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James R. Wilson has been predicting the future for the US government for 26 years using probabilistic risk assessment. Part of his work involved predicting climate at the Yucca Mountain Nuclear Waste Repository one million years hence. Insights from this work led to five published papers on global climate prediction and the collaboration with Patrick Ray. Dr. Wilson is the manager of the Centre for Future Technologies, Inc .

LONG-TERM PREDICTIONS OF GLOBAL CLIMATE USING THE OCEAN CONVEYOR

PATRICK RAY AND JAMES R. WILSON

ABSTRACT

Many have attributed the Great Ocean Conveyor as a major driver of global climate change over millennia as well as a possible explanation for shorter (multidecadal) oscillations. The conveyor is thought to have a cycle time on the order of 1000 years, however recent research has suggested that it is much faster than previously believed (about 100 years). A faster conveyor leads to the possibility of the conveyor's role in even shorter oscillations such as the El Niño/Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO). The conveyor is primarily density driven. In this study the salty outflow of the Red Sea is used to predict its behavior ten years into the future. A successful model could lead to a long-term prediction (ten years) of El Niños, Atlantic hurricane season intensity, as well as global temperature and precipitation patterns.

INTRODUCTION

The Great Ocean Conveyor is a system of currents driven by thermohaline circulation that spreads heat, salt, and nutrients around the Earth (See Figure 1). Thermohaline circulation occurs largely in the North Atlantic, where, as water flows northward from the tropical Atlantic, evaporation is greater than precipitation, making the water saltier over time. In the North Atlantic the water cools as it gives off heat and the cooler, saltier water becomes more dense and sinks. The deep water then flows southward, eventually joining the Antarctic Circumpolar Current and spreading the water throughout the oceans (Musgrave, 2000). The resulting current system dwarfs the flow and size of any river system on Earth. The conveyor is a major driver of global climate. For example, Europe experiences a much warmer climate than regions at the same latitude because of the heat it receives from the warm northerly flowing conveyor in the North Atlantic(Gray, 1998).

Traditionally, the conveyor cycle time is thought to be on the order of a thousand years, precluding it from affecting short-term climatic oscillations such as the El Niño/Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO). ENSO and NAO are believed to be affected by the conveyor on multidecadal scales (Gray,1998). Research indicating that shorter oscillations (2 to 8 years) are linked to the conveyor has not been located. New research suggests that the cycle time of the conveyor is much faster, about 100 years (Wilson, 2001), allowing the conveyor to be a more active player in short-term oscillations. The conveyor is sensitive to changes in salinity, and Wilson suggests that the ultra-saline Red Sea may play a major role in the behavior of the conveyor (Wilson, 2001). Recently Red Sea water has been found in eddies rounding the tip of Africa (Philippens, 2001). The area lies along the path of the conveyor and shows that Red Sea water is indeed picked up by the conveyor.

We suggest that the flow of the conveyor affects short-term climatic oscillations such as those found in ENSO, NAO, Atlantic hurricane activity, as well as typical temperature and precipitation trends around the globe. We also suggest that an oscillating volume of salt entering the conveyor from the Red Sea causes salinity changes which in turn cause the short-term oscillations.

The outflow of the Red Sea is not constant. More salt enters the Gulf of Aden and eventually the Indian Ocean when winds blow from the Gulf of Aden into the Red Sea. When this happens, a two way flow is set up through the Bab el Mandab Strait sending Red Sea water into the Gulf of Aden where it is picked up by the conveyor. The winds in

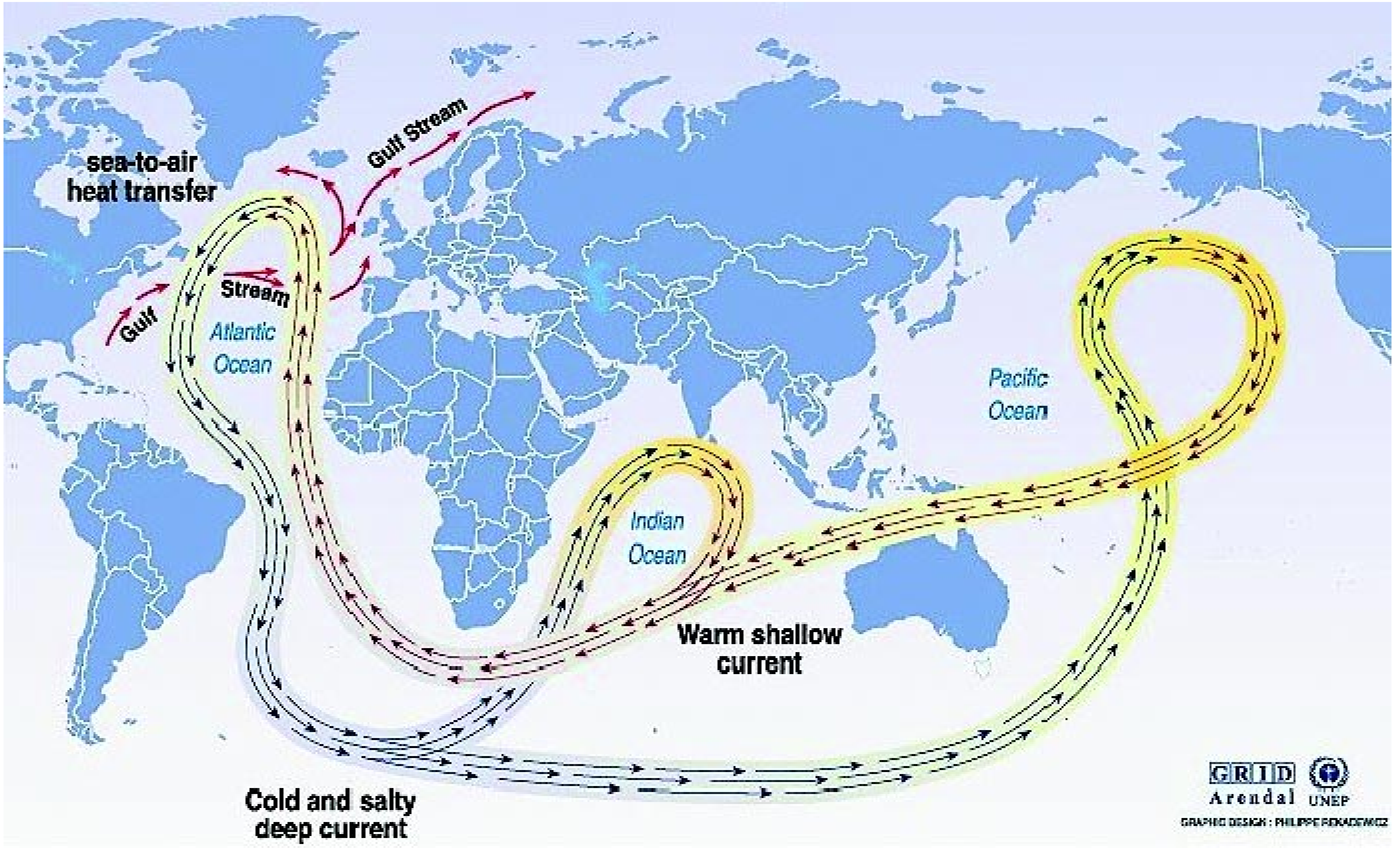

Figure 1: Great Ocean Conveyor Belt

the area are monsoonal and during tor that governs how much salt enters the conveyor from the Red Sea. (see Figure 2)

Salt exiting the Red Sea would most likely not have an immediate effect on the conveyor, because in areas where the conveyor runs "smoothly" a change in salinity has negligible effects. However, at certain points along its journey, it is likely to encounter places where a small salinity change could greatly increase or decrease the flow of the conveyor. We consider the conveyor to act as a train, meaning an increase or decrease in speed in one area will cause a similar result, or at least affect the flow in other areas. The dynamics of how different parts of the conveyor affect each other are unknown.

The goal of this work was to create a simple model intended to predict the behavior of the conveyor over time. As salt "bumps" come out of the Red Sea, they can be tracked through weather stations around the globe, and at certain points oceanic and atmospheric reactions (such as El Niño) can be consistently observed. Though our assumed cycle time of the conveyor is much shorter than the accepted cycle time, it is still fairly long and salt bumps are present for many decades. Therefore, we believe it is possible to use the salt bumps to make long-term predictions of conveyor behavior.

A successful model would help guide other researchers who may be able to improve upon the model. The accurate prediction of events such as El Niños, droughts, floods, heat waves, and cold spells ten years in advance has enormous economic implications. Current computer models run by supercomputers are only reliable for short-term predictions (a few months). A ten year prediction run by a simple spreadsheet would certainly be an achievement.

METHODS

A monthly time series of wind speed and direction in Northeastern Africa was sought. Unfortunately the area does not have many weather stations and those that exist are often poorly maintained. However, there was a station that operated between 1902 and 1991 with a monthly time series of precipitation. Djibouti is an African city in the country of the same name. It is located on the western tip of the Gulf of Aden, very near the Bab el Mandab Strait and therefore, well placed to use as a resource for local weather patterns. The area is a desert with little rainfall, however the rain that does fall follows a well-defined pattern (Climate, 2002). Most of the rain falls between October and April when the winter monsoonal winds carry in moisture from the ocean; these same winds drive the salt out of the Red Sea into the ocean. Djibouti rainfall is therefore used as an indicator of salt volume exiting the Red Sea (see figure 2).

The Southern Oscillation Index (SOI) is defined as a

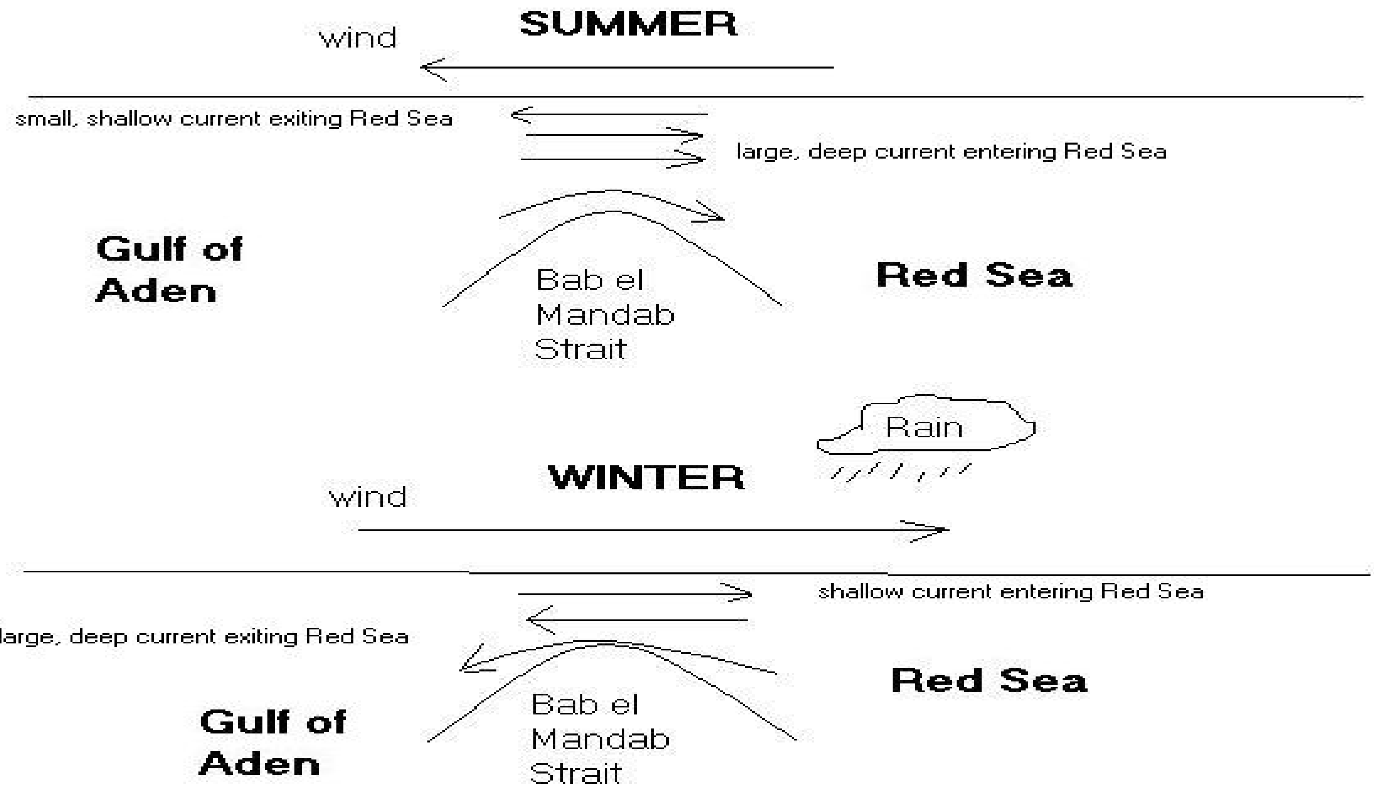

Figure 2: Seasonal Red Sea Outflow Cycle

normalized atmospheric pressure difference between weather stations on the island of Tahiti and at Darwin, Australia (SOI, 2001). The SOI is commonly used as a measure of ENSO (Daley, 2002). If ENSO is caused by changes in the conveyor, and the SOI is a good measure of ENSO, then the SOI also is a good measure of conveyor behavior. Since the conveyor works as a train its geographic location is of little importance. The SOI monthly time series has the advantage of having data from 1866 until the present with no missing values.

The time consuming part of the research involved finding where the salt "bumps" alter the flow of the conveyor. By looking at Sea Surface Temperature (SST) anomalies, we noticed that before the onset of an El Nino a cold SST anomaly appeared on the Atlantic side of southern Africa and a warm SST anomaly occurred southeast of the Cape of Good Hope (See Figure 3). In this area the warm Agulhas Current carries warm water around the tip of Africa, but the current comes very close to the much larger Antarctic Circumpolar Current. The cold water anomaly off of the west coast of Africa and the warm water anomaly to the southeast of the Cape of Good Hope suggest that warm water is no longer rounding the tip of Africa (meaning the conveyor has slowed or stopped). Air temperature data from Luanda confirmed a correlation with the SOI (see Figure 4). A graph of Luanda temperatures resembles the graph of SOI over time, however Luanda temperatures precede the SOI. Though they do not precede the SOI by much (approximately 1 year), this fact seems to indicate that the initial reaction to a change in the conveyor happens far west of the Pacific. As time goes on, warm water piles up in the Indian Ocean as if a dam were thrown into the conveyor. This causes a buildup of warm water that extends eastward with time. At some point, the warm water piling up in the Indian Ocean seems to trigger the atmospheric domino effect, resulting in an El Nino.

The observation still does not tell us where the conveyor slows or stops, it merely tells us what happens when it does. The lags, the time between a salt bump exiting the Red Sea and its having an observed effect, were found simply by matching data. We attempted to match the SOI with Djibouti rainfall (indicator of salt) from past years. The lag producing the best fit then became our crude model. We then took the residual of the model and compared it to Djibouti rainfall at different lags. The lag that produced the best match to the residual was then mathematically scaled for best fit and added to the first model to create an improved model. The residual from the new model was then found and matched with yet another different lag, creating a model that incorporated three lags.

RESULTS

The lags were found to be 10, 35, and 13.5 years respectively. The 35 year lag is thought to be the downwelling point in the North Atlantic. This would lead to an approximate average speed of 0.07 mph for the conveyor. A one thousand year cycle time for the conveyor would lead to a half cycle of slightly less than 500 years for the short loop through the Indian ocean, and an approximate average speed of .001 mph. Some currents such as the Agulhas Current, which is part of the conveyor, can reach speeds of more than 4 mph (Agulhas, 2002), so even the faster conveyor is very slow compared to some of the currents through which it propagates. The 10-year lag is thought to correspond to area around the Cape of Good Hope where the Agulhas, the Benguelas, and the Antarctic Circumpolar Currents all meet. The reasons for the 13.5 year lag are unknown. A change in salinity has some effect on the flow of the conveyor at each time location corresponding to a lag. The initial fit was calculated using SOI data from 1940-1970 compared to Djibouti rainfall from years prior to that. The danger of this type of modeling is over-manipulation of the data (i.e. matching data together after the fact proves nothing). Our initial hope was to show a salt oscillator could produce variations of the correct frequency as those observed for ENSO. After manually fitting the short-term oscillations for 1940-1970, the model was expanded without alteration for the rest of the time period. Not surprisingly, the short-term oscillations did not generally fit for all time periods (See figure 5). However, according to trendlines created by Microsoft Excel (labeled "poly" on figure 5), the model's long-term oscillations matched those of the SOI for all time periods despite the fact that no effort had been made to fit long-term oscillations.

Encouraged by the model's relative success at predicting long-term oscillations, we sought out to find out why the short-term oscillations did not fit. The short-term oscillations seemed only to be off during the time period 1976-1991. On further investigation, it was found that the structure

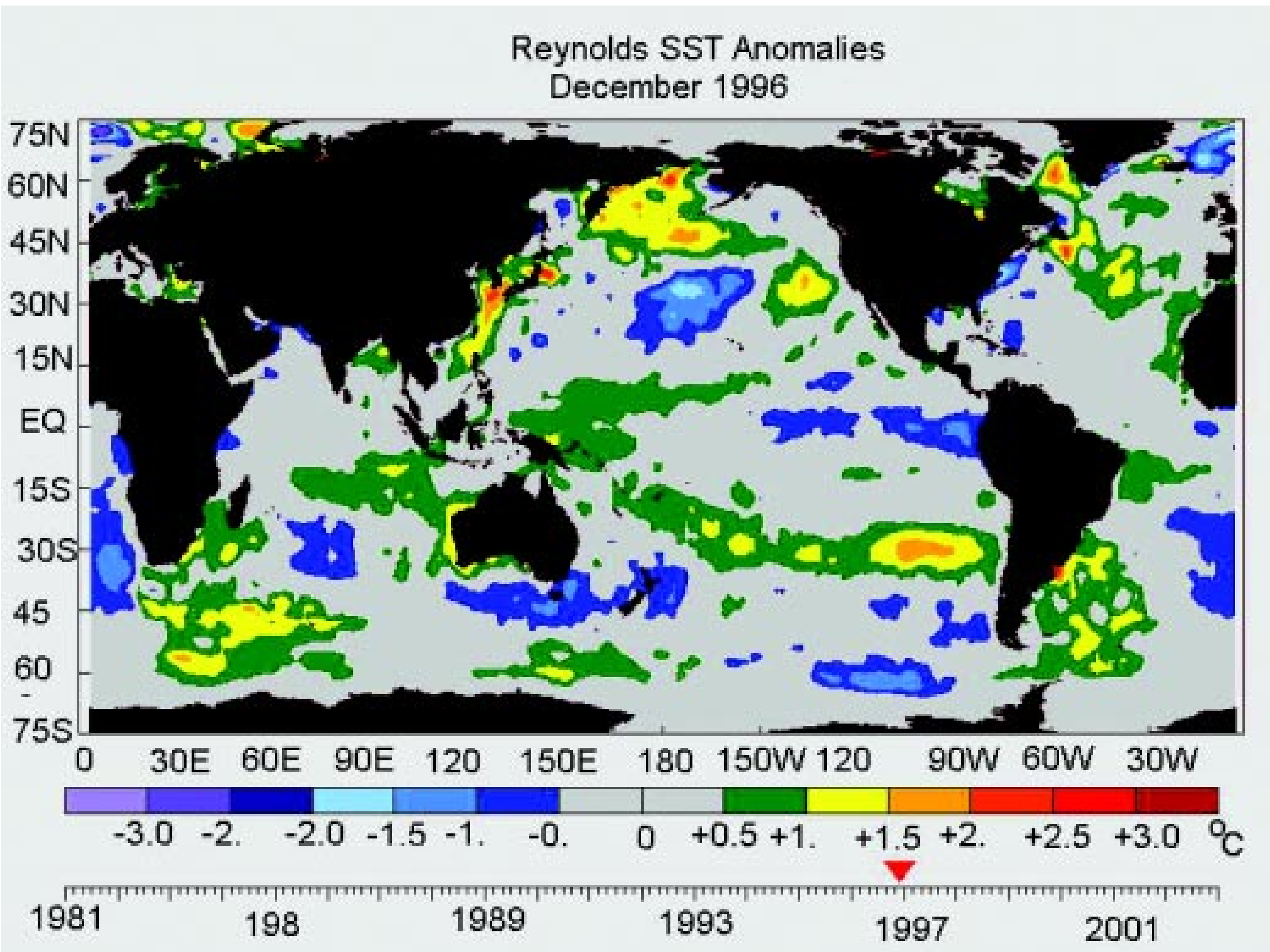

Figure 3: Water Tempterature Anomaly

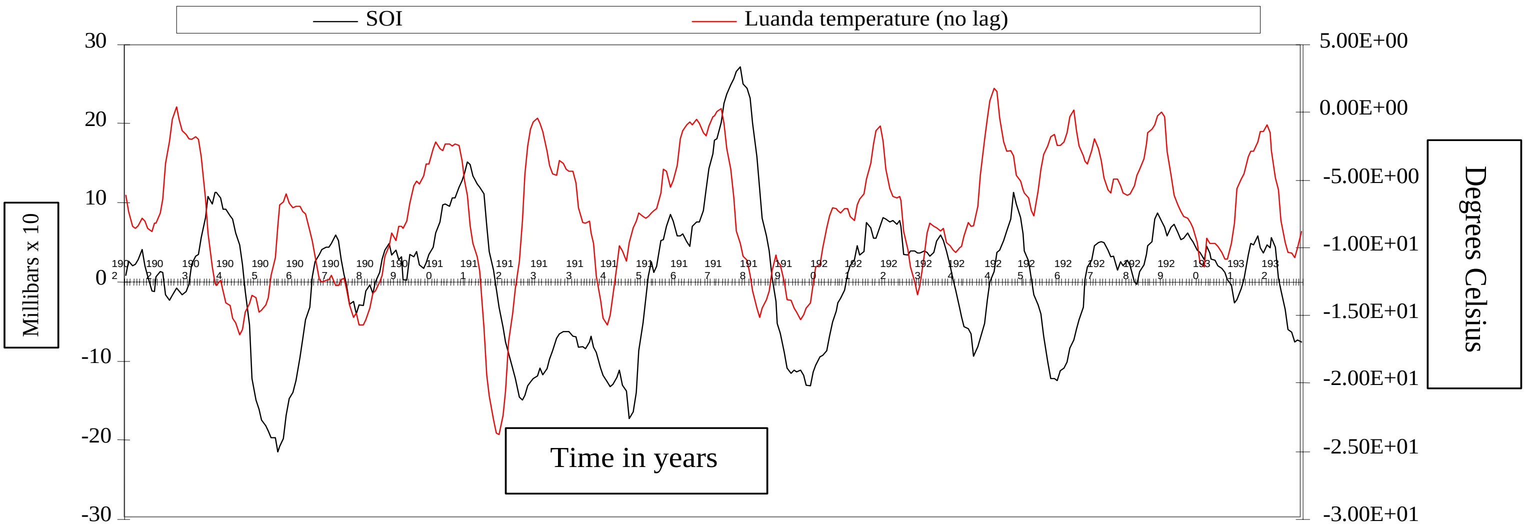

Figure 4: Luanda Temperature v. SOI. Temperature anomalies in Luanda, Africa plotted against the SOI. Note that Luanda temperatures tend to lead the SOI.

was still correct, but the SOI had suddenly shifted to become out of phase with the model by 2 years (i.e. proper lags would now be 8, 33, and 11.5 years, respectively) (see figure 6). This would indicate an increase in the speed of the conveyor during these years. This time period matched the "Great Pacific Climate Shift," a period in which global temperatures very suddenly rose (Beliunas, 2002) (see figure 7). The reasons for this shift are unknown and the model failed to predict it, however the model simply measures the input from the Red Sea. Many other factors may affect the conveyor.

When the model was manually adjusted for the "Great Pacific Climate Shift," the model accurately predicts long-term and, to a lesser extent, short-term oscillations in the SOI (see figure 8). The model enables predictions to be made 10 years into the future. Unfortunately the time series in Djibouti ended in 1991, allowing the model to predict only until 2001. A monthly time series of precipitation in Ethiopia has been used to extend the model, however it is too early to tell whether it will be as successful as the Djibouti data.

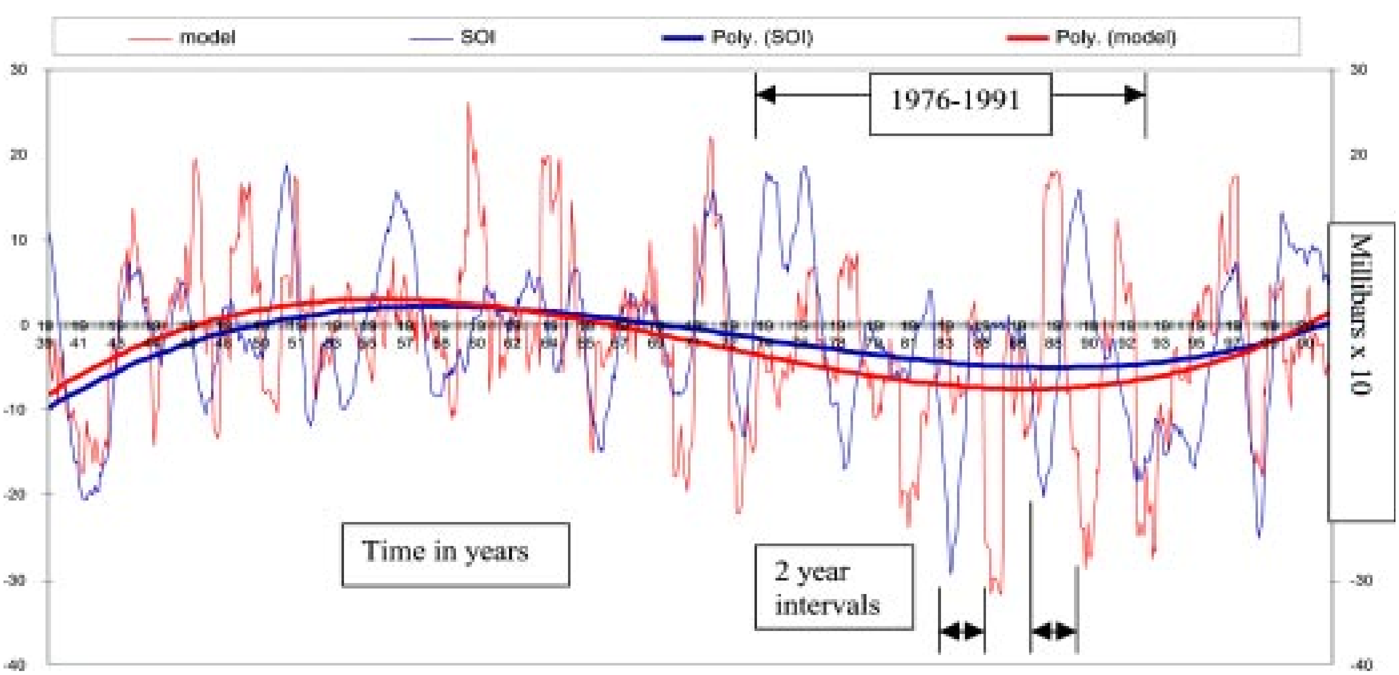

Figure 5: SOI Model v. SOI Actual. Model outputs before any manual adjustments are made. Trendlines show long-term oscillations. Note that the short-term oscillations also fit for all times except for between 1976 - 1991. During this time period the Great Pacific Climate Shift occured, and the graph becomes out of phase by 2 years.

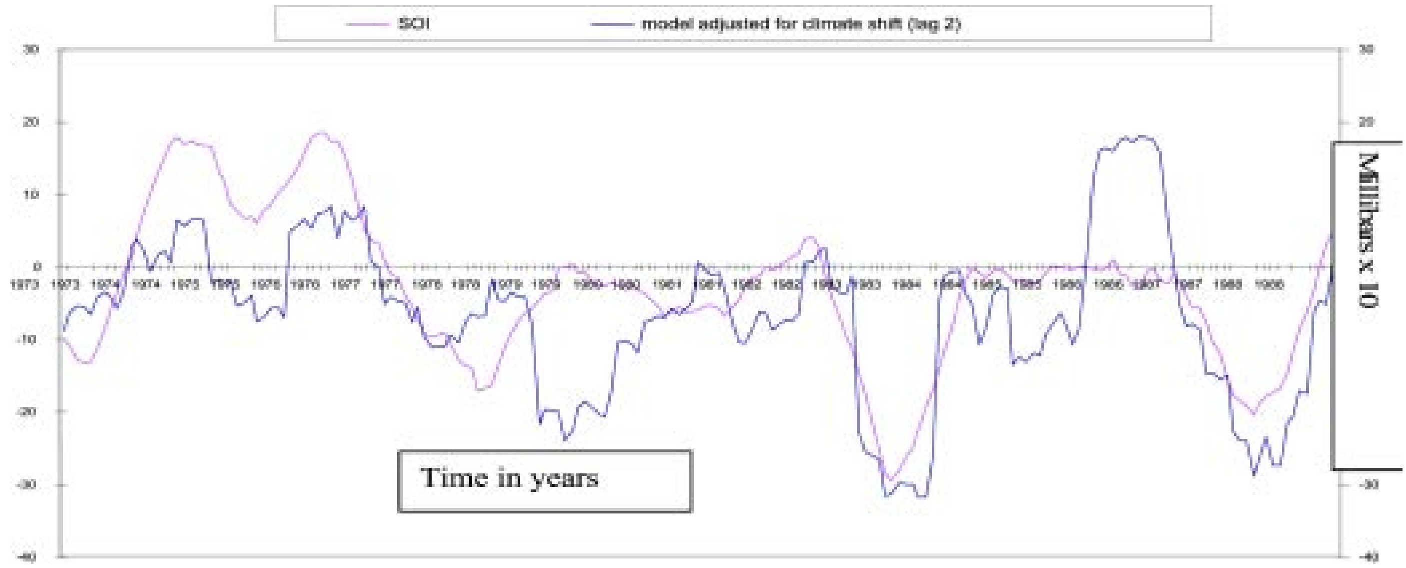

Figure 6: Model v. SOI for 1975 - 1991after shifting the phase by 2 years to produce a fit.

CONCLUSIONS

We have a simple computer model which predicts the SOI ten years in advance. The model is based on assumptions that the conveyor is much faster than generally accepted and that changes in conveyor behavior in the Atlantic Ocean can have an immediate effect on conveyor behavior in the Pacific. These assumptions have not been proven valid and warrant more research before they can be accepted.

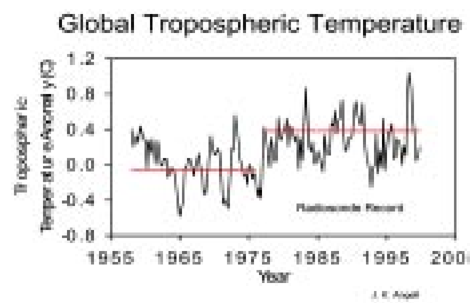

Figure 7: Global Tropospheric Temperature

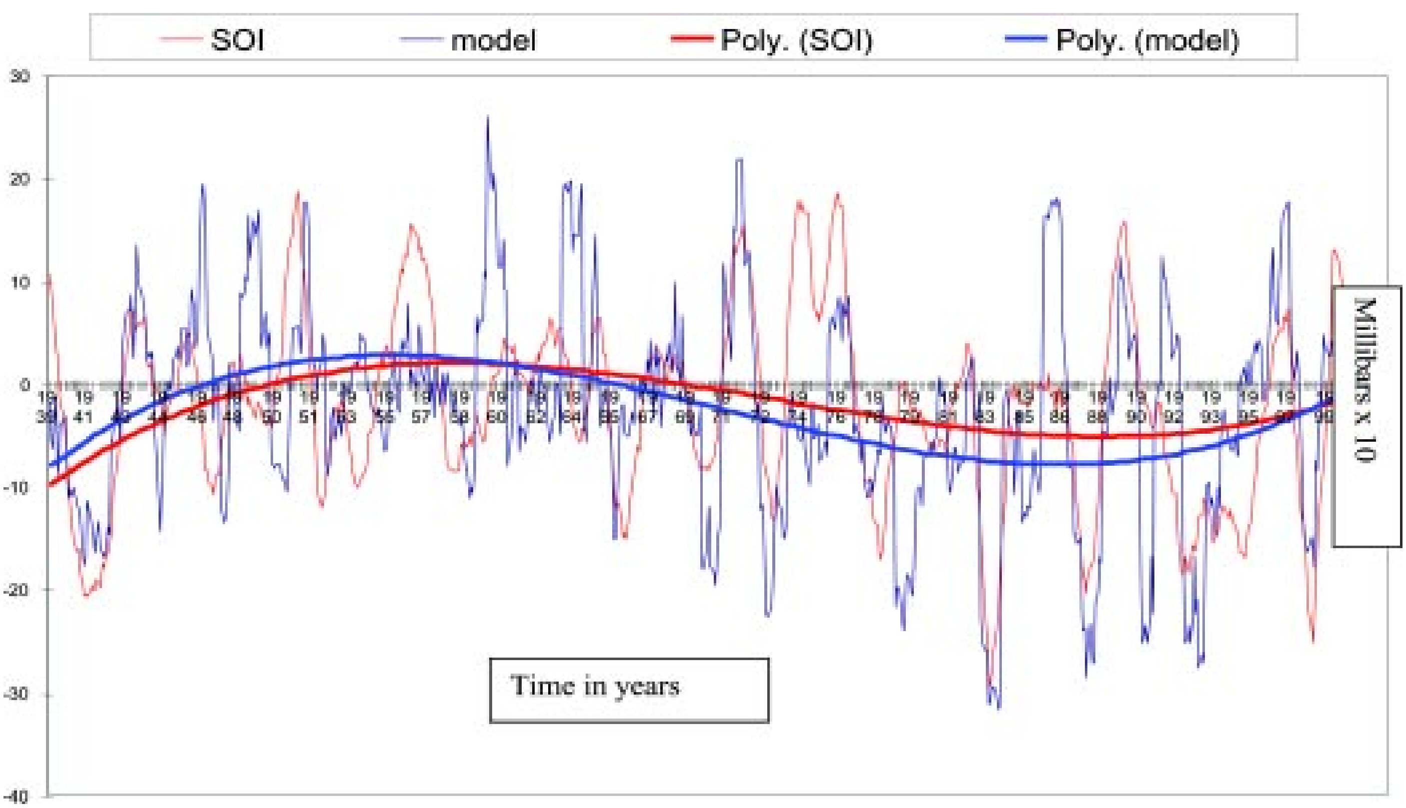

Figure 8: Final SOI Model v. SOI Actual

The model does show, if nothing else, that salt influence from the Red Sea could produce oscillations of the proper frequency as those observed in ENSO. Furthermore, the model correctly predicts long-term oscillations in the SOI that were not manually fitted. The short-term oscillations fit properly only for the time period that they were manually fitted, but the structure (i.e. width, distance between and approximate magnitude of major peaks) was also accurate for times in which the model was not manually fitted. Though the phase difference had to be manually eliminated, it is shown that the adjustment corresponds with another known climatological phenomenon. A model which incorporates changing lags due to varying conveyor speed rather than fixed lags would theoretically be more accurate.

The model actually predicts conveyor behavior, opening the possibility of its ability to predict other climatological factors with little adjustment. More research should be done to improve the SOI model itself as well as use the model to predict Atlantic hurricane seasons, global and local average temperatures and precipitation, and other global climate phenomenon.

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