

A Glow from Below: Bioluminescent Milky Seas and their Role in the Earth System

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5th IOCS Meeting

St Petersburg, FL

15 November 2023



Maritime Folklore: *Degrees of Truth*



Toy Submarine



Manatees!



Release the Kraken!!

Surreal Tales of Glowing Seas Near Java

U.S. Clipper Ship *Shooting Star*, June 1854



The *whole appearance of the ocean* was like a plain covered with snow. There was scarce a cloud in the heavens, yet the sky appeared as black as if a storm was raging.



The scene was one of awful grandeur, *the sea having turned to phosphorus*, and the heavens being hung in blackness, and the stars going out, seemed to indicate that all nature was preparing for that last grand conflagration which we are taught to believe is to annihilate this material world!

– Captain Warner E. Kingman, *Shooting Star*

...And in the Northwest Indian Ocean *C.S.S. Alabama*, January 1864

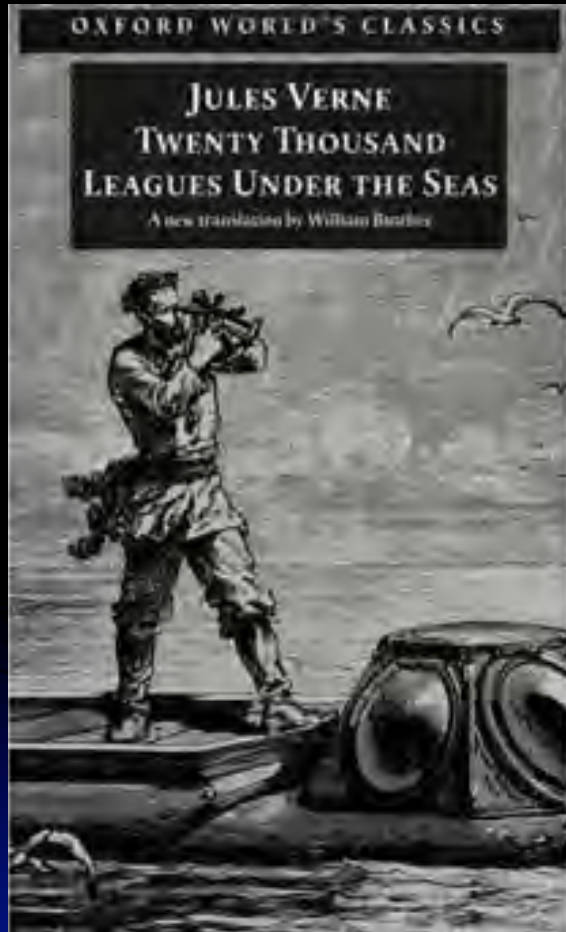


At about eight P. M., there being no moon (...) and the stars shining brightly, we suddenly passed (...) into a patch of water so white that it startled me; so much did it appear like a shoal.

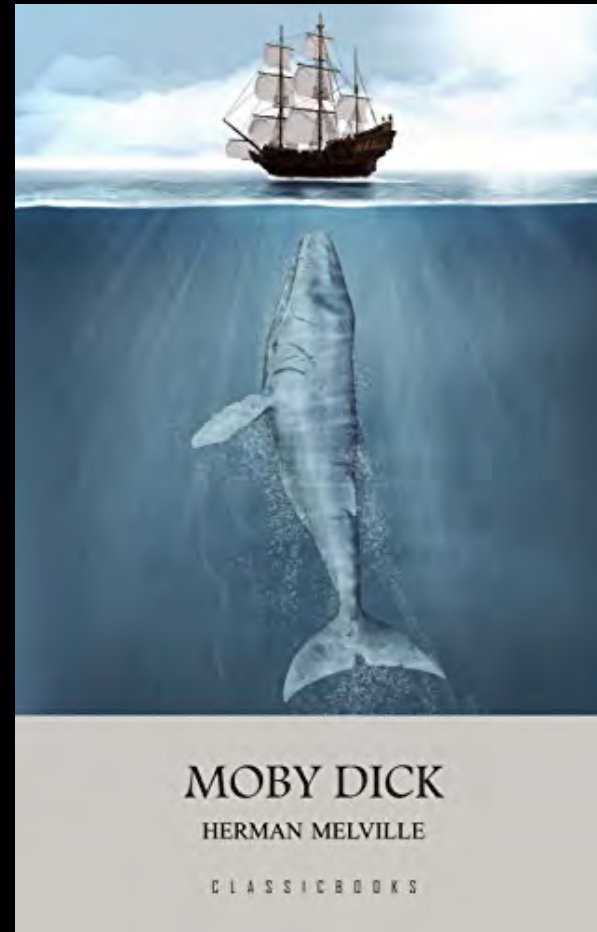
The whole face of nature seemed changed, and with but little stretch of the imagination, the *Alabama* might have been conceived to be a phantom ship, lighted up by the sickly and unearthly glare of a phantom sea and gliding on under the pale stars one knew not whither.

– Captain Semmes, *C.S.S. Alabama*

Accounts Inspired Maritime Adventure Novels



“About seven o’clock in the evening, the Nautilus, half-immersed, was sailing in a sea of milk. At first sight the ocean seemed lactified...”



“...let him be called from his hammock to view his ship sailing through a midnight sea of milky whiteness—(...) then he feels a silent, superstitious dread; the shrouded phantom of the whitened waters is as horrible to him as a real ghost...”

Milky Seas have long straddled the fence between fact and fiction!

When We Think of *Bioluminescence*...

Function: Startling / Repelling



Startle



Burglar alarm

A "NORMAL" BIOLUMINESCENT
RED TIDE (Dinoflagellates)

Such a transient, localized flash source
is challenging to detect from space...

Picture a Sustained, Pan-Horizon Glow...



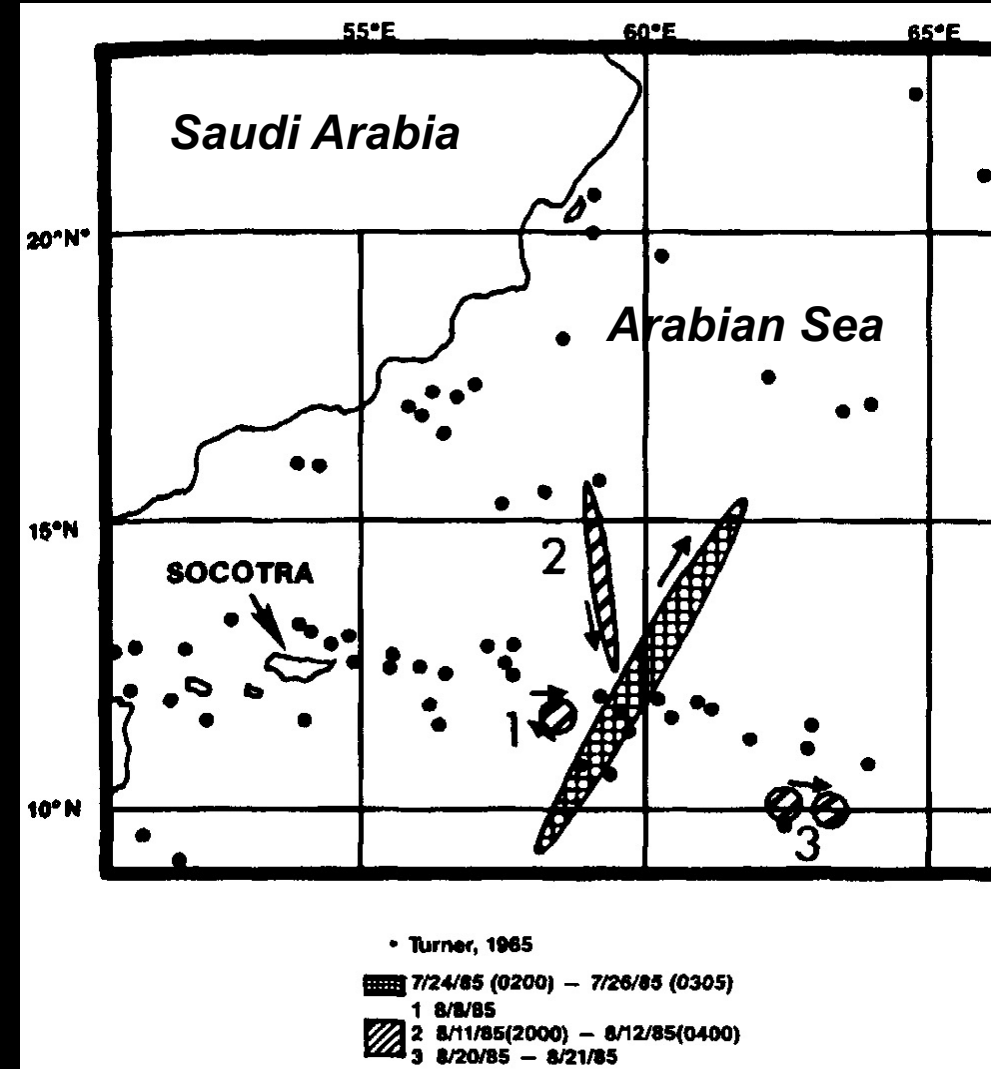
Could this Really Be Possible?!

The First Research Vessel Encounter

Arabian Sea: 24-26 July 1985



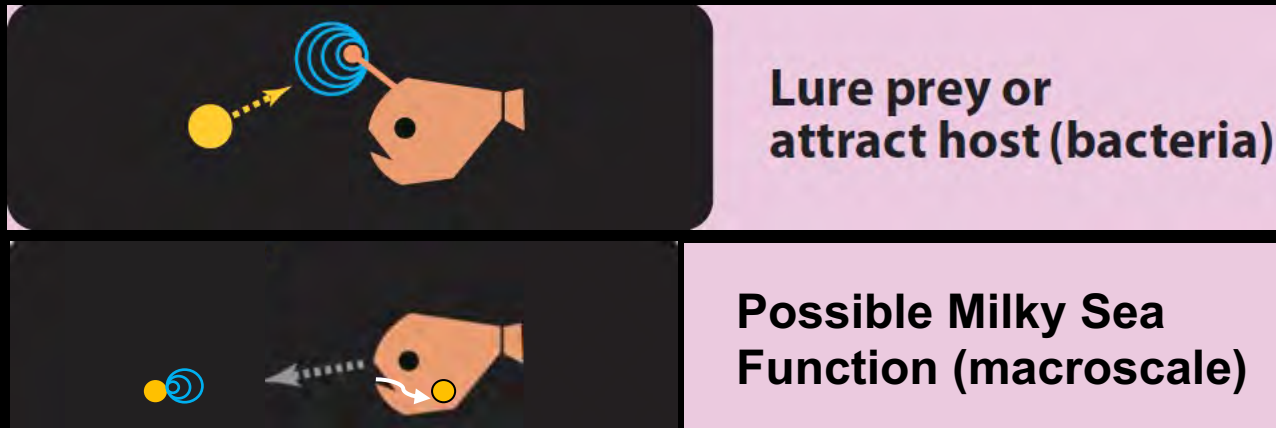
- Dave Lapota's Naval team on the USNS *Wilkes* is the only research vessel to encounter a milky sea, east of Socotra.
- “Dark stratocumulus on the horizon contrasted sharply with the milky-white sea. The display extended from horizon to horizon in all directions with ~10-mi visibility”
- They found the luminous bacteria *Vibrio harveyi* in association with *Phaocystis* algae.
- They crossed a sharp barrier between glowing and dark (normal) waters, suggesting the presence of an oceanic front.
- They postulated an organic slick, with airborne luminous particles accounting an apparent ‘milky fog’ just above surface.
- Other reports challenge the slick hypothesis—with the glow coming from depth and persisting unbroken, even under strong winds and rough seas.



Luminous Bacteria are the Suspected Culprits

1. Based on reports of steady glow, and Lapota's findings, the most likely cause for milky seas is *luminous bacteria*.
2. *Quorum Sensing*: when these bacteria exceed 10^8 cells/mL, they sense each other, triggers light production.
3. Growing bacterial colony secretes increasing levels of autoinducer into environment—stimulating further glow.

Functions: Luring / Attracting



*A population explosion of luminous bacteria (e.g., *Vibrio harveyi*) are thought to cause milky seas.*

Photo Credit: S. Haddock (MBARI)

A Key Report Near Somalia

S.S. *Lima*, 25 January 1995



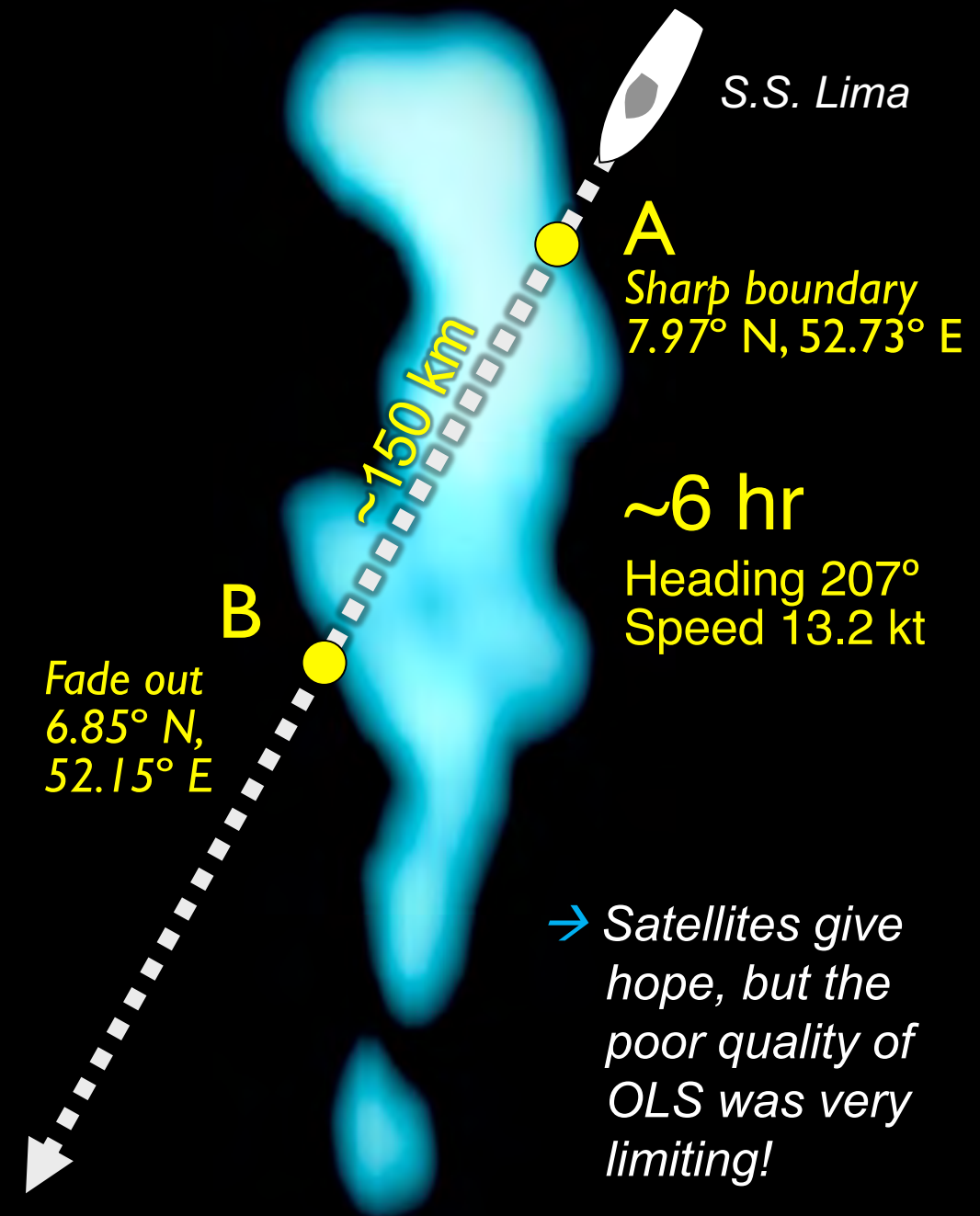
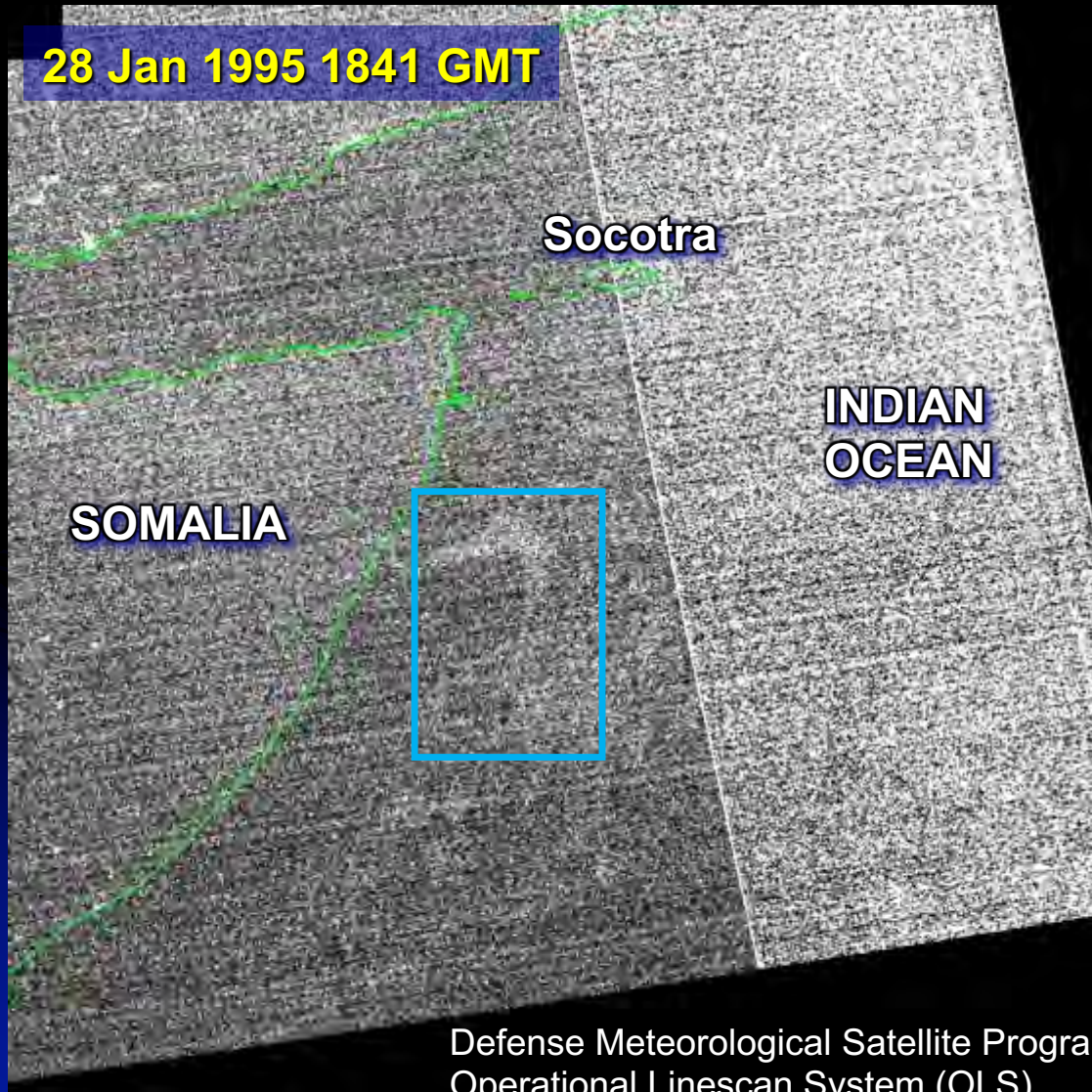
At 1800 UTC on a clear moonless night while 150 n. mile east of the Somali coast a whitish glow was observed on the horizon and, after 15 minutes of steaming, the ship was completely surrounded by a sea of milky-white colour

...it covered the entire sea area, from horizon to horizon and it appeared as though the ship was sailing over a field of snow or gliding over the clouds

The bow waves and the wake appeared blackish in colour and thick black patches of oil were passing by. Later, the Aldis lamp revealed that the 'oil patches' were actually light green kelp, amazingly black against the white water

—Captain J. Briand, S.S. *Lima*

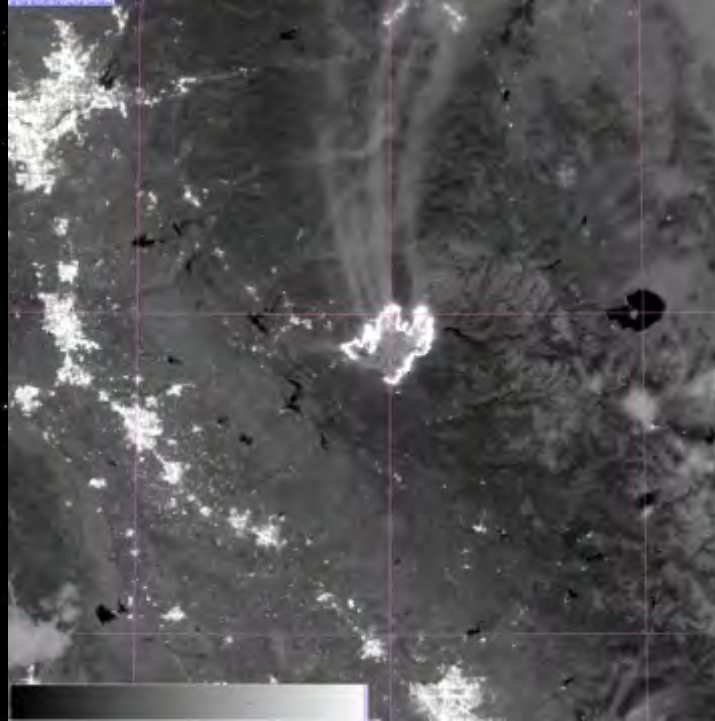
The *Smudge* that Changed Everything...



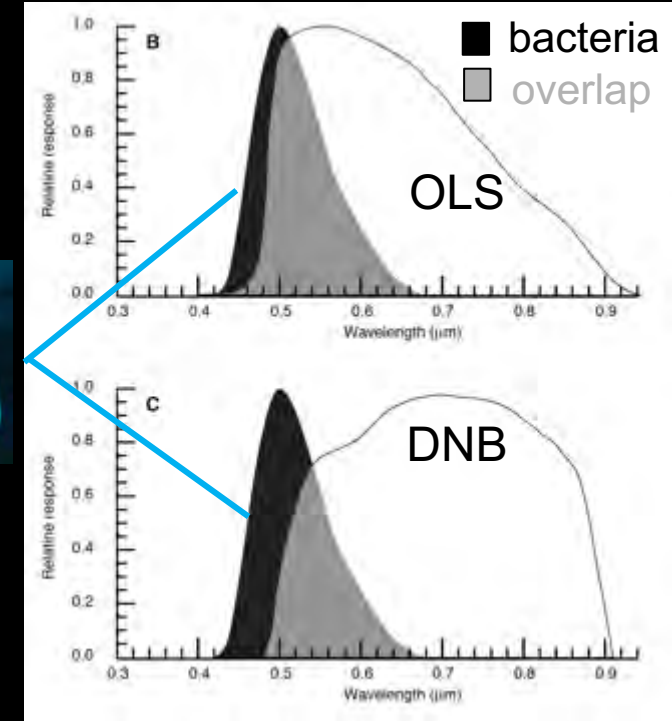
Can *New Generation* Low-Light Sensors See More?



The Day/Night Band flies on Suomi-NPP and NOAA-20
~3000 km swath, 742 m pixels,
500-900 nm bandpass
Sensitive to light ~10 million times fainter than sunlight!



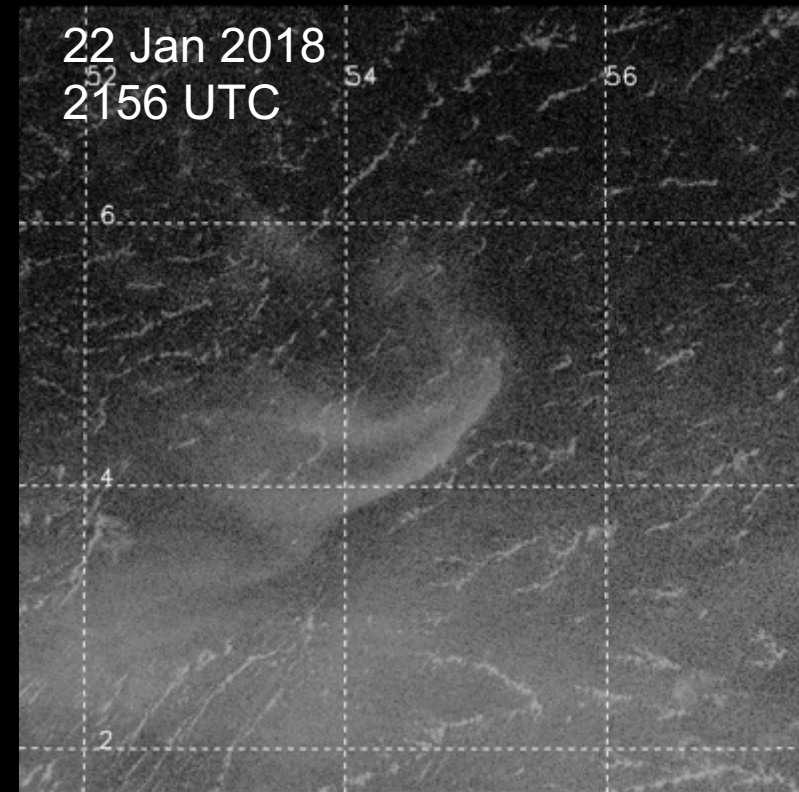
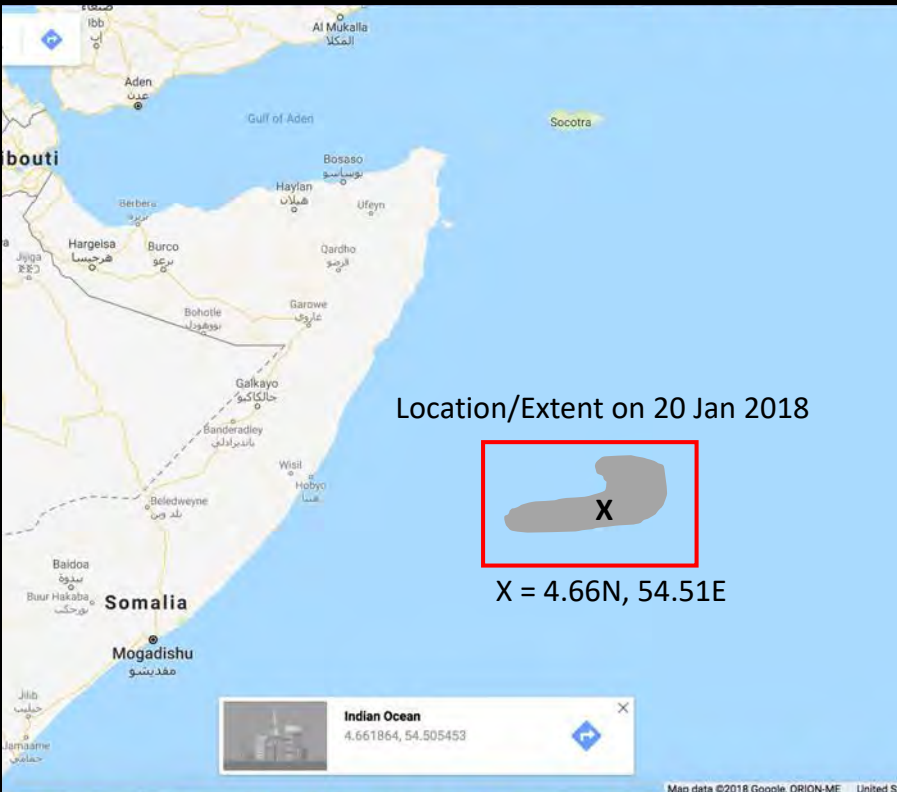
Myriad uses, from both emissive light (cities, fires, etc.) and reflected moonlight (clouds, snow, sea ice)!



Similar sensor response, but DNB is slightly red-shifted, making it ~2x less sensitive to bioluminescence...

After years of scouring the DNB imagery in the reported milky sea 'hot spots' to no avail, finally a breakthrough...

Return to Somalia, January 2018



(W. Straka) It's in SNPP and N20 at about the same spot. Relatively clear sky too. Thoughts?

(S. Miller) Climatologically speaking, it's the right spot (off Somalia) to see something, and very close to the date when the confirmed report back in 1995 occurred. Best thing might be to look at adjacent nights....the night before last and tonight...

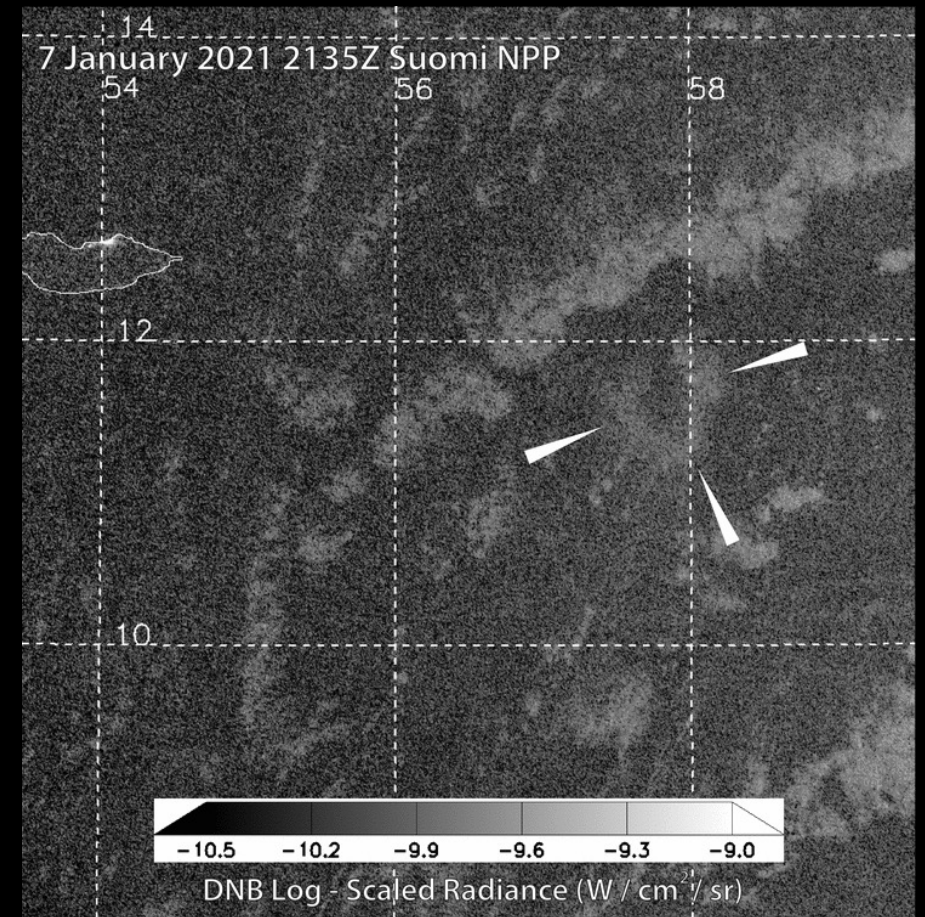
→ I just did this... Holy Cow...I think we have something here!!! Look—a stable feature over multiple nights!

NW Indian Ocean Hot-Spot

Northwest Indian Ocean

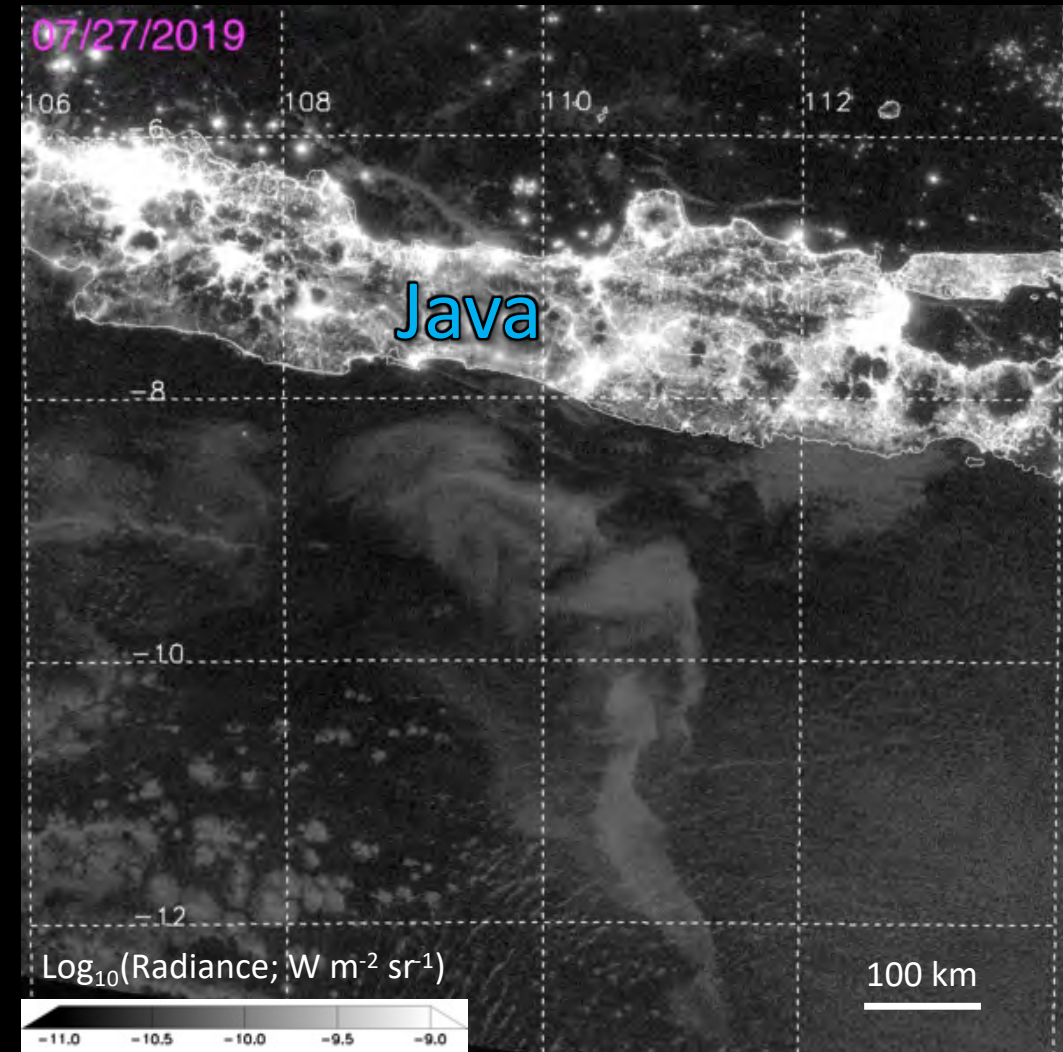


<i>Case Year and Region</i>	<i>Center Lat/Lon</i>	<i>Start Obs</i>	<i>End Obs</i>	<i>Area (km²)</i>
2013 Socotra	15N / 58E	31 Jul	13 Aug	9,000
2014 Banda	5S / 126E	20 Aug	24 Aug	18,000
2015 Somalia Phase 1	0 / 44E	15 Jan	28 Jan	23,000
2015 Somalia Phase 2	0 / 50E	21 Jan	26 Jan	60,000
2015 Banda	5S / 129E	12 Aug	18 Aug	30,000
2015 Socotra Phase 1	10N / 53E	07 Sep	11 Sep	750
2015 Socotra Phase 2	11N / 52E	12 Sep	20 Sep	12,000
2017 Somalia	2N / 47E	21 Jan	31 Jan	17,000
2018 Somalia Phase 1	2N / 47E	12 Jan	19 Jan	30,000
2018 Somalia Phase 2	5N / 55E	19 Jan	24 Jan	15,000
2019 Somalia	2N / 50E	28 Jan	07 Feb	100,000
2019 Java Phase 1	9S / 110E	25 Jul	09 Aug	100,000
2019 Java Phase 2	9S / 110E	25 Aug	07 Sep	50,000
2019 Banda	5S / 127 E	26 Jul	04 Aug	60,000
2021 Socotra/Somalia Phase 1	11S / 58E	07 Jan	22 Jan	10,000
2021 Socotra/Somalia Phase 2	7N / 52E	15 Jan	18 Jan	20,000
2021 Socotra	8N / 56E	07 Feb	20 Feb	6,000

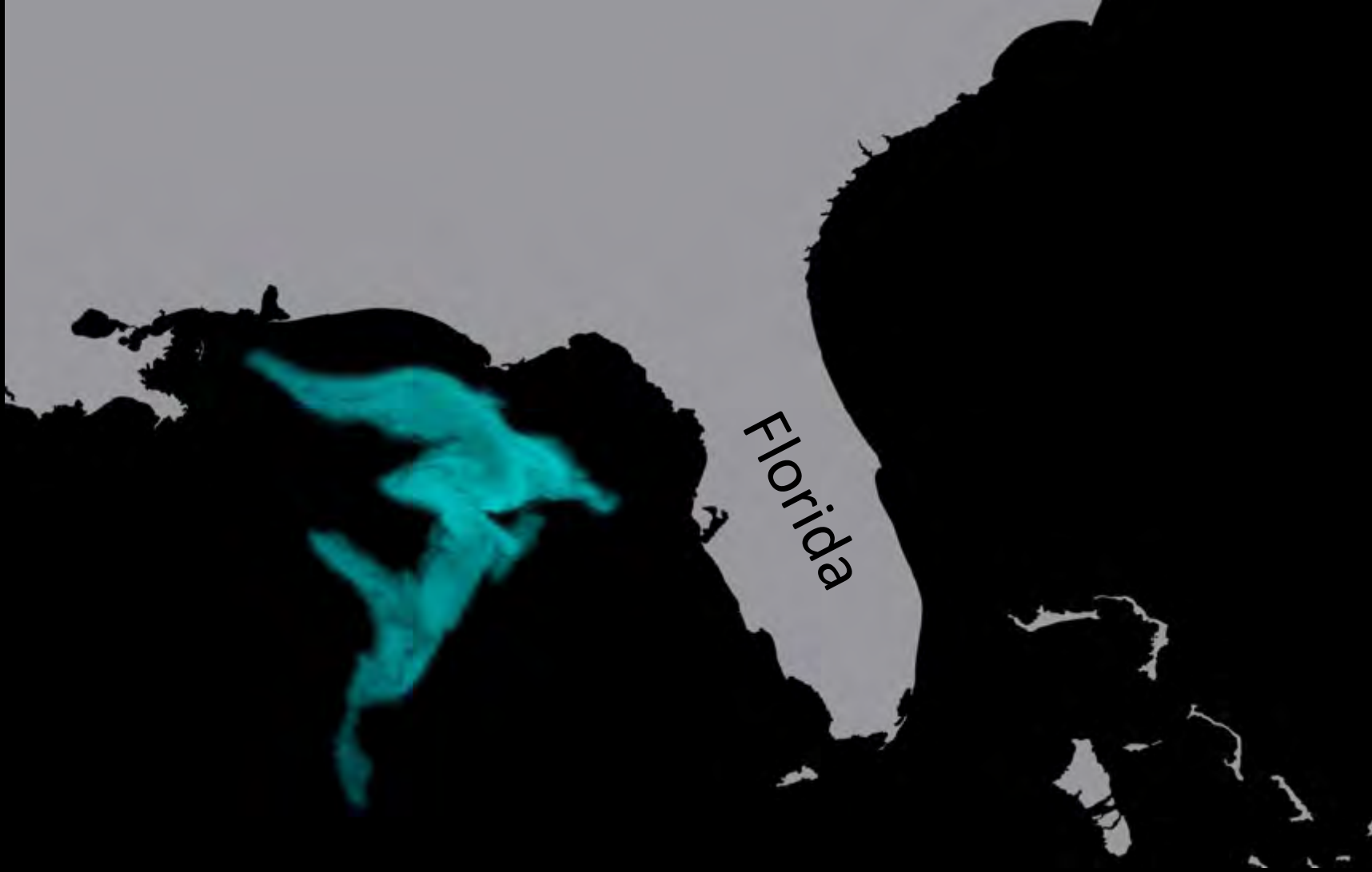


A Capstone Event: Java 2019

- While searching for examples of false alarms, we stumbled on a large milky sea south of Java.
- Wedged between two counter-clockwise warm eddies, it lasted *at least 45 nights* (observed 25 Aug – 7 Sep)
- Spatial coverage exceeded 100,000 km²
- All tests (cloud mask, parallax, persistent structure, correlation with currents, etc.) pointed to it being a milky sea...
- *But we lacked surface confirmation*
- We published the findings anyway, with hopes of making a connection...



For an Appreciation of Scale...

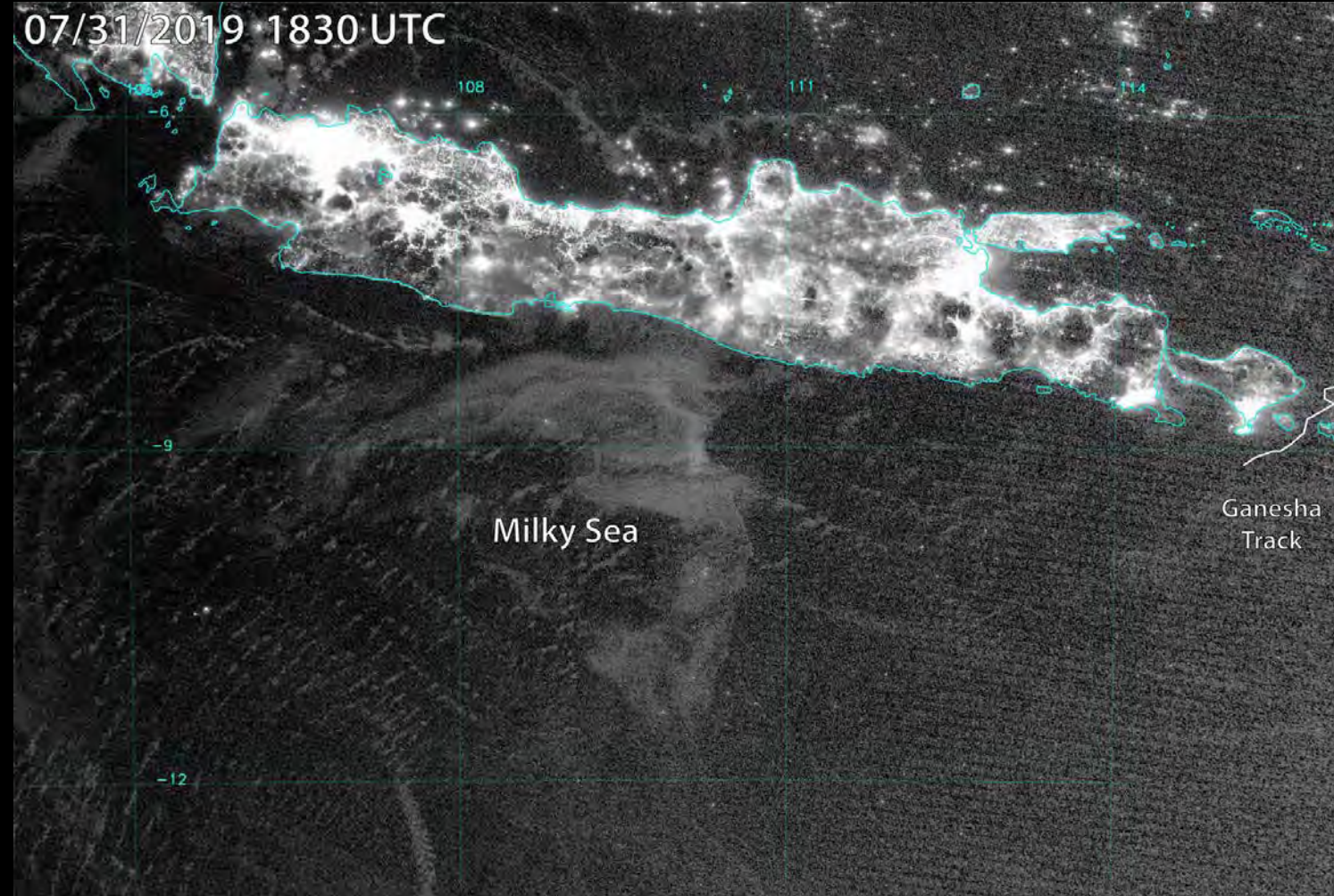


Ganesha's Milky Sea Encounter



Naomi McKinnon (left), a crew member of the yacht *Ganesha*, (Captain Johan Lemmens; right) reached out to us after reading an article in *The Conversation*.

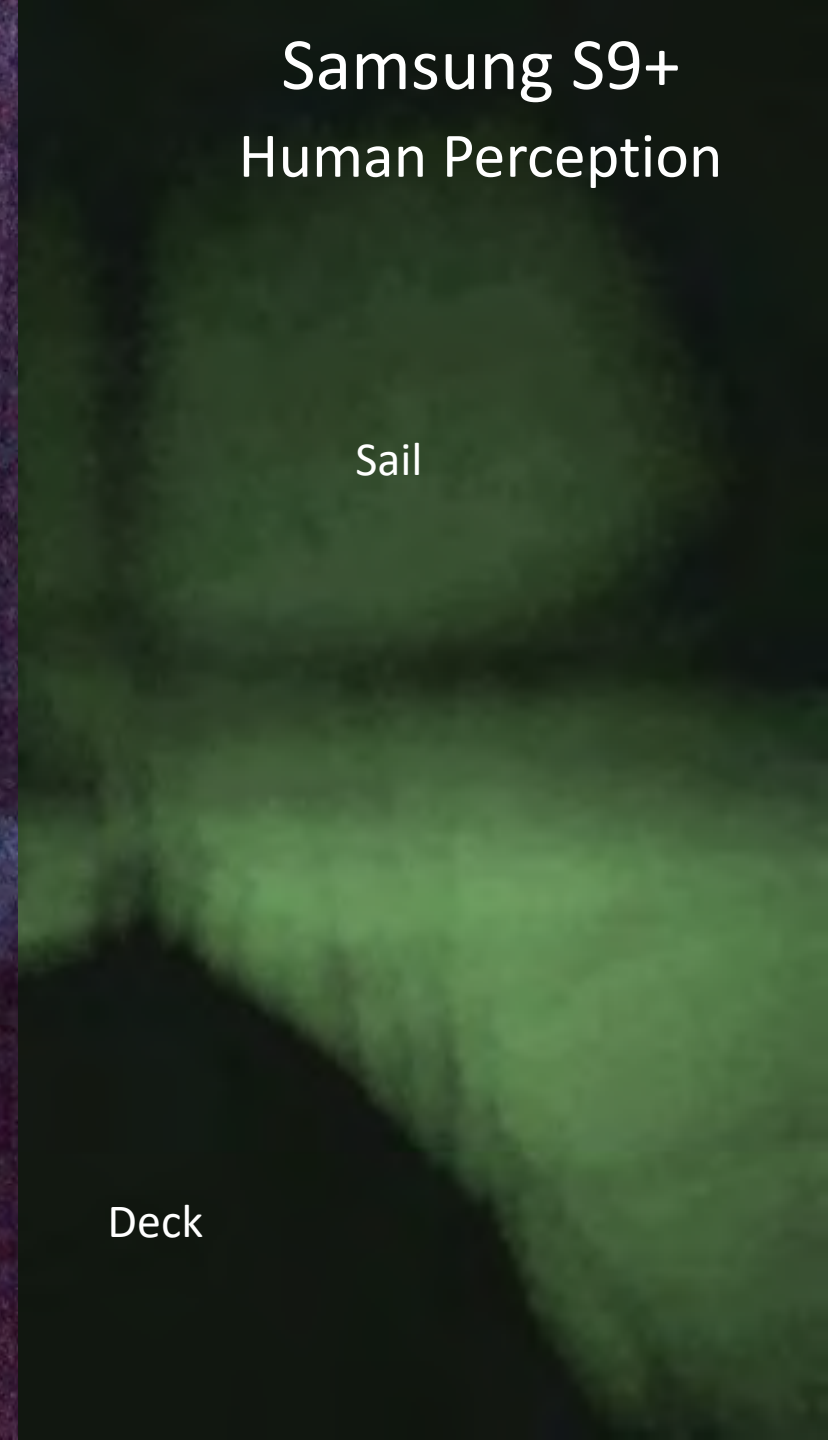
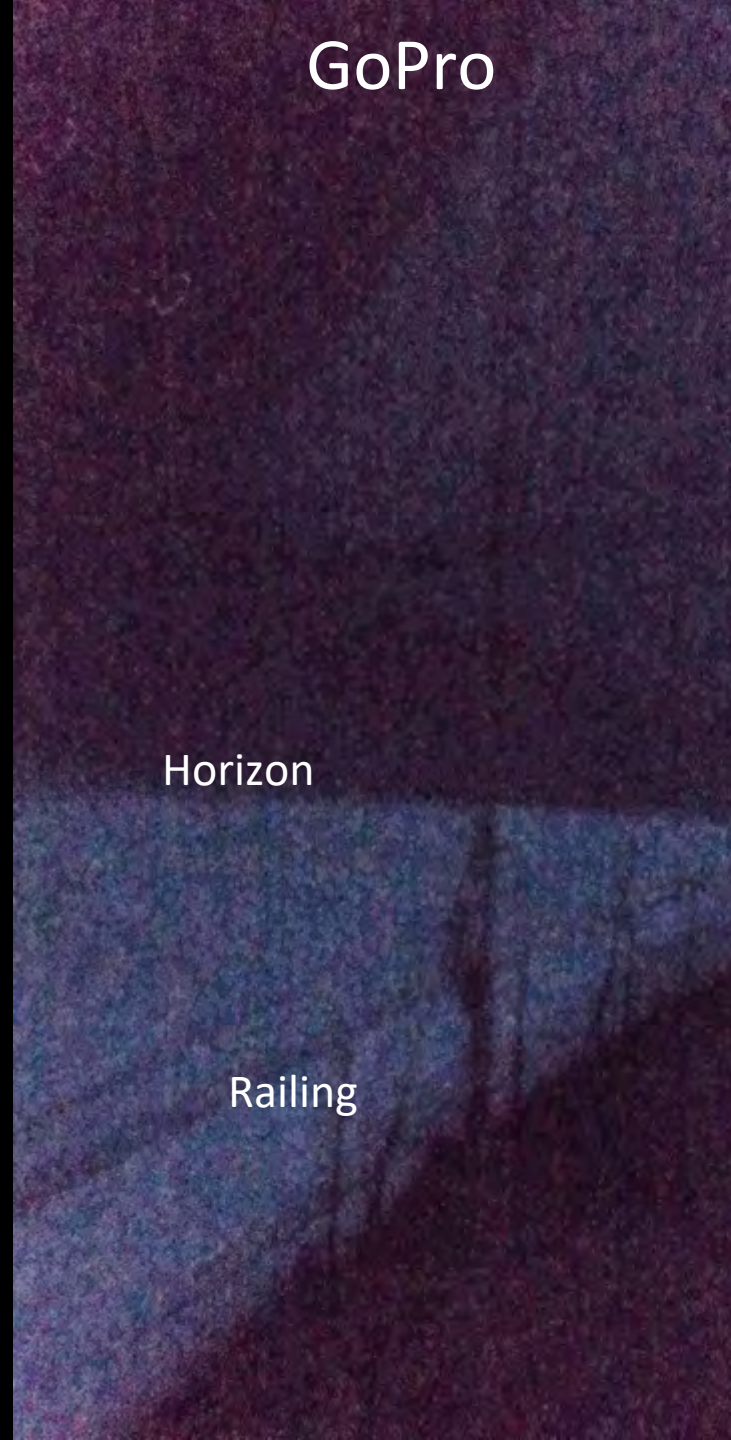
The crew shared their encounter with mysterious glowing seas south of Java on the night of 2 August 2019.



GPS-tracked course of Ganesha 7/31-8/4 2019

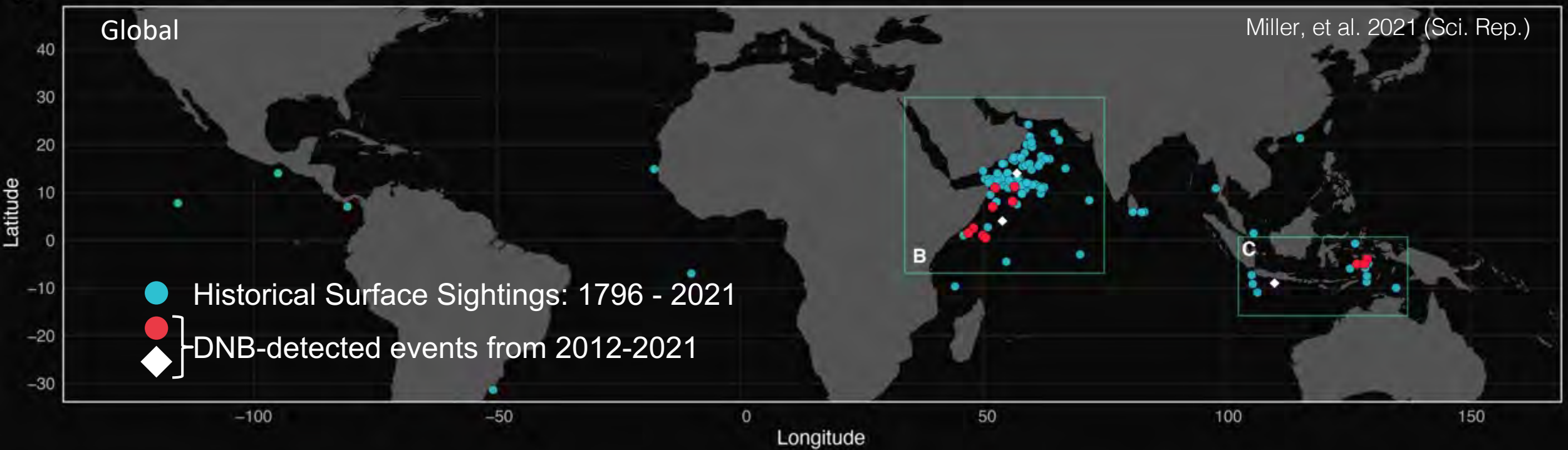
What They Saw...

- Crew captured first known photos of a milky sea!
- Steady glow appearing to emanate from ~10 m depth
- The bow waves were *black* (opposite to common bioluminescence)
- A bucket sample contained many pinpoints of glow that *darkened* upon stirring!
- Toilet water was glowing! :-)



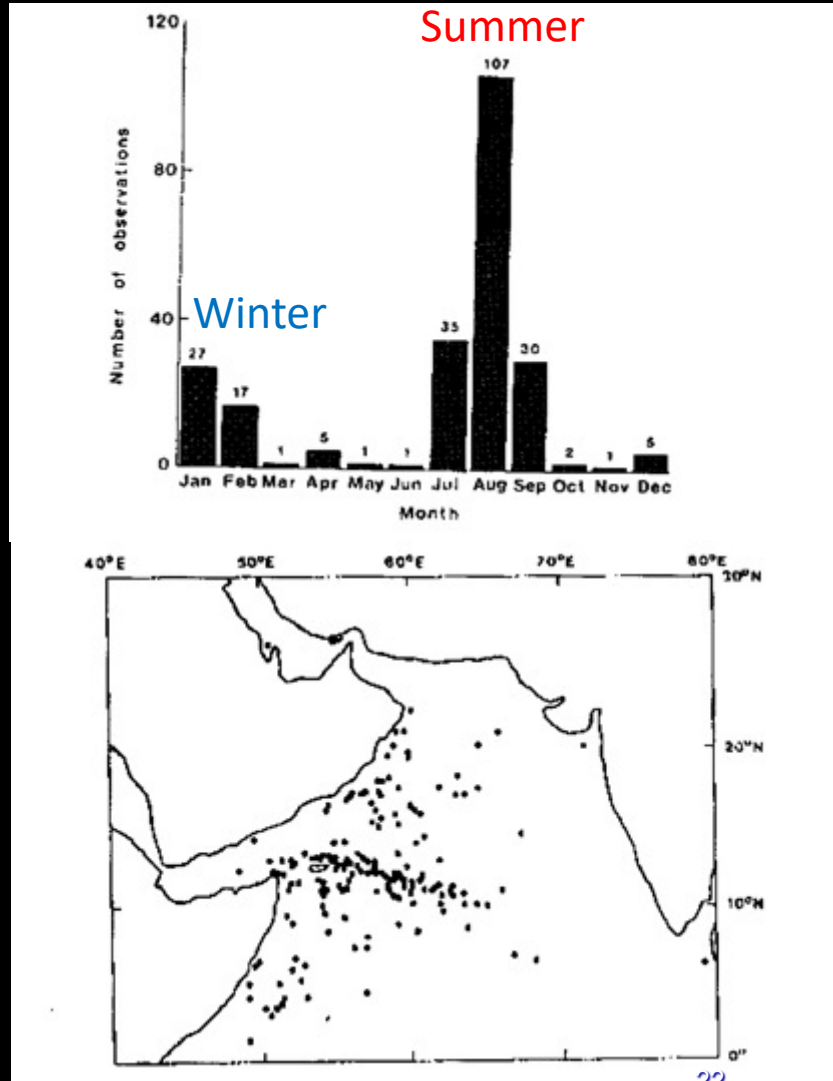
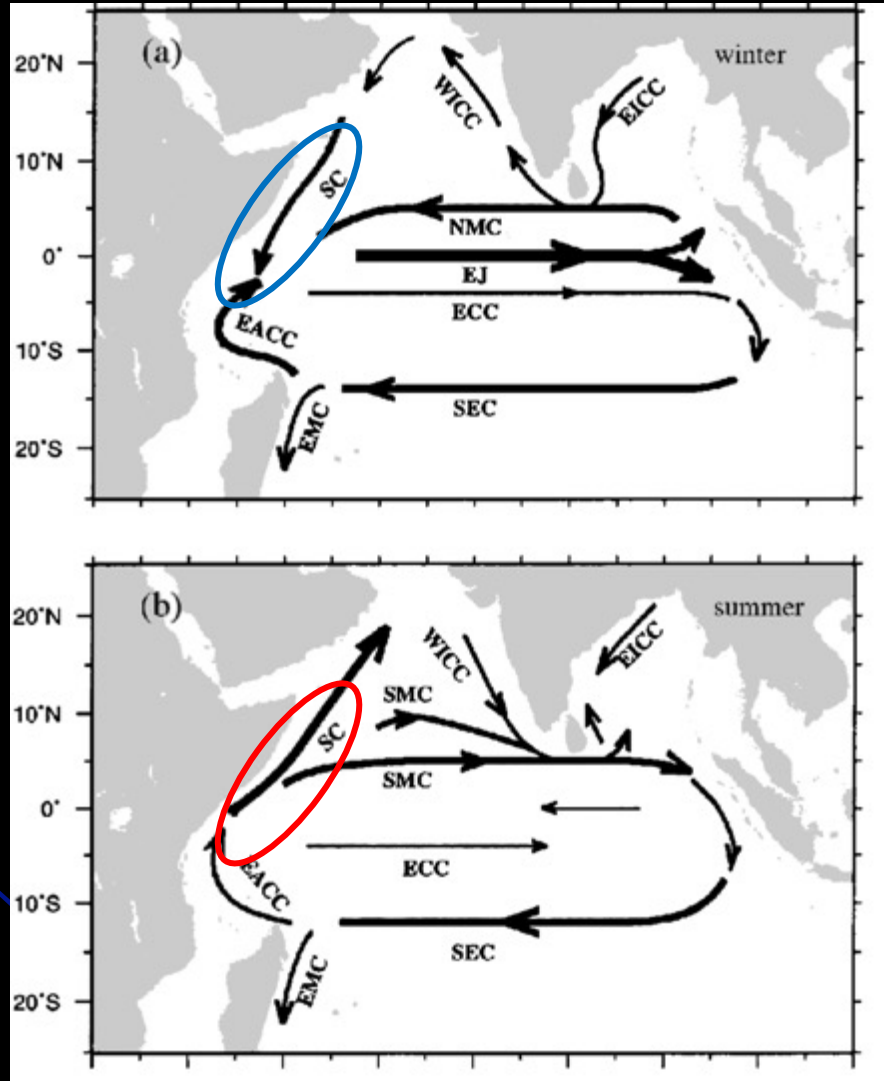
Aside from Toilet Water, how Can We Learn
More About Milky Seas...?

A



→ Distribution of Milky Sea Reports is Heavily Biased to the Indian Ocean

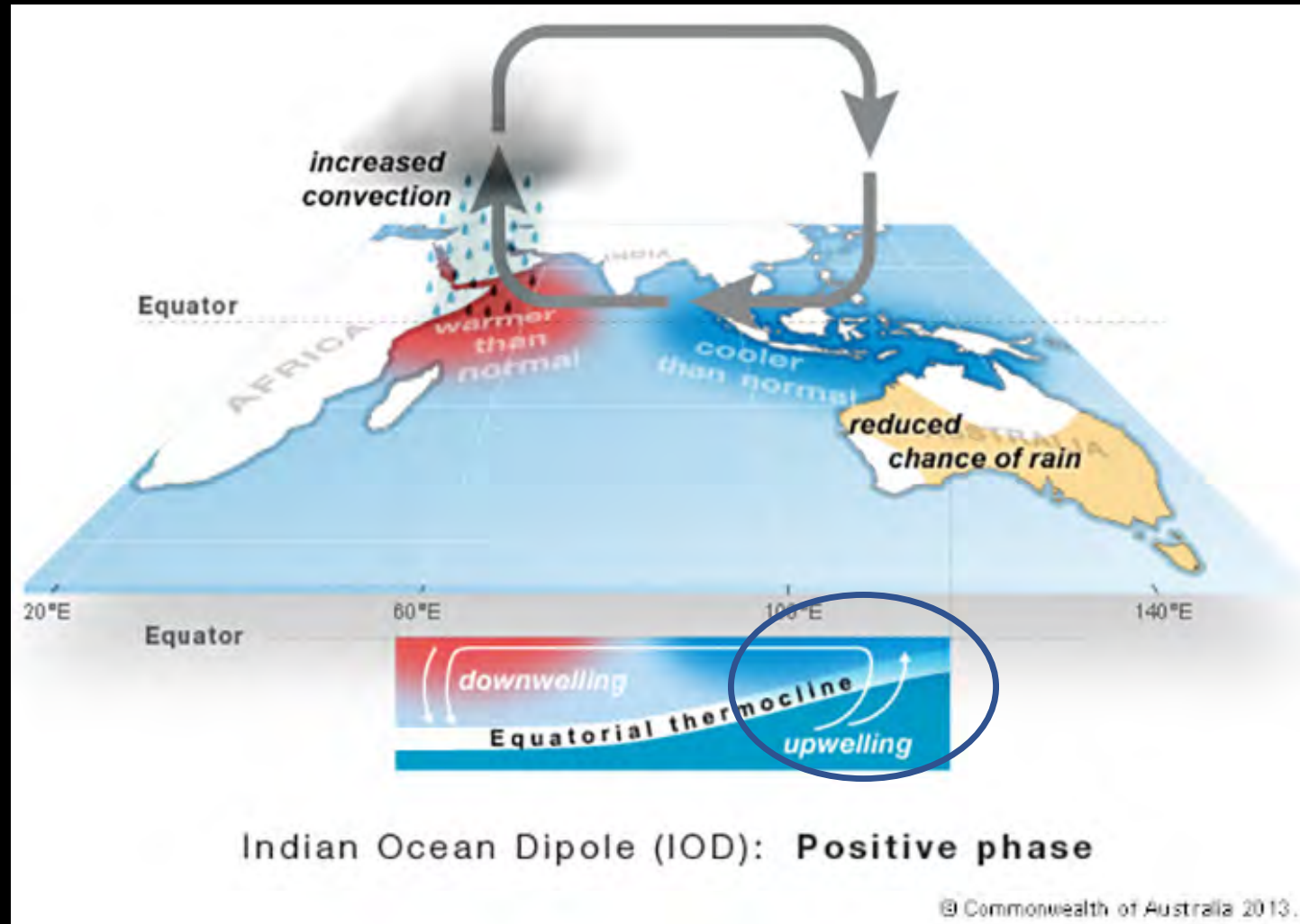
Northwest Indian Ocean: Synchronized with the Indian Monsoon



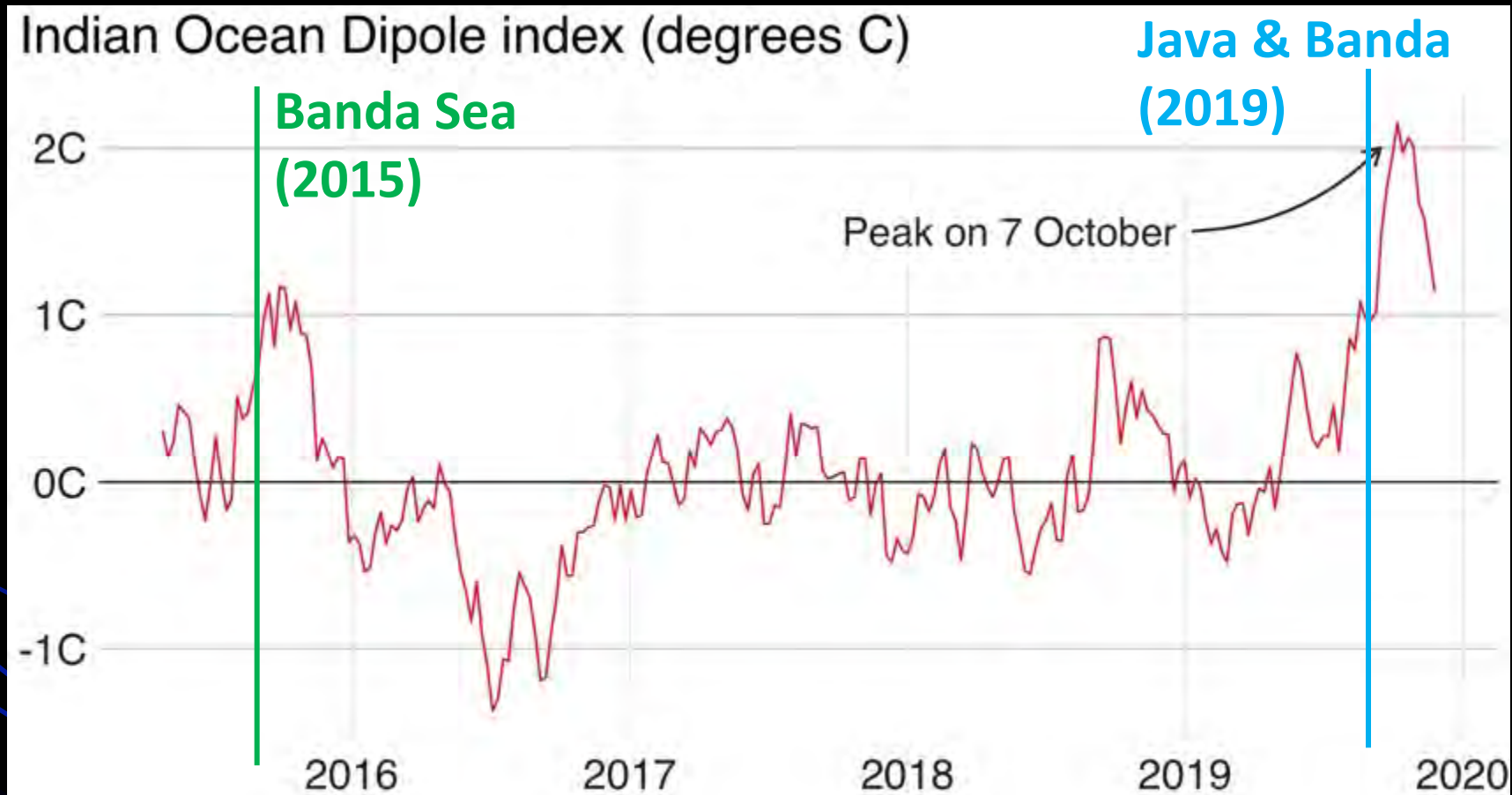
Shenoi et al., J. Mar. Res. 57, 885-907, 1999

Herring and Watson, Mar. Obs., 63, 22-30, 1993

Maritime Continent: *Links to the Indian Ocean Dipole (IOD)*



Correlation of Maritime Continent Events with Ramp-Ups of the Dipole Mode Index (DMI)

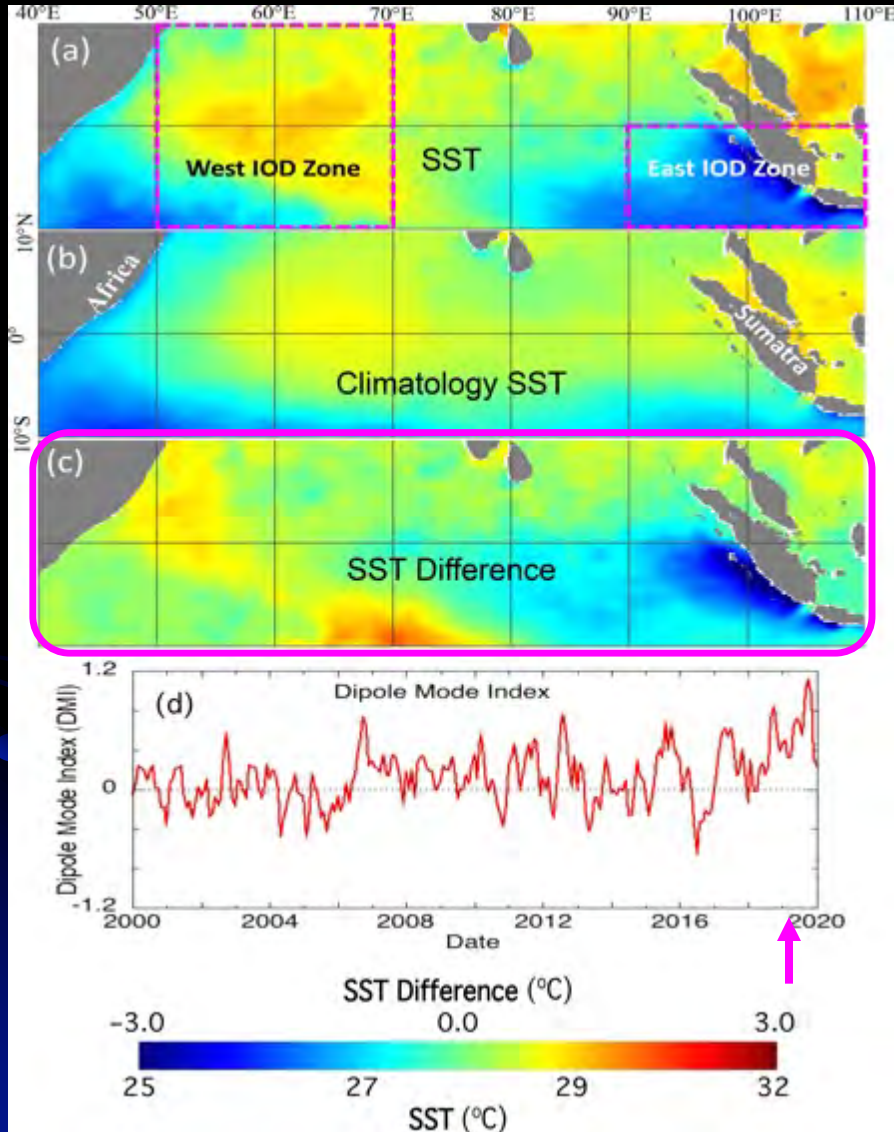


Note: Index refers to the temperature difference between two points in the Indian Ocean

Source: Australia's Bureau of Meteorology

BBC

Java 2019: A Major Positive IOD Phase



Unusually high whale shark sightings near Christmas Island in mid/late 2019!

But oceanic upwelling and chlorophyll blooms occur commonly, worldwide...

Why are milky seas seemingly so rare and regionally confined?

Some Observations, and Questions, Follow

Alignment with *Doldrums*

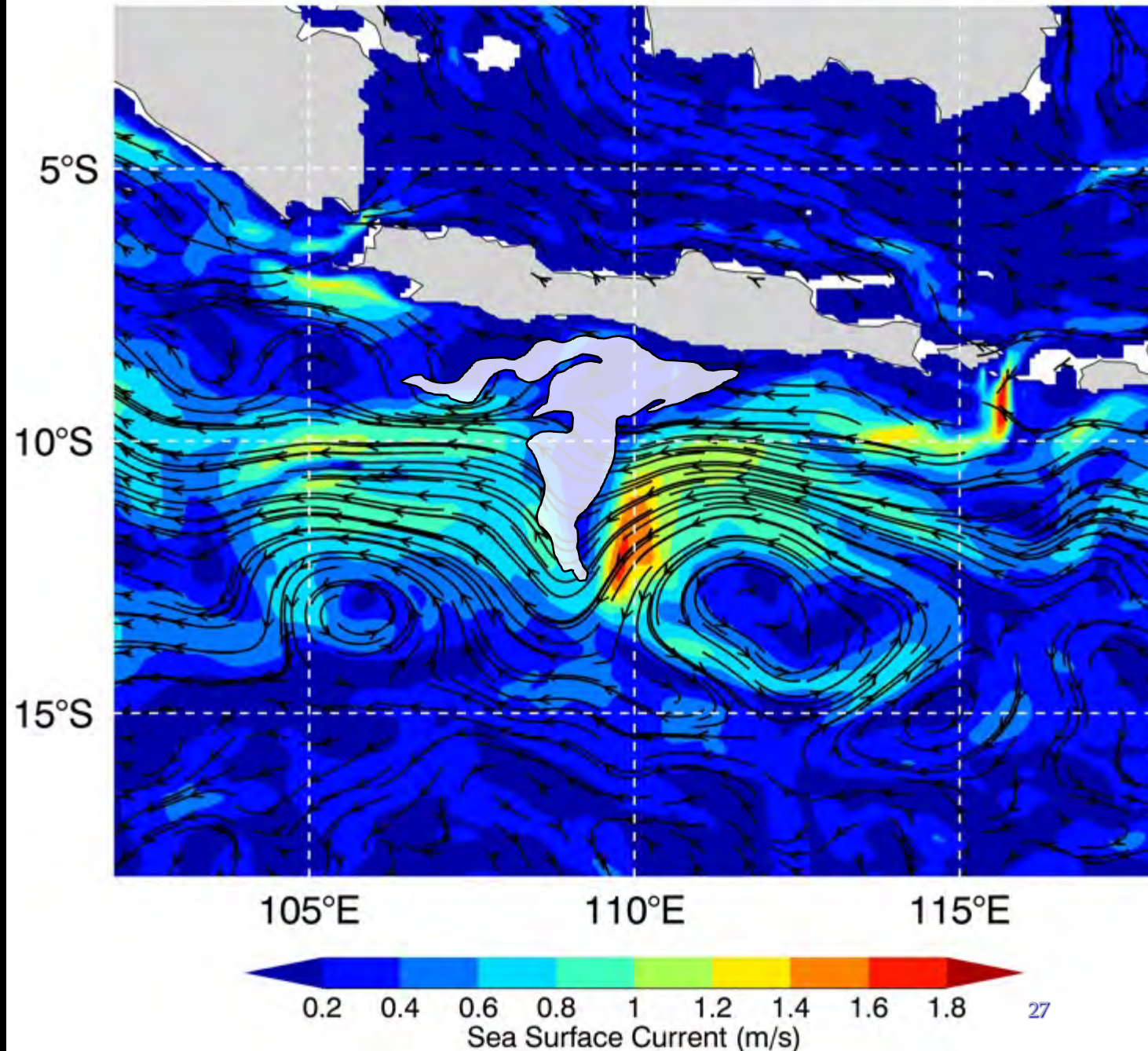
Observation:

Milky seas often form in quiescent environments, pooling areas, often nestled between stronger sea surface currents nearby...

Question:

What is the 3D structure of the water properties near these interfaces?

HYCOM 06 hour forecast valid 2019/08/07 at 18:00 UTC



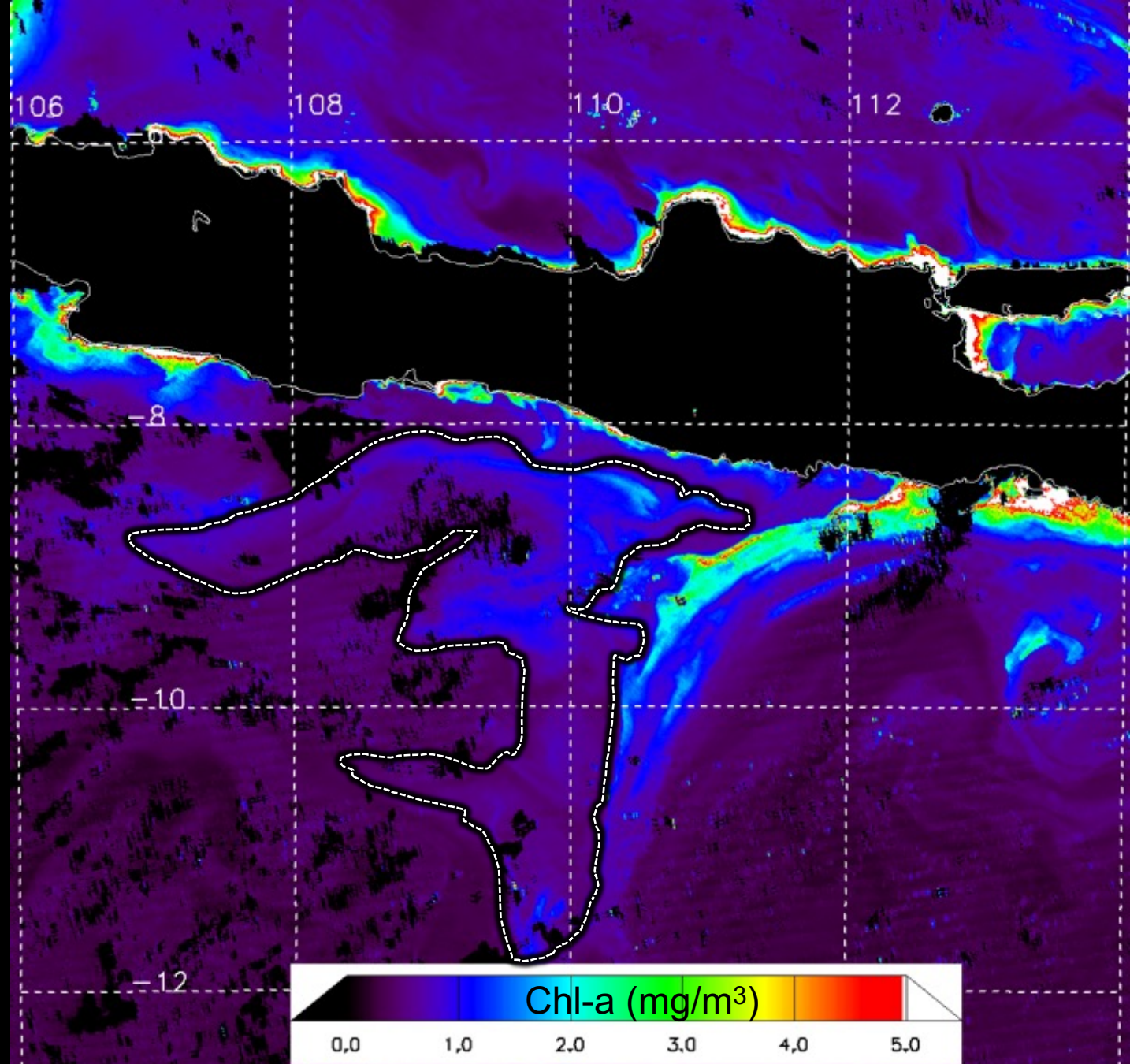
Links to SST Minima, Chl-a Maxima

Observation:

The strongest glow often occurs *adjacent to the coolest waters* and the highest biomass...

Questions:

1. How do Chl-a retrievals differ for *healthy* vs. *dying* algal blooms?
2. Does chlorophyll fluorescence (detectable by hyperspectral sensors in the *Red* part of the spectrum) tell us something about algal bloom health?

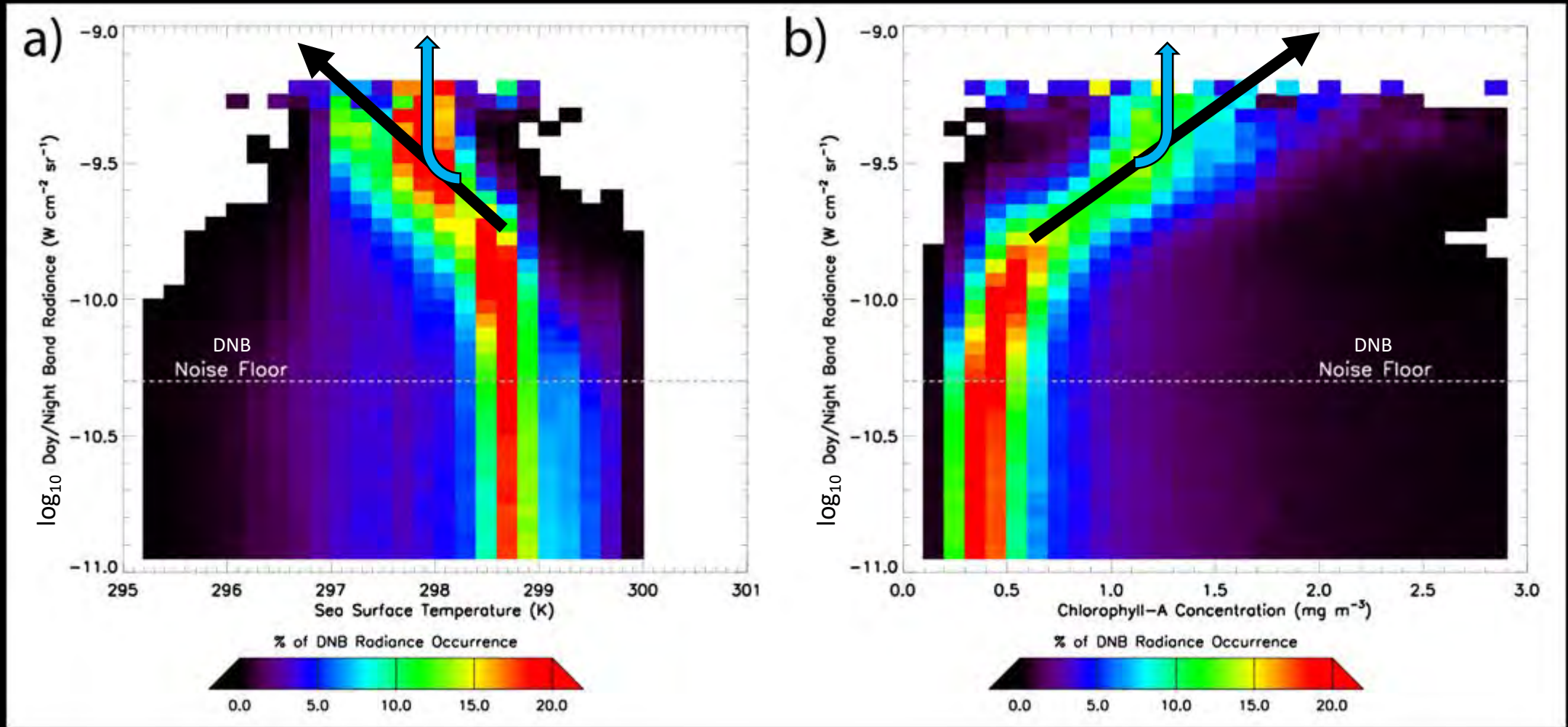


Observations: An Apparent Preferred Habitat...

Milky Sea Brightness

Sea Surface Temperature

Chlorophyll-a Concentration



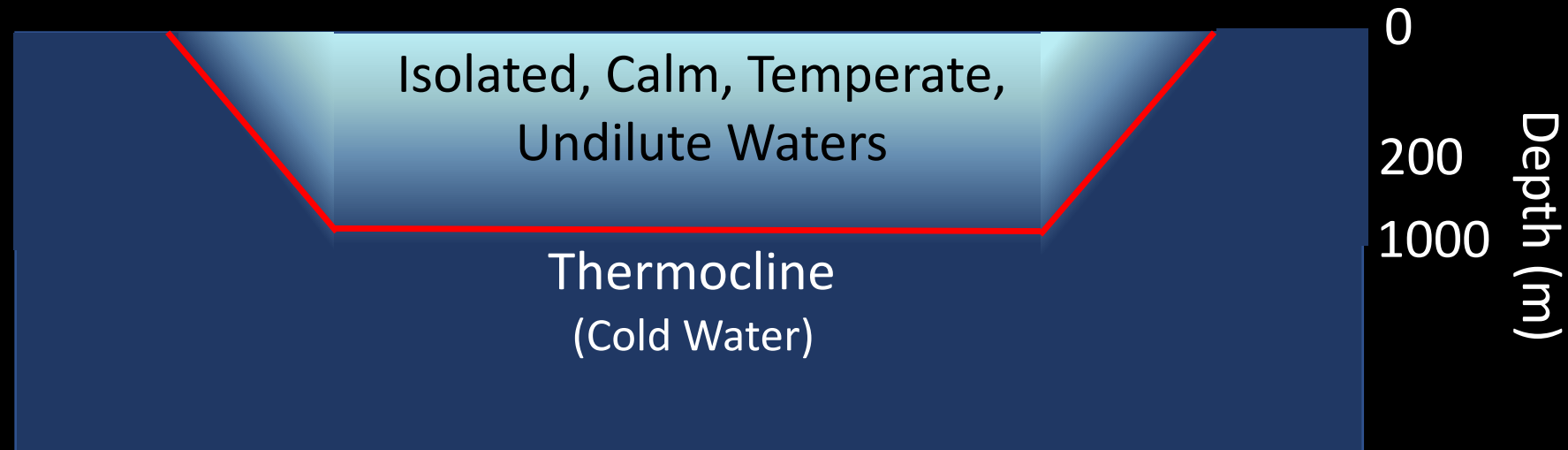
Goldilocks Hypothesis: A 'Natural Flask'?



What physical processes could produce an isolated body of water in the open ocean?

Shear-Induced Barrier Layers

Oceanic Fronts



Question:

Combined with the right temperature, organic content, chemistry, and strain(s) of luminous organisms, could a 'Natural Flask' contain & incubate a milky sea...?

In Pursuit of a Deeper Knowledge, We Must Dive into the Problem, Literally!



BIOSPHERE
FOUNDATION



Based in Bali



Well-Equipped



DIRECTOR SHARON SHATTUCK is an Emmy-nominated documentary filmmaker and podcast host. PICTURE A SCIENTIST (2020), about women scientists fighting gender discrimination and sexual harassment, was nominated for a 2022 News & Documentary EMMY and was distributed on NOVA (PBS) and Netflix. FROM THIS DAY FORWARD (2015), an autobiography about growing up with a transgender parent, was a New York Times Critic's Pick and was distributed on POV (PBS), Netflix, SundanceNow, Amazon, and iTunes. She's the co-host of the podcast 'CONVICTION: AMERICAN PANIC', about a family caught up in the 'satanic panic' of the 1990s, from Gimlet/Spotify. In February 2023, the protagonist of the podcast was exonerated by the state of Texas in part thanks to their reporting. Sharon is the co-creator of the EMMY-nominated New York Times Op-Docs series ANIMATED LIFE, which tells stories of scientific discoveries using delicate papercut animations. Sharon was one of DOC NYC and HBO Documentaries' 40 UNDER 40 filmmakers for 2021.

Grass Roots

The Quest Continues...

- The Day/Night Band has a *demonstrated ability* to detect and track bioluminescent milky seas from space.
- There remain *more questions than answers* in terms of milky sea composition, structure, and causality.
- *Potential new insights* to primary production on Earth, & to the search for life on ocean-world exoplanets?
- *In situ* sampling is needed to learn more about them.
- *Air-sea coupling* may help to explain and anticipate milky seas down to regional & sub-seasonal scales.
- Our satellite-based *eyes in the sky* can help researchers get to the right locations in time to sample them!



Thank You!!

Thoughts, Reactions, Advice...?

Steven.Miller@colostate.edu

Please Google "Milky Seas" to Learn More!

<https://www.nature.com/articles/s41598-021-94823-z>

<https://www.pnas.org/doi/10.1073/pnas.2207612119>

Backups

The Night is Replete with Light



Courtesy, the COMET Program

These sources are 1,000 to 1,000,000 times fainter than the daytime signals measured by conventional visible-band sensors.

Progress Will Take a Village...

US and British Navies



Private Mariners



The "Bio-Luminaries"

Peter Herring



Steve Haddock



Woody Hastings



Ken Neelson



Dave Lapota



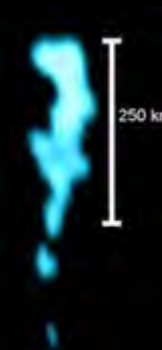
Commercial and Historical



Avoid the Pirates!

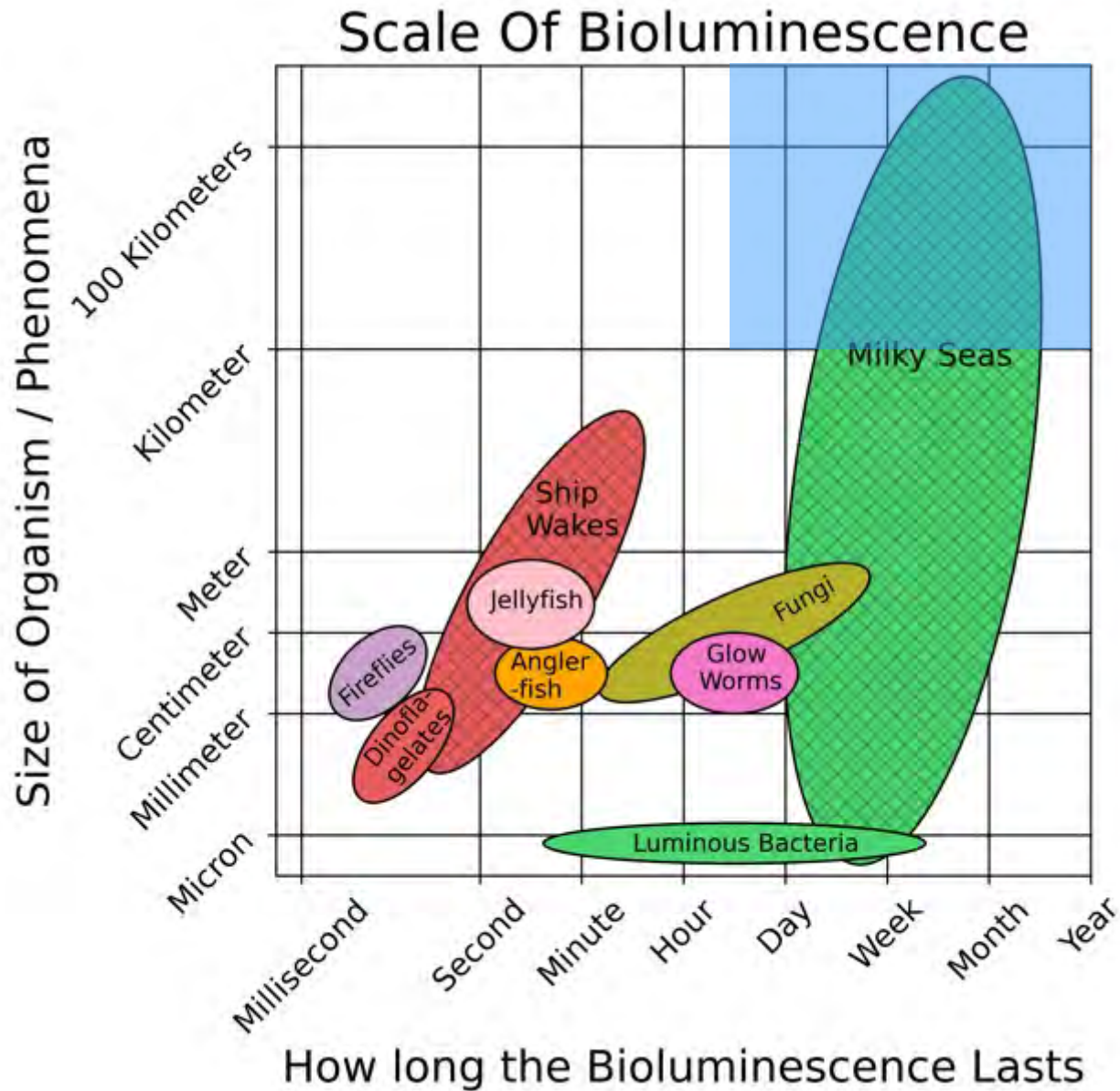


Navigate Social Media



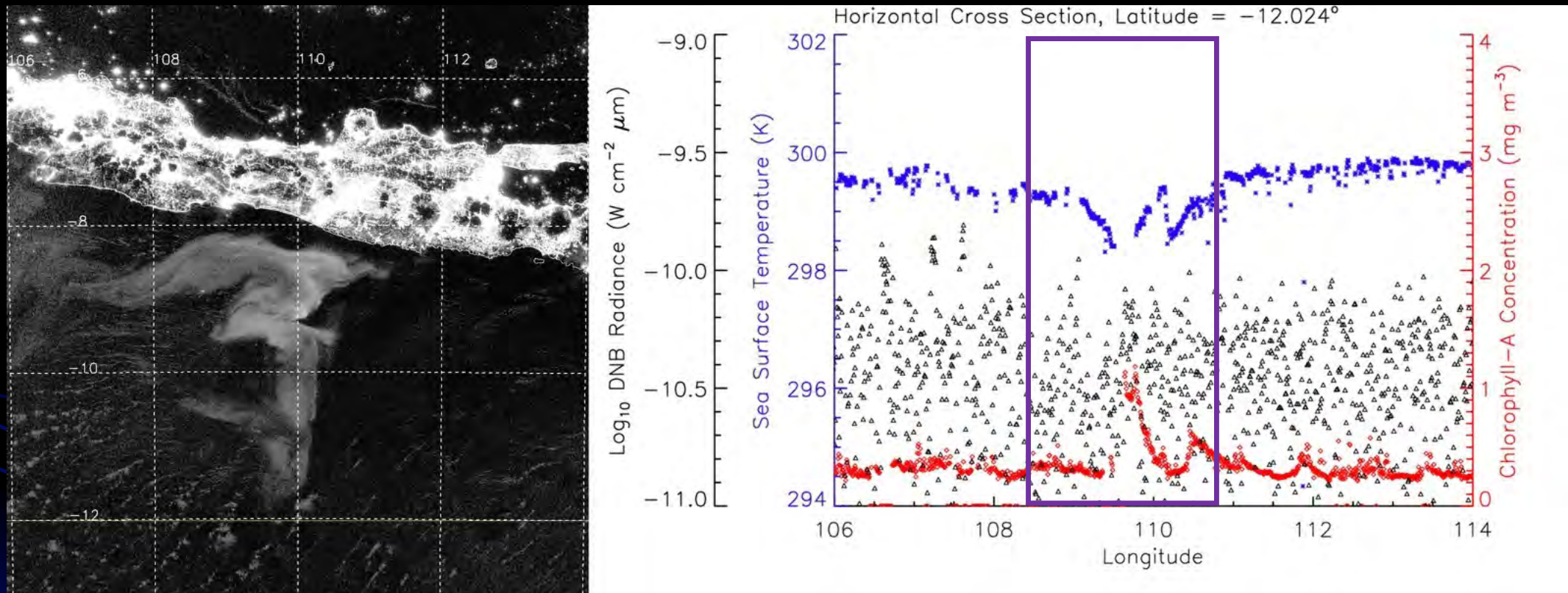
Thanks to Sponsors/Advocates!





Resolving Capabilities
of Current Satellite
Remote Sensing
Technology

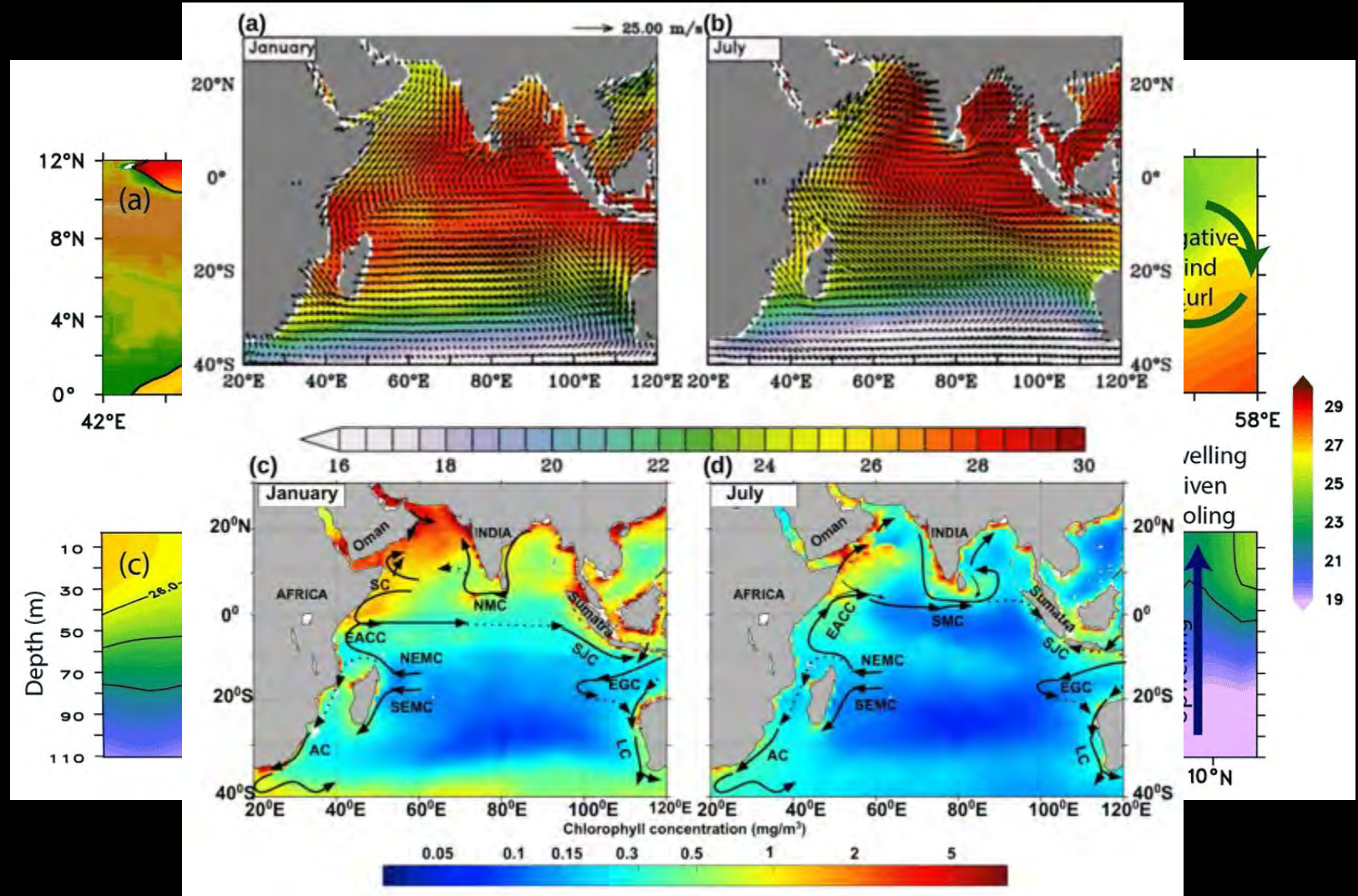
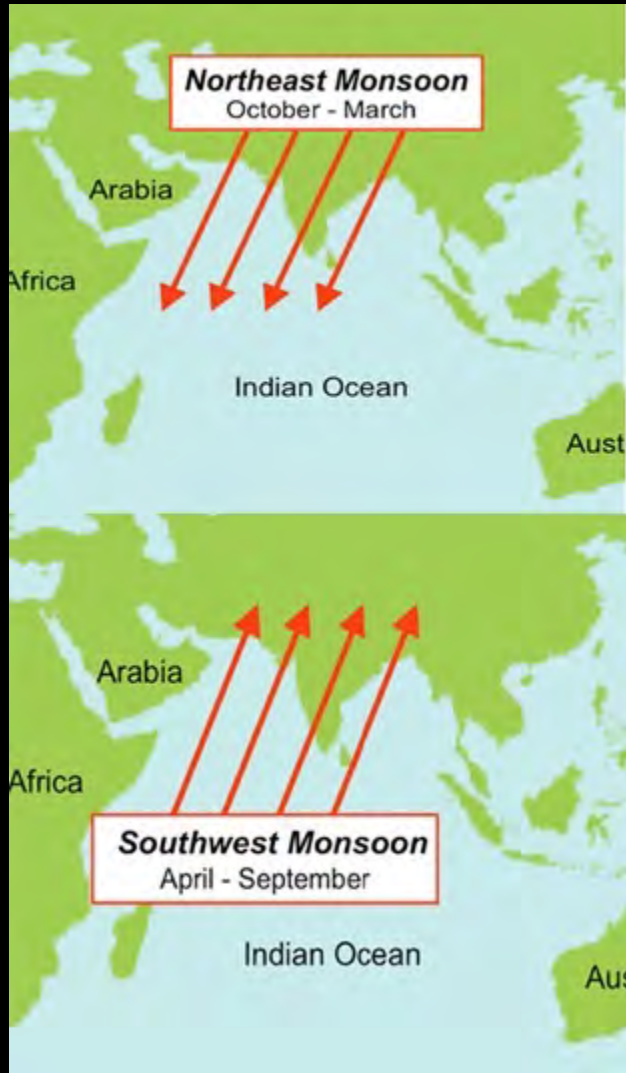
Cross Sections Show 'Glowing Waters' +/- Correlation with SST and Chl-a...



→ Correlations between glow intensity and sea-surface biomass and temperature are apparent. [Statistics on Chart 30 of this presentation.](#)

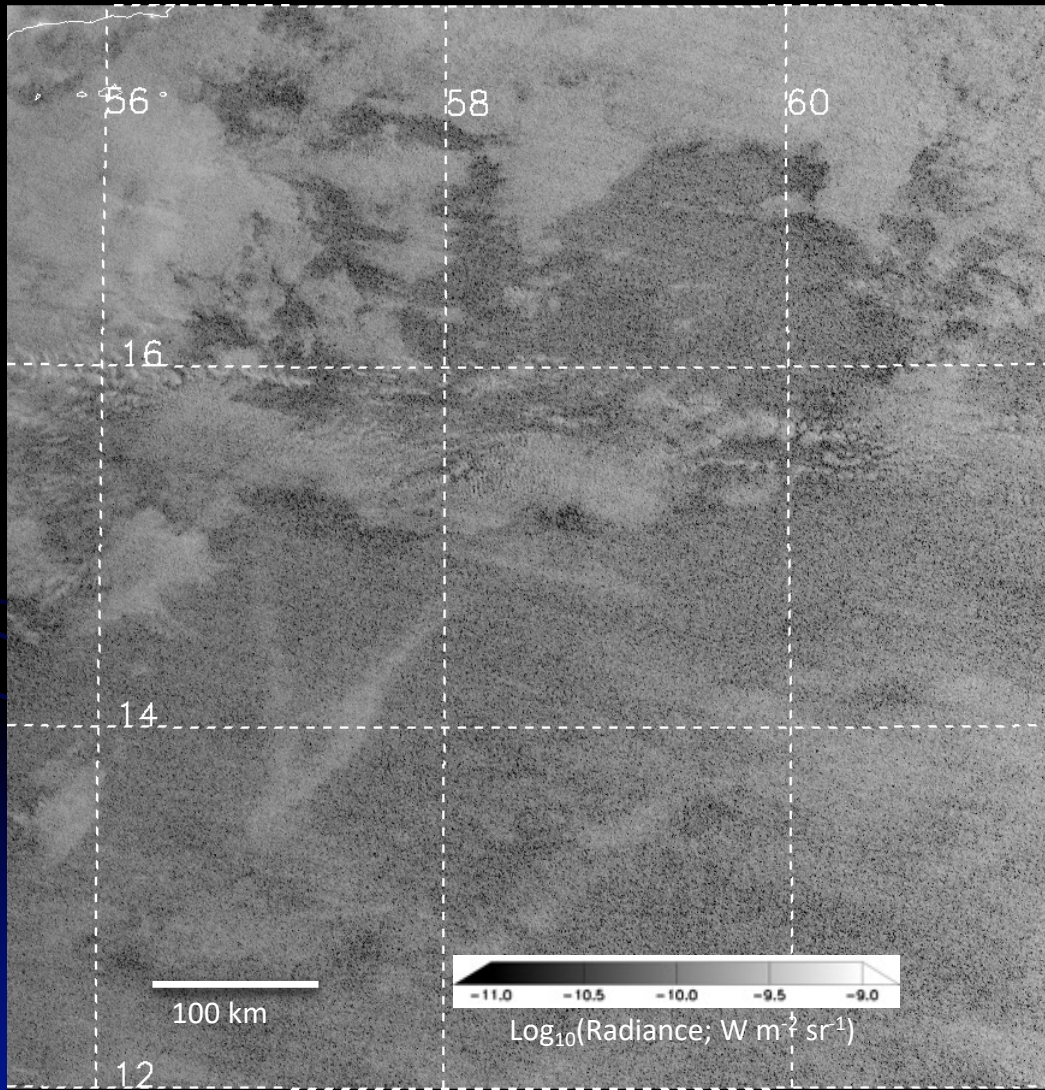
Air-Sea Coupling: The Indian Monsoon

Tibetan Plateau Cooling/Heating

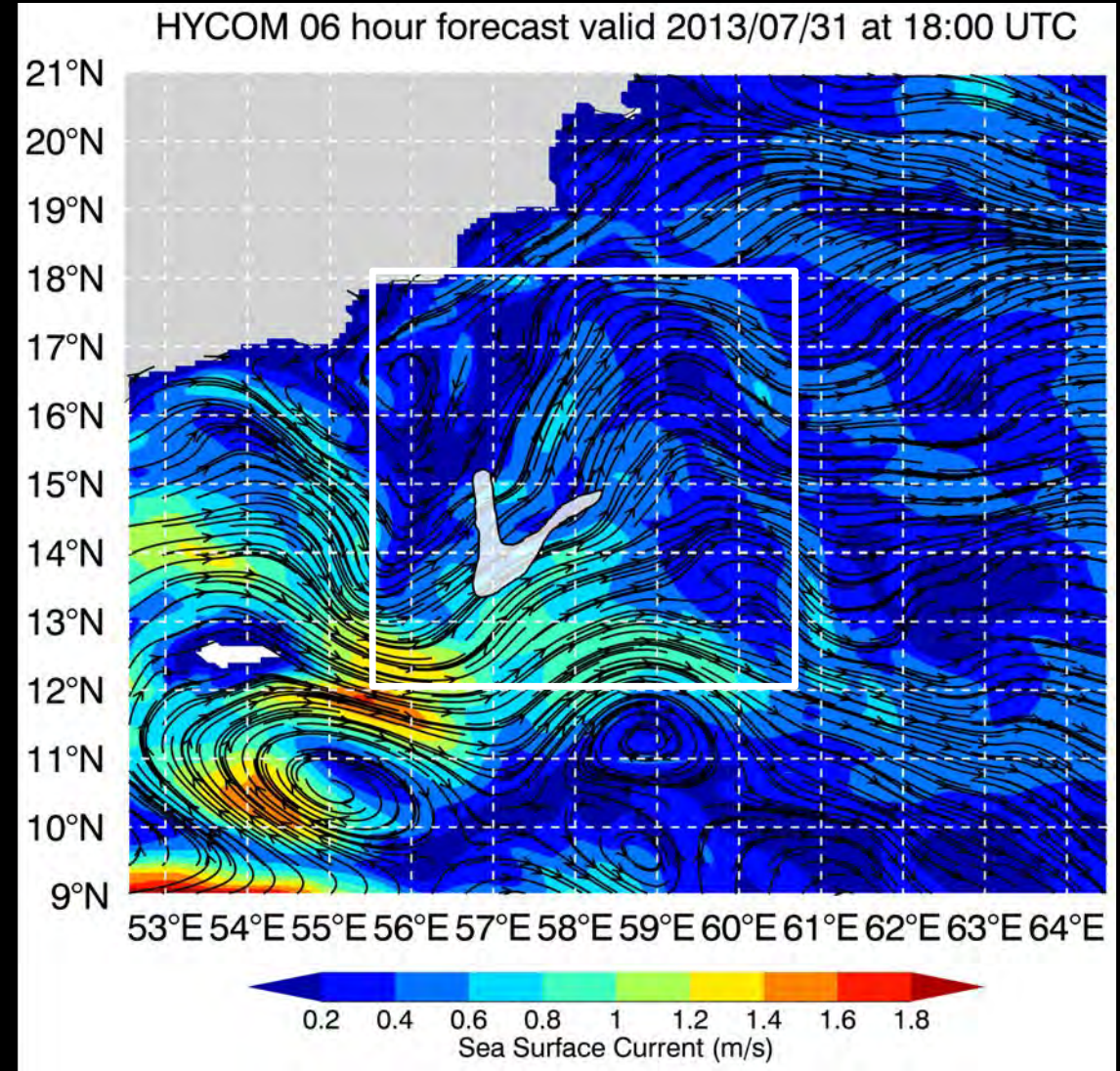


Vinayachandran et al., Biogeosciences, 2021

2013 Socotra Milky Sea: *Drifting Out of Doldrums Between Eddies*



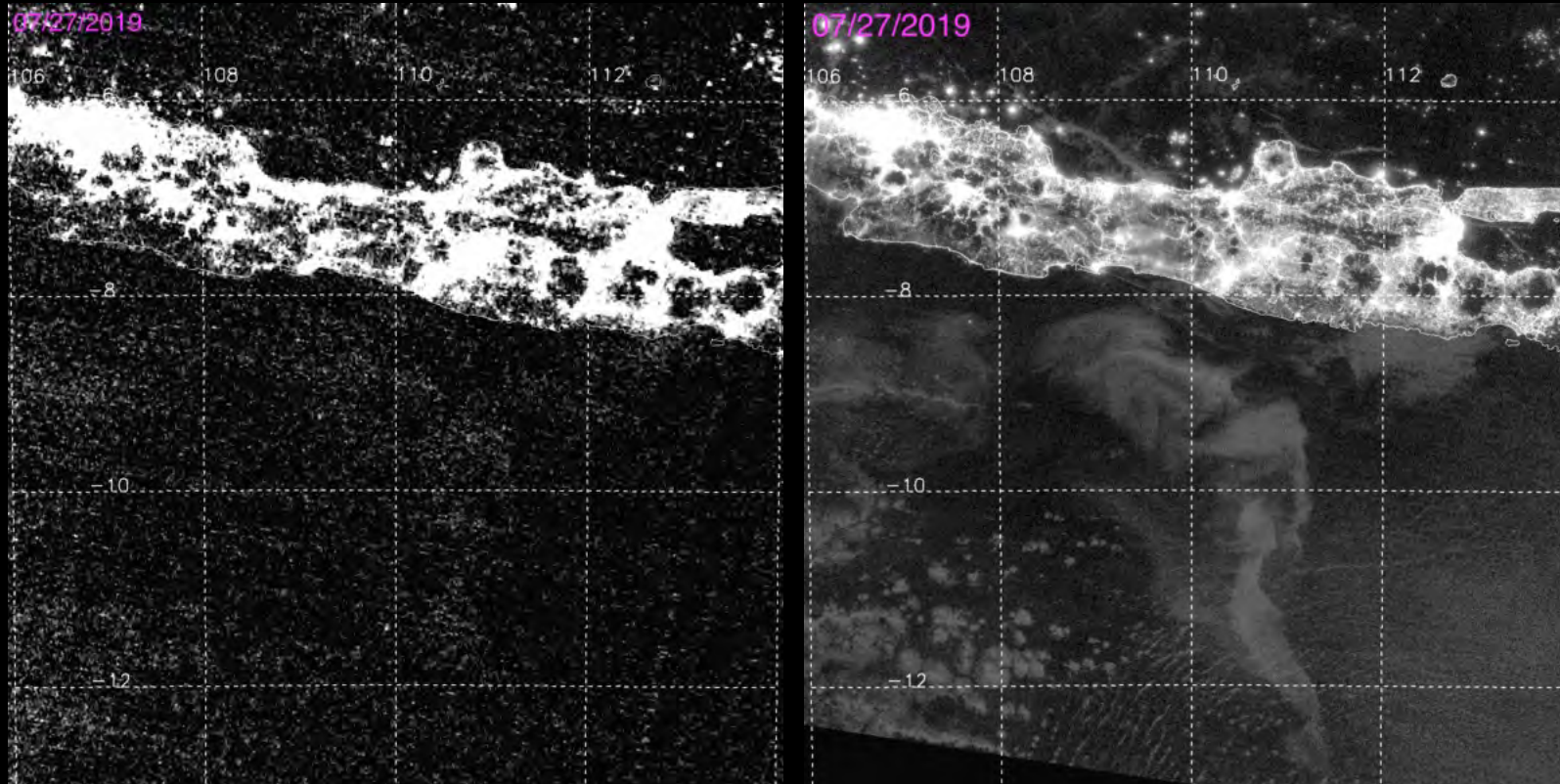
Areal coverage: $\sim 10,000 \text{ km}^2$



Technology Improvement Over Legacy Sensors!

OLD: DMSP/OLS

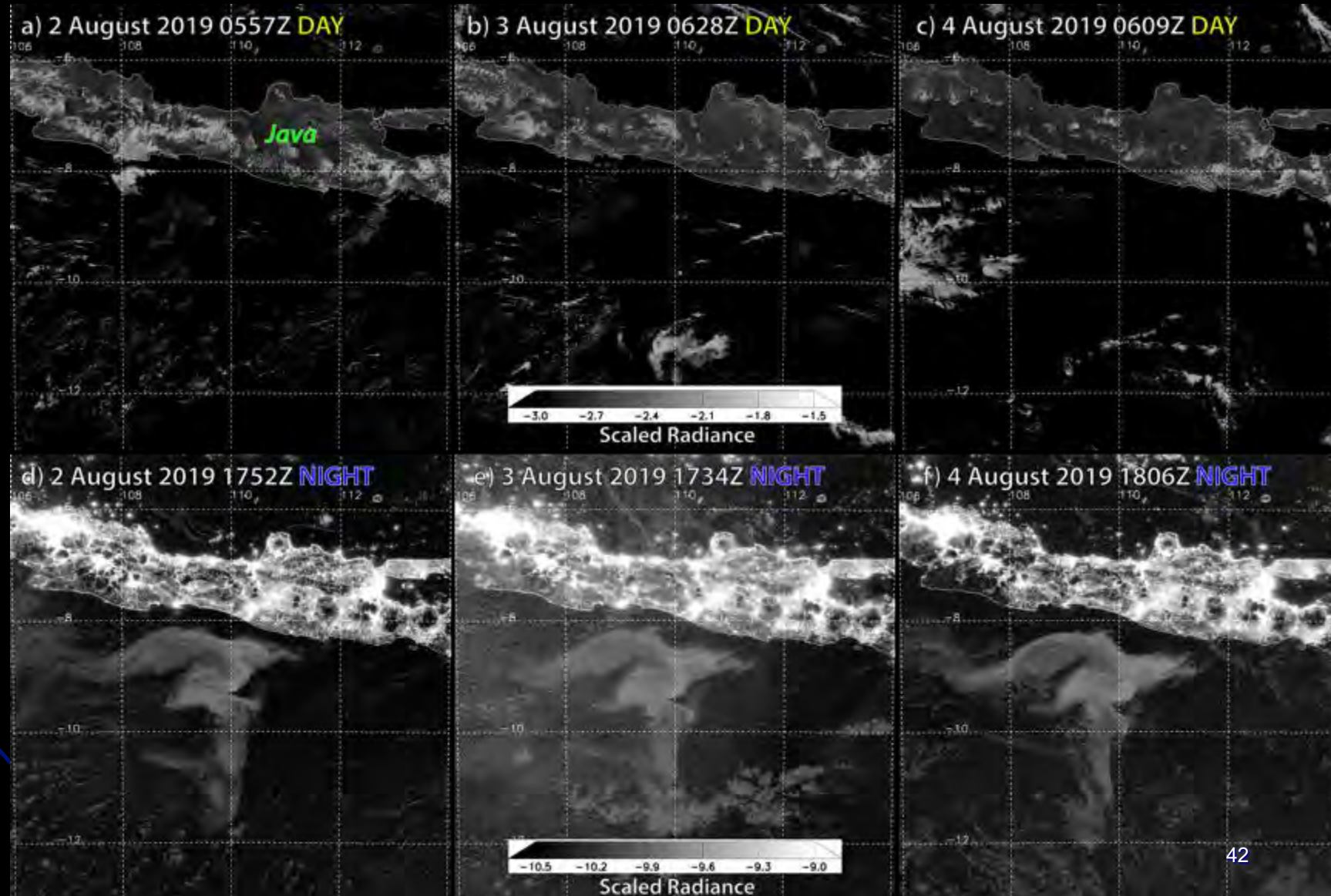
NEW: VIIRS/DNB



→ The DNB can help us detect milky seas *remotely, and perhaps autonomously* (e.g., machine learning techniques)

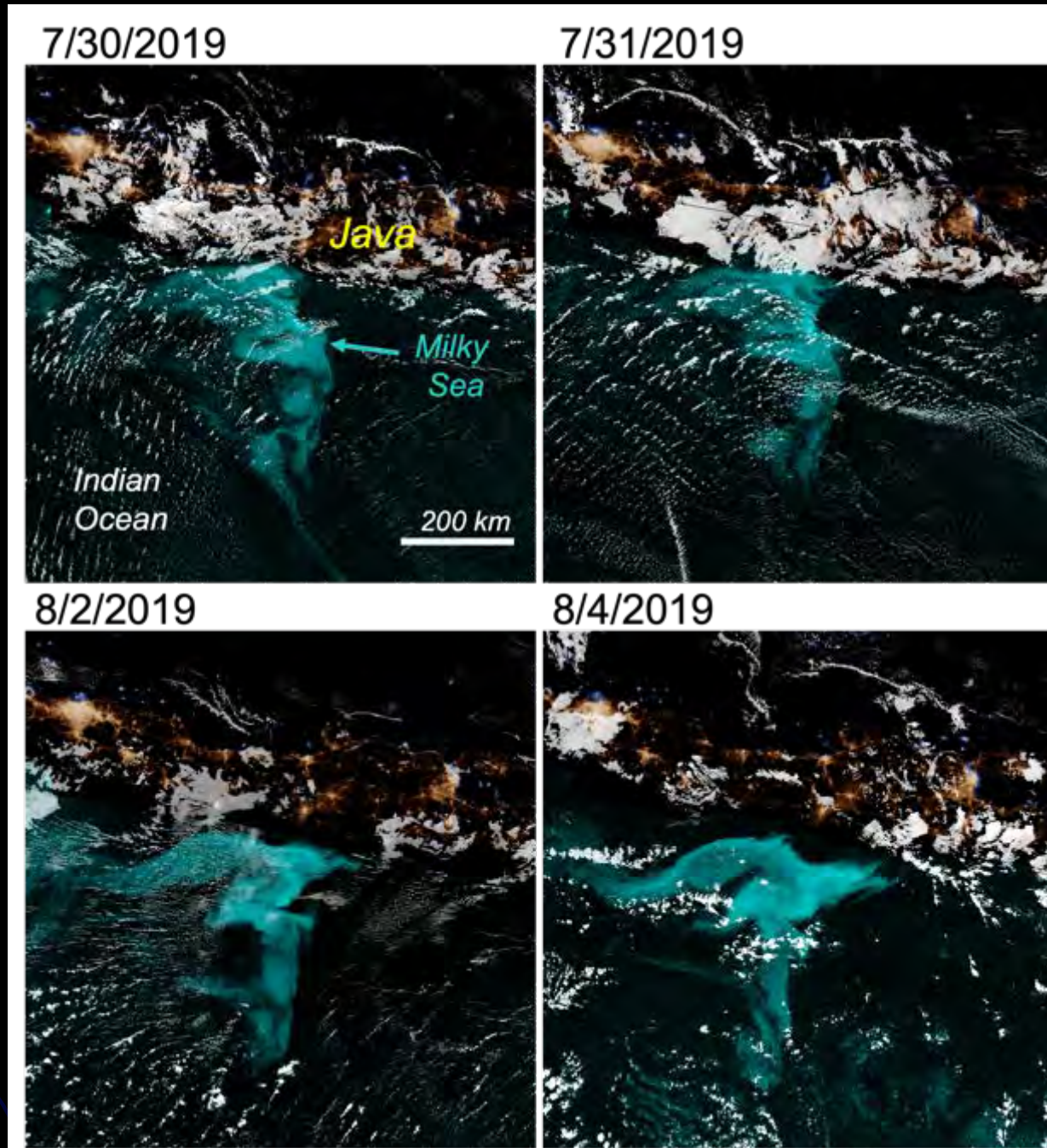
Daytime Vanishing Act → *Emissive Signal!*

- Persistent feature amidst the ever-changing cloud field. Produced neither IR nor reflective signatures.
- Detectable only on moonless nights (moonlight is 100-1000x stronger than most bioluminescence signals).
- Slow drift consistent with U.S. Navy HYCOM model sea surface currents

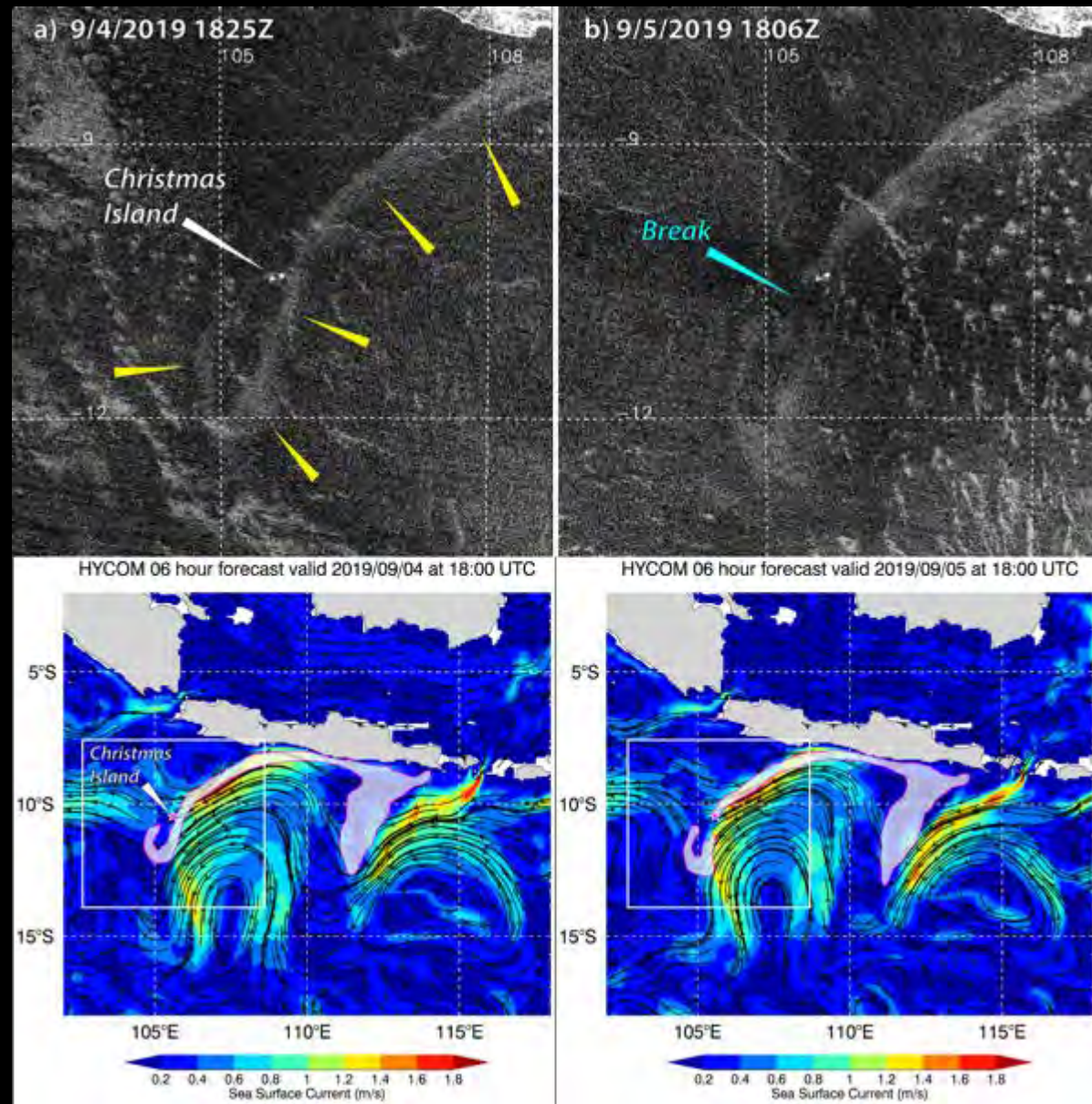
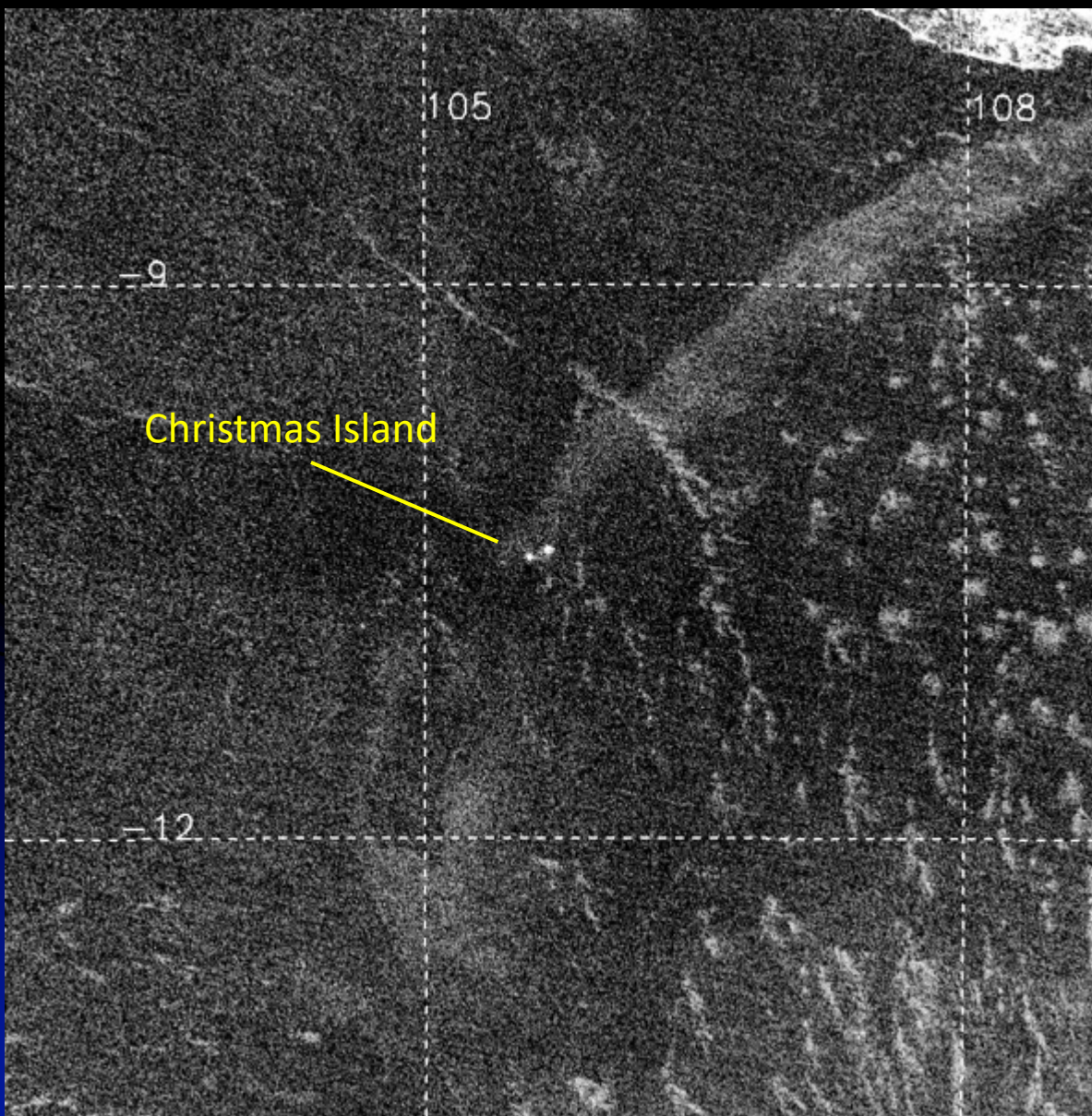


2019 Java

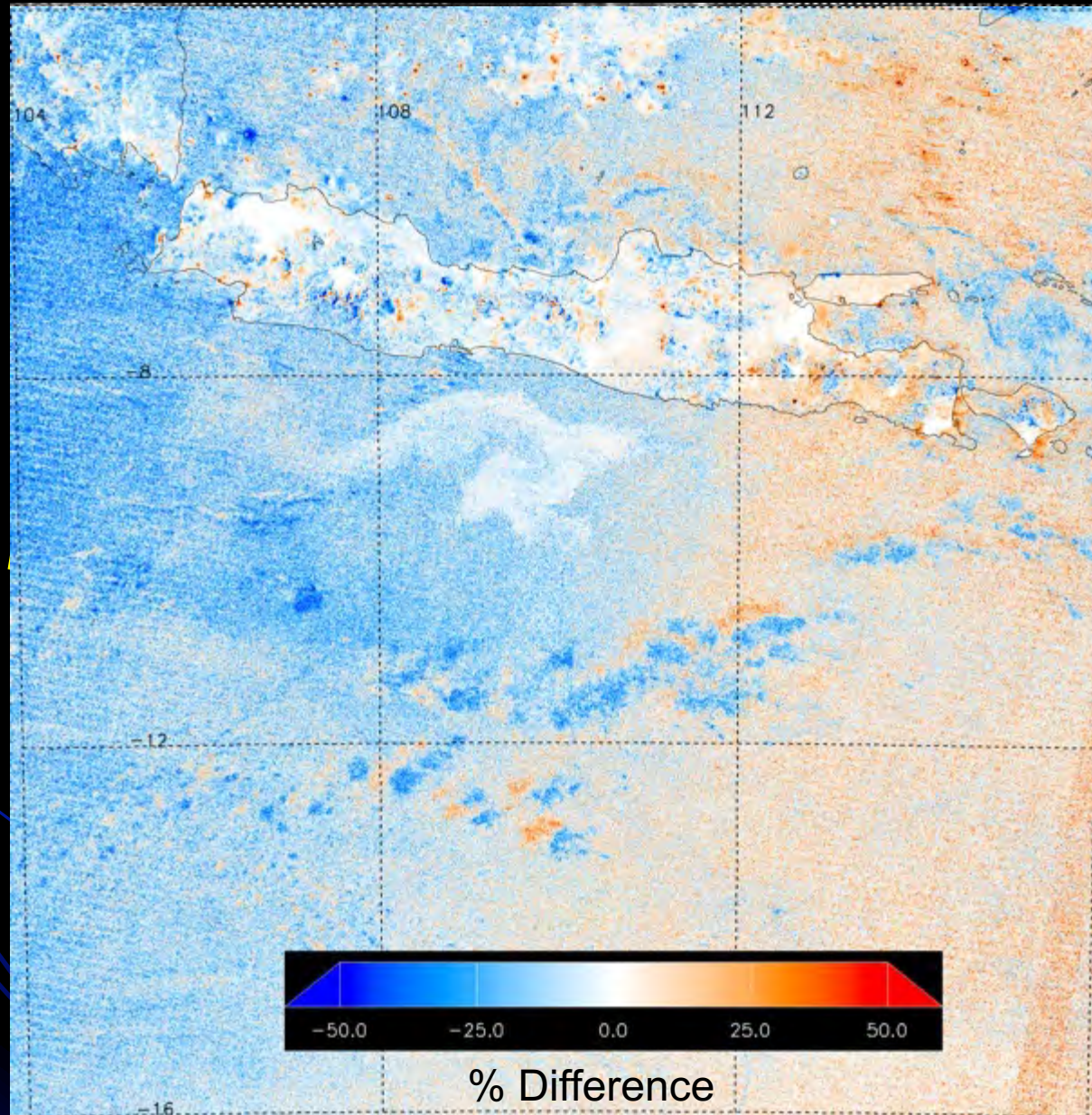
False Color Sequence



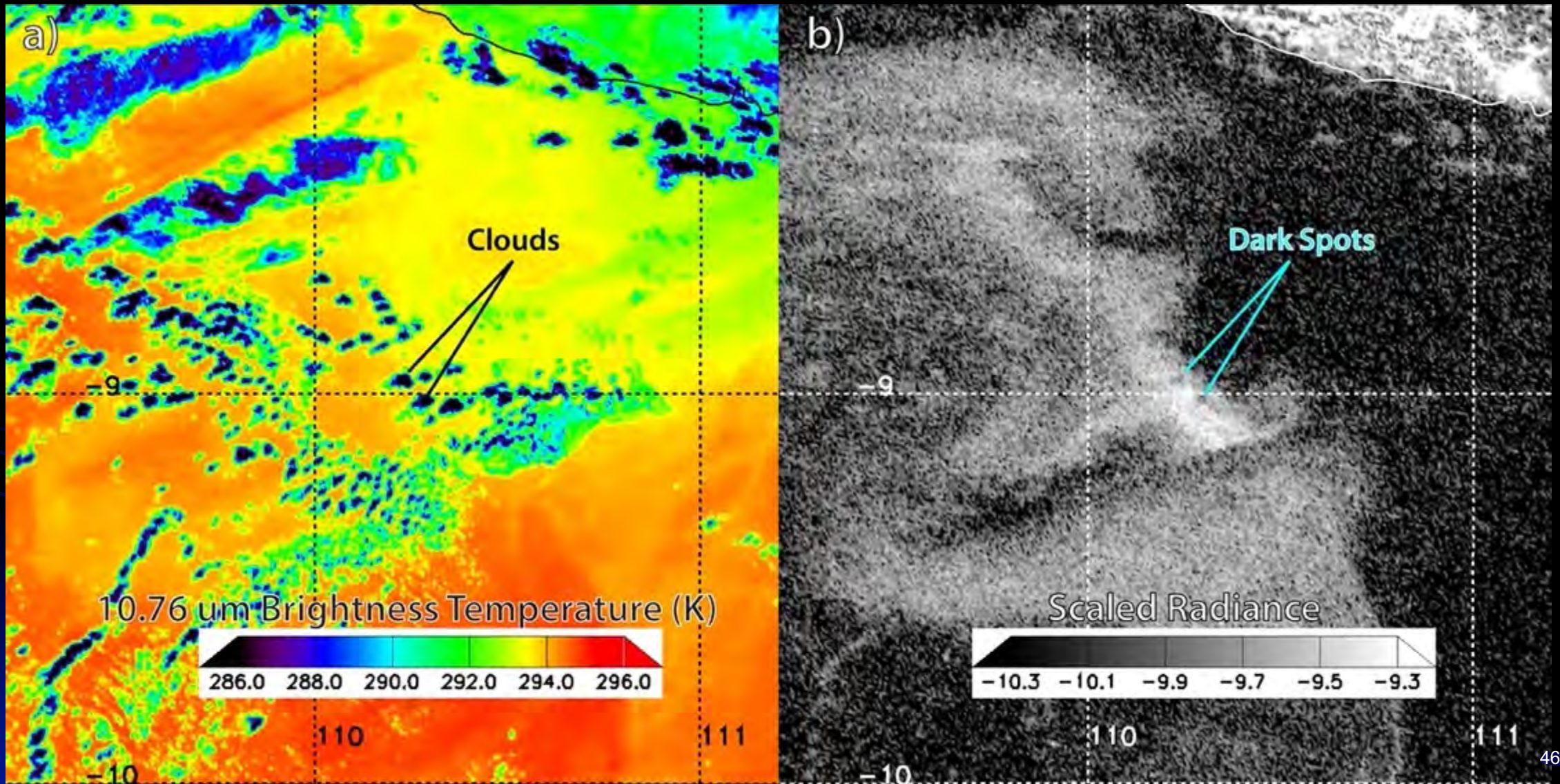
Christmas Island Filament Break, 4-5 Sep 2019



Zero Parallax Shift Pins Feature to Surface



Optically Thick Clouds Attenuate Surface Light!



New Capabilities == New Complications...

We were initially surprised to see clouds in DNB imagery in moonless scenes...

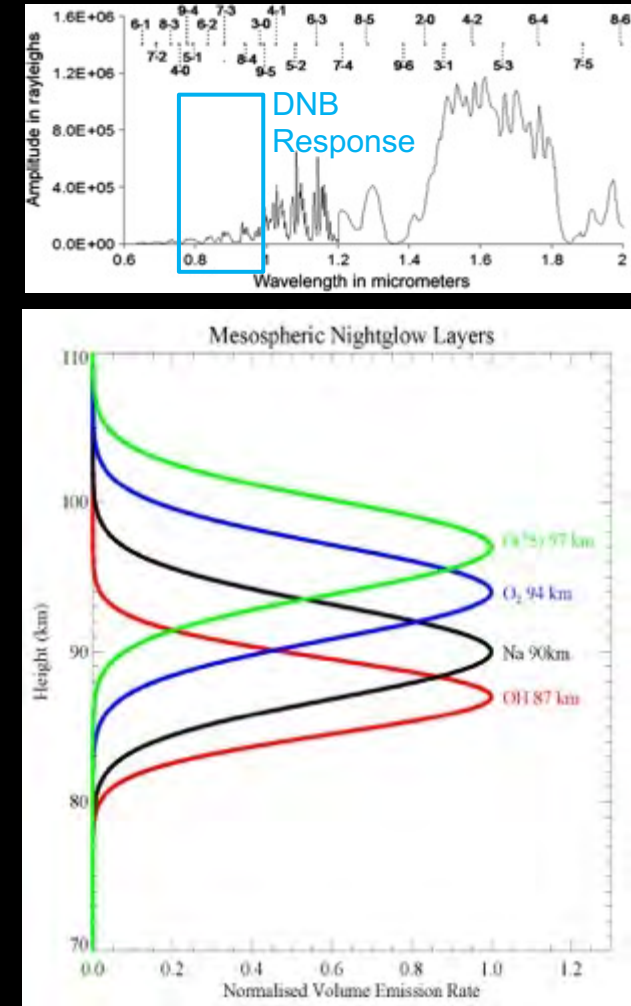
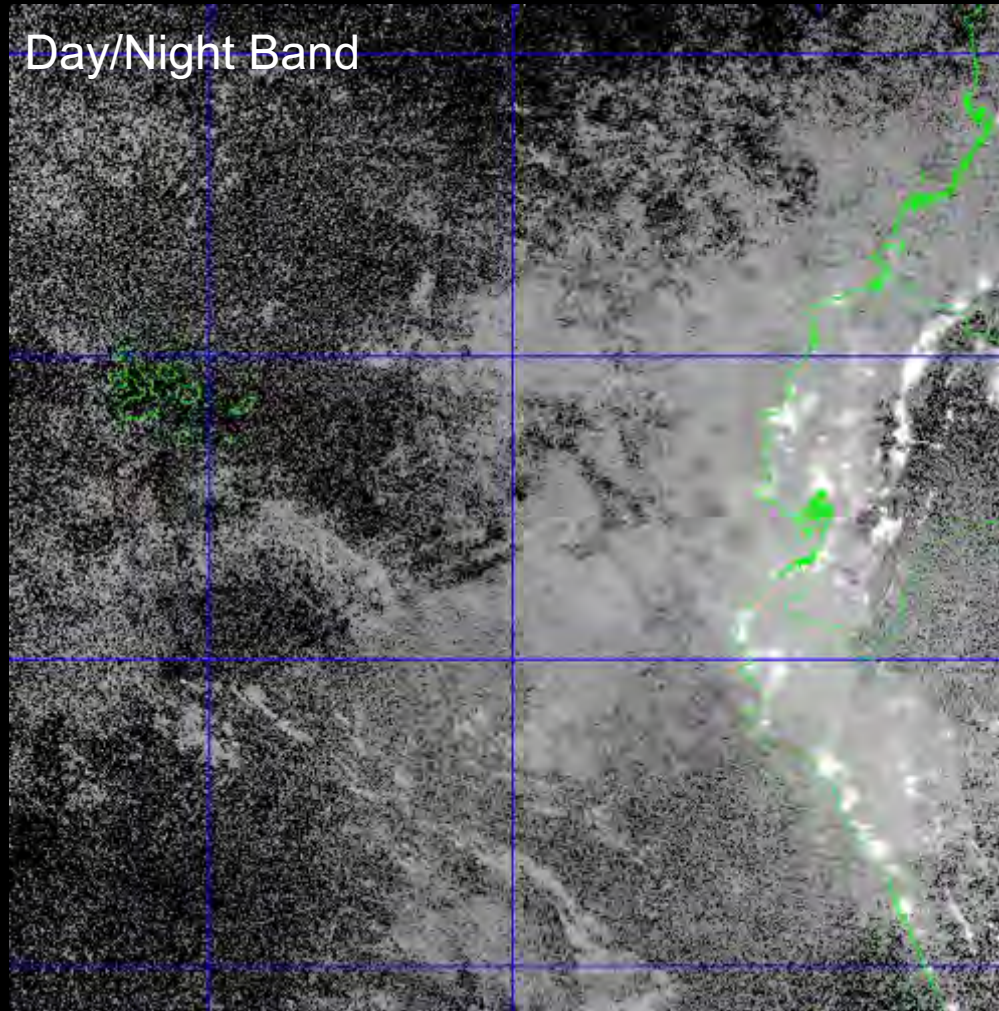
We soon learned that the Day/Night Band was sensitive enough to detect atmospheric airglow emissions.

Strongest emissions from OH* (excited hydroxyl) near 87 km.

We could even see structures in the airglow, caused by gravity waves, tides, bores, etc.

Terrific for scientific research!

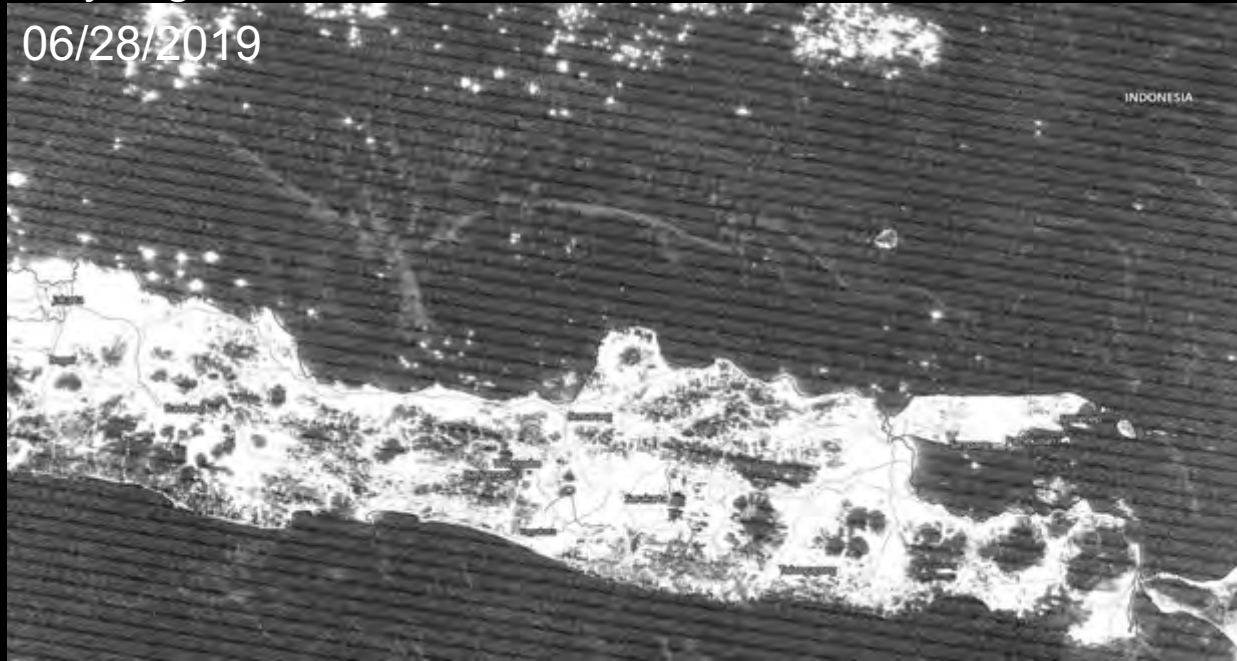
Terrible for milky sea hunting!



Diurnally-Locked Cloud Patterns Confound Detection

Day/Night Band

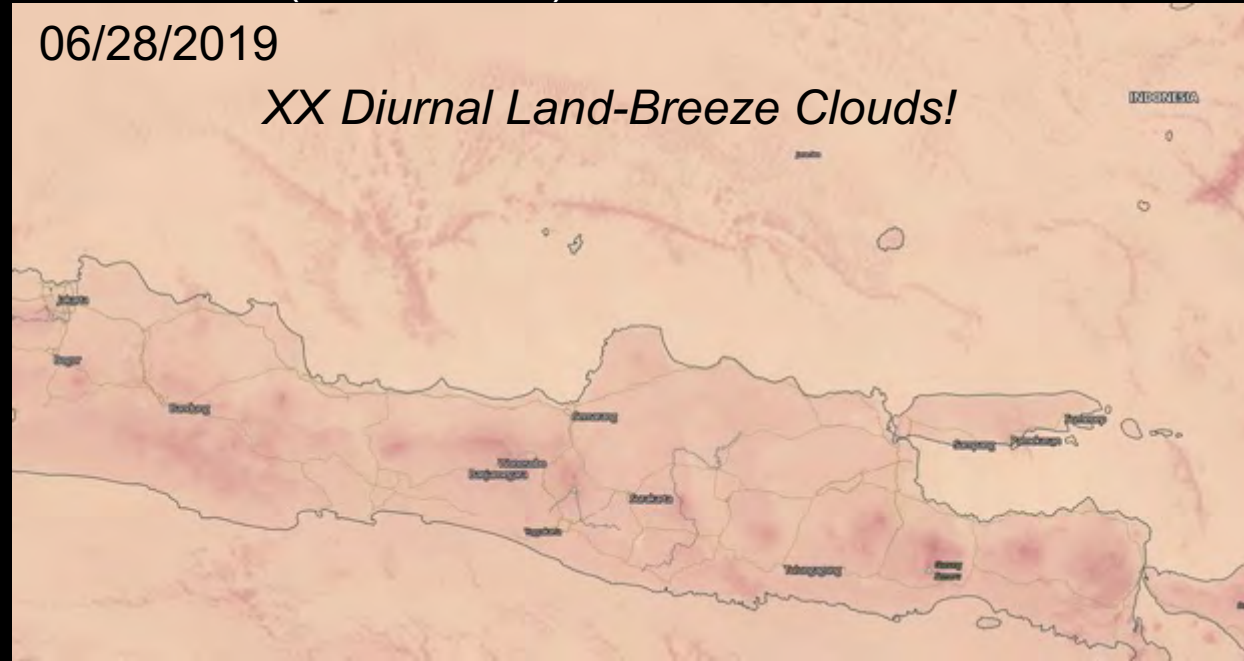
06/28/2019



VIIRS M15 (10.7 micron)

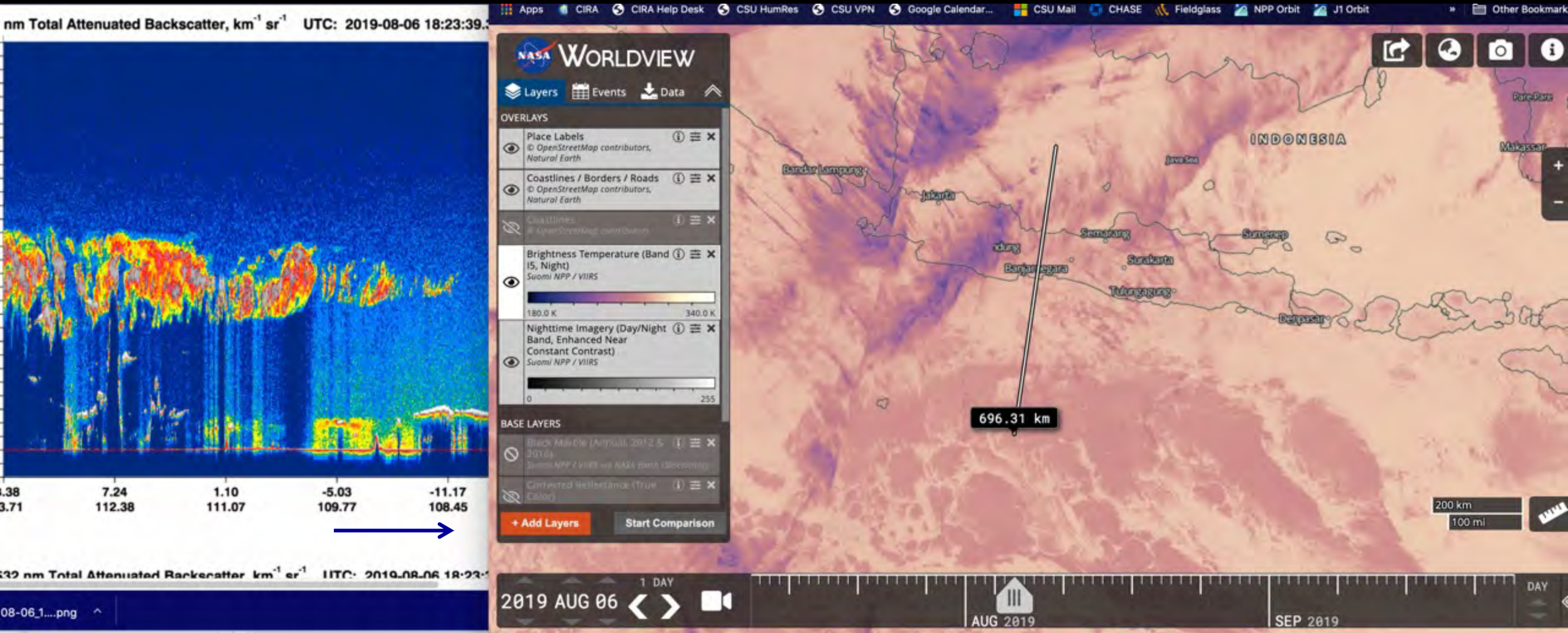
06/28/2019

XX Diurnal Land-Breeze Clouds!



With the non-ideal spectral overlap, the airglow contamination, and lack of success despite intensive searching worldwide, we started to lose hope...

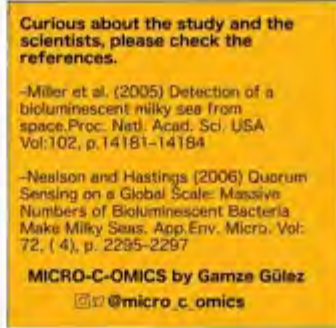
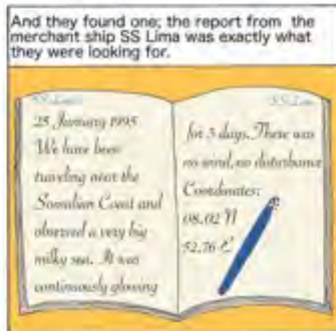
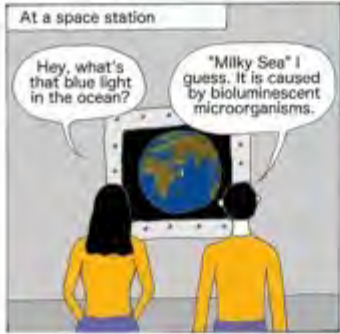
6 August 2019 Java Milky Sea Case—closest CALIPSO overflight identified
White segment shows CALIPSO track from (-5.03, 109.77) to (-11.17, 108.45)



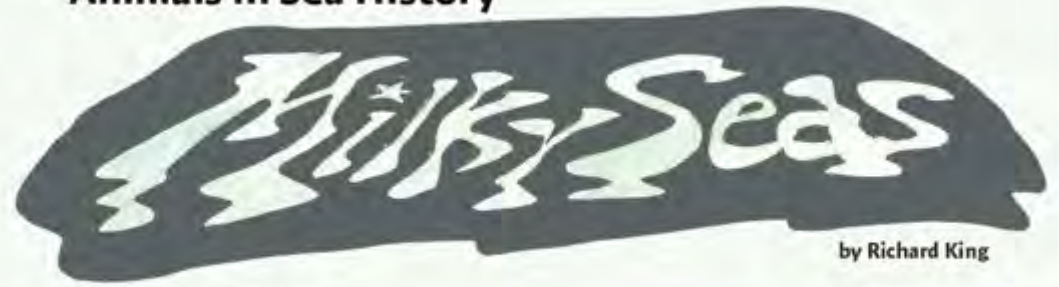
NOTE: CALIPSO was not sensitive enough to pick up city lights over Java (would have appeared as a column of background noise in the imagery at lower-left), so there was little hope of picking up the milky sea signal with CALIPSO. An idea worth checking, though!



MICRO-C-OMICS-52
Bioluminescent "Milky Sea" Detected from Space



Animals in Sea History



In the early evening of 27 July 1854, the American clipper ship *Shoobing Star* was sailing toward Java, Indonesia, from the southwest. The sailors on deck noticed that the ocean's surface had become entirely white. The men summoned their captain, W. E. Kingman, who, upon looking over the rail and seeing the odd color of the water, decided to stop the ship to take a sounding in case they were way off course and sailing over dangerous, shallow water. Satisfied this was not the case, he continued sailing through what he later described in a letter as "a plain covered with snow." Kingman measured the slick of milky-looking water to be some twenty-three nautical miles long interrupted by only a half-mile dark strip in the center. In all his years at sea he had seen "nothing that would compare with this in extent or whiteness." He had his crew fill a sixty-gallon tub with the glowing seawater and, in part by using the magnifying glass of his sextant, Kingman identified among the glow what we'd describe today



as a dense bloom of a variety of clear jelly-like zooplankton, some circular and some thin, like long hairs. If you're thinking this was bioluminescence—the microscopic marine organisms well known for making seawater glow at night when disturbed—you would be right. But the phenomenon the crew of the *Shoobing Star* witnessed was an exceptionally rare event, in which the surface was completely glowing without any agitating motion. What they saw that night was full coverage of the surface, opaque and consistent, as if lit up from below. This was not only flickering blue-green light from the organisms Kingman could