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THESIS

IMPLICATIONS OF SHIPTRACKS ON SHIP SURVEILLANCE

by

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June, 1995

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IMPLICATIONS OF SHIPTRACKS ON SHIP SURVEILLANCE

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Submitted in partial fulfillment
of the requirements for the degree of

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ABSTRACT

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LIST OF SYMBOLS, ACRONYMS AND/OR ABBREVIATIONS

μm	Micrometers (10^{-6} meters)
R	Sample Correlation Coefficient
R^2	Sample Coefficient of Determination
ARWD	Actual Relative Wind Direction
AVG	Average of SB and RWD
AVHRR	Advanced Very High Resolution Radiometer
CNO	Chief of Naval Operations
DSL	Diesel
DTG	Date-Time-Group
FNMOC	Fleet Numerical Meteorological and Oceanographic Center
CG	Coast Guard
J1	JSS Production System
J2	JSS Development Database
JMIE	Joint Maritime Information Element
JSS	JMIE Support System
KTS	Knots (NM/Hour)
M/V	Merchant Vessel
MABL	Marine Atmospheric Boundary Layer
MAST	Monterey Area Shiptrack Experiment
NM	Nautical Mile
NOAA	National Oceanic and Atmospheric Administration
NPS	Naval Postgraduate School
ONR	Office of Naval Research
RWD	Relative Wind Direction
RWS	Relative Wind Speed
SB	Separation Bearing
SD	Separation Distance
ST	Separation Time (ST=SD/RWS)
STM	Steam
USCG	United States Coast Guard
USN	United States Navy

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Finally, my heartfelt appreciation goes to my wife Marnee and son Christian for their constant support and understanding, without which I would not have had the drive to finish. I dedicate this thesis and my degree to them with all my love.

I. INTRODUCTION

A. BACKGROUND

Shiptracks routinely form in the stratus layer common to the west coasts of most continents and are observed with relative ease in channel 3 (3.7μm) Advanced Very High Resolution Radiometer (AVHRR) imagery available from the polar orbiting National Oceanic and Atmospheric Administration (NOAA) satellites. The tracks consist of water droplets which are both more numerous in quantity and of smaller radius than the ambient cloud (Twomey and Cocks, 1982). They are most readily observed in channel 3 imagery because cloud reflectance at 3.7μm is a function of droplet radius alone. Figure 1 illustrates how tracks form when aerosol from a passing ship rises into the cloud layer and causes a local change in the structure of the cloud (Mineart, 1988). Figure 2 demonstrates how the differences between the shiptrack formed by the aerosol plume and the ambient cloud are observed as radiance differences in satellite imagery.

While there are many factors which affect the formation and structure of a shiptrack, the first prerequisite is that a low cloud layer be present. The Naval Postgraduate School (NPS) hosted the Monterey Area Shiptrack Experiment (MAST) in June of 1994 to make use of the shiptrack-conducive summer climate off the coast of California. A total of 1362 shiptracks were observed in AVHRR imagery of the Eastern North Pacific Ocean during the thirty-day period and a large quantity of in-situ data was collected by the five platforms (four aircraft and one research vessel) involved in the experiment.

B. MOTIVATION

Figure 3 outlines the triangular geometry of a shiptrack. Aerosol is emitted from the ship at the time of emission (point A). The ship moves away on its given course and speed (vector AB). The aerosol is advected in the direction of the true wind (vector AC) as it rises through the Marine Atmospheric Boundary Layer (MABL). The head of a shiptrack in an image is the point where aerosol has most recently reached the top of the cloud layer within the MABL (point C). The shiptrack trails away from the head in the direction of the relative wind (vector BC) and points back to the position of the ship at the time of the image (point B). Thus a ship's location could be determined from a shiptrack (which gives the direction of the relative wind) if the separation distance from shiptrack to ship is known or can be accurately estimated.

This could be done most directly if the linear relationship between separation distance and relative wind speed expected from Figure 3 could be confirmed. A previous attempt to show such a relationship proved inconclusive (primarily due to the small size of the dataset used) and indicated that the relationship between shiptrack generation mechanisms was complex (Pettigrew, 1992).

Previous studies of shiptracks have used case studies to analyze the atmospheric variables related to correlated shiptracks. The objective of this thesis is to take a step towards using the shiptrack phenomenon operationally. This is done first by confirming a partial dependence of separation distance from ship to shiptrack on relative wind speed; and second by presenting composite data from 99 correlations as a proposed tool for determining separation distance and relative wind speed for future shiptrack observations in the Eastern North Pacific Ocean. Additional analyses include an operational survey of U. S. Coast Guard Operations Center personnel on how shiptrack data could be useful to the Coast Guard Law Enforcement community and examination of the operational usefulness of 209 correlated shiptracks as input to the Joint Maritime Information Element (JMIE) Support System (JSS).

Chapter II will describe the data and procedures used to obtain and analyze 209 ship-shiptrack correlations and Chapter III will present the results of these analyses. The operational applicability of shiptracks is discussed in Chapter IV. Chapter V closes with conclusions and recommendations for further study.

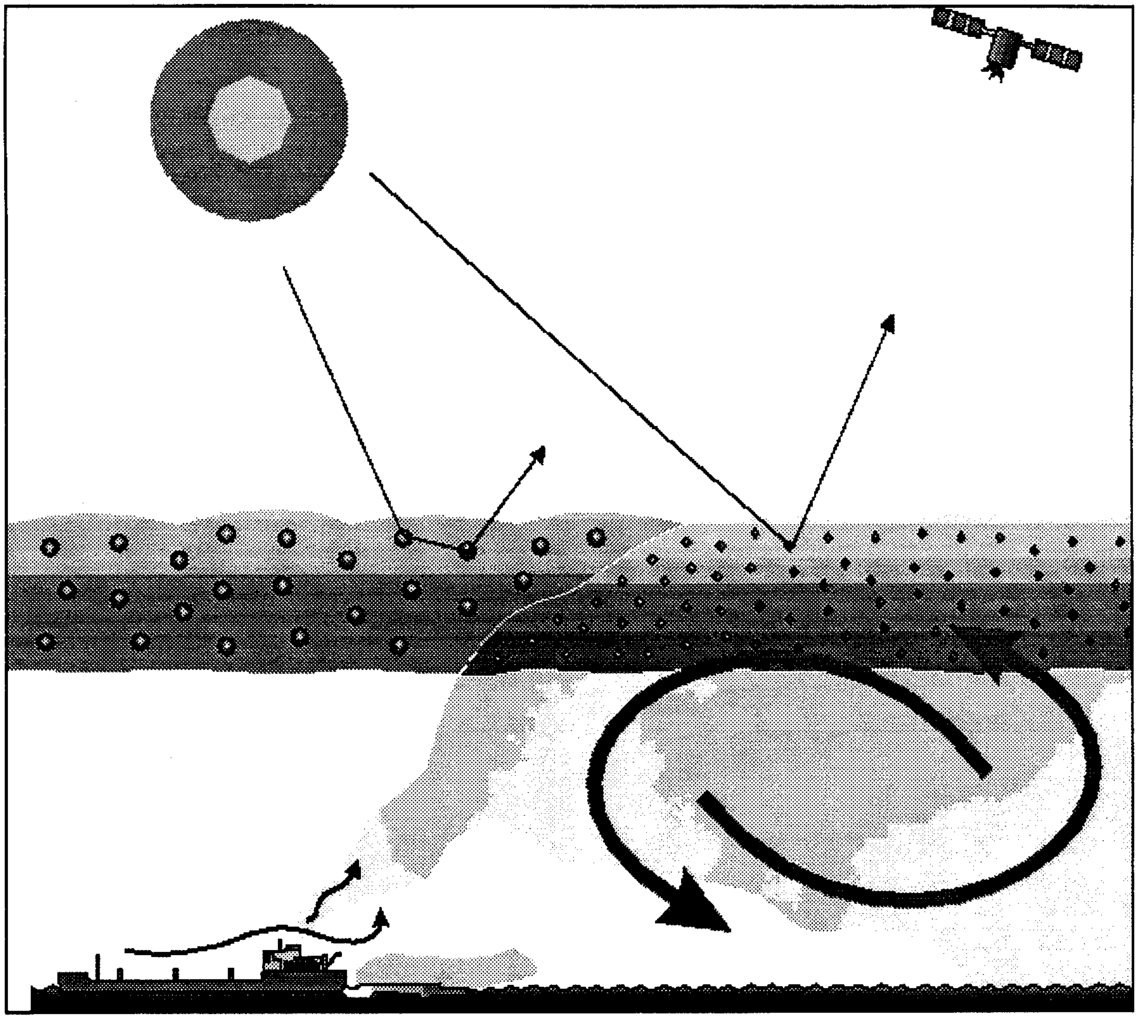

Figure 1. Shiptrack Formation Mechanisms. Aerosol Produced by Ship Stack and Ship Wake are Introduced into the Marine Atmospheric Boundary Layer (MABL). Large, Curved Arrows Represent Turbulent Mixing in the MABL. Thin, Linear Arrows Represent Solar Radiation at 3.7μm. Increased Reflection of Solar Radiation at this Wavelength from Ship-Influenced Cloud is due to Greater Scattering by Smaller Radius Water Droplets Formed by Ship-Produced Aerosol. Lower Reflection from Uncontaminated Cloud is due to Greater Absorption by Larger Radius Water Droplets at 3.7μm. From Brown (1995).

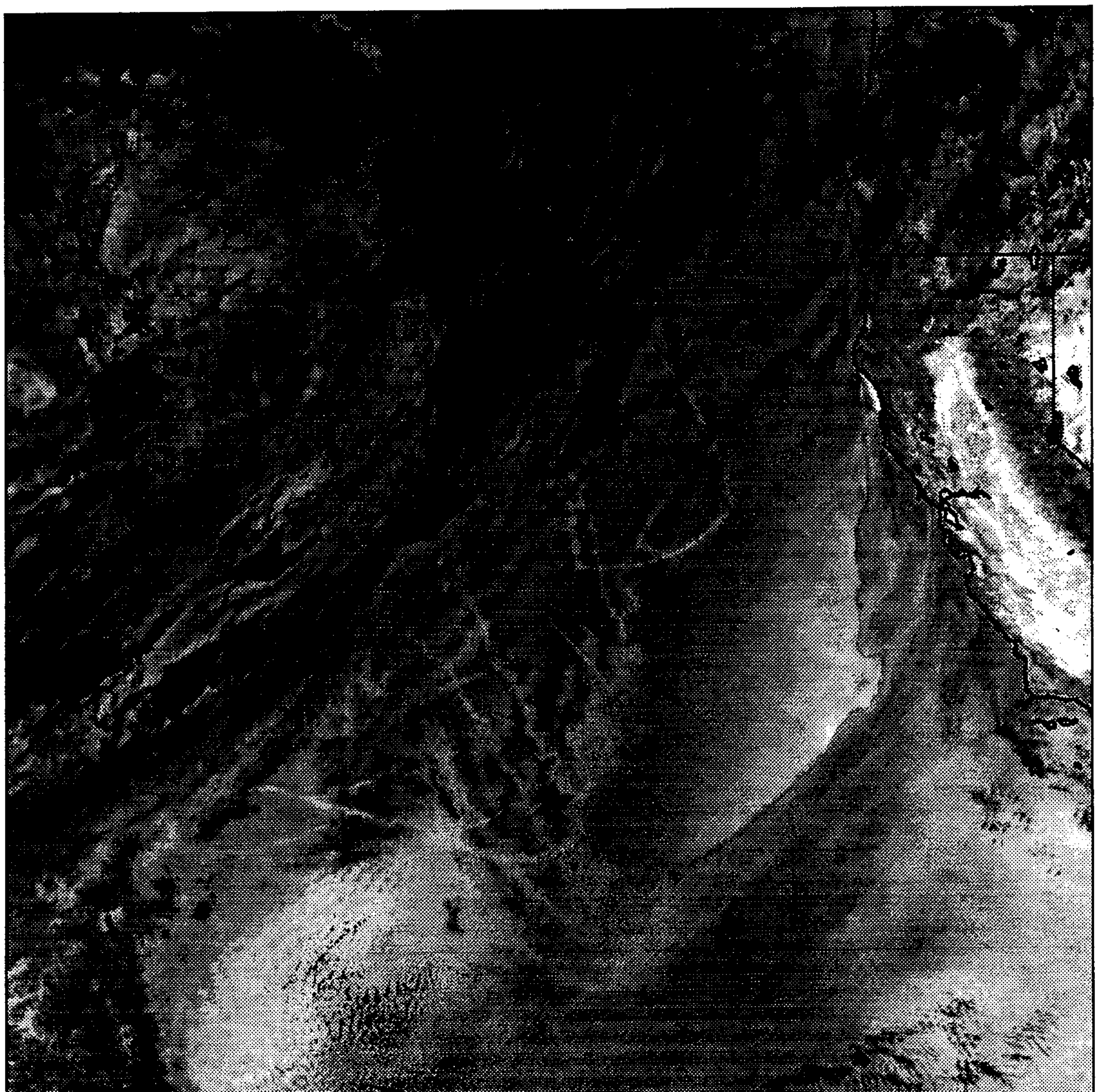

Figure 2. Satellite Imagery of Shiptracks at 3.7μm at 1758Z on 11 June 1994.

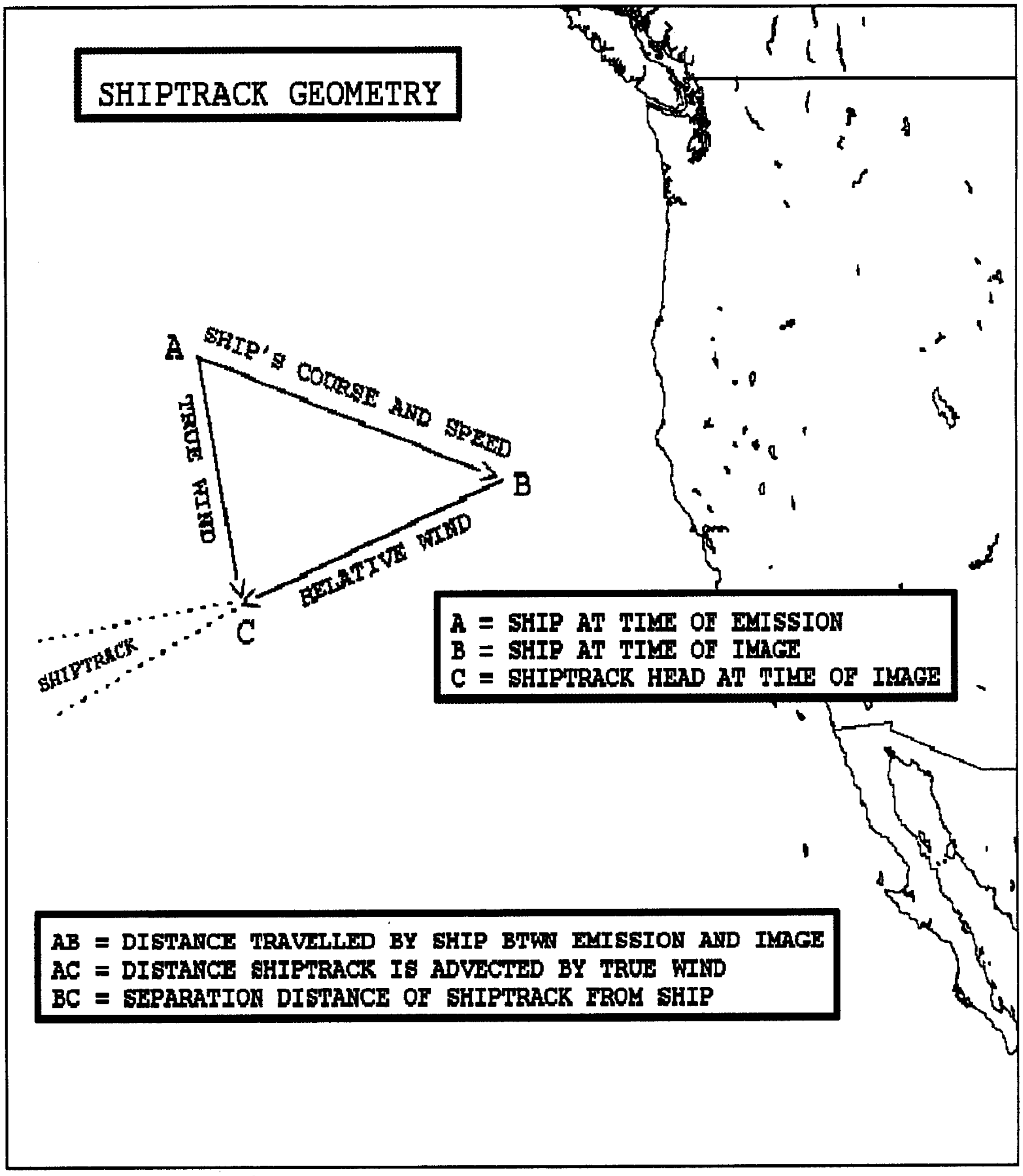

Figure 3. Shiptrack Geometry.

II. DATA AND PROCEDURES

A. DATA

1. Shiptracks

The Monterey Area Shiptrack Experiment (MAST) of June 1994 (CNO Project K-1420) resulted in 1362 shiptracks found in AVHRR images from the four NOAA polar orbiting satellites operational at the time (NOAA 9 thru 12). Figure 4 shows the position of the head of each of these shiptracks, which were identified automatically with an algorithm (Nielsen and Durkee, 1992) and/or by hand analysis. Many of the shiptracks were connected to others in subsequent images through image flickering if they appeared to follow a linear progression of a ship's transit. These linked heads were saved as a shiptrack file. These processes are described in detail in Brown (1995). Each image that had shiptracks on it was then stored for comparison with the maritime databases described below.

2. Ship Reports

a. FNMOC

Synoptic weather reports from voluntary ships received by the Fleet Numerical Meteorology and Oceanography Center in Monterey, California provided 7693 ship positions for the month of June. These reports, which are summarized in Figure 5, include the call sign, date-time-group (DTG), position, course and speed, and local meteorological and oceanographic conditions. These were formatted as files for overlay on the stored satellite images for comparison with the shiptrack data described above.

b. JSS

The Joint Maritime Information Element (JMIE) Support System (JSS) helped fill in the blanks found in the FNMOC data by providing the 10,788 ship positions illustrated in Figure 6. The JSS is a U. S. Coast Guard (USCG) maintained database and consists of multi-source, world-wide, maritime-related data pooled into one central database (ONI, 1994). Through remote access at NPS Monterey, the JSS database was queried day by day until all applicable shipping data for the month of June had been downloaded for local use with the FNMOC data discussed above. Of note is that the FNMOC data was essentially a subset of the JSS data such that a combined data set resulted in the 10,806 ship positions shown in Figure 7. This joint data set was then used in the correlation process described below.

B. PROCEDURES

1. Correlations

Shiptracks were correlated with their responsible ship thru manual comparison of all shiptrack heads on an image with the available FNMOC and JSS ship position data. After identification of possible matches due to close proximity in time and space, a final check was done to ensure the geometry of the shiptrack matched the triangular relationship previously discussed.

Satisfactory orientation resulted in a correlation, which was saved as an individual image with all appropriate data overlaid. Figure 8 is an example of a typical correlation. It shows the trackline of the Merchant Vessel (M/V) SCARLET SUCCESS (solid line) with the shiptrack file S162 (dashed line). The correlation between the ship and the shiptrack at 1753Z on 11 June is outlined with dotted lines.

This was done for all images possible until 209 correlations (Appendix A) were saved. Figure 9 presents the distribution of the 209 correlations. Of note are that there were only 72 ships identified through the month (i.e., most ships were correlated more than once) and that most of the correlations occurred during two separate periods (9-14 and 27-30 June). The importance of these facts is discussed in Chapter IV.

2. Calculated Positions

The interpolated position of each ship for the time of a correlation's image was calculated based on the previous and subsequent positions from the joint FNMOC and JSS data set. The image DTG was matched with a latitude and longitude for the ship. This was used to calculate the separation bearing and distance from the shiptrack to the calculated position of the ship. A course and speed for the ship at the time of the image was determined in a similar fashion and was used to calculate the relative wind direction and speed based on the reported true wind direction and speed. A wind report from a ship in close proximity to the ship in question was used if the correlated ship had not submitted a weather report for the time of the image. Additional interpolation was occasionally required due to the time gaps between the weather reports, which are made approximately every six hours, and the satellite passes, which varied from day to day.

3. Separation Data

The separation data (bearing and distance) were compared to the relative wind (direction and speed) to determine the quality of the 209 correlations as a whole. The accuracy of the calculated positions just discussed depended on the accuracy of the joint FNMOC and JSS data set. Figure 10 indicates how sparsity in the original reports for some cases could result in errors in both the calculated positions and in the separation and relative wind data. Note how the tracks between ship reports for the M/V HANJIN BARCELONA (3EXX9) indicate that she crossed land in subsequent transits into San Francisco and Los Angeles. This is an obvious sign that there will be some error in any attempt to estimate her position between reports. Additional errors could result from the necessary (but inaccurate) assumption that ships steer constant courses and speeds between reports.

Four different elimination criteria were applied to the 209 correlations to ensure that a good data set was used for all further analyses. The first criteria applied required that separation data exist. A correlation would not meet this requirement if a shiptrack had been correlated with a single ship report or outside of a set of ship reports (such that it was not possible to calculate the position of the ship at the time of the image). The second criteria applied required that the separation distance be less than 20NM. This value was determined based on previous studies and on review of the separation distance distribution within the data set. The third elimination made was of the correlations whose values for separation bearing differed from the calculated relative wind direction by more than 70 degrees. A perfect correlation would have had a difference of zero in that both calculated values would match the real value found from the shiptrack/image. Some leniency was required here due to possible errors in the data due to the calculations made. Further discussion on these errors is presented in Chapter III. Finally, correlations with a normalized separation distance (Norm SD = SD * True Wind Speed / Relative Wind Speed) greater than 18NM were eliminated due to the possibility that the wind data was inaccurate. Table 1 provides a summary of the four criteria and how many correlations were eliminated as each was applied.

Elimination Criteria	Number of Correlations Eliminated
No Separation Data Available (No Calculated Positions)	21
Separation Distance Greater than 20NM (Poor Calculated Positions)	42
Difference between Separation Bearing and Relative Wind Direction Greater than 70 Degrees (Poor SB and/or RWD Calculations)	42
Normalized Separation Distance Greater than 18NM (Poor Separation, Relative Wind, or True Wind Data)	5

Table 1. Elimination Criteria Used to Ensure Accuracy of Separation Data Analyses.

The 99 correlations that passed this elimination process were kept for further analysis (Appendix B). The balance of the correlations (110) were noted for their value as a ship and shiptrack correlation but were eliminated from the separation distance data set. The final 99 correlations were analyzed to establish the appropriate statistics relating separation distance to relative wind speed. Finally, composite data was calculated for 12 bins of relative wind direction. This information was used to establish an initial tool to determine separation distance and relative wind speed for a given relative wind direction (given by a shiptrack on an AVHRR image).

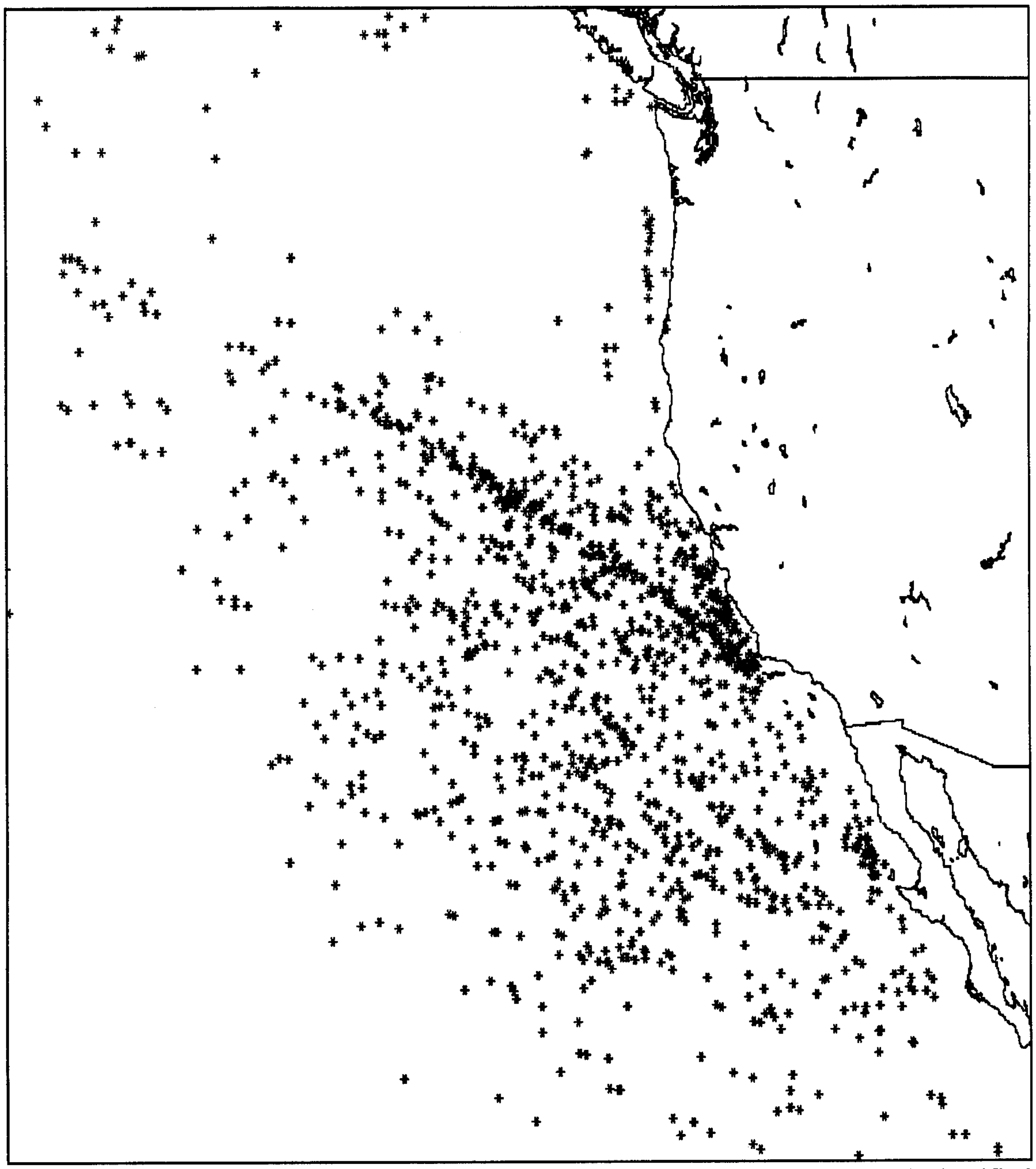

Figure 4. Shiptrack Head Points (1362) from MAST Experiment of June 1994 Identified from NOAA 9/10/11/12 AVHRR Channel 3 (3.7μm) Imagery.

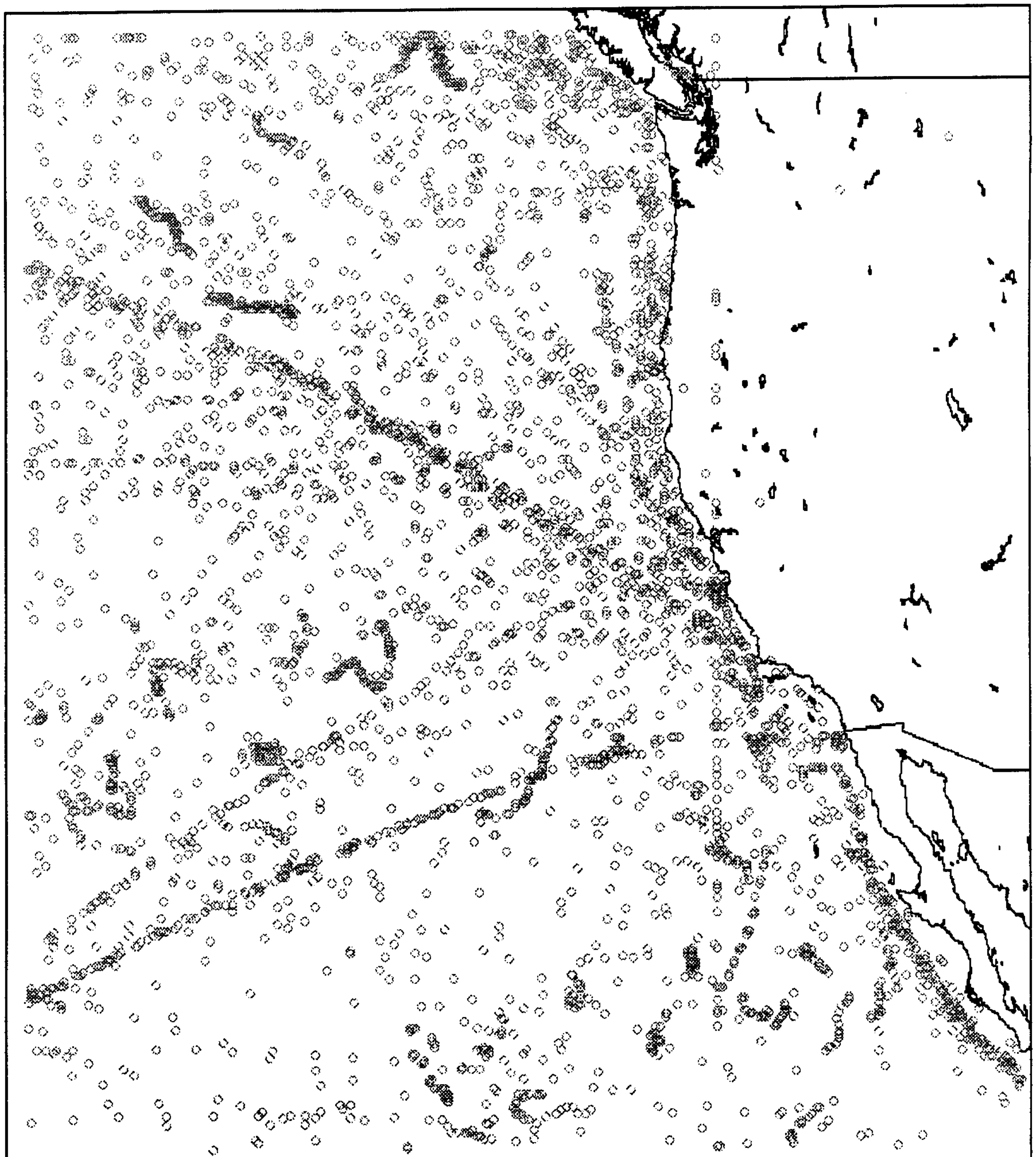

Figure 5. Ship Reports (7693) from FNMOC Database for June 1994.

Figure 6. Ship Reports (10,788) from JSS Database for June 1994.

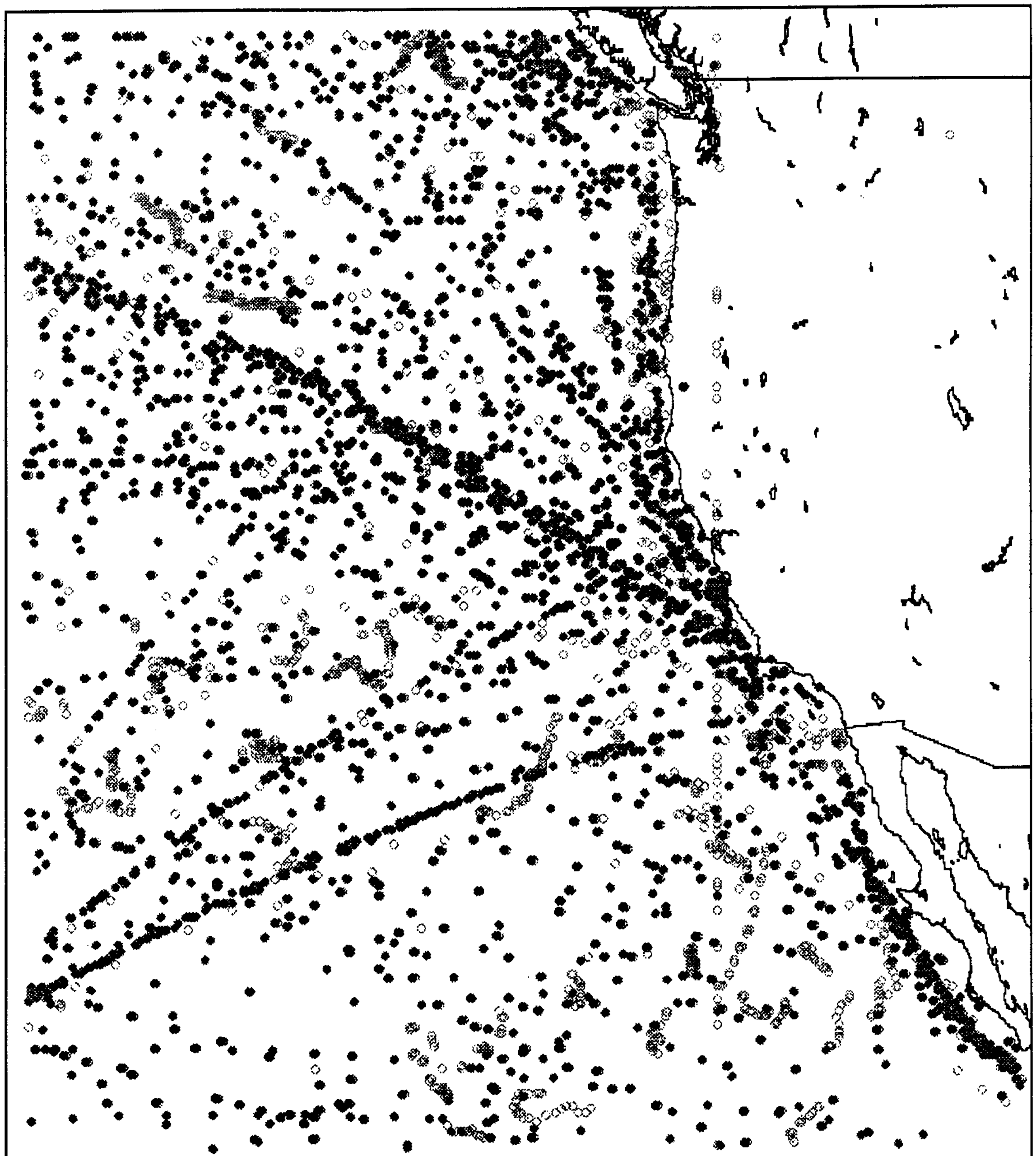

Figure 7. Ship Reports (10,806) from FNMOC (Circles) and JSS (Dots) Databases for June 1994. Note that Most of the FNMOC Reports are Contained within the JSS Database.

Figure 8. Zoomed Image with a Typical Ship-Shiptrack Correlation.

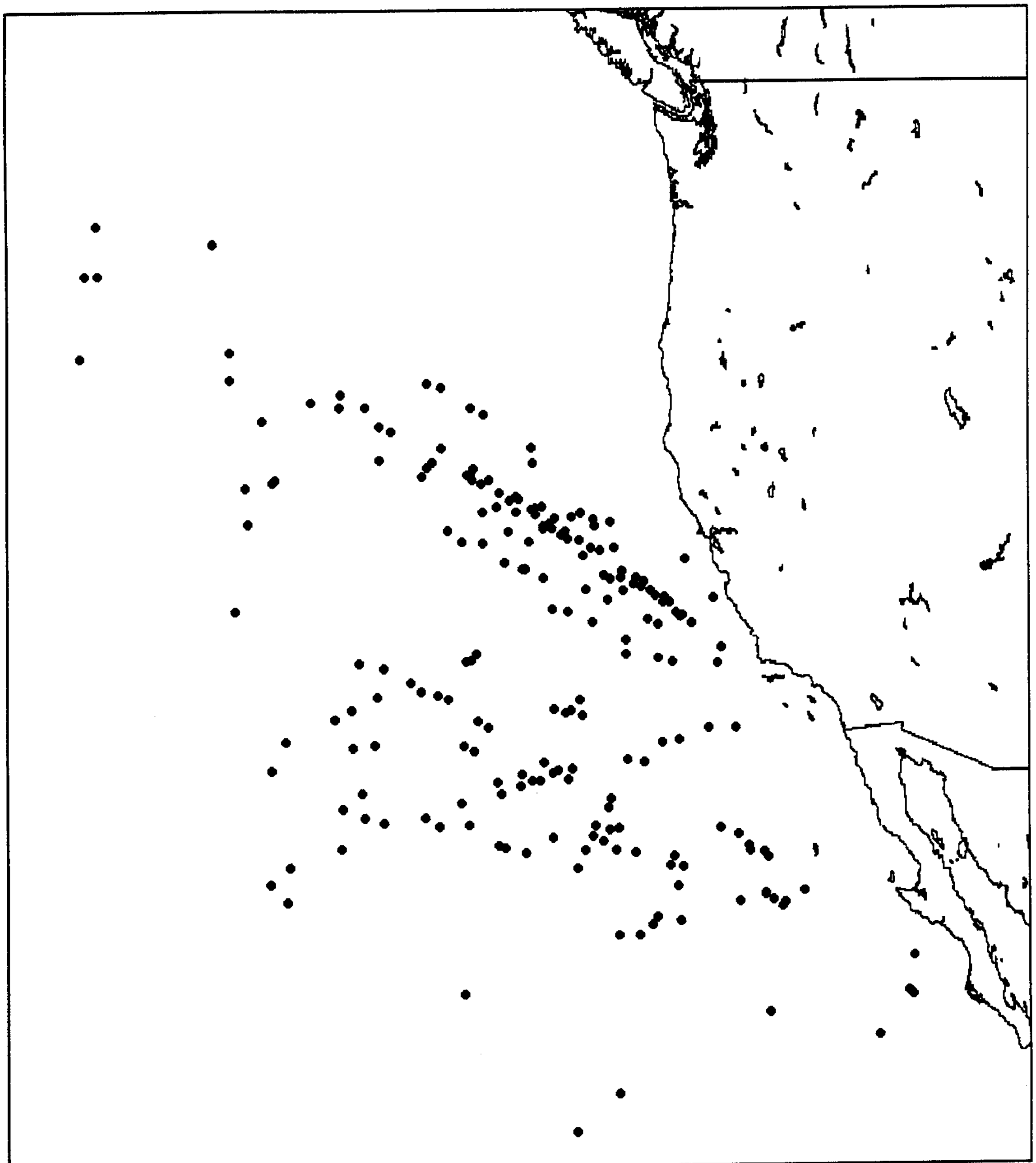

Figure 9. Correlations (209) Made Between Shiptracks from MAST and Ship Reports from FNMOC and JSS Databases.

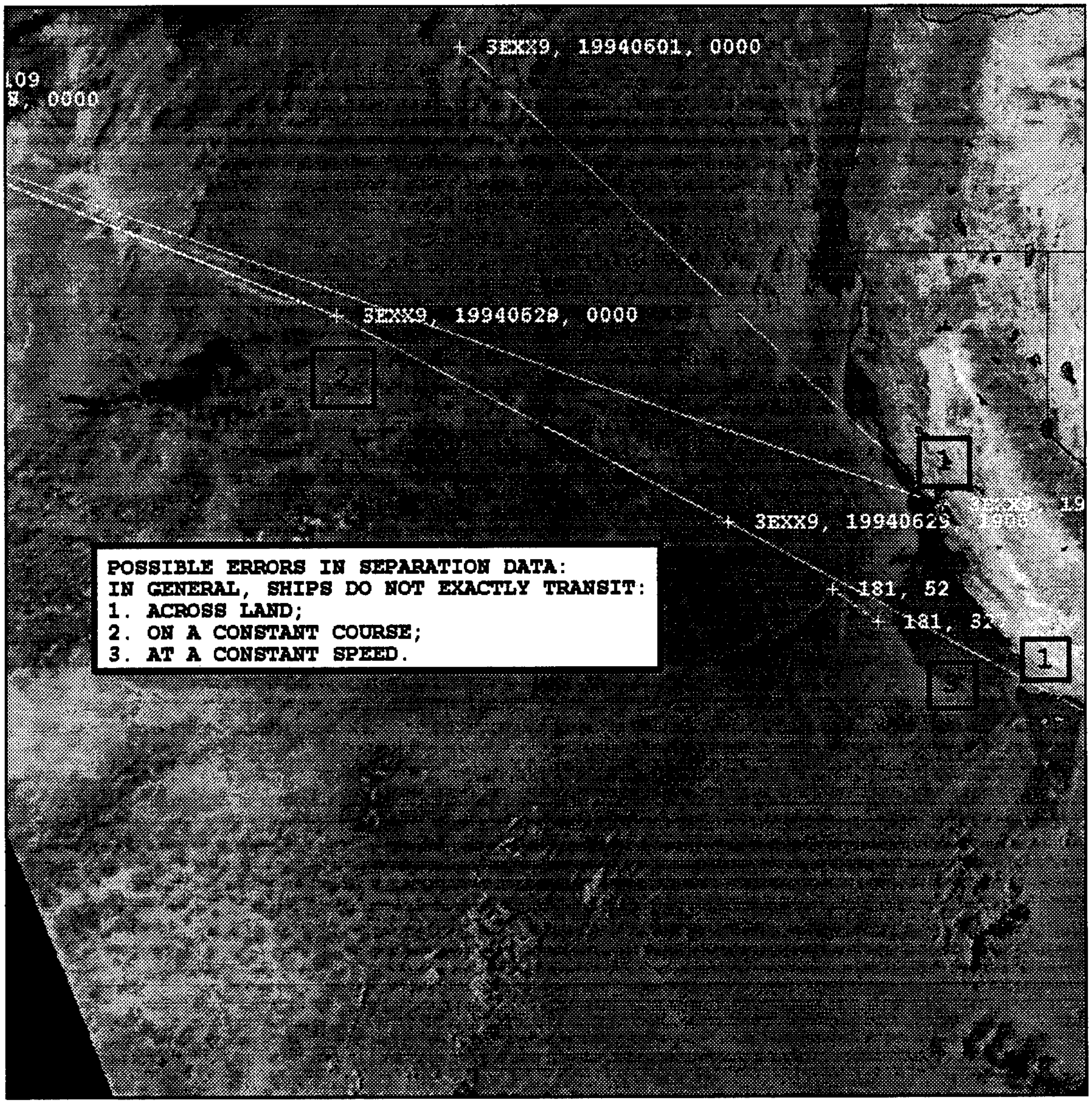

Figure 10. Possible Errors in Separation Data due to Sparse Ship Report Data. The Ship Reports for 3EXX9 Indicate She Crossed Point Reyes and Point Conception on Subsequent Transits. Ships' Positions were Interpolated from the Available Ship Reports and used to Calculate Separation Bearing and Distance. Errors in the Interpolated Positions Resulted in Errors in the Separation Data.

III. RESULTS

A. SEPARATION DISTANCE AND RELATIVE WIND SPEED

The ship-to-shiptrack separation data from the 99 best correlations (Appendix B) were analyzed both graphically and statistically to determine the dependence of separation distance on relative wind speed. The importance in doing this cannot be overstated. Effective operational use of shiptracks for ship surveillance will only be possible through identification of the actual location of a ship at the time of an image. This can only be done by knowing the separation bearing and distance from the head of a shiptrack to the ship in question. The bearing can be determined from the shiptrack itself per the discussion in Chapter I on shiptrack geometry. The distance, however, cannot be determined from an image directly. The first step in making this determination is to understand what factors affect separation of the shiptrack from the ship.

Figure 11 shows a linear increase in both separation distance and relative wind speed with course and gives an initial indication that SD is related to RWS. Ships heading more into the true wind, which was predominantly from the northwest to north (315 to 000 degrees true) throughout the month, have greater values of both SD and RWS.

Figure 12 shows the linear fit between SD and RWS for:

- All 99 correlations (ALL);
- The 79 correlations made with diesel-powered ships (DSL); and
- The 20 correlations made with steam-powered ships (STM).

Table 2 presents the appropriate statistics relating SD to RWS for the same three categories. Both Figure 12 and Table 2 show a stronger relationship between SD and RWS for the diesel ships than for the steam ships. The correlation statistics indicate that there is some dependence of SD on RWS but that other factors must also exist. The break-down of what those factors are and how much weight each carries has not yet been determined. The P-Values, which indicate at what level one can reject the null hypothesis that there is no linear relationship between SD and RWS, amplify these results. This hypothesis can be rejected for the diesel ships with 99.28% confidence [1-2(0.00361)].

Statistics: Ships	Average SD (nm)	Average RWS (kts)	Correlation (R)	R-Squared (R^2)	P-Value (Sig F)
All (99)	8.6	23.0	0.275	0.075	0.00589
Diesel (79)	8.6	23.2	0.324	0.105	0.00361
Steam (20)	8.8	22.2	0.124	0.015	0.602

Table 2. Statistical Analyses of Linear Relationship between SD and RWS.

The same cannot be said for the steam ships (i.e., the null hypothesis cannot be rejected for the steam ships). This is not to say that the null hypothesis must be accepted and that there is no linear relationship between SD and RWS for the steam ships. On the contrary, some of the variation in SD can be explained by the changes in RWS. However, more of this variation can be explained by the RWS for the diesel ships than for the steam ships. There is no simple or full explanation for this finding. However, it is possible that the smaller number of correlations (and thus the lower degrees of freedom) for the steam ships had a negative effect on these statistics. A more extensive database of shiptracks caused by steam ships would be needed to make any significant conclusions.

The time that passes between emission of aerosol from a ship and observation of a shiptrack can be calculated by dividing separation distance by relative wind speed. This quantity, which can be called separation time (ST), is the time required for aerosol to reach the top of the MABL and is a measure of how rapidly mixing occurs within the boundary layer. The average separation time for the 99 correlations analyzed in this study is 24.7 minutes. Figure 13 presents the distribution of calculated separation time for the 99 analyzed correlations. The range of ST values (from 5 to 90 minutes) confirms that mixing is not uniform. However, the concentration of approximately 90 percent of the ST data in the 10 to 45 minute range indicates that mixing is only one of several factors that affects shiptrack formation and observation. These results lay a foundation for future identification of some of these factors and their relative importance.

The fact that a linear relationship between separation distance and relative wind speed can be shown for the separation data as a whole allows further analysis. The next logical step is to develop a tool for determining separation distance (and relative wind speed) from a satellite image.

B. DETERMINATION OF SEPARATION DISTANCE

The first step in creating a SD prediction tool is to determine and limit the errors in the separation bearing (SB) and relative wind direction (RWD) values of the separation data. Recall that SB and SD were determined by calculating the bearing and range from the head of each shiptrack to the interpolated position of the ship at the time of the image while RWD and RWS were determined by vector subtraction of the true wind from the ship's course and speed. SB and RWD would be equal to each other and in line with the orientation of the shiptrack [actual relative wind direction (ARWD)] for a correlation with perfectly clean data. Inaccuracies arise since different components (SB and SD, RWD and RWS) are derived from different sources/calculations.

Table 3 contains the results of accuracy analyses performed on the separation and relative wind data. Separation bearing was found to be accurate within 14 degrees of ARWD. Relative wind direction was found to be accurate within 18 degrees of ARWD.

Variable	Accuracy (+/-)
Separation Bearing (SB)	14 Degrees
Relative Wind Direction (RWD)	18 Degrees
Average of SB & RWD (AVG)	11 Degrees

Table 3. Accuracy of Separation Data.

The average of SB and RWD was calculated for each correlation in an attempt to eliminate some of the inaccuracies in the data. An example of how this can occur is shown in Figure 14. The average value (AVG) is closer to ARWD than either SB or

RWD by itself when the calculated values fall to either side of the actual value. This occurred with regularity through the 99 correlations and AVG was found to be accurate within 11 degrees of ARWD. The decision to use AVG to develop a separation distance prediction tool followed this finding.

The final step in creating a prediction tool was to calculate the composite separation distance for equal AVG bins. Review of Figure 15, which shows the distribution of SD with AVG from 0^0 to 360^0, led to the decision to use 12 equal bins of 30^0 each. This was the best combination to ensure the bins were large enough to prevent misrepresentation by individual correlations yet small enough to show the differences through the 360^0 range of relative wind direction. The first bin was centered at 000^0 for convenience of operational application. The composite values of SD and RWD were calculated and are shown in Table 4 along with the standard deviation that can be expected for each value. The absence of values for RWD from 135^0 through 225^0 is explained by understanding that ships off the California coast do not generally steer southerly courses at speeds greater than the magnitude of the true wind (which is what would have to occur for the relative wind to be from the south). Interpolation could be used as necessary if an image contained a shiptrack with a RWD in this range.

Figure 16 is a polar plot that illustrates most clearly the distribution of separation distance and relative wind speed with relative wind direction. Either Table 4 or Figure 16 can be used to predict the distance from a shiptrack on an image to its respective ship and to make an estimation of the general direction the ship is heading (e.g., west, northwest, east, etc.) through use of shiptrack geometry. Figure 17 demonstrates this by applying the results in Table 4 to two shiptracks in an image that has been enhanced and zoomed for clarity. The upper shiptrack in Figure 17 points towards 082^0 True. This is the relative wind direction (RWD) and the bearing from the shiptrack to the ship (SB). Upon entering Table 4 with this value for RWD, one can determine that the separation distance (SD) is predicted to be 8.1 NM and the relative wind speed (RWS) is predicted to be 19.9 KTS. Furthermore, as the triangle to the left of the shiptrack indicates, the ship's course can be approximated through vector addition of the true and relative winds.

RWD Center	RWD Range	SD (NM)	SD Error (+/-)	RWS (KTS)	RWS Error (+/-)
000	345-015	11.2	1.7	31.3	4.7
030	015-045	7.5	1.1	21.2	3.2
060	045-075	7.1	1.1	17.5	2.6
090	075-105	8.1	1.2	19.9	3.0
120	105-135	4.2	0.6	12.4	1.9
150	135-165	- -	- -	- -	- -
180	165-195	- -	- -	- -	- -
210	195-225	- -	- -	- -	- -
240	225-255	2.8	0.4	13.3	2.0
270	255-285	8.6	1.3	31.5	4.7
300	285-315	6.8	1.0	22.1	3.3
330	315-345	11.1	1.7	26.9	4.0
360	345-015	11.2	1.7	31.3	4.7

Table 4. Determination of SD and RWS from RWD.

The result in this case is a ship's course of roughly 135^0 True (or towards the southeast). Note that this is only a first approximation because neither the speed of the ship nor the magnitude of the true wind are known, although these too can be estimated from the vectors. The same process can be applied to the lower shiptrack. The results of both evaluations are shown in the boxes in Figure 17.

This is a significant step towards using shiptracks for ship surveillance. A ship's position can now be estimated from shiptrack data alone with accuracy of one to two nautical miles. Likewise, relative wind speed and the course and speed of the ship can be estimated. Subsequent images could be analyzed to track a ship and to better identify its course and speed. Applications are as varied and numerous as the missions of the agencies with interests in maritime data. Some of these are discussed in the next chapter.

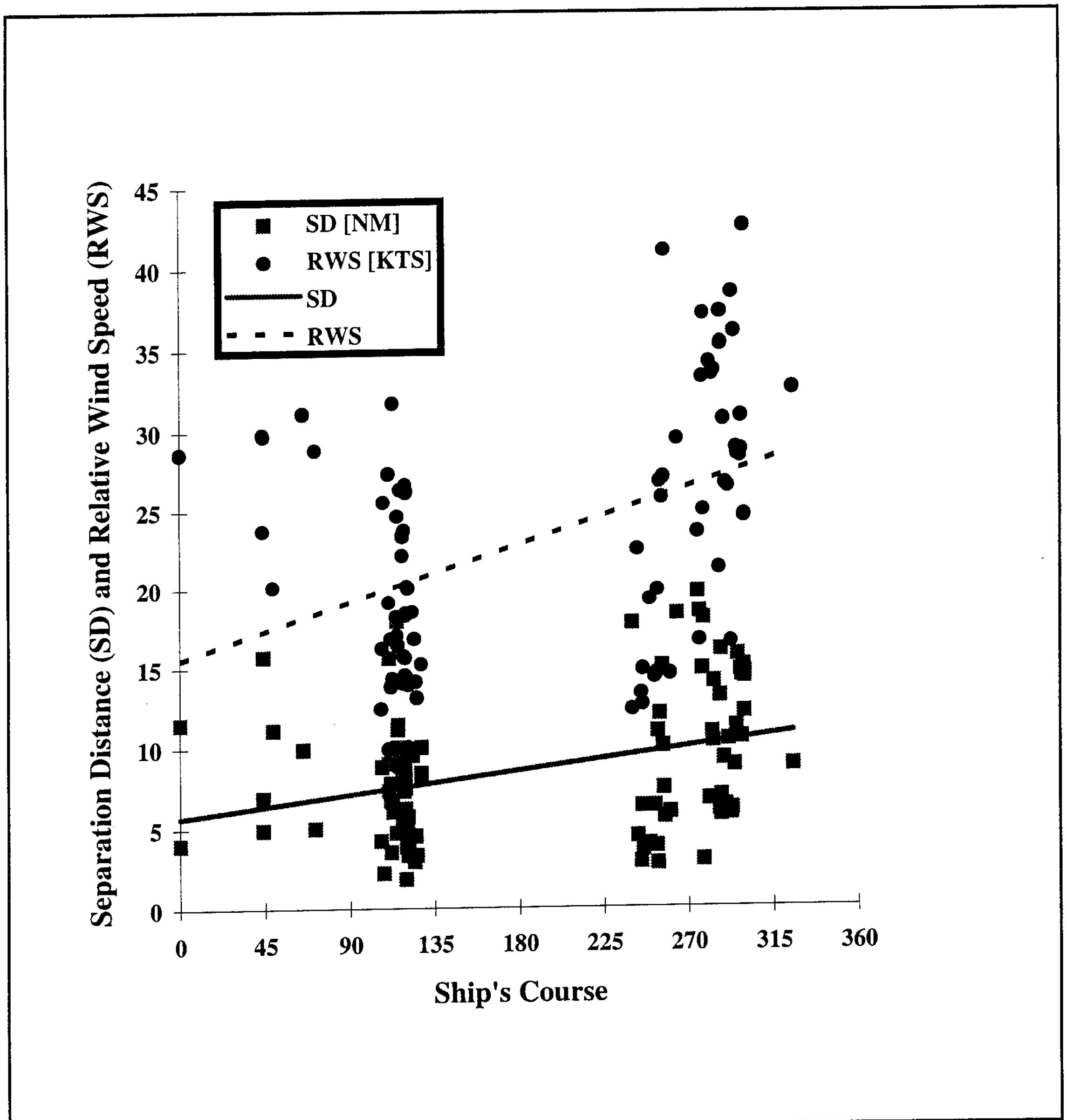

Figure 11. Separation Distance and Relative Wind Speed versus Ship's Course. Note the Linear Increase in Both SD and RWS as Ships Steer into the True Wind (~315 to 360 Degrees).

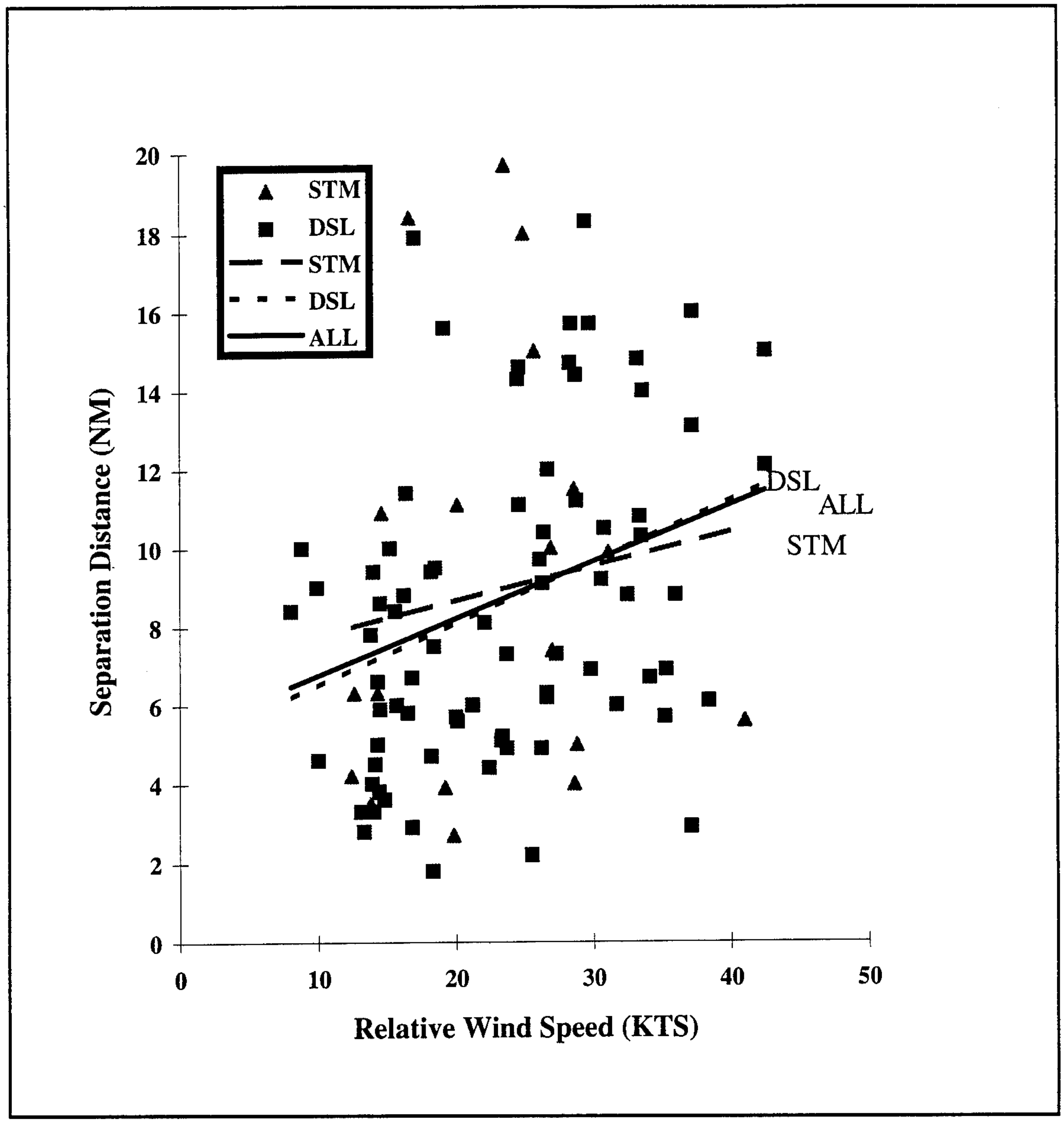

Figure 12. Separation Distance versus Relative Wind Speed. Note the Linear Relationship for all Three Datasets (All 99, 79 DSL, 20 STM).

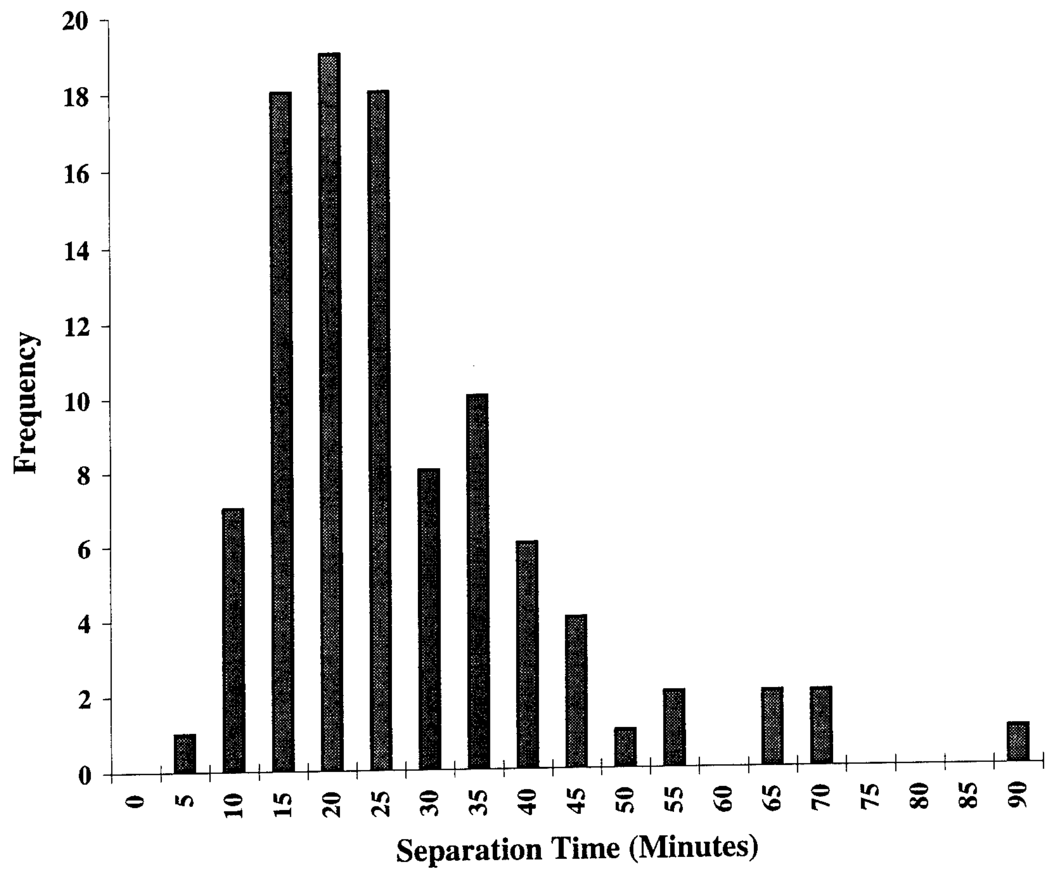

Figure 13. Distribution of Separation Time (ST) for 99 Correlations. ST (=SD/RWS) is the Time Required for Aerosol to Transit from Ship to Cloud Top and is a Measure of How Quickly Mixing is Occurring within the MABL. The Average Value for this Data is 24.7 Minutes with ~90% of the Values falling between 10 and 45 Minutes.

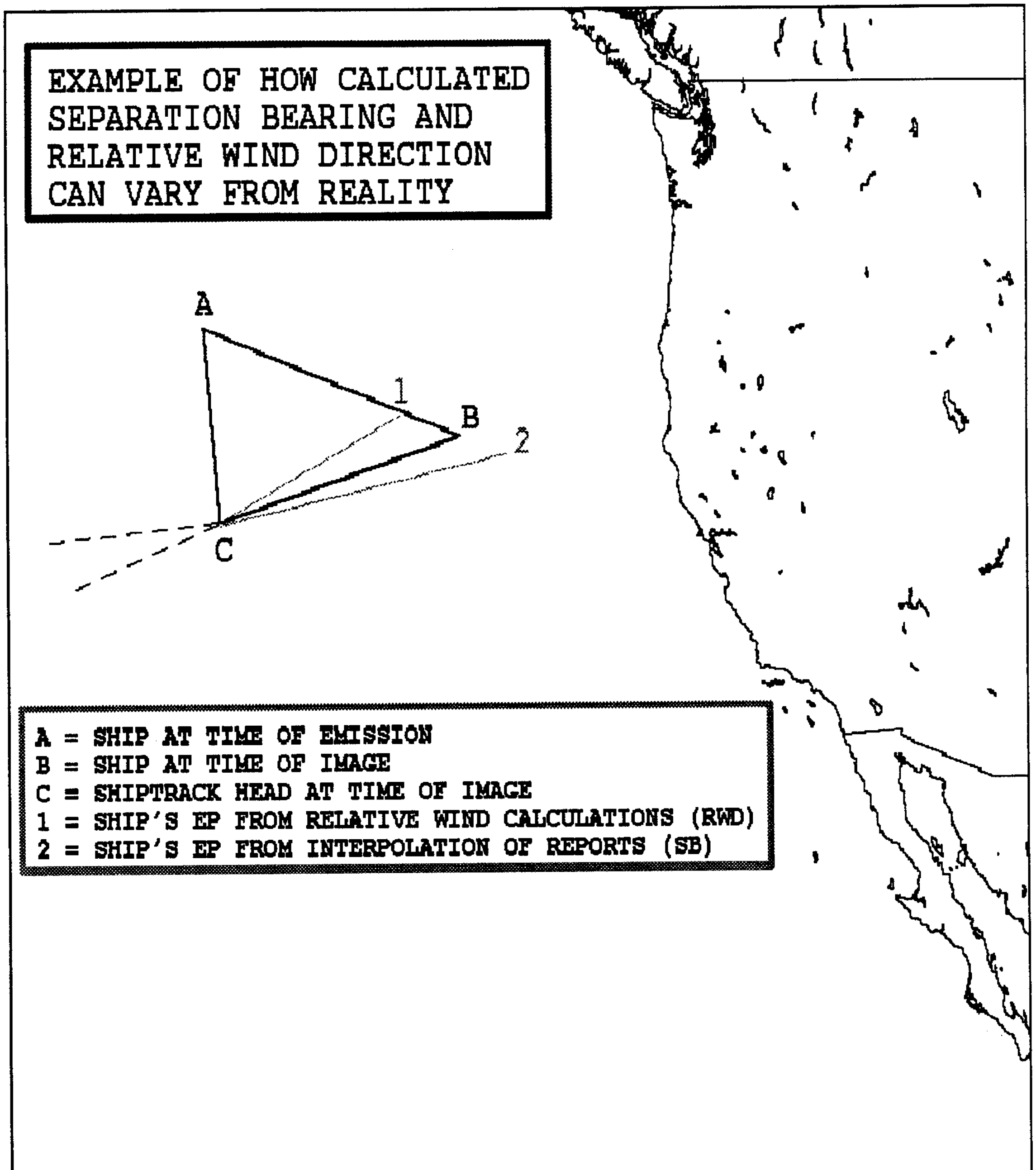

Figure 14. Calculated Separation Bearing and Relative Wind Direction were within 14 and 18 Degrees of the Actual Values, Respectively. The Average of the Two was within 11 Degrees and was used to Establish a Prediction Tool for Separation Distance and Relative Wind Speed.

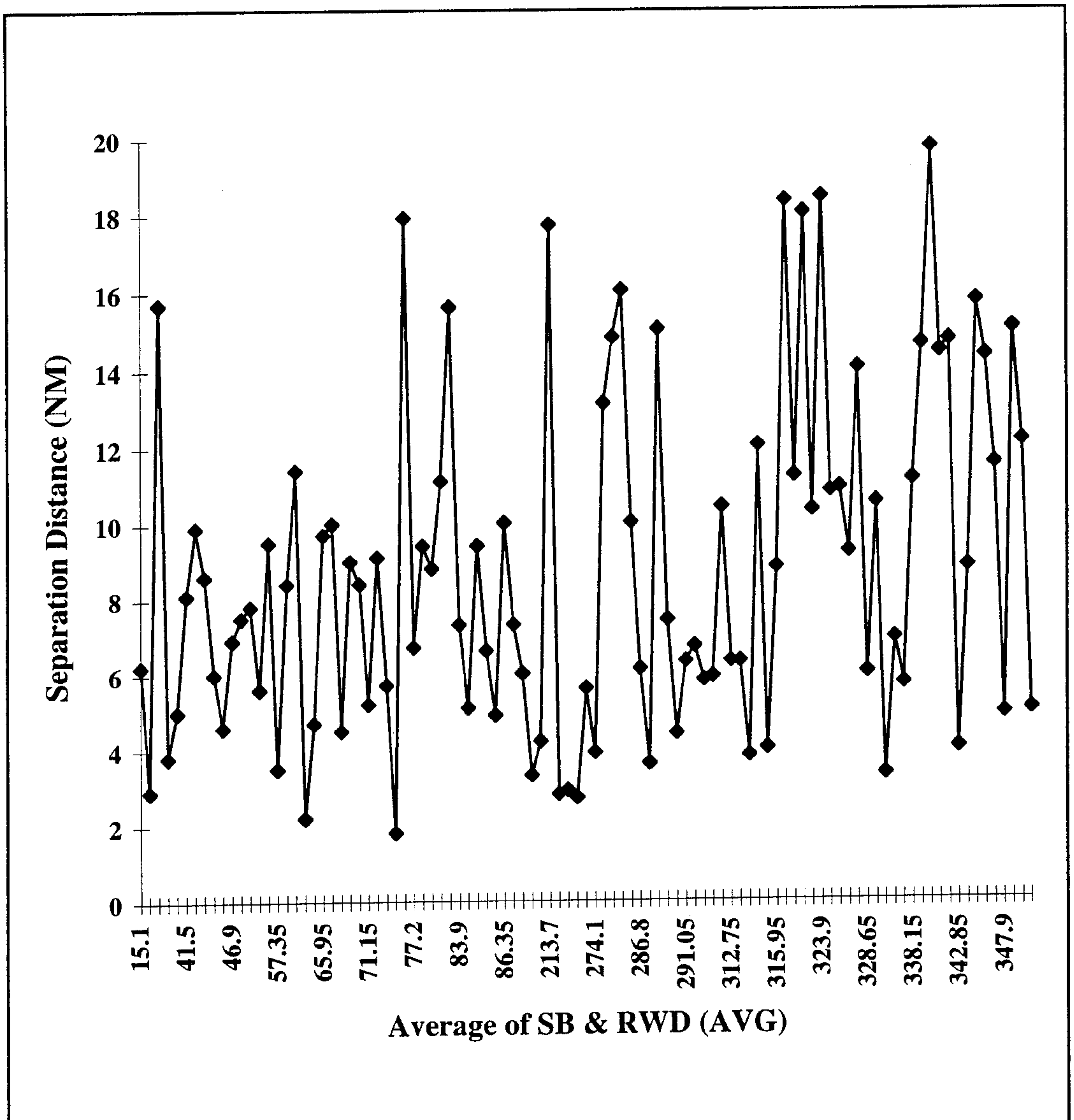

Figure 15. Distribution of SD with AVG.

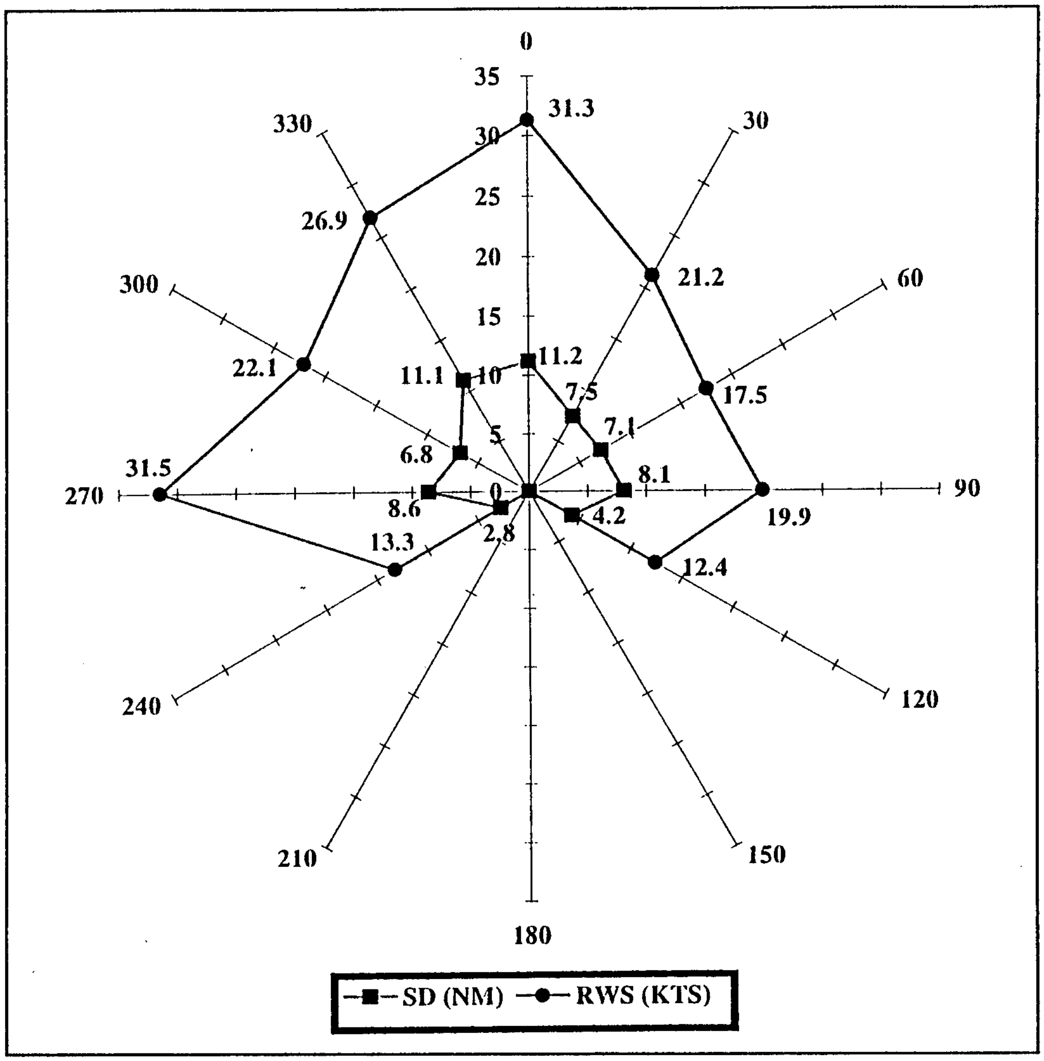

Figure 16. Determination of SD and RWS from RWD. Distribution of SD and RWS Shows that Both Increase as Ships Steer into the True Wind (~315 to 360 Degrees).

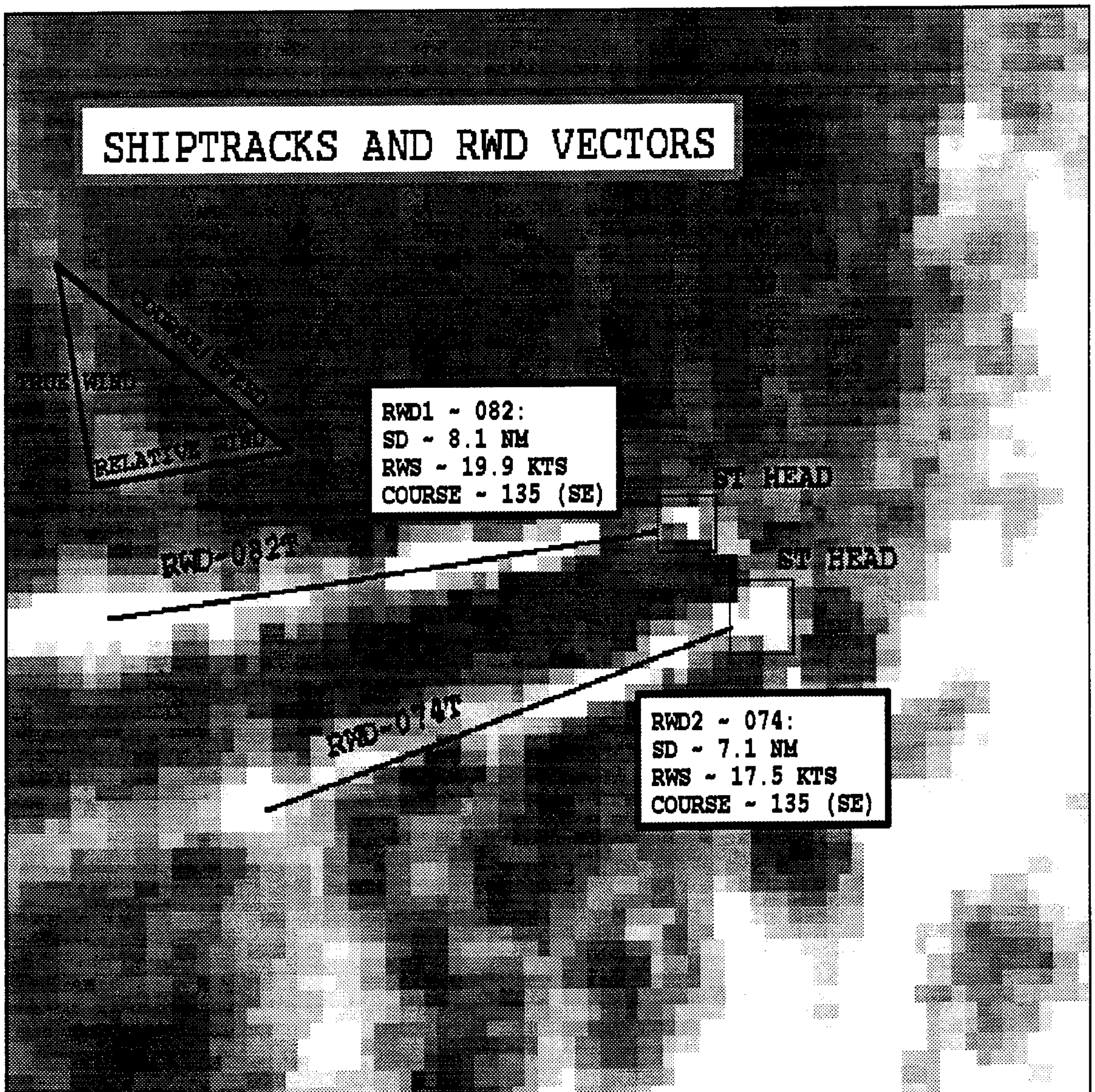

Figure 17. Application of Separation Distance Prediction Data (Table 4) to an Image.

IV. OPERATIONAL APPLICATIONS

A. OPERATIONAL SURVEY

An Operational Survey (Appendix C) was sent by electronic mail to key JSS users at USCG Operations Centers in Alameda, California (CG Pacific Area); Long Beach, California (CG District Eleven); and Seattle, Washington (CG District Thirteen) to help determine how shiptracks might be operationally useful. Figure 18 shows the distribution of the 1362 shiptrack heads from MAST within the CG District/Area boundaries and illustrates the potential for each of these centers to use shiptrack data as an intelligence source. The main goals of the survey were to obtain feedback from the operators who use shipping data on a regular basis and to better determine under what circumstances shiptrack data would be considered useful.

Table 5 presents the answers to the Operational Survey. A numerical average was computed to aid in analyzing the overall results. This proved very useful as it allowed inference of three key conclusions on the potential for use of shiptrack data as an intelligence source for USCG operations:

- Correlated data would be more useful than uncorrelated data.
- There is high interest in using shiptracks as an additional data source to identify vessels following non-standard transits or conducting abnormal operations. Critical applications include Alien Migration Interdiction Operations and Marine Environmental Protection.
- While both timeliness and accuracy are desired, the former is considered slightly more important (due to the tendency of ships to move with time).

A compromise between the need for timely data and the desire for correlated data will have to be found due to the time required to obtain shiptrack correlation. A likely resolution will be for uncorrelated data to be used for near-real time operations in conjunction with other sources of shipping data while correlated shiptrack data could be used for applications that are less time-critical. Long term vessel tracking is one example and is the subject of the next section.

Question Number \\ Ops Center	CGD11	CGD13	PACAREA	AVG
1. Usefulness of raw data?	2	2	1	1.7
2. Usefulness of correlated shiptrack data?	2	3	2	2.3
3. Interest in shiptrack data showing abnormal operations?	3	3	3	3
4. Interest in a shiptrack that cannot be correlated?	3	2	2	2.3
5. Use as an additional source?	2	3	2	2.3
6. Use in lieu of other sources?	1.5	1	2	1.5
7a. Use for law enforcement?	3	3	2	2.7
7b. Use for search and rescue?	2	2	1	1.7
7c. Use for other missions?	2	2	1	1.7
8. Accuracy required for data to be considered useful?	2	1.5	2	1.8
9. Timeliness required for data to be considered useful?	2	2	2	2

Table 5. Answers to Operational Survey (1=Low, 2=Medium, 3=High).

B. JSS DATA SOURCE

The 209 initial correlations (Appendix A) were submitted to Ms. Ann Morris of JMIE Customer Service at USCG Headquarters. The goals in doing this were to analyze the compatibility of the shiptrack data with the JSS and to determine the procedures for data entry. Ms. Morris worked with the data as it appears in Appendix A and determined that it could be entered into the JSS after two simple format modifications were applied:

- The numbers for latitude and longitude had to be changed from decimal format to the degrees-minutes format used in the JSS (e.g., 36.5 = 3630). This was done without too much difficulty thru use of the tools available within EXCEL, the file format in which the data had been submitted.

- The format used in the correlation data to indicate the correct hemisphere had to be changed from positive/negative to letter abbreviations [e.g., positive values = north latitude (N) and east longitude (E); negative values = south latitude (S) and west longitude (W)]. This modification was made easier by the fact that all of the correlations had north latitude and west longitude.

After making these format changes, Ms. Morris tested the data upload process by entering the correlation data into a JSS development database (J2) that is used to experiment and test data prior to entering it into the production system (J1) that is accessible to JMIE users around the world. The results were encouraging as she was able to run queries and download the data from J2 into the various forms and applications available on the JSS terminal.

The next step in this process will be to enter the existing data into J1. Figure 19 illustrates how correlated shiptrack data for the Merchant Vessel (M/V) SCARLET SUCCESS fills in some blanks in the JSS data. Existing reports for the ship were 47 hours and 631 NM apart (2105Z on 11 June to 2000Z on 13 June). Seven correlations were made between these reports. These show her positions along her transit and significantly enhance our knowledge of her activity through the period.

Upon entry, analysis, and review of this process, it is hoped that actual JSS users will be able to use the additional data available from shiptrack correlation. This will be an ongoing process that will require continued coordination between NPS Monterey and JMIE Customer Service.

A valid goal is to make shiptrack analysis available to USCG Operations Centers. Doing so would allow both real-time use of shiptrack data and additional long-term vessel tracking. Qualified JSS users could actively correlate shiptracks on a regular basis and submit the new shipping data to J1 for use by others as needed.

C. GLOBAL APPLICABILITY

Discussion in the previous sections has focused on shiptracks off the west coast of the United States. The phenomenon is observed in other areas of the world as well. Figure 20 presents an overview of the regions of the globe where shiptracks have been observed with some regularity. Regions 1 through 4 are the areas that have been studied most extensively due to the more common occurrence of both ample vessel traffic and shiptrack-conducive conditions. Shiptracks have also been observed in regions 5 thru 8. However, these areas do not have a high occurrence of both vessel traffic and conditions that are conducive for shiptrack formation, and thus have not been well studied (Nielsen, 1995).

Interest in shiptracks will continue to increase as additional regions are identified, as formation mechanisms are more clearly understood, and as operational applications are more fully appreciated. Shiptracks may someday be used globally for both scientific and operational analyses.

D. USN INTERESTS

Two major operational interests in shiptracks exist for the U.S. Navy:

- Use shiptracks to find, track and/or identify the naval vessels of other nations.
- Ensure other nations are not able to use shiptracks to find, track and/or identify the naval vessels of the United States.

Attempts to identify and analyze shiptracks caused by U.S. Naval vessels resulted in two findings. First, very few naval ships can be correlated with shiptracks. Second, the shiptracks caused by the ships that were observed were barely discernible compared to the tracks formed by commercial vessels (Mays, 1993).

These findings are encouraging in that they reduce the need for concern that other nations can use shiptracks against the U.S. Navy. However, they also raise questions about how well the U.S. may be able to use shiptracks tactically against other nations. Thus, more research is needed to better determine the tactical application of shiptracks towards naval operations.

E. LIMITATIONS

There are limitations to using shiptracks operationally. The most important of these is the dependence of track formation on conducive meteorological conditions. Shiptracks do not form when there is no cloud cover or if the cloud layer is too high

(Trehubenko, 1994). Table 6 contains one view of how conducive the synoptic conditions were for shiptrack correlation during MAST. Five or fewer correlations were made on 19 of the 30 days during the month. Over 80 percent of the 209 total ship-shiptrack correlations were made during two separate periods totalling only 11 days (9-15 June and 27-30 June). Thus, the ability to use shiptracks at any given time is strongly dependent on environmental conditions.

Quality of Meteorological Conditions for Shiptrack Correlation (Number of Correlations)	Number of Days (out of 30) during MAST
Low (0-5)	19
Medium (6-15)	6
High (16-25)	5

Table 6. Correlation Distribution during MAST.

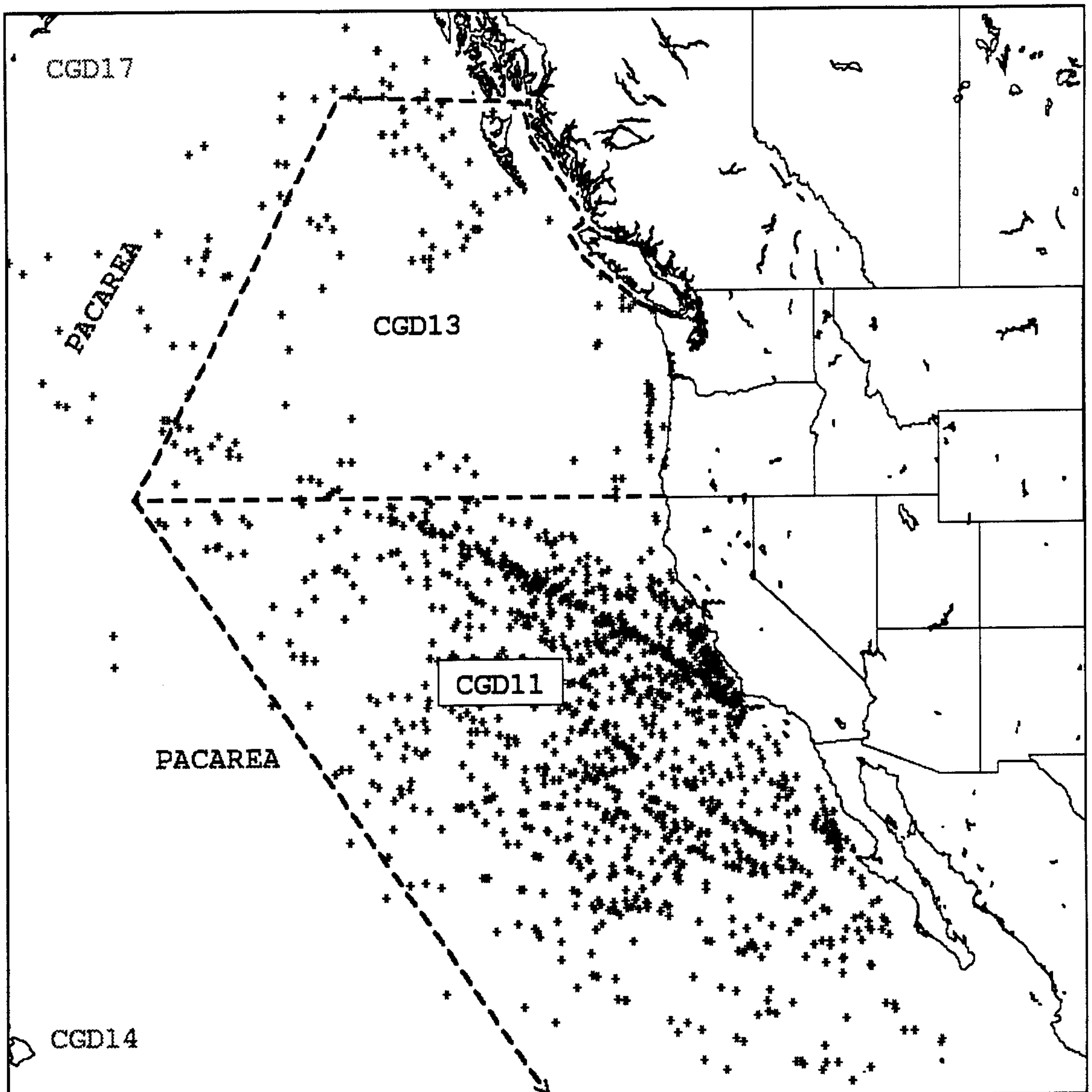

Figure 18. Distribution of Shiptrack Head Points (1362) within USCG District Boundaries (PACAREA includes the 11th, 13th, 14th and 17th Districts).

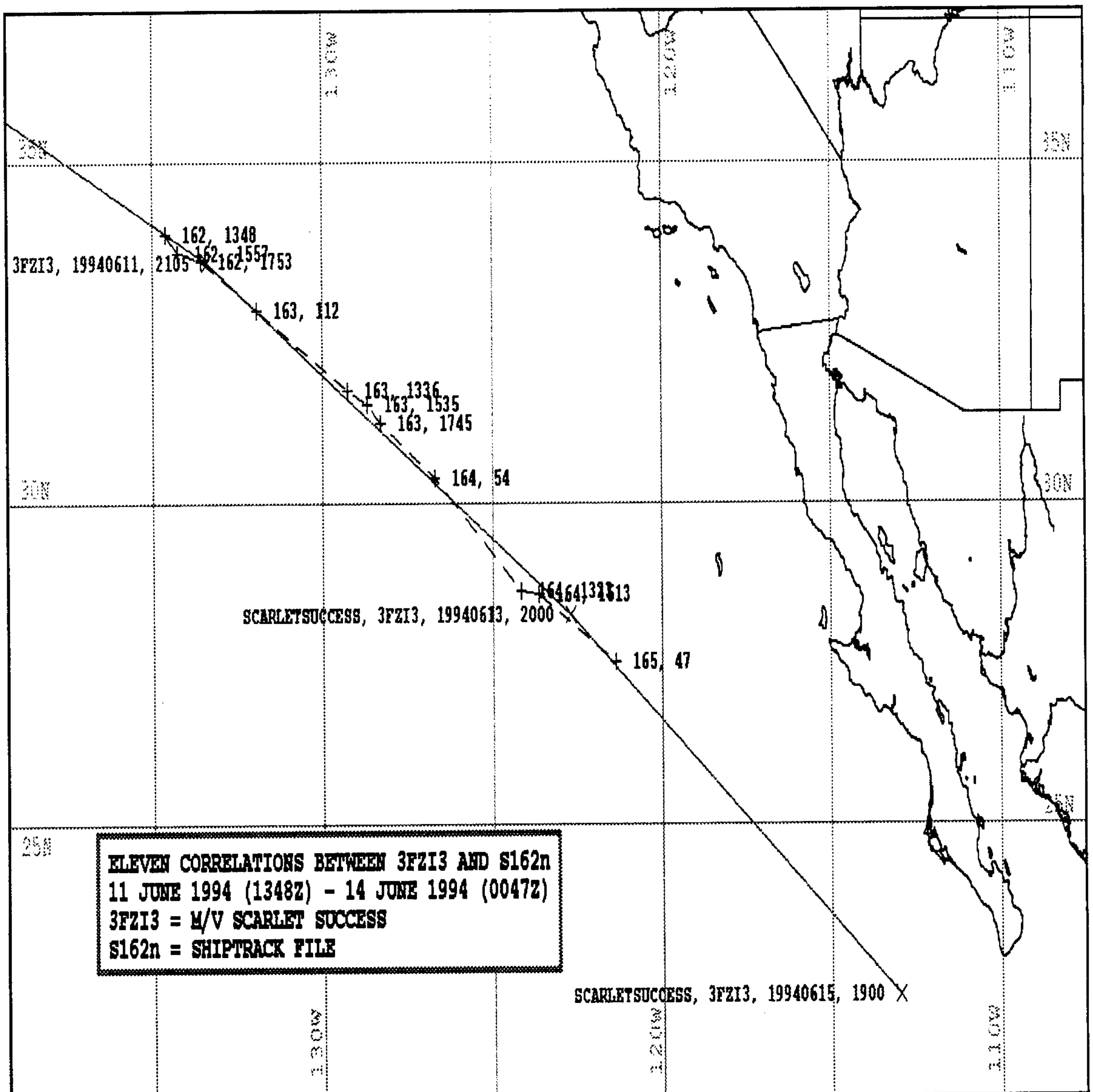

Figure 19. Correlated Shiptracks can Supplement Other Sources. Ship Reports for 3FZI3 (SCARLET SUCCESS) were not in the FNMOC Database and were Sparse in the JSS Database. (NOTE: Some Reports for SCARLET SUCCESS List Her Call Sign as DVZR).

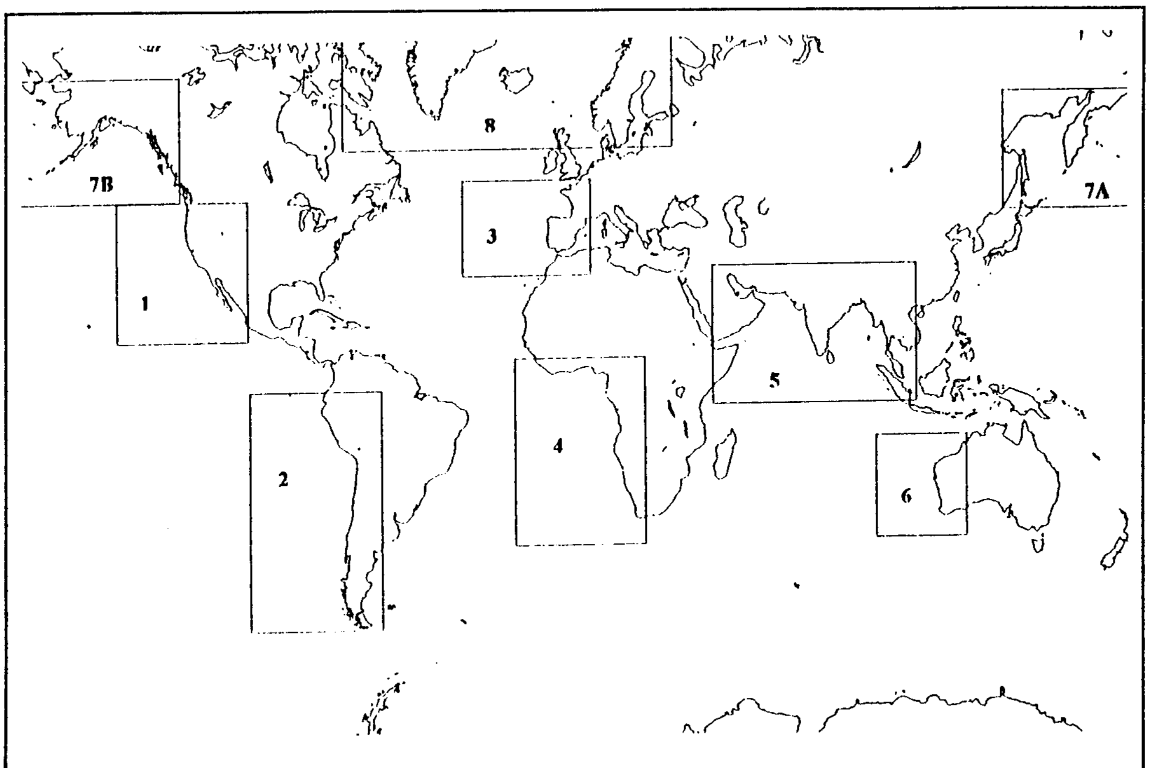

Figure 20. Global Applicability of Shiptracks. The Phenomenon has been Observed in Nearly Every Coastal Region with Routine Shipping Traffic.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The objective of this thesis was to use shiptrack data from the Monterey Area Shiptrack Experiment (MAST) of June 1994 to progress towards using the shiptrack phenomenon operationally. Efforts in several areas met this objective with great success.

A subset of 99 ship-shiptrack correlations revealed a linear relationship between separation distance (from the ship to the head of the shiptrack in a satellite image) and relative wind speed (generated by the ship's course and speed combined with the true wind). The average values for separation distance and relative wind speed were 8.6 nautical miles (15.9 kilometers) and 23.0 knots (11.8 m/s), respectively. The sample correlation coefficient (R) and P-value for this data were 0.275 and 0.00589, respectively. Thus, separation distance is partially dependent on relative wind speed. Separation time from aerosol emission to shiptrack detection averaged 24.7 minutes. This is a good measure of how rapidly mixing occurs within the Marine Atmospheric Boundary Layer and provides the groundwork for further study.

A prediction table relating separation distance and relative wind speed to relative wind direction was developed from composite data of the 99 analyzed correlations. This allows determination of a ship's position (within one to two nautical miles) in a satellite image based solely on its shiptrack. The operational implications of this capability will not be fully appreciated until shiptracks are actively used for ship surveillance on a regular basis.

An operational survey sent to USCG Operations Center personnel revealed that there is great interest in applying shiptracks to CG law enforcement operations. Alien Migration Interdiction Operations and Marine Environmental Protection are two mission areas where shiptracks could be particularly useful.

Over 200 ship-to-shiptrack correlations were submitted to the Joint Maritime Information Element (JMIE) Suport System (JSS) as a first test on how shiptrack data could be used to supplement existing ship reports. JMIE Customer Service expressed enthusiasm at both the compatibility and the usefulness of the new shipping data available for the 72 ships that had been correlated with shiptracks during the month of June 1994. Continued coordination between NPS Monterey and JMIE Customer Service should refine the data submission process and enhance the ability of JSS users to track ships at sea.

B. RECOMMENDATIONS

Continued research in how to apply shiptracks operationally is desired. Only by enhancing our understanding of the phenomenon as a whole will we be able to apply our knowledge in the most effective and efficient means possible. Key questions that need to be answered include:

- What are the factors that determine whether or not a shiptrack will form and how strong it will be if it does form?
- What are the critical ship, true wind, and relative wind speeds that result in a shiptrack? Can a ship avoid detection by altering its course and/or speed?
- Can shiptracks be used for real operations by the USCG and/or USN?

The discussion and results presented covered one aspect of the complexity of the variables and factors involved in shiptrack formation. Continued efforts toward understanding the physical parameters involved will only enhance our knowledge of shiptracks and their usefulness. Thus, additional studies of a scientific nature are desired to complement future efforts toward using shiptracks operationally.

APPENDIX A. CORRELATION DATA

Corr Number	Call Sign	Ship Name	DTG (yymmddhhmm)	Latitude (N)	Longitude (W)
1	3EFY7	TOLUCA	9406221519	36.2	-126.7
2	3EFY7	TOLUCA	9406221659	36.5	-127.5
3	3ENR6	NIPPON HIGHWAY	9406271753	38.7	-131.1
4	3ENR6	NIPPON HIGHWAY	9406280116	39.8	-134
5	3ENR6	NIPPON HIGHWAY	9406281340	41.4	-137.5
6	3EOB9	HYUNDAI NO 11	9406160022	20.5	-128
7	3EOF7	KURAMA	9406121336	36.8	-129.3
8	3EOF7	KURAMA	9406121535	37.1	-130.1
9	3EOF7	KURAMA	9406121745	37.2	-130.9
10	3EXH4	CANADIAN HIGHWAY	9406271651	38.2	-128.9
11	3EXH4	CANADIAN HIGHWAY	9406271753	38.1	-128.4
12	3EXH4	CANADIAN HIGHWAY	9406280116	37	-126.1
13	3EXX9	HANJIN BARCELONA	9406291328	38.5	-129.6
14	3EXX9	HANJIN BARCELONA	9406291608	38	-128.4
15	3EXX9	HANJIN BARCELONA	9406291727	37.8	-127.8
16	3EXX9	HANJIN BARCELONA	9406300046	36.3	-124.7
17	3EXX9	HANJIN BARCELONA	9406300327	35.8	-123.7
18	3EZJ9	BROOKLYN BRIDGE	9406300052	41.7	-137.4
19	3EZJ9	BROOKLYN BRIDGE	9406300327	41.3	-136.5
20	3EZJ9	BROOKLYN BRIDGE	9406301316	39.6	-132.2
21	3EZJ9	BROOKLYN BRIDGE	9406301546	39.1	-131.1
22	3EZJ9	BROOKLYN BRIDGE	9406301714	38.9	-130.2
23	3FFJ4	CENTURY HIGHWAY NO 1	9406271651	39.5	-140.1
24	3FFJ4	CENTURY HIGHWAY NO 1	9406271753	39.4	-140.2
25	3FGH3	NEWPORT BRIDGE	9406091640	38.1	-130.7
26	3FGH3	NEWPORT BRIDGE	9406091824	37.8	-129.8
27	3FGI3	EVER ROYAL	9406101618	38.6	-131.7
28	3FSB3	HANJIN PORTLAND	9406121745	42.8	-141.9
29	3FSI3	CALIFORNIA ORION	9406271753	38.7	-129.6
30	3FSI3	CALIFORNIA ORION	9406280116	37.6	-127
31	3FZI3	SCARLET SUCCESS	9406110124	34.5	-136.7
32	3FZI3	SCARLET SUCCESS	9406111348	34	-134.6
33	3FZI3	SCARLET SUCCESS	9406111557	33.7	-134.2
34	3FZI3	SCARLET SUCCESS	9406111753	33.6	-133.6
35	3FZI3	SCARLET SUCCESS	9406120112	32.9	-131.9
36	3FZI3	SCARLET SUCCESS	9406121336	31.7	-129.3
37	3FZI3	SCARLET SUCCESS	9406121535	31.5	-128.7

Corr Number	Call Sign	Ship Name	DTG (yymmddhhmm)	Latitude (N)	Longitude (W)
38	3FZI3	SCARLET SUCCESS	9406121745	31.2	-128.3
39	3FZI3	SCARLET SUCCESS	9406130054	30.4	-126.7
40	3FZI3	SCARLET SUCCESS	9406131323	28.6	-124.2
41	3FZI3	SCARLET SUCCESS	9406131513	28.6	-123.6
42	3FZI3	SCARLET SUCCESS	9406140047	27.6	-121.4
43	4XGR	ZIM AMERICA	9406271651	39.5	-132.1
44	4XGR	ZIM AMERICA	9406271753	39.3	-131.7
45	4XGR	ZIM AMERICA	9406280116	38.3	-129
46	4XGR	ZIM AMERICA	9406280231	38	-128.5
47	4XGR	ZIM AMERICA	9406281629	35.8	-123.7
48	4XGR	ZIM AMERICA	9406281740	35.6	-123.3
49	4XGV	ZIM JAPAN	9406091640	33.2	-128.2
50	4XGV	ZIM JAPAN	9406091824	33.2	-128.8
51	4XGV	ZIM JAPAN	9406101400	32.2	-136.1
52	4XGV	ZIM JAPAN	9406101618	32.1	-137
53	4XIL	ZIM SAVANNAH	9406210102	33.5	-127.8
54	7JOB	CALIFORNIA CERES	9406181645	44.6	-147.8
55	7JOB	CALIFORNIA CERES	9406181808	44.6	-147.2
56	7KFY	GLOBAL HIGHWAY	9406281629	35.6	-124.6
57	7KFY	GLOBAL HIGHWAY	9406281740	35.7	-125.1
58	7KFY	GLOBAL HIGHWAY	9406291328	37.8	-131.7
59	7KFY	GLOBAL HIGHWAY	9406291608	37.8	-132.5
60	7KFY	GLOBAL HIGHWAY	9406291727	38.1	-133.1
61	7LHH	CENTURY LEADER NO 1	9406261806	36	-141.7
62	7LHH	CENTURY LEADER NO 1	9406280116	32.7	-131.5
63	7LHH	CENTURY LEADER NO 1	9406281740	30.6	-126.6
64	7LHH	CENTURY LEADER NO 1	9406291438	27.8	-120.3
65	7LHH	CENTURY LEADER NO 1	9406291608	27.6	-120
66	7LHH	CENTURY LEADER NO 1	9406291727	27.4	-119.6
67	8JNP	CENTURY HIGHWAY NO 3	9406131653	33	-127.7
68	8JNP	CENTURY HIGHWAY NO 3	9406140047	31.7	-125.2
69	8JNP	CENTURY HIGHWAY NO 3	9406141311	29.6	-121.4
70	8JNP	CENTURY HIGHWAY NO 3	9406141632	29	-120.4
71	8JNP	CENTURY HIGHWAY NO 3	9406141720	28.9	-120.2
72	9VYK	CALIFORNIA GALAXY	9406121336	38.3	-126.6
73	9VYK	CALIFORNIA GALAXY	9406121535	38.4	-127.2
74	9VYK	CALIFORNIA GALAXY	9406121745	38.5	-128.1

Corr Number	Call Sign	Ship Name	DTG (yymmddhhmm)	Latitude (N)	Longitude (W)
75	A8GJ	PRINCE OF TOKYO	9406121535	36.1	-124.4
76	A8GJ	PRINCE OF TOKYO	9406121745	35.9	-123.9
77	BMEJ	OOCL FAME	9406301546	42	-134
78	BMEJ	OOCL FAME	9406301714	41.9	-133.4
79	BOAB	TAI HE	9406251818	42.6	-140.7
80	BOAB	TAI HE	9406261405	40.3	-133.4
81	BOAB	TAI HE	9406261806	39.8	-132.1
82	BOAB	TAI HE	9406270129	38.8	-129.3
83	BOAB	TAI HE	9406270252	38.4	-128.8
84	BOAB	TAI HE	9406271353	36.6	-125.3
85	BOAB	TAI HE	9406271511	36.5	-124.9
86	BOAB	TAI HE	9406271651	36.3	-124.4
87	BOAB	TAI HE	9406271753	36.1	-124.2
88	BOAB	TAI HE	9406280116	34.9	-122.1
89	C6LY4	BRISBANE STAR	9406020333	26.5	-126.3
90	D5NZ	POLYNESIA	9406031530	29.1	-127.6
91	D5NZ	POLYNESIA	9406031801	28.6	-127.9
92	D9MX	HANJIN SAVANNAH	9406271753	33.5	-133.1
93	D9MX	HANJIN SAVANNAH	9406280116	34.4	-135.7
94	DJNN	NED LLOYD SINGAPORE	9406141311	29	-130
95	DJNN	NED LLOYD SINGAPORE	9406141632	29.2	-130.8
96	DJNN	NED LLOYD SINGAPORE	9406141720	29.3	-131.1
97	ELBX3	PACKING	9406231704	24.7	-132.5
98	ELED7	PACPRINCE	9406141311	26.5	-125.4
99	ELED7	PACPRINCE	9406141632	26.8	-124.9
100	ELED7	PACPRINCE	9406141720	27.1	-124.7
101	ELFV2	OOCL FAIR	9406301316	35.6	-127.3
102	ELFV2	OOCL FAIR	9406301546	35.9	-128.3
103	ELFV2	OOCL FAIR	9406301714	36	-128.9
104	ELFV8	OOCL FIDELITY	9406091413	37.6	-126.4
105	ELFV8	OOCL FIDELITY	9406091640	38.2	-127.2
106	ELFV8	OOCL FIDELITY	9406091824	38.6	-127.8
107	ELFV8	OOCL FIDELITY	9406092357	39.9	-129.7
108	ELJO8	ALLIGATOR PRIDE	9406101618	37.1	-130
109	ELJT7	ORION HIGHWAY	9406011606	28	-123.9
110	ELJT7	ORION HIGHWAY	9406020333	29.5	-127.3
111	ELJT7	ORION HIGHWAY	9406021551	31.1	-131.1

Corr Number	Call Sign	Ship Name	DTG (yymmddhhmm)	Latitude (N)	Longitude (W)
112	ELKD6	OCEAN HIGHWAY	9406080020	23.4	-115.8
113	ELKD	CONVEYOR	9406131323	29	-125.6
114	ELKD	CONVEYOR	9406131513	29.1	-126.3
115	ELKD	CONVEYOR	9406131653	29.4	-126.9
116	ELKD	CONVEYOR	9406140047	29.5	-128.9
117	ELKD	CONVEYOR	9406141311	29.9	-132.3
118	ELKD	CONVEYOR	9406141720	29.8	-133.5
119	ELKD	CONVEYOR	9406150035	29.9	-135.7
120	ELKD	CONVEYOR	9406150351	30.1	-136.5
121	ELND4	SAN MARCOS	9406141720	21.7	-126.3
122	HPPK	GLORIA PEAK	9406121535	32.2	-132.5
123	HPPK	GLORIA PEAK	9406121745	32	-132.1
124	HPPK	GLORIA PEAK	9406130054	31.3	-130.1
125	HPPK	GLORIA PEAK	9406131323	29.8	-127.2
126	HPPK	GLORIA PEAK	9406131513	29.7	-126.6
127	HPPK	GLORIA PEAK	9406131653	29.7	-126.3
128	HPPK	GLORIA PEAK	9406140047	28.9	-124
129	HPPK	GLORIA PEAK	9406141311	27.8	-120.3
130	HPPK	GLORIA PEAK	9406141632	27.5	-119.5
131	JBCN	CAPE MAY	9406171821	45.8	-147.3
132	JBCN	CAPE MAY	9406181808	41	-140.6
133	JFKC	GINGA MARU	9406280116	40	-135.9
134	JGPN	CALIFORNIA MERCURY	9406091413	38.6	-130.4
135	JGPN	CALIFORNIA MERCURY	9406091640	38.2	-129.3
136	JGPN	CALIFORNIA MERCURY	9406091824	38	-128.5
137	JKLS	HENRY HUDSON BRIDGE	9406251818	42.6	-148
138	JKOW	HERCULES HIGHWAY	9406131653	33.1	-128.4
139	JKOW	HERCULES HIGHWAY	9406140047	31.8	-125.9
140	JKOW	HERCULES HIGHWAY	9406141311	29.8	-122.1
141	JKOW	HERCULES HIGHWAY	9406141632	29.2	-121
142	JKOW	HERCULES HIGHWAY	9406141720	29.1	-120.9
143	JKOW	HERCULES HIGHWAY	9406150035	27.9	-118.8
144	JKOW	HERCULES HIGHWAY	9406151610	24.8	-114.5
145	JKOW	HERCULES HIGHWAY	9406151707	24.7	-114.4
146	JPAQ	NYK SUNRISE	9406291608	40.8	-135.9
147	JPAQ	NYK SUNRISE	9406291727	40.7	-135.4
148	JPAQ	NYK SUNRISE	9406300046	39.6	-132.3

Corr Number	Call Sign	Ship Name	DTG (yymmddhhmm)	Latitude (N)	Longitude (W)
149	JPAQ	NYK SUNRISE	9406301546	36.8	-126.1
150	JPAQ	NYK SUNRISE	9406301714	36.6	-125.6
151	KHRC	MATSONIA	9406120112	34.8	-132
152	KJDG	TONSINA	9406301546	39.6	-134.2
153	KJDG	TONSINA	9406301714	39.9	-133.8
154	KNIJ	MANULANI	9406121336	31.5	-128.1
155	KNIJ	MANULANI	9406121535	31.4	-128.9
156	KNIJ	MANULANI	9406121745	31.1	-129.7
157	KNIJ	MANULANI	9406130054	30.5	-132.6
158	KNIJ	MANULANI	9406131323	29.2	-137.5
159	KSFK	KEYSTONE CANYON	9406081522	34.7	-125.9
160	KSFK	KEYSTONE CANYON	9406081656	35.1	-125.9
161	LACP4	DIRECT KIWI	9406040109	32.3	-139.7
162	LADB2	SKAUGRAN	9406101400	39	-130.4
163	LADB2	SKAUGRAN	9406101618	38.7	-129.7
164	MQWA5	LONDON ENTERPRISE	9406071543	25.9	-114.3
165	OULL2	MARIE MAERSK	9406130054	39.3	-141.3
166	OUSH2	MAGLEBY MAERSK	9406261806	41.5	-138.7
167	OUSH2	MAGLEBY MAERSK	9406270129	42.1	-141.9
168	OXIT2	ANDERS MAERSK	9406131513	34.5	-124.1
169	OXIT2	ANDERS MAERSK	9406131653	34.6	-124.6
170	OXIT2	ANDERS MAERSK	9406151846	28.2	-140.3
171	OYKS2	ANNA MAERSK	9406201743	34.5	-122.3
172	PGAF	MONTERREY	9406011606	36.3	-122.4
173	PGLA	OAXACA	9406171821	27.6	-139.6
174	PJLS	JO OAK	9406071543	24.2	-120.1
175	S6BO	STAR LIVORNO	9406291608	36.7	-125.2
176	S6BO	STAR LIVORNO	9406291727	36.8	-125.5
177	S6BO	STAR LIVORNO	9406300052	37.6	-127.3
178	S6BO	STAR LIVORNO	9406301316	38.9	-130.6
179	S6BO	STAR LIVORNO	9406301714	39.5	-131.5
180	V7AF	MERCURY	9406011606	27	-123.8
181	VRCV	OOCL FREEDOM	9406091640	41.3	-132.2
182	VRCV	OOCL FREEDOM	9406091824	41.2	-131.7
183	VRCV	OOCL FREEDOM	9406092357	40.3	-129.8
184	VRUC6	OOCL FRONTIER	9406151846	45.4	-142.6
185	WBWK	MOKU PAHU	9406121745	37.3	-123.6

Corr Number	Call Sign	Ship Name	DTG (yymmddhhmm)	Latitude (N)	Longitude (W)
186	WBWK	MOKU PAHU	9406150035	30.8	-136.6
187	WBWK	MOKU PAHU	9406150351	30.4	-137.4
188	WCHF	SEA-LAND CONSUMER	9406121336	31.2	-129.4
189	WCHF	SEA-LAND CONSUMER	9406121535	31	-130.2
190	WCHF	SEA-LAND CONSUMER	9406121745	30.8	-131
191	WCHF	SEA-LAND CONSUMER	9406130054	30.1	-134.1
192	WCHF	SEA-LAND CONSUMER	9406131323	28.6	-139.5
193	WFLH	SEA-LAND RELIANCE	9406101618	34.5	-132.4
194	WGJC	SEA-LAND INDEPENDENCE	9406111348	38.2	-129.3
195	WGJC	SEA-LAND INDEPENDENCE	9406111557	37.9	-128.3
196	WGJC	SEA-LAND INDEPENDENCE	9406111758	37.4	-127.7
197	WGJT	KAIMOKU	9406050057	32.6	-122.6
198	WLVD	LURLINE	9406271753	34.6	-132.2
199	WNRD	PRESIDENT MONROE	9406111348	33.6	-136
200	WNRD	PRESIDENT MONROE	9406111557	33.2	-137.1
201	WNRD	PRESIDENT MONROE	9406111758	32.9	-137.7
202	WRJP	R. J. PFIEFER	9406091824	31.5	-140.3
203	WRJP	R. J. PFIEFER	9406151846	38.3	-141.2
204	WRYW	PRESIDENT ADAMS	9406241616	36.9	-126.8
205	WRYW	PRESIDENT ADAMS	9406241651	36.8	-126.6
206	WRYW	PRESIDENT ADAMS	9406241831	36.5	-126
207	WSLH	MAUI	9406121535	32.2	-124.5
208	WSLH	MAUI	9406121745	32.3	-123.8
209	WSLH	MAUI	9406130054	32.6	-121.5

APPENDIX B. SEPARATION DATA

Corr Number	Ship Name	Ship Type	DTG (yymmddhhmm)	SB/RWD [AVG]	SD [NM]	RWS [KTS]
1	TOLUCA	Dsl	9406221519	303	10.4	26.4
3	NIPPON HIGHWAY	Dsl	9406271753	333	10.5	30.8
7	KURAMA	Dsl	9406121336	281	16	37.2
8	KURAMA	Dsl	9406121535	276	13.1	37.2
10	CANADIAN HIGHWAY	Dsl	9406271651	42	8.1	22.1
13	HANJIN BARCELONA	Dsl	9406291328	46	6	15.7
14	HANJIN BARCELONA	Dsl	9406291608	51	7.5	18.4
15	HANJIN BARCELONA	Dsl	9406291727	77	1.8	18.3
25	NEWPORT BRIDGE	Dsl	9406091640	66	9.7	26.1
27	EVER ROYAL	Dsl	9406101618	95	6	31.7
29	CALIFORNIA ORION	Dsl	9406271753	93	7.3	23.7
43	ZIM AMERICA	Dsl	9406271651	71	5.2	23.4
44	ZIM AMERICA	Dsl	9406271753	84	5.1	23.3
46	ZIM AMERICA	Dsl	9406280231	15	6.2	26.6
47	ZIM AMERICA	Dsl	9406281629	34	3.8	14.4
48	ZIM AMERICA	Dsl	9406281740	38	5	14.3
49	ZIM JAPAN	Dsl	9406091640	319	18.3	29.4
50	ZIM JAPAN	Dsl	9406091824	316	12	26.7
51	ZIM JAPAN	Dsl	9406101400	301	5.9	14.5
55	CALIFORNIA CERES	Dsl	9406181808	79	8.8	16.2
56	GLOBAL HIGHWAY	Dsl	9406281629	336	6.9	35.3
57	GLOBAL HIGHWAY	Dsl	9406281740	338	5.7	35.2
58	GLOBAL HIGHWAY	Dsl	9406291328	313	6.3	26.6
60	GLOBAL HIGHWAY	Dsl	9406291727	326	9.2	30.6
61	CENTURY LEADER NO 1	Dsl	9406261806	84	7.3	27.3
62	CENTURY LEADER NO 1	Dsl	9406280116	83	11.1	24.6
63	CENTURY LEADER NO 1	Dsl	9406281740	73	9.1	26.3
68	CENTURY HIGHWAY NO 3	Dsl	9406140047	53	9.5	18.5
69	CENTURY HIGHWAY NO 3	Dsl	9406141311	67	4.5	14.1
71	CENTURY HIGHWAY NO 3	Dsl	9406141720	105	3.3	13.1
74	CALIFORNIA GALAXY	Dsl	9406121745	278	14.8	33.2
75	PRINCE OF TOKYO	Dsl	9406121535	333	3.3	14
76	PRINCE OF TOKYO	Dsl	9406121745	343	4	13.9
78	OOCL FAME	Stm	9406301714	57	3.5	13.8
79	TAI HE	Dsl	9406251818	53	7.8	13.8
81	TAI HE	Dsl	9406261806	67	9	9.9
87	TAI HE	Dsl	9406271753	45	4.6	10
92	HANJIN SAVANNAH	Dsl	9406271753	287	6.1	38.4
93	HANJIN SAVANNAH	Dsl	9406280116	316	8.8	36

Corr Number	Ship Name	Ship Type	DTG (yymmddhhmm)	SB/RWD [AVG]	SD [NM]	RWS [KTS]
95	NED LLOYD SINGAPORE	Dsl	9406141632	340	14.6	24.6
96	NED LLOYD SINGAPORE	Dsl	9406141720	345	14.3	24.5
98	PACPRINCE	Dsl	9406141311	47	6.9	29.8
100	PACPRINCE	Dsl	9406141720	30	15.7	29.7
101	OOCL FAIR	Dsl	9406301316	327	14	33.6
102	OOCL FAIR	Dsl	9406301546	322	10.3	33.5
103	OOCL FAIR	Dsl	9406301714	324	10.8	33.4
108	ALLIGATOR PRIDE	Dsl	9406101618	64	2.2	25.5
109	ORION HIGHWAY	Dsl	9406011606	342	14.7	28.3
111	ORION HIGHWAY	Dsl	9406021551	299	5.8	16.5
114	CONVEYOR	Stm	9406131513	341	19.7	23.5
116	CONVEYOR	Stm	9406140047	322	18	24.9
117	CONVEYOR	Stm	9406141311	324	18.4	16.6
121	SAN MARCOS	Dsl	9406141720	329	6	21.2
123	GLORIA PEAK	Dsl	9406121745	77	6.7	16.8
124	GLORIA PEAK	Dsl	9406130054	86	6.6	14.3
128	GLORIA PEAK	Dsl	9406140047	67	10	8.8
133	GINGA MARU	Dsl	9406280116	83	15.6	19.1
134	CALIFORNIA MERCURY	Dsl	9406091413	77	17.9	17
135	CALIFORNIA MERCURY	Dsl	9406091640	63	11.4	16.4
136	CALIFORNIA MERCURY	Dsl	9406091824	63	8.4	15.6
139	HERCULES HIGHWAY	Dsl	9406140047	67	8.4	8
140	HERCULES HIGHWAY	Dsl	9406141311	29	2.9	16.8
145	HERCULES HIGHWAY	Dsl	9406151707	86	10	15.2
147	NYK SUNRISE	Dsl	9406291727	66	4.7	18.2
148	NYK SUNRISE	Dsl	9406300046	86	9.4	18.2
149	NYK SUNRISE	Dsl	9406301546	53	5.6	20.1
150	NYK SUNRISE	Dsl	9406301714	76	5.7	20
152	TONSINA	Stm	9406301546	338	11.1	20.1
154	MANULANI	Stm	9406121336	325	10.9	14.6
155	MANULANI	Stm	9406121535	315	3.8	14.5
156	MANULANI	Stm	9406121745	313	6.3	14.3
157	MANULANI	Stm	9406130054	271	2.7	19.8
159	KEYSTONE CANYON	Stm	9406081522	347	11.5	28.6
160	KEYSTONE CANYON	Stm	9406081656	316	4	28.6
164	LONDON ENTERPRISE	Dsl	9406071543	345	8.8	32.5
165	MARIE MAERSK	Dsl	9406130054	257	2.9	37.1
171	ANNA MAERSK	Dsl	9406201743	293	6.7	34.1

Corr Number	Ship Name	Ship Type	DTG (yymmddhhmm)	SB/RWD [AVG]	SD [NM]	RWS [KTS]
175	STAR LIVORNO	Dsl	9406291608	353	12.1	42.5
176	STAR LIVORNO	Dsl	9406291727	348	15	42.5
177	STAR LIVORNO	Dsl	9406300052	342	14.4	28.7
178	STAR LIVORNO	Dsl	9406301316	345	15.7	28.4
179	STAR LIVORNO	Dsl	9406301714	321	11.2	28.8
184	OOCL FRONTIER	Stm	9406151846	109	4.2	12.4
185	MOKU PAHU	Dsl	9406121745	290	4.4	22.4
188	SEA-LAND CONSUMER	Stm	9406121336	288	7.4	27
189	SEA-LAND CONSUMER	Stm	9406121535	283	10	26.9
190	SEA-LAND CONSUMER	Stm	9406121745	287	15	25.7
191	SEA-LAND CONSUMER	Stm	9406130054	274	3.9	19.2
193	SEA-LAND RELIANCE	Stm	9406101618	291	6.3	12.6
194	SEA-LAND INDEPENDENCE	Dsl	9406111348	78	9.4	14
196	SEA-LAND INDEPENDENCE	Dsl	9406111758	43	8.6	14.5
197	KAIMOKU	Stm	9406050057	274	5.6	41
198	LURLINE	Stm	9406271753	42	9.9	31.1
199	PRESIDENT MONROE	Dsl	9406111348	287	3.6	14.8
201	PRESIDENT MONROE	Dsl	9406111758	250	2.8	13.3
202	R. J. PFEIFFER	Dsl	9406091824	214	17.7	12.3
203	R. J. PFEIFFER	Dsl	9406151846	348	4.9	23.7
205	PRESIDENT ADAMS	Dsl	9406241651	86	4.9	26.2
208	MAUI	Stm	9406121745	357	5	28.8

APPENDIX C. OPERATIONAL SURVEY

After an overview of shiptracks and MAST, the following questions were posed to CG personnel stationed at the Operations Centers of CG Pacifica Area (Alameda, CA), CG District Eleven (Long Beach, CA), and CG District Thirteen (Seattle, WA):

1. How useful would raw shiptrack data be to you (i.e., the location and DTG of a track without correlation to a ship name...we know someone is out there, but we don't know who)?

2. How useful would correlated location data be to you?

3. If it were possible to track a vessel thru successive satellite passes (e.g., every 1-3 hours) and to determine that it was not following a "normal" transit (e.g., not following great circle route, abnormal course/speed changes, etc.), would this be of interest to you?

4. How useful would information on an uncorrelated track be after correlation attempts fail (i.e., tracks exist for a ship but we cannot determine who made them after checking available databases)?

5. How likely is it that you would want to track a ship this way IN ADDITION TO other available means?

6. How likely is it that you would want to track a ship this way IN LIEU OF other available means?

7. How useful could shiptrack data of any kind be to you for:
   a. Maritime Law Enforcement?
   b. Search and Rescue?
   c. Other?

8. How accurate would you need a reported position to be for it to be considered useful?

9. How timely would you want shiptrack data to be for it to be considered useful?

10. Comments? Any comments you might have would be greatly appreciated.

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