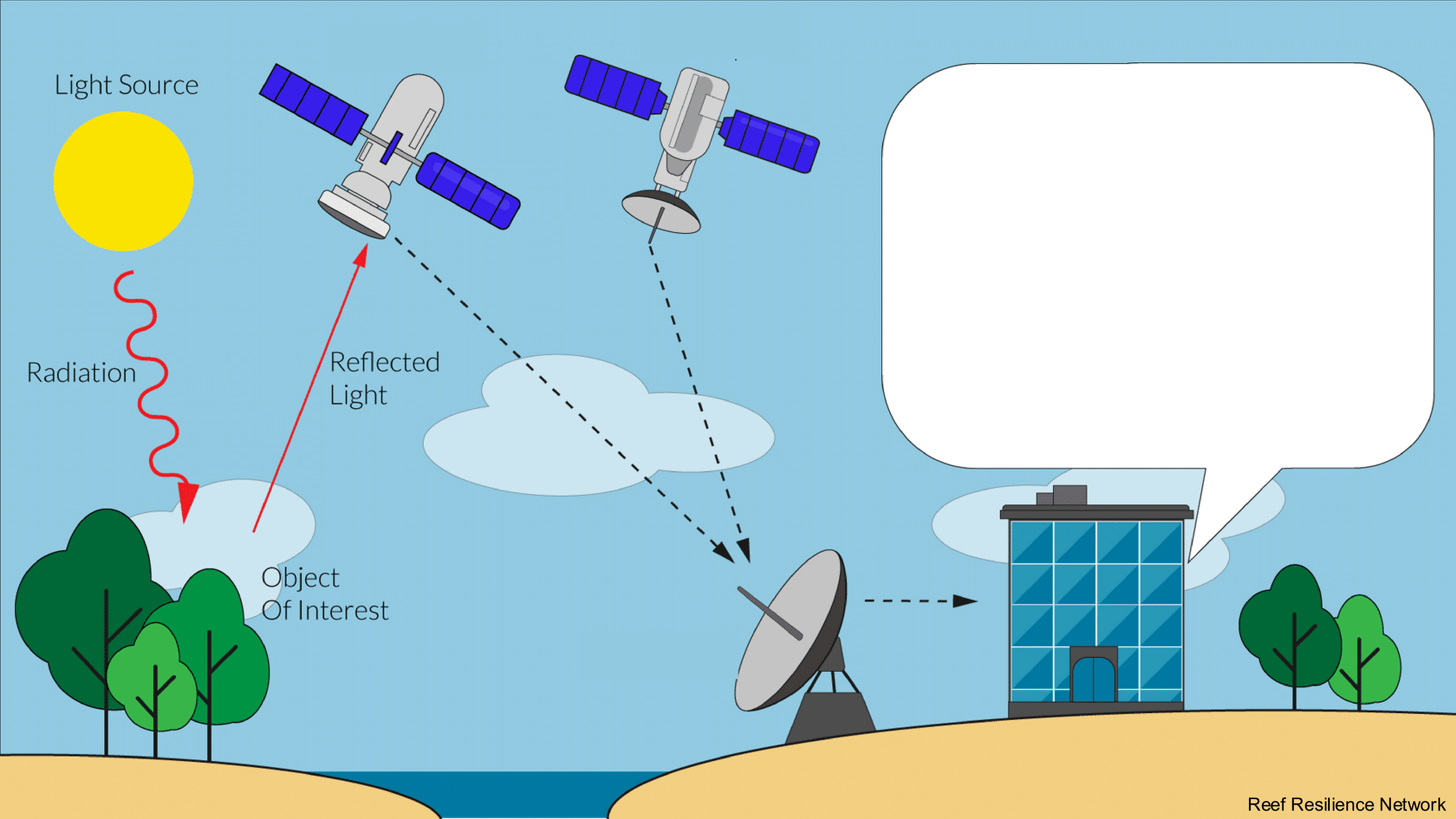

Reef Resilience Network

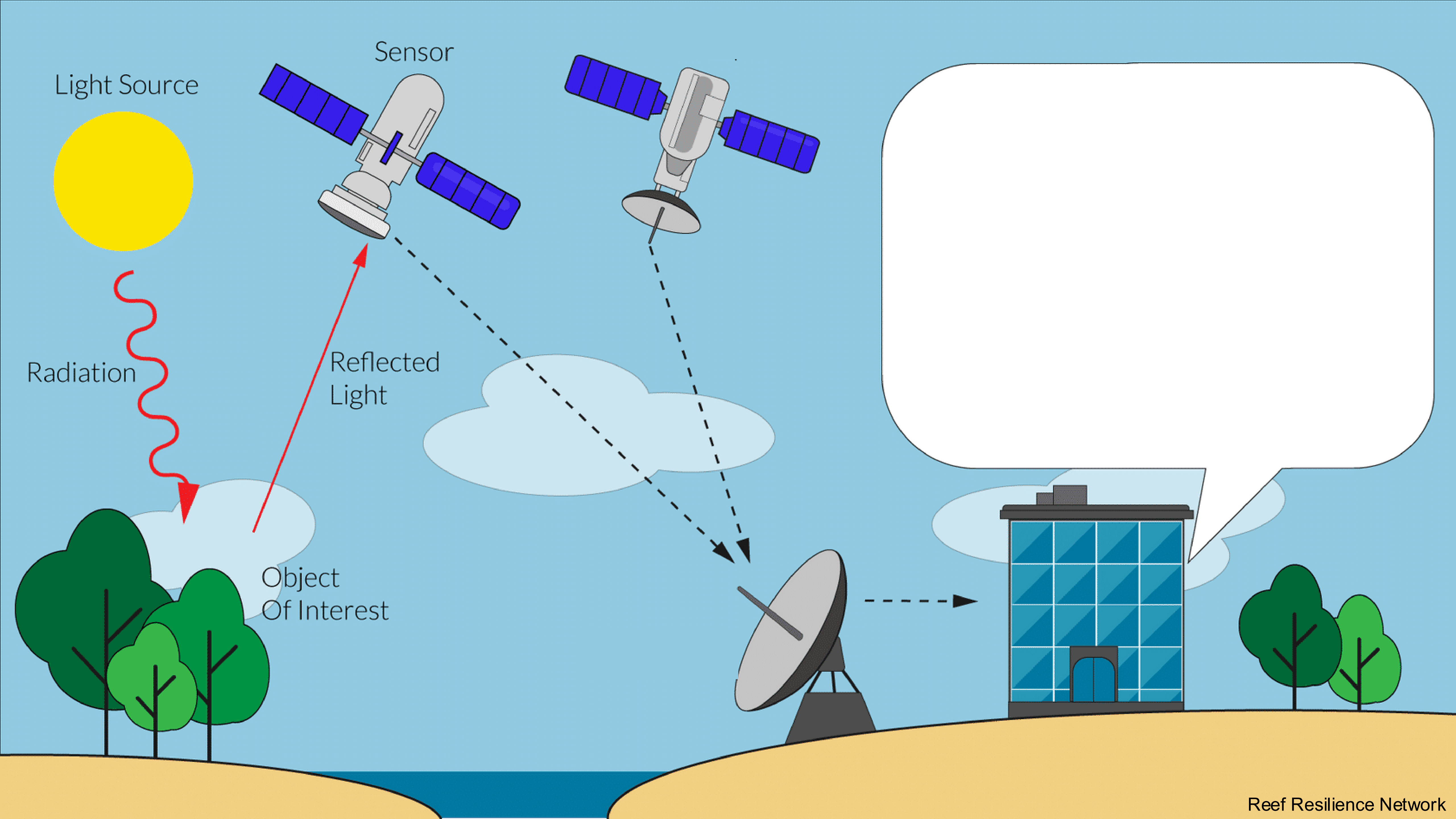

Light Source
Reef Resilience Network


Light Source
Radiation
Reef Resilience Network

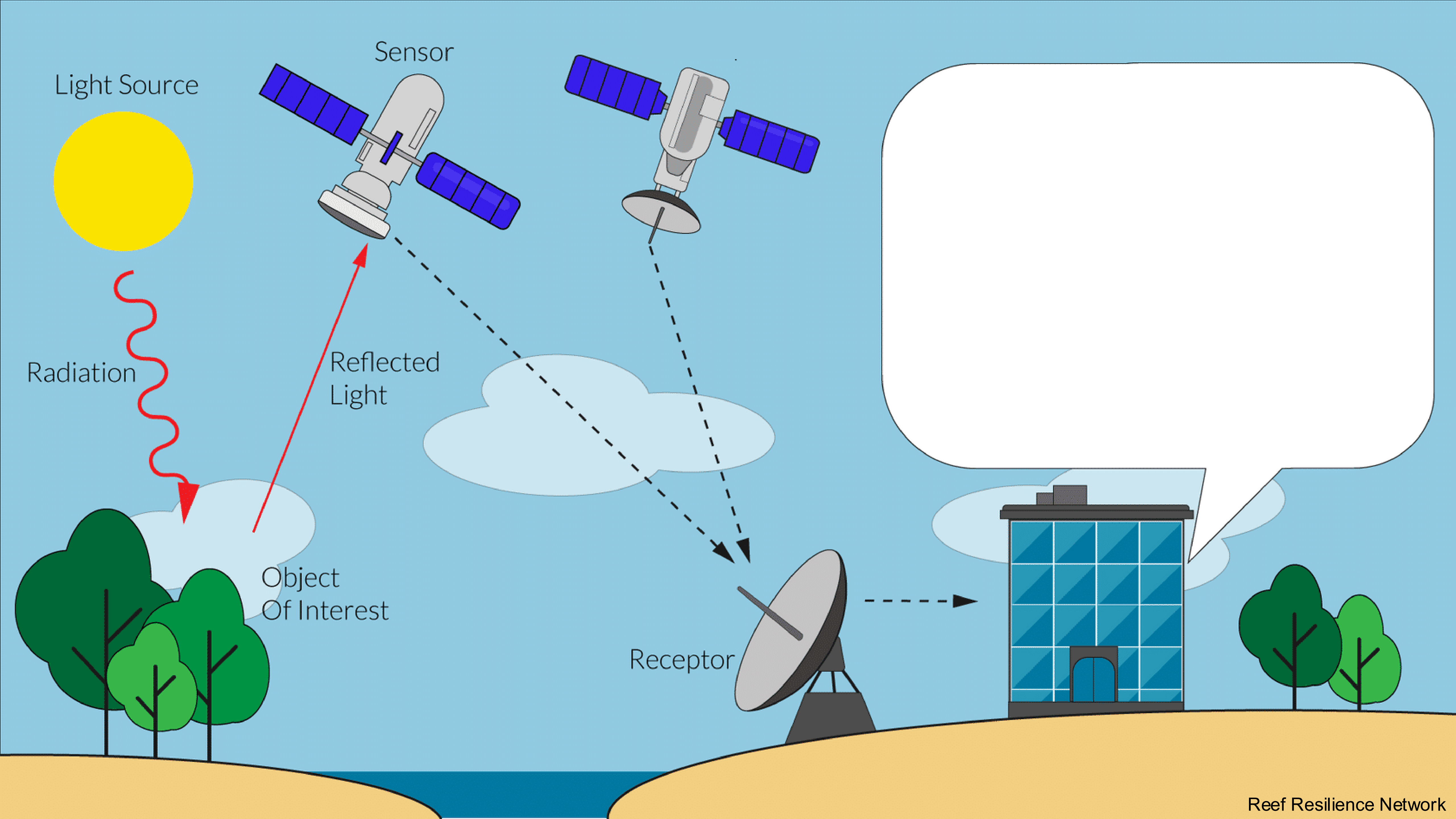


Light Source
Radiation
Object
Of Interest
Reef Resilience Network

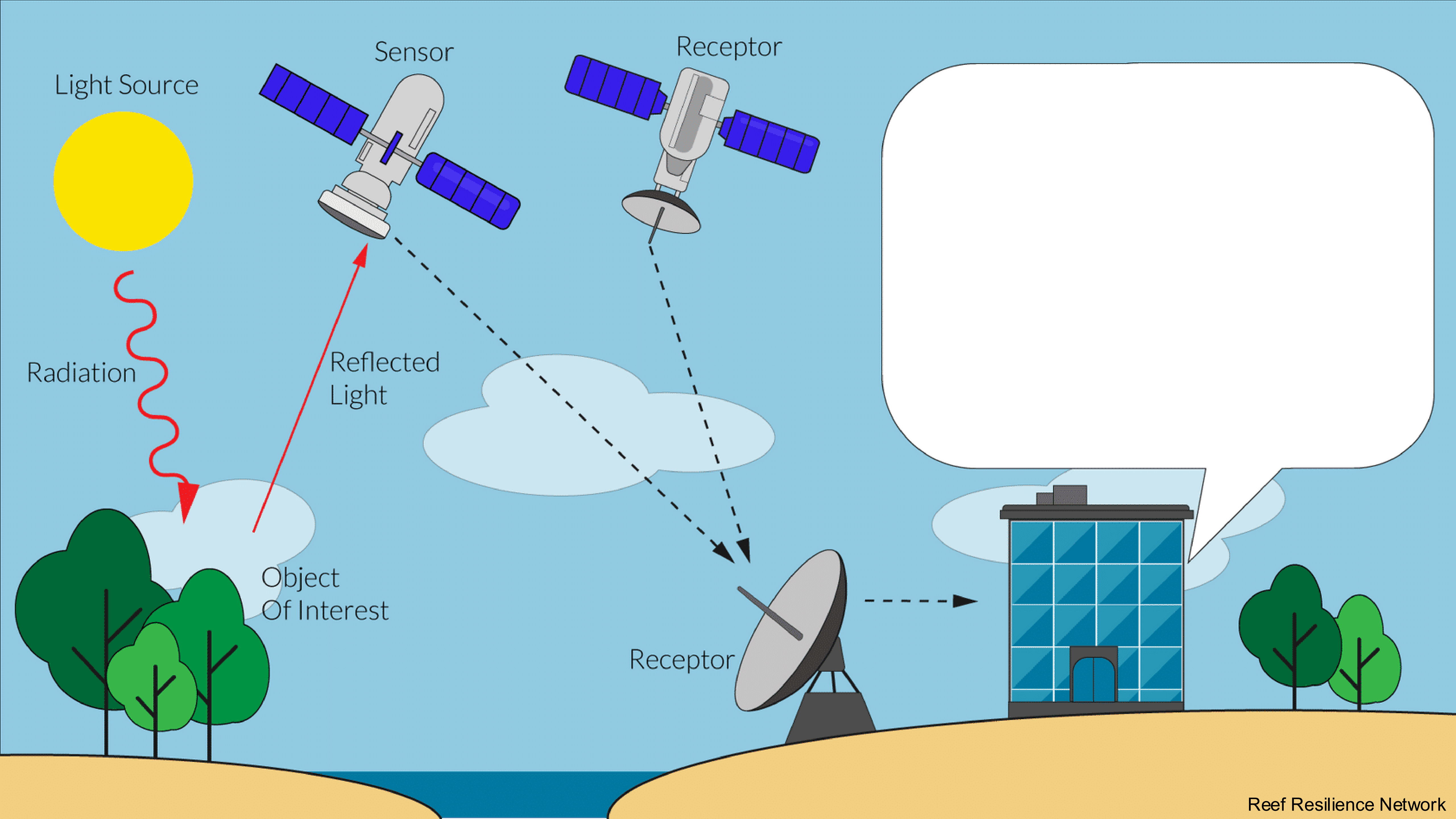

Light Source
Radiation
Reflected Light
Object Of Interest
Reef Resilience Network

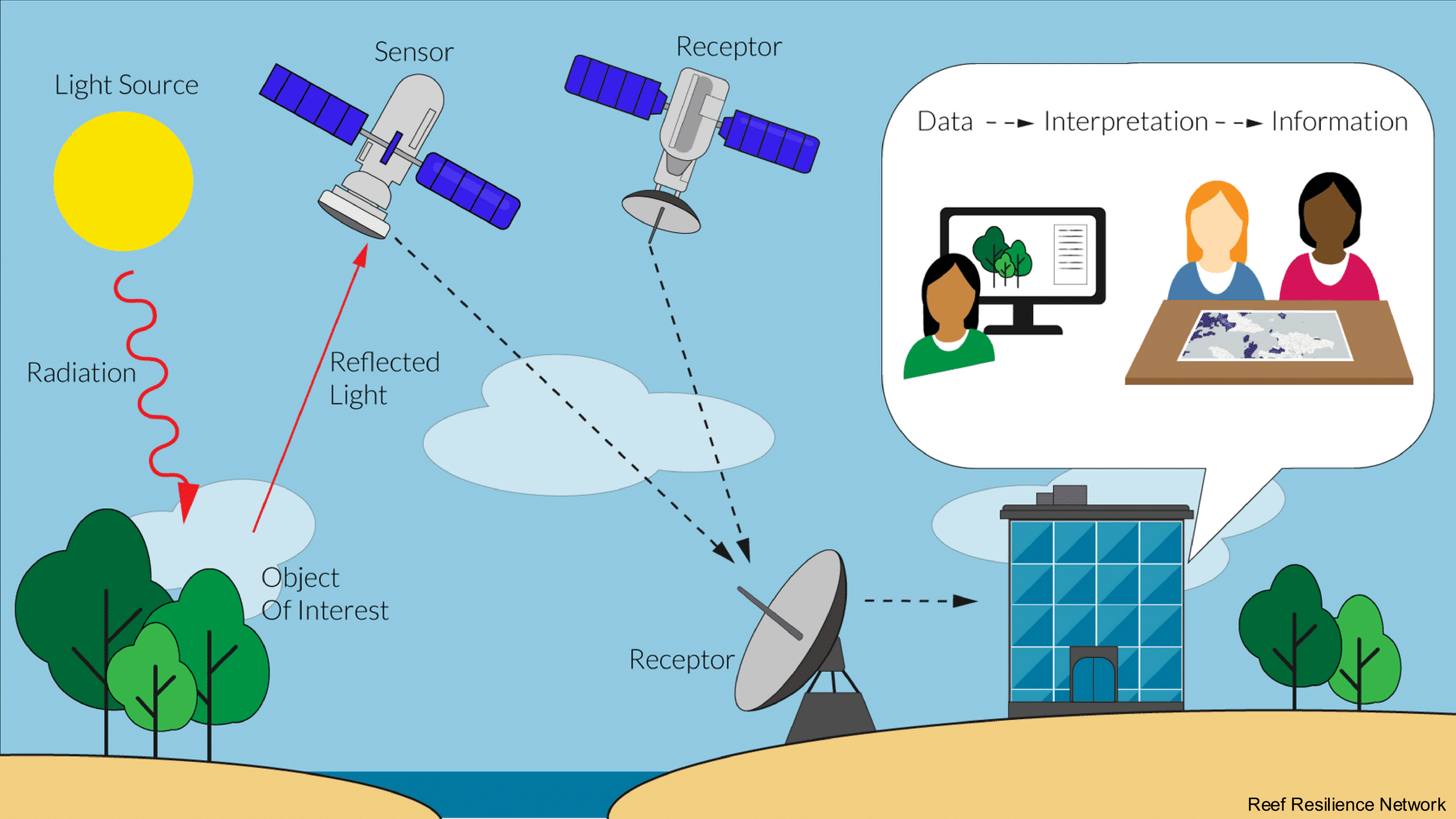


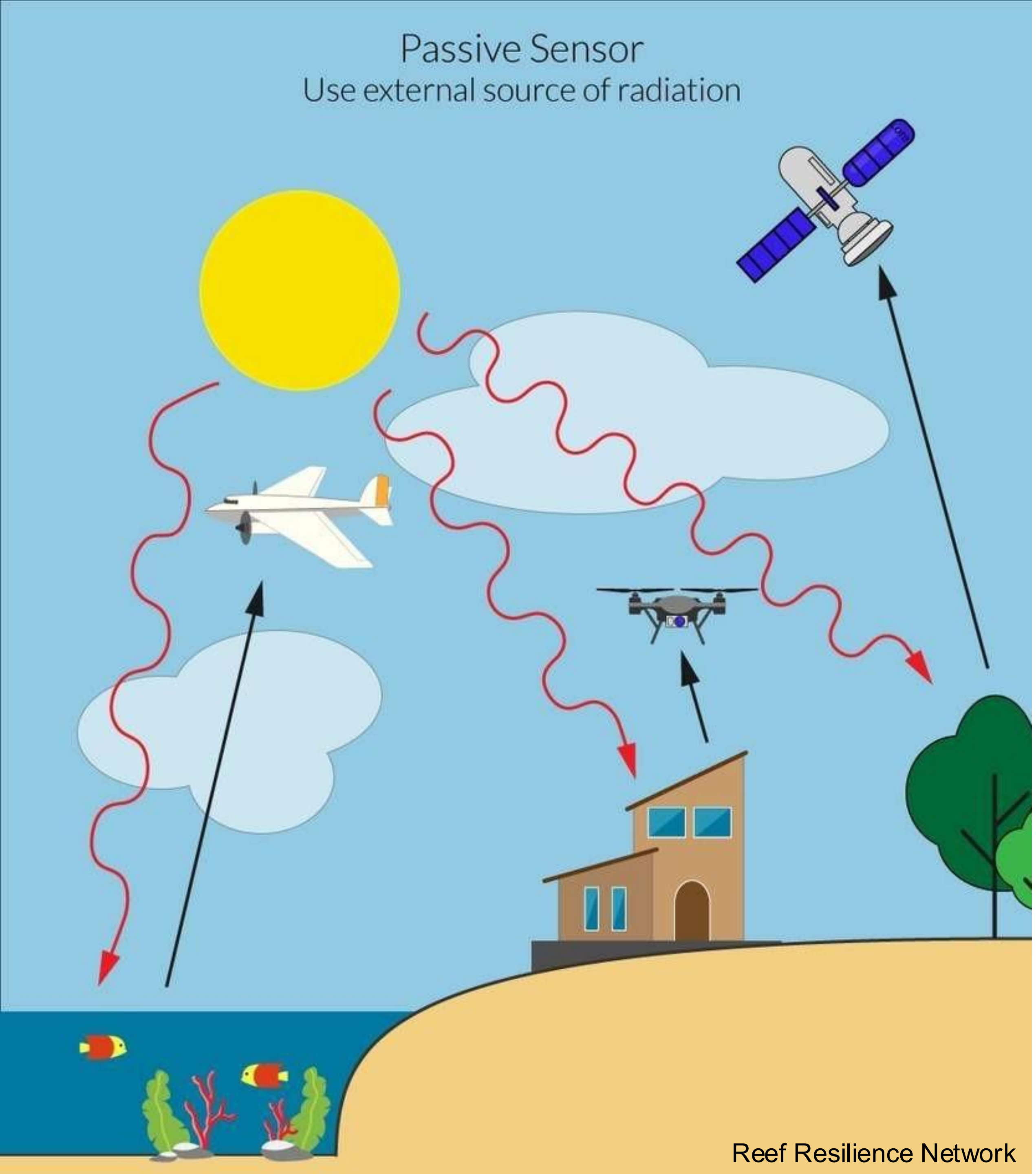
Light Source
Sensor
Radiation
Reflected
Light
Object
Of Interest
Reef Resilience Network



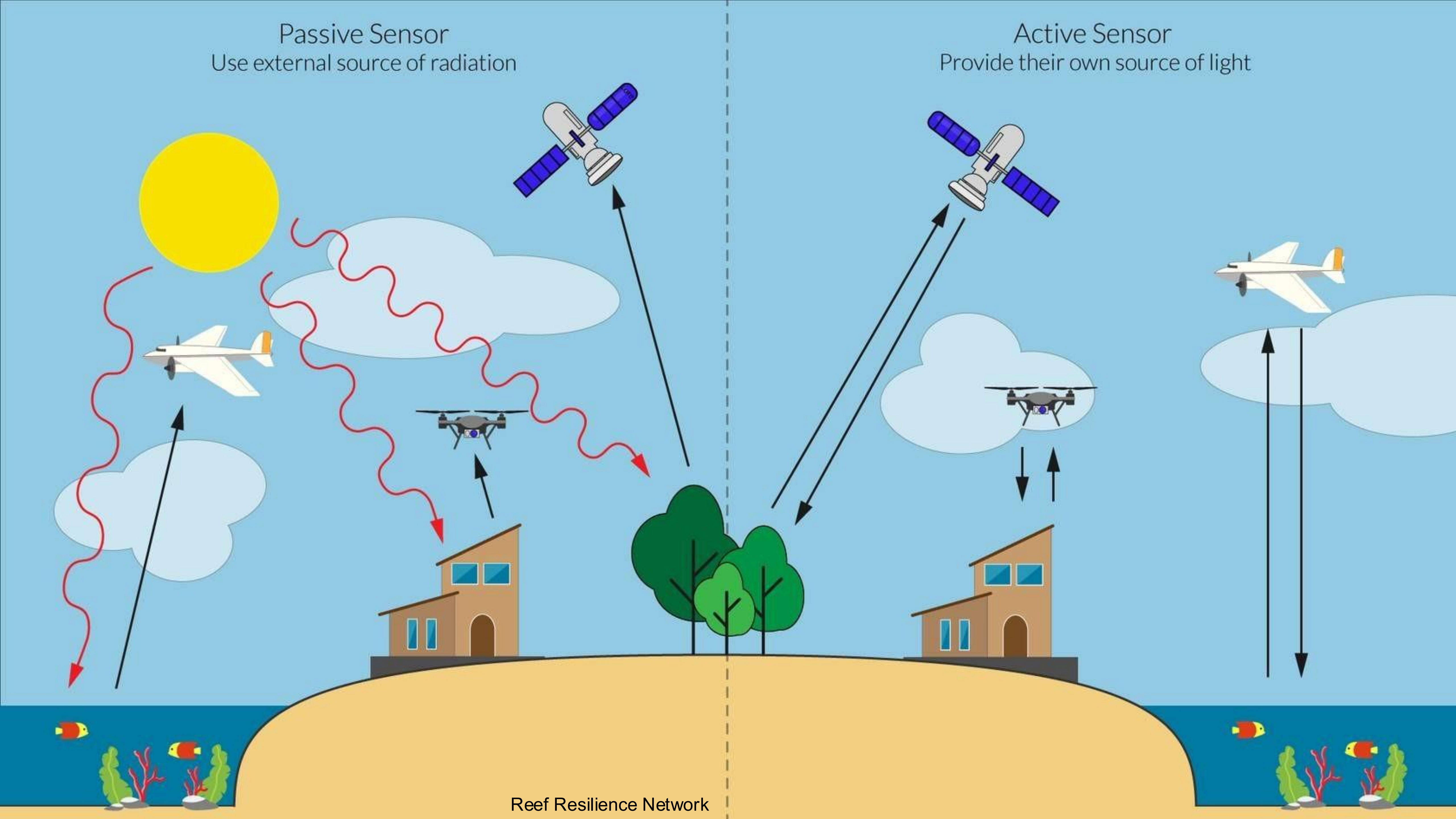
Sensor
Light Source
Radiation
Reflected Light
Object Of Interest
Receptor
Reef Resilience Network


Light Source
Sensor
Receptor
Radiation
Reflected
Light
Object
Of Interest
Receptor
Reef Resilience Network

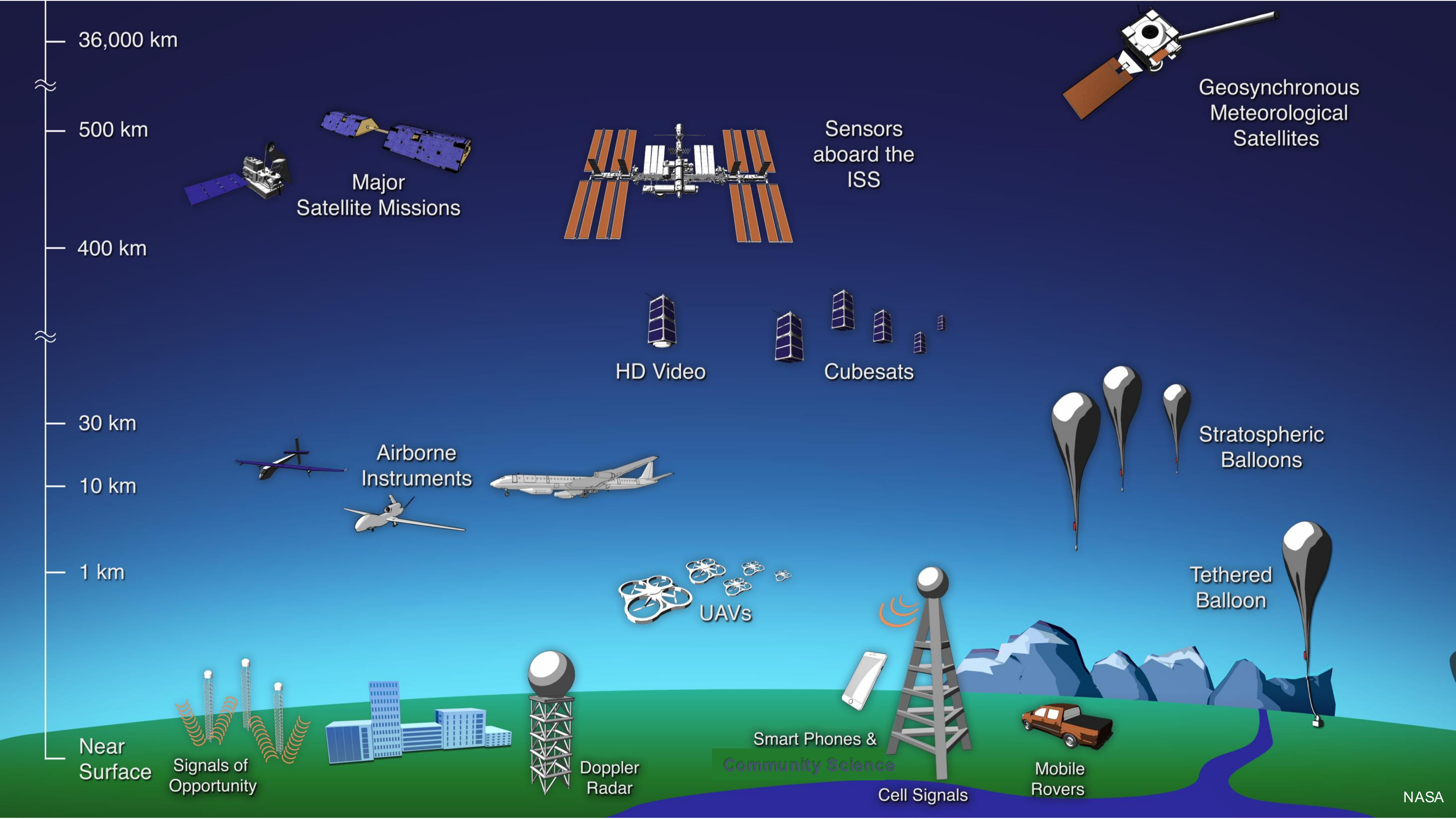

Light Source
Sensor
Receptor
Data - - ► Interpretation - - ► Information
Radiation
Reflected
Light
Object
Of Interest
Receptor
Reef Resilience Network



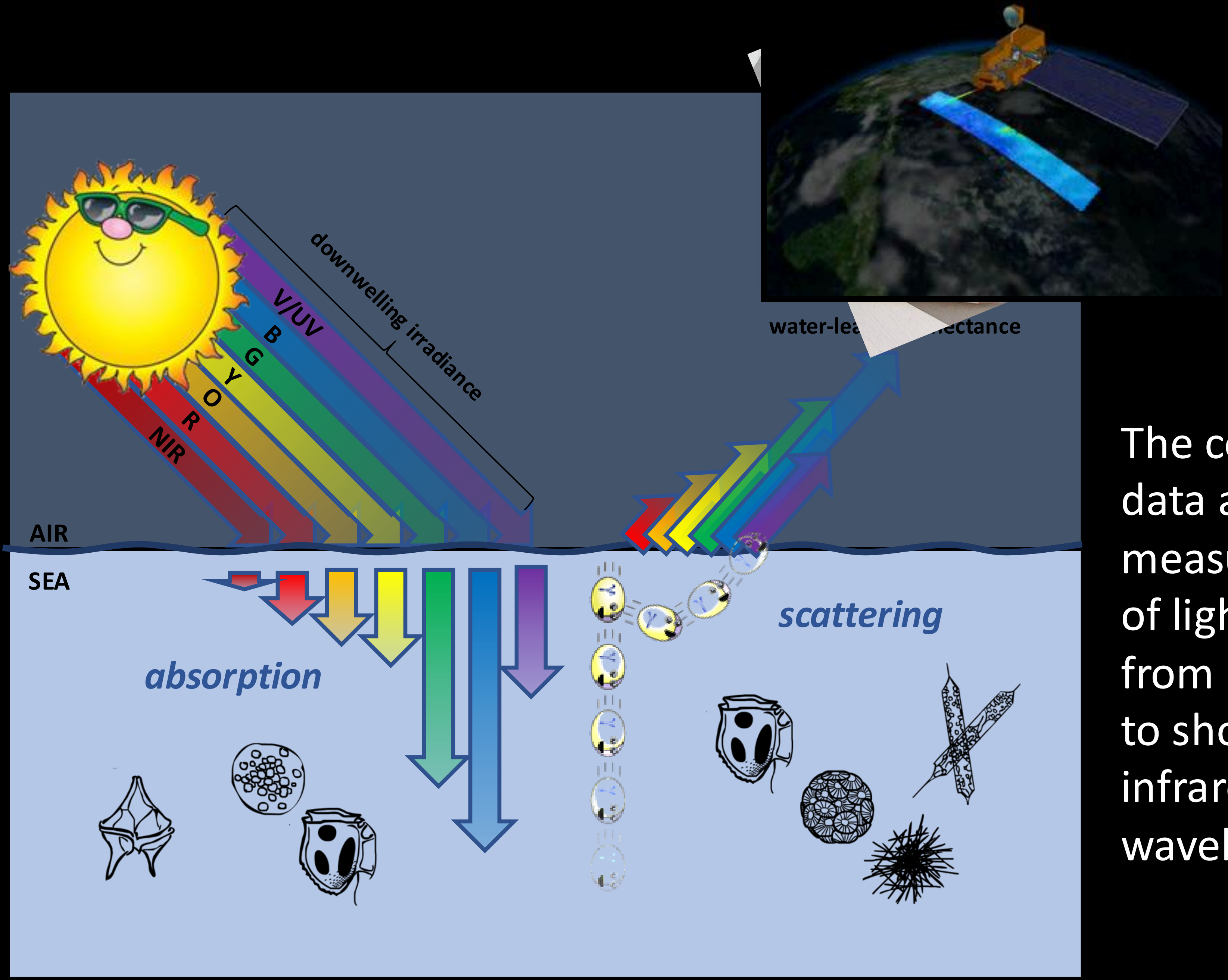
Reef Resilience Network



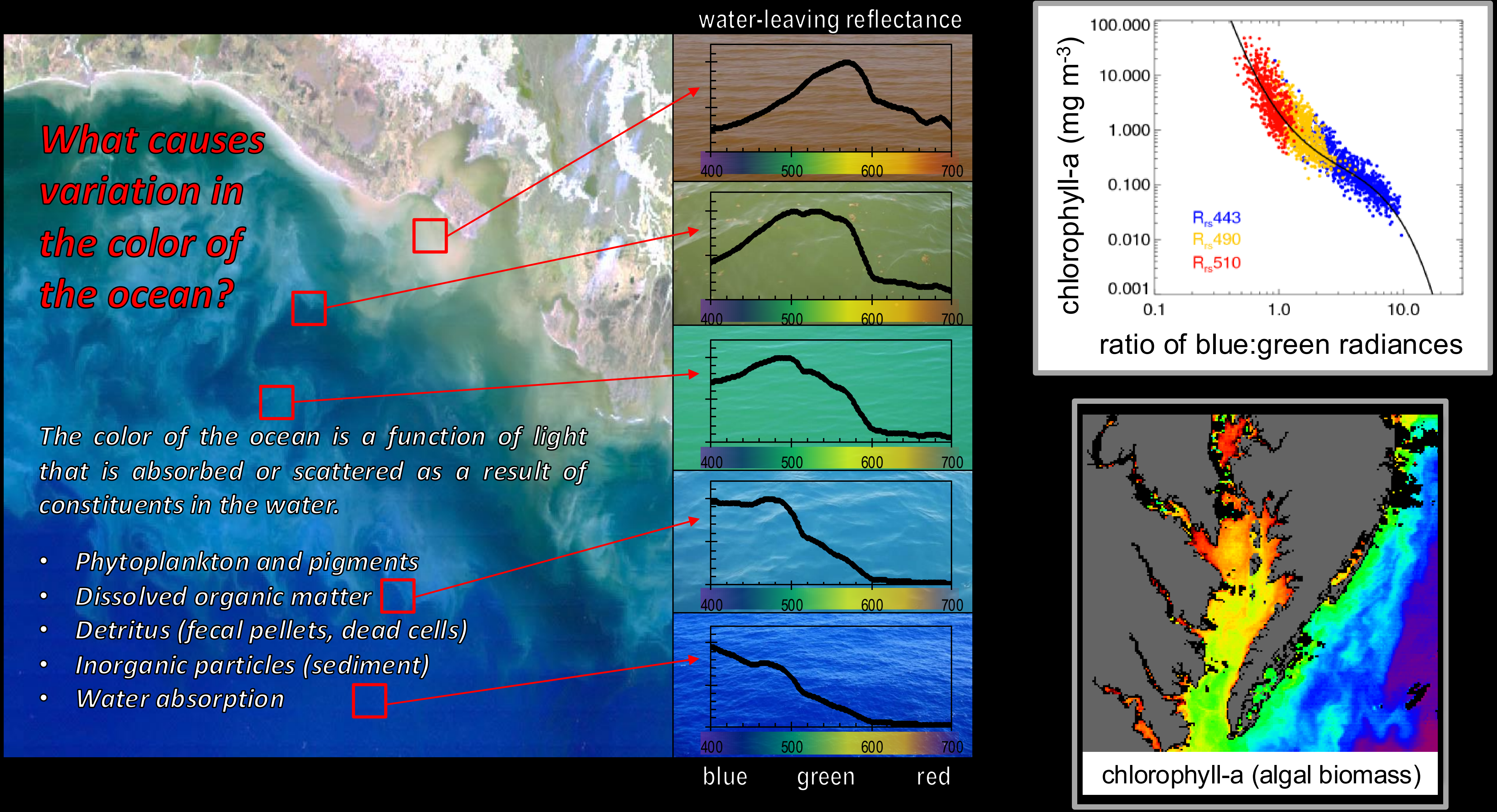
Reef Resilience Network

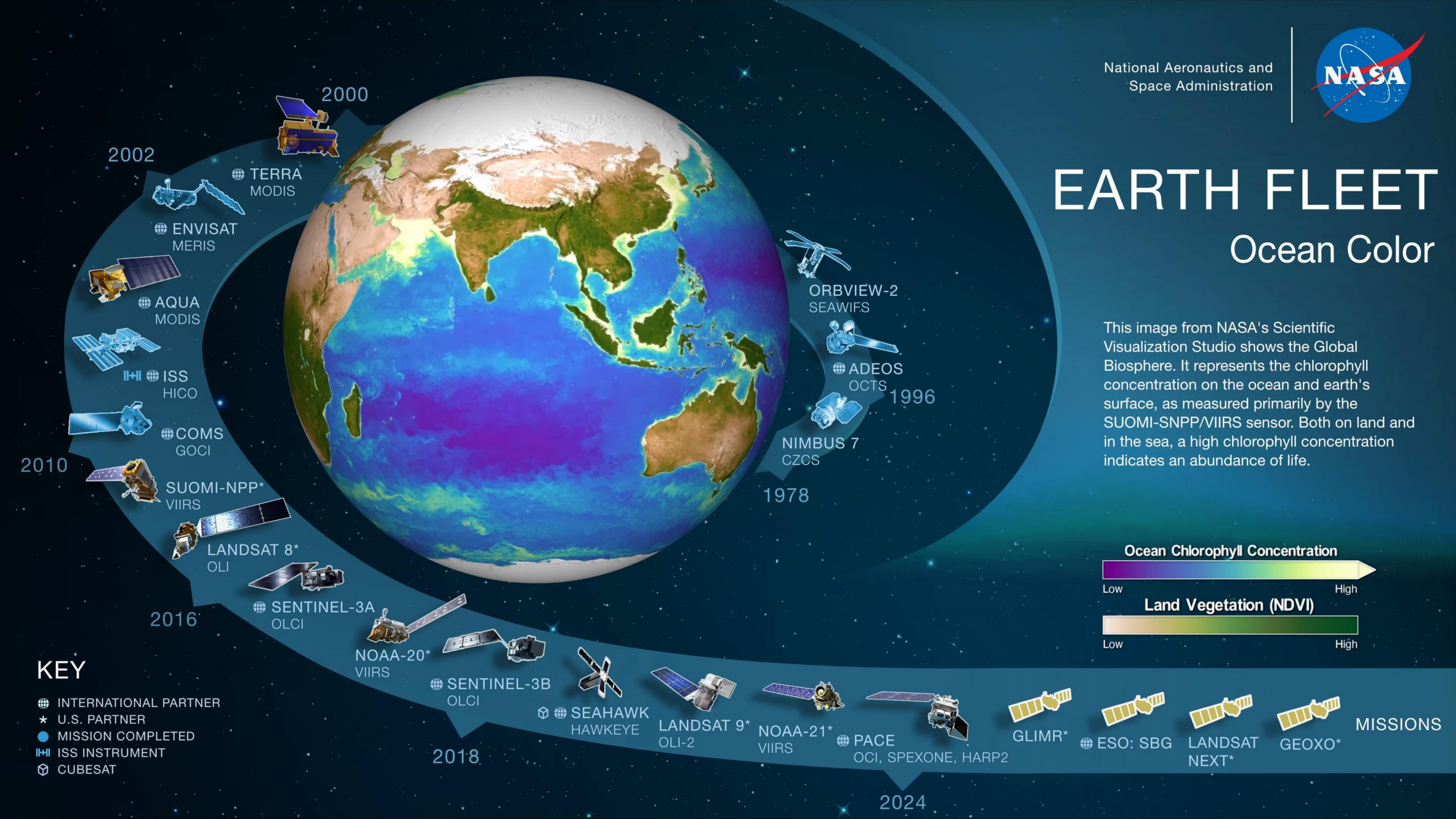

36,000 km
500 km
400 km
30 km
10 km
1 km
Near Surface
Major Satellite Missions
Sensors aboard the ISS
Geosynchronous Meteorological Satellites
HD Video
Cubesats
Airborne Instruments
Stratospheric Balloons
UAVs
Tethered Balloon
Signals of Opportunity
Doppler Radar
Smart Phones &
Community Science
Cell Signals
Mobile Rovers
NASA

The “color” of the ocean or atmosphere is determined by the interactions of incident light with substances or particles present in the water or atmosphere.



The core satellite data are accurate measurements of light intensity from ultra-violet to shortwave infrared wavelengths.


What causes variation in the color of the ocean?
The color of the ocean is a function of light that is absorbed or scattered as a result of constituents in the water.
• Phytoplankton and pigments
• Dissolved organic matter
• Detritus (fecal pellets, dead cells)
• Inorganic particles (sediment)
• Water absorption
water-leaving reflectance
400
500
600
700
blue
green
red
100.000
10.000
1.000
0.100
0.010
0.001
0.1
1.0
10.0
chlorophyll-a (mg m-3)
ratio of blue:green radiances
Rrs443
Rrs490
Rrs510
chlorophyll-a (algal biomass)


National Aeronautics and Space Administration
NASA
EARTH FLEET
Ocean Color
This image from NASA's Scientific Visualization Studio shows the Global Biosphere. It represents the chlorophyll concentration on the ocean and earth's surface, as measured primarily by the SUOMI-SNPP/VIIRS sensor. Both on land and in the sea, a high chlorophyll concentration indicates an abundance of life.
Ocean Chlorophyll Concentration
Low
High
Land Vegetation (NDVI)
Low
High
1978
NIMBUS 7
CZCS
1996
ADEOS
OCTS
ORBVIEW-2
SEAWIFS
2000
TERRA
MODIS
2002
ENVISAT
MERIS
AQUA
MODIS
ISS
HICO
COMS
GOCI
2010
SUOMI-NPP*
VIIRS
LANDSAT 8*
OLI
2016
SENTINEL-3A
OLCI
NOAA-20*
VIIRS
SENTINEL-3B
OLCI
2018
SEAHAWK
HAWKEYE
LANDSAT 9*
OLI-2
NOAA-21*
VIIRS
PACE
OCI, SPEXONE, HARP2
2024
GLIMR*
ESO: SBG
LANDSAT NEXT*
GEOXO*
MISSIONS
KEY
INTERNATIONAL PARTNER
U.S. PARTNER
MISSION COMPLETED
ISS INSTRUMENT
CUBESAT

Remote sensing considerations

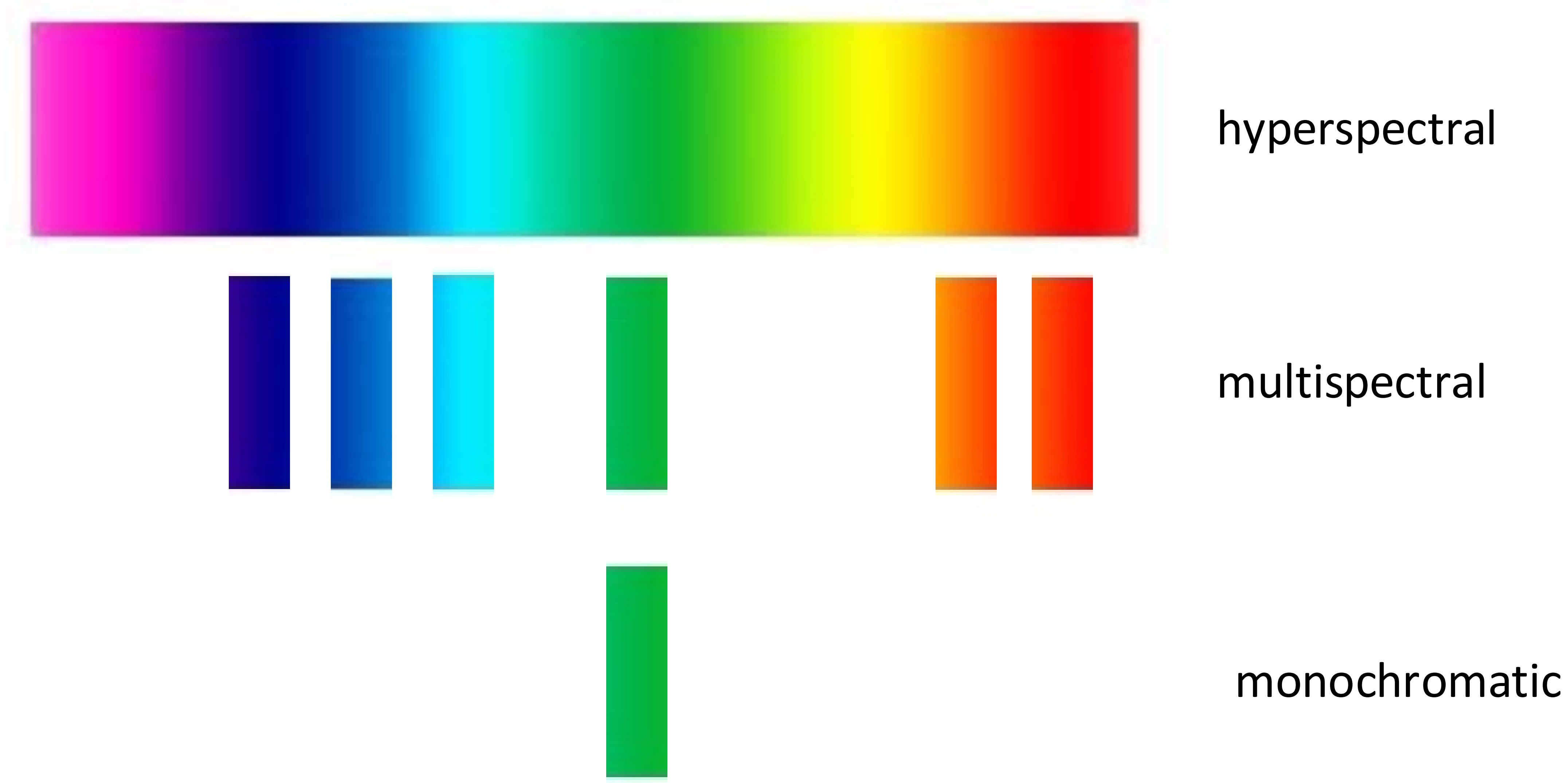
Spectral resolution

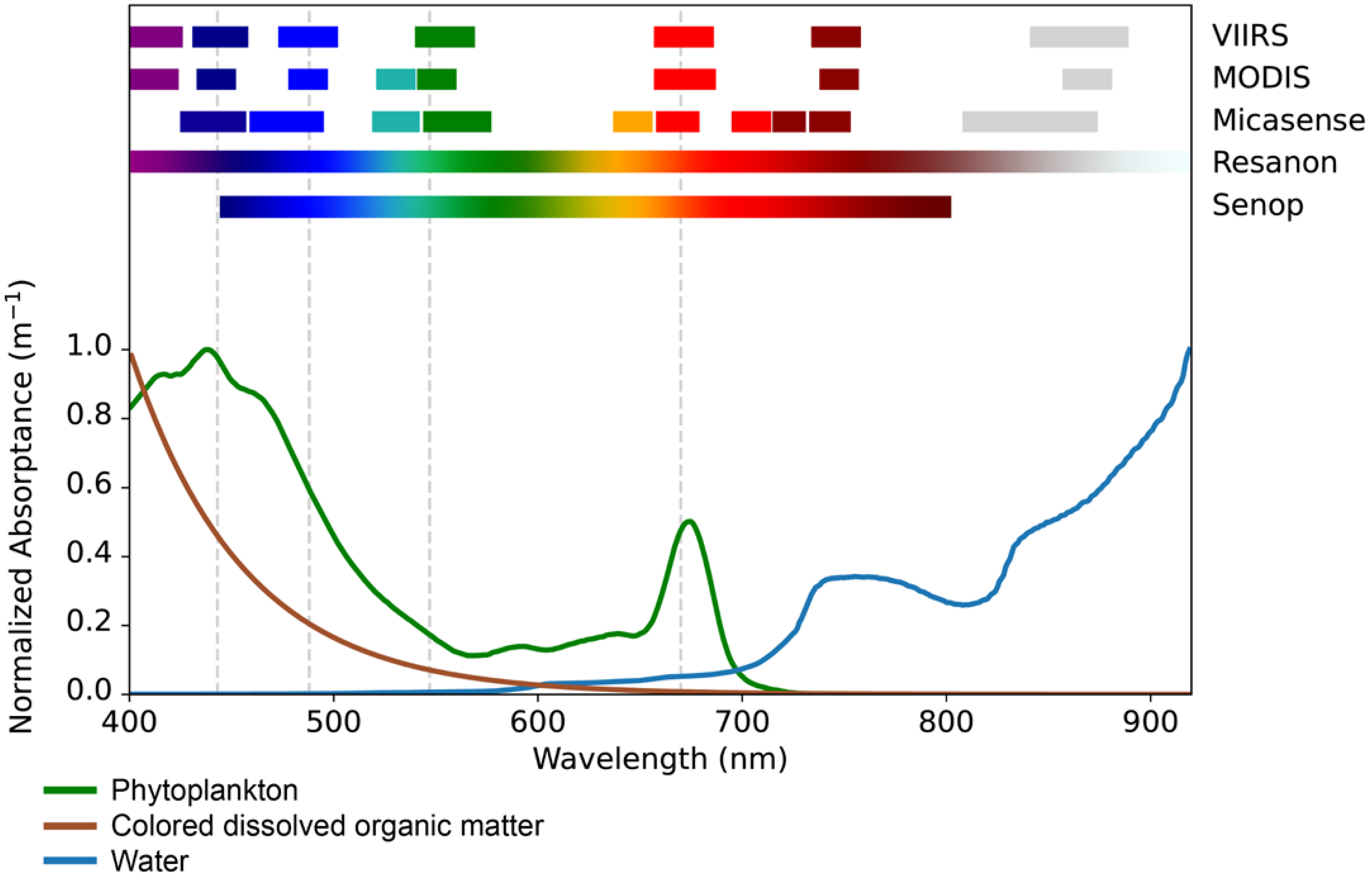
Spatial resolution

Time resolution (coverage)

Signal strength (relative to noise)

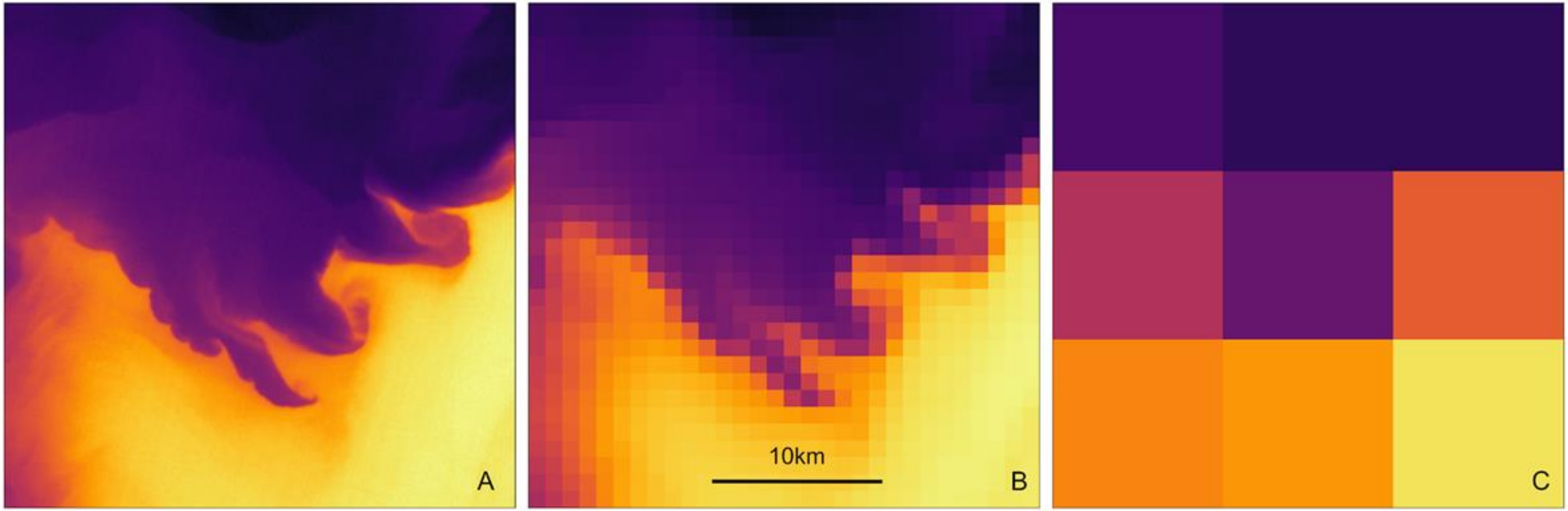
Spectral resolution

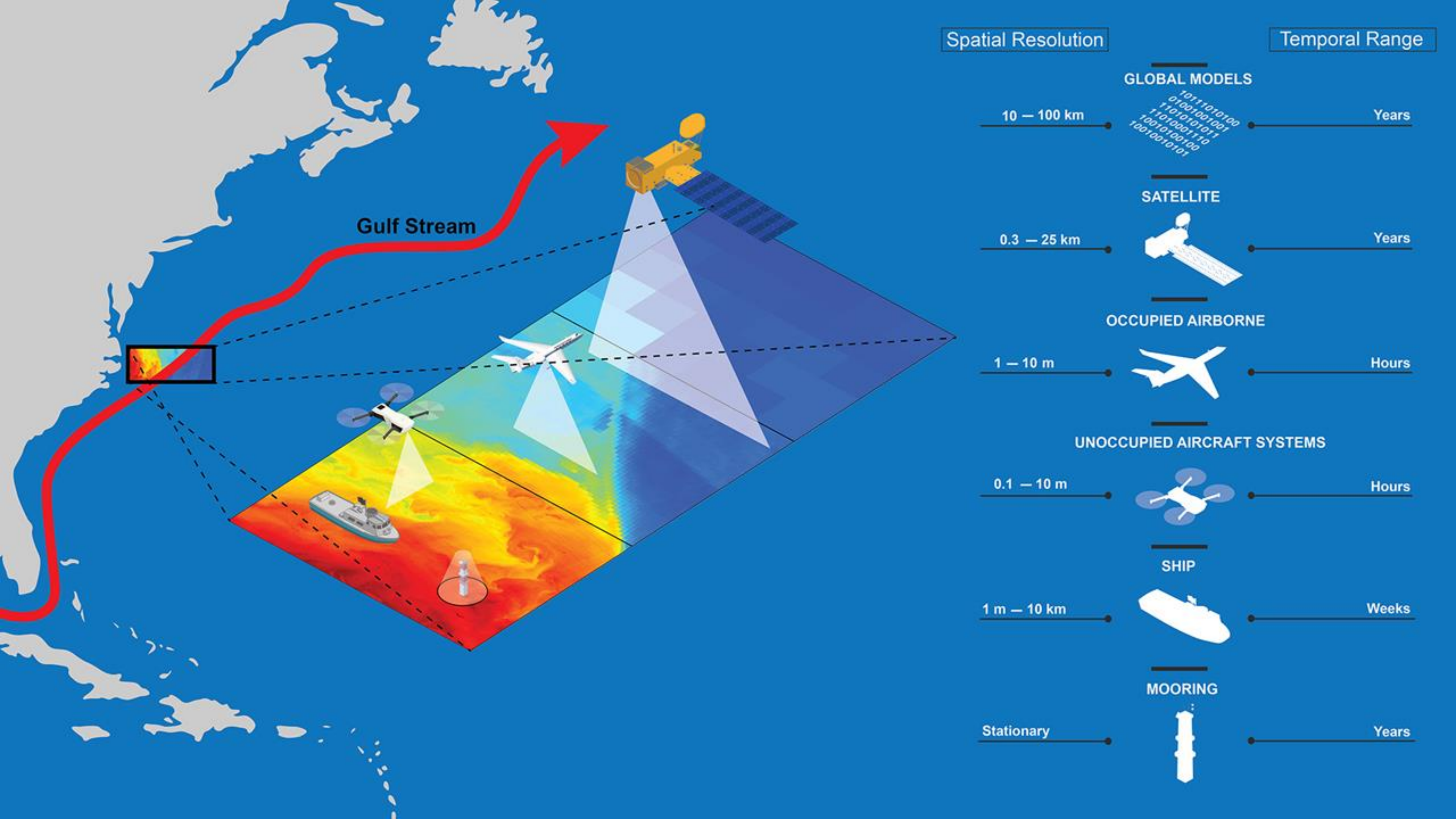




VIIRS
MODIS
Micasense
Resanon
Senop
Normalized Absorptance (m^{-1})
1.0
0.8
0.6
0.4
0.2
0.0
400
500
600
700
800
900
Wavelength (nm)
Phytoplankton
Colored dissolved organic matter
Water

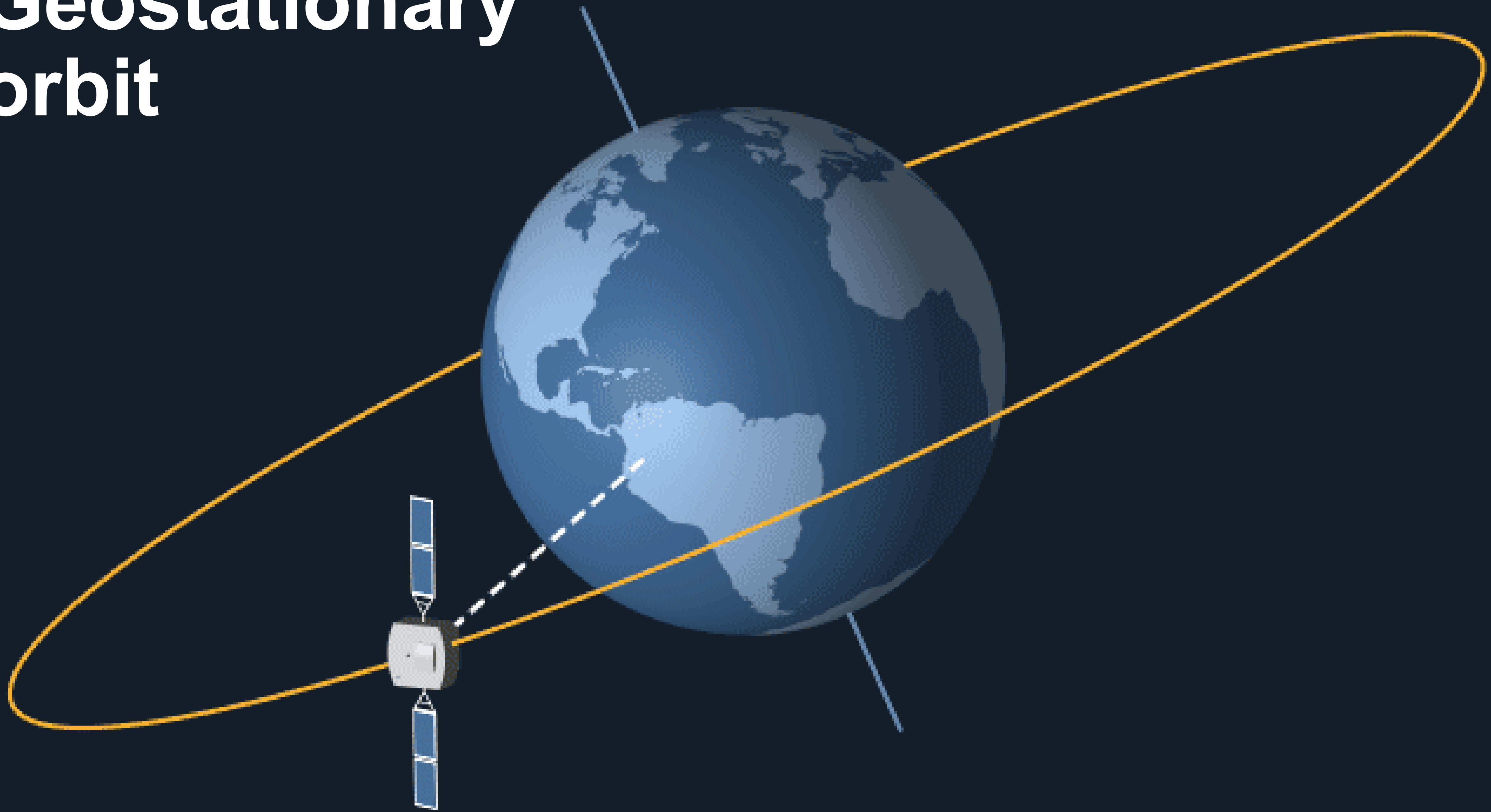
Space/time resolution





Gulf Stream
Spatial Resolution
Temporal Range
GLOBAL MODELS
10 — 100 km
Years
SATELLITE
0.3 — 25 km
Years
OCCUPIED AIRBORNE
1 — 10 m
Hours
UNOCCUPIED AIRCRAFT SYSTEMS
0.1 — 10 m
Hours
SHIP
1 m — 10 km
Weeks
MOORING
Stationary
Years

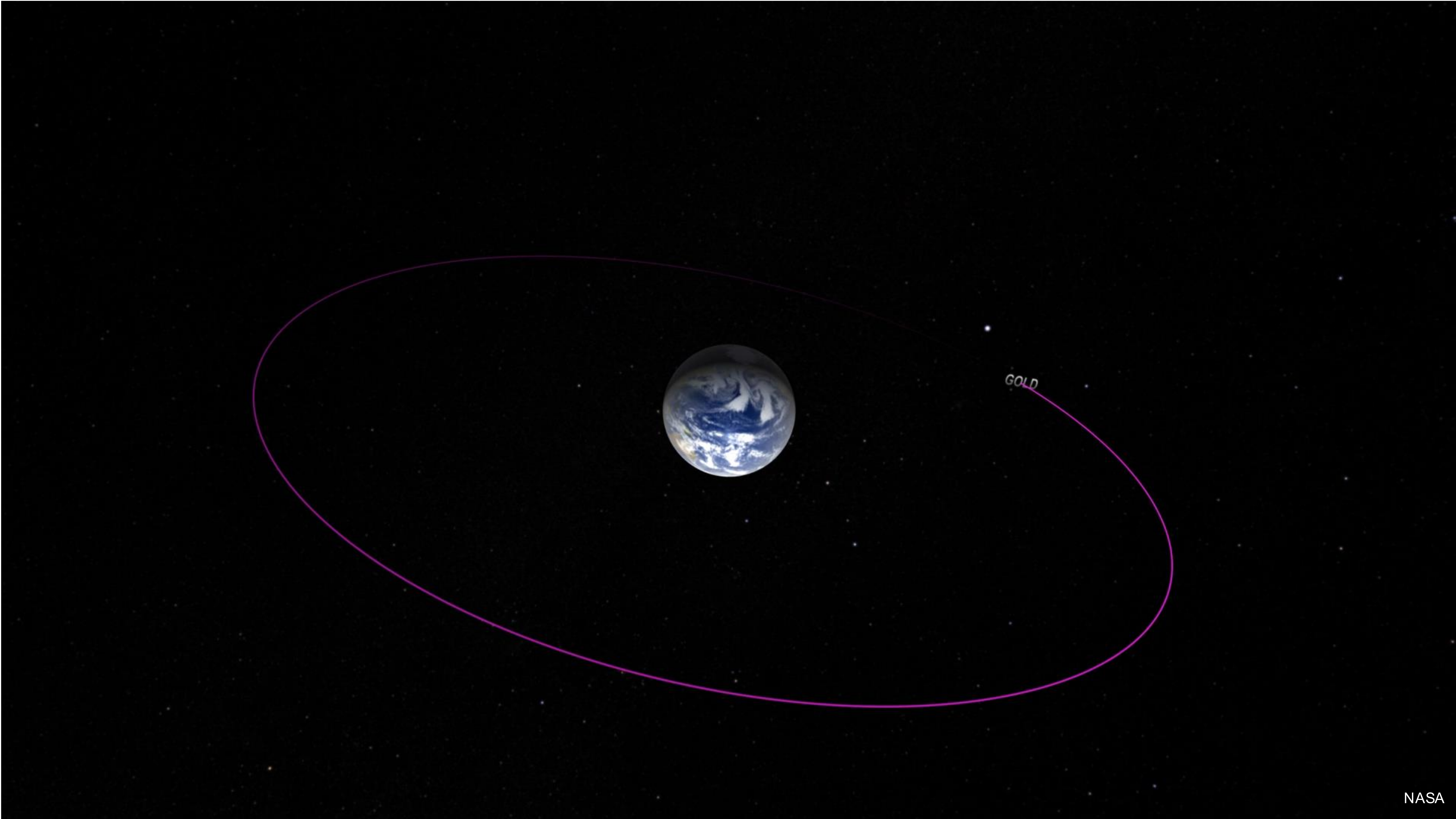
Geostationary orbit



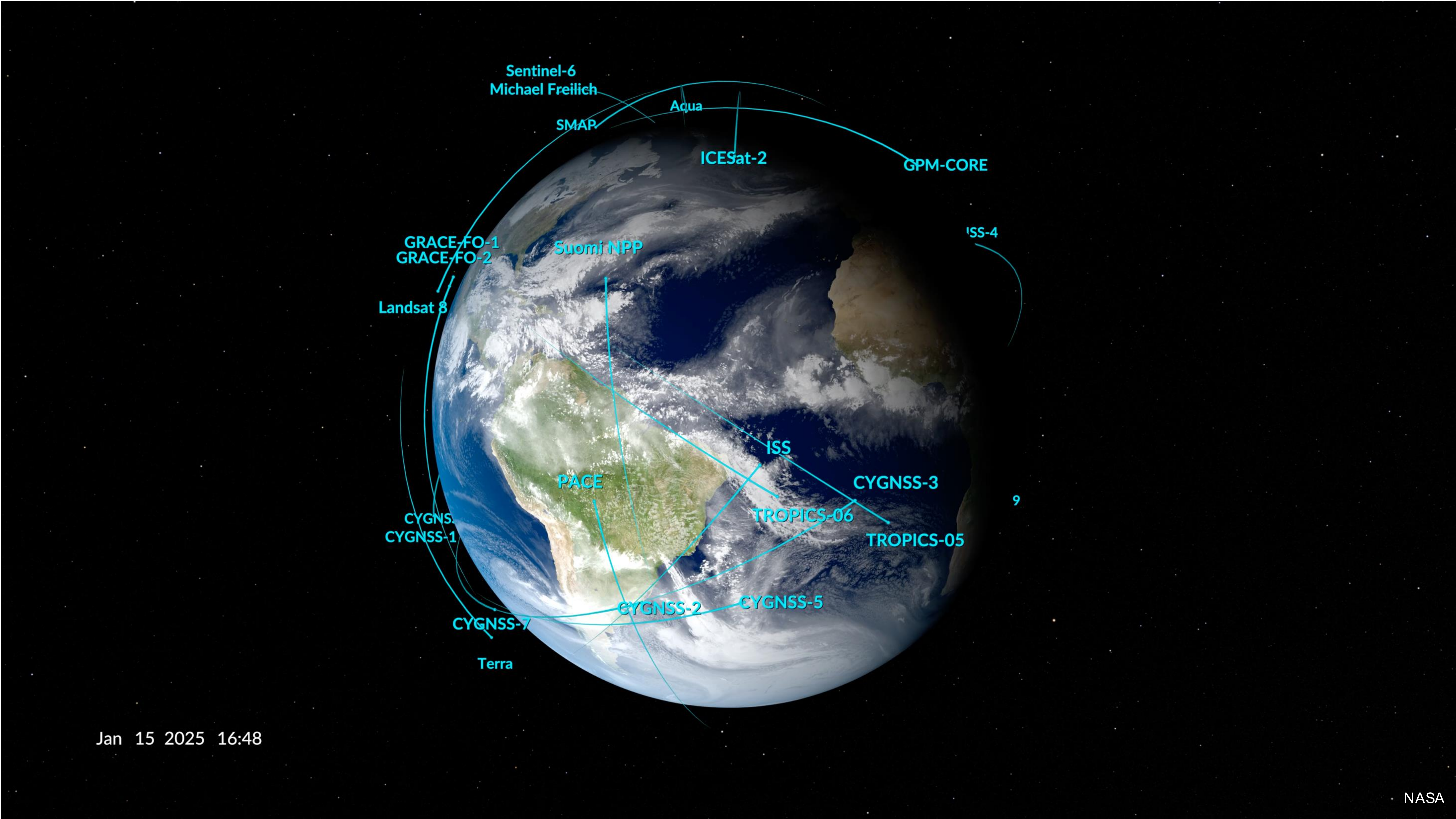
NASA

Polar orbit

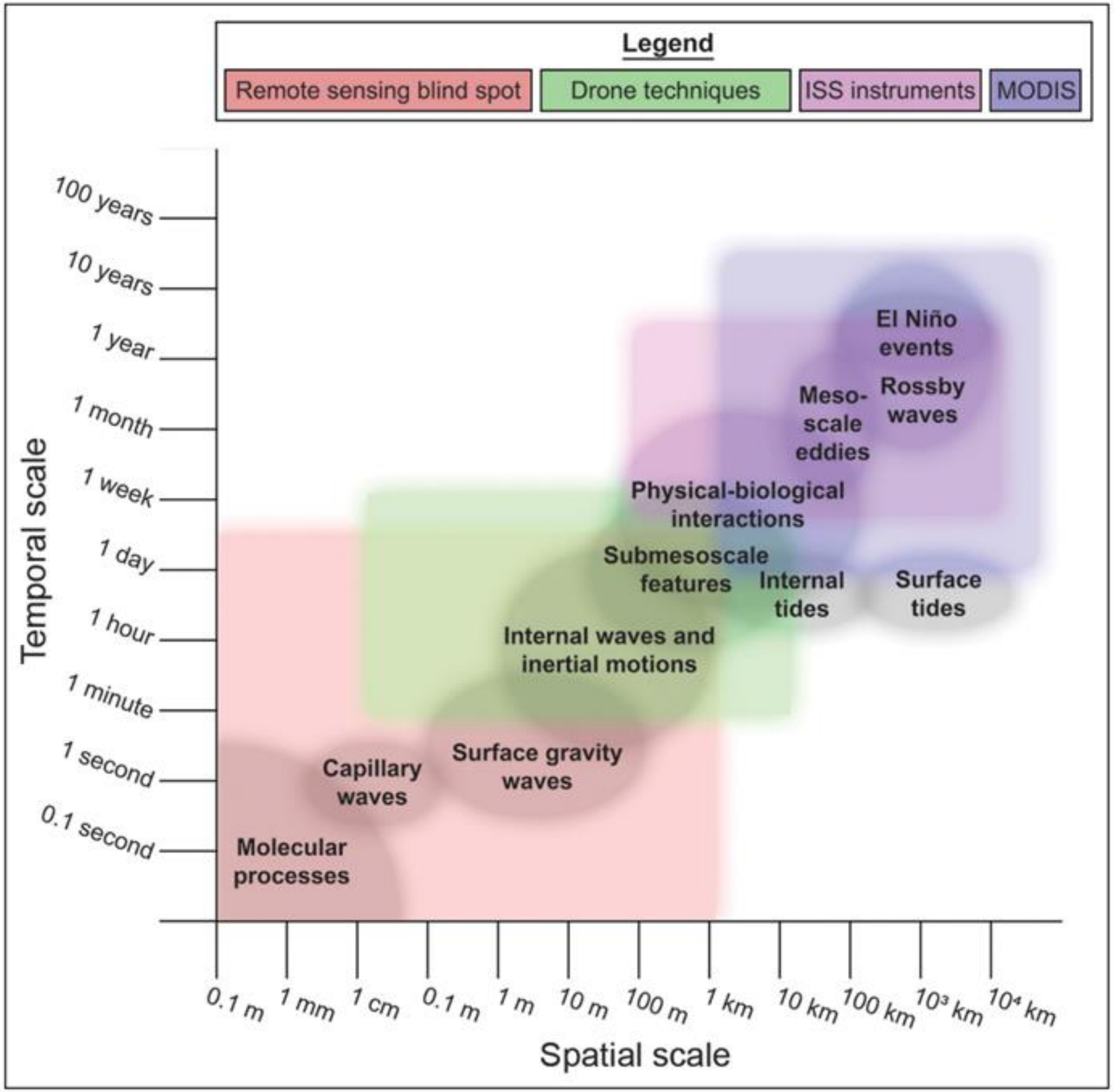

NASA
SPEXone
SPEXone
Orbit: 04 elapsed: 06 hours 04 minutes



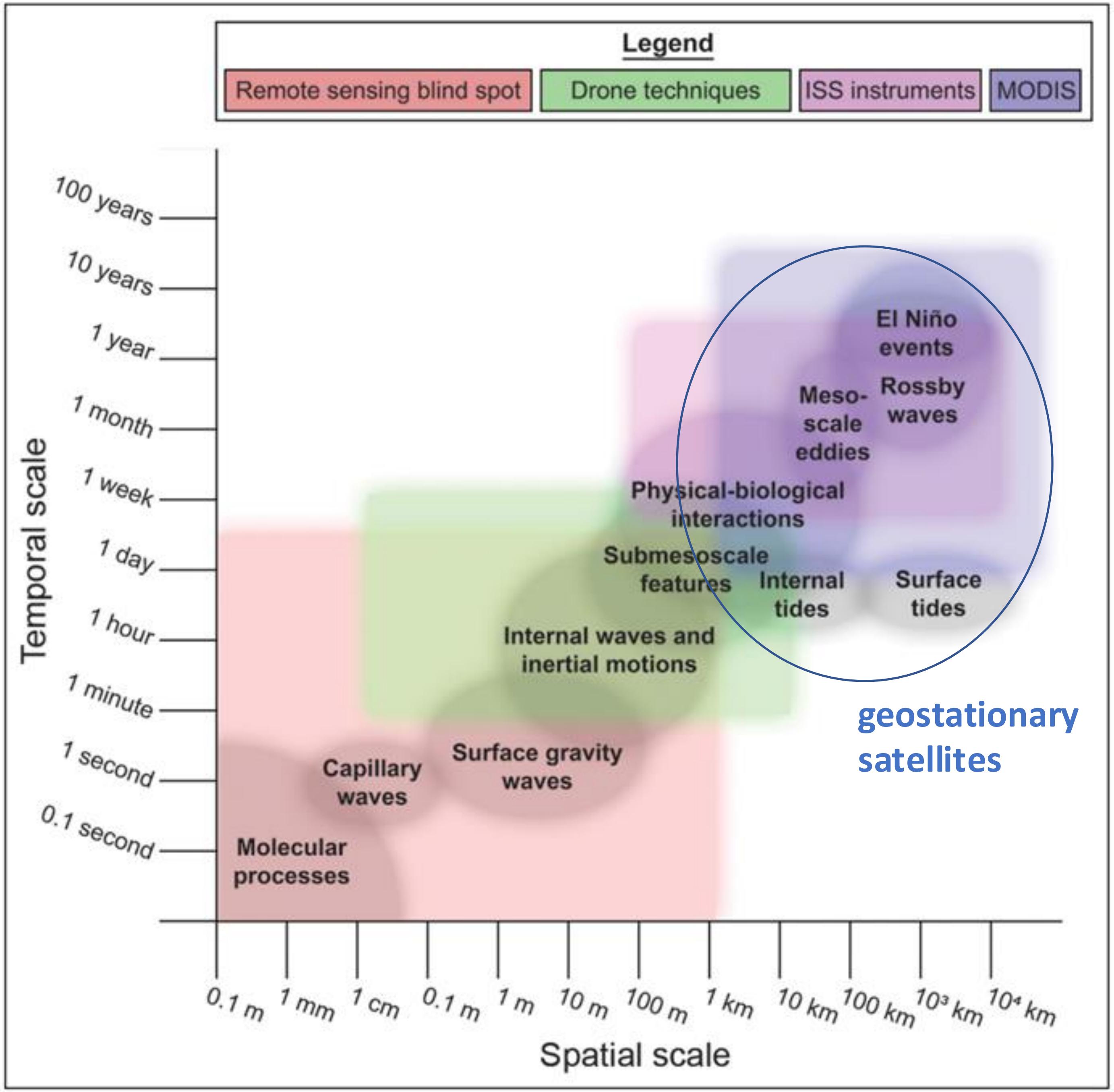
NASA

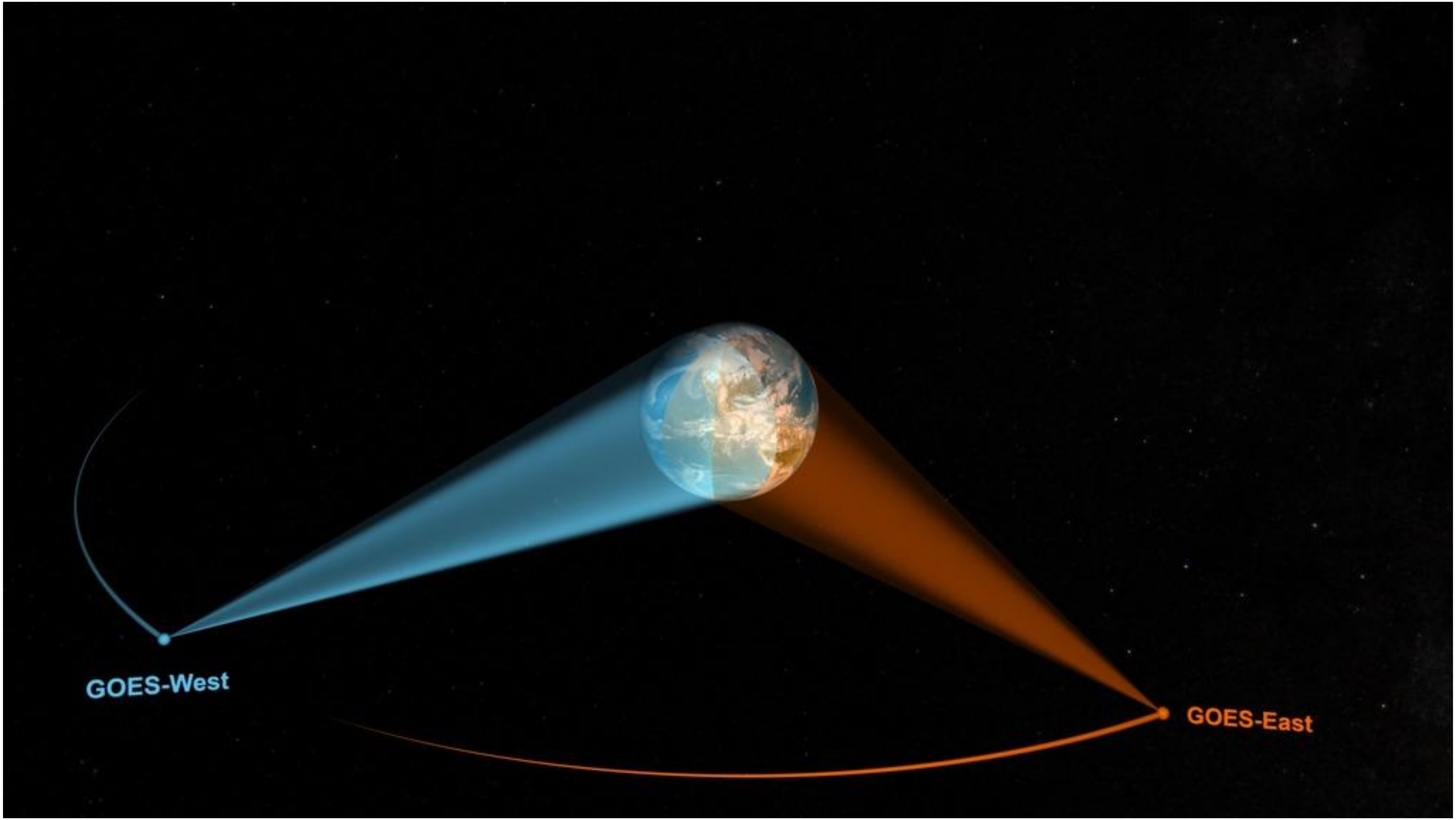

Sentinel-6
Michael Freilich
Aqua
SMAP
ICESat-2
GPM-CORE
'SS-4
GRACE-FO-1
GRACE-FO-2
Suomi NPP
Landsat 8
ISS
CYGNSS-3
PACE
9
CYGNS
CYGNSS-1
TROPICS-06
TROPICS-05
CYGNSS-5
CYGNSS-2
CYGNSS-7
Terra
Jan 15 2025 16:48
NASA

Space/time resolution

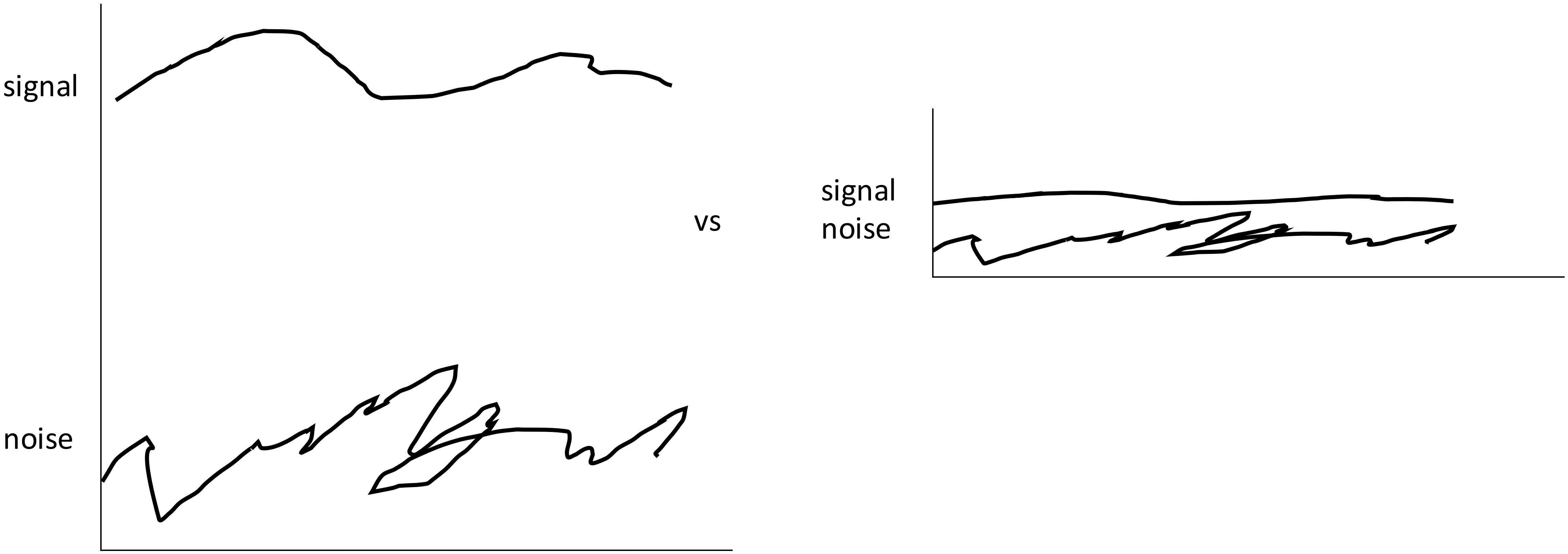


Space/time resolution




GOES-West
GOES-East

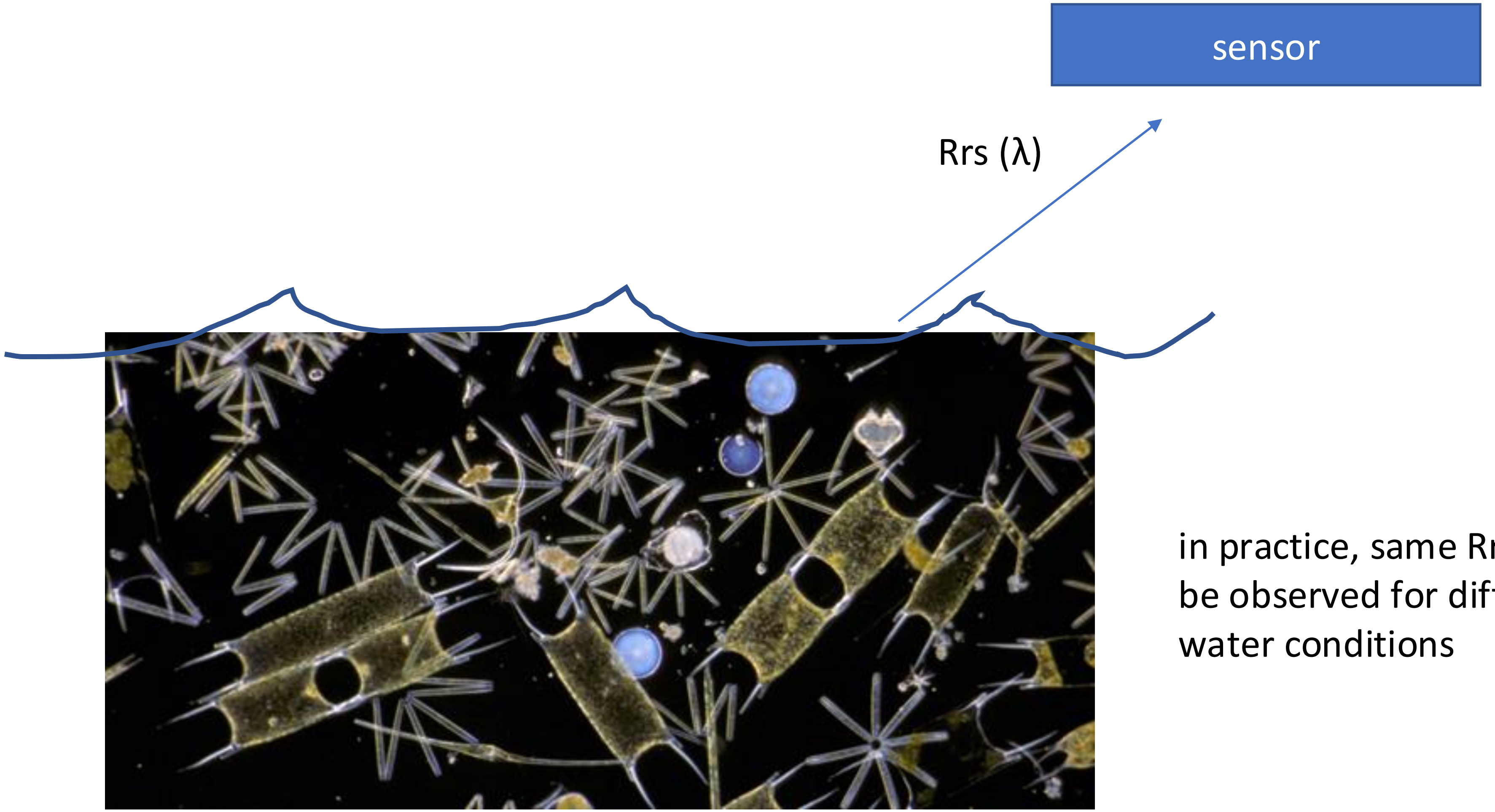
Signal strength relative to noise



What studies are enabled from the left plot compared to right?

Ocean color remote sensing is an INVERSE PROBLEM

Radiometers observed the combined effects of optical constituents, not the constitutes themselves

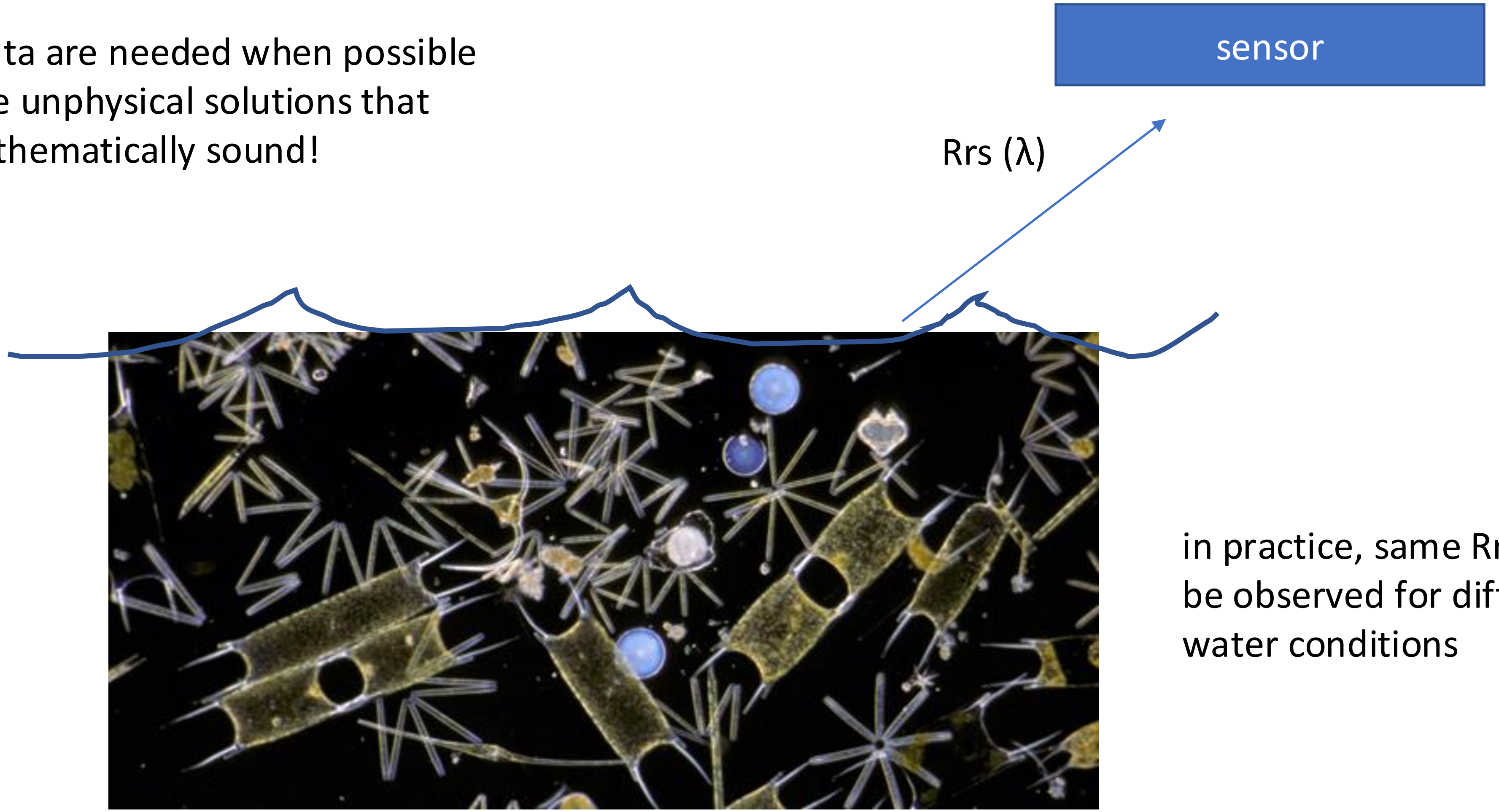


in practice, same Rrs can be observed for different water conditions

Ocean color remote sensing is an INVERSE PROBLEM

Radiometers observed the combined effects of optical constituents, not the constitutes themselves

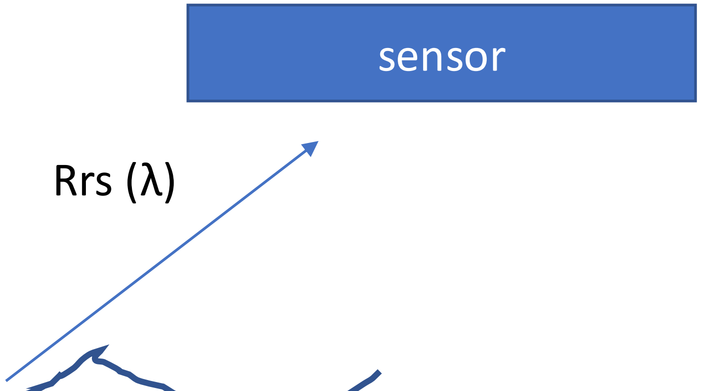
Ancillary data are needed when possible to eliminate unphysical solutions that may be mathematically sound!

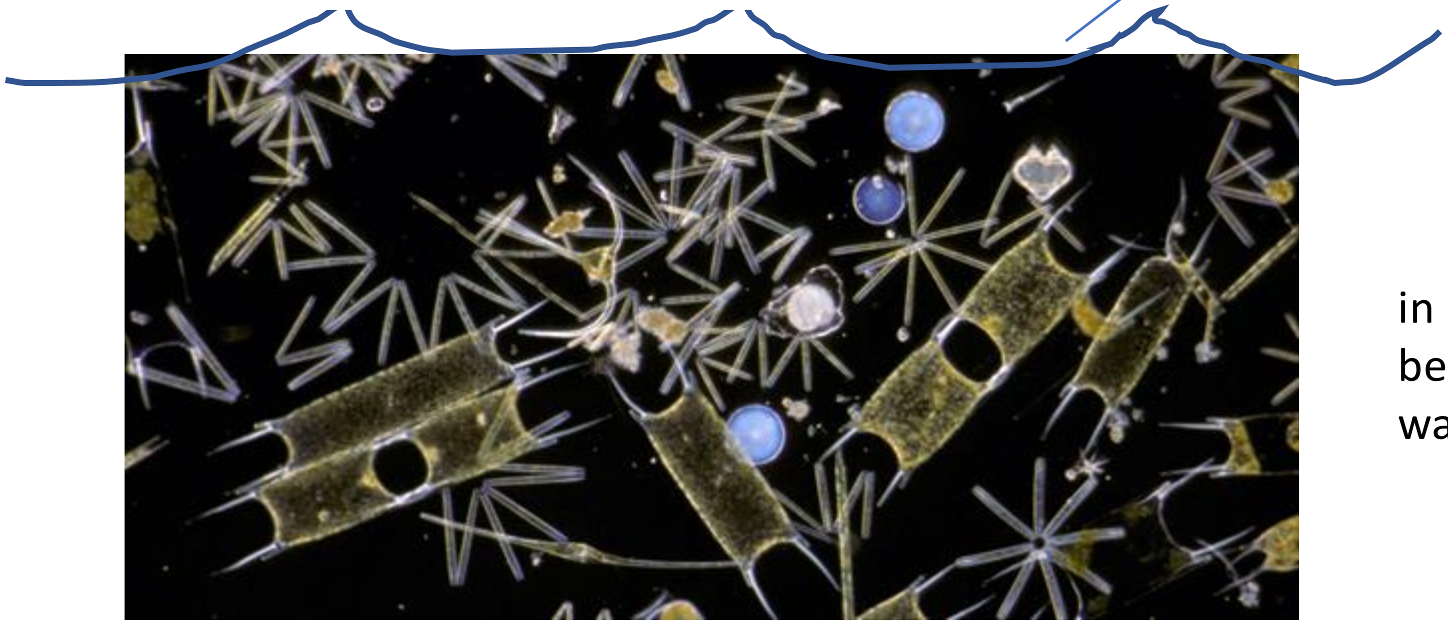


in practice, same Rrs can be observed for different water conditions

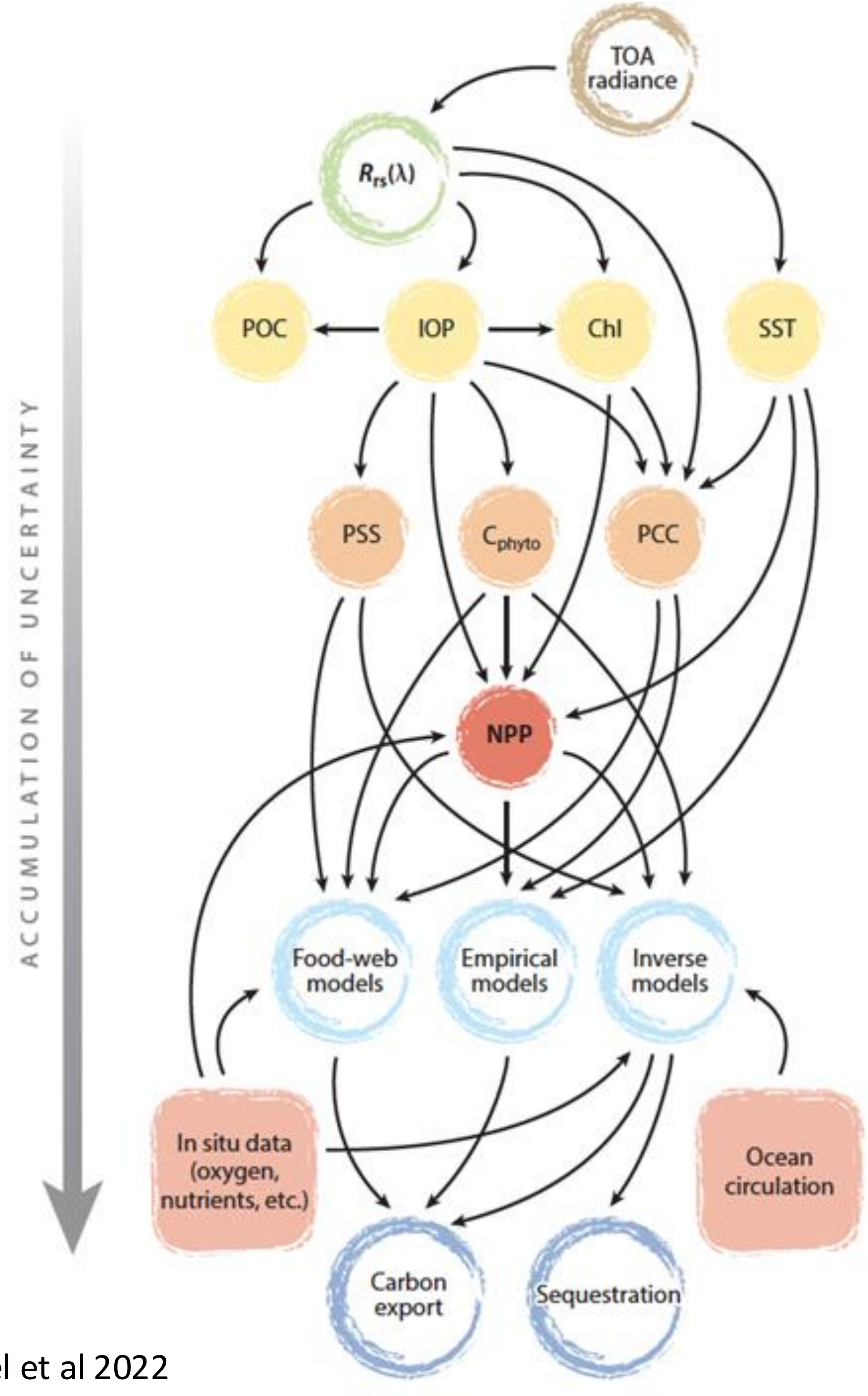
- $r_{rs}(\lambda) = \frac{L_u(\lambda)}{E_d(\lambda)} (sr^{-1})$
  - $= \sum_{i=1}^{2} g_i(\lambda)[u(\lambda)]^i$
  - $u = \frac{b_b(\lambda)}{a(\lambda)+b_b(\lambda)}, \; g_i(sr^{-1})$
  - $g_1 = 0.0949$
  - $g_2 = 0.0794$, generally ignored

$\rightarrow 0.0794 \times \left(\frac{b_b(\lambda)}{a(\lambda)+b_b(\lambda)}\right)^2$





in practice, same Rrs can be observed for different water conditions

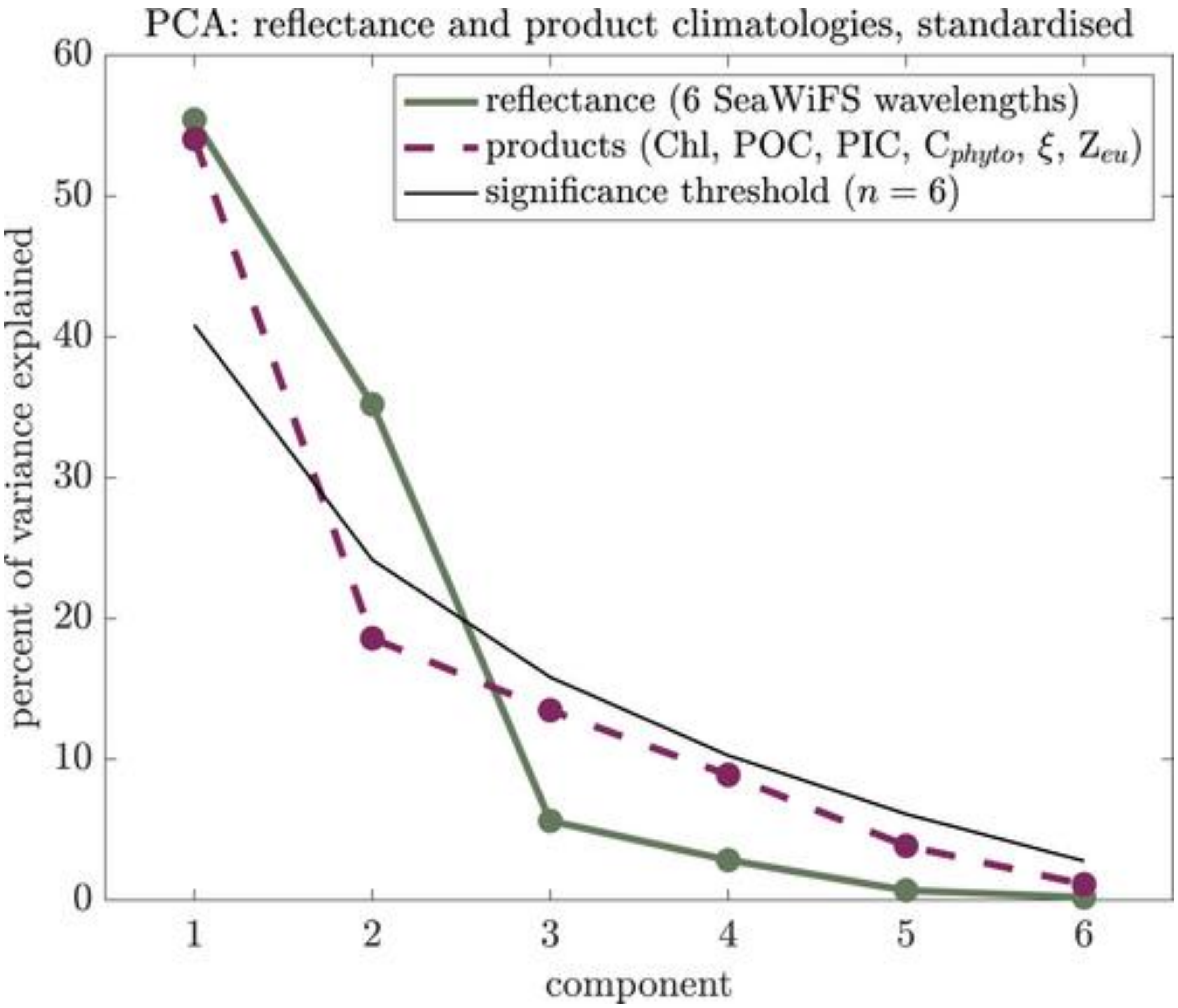


Siegel et al 2022

How independent are RS products?

Many products are retrieved from remote sensing that are used by modelers as independent products

However, these products are highly correlated with each other as they are derived from one central product



Scree plot of percent variance explained vs. component for climatologies of SeaWiFS Rrs(λ) and of six SeaWiFS Rrs(λ)-derived products

Cael et al 2023

Way forward?

Derive a single product such as chlorophyll as a function of all reflectance wavebands, derive an anomaly from chlorophyll-based expectations of a secondary product, then specify all other products explicitly as a function of these two


Europe
Africa
SWOT

Primary Production of the Biosphere: Integrating Terrestrial and Oceanic Components

Christopher B. Field,* Michael J. Behrenfeld, James T. Randerson, Paul Falkowski

Integrating conceptually similar models of the growth of marine and terrestrial primary producers yielded an estimated global net primary production (NPP) of 104.9 petagrams of carbon per year, with roughly equal contributions from land and oceans. Approaches based on satellite indices of absorbed solar radiation indicate marked heterogeneity in NPP for both land and oceans, re¯ecting the in¯uence of physical and ecological processes. The spatial and temporal distributions of ocean NPP are consistent with primary limitation by light, nutrients, and temperature. On land, water limitation imposes additional constraints. On land and ocean, progressive changes in NPP can result in altered carbon storage, although contrasts in mechanisms of carbon storage and rates of organic matter turnover result in a range of relations between carbon storage and changes in NPP.

Biological processes on land and in the oceans strongly affect the global carbon cycle on all time scales (*1–4*). In both components of the biosphere, oxygenic photosynthesis is responsible for virtually all of the biochemical production of organic matter. Mecha-

NPP, originally defined as the amount of photosynthetically fixed carbon available to the first heterotrophic level in an ecosystem (*5*), is also the difference between autotrophic photosynthesis and respiration (*6*). NPP is a major determinant of carbon sinks on land

strongly connected to global-scale observations. For the oceans, APAR can be related to satellite-derived measurements of surface chlorophyll (C_{sat}) (*14*), and for terrestrial systems, it can be determined from satellite-based estimates of vegetation greenness, often the normalized difference vegetation index (NDVI) (*15*). APAR depends on the amount and distribution of photosynthetic biomass (the primary source of variability in C_{sat} and NDVI), as well as the amount of downwelling solar radiation and the fraction that is in the visible (photosynthetically active) wavelengths. ε is an effective photon yield for growth that converts the biomass-dependent variable (APAR) into a flux of organic compounds (NPP). For both terrestrial and oceanic models, ε cannot be directly measured from space and must be parameterized with field measurements.

For marine systems, ε can be parameterized from thousands of ^{14}C-based field measurements of NPP (*16–18*). Terrestrial values are less abundant, largely because ε depends on time-consuming determinations of NPP and APAR (*19*, *20*). Uncertainty in ε is a primary source of error in land and ocean NPP estimates. With few exceptions, ocean NPP models estimate ε solely as a function of sea-surface temperature (*11*, *16*, *21–23*). In terrestrial ecosystems, ε varies with ecosystem type and with stresses from unfavorable levels of temperature, nutrients, and water (*20*, *24*, *25*).

Primary Production of the Biosphere: Integrating Terrestrial and Oceanic Components

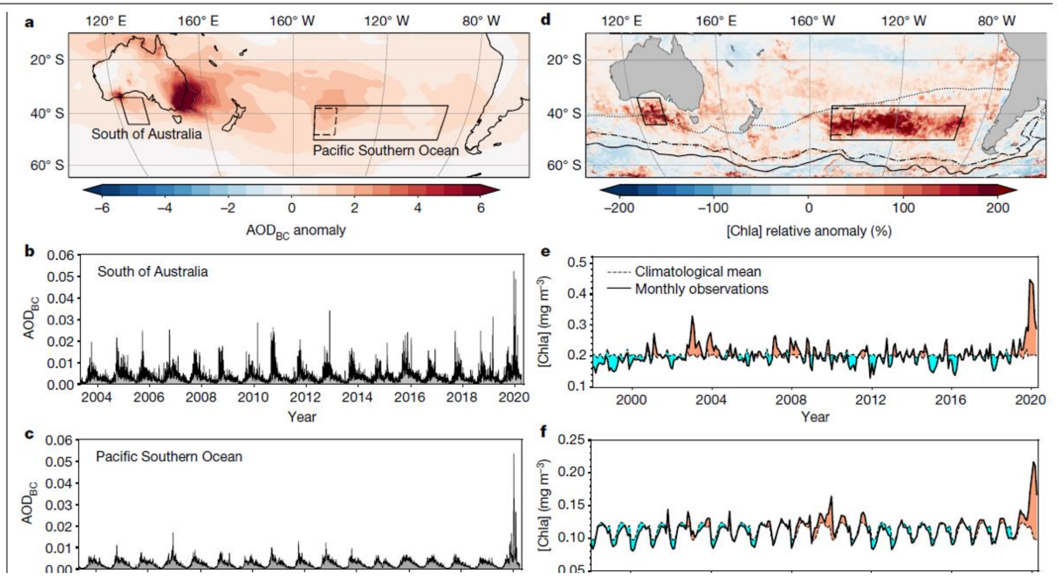
Christopher B. Field,* Michael J. Behrenfeld, James T. Randerson, Paul Falkowski

Integrating conceptually similar models of the growth of marine and terrestrial primary producers yielded an estimated global net primary production (NPP) of 104.9 petagrams of carbon per year, with roughly equal contribution land and oceans. Approaches based on satellite indices of absorbed so diation indicate marked heterogeneity in NPP for both land and ocea ˉecting the inˉuence of physical and ecological processes. The spati temporal distributions of ocean NPP are consistent with primary limitat light, nutrients, and temperature. On land, water limitation imposes add constraints. On land and ocean, progressive changes in NPP can result in a carbon storage, although contrasts in mechanisms of carbon storage an of organic matter turnover result in a range of relations between carbon s and changes in NPP.

Biological processes on land and in the oceans strongly affect the global carbon cycle on all time scales (*1–4*). In both components of the biosphere, oxygenic photosynthesis is responsible for virtually all of the biochemical production of organic matter. Mecha-

NPP, originally defined as th photosynthetically fixed carbor the first heterotrophic level in (*5*), is also the difference betwe photosynthesis and respiration major determinant of carbon s

strongly connected to global-scale o tions. For the oceans, APAR can be rel satellite-derived measurements of surfac rophyll (C_{sat}) (*14*), and for terrestrial sys can be determined from satellite-base mates of vegetation greenness, often tl malized difference vegetation index ((*15*). APAR depends on the amount anc bution of photosynthetic biomass (the p source of variability in C_{sat} and NDVI), as the amount of downwelling solar ra and the fraction that is in the visible (ph thetically active) wavelengths. ε is an e photon yield for growth that converts t mass-dependent variable (APAR) into a



Article

Widespread phytoplankton blooms triggered by 2019–2020 Australian wildfires

https://doi.org/10.1038/s41586-021-03805-8

Received: 25 August 2020

Accepted: 5 July 2021

Published online: 15 September 2021

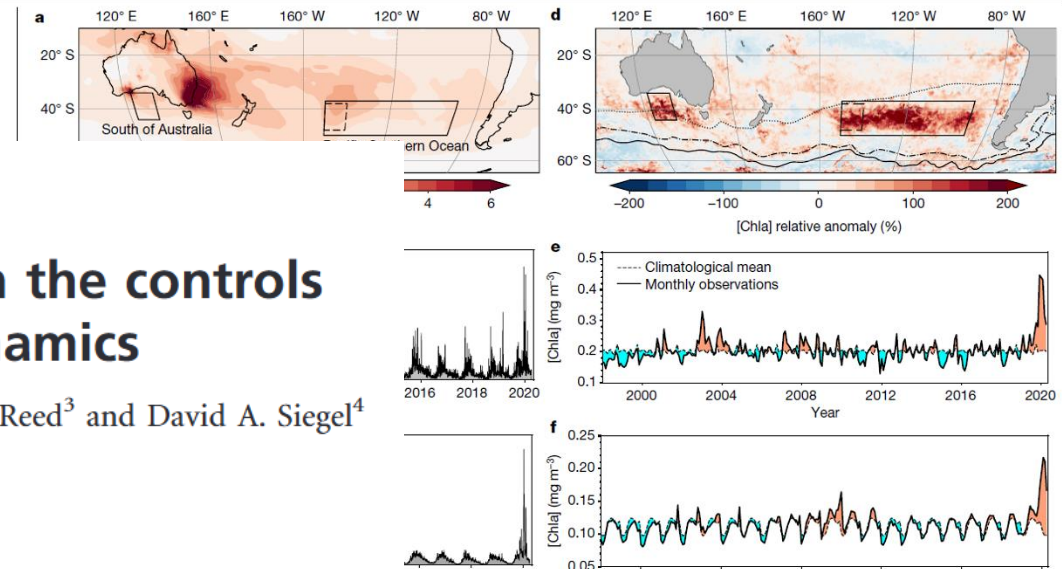
Check for updates

Weiyi Tang[1,11,12], Joan Llort[2,3,12], Jakob Weis[2,4], Morgane M. G. Perron[2], Sara Basart[3], Zuchuan Li[1,5], Shubha Sathyendranath[6], Thomas Jackson[6], Estrella Sanz Rodriguez[7], Bernadette C. Proemse[2], Andrew R. Bowie[2,8], Christina Schallenberg[2,8], Peter G. Strutton[2,4], Richard Matear[9] ✉ & Nicolas Cassar[1,10] ✉

Droughts and climate-change-driven warming are leading to more frequent and intense wildfires[1–3], arguably contributing to the severe 2019–2020 Australian wildfires[4]. The environmental and ecological impacts of the fires include loss of habitats and the emission of substantial amounts of atmospheric aerosols[5–7]. Aerosol emissions from wildfires can lead to the atmospheric transport of macronutrients and bio-essential trace metals such as nitrogen and iron, respectively[8–10]. It has been

REPORTS

strongly connected to global-scale o



Journal of Biogeography (*J. Biogeogr.*) (2015) **42**, 2010–2021

ORIGINAL ARTICLE

Geographical variability in the controls of giant kelp biomass dynamics

Tom W. Bell[1]*, Kyle C. Cavanaugh[2], Daniel C. Reed[3] and David A. Siegel[4]

[1]*Earth Research Institute, University of California, Santa Barbara, Santa Barbara, CA 93106-3060, USA,* [2]*Department of Geography, University of California, Los Angeles, Los Angeles, CA 90095, USA,* [3]*Marine Science Institute, University of California, Santa Barbara, Santa Barbara, CA 93106-3060, USA,* [4]*Earth Research Institute and Department of Geography,*

ABSTRACT

Aim Coastal marine environments experience a wide range of biotic and abiotic forces that can limit and punctuate the geographical range and abundance of species through time. Determining the relative strengths and nonlinear effects of these processes is vital to understanding the biogeographical structures of species. There has been an ongoing discussion concerning the relative importance of these processes in controlling the dynamics of giant kelp, *Macrocystis pyrifera*, an important structure-forming species on shallow reefs in the eastern Pacific. We used novel spatial time-series that span nearly three

ton blooms Australian wildfires

Jakob Weis[2,4], Morgane M. G. Perron[2], Sara Basart[3], ndranath[6], Thomas Jackson[6], Estrella Sanz Rodriguez[7], rew R. Bowie[2,8], Christina Schallenberg[2,8], Peter G. Strutton[2,4], Richard Matear[9] & Nicolas Cassar[1,10]

Accepted: 5 July 2021

Published online: 15 September 2021

Check for updates

Droughts and climate-change-driven warming are leading to more frequent and intense wildfires[1–3], arguably contributing to the severe 2019–2020 Australian wildfires[4]. The environmental and ecological impacts of the fires include loss of habitats and the emission of substantial amounts of atmospheric aerosols[5–7]. Aerosol emissions from wildfires can lead to the atmospheric transport of macronutrients and bio-essential trace metals such as nitrogen and iron, respectively[8–10]. It has been

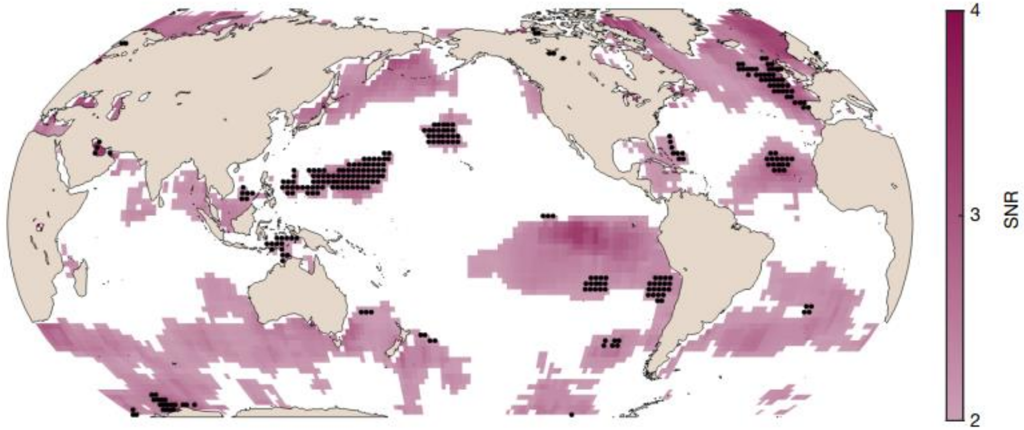
Article

Global climate-change trends detected in indicators of ocean ecology

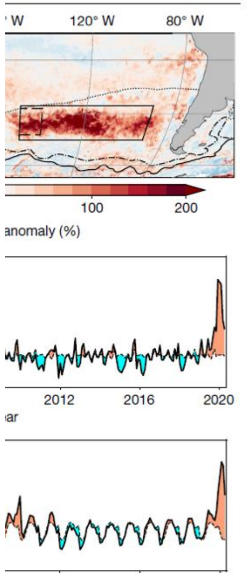
https://doi.org/10.1038/s41586-023-06321-z
Received: 4 January 2023
Accepted: 14 June 2023
Published online: 12 July 2023
Open access
Check for updates

B. B. Cael[1]✉, Kelsey Bisson[2], Emmanuel Boss[3], Stephanie Dutkiewicz[4] & Stephanie Henson[1]

Article



observed trends indicate shifts in ocean colour—and, by extension, in surface-ocean



ildfires

, Sara Basart[3],
Sanz Rodriguez[7],
g[2,8], Peter G. Strutton[2,4],

Check for updates

Droughts and climate-change-driven warming are leading to more frequent and intense wildfires[1–3], arguably contributing to the severe 2019–2020 Australian wildfires[4]. The environmental and ecological impacts of the fires include loss of habitats and the emission of substantial amounts of atmospheric aerosols[5–7]. Aerosol emissions from wildfires can lead to the atmospheric transport of macronutrients and bio-essential trace metals such as nitrogen and iron, respectively[8–10]. It has been

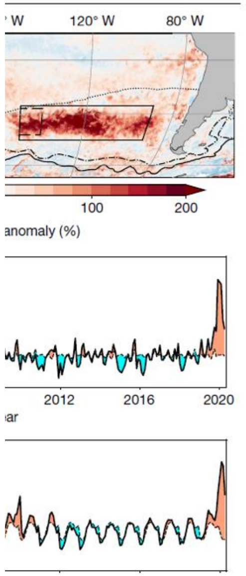
Remote Sensing of Environment
Volume 259, 15 June 2021, 112414

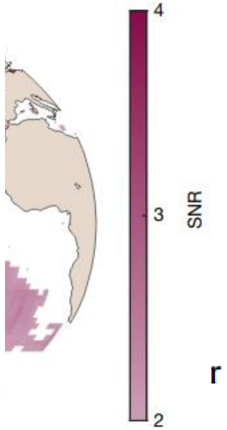
Remote detection of marine debris using satellite observations in the visible and near infrared spectral range: Challenges and potentials

Chuanmin Hu

in

hanie Henson[1]





vildfires

, Sara Basart[3],
Sanz Rodriguez[7],
rg[2,8], Peter G. Strutton[2,4],

urface-ocean

rming are leading to more frequent and intense wildfires[1–3], arguably contributing to the severe 2019–2020 Australian wildfires[4]. The environmental and ecological impacts of the fires include loss of habitats and the emission of substantial amounts of atmospheric aerosols[5–7]. Aerosol emissions from wildfires can lead to the atmospheric transport of macronutrients and bio-essential trace metals such as nitrogen and iron, respectively[8–10]. It has been

ELSEVIER

R

Remote (
using sa
visible a
range: C

Chuanmin Hu

frontiers | Frontiers in Marine Science

TYPE Original Research
PUBLISHED 05 March 2025
DOI 10.3389/fmars.2025.1507638

Check for updates

OPEN ACCESS

EDITED BY
Cédric Jamet,
UMR8187 Laboratoire d'Océanologie et de Géosciences (LOG), France

REVIEWED BY
Robert J. Frouin,
University of California, San Diego, United States
Agnieszka Bialek,
National Physical Laboratory, United Kingdom

*CORRESPONDENCE
Catherine Mitchell
cmitchell@bigelow.org

RECEIVED 08 October 2024
ACCEPTED 12 February 2025
PUBLISHED 05 March 2025

Ocean color anomaly detection to estimate surface *Calanus finmarchicus* concentration in the Gulf of Maine

Rebekah Shunmugapandi[1], Cait L. McCarry[1], David McKee[2,3] and Catherine Mitchell[1]*

[1]Bigelow Laboratory for Ocean Sciences, East Boothbay, ME, United States, [2]University of Strathclyde, Glasgow, United Kingdom, [3]University of the Arctic in Tromsø, Tromsø, Norway

The planktonic copepod, *Calanus finmarchicus*, plays a pivotal role in the Gulf of Maine (GoM) pelagic food web as a primary food source for many species,

intense wildfires, arguably contributing to the severe 2019–2020 Australian wildfires[4]. The environmental and ecological impacts of the fires include loss of habitats and the emission of substantial amounts of atmospheric aerosols[5–7]. Aerosol emissions from wildfires can lead to the atmospheric transport of macronutrients and bio-essential trace metals such as nitrogen and iron, respectively[8–10]. It has been

frontiers | Frontiers in Marine Science

TYPE Original Research
PUBLISHED 05 March 2025
DOI 10.3389/fmars.2025.1507638

J R

ELSEVIER

Remote Sensing of Environment

Volume 112, Issue 3, 18 March 2008, Pages 836-844

On the use of ocean color remote sensing to measure the transport of dissolved organic carbon by the Mississippi River Plume

Carlos E. Del Castillo [a], Richard L. Miller [b]

Show more

' anomaly detection
surface *Calanus*
s concentration in
Maine

ıdi[1], Cait L. McCarry[1], David McKee[2,3]
1*

ces, East Boothbay, ME, United States, [2]University of Strathclyde,
y of the Arctic in Tromsø, Tromsø, Norway

anus finmarchicus, plays a pivotal role in the Gulf of
web as a primary food source for many species,

ıbly contributing to the severe 2019–2020 Australian
ental and ecological impacts of the fires include loss of
ı of substantial amounts of atmospheric aerosols[5–7]. Aerosol
can lead to the atmospheric transport of macronutrients and
bio-essential trace metals such as nitrogen and iron, respectively[8–10]. It has been

LIMNOLOGY AND OCEANOGRAPHY

ASLO
Association for the Sciences of Limnology and Oceanography

Article | Free Access

Ocean color remote sensing of seagrass and bathymetry in the Bahamas Banks by high-resolution airborne imagery

Heidi M. Dierssen, Richard C. Zimmerman, Robert A. Leathers, T. Valerie Downes, Curtiss O. Davis

First published: 21 January 2003 | https://doi.org/10.4319/lo.2003.48.1_part_2.0444 | Citations: 213

ELSEVIER

On the
sensin
dissol
Missis

Carlos E. Del (

Show more

38

yde,

lf of
cies,

rosol
can lead to the atmospheric transport of macronutrients and
bio-essential trace metals such as nitrogen and iron, respectively[8–10]. It has been

LIMNOLOGY AND OCEANOGRAPHY
ASLO
Association for the Sciences of Limnology and Oceanography

Article | Free Access

Ocean color remote sensing of seagrass and bathymetry in the Bahamas Banks by high-resolution airborne imagery

Heidi M. Dierssen, Richard C. Zimmerman, Robert A. Leathers, T. Valerie Downes, Curtiss O. Davis

First published: 21 January 2003 |
https://doi.org/10.4319/lo.2003.48.1_part_2.0444 | Citations: 213

ELSEVIER

On the
sensin
dissol
Missis

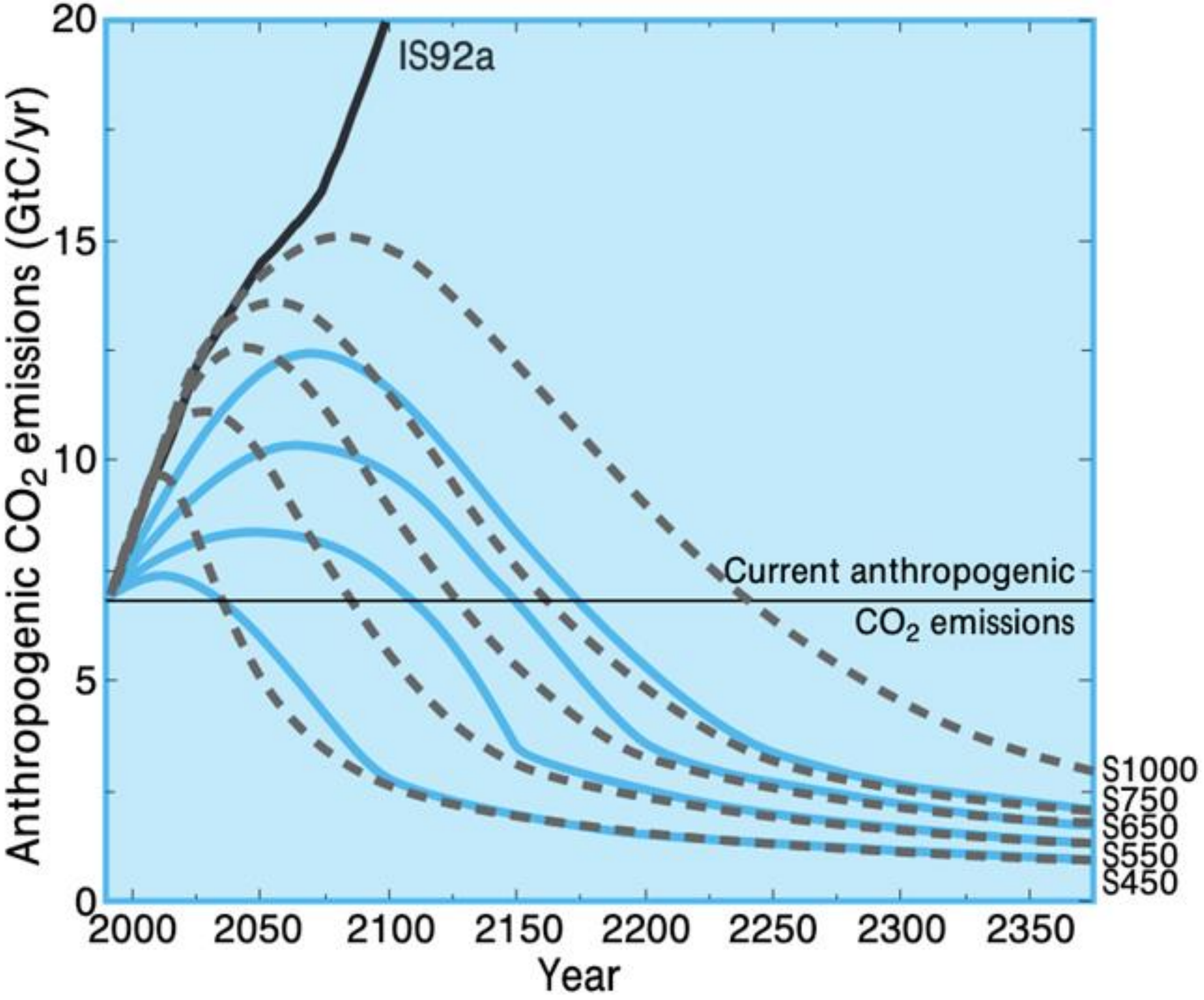
Carlos E. Del

Show more

n lead to the atmospheric transport of macronutrients and
such as nitrogen and iron, respectively[8–10]. It has been

[your paper here]

Significance for future PIs



Missions and analyses we design now will be measuring peak periods of CO2 and unprecedented temperature changes

We may be close to tipping points

(from Dave Schimel, With appreciation to Lovenduski and Bonan)

National Aeronautics and Space Administration

www.nasa.gov