JP1.6 DEVELOPMENT OF A LOW PRESSURE INDEX AS A PROXY FOR DRY SEASON SEVERE WEATHER IN FLORIDA AND ITS RELATIONSHIP WITH ENSO

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1. INTRODUCTION

Hagemeyer (1991, 1996 and 1997), Hagemeyer and Schmocker (1991a-b,1992 and 1993), and Hagemeyer and Matney (1993a-b,1994) investigated the nature of Florida tornadoes. They refined the conceptual model of the synoptic environment favorable for significant tornadogenesis (F2 and greater or death) in the Florida dry season (DS, November - April) and found the presence of a strong jet stream and strong low-level shear to be common factors.

In late summer 1997, the Climate Prediction Center (CPC) forecast a very strong El Nino to continue through the 1997-98 Florida DS. Considering CPC's forecast, and case studies of tornado events during the strong El Nino/La Nina's of 1982-83/1988-89, the author developed a thesis that strong EL Nino's greatly increase the chance that a favorable environment for significant tornadoes would exist over Florida due to the prolonged presence of a stronger and more southerly than normal jet stream and coincident development of more frequent, strong, extratropical (ET) cyclones in the Gulf of Mexico. The preliminary results and a forecast of above normal severe weather activity for the rest of the 97-98 DS were presented on 15 December 1997 at the **"Florida El Nino Summit"** in Tallahassee, FL.

The 1997-98 DS produced the deadliest tornadoes in Florida history, and was second only to the 1982-83 DS in number of significant tornadoes. Extensive severe weather coverage in early 1998 often left the impression that El Nino was to blame for specific killer tornados. While the popular press embraced this, in part because of the simplicity in framing a story, weather experts generally recoiled at the notion. However, lost in the commotion was the observation by the author that there is likely a strong relationship between El Niño-Southern Oscillation (ENSO) and a favorable environment for significant tornados in Florida on a *seasonal* basis.

At the end of the 1997-98 DS the author summarized the striking similarities in tornado activity, location and strength of the mean jet streams, and mean sea level pressure (MSLP) anomalies over Florida between the 1982-83 and 1997-98 dry seasons (Hagemeyer 1998). Subsequent comparisons of the strong La Nina's of 1988-89 and 1998-99 revealed the mean jet stream was not present over Florida and only one F2 tornado occurred in each DS.

Hagemeyer (1998) noted the next steps beyond case studies of the most significant events should be statistical studies of the relationship between ENSO and regional forecast problems. The goal should be to understand the physical links between ENSO and the strength better and position of the jet stream and the number and intensity of ET cyclones and aid preparedness and mitigation efforts in the process. The issue of the impacts of ENSO will only grow in importance. This study attempts to advance the debate and eventually lead to regional seasonal forecasts.

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2. DATA AND METHODOLOGY

Tornado statistics, including number of F2 tornado days, tornado days, $5 million tornado events, and total tornado damage were collected for the 1980-81 to 1998-99 DS's from **Storm Data**. Tornado data before 1980 were not included due to less reliable reporting procedures. Mean daily and monthly MSLP and mean monthly 250 mb U anomaly were computed from Climate Data Assimilation System (CDAS) re-analysis data averaged over a grid that included all of Florida and the adjacent eastern Gulf of Mexico (24°-31°N and 80°-88°W, Fig. 1) from 1958 through 1999. ENSO was represented by mean monthly sea surface temperature (SST) anomaly averaged over the Nino 3.4 area (5°N-5°S and 120°-170°W, Fig. 1) from 1958-1999 obtained from the CPC.

First, spatial and temporal issues were examined via selected experiments. The greatest positive 250 mb U anomaly was in February 1998 when Nino 3.4 was near record levels and near record significant tornadoes occurred. February 250 mb U anomaly in 7° by 8° squares (equal to Florida grid) were regressed on February Nino 3.4 over an area bounded by 3°-52°N and 64°-128°W to assess the spatial relationship with ENSO. Correlation coefficient (R^2) contours (Fig. 2) revealed a large east-west orientated area from the eastern Pacific around 24°N to Florida with significant positive correlation ($R^2 > .50$, $R > 0$). The highest correlation ($R^2 > .70$) was south of Baja California. The highest negative correlation ($R^2 > .50$, $R < 0$) was over the Great Plains. Mean jet stream axes for February 1989 (strong La Nina) and 1998 (strong El Nino) are shown for comparison. The $\mathbf{R^2 \approx 0}$ line falls roughly between these two historically extreme jet stream positions in the eastern US, and is very close to the average jet stream position for 1958-99 (not shown). These results support the idea of higher than normal DS 250 mb U in EL Nino's over Florida and the Gulf of Mexico, an eastward extension of the Pacific jet, and a more southerly storm track.

Interestingly, R^2 contours for February 250 mb U anomaly regressed on preceding June Nino 3.4 (not shown) were very similar to Figure 2, with a maximum positive correlation from Baja California to central Florida ($\mathbf{R^2 > .60}$), and a maximum negative correlation over the Great Plains. This suggested potential for significant lead time on Florida DS predictions. Clearly there must be a delay between changes in ocean temperature and distant, regional atmospheric response.

To gain further insight into the temporal evolution of ENSO and atmospheric response in Florida a comparison of the El Nino's of 1982-83 and 1997-98, when the February jet streams over Florida were very similar, was completed (Fig. 3). Nino 3.4 was nearly the same from March to June, then deviated significantly in July 1982, remaining less than 1997-98 until December, and then higher afterward. In 1997-98 Nino 3.4 steadily rose to a peak in November and remained high through January before beginning a downward trend to La Nina conditions by May. Monthly 250 mb U anomaly increased dramatically from October 97 to December

Figure 1. Locations of Florida grid and Nino 3.4 area.

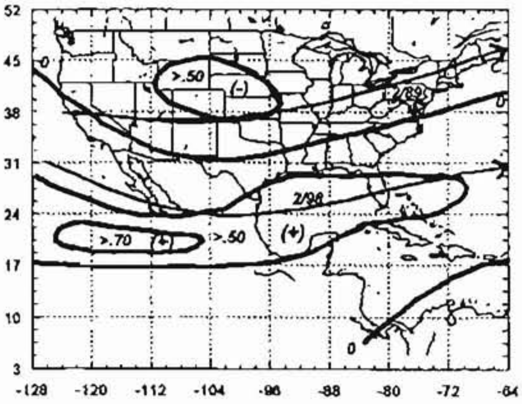


Figure 2. Contours of R^2 (0, .50, and .70) resulting from regression of February 250 mb U anomaly in 7°x8° grids on February Nino 3.4 (1958-1999). Mean 250 mb maximum wind axes for February 1989 and 1998 (labeled 2/89 and 2/98) are shown as bold lines with arrowheads.

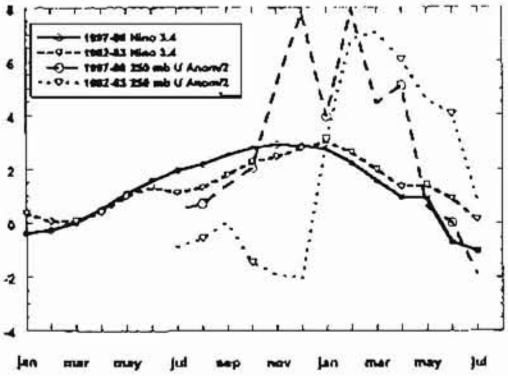


Figure 3. Comparison of Nino 3.4 and Florida region 250 mb U anomaly (ms^{-1}/ 2) for El Nino's of 1982-83 (1/82 to 7/83) and 1997-98 (1/97 to 7/98).

Figure 7. Mean, observed, and predicted Low Pressure Index (LPI) for 1958 to 1998 dry seasons. →

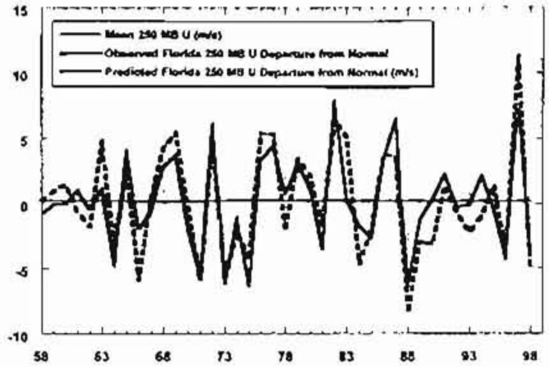


Figure 4. Observed versus predicted 250 mb U anomaly (ms^{-1}) for 1958 to 1998 dry seasons.

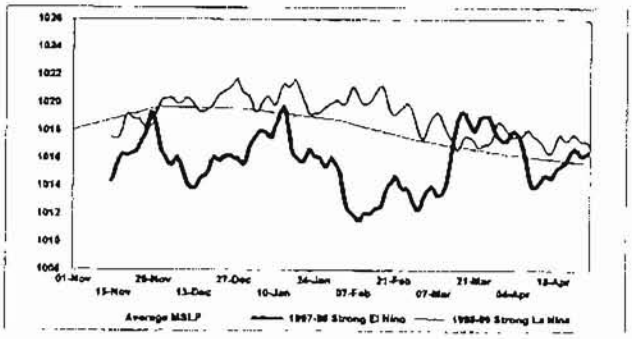


Figure 5. Comparison of 14-day running means of daily MSLP from 1 November to 30 April for 1997-98 El Nino and 1998-99 La Nina.

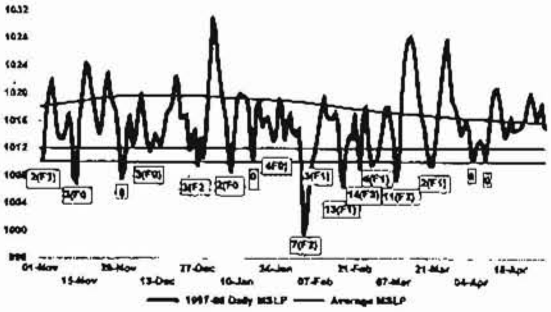
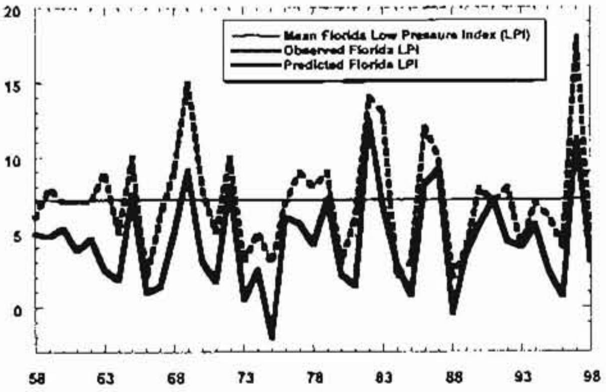


Figure 6. Daily mean MSLP from 1 November 1997 to 30 April 1998. Tornado events are indicated by boxes centered on the day they occurred with number of tornadoes and maximum F-scale indicated within.



97, then a distinct break occurred in January 98, followed by a sharp rise in February to the highest value of the entire data set. The 1997-98 severe weather season was characterized by tornadoes and flooding rains in November, December, February and early March. Most noteworthy were record-breaking tornado outbreaks on February 2-3 and 22-23.

In 1982-83 Nino 3.4 peaked in January 1983 and 250 mb U anomaly increased dramatically from December to February peaking in March. The 1982-83 severe weather season started in early February and lasted until late April with significant tornadoes in February, March, and April. The 1997-98 severe weather season started three months earlier than 82-83, but the 1982-83 season lasted two months longer. However, the integrated area of positive 250 mb U anomaly was very similar in both cases, as was DS tornado activity.

It appears there is about a 2-3 month lag between Nino 3.4 and 250 mb U response, however, the nature of preceding trends is crucial. In strong El Nino/La Nina events such as 82-83, 88-89, 97-98, 98-99 and 72-73 mean Nino 3.4 of the preceding wet season was similar to the DS suggesting the cumulative effect of long-term trends may be important. The influence of a waning ENSO on the transition from dry season to wet season is less clear. As the dry season ends the trend in Florida is always toward a reduced influence of the westerlies and thus an eventual decoupling of the influence of NINO 3.4 and this could take place much faster compared with the buildup going into the dry season. Considering the exploratory spatial and temporal analyses, it was decided to complete multiple linear regression of DS tornado and environmental variables on mean monthly Nino 3.4 from the preceding wet season through the end of the subject dry season (i.e., predict November - April values with May - April monthly Nino 3.4).

3. SEASONAL TORNADO RELATIONSHIPS

The total number of F2 tornado days, tornado days, $5 million tornado events, and total tornado damage for the 1980-81 to 1998-99 DS's were regressed on May to April Nino 3.4. It was expected results might be poor due to tornado reporting vagaries, the small sample size (low degree of freedom), and the fact that tornadogenesis is affected by stormscale/mesoscale factors. None of the results were significant at the 95% level. The $5 million tornado events showed the highest correlation with Nino 3.4 (R^2 =.78), followed by seasonal tornado damage (R^2 =.72). F2 days (R^2 =.46) and tornado days (R^2 =.50) displayed less skill.

Nino 3.4 appeared an excellent predictor of DS $5 Million tornado events in the two strong El Nino's of 82-83 and 97-98, and the weak El Nino of 92-93, the three DS's with the most tornado damage (not shown). Tornado damage in the 1992-93 DS was almost entirely due to events during the March 1993 "Superstorm", while the 82-83 and 97-98 events occurred over a period of several months. Nino 3.4 predicted the normal number of DS $5 million tornado events (2) for the moderate El Nino of 1991-92, and none occurred. However, the two most expensive hailstorms in Florida history up to that time occurred on March 6th and 25th 1992. Supercells with intense mesocyclones produced giant hail in central Florida, but did not produce significant tornadoes. This illustrates the problem with using ENSO measures to predict tornado-related variables. Such predictions are difficult even on the scale of minutes!

Clearly the ephemeral tornado cannot be directly related to ENSO. One could at best predict above/below normal significant tornado activity in strong EL Nino's/La Nina's with well-established trends, but season to season skill/confidence is lacking. There would have to be so many caveats as to make such a forecast counterproductive. However, the thesis always was that ENSO could set the stage for hazardous weather over a dry season. What was clearly needed was a proxy variable to quantify the dry season threat of severe weather for Florida.

4. DEVELOPMENT OF A SEASONAL SEVERE WEATHER PROXY

250 mb U anomaly and MSLP for the dry seasons of 1958-98 were regressed on monthly May - April Nino 3.4 as in the tornado cases. Figure 4 compares observed versus predicted dry season 250 mb U anomaly for 1958-1999. The regression results are significant at the 99% level and support a strong seasonal relationship between ENSO and the jet stream over Florida and the eastern Gulf of Mexico. Results for seasonal MSLP (not shown) were very similar to 250 mb U anomaly due to high inter-correlation of the variables (R^2 = .67, 99% significance level) such that MSLP is a good proxy for 250 mb U and vice versa. These results support the author's thesis regarding the relationship of the jet stream and MSLP to ENSO. However, the question remained: what measure would characterize the nature of a Florida dry season and synthesize the physical link between ENSO and observed weather? Perhaps MSLP is the most basic descriptor of average weather conditions at the ground, but a seasonal measure of MSLP is not easily relatable to how people are generally affected by the "weather". It was decided to focus on the model that significant DS Florida severe weather is associated with the warm sector of ET cyclones passing over the eastern Gulf of Mexico and/or the southeastern states.

Figure 5 compares 14-day running averages of DS mean daily MSLP from 1 November to 30 April for the strong El Nino/La Nina of 1997-98/1998-99 for the Florida grid. For the strong La Nina MSLP running means are above normal for nearly the entire dry season. Conversely, the strong El Nino brought long periods of below normal MSLP. These extended periods of below normal MSLP represent "storminess", and are indicative of the passage of a procession of ET cyclones, or sometimes, passing disturbances within quasi-stationary areas of broad low pressure. The "El Nino effect" began early in the DS of 1997-98 and continued until early March when an abrupt change to above normal MSLP marked the transition to La Nina conditions and the beginning of an extreme drought. There are two notable breaks in the El Nino effect in late November and mid-January. The mid-January increase in MSLP and minima in severe weather is notable because it illustrates that significant inter-seasonal changes can take place even in the presence of a steady, strong, El Nino and therefore the relationship is not simply linear [compare increase in January MSLP (Fig. 5) with concomitant decrease in 250 mb U anomaly (Fig 3)].

Hagemeyer and Matney (1993) found that out of 20 variables the 0-6K mean wind of the Florida tornado proximity environment had the highest correlation with tornado strength. Generally, the deeper the ET cyclone central pressure, the more likely the environmental winds will be favorable for significant tornadogenesis and severe weather. To quantify this further, the lowest daily MSLP associated with each case of F2 and greater tornado events from 1980-1999 was calculated. All events occurred with MSLP of 1014 mb or less, and about 82% occurred with MSLP of 1012 mb or less (MSLP averaged over Florida grid so actual central pressure of cyclone could be much lower). Of the 7,421 daily MSLP observations in the 1958-98 DS data set, approximately 14% were 1012 mb or less. The 1012 mb threshold was identified as defining a significant ET cyclone/severe weather threat event. The number of times the daily MSLP dropped to minima of 1012 mb or less in a DS was defined as the Low Pressure Index (LPI).

The LPI is a measure of storminess that combines both seasonal and day-to-day variability. Figure 6 illustrates the LPI calculation for the 1997-98 DS. Daily MSLP reached a minima at or below 1012 mb 18 times, so LPI was 18, the highest of any DS since 1958. The LPI were calculated in this manner for each dry season from 1958 -98. Daily DS MSLP plots during strong El Nino's such as 97-98 and 82-83 had much higher frequency and amplitude patterns compared with strong La Nina's such as 1988-89 and 1998-99. This high frequency/amplitude pattern correlated closely with seasonal tornado activity. This is illustrated on Figure 6 where each tornado event during the 97-98 DS is represented by a box containing the number of tornadoes and maximum F-scale. Of the 17 tornado events, only one occurred when MSLP was above 1012 mb, an F0 event. Five of the 16 events at or below 1012 mb produced significant tornadoes.

The LPI is closely correlated with seasonal MSLP (R^2 = .73, 99% significant) and 250 mb U (R^2 = .72, 99% significant), but is a better statistical proxy for tornado variables. LPI is also considered to better represent the synthesis of the sensible weather effects of ENSO. The LPI values for the 1958-98 dry seasons were regressed on monthly May - April Nino 3.4. The regression results were significant at the 99% level. Figure 7 compares observed and mean LPI ($\approx$7 per season) versus predicted dry season LPI. The results show considerable skill and confirm a strong seasonal relationship between ENSO and ET cyclone frequency over Florida and the eastern Gulf of Mexico. The LPI were not over forecasted in any of the 42 dry seasons. If one were to assume a perfect forecast this would be expected, since Nino 3.4 clearly cannot be responsible for all the variability in the LPI, and other unknown factors play a role. However, NINO 3.4 does accurately predict LPI relative to normal values.

As the statistical investigation ultimately lead to the LPI as a tornado proxy, one remembers that tornadoes are just one aspect of ET cyclone hazards. Historically, significant hazardous DS weather in Florida has rarely occurred without an ET cyclone in the westerlies. ET cyclones can be accompanied by severe thunderstorms with tornadoes, hail, and damaging winds, and/or flooding rain, coastal flooding, strong gradient winds, and hazardous marine weather. A lack of ET cyclones can cause drought and wildfires. Both scenarios can have significant effect on the population and economy of the state. There is significant variability in primary weather hazards from cyclone to cyclone. Some may bring heavy rains, others severe thunderstorms and hail, others severe thunderstorms and tornadoes etc. However, the cumulative effect of the influence (or lack) of ET cyclones characterizes a Florida dry season.

This is somewhat analogous to seasonal tropical cyclone (TC) predictions in that the focus is on environmental conditions favorable for TC formation, not forecasting the attendant flooding rain, high winds, tornadoes, and storm surge TC's may bring. People generally understand the intrinsic hazards of TC's. The same model could be applied to the forecast of ET cyclones over Florida. However, there may not be as clear an understanding of the threats an ET cyclone can bring to Florida because traditionally they have not been treated as a singular entity with multiple threats to prepare for as with TC's. However, it is not uncommon for ET cyclones to produce more damage and economic impact than some TC's, the March 93 "superstorm" or the February 98 ET cyclones that affected south and central Florida being the obvious examples.

5. CONCLUDING REMARKS

The early results of this study confirm ENSO has a significant effect on Florida's weather during the dry season. In particular, 250 mb U and MSLP have a strong relationship to NINO 3.4, and the LPI is a good proxy for both variables and seasonal severe weather activity. Strong EL Nino's bring a greater than normal threat of a stronger jet stream, more and stronger ET cyclones, and severe weather-related damage. Strong La Nina's bring a greater threat of drought and wildfires. However, one singular event such as the March 93 "Superstorm" could occur in any year and produce several season's worth of devastation regardless of the state of ENSO. It is now generally accepted that La Nina also brings an increase in Atlantic Basin TC activity (see for example: Pielke and Landsea 1999). Changnon (1999) recently assessed the losses and benefits of El Nino to the Nation. Losses and benefits varied by region, but it appears that, at least for Florida, there are serious risks associated with both extreme phases of ENSO.

ENSO is obviously not responsible for all the variability of Florida dry season weather and the relationship is nonlinear. Results of experimental multiple regression for 1958-78, 1970-90, and 1978-98 show that some periods have greater skill than others. For example, 1970-90 Nino 3.4 regressed on the LPI and 250 mb U anomaly produced better results than the other time 20-year periods. There is no guaranty that correlations in the historical record will hold up in the future. The accuracy of any forecast scheme also depends on accuracy of Nino 3.4 forecasts input into it. Nevertheless, it appears reasonable seasonal forecasts of below or above normal ET cyclones are possible.

The LPI will continue to be refined and improved. For example, there are indications that south and central Florida are generally more sensitive to NINO 3.4 than north Florida. This study has advanced the understanding of the physical link between ENSO and Florida weather, and provided a template to be applied to other regions of the nation. Improved knowledge of the influences of ENSO on Florida weather, and a multi-threat consideration of ET cyclones can only help advance education, preparedness and mitigation efforts.

6. REFERENCES

http://www.srh.noaa.gov/mlb/research.html

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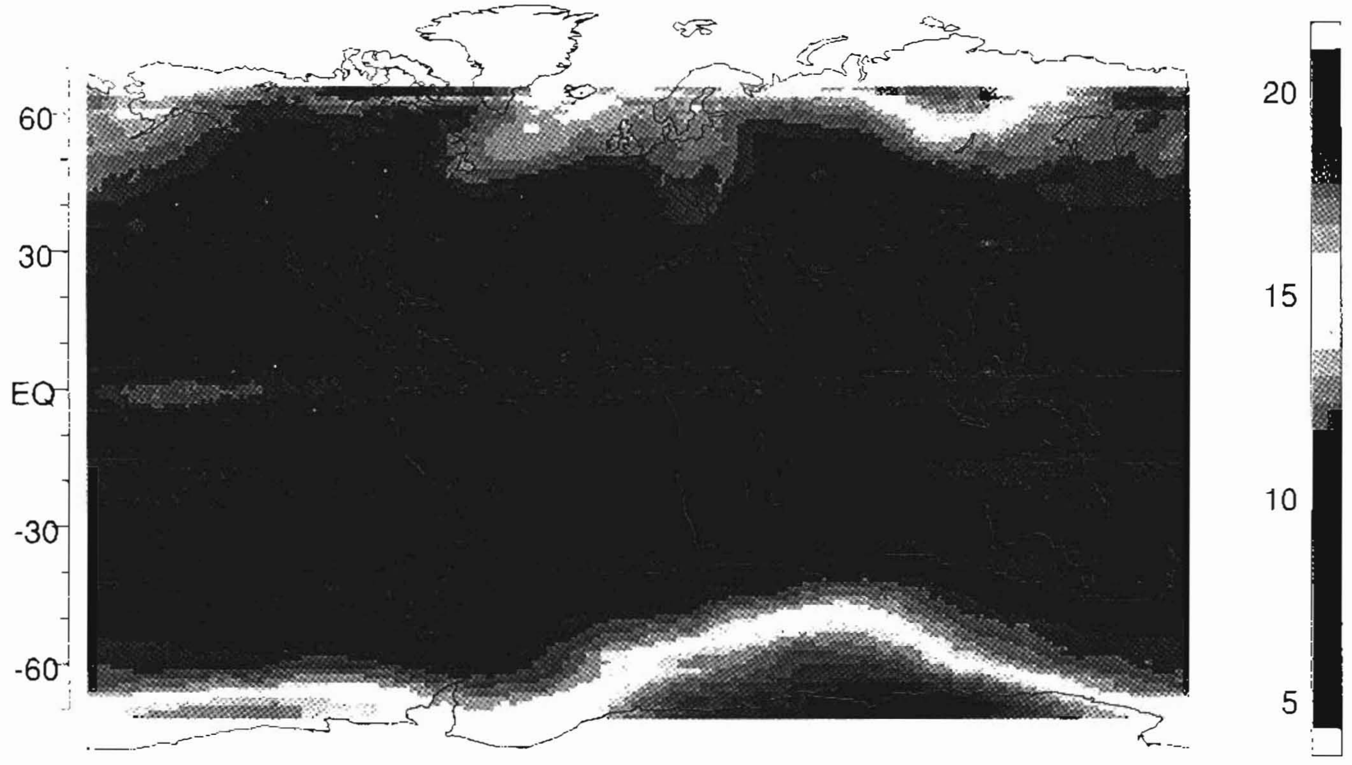

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