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AUTOMATED DETECTION OF SHIP TRACKS IN MULTISPECTRAL SATELLITE DATA

PROGRESS REPORT #2

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Automated Detection of Ship Tracks

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A Objectives

The objectives of this work are to develop robust ship track detection methods, demonstrate their utility using satellite imagery, and design the framework of an automated ship track detection system for operational use.

Our approach is to (1) use geographical and multispectral information to reduce the data stream greatly based on contexts for which ship tracks are physically allowed; (2) optimally enhance satellite images using multispectral signals; (3) apply state-of-the-art edge-detection, dilation and erosion operators in order to find and enhance candidate ship tracks with weak signatures; (4) determine features or parameters that best characterize the higher reflectivity and curvilinearity of ship tracks; (5) apply rule-based and cluster analysis techniques to reduce the data stream to a limited number of subscenes with potential tracks; (6) apply state-of-the-art neural net and statistical discriminant analysis methods as final detection filters; (7) assess detection success and error rates; (8) develop a prototype design of the automated system. The algorithms used here are ones that have exhibited success on this or similar problems.

Other related objectives of this effort are to (1) provide a critical review of successful elements of existing ship track detection schemes and refined multispectral enhancement methods that optimize track signatures; (2) establish the best set of features that objectively characterize ship tracks; (3) demonstrate the utility of advanced clustering, statistical and neural net classifiers and describe how they can be incorporated in an automated detection package; and (4) provide methods to assess detection error rates so that the performance of the system may be measured and clearly reported to policy makers. This work will also benefit other detection procedures, either by addressing unresolved issues, or by providing a framework to combine promising elements of those procedures in a single automated system.

B Progress

B.1 Introduction

This report describes progress we have made in developing a system for automated detection of ship tracks. The algorithm analyzes multispectral digital image data acquired from the Advanced Very High Resolution Radiometers (AVHRR) aboard NOAA polar orbiting satellites. These images, both in the visible as well as near IR bands, contain characteristic signatures where ship effluents have enhanced the reflectivity of shallow marine layer clouds. The variability of meteorological conditions, combined with unknown ship track size, orientation and age provide a challenge for the design of a robust automated identification system.

Our approach for automated ship track identification proceeds in three distinct stages. The first stage consists of image enhancement of the AVHRR data. This preprocessing is detailed in Section B.2, which also includes examples of AVHRR images. Next is the cluster enumeration and feature calculation stage, as described in Section B.3, where potential ship tracks are isolated, processed and parameterized. The third stage then provides statistical classification analysis and probability assessment on the identified objects and their features, discriminating ship tracks from anomalous contrast variations. This statistical postprocessing stage is described in Section B.4. Here the probability assessment specifically addresses both success and error rates as applied to ship track detection using a database of known events. Progress to date has focused on the first two stages to quickly reduce the data stream significantly to a manageable number of potential ship track objects that can then be identified using state-of-the-art statistical classifiers.

On 21 January 1994, we briefed and provided a software demonstration to Prof. Phillip Durkee and Kurt Nielsen of the Naval Postgraduate School.

B.2 AVHRR Image Enhancement

Our shiptrack detection algorithm uses as input a matched set of three AVHRR images: the visible channel 1 data (0.63 μm ± 0.05 μm), the near IR channel 3 data (3.74 μm ± 0.19 μm), and the channel 4 temperature data (10.8 μm ± 0.5 μm). These files have 8-bit pixel values and are typically 2048 pixels wide, although any pixel depth and size will be usable. For a typical scan of 4320 lines the three images require almost 30 Mbytes of storage. Clearly computational efficiency is an issue.

Figures 1, 2, and 3 depict an interesting North Pacific scan of 1024x1280 pixels taken from larger images. While the visible data shown in Figure 1 displays cloud structure, the channel 3 data clearly accentuates the apparent shiptrack detail. The channel 4 data is used as a temperature mask, with black (pixel value 0) calibrated to T=262K and white (pixel value 255) calibrated to T=313K. For example, Figure 4 illustrates a mask which excludes pixels with temperatures outside the interval 270K-290K. This clearly masks the land mass and is useful in the absence of geographical reference information on the satellite image location. In general, geographical information will be available and used. Further use of channel 4 data is described below.

Image Thresholding

The temperature mask, as illustrated in Figure 4, can be applied to the channel 3 data to remove the land mass. The resultant pixmap is then enhanced by removing a smoothed background created from boxcar averaging of the image. Typically, a 31x31 window is used for this smoothing. At this point, the (8-bit deep) pixmap is converted to a (1-bit deep) bitmap by intensity thresholding. A cutoff, somewhere between the top 5% and the top 15% of the intensity histogram, is chosen to be imaged onto the bitmap. Selection of this parameter depends upon the apparent level of detail contained in the image. Feedback from the following cluster enumeration operation is used to adjust the intensity thresholding parameter if necessary. Figure 5 depicts a 9% threshold of the temperature-masked channel 3 sample data.

Figure 1. AVHRR channel 1 8-bit 1024x1280 image.

Figure 2. AVHRR channel 3 8-bit 1024x1280 image.

Figure 3. AVHRR channel 4 8-bit 1024x1280 image.

Figure 4. Temperature mask of 1024x1280 channel 4 image.

Figure 5. Temperature masked and 9% thresholded bitmap image.

Angular Convolution

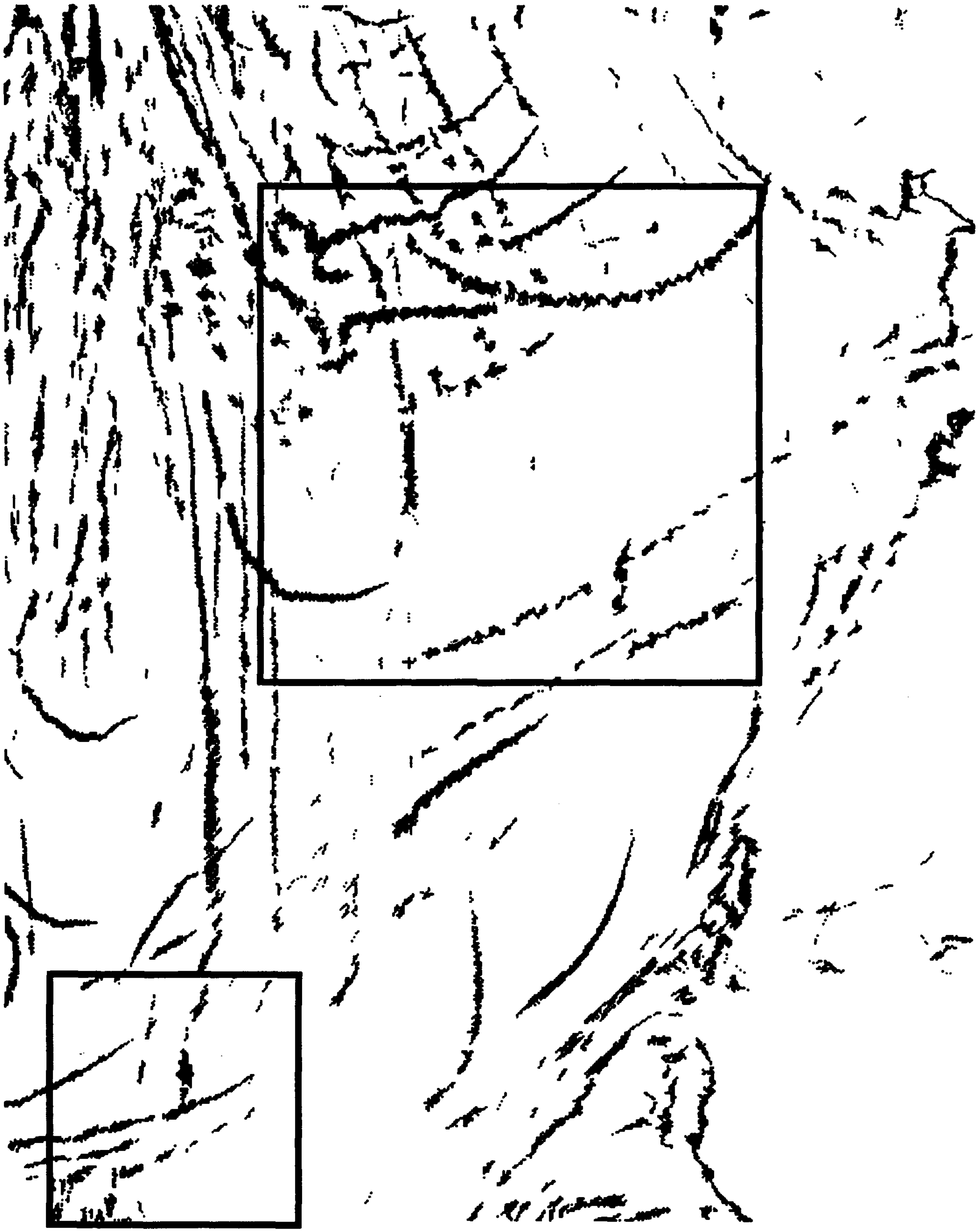
The next step of image preprocessing is a convolution of the data with a set of linear kernels. Note the significant amount of random noise present in the thresholded image of Figure 5. Potentially interesting ship tracks have linear components on a scale of, say, 10 km or more. The purpose of the convolution is to filter out active pixel regions which have no linear component on a scale of at least 10 pixels, thereby improving the ship track signal-to-noise ratio and enhancing the remaining curvilinear objects present in the bitmap.

To accomplish this convolution, a set of NxN kernels is constructed representing single-pixel-width straight lines passing through the origin at every discrete angle. Using N=11, there are 49 such unique kernels in the set. Successively applying each kernel, we first *erode* the image and then *dilate* the result. These operations represent line thinning and thickening, respectively, with respect to the structure of the kernel. The kernels are applied on a sliding window across the full image, and the *union* of this dilate/erode operation comprises the convolved image. Consequently any orientation angle feature will survive as long as a linear component greater than 10 pixels exists.

Figure 6 depicts the convolved image for the 1024x1280 subscene in our example. In comparison with Figure 5, the reduced noise content is obvious while the ship track structures appear intact. This convolution has the added advantage of being computationally efficient.

Note that some of the coastline structure has survived along the right hand portion of the image. In addition, the far upper left region of the image appears to be obscured by cloud structure. The feature analysis stage, as described in the next section, will be responsible for discriminating this remaining coastline and cloud structure from the desired ship tracks. To do this, channel 1 visible data and channel 4 temperature data will be analyzed.

Figure 6. Angular convolution of 1024x1280 bitmap image.



B.3 Feature Analysis

The previous processing steps have converted the original channel 3 8-bit pixmap into a binary image or bitmap, removed geographical regions for which ship tracks are infeasible, and filtered out elements of the bitmap that do not possess linear structure consistent with that of ship tracks. This results in a bitmap which retains the ship tracks while greatly enhancing the signal-to-noise and simplifying the remaining structure to be further analyzed.

The next processing task is region enumeration. Rather than compute properties of individual pixels, groups of connected pixels are formed which break the entire image into disjoint regions. This reduces the number of objects for which detailed properties are computed by several orders of magnitude. Neighboring regions of every object can be examined to determine if they belong together or require further decomposition. This analysis is motivated by the fact that low thresholds may yield combined regions in the bitmap that are physically distinct in the original image or multiple ship tracks may intersect, resulting in complicated bitmap objects that require decomposition before attempting to classify. Alternatively, if the threshold is set too high or the cloud field is broken, a ship track may appear in the bitmap as a set of piecewise collinear regions which need to be joined together. This analysis, in fact, provides a feedback mechanism with which to adjust the intensity threshold.

Region Enumeration

Region enumeration is designed to identify all disjoint regions that comprise the entire image. Neighboring pixels (i.e., lying in any one of eight adjacent pixels), both with value 1 in the bitmap, are considered members of the same region. Any two distinct regions may not have any such neighbors.

The number of enumerated disjoint regions ranges from one to one-fourth of the number of pixels in the image. The channel 3 intensity threshold set above controls the number of regions and their average size. The enumerated regions must be large enough to contain linear components of some useful size, perhaps 10 km, yet small enough so that multiple ship tracks are disconnected. In this regard, it is more efficient to limit region sizes to smaller levels, since it is easier to combine multiple disjoint regions of ship tracks that display a piecewise linear character.

Once regions are initially enumerated, preliminary *features* are computed for each. Computed are the region's area, center of gravity, length, width, orientation angle, aspect ratio, two nearest neighbors and their relative distances. The number of regions and their features are re-computed after the chunk decomposition and linear recombination stages.

Figure 7 expands the 256x256 subsection identified in the lower left corner of Figure 6. This particular subsection has been thresholded at 7% and exactly 22 disjoint regions are present. The areas of the initially enumerated regions range from 21 to 626 pixels, with lengths ranging from 15 to 109 pixels. Many of these disjoint regions will be combined in the following analyis. Figure 8 shows the six ship tracks which ultimately survive.

Feature Calculation and Cluster Categoration

The aspect ratio of the disjoint regions (which we also refer to as objects) is a particularly useful feature for discriminating components of ship tracks from other objects. To estimate the aspect ratio of a region, we use the 2D moment of intertia taken about its center of gravity. The aspect ratio is given by the square root of the ratio of minimum-to-maximum intertia eigenvalues. In addition, the orientation angle of the object is estimated from the 2D eigenvector rotation angle.

Regions are categorized into clusters. Large objects having sizeable aspect ratios, perhaps > 0.35 with area > 5000, are identified as *chunks*. Those objects with sizeable aspect ratios which fail the large area test are identified as *blobs*. Objects with linear-like aspect ratios having short lengths, perhaps < 50 pixels, are called *stubs*. The remaining objects constitute potentially interesting curvilinear regions.

Figure 7. 256x256 subsection of image thresholded at 7%.

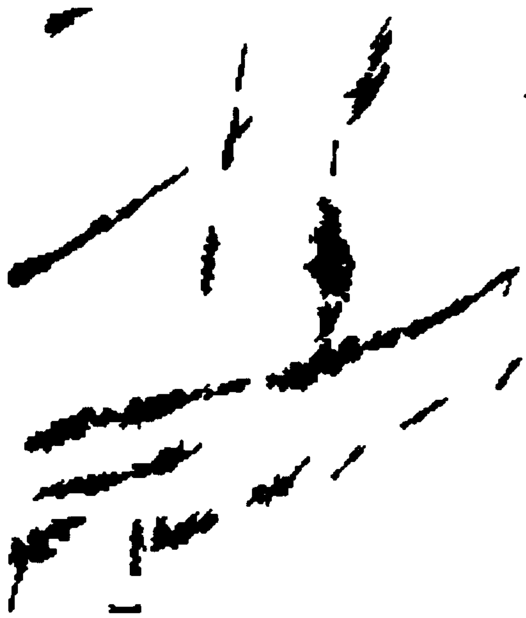


Figure 8. Ship tracks identified from 256x256 subsection.

Physically, coastlines exhibit a fractal-like structure and are thus generally enumerated into multiple short regions or stubs. If these regions are allowed to become interconnected, perhaps by inefficient thresholding of the image, they can appear to be jagged piecewise-linear segments. This is exhibited somewhat in the lower right portion of Figure 5. In severely under-thresholded cases, coastline will appear to be one or more chunks.

Cloud cover can break ship tracks into multiple disjoint objects as well. The image processing stage must be able to reconstruct piecewise-linear segments from so many disjoint components. This we will call collinear recombination. Additionally, ship tracks may spread and/or weaken significantly with age, hence the aspect ratios of the individual disjoint component regions may appear as blobs.

Chunk Decombobulation

Large chunks, whether from semifragmented coastline or from connected linear elements of multiple ship tracks, must be either eliminated or decomposed into more fundamental objects. If too many chunks are present in the thresholded bitmap, the image should be re-thresholded at a lower intensity cutoff. Otherwise, chunks can be decomposed into smaller objects. This is done by computing the mean number of nearest neighbors for the region and choosing a zeroing level less than this mean. Pixels which have fewer neighbors than the zeroing level are zeroed, and the chunk is re-enumerated. The process is repeated (rarely necessary) until the decomposed objects contain no chunks.

Figure 9 represents an 11% thresholded subsection of Figure 2. This subsection is a 512x512 cut taken from the top central portion of the larger image, as indicated by the larger box displayed within Figure 6, specifically containing the large (about 400 pixels in length) parabolic ship track near the top of the cut. Here the increased thresholding level has created a chunk immediately to the left of the noted parabolic track. The chunk appears as an "H" on its side, has an area of 5581 pixels, and the mean number of nearest neighbors 6.26. This chunk is decombobulated by zeroing all pixels with less than 6 nearest neighbors. The net effect is to break the "H" into

Figure 9. 11% thresholded 512x512 subsection.

Figure 10. Potential ship tracks identified from 512x512 subsection.

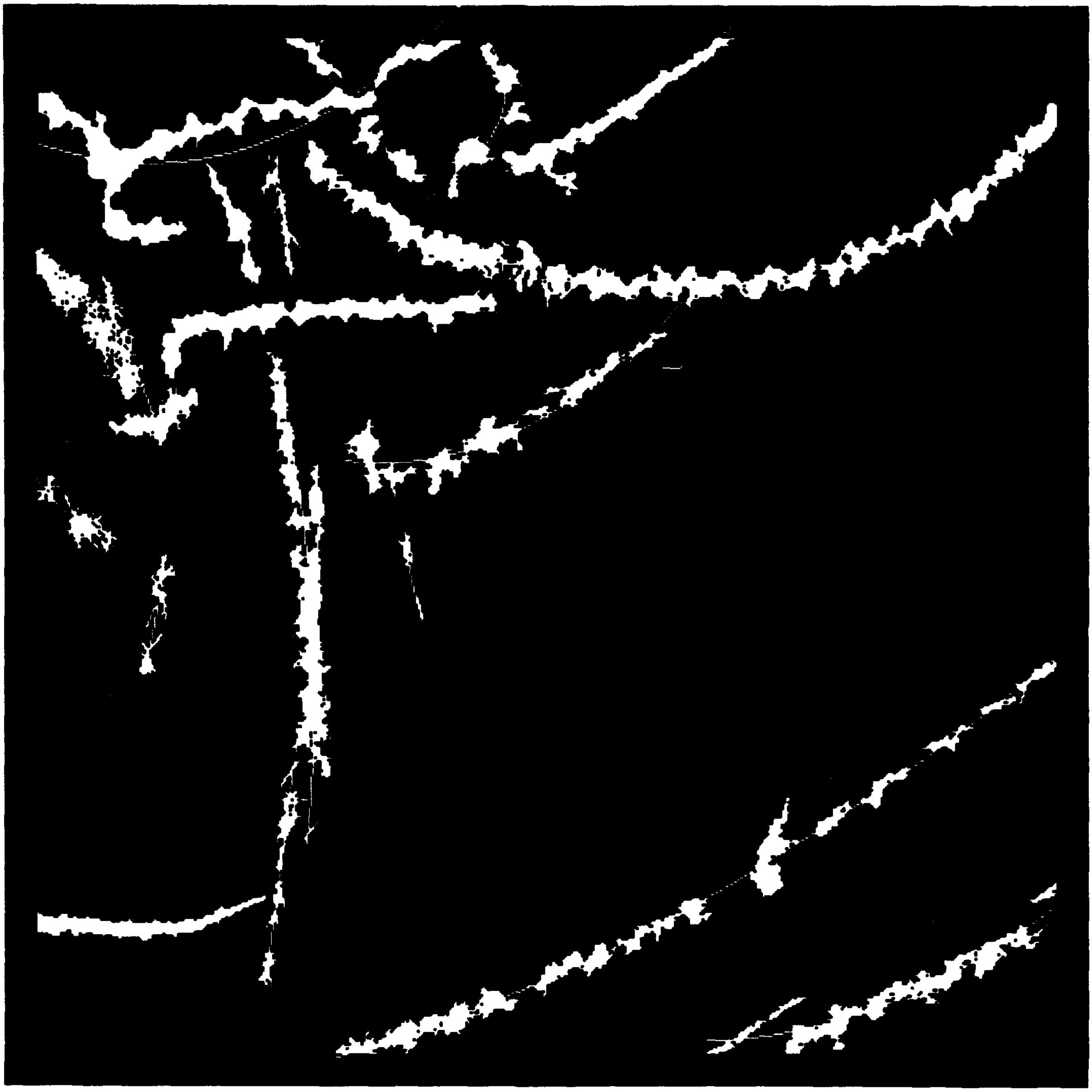


Table 1: Features of 68 Objects Identified from 512x512 Subsection.

```
Region Size Analysis for  68 features:
                 20   50  100  200  500 1000 2000 5000
                  9   15   15    4   12    4    8    1     0

 16 Blobs
... r#  58 Area  453 <X>  72 <Y> 193 Asp 0.386 Ang  25 Len  48 nn#  57 Dist  15
... r#  11 Area  302 <X> 359 <Y> 442 Asp 0.399 Ang  76 Len  41 nn#  17 Dist  11
... r#  63 Area  264 <X> 219 <Y> 171 Asp 0.416 Ang -47 Len  38 nn#  54 Dist  14
... r#  93 Area  201 <X>  77 <Y>  24 Asp 0.852 Ang -64 Len  28 nn#  97 Dist  39
... r#  76 Area  185 <X> 275 <Y> 106 Asp 0.470 Ang -40 Len  27 nn#  73 Dist  22
... r#  89 Area  145 <X> 213 <Y>  48 Asp 0.455 Ang -56 Len  24 nn#  79 Dist  10
... r#  87 Area  116 <X> 393 <Y>  57 Asp 0.571 Ang  43 Len  20 nn#  78 Dist  26
... r#   2 Area   93 <X>  33 <Y> 491 Asp 0.666 Ang   4 Len  18 nn#  13 Dist  53
... r#   8 Area   73 <X> 123 <Y> 456 Asp 0.418 Ang  80 Len  19 nn#  18 Dist   9
... r#  40 Area   69 <X> 269 <Y> 299 Asp 0.368 Ang  89 Len  22 nn#  38 Dist   9
... r#  28 Area   65 <X> 467 <Y> 354 Asp 0.779 Ang  15 Len  16 nn#  32 Dist   7
... r#  45 Area   62 <X> 231 <Y> 271 Asp 0.639 Ang -15 Len  16 nn#  48 Dist  23
... r#  44 Area   61 <X>  17 <Y> 276 Asp 0.485 Ang  83 Len  15 nn#  47 Dist  36
... r#  29 Area   60 <X> 175 <Y> 344 Asp 0.546 Ang -75 Len  21 nn#  27 Dist  33
... r#  23 Area   57 <X> 422 <Y> 389 Asp 0.394 Ang -80 Len  16 nn#  26 Dist  15
... r#  39 Area   51 <X> 214 <Y> 304 Asp 0.352 Ang -69 Len  16 nn#  46 Dist  15

 31 Short features
... r#  17 Area  412 <X> 362 <Y> 403 Asp 0.326 Ang  76 Len  48 nn#  11 Dist  11
... r#  85 Area  218 <X> 337 <Y>  70 Asp 0.256 Ang  10 Len  44 nn#  82 Dist   3
... r#  77 Area  100 <X> 349 <Y>  91 Asp 0.137 Ang  63 Len  41 nn#  85 Dist   4
... r#  56 Area   98 <X> 416 <Y> 205 Asp 0.184 Ang -55 Len  40 nn#  50 Dist   8
... r#  90 Area   67 <X> 335 <Y>  48 Asp 0.296 Ang  86 Len  20 nn#  88 Dist  10
... r#  82 Area   54 <X> 311 <Y>  81 Asp 0.242 Ang  40 Len  18 nn#  85 Dist   3
... r#  33 Area   54 <X>  40 <Y> 330 Asp 0.304 Ang -77 Len  18 nn#  42 Dist  27
... r#  25 Area   50 <X> 307 <Y> 382 Asp 0.218 Ang  52 Len  23 nn#  20 Dist  21
... r#  57 Area   49 <X>  33 <Y> 203 Asp 0.766 Ang  34 Len  15 nn#  58 Dist  15
... r#  50 Area   46 <X> 426 <Y> 231 Asp 0.250 Ang  69 Len  17 nn#  56 Dist   8
... r#  88 Area   45 <X> 320 <Y>  54 Asp 0.195 Ang -67 Len  18 nn#  90 Dist  10
... r#  49 Area   44 <X> 249 <Y> 236 Asp 0.727 Ang  11 Len  20 nn#  48 Dist  17
... r#  21 Area   40 <X> 477 <Y> 394 Asp 0.391 Ang  66 Len  19 nn#   5 Dist  28
... r#  55 Area   36 <X> 351 <Y> 224 Asp 0.476 Ang  32 Len  18 nn#  66 Dist  57
... r#  66 Area   34 <X> 391 <Y> 168 Asp 0.432 Ang -78 Len  15 nn#  56 Dist  16
... r#  71 Area   33 <X> 491 <Y> 127 Asp 0.137 Ang -54 Len  19 nn#  72 Dist  77
... r#  78 Area   33 <X> 379 <Y>  94 Asp 0.246 Ang  90 Len  17 nn#  87 Dist  26
... r#  32 Area   32 <X> 478 <Y> 347 Asp 0.244 Ang -10 Len  15 nn#  28 Dist   7
... r#  64 Area   30 <X>  19 <Y> 174 Asp 0.699 Ang  57 Len  15 nn#  57 Dist  28
... r#  83 Area   28 <X>  16 <Y>  79 Asp 0.208 Ang -85 Len  14 nn#  99 Dist  27
... r#  38 Area   27 <X> 282 <Y> 309 Asp 0.172 Ang  27 Len  17 nn#  40 Dist   9
... r#  20 Area   26 <X> 276 <Y> 400 Asp 0.363 Ang   8 Len  14 nn#  25 Dist  21
... r#  36 Area   20 <X>  88 <Y> 311 Asp 0.127 Ang -63 Len  16 nn#  42 Dist  16
... r#  10 Area   15 <X> 189 <Y> 458 Asp 0.109 Ang  85 Len  15 nn#   9 Dist  44
... r#  48 Area   13 <X> 253 <Y> 254 Asp 0.092 Ang   4 Len  14 nn#  49 Dist  17
... r#  15 Area   13 <X> 144 <Y> 422 Asp 0.073 Ang  58 Len  16 nn#  18 Dist  16
... r#  22 Area   13 <X> 143 <Y> 392 Asp 0.068 Ang  52 Len  15 nn#  18 Dist  18
... r#  19 Area   13 <X> 395 <Y> 403 Asp 0.108 Ang  83 Len  13 nn#  26 Dist  13
... r#   9 Area   11 <X> 144 <Y> 458 Asp 0.000 Ang   0 Len  13 nn#   8 Dist  22
... r#  31 Area   11 <X> 250 <Y> 348 Asp 0.080 Ang -12 Len  13 nn#  38 Dist  42
... r#  75 Area   11 <X> 163 <Y> 120 Asp 0.071 Ang -23 Len  14 nn#  74 Dist  24

 21 Possibly interesting features
... r#  99 Area 2387 <X>  90 <Y>  62 Asp 0.318 Ang  18 Len 233 nn#  62 Dist   3
... r#  27 Area 1805 <X> 141 <Y> 272 Asp 0.086 Ang -85 Len 217 nn#  97 Dist  33
... r#  95 Area 1580 <X> 144 <Y> 146 Asp 0.110 Ang   6 Len 193 nn#  73 Dist   8
... r#   5 Area 1360 <X> 421 <Y> 466 Asp 0.136 Ang  23 Len 182 nn#  11 Dist  28
... r#  73 Area 1335 <X> 198 <Y> 105 Asp 0.166 Ang -26 Len 144 nn#  95 Dist   8
... r#   3 Area 1332 <X> 243 <Y> 465 Asp 0.064 Ang  23 Len 218 nn#  17 Dist  20
... r#  69 Area 1273 <X> 315 <Y> 130 Asp 0.108 Ang   1 Len 151 nn#  72 Dist   3
... r#  54 Area 1238 <X> 224 <Y> 200 Asp 0.194 Ang  23 Len 185 nn#  46 Dist  31
... r#  72 Area 1131 <X> 446 <Y>  91 Asp 0.117 Ang  34 Len 158 nn#  69 Dist   3
... r#  62 Area  980 <X>  41 <Y> 148 Asp 0.264 Ang -54 Len  89 nn#  99 Dist   3
... r#  80 Area  960 <X> 281 <Y>  54 Asp 0.158 Ang  33 Len 137 nn#  73 Dist  25
... r#  13 Area  727 <X>  60 <Y> 435 Asp 0.120 Ang   4 Len 117 nn#  18 Dist   9
... r#  26 Area  519 <X> 435 <Y> 354 Asp 0.049 Ang  36 Len 175 nn#  32 Dist  18
... r#  79 Area  496 <X> 228 <Y>  53 Asp 0.322 Ang  68 Len  90 nn#  99 Dist  10
... r#  84 Area  467 <X> 169 <Y>  52 Asp 0.121 Ang -50 Len 118 nn#  73 Dist  35
... r#  97 Area  355 <X> 109 <Y> 104 Asp 0.175 Ang -69 Len  62 nn#  74 Dist  16
... r#  18 Area  296 <X> 131 <Y> 396 Asp 0.100 Ang  82 Len  89 nn#  27 Dist  11
... r#  47 Area  280 <X>  35 <Y> 243 Asp 0.321 Ang -44 Len  51 nn#  42 Dist  21
... r#  42 Area  212 <X>  70 <Y> 287 Asp 0.130 Ang  80 Len  75 nn#  36 Dist  24
... r#  74 Area  184 <X> 130 <Y>  98 Asp 0.150 Ang -78 Len  62 nn#  73 Dist  14
... r#  46 Area   80 <X> 191 <Y> 264 Asp 0.095 Ang -78 Len  53 nn#  54 Dist  17
```

three disjoint segments. Figure 10 illustrates the resulting ship tracks identified from within this subsection.

Collinear Recombination

Once the chunks are removed, we are left with blobs, stubs, and potentially interesting ship track components. The purpose of the collinear recombination is to assemble piecewise linear tracks from the remaining enumerated regions. Each region is tested with its immediate neighbors for collinearity. If two regions are neither blobs nor stubs, their orientation angle's difference tangent must fall below a specified limit, which is typically 0.5. Additionally, the difference in the tangent of the mean orientation angle and a line connecting the two center of gravities must pass a similar test. Table 1 identifies the 68 objects associated with Figure 10, of which 16 are blobs and 31 are stubs.

Remaining potentially interesting objects are then fit with polynomials, typically either quadratics or cubics. These curves are extrapolated on each end some specified distance, typically 30 to 50 pixels, and more collinearity tests are applied to the intersecting regions. Collinear regions are combined if they pass the tests. In the case illustrated by Figure 10 and summarized in Table 1, two blobs, two stubs, and one possibly interesting object represent the curve fit acquisitions. This leaves 20 possibly interesting objects, and their fits, which are those plotted in Figure 10. The curve fits are parameterized as either i(j) or j(i), depending upon the curve's orientation angle, where i is the horizontal vector and j is the vertical. In the coordinate system of the figures, i=j=0 represents the top left hand corner of the plot. Table 2 summarizes the quadratic fits applied in this case.

Temperature Exclusion

Channel 4 data is now referenced for each prospective ship track. Here we use the temperature calibration of 0.2K/pixel-value with a temperature band of 262K to 313K, for pixel values ranging from 255 to 0, respectively. The mean and rms temperatures along each curve are computed, as well as along parallel curves spaced some specified distance (typically 10 pixels) along either side. The curve's mean temperature must fall within a specified interval appropriate for the geographical area. Additionally, the lateral temperature gradient using both excursion paths is tested to indicate coastline or cloudcover bordering the object. Prospective ship tracks may be rejected at this stage; if not, the information will be available to the statistical classifier for further processing.

Visible Exclusion

Channel 1 visible data is also referenced for each prospective ship track. The mean and rms values are computed along each curve, as are the lateral excursion mean and rms values. As with the temperature data, the lateral gradient is examined to ensure the curve's central mean value is a local maximum. Prospective tracks may either be rejected or retained for the statistical classification stage.

Table 2: Quadratic Fits for Interesting Objects of 512x512 Subsection.

```
... 20 features coded into  13240 bytes.
... 14 blobs have NOT been plotted.
... 29 short regions have NOT been plotted.
... r#   1 j= 430 497 i(j)= 1.03E+03-2.93E+00*j*(1-7.79E-04*j)
... r#   1 Area  467 <X> 169 <Y>  52 Asp 0.121 Ang -50 Len 117.6 Width   4.0
... r#   2 j= 422 495 i(j)=-2.92E+03+1.34E+01*j*(1-1.06E-03*j)
... r#   2 Area  496 <X> 228 <Y>  53 Asp 0.322 Ang  68 Len  89.8 Width   5.5
... r#   3 i= 236 345 j(i)= 5.35E+02-1.16E+00*i*(1-2.68E-03*i)
... r#   3 Area  960 <X> 281 <Y>  54 Asp 0.158 Ang  33 Len 136.8 Width   7.0
... r#   4 i=  17 216 j(i)= 4.54E+02-4.60E-01*i*(1-7.36E-03*i)
... r#   4 Area 2387 <X>  90 <Y>  62 Asp 0.318 Ang  18 Len 233.1 Width  10.2
... r#   5 i= 386 497 j(i)= 8.97E+02-2.84E+00*i*(1-1.39E-03*i)
... r#   5 Area 1131 <X> 446 <Y>  91 Asp 0.117 Ang  34 Len 158.1 Width   7.2
... r#   6 j= 386 442 i(j)= 2.23E+01+7.35E-01*j*(1-1.55E-03*j)
... r#   6 Area  184 <X> 130 <Y>  98 Asp 0.150 Ang -78 Len  62.3 Width   3.0
... r#   7 j= 382 438 i(j)=-5.64E+02+3.68E+00*j*(1-1.35E-03*j)
... r#   7 Area  355 <X> 109 <Y> 104 Asp 0.175 Ang -69 Len  62.1 Width   5.7
... r#   8 i= 142 254 j(i)= 6.78E+02-2.31E+00*i*(1-2.01E-03*i)
... r#   8 Area 1335 <X> 198 <Y> 105 Asp 0.166 Ang -26 Len 144.2 Width   9.3
... r#   9 i= 254 384 j(i)= 4.68E+02-5.58E-01*i*(1-1.61E-03*i)
... r#   9 Area 1273 <X> 315 <Y> 130 Asp 0.108 Ang   1 Len 151.2 Width   8.4
... r#  10 i=  74 233 j(i)= 3.21E+02+5.40E-01*i*(1-2.67E-03*i)
... r#  10 Area 1580 <X> 144 <Y> 146 Asp 0.110 Ang   6 Len 193.4 Width   8.2
... r#  11 j= 305 398 i(j)=-4.05E+02+3.27E+00*j*(1-1.71E-03*j)
... r#  11 Area 1433 <X>  51 <Y> 162 Asp 0.250 Ang -55 Len 129.4 Width  11.1
... r#  12 i= 161 320 j(i)= 4.19E+02-1.37E+00*i*(1-2.79E-03*i)
... r#  12 Area 1238 <X> 224 <Y> 200 Asp 0.194 Ang  23 Len 185.1 Width   6.7
... r#  13 i=  16  53 j(i)= 3.17E+02-2.08E+00*i*(1-9.13E-03*i)
... r#  13 Area  280 <X>  35 <Y> 243 Asp 0.321 Ang -44 Len  50.9 Width   5.5
... r#  14 j= 222 264 i(j)= 4.48E+02-1.90E+00*j*(1-1.84E-03*j)
... r#  14 Area   80 <X> 191 <Y> 264 Asp 0.095 Ang -78 Len  52.8 Width   1.5
... r#  15 j= 115 349 i(j)= 1.21E+02+2.72E-01*j*(1-2.71E-03*j)
... r#  15 Area 1818 <X> 141 <Y> 273 Asp 0.086 Ang -85 Len 220.2 Width   8.3
... r#  16 j= 196 253 i(j)=-4.66E+00+5.14E-01*j*(1-1.51E-03*j)
... r#  16 Area  212 <X>  70 <Y> 287 Asp 0.130 Ang  80 Len  74.6 Width   2.8
... r#  17 j=  48 154 i(j)= 1.15E+02+1.73E-01*j*(1-1.13E-03*j)
... r#  17 Area  369 <X> 129 <Y> 408 Asp 0.068 Ang  82 Len 125.6 Width   2.9
... r#  18 i= 157 497 j(i)=-1.33E+01+5.07E-02*i*(1+1.54E-02*i)
... r#  18 Area 2263 <X> 309 <Y> 428 Asp 0.069 Ang  29 Len 422.2 Width   5.4
... r#  19 i=  16 123 j(i)= 8.31E+01-3.44E-01*i*(1-9.19E-03*i)
... r#  19 Area  727 <X>  60 <Y> 435 Asp 0.120 Ang   4 Len 116.6 Width   6.2
... r#  20 i= 332 497 j(i)= 2.60E+02-1.46E+00*i*(1-1.53E-03*i)
... r#  20 Area 1360 <X> 421 <Y> 466 Asp 0.136 Ang  23 Len 181.8 Width   7.5
... # features selected:  20
```

B.4 Statistical Classification

Having greatly reduced the data stream to a manageable number of potentially interesting objects and computed their characteristic features, advanced statistical classification methods can be employed to further distinguish ship tracks from other nondescript objects. Table 3 lists 31 features which were computed for each object. These may be combined with other contextual features: ocean basin, relative wind velocity information, temperature, humidity, cloud type and temperature, meteorological and boundary layer background conditions, etc.

We are in the process of establishing reference data sets with a high degree of ground-truth to train our statistical classifiers. We will describe these methods and their applications in the third progress report.

Table 3: Computed Features for Potentially Interesting Objects.

1	FLAG	<0 if object failed a previous test
2	R#	Region number from 2 through N
3	AREA	Area of region in pixels
4	<X>	CG of region
5	<Y>	
6	<L>	Integrated path length
7	<W>	Computed width of region
8	asp	Aspect ratio
9	ang	Orientation angle
10	rms	Quadratic (or higher) fit's RMS for this region
11	delta	Maximum distance any part of the fit is away from region
12	<T>	Mean temp (& rms) along fit of region
13	Trms	
14	<T+>	Excursion temp (& rms) on +10 pixel parallel fit path
15	T+rms	
16	<T->	Exccursion temp (& rms) on -10 pixel parallel fit path
17	T-rms	
18	<v>	Same as temp, except visible (.63micron) image
19	vrms	
20	<v+>	
21	v+rms	
22	<v->	
23	v-rms	
24	fitflag	1 => i(j), 2 => j(i) for the fit's parameterization
25	imin (jmin)	Extrema of fit
26	imax (jmax)	
27	c0	
28	c1	Assuming a quadratic fit, these are the 3 parameters
29	c2	
30	nn	Nearest neighbor to this region
31	nndist	Distance of nearest neighbor

C. Difficulties Encountered

None

D. Plans for the Next Reporting Period

During the next reporting period, we will apply statistical classification and outlier detection methods to the feature data of objects extracted from the prelimary stages of analysis. We will demonstrate that these methods are useful and efficient for identifying ship tracks. This effort requires that we first establish training sets based on images for which ship tracks have been identified to a high degree of confidence. During the last period of this Phase I effort, we will also examine issues associated with developing a prototype system and fusing data from multiple external sources such as JMIE, and compiling .

E. Property

None

F. Personnel Changes and Important Administrative Changes

None

G. Travel

On 3 December 1993, Dr. Mark Fisk met with Dr. Robert Bluth of ONR to discuss progress on this project. On 23, 24 December 1993, Dr. Fisk met with Prof. Henry Gray (Consultant to MRC) to discuss the status and future direction of this work.

H. Funding

Of the total contract funds of $59,972 authorized for 6 months, approximately $49,787 have been expended for 4 months, and 83% of the work has been completed.

MATERIAL INSPECTION AND RECEIVING REPORT

Form Approved OMB No 0704-0248

1 PROC INSTRUMENT IDEN (CONTRACT)	ORDER NO	6 INVOICE	7 PAGE	OF	8 ACCEPTANCE POINT
N00014-93-C-0197			1	1	D

2 SHIPMENT NO	3 DATE SHIPPED	4 B/L	5 DISCOUNT TERMS
MRC002	94FEB28		NET 30 DAYS

9 PRIME CONTRACTOR CODE 1G992

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15. ITEM NO	16. STOCK/PART NO. DESCRIPTION (Indicate number of shipping containers - type of container - container number)	17. QUANTITY SHIP/REC'D*	18. UNIT	19. UNIT PRICE	20 AMOUNT
0001AB	Progress Report	1	ea	$19,991	$19,991

21. PROCUREMENT QUALITY ASSURANCE

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