Editing and correcting the PIRS tanker data

The PIRS data for 1973-1975 contains about 4,100 spill records in which the spill source is nominally a tankship or tank barge. For the purpose of this report, we have limited our investigation to spills from tankships. While this is obviously just a portion of the total oil-carrying fleet in the U.S., tankships are nevertheless the principal alternative to pipelines for the transport of OCS crude oil. Our first task was to verify the classification provided in the PIRS record for the spill source, be it tankship or tank barge. This verification was undertaken by cross-referencing the PIRS source identifier data to the MVF and ABS tankship file.

Radio call sign is the source identifier for 1,100 of the 4,100 tank barge and tankship records; 2,700 records identify the vessel by its registration number ("official number"); and the remaining 300 tanker and tank barge records had nonsensical identifiers and were ignored. In addition to these 4,100 tanker and tank barge spills, the PIRS data nominally attributes 774 spills to dry cargo ships, 505 spills to tugboats and towboats, and 600 spills to fishing vessels. A further 1,147 spills were suspected to have been caused by vessels of some type, but positive identification was not possible. Moreover, there were several hundred incidents attributable to Navy and Coast Guard vessels.

Using the vessel identifier to access the MVF and ABS data, we determined that a majority of the incidents nominally attributed to U.S.-flag tankers were improperly coded. The same was true for a smaller portion of those incidents nominally attributable to foreign tankers.

Seven hundred of the 1,100 records bearing call-sign identifiers and tanker or tank barge source codes had call signs that corresponded to tankers listed in the MVF. All of these records should have shown a tankship as the source, but some 30 records erroneously indicated a tank barge as the source. Additionally, 148 of the remaining 670 records indicated an improper size range for the vessel. About 80 of the 700 call-sign-identified records were attributable to tankers of U.S. registry. This in itself is a coding error, since all U.S.-flag vessels should be identified by their "official number" according to the Coast Guard Coding Instruction Manual (CG-450). Ninety-five percent of the 400 call-sign-identified records that could not be traced to a tanker bore plausible call signs.

Of the 2,700 records bearing "official number" identifiers, about 1,000 were nominally U.S.-flag tankships. However, a check of the official number revealed that only 300 records had official numbers corresponding to the official numbers of U.S.-flag tankers. About 60 of the remaining records are attributable to Canadian tankships and barges, but fully 640 of the 1,000 nominal U.S. tanker incidents were caused by vessels that are not listed as tankers in any of the common vessel registers.

We corrected those records for which MVF or ABS data was available, and sorted the corrected data by vessel identifier to allow us to determine how many distinct vessels the PIRS data shows contributing to the tanker spill category. This process, which takes the PIRS data at nearly face value, suggested that there were 734 active U.S.-flag tankers in the period 1973-1975, of which fully 608 were over 1,000 GRT. That this number is ridiculously large can be readily shown by comparison with MarAd's estimate that there were only 235 active U.S. tankers over 1,000 GRT during this period, including scrapping and new construction.

On this basis, it was obvious that we had to do some very serious thinking about the PIRS data. Obviously, any analysis of U.S. tanker spillage based on the PIRS information in its raw form would be of questionable validity.

One possible explanation for this proliferation of the U.S. tanker fleet is that there was a very high error rate in transcribing the vessel identifier in the PIRS file. We made some preliminary tests based on transposing digits in known U.S. tanker official numbers. Thus, ON246773 might be erroneously entered as ON236737, ON246377, ON247673, ON264773, etc. In ten checks of simple two-digit transpositions we failed to find one spill record that might have been miscoded in this manner. We also tested for random one-digit substitution in the last two places, but again had negative results.

Another explanation is that the MVF and ABS files are unexpectedly deficient in their listing of the U.S. tanker fleet and that the MarAd figures are very much in error. To check the former possibility, we obtained a chronological list of all the vessels that called at Boston in 1975. We determined that 76 U.S.-flag tankers made 363 port calls in this period. All 76 U.S. tankers were listed in the MVF and ABS files. Further, we found that 45 different Liberian tankers called at Boston in 1975, and 41 of these were found in the MVF and ABS files. Of the four missing Liberian tankers, three were in the MVF but under different flags. One of these, the Stolt Zeus, was listed in the MVF and ABS files as Norwegian, but Clarkson carried her as Liberian. Whether these four examples indicate an error in the MVF and ABS files or whether they were caused by Port Authority transcribing errors is difficult to say. Nevertheless, on this basis, it appears to us that the MVF is reasonably complete, at least as it applies to the U.S. fleet, and probably for the other major fleets as well. Thus, if the vessel identifier is properly encoded, a screening based on the MVF and ABS files is most likely to separate the real tanker spills from those caused by other kinds of vessel.

As a final check, we made a list of about 100 of the official numbers associated with the unidentified tankships. These numbers were chosen in sequential groups to aid in recognition, e.g. 002002, 002018, 002089, etc. We then obtained a copy of the 1973 Merchant Vessels of the United States (CG-408), and performed a tedious manual search. Nineteen vessels were identified in this search, after approximately half a person-week. Table 2 shows the results. Not one tankship was found. Only the Carolinian, a small, oil-fueled, screw-propelled freighter, departed from the pattern of medium-sized tank barges. While this sample was not completely random, we believe that these results make it very unlikely that the remaining four or five hundred vessels include more than a few tankships, if any at all.

For all of these reasons, and because MarAd's figures are probably correct, we decided to discard those records that indicated a U.S. tanker in their source code, but which had vessel identifications that did not correspond to any known U.S. tanker. With this decision, our database went from 1,000 spill incidents attributable to 734 "tankers" down to 380 spill incidents attributable to 180 ships, of which about 170 were over 1,000 GRT. In terms of number of spills per ship, this caused the spill rate to rise from 1.36 spills per ship (in these years) to 2.11 spills per ship.

TABLE 2
VESSELS IDENTIFIED AS TANKSHIPS IN THE 1973-1975 PIRS DATA AND SUBSEQUENTLY FOUND IN CG-408[a]

ON	Vessel Name	Rig	Service	Yr/Blt	GRT	CG-408 Pg. No. (1973)
170613	George E	BRG	TNK	1930	743	386
172301	CTCO 177	BRG	TNK	1936	895	252
172436	E 17	BRG	TNK	1936	1012	303
172599	Progress	BRG	TNK	1936	265	849
173680	Interstate No. 8	BRG	TNK	1937	767	461
174114	No. 11	BRG	TNK	1938	723	745
176390	B No. 50...L	BRG	TNK	1945	1148	89
176450	B No. 60...L	BRG	TNK	1945	1430	89
176452	Interstate 18	BRG	TNK	1945	1151	461
176469	RCT 120	BRG	TNK	1942	619	901
176488	Blue Line 106	BRG	TNK	1945	1148	130
176520	RTC No. 200	BRG	TNK	1945	1047	862
176536	RTC No. 300	BRG	TNK	1946	1047	862
176709	Esso Barge No. 257	BRG	TNK	1945	620	333
176732	Hygrade No. 8	BRG	TNK	1946	1495	451
176751	H T CO No. 29	BRG	TNK	1940	798	415
223675	The Independent	BRG	TNK	1924	1176	1056
229378	Carolinian	Ol.S.	Frt.	1930	198	187
500203	TCB 67	BRG	TNK	1965	1359	1045

Abbreviations:

BRG	Barge
TNK	Tanker (service)
Ol.S.	Oil screw
Frt.	Freight (service)

[a]CG-408, Merchant Vessels of the United States, 1973, Washington, Government Printing Office, Stock No. 5012-00D72.

U.S. tanker spill incidence model

In most of the following we limit our remarks to U.S. tankers over 1,000 GRT. While there are fifty-one U.S. tankers smaller than this in the MVF, ten of which had spills in 1973-1975, we have no way of determining how many of these small vessels were active in the years 1973-1975. Further, tankers of such a small size are almost certain not to be used for transport in prospective frontier OCS petroleum developments. Comparing pipelines and tankers in several hypothetical OCS developments, Lahman et al. (1973) found tankers to be the economically preferable mode of transport for finds more than 150 miles from the crude depot. Further, Lahman found that the most efficient tankers for routes of around 150 miles were 20,000 DWT to 40,000 DWT, depending on production rate. These results are no doubt somewhat out of date, but they do suggest that it is very unlikely that small tankers (less than 1,000 GRT) will play an important role. This is even more true as the distance becomes larger. The Valdez oil is a case in point. Here the vessels in use today are typically 120,000 DWT (or 70,000 GRT), and the trip is on the order of 1,000 to 2,000 miles.

The first substantive test we performed on the data was to see how many spills each U.S. tanker had over the entire three-year period. The resulting distribution suggested a Poisson distribution with ship-years as the exposure variable, but the Fisher test of dispersion (see Snedelor and Cochran, Section 9.3) indicated considerable heterogeneity. Since there was a rather pronounced drop in the total number of spills in 1975 compared to 1973 and 1974, we decided to classify the data by year. Suspecting that there might also be some size-related effects, we divided each year group into tankers of 1,000-6,000 GRT (1,600-10,000 DWT) and tankers greater than 6,000 GRT. The data is shown in Table 3. The number of ships having 0, 1, 2, etc. spills in each of these years, both by size range and as an aggregated total, are shown on the left and middle of the table. The Chi Square test of goodness of fit and the Fisher test of dispersion are shown on the right. The Fisher test of dispersion (the last column on the right) shows 1974 to be the only year in which the pattern of the aggregated vessels departed appreciably from homogeneity. And in this year, the two ships having five and six spills (the Polaris, 4,400 DWT, 1945, and the Santa Clara, 35,000 DWT, 1957), are entirely responsible for this deviation. The Chi Square test shows that a Poisson distribution based on the observed number of spills and the number of active ships fits all three years acceptably. The data shows that between 1974 and 1975, there was a rather sharp reduction in the spill rate per vessel. This accounts in part for the heterogeneity we observed when we aggregated all three years.

To determine whether there was a significant difference in spill rates based on the size of the tanker, we employed the Bayesian hypothesis test outlined in Jeffreys (Section 5.15, p. 267-8) for Poisson-distributed populations. The test as we use it here determines the posterior probability that both subpopulations have the same rate constant. The

TABLE 3
SUMMARY OF U.S. TANKER SPILL HISTORY 1973-1975 (CORRECTED USCG PIRS DATA)

Year	Ship Size	Number Ships Having Indicated Number of Spills								Total No. Spills	Goodness of Fit Tests[a]		Fisher Dispersion		
		Number of Spills = 0	1	2	3	4	5	6	7		χ^2_{PDF}	%[b]	χ^2_{PDF}	DF	%[b]
1973	1K-6K GRT	20	16	6	1	0	0	0	0	31					
	>6K GRT	112	49	15	6	0	0	0	0	97					
	All	132	65	21	7	0	0	0	0	128	2.28^{3df}	50	244.7	224	16
1974	1K-6K GRT	26	11	3	2	0	1	0	0	28					
	>6K GRT	111	57	15	1	1	0	1	0	101					
	All	137	68	18	3	1	1	1	0	129	1.52^{3df}	60	308.5	229	.08
1975	1K-6K GRT	30	9	4	0	0	0	0	0	17					
	>6K GRT	134	45	11	1	1	0	0	0	74					
	All	164	54	15	1	1	0	0	0	91	1.92^{2df}	35	268.0	234	6

[a]Based on Poisson model fit to observations. Spill incidence rate is based on maximum likelihood estimator.

[b]% indicates level of significance measured in percent.

prior probability used in this test holds this equality to be just as likely true as untrue. The test indicated that both big and little tankers had spills at the same rate with posterior probabilities of .79, .88, and .91 for 1973 to 1975 respectively. This is a fairly strong statement that tanker size, at least in terms of the two size ranges we looked at, is not directly related to spill incidence. However, the posterior probabilities are not so large as to be conclusive. This result is also in agreement with Beyer and Painter's findings for worldwide tanker spills. Their results, however, included vessel sizes from 20,000 DWT to 250,000 DWT.

Performing the same test on subpopulations based on tanker age yielded a more interesting result. Table 4 shows the number of ships having 0, 1, 2, etc. spills in 1973 to 1975 for tankers built in 1955 and after and for tankers built before 1955. The figures in this table readily suggest that the older group has a higher spill incidence rate. Jeffrey's test quantified this observation, indicating posterior probabilities of .085, .584, and .036, for 1973 to 1975 (respectively), that the rate constants were equal. Thus, age serves as a useful parameter for categorizing tankers for spill incidence purposes. Table 5 shows the spill incidence rates by year for these two age groups. The older ships are seen to have 1½ to 2 times as many spills per year as the younger ships. A strong trend is evident, particularly in the change from 1974 to 1975.

Since newer tankers are generally larger tankers, it is surprising that this age effect did not show up in the size grouping discussed above. This may be related to the particular size categories chosen. A number of small, special-purpose product tankers were built in the period

TABLE 4
U.S. TANKER SPILL HISTORIES BY AGE GROUP

	Yr. Blt.	0	1	2	3	4	5	6
1973	1955-1973	78	33	4	3	--	--	--
	Pre-1955	54	32	17	4	--	--	--
1974	1955-1974	82	31	7	1	1	--	1
	Pre-1955	55	38	11	2	--	1	--
1975	1955-1975	101	21	5	1	--	--	--
	Pre-1955	63	33	10	--	1	--	--

TABLE 5
SPILL RATES BY AGE GROUP (U.S. TANKERS OVER 1,000 GRT)

	Year Built		
Year	1955 to Present	Pre-1955	All
1973	.424	.729	.569
1974	.472	.664	.561
1975	.265	.533	.387

1955 to 1975, and so the 1,000-6,000 GRT category may have had an age structure more representative of the whole population than a group of 1,000-15,000 GRT tankers, for example.

This paradox suggests that a more detailed analysis of age and size effects might prove to be of some interest. Although the database is rather sparse when we consider dividing it into more than two parts in any one year, it might be sufficient to yield to an attack based on the analysis of variance techniques. The application is not trivial, however, and we have not pursued the matter.

In addition to vessel age and size effects, we examined the effects of the environmental factors listed in the PIRS data. For these tests the sample population consisted of all U.S. tankers, and not just those over 1,000 GRT. The environmental parameters are principally wind and current speed (we ignored direction), and wave height (again we ignored direction). Table 6 shows the number of incidents that occurred for each wind speed. Except for the rather unusual clustering at increments of 5 knots, there is nothing remarkable about the data. The average wind speed is 8.23 knots and the standard deviation is 7.15 knots. The average value is rather typical of wind speeds at coastal sites. The standard deviation is not unduly large, particularly when we recall that all U.S. ports and coastal waters are included in the samples. There is certainly no reason, based on Table 6, to suspect that high wind speeds are related to the incidence of oil spills.

TABLE 6
WIND SPEED HISTOGRAM

Wind Speed	Number of Incidents	Wind Speed	Number of Incidents
0	18	20	3
1	1	21	--
2	4	22	--
3	5	23	--
4	1	24	--
5	18	25	1
6	3	26	--
7	2	27	--
8	2	28	1
9	--	29	--
10	27	30	2
11	1	31	--
12	1	32	--
13	--	33	--
14	--	34	--
15	11	35	1
16	1	>35	1
17	--		
18	--		
19	--		

Mean = 8.23 knots

Standard deviation = 7.15 knots

We also examined the wind speeds listed for the subclass of spill incidents in which the hull was ruptured. We found behavior that was entirely analogous. As we show in the following section, this subclass has the property that their spill volumes are likely to be very much larger than for spills in which the hull was not ruptured. Thus, wind speed does not appear to have any noticeable effect on spill size.

These results must be qualified, however, by the low reporting rate for this wind speed statistic. Only 108 of the 370 incident reports, or 29%, included wind speed. The omission of the remaining 262 wind speed values may cause some bias in the mean and standard deviation statistics. Further, several fairly large spills were reportedly caused by adverse weather. The fact that there were not enough incidents of this type to affect averages for the aggregated data does not imply that they are unimportant. It does suggest, however, that wind speed is not a useful predictor for the total population of spill incidents.

The story was much the same for the current speed and wave height statistics, although as shown in Table 7, the reporting was even more sparse. Only 60 incidents included current speed data, and only 53 incident reports showed wave height. Nevertheless, the mean values were so small (see Table 7) as to suggest little correlation to spill incidence. In fact, the mean value of the current speed was 1.92 knots and not 1.32 knots, only because of the one incident reported with a 10-knot current. This entry is almost certainly in error, as currents exceed 5 knots in only a

TABLE 7
CURRENT SPEED AND WAVE HEIGHT HISTOGRAM

Current Speed=Knots Wave Height=Feet	Number Incidents at Current Speed	Number Incidents at Wave Height
0	18	29
1	12	16
2	10	4
3	11	1
4	1	--
5	6	--
6	1	--
7	--	--
8	--	--
9	--	--
10	1	--
Mean	1.92 knots	.74 feet
Standard deviation	1.99 knots	1.08 feet

few rivers and narrow tidal channels. We know of no region where it is 10 knots. It is certainly not 10 knots on the Hudson River, where this incident occurred. As in the wind speed case, there was no apparent spill size effect.

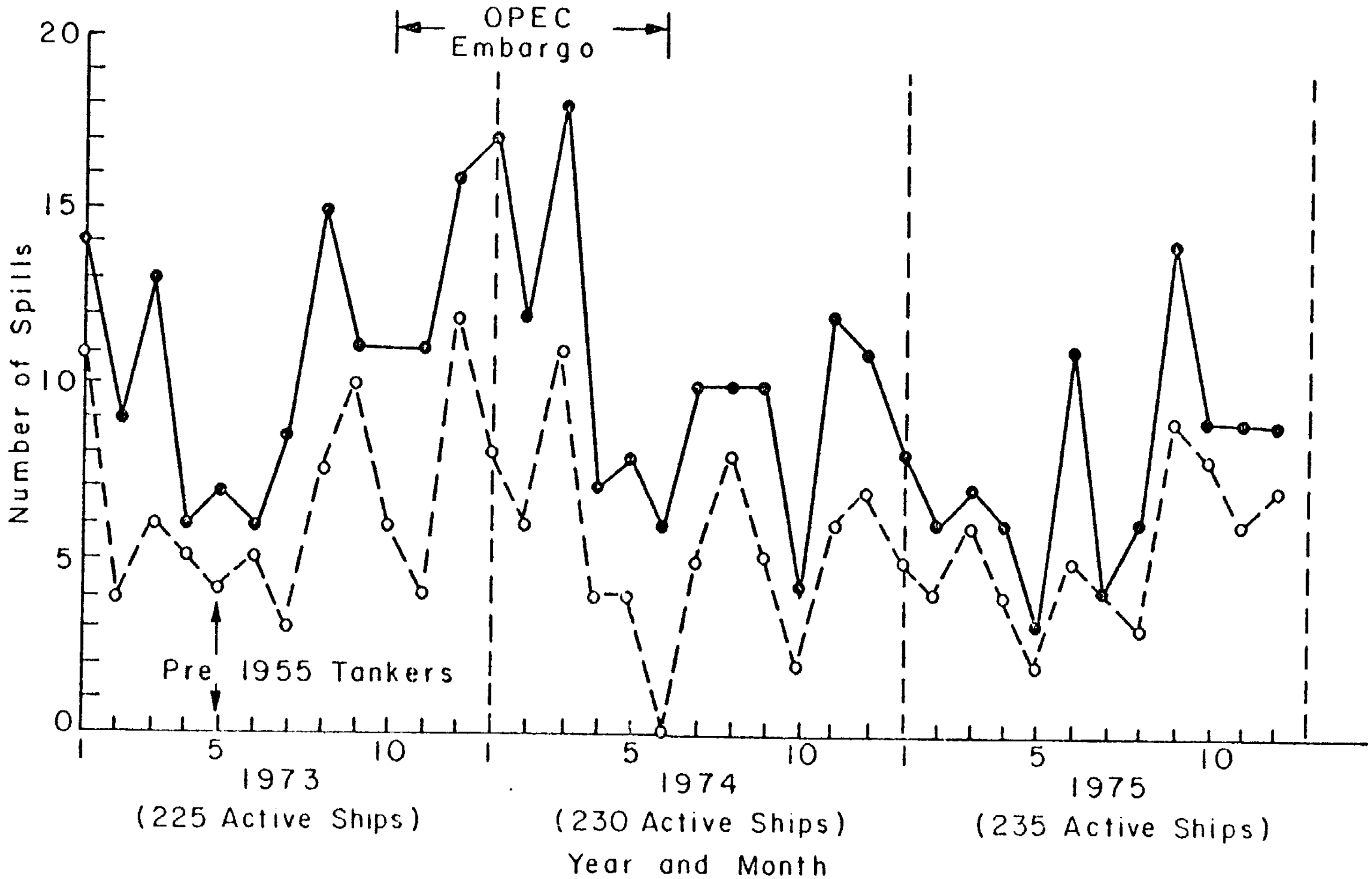
The time and day of week data were also examined. They showed that Monday through Thursday were the prime spill days, with some decrease on Friday, followed by significantly lower rates (three-fifths the average weekday rate) on Saturday and Sunday. Likewise, the hours from 2000 (8 p.m.) through midnight to 0700 (7 a.m.) were periods of relatively low incidence, while spills occurred at the highest rate in the period 0800 through 1100., On a % hourly basis, the hours 0800 through 1100 averaged about 8% of the incidents, the hours 1200 through 1900 averaged about 4.5% of the incidents, and the night hours (2000-0700) averaged 2.5%. Whether these results reflect decreased tanker activities at night or decreased monitoring and reporting was not evident in the data. If the rash of morning spills is real and not a reporting artifact, then increased supervision might be suggested for the morning operations. The hours of 1500 and 1600 also showed a slight increase over their neighbors. As this is towards the end of the working day, we might attribute this to some lack of attention by the operators, again suggesting increased supervision.

The tables and statistics above show rather conclusively that in each of the three yearly intervals considered, a simple Poisson model based on ship-years as the exposure variable accurately described the incidence of oil spills from U.S. tankers. This model apparently could be slightly improved by considering spillage from old and new tankers separately. The other parameters investigated appear to have little effect. The key question that must now be attacked is how we use this information to predict spillage in the future. The first thing to recognize is that tanker spills are caused ultimately by people. There is no underlying force or fundamental natural phenomenon that leads inexorably to an oil spill. As such, there is no reason to believe that there is either a minimum or a maximum spill rate, other than zero and infinity. Thus, any prediction of future spill incidence must rely to some extent on hypotheses that are not verifiable since they relate to human behavior. These hypotheses can only be judged by their reasonableness and simplicity.

A simple set of assumptions that appears reasonable to us is that (1) the Poisson model will continue to be a good descriptor of tanker spill incidence; and (2) the spillage rate constant will be similar to the 1975 data. We have seen that the Poisson model has been acceptable in each of the three years. The Chi Square values were, if anything, a little low. We can think of no reason why this model should not continue to be a reasonable descriptor. Thus, Hypothesis (1) is reasonable.

The reasonableness of using 1975 as a "typical" year (Hypothesis (2)) is best shown with a plot of the number of spill incidents per month over the 1973-1975 period, Figure 1. This figure shows that with the exception of the period August 1973 through March 1974, which appears anomalous, the number of U.S. tanker spills oscillated rather predictably in the range 3 to 14 spills per month. If we delete the anomalous period, we find that the average was 8.32 spills per month, with a standard deviation of 2.91 (variance = 8.45). In 1975, the average was 7.58 spills per month, with a standard deviation of 3.03. If we hypothesize

FIGURE 1
U.S. TANKER SPILLS BY MONTH, 1973-1975
(INCLUDES ALL TANKERS OVER 1000 GRT)



that spills were generated over the 28 "normal" months by a Poisson process with the 1975 rate constant, then we would expect the monthly average to fall in the range 6.40 to 8.46 (95% confidence interval). This encompasses the observed result of 8.32. This implies that 1975 is at least a reasonable year to select for characterizing tanker spillage, if we assume that the 28 "normal" months are representative of long-term behavior.

The average number of spills in the anomalous period of August 1973 to March 1974 was 13.38 spills per month (see Figure 1). This is a significant departure from the remainder of the data, and it warrants additional treatment in future studies. In particular, this perturbation may well explain some of the dispersion noted in Fisher's test for the 1974 data. It obviously caused the downward trend in spill rate evident in the annual data. Among the several explanations that might be investigated is that industry partially foresaw the coming embargo and activated a number of older vessels to assist in transporting oil from sources not participating in the embargo. Alternatively, this might simply have been a period of enhanced spill monitoring activity. Unfortunately, we were not in a position to pursue these questions, although they do relate to the reliability of our estimates.

The absence of pronounced periodicity (other than artifacts of the anomaly) in Figure 1 tends to reinforce the validity of the hypothesis. Strong periodicity would be somewhat disconcerting with respect to Hypothesis (1), since this would suggest weather- or activity-related