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An oceanographic expert system to describe the evolution of the Gulf Stream and its rings has been developed at NOARL. Our latest results show the expert system to be more than 60 percent accurate in ring location predictions. The structural composition of the implemented expert system consists of an OPS83 rule based shell and modules, using primarily C for algorithms. Past funding and time allocation decisions affected design and software construction, in turn significantly impacting the project. This paper describes some of the computer related problems encountered during our drive to obtain a production version for the oceanographic analyst.

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IMPLEMENTATION OF AN OCEANOGRAPHIC EXPERT SYSTEM: PROBLEMS, FEEDBACK, SOLUTIONS

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Abstract

An oceanographic expert system to describe the evolution of the Gulf Stream and its rings has been developed at NOARL. Our latest results show the expert system to be more than 60 percent accurate in ring location predictions. The structural composition of the implemented expert system consists of an OPS83 rule based shell and modules, using primarily C for algorithms. Past funding and time allocation decisions affected design and software construction, in turn significantly impacting the project. This paper describes some of the computer related problems encountered during our drive to obtain a production version for the oceanographic analyst.

Introduction

In order to aid in the repeated analysis of the northwest Atlantic Ocean, an oceanographic expert system to describe the evolution of the Gulf Stream and its rings or eddies, has been developed and implemented in a research setting. Our latest results show the expert system to be more accurate in ring location predictions than an assumption of no motion by more than 60 percent (table 1).

The Naval Oceanographic and Atmospheric Research Laboratory (NOARL); previously the Naval Ocean Research and Development Activity (NORDA) has sponsored the development of this oceanographic expert system since 1984, and has reported on its preliminary conception [1], and mid-life functional description [2]. The system depicts motion and size in warm-core rings (WCRs) and cold-core rings (CCRs); their interaction with each other and the Gulf Stream; plus the movement of the Gulf Stream track over time. Time segments are normally in seven day increments, although the capacity for any step value is available. The rule-based system utilizes a domain of the northwest Atlantic Ocean divided into nine regions.

Table 1
Ring Motion Results

Days	Ring-Type	Percent Better Than No Motion
7	WCR	61% (based on 31 comparisons)
	CCR	64% (based on 39 comparisons)
total		63% (based on 70 comparisons)
14	WCR	55% (based on 11 comparisons)
	CCR	67% (based on 15 comparisons)
total		62% (based on 26 comparisons)

Tests of NOARL's oceanographic expert system with 10 data sets also used to validate the Harvard "Gulfcast" model. All results are consistent or better than previous results using GEOSAT Ocean Applications Program (GOAP) mesoscale products as "ocean truth".

This oceanographic expert system or "intelligent assistant" currently resides on a VAX 8300, with the rule-based modules coded in OPS83 (3,4). The languages of C and FORTRAN provide the rest of the implementation shell, and it uses the Graphical Kernel System (GKS) as the interface to a Chromatics computer display unit. DISSPLA, a commercial graphics package [5], has been added to provide an outlet for all plottable hardcopy graphics.

The rule-based portion of the expert system and inference engine operates quite successfully throughout the "recognize-act" cycle. The nine regions of the domain (Figure 1) provide for tuning based on different oceanographic processes associated with these areas, the predomininant process being the speed and direction of surface water. Over this area along the average Gulf Stream track is a nominal Gulf Stream axis depicted as a seven segment line. This segmented axis is used in calculations during the execution of the software module NRMLZ (normalize), whose algorithm and involvement with movement will be addressed later. Initialization input to the expert system is usually done from data files whose points define the "upper" Gulf Stream boundary, the "lower" Gulf Stream boundary, and the rings' center coordinates and radii. Optionally a 100 km width reference Gulf Stream based on the nominal Gulf Stream is available. A brief description of most of the other modules may be found in the expert system's functional description [2].

The Chromatics screen output, which can consist of incremental time-stepped views, graphically displays the rings and Gulf Stream in a pseudo-mercator grid format. An underlay of the coastline and seamount chains is also displayed. As an analyst option, the past history of the WCRs, CCRs, and Gulf Stream can remain visible or be cleared each cycle. The original design did not address the need for hardcopy replication of the results. In its current form, the expert system executable module takes up approximately 204,000 bytes or 400 blocks in VAX terminology. The entire system and supporting files (including DISSPLA) require less than one megabyte, lending itself to future operational status on workstations or enhanced microcomputers.

Now that the oceanographic expert system has proven itself to a certain extent, it is coming out from the laboratory and being phased into the early stages of a production version. Oceanographic analysts at the Naval Oceanographic Office (NAVOCEANO) will be the recipients of the conversion from mini-computer to PC form, including enhancements to the rule base and the resolution of some of the problems discussed in this paper.

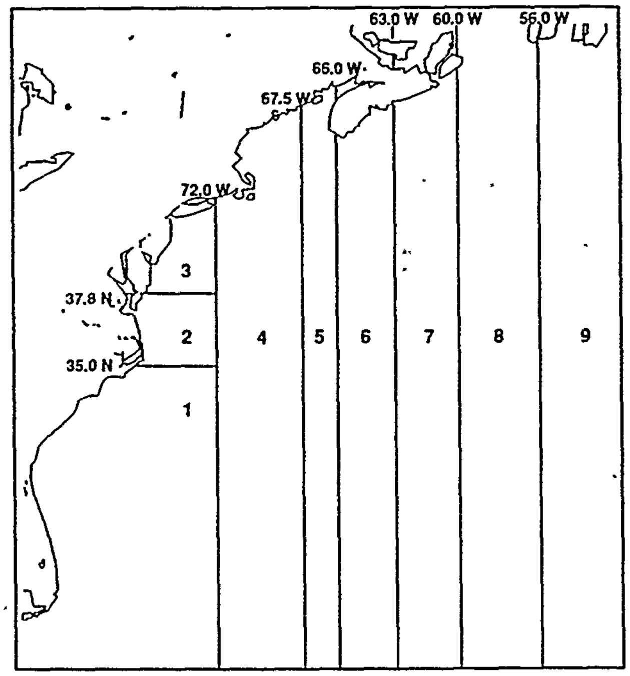

Figure 1. Nine regions of the expert system domain.

Discussion

During the final stages of verifying the application and adding an external graphics capability, past design implementations by contractors complicated progress. The basic stumbling blocks were: no reusable latitude-longitude points, but only Chromatics specific "hardcode"; no logic documentation nor pseudocode representation, especially on the algorithms, modules, and memory (working storage); and the aforementioned lack of a migration path for output data. They seem like a simple group; easily overlooked or cut back in the interest of time. Unfortunately, rather than a time-sensitive expert system project, their interaction drove later alterations and enhancements into duplication, patches, and convoluted solutions. Do not assume that if the rules of an expert system can be changed, the rest of the expert

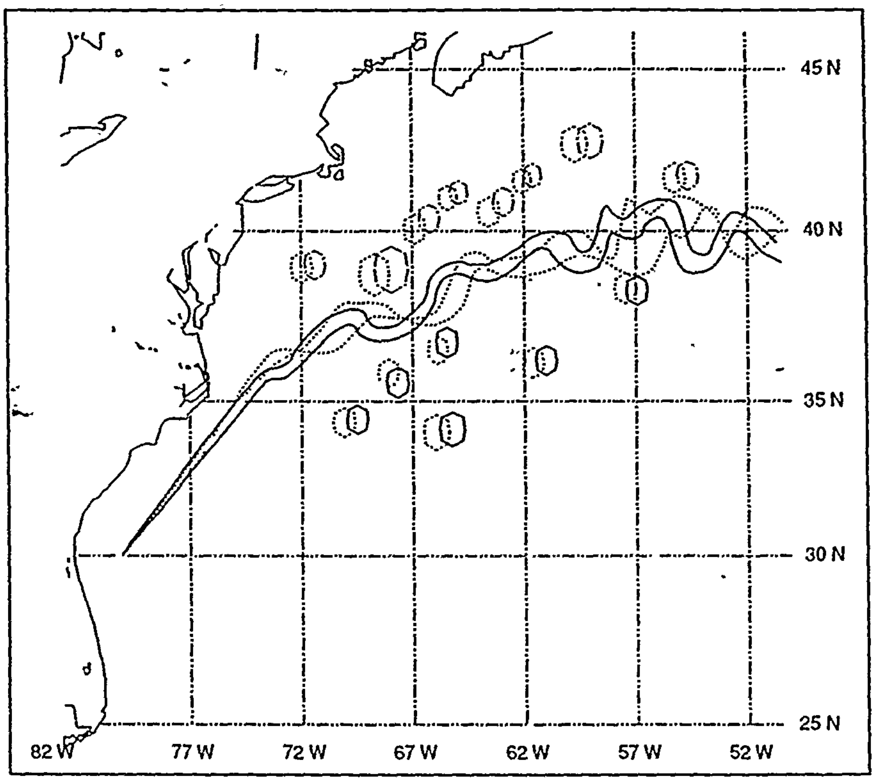

Figure 2. Rings and Gulf Stream at 0 and 7 days.

system, its interface, and data manipulation are of no consequence.

The most straightforward case affecting system development was the coding of the grid, coastline, and other display graphics not by passing reusable latitude and longitude points with an intervening conversion module, but by hardware specific points drawn on the display screen. To resolve this, we had to delve within the OPS83 modules. Upon determining the data array in its final generation per cycle, we intercepted and copied the information. The current values were then passed through all the modules normally used in processing, bringing out the lost points for combination with the graphics software packages' coastline database, or future graphical displays. We now keep track of an extra cycling data array plus a global array of flags and counters. The plot file data is scaleable producing a true image, and identifiable in a computer aided design (CAD) sense with "key", "group", and "sequence" numbers attached. The result can be passed through a graphics post-processor such as DISSPLA for a variety of geographic projection types (e.g.: Mercator (Figure 2), UTM, polyconic), and a non-graphics terminal may be used in processing the data if the visual display is not necessary.

A more subtle problem involved the algorithms used to define the normalized Gulf Stream and

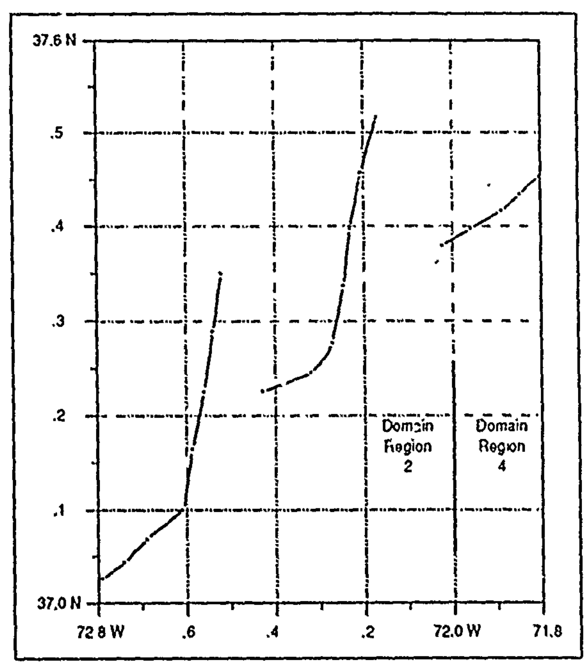

Figure 3. A segment of Gulf Stream boundary, with "J"-shaped errors shown. The number of points defining the edge has been expanded from the original input, and all are displayed in a continuous line.

manipulate its movement over time. Typical downstream motion is to the east along the normalized axis. The primary redefinition algorithms are in the module NRMLZ, written in C. They use an array of location points, "gsarray", defining the "north" and "south" edges of the Gulf Stream. The results of processing with respect to the nominal mid-Gulf Stream axis plus propagation of the points, showed several non-realistic features. Three distinct problems of this type were encountered. At certain points along the Gulf Stream wall there would appear "drop-outs" of one to several location points; along the northwestern Gulf Stream "J"-shaped line segments were produced (Figure 3); and where the original Gulf Stream meanders data looped both west and east (Figure 4) the mathematical model might give up completely by returning a negative array index. Since we could not break down the program code, the algorithms were treated as "black boxes". Error conditions are trapped after they occur, remedies taken, and processing resumed.

The drop-outs are resolved by means of a "noise filter" in-line after the gsarray is passed along. This goes through the array looking within the domain of region-2 to region-4 for lowered values where the next or second next point is greater than the one before the drop, that is, continuing the latitude's increase as expected. This filter will catch single or double points so defined while allowing those either descending or increasing as in a normal Gulf Stream oscillation to pass without alteration. In the special case of a drop and then "slow" rise, it is assumed that the previous points are too high to the "correct" latitude sequence. Only the latitude need be followed in this ocean area, except for the initial target window.

The points causing the "J"-shaped line segments are also treated after the fact, by code designed to smooth the total gsarray of that area into a reasonable Gulf Stream boundary. The array of points is examined until a rapidly ascending series with a sudden return to the average trend is detected. Usually found in region-2 and propagating to region-4, the points are adjusted down into a straight line average. We acknowledge that this is not the optimum solution, but it does work, given our knowledge of input, expected output, and physical oceanographic probabilities. The modification of the algorithm continues to be addressed and performance improvements are expected.

Gulf Stream meanders in a region may loop back so that within a group of three points, the center longitude will be west or greater than the other two (Figure 4). From the vertical case to westward, a zero divide error and infinite slope may be generated. After trapping this error, the input array is examined to locate the suspected critical point, which is then removed. The array is compressed, variables reini-

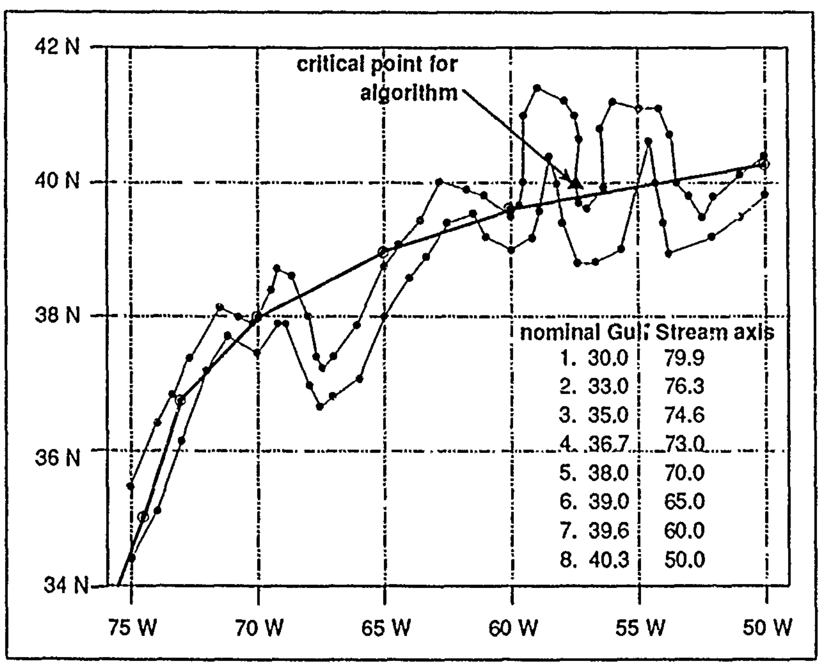

Figure 4. The nominal Gulf Stream axis with the original input of observed Gulf Stream boundary points. Note the critical point causing a calculation error in the module NRMLZ.

tialized, and processing of the module restarted. Trapping of known unique errors is repeated until the module completes successfully. Most input boundary data sets require very few adjustments to continue beyond this stage, and we have seen no adverse effect on ring interactions. The individual points deleted are flagged and a total count provided to the operator-analyst, allowing a measure of the Gulf Stream's variance from a true representation.

Overall, the oceanographic expert system is a usable product, describing the evolution of the Gulf Stream and its rings a week or two from the initial observation. Some of the techniques such as modularization of algorithms have proved out very well, while segmentation of some computer routines into disassociated procedures only added to the cost. Although this is a rule-based expert system, the problems derived from funding and time allocation decisions limiting basic systems analysis and follow through, thereby preventing an optimal solution.

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