7B.1 **CLIMATOLOGICAL ASPECTS OF CONVECTIVE PARAMETERS FROM THE NCAR/NCEP REANALYSIS**

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1. Introduction

For many years, proximity sounding analysis has been an important tool in understanding the relationship between environmental conditions and the occurrence of severe convection (e.g., Fawbush and Miller 1952, 1954; Beebe 1955, 1958, 1963; Darkow 1969; Johns et al. 1993; Rasmussen and Blanchard 1998; Brooks et al. 2002). Recently, Lee (2002) created artficial soundings from the NCAR/NCEP reanalysis data (Kalnay et al. 1996) that Brooks et al. (2003b) then used in proximity studies. Brooks et al. then used relationships developed from those proximity soundings to estimate the occurrence of environments favorable to severe convection around the world.

The reanalysis data provides an intriguing source of information. Coverage is global and analyses are available every six hours (00, 06, 12, and 18 UTC) since 1 June 1957. The implied grid of locations from the spectral coefficients is 192 x 94 points, yielding a spacing of 1.91º latitude by 1.875º longitude. There are 27 points on sigma surfaces above the ground in the vertical with five in roughly the lowest kilometer and ten in roughly the lowest three kilometers. This density of coverage provides a more complete picture of the atmosphere, particularly outside of North America and Europe, than the radiosonde network. Although the balloon soundings are clearly preferable in many regards, the lack of coverage makes extending studies to the entire globe challenging. Lee (2002) showed that, for many convectively-important parameters, the reanalysis soundings resemble collocated observed soundings. In particular, convective available potential energy (CAPE) and measures of deep tropospheric shear are highly correlated with the observed soundings. Quantities associated with strong vertical gradients (e.g., shallow shear, measures of the strength of the cap) are not as well-represented.

We are working on creating a database of all soundings from 1958-1999. As of 31 July 2004, 39 of the 42 years are complete (with three total days missing), with a total of slightly over 1 billion soundings created. Analysis of the soundings is underway using the GEMPAK and SHARP programs. Three years worth of soundings (1997-9) have been looked at over every other grid point over land (except for Greenland and Antarctica), as well as seven years (1973, 1987, 1995-1999) worth of soundings over all points in the eastern two-thirds of the US, Europe south of 70º N, and Australia and surrounding waters. In addition, selected points have been studied for all soundings at one time per day through the entire record. Because of the focus on convection, the time for the long records is typically the closest reanalysis time to late afternoon, e.g., 00 UTC in the US. Here we will report a potpourri of results from the reanalysis.

2. Distribution of severe environments

Brooks et al. (2003b) estimated the spatial distribution of conditions favorable for the development of significant tornadoes (F2 or greater) and significant severe thunderstorms (hail at least 2 in. in diameter and/or 65 kt wind gusts and/F2 or greater tornado). To do this, relationships between sounding parameters and reported severe weather for the US, east of the Rockies, were developed using 0000 UTC reanalysis soundings from 1997-9. It was assumed that such relationships would hold true everywhere. For every other grid point over land (expect for locations covered by ice year-round), the frequency of favorable conditions was computed. Only one time per day, nearest the late afternoon, was used in the analysis. With the additional number of soundings analyzed since then, slight refinements to the relationships have been made and soundings at all four times have been considered. If at least one sounding at a location on a day meets the thresholds for the appropriate event, then that day is counted as favorable. The results of the new analysis aren't that different from the previous analysis (Fig. 1). Queensland, in northeastern Australia, is shown as a more favorable location, relative to the rest of the world, for significant severe thunderstorms, and southeastern China is a more prominent feature in the tornadic environments.

Regional analyses for the seven year period for over the US, Europe, and Australia show some differences between the 1997-9 period and the full seven years (Fig. 2). In particular, the significant tornado distribution in the US is further to the west, closer to the center of the Plains. Brooks et al. (2003b) pointed out that the initial distribution was shifted further east than climatological distributions of strong and violent tornadoes suggest (e.g., Concannon et al. 2000). They speculated that part of the reason was that the relationships focus on large-scale observations and that, perhaps, this forced an emphasis on large-scale outbreaks in the relationships and may have underemphasized small-scale isolated events with strong tornadoes. In addition, the values for Europe are smaller for the seven year period than for the 1997-9 period, suggesting that the latter period was more supportive of significant severe thunderstorms. Caution must be used in interpreting these small samples.

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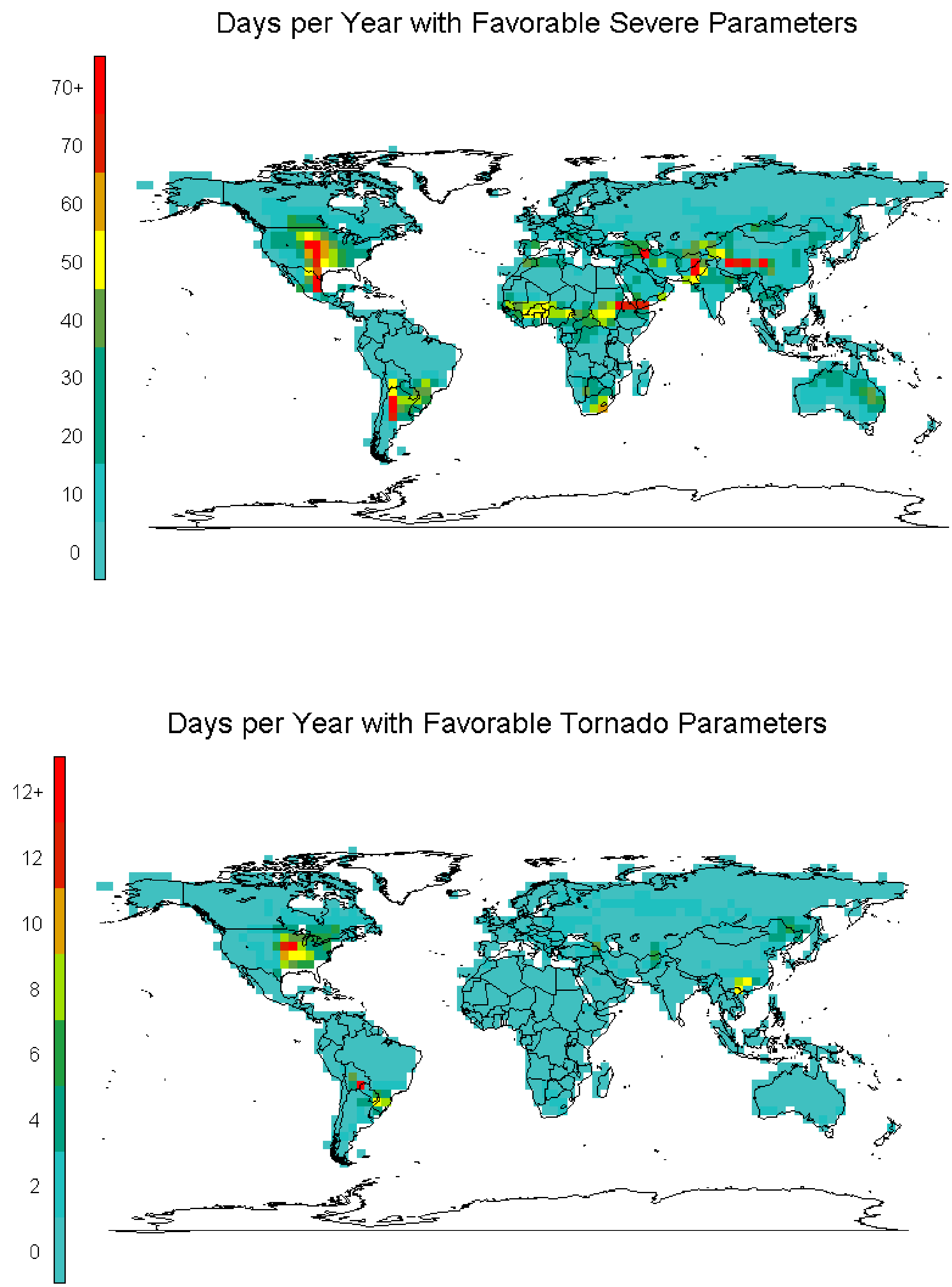

Fig. 1: Updated estimate of distribution of favorable conditions for significant severe thunderstorms (top) and significant tornadoes (bottom), based on 1997-9 data.

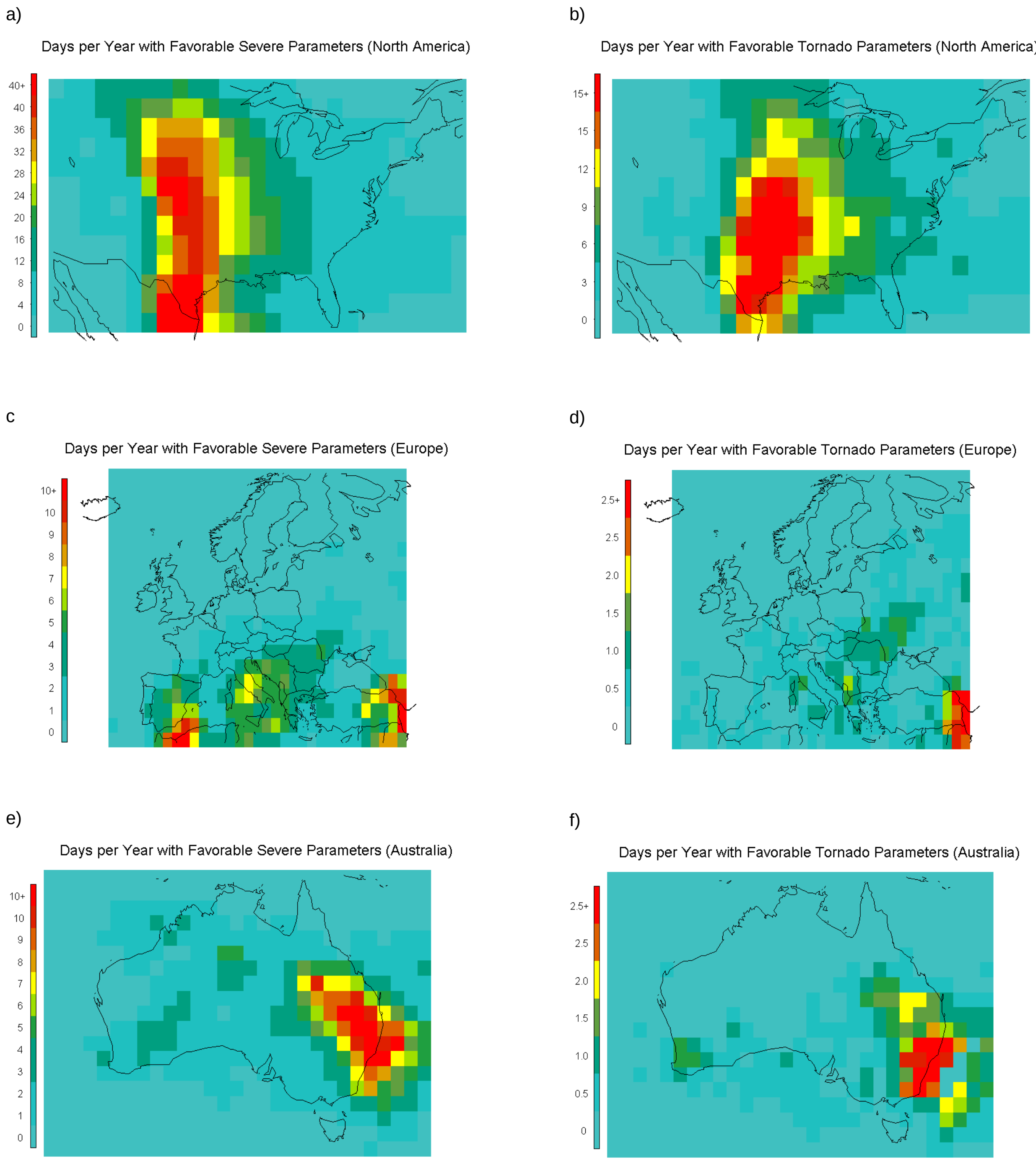

Fig. 2: Regional estimates of distribution of significant severe thunderstorms (left) and significant tornadoes (right) for eastern US (a, b), Europe (c,d), and Australia (e,f). Note that color scales are different for severe thunderstorms and tornadoes and that US scale is different from other two regions.

Comparison of the estimated distributions of favorable environments to the actual occurrence of severe weather is problematic outside of the US because of less reliable report databases and, in the case of Australia, particularly, low population density. The Australian analysis does provide, however, some interesting clues. The region of significant tornado environments in southwestern Australia has been discussed by Hanstrum et al. (2002). The eastern Australian severe environments will be discussed at this conference by Schuster et al. (2004).

3. Annual cycles of convective parameters

Another aspect of interest that is illustrated well by the reanalysis data is the annual cycle of parameters of interest for convective climatology. Here, we highlight the relationship of lapse rates aloft (from 700-500 hPa) to the mean mixing ratio of the lowest 100 hPa of the sounding for a box of four points in the US—Oklahoma City on the southwest, Nashville, Tennessee on the southeast, Pierre, South Dakota, and Alpena, Michigan on the northeast. The locations are selected to highlight the relationship of distance from two major topographic features: the Rocky Mountains as a source of high lapse rate air aloft (Lanicci and Warner 1991) and the Gulf of Mexico as a source of lower tropospheric moisture. These two features are important in assessing the ingredients for deep convection (Doswell et al. 1996).

Day-to-day and interannual variability is large. In order to get a handle on the average behavior, we have taken the mean of the 00 UTC values for each day of the year from the seven years analyzed and then carried out a 31-day running mean over the daily values with the mean wrapping around the end of the year (i.e., 31 December is one day away from 1 January.) The picture that emerges is not surprising, but illustrates much of the behavior of convection in the US. All four locations start off with low lapse rates and low moisture content (bottom left hand corner of Fig. 3) in the winter. As spring approaches, lapse rates get higher without large changes in the low-level moisture. Through the spring, high lapse rate aloft is relatively consistent and the low-level moisture increases. Then, in the middle of summer, lapse rates decline precipitously with high moisture values

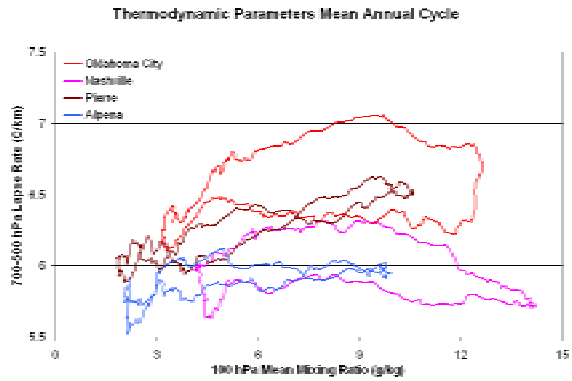

Fig. 3: Mean annual cycle of 700-500 hPa lapse rates vs. lowest 100 hPa mean mixing ratio for Oklahoma City (red), Nashville (magenta), Pierre (brown), and Alpena (blue.)

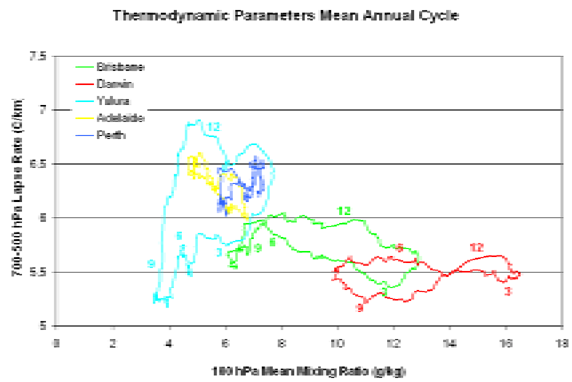

Fig. 4: Same as Fig. 3, except for Australian locations-Brisbane (eastern Australia-green), Darwin (northern Australia-red), Yulura (central-cyan), Adelaide (southern-yellow), and Perth (west-blue). Numbers on lines show first of calendar months.

in place. In the late summer and autumn, the moisture slowly decreases with relatively constant lapse rates. As one goes north from the Gulf of Mexico, the primary effect is to decrease the moisture values. As one goes east from the Rockies, the lapse rates decrease. The primary thermodynamic difference between spring and autumn is the presence of high lapse rate air in the spring. The difference is larger in the two southern locations. Locations in Australia (Fig. 4) and Europe (not shown) typically show less difference in the lapse rates in spring and fall. Yulura, in fact, has a very different cycle. Lapse rates increase at low moisture values in the spring, with the moisture increasing in summer into fall, and lapse rates decreasing in fall.

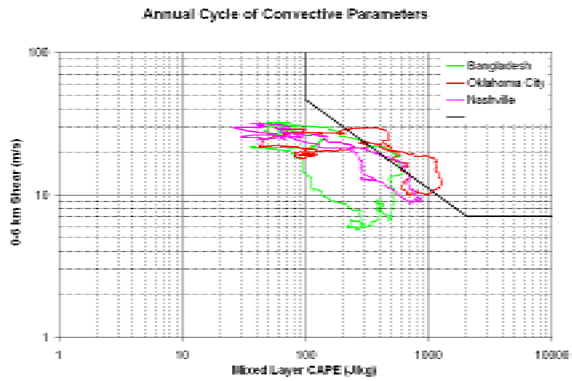

Fig. 5: Mean annual cycle of mean 0-6 km vector wind difference and mixed layer CAPE for Oklahoma City (red), Nashville, TN (magenta), and central Bangladesh (green). Black line indicates best discriminator between significant severe thunderstorm environments and non-significant environments from Brooks et al. (2003b), modified to include minimum threshold of 7 m/s for wind difference. Locations above the line are much more likely to support significant severe convection.

We can do a similar analysis for convective available potential energy and shear over the lowest 6 km, which have been shown to be crucial for significant severe storm development (e.g., Rasmussen and Blanchard 1998). In this case, our measure of the shear is the vector difference between the surface and 6 km, as measured by the SHARP analysis package. We have averaged the values only for those days with CAPE>0, in order not to include the effects of strong shear in environments that are unlikely to have any convection. The annual cycles for Oklahoma City and Nashville are shown in Fig. 5, along with a point from central Bangladesh (the Bangladeshi point is based on three years of data). The Oklahoma City cycle indicates that for most of the spring and for a small part of autumn, the climatological mean conditions, assuming CAPE exists, are supportive of significant severe thunderstorms. Thus, the forecast problem becomes one of initiation of convection. Neither the Nashville nor the Bangldeshi cycles spend as long during the year or go as far above the discriminator line. The Nashville cycle, however, remains close to the discriminator line for a very long time. This suggests that it is likely that there are a number of days in any

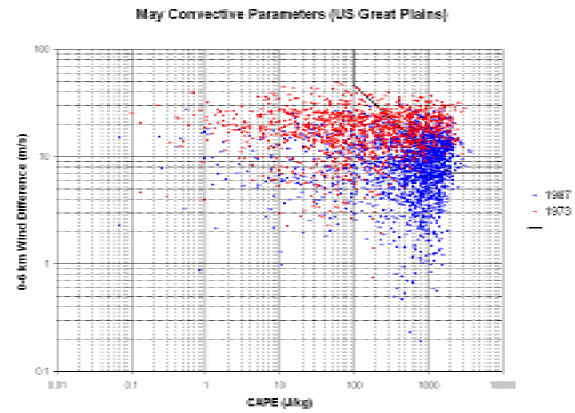

Fig. 6: Scatter plots of CAPE and 0-6 km vector wind difference for all points from 95 W-102 W, 30N-40 N in May for 1973 (red) and 1987 (blue.)

particular year where conditions are favorable throughout a long period.

We can also look at individual point values for periods of interest. The year 1973 was an active tornado year in the Central Plains and 1987 was an inactive tornado year, even though there were severe thunderstorms. The differences in climatological conditions between the two years are clear when the values for May are plotted on a Shear/CAPE diagram (Fig. 6). Although the distribution of CAPE was similar for the two years, the shear was dramatically less in 1987. In particular, 1987 was characterized by many more days with low shear. 0-6 km wind differences rarely went below 10 m/s in 1973, but that was above the median in 1987. Thus, the “cloud” of points associated with 1987 is lower on the diagram. It is possible to imagine better display mechanisms that would show the differences between different years or parts of a year or locations.

4. Maps of features of interest

The complete coverage of the reanalysis dataset is ideal for looking at large-scale fields of interest. As a sample, we’ve computed the first date that the mean annual cycle of lowest 100 hPa mixing ratio reaches 6, 7, and 8, g/kg for the eastern US and Europe (Fig. 7). (Note that this is not the same as the mean first date that these values are reached, which is biased earlier in the year, highlighting early surges of moisture.) The maps highlight two features of interest. First is the lack of high moisture values at

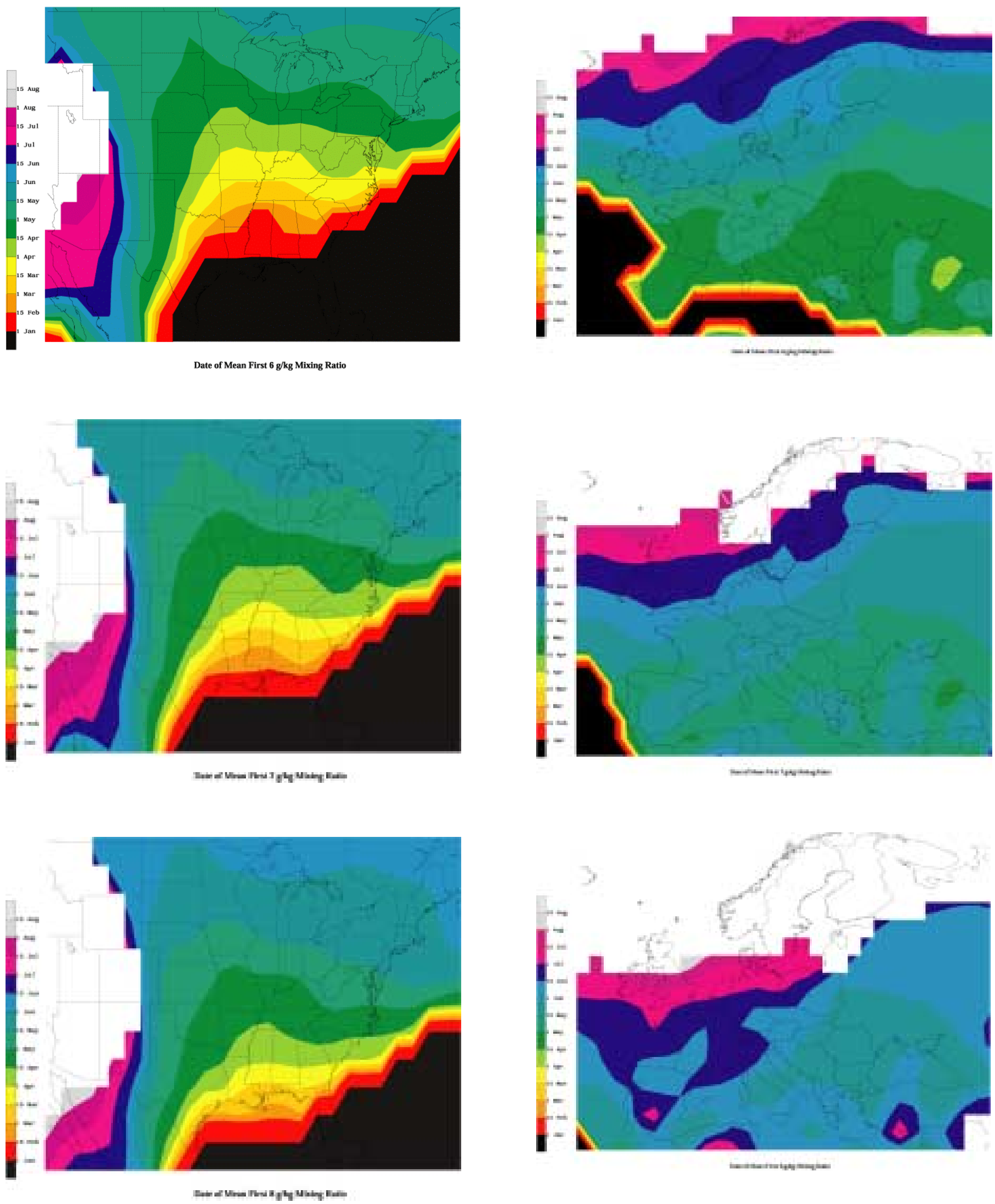

Fig. 7: Date of first date with mean mixing ratio in lowest 100 hPa greater than specified amount. Note that black regions indicate every day of year has value, white regions indicate no days during year reach value. First color shade above black indicates date between 2 January and 15 February. After that each color indicates half of a month. Left side for eastern US, right side for Europe. Top panels for 6 g/kg, middle for 7 g/kg, bottom for 8 g/kg.

any time in Europe. The Saraha Desert to the south, coupled with the more northern latitude of the continent severely limits moisture. This is the primary limiting factor for the occurrence of severe thunderstorms in the continent (Brooks et al. 2003b).

The second feature of interest is the extremely rapid return of moisture in the climatological mean in the Central and Southern Plains of the US. The difference in timing between mean arrival of 6 g/kg and 8 g/kg is only 20 days in western Oklahoma, for instance, whereas it is nearly 40 days over central Ohio. As a result, the climatological probability of severe weather has a very sharp increase in the Plains at the beginning of the season compared to points to the east, where the probability increases more gradually (Brooks et al. 2003a).

5. Climate trends

The final aspect of the reanalysis data that we illustrate is the possiblity of looking at long-term climate trends in convective parameters. The question of possible effects of climate change on convection is an important one. Databases of severe weather reports are inadequate for addressing the question, but it is possible that observations of environments might be adequate (IPCC 2002). CAPE is an obvious first choice. As examples of very different long-term trends, consider the 75th percentile value of CAPE (after removing days with 0 CAPE) for each year from Oklahoma City in the US and Brisbane, Australia (Fig. 8). The 75th percentile was chosen as value of interest because it might serve as an indicator of relatively high, but not extreme, values of CAPE for a particular year and, so, might be indicative of what a "pretty big" value is for a location. The Brisbane value is relatively consistent around 500 J/kg, but the Oklahoma City value varies widely from around 750 J/kg to over 2000 J/kg. There's a suggestion of low-frequency interannual variability in Oklahoma City, with the late 1960s being a time of low CAPE and the late 1980s have high CAPE. In passing, we note that the Brisbane soundings are much less likely to have no CAPE (over 90% of the soundings have positive CAPE, whereas the Oklahoma City soundings have positive CAPE only about 60% of the time), so that there may be some effects of larger sample size leading to a more resistant calculation, but that seems unlikely to be the full explanation of the differences. Obviously, consideration of a larger number of locations and greater number of variabiles is necessary before any conclusions can be drawn.

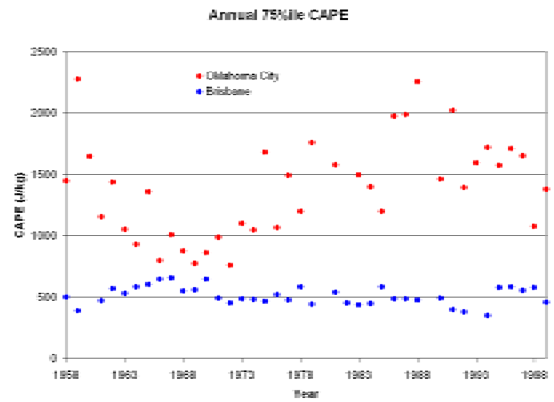

Fig. 8: 75th percentile value of CAPE (soundings with 0 CAPE not considered) by year for Oklahoma City (red) and Brisbane, Australia (blue) from 1958-1999 (1980, 1982, and 1989 data incomplete, so not plotted.)

6. Future work

We hope to complete the generation and analysis of the soundings in the relatively near future and to make the soundings and analyzed values available for the community. There is no reason to believe that the reanalysis soundings will be accurate within some small degree of tolerance for any particular event and location, but it seems likely that they will capture large-scale climatologial variability and, as such, be a valuable tool in understanding the distribution of events.

Acknowledgments

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References

Beebe, R. G., 1955: Types of airmasses in which tornadoes occur. *Bull. Amer. Meteorol. Soc.*, **36**, 349-350.

_____, 1958: Tornado proximity soundings. *Bull. Amer. Meteorol. Soc.,* **39**, 195-201.

_____, 1963: Tornado proximity soundings. *Proc*., 3rd Conf. on Severe Local Storms, Urbana, Illinois, USA, Amer. Meteorol. Soc., 1-6.

Brooks, H. E., and J. P. Craven, 2002: A database of proximity soundings for significant severe thunderstorms, 1957-1993. *Preprints*, 21st Conference on Severe Local Storms, San Antonio, Texas, Amer. Meteorol. Soc., 639-642.

_____, C. A. Doswell III, and M. P. Kay, 2003a: Climatological estimates of local daily tornado probability. *Wea. Forecasting*, **18**, 626-640.

_____, J. W. Lee, and J. P. Craven, 2003b: The spatial distribution of severe thunderstorm and tornado environments from global reanalysis data. *Atmos. Res.*, **67-68**, 73-94.

Concannon, P. R., H. E. Brooks, and C. A. Doswell III, 2000: Climatological risk of strong and violent tornadoes in the United States. *Preprints*, 2nd Symposium on Environmental Applications, Long Beach, California, American Meteorological Society, 212-219.

Darkow, G. L., 1969: An analysis of over sixty tornado proximity soundings. *Preprints*, 6th Conf. on Severe Local Storms, Chicago, Illinois, USA, Amer. Meteorol. Soc., 218-221.

Doswell, C. A., III, H. E. Brooks, and R. A. Maddox, 1996: Flash flood forecasting: An ingredients-based methodology. *Wea. Forecasting*, **11**, 560-581.

Fawbush, E. J., and R.C. Miller, 1952: A mean sounding representative of the tornadic airmass environment. *Bull. Amer. Meteorol. Soc.*, **33**, 303-307.

_____, and _____, 1954: The types of airmasses in which North American tornadoes form. *Bull. Amer. Meteor. Soc.*, **35**, 154-165.

Hanstrum, B. N., G. A. Mills, A. I. Watson, J. P. Monteverdi, and C. A. Doswell III, 2002: The cool-season tornadoes of California and southern Australia. *Wea. Forecasting*, **17**, 705–722.

IPCC, 2002: *IPCC Workshop on Changes in Extreme Weather and Climate Events Workshop Report*, Beijing, 11-13 June 2002, 107 pp.

Johns, R. H., J. M. Davies, and P. W. Leftwich, 1993: Some wind and instability parameters associated with strong and violent tornadoes, 2. Variations in the combinations of wind and instability parameters. *The Tornado: Its Structure, Dynamics, Prediction and Hazards, Geophys. Monogr.*, No. 79, Amer. Geophys. Union, 583-590.

Kalnay, E., M. Kanamitsu, R. Kistler, W. Collins, D. Deaven, L. Gandin, M. Iredell, S. Saha, G. White, J. Woollen, Y. Zhu, A. Leetmaa, B. Reynolds, M. Chelliah, W. Ebisuzaki, W. Higgins, J. Janowiak, K.C. Mo, C. Ropelewski, J. Wang, R. Jenne, and D. Joseph, 1996: The NCEP/NCAR 40-year reanalysis project. *Bull. Amer. Meteorol. Soc.*, **77**, 437-472.

Lanicci, J. M., and T. T. Warner, 1991: A synoptic climatology of the elevated mixed-layer inversion over the southern Great Plains in spring. Part II: The life cycle of the lid. *Wea. Forecasting,* **6,** 198–213.

Lee, J. W., 2002: Tornado proximity soundings from the NCEP/NCAR reanalysis data. M. S. Thesis, University of Oklahoma, 61 pp.

Rasmussen, E. N., and D. O. Blanchard, 1998: A baseline climatology of sounding-derived supercell and tornado forecast parameters. *Wea. Forecasting*, **13**, 1148–1164.

Schuster, S. S., R. J. Blong, and M. S. Speer, 2004: Climatological aspects of south-eastern Australian hailstorms and applications using radar data. *This CD.*