OCEANOGRAPHIC DATA
AND
CLIMATE RESEARCH

EXPLORATORY THOUGHTS

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J. R. Schubel
1. Oceanographic Data

1.1 Oceanographic Data Ignored

In reading and hearing about recent major climate research projects I have been disturbed by the quality of the oceanographic input to such efforts. They seem to focus on variables that are easy to measure and ignore essential parameters. The interaction between the ocean and the atmosphere connects two reservoirs having very different time constants. The sea surface temperature is usually considered as a lower boundary condition for the atmosphere. The crucial factor however is the response of the intensive characteristics of the surface ocean to fluxes of heat, water and chemical substances (eg. CO2).

The response of the surface ocean to exchange with the atmosphere depends primarily on the thermo haline structure of the ocean. For example, the heat loss per unit area required to form sea ice can vary by many orders of magnitude. A shallow halocline results in the formation of sea ice near Greenland, while the largely isohaline eastern Greenland-Norwegian Sea remains ice free. The difference in haline structure between the North Atlantic and the North Pacific led me to propose a mechanism for the initiation of the ice ages (Weyl 1968).

The thermo-haline structure near the ocean surface is largely ignored by current climate research because:

1. Salinity is not a meteorological variable

2. Surface salinity can not be determined by remote sensing

3. It is very expensive to determine the thermo-haline structure near the sea surface

4. It is virtually impossible with even large resources to monitor the change in the thermo-haline structure over time and space

5. Significant changes in the thermo-haline structure occur primarily under weather conditions that preclude direct shipboard observations
1.2 Data and Information

The National Oceanographic Data Center is a valuable storehouse of data on the time space variations of oceanographic parameters. The problem we face is how to convert these data into information relevant to climatic change. To be useful, information must interact with the thought processes of the climate researcher. Two types of oceanographic information products are currently available:

1. Atlases showing oceanographic parameters as observed during major ocean expeditions, eg: the GEOSECS Atlases issued by the National Science Foundation

2. Atlases based on large data sets that summarize average conditions of individual ocean basins or the World Ocean, eg: the recent Climatological Atlas of the World Ocean (NOAA Professional Paper No 13. by Levitus)

These products are useful for obtaining an overview of oceanographic conditions. They provide a picture during the space-time frame of an expedition and a statistical average of objectively analyzed data. Climatologically significant conditions, however, seldom coincide with times of observation and differ from statistical averages. Horizontal boundaries between water types tend to be sharp but variable in location. Boluses of anomalous water types are often trapped in other waters. A good example of the effect of horizontal resolution in depicting water properties is offered in the Fuglister Atlas (1960). Compare the sharp boundaries of the cold core eddy at 40 North, 45 West as depicted by the high resolution bathythermograph data (pg. 15) and by the low resolution hydrographic data (pg.41). Internal waves give rise to vertical oscillations of the water. Because of the nature of waves, randomly timed samples are more likely to occur when the wave is near its extreme displacement than when the displacement is small. As a result, isolines in the first type of atlases display meaningless vertical oscillations.

1.3 A New Approach to Oceanographic Data

To deal with climatic change, we must look at existing oceanographic data, not as fixed values, but rather as parameters that change in response to the exchange of heat, water and chemicals and as a result of biological processes. Using our knowledge of the orders of magnitude of such processes, we can numerically simulate the resultant changes of the characteristics of the ocean and its interface with the atmosphere. Such simulations can never prove that specific conditions were actually produced by the assumed forces. However, simulations can identify mechanisms that are inadequate to make a contribution.

Simulations of oceanic processes acting on observed values of oceanic parameters can help us identify times, locations and mechanisms that may be important in climatic change, processes that alter the content of heat and/or chemical substances of the ocean in excess of the normal seasonal cycle. The results of such simulations can then be the basis for planning observational programs that test the proposed models and improve our knowledge of the inferred quantitative relationships. They can assist us in designing monitoring
programs to help predict future climatic change. They help replace statistically inferred correlations by a mechanistic understanding of ocean atmosphere interactions.

2. The Microcomputer, a New Thinking Tool

The scarcity of simulation studies in the past is in part a result of the large effort required to carry out the needed computations and the difficulties of translating the output into comprehensible formats. Recent advances in microcomputer hardware and software have revolutionized our ability to carry out simulations. Complex interactive analyses of oceanographic data can be carried out rapidly and the investigator can scan a variety of graphical outputs almost instantaneously to facilitate thinking constructively about the results.

Recently, I have been exploring the power of these tools for analyzing oceanographic data. To use microcomputers effectively for the analysis of oceanographic and climatic data, one must develop integrated Information Systems.

2.1 Applications Program Based Information Systems

Prior to the availability of powerful microcomputer applications programs, information systems depended on the development of adequate programs using one of the computer languages such as BASIC, Pascal or Fortran. The development of such programs required skilled programmers and the resultant systems were difficult to adapt to changing needs. Programming with applications programs is much easier, the required skills can be learned in a few weeks rather than a few years. Further, the resultant systems can easily be modified and enhanced. Using Lotus 1-2-3 and more recently Lotus Symphony, graduate students without previous computer experience have been able to learn to develop complex information systems in a few weeks. The use of the new generation of software will revolutionize the analysis of environmental data.

A new technology, the use of laser disks to store very large data files (several hundred megabytes) on inexpensive optical disks for use in microcomputers will be available within a year. This will provide an ideal format for information products from environmental data centers. The integration of these files into microcomputer based information systems will provide powerful new tools to deal with the complex problems of environmental and climatic change. I have begun development of the following information systems:

1. A World Ocean Chemistry Information System for information about the "non-seasonal" ocean below 200 meters. The system is designed to provide quantitative information about the chemical characteristics of the World Ocean in order to enlarge our understanding of oceanographic processes.

2. An Ocean Surface Information System to provide information about the variable surface layer of the ocean. This system develops indices of the surface oceans responsiveness to atmospheric forcing and methods to simulate ocean atmosphere interaction.
oceanographic and climate research. The new microcomputer tools can greatly increase the power of scientific analysis. They will also create a demand for new types of products from environmental data centers.

The scientific information systems I am working on are an outgrowth of several years of experience developing Management Information Systems for Coastal Zone Management. With funding from NODC and the William H. Donner Foundation, we have developed a system for the Port of New York and New Jersey and with funding from the Maritime Administration we have developed a system for the Port of New Orleans. Both these systems are available at NODC (contact Jim Audet). The management systems use the Lotus 1-2-3 software operating on an IBM Personal Computer XT.

3. The World Ocean Chemistry Information System

The purpose of this system is to provide a quantitative inventory of the chemistry of the world ocean. The system is an elaboration of the Temperature - Salinity Statistics of the World Ocean pioneered by Montgomery (1985). The statistics are limited to the ocean below 200 meters, to reduce seasonal variability. The GEOSECS data set provides a comprehensive overview. Worksheets have been developed to decompose individual station data into averages over T-S classes using the following class boundaries for potential temperatures (T) and salinity (S):

<table>
<thead>
<tr>
<th>Class</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
</tr>
</thead>
<tbody>
<tr>
<td>T:</td>
<td>-2</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>6</td>
<td>8</td>
<td>10</td>
<td>12</td>
<td>14</td>
<td>16</td>
<td>18</td>
</tr>
<tr>
<td>S:</td>
<td>30</td>
<td>32</td>
<td>34</td>
<td>34.2</td>
<td>34.4</td>
<td>34.6</td>
<td>34.7</td>
<td>34.8</td>
<td>34.9</td>
<td>35.0</td>
<td>35.2</td>
<td>36</td>
<td></td>
</tr>
</tbody>
</table>

A class designation of 207 implies that the potential temperature is equal to or greater than 0 and less than 1 degree and that the salinity is equal to or greater than 34.7 and less than 34.8 ppt.

For a preliminary survey of the chemical compositions of the world ocean, a total of 38 GEOSECS stations covering the extremes of chemical composition have been entered. Each class is further subdivided to isolate separate water volumes in the same T-S class and to separate connected water volumes with distinct water chemistry.

A printout of part of the listings sorted by T-S class is shown as Table 1. The location column (A) indicates the ocean area, 100 for the Southern Ocean, 210 for the South Atlantic and so on. Each row represents vertically averaged data for one station over a layer whose vertical extent is given in column D and the average elevation of the layer is given in column M. Columns A through L are obtained directly from the GEOSECS data. Column N is the computed solubility of oxygen at one atmosphere for the average T and S of the layer. Column O, the O2 loss is the difference between oxygen saturation and the observed average concentration of dissolved oxygen. Additional columns that are functions of the observed parameters, for example the nitrate to phosphate ratio (column Q) can readily be added.
Table 1  GEOSECS Data arranged by T-S Class

<table>
<thead>
<tr>
<th>Loc 1n</th>
<th>Class 2</th>
<th>Pot 3</th>
<th>Bot 4</th>
<th>D 5</th>
<th>Slo 6</th>
<th>Fno 7</th>
<th>NO3 8</th>
<th>All 9</th>
<th>C02 10</th>
<th>Ave 11</th>
<th>O2 12</th>
<th>pH 13</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>E</td>
<td>F</td>
<td>G</td>
<td>H</td>
<td>I</td>
<td>J</td>
<td>K</td>
<td>L</td>
<td>M</td>
</tr>
<tr>
<td>230</td>
<td>121</td>
<td>308</td>
<td>910</td>
<td>1.837</td>
<td>34.899</td>
<td>270</td>
<td>33.7</td>
<td>1.25</td>
<td>18.8</td>
<td>2343</td>
<td>2185</td>
<td>-3176</td>
</tr>
<tr>
<td>210</td>
<td>11</td>
<td>308</td>
<td>111</td>
<td>1.854</td>
<td>34.815</td>
<td>223</td>
<td>70.4</td>
<td>1.98</td>
<td>26.2</td>
<td>2350</td>
<td>2224</td>
<td>-3714</td>
</tr>
<tr>
<td>230</td>
<td>11</td>
<td>308</td>
<td>2178</td>
<td>1.684</td>
<td>34.866</td>
<td>255</td>
<td>51.2</td>
<td>1.50</td>
<td>22.2</td>
<td>2360</td>
<td>2222</td>
<td>-4999</td>
</tr>
<tr>
<td>220</td>
<td>39</td>
<td>308</td>
<td>996</td>
<td>1.627</td>
<td>34.859</td>
<td>258</td>
<td>50.4</td>
<td>1.44</td>
<td>21.7</td>
<td>2354</td>
<td>2202</td>
<td>-6596</td>
</tr>
<tr>
<td>210</td>
<td>103</td>
<td>308</td>
<td>440</td>
<td>1.745</td>
<td>34.829</td>
<td>231</td>
<td>68.2</td>
<td>1.75</td>
<td>25.4</td>
<td>2374</td>
<td>2239</td>
<td>-2304</td>
</tr>
<tr>
<td>220</td>
<td>109</td>
<td>308</td>
<td>1104</td>
<td>1.840</td>
<td>34.869</td>
<td>248</td>
<td>51.5</td>
<td>1.49</td>
<td>22.7</td>
<td>2350</td>
<td>2206</td>
<td>-4950</td>
</tr>
<tr>
<td>230</td>
<td>115</td>
<td>308</td>
<td>752</td>
<td>1.953</td>
<td>34.897</td>
<td>249</td>
<td>48.7</td>
<td>1.50</td>
<td>22.1</td>
<td>2364</td>
<td>2211</td>
<td>-4934</td>
</tr>
<tr>
<td>230</td>
<td>11</td>
<td>308.1</td>
<td>193</td>
<td>1.335</td>
<td>34.882</td>
<td>299</td>
<td>8.3</td>
<td>0.92</td>
<td>14.3</td>
<td>-4478</td>
<td>322</td>
<td>23</td>
</tr>
</tbody>
</table>

- 6 -
The listing can be resorted to find areas in the ocean where specific parameters are anomalous. Alternatively, one can use the data query facilities of the Lotus Symphony worksheet to find all segments where specified parameters have particular values. Selected parameters from selected stations can also be shown in graphical form.

For example, I have been interested in the problem of the storage of excess CO₂ in the ocean. Because they are invariant to temperature changes and vertical displacements, alkalinity and total CO₂ are useful descriptors of the CO₂ system. However, in the sea, the alkalinity and total CO₂ are altered by carbonate precipitation and dissolution and by the oxidation and production of organic matter. If one modifies the total CO₂ concentration by using up all the alkalinity to precipitate carbonates and restores the dissolved oxygen concentration to saturation with the atmosphere at 1 bar, one obtains a parameter that is essentially invariant to these processes. A parameter, the "CO₂ index" is defined by the following equation:

\[ \text{CO}_2 \text{ Index} = \text{Total CO}_2 - \frac{\text{Alkalinity}}{2} - (\text{O}_2 \text{ at saturation} - \text{Actual O}_2). \]

The distribution with depth of this "CO₂ Index" for all T-S classes from the selected GEOSECS stations is shown in Figure 1. The index ranges from a low of 830 to a high of 1012 micromoles/kg. The low value is for Red Sea Water, in the open ocean, the lowest value in the data set is 860, giving a range of only 152 for this parameter. The range in values decreases significantly with depth. High values of the parameter, suggesting the injection of excess CO₂ are found at stations in the North Atlantic (Station 32), The Southern Ocean (Stations 76, 280, 430, 432) and in the SW Pacific (Station 303).

The higher values near the surface, however, only exceed near bottom values by about 30 micromoles/kg. The index as here defined ignores nutrient cycling which affects both the alkalinity and the dissolved oxygen concentration. Since the nutrient concentrations undergo variations of similar magnitude, the index will have to be refined before it can be used to study changes in the storage of CO₂ in the ocean.

So far, only selected stations have been processed. To complete the inventory, the rest of the GEOSECS data must be processed. To assign volumes to the T-S classes, the GEOSECS data set must be supplemented by other hydrographic data. The final product will give the volume for each T-S class by ocean area. This will give us a quantitative estimate of the chemical contents of the world ocean. In addition, the information set can be used to develop dynamic models in T-S space. These consider the change in the ocean content in response to assumed processes of water formation, upwelling and mixing.

The information system, by providing a broad overview of the chemistry of the world ocean will enable us to discern important appropriate questions and, in environmental research, that is a major step towards obtaining answers. The system should find wide application in instruction in descriptive oceanography and in research.
Figure 1.
4. The Surface Ocean Information System

The surface ocean, here defined as the upper 200 meters presents a more formidable problem, since time variations are important. Not only must one deal with seasonal changes, it is the deviations from average seasonal behavior that must be explored to improve our understanding of short term climatic change.

As an initial effort, I have developed indices of the thermal inertia of the sea surface, independent of atmospheric conditions. A draft paper, including results using the West Pacific Profile from the GEOSECS Expedition is appended. It demonstrates the large space-time variability of the sea surface.

A large variety of complex physical, chemical and biological processes take place in the surface layer of the ocean. To help us understand how these processes may lead to climatic change, it is necessary to examine oceanographic data in an iterative way. One starts with a hypothesis. This leads to an examination of average oceanographic parameters to locate the prime regions where the assumed mechanism is likely to be important. Next, one requires hydrographic data from the area. This is combined with quantitative information on the forces acting and their time variability, to develop worksheets that simulated the hypothetical process.

The task is difficult, however, the new tools of analysis are very powerful. The trick is to identify a few tractable problems and develop appropriate simulations that capture the essence of the processes. At worst, one will learn that the proposed mechanism can not be significant. Compared to observational programs, the costs are small. The benefits can lead to important new insights on how the ocean interacts with the atmosphere to produce our climate.

REFERENCES

Fuglister, F. C. 1960; Atlantic Ocean Atlas from the International Geophysical Year; Woods Hole Oceanographic Institution.

