The Influence of Anthropogenic Landscape Changes on Weather in South Florida

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ABSTRACT

Using identical observed meteorology for lateral boundary conditions, the Regional Atmospheric Modeling System was integrated for July–August 1973 for south Florida. Three experiments were performed—one using the observed 1973 landscape, another the 1993 landscape, and the third the 1900 landscape, when the region was close to its natural state. Over the 2-month period, there was a 9% decrease in rainfall averaged over south Florida with the 1973 landscape and an 11% decrease with the 1993 landscape, as compared with the model results when the 1900 landscape is used. The limited available observations of trends in summer rainfall over this region are consistent with these trends.

1. Introduction

The importance of the sea breeze on the precipitation pattern of south Florida in the United States has been known for many years (e.g., Arritt et al. 1996; Blanchard and Lopez 1985; Burpee and Lahiff 1984; Byers and Rodebush 1948; Gannon 1977; Lyons 1995; Lyons et al. 1992; McQueen and Pielke 1985; Michaels et al. 1987; Pielke 1974; Pielke and Mahrer 1978; Segal et al. 1997; Pielke 1984; Simpson 1994; Song 1986). Less recognized, however, is the role of the region's landscape on this aspect of the region's water budget. Whether the land is urbanized, covered with water, in agriculture, etc., influences the amount of water transpired and evaporated into the atmosphere as well as generates local wind circulations that focus the cumulonimbus activity (Gannon and Warner 1990). In Pielke and Cotton (1977, their Figs. 27 and 28), the very large spatial variations in surface radiative temperatures across south Florida due to landscape variations was shown.

The Everglades is a major component of the south Florida environment, and this region's landscape has been changed substantially during this century (Davis and Ogden 1994; De Angelis et al. 1998; Lodge 1994). Two pioneers concerned with the fate of the Everglades, Douglas and Rothchild (1987), had the following conclusion regarding the role of the Everglades in weather.

> Much of the rainfall on which south Florida depends comes from evaporation in the Everglades. The Everglades evaporate, the moisture goes up into the clouds, the clouds are blown to the north, and the rain comes down over the Kissimmee River and Lake Okeechobee. Lake Okeechobee, especially, is fed by these rains. When the lake gets filled, some of the excess drains down the Caloosahatchee River into the Gulf of Mexico, or through the St. Lucie River and

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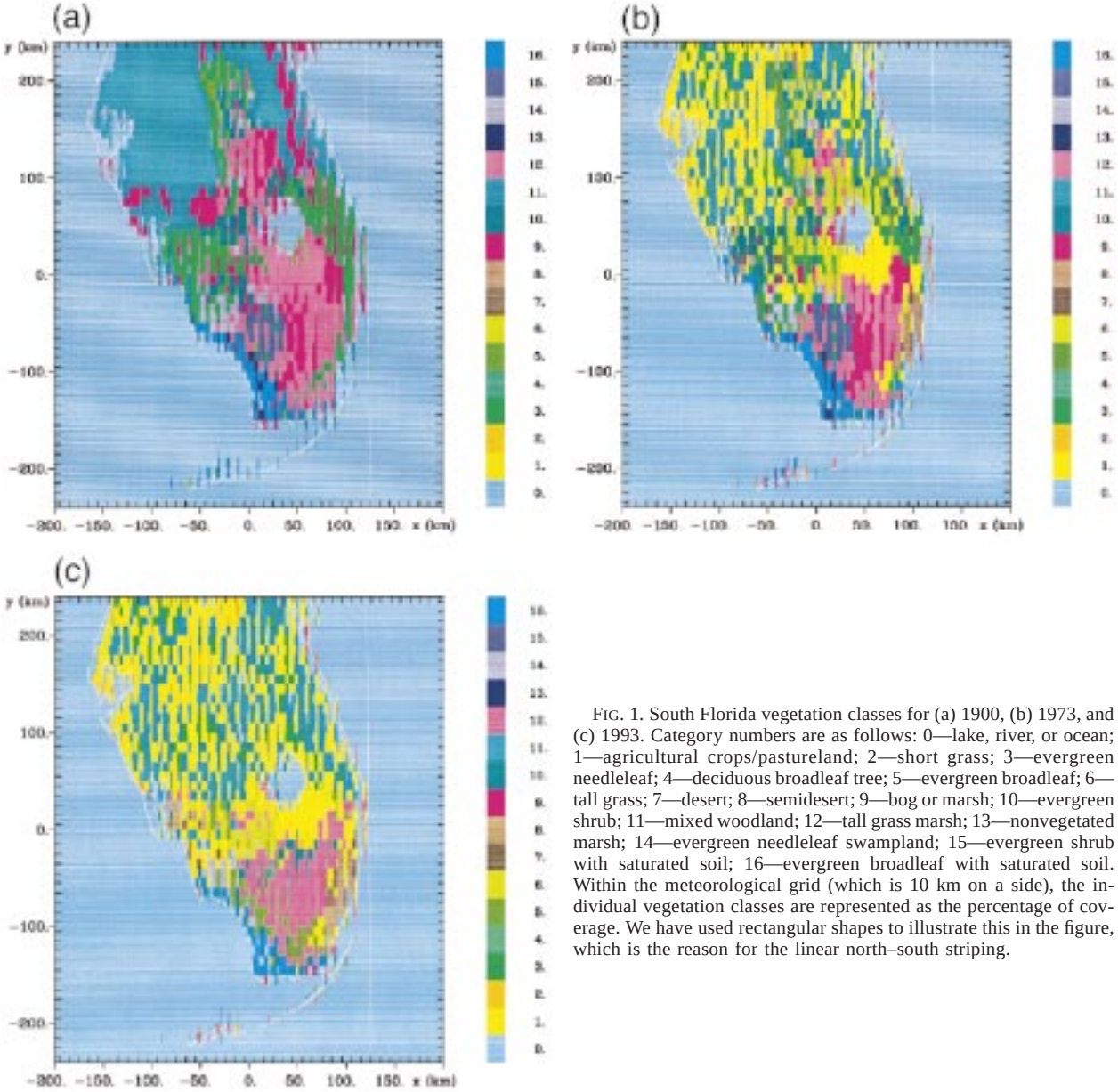

FIG. 1. South Florida vegetation classes for (a) 1900, (b) 1973, and (c) 1993. Category numbers are as follows: 0—lake, river, or ocean; 1—agricultural crops/pastureland; 2—short grass; 3—evergreen needleleaf; 4—deciduous broadleaf tree; 5—evergreen broadleaf; 6—tall grass; 7—desert; 8—semidesert; 9—bog or marsh; 10—evergreen shrub; 11—mixed woodland; 12—tall grass marsh; 13—nonvegetated marsh; 14—evergreen needleleaf swampland; 15—evergreen shrub with saturated soil; 16—evergreen broadleaf with saturated soil. Within the meteorological grid (which is 10 km on a side), the individual vegetation classes are represented as the percentage of coverage. We have used rectangular shapes to illustrate this in the figure, which is the reason for the linear north–south striping.

into the Atlantic Ocean. The rest of the excess—the most useful part—spills over the southern rim of the lake into the great arc of the Everglades.

South Florida depends on this summer rainfall for its water. As discussed in Kushlan (1990) there is almost no carryover of water from one year to the next. There is also relatively little runoff to the ocean compared to evaporation and transpiration (e.g., for the Everglades Basin, Kushlan estimates an average annual rainfall of 127 cm with a total runoff of only 19 cm).

In this paper, we use a model simulation to assess the extent to which land-use change in south Florida may have affected local precipitation. Boyle and Mechem (1982) speculated in a popular magazine that land use may be causing drought in south Florida. Previous studies in other geographic areas have demonstrated that landscape patterns can generate local atmospheric circulations due to contrasting surface properties that can be as strong as a sea breeze caused by a land–water contrast (e.g., Anthes 1984; Avissar 1995; Avissar and Chen 1993; Dalu and Pielke 1993; Emori 1998; Hong et al. 1995a,b; Lohar and Pal 1995; Mahfouf et al. 1987; Rabin et al. 1990; Schickedanz 1976; Segal and Arritt 1992; Segal et al. 1988, 1989; Wetzel 1990), as well as directly influence sea-breeze circulations where they occur (Lohar and Pal 1995; Xian 1991).

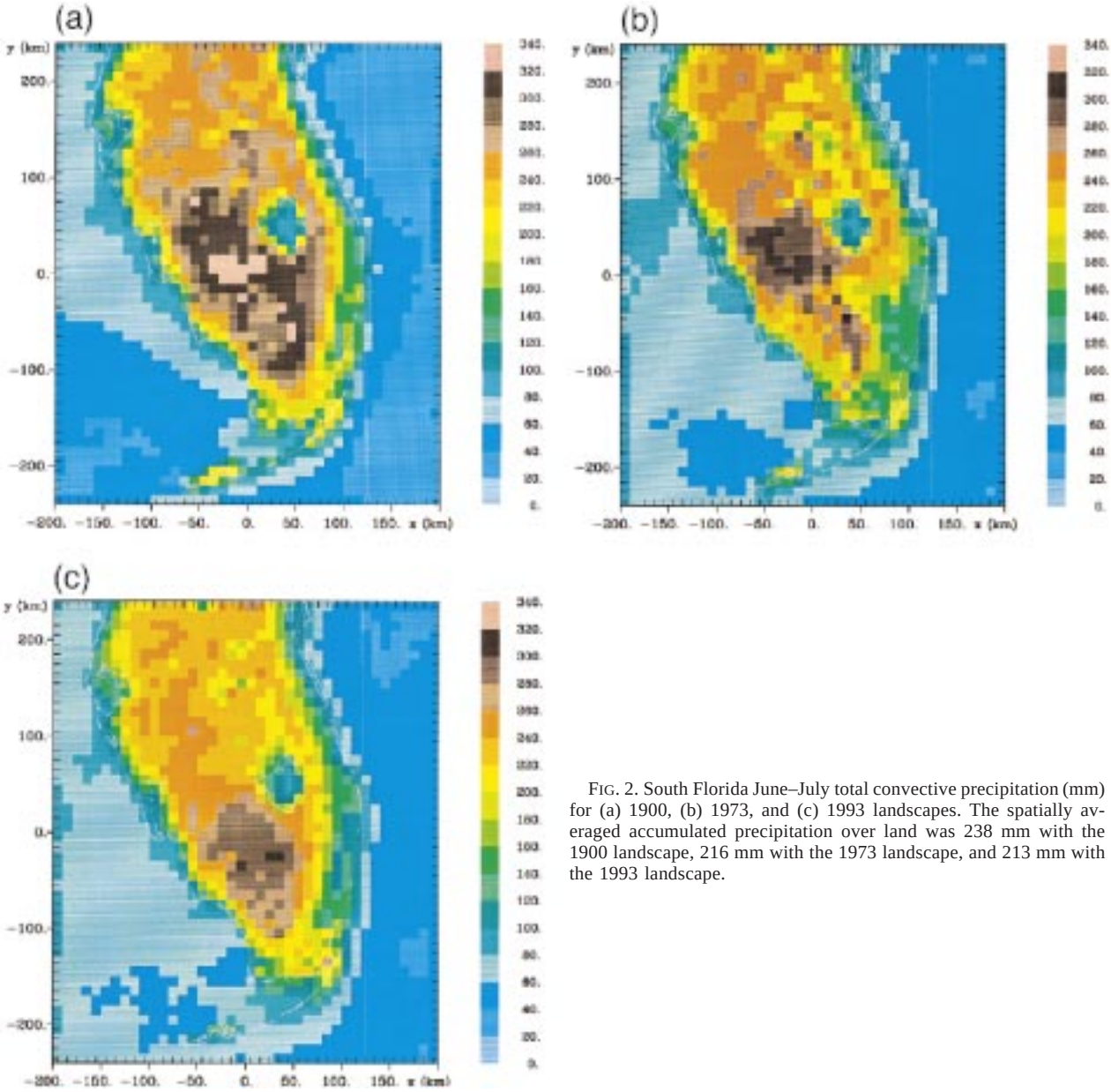

FIG. 2. South Florida June–July total convective precipitation (mm) for (a) 1900, (b) 1973, and (c) 1993 landscapes. The spatially averaged accumulated precipitation over land was 238 mm with the 1900 landscape, 216 mm with the 1973 landscape, and 213 mm with the 1993 landscape.

2. Methodology

The Regional Atmospheric Modeling System (RAMS; Pielke et al. 1992; Nicholls et al. 1995), as modified for long-term integrations by G. Liston and R. Pielke (1999 unpublished manuscript), is used for this study. The simulations were run for two months using the National Centers for Environmental Prediction (NCEP) reanalysis (Kalnay et al. 1996) for July and August 1973 as lateral boundary conditions. Two grids were used, the coarse one having a 40-km mesh size and 42 × 42 mesh cells, and the fine nested grid having a 10-km mesh size and 48 × 50 mesh cells. The grids were centered at a location just southwest of Lake Okeechobee. Both grids used 30 vertical levels that were stretched from a 100-m vertical spacing near the ground to 1 km near the model top at 20 km. A 1-min time step was used on the coarse grid and 30 s on the fine grid. A cumulus parameterization (a modified Kuo scheme; see Tremback 1990) and radiative transfer scheme (the Mahrer–Pielke scheme; see Pielke et al. 1992) were employed.

The experiments differed solely in the definition of land-use category (in terms of type and amount of vegetation cover; Fig. 1) and initial soil moisture in southern Florida. For the region approximately south of a line running west-southwest to east-northeast and passing

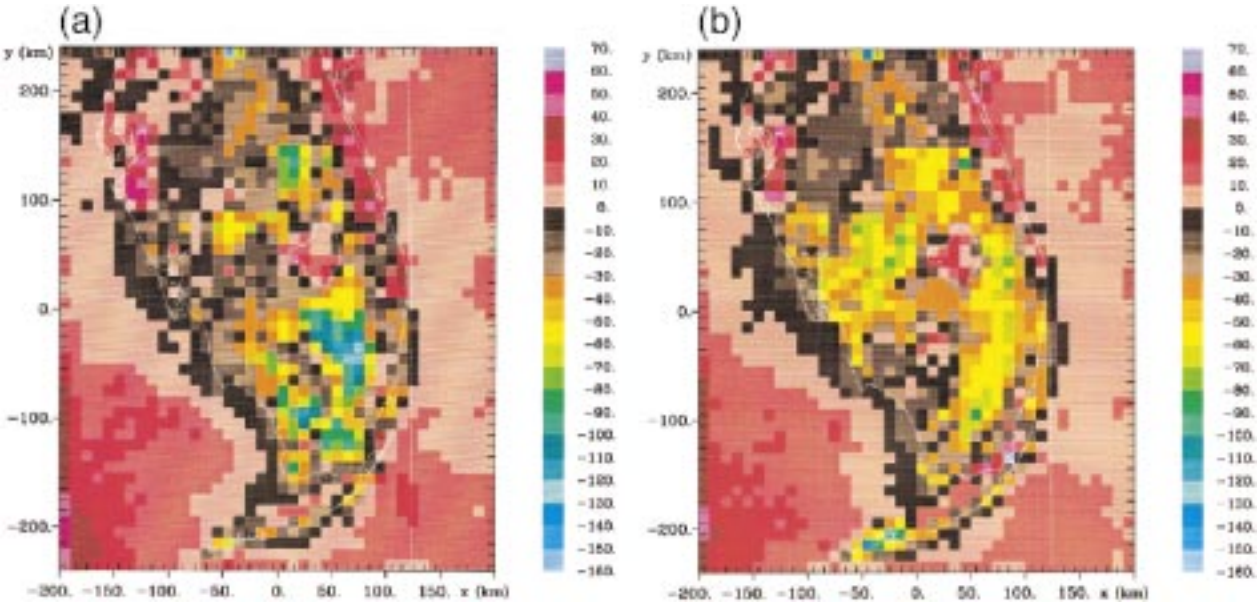

FIG. 3. The change in June–July total convective rainfall for (a) 1973–1900, and (b) 1993–1900.

just north of Lake Okeechobee, land cover data were available for the years 1900 and 1973 (Fig. 1) based on information collected by Costanza (1975,[1] 1979). The data for 1900 represent the landscape in the Costanza (1975) (appendix; top figure) classification for the southern portion of Florida (including Lake Okeechobee) and the natural (Küchler) landscape for the northern part (Küchler 1964). The data for 1973 includes the Costanza classification (see appendix; bottom figure) in the southern Florida region and the U.S. Geological Survey (USGS; Belward and Loveland 1995) classification in the north. The 1993 case was simulated based on the 1993/94 land cover classification, which was adapted from Landsat thematic mapper-based land cover analysis at 30-m resolution using the Nature Conservancy (TNC) southeastern region classification scheme.[2] The TNC classification scheme was converted to the landscape classes described in Fig. 1 and used in the southern part of the domain. The 1-km USGS classification using 1992–93 Advanced Very High Resolution Radiometer (AVHRR) data (Belward and Loveland 1995) was used farther north. For areas in south Florida that were identified as swamp or marsh, soil moisture was initialized as saturated with 10 cm of standing water on top (everywhere else in the domain, 0.4 of soil saturation at the surface to 0.6 of soil saturation at 0.5-m depth was used). G. Burba, S. Verma, and J. Kim (1998, personal communication) have observed in Nebraska how marshy areas affect the surface energy budget. Their work demonstrates the need to include swamps and marshes in our model calculations. The soil was assumed to be sandy clay loam everywhere in the domain.

The representation of the surface heat energy and moisture budgets used the LEAF-2 scheme (Walko et al. 1998). LEAF-2 provides algorithms to partition incoming net radiation into sensible heat fluxes, evaporation, and transpiration based on landscape type and more rapidly varying land surface conditions such as soil moisture. Sea surface temperatures were obtained from the global climatological files at the National Center for Atmospheric Research (NCAR). We used the July and August average values.

3. Results

Figure 2 shows the accumulated 2-month deep cumulus precipitation for the three model runs simulated over south Florida. The differences in precipitation between 1973 and 1900, and 1993 and 1900 are shown in Fig. 3. With differences in values exceeding 50 mm

[1] Costanza (1975) describes the widespread conversion of natural vegetation classes to urban and agricultural land uses including the conversion of pine land systems into either urban and agricultural lands, or into grassy scrub by clearing of trees and increased frequency of fire. Specifically, he noted that large drainage projects begun at the turn of the century initially caused a shift from sawgrass marshes to freshwater marshes, followed by the subsequent conversion of these freshwater marshes, as well as wet prairies, to agricultural and urban land uses. As illustrated in Fig. 1 (and the appendix), these regional land cover changes were especially pronounced in the Everglades to the southeast of Lake Okeechobee and in eastern coastal areas. Appendix A presents the higher spatial resolution maps of the Costanza data.

[2] For detailed descriptions of the Nature Conservancy classification scheme, ask for the report: International Classification of Ecological Communities; Terrestrial Vegetation of the Southeastern United States The Nature Conservancy, 101 Conner Dr., Suite 202, Chapel Hill, NC 27514.

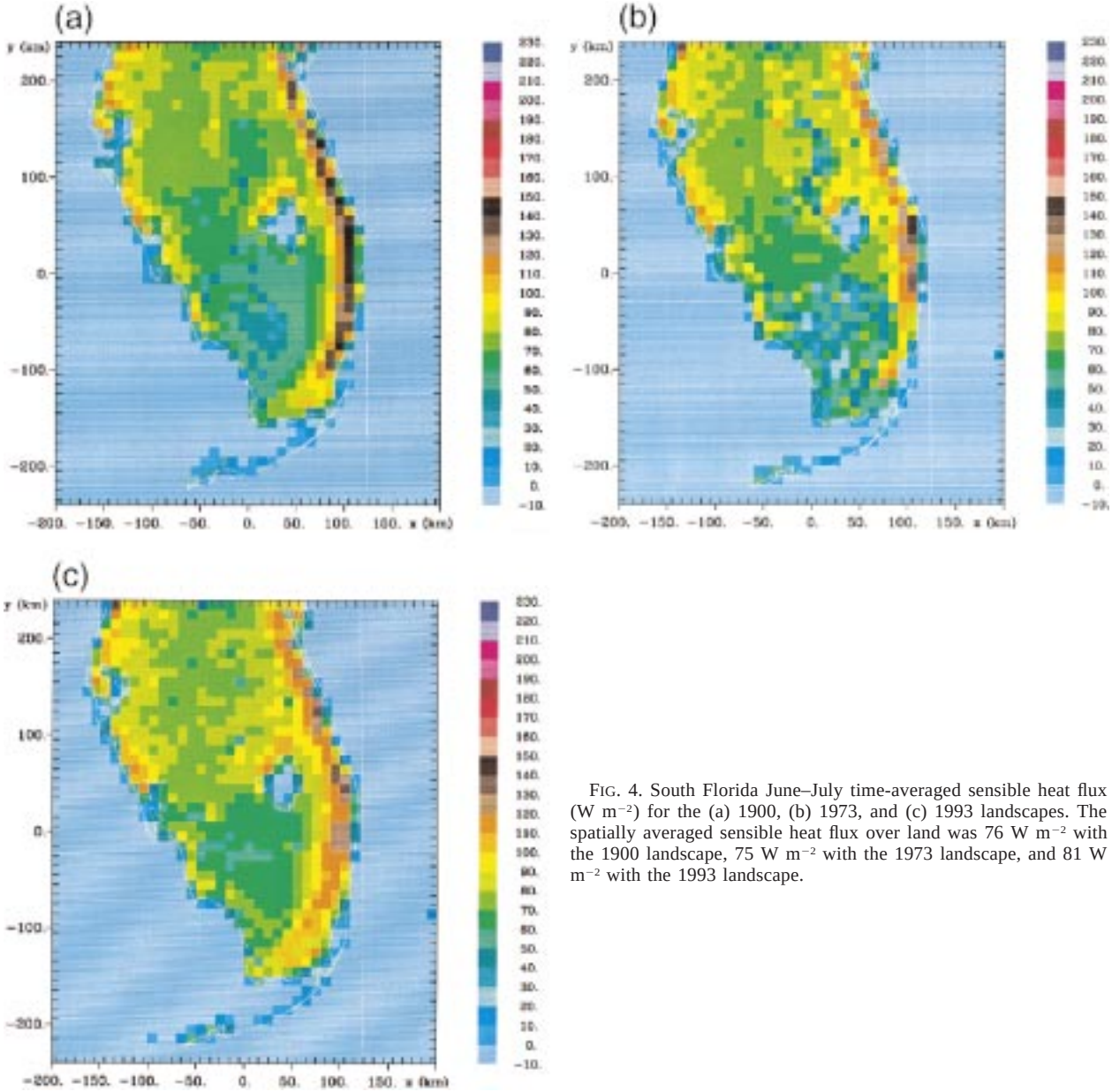

FIG. 4. South Florida June–July time-averaged sensible heat flux (W m^{-2}) for the (a) 1900, (b) 1973, and (c) 1993 landscapes. The spatially averaged sensible heat flux over land was 76 W m^{-2} with the 1900 landscape, 75 W m^{-2} with the 1973 landscape, and 81 W m^{-2} with the 1993 landscape.

in places, and an altered spatial pattern, the human-caused landscape change apparently has had a major effect on the hydrology of the region. The spatial pattern of the simulated rainfall for the 1973 model run is consistent with the climatological pattern of rainfall [e.g., compare the spatial pattern of convective precipitation in Fig. 2b and the thunderstorm pattern in Figs. 2 and 3 in Michaels et al. (1987)]. The accumulated precipitation, spatially averaged over the land area in the fine grid, is 238 mm for 1900 but only 216 mm for 1973 and 213 mm for 1993, which constitutes a 9% reduction from 1900 to 1973, and an 11% reduction between 1900 and 1993. This reduction in rainfall reduces the amount of water that reaches the Everglades areas. This is in addition to the reduction in southwest water flow noted by Costanza (1975) due to canal diversions and drainage. In contrast, the spatially averaged precipitation over water has increased.[3]

The 2-month (day and night) time-averaged surface sensible heat flux changed significantly from the 1900 simulation to the 1973 and 1993 simulations (Fig. 4) with the spatially averaged value for land changing from

[3] Poveda and Mesa (1997), on a somewhat larger spatial scale, also find that land–atmospheric interactions over land (in their case tropical South America) affect weather over the adjacent ocean, and even over longer distances.

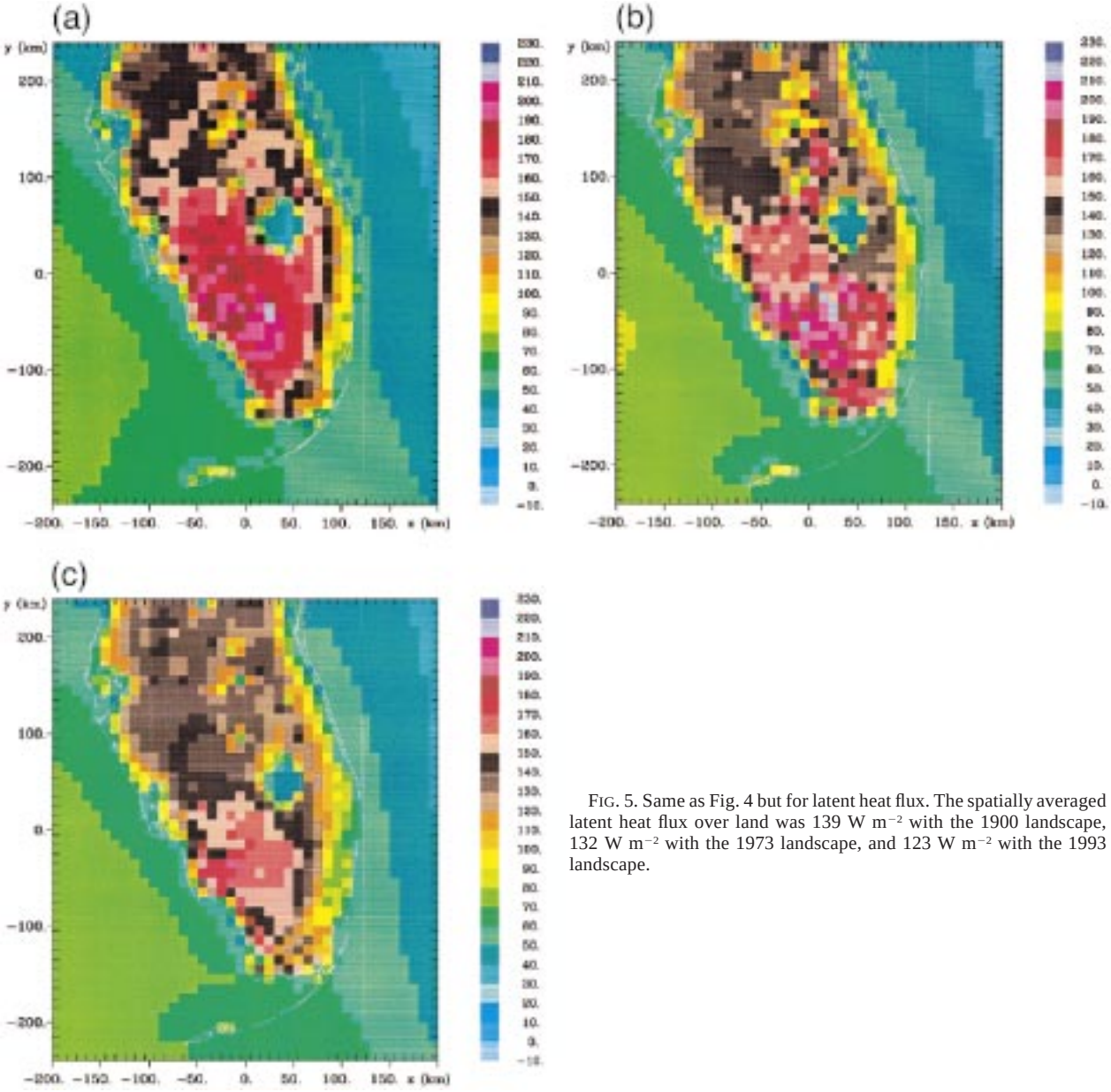

FIG. 5. Same as Fig. 4 but for latent heat flux. The spatially averaged latent heat flux over land was 139 W m^{-2} with the 1900 landscape, 132 W m^{-2} with the 1973 landscape, and 123 W m^{-2} with the 1993 landscape.

76 W m^{-2} in 1900 to 75 W m^{-2} in 1973 and to 81 W m^{-2} in 1993. The time-averaged latent heat flux, on the other hand, has decreased (Fig. 5), with a land-averaged value of 139 W m^{-2} in 1900 to 132 W m^{-2} in 1973 and 123 W m^{-2} in 1993. The maximum surface air temperature occurring for the entire period has increased by about 2°C for most inland areas from 1900 to the 1973 and 1993 cases (not shown), while the average maximum over land for the 2-month period increased by about 0.4°C by 1973 and 0.7°C for 1993 (Fig. 6). The average minimum temperatures over land also were 0.4°C warmer using the more recent landscape.

There is, unfortunately, only limited data to evaluate temporal trends over south Florida, which makes comparison with the model results difficult. Figure 7 shows precipitation data during July and August for at least part of this past century for three south Florida locations. The model results indicate that if land-use change were the only factor influencing rainfall, we would expect a general decrease of rainfall over the interior, although there is considerable grid point to grid point variability near Lake Okeechobee and the coastlines. Some locations along the coast show a modest increase in rainfall. Belle Glade does show a drying trend.

The differences in the precipitation in the model are due to the alteration in the spatial pattern of transpiration and evaporation due to the land cover change. The reduction in this water flux to the atmosphere results in

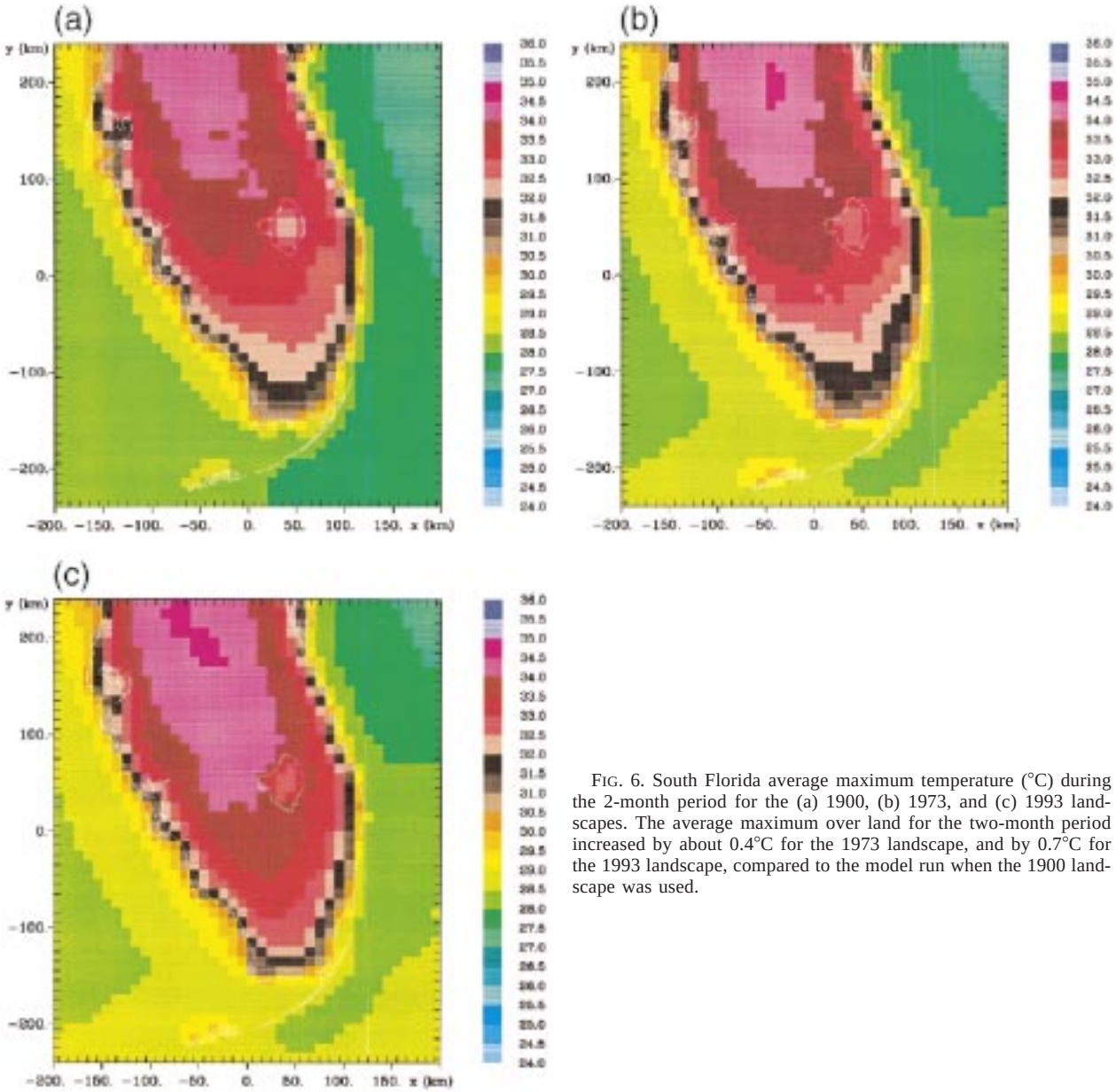

FIG. 6. South Florida average maximum temperature (°C) during the 2-month period for the (a) 1900, (b) 1973, and (c) 1993 landscapes. The average maximum over land for the two-month period increased by about 0.4°C for the 1973 landscape, and by 0.7°C for the 1993 landscape, compared to the model run when the 1900 landscape was used.

less precipitation in the interior of the peninsula from thunderstorms and a spatial displacement in the rainfall pattern.

Figure 8 presents temperature trends for the same sites as in Fig. 7. The observed increase in average temperature for July and August at Everglades City and Belle Glade can be explained solely by land-use change in the area, as the magnitude of change in the model and observations are nearly the same.

4. Conclusions

Over south Florida during the past 100 years, there has been a widespread conversion of natural vegetation classes to urban and agricultural land, and into grassy shrubland. These landscape changes over south Florida are likely to have altered the local weather patterns, with south Florida averaged summer rainfalls perhaps as much as 11% less than what would have occurred if the landscape had been left undisturbed by man. This reduction in precipitation due to land cover changes would be in addition to precipitation variability (which is also evident in Fig. 7) caused by year-to-year variability and long-term trends in synoptic weather features (e.g., Davis et al. 1997).

Along with the reduction in deep cumulus rainfall, the model indicated that surface temperatures should warm in response to the landscape conversion. A warm-

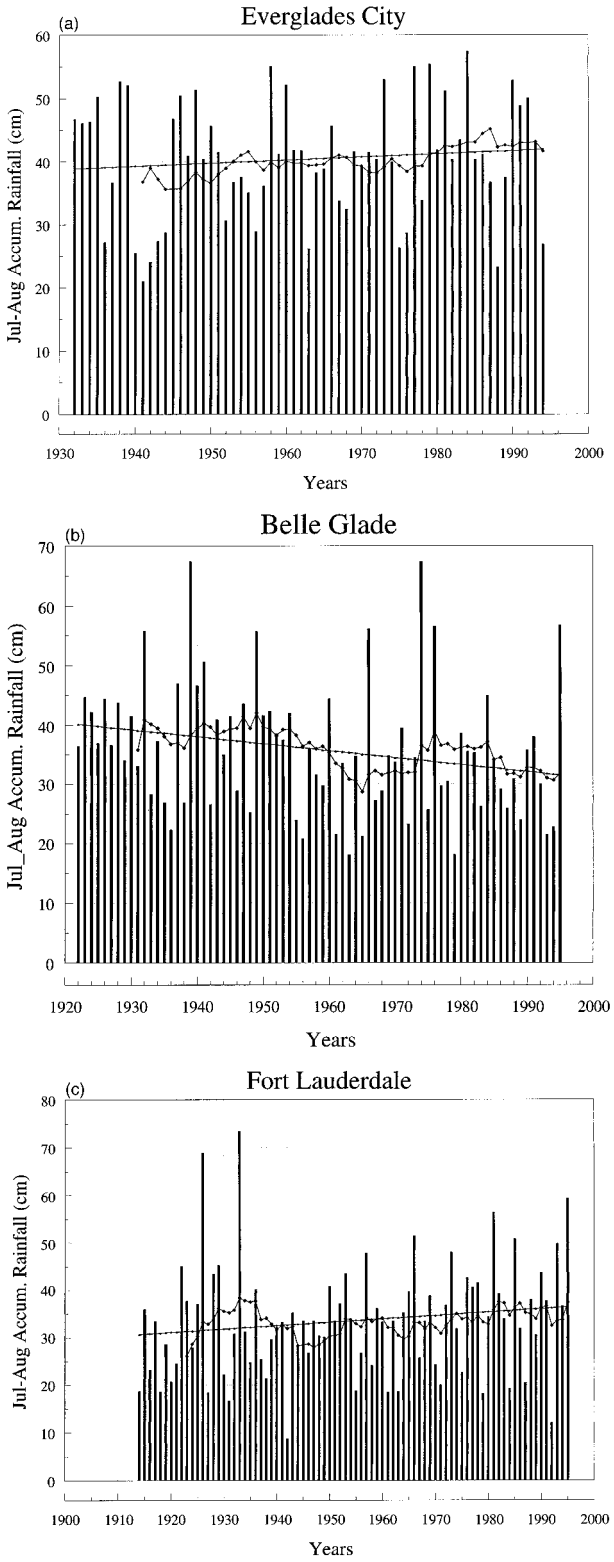

FIG. 7. Rainfall amounts in the months of July and August for (a) Everglades (on the southwest coast of Florida), (b) Belle Glade (along the south shore of Lake Okeechobee), and (c) Fort Lauderdale (along the east coast of Florida), over the time period indicated in the figures. The total rainfall is shown by the gray bars. The linear regression is shown, as well as a 10-yr moving average.

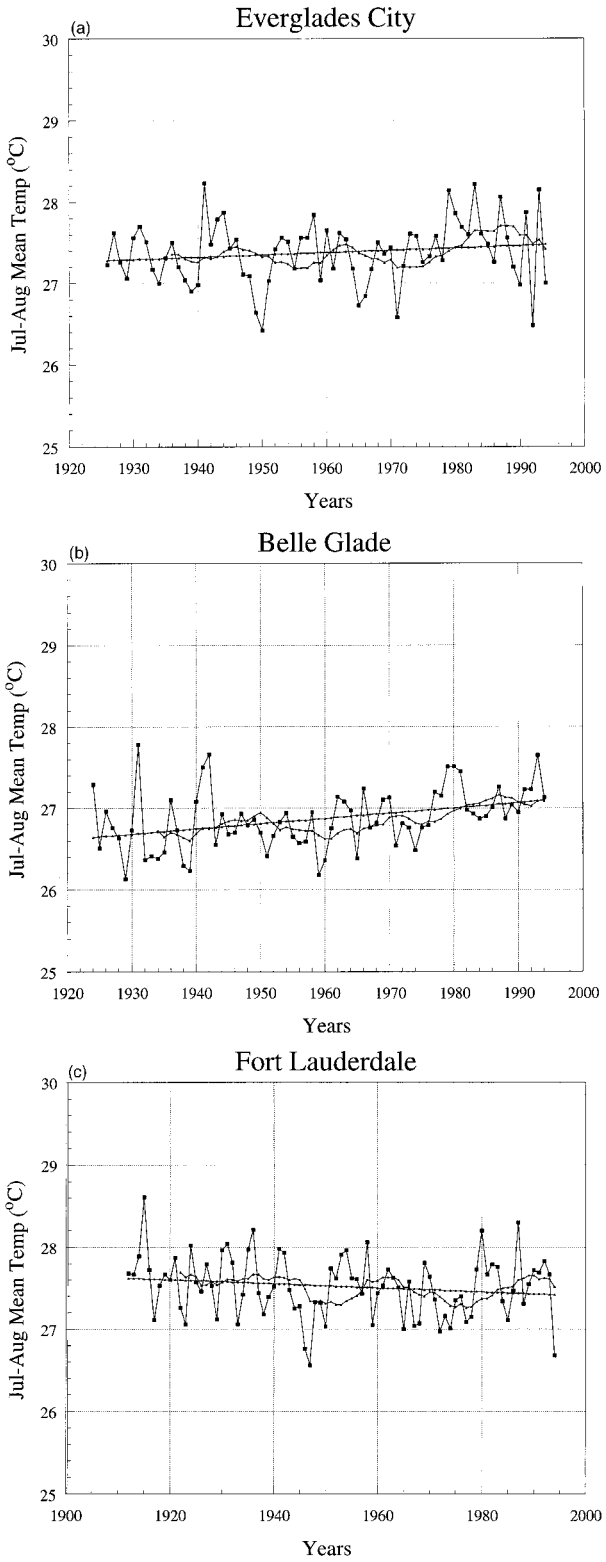

FIG. 8. Same as Fig. 7 but for temperature.

ing is observed for two of the three stations for which data is available. These results indicate that unless land-use change effects on weather are included in climate trend analyses, the reasons for climate change can be erroneously concluded. In addition, because of the permanent landscape changes in the regions around the Everglades, it will be impossible to restore the climate in this region to what it was prior to the landscape change, thereby making the restoration of the Everglades ecosystem even more difficult. Rainfall, for example, is likely to be permanently less in the absence of changes in larger-scale climate influences.

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REFERENCES

Anthes, R. A., 1984: Enhancement of convective precipitation by mesoscale variations in vegetative covering in semiarid regions. *J. Climate Appl. Meteor.,* **23,** 541–554.

Arritt, R. W., M. Segal, M. Leuthold, C. J. Anderson, and R. W. Turner, 1996: An observational study of the Lake Okeechobee lake breeze and its effect on deep convection. Preprints, *Conf. on Coastal and Oceanic and Atmospheric Prediction,* Atlanta, GA, Amer. Meteor. Soc., 350–353.

Avissar, R., 1995: Recent advances in the representation of land–atmosphere interactions in general circulation models. *Rev. Geophys.,* **33** (Suppl.), 1005–1010.

——, and F. Chen, 1993: Development and analysis of prognostic equations for mesoscale kinetic energy and mesoscale (subgrid scale) fluxes for large-scale atmospheric models. *J. Atmos. Sci.,* **50,** 3751–3774.

Belward, A. S., and T. R. Loveland, 1995: The IGBP-DIS 1 km land cover project: Remote sensing in action. *Proc. 21st Annual Conf. of the Remote Sensing Society,* Southampton, United Kingdom, 1099–1106.

Blanchard, D. O., and R. E. Lopez, 1985: Spatial patterns of convection in South Florida. *Mon. Wea. Rev.,* **113,** 1282–1299.

Boyle, R. H., and R. M. Mechem, 1982: Anatomy of a man-made drought. *Sports Illus.,* **56,** 46–54.

Burpee, R. W., and L. N. Lahiff, 1984: Area-average rainfall variations on sea-breeze days in south Florida. *Mon. Wea. Rev.,* **112,** 520–534.

Byers, H. R., and H. R. Rodebush, 1948: Causes of thunderstorms of the Florida peninsula. *J. Meteor.,* **5,** 275–280.

Costanza, R., 1975: The spatial distribution of land use subsystems, incoming energy and energy use in south Florida from 1900 to 1973. M.S. thesis, Dept. of Architecture, University of Florida. [Available from Department of Architecture, University of Florida, P.O. Box 115702, Gainesville, FL 32611.]

——, 1979: Embodied energy basis for economic-ecologic systems. Ph.D. dissertation, University of Florida, 253 pp. [Available from Department of Achitecture, University of Florida, P.O. Box 115702, Gainesville, FL 32611.]

Dalu, G. A., and R. A. Pielke, 1993: Vertical heat fluxes generated by mesoscale atmospheric flow induced by thermal inhomogeneities in the PBL. *J. Atmos. Sci.,* **50,** 919–926.

Davis, R. E., B. P. Hayden, D. A. Gay, W. L. Phillips, and G. V. Jones, 1997: The North Atlantic subtropical anticyclone. *J. Climate,* **10,** 728–744.

Davis, S. M., and J. C. Ogden, Eds., 1994: *Everglades: The Ecosystem and its Restoration.* St. Lucie Press, 826 pp.

DeAngelis, D. L., L. J. Gross, M. A. Huston, W. F. Wolff, D. M. Fleming, E. J. Comiskey, and S. M. Sylvester, 1998: Landscape modeling for Everglades ecosystem restoration. *Ecosystems,* **1,** 64–75.

Douglas, M. S., with J. Rothchild, 1987: *Marjory Stoneman Douglas: Voice of the River.* Pineapple Press, 268 pp.

Emori, S., 1998: The interaction of cumulus convection with soil moisture distribution: An idealized simulation. *J. Geophys. Res.,* **103,** 8873–8884.

Gannon, P. T., 1977: On the influence of surface thermal properties. Ph.D. dissertation, University of Miami, 415 pp. [Available from University of Miami, Coral Gables, FL 33124.]

——, and T. E. Warner, 1990: Drought over south Florida: Mesoscale or synoptic scale? Preprints, *Eighth Conf. on Hydrometeorology,* Kananaskis Park, AB, Canada, Amer. Meteor. Soc., 3–6.

Hong, X., M. J. Leach, and S. Raman, 1995a: A sensitivity study of convective cloud formation by vegetation forcing with different atmospheric conditions. *J. Appl. Meteor.,* **34,** 2008–2028.

——, ——, ——, 1995b: Role of vegetation in generation of mesoscale circulation. *Atmos. Environ.,* **29,** 2163–2176.

Kalnay, E., and Coauthors, 1996: The NCEP/NCAR 40-Year Reanalysis Project. *Bull. Amer. Meteor. Soc.,* **77,** 437–471.

Küchler, A. W., 1964: Potential natural vegetation of the conterminous United States. Special Publ. No. 36. American Geophysical Society.

Kushlan, J. A., 1990: Freshwater marshes. *The Ecosystems of Florida,* R. L. Meyers and J. J. Ewel, Eds., University Presses of Florida, 324–363.

Lodge, T. E., 1994: *The Everglades Handbook: Understanding the Ecosystem.* St. Lucie Press, 228 pp.

Lohar, D., and B. Pal, 1995: The effect of irrigation on premonsoon season precipitation over south west Bengal, India. *J. Climate,* **8,** 2567–2570.

Lyons, W. A., 1995: Soil moisture influences on the performance of mesoscale and cloud-scale prognostic models. *Environmental Modeling,* P. Zannetti, Ed., Vol. 3, Computational Mechanics Publications, 183–213.

——, R. L. Walko, M. E. Nicholls, R. A. Pielke, W. R. Cotton, C. S. Keen, and A. I. Watson, 1992: Observational and numerical modeling investigations of Florida thunderstorms generated by multi-scale surface thermal forcing. Preprints, *Fifth Conf. on Mesoscale Processes,* Atlanta, GA, Amer. Meteor. Soc., 85–90.

Mahfouf, J.-F., E. Richard, and P. Mascart, 1987: The influence of soil and vegetation on the development of mesoscale circulations. *J. Climate Appl. Meteor.,* **26,** 1483–1495.

McQueen, J. T., and R. A. Pielke, 1985: A numerical and climatological investigation of deep convective cloud patterns in south Florida. Atmospheric Science Paper 389, Department of Atmospheric Science, Colorado State University, Fort Collins, CO, 177 pp. [Available from Department of Atmospheric Science, Colorado State University, Fort Collins, CO 80523.]

Michaels, P. J., R. A. Pielke, J. S. McQueen, and D. E. Sappington, 1987: Composite climatology of Florida summer thunderstorms. *Mon. Wea. Rev.,* **115,** 2781–2791.

Nicholls, M. E., R. A. Pielke, J. L. Eastman, C. A. Finley, W. A. Lyons, C. J. Tremback, R. L. Walko, and W. R. Cotton, 1995: Applications of the RAMS numerical model to dispersion over urban areas. *Wind Climate in Cities,* J. E. Cermak et al., Eds., Kluwer Academic, 703–732.

Pielke, R. A., 1974: A three-dimensional numerical model of the sea breezes over south Florida. *Mon. Wea. Rev.,* **102,** 115–139.

——, 1984: *Mesoscale Meteorological Modeling.* Academic Press, 612 pp.

——, and W. R. Cotton, 1977: A mesoscale analysis over south Florida for a high rainfall event. *Mon. Wea. Rev.,* **105,** 343–362.

——, and Y. Mahrer, 1978: Verification analysis of the University of Virginia three-dimensional mesoscale model prediction over south Florida for July 1, 1973. *Mon. Wea. Rev.,* **106,** 1568–1589.

——, and Coauthors, 1992: A comprehensive meteorological modeling system—RAMS. *Meteor. Atmos. Phys.,* **49,** 69–91.

Poveda, G., and O. J. Mesa, 1997: Feedbacks between hydrological processes in tropical South American and large-scale ocean–atmospheric phenomenon. *J. Climate,* **10,** 2690–2702.

Rabin, R. M., S. Stadler, P. J. Wetzel, D. J. Stensrud, and M. Gregory, 1990: Observed effects of landscape variability on convective clouds. *Bull. Amer. Meteor. Soc.,* **71,** 272–280.

Schickedanz, P. T., 1976: The effect of irrigation on precipitation in the Great Plains. NSF-RANN, Grant GI-43871, Final Report, Atmospheric Science Section, Illinois State Water Survey, Urbana, IL, 105 pp. [Available from Illinois State Water Survey, University of Illinois, 2204 Griffith Dr., Champaign, IL 61820.]

Segal, M., and R. W. Arritt, 1992: Non-classical mesoscale circulations caused by surface sensible heat-flux gradients. *Bull. Amer. Meteor. Soc.,* **73,** 1593–1604.

——, R. Avissar, M. C. McCumber, and R. A. Pielke, 1988: Evaluation of vegetation effects on the generation and modification of mesoscale circulations. *J. Atmos. Sci.,* **45,** 2268–2292.

Segal, M., W. Schreiber, G. Kallos, R. A. Pielke, J. R. Garratt, J. Weaver, A. Rodi, and J. Wilson, 1989: The impact of crop areas in northeast Colorado on midsummer mesoscale thermal circulations. *Mon. Wea. Rev.,* **117,** 809–825.

——, R. W. Arritt, J. Shen, C. Anderson, and M. Leuthold, 1997: On the clearing of cumulus clouds downwind from lakes. *Mon. Wea. Rev.,* **125,** 639–646.

Simpson, J. E, 1994: *Sea Breeze and Local Winds.* Cambridge University Press, 234 pp.

Song, J.-L., 1986: A numerical investigation of Florida's sea breeze–cumulonimbus interactions. Ph.D. dissertation, Department of Atmospheric Science, Colorado State University, 187 pp. [Available from Department of Atmospheric Science, Colorado State University, Fort Collins, CO 80523.]

Tremback, C. J., 1990: Numerical simulation of a mesoscale convective complex: Model development and numerical results. Ph.D. dissertation, Department of Atmospheric Science, Colorado State University, Fort Collins, CO, 247 pp. [Available from Department of Atmospheric Science, Colorado State University, Fort Collins, CO 80523.]

Walko, R. L., and Coauthors, 1998: Coupled atmosphere–terrestrial ecosystem–hydrology models for environmental modeling. Department of Atmospheric Science Class Rep. 9, Colorado State University, Fort Collins, CO, 46 pp. and figures. [Available from Department of Atmospheric Science, Colorado State University, Fort Collins, CO 80523.]

Wetzel, P. I., 1990: A simple parcel method for prediction of cumulus onset and area-averaged cloud amount over heterogeneous land surfaces. *J. Appl. Meteor.,* **29,** 516–523.

Xian, Z., 1991: A 2-D model study of the influence of the surface on mesoscale convection during the Indian monsoon. M.S. thesis, Department of Atmospheric Science, Colorado State University, 110 pp. and appendix. [Available from Department of Atmospheric Science, Colorado State University, Fort Collins, CO 80523.]

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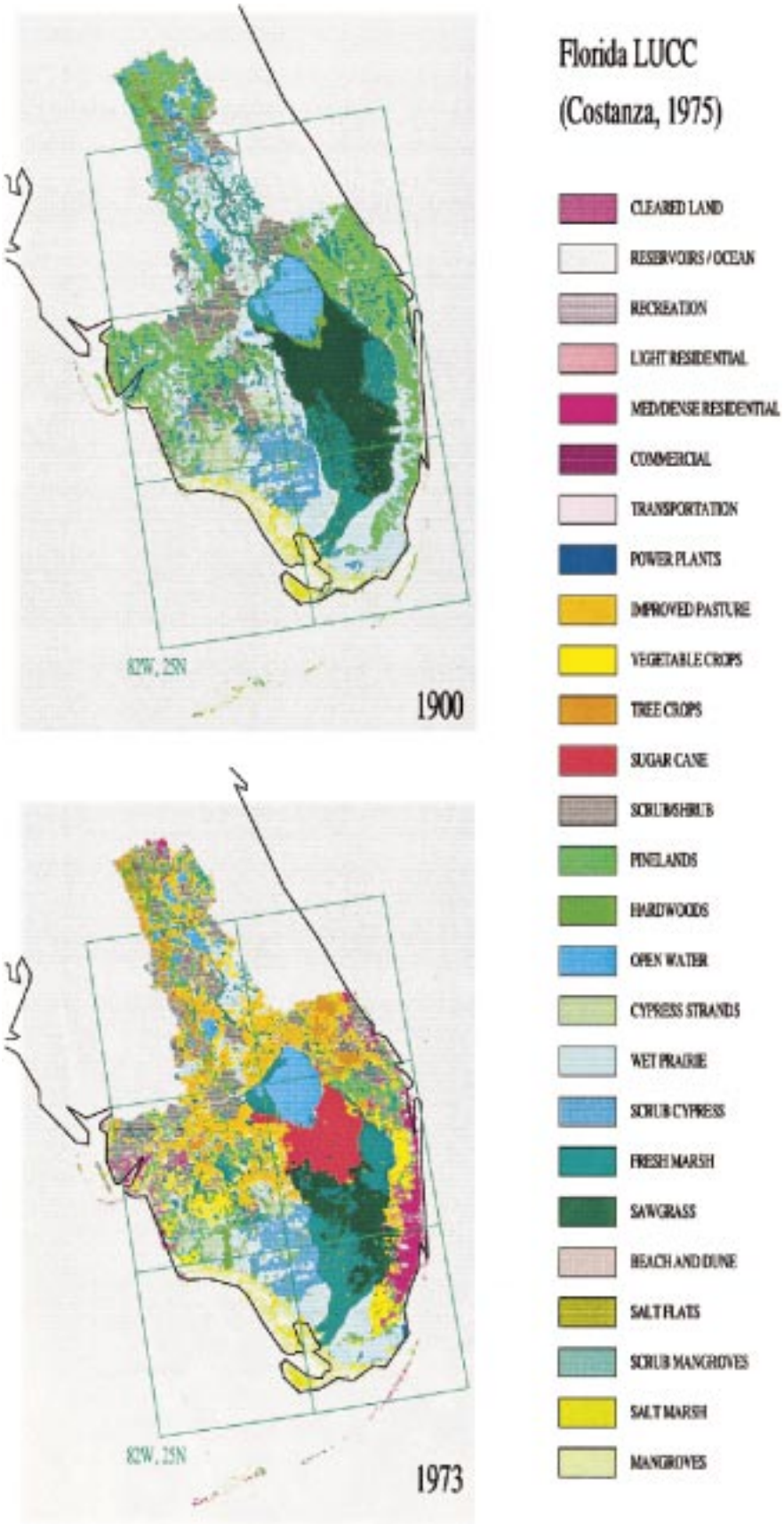
APPENDIX

Land Use Cover Change


Florida LUCC
(Costanza, 1975)
CLEARED LAND
RESERVOIRS / OCEAN
RECREATION
LIGHT RESIDENTIAL
MED/DENSE RESIDENTIAL
COMMERCIAL
TRANSPORTATION
POWER PLANTS
IMPROVED PASTURE
VEGETABLE CROPS
TREE CROPS
SUGAR CANE
SCRUB/SHRUB
PINELANDS
HARDWOODS
OPEN WATER
CYPRESS STRANDS
WET PRAIRIE
SCRUB CYPRESS
FRESH MARSH
SAWGRASS
BEACH AND DUNE
SALT FLATS
SCRUB MANGROVES
SALT MARSH
MANGROVES
82W, 25N
1900
82W, 25N
1973