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CLIMATIC FLUCTUATIONS, VOLCANIC AEROSOL

AND

CARBON DIOXIDE CHANGES

Annual Progress Report

Contract Period 1 October 1979- 30 September 1980

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Progress Report

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ABSTRACT

Technical progress made for the contract period 1 October 1979-30 September 1980, and in fact since the last progress report was prepared on 18 June 1979, is summarized. The relationship between tropospheric air temperature, sea surface temperature patterns and volcanic aerosol has been derived by the application of generalized least squares analysis, which takes account of significant autocorrelation between the variables. Up to 50% of the variance of the tropical tropospheric air temperature can be explained in terms of preceding values of the variables. The technique is being applied to make a preliminary climatic forecast of the effect of the Mt. St. Helen's eruption of 18 May 1980 on zonal mean Northern Hemisphere temperature. A regression approach was used to forecast winter temperature over the continental US using parameters from our data base. Techniques for experimental climatic forecasting are being developed and studies of the background sea-air interaction processes are being made.

We have shown that surface effects extend up to at least 500 mb in the atmosphere. Tropical rainfall has been found to vary with the Southern Oscillation Index; this rainfall provides the main energy supply to the atmosphere in the form of latent heat liberation.

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The following is an account of technical progress made since October 1, 1979 and that is expected to be made up to September 30, 1980.

Our main goal is to try to understand the physical processes that produce climatic fluctuations. Two processes that we have been studying are sea-air interaction and the influence of volcanic aerosol on temperature. We have assembled a data set of global monthly mean sea surface temperature (SST) and free air temperature observations and are studying the inter-relation between the two by regression techniques. These data sets are now at the stage where we have been able to begin some experimental climatic forecasting. Data for the Pacific SST's are available from January 1949 to the present. They are gridded when received and zonal means and deviations from long term averages are computed.

Data for March have just been received and by special arrangement with the SW Fisheries Center at La Jolla we have access to the data for April 1980. Our empirical orthogonal function analysis (EOF) of these data indicates that the eastern equatorial Pacific region contributes the largest fraction of the Pacific pattern variance. (This item has been verified in a new analysis by Billing for his S.M. thesis submitted in September 1979; Billings work will be discussed later in this report). During the past year we have performed an EOF analysis on zonal mean SST's computed separately for each ocean; it is again the equatorial Pacific that contributes the largest fraction of the global pattern variance. Because of the importance of this region we compute the zonal mean SST for this region within 3 weeks of the end of each month so that it can be used in our experimental forecasting schemes.

Data for the Atlantic SST's are available from 1949-1972 from 67N to 35S and are received in close to real time from 67 N to 2 N. Again data are mapped and zonal means computed; examples for April 1980 are shown in Figure 1 and Table 1.

The Indian Ocean SST's are available for 1949-1972 but there is a gap in our set after that period. The Dutch group are responsible for reporting for this region but are many years behind in data processing. We have partly rectified this problem by arranging to receive all Southern Hemisphere SST's in close to real time (about 3 weeks after the end of the month). This procedure with gridding and computations of zonal means should be in operation by the end of the current contract period. The historical record for this data set is not available and our records start in January 1979; there is some coverage for the 1949-1972 period for the S. Atlantic and Indian Ocean.

To represent the free air temperature we follow the approach used by Angell and Korshover (Mon. Weath. Rev. 103, 1007-1012, 1975) and represent the zonal mean average temperature of atmospheric layers by the geopotential thickness between pressure levels, computed from monthly mean data. A group of representative radiosonde stations is used for the northern and southern hemisphere extra-tropical regions and for the tropics (as listed in the attached paper by Navato et. al. submitted to Mon. Weath. Rev.)

The other main factor influencing free air temperature is volcanic aerosol in the stratosphere. This is represented by the atmospheric transmission measured at Mauna Loa (available through NOAA for January 1958 to November 1978) and an atmospheric dust index measured at Aspendale, Australia (available from CSIRO for January 1959 to March 1977).

The free air temperature is treated as a dependent variable and related through multiple regression analysis to preceding values of parameters representing volcanic aerosol and sea surface temperature. The statistical details are described in the attached paper by Navato et.al. (submitted to Mon. Weath. Rev.). Up to 50% of the tropical free air temperature may be explained by preceding values of sea temperature and aerosol. The oceanic parameters are of most importance for explaining tropical air temperature evolution. The problem of long autocorrelations in the regression variables was solved by resorting to generalized least squares procedures.

There are three practical applications of these sea-air-aerosol interaction studies that have been made during the current year:

1) Winter temperature forecasts for the Continental U.S.

Dr. Navato made forecasts of January mean temperature for 12 cities in the U.S. Three predictors were selected by step-wise regression from zonal mean SST for the equatorial Pacific for selected months and the Southern Oscillation Index derived from Easter Island and Darwin pressures. The results, supplied to the Lawrence Livermore Laboratory for their "consensus" forecast on November 30, 1979 showed an expectation of an above-normal January for the East Coast and a colder than normal central region. These two areas were forecast correctly but the West Coast was forecast as normal or below and turned out to be above normal. This was our first participation in the consensus forecast. Our limitation was again readily available almost-real-time data. We have brought the Atlantic up to date also in the current year and are in the process of including the Southern Hemisphere. Participation next year should be possible with the global oceanic data up to September 1980.

2) Forecast of equatorial Pacific zonal mean temperature.

As noted several times above this parameter seems to be a valuable predictor of subsequent air temperature changes. It is also generally related to the occurrence of El Niño of Peru, which has major economic consequences. This year we continued to take part in the SCOR Working Group 55 El Niño forecasting effort. Rennie Selkirk, a first year graduate student, developed a regression model of the Pacific zonal mean SST, 75°W to 140°W at 2.5°S; this parameter is highly correlated with El Niño occurrences. The model uses two parameters: the 2.5°S zonal mean SST at 2, 3, and 4 months leads, and a 5-month average of the Southern Oscillation Index at leads of 3, 4, and 5 months. The Southern Oscillation Index is computed from the pressure difference between Darwin and Easter Island. He has made three three-month forecasts with this model. This exercise has proved very valuable in drawing attention to problems with the specification of El Niño. In 1980 the forecast has been for above-average temperatures; these have actually occurred off the coast of Peru but do not yet show in the zonal means used for verification. Selkirk is presently examining time series of temperature from regions near the coast to try to establish a better specification of El Niño; he is also relating surface wind patterns provided by Prof. Wyrtki at Hawaii to temperature changes.

3) Forecast of northern hemisphere temperature effect of Mt. St. Helens eruption on 18 May 1980.

The regression approach described by Navato et. al. in the attached paper is being applied to northern hemisphere zonal mean temperature to try to assess the approximate magnitude of the change to be expected during 1980.

A predictor resembling the first EOF for the Atlantic is to be used based on zonal mean SST's at 20N and 42N together with a predictor for the Pacific SST and one to represent dust. We note that while the North Pacific is presently cold the Atlantic at 42 N is warmer than average so that the influence of the aerosol will be partly offset. It will be our aim in the next few weeks to make a quantitative estimate of this partial compensation.

We intend to monitor the situation closely and revise our numbers monthly as new data are received. We shall also include real dust index data as soon as possible. Notice that there is no middle latitude dust monitoring station in the Northern Hemisphere with a good record. In Navato et al. (1980) we recommended that such a station be established. We believe that the value of keeping the ocean data current is shown by this. Within a few weeks of the eruption we expect to be able to obtain a first estimate of its effect on Northern Hemisphere temperature which can be revised as more details about the stratospheric aerosol becomes available. Dr. Navato reviewed the regression approach to the study of volcanic effects at the NOAA Climate Diagnostic Workshop held at Madison, Wisconsin in October 1979 (see attached paper). Considerable interest was shown in his work.

The influence of Mt. Agung in March 1963 on tropospheric temperature has been further studied by geopotential differences for the layers 850-700, 700-500, 500-300, 300-200, 200-150, and 150-100 mb. There was a one degree decrease in the tropical upper troposphere which is thought to have been caused by depletion of near-infrared radiation by stratospheric aerosol. Concomitantly, stratospheric temperature increased, possibly by the absorption of this near-infrared energy. Normally the troposphere is heated by the absorption of near-infrared by CO₂, O₂, and H₂O. This work (see attached paper) was presented by Newell to the IUGG Symposium on Volcanoes and Climate held in Canberra Australia in December 1979.

Those papers from this Symposium which survive the reviewing process will be published in a single issue of "Paleogeography, Paleoclimatology, and Paleoecology."

As part of our air-sea interaction studies we have made an harmonic analysis of zonal mean sea surface temperature for each ocean as well as a spectral analysis of the data for each grid square. The zonal mean results were presented and discussed by Newell and L. Chiu (a graduate student supported here by NSF) as part of a paper "Climatic changes and variations: a geophysical problem," given at the NATO Advanced Study Institute on Climatic Variations held in Erice, Sicily in March 1980. This paper includes several items from our recent work on sea-air interactions. It is to be published later this year in a book summarizing the Institute (a copy is attached to this report). The spectral analysis results which are particularly relevant to the biennial oscillation will be submitted for publication later this summer.

In the Erice paper we demonstrate that the influence of the lower boundary is felt in the atmosphere up to heights of at least 500 mb. We also show that the "Greenland seesaw" phenomenon discussed from surface data by Van Loon and Rogers (Mon. Wea. Rev. 106, 296-310, 1978) is the most important non-seasonal component of the circulation in middle latitudes up to 500 mb; this pattern shows the largest eigenvector in EOF analyses. We are investigating whether this indication of order in the non-seasonal air temperature patterns is related to the patterns of sea surface temperature fluctuations.

We have obtained a tape of Pacific trade wind data for the 28 year period beginning 1947 from Prof. Wyrski at the University of Hawaii. Although the difficulty of obtaining similar data in "real time" prohibits our use of the wind data in our forecasts of the zonal mean temperature (see above), we have been able to examine the relationship of these observed winds to sea surface temperatures and our Southern Oscillation Index. Among other findings, we have verified the strong connection between equatorial mid ocean sea surface temperature and surface windstress. We are also looking at the relationship between the surface and 200 mb winds with respect to the Walker circulation.

Two students supported under this contract completed S.M. theses since the last Progress Report: Billing in September 1979 and Stoeckenius in February 1980. Billing's work was entitled "Statistical predictability of Pacific Ocean surface temperature anomalies." He

made a new EOF analysis of the Pacific SST's. The first eigenvector showed the strongest weight in the equatorial Pacific with an opposite sign weight in the North Pacific. The second eigenvector was dominated by a discontinuity in the data set in 1963 (discovery of poor data is one of the fringe benefits of eigenvector analysis). The third resembles the patterns for the North Pacific discussed by Namias and Davis (see refs. in Erice paper). Billing reported some success with prediction of the SST fields using a first order autoregressive model and he applied his approach to the El Niño prediction work which we have done as part of the SCOR Working Group 55 oceanic forecast described earlier. Stoeckenius' thesis was entitled "Interannual variations of tropical precipitation patterns." The preferred mode of variation turned out to be governed by the Southern Oscillation Index (obtained from the difference of pressure between Darwin and Easter Island). He interpreted his results in terms of modulation of the equatorial zonal circulations, often termed the Walker circulation. Our other studies have shown this index and these circulations to be related to sea surface temperature changes. This work has great importance for the main energy supply to the atmosphere is through latent heat liberation. Stoeckenius' work has been submitted to Monthly Weather Review for publication.

An undergraduate, Crystal Barker, is doing further studies of the modulation of the Walker circulation from satellite wind data. Her participation in the MIT UROP program (Undergraduate Research Opportunities Program) is at no cost to the contract. She finds significant latitudinal and longitudinal shifts in the Walker circulation cells from year to year. Her work is being coordinated with the wind and sea temperature studies by Selkirk.

During the summer we are planning to perform further work on the CO₂ problem. We advertised for a person to work on this problem here at MIT and after conducting a search and holding interviews we offered the post to a highly qualified woman mathematical physicist. Unfortunately another university offered her better prospects. We have therefore initiated another search. Meanwhile we have made a temporary appointment of a recent graduate physicist who will work on the problem during the summer. The first step will be to run the radiation program for a number of different water vapor distributions. In our previous publication on this topic we only made "a first iteration" with higher water vapor. (J.App.Met. 18, 822-825, 1979). As the water content

increases so also does the infrared cooling rate and we plan to explore this dependence. Some comments critical of our paper have been submitted to JAM and we are presently composing a reply.

Bob Chen a half-time Research Assistant last year left in June 1979 to take up a post with the National Climate Board and has not yet completed his SM thesis concerned with zonal mean air temperature that was described in the last report.

Meetings Attended.

Dr. Alfredo Navato attended the NOAA Climate Diagnostic Workshop in Madison, Wisconsin in October 1979. (paper attached)

Newell attended the IUGG General Assembly in Canberra, Australia in December 1979. Travel funds were provided by NSF and much of Newell's time at Canberra was taken up with IAMAP business in his role as President of the IAMAP Commission on Climate. DOE funds were used for the paper on the influence of volcanoes on climate presented by Newell to the IUGG Symposium on Volcanoes and Climate (paper attached).

Newell also attended the DOE meeting on CO₂ held in Washington in April 1980.

Professional personnel.

The PI devoted 30% of his time to the project during the academic year and one full time month during the summer. Dr. Alfredo Navato has again worked half time for this contract as a scientific programmer. At present there is a one temporary research staff physicist working on CO₂ problems (Jay Olaguer, B.Sc.) and there are two Research Assistants (Rennie Selkirk and Wesley Ebisuzaki). In the fall the two Research Assistants will be Rennie Selkirk and Jane Hsiung, formerly of our group who will return to MIT in September 1980.

Scientific papers.

Four papers presently being submitted for publication are attached:

1. Navato, A.: Influence of Volcanic aerosols and oceanic surface temperatures on tropospheric temperatures. NOAA Climate Diagnostic Workshop, Madison, Wisconsin in October 1979. (in press).
2. Navato, A., et al.: Tropospheric mean temperature and its relationship to the oceans and atmospheric aerosols. Mon. Wea. Rev.
3. Newell, R.E., L.S. Chiu: Climatic changes and variations: a geophysical problem. NATO-ASI on 'Climatic Variations and Variability: Facts and Theories,' held at Erice, Italy, March 9-21, 1980. (in press)
4. Newell, R.E.: Further studies of the atmospheric temperature change produced by the MT. Agung Volcanic eruption in 1963. Paleogeography, Paleoclimatology, and Paleoecology (in press).

Two reprints have become available since the last Progress Report and are included here:

1. Newell, R.E., J. Hsiung, 1979: Fluctuations in zonal mean sea surface temperature. Rivista Italiana di Geofisica e Scienze Affini, 5, 151-155.
2. Newell, R.E., 1979: Climate and the ocean. American Scientist, 67, 405-416.

ATLANTIC OCEAN SEA SURFACE TEMPS, IN 1/10TH DEG. C														1 YEAR= 80, MONTH= 3											
1	0	975	925	875	825	775	725	675	625	575	525	475	425	375	325	275	225	175	125	75	25	-25	-75	-125	-175
1	0	675																	999	999	47	56	51		
2	0	625										999	999	54	60	64	71	72	72	74	77	68			
3	0	575										37	41	48	999	999	94	96	97	99	70	58	54		
4	0	525										39	73	73	86	98	107	114	109	96	90	75	66		
5	0	475								11	12	32	104	125	126	127	126	123	120	114	109				
6	0	425						68	85	94	85	111	152	153	154	148	144	139	136	134	128				
7	0	375					158	191	187	187	179	177	174	176	171	170	173	166	164	166					
8	0	325				228	208	197	195	198	195	194	193	194	195	194	193	188	182	177					
9	0	275	999	999	236	233	243	232	230	223	226	220	219	220	222	221	217	209	204	190					
10	0	225	999	999	263	265	264	259	253	252	249	247	240	233	232	243	225	228	209						
11	0	175		302	273	272	269	265	260	269	254	257	253	249	238	240	234	215							
	0	125			266	268	261	264	265	269	259	257	252	250	999	256	248	234							
	0	75									278	264	999	269	272	268	276	277	283						
	0	25											277	283	275	280	279	999	290	285	289	288	283		
ATLANTIC OCEAN SEA SURFACE TEMPS, IN 1/10TH DEG. C														1 YEAR= 80, MONTH= 4											

FIGURE 1.

	80	4	$\sum T_s$	$[T_s]$
1		3	154	5.10
2		9	612	6.80
3		8	606	7.50
4		11	987	8.90
5		10	1106	11.00
6		10	1399	13.90
7		9	1537	17.00
8		9	1710	19.00
9		13	2833	21.70
10		12	2875	23.90
11		12	3003	25.00

TABLE 1.