International Ocean Colour Science Meeting 2025

Advancing Global Ocean Colour Observations

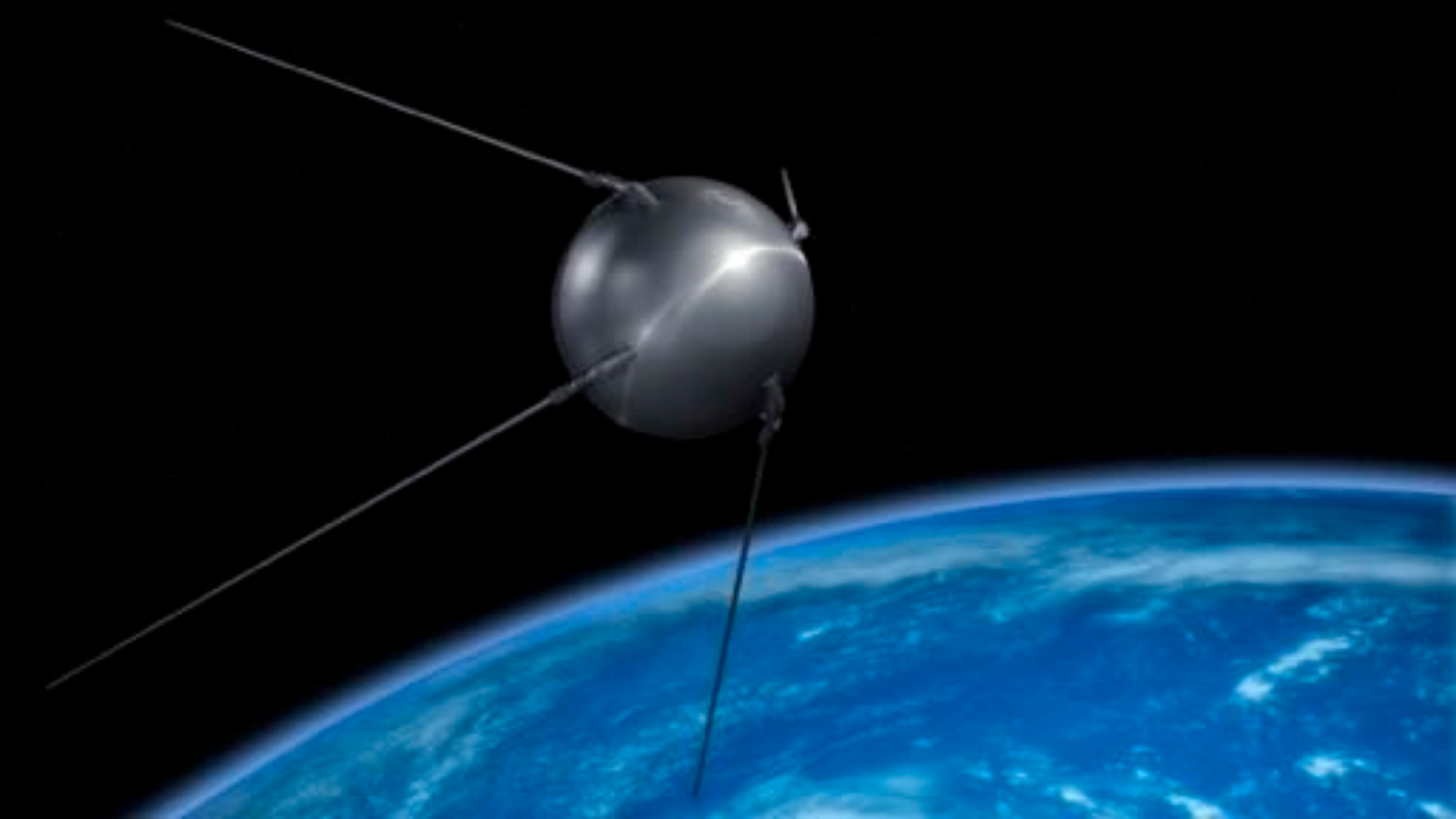
The Art of the Possible

Dr. Paula S. Bontempi

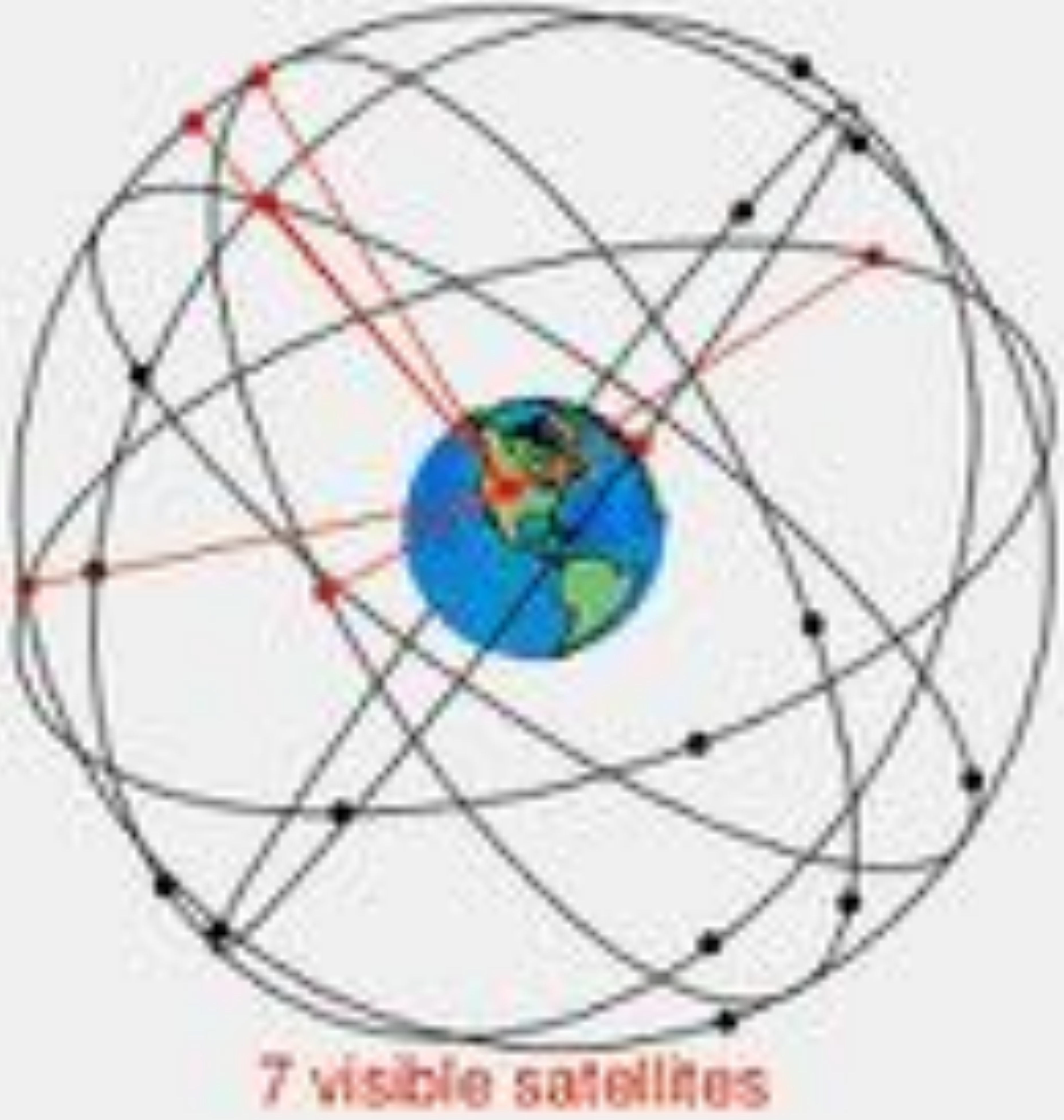
University of Rhode Island – Graduate School of Oceanography, USA

Darmstadt, Germany

1 December 2025

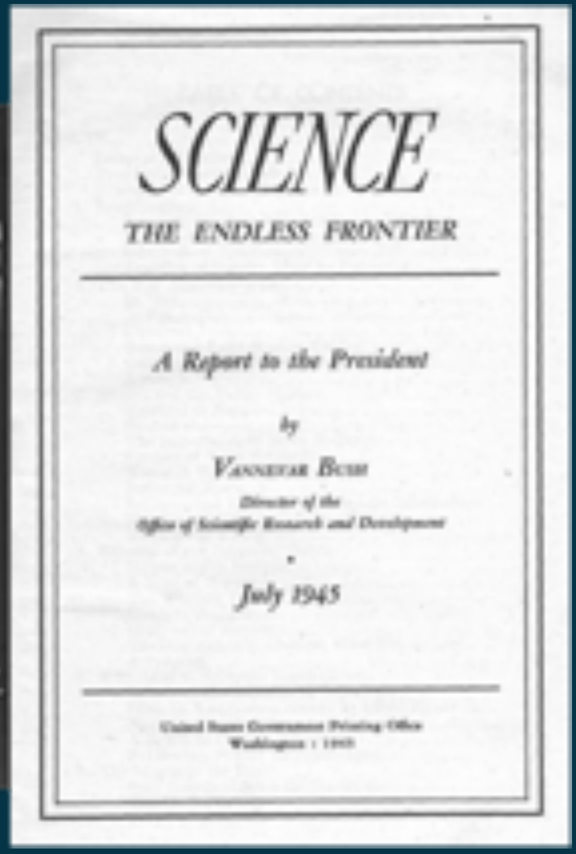


NAVSTAR GPS



Why Invest In Science?

- Vannevar Bush (1945) – Science, The Endless Frontier
  - Fuller & fruitful employment and life (FDR, 1944)
  - Scientific progress essential (disease to national security) a
  - Freedom of Inquiry – discovery – teach each other to inquire
    Language Models)
  - Renew scientific talent - higher education for all



SCIENCE

THE ENDLESS FRONTIER

A Report to the President

by

Vannevar Bush

Director of the
Office of Scientific Research and Development

July 1945

- Chairman Mao (1949) – the power of the ocean for national security and marine resources
  - Ocean development and management - key strategy for building a prosperous and powerful country (Long, 2025)
  - Three stages
    - Over-coming challenges and building the foundation (1949 to 1978)
    - Rapid development and heading towards the deep blue (1979 to 2000)
    - Innovating and striding towards the forefront (2001 to 2020)

Challenges yet Opportunities

- Cost: Infrastructure (in situ instruments, ships, satellites) is too expensive

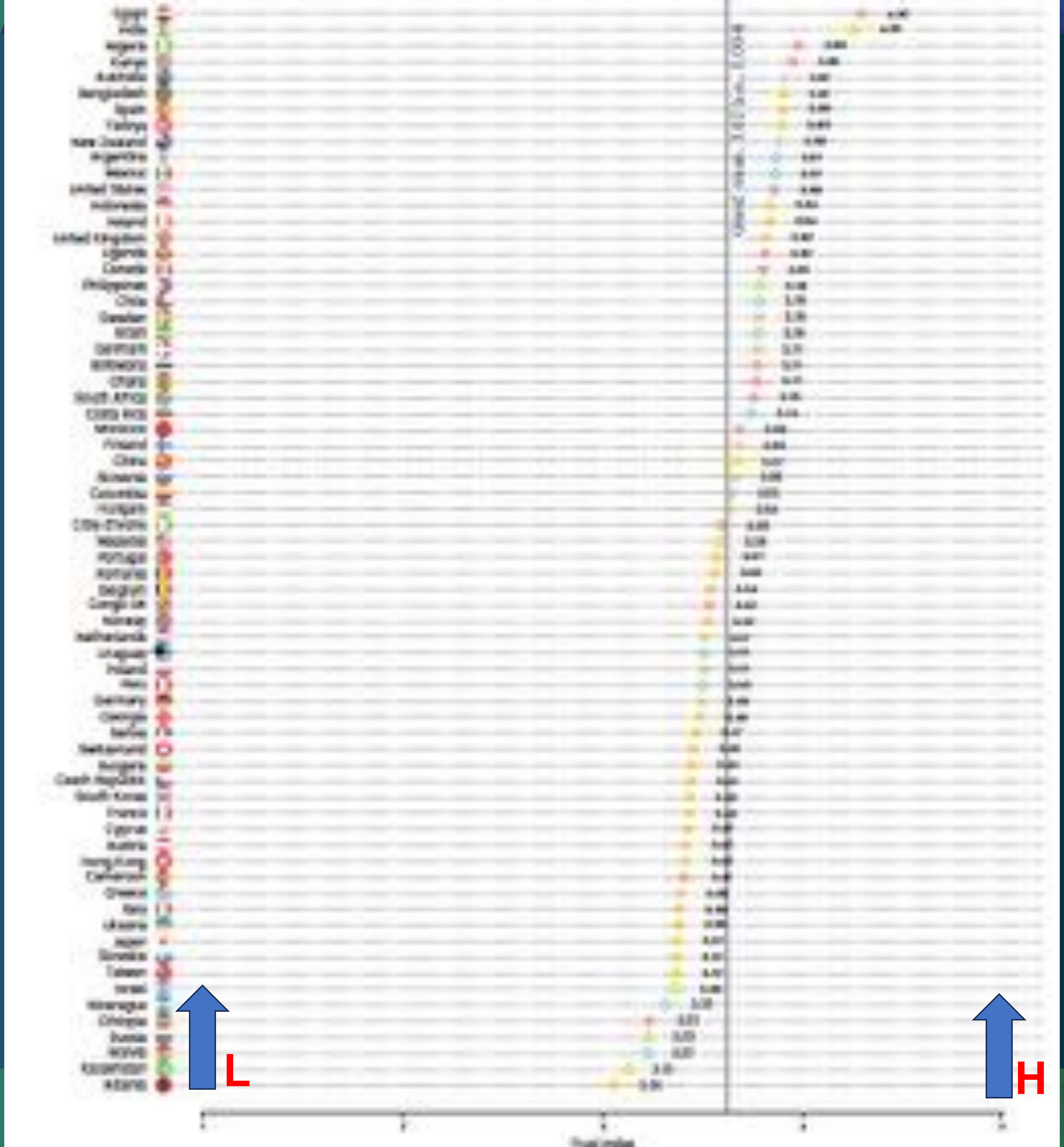
Gross global domestic expenditures on R&D in 2023?

US $3T

Challenges yet Opportunities

- Cost: Infrastructure (in situ instruments, ships, satellites) is too expensive
- Time: to brainstorm ideas and discuss partnerships
- Geography: Understanding the global ocean is a must, but lakes, inland, and coastal waters a challenge
- Technology: Passive radiometry (hyperspectral) continues the time series; active and dual/multi-use sensors/missions hold promise, but many are not ocean-focused
- Partnerships: the Committee on Earth Observing Satellites (CEOS) and Virtual Constellation premise – a modular approach
- Trust: geopolitical and public - scientific challenges cross national boundaries; science is a public trust, but does the public trust science and scientists?

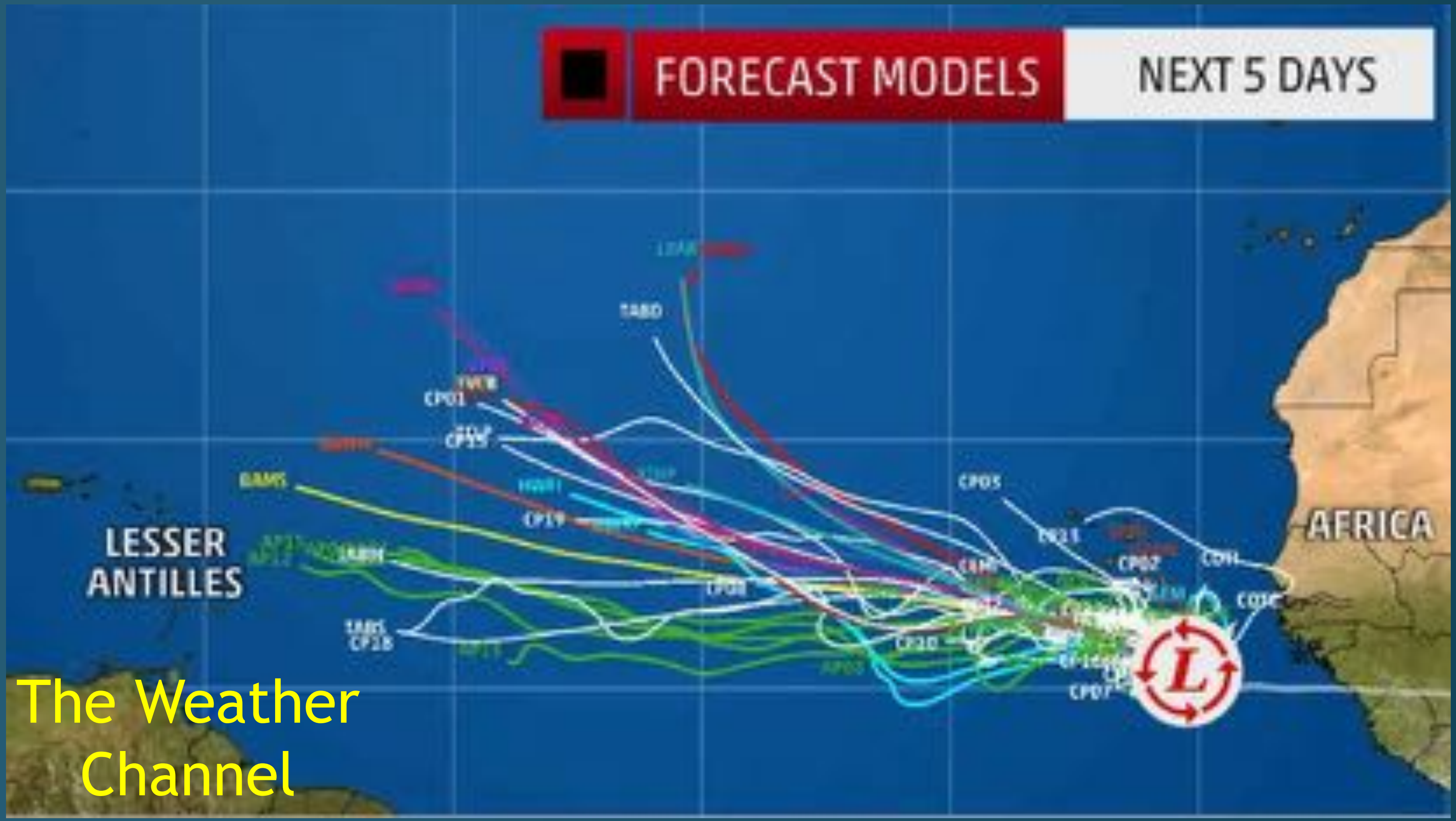
Trust in Science – 68 countries weighted mean scale 1 to 5, low to high



People trust science – BUT – does the public trust scientists / institutions?
How do we know what information the public would like?

(Cologna et al, 2025)

Weather Forecasting



What is the value of science to the public?

Love your iPhone? Don’t thank Apple. Thank the government.

Siri? Straight out of DARPA

GPS? Navstar

Semiconductors and Microchips? NASA and DOD

So many aspects including the touchscreen? NSF

Components? Built all over the world

Apple generated $390.8 billion revenue in 2024, 51% from iPhone sales - 232 million iPhones, 52 million iPads, and 22 million Mac and MacBook units

$209.59 billion in iPhone revenue during its fiscal year 2025, which ended on September 27, 2025

1999/2002 - NASA’s Terra and Aqua ~$3B (active in 2025)

2014 – ESA estimate to build 7 Sentinel satellites and launch 3 - €2.5B (still on orbit)

2024 - NASA’s PACE mission ~ US$998M (3 yr prime life, fuel for 10 yrs)

Average amount of time people keep smartphones?
2 yrs 5 months

What is the value of the ocean to the public?

- Ocean economy ~US$24T - 7th largest economy globally (UN/World Wildlife Fund/World Bank)
- Generates ~US$2.5 trillion in blue sector revenue annually (e.g., fisheries, tourism, shipping)
- Marine/coastal resources + associated industries valued at 3-5% global GDP (Patil et al. 2016)
- Partnerships: consider well-being of communities, ecosystems, business will revolutionize how sectors work together sustainably. Sharing ideas/solutions/roadmaps for sustainable practices ensures least developed countries have resources
- Valuing the ocean's assets is vitally important to helping inform effective decision-making
- An international platform is needed to support and share ocean knowledge - interdisciplinary and blend natural science, social and economic data

Global challenges require global solutions and bring opportunities and economic prosperity

A Tale of Fisheries

Ocean and coastal resources are integral to sustaining life on Earth

DELAYED ACTION THREATENS OUR PLANET

OBSERVATIONS WILL ADDRESS THESE CHALLENGES AND BRING ECONOMIC PROSPERITY

Imagine if we were able to produce a 4D ecological resource assessment?

Public Needs + Scientific Grand Challenges: A Sample

NASA Ocean Biology and Biogeochemistry Program (2023)

- Global biosphere
- Climate and the Elements of Life
- Interface Habitats
- Transient Events

Japan – Basic Plan for Space Policy (2013, 2023)

- Maritime domain awareness/monitoring
- Integration of ocean science & ocean policy
- Resource exploration and development, sustainability
- Disaster management, environmental and climate monitoring, safety
- Human spaceflight

United Nations Sustainable Development Goals

2 – Food	6 – Clean Water and Sanitation
3 - Health	14 – Life Below Water

ESA Earth Observation Science Strategy (2024)

- Enhanced understanding of the Earth and its environment
- Economic Growth, Innovation and Prosperity
- Security
- Risk Mitigation and Preparedness
- Prestige
- Inspiration and Education

European Commission Ocean Pact (2025)

- Integrated ocean health/sustainability
- Competitiveness/Sustainable Blue Economy
- Protect/empower coastal/island communities
- Ocean research/literacy/skills for blue innovation
- Maritime security and defense
- International governance/diplomacy

Public Needs + Scientific Grand Challenges: A Summary

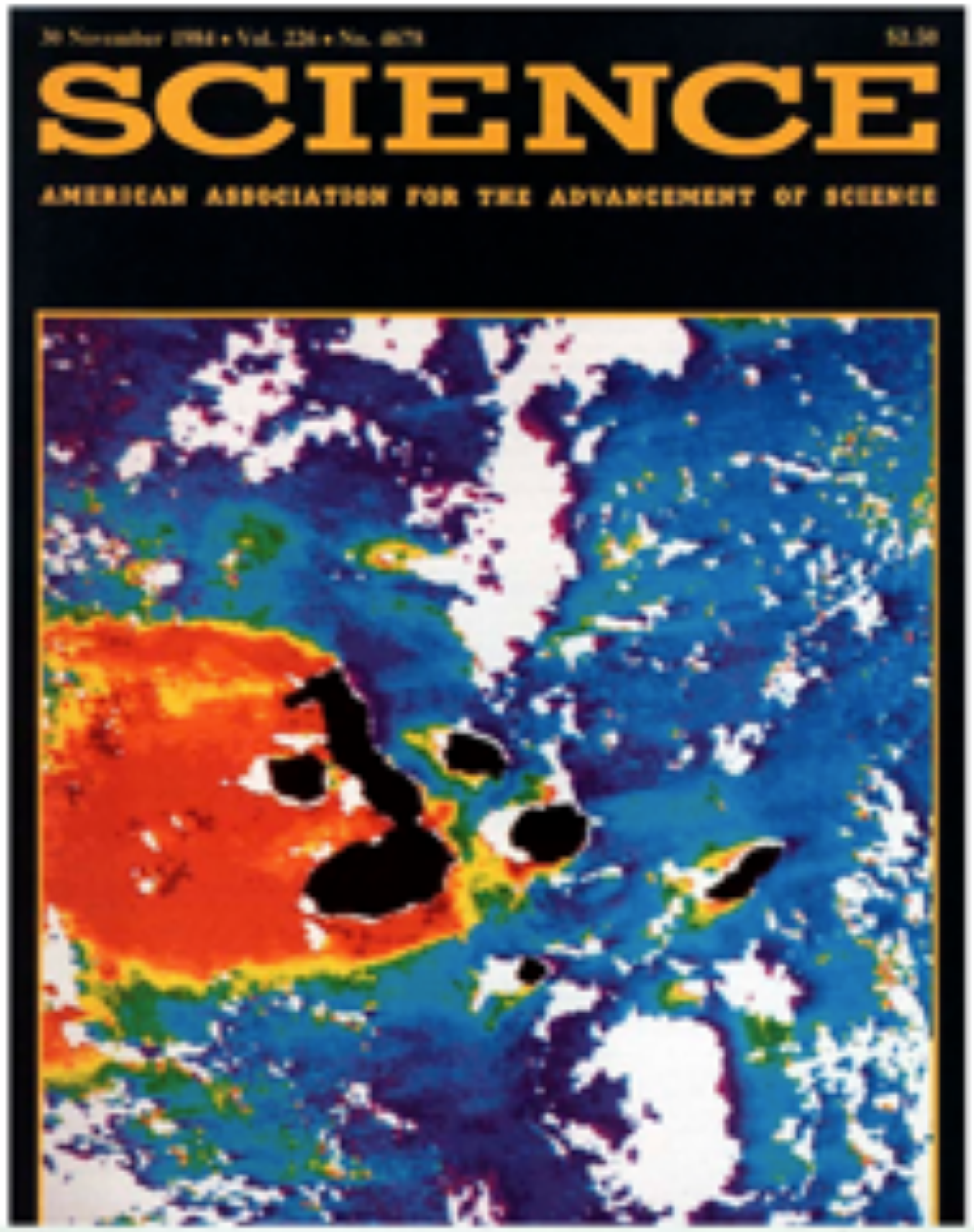
Planetary Protection and Health

- Protect Earth, Climate, People, Resources, Employment
- Exploration and Discovery
- National Leadership, Autonomy, Resilience
- Economic Growth and Competitiveness
- Inspire the Next Generation of Explorers/Scientists and Public

Earth System Science

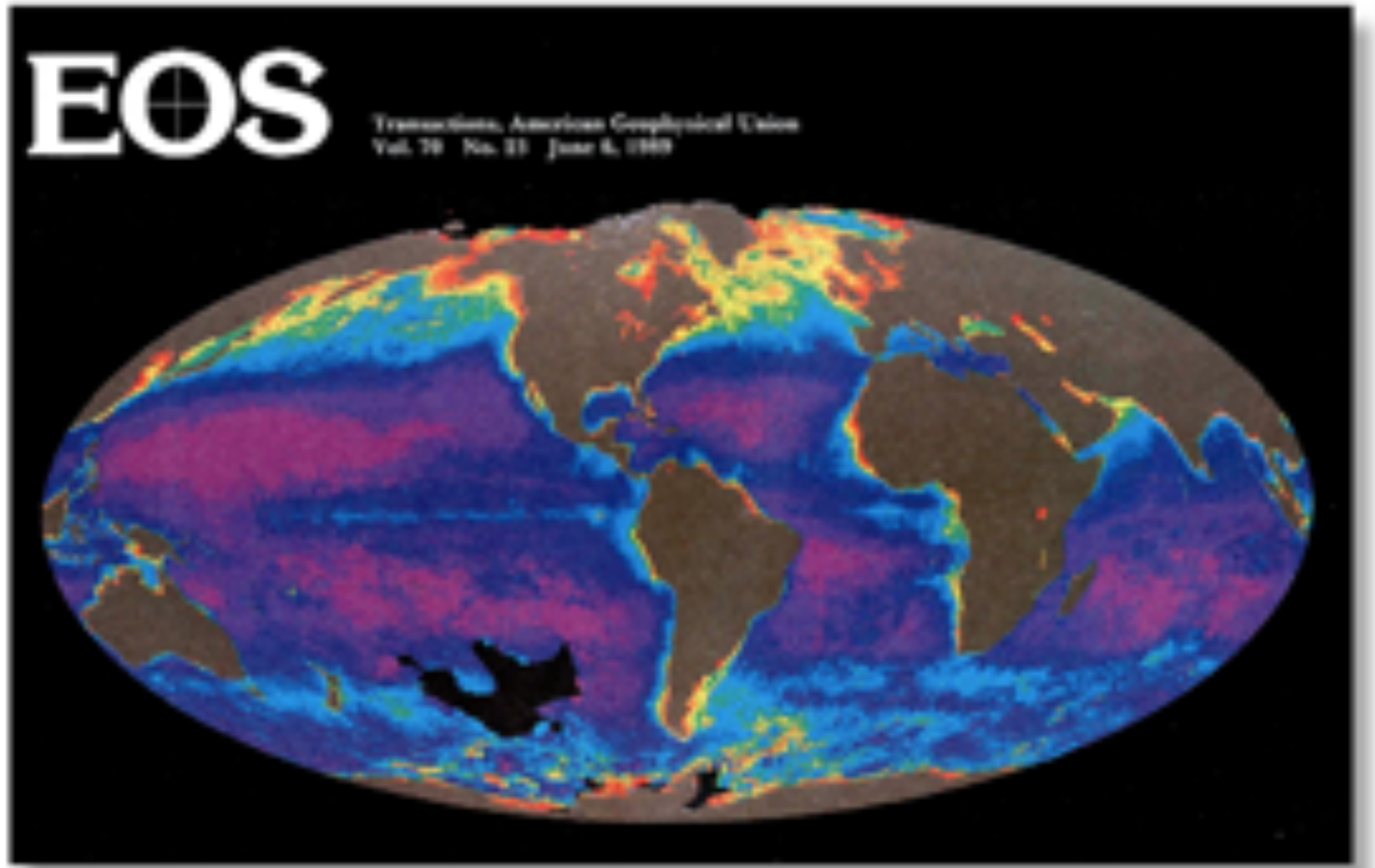
- Climate and environmental variability and change
- Global marine ecosystem health, food security, water quality (HABs, contaminants, plastics, drinking water)
- Biogeochemical cycling/carbon cycle science
- Circulation, currents, and ocean dynamics
- Maritime safety and security
- Disasters and event scale phenomena (storms, oil spills)
- Blue economic sector prosperity (maritime trades)
- Coastal ocean, lakes, inland waters + coastal resilience
- Global resource management/sustainability and policy
- Dynamic Interfaces (ocean/ice, ocean/atm, land/ocean, etc.)

revolutionized perceptions of the ocean

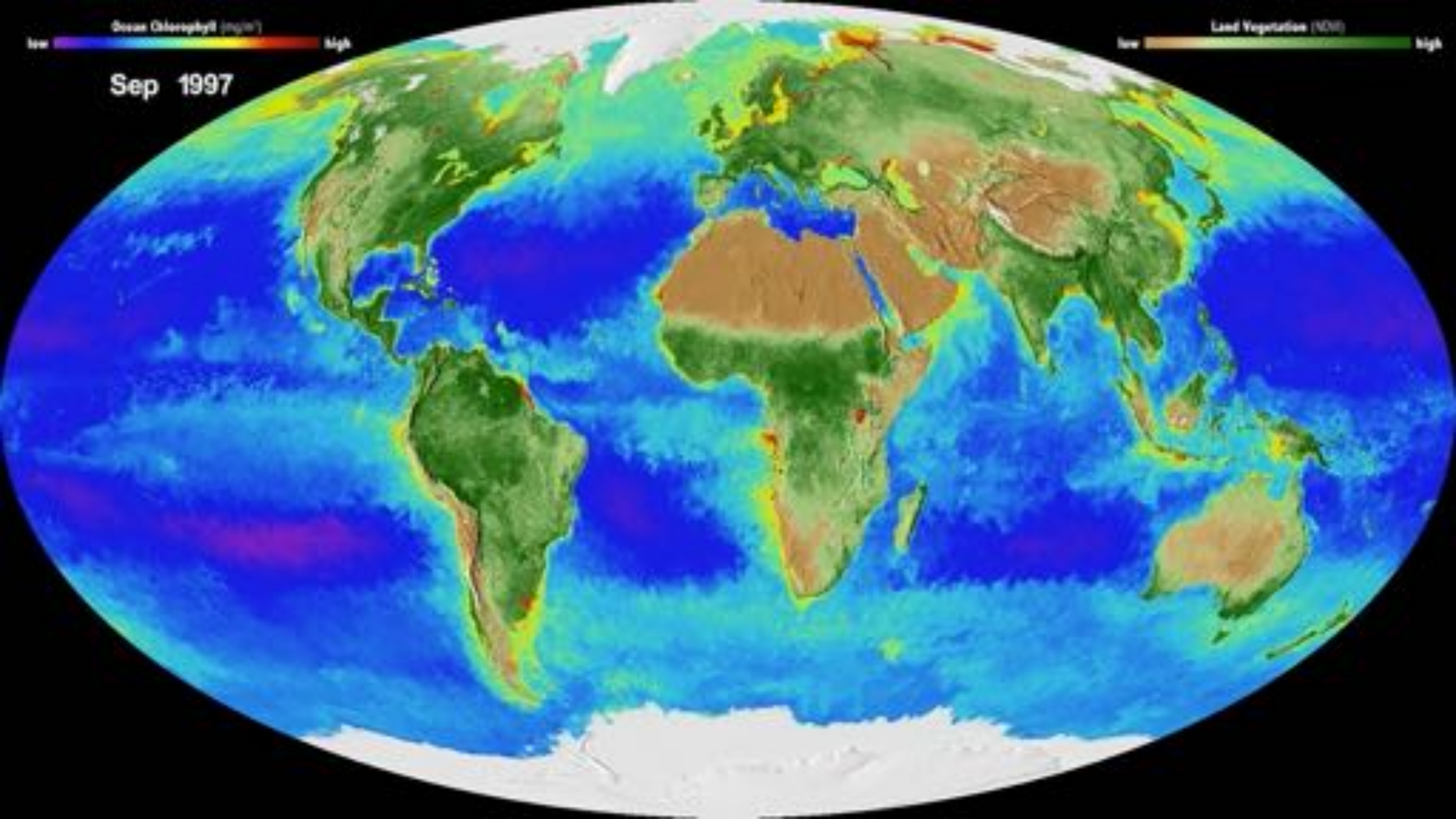


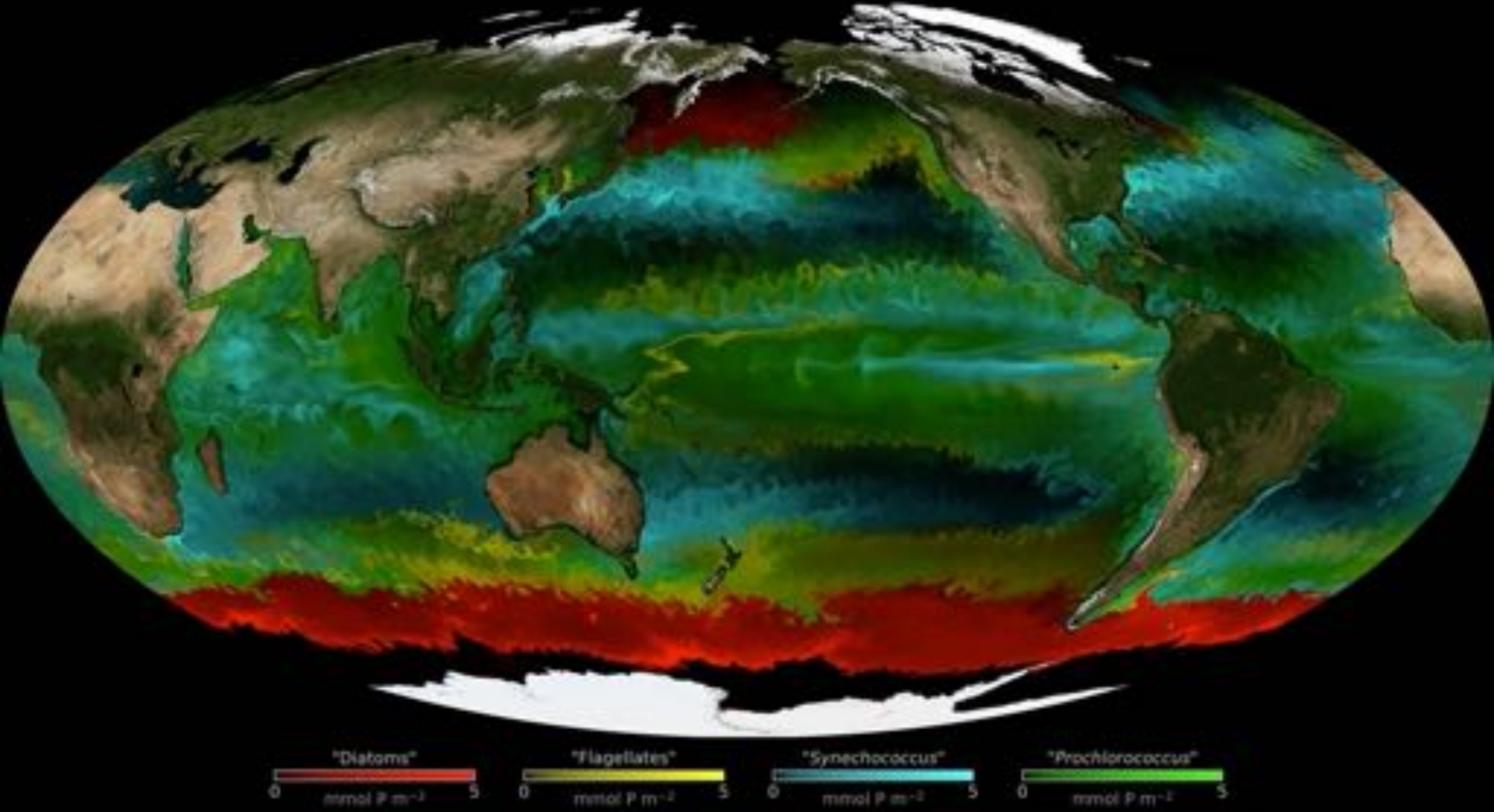
Satellite Color Observations of the Phytoplankton Distribution in the Eastern Equatorial Pacific During the 1982–1983 El Niño

first ever look at global distribution of marine phytoplankton, ocean productivity



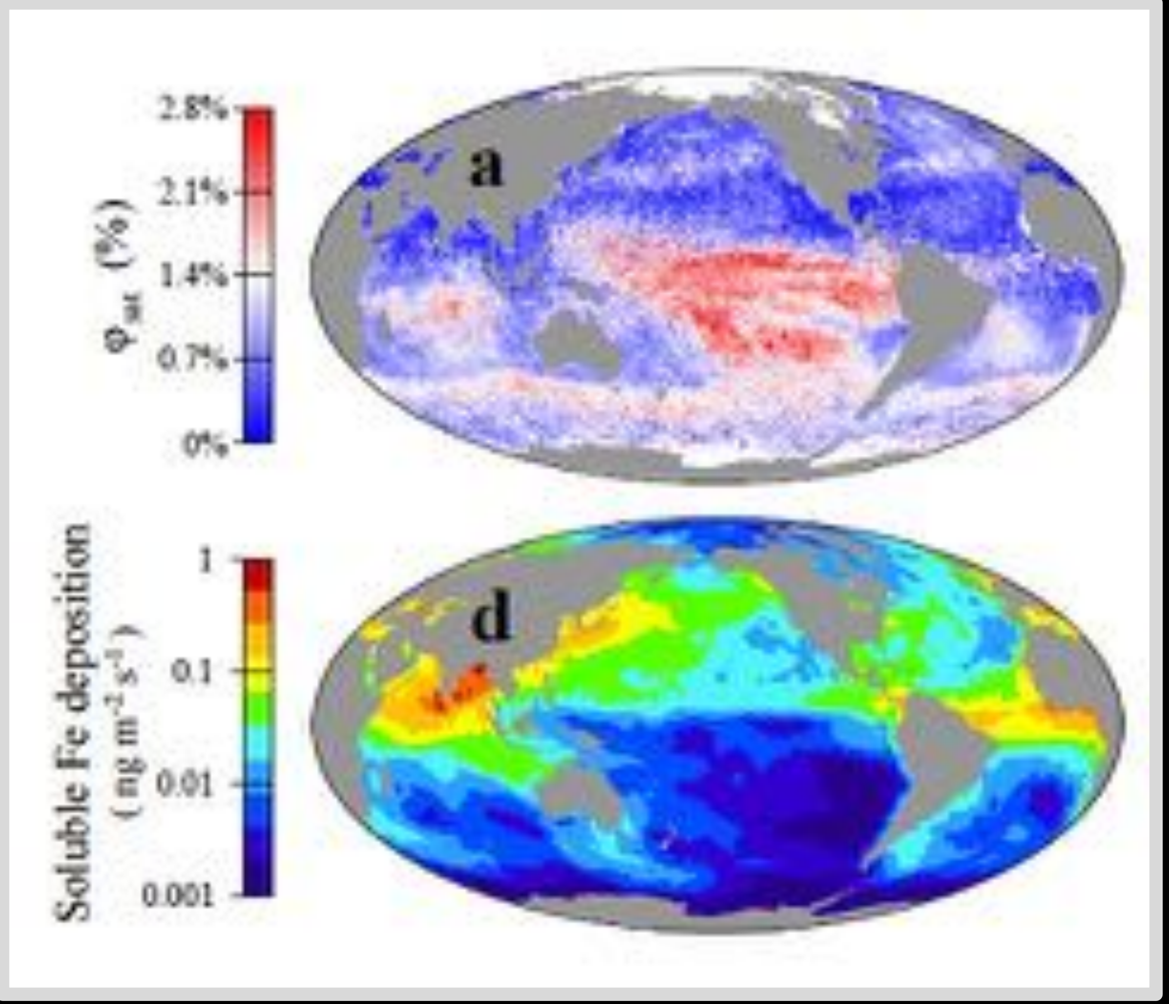
Feldman et al. 1984 and 1989


Ocean Chlorophyll
low
high
Sep 1997
Land Vegetation
low
high


"Diatoms"
0
mmol P m⁻²
5
"Flagellates"
0
mmol P m⁻²
5
"Synechococcus"
0
mmol P m⁻²
5
"Prochlorococcus"
0
mmol P m⁻²
5

MODIS
1999-present

- Fluorescence band
- SWIR for turbid water
- 250 & 500 m atmosphere & land bands



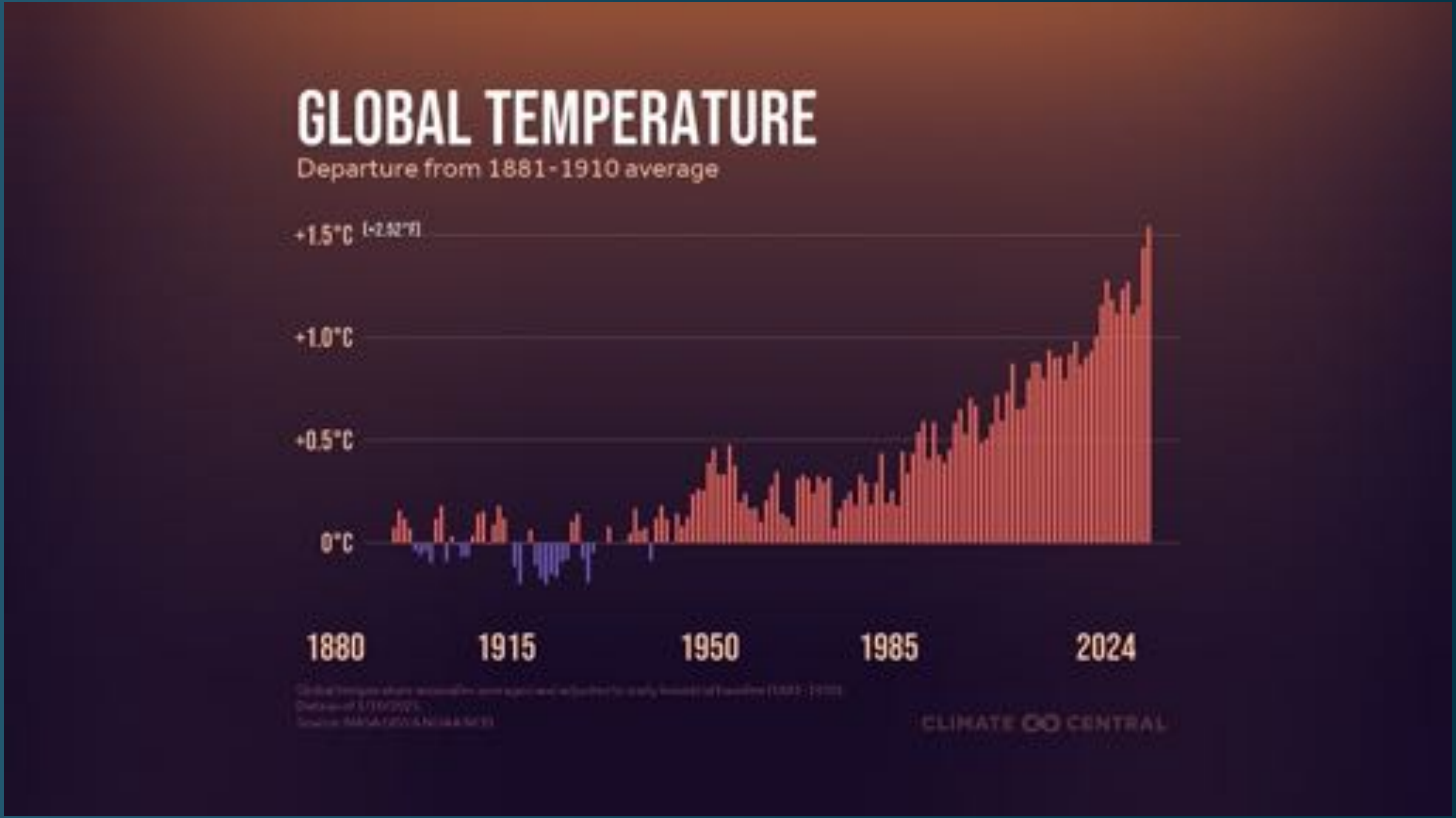
Behrenfeld et al. 2009, BGS

metric	CZCS	SeaWiFS	MODIS
primary ocean bands (nm)	443, 520, 550, 670	412, 443, 490, 510, 555, 670, 765, 865	412, 443, 488, 531, 547, 667, 678, 748, 869, plus SWIR
nadir res.	825 m	110	
nadir swath	1636 km discontinuous operation	1500 km GAC (2-day global) 2875 km LAC	2230 km (2-day global)

+ fluorescence line height
+ photosynthetic quantum yield
+ turbidity index

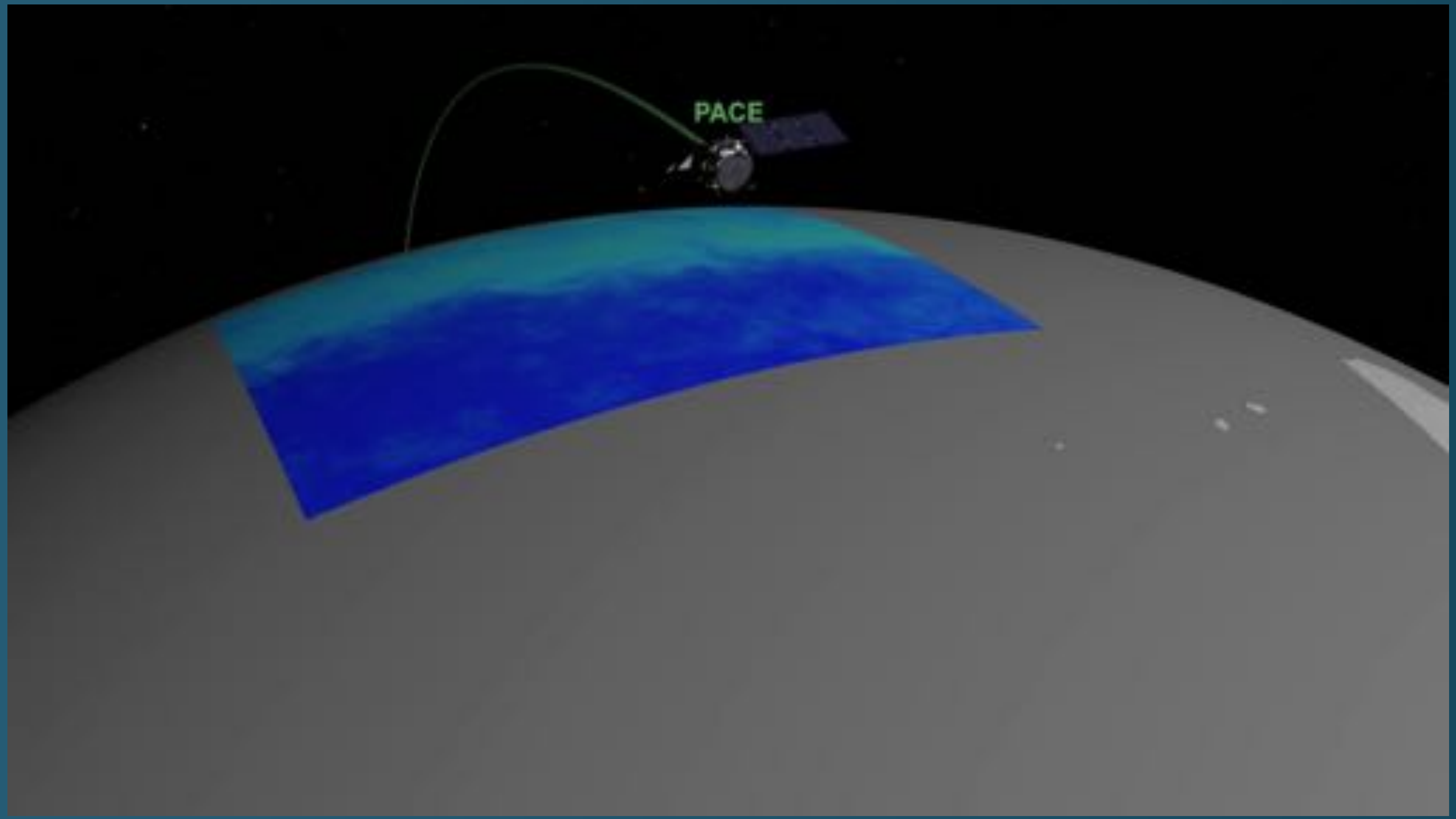
+ GOCI, HICO, MERIS, MOS, OCM, OSMI, SeaHaWK, VIIRS, others …

IT KEEPS GETTING WARMER



The Next 50 years of Ocean Science from Space: Are We Ready?

Hyperspectral “ocean color” - Plankton, Aerosol, Cloud and ocean Ecosystem (PACE) mission



Public Needs and Grand Challenges addressed:

- Climate and environmental variability and change
- Global marine ecosystem health, food security, water quality (HABs, etc.)
- Maritime security + resource management
- Biogeochemical cycling and carbon cycle science
- Disasters and event scale phenomena (storms, oil spills)
- Blue economic sector prosperity (maritime trades)
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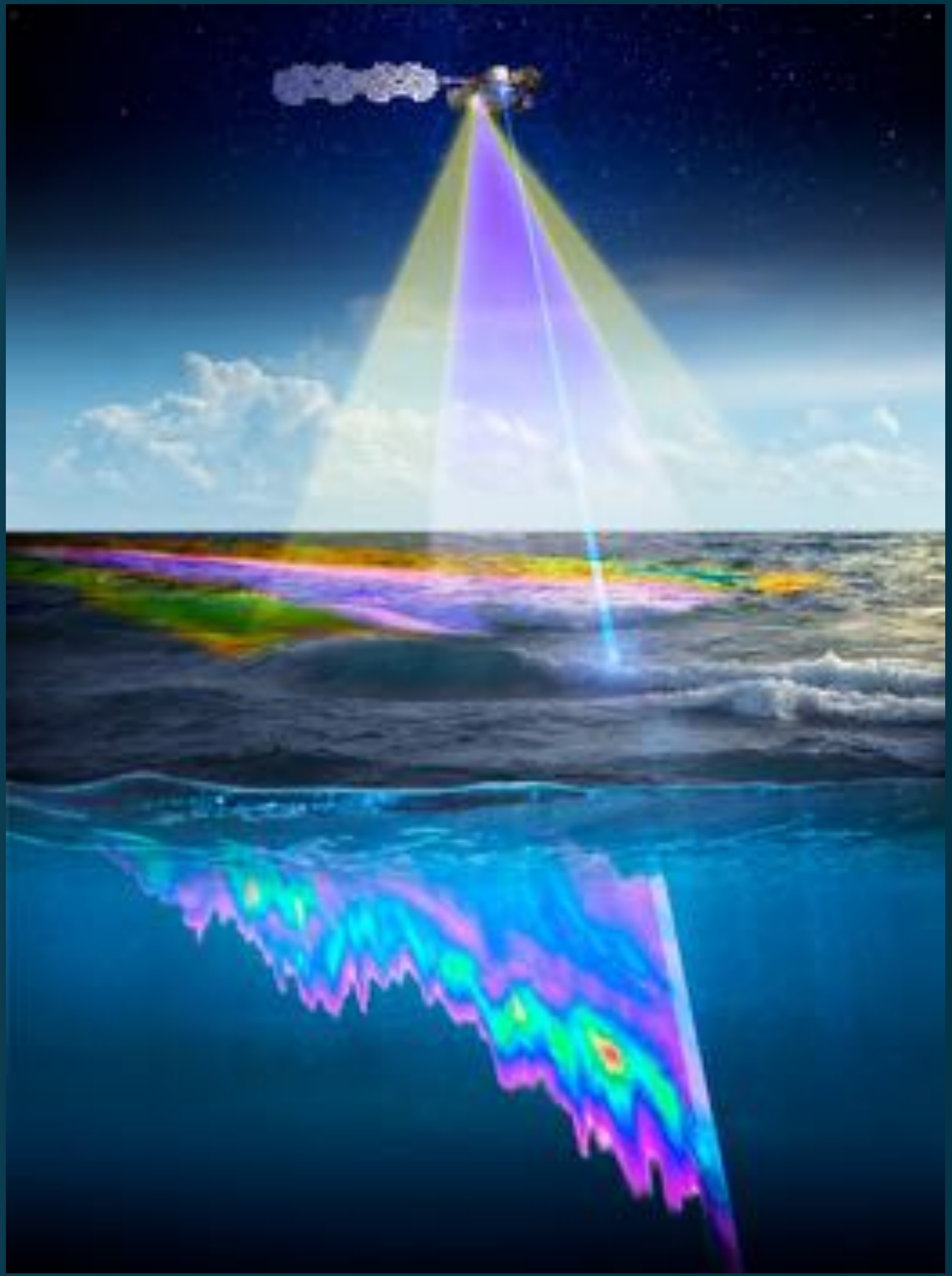
- Dynamic Interfaces (ocean/ice; ocean/atm, etc.)

Blue LiDAR



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NASA’S PACE SATELLITE:
MONITORING THE PROGRESSION OF HARMFUL ALGAL BLOOMS IN AUSTRALIA

- *Karenia mikimotoi* (dinoflagellate) is identified and located among other types of phytoplankton using unique hyperspectral PACE data


The Guardian

US

News Opinion Sport Culture Lifestyle

World Europe US news Americas Asia Australia Middle East Africa Inequality Global development

South Australia

Mysterious sea foam on South Australian beaches reportedly leaves more than 100 surfers ill

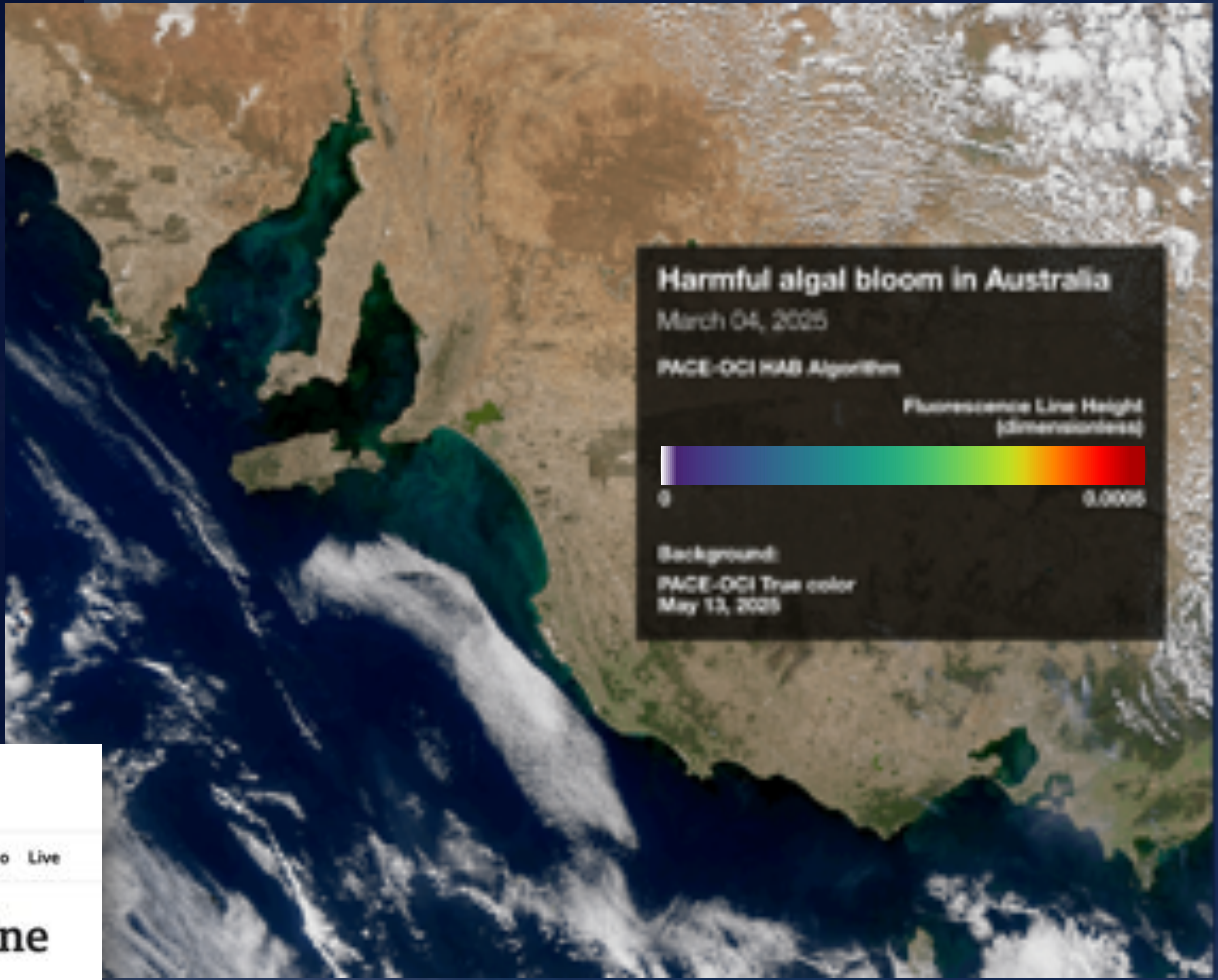

BBC

Home News Sport Business Innovation Culture Arts Travel Earth Audio Video Live

Toxic algae kills more than 200 marine species in Australia

13 May 2025

Share Save



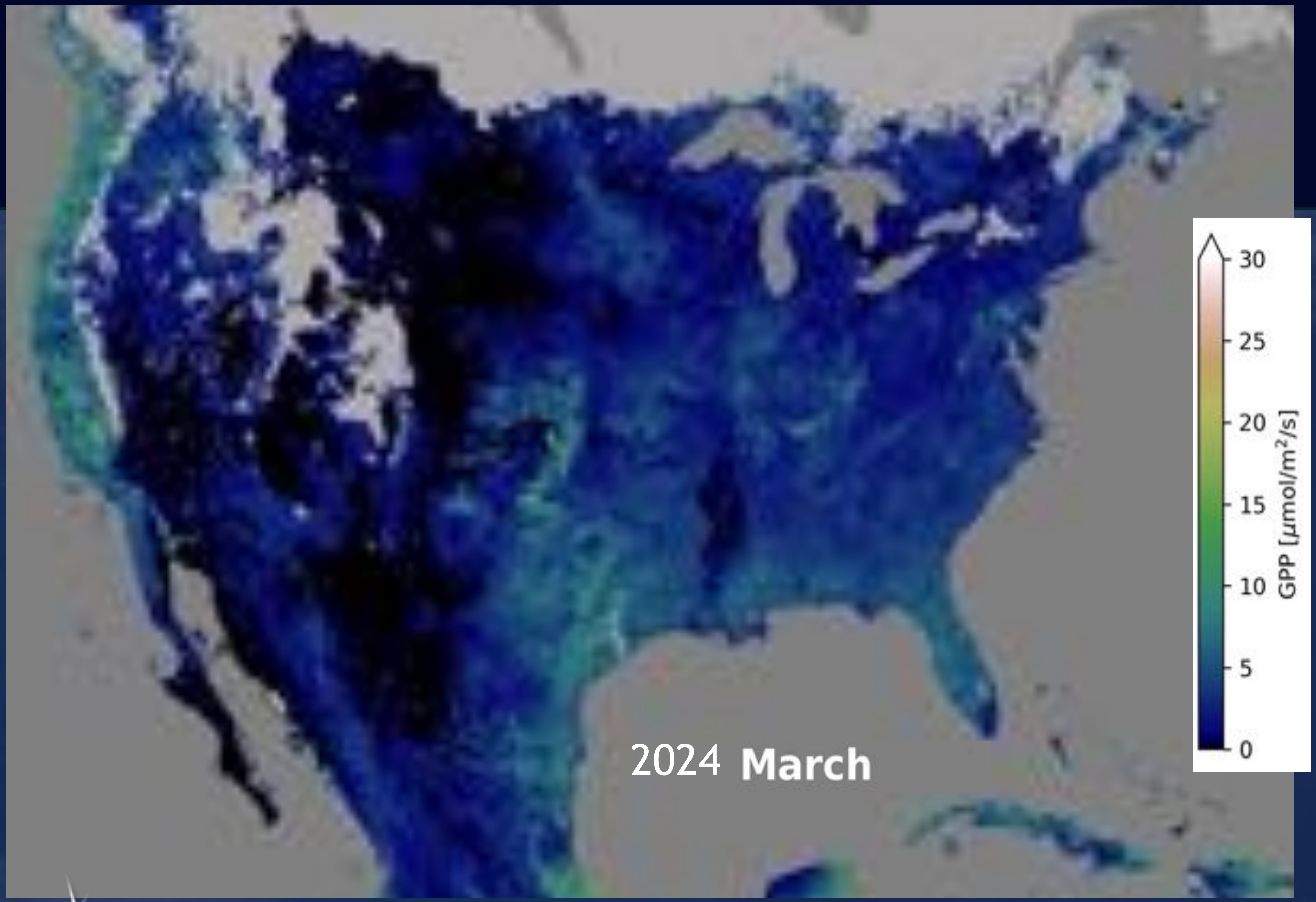
GODDARD EARTH SCIENCES
PACE

NEW PUBLICATION: ADVANCED TERRESTRIAL PRODUCTIVITY MEASUREMENTS

Huemmrich, K.F. et al (2025) Determining Terrestrial Ecosystem Gross Primary Productivity From PACE OCI
DOI: 10.1109/LGRS.2025.3587584

All new PACE Gross Primary Productivity (GPP) product uniquely calculates GPP with spectral reflectance alone

- Improved GPP enabled by PACE: Spectral-based PACE GPP (right), developed across major ecosystem types in the USA, is an independent measurement unlike previous satellite GPP models
- Only PACE can provide far more sites, better temporal coverage for training & the repeated, hyperspectral observations needed for algorithm development & continental-scale GPP maps.
- PACE GPP supports agriculture and forestry applications by independently describing seasonal and transient variability in productivity



PACE Monthly Gross Primary Productivity
March – November 2024

Work supported by NASA PACE Science & Applications Team through GESTAR-II Coop Agreement Award #80NSSC22M0001.

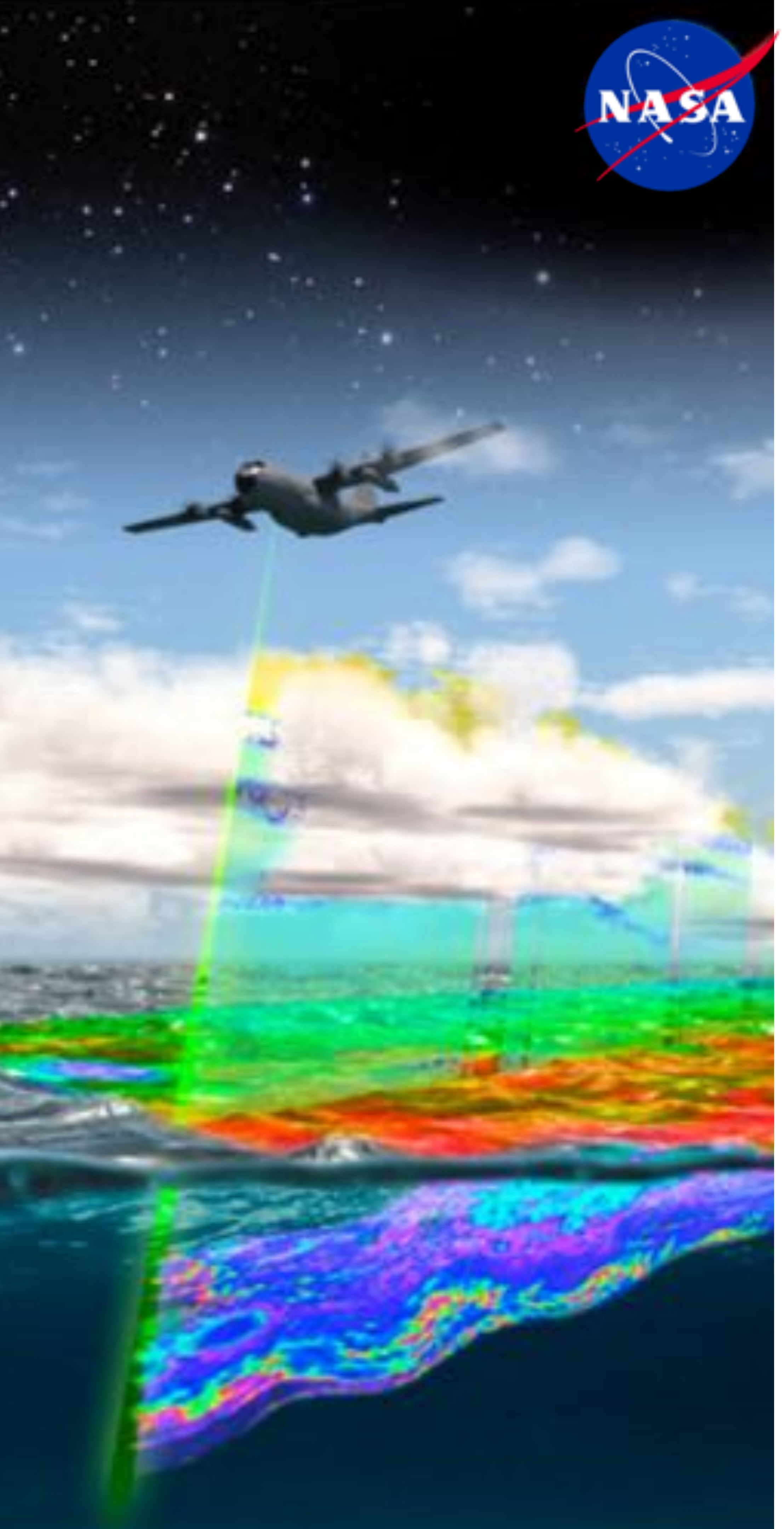
A PACE FIRST: OCEANS IN LIVING COLOR

GLOBAL IDENTIFICATION OF PLANKTON TYPES ENABLED BY HYPERSPECTRAL DATA

Tiny, but ubiquitous, phytoplankton are responsible for >10% of global net primary production, playing a crucial role in oceanic food webs that support commercial fisheries and pelagic predators.

PACE daily imagery provides 5-10X more datapoints than the largest combined picophytoplankton dataset, allowing better understanding, monitoring and prediction of the role that picophytoplankton play in world’s ocean and global economy.

Airborne and space-based lidars

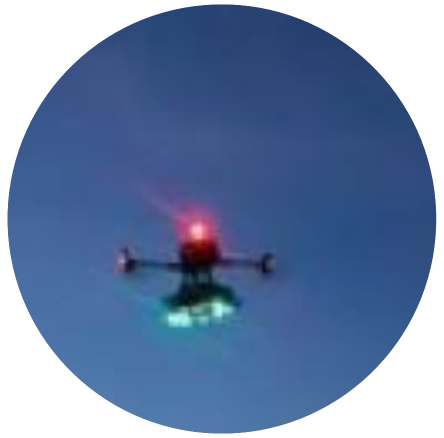


Coastal and littoral ecosystems

Airborne and space-based platforms capture fast changing coastal and littoral environments with new sensors and approaches.

Coastal & littoral environments are highly dynamic and observationally challenging; highly populated areas (2.86 billion - 38.1%- live within 100 km) and contribute billions of dollars to global economies.

Airborne and space-based lidar sensing – advancing atmosphere, ocean biology, ocean physics.



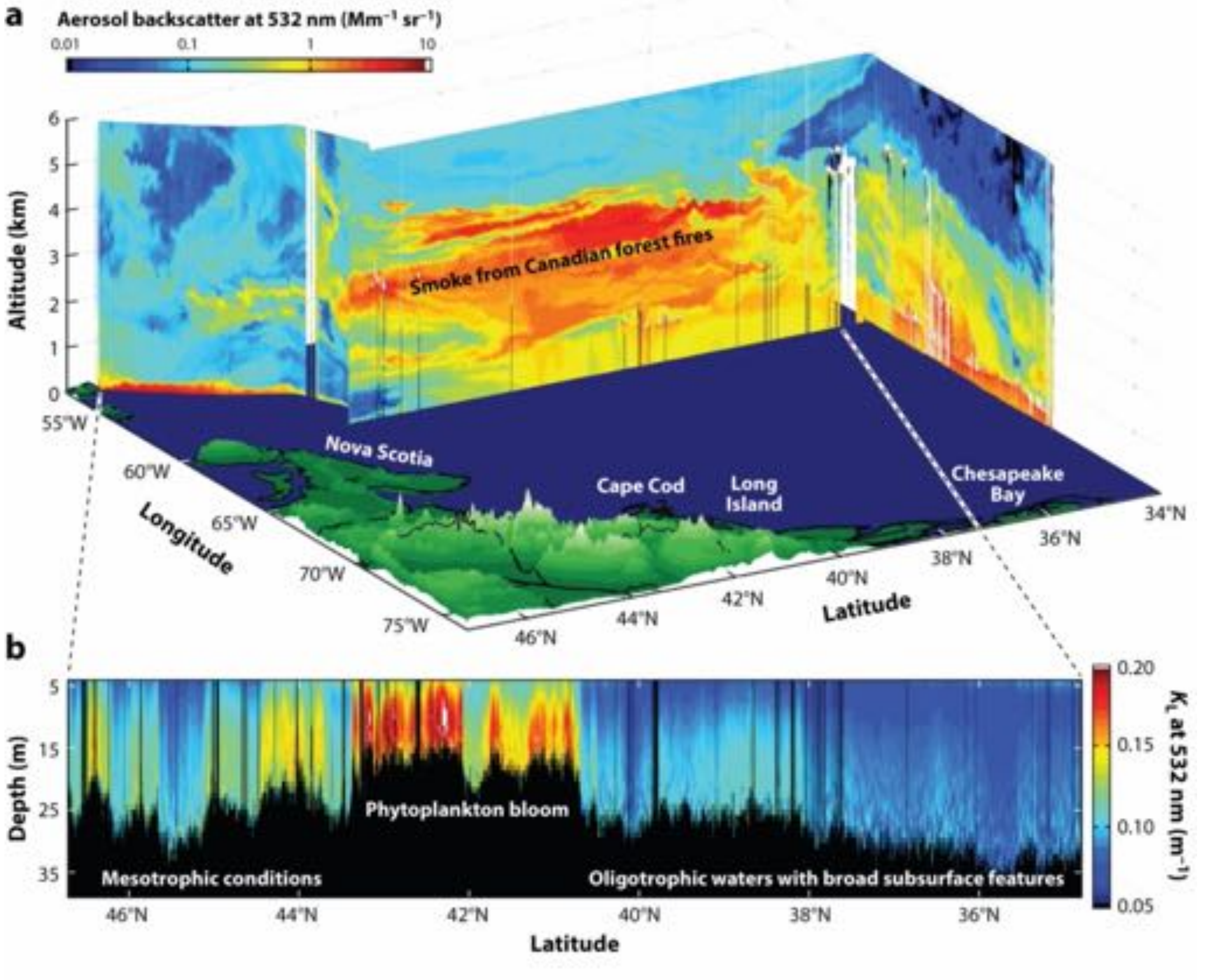
Drone observations for coastal and littoral zones; satellite observations for fast changing regions.

Advancements in AI assisted models; quantum computing; data collection.

Airborne and space-based lidar capabilities for the coastal zone

HSRL-2 (High Spectral Resolution Lidar - Airborne)

- Ocean and atmosphere properties in tandem. Lidar signal can penetrate thin clouds and during nighttime at variable water depth (~15-20m).



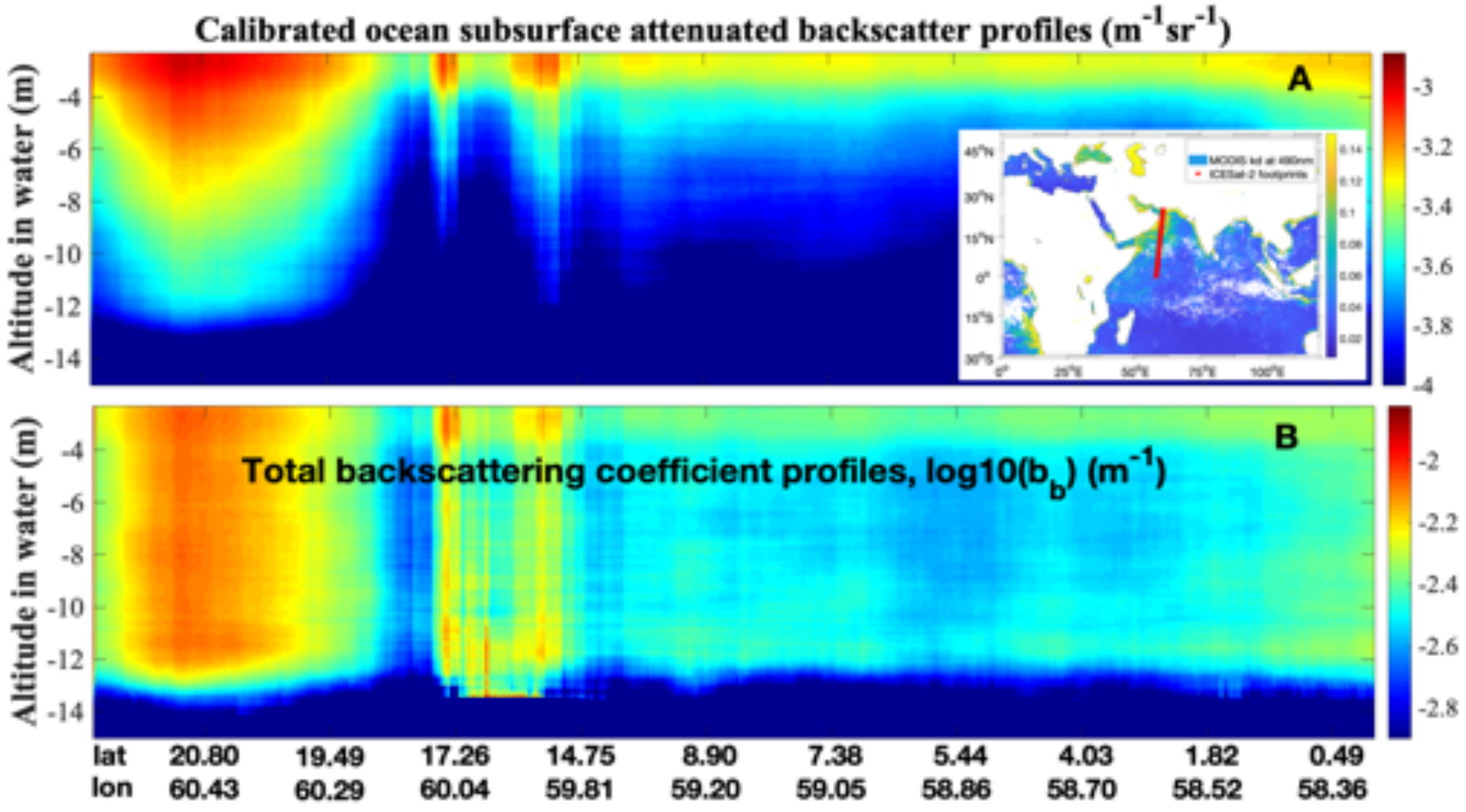
Hostetler CA, et al. 2018. Annu. Rev. Mar. Sci. 10:121–47

Airborne and space-based lidar capabilities for the coastal zone

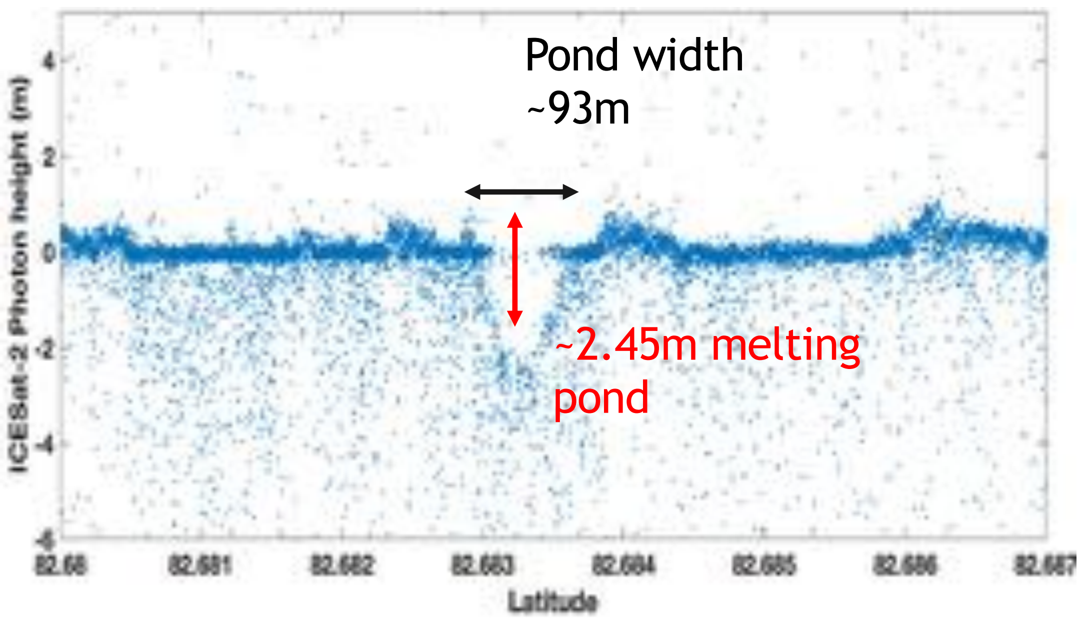
IceSAT-2

- Ability to obtain vertical profiles over open ocean and coastal regions; shallow penetration depth (15m).
- 90-day revisit time; Data require corrections.
- Receiving channels can be easily saturated.

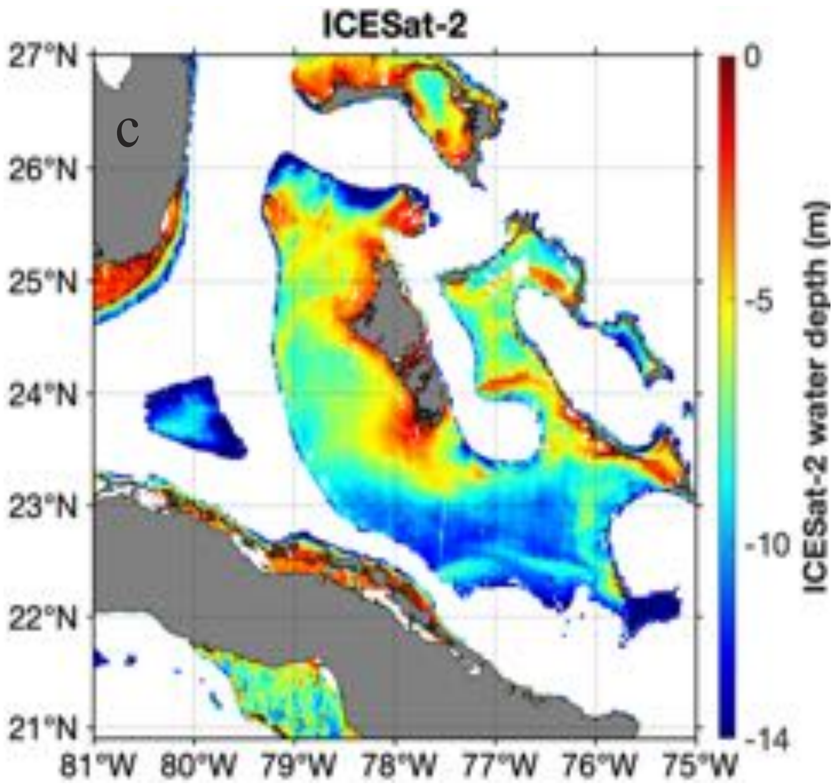
Depth-resolved ocean structure



Arctic melt ponds

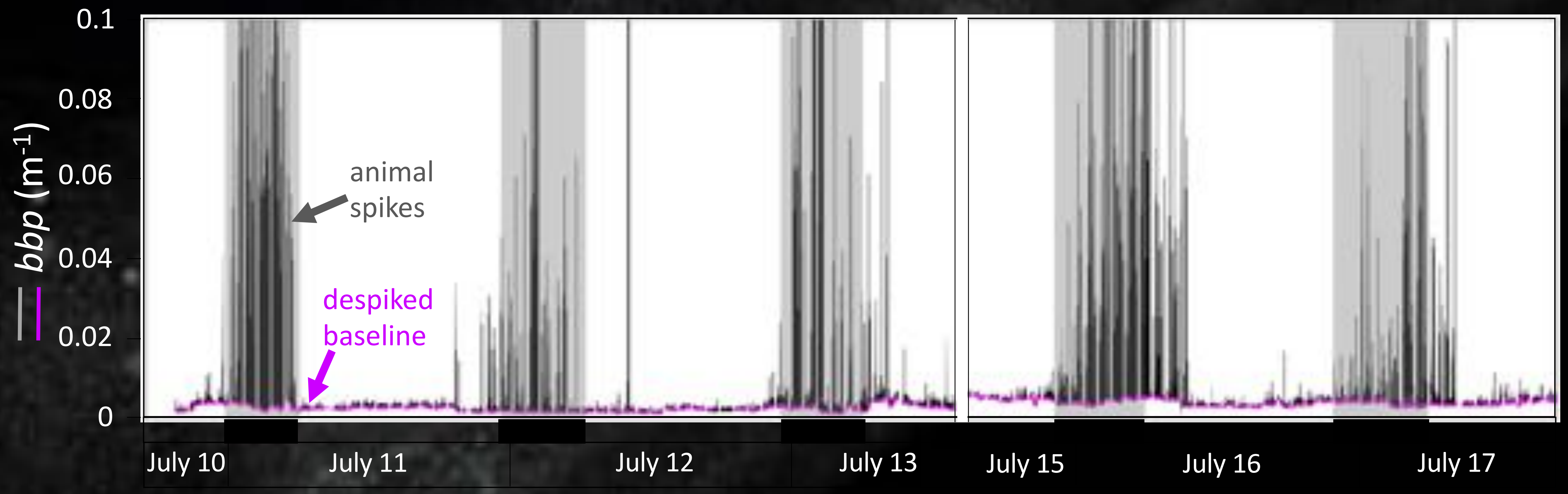


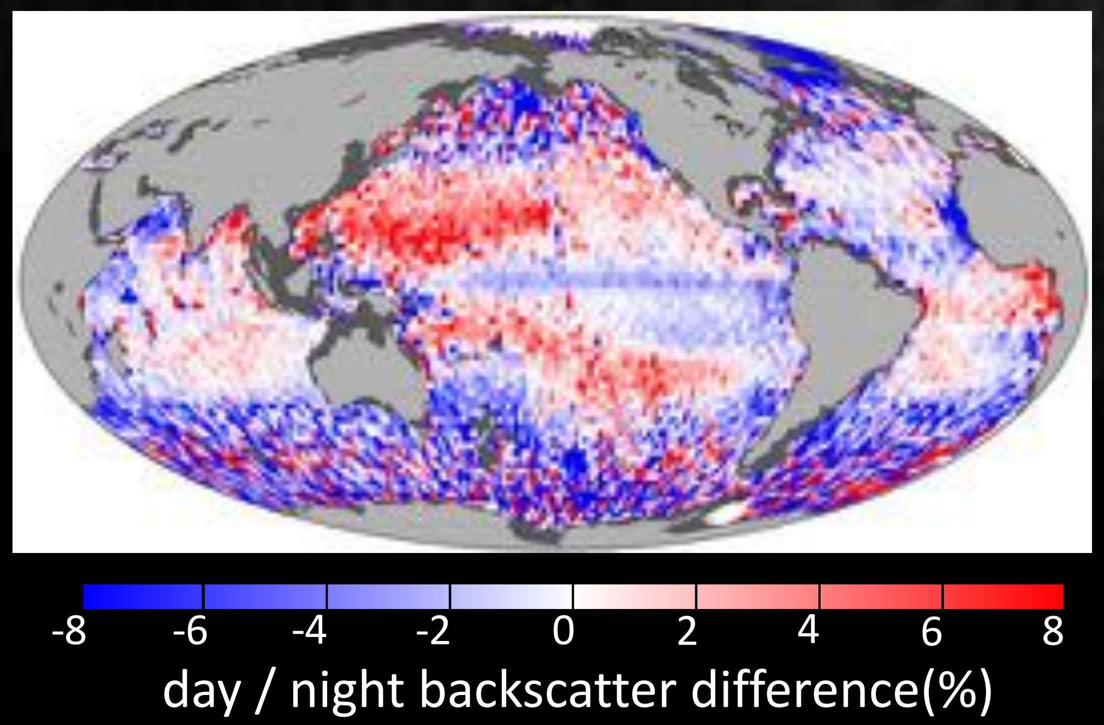
Near shore bathymetry



Lu, et al. (2019, 2020)

Spaceborne diel observations from CALIPSO

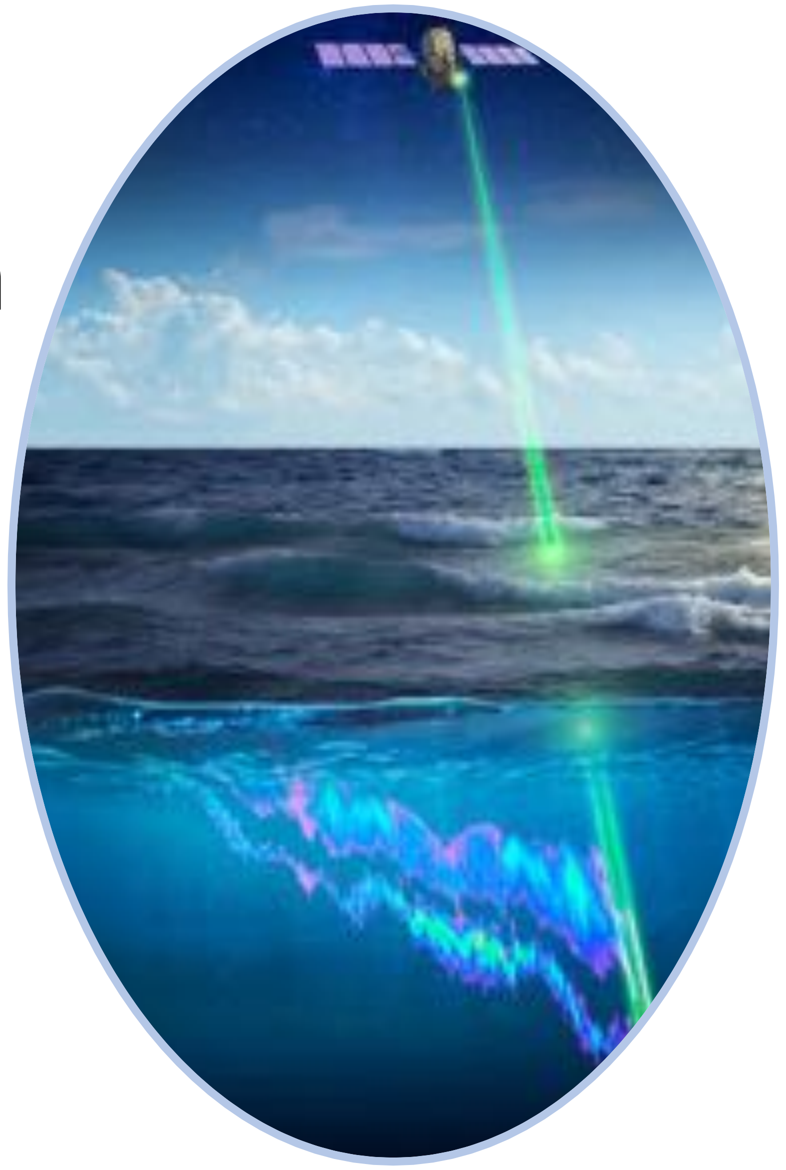


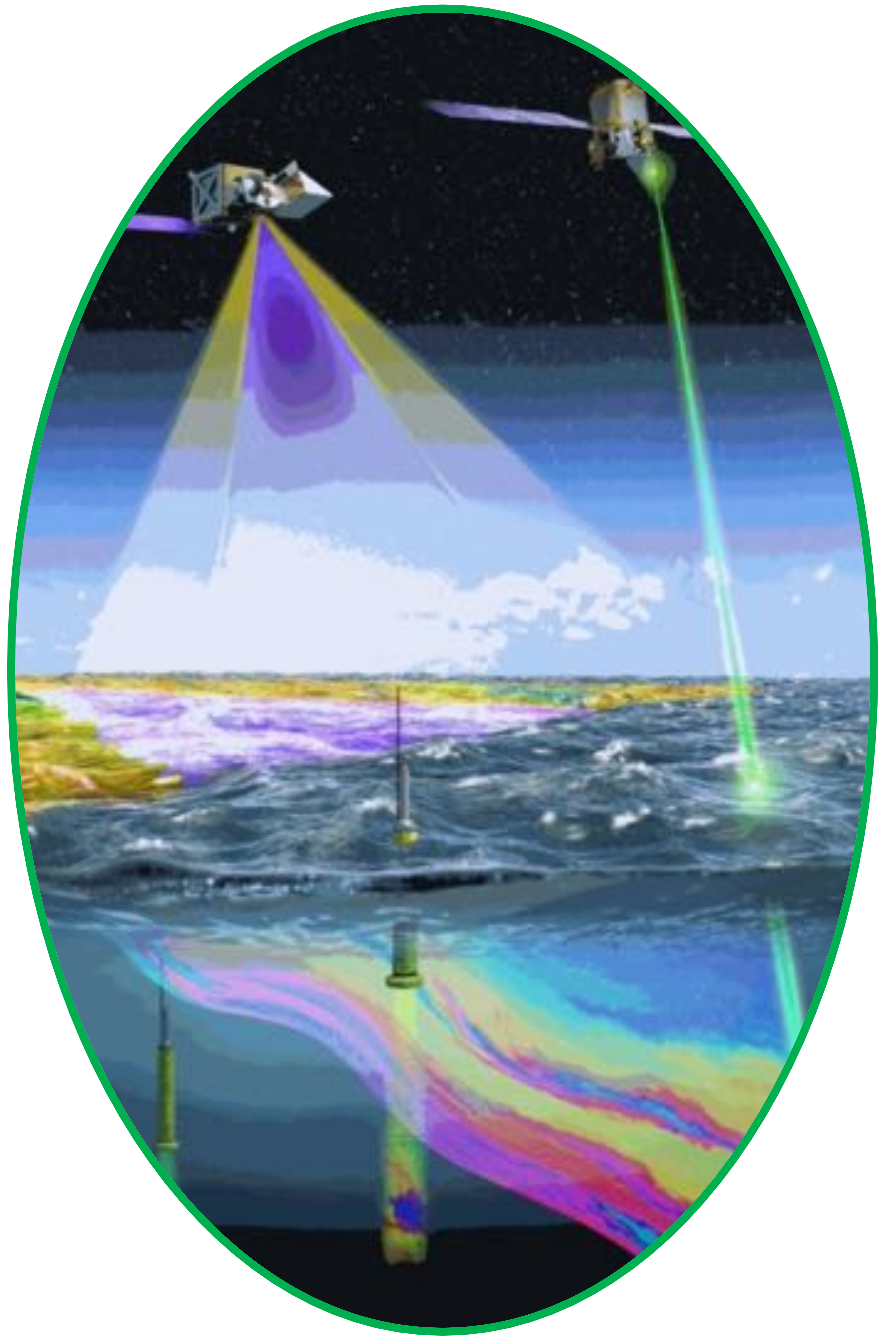


Heritage Capabilities → LiDAR Innovation

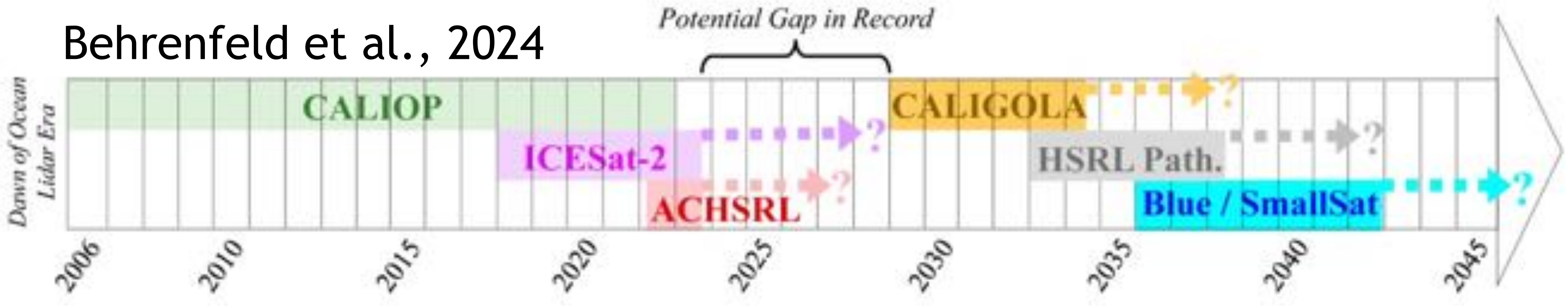
We currently have no ocean-optimized lidar in orbit.

Non-optimized missions present issues that limit innovation and discovery.





Behrenfeld et al., 2024



Salinity lidar - retrieve subsurface temperature and salinity.

Blue lidar - deeper penetration than heritage 532nm.

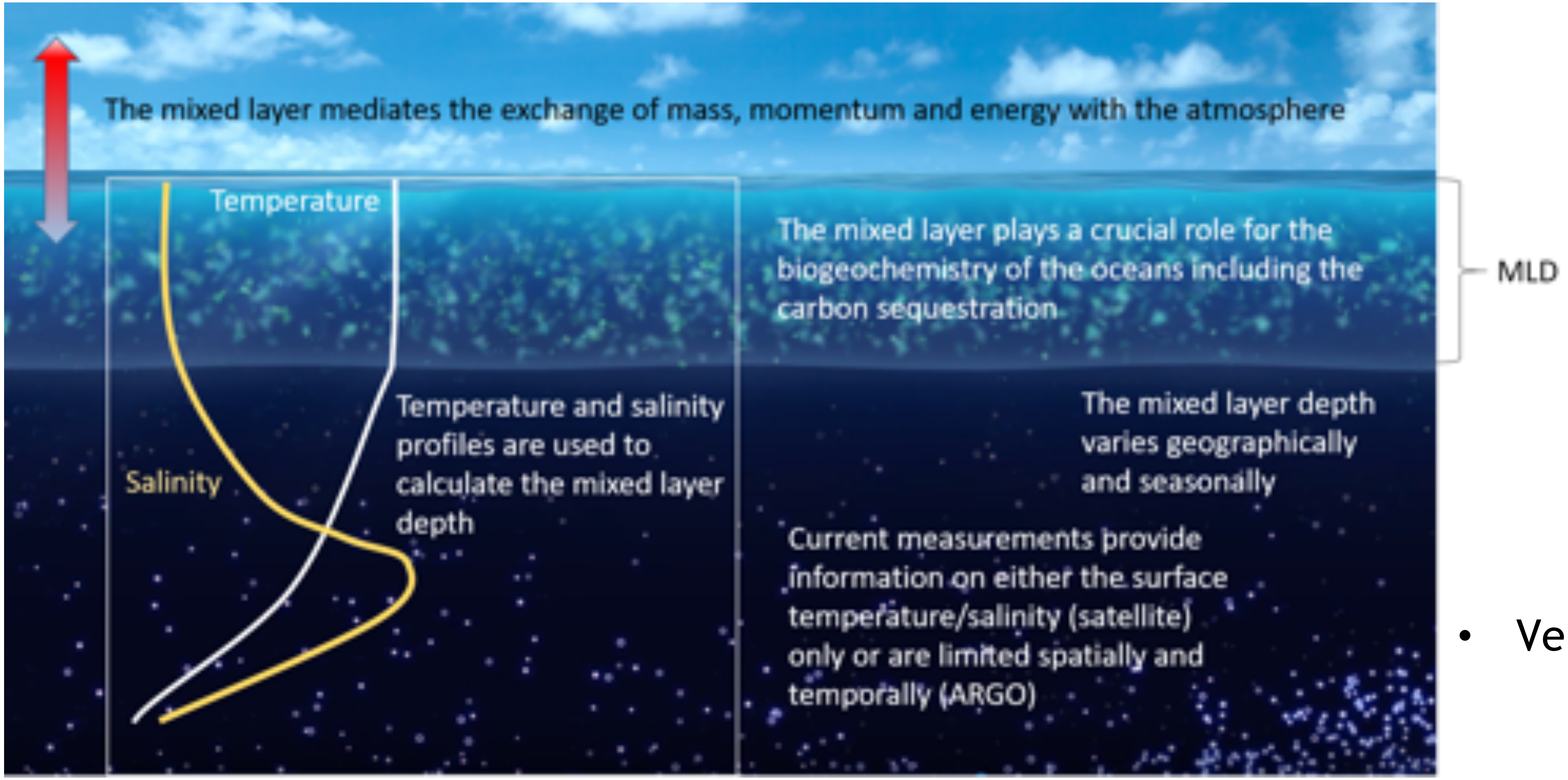
ASI's Luce mission - polarization-sensitive Raman lidar.

Combination of lidar, hyperspectral, and radar.

Can add EarthCare to this timeline – 100m resolution but not ocean focused.

Salinity lidar (in development)

Improvements in hurricane prediction, short term prediction of currents & navigation, disaster planning, seasonal-to-interannual forecasting (e.g., El Niño) and large Earth system models



Uses Brillouin scattering spectra to retrieve sub-surface temperature and salinity profiles

- Vertical resolution of ~1 m.

PI: Dr. Cecile Rousseaux, cecile.s.rousseaux@nasa.gov

Luce

A multi-wavelength elastic-Raman-fluorescence backscatter lidar

Agenzia Spaziale Italiana

8 receiver channels

3 wavelength laser

Transmitted wavelengths	Receiver Wavelengths [nm]				
	Parallel elastic backscatter	Perpendicular elastic backscatter	N_2+O_2 rotational Raman backscatter	H_2O rotational-vibrational Raman backscatter	Fluorescence
355 nm	355 nm A O L C	355 nm A O L C	353.95 nm + 355.7 nm A	405 nm A O L C	685 nm A O L
532 nm	532 nm A O L	532 nm A O L			
1064 nm	1064 nm A L				

Channel Usage:
Atmosphere
Ocean Land
Cryosphere

Elastic backscatter with polarization sensitivity

- Foundational to nearly all types of retrievals

Raman backscatter

- Atmosphere (N_2+O_2) & ocean (H_2O) calibration
- Water vapor and snow density retrievals

Fluorescence

- indicator of chlorophyll

Heritage measurements

- CALIOP on CALIPSO (2006 – 2023)
- ATLID on EarthCARE (2024 – 2027+)

Luce's first-ever measurements

- Relatively weak signals that are stimulated more effectively by shorter wavelengths (i.e. 355nm)

Novel technology and application development

Multi-functional airborne fluorescence lidar to assess ocean systems health and marine pollution

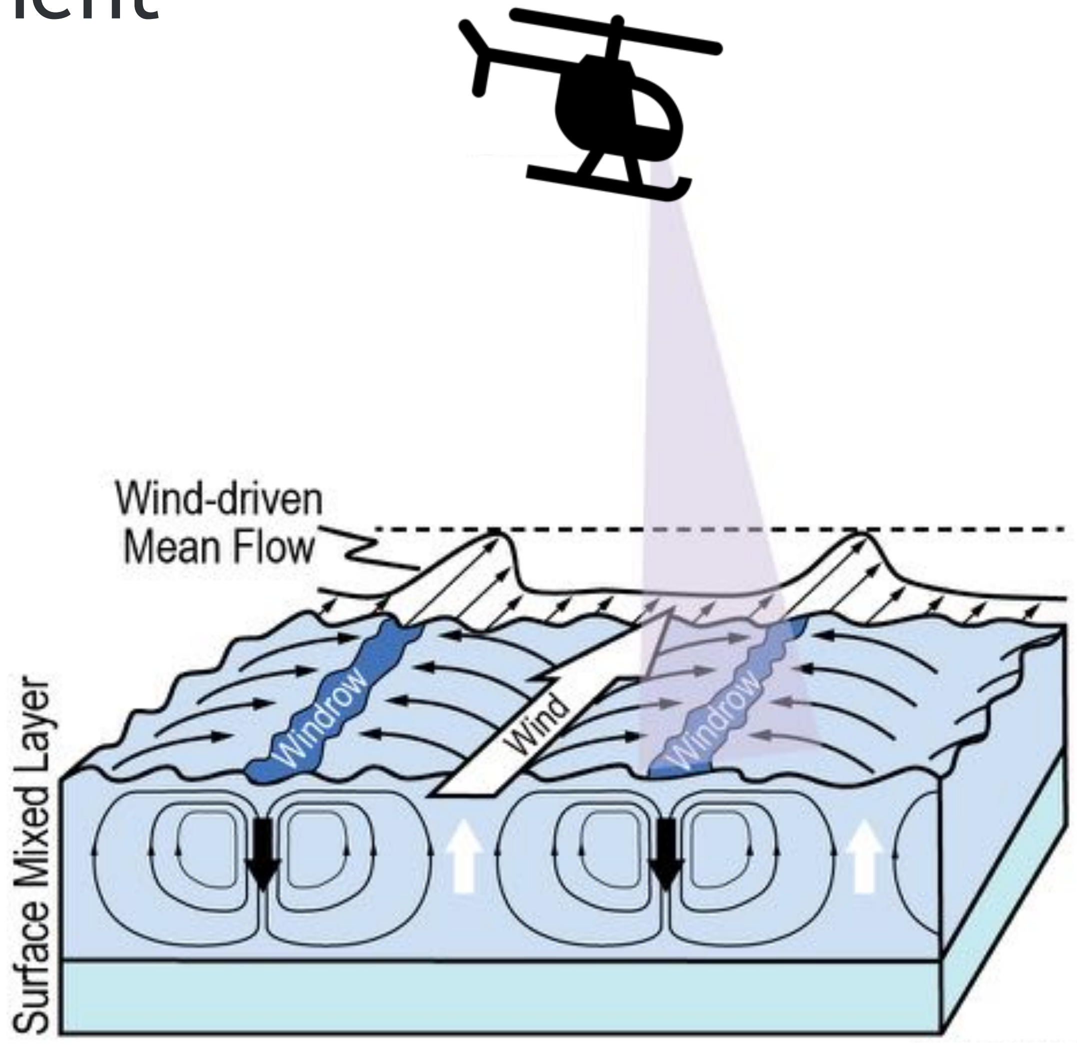
Fluorescence Lidar for Ocean Research - Airborne (FLOR-A) Instrument

Map plastic concentrations in accumulation zones such as litter windrows

Build a dual wavelength **ocean lidar** with a SPAD array spectrometer

Fly in a **field campaign** off the coast of Miami by 2027

Compare FLOR-A's results to in-situ measured **plastic concentrations in windrows**



Vertically resolve the water column with backscatter at the transmit wavelengths of 355 & 532nm and measure ocean-column-integrated laser induced fluorescence and Raman returns from 380-760nm of ocean content and plastic pollution

PI: Madeline Cowell

madeline.cowell@baesystems.us

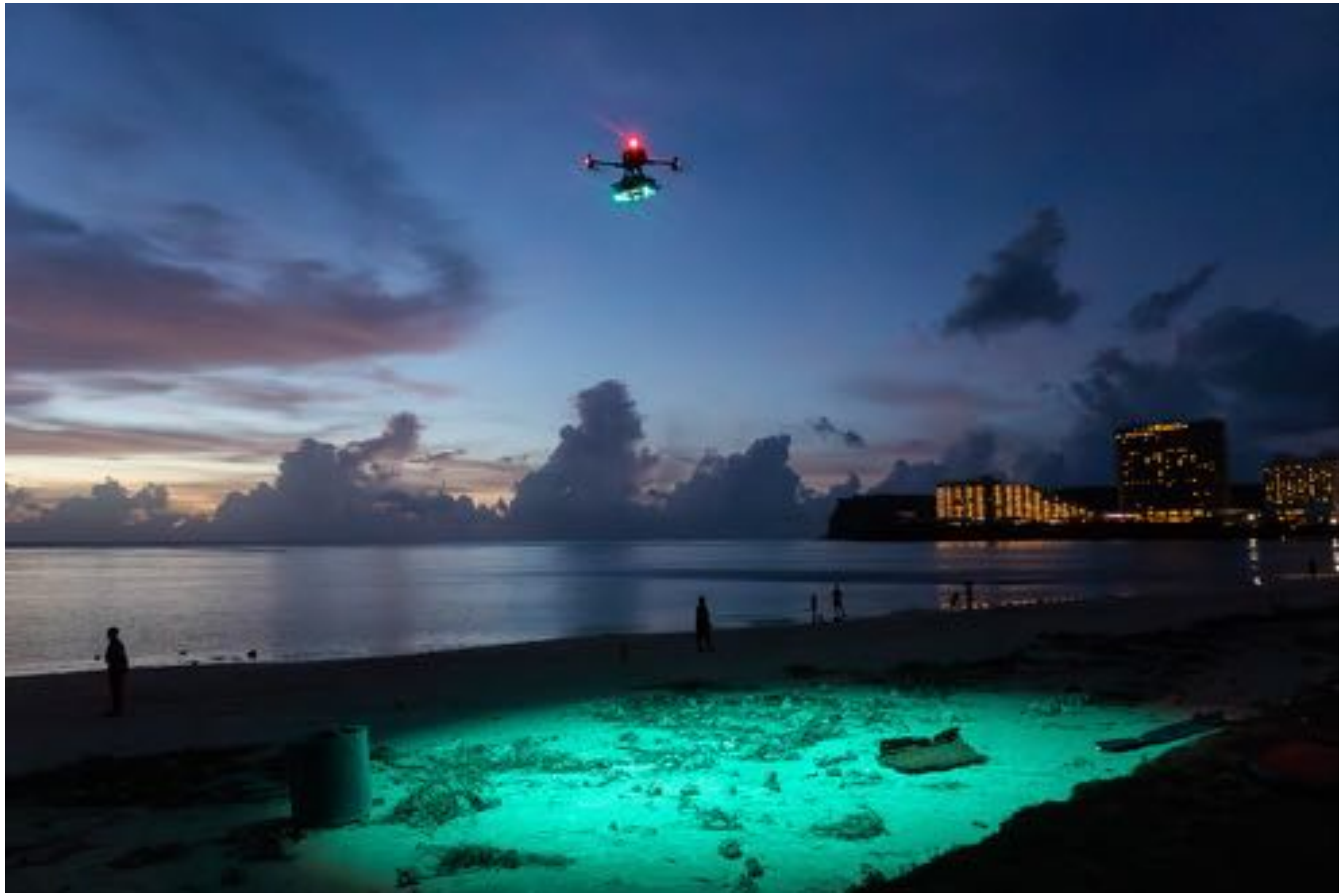
NASA ESTO GRANT 80NSSC25K7308

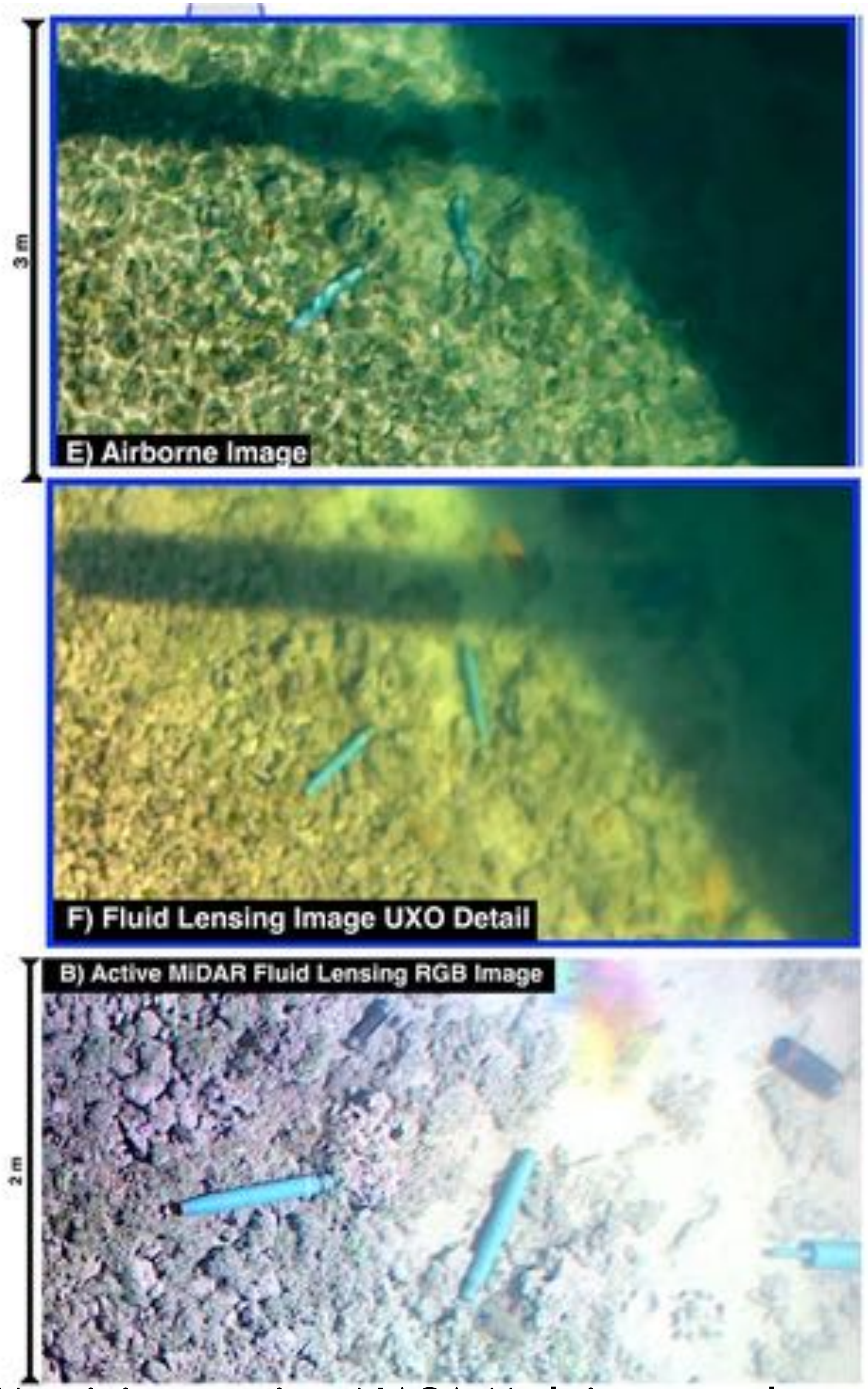
Co-Is/Collaborator: Collin Ward WHOI, Ved Chirayath Univ. of Miami, Mike Behrenfeld OSU, Davida Streett NOAA

BAE SYSTEMS

MiDAR (Multispectral Imaging, Detection, and Active Reflectance) which remotely senses living and non-living structures in light-limited environments (drone flights).

Current research looks to prove whether MiDAR can detect marine debris in the natural environment at the surface and underwater through waves.





Ved Chirayath et al., “Automated Airborne Detection of Underwater Munitions using NASA Multispectral Passive & Active MiDAR Fluid Lensing.” 2025. vxc463@miami.edu


SWOT
the complete story of Earth's
surface water
(from ocean to land and back)

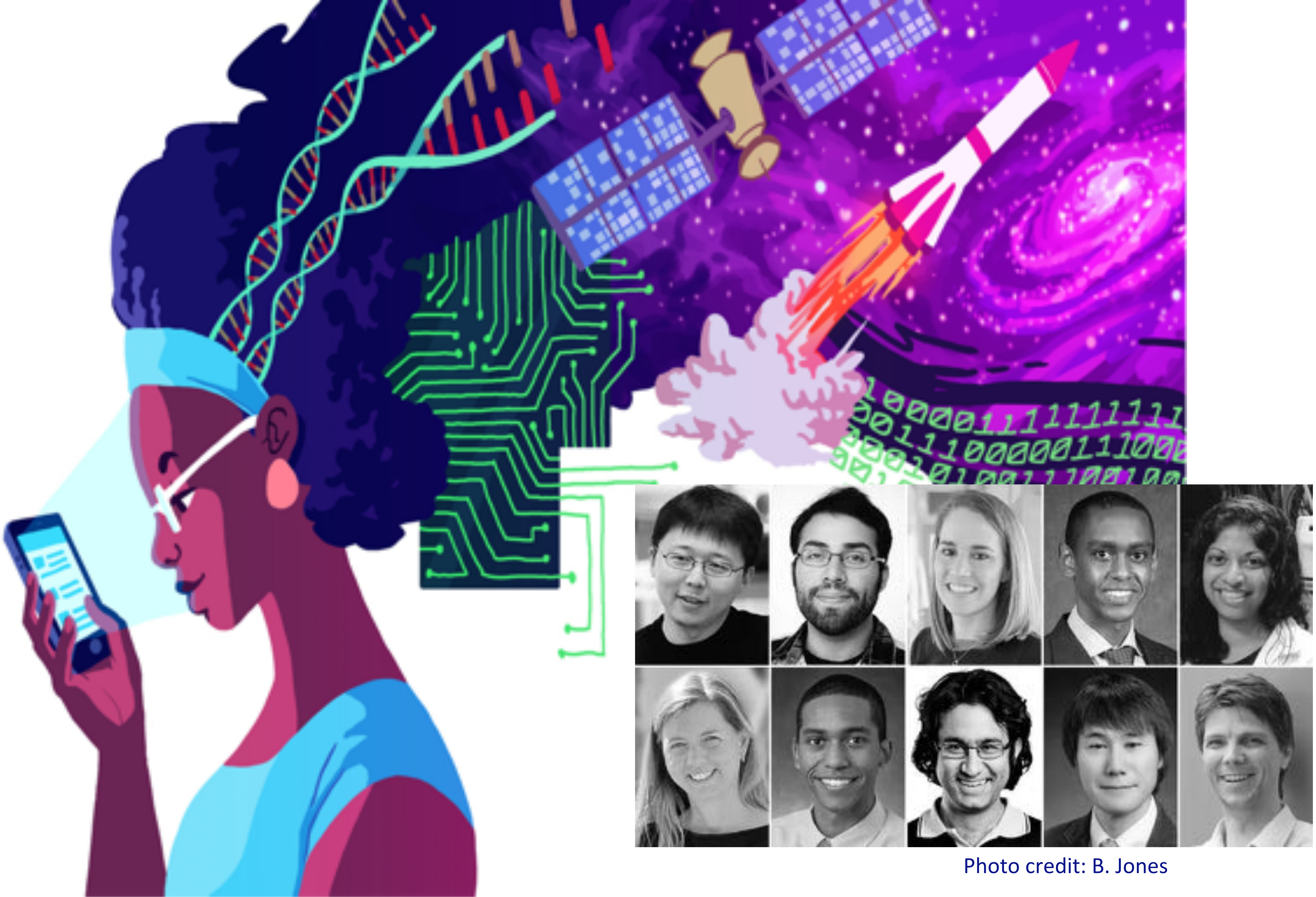


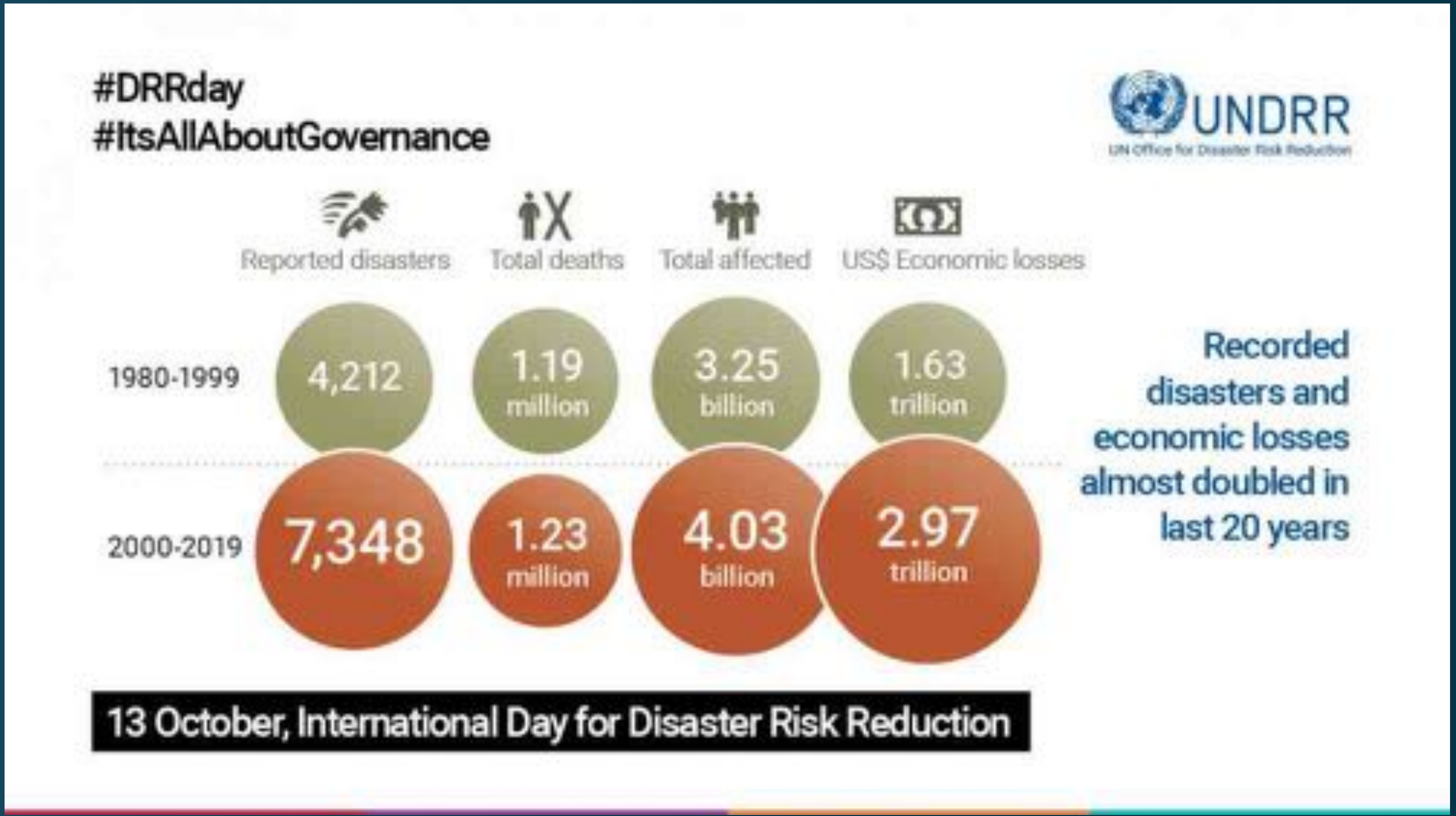
Photo credit: B. Jones

Costliest Wildfires Globally, 1900-2025 (Inflation-adjusted)

Rank	Location	Year	Cost	Deaths
1	Los Angeles, California	2025	$65 Billion*	30
2	Paradise, California (Camp Fire)	2018	$20 Billion	85
3	California (Tubbs/Atlas/Nunn Fires)	2017	$16 Billion	43
4	Indonesia	1997	$15 Billion	240
5	California (August Complex)	2020	$13 Billion	43
6	Fort McMurry, Alberta, Canada	2016	$10 Billion	0
7	California (Woolsey Fire)	2018	$6.3 Billion	2
8	San Bernardino, California	2003	$5.8 Billion	4
9	Oakland, California	1991	$5.6 Billion	26
10	Maui, Hawaii, U.S.	2023	$5.5 billion	102

*2025 data is from Gallagher Re; other years are from EM-DAT, inflation-adjusted to 2024 dollars.

Figure 1. Costliest inflation-adjusted wildfires globally, according to EM-DAT, NOAA, and Gallagher Re (total economic damage, not just insured). (Yale Climate Connections)



During the past 10 years - average annual insured loss:

Q1 (15%) - Q2 (25%) - Q3 (44%) - Q4 (16%)

Q3 is the peak period for Northern Hemisphere hurricanes and typhoons.

In 2025, Americans spent:

$3.9 billion for Halloween candy

$49 billion for the year

Global spending: ~ $75B

The Art of Possibilities

I appreciated Jeffrey Goldberg's article, "Nuclear Roulette", which quotes me in its last sentence: "Most of all, we forget the rule articulated by the mathematician and cryptologist Martin Hellman: that the only way to survive Russian roulette is to stop playing."

Society neglects the nuclear threat at its peril. If we would honestly face that threat— and others, such as climate change—they could transform into opportunities to finally build the more peaceful, cooperative world we have dreamed of for ages, but thought ourselves incapable of achieving.

To quote a paper I wrote some years ago, "Technology has given a new, global meaning to the Biblical injunction: 'I have set before you life and death, blessing and curse; therefore choose life that you and your descendants may live. "

Martin E. Hellman - Stanford, California (Atlantic Monthly, October 2025)

Thank you and Questions?

International Ocean Colour Science Meeting 2025
Advancing Global Ocean Colour Observations

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