Edge Data Buoy Collection vs. Ocean Forecast Models: Why the US Must Invest in Model Infrastructure

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Abstract

The United States pioneered ocean observation and numerical weather prediction, yet American maritime operators increasingly depend on European ocean data products due to chronic underinvestment in domestic model infrastructure. This paper documents the widening gap between US edge-data buoy networks and Europe's Copernicus Marine Service, which delivers higher-resolution, more reliable, and freely available ocean forecasts globally. We present a comprehensive comparison of wave models, analyze the institutional and budgetary factors driving US decline, and propose a six-point strategy for restoring American leadership in operational ocean prediction.

1 The Quiet Migration

Something unusual is happening in the American maritime industry. Commercial fishermen, offshore energy operators, marine logistics companies, and ocean data startups are increasingly turning to European ocean data products, not out of preference, but out of necessity. The United States, which pioneered ocean observation and numerical weather prediction, is losing its users to foreign models that are simply better.

This isn't a story about European superiority. It's a story about American underinvestment, and it should bother every one of us. The United States built the greatest maritime economy in the world. American fishermen, offshore workers, and sailors deserve ocean data infrastructure worthy of the nation they serve. Right now, they're not getting it.

The core issue is a strategic mismatch: the US continues to pour resources into aging edge-data collection infrastructure, physical buoys scattered across the ocean, while Europe has invested heavily in the computational model infrastructure that has become the backbone of modern ocean forecasting. The result is a widening gap that grows more consequential with every budget cycle.

2 The Buoy Paradigm: An American Innovation That Served Us Well

The National Data Buoy Center (NDBC), operated by NOAA, maintains a network of moored buoys, coastal stations, and drifting platforms that have served as the primary source of real-time ocean observations in US waters since the 1970s. America built this network from scratch; it was world-leading at the time, and it saved countless lives at sea. These stations measure wave height, period, wind speed, atmospheric pressure, sea surface temperature, and other parameters at fixed points in the ocean.

For decades, this made sense. Numerical models lacked the resolution and accuracy to produce reliable ocean state estimates between observation points. Satellite coverage was intermittent. Computing power was expensive. Physical measurement was the only trustworthy source of ocean data.

But the buoy paradigm has fundamental limitations that have become increasingly untenable:

Sparse coverage. The NDBC network covers the US coastline with roughly 100 active offshore buoy stations. In practice, this means gaps of 50 to 200+ nautical miles between measurement points. For a commercial fishing captain operating at a specific inlet 80 miles from the nearest buoy, the data is directionally useful but operationally inadequate.

Chronic maintenance failures. Buoys are physical assets anchored in one of the most corrosive environments on Earth. They break, drift off station, lose sensors, and go offline, sometimes for months. In 2024, three critical buoys in the New York Bight (stations 44025, 44066, and 44017) all had maintenance listed as "Deferred." Users on maritime forums described NDBC's repair posture as "they get to it when they can get to it." For a region that serves one of the densest maritime corridors in the world, this is not acceptable.

Prohibitive cost-per-data-point. Deploying a single deep-water buoy costs between \$100,000 and \$300,000. Annual maintenance runs \$20,000 to \$50,000 per station, when maintenance actually occurs. Multiply this across hundreds of stations, add vessel time for servicing, and the cost of maintaining comprehensive spatial coverage through physical infrastructure becomes astronomical. And even at full funding, the coverage is still sparse.

Single point of failure. When a buoy goes offline, there is no data for that location until it's repaired. There is no graceful degradation. The data simply disappears.

These aren't new problems. They are structural features of edge-data collection that no amount of incremental improvement can resolve. The ocean is too large, too hostile, and too dynamic to observe comprehensively through fixed physical sensors. The buoy network was the right answer for its era. But the era has changed, and America's ocean infrastructure needs to change with it.

3 The Model Revolution: Europe's Strategic Bet

While the US was maintaining buoys, Europe was building something fundamentally different: a continent-scale investment in ocean model infrastructure that has produced the most comprehensive, highest-resolution, freely available ocean data in history.

3.1 The Copernicus Marine Service

At the center of this effort is the Copernicus Marine Service (CMEMS), one of six thematic services within the European Union's Copernicus Programme. Funded under the EU's Multiannual Financial Framework at 5.421 billion EUR for 2021–2027, Copernicus represents a sustained, strategic commitment to Earth observation that has no American equivalent.

The Copernicus Marine Service provides free, open-access ocean data covering waves, currents, sea surface temperature, salinity, sea level, biogeochemistry, and sea ice, globally. The data comes from a combination of satellite observations, in situ measurements, and state-of-the-art numerical models, all integrated through data assimilation systems that produce continuous, gap-free analysis and forecast products.

The key word is *continuous*. Unlike a buoy network, which provides data at scattered points, model-based products provide data everywhere, all the time.

3.2 Wave Models: A Comprehensive Comparison

For commercial maritime users, wave data is often the most operationally critical product. Here is where the transatlantic gap is most visible.

Table 1: European wave models

Model	Operator	Resolution	Coverage	Forecast	Key Features
MFWAM	Météo-France	1/12° (∼5 nm)	Global	10 days	Spectral partitions, sat. assim.
ECMWF HRES-WAM	ECMWF	∼28 km	Global	15 days	Coupled to IFS, 4 runs/day
ECMWF ENS-WAM	ECMWF	∼55 km	Global	15 days	51-member ensemble
Med. WAV	Copernicus	1/24° (∼2.5 nm)	Med.	10 days	Current-wave coupling
Baltic WAV	Copernicus	∼1 nm	Baltic	10 days	Ice-wave interaction
Arctic WAV	Copernicus	∼3 km	Arctic	10 days	Ice edge dynamics

Table 2: US wave models

Model	Operator	Resolution	Coverage	Forecast	Key Features
GFS-Wave (WW3)	NOAA/NCEP	0.167° (∼10 nm)	Global	16 days	Primary US global wave model
FNMOC WW3	US Navy	∼0.5°	Global	10 days	Military-focused, limited access
HRRR	NOAA	3 km	CONUS	48 hours	Atmospheric, limited wave coupling

3.2.1 European Models

3.2.2 US Models

The numbers tell the story. MFWAM operates at 1/12° resolution, roughly 5 nautical miles between grid points at mid-latitudes. NOAA's GFS-Wave runs at 0.167°, roughly 10 nautical miles. That's half the resolution. In the Mediterranean, Copernicus provides wave data at 1/24°, four times the resolution of the primary US global product.

But resolution is only part of the advantage. MFWAM includes spectral wave partitioning, the decomposition of the wave field into distinct swell systems and local wind waves. For any mariner who has experienced the dangerous intersection of a long-period Atlantic swell with locally generated wind chop, this isn't an academic distinction. It's the difference between understanding the sea state and merely knowing the significant wave height.

3.3 Why Europe Got This Right

Europe's success wasn't inevitable. It was the result of deliberate institutional design:

Centralized investment. The Copernicus Programme concentrates resources through a single governance framework, with the European Commission providing sustained multi-year funding. This eliminates the annual appropriations uncertainty that plagues American science agencies.

Focused computing. ECMWF operates supercomputers with approximately 30 petaflops of , historically an order of magnitude greater than what NOAA has dedicated to numerical weather prediction. ECMWF focuses this power on a single, world-leading integrated forecasting system. The result is that Europe's primary atmospheric model (IFS), which drives its wave models, consistently outperforms the American GFS in independent verification.

Open data as strategy. All Copernicus Marine products are free and open. This isn't charity; it's an economic multiplier. By removing barriers to access, Europe has built a global ecosystem of downstream commercial applications, academic research, and operational users that feeds back into model improvement.

International collaboration. ECMWF is funded by 35 member and cooperating states. This shared investment model distributes cost while concentrating , a model the US has never replicated for ocean prediction.

4 The US Gap: Organizational Dysfunction Meets Budget Reality

The United States spends more on weather and ocean prediction than any single European country. But it distributes that spending across at least five federal agencies (NOAA, the Navy/FNMOC, the Air Force, NASA, and the Department of Energy), each operating its own models, its own computing infrastructure, and its own institutional priorities. The result is diffusion of talent, duplication of effort, and a collective output that falls short of what a focused investment could achieve.

4.1 The NOAA Problem

NOAA is nominally the lead civilian agency for ocean and atmospheric prediction, but it has struggled for over a decade to modernize its core modeling infrastructure. In October 2024, University of Washington atmospheric scientist Cliff Mass published a detailed critique titled "The Unnecessary Decline of U.S. Numerical Weather Prediction," documenting how NOAA spent years on a troubled transition to the FV-3 dynamical core for its Global Forecast System while ECMWF steadily extended its lead.

The ocean side is worse. GFS-Wave, NOAA's primary global wave product, runs on WaveWatch III, a capable model framework, but one that is operationally configured at lower resolution than its European counterparts and lacks the assimilation sophistication of MFWAM. NOAA does not produce a freely available spectral wave partition product comparable to what Copernicus provides as a standard output.

4.2 The Budget Crisis

Whatever challenges NOAA faced from institutional design are now being compounded by active destruction of capability.

The proposed FY2026 federal budget would cut NOAA's overall funding by approximately 27%, representing a reduction of roughly $1.7 billion. Specific cuts include:

- Elimination of the Integrated Ocean Observing System (IOOS), the very regional observation networks that supplement the buoy network and feed ocean models
- Elimination of all funding for NOAA's climate, weather, and ocean laboratories and cooperative , the research pipeline that develops next-generation models
- Closure or defunding of NOAA research labs that produce the science underpinning operational forecasts
- Elimination of the National Sea Grant College Program, which funds applied ocean research at universities

Meanwhile, the effects of 2025 staffing cuts at the National Weather Service are already measurable. Hundreds of positions have been eliminated or left vacant. Staffing is down 20% or more at many local forecast offices. Weather balloon soundings, critical inputs to atmospheric models that drive wave forecasts, have been suspended at approximately 18% of upper-air stations due to insufficient staff.

These cuts do not distinguish between "weather" and "ocean" prediction. The atmosphere drives the ocean. Degraded atmospheric forecasts produce degraded wave forecasts, degraded current forecasts, degraded storm surge forecasts. The system is coupled; the cuts are not.

5 Real-World Impact: When the Data Fails

Consider the experience of a US-based marine data company that provides ocean conditions to commercial fishing operations along the Atlantic seaboard.

For years, this company relied on the standard American data stack: NDBC buoy observations for real-time conditions and GFS-Wave for forecasts. The workflow was familiar but fragile. Buoys would go offline without warning. Coastal stations would report stale data. GFS-Wave forecasts at 10-nautical-mile resolution couldn't resolve the swell dynamics that matter for inlet crossings and offshore fishing grounds.

When the company evaluated European alternatives, the comparison was stark:

- **Resolution:** MFWAM provided data at twice the spatial resolution of GFS-Wave: 5 nm vs. 10 nm grid spacing. For any given inlet or coastal feature, the nearest MFWAM grid point was closer than the nearest *working* NDBC buoy.

- **Reliability:** The model produced data continuously, globally, without the outages that plagued the buoy network. No more early-morning scrambles when a buoy went dark before a charter fleet departure.
- **Richness:** Swell and wind-wave partitions allowed the company to present sea state information that mariners could actually use, distinguishing between a 6-second wind chop and a 12-second groundswell arriving from a distant storm.
- **Scalability:** Expanding to new markets (the Gulf Coast, the Caribbean, international waters) became a configuration change rather than an infrastructure project. The model covers the globe.

The company switched its primary wave data source from US to European products. Not because of ideology, but because the European data was better, more reliable, and free.

This is not an isolated case. It is a pattern that is quietly accelerating across the US maritime industry.

6 The Path Forward: Restoring American Leadership

America has every advantage needed to lead the world in ocean prediction. We have the largest meteorological research establishment on Earth. We invented numerical weather prediction. Our private sector pioneered machine learning for weather forecasting. Our Navy operates in every ocean on the planet. The talent, the technology, and the strategic need are all ; what's missing is the focus and the commitment.

6.1 Consolidate Ocean Modeling Efforts

The current distribution of wave and ocean modeling across NOAA, the Navy, and other agencies produces redundancy without excellence. The US should designate a single center of excellence for operational ocean prediction, adequately funded and empowered to produce world-class products. The Earth Prediction Innovation Center (EPIC), created in 2020 to modernize NOAA's modeling, is a potential , but only if it receives sustained funding and a clear mandate.

6.2 Invest in Computing Infrastructure

ECMWF operates at approximately 30 petaflops dedicated to weather and ocean prediction. NOAA's computing capacity for NWP has historically been a fraction of this. Higher resolution requires more compute. More ensemble members require more compute. Data assimilation requires more compute. There is no shortcut: the US must invest in the hardware that makes competitive ocean models possible.

6.3 Adopt Open Data as National Strategy

The Copernicus model (free, open, comprehensive ocean data) has generated enormous downstream value for European industry, research, and public safety. The US should adopt the same approach for its ocean products. Data paywalls and access restrictions on publicly funded ocean forecasts are economically counterproductive and strategically foolish.

6.4 Increase Model Resolution and Capability

GFS-Wave should operate at minimum 1/12° resolution globally, with regional nests at 1/24° or higher for US coastal waters. Spectral wave partition products should be standard outputs. Current-wave coupling should be operational, not experimental. These are not aspirational ; they are capabilities that Europe delivers today.

6.5 Protect the Research Pipeline

Eliminating NOAA's research laboratories and cooperative institutes doesn't save ; it destroys the human capital and institutional knowledge required to build next-generation models. The scientists developing data assimilation techniques, spectral wave physics, and coupled Earth system models cannot be rehired on demand. Once dispersed, this expertise takes a generation to rebuild.

6.6 Learn from the Copernicus Governance Model

Multi-year, programmatic funding, as opposed to annual appropriations subject to political disruption, is essential for infrastructure investments that take years to mature. The US should explore governance structures that provide ocean prediction programs with the funding stability that Copernicus enjoys through the EU's Multiannual Financial Framework.

7 Conclusion: This Is America's Fight to Win

The United States built the first weather satellites, pioneered numerical weather prediction, and created the buoy networks that defined ocean observation for a generation. Americans did that. It is part of our legacy of innovation, and it should be a source of pride.

But pride in what we've built doesn't excuse complacency about where we're headed. Right now, American fishermen and maritime operators are relying on European data to do their jobs , not because they want to, but because we've left them no choice. That's not acceptable for a nation with 95,000 miles of coastline, the world's largest exclusive economic zone, and a commercial fishing industry that feeds millions.

This is not a partisan issue. The captain running out of Oregon Inlet at 4 AM doesn't care about budget politics. He cares whether the wave forecast is accurate enough to bring his crew home. The offshore energy worker in the Gulf needs reliable sea state data regardless of which party controls the appropriations committee. These are Americans doing hard, dangerous work on the water, and they deserve the best ocean data in the , not the best we used to have.

The ocean doesn't wait for budget negotiations. The US must invest in model , not as an alternative to observation, but as the computational backbone that makes observation data useful at scale. Europe has shown what sustained, focused investment can achieve. America has every capability needed to match and exceed that standard.

We built the tools that made modern ocean prediction possible. Now it's time to finish the job.