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Semi-Annual Progress Report

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Semi-Annual Progress Report for the period 4/1/91-9/30/91

TASK A: CLIMATE AND ATMOSPHERIC MODELING STUDIES

Climate Model Development and Applications

The research conducted during the past year in the climate and atmospheric modeling programs has concentrated on the development of appropriate atmospheric and upper ocean models, and preliminary applications of these models. Principal models are a one-dimensional radiative-convective model, a three-dimensional global climate model, and an upper ocean model. Principal applications have been the study of the impact of CO_2, aerosols and the solar 'constant' on climate.

Progress has been made in the 3-D model development towards physically realistic treatment of these processes. In particular, a map of soil classifications on 1° x 1° resolution has now been digitized, and soil properties have been assigned to each soil type. Using this information about soil properties, a method has been developed to simulate the hydraulic behavior of soils of the world. This improved treatment of soil hydrology, together with the seasonally varying vegetation cover, will provide a more realistic study of the role of the terrestrial biota in climate change.

A new version of the climate model has been created which follows the isotopes of water and sources of water (or colored water) throughout the planet. Each isotope or colored water source is a fraction of the climate model's water. It participates in condensation and surface evaporation at different fractionation rates and is transported by the dynamics. A major benefit of this project has been to improve the programming techniques and physical simulation of the water vapor budget of the climate model. Applications include simulations of deuterium and oxygen-18 for both current climate and 18,000 years ago, the source of precipitation in each grid box in the North Hemisphere, and a stratospheric tritium experiment to simulate the atomic testing of the 1950s and 60s (Koster et al., 1990).

During the past year, papers have been published, which investigate the impact of altered ocean heat transport on climate (Rind and Chandler, 1991), and the likelihood of future drought caused by the projected increase in temperatures (Rind et al., 1990).

Modeling of the climate and vegetation change of the last 30,000 years, and of the Little Ice Age, has begun with the assistance of Rick Healy and initial attempts to compile appropriate boundary conditions for GCM runs.

Paleoclimatic work in progress centers on both the Atlantic and Pacific coasts. The North Atlantic research continues on the record of vegetation and climatic change from 18,000 years ago to the present. Pollen analysis from Allamuchy Pond, western New Jersey, and Linsley Pond, Connecticut cores, as well as macrofossil identifications from both sites have been completed. Accelerator mass spectrometry (AMS) dating on macrofossils from both cores indicates the presence of the Younger Dryas reversal, from 11,000-10,000 yr BP. These results are being summarized for publication in Quaternary Research. The southeastern U.S. paleoclimate research has continued, and M. Kneller (Graduate Research Associate, Columbia University) ahs completed the pollen, macrofossil, and loss-on-ignition record for one site, Brown Pond, Virginia, which extends to 18,000 yrs BP. She has re-cored the site several times, and is working on the correlation of the stratigraphy from one core to another. AMS dating of the core will provide a high-resolution chronology. The data will be presented for her orals.

Results from the North Pacific initiative on tephra deposits in southeastern Alaska will be published shortly (Rheile et al., 1991). A record of climatic and vegetation migration history in southeastern Alaska has also been published recently (Peteet, 1991).

North Pacific field work last summer resulted in the acquisition of basal peat from about 40 peat cores in Alaska. The sites range from the Kenai Peninsula northwestward in permafrostareas to the Yukon-Kuskokwim Delta. The frozen peat reaches at least 6 meters depth in some regions. This material will be analyzed in the coming year.

The computer code of the ocean general circulation model has been streamlined so that different numerical treatments can be implemented and tested. The streamlined code has been verified against the simulations of Cox (1984). Progress has been made in implementing several vertical differencing schemes in the model, which include second and fourth order schemes. Sensitivity experiments are ongoing to test the effects of these schemes. A paper on computational diffusivity in the ocean model has been published in J. Geophys. Res. (Yin and Fung, 1991).

A necessary step in using ocean color data to understand the ocean's role in the global carbon cycle is the derivation of incident solar radiation at the surface, as a forcing term for marine productivity. A computationally-efficient scheme for deriving surface solar radiation has been developed. The scheme incorporates 3-hourly data on cloud properties derived from the International Satellite Cloud Climatology Project.

Comparison with ground truth shows that the scheme is accurate to ± 7 w/m^2. The paper documenting the algorithm and results will appear in the Journal of Geophysical Research (Bishop and Rossow, 1991).

Research has been initiated to study the natural ocean variability on a thousand year time-scale. This research project utilizes the NASA-GISS version of Cox's oceanic general circulation model to perform a hierarchy of numerical experiments. A first set of experiments was initiated for an idealized sector model describing one third of the world ocean, and one third of the world land masses, but with a geometry similar to the Atlantic ocean, which describes a dynamically important part of the world ocean. This idealized model is designed to have some realistic characteristics, such as the transport of the circumpolar current.

The ocean model has coarse resolution, with a horizontal grid spacing of 5 degrees longitude by 3.91 degrees latitude, and 15 vertical levels. The model has been run for the barotropic case; a baroclinic run initialized from zonally averaged climatological data is being performed, aimed at describing the equilibrium of the ocean in time scales of decades. A second experiment is being run initialized from rest, that will describe the ocean response to climate forcing at longer time scales.

The model physics was modified to include Philander and Pacanowski's parameterization of viscosity and diffusivity, to better describe the main thermocline. Complete mixing of gravitationally unstable parts of water columns is being introduced, for a better description of deep convection. Updated equations of state are used, fitted to give in situ density as a function of potential temperature.

Sensitivity studies were applied to the diffusion parameters, choosing 8×10^9 cm^2/sec and 1.6×10^8 cm^2/sec for horizontal viscosity and diffusivity respectively. The time steps are 1 day for thermodynamic variables and 1 hour for dynamic variables. Experiments for climate variability will be performed with this model.

A coastal hazards data base is being compiled to identify shorelines at high risk to future sea level rise, attributed to climate warming. Data compilation has been completed for geological variables, for the U.S., and the data base is currently being extended into Canada and Mexico (Gornitz, 1990, 1991). Six additional climatological variables, relating to storm frequency and intensity, are being added to the data base. An overall coastal vulnerability index, CVI, combines the relative risk factors of each of the variables, relating to inundation and erosion hazards. Experimentation with various forms of CVI and weighting factors is in progress.

The CVI has been used to identify high risk areas along sections of the East Coast, including parts of Cape Cod, Long Island and the New Jersey barrier beaches, the North Carolina Outer Banks, the southern Delmarva Peninsula, and the Georgia-South Carolina. Other high risk regions include the Louisiana-Texas coast and the Sacramento-San Joaquin Delta, California. Results to date were presented at the recently concluded Coastal Zone 91 Conference, in Long Beach, CA (Gornitz et al., 1991).

SAGE II

In accordance with the task to carry out modeling and interpretation of SAGE II data, a 23-level version of the 3-D GCM to be used has been developed. This model extends from the surface up to 0.01 mb (≈85 km).

Model improvements during the past year include the incorporation of gravity wave-induced stratospheric drag. With the incorporation of parameterization for model generated gravity waves from the sources of topography, wind shear and convection, realistic simulations of the middle atmospheric climatology have been made. An analysis of the SAGE retrieval of water vapor in the tropical lower stratosphere has been investigated.

A paper has been recently published, which investigates the impact of doubled CO_2 on the climate of the stratosphere (Rind et al., 1990).

TASK B: CLIMATE APPLICATIONS OF EARTH AND PLANETARY OBSERVATIONS

Cloud Climatology

During the past year, further refinements were made to the analyses of cloud detection over polar regions and winter land areas. For the polar regions, the use of the 3.7 km wavelength channel on AVHRR helps to detect optically thin, low-level clouds missed by the regular cloud detection method. This raises the ISCCP annual mean cloud amount in the Arctic to about 60%, which is in better agreement with the estimates based on surface observations. The variations of land surface temperature cause some false cloud-detection; however, the estimated error in the satellite-based surface temperature is about 3-4K, which is smaller than the 6K assumed in the cloud detection algorithm. If the infrared threshold is lowered from 6K to 4K, the average cloud amount over higher latitude land areas is increased by about 3-5%, producing very good agreement with surface observations. Descriptions of both of these results are being prepared for publication.

The initial study of tropical convection using ISCCP data showed that the occurrence of deep convection is not simply related to sea surface temperature (SST). There are both locations with high SST that do not have convection and locations with low SST that do (Rossow and Schiffer, 1991). Further analysis of observations to determine the reasons for these variations of tropical convection, which do not simply follow warmer SSTs, as commonly supposed, has shown that the moisture budget of the marine boundary layer plays a key role in inhibiting convection over some warm water areas; convection is also stimulated over colder water by dynamical de-stabilization of both the boundary layer and the lower troposphere. A preliminary examination of changes in convection during El Nino events also shows that the nature of the shift in convective properties associated with this slow change is not the same as the rapid variations that occur on daily to monthly time scales. These results, presented by R. Fu at the international Tropical Ocean Global Atmosphere Conference, formed part of Fu's Ph.D. thesis, that was successfully completed and defended this year.

The extensive analysis of the variations of the optical thickness of low level clouds, at low and middle latitudes, for one whole year, has been presented at the American Meteorological Society Conference on Atmospheric Radiation, and submitted for publication. The analysis is continuing by investigating the role played by other factors that can influence the cloud optical thickness, primarily cloud vertical extent. This study, combining satellite and surface weather observations, can also look at the large scale synoptic relationships that control the properties of low-level cloudiness. The significance of these optical thickness variations with temperature is being tested in a diagnostic model, that evaluates the implied radiative feedback. This work forms the thesis research of one GRA.

The new cloud parameterization for the GISS climate GCM continues to be tested by comparisons against the ISCCP data and by performing climate sensitivity studies with the climate model.

Testing of the cloud particle size retrieval scheme also continues. A preliminary survey of cloud particles sizes, over one month of global data, shows excellent agreement with available information. In particular, the systematically larger sizes in marine clouds, as compared to land clouds, is readily apparent. This study already shows that the relationship among cloud particle size, optical thickness and water content is more variable than commonly assumed in most climate models. This work constitutes the thesis research of another GRA.

Comparisons of ISCCP cloud properties, microwave-based and surface-observed estimates of preciptitation show that cloud type is strongly correlated to precipitation amounts only in the tropics. No clear relation seems to hold at higher latitudes. Thus, the research effort has shifted to a comparison of ISCCP and microwave values of cloud water content. If good agreement can be obtained for liquid water clouds, then the difference for mixed-phase clouds at higher latitudes can be used to estimate cloud ice contents for the first time. Moreover, if these estimates of cloud water content can be made accurately enough, it may be possible to estimate precipitation from a microphysical model. This work represents the thesis research of a third GRA.

The analysis of infrared spectra of Jupiter's atmosphere collected by Voyager has been concluded, resulting in four papers so far (Carlson et al., 1991a-d). The first paper is a re-analysis of the determination of the abundance of water on Jupiter that shows that earlier analyses, which neglected or mis-represented cloud spectral effects, were incorrect in claiming that the water to hydrogen ratio is sub-solar. Our analysis places a lower limit on this ratio of 1.5 times the solar value. The second paper refines the earlier analysis of the vertical and horizontal variations of the two species of hydrogen to show that their abundance ratios are influenced by equilibration on ammonia cloud particle surfaces and are significant indicators of atmospheric motions. The third paper completes a detailed analysis of the North Equatorial Belt, retrieving the properties of three cloud layers, the temperature profile, and the abundances of seven gas species. The fourth paper extends this analysis to the other low latitude regions and shows that the correlated variations of gas abundances, temperature and cloud structure all provide consistent indicators of atmospheric motions.

Global, total solar and thermal infrared fluxes at the top of the atmosphere and at the surface have been calculated for six months using cloud, surface and atmospheric datasets from ISCCP. Validation studies and sensitivity tests are continuing. Initial results were presented at the American Meteorlogical Society Conference on Atmospheric Radiation. Routine calculations will begin to produce such datasets covering several years, including an El Nino event. These results will be used to study cloud radiative feedbacks on synoptic, seasonal and longer-term variations.

The simpler method for calculated surface solar irradiance has been completed and tested. The method is described, along with the early analysis results, in a paper submitted to the Journal of Geophysical Research.

ISCCP deep convective cloud indices have been combined with Climate Analysis Center sea surface temperatures (SST), Florida State University surface wind data, as well as radiosonde temperature and humidity profiles, in order to explain the large-scale distribution of deep convection over the tropical Pacific Ocean. Deep convection and convergence lead the seasonal migration of SST by several months. Convection can be suppressed over warm ocean waters because of either a stable layer capping the Pacific Bottom Layer (PBL) or low PBL humidity. The sense of cloud feedback in the tropical Pacific on interannual time scales can be either negative or positive depending on the spatial scale over which the data are averaged (Rong Fu, Ph.D dissertation, 1991; Fu et al., 1990).

Planetary Studies

Tracking techniques for deducing winds above the visible cloud level on Venus have been refined and applied to additional image pairs. A manuscript describing the retrieval of ortho-para hydrogen fractions on Jupiter, including regional differences and implications for vertical structure and dynamics, was submitted for publication.

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TASK C: CHEMISTRY OF EARTH AND ENVIRONMENT

As part of the joint Goddard Institute for Space Studies - Lamont-Doherty Geological Observatory program several projects have reached near completion or are well underway.

As described in the previous semi-annual progress report, the link between atmospheric water vapor transport and salt transport through the sea has been studied. The fresh water balance of the major ocean basins influences the density stratification and therefore the stability of the water column. Atmospheric import or export of fresh water into regions of deep water formation (Antarctic and North Atlantic Oceans) might influence these processes significantly.

During the last year, the Atlantic fresh water balance using the GISS 4° x 5° grid model was examined under three climate scenarios: current climate (control run), double CO_2 and the last glacial maximum (18000 BP). Furthermore, the same calculations were done with a data set of observations of wind and humidity compiled by Oort (1983).

Results are summarized below (see also Zaucker and Broecker, 1991, Appendix I):

- The Atlantic drainage basin looses about twice as much fresh water in the double-CO_2 scenario than in the control run (0.30 Sv versus 0.13 Sv). The estimate for the fresh water balance of the Atlantic Ocean based on Oort's data set (0.32 Sv) is significantly larger than the result from the control run [Zaucker and Broecker, 1991; Table 1].

- The transport patterns ([Zaucker and Broecker, 1991; Figures 1 and 2]) in the model runs and Oort's data set show large differences especially near mountain ranges. This is probably caused by an inadequate representation of high orography in the model (averaging over a grid box).

- Using the same drainage divides as in the control and double-CO_2 run, a freshwater loss by the Atlantic of 0.24 Sv occurred in the glacial climate scenario. This preliminary result should not be taken too seriously, however. The large ice shields over North America and Europe must probably be taken into account when defining the drainage divides. Especially during the growing period of the ice shields not much water raining onto them will run off into the rivers and oceans. Work on this subject is currently in progress.

Figures 3 and 4 show some results of the ^{222}Rn runs with the GISS 8° x 10° grid model. The differences of the uniform (1 atom/cm^2/sec) and the source function defined by Dörr [1991] can clearly be seen in regions with stronglyvarying soil grain sizes. This variable source function is certainly a first order approximation. Some regions, especially wetlands and tropical rain forests must be studied in much more detail (dependency of source strength on soil moisture, etc.).

In addition to the work on water vapor and radon, three student projects have been funded from this Cooperative Agreement during the last year. A brief summary of their research activities follows.

1) **Rachel Oxburgh: The role of the oceanic $CaCO_3$ cycle in glacial to interglacial atmospheric CO_2 change:**

Evidence has been recently uncovered that the glacial to interglacial change in $CO_3^=$ ion concentration in the deep sea is underestimated because the true change has been masked in the sedimentary record by chemical erosion. Intense $CaCO_3$ dissolution during times of peak interglaciation exhumes $CaCO_3$ rich sediments of glacial age. ^{14}C and ^{18}O measurements on foraminifera from thse sediments will be made in an attempt to reconstruct the true $CO_3^=$ change. The cause of this change and its impact on the CO_2

content of the atmosphere will also be investigated. While these results are aimed at understanding the natural CO_2 changes associated with glacial cycles, they also have applicability to what will occur as fossil fuel CO_2 builds up in the deep sea.

2) Jordan Clark: Noble gas temperatures for glacial age aquifer water:

An enigma exists with regard to the temperature distribution on our planet during glacial time. The position of the snowlines on tropical mountains suggest that a 5°C cooling occured several kilometers above sea level. By contrast, planktonic forminifera from deep sea sediments, both through their relative abundances, and through their oxygen isotope ratios, indicate that the tropical sea surface temperature was only 1 ± 1°C colder during glacial time. As means of attacking this problem, the Lamont-Doherty group headed by Peter Schlosser has been studying water from deep aquifers, which through water isotope ratios and radiocarbon to carbon ratios, can be shown to have left the surface during glacial time. The objective is to use the noble gas concentrations in this water to obtain soil temperatures for glacial time. So far, research of this type has shown that in Europe, North America and South Africa, temperatures were about 5°C colder during glacial time. Jordan Clark is working closely with this group and checking some the assumptions associated with this method. For example, is the chemical composition of the salt in this water consistent with a simple piston-like flow? What factors other than radioactive decay influence the $^{14}C/C$ ratio?

3) Jo Lin: Comparison of uranium series and radiocarbon ages on tufas from the shorelines of Lake Lahontan.

Closed-basin lakes of desert regions are the best recorders of precipitation rate changes associated with glacial cycles. The water reaching these lakes from their mountain-fed rivers can only leave by evaporation. Hence the size of the lake (and also the elevation of the lake surface) changes with changing precipitation. In the Great Basin of the United States, these lakes were larger during glacial time than they are today. Of particular interest are the highest levels which were achieved around 13,500 years ago, which is when deglaciation began on a global scale. This period of very high precipitation falls between two major steps in the warming of northern Europe. The first is the deglaciation of the major Alpine valleys, which occurred between 14,800 and 14,200 radiocarbon years ago. The second is the sudden appearance of trees 12,800 radiocarbon years ago, in the Alpine Valleys, and the associated 3‰ shift in the $^{18}O/^{16}O$ ratio of $CaCO_3$ deposited in Swiss Lakes. What was global climate like during the interval between these events? Could the high precipitation rates in the Great Basin be related to a larger scale climatic pattern? The first step in this study is to document the reliability of the age of the high shorelines. Jo Lin is doing both radiocarbon and ^{230}Th - ^{234}U dating of tufas from this shoreline. As the tufas contain ^{232}Th, a number of samples must be measured to construct an isochron. A first attempt yielded a ^{230}Th age of 16,000 years for tufas previously dated at 13,500 radiocarbon years. The 2500 year difference between these ages agrees with Bard et al.'s finding for Barbados corals of this age. Hence it appears that the timing of this event does lie between that of the Alpine deglaciation event and the Alpine reforestation event.

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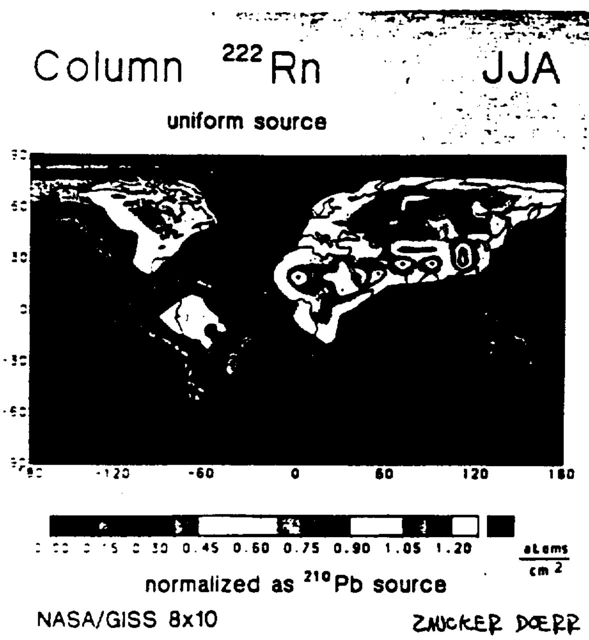
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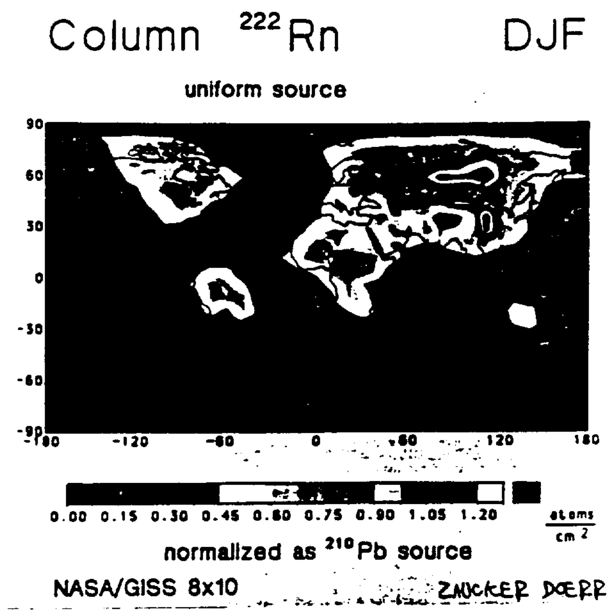
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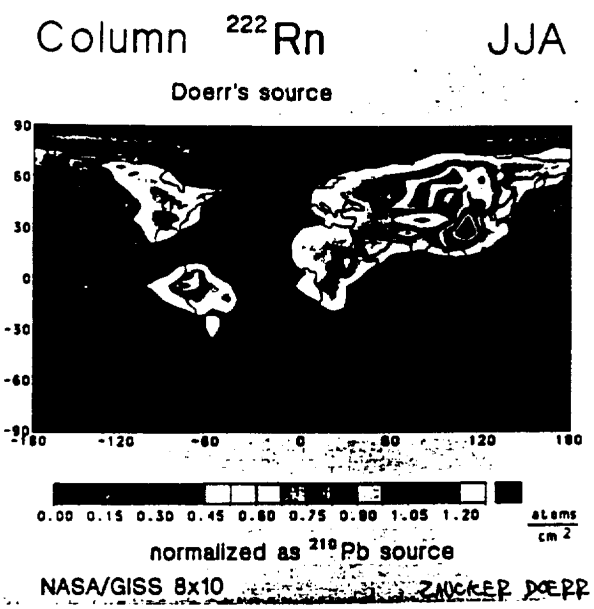
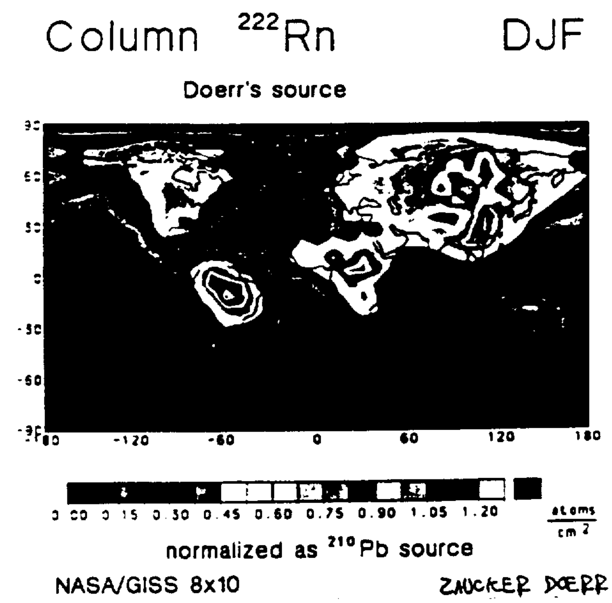
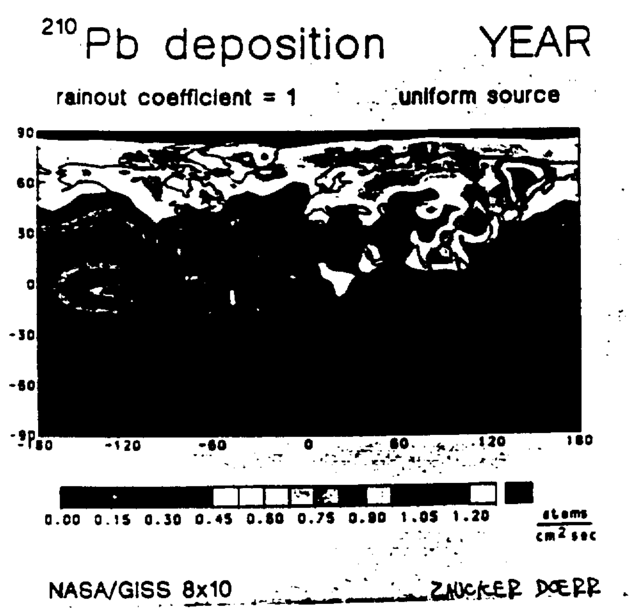
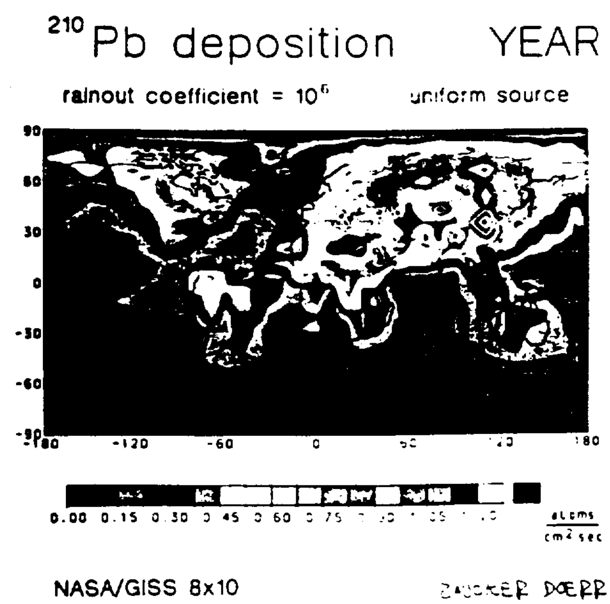
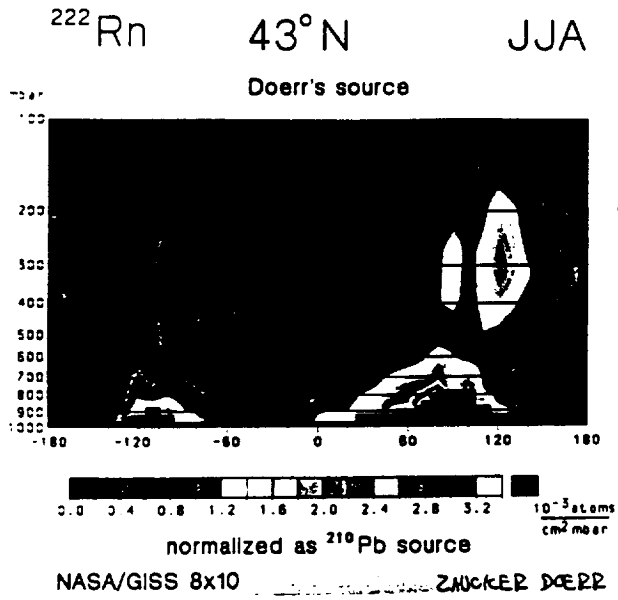
0.00 0.15 0.30 0.45 0.60 0.75 0.90 1.05 1.20
atoms/cm2
normalized as 210Pb source
NASA/GISS 8x10
ZMUCKER DOERR

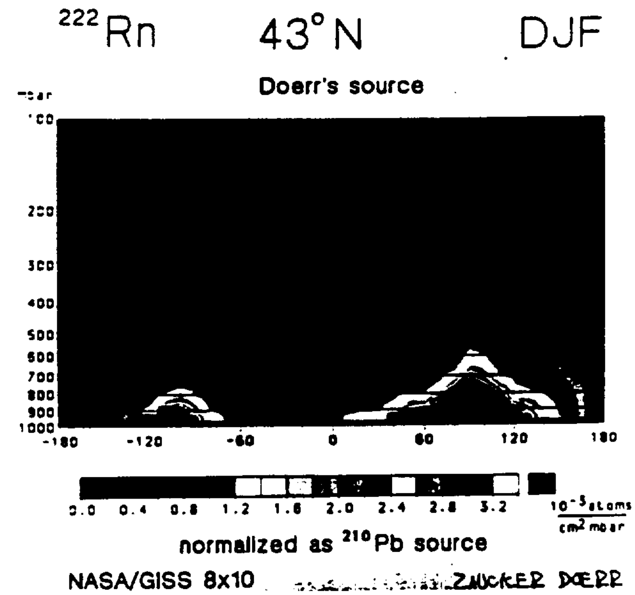

Column 222Rn JJA
Doerr's source
90
60
30
0
-30
-60
-120
-60
0
60
120
180
0.00 0.15 0.30 0.45 0.60 0.75 0.90 1.05 1.20
atoms/cm2
normalized as 210Pb source
NASA/GISS 8x10
ZMUCKER DOERR

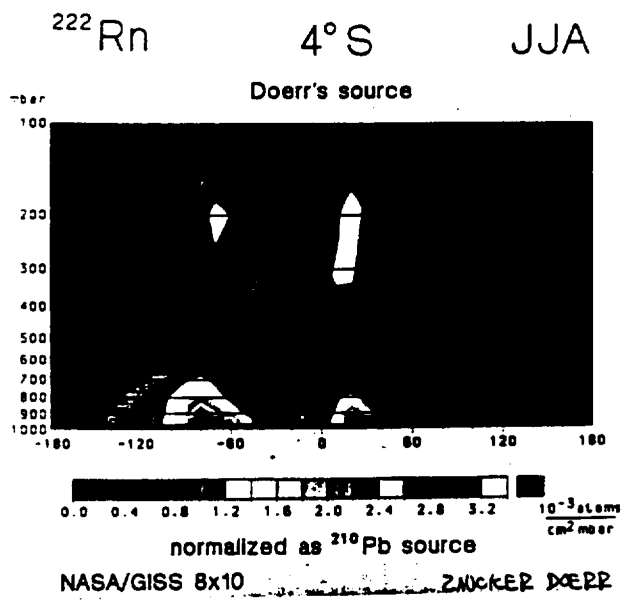

Column 222Rn DJF
Doerr's source
-120
-60
0
60
120
180
atoms/cm2
normalized as 210Pb source
NASA/GISS 8x10
ZMUCKER DOERR

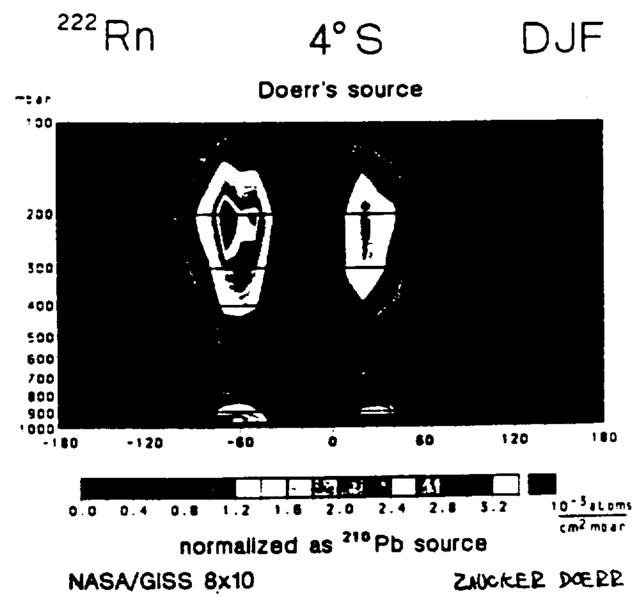

210Pb deposition YEAR
rainout coefficient = 1
uniform source
90
60
30
0
-30
-60
-120
-60
0
60
120
180
0.00 0.15 0.30 0.45 0.60 0.75 0.90 1.05 1.20
atoms/cm2 sec
NASA/GISS 8x10
ZMUCKER DOERR


210Pb deposition YEAR
uniform source
90
60
30
0
-30
-60
-120
-60
0
180
atoms/cm2 sec
NASA/GISS 8x10
DOERR


²²²Rn 43°N JJA
Doerr's source
mbar
100
200
300
400
500
600
700
800
900
1000
-180 -120 -60 0 60 120 180
0.0 0.4 0.8 1.2 1.6 2.0 2.4 2.8 3.2
10⁻³ atoms / cm² mbar
normalized as ²¹⁰Pb source
NASA/GISS 8x10
ZUCKER DOERR


²²²Rn 43°N DJF
Doerr's source
mbar
100
200
300
400
500
600
700
800
900
1000
-180 -120 -60 0 60 120 180
0.0 0.4 0.8 1.2 1.6 2.0 2.4 2.8 3.2
10⁻³ atoms / cm² mbar
normalized as ²¹⁰Pb source
NASA/GISS 8x10
ZUCKER DOERR


²²²Rn 4°S JJA
Doerr's source
mbar
100
200
300
400
500
600
700
800
900
1000
-180 -120 -60 0 60 120 180
0.0 0.4 0.8 1.2 1.6 2.0 2.4 2.8 3.2
10⁻³ atoms / cm² mbar
normalized as ²¹⁰Pb source
NASA/GISS 8x10
ZUCKER DOERR


²²²Rn 4°S DJF
Doerr's source
mbar
100
200
300
400
500
600
700
800
900
1000
-180 -120 -60 0 60 120 180
0.0 0.4 0.8 1.2 1.6 2.0 2.4 2.8 3.2
10⁻³ atoms / cm² mbar
normalized as ²¹⁰Pb source
NASA/GISS 8x10
ZUCKER DOERR