

Light on the Horizon: In search of Bioluminescent Milky Seas from Space

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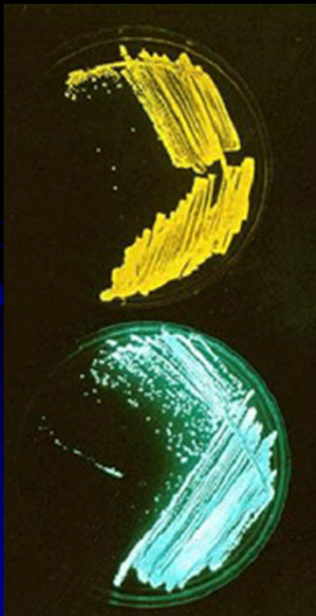
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⁵Seoul National University, South Korea

NOAA ocean color coordinating Group (NOCCG)

Seminar Series

23 February 2022



Maritime Folklore: *Degrees of Truth*



Toy Submarine



Manatees



Release the Kraken!!

A Normal Nighttime Ocean Scene



The Milky Seas of Maritime Lore!



Stories of *Glowing Oceans* Near Java American 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.

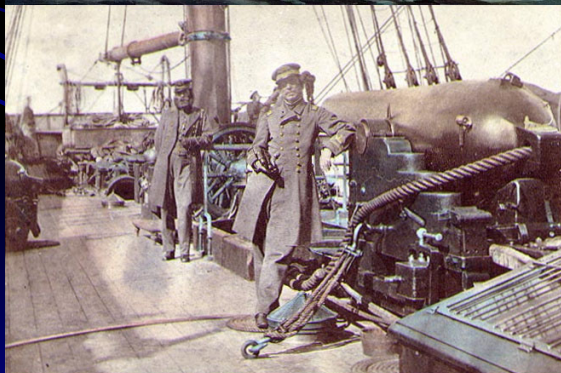
The scene was one of awful grandeur, *the sea having turned to phosphorus*, and the heavens being hung in blackness, and the stars going out, seemed to indicate that all nature was preparing for that last grand conflagration which we are taught to believe is to annihilate this material world!

– Captain Kingman, *Shooting Star*



And in the Somali Sea...

C.S.S. Alabama, January 1864

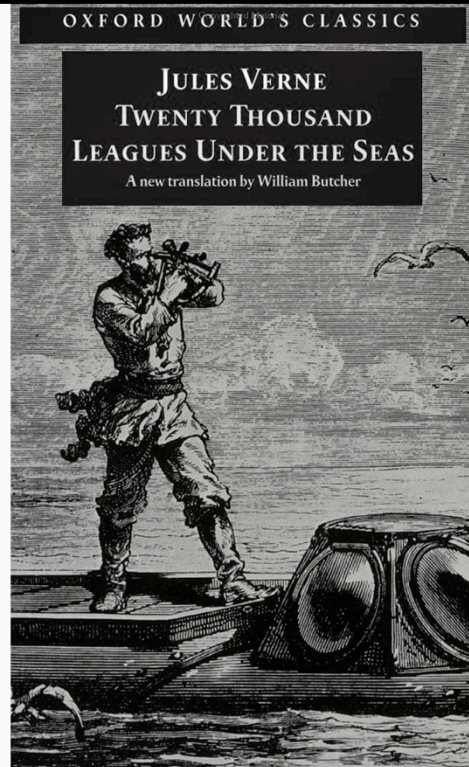


At about eight P. M., there being no moon (...) and the stars shining brightly, **we suddenly passed (...) into a patch of water so white that it startled me;** so much did it appear like a shoal.

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*

Truth Inspiring Fiction



20,000 LEAGUES UNDER THE SEA 151

The 27th of January, at the entrance of the vast Bay of Bengal, we met repeatedly a forbidding spectacle, dead bodies floating on the surface of the water. They were the dead of the Indian villages, carried by the Ganges to the level of the sea, and which the vultures, the only undertakers of the country, had not been able to devour. But the sharks did not fail to help them at their funeral work.

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. Was it the effect of the lunar rays? No; for the moon, scarcely two days old, was still lying hidden under the horizon in the rays of the sun. The whole sky, though lit by the sidereal rays, seemed black by contrast with the whiteness of the waters.

Conseil could not believe his eyes, and questioned me as to the cause of this strange phenomenon. Happily I was able to answer him.

"It is called a milk sea," I explained. "A large extent of white wavelets often to be seen on the coasts of Amboyna, and in these parts of the sea."

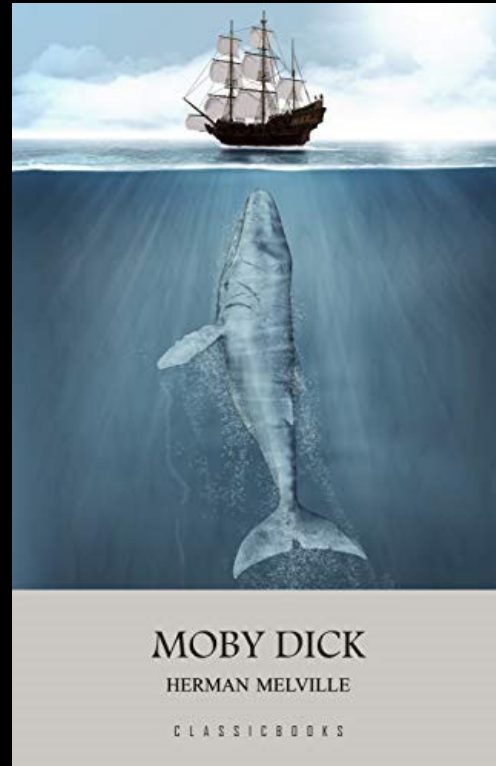
"But sir," said Conseil, "can you tell me what causes such an effect? for I suppose the water is not really turned into milk."

"No, my boy; and the whiteness which surprises you is caused only by the presence of myriads of infusoria, a sort of luminous little worm, gelatinous and without colour, of the thickness of a hair, and whose length is not more than seven-thousandths of an inch. These insects adhere to one another sometimes for several leagues."

"Several leagues!" exclaimed Conseil.

"Yes, my boy; and you need not try to compute the number of these infusoria. You will not be able, for, if I am not mistaken, ships have floated on these milk seas for more than forty miles."

Towards midnight the sea suddenly resumed its usual colour; but behind us, even to the limits of the horizon, the sky reflected the whitened waves, and for a long time seemed impregnated with the vague glimmerings of an aurora borealis.



and feels just enough of trepidation to sharpen all his faculties; but under precisely similar circumstances, let him be called from his hammock to view his ship sailing through a midnight sea of milky whiteness—as if from encircling headlands shoals of combed white bears were swimming round him, then he feels a silent, superstitious dread; the shrouded phantom of the whitened waters is horrible to him as a real ghost; in vain the lead assures him he is still off soundings; heart and helm they both go down; he never rests till blue water is under him again. Yet where is the mariner who will tell thee, "Sir, it was not so much the fear of striking hidden rocks, as the fear of that hideous whiteness that so stirred me?"

Second: To the native Indian of Peru, the continual sight of the snow-howdahed Andes conveys naught of dread, except, perhaps, in the mere fancying of the eternal frosted desolateness

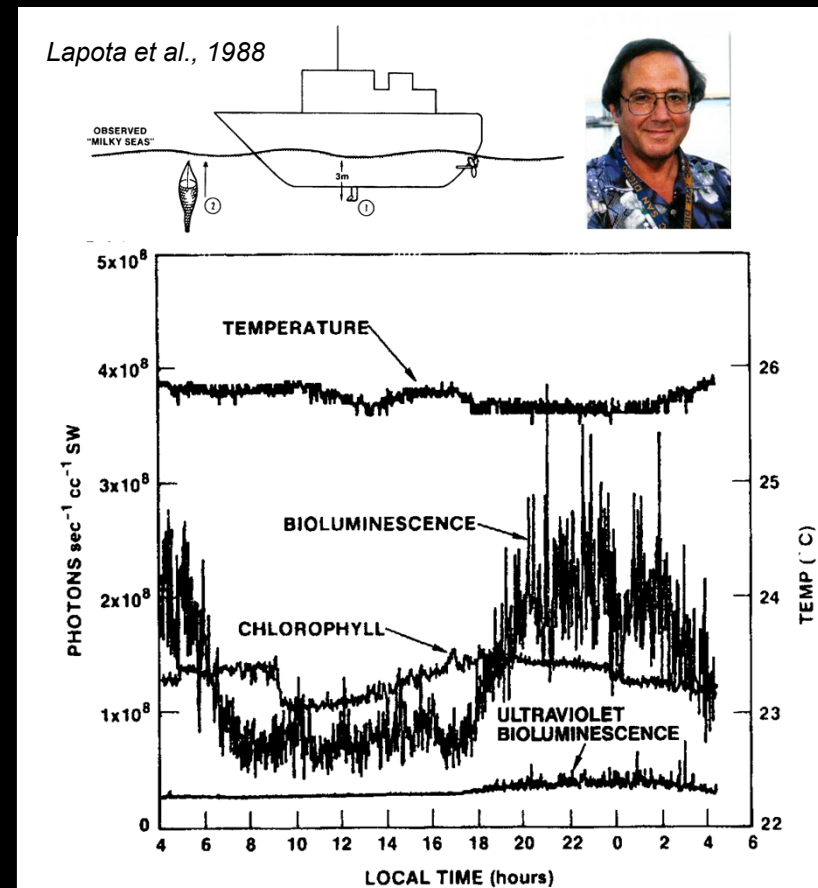
← 280 →

This study pursues one of the "white whales" of satellite-based nighttime low-light remote sensing—**bioluminescence!**

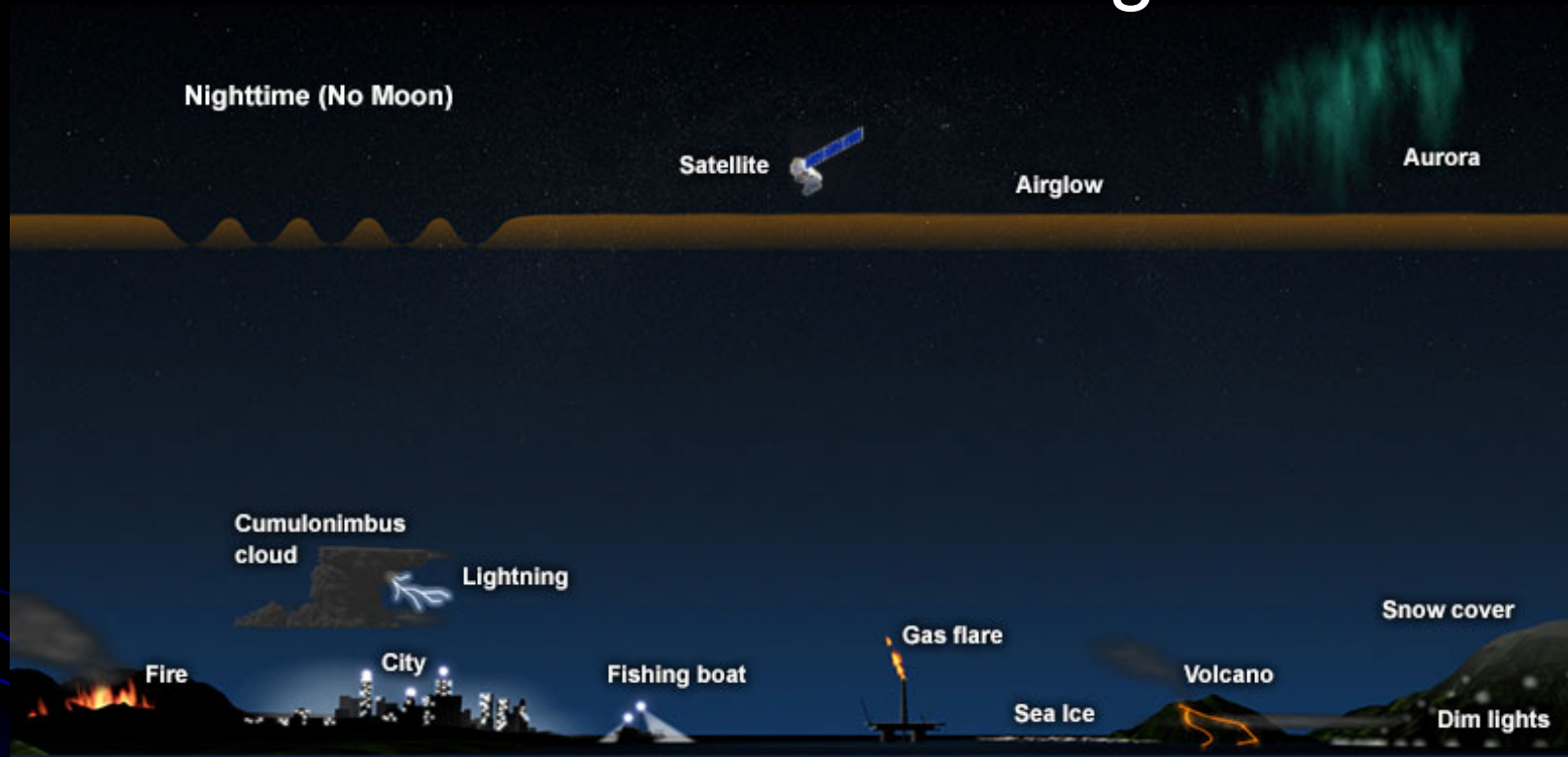
A Chance Encounter in the Arabian Sea

24-26 July 1985

- Dave Lapota's Naval team on the USNS *Wilkes* is the first and only research vessel encounter with 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”
- Measurements found luminous bacteria *Vibrio harveyi* in association with a *Phaeocystis* algal bloom.
- Ship crossed sharp barrier between glowing and dark (normal) waters, suggesting an oceanic front.
- They postulated an organic slick, with possible airborne luminous bacteria in a ‘milky fog’ just above surface.
- However, many other reports contradict the slick hypothesis—with uniform glow persisting under strong winds and swell.
- We need a way to detect milky seas remotely, and direct resources toward additional *in situ* observations, *but how?*



The Not-So-Dark Night



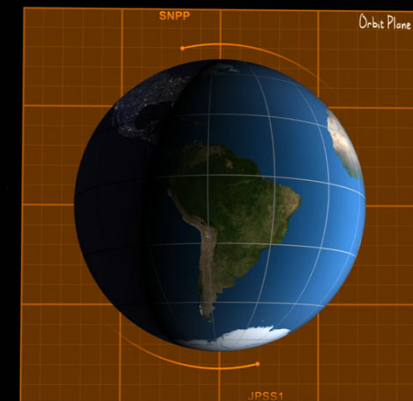
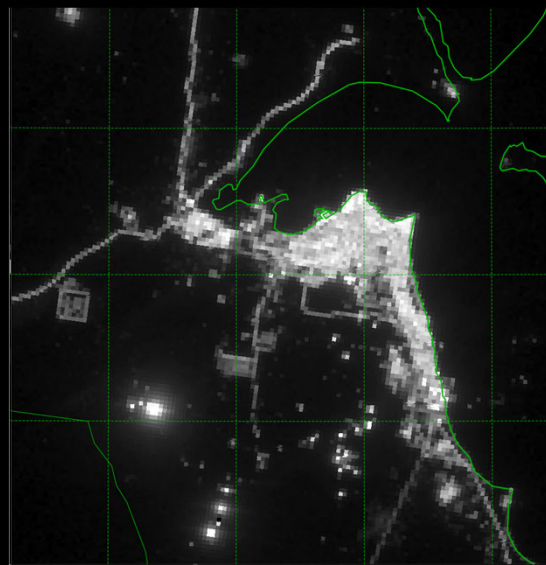
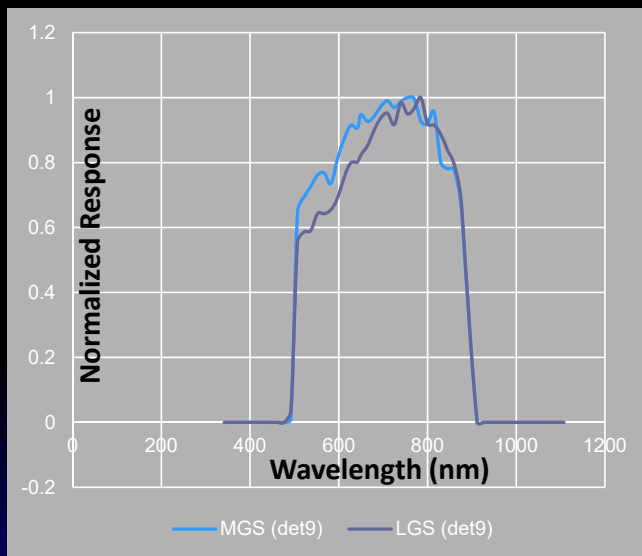
Courtesy, the COMET Program

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

The Day/Night Band (DNB)

A New Generation Nocturnal Low-Light Sensor

The *Day/Night Band (DNB)* is part of the *Visible/Infrared Imager Radiometer Suite (VIIRS)*, drawing heritage from *Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS)*



500-900 nm Spectral Bandpass
~70 nm Peak Response (VNIR)

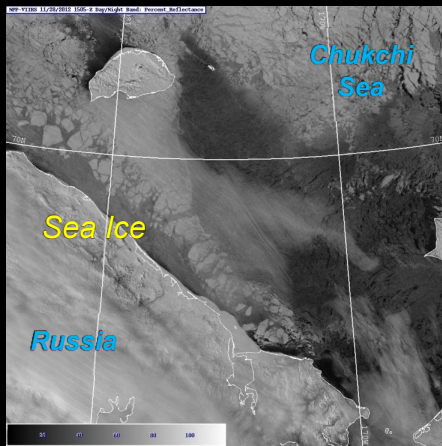
742 m pixel size, 3000 km Swath
(vs. DMSP 3-5 km)

Global Coverage via Suomi NPP
and NOAA-20 (N20)

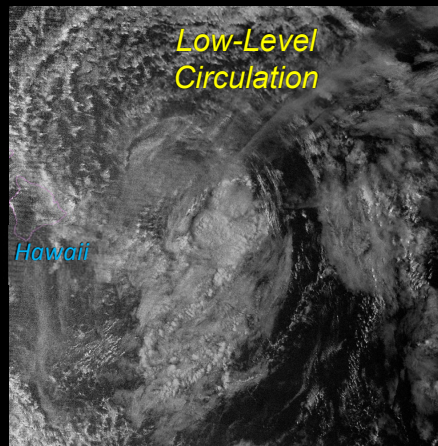
Together, Suomi/NOAA-20 provide about 2 nighttime (~0130) views at the low to mid-latitudes, separated in time by about 50 min.

The Value of Nighttime Visible Sensing

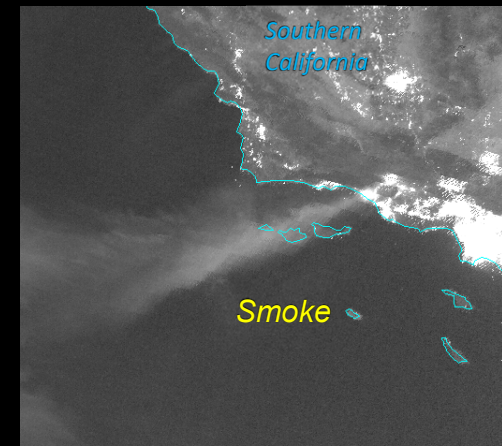
Sea Ice Detection



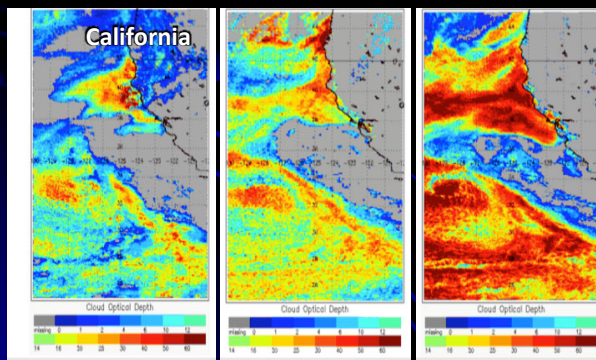
Clouds Below Cirrus



Aerosol Detection



Cloud Optical Depth & Water Path

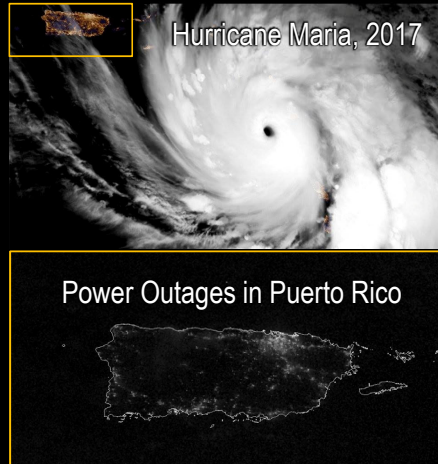


6:30 PM

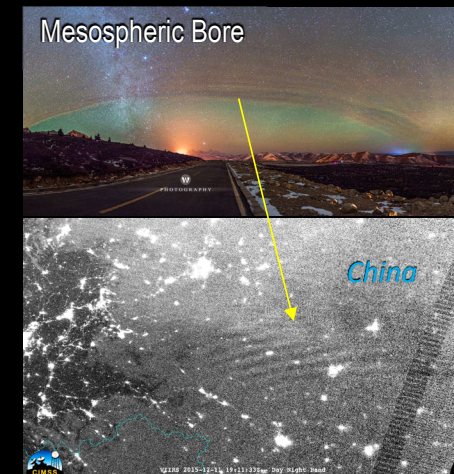
1:30 AM

9:30 AM

Artificial Lights Studies



Airglow Detection



A Breakthrough Event in the Somali Sea...

The S.S. *Lima*, January 1995



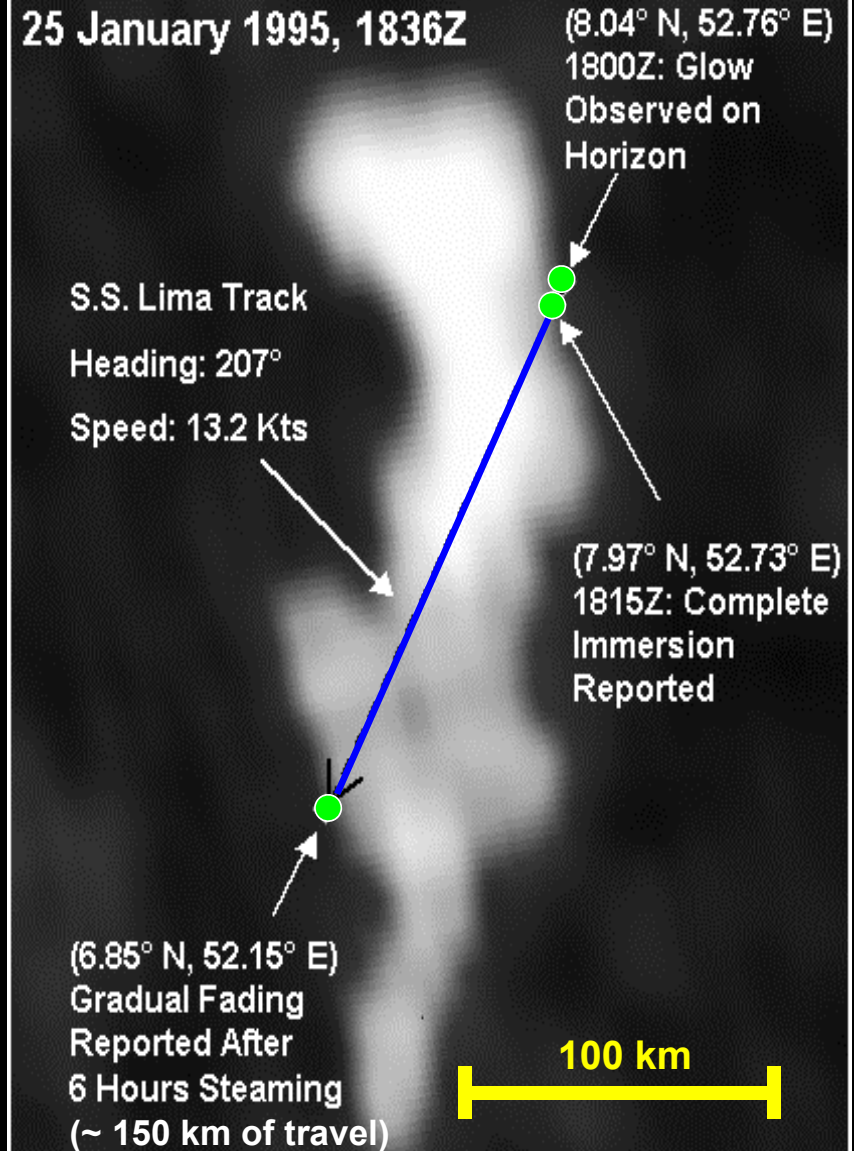
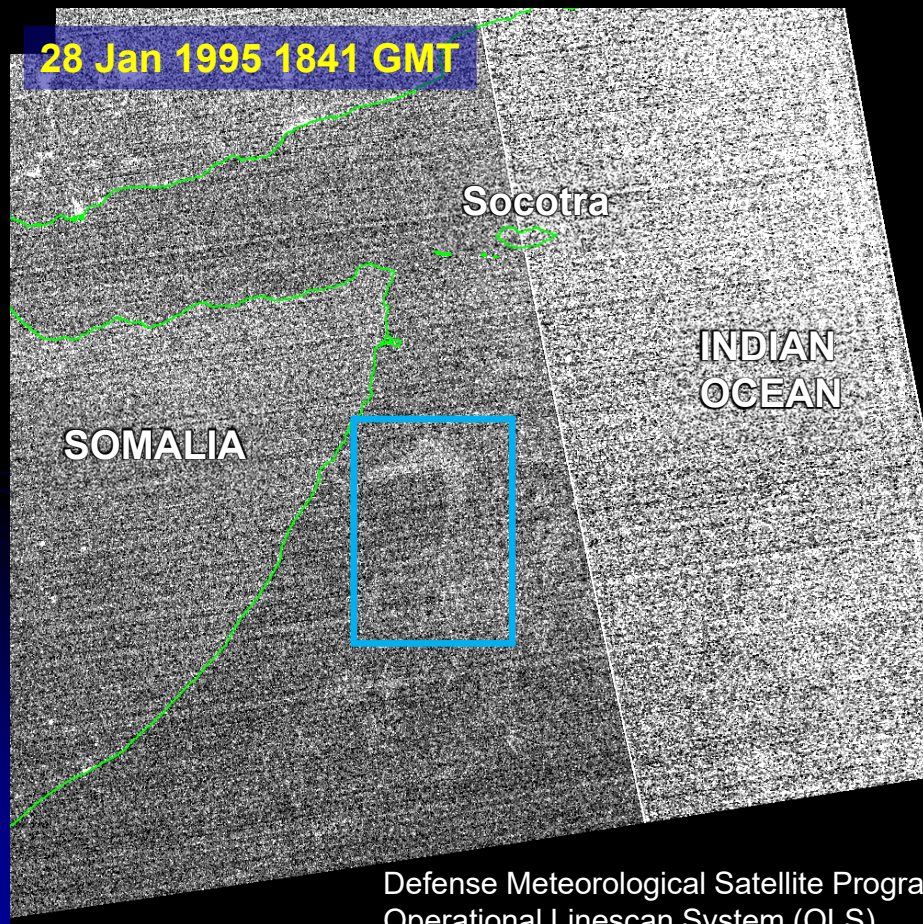
At 1800 UTC on a clear moonless night while 150 n. mile east of the Somalian coast a whitish glow was observed on the horizon and, after 15 minutes of steaming, the ship was completely surrounded by a sea of milky-white colour

...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

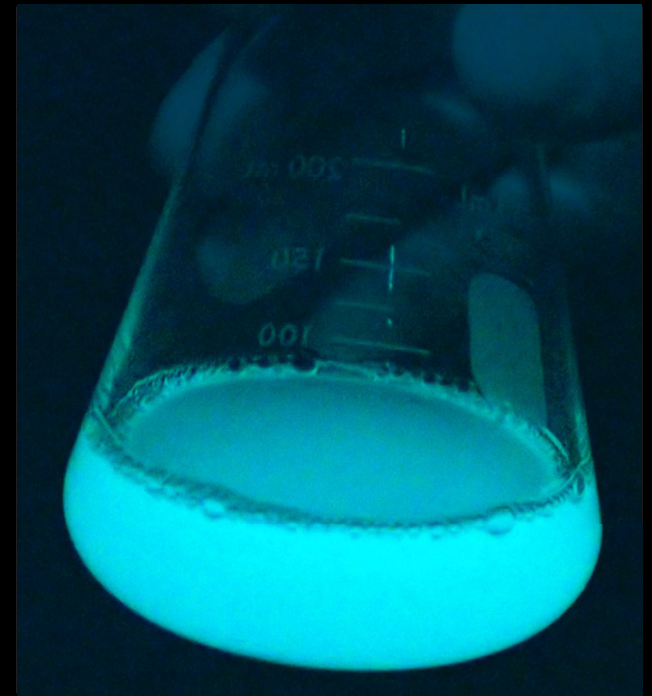
Satellite Imagery Confirms the S.S. Lima's Report



What We Think We Know...and What We Don't

- Steady glow points to luminous bacteria.
- Such signal might be detectable by the Day/Night Band on moonless nights.
- Nutrient rich upwelling waters offer ideal habitats for phytoplankton blooms, which can serve as focal points for luminous bacterial colonization.
 - *But blooms are common—why are milky seas so rare...?*
- 'Quorum sensing' occurs when bacterial populations exceed 10^8 cells/mL, triggering localized light production.
- Growing bacterial colony secretes more autoinducer into environment—stimulating further bacterial light emission upon additional colonized particles.

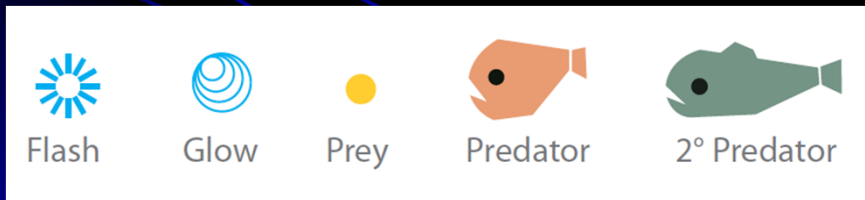
But for What Purpose...?



*A population explosion of luminous bacteria (here, *Vibrio fischeri*) in photobacterium broth.
S. Haddock (MBARI)*

Survival! A Macroscale Expression of What is Typically a Microscale Process...

Startling / Repelling



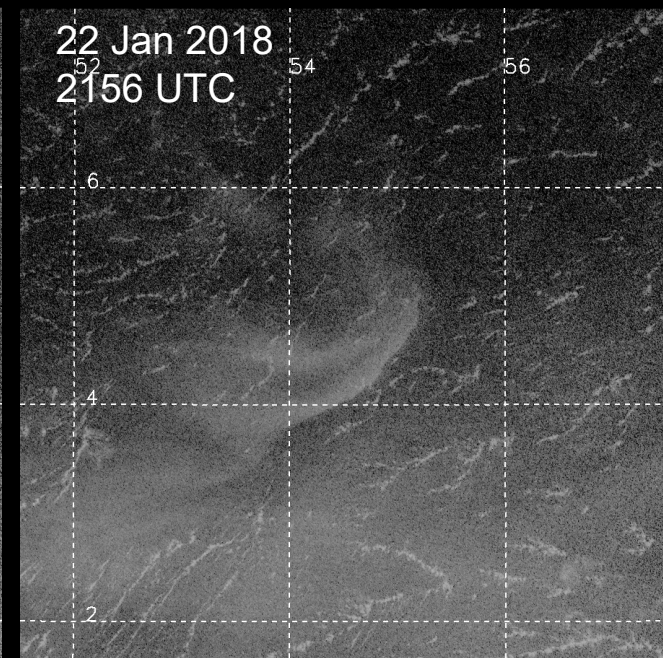
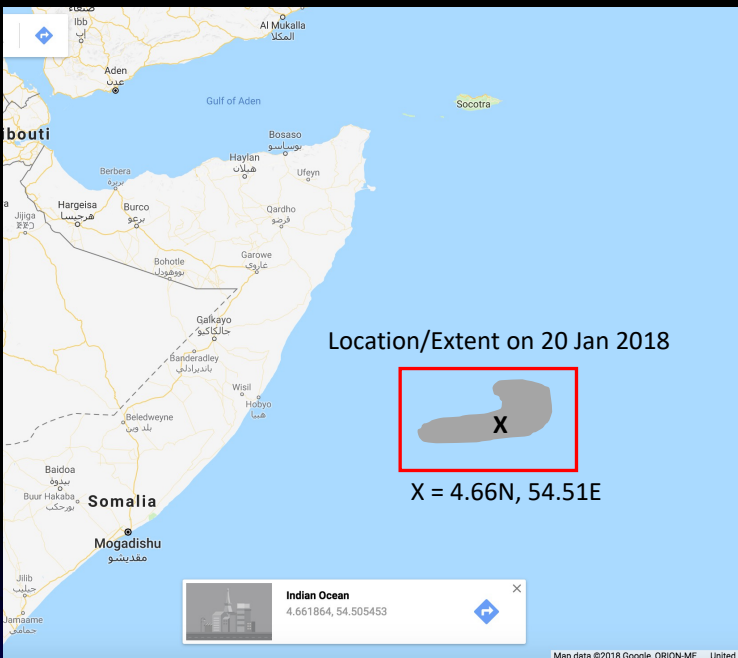
Adapted from:
Haddock, Moline, and Case, *Annu. Rev. Mar. Sci.* 2010. 2:443-93

Luring / Attracting



- We still don't know the details of milky sea composition, structure, how they set up, and why they are so uncommon in nature!
- NOAA's Day/Night Band offered the best chance of detecting milky seas remotely, but years of searching had turned up nothing...

The Tides Turn: Return to Somalia, January 2018



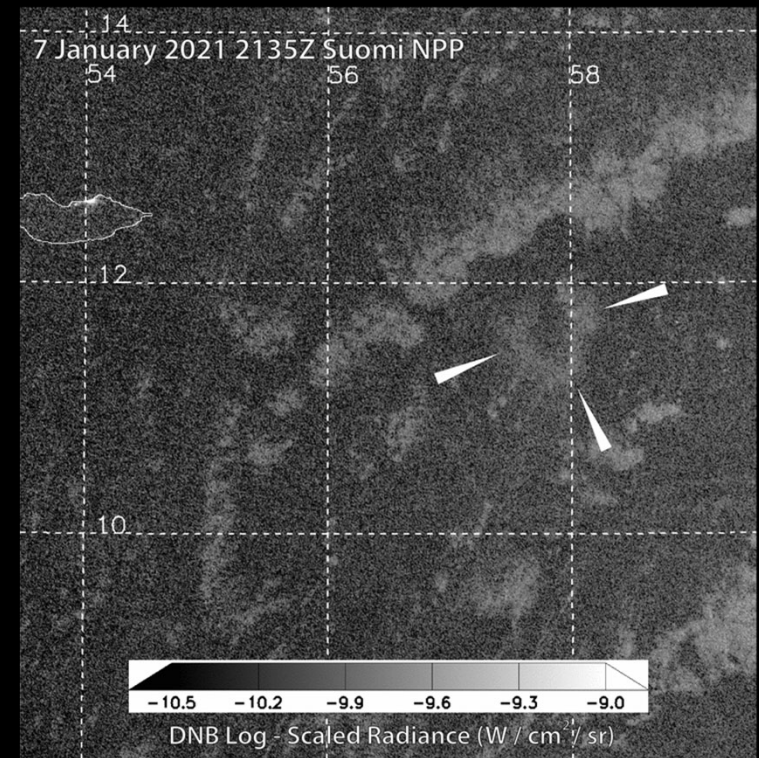
(W. Straka) It's in SNPP and N20 at about the same spot. Relatively clear sky too. Thoughts?

(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!

The Flood Gates Open

<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

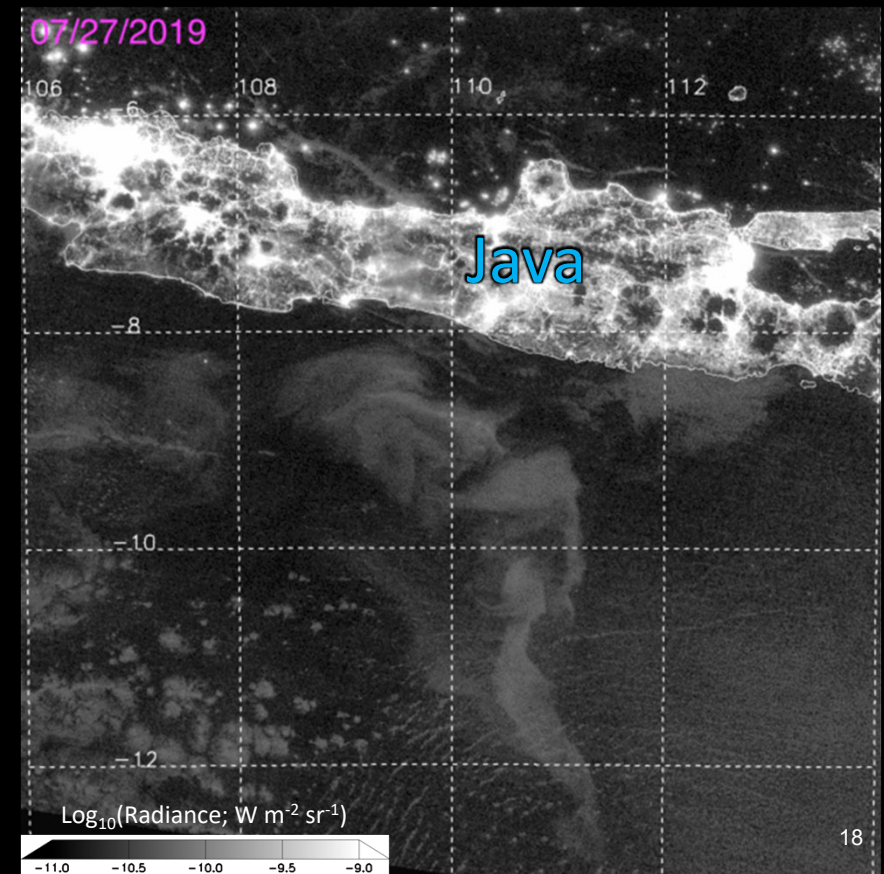
Northwest Indian Ocean



And Then....A Landmark Event

The Java Milky Sea: 25 Aug – 7 Sep 2019

- While searching DNB imagery for examples of diurnal cloud patterns around the Maritime Continent, we stumbled upon the largest milky sea detected from space to date!
- The DNB observed a glowing swath of ocean spanning over 100,000 km² (the size of Kentucky) and lasting over 40 nights.
- The feature could be ruled out immediately as thermal emission in the DNB's 500-900 nm spectral bandpass.
- Per the Planck function, the sea surface temperature would have had to be an unrealistic **~600 K** to produce a thermal signal even at the DNB's noise floor ($\sim 3e-7 \text{ W m}^{-2} \text{ sr}^{-1}$)...



For Appreciation of Scale ...

Apparent Even on the Global Scale



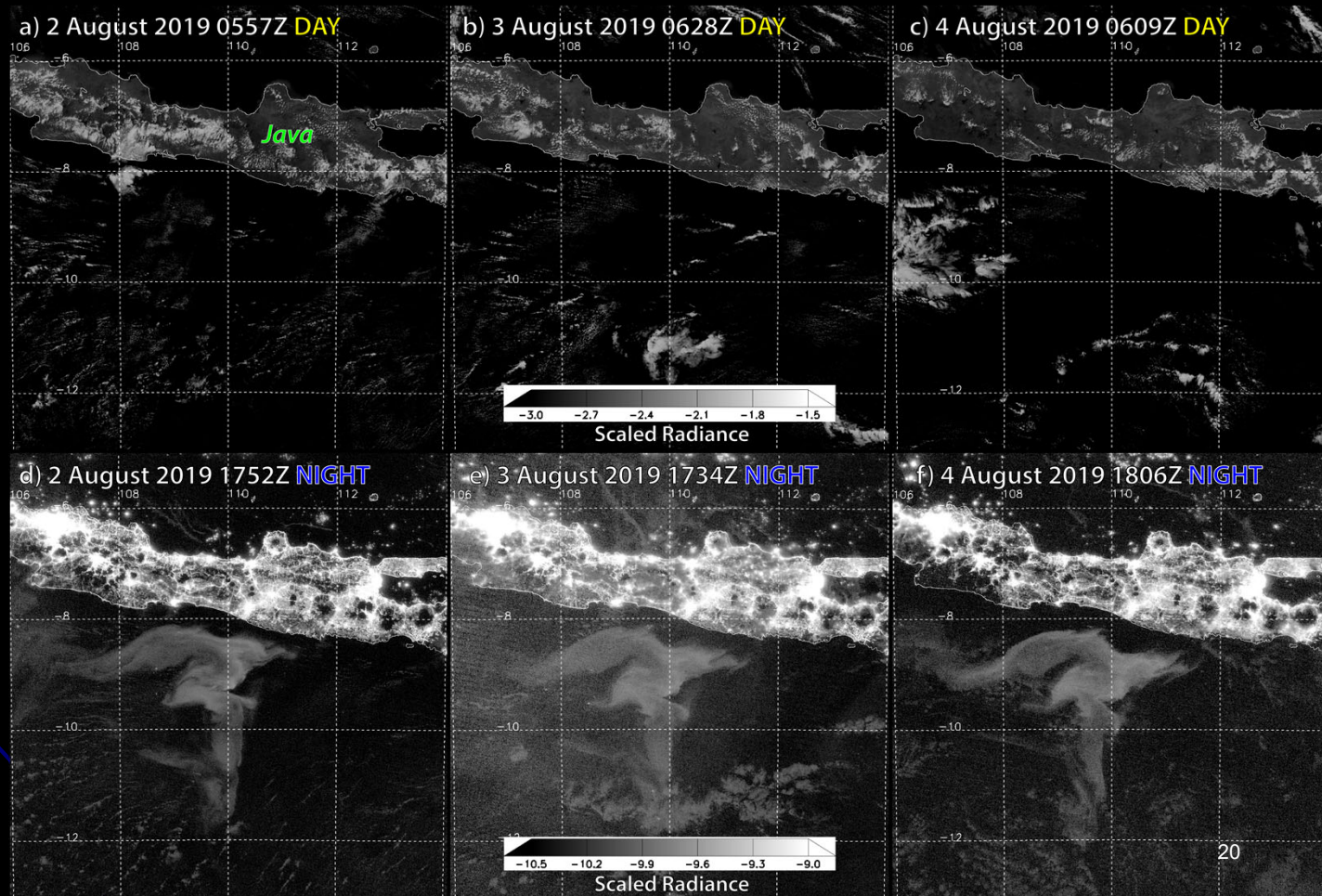
Comparison to US East Coast



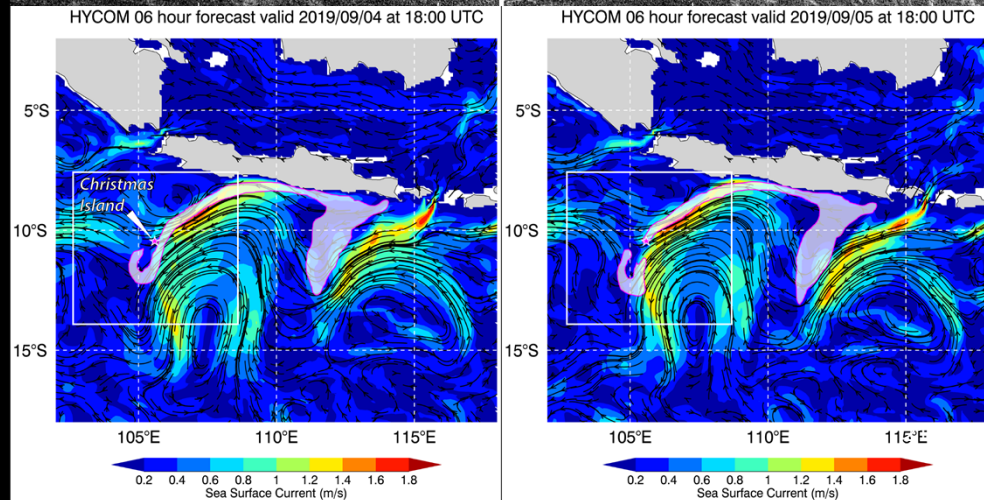
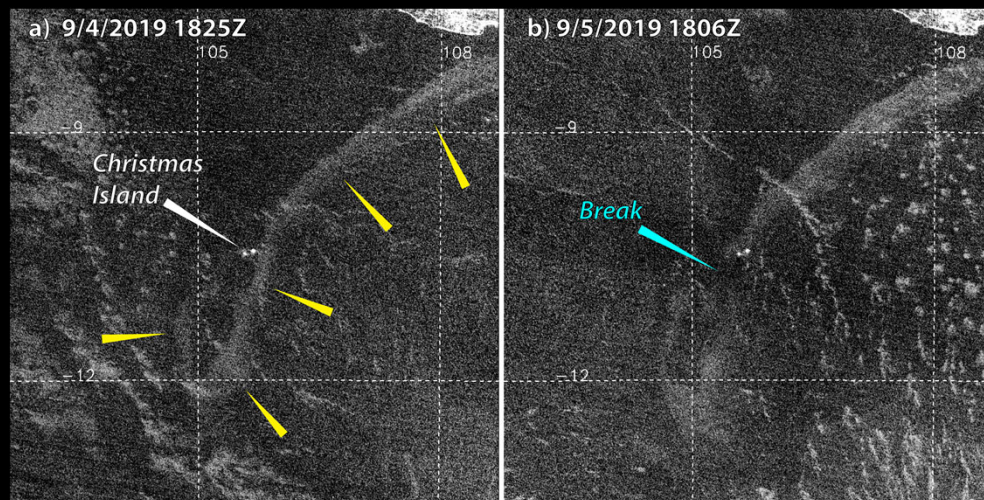
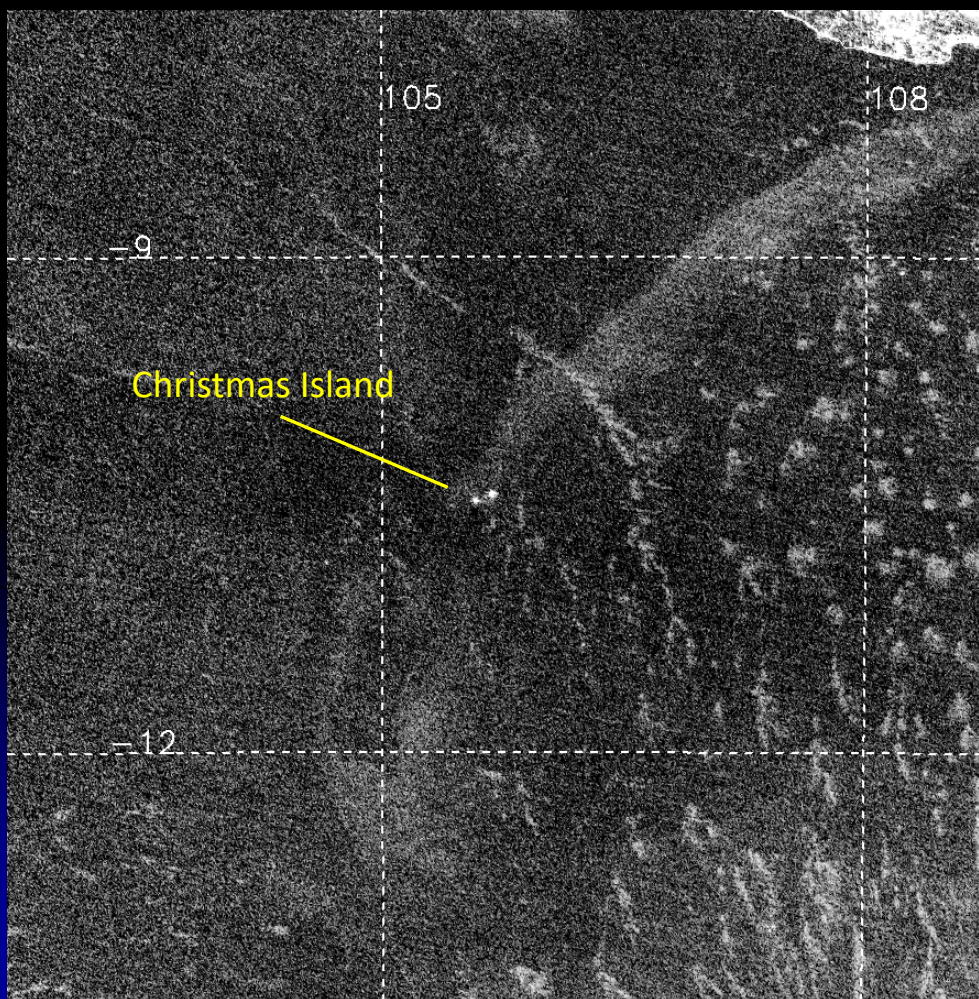
→ Roughly the same size as Iceland, or the state of Kentucky

Unseen During the Day...

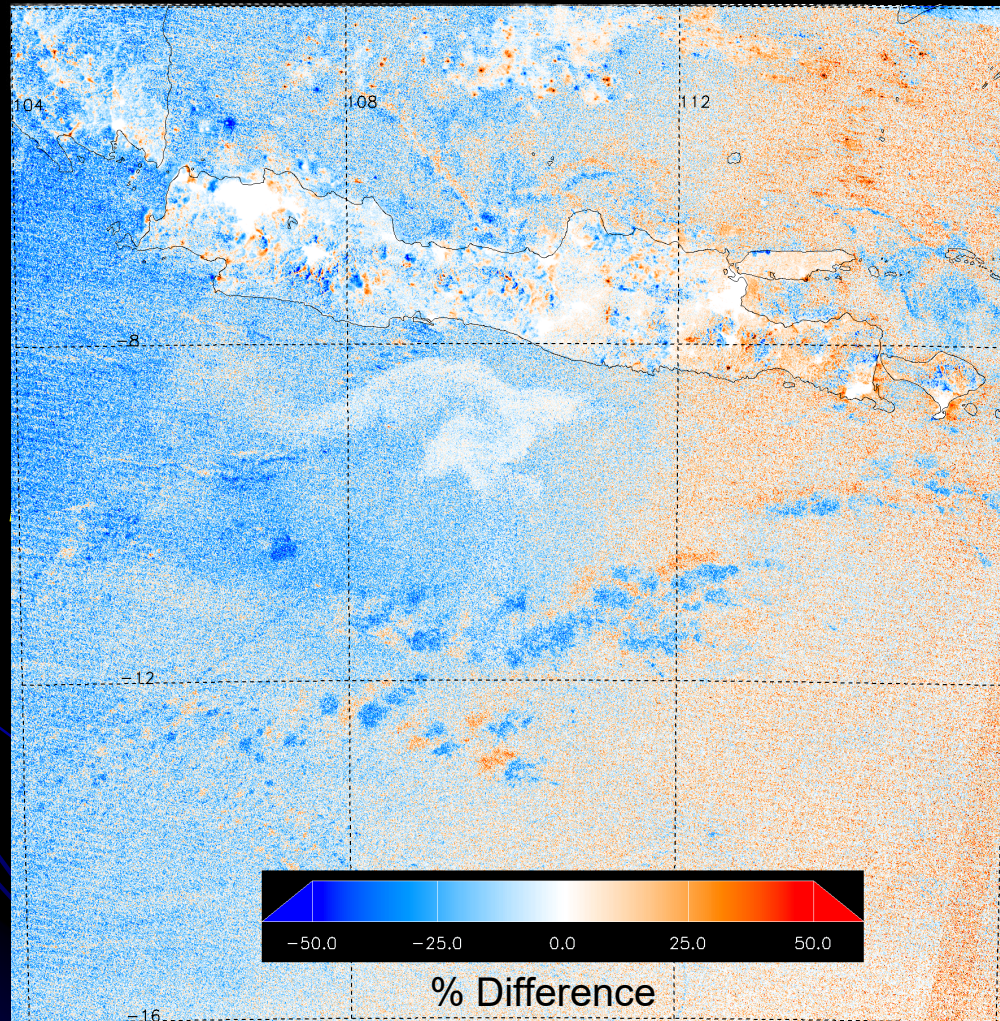
- Persistent feature does not correspond to the ephemeral cloud patterns.
- Detectable on moonless nights (moonlight is 100-1000x stronger than most bioluminescence signals).
- Slow drift of the feature was consistent with U.S. Navy HYCOM model-analyzed sea surface currents.



Christmas Island Filament Break, 4-5 Sep 2019

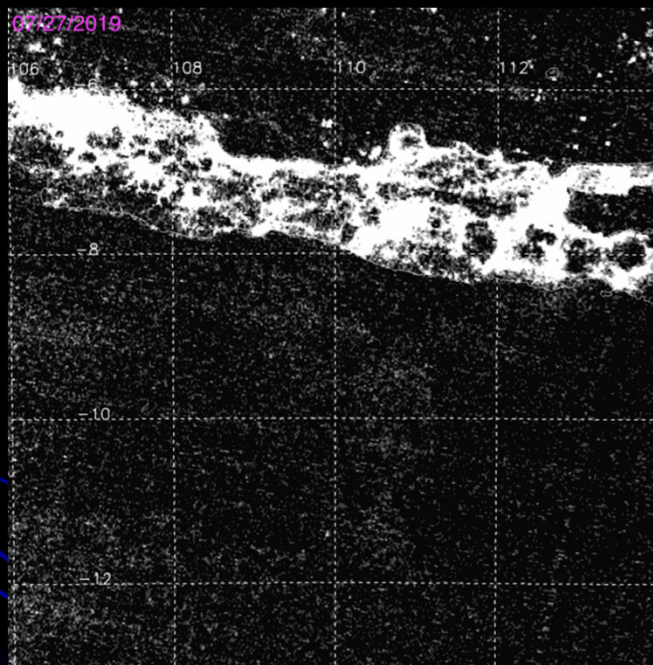


Zero Parallax Shift Pins Feature to Surface

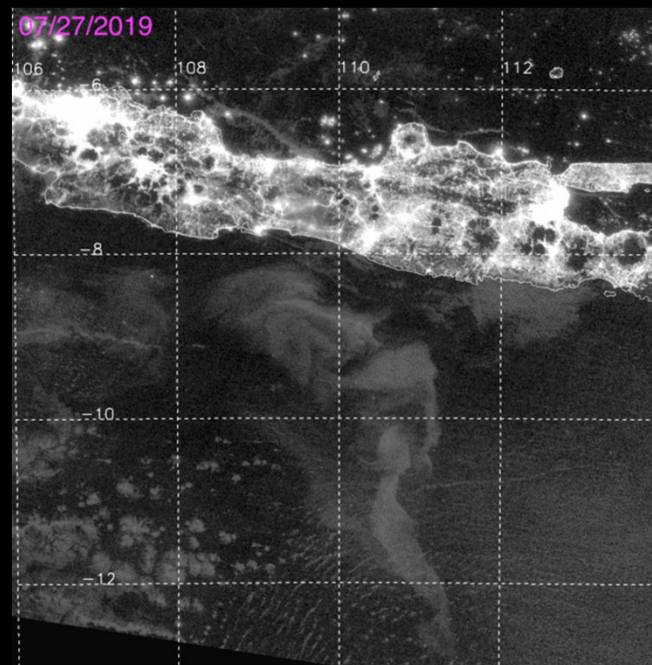


A Dramatic Improvement to DMSP/OLS!

DMSP/OLS

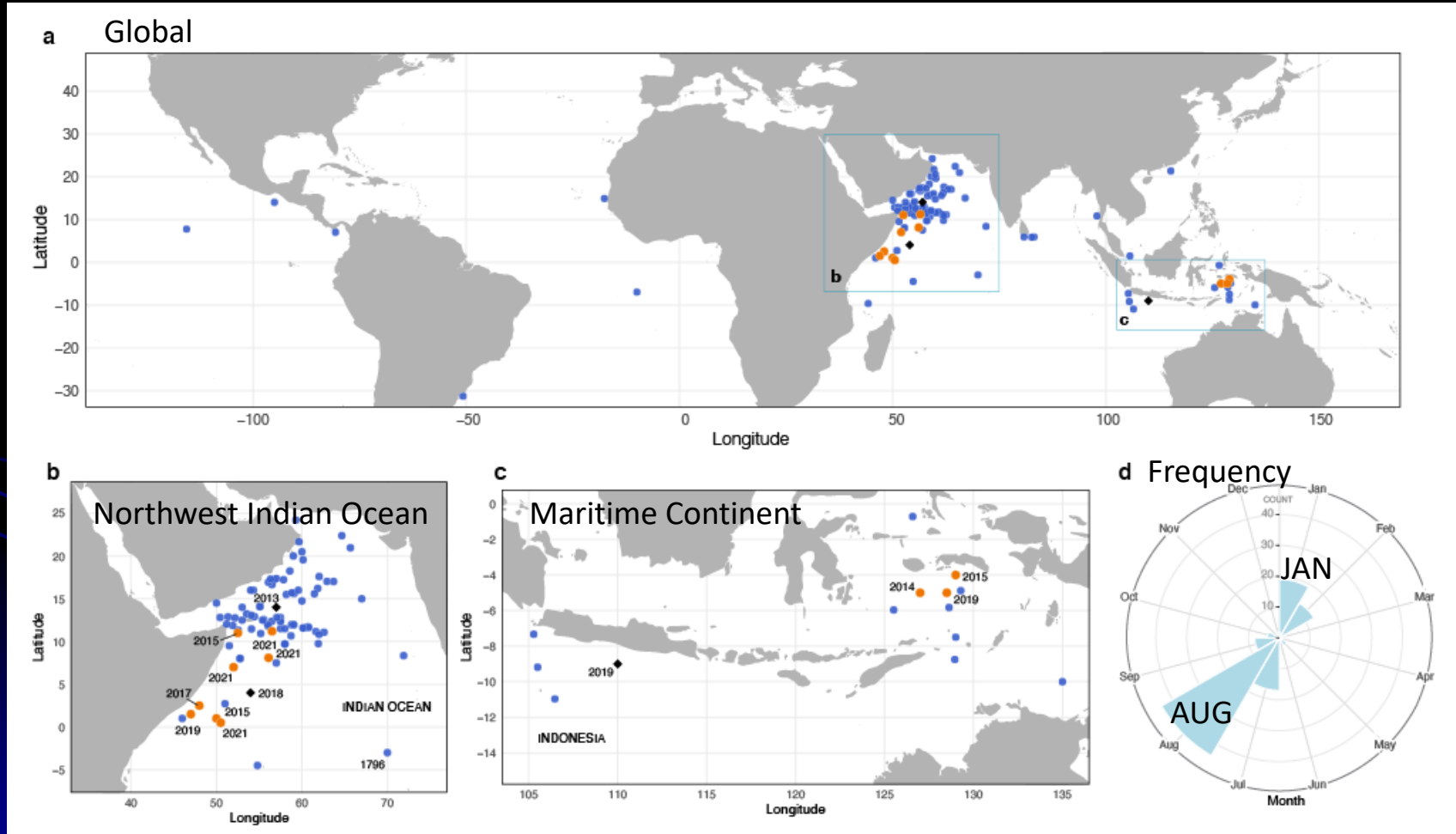


VIIRS/DNB

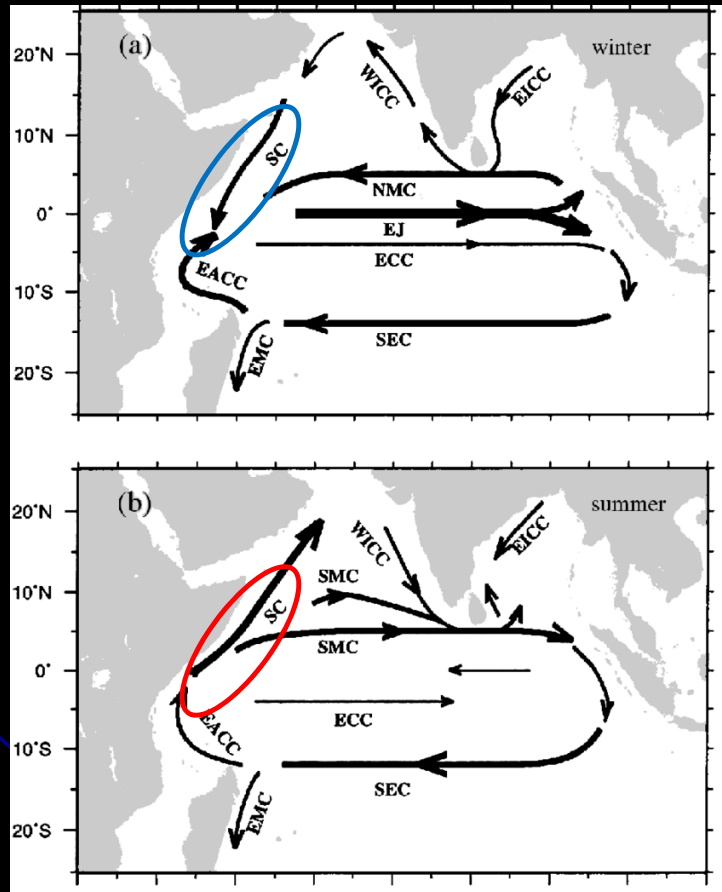
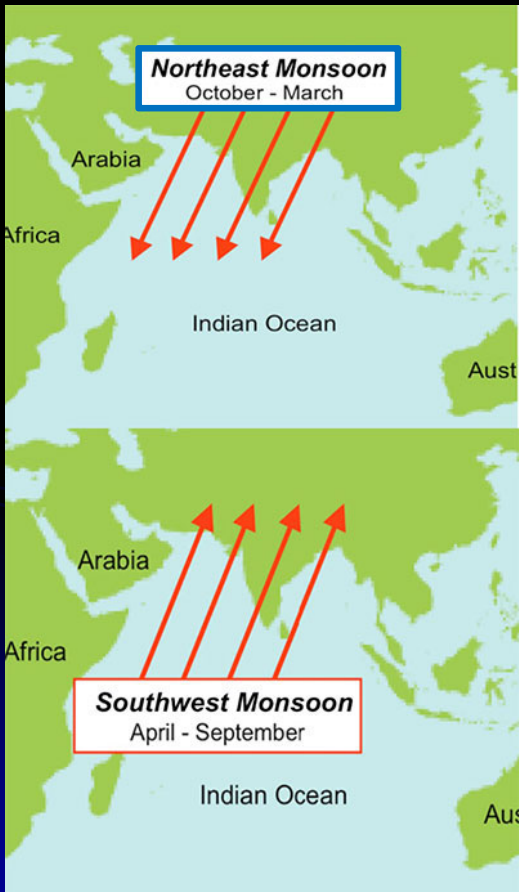


→ The DNB can help us detect milky seas *remotely, and perhaps autonomously* (machine learning techniques now being explored)

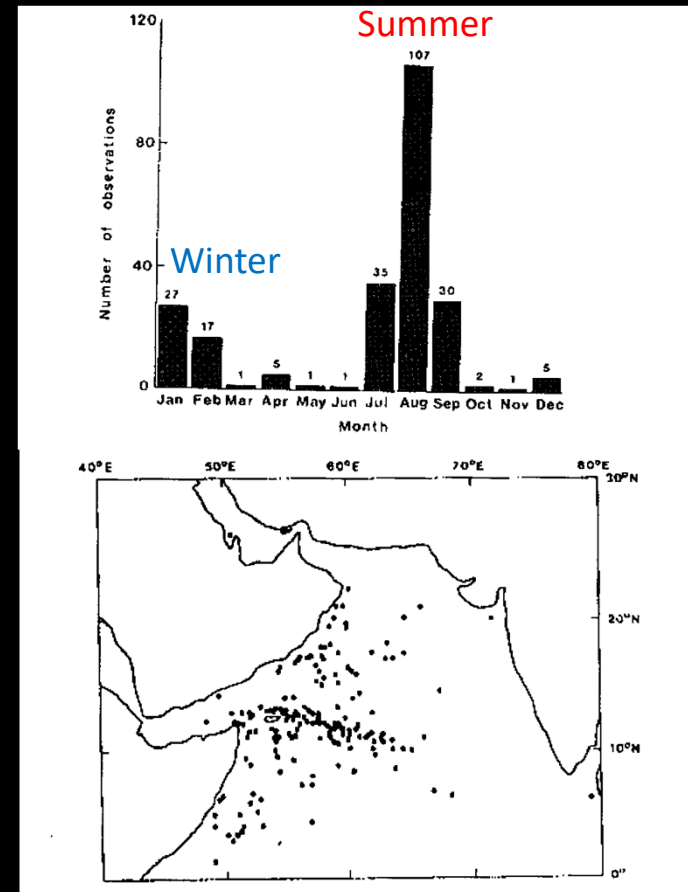
Compendium of Milky Sea Sightings: 1796 - 2021



Northwest Indian Ocean Events Synchronized with the Indian Monsoon



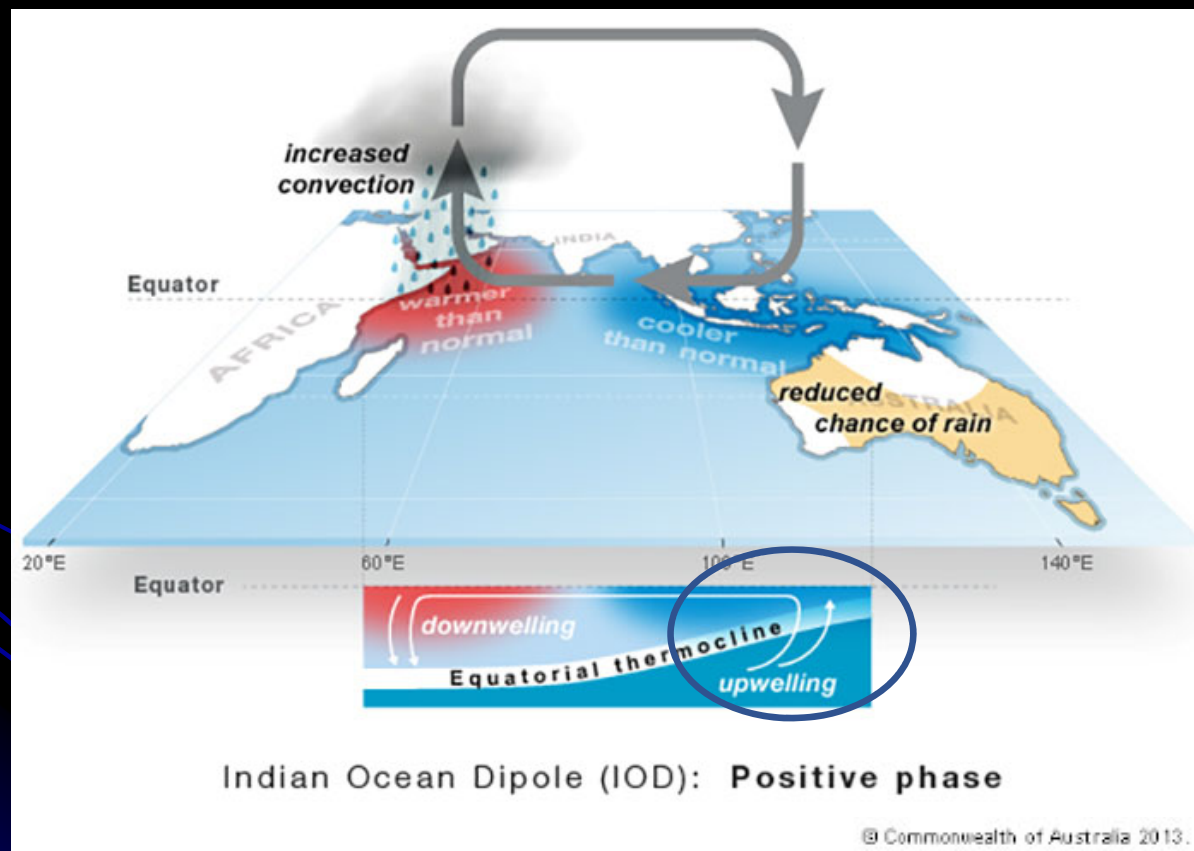
Shenoi et al., J. Mar. Res. 57, 885-907, 1999



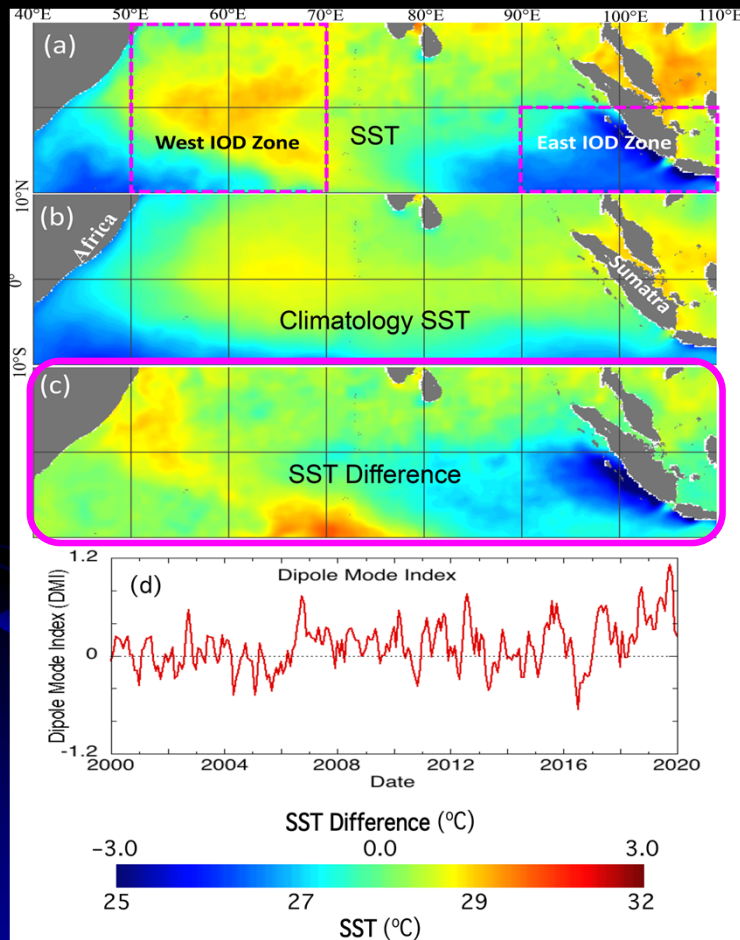
Herring and Watson, Mar. Obs., 63, 22-30, 1993

Maritime Continent Mechanism is Less Obvious

Hypothesis: The Indian Ocean Dipole



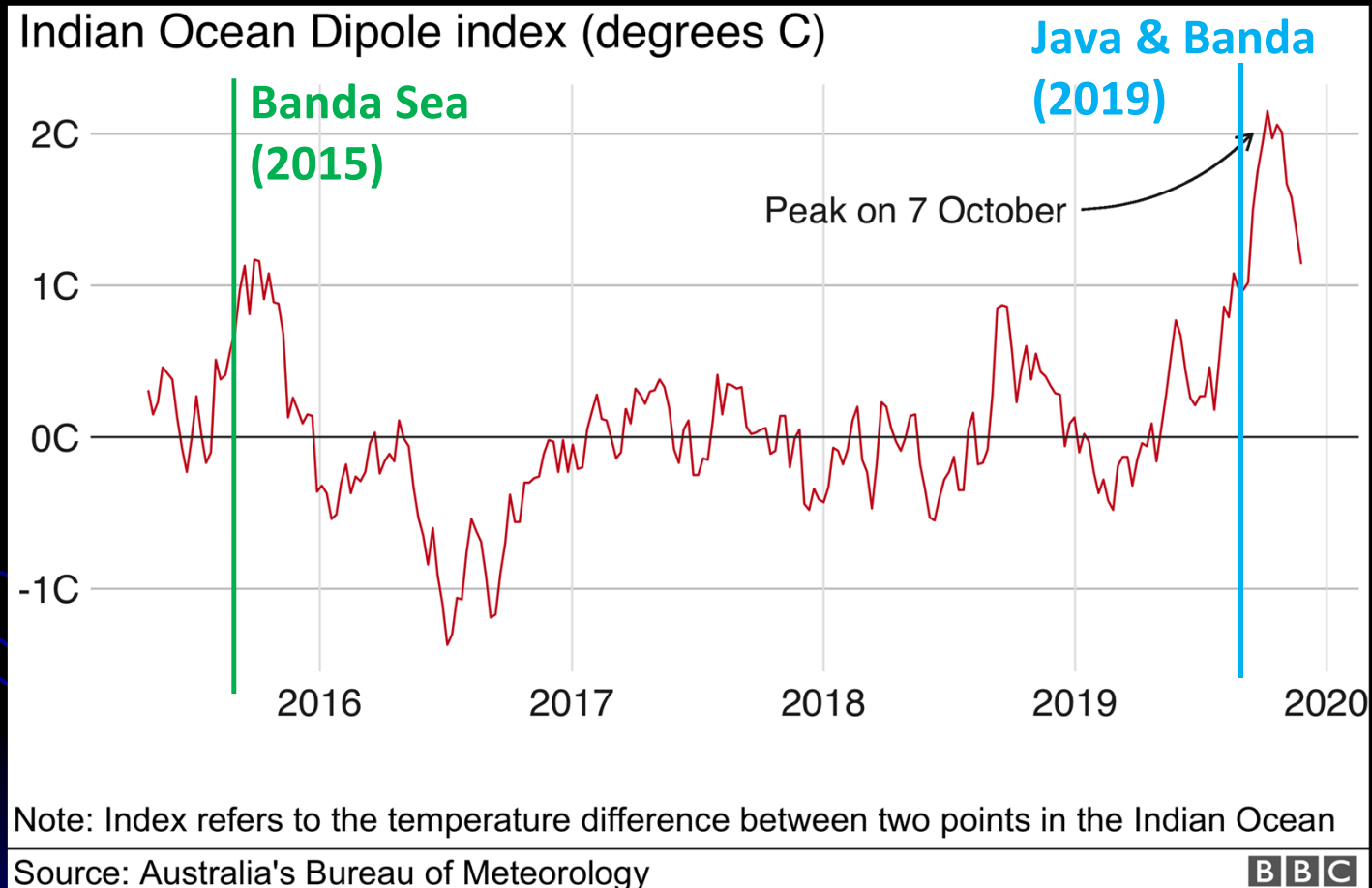
Suppressed Sea Surface Temps, Enhanced Biomass



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

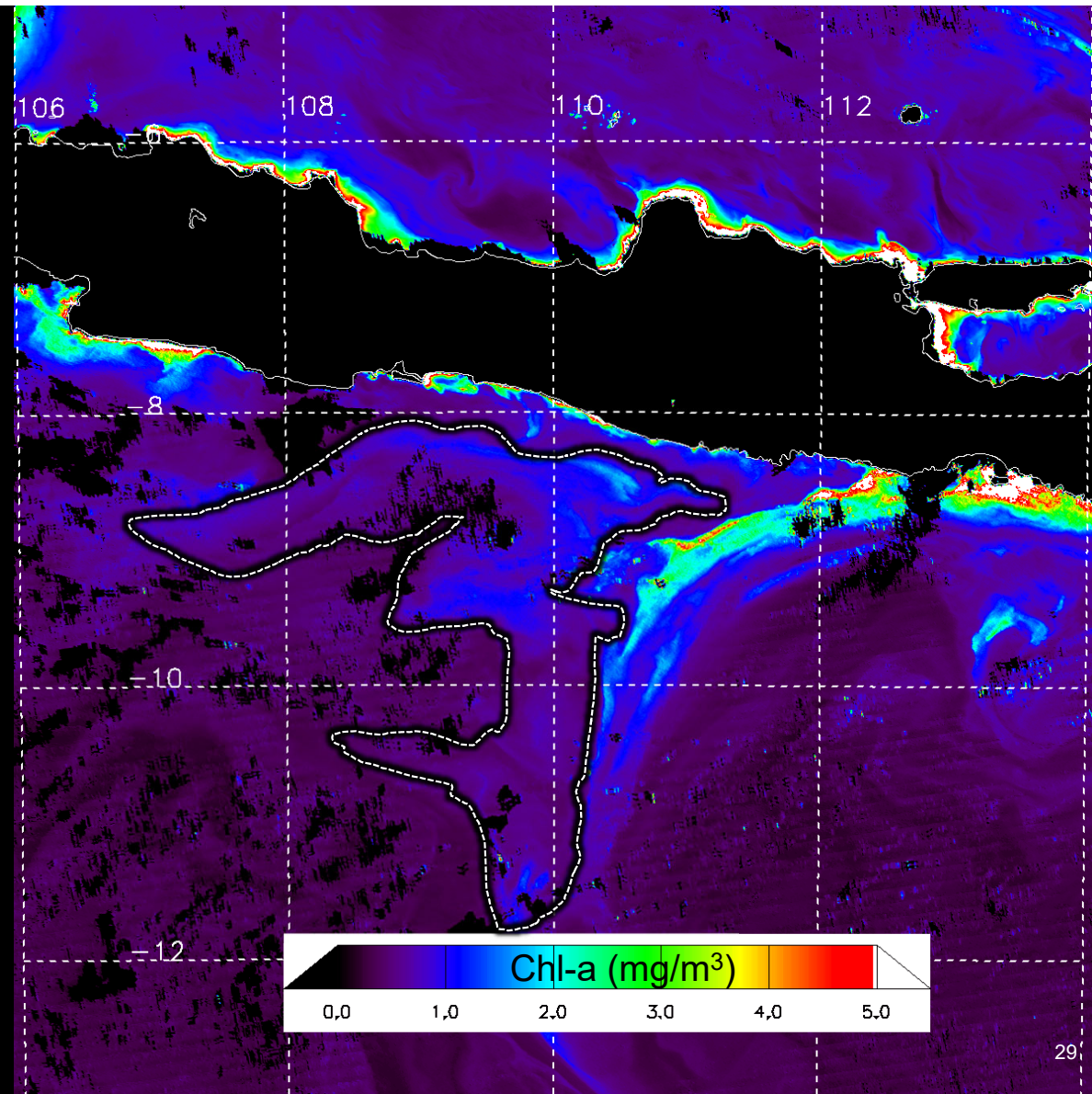
Shi, W., and M. Wang. Sci. Rep. 11, 2452 (2021)

Observed Milky Sea Correlation with Dipole Mode Index

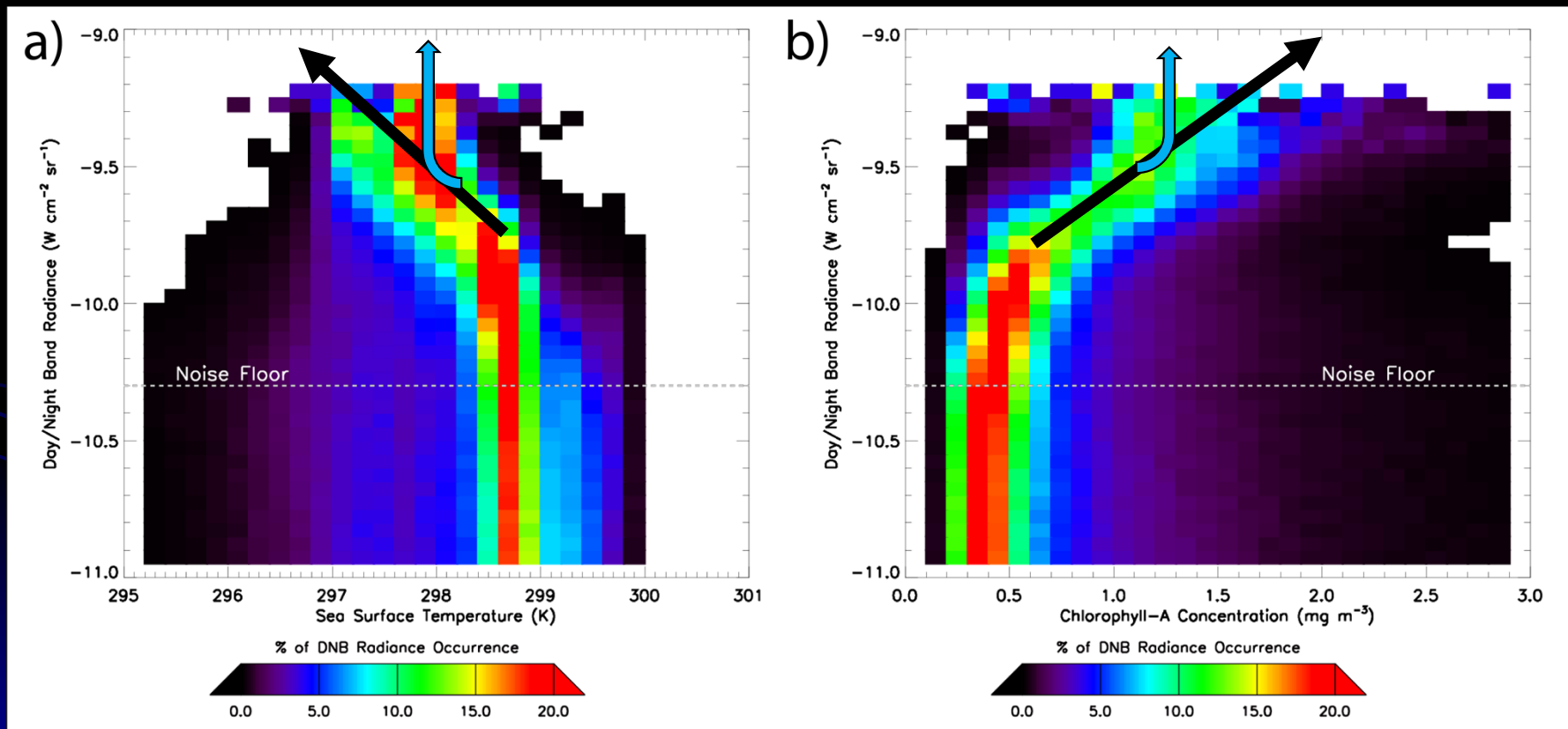


Observation #1:

Brightest Glow
Adjacent to the
Coolest Waters
and Highest
Biomass...

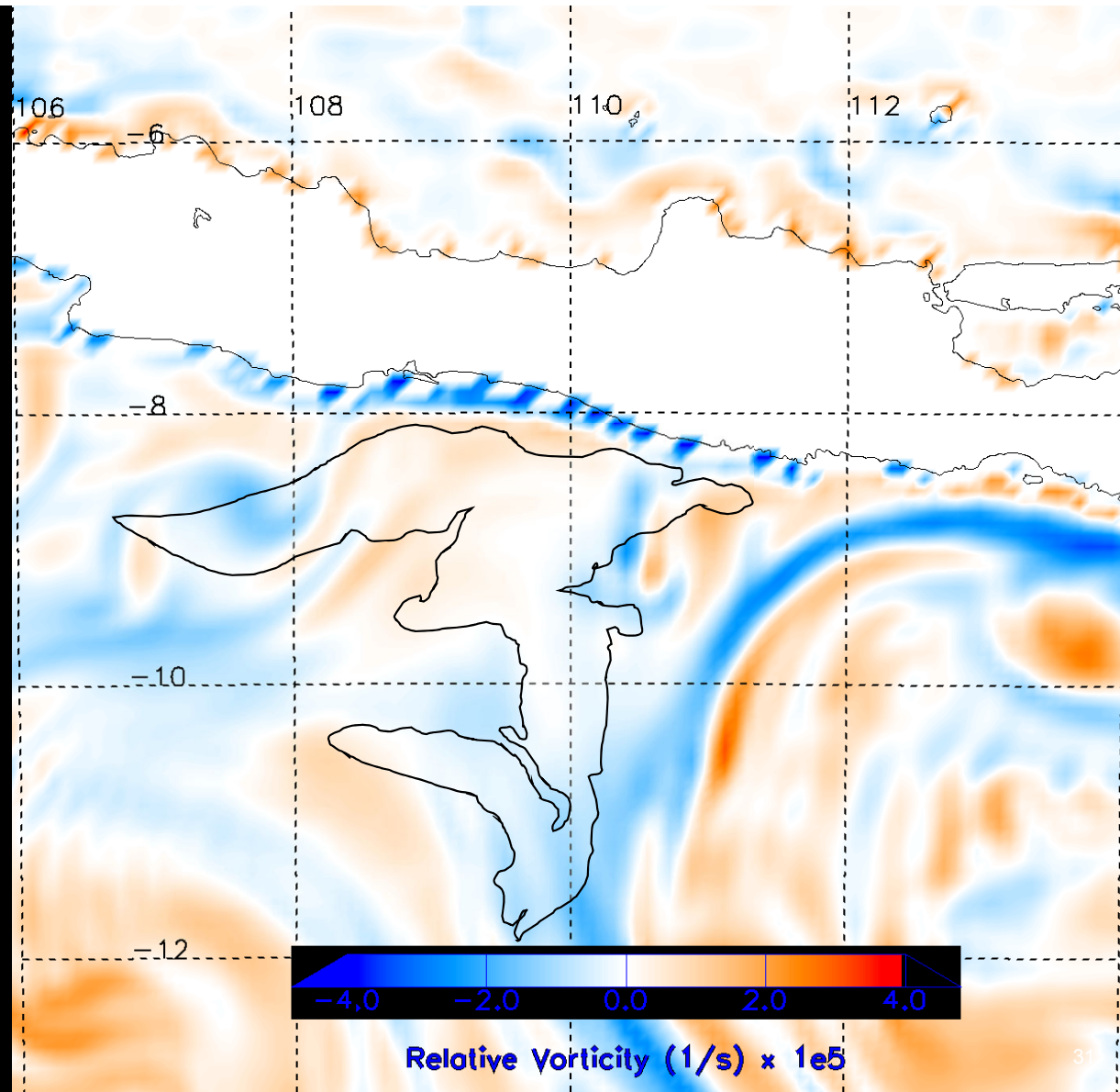


Temperature & Biomass Truncation Suggests Preferred Milky Sea Environment

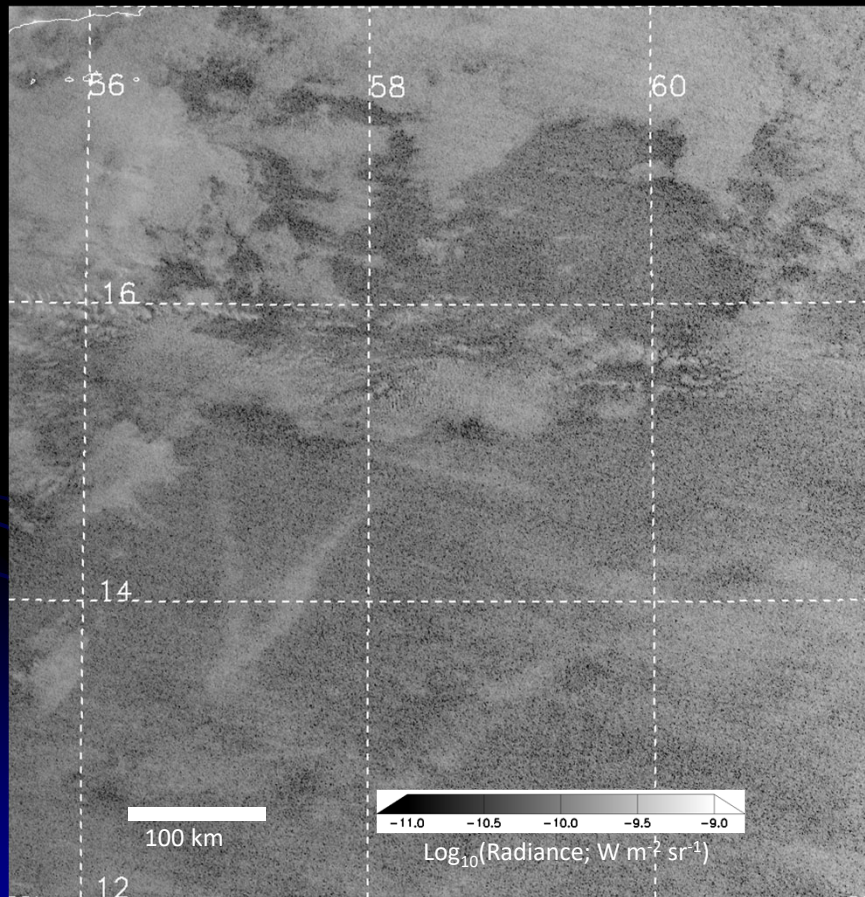


Observation #2:

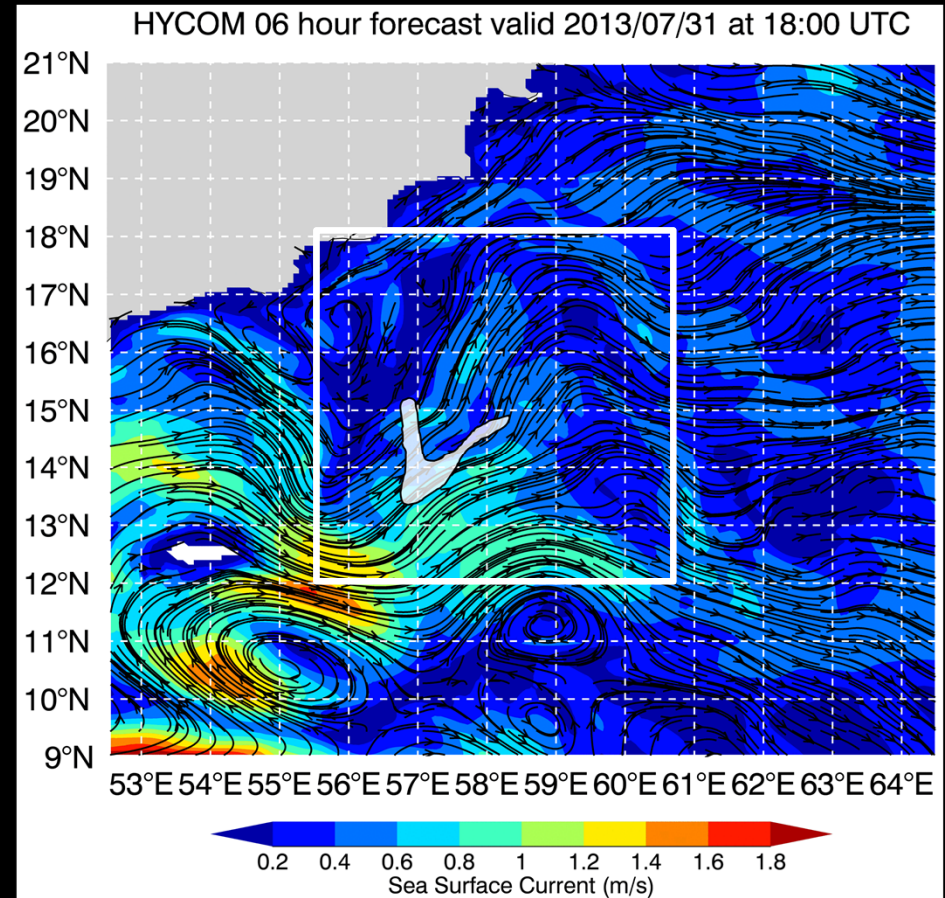
Brightest Glow
Aligns with
Doldrums, Frontal
Boundaries, and
Shear Layers



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



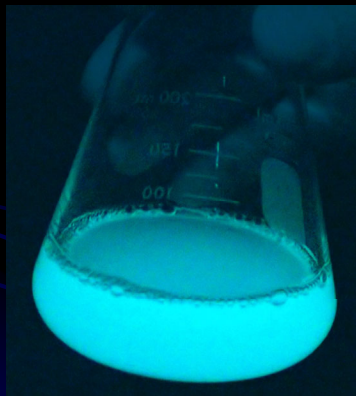
Areal coverage: $\sim 10,000 \text{ km}^2$



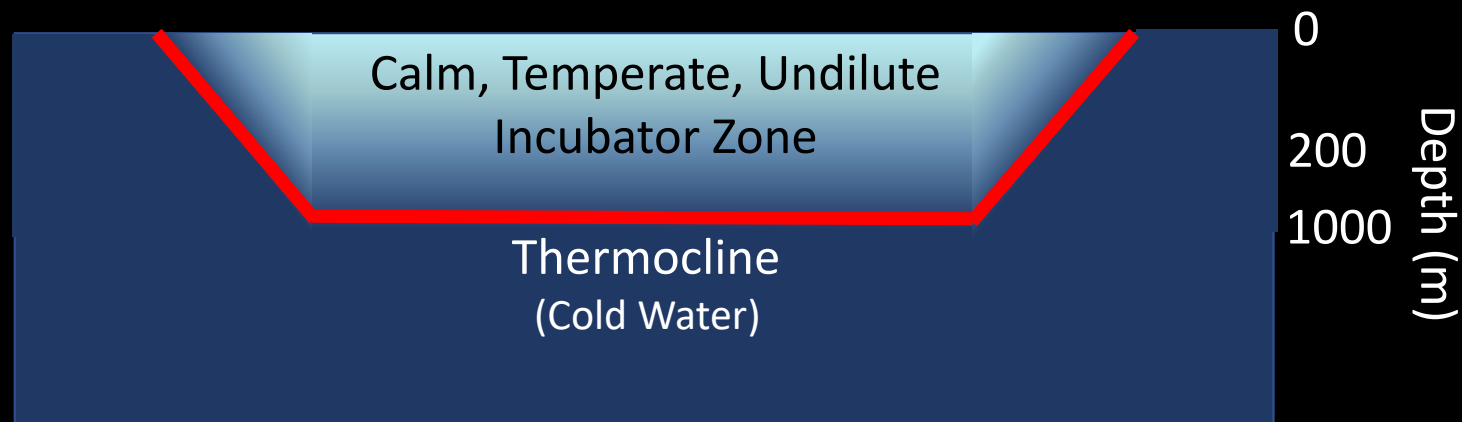
A '*Natural Flask*' Hypothesis Emerges

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

Shear-Induced Barrier Layers
Oceanic Fronts / Upwelling



V. fischeri in a flask of photobacterium broth



Combined with the right temperature, organic content, water chemistry, and strain(s) of luminous organisms, could such 'flask waters' incubate milky seas?

The Quest Continues!!

- The Day/Night Band has demonstrated the first potentially autonomous capability to detect bioluminescent milky seas on moonless nights
- There remain more questions than answers related to milky sea composition, structure, and their rarity in nature
- In situ sampling is desperately needed to answer these and other questions related to process and linkage to climate
- Air-sea coupling tied to Indian Ocean modes may help to explain/anticipate and deploy to future events
- Satellite-based autonomous detection will play a key role in directing resources to the right locations in time!



It Takes a Village...

US and British Navies



Private Mariners



The "Bio-Luminaries"

Peter Herring



Steve Haddock



Woody Hastings



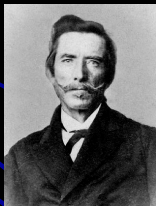
Ken Neilson



Dave Lapota



Commercial and Historical

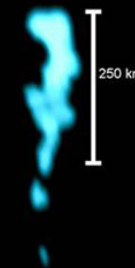


H.M.S. Eagle in Straits of Magellan. M. Sarmiento in the distance.

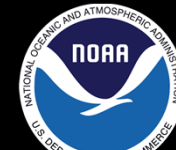
Avoid the Pirates!



Navigate Social Media



Thanks to Sponsors/Advocates!



Thank You!

Miller, S.D., Haddock, S.H.D., Straka, W.C., Seaman, C.J., Combs, C.L., Wang, M., Shi, W. and Nam, S.-H. Honing in on bioluminescent milky seas from space. *Sci Rep* 11, 15443 (2021).

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

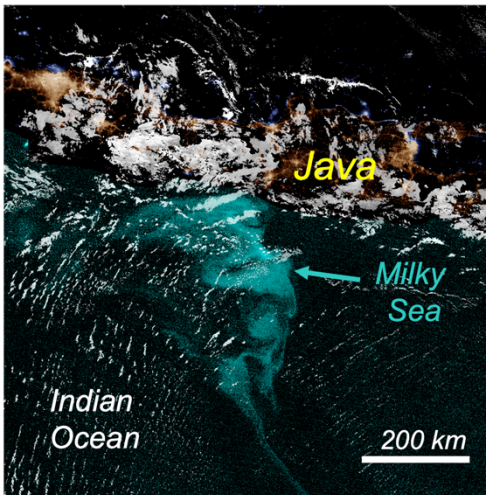
(Or Just Google “Milky Seas” to Learn More!)

CONTACT:

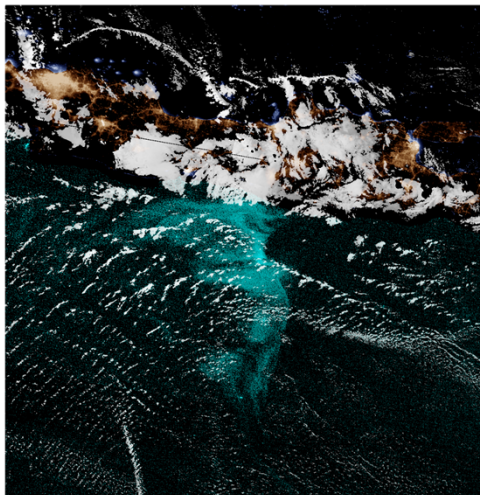
Steven.Miller@colostate.edu

Backup Slides

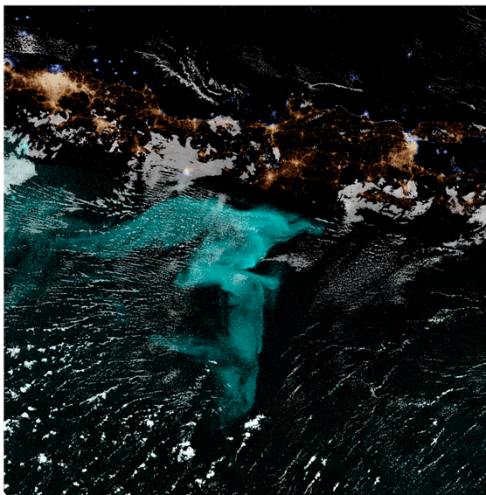
7/30/2019



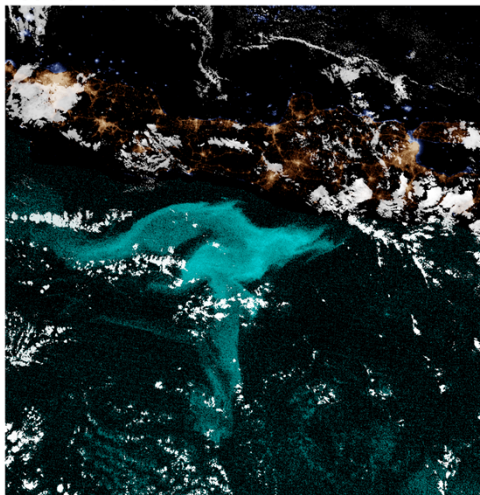
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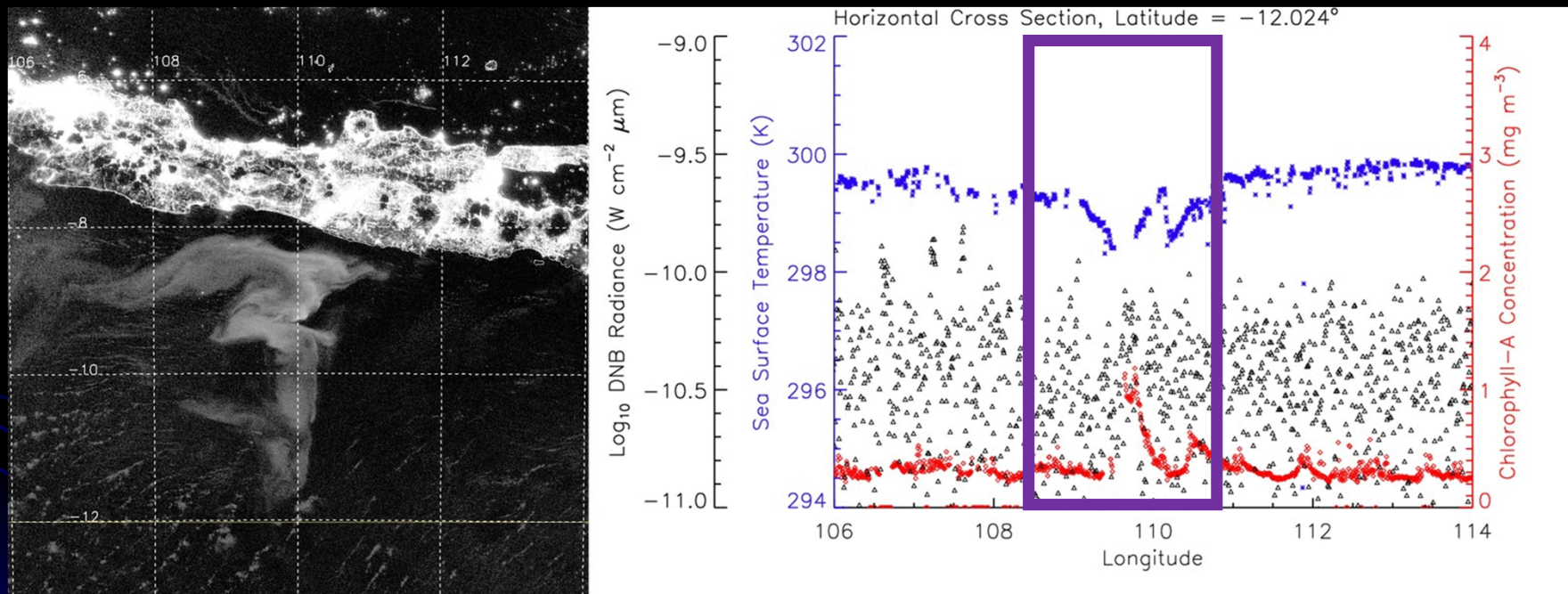
8/2/2019



8/4/2019

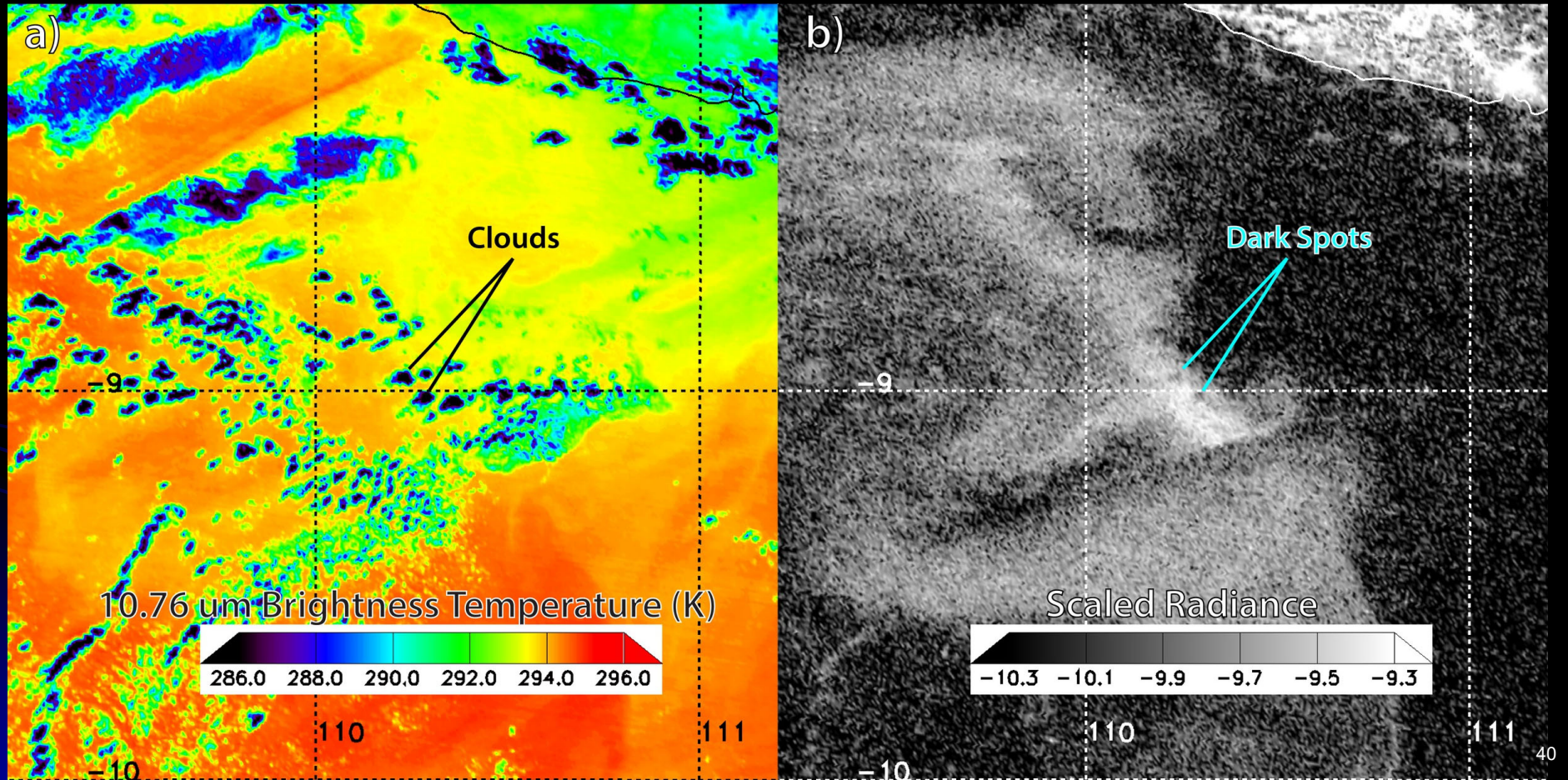


Cross Sections Show Glowing Waters' +/- Correlation with SST and Chl-a...



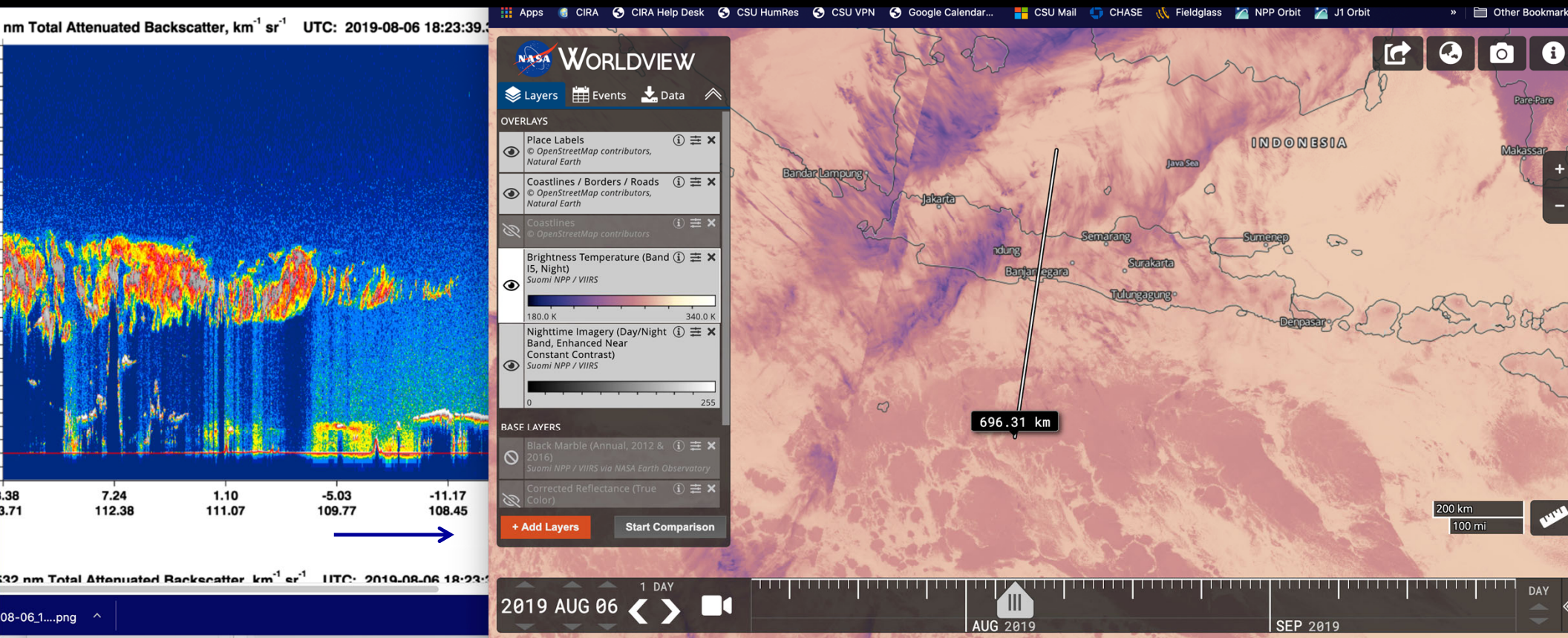
→ Correlations between glow intensity and sea-surface biomass and temperature are apparent. [Statistics on Chart 30 of this presentation.](#)

Optically Thick Clouds Attenuate Surface Light!

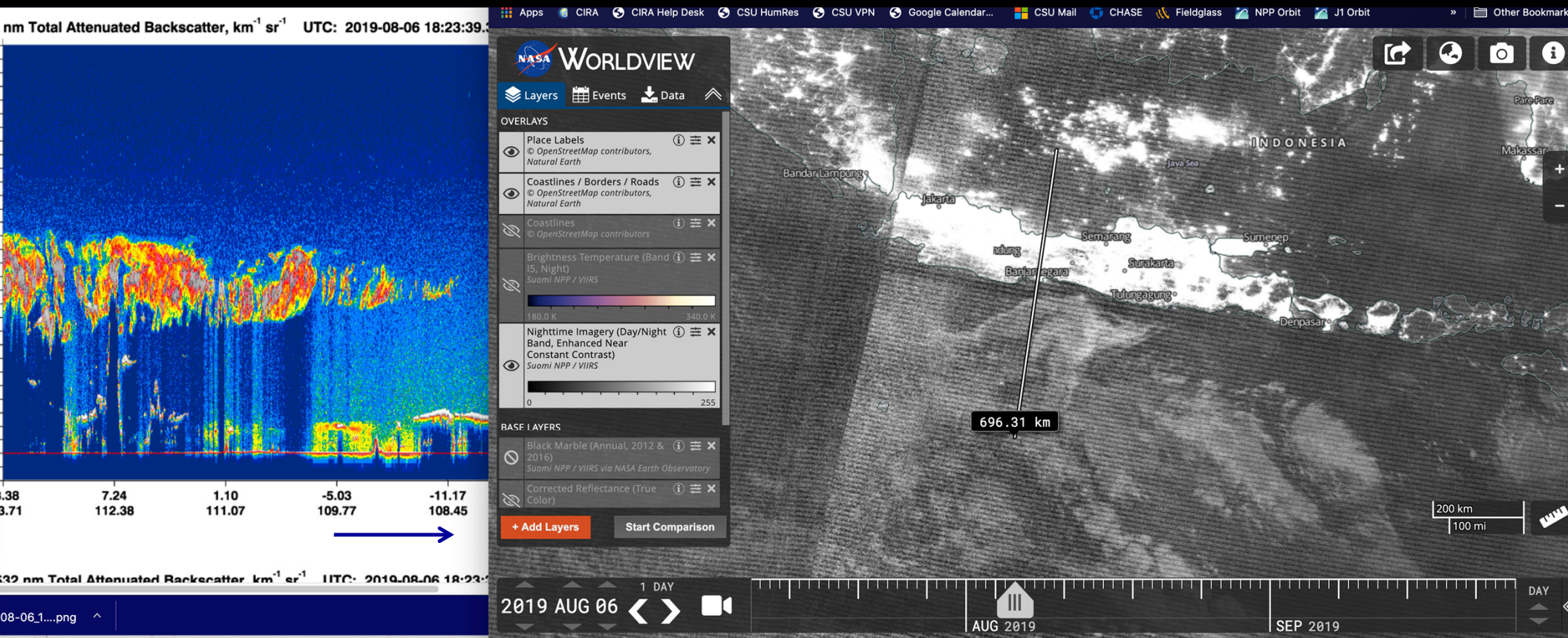


6 August 2019 Java Milky Sea Case—closest CALIPSO overflight identified

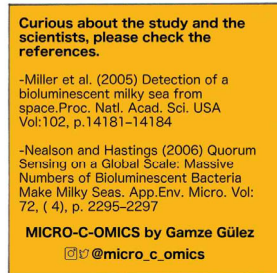
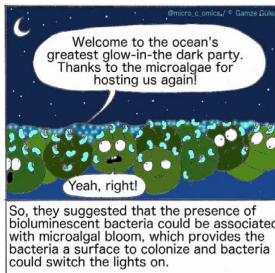
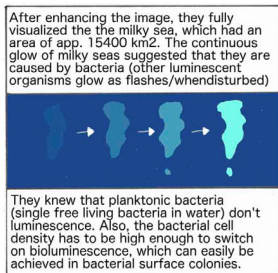
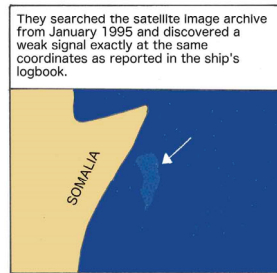
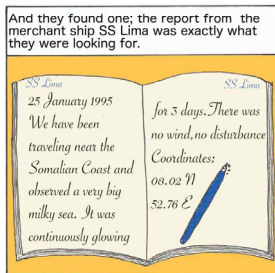
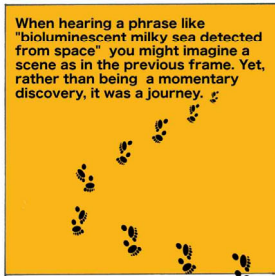
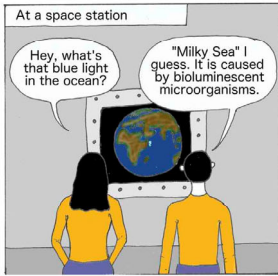
White segment shows CALIPSO track from (-5.03, 109.77) to (-11.17, 108.45)



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



© Gamze Gülez

Animals in Sea History



by Richard King

In the early evening of 27 July 1854, the American clipper ship *Shooting 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 sick 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 *Shooting 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