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An AVHRR Cloud Classification Database Typed by Experts

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The primary objective of this project was to utilize satellite data from the NOAA Advanced Very High Resolution Radiometer (AVHRR) sensor, and the satellite data interpretation knowledge of experts, to develop environmental algorithms for the Navy. This objective was met by the design and implementation of software to extract information from the experts and the satellite sensor images, e.g., cloud type, five channels of spectral data, and three textural parameters. The experts classified clouds over seven regions in the Northern Hemisphere covering a one year period. Although these data will be used to develop a tactical algorithm to automatically classify clouds by type, the agreement among experts will help to form a baseline for the developed objective technique.

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AN AVHRR CLOUD CLASSIFICATION DATABASE TYPED BY EXPERTS

1. THE IMPORTANCE OF CLOUDS TO NAVY OPERATIONS

Since the first U.S. Television and Infrared Observation Satellite (TIROS) was launched in 1960, the earth, figuratively speaking, has grown smaller: essentially, no portion of the earth's surface and atmosphere escapes daily observation by satellite sensors.

With 32 years of continuous global coverage of the earth by satellites, these data are the foundation of the scientific discipline of remote sensing. Although the field is young, the satellite observations of the earth have directly affected meteorology. Those first satellite images from TIROS showed the earth through patches of clouds. As processing techniques and sensors became increasingly sophisticated, more and more information was extracted from the satellite imagery. In the late 1960's and early 70's, the war in southeast Asia produced a need to derive as much information as possible from satellite imagery. Satellite image interpretation became a skill of many meteorologists (Fett, 1985).

From these satellite images, positions of cyclones, jet streams and the intertropical convergence zone are apparent. In addition to the positions of features, recognition of stratus and cumulonimbus cloud types in satellite images was important to aviation briefs. As forecasting knowledge using satellite imagery grew, the size and appearance of such weather features as tropical cyclones, were related to the severity of the weather.

Clouds are particularly important phenomena to the Navy. For naval aviation, for example, cloud types and their associated characteristics delineate areas of possible aircraft icing. During tactical encounters, cloud coverage is used to conceal ships as well as help define go/no-go target situations.

Classification of clouds found in satellite data into cloud types enhances the communication of information to the meteorological community. Perhaps cloud classification's greatest strength is the ability to change or modify a satellite image of gray shades into a picture depicting cloud types and the latent information carried in a cloud type.

Quantitative information can be extracted from satellite data. Liljas (1982, 1987) and Saunders and Kriebel (1988a,b) have used threshold techniques to classify clouds. Gallaudet and Simpson (1991) have used split-and-merge clustering techniques, coupled with labeling rules, to determine cloudy pixels in satellite data. The textural work done by Haralick *et al.* (1973) and Troy *et al.* (1973) investigated techniques that use gray shades of the satellite data and their spatial dependencies; and Kittler *et al.* (1985) and Welch *et al.* (1988) incorporated textures into cloud classification.

The techniques of thresholding and textures exist, but the capability to test these techniques on a large and varied data sample was not readily available. Although the techniques exist, the ground truth data are usually based on observations from the surface. This produces disparity between actual and observed data in both temporal and spatial scales because most surface observations are taken, at best, every 3 hours, and most commonly every 12 hours, and an observer's field of view is approximately a 32 km radius. The difference in time between surface observation and satellite data could be as great as 6 hours. The spatial resolution of the satellite sensor covers the observer's area with approximately 1024 samples.

The need for the database was evident, to validate objective techniques developed for the Navy's tactical situations. What was the alternative to ground-based observations for the ground truth data? The alternative would be a supervised classification with the same perspective as the satellite. Therefore, meteorologists with satellite image interpretation expertise were selected to type the cloud masses viewed on the satellite imagery.

The primary advantage is the removal of temporal and spatial disparities between ground truth and satellite imagery. The disadvantage is the risk associated with a subjective interpretation. However, the subjectivity can be controlled to a great extent by a clear, concise set of rules that define a selection. The validation of a selection was deemed accurate if three or four experts were in agreement.

The task is easier said than done. There existed no software which would bring together the knowledge of an expert, and the information from the satellite sensor. Nor did there exist the ability to create a database from that information for future use. To create a cloud classification database, software had to be designed and developed for this specific purpose.

2.2 Description of the Satellite Data Source

The AVHRR Cloud Classification Database (ACCD) is fairly extensive in geographic, temporal and spectral coverage. The database consists exclusively of NOAA Advanced Very High Resolution Radiometer (AVHRR) satellite data. The satellite data sampled come from a satellite archive at the Naval Research Laboratory, Monterey, CA. Kuciauskas (1991) developed the satellite archive database that consists of approximately 3180 individual satellite passes. The satellite data extend from October, 1988 through September, 1989. Table 1 displays the subset of this archive used to create the ACCD.

The NOAA AVHRR satellite passes in the database were randomly selected from all regions highlighted in Fig. 1. The data cover most of the oceans in the Northern Hemisphere and are fairly evenly distributed throughout the available time period as shown in Fig. 2.

Table 1. Summary of regions selected for classification database.

ID	NAME	PASSES
[6]	Atlantic Ocean	(22)
[2]	Pacific Ocean	(17)
[4]	Mediterranean Sea	(22)
[5]	Persian Gulf	(22)
[1]	Barents Sea	(23)
[7]	China Sea	(20)
[3]	Kuroshio	(16)

2.3 The Cloud Selection Interface

In order to blend information from the satellite with the knowledge of the experts, a graphical user interface was developed. The software was developed for the NRL-AD research computer, which is a Hewlett-Packard 835 Turbo SRX computer with a UNIX operating system and a C Language compiler. The graphics terminals have 24 image bit planes that allow three eight-bit images to be displayed and stored in frame buffers at one time.

The graphical interface design needed to provide all the pertinent satellite information to the expert, yet allow a non-computer-oriented person to be at ease and comfortable with the method to capture their knowledge. At the same time, the software needed to gather the input from the expert, the spectral values from the satellite sensor, and process three texture variables at three different convolution sizes fast enough to hold the expert's attention.

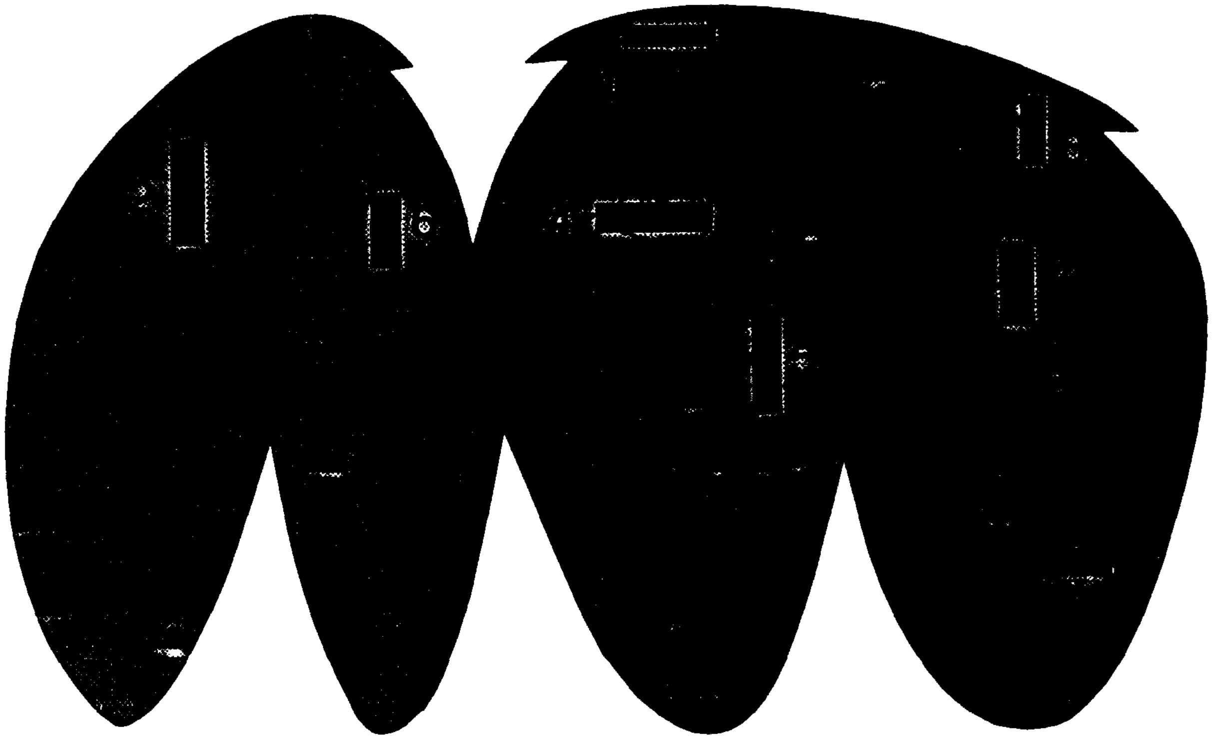

Fig. 1. ACCD region location map.

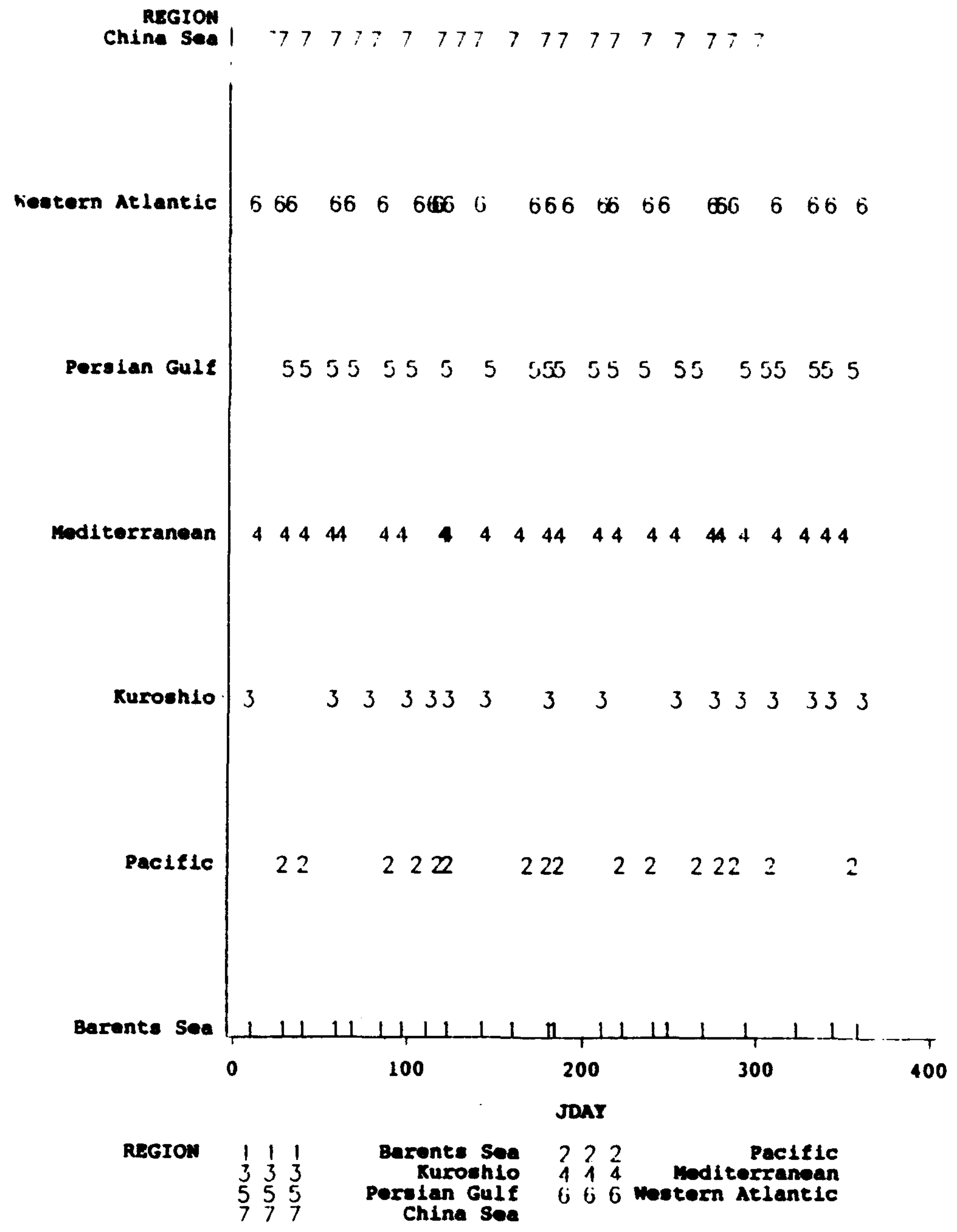

Fig. 2. Temporal distribution of ACCD's satellite imagery.

The software was developed so that the experts used only a graphics terminal and a mouse and to minim.ze the expert's time and maximize the efficiency of the selection process. Figure 3 shows the design flow of the software. To start the classification process, the expert is presented with the screen image displayed in Fig. 4. This shows the whole pass, contained in 1024 x 1024 pixels, in the thermal frequencies. All images to the screen were normalized which provided enhanced satellite images.

The five icons to the right of the image provide the classifer with options that are activated through the click of a mouse button. Clicking the top icon displays the initial screen in Fig 4. The green box surrounds the region to be classified. Clicking the second icon displays the full resolution visible image, channel 1, with a 25 point cyan grid overlaid on the image. This cyan grid represents the areas for the expert to type. A click on the third or middle icon displays the full resolution thermal image, or channel 4 data. This screen also has the 25 point cyan grid overlaid on the image. Clicking on the fourth icon toggles the 25 point grid on and off.

The fifth or bottom icon allowed the expert to exit from their task. From there the database manager could cycle the file to set up a different expert or exit from the program altogether.

The icon in the upper left corner of the screen shown in Fig. 5 gives the Line and the Element in the pass corresponding to the current location of the cursor and the temperature in degrees Kelvin, as derived from the full resolution channel 4 data. This icon is continuously displayed while a full resolution visible or thermal image is on the screen.

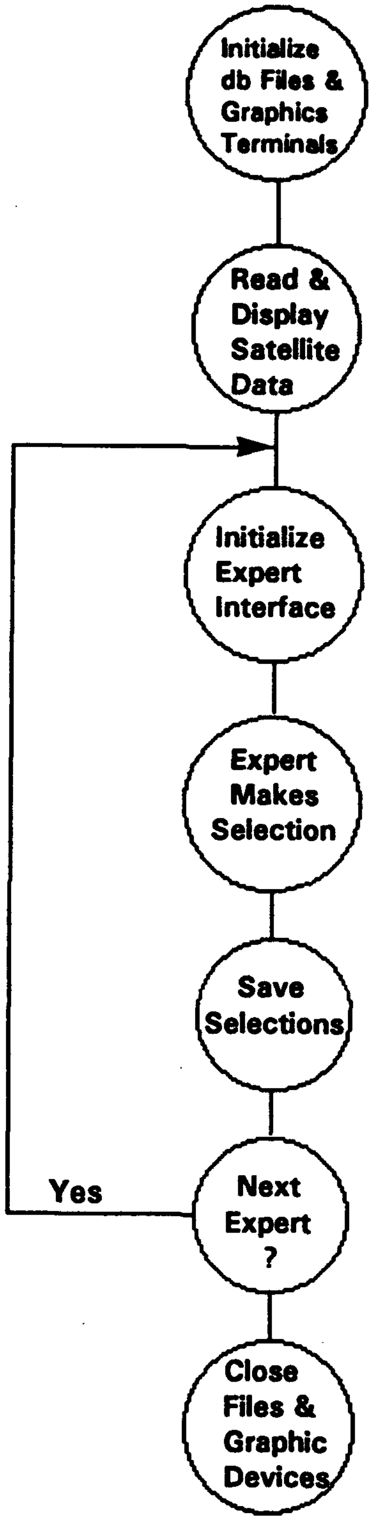

Fig. 3. Overall design flow of ACCD's software.

Fig. 4. Initial screen displayed for expert cloud typing.

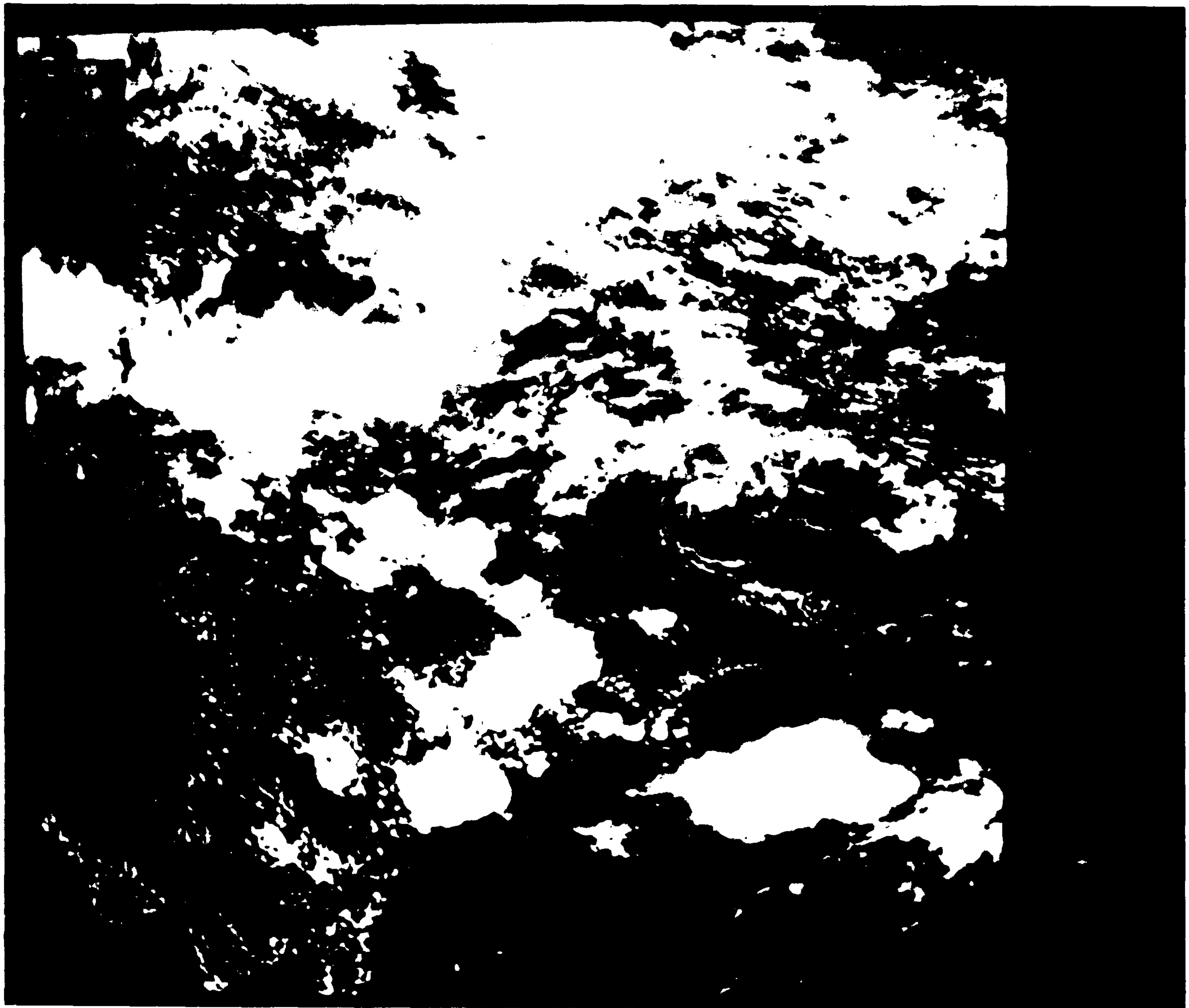

Fig. 5. Selection screen with 5 x 5 grid.

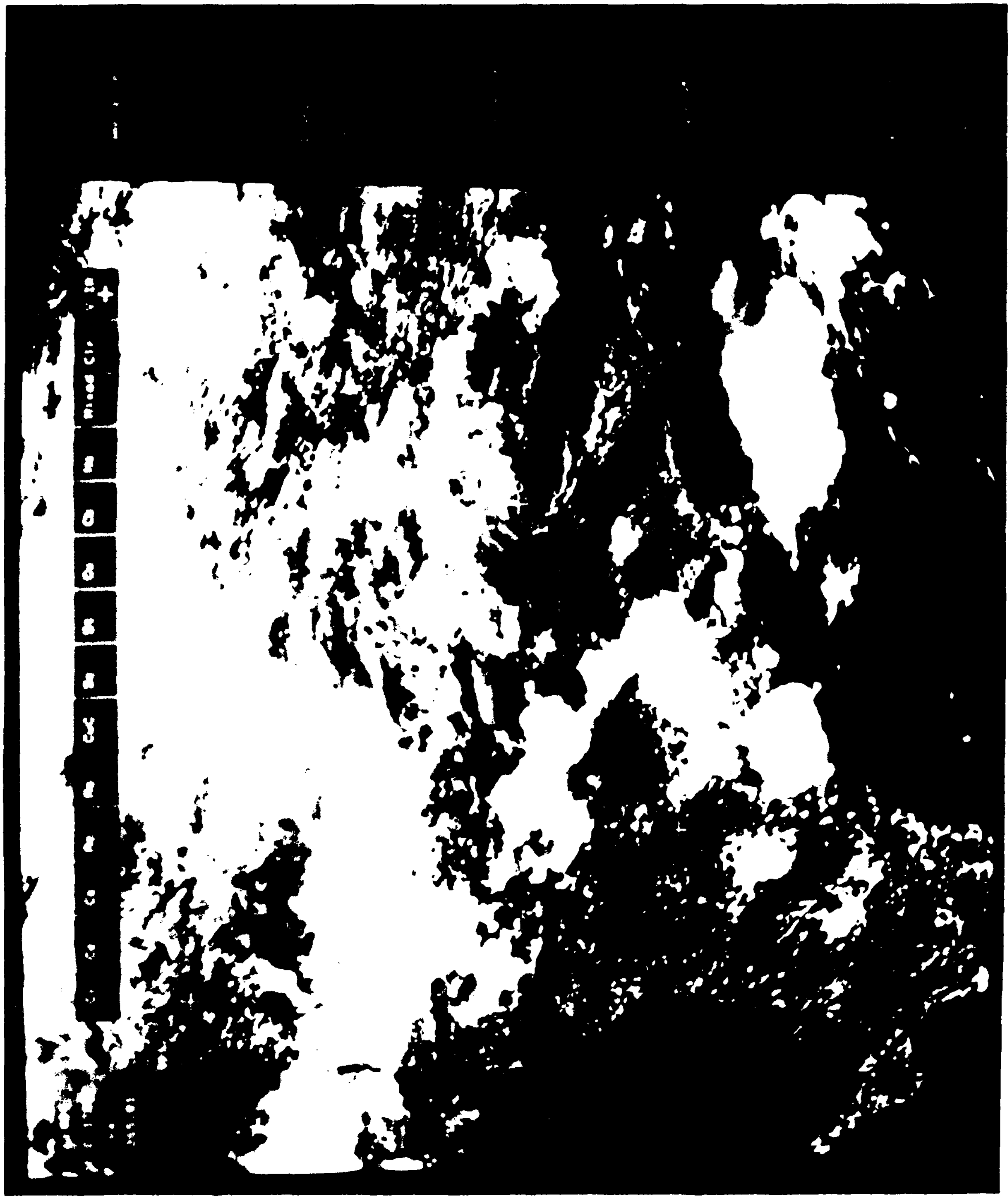

Fig. 6. Selection screen in progress with cloudbar.

To type a cloud, the expert positions the cursor over one of the 25 cyan grid points and clicks the mouse. The changes to the screen are demonstrated in Fig. 6. The cross representing the grid point is then replaced with a 32 x 32 pixel blue box surrounding the region represented by the grid point location, and a 14-box horizontal cloud bar appears. The cursor automatically relocates to the V IR box of the cloudbar. The expert can choose from 11 different cloud types, a mixed cloud category and a clear category as follows:

0	Cirrus	(Ci)	
1	Cirrocumulus	(Cc)	**Upper**
2	Cirrostratus	(Cs)	
3	Altocumulus	(Ac)	
4	Altostratus	(As)	**Mid**
5	Cumulus Congestus	(CuC)	**Convective**
6	Stratocumulus	(Sc)	
7	Stratus	(St)	**Low**
8	Cumulus Humilis	(Cu)	
9	Cumulonimbus	(Cb)	
10	Nimbostratus	(Ns)	**Rain**
11	Mixed	(Mi)	
12	Clear	(Cl)	

The first three classes (0-2) were chosen as representative of upper level clouds. Classes 3 and 4 are mid level clouds while 6, 7 and 8 are low level clouds. Class 5 is representative of a convective cloud and classes 9 and 10 were chosen to represent rain clouds. These classical cloud types were chosen for three reasons: (1) initial work in thresholding techniques were adapted from Liljas (1982); (2) inherent in these types are differences in altitude, shape, size, thickness, drop size, distribution and concentration; and (3) the Navy is very interested in the tactical advantages of the aforementioned cloud types. Class 11 is discussed later in the text while the last category 12 is the absence of clouds.

The classifier is free to select grid points in any order, and even reselect points if desired. The tools available to the expert include pixel temperatures, the toggle between the visible and infrared images and a detailed analysis of the surface and upper air levels. The detailed analyses available to the expert were the Navy Operational Global Atmospheric Prediction System (NOGAPS) analysis charts, a generic skew-T and a temperature conversion table. At each graphics terminal for the satellite pass displayed, the corresponding surface, 500 mb and 200 mb charts were available for the area of the satellite pass. The average time disparity between satellite overpass and NOGAPS analysis charts were 2 hours and 24 minutes. The greatest time difference was 6 hours while the minimum disparity in time was less than a quarter of an hour.

The expert decision is made by clicking the mouse while the cursor is positioned over the appropriate cloud classification box. Once the selection is made, the box surrounding the classification area is replaced with a red cross, and the cloud classification bar disappears. At this time the cloud bar and the 32 x 32 box are removed and the grid point is redisplayed in red. This color indicates to the expert that the point has been processed.

After the 25 grid points have been classified, the expert positions the cursor over the exit icon and clicks the mouse. This brings up the screen showing five icons numbered 0 to 4 and an exit icon. This screen allows another expert to type the same image, which avoids having to waste time reloading the imagery into memory.

The next expert begins the classification by clicking the mouse while the cursor is over his or her identification number which is one of the numbers 0 through 4. The 5 x 5 grid field is then redisplayed in cyan. After all experts are finished, the program is completed by a mouse click on the exit icon.

This interface software package was written in C and serves as a shell to the Empress relational database. Fig. 7 is a flow diagram that illustrates the interface software. The driver for the interface software is **runfgrid.c**. The image files are initialized through a separate program called **runinitf.c**.

There are a few guidelines the expert follows. This ensures each expert interprets what is in the 32 x 32 box with limited ambiguity. First, in order to type a cloud the box must have 75% of that cloud present in the box. If the cloud type is cumulus humulis or open cell stratocumulus, the box must have 50% coverage. If a box does not meet that percentage criteria, the box is typed mixed.

2.4 Variables in the Database

This cloud classification database contains satellite data and cloud types for approximately 3600 points for each of four meteorological satellite interpretation experts. Each of the points in the database are associated to 62 different parameters. This section discusses these parameters in some detail.

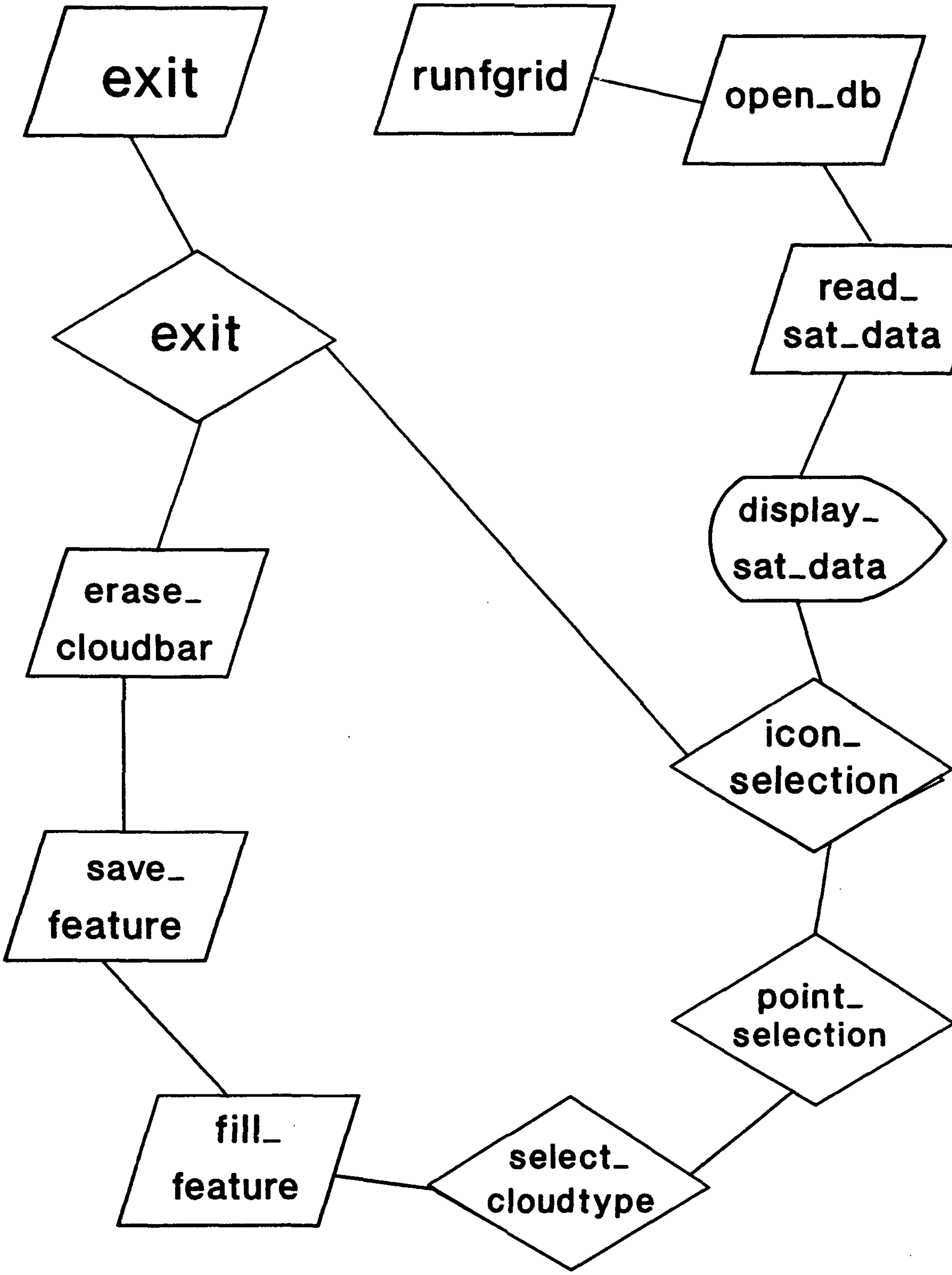

Fig. 7. Interface software flow diagram.

Line:	The line number of the pixel in the satellite pass.
Element:	The element number of the pixel in the above line.
Imid:	The identification number of the image in the NEONS database at NRL-AD.
Region:	The region number of the pass as listed in the ACCD.
Year:	The year of the satellite pass.
Month:	The month of the satellite pass.
Day:	The day of the satellite pass.
Hour:	The hour of the satellite pass in Greenwich Mean Time (GMT).
Expert:	The expert's identification number.
Point:	The grid point number of the observation (1 to 25).
Cloudtype:	The number that represents cloud type as listed previously.
Albedo[1]:	The albedo as calculated from channel 1 of the AVHRR sensor.
Albedo[2]:	The albedo as calculated from channel 2 of the AVHRR sensor.
Temperature[3]:	The temperature as calculated from channel 3 data off the AVHRR sensor.
Temperature[4]:	The temperature as calculated from channel 4 data off the AVHRR sensor.
Temperature[5]:	The temperature as calculated from channel 5 data off the AVHRR sensor.
Diff45:	The difference between the temperature derived from channel 4 and channel 5 of the AVHRR sensor.

The following 45 variables are texture values calculated at three different convolution sizes. The smallest convolution is a 16 x 16 filter (16) about the grid point. A convolution of 32 x 32 (32) as well as 64 x 64 (64) are also calculated at each grid point. For each of the five channels of the AVHRR, angular second moment (asm), entropy (entro) and local homogeniety (lh) are computed. The entry in the database appears as follows:

asm16ch1 asm16ch2 asm16ch3 asm16ch4 asm16ch5
entro16ch1 entro16ch2 entro16ch3 entro16ch4 entro16ch5
lh16ch1 lh16ch2 lh16ch3 lh16ch4 lh16ch5
asm32ch1 asm32ch2 asm32ch3 asm32ch4 asm32ch5
entro32ch1 entro32ch2 entro32ch3 entro32ch4 entro32ch5
lh32ch1 lh32ch2 lh32ch3 lh32ch4 lh32ch5
asm64ch1 asm64ch2 asm64ch3 asm64ch4 asm64ch5
entro64ch1 entro64ch2 entro64ch3 entro64ch4 entro64ch5
lh64ch1 lh64ch2 lh64ch3 lh64ch4 lh64ch5

These three textures and the gray level difference vector (GLDV) technique were recommended by Dr. R.M. Welch (1988). The GLDV technique produces a histogram based on the absolute differences between pairs of gray levels. For clarity, the texture formulas for angular second moment, entropy and local homogeneity (Chen et al 1989) follow:

<u>Angular second moment</u>:

$$asm = \sum_{m} [P^{A}(m)]^{2}$$

is a measure of homogeneity in the scene. A small value of asm indicates that the values of M = |i-j| are approximately equal, and that there are few dominant gray tones. A large value for asm indicates some M values are much larger than others.

<u>Entropy</u>:

$$entro = -\sum_{m} P^{A}(m) \log P^{A}(m)$$

is a measure of disorder in the scene. Entropy is largest for equal M and is small when they are very unequal.

Local homogeneity:

$$lh=\sum_{m} P^{\Delta}(m) / [1+m^{2}]$$

represents a measure of the amount of local similarity in the scene. The above three equations have the following variable identification:

Symbol	Description
i	Represents one pixel gray level.
j	Represents adjacent pixel gray level.
m	Effective number of gray levels in use. This study has 256.
$P^{\Delta}(M)$	Difference vector density function. $M = \|i - j\|$

3. RESULTS

The database represents a blend of human interpretation knowledge and satellite spectral information on clouds. The primary goal in the utilization of this database is the development of a statistical discriminant function that types the clouds. With this function, the transition of this capability into operations is expected.

There were three key considerations to the development of the database: computer graphics, satellite data management, and the experts' time to do the cloud classification.

Experts' time to classify impacted the development of the database in two significant ways. The initial estimate was one minute to type one cloud. Although an overestimate, the initial request called for 50 hrs of an expert's time. After the interface was developed, however, a more realistic estimate was two or three typed clouds per minute, which reduced the expert's time to 25 hrs.

The second impact on expert time was in the wait for satellite data to be loaded into memory. For example, one satellite pass is approximately 60 MB. For the software to retrieve a pass from the database, make the necessary calculations, and display three 1024 x 1024 images on the screen took just under 16 minutes wall clock. To make these transfer times possible, the imagery was transferred from CD-ROM to magnetic disk which took about one minute per 8 MB. To save waiting for the image to load into memory, a modification to the design was necessary, which allowed multiple experts to type an image using only one memory load.

Another modification that would have had satisfactory results, if implemented, was immediate feedback to experts. Once a grid point was selected, in addition to a red grid point, a display of cloud type selected would have proved useful. Also, although the option existed to toggle the grid of points on and off, the users did not use this option.

4. STATISTICAL SUMMARY OF THE ACCD

The ACCD's initial development consisted of each of four experts classifying 3,625 clouds. Table 2 provides the numbers of experts in agreement for the seven regions in the study. For example, each expert typed 600 clouds in the Mediterrean region or a total of 2400 points. All four experts were in agreement on 248 points. With those 248 removed, three experts were in agreement on 148 points. Those 148 removed, 231 points were agreed on by two experts; 502 points remained where there were no agreements.

Table 2 indicates that of the 14,500 points typed, 33% were agreed on by all four experts and three experts were in agreement 19.7% of the time. A frequency distribution of the cloud types agreed on by three and four experts is given in Fig. 8. A significant feature in this graph is the lack of agreement for the class nimbostratus. Although 15 points were typed Ns, none of those points were in agreement by 3 or 4 experts.

Table 2. Number of agreements between experts for each region.

Region	4 Agree	3 Agree	2 Agree	1 Agree	Total
Mediterranean	248	148	231	502	2400
China Sea	128	150	251	536	2000
Barents Sea	138	150	274	650	2200
Centl Pacific	67	109	214	577	1600
Persian Gulf	313	115	123	357	2200
Kuroshio	108	104	199	458	1600
W. Atlantic	196	177	285	615	2500

Figure 9 is a frequency distribution by region for those points typed clear, where three and four experts agreed. From this figure both the Mediterranean and the Persian Gulf regions had a high number of clear scenes. Although these regions are tactically important, the weather in those regions produced few clouds for this study. Figure 10 is a frequency distribution for those points typed mixed. The Persian Gulf region has the least number of such classifications. For all 14,500 points, 33.2% were typed clear and 19.2% were typed mixed.

Figure 11 illustrates how often an expert agreed with another expert. Overall, Fig. 11 indicates that all four experts were in good agreement with one another. Experts 0 and 3 were in agreement most often, while experts 1 and 2 had the fewest agreements of the paired experts.

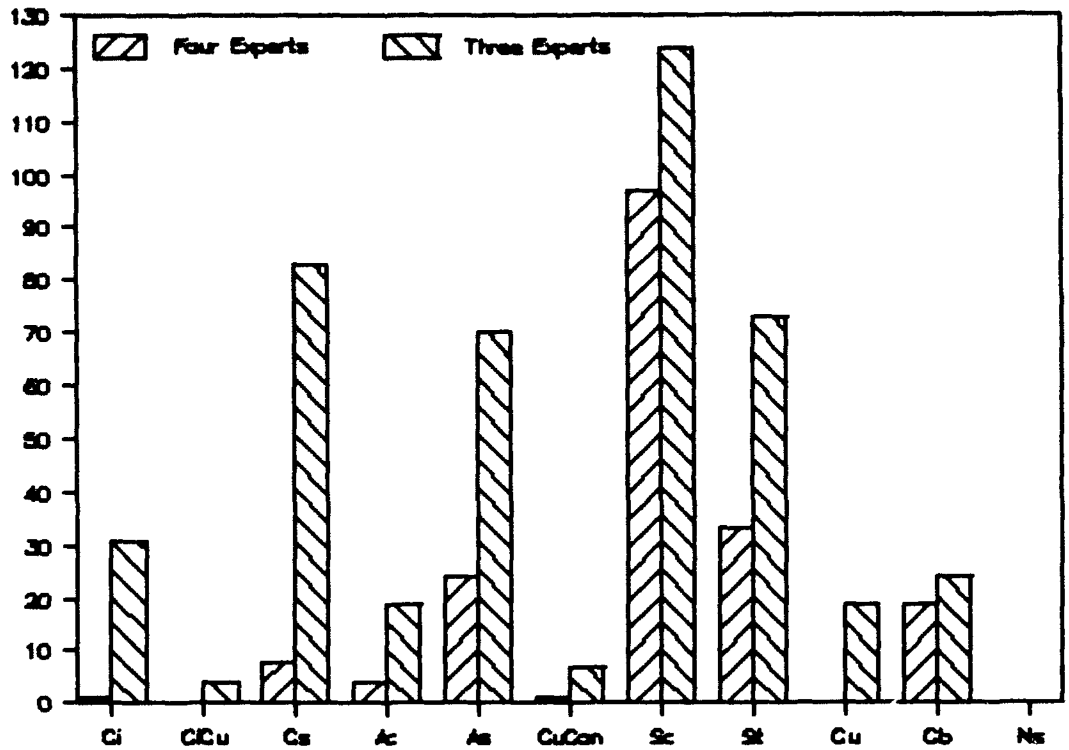

Fig. 8. Frequency distribution of cloud types for three and four experts in agreement.

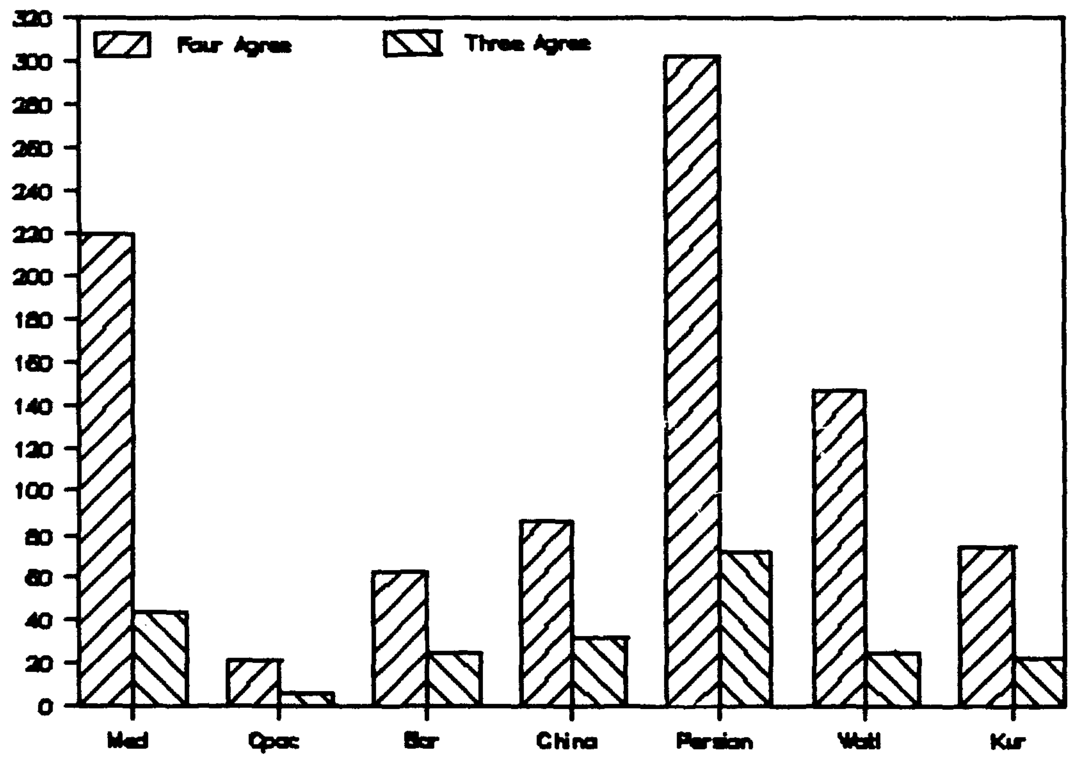

Fig. 9. Frequency distribution of clear points where three and four experts agree.

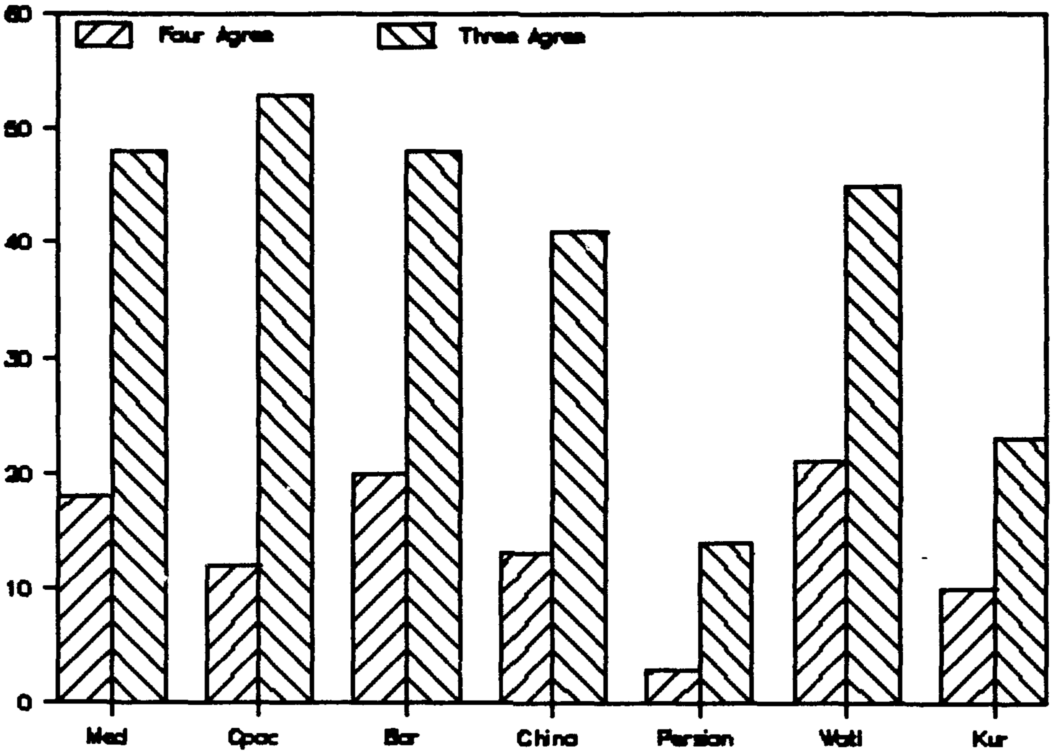

Fig. 10. Frequency distribution of mixed cloud types where three and four experts agree.

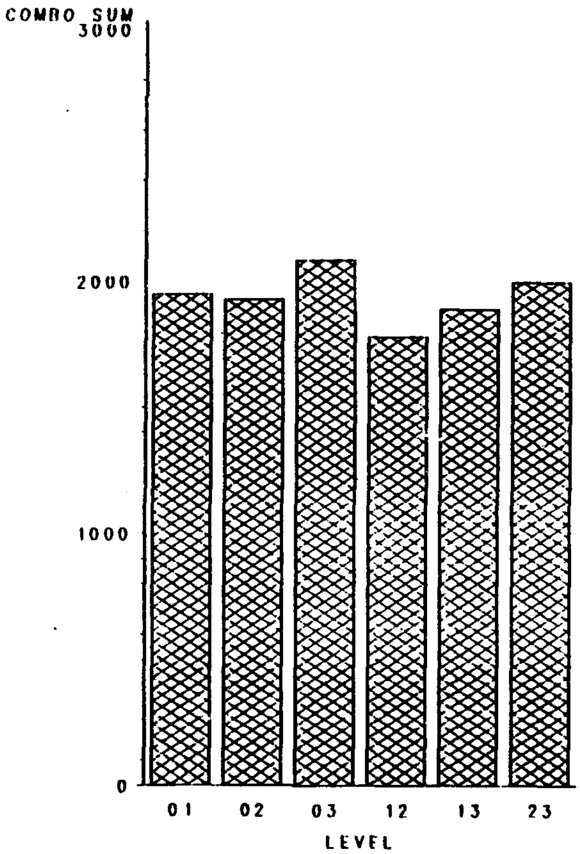

Fig. 11. Frequency distribution of agreements between two experts over all regions.

5. DIRECTIONS FOR FUTURE WORK

This work is the first step in developing tactical decision aids for the Navy in order to describe the impact of clouds on operations. The plan is to develop discriminant functions which will type clouds in the northern hemisphere. After the functions are developed, tactical decision aids would be created.

This work has been shared both at Naval Research Laboratory, Monterey and at the Scripps Institution of Oceanography, San Diego. These groups have taken the database and used the data to develop neural networks. Bankert (1993) has reported his results on the incorporation of the data into a neural network.

The ACCD would also be an excellent starting point for studies that will probe the microphysics of clouds. Both the spectral and textural signatures of these clouds have microphysical information contained therein. Could the supercooled cloud droplets of clouds be recognized in the satellite data? Is a textural change in the cloud depicting cold, dry air entrainment? Perhaps a combination of spectral and textural information would define a microphysical process not yet described. The database awaits the inquisitive researcher.

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