PAPER

The Value of Ocean Surface Wind Information for Maritime Commerce

AUTHOR
Hauke Kite-Powell
Marine Policy Center, Woods Hole Oceanographic Institution

ABSTRACT

Observations, nowcasts, and forecasts of ocean surface wind conditions are of economic value to activities such as maritime transportation, commercial fishing, offshore energy, recreational boating, and search and rescue. In this paper, we estimate the value to the maritime shipping industry of ocean surface wind information and of wind and wave condition forecasts based on this information. Commercial ships transiting the North Pacific and North Atlantic oceans are exposed to severe wind and wave conditions associated with extratropical storms. These storms impose costs on maritime commerce by delaying and sometimes damaging vessels or causing loss of cargo. Ocean surface wind information allows ships to limit their exposure to these conditions. We estimate that average expected annual losses to container shipping (lost containers and associated damage to vessels) in the absence of good information about extratropical storm conditions would be on the order of $250 million/year in the North Pacific and $120 million/year in the North Atlantic, and we estimate average expected annual losses to bulk shipping operations from extratropical storm exposure in these regions to be on the order of $150 million/year. A significant fraction of this risk can be avoided with ocean surface vector wind observations and forecasts. Our model results suggest that the QuikSCAT information (available until November 2009) and associated forecasts enabled a reduction in annual exposure for shipping traffic in the North Atlantic and North Pacific of about 50%, with total annual net savings around $150 million. The estimate of annual benefits to shipping operations from a hypothetical improved satellite instrument is around $200 million.
Keywords: ship routing, extratropical storms, scatterometry, ocean surface wind, value of information

Introduction and Background

Observations, nowcasts, and forecasts of ocean surface wind conditions are of economic value to activities such as maritime transportation, commercial fishing, offshore energy, recreational boating, and search and rescue. In this paper, we estimate the value of information about extratropical storms to important segments of the maritime transportation industry.

Commercial ships transiting the North Pacific and North Atlantic oceans are exposed to severe wind and wave conditions associated with extratropical storms. Our models (see below) suggest that, in the absence of forecast information, 10-20% of winter transits on the northern Atlantic and Pacific oceans would be exposed to some degree to such storms. Storms impose costs on maritime commerce by delaying and sometimes damaging vessels or causing loss of cargo. In particular, container ship traffic in these regions is at risk of losing containers overboard in severe weather conditions, and dry bulk ships carrying grain (Pacific and Atlantic) and coal (Pacific) face risk of structural damage from these conditions. Ocean surface wind information allows ships to limit exposure to these conditions.

The degree to which information (nowcast, forecast) about extratropical storms is of value to the shipping industry depends in part on the quality of the information, e.g., the time horizon, resolution, and accuracy of storm forecasts. The observing systems and ocean-atmosphere models required to produce accurate nowcasts and forecasts of marine conditions are costly. Understanding the benefits derived from different levels of information produced by such systems is an important ingredient to a rational process of economic design of ocean observing systems (Kite-Powell, 2009a). This paper illustrates one approach to estimating these benefits.

Satellite-Based Surface Wind Data

Effective ocean surface wind nowcasts and forecasts depend on satellite scatterometer-based observations of surface winds across wide stretches of ocean; there are no other observing systems that produce broad and consistent coverage. Examples of satellite-based scatterometers include NASA's Quick

Scatterometer (QuikSCAT, launched in 1999 and operational until its failure in November 2009; Chang & Jelenak, 2006) and the Advanced Scatterometer (ASCAT, on the European MetOp-A satellite, launched in 2006; Sienkiewicz et al., 2008). A next-generation ocean vector wind measurement (Extended Ocean Vector Wind Mission, XOVWM) instrument was defined at the conceptual level for deployment on two satellites (Jelenak & Chang, 2008; Rodriguez and Gaston, 2008), and a separate conceptual assessment has been carried out for a dual-frequency scatterometer (DFS) with advanced microwave scanning radiometry on the Global Change Observation Mission-W2 satellite (Jelenak et al., 2009). Table 1 summarizes some of the key features of surface wind data obtained from these instruments; for details, please see the references listed in this paragraph.

Observing system simulation experiments to determine the contribution of different data sources to the quality of extratropical ocean storm condition forecasts have been conducted only for a few limited cases designed to compare QuikSCAT and XOVWM (Jelenak & Chang, 2008). Nonetheless, the importance of high-quality satellite-based scatterometry to storm detection is widely recognized. The instances in which hurricane-force extratropical storm conditions were observed by NOAA's Ocean Prediction Center in the North Atlantic and North Pacific each year increased from fewer than 10 prior to QuikSCAT to more than 100 using QuikSCAT data at 12.5-km horizontal resolution with advanced wind algorithms and rain impact analysis (Jelenak & Chang, 2008). Comparisons of ASCAT and QuikSCAT data suggest that only 10-20% of the extratropical hurricane-force storm events observed by QuikSCAT can be reliably identified using ASCAT data (Sienkiewicz et al., 2008). XOVWM or DFS data would improve on QuikSCAT by providing better observation of cyclone development and intensity and evolution of wind fields (more frequent observations at finer resolution), better nearshore data, and avoidance of rain degradation (Jelenak & Chang, 2008).

Information about ocean surface winds is valuable to organizations and individuals who plan and carry out operations on the ocean. Since operators are interested in wind information for the geographic areas in which they are active, the value of ocean surface wind information is determined in part by the geographic distribution of the user activities. Also, because ocean surface wind information is usually not an end in itself but a means to anticipating some other event (for example, the drift of a life raft, or the severity of the sea state), the value of satellite-based ocean surface wind data also depends on what other sources of surface wind information are available for the region (for example, surface- or buoy-based observing stations) and what alternate information is available to predict the event (for example, the deployment of

TABLE 1

Alternatives instrument systems for acquisition of ocean surface vector wind data.

Instrument	Coverage	Resolution	Accuracy
QuikSCAT (Ku-band radar)	90% daily coverage	12.5/25 km horizontal	±2 m/s or 10% degraded by rain
	18 h revisit	100 knots max. speed	
	20-30 km land mask		
ASCAT (C-band radar, 5.255 GHz)	54% daily coverage	25/50 km horizontal	less sensitive to rain
	40-50 km land mask		
DFS with AMSR on GCOM-W2	90% daily coverage	<10 km horizontal	±1 m/s or 10%
	24 h revisit		
	10 km land mask		
XOVWM (two satellites)	100% daily coverage	<5 km horizontal	±1 m/s or 10%
	6 h revisit	165 knots max. speed	
	2.5-5 km land mask		
Ships and buoys	minimal, except immediately nearshore	single point observations	

AMSR, advanced microwave scanning radiometry; GCOM, Global Change Observation Mission.

locator beacons with life rafts). The estimate of the value of satellite-based ocean surface wind observations, therefore, must take into account

- the value of wind nowcasts/forecasts to each user group, as a function of location, taking into account the use of other technologies to address the underlying information requirement;
- the availability of wind observations from other sources, as a function of location; and
- the coverage/quality of wind observations provided by the satellite system.

Ocean surface wind information is provided, mainly for nearshore waters, by a number of technologies other than satellite systems. Wind sensors on shore-based meteorological stations, coastal buoys and towers, offshore buoys, and vessels of opportunity provide single-point wind observations with considerable density along the immediate coastline, with some degree of coverage through nearshore waters to 10 km or so from shore and only very sporadically beyond 10 km.[1] Satellite-based ocean surface wind systems provide more uniform coverage that is limited nearshore by land mask effects. For ocean waters, more than 20 km from the coastline, surface-based observation coverage is very sparse; open ocean buoys and ships of opportunity likely achieve less than 1% coverage at any one time (Kite-Powell, 2009b).

Approach

We develop and apply a computer model to simulate the storm exposure of commercial ship transits of the North Atlantic (between the U.S. East Coast and the Atlantic coast of Europe) and North Pacific (between the U.S. and Central American West Coast and Southeast Asia/Japan) during months when extratropical storms are known to occur (September-May). The model includes a simple decision process by which the ship adjusts its course and speed in response to information about stochastically generated storm conditions. By Monte Carlo modeling of transits under different sets of information about ocean surface vector winds, we can compare transit duration and storm exposure for a range of nowcast/forecast scenarios.

We model extratropical storms as moving and temporally transient geographic regions in which severe wind/wave conditions exist. The model treats storminess as a binary condition: the weather at a given location is characterized by severe winds and waves, or it is not. When a ship is geographically within an active storm region, it is forced to slow its speed (in the model) to 10 knots. Ships are assumed to travel on great circle routes, except when they deviate to avoid storm exposure.

One model run simulates a single ocean transit in 1-h time steps, tracking to location of the ship and of stochastically generated storm systems to determine whether the ship is experiencing storm conditions or not. The ship sets out on the shortest great circle route to its destination. The ship receives new information about storm at time intervals, as described in the scenarios below. At each 1-h time step, the ship makes a decision either to stay on course or to divert in order to avoid a storm in its path. If the ship diverts to avoid a storm, it resumes on a great circle course once it is clear of the storm. Transits are repeatedly modeled for a given information scenario until the results converge.

We consider seven information scenarios and examine the implications of each for ship routing and storm exposure. Under each scenario, the vessel operator seeks to minimize storm exposure on each transit. We simulate ocean transits for a randomly generated storm sequence (using the parameters described in Appendix I) using each information scenario and repeat the process with a new storm sequence until the average per transit storm exposure converges.

Blind

In the "Blind" scenario, the ship has no information other than what is observed on board (it is either in storm conditions, or it is not). The ship slows when conditions require this but does not change course.

History

In this "Historical pattern" scenario, the ship has little or no information about specific storm events other than what is observed on board the ship but knows the historical distribution of storms and can choose a route other than the shortest distance great circle to avoid historically stormy regions. This is an approximation of a simple routing procedure that might be followed in the absence of ocean surface vector wind observations, other than those from buoys and ships of opportunity, if ships put a high premium on avoiding storm conditions.

Nowcast

In the "Nowcast" scenario, the ship receives nowcasts of observed storm conditions at specified intervals (6 h) and with specified time delay (1 h) and can choose to modify its course to avoid a specific stormy area that may be in its path. With two or more consecutive nowcasts, the ship also can generate a primitive forecast of which areas may see storm conditions in the

[1] See for example the ICOADS database, http://www.ncdc.noaa.gov/oa/climate/coads/.

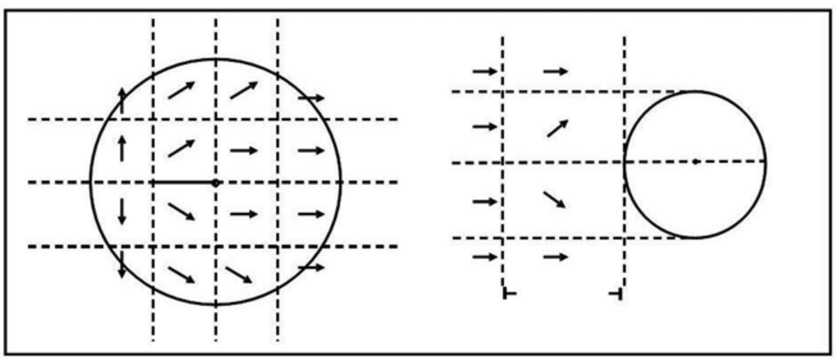
future (assuming the weather system continues to move/evolve as suggested by past observations) and can take this into account.

Figure 1 illustrates one possible set of course decisions taken by a vessel traveling from left to right that finds itself inside or in the path of a stormy area and has nowcast information about the area's size (diameter) and the location of its center.

extratropical storm conditions are observed, and forecasts are 75% accurate for 24 h and 60% accurate for 48 h. This scenario approximately reflects the less detailed, timely, and complete nature of QuikSCAT data as compared to that from DFS or XOVWM. The ship receives the nowcasts and forecast at 6-h intervals and uses nowcast, observations, and these forecasts to adjust its course.

FIGURE 1

Nowcast scenario course decisions. Arrows indicate the course (direction) chosen by the vessel depending on its location within (left) or in the path of (right) the stormy area (designated by the circle).



Forecast 3

In the Forecast 3 scenario, we assume that forecast and routing services observe nearly all significant extratropical storm activity and are able to generate forecasts that are accurate for 24 h and 75% accurate for 48 h. These forecasts are transmitted to the ship at 6-h intervals. The ship uses nowcast, observations, and forecasts to adjust its course. This scenario is approximately representative of information available with a satellite system equivalent to DFS or XOVWM.

Forecast 2

The Forecast 2 scenario includes less complete and less accurate information than Forecast 3: only 80% of

Forecast 1

The Forecast 1 scenario is similar to Forecast 2, but only 30% of extratropical storm events are observed. This is representative of information available with the ASCAT satellite system.

Perfect

In the "Perfect Forecast" scenario, the ship has a perfect forecast at the outset of the voyage for its entire duration and can plan an optimal route to avoid all stormy areas. This is unrealistic given present technology and modeling capability and is included only to illustrate the upper bound on hypothetical forecast value.

Traffic and Storm Loss Data

Container and dry bulk ships are the major commercial maritime users of North Atlantic and North Pacific transoceanic routes.

Container Ships

Large containerships are rarely lost at sea, unlike dry bulkers and smaller general cargo vessels (IMO MSC 2003). However, storm exposure implies a risk of cargo loss and/or damage to the vessel. Globally, some 10,000 containers are lost annually at sea, often with some associated damage to the vessels and largely due to severe wind and wave conditions (American Institute of Marine Underwriters). Although specific statistics on the immediate cause of container losses are not available, we estimate that at least half of these losses are associated with extratropical storm events and that half of those losses occur in the Pacific. This produces an estimate of 2,500 containers lost per year in the Pacific.

Estimates of costs to the shipping industry per lost container range from $50,000 to more than $200,000. We assume for the purpose of this analysis an average economic loss of $100,000/lost container.

Large trans-ocean container ships (those in excess of 1,000 TEU capacity, as distinguished from smaller coastal feeder ships) typically operate at speeds around 20 knots. Slowing in a storm or deviating from shortest great circle route implies increased operating time for the voyage. In this analysis, we use a daily cost for large container vessels of $50,000/day (U.S. Army Corps of Engineers, 1995-2000; IMO, 2009).

We model container vessel traffic through the northern Pacific on a great circle route between San Francisco and Hong Kong. There are approximately

6,000 large container ship movements across the North Pacific each year (Kite-Powell, 2001, adjusted). We model container vessel traffic through the northern Atlantic on a great circle route between New York and Rotterdam. There are approximately 4,000 large container ship movements across the North Atlantic each year (Kite-Powell, 2001, adjusted).

Dry Bulk Ships

The primary dry bulk commodities on routes traversing the northern Pacific are grain and coal. Grain cargos move from ports along the west coast of North America and from Central America (Panama Canal) to Asia; coal cargos move primarily from northern South America (Colombia) to Asia. Approximately 500 grain shipments (mainly Panamax vessels) and 1,000 coal shipments (mainly Capesize vessels) cross the Pacific annually (Kite-Powell, 2001, adjusted).

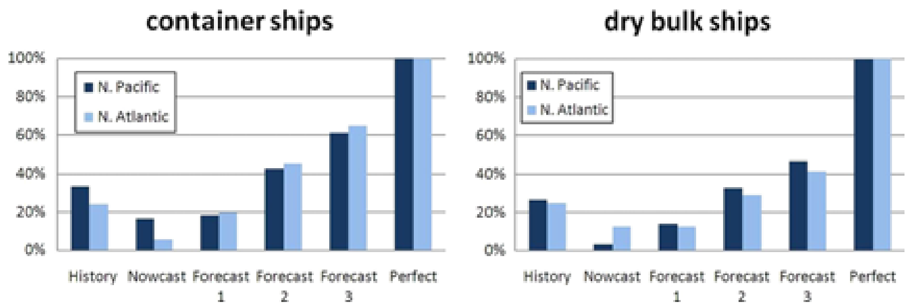
The primary dry bulk commodity traversing the northern Atlantic is grain moving from the Gulf of Mexico to western Europe. Approximately 500 such shipments take place each year (Kite-Powell, 2001, adjusted).

In combination, these bulk trades account for about 10% of global transoceanic bulk shipments. Historically, the global dry bulk fleet loses about 16 vessels per year at sea, primarily due to structural failures exacerbated by severe weather conditions (IMO MSC, 2003). If we assume that the North Atlantic and North Pacific trades are representative of the global risk level facing the dry bulk trades, this suggests an expected loss of one or two dry bulk vessels per year on those routes.

A representative price for a dry bulk vessel on these trades is $50 million (U.S. Army Corps of Engineers, 1995-2000), and loss of life and cargo may amount to another $50 million, for a total loss of $100 million per dry bulk vessel.

FIGURE 2

Fraction of total storm exposure avoided under each information scenario.



Dry bulk carriers typically operate at speeds around 12-15 knots. Operating delays are assumed in our analysis to result in costs based on an average operating expense of $20,000/day (U.S. Army Corps of Engineers, 1995-2000).

We model dry bulk carrier traffic as moving across the northern Pacific on a great circle route between southern Central America and South Korea. There are approximately 3,000 dry bulk vessel movements across the North Pacific each year (1,500 loaded shipments and 1,500 return voyages). We model dry bulk carrier traffic across the northern Pacific on a great circle route between Miami and Rotterdam. There are approximately 1,000 dry bulk vessel movements across the North Atlantic each year (500 loaded shipments and 500 return voyages).

Results

Key results are shown here in graphic form. Numerical summaries of model runs are shown in tabular form in Appendix II.

Storm Exposure Avoidance

Each information scenario allows ships to avoid storm exposure to a certain degree. Figure 2 shows the maximum storm exposure avoidance possible for container and dry bulk ships on the Pacific and Atlantic routes.

Relying on historical information only ("History" scenario) allows ships to avoid more than 20% of storm exposure; but as we will show below, this can be done only at considerable expense due to longer voyage duration. Nowcast and simple forecast information also permit avoidance of up to 20% of storm exposure; and more sophisticated forecasts permit exposure reduction around 60% for container ships and 40% for dry bulk ships. Exposure reduction potential with good forecasts is higher for container ships because they are faster and can more effectively move away from storms.

Trading Off Storm Exposure and Voyage Duration

As Figures 3 and 4 illustrate, each storm avoidance scenario is associated not only with cost savings (lower expected damages from storm exposure) but also generally with a counterbalancing cost increase due to longer voyage duration (because avoiding storms requires deviation from the shortest great circle route).

The net economic effect from using each information set is the sum of the expected savings from reduced storm

FIGURE 3

Savings from reduced storm exposure and cost increase from longer voyage duration: container ships.

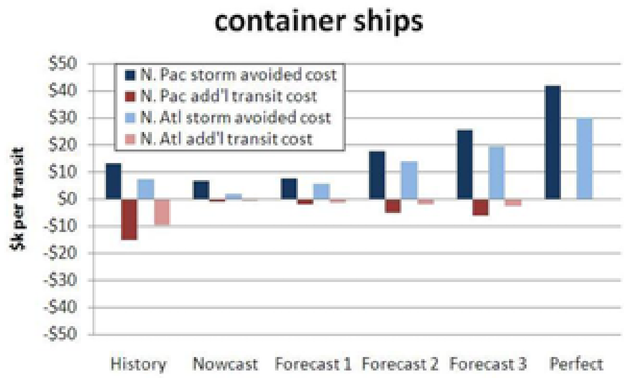
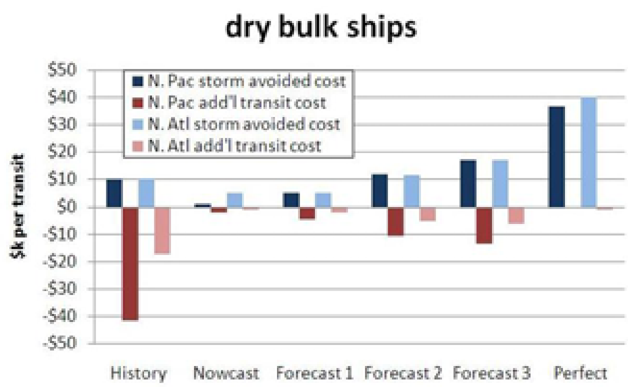


FIGURE 4

Savings from reduced storm exposure and cost increase from longer voyage duration: dry bulk ships.



exposure and the incremental cost due to the longer voyage duration. From Figures 3 and 4, it is clear that ships are unlikely to use the historical data alone, as the net economic result is negative on all shipping routes modeled here. Nowcasts and simple forecasts (Forecast 1) can have small net positive results on some routes. More sophisticated forecasts have larger net positive benefits, particularly for container ships and for dry bulk ships on the North Atlantic route. The net value of sophisticated forecasts is on the order of $10,000/transit for dry bulk and $20,000/transit for container ships. Figure 5 summarizes the economic results by showing how the value of information increases with the sophistication of the forecast, rising to about 50% of the value of perfect information for container ships and 20% for dry bulk ships with a 48-h storm forecast of 75% accuracy.

FIGURE 5

Value of information from different scenarios as fraction of the value of perfect information.

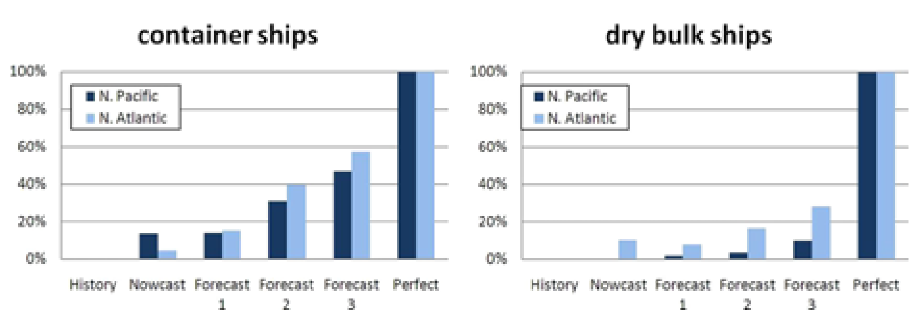


Table 2 summarizes the main results in terms of storm exposure reduction and net economic benefit to shipping operations, given the assumptions described above. Note that these net benefits reflect only the economic gains from modified routing decisions; they do not take into account the cost of deploying and operating the satellite instrument or the cost of processing its data and disseminating forecasts to ships.

The History scenario—storm condition avoidance based primarily on annual storm patterns as opposed to specific observations and forecasts—generates little or no net benefit for either container ships or bulk carriers because the increased operating costs due to persistently longer routes counteract the effect of reduced storm exposure.

As the coverage (instances of storm conditions observed) and forecast quality of information scenarios improves, net benefits to ship operations increase. In general, better information results in slight increases in voyage length as ships take measures to avoid storm conditions and in decreases in exposure. The avoided losses from reduced exposure must be adjusted by the additional cost due to longer voyages to obtain the net benefits from each information scenario. Container ships

TABLE 2

Summary of model results for Atlantic and Pacific traffic.

Information Scenario and Approximate Instrument Equivalent	Reduction in Storm Exposure Relative to Blind	Total Net Benefit to Shipping ($ million/year)	Net Benefit to Container Shipping ($ million/year)	Net Benefit to Dry Bulk Shipping ($ million/year)
Forecast 1 (ASCAT)	18 %	58	53	5
Forecast 2 (QuikSCAT)	44 %	135	124	11
Forecast 3 (DFS)	63 %	207	185	22

are better able to make use of short-term forecast information to avoid storm exposure because of their higher operating speed, and so the net value of better information per transit is greater for container ships than for bulk carriers.

For container ships, the model suggests that intermediate-quality forecasts (roughly equivalent to the information that was available with QuikSCAT) allow for the reduction of storm condition exposure by an estimated 44% over the Blind scenario and deliver expected annual benefits of an estimated $124 million in avoided losses, net of increased operating costs, for the main North Atlantic and North Pacific routes. This compares to a possible 63% reduction in exposure with hypothetical superior forecast capability (approximately equivalent to DFS or XOVWM) at a net value of $185 million/year and a reduction of 18% (value of $53 million/year) under a simpler system such as ASCAT. About two thirds of the value generated by this kind of information for the container trades is generated on the Pacific. The Perfect Forecast delivers expected annual benefits of $370 million by allowing for the virtual elimination of storm condition exposure with no significant increase in operating costs.

Compared with container vessels, bulk carriers operate at lower speeds and are less easily able to move out of the way of stormy regions in their path, and course deviations tend to take longer and therefore be relatively more expensive. This reduces the value of nowcasts and short-term forecasts to bulk vessels. The QuikSCAT scenario generates an estimated $11 million in annual benefits, net of increased operating costs. In comparison, the hypothetical DFS/XOVWM information would produce $22 million and the ASCAT scenario $5 million in annual net benefits. The Perfect Forecast could deliver expected annual benefits of $150 million ($110 million on the Pacific and $40 million on the Atlantic) by allowing for the virtual elimination of exposure with no significant increase in operating costs.

While these costs and potential savings are significant, they are a small fraction of the total operating expenses of Atlantic and Pacific shipping operations. Even the perfect forecast value is less than 0.5% of the estimated annual operating cost of transatlantic and transpacific shipping that calls on U.S. ports (Kite-Powell, 2001).

Conclusions

We estimate that average expected annual losses to container shipping (lost containers and associated damage to vessels) in the absence of good information about extratropical storm conditions would be on the order of $250 million/year in the North Pacific and $120 million/year in the North Atlantic, and we estimate average expected annual losses to bulk shipping operations from extratropical storm exposure in these regions to be on the order of $150 million/year.

A significant fraction of this risk can be avoided with ocean surface vector wind observations and forecasts. We model the change in storm conditions exposure that becomes possible with nowcasts and forecasts of ocean surface vector wind fields under information scenarios representing observations and forecast of varying quality. Model results suggest that a level of information roughly equivalent to that produced by the recent QuikSCAT sensor enables a reduction in annual exposure for shipping traffic in the North Atlantic and North Pacific of about 50%, with total annual net savings of $155 million. This is due mostly to avoided losses in the container ship trades, with $89 million/year in net avoided losses on the Pacific and $66 million/year on the Atlantic. The combined estimate of net annual benefits to shipping operations from the European ASCAT sensor is $58 million, and hypothetical net benefits from a more sophisticated DFS or XOVWM are $204 million. A perfect long-term forecast (not feasible with present technology) could deliver expected annual benefits of $520 million from all shipping by allowing for the virtual elimination of storm conditions exposure with no significant increase in operating costs.

For the purpose of planning future satellite-based ocean surface wind sensing systems, it is instructive to consider the range of values potentially generated by observations and forecasts of different quality. For the maritime shipping industry on the major North Atlantic and North Pacific routes, the combined estimate of net annual benefits from avoidance of extratropical storm exposure ranges from $58 million to $207 million. The value of this information increases with the completeness and accuracy of the forecast and is greater for faster vessels (primarily container ships). With high quality observations and storm condition forecasts of 75% accuracy out to 48 h , container ships can achieve about 60% of the cost savings that would be possible with perfect information.

The values estimated in this paper are only part of the total value generated by satellite-based ocean surface wind observations and forecasts. They do not include all maritime shipping, nor do they consider benefits generated by this information in other applications, such as fishing, recreational boating, and search and rescue.

Acknowledgments

I am grateful to Paul Chang, Zorana Jelenak, and Joe Sienkiewicz of National Oceanic and Atmospheric Administration (NOAA) for help with the assembly of data on ocean surface wind instruments and storm parameters. I am also grateful to three anonymous reviewers and two editors for helpful suggestions on the manuscript. Funding to support this work was provided by NOAA and the Marine Policy Center of the Woods Hole Oceanographic Institution.

Lead Author:

Hauke Kite-Powell
Marine Policy Center
Woods Hole Oceanographic Institution
Email: hauke@whoi.edu

Appendix I: Storm Conditions Submodel

Atlantic

Likelihood of storm starting on a given day in…

January	0.26
February	0.25
March	0.02
April	0.01
May	0.02
…	
September	0.05
October	0.07
November	0.09
December	0.15

Starting latitude:

Normally distributed between 33°N and 69°N.

Starting longitude:

Normally distributed between 10°W and 70°W.

Starting diameter:

Initial: uniform over [100-500] nm

Change per hour: uniform over [–10-10] nm

Starting velocity:

Initial: uniform over [20-30] knots

Change per hour: normally distributed around mean = 0 and SD = 2.3

Starting heading:

Initial: uniform over 0-360°

Change per hour: normally distributed around mean = 0 and SD = 9

Duration:

Hours	Likelihood
6	0.15
12	0.15
18	0.13
24	0.10
30	0.09
36	0.06
42	0.02
48	0.01
54	0.05
60	0.04
66	0.03
72	0.05
78	0.05

Pacific

Likelihood of storm starting on a given day in…

January	0.20
February	0.13
March	0.10
April	0.03
May	0.01
…	
September	0.04
October	0.11
November	0.11
December	0.24

Starting latitude:

Normally distributed between 18°N and 63°N

Starting longitude:

Between longitude	Likelihood
140-150	0.04
150-160	0.12
160-170	0.17
170-180	0.19
180-–170	0.14
–170-–160	0.09
–160-–150	0.08
–150-–140	0.10
–140-–130	0.07

Starting diameter:

Initial: uniform over [200-300] nm

Change per hour: uniform over [–10-10] nm

Starting velocity:

Initial: uniform over [20-30] knots

Change per hour: normally distributed around mean = 0 and SD = 2.3

Starting heading:

Initial: uniform over 0-360°

Change per hour: normally distributed around mean = 0 and SD = 9

Duration:

Hours	Likelihood
6	0.18
12	0.22
18	0.18
24	0.20
30	0.10
36	0.06
42	0.03
48	0.02
54	0.01

Appendix II: Model Results

TABLE AII-1

Model results for container vessels, North Pacific, 6,000 transits/year.

Information Scenario	Average Hours/Transit	Total Storm Exposure (h/year)	Avoided Losses Relative to Blind ($ million/year)	Additional Voyage Costs Relative to Blind ($ million/year)
Blind	300	1,800	–	–
History	305-310	1,200	80	60-120
Nowcast	300.5	1,500	40	6
Forecast 1 (ASCAT)	301	1,470	46	11
Forecast 2 (QuikSCAT)	302.5	1,030	107	30
Forecast 3 (XOVWM)	303	700	153	36
Perfect	299.7	[0]	250	(minimal)

TABLE AII-2

Model results for container vessel, North Atlantic, 4,000 transits/year.

Information Scenario	Average Hours/Transit	Total Storm Exposure (h/year)	Avoided Losses Relative to Blind ($ million/year)	Additional Voyage Costs Relative to Blind ($ million/year)
Blind	110	860	–	–
History	115	650	29	38
Nowcast	110.2	810	7	2
Forecast 1 (ASCAT)	110.5	690	23	5
Forecast 2 (QuikSCAT)	111	470	55	8
Forecast 3 (XOVWM)	111.2	300	78	10
Perfect	109.5	[0]	120	(minimal)

TABLE AII-3

Model results for dry bulk vessels, North Pacific, 3,000 transits/year.

Information Scenario	Average Hours/Transit	Total Storm Exposure (h/year)	Avoided Losses Relative to Blind ($ million/year)	Additional Voyage Costs Relative to Blind ($ million/year)
Blind	500	1,500	–	–
History	550	1,100	29	125
Nowcast	502.5	1,450	4	6

continued

TABLE AII-3

Continued

Information Scenario	Average Hours/Transit	Total Storm Exposure (h/year)	Avoided Losses Relative to Blind ($ million/year)	Additional Voyage Costs Relative to Blind ($ million/year)
Forecast 1 (ASCAT)	505	1,290	15	13
Forecast 2 (QuikSCAT)	512.5	1,010	36	32
Forecast 3 (XOVWM)	515	800	51	40
Perfect	499	[0]	110	(minimal)

TABLE AII-4

Model results for dry bulk vessels, North Atlantic, 1,000 transits/year.

Information Scenario	Average Hours/Transit	Total Storm Exposure (h/year)	Avoided Losses Relative to Blind ($ million/year)	Additional Voyage Costs Relative to Blind ($ million/year)
Blind	180	240	–	–
History	200	180	10	17
Nowcast	181	210	5	1
Forecast 1 (ASCAT)	182	210	5	2
Forecast 2 (QuikSCAT)	184.5	170	11.5	5
Forecast 3 (XOVWM)	185.5	140	17	6
Perfect	179	[0]	40	(minimal)

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