CHAPTER 3.
Climate Change Summary

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KEY FINDINGS

- Since 1960, all but two southern capital cities (Montgomery, AL, and Oklahoma City, OK) have experienced a statistically significant increase in average annual temperature (approximately 0.016° C), but none has experienced significant trends in precipitation.
- The South is forecasted to experience warmer temperatures for the duration of the 21st century; forecasts are mixed for precipitation changes during the same period.
- Climate predictions range from wet and warm (1167 mm/19.06° C) to moderate and warm (1083 mm/19.45° C and 1106 mm/19.27° C) to dry and hot (912 mm/20.22° C).

INTRODUCTION

This chapter summarizes the climate predictions that have been used throughout the Southern Forest Futures Project (IPCC 2007b). Four distinct combinations of general circulation models (GCMs) and special report emissions scenarios were selected as Cornerstone Futures. GCMs are complex models that provide geographically and physically consistent estimates of regional climate change (IPCC 2009). The emissions scenarios are global storylines representing alternative demographic, socioeconomic, and environmental futures (Nakicenovic 2000).

The GCMs selected for the Futures Project were the MK2 and MK3.5 from the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO), the HadCM3 from the United Kingdom Meteorological Center, and the MIROC 3.2 from the Japanese National Institute for Environmental Studies.

Two emissions scenarios were selected for the Futures Project. The A1B scenario is characterized by low population growth, high energy use, and high economic growth. The B2 scenario is characterized by medium population growth, medium energy use, and medium economic growth (IPCC 2007b). These scenarios represent two levels of global carbon dioxide (CO_2) emissions by 2100: 60 gigatons of CO_2-equivalents (eq) (IPCC 2007a) in the A1B scenario (resulting in an atmospheric concentration of approximately 700 ppm) (Solomon and others 2007) and 65 gigatons of CO_2-eq (IPCC 2007a) in the B2 scenario (resulting in an atmospheric concentration of approximately 600 ppm) (Solomon and others 2007). The relationship between CO_2 equivalent emissions and atmospheric CO_2 concentration is not linear, and the estimates for 2100 are influenced by emission rates throughout the 21st century. The A1B scenario peaks higher around 2050 and tapers off, while the B2 scenario increases more slowly and steadily. For comparison, carbon dioxide emissions for 2009 were estimated at 40 gigatons of CO_2-eq (resulting in an atmospheric concentration of 387 parts per million) (IPCC 2007a, Tans 2011).

The Futures Project combines GCMs and emissions scenarios into four Cornerstone Futures—CSIROMK3.5+A1B, MIROC3.2+A1B, CSIROMK2+B2, and HadCM3+B2—which are described in this chapter. Although this chapter does not discuss subregional variations in detail, the GCM summary data have been provided in both tabular and graphic formats to allow the reader to examine climate change impacts for subregions of interest.

DATA SOURCES AND METHODS

Because the original scale of the GCMs was too coarse for regional analysis, the Cornerstone Futures were downscaled from their original resolution of approximately 2 degrees by the World Climate Research Programme's Coupled Model Intercomparison Project phase 3 (CMIP3) (Maurer and others 2007). Each GCM was spatially downscaled to one-twelfth degree (5 arc minute) using ANUSPLIN, a interpolation model that incorporates four dimensions (climatic variable, latitude, longitude, and elevation) to produce gridded surfaces for both monthly precipitation and surface air temperature (Hutchinson 2009).

The CMIP3 data were obtained and processed by Coulson and others (2010) for use in the 2010 Resources Planning Act (RPA) Assessment. Monthly precipitation and

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temperature data from 2000 to 2100 were scaled to the county level for the conterminous United States. All chapters in this assessment use the county level precipitation and temperature data. All regional and subregional averages were area-weighted to remove bias that would result from averaging counties of different areas.

For this chapter, annual and decadal averages were generated for the South and for its five subregions using the JMP 8.0 software application (SAS Institute Inc. 2010). For a historical perspective, trends in air temperature and precipitation for the 13 southern capital cities from 1960 to 2007 were obtained from the PRISM Climate Group (Gibson and others 2002). Maps were generated using the ArcMap version 9.3.1 software application (ESRI 2010). The decades selected for this chapter were 2010, 2020, 2040, 2060, and 2090. To calculate the decadal averages, the ten years surrounding each period were summed, in the case of precipitation, and then averaged. The decadal average for 2010 included data from the years 2005–14, 2020 included data from 2015–24, 2040 included data from 2035–44, etc. The results section describes averages and anomalies for each of the four Cornerstones.

RESULTS

Regional Forecasts

Table 3.1 summarizes precipitation and temperature averages forecasted for the South through 2100, with historical data for comparison. Figures 3.1 through 3.4 present graphic and map displays of precipitation data, and figures 3.5 through 3.8 present graphic and map displays of temperature data.

Characterized by low population growth and high energy-use/economic-growth (MIROC3.2+A1B), Cornerstone A is forecasted to be dry and hot, with average annual precipitation of 912 mm and average annual temperature of 20.22° C. Annual precipitation expected for any southern county ranges from 103 to 4999 mm, and temperature ranges from -12.01 to 50.24° C. Average maximum monthly temperatures would exceed the single-day southern maximum of 48.89° C, which was set in Oklahoma in 1994 (Burt 2007).

Also characterized by low population growth and high energy-use/economic-growth (CSIROMK3.5+A1B), Cornerstone B is forecasted to be wet and warm, with average annual precipitation of 1167 mm and average temperature of 19.06° C. Annual precipitation expected for southern counties ranges from 93 to 3912 mm, and temperature ranges from -11.21 to 44.24° C.

Characterized by moderate population/income growth and energy use (CSIROMK2+B2), Cornerstone C is forecasted to be moderate and warm, with average annual precipitation of 1083 mm and average annual temperature of 19.45° C. Annual precipitation expected for any southern county ranges from 35 to 2641 mm. That precipitation minimum would break the 1956 regional low of 42 mm in Texas (Burt 2007). Temperature is expected to range from -19.73 to 45.39° C.

Also characterized by moderate population/income growth and energy use (HadCM3+B2), Cornerstone D is also forecasted to be moderate and warm, with average annual precipitation of 1106 mm (higher than Cornerstone C) and average annual temperature of 19.27° C (lower than Cornerstone C). Annual precipitation expected for

Table 3.1—Summary statistics for predicted (2010–2100) and historical (2001–09) annual precipitation and temperature forecasts for the Southern United States by four Cornerstone Futures A through D

	Precipitation (mm)				Temperature (°C)			
Cornerstone[a]	Minimum	Maximum	Average	Standard deviation	Minimum	Maximum	Average	Standard deviation
A	733	1675	912	198	17.29	21.35	20.22	1.05
B	627	1517	1167	138	17.98	23.93	19.06	1.33
C	803	1369	1083	126	17.07	21.74	19.45	1.08
D	724	1383	1106	121	16.76	22.36	19.27	1.10
Average all Cornerstones	NA	NA	1066	NA	NA	NA	19.57	NA
Historical (2001 to 2009)	864	1552	1136	NA	16.97	19.45	17.87	NA

NA = not applicable.
[a]Each Cornerstone represents a general circulation model paired with one of two emission scenarios (A1B represents low-population/high-economic growth, high energy use; B2 represents moderate growth and use): A is MIROC3.2+A1B, B is CSIROMK3.5+A1B, C is CSIROMK2+B2, and D is HadCM3+B2.
Source: Intergovernmental Panel on Climate Change 2007b.

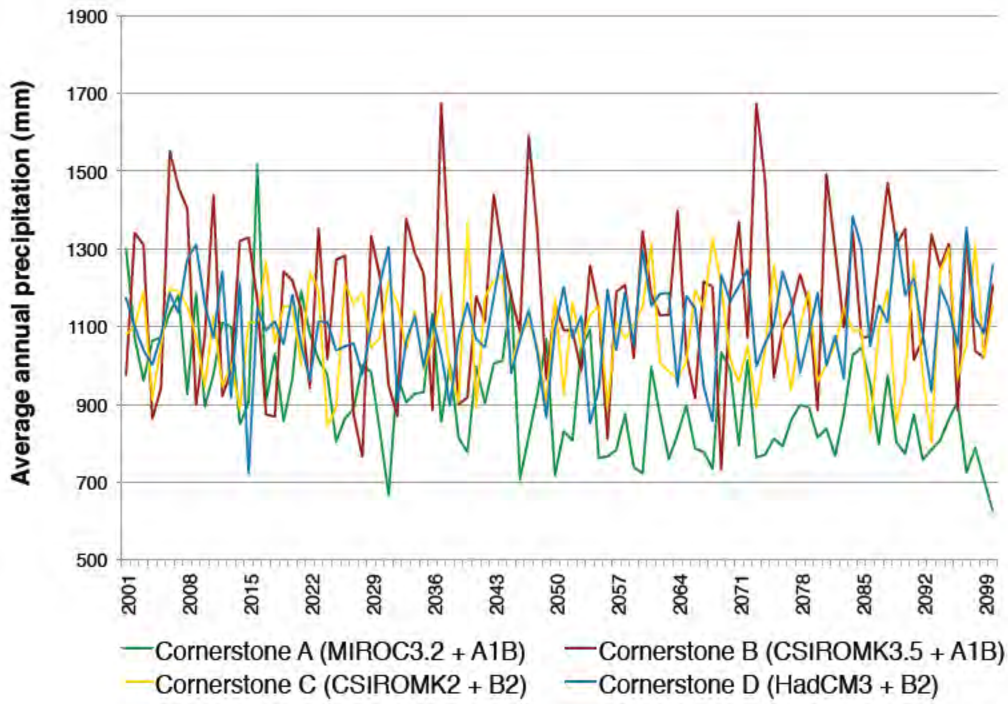

Figure 3.1—Historical and predicted annual precipitation for the Southern United States as forecasted by four Cornerstones Futures (A through D), each of which represents a general circulation model paired with one of two emission scenarios—A1B representing low-population/high-economic growth, high energy use, and B2 representing moderate growth and use. (Source: Intergovernmental Panel on Climate Change 2007b)

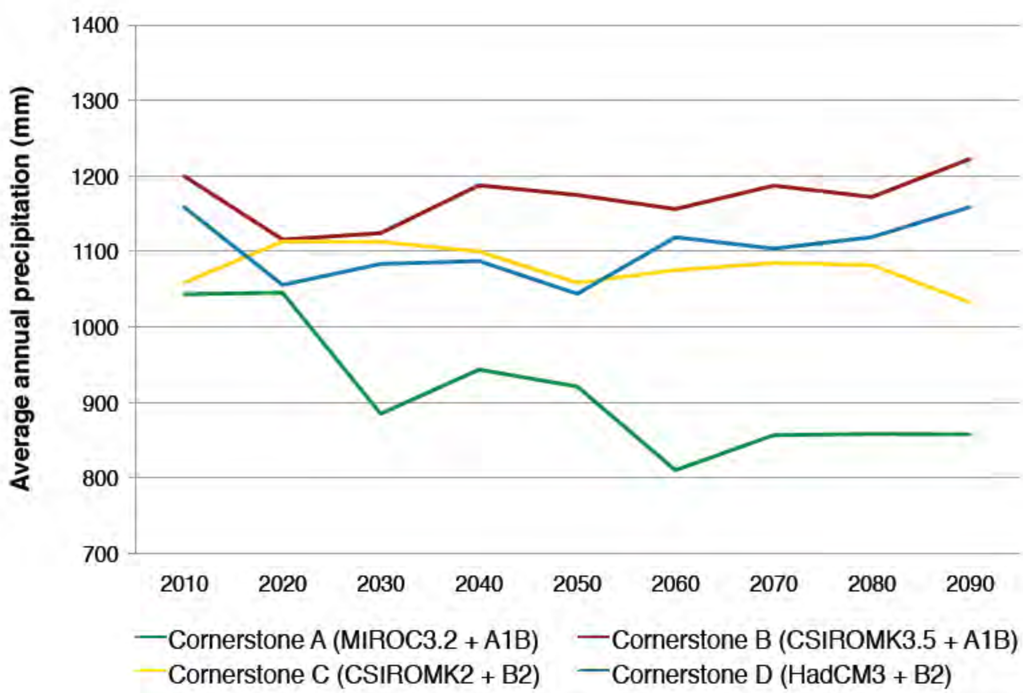

Figure 3.2—Predicted annual precipitation (2010, 2020, 2040, 2060, and 2090) for the Southern United States as forecasted by four Cornerstones Futures (A through D), each of which represents a general circulation model paired with one of two emission scenarios—A1B representing low-population/high-economic growth, high energy use, and B2 representing moderate growth and use. (Source: Intergovernmental Panel on Climate Change 2007b)

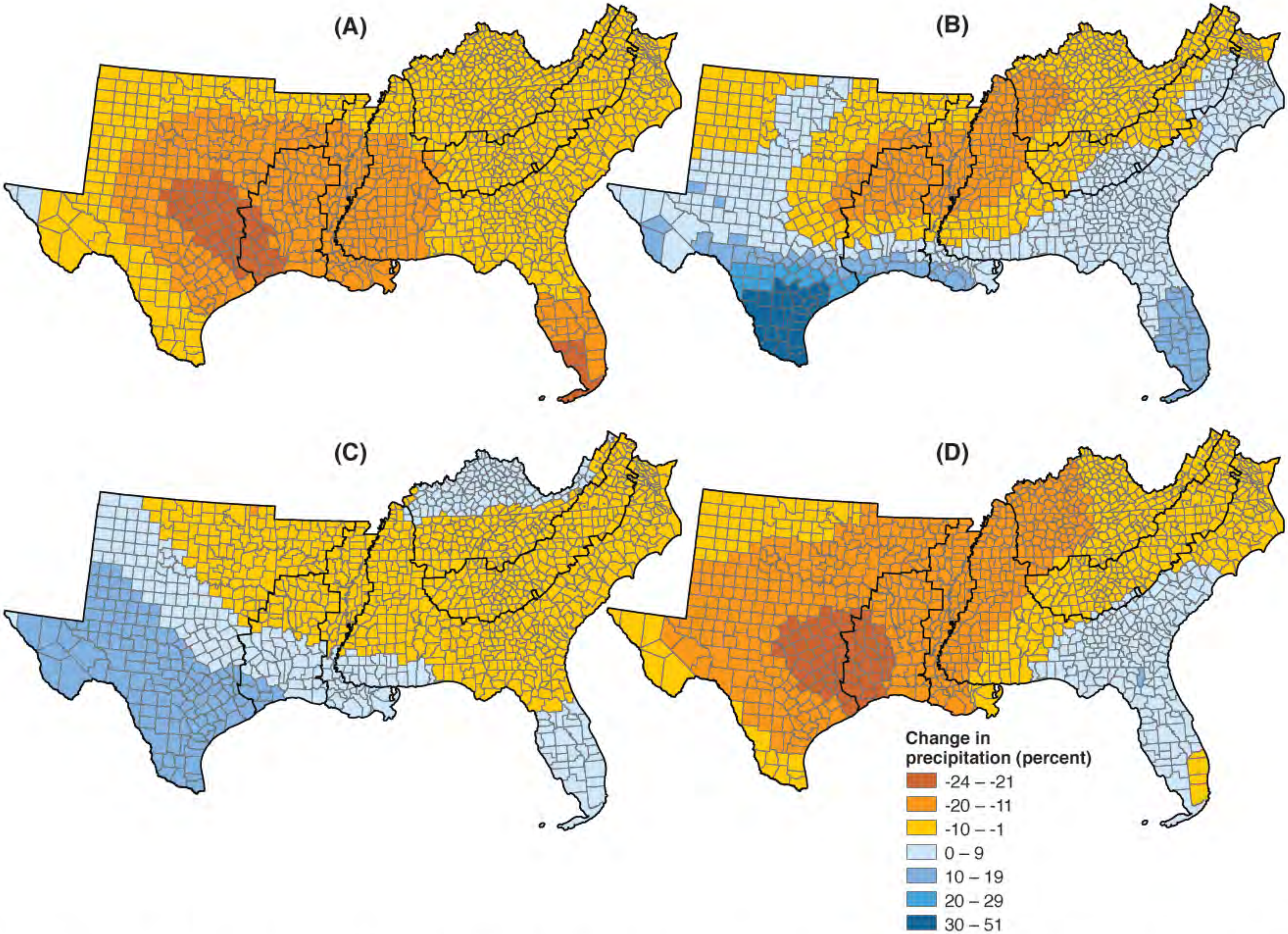

Figure 3.3—Predicted change in precipitation from 2010 to 2050 for the Southern United States as forecasted by four Cornerstones Futures, each of which represents a general circulation model paired with one of two emission scenarios—A1B representing low-population/high-economic growth, high energy use, and B2 representing moderate growth and use—(A) MIROC3.2+A1B, (B) CSIROMK3.5+A1B, (C) CSIROMK2+B2, and (D) is HadCM3+B2. (Source: Intergovernmental Panel on Climate Change 2007b).

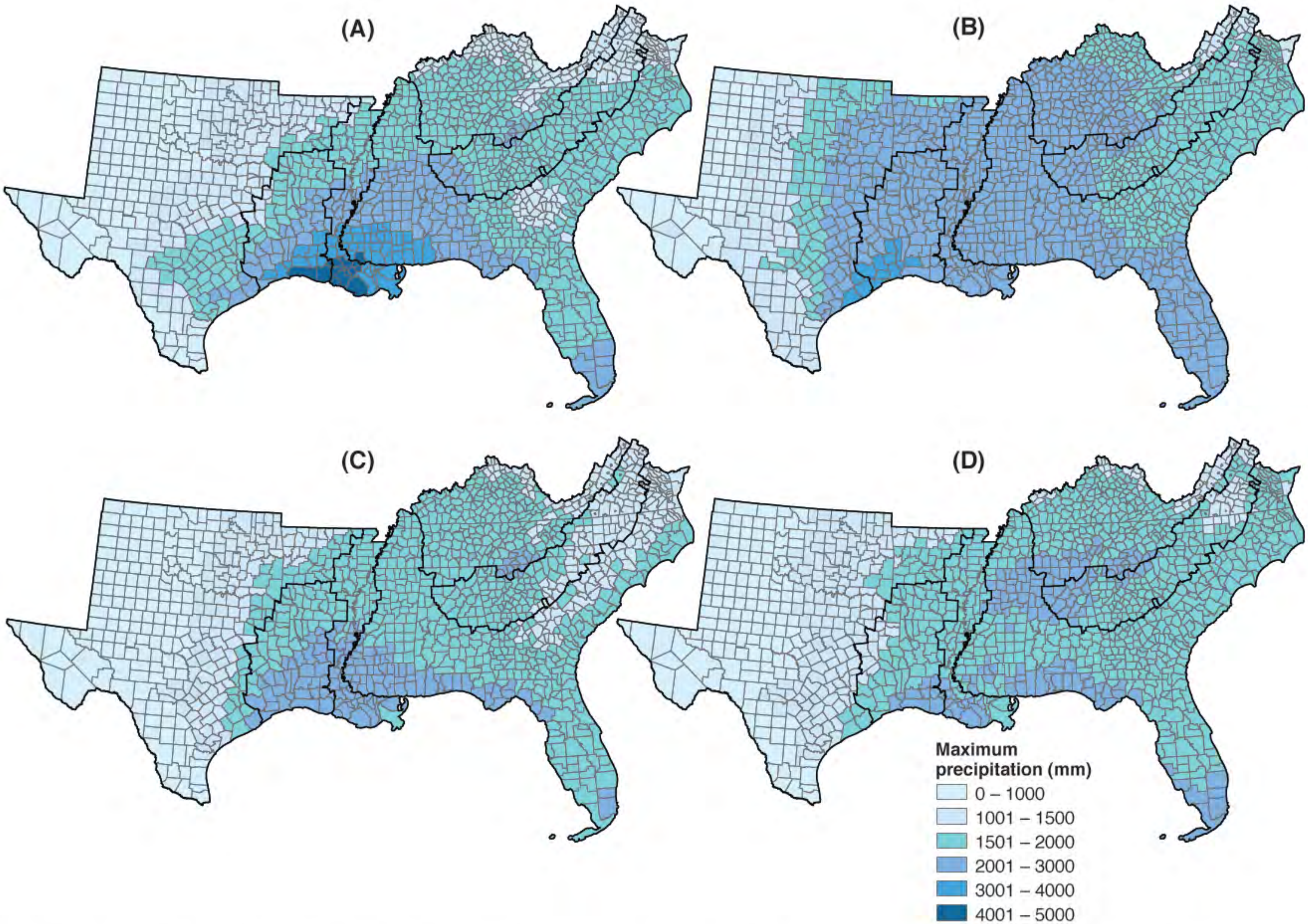

Figure 3.4—Maximum precipitation from 2010 to 2060 for the Southern United States as forecasted by four Cornerstones Futures, each of which represents a general circulation model paired with one of two emission scenarios—A1B representing low-population/high-economic growth, high energy use, and B2 representing moderate growth and use—(A) MIROC3.2+A1B, (B) CSIROMK3.5+A1B, (C) CSIROMK2+B2, and (D) is HadCM3+B2. (Source: Intergovernmental Panel on Climate Change 2007b)

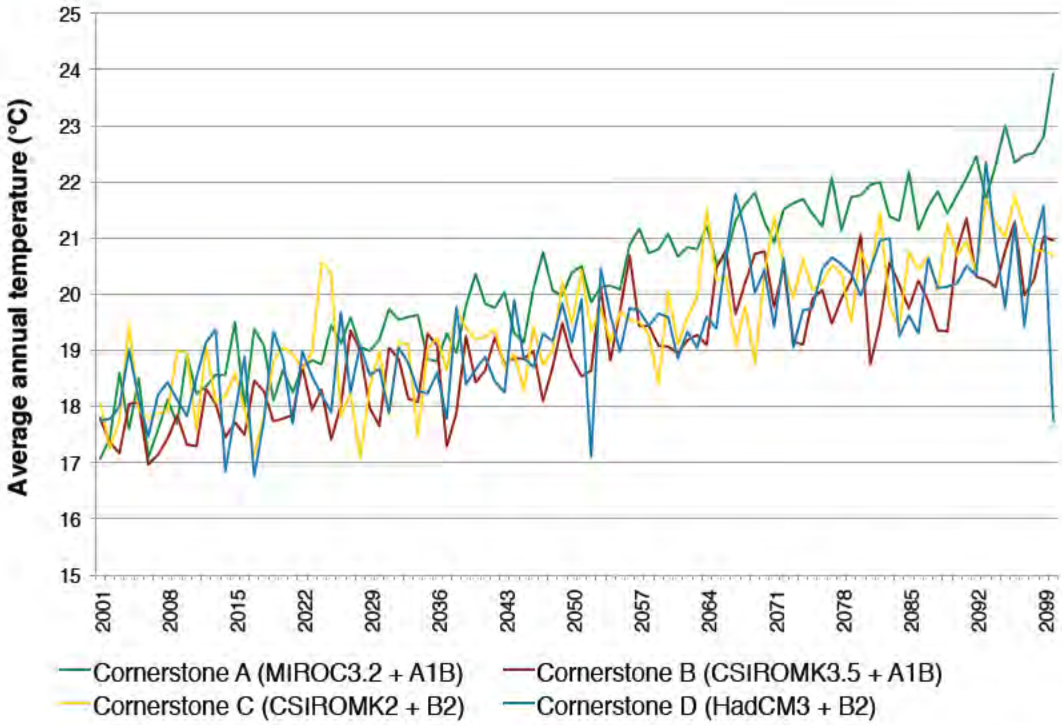

Figure 3.5—Historical and predicted annual air temperature for the Southern United States as forecasted by four Cornerstones Futures (A through D), each of which represents a general circulation model paired with one of two emission scenarios—A1B representing low-population/high-economic growth, high energy use, and B2 representing moderate growth and use. (Source: Intergovernmental Panel on Climate Change 2007b)

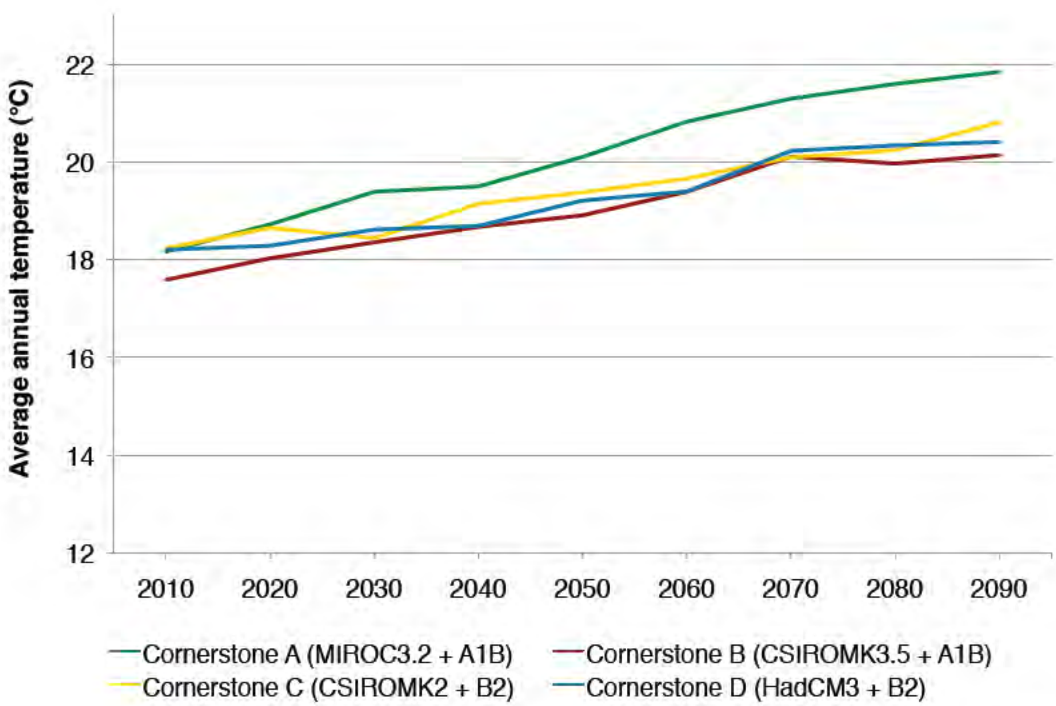

Figure 3.6—Predicted annual air temperature (2010, 2020, 2040, 2060, and 2090) for the Southern United States as forecasted by four Cornerstones Futures (A through D), each of which represents a general circulation model paired with one of two emission scenarios—A1B representing low-population/high-economic growth, high energy use, and B2 representing moderate growth and use. (Source: Intergovernmental Panel on Climate Change 2007b)

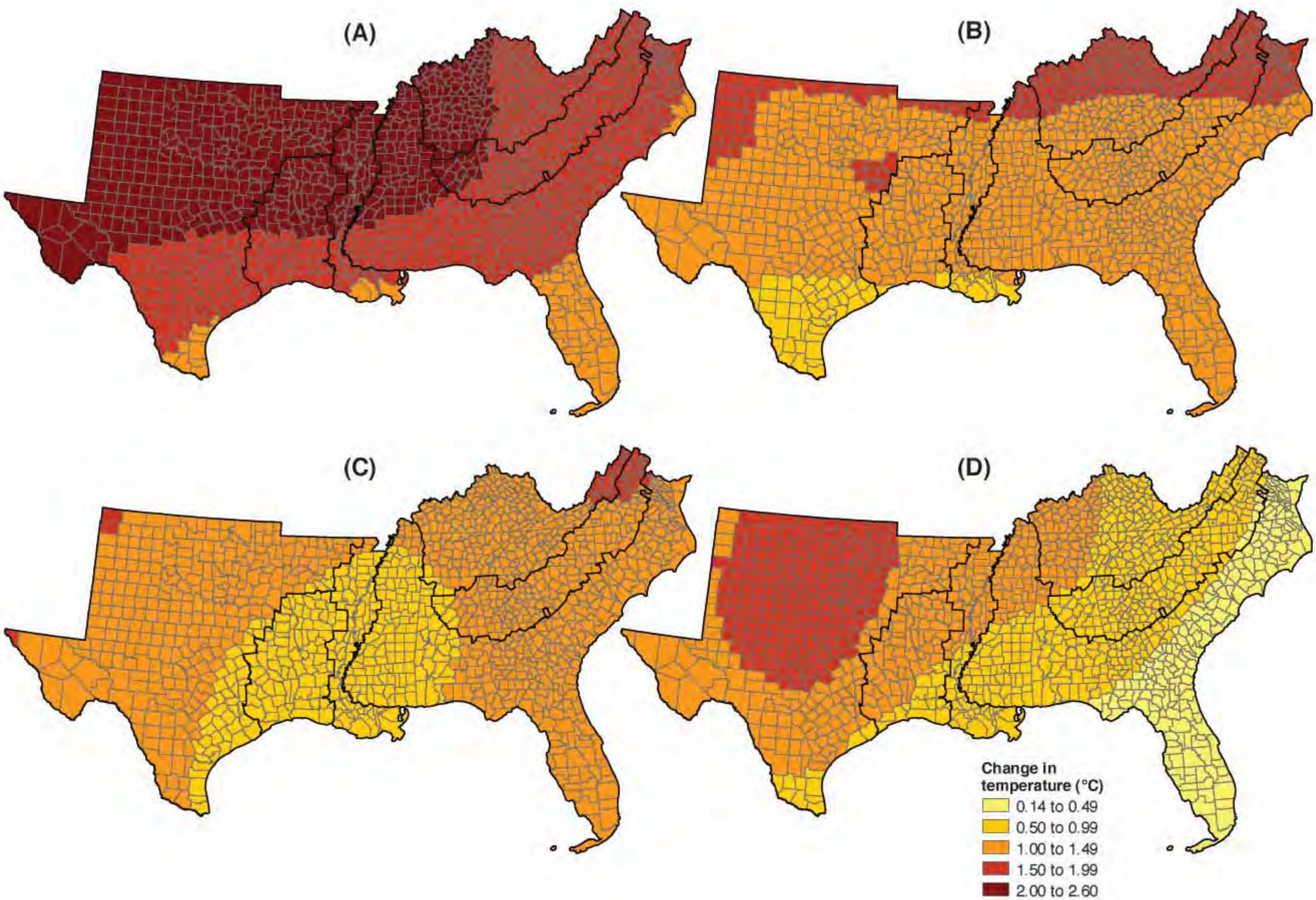

Figure 3.7—Predicted change in air temperature from 2010 to 2050 for the Southern United States as forecasted by four Cornerstones Futures, each of which represents a general circulation model paired with one of two emission scenarios—A1B representing low-population/high-economic growth, high energy use, and B2 representing moderate growth and use—(A) MIROC3.2+A1B, (B) CSIROMK3.5+A1B, (C) CSIROMK2+B2, and (D) is HadCM3+B2. (Source: Intergovernmental Panel on Climate Change 2007b)

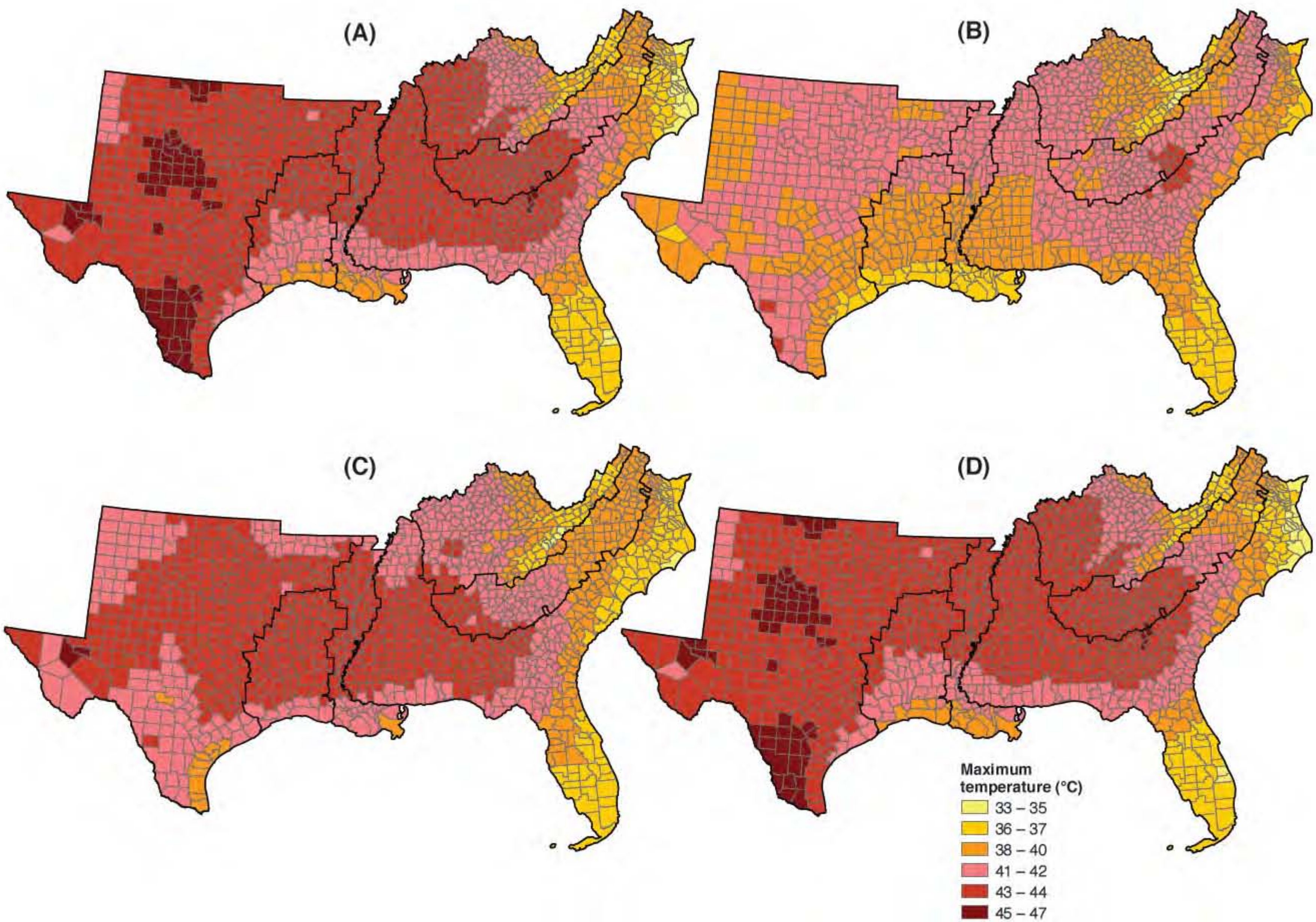

Figure 3.8—Maximum air temperature from 2010 to 2060 for the Southern United States as forecasted by four Cornerstones Futures, each of which represents a general circulation model paired with one of two emission scenarios—A1B representing low-population/high-economic growth, high energy use, and B2 representing moderate growth and use—(A) MIROC3.2+A1B, (B) CSIROMK3.5+A1B, (C) CSIROMK2+B2, and (D) is HadCM3+B2. (Source: Intergovernmental Panel on Climate Change 2007b).

any southern county ranges from 102 to 2708 mm, and temperature ranges from -18.68 to 48.01° C.

Subregional Forecasts

In the Southern United States, forecasted precipitation (table 3.2) and temperature averages (table 3.3) are not expected to be uniform, with significant variations across the five subregions and between seasons (table 3.4). Figures 3.9 and 3.10 present graphic and map displays of precipitation and temperature data.

Cornerstone A's high energy-use/economic-growth (MIROC3.2+A1B) is predicted to result in the least decadal precipitation by 2060, with an overall average of 810 mm for all five southern subregions and a low of 525 mm in the Mid-South. This trend is expected to abate only slightly by 2090 to an average of 858 mm for all subregions and 535 mm for the Mid-South—still much drier than the historical overall average of 1136 mm.

Although also based on high energy-use/economic-growth, Cornerstone B (CSIROMK3.5+A1B) predicts more decadal precipitation than the other Cornerstones by 2060, with an overall average of 1156 mm. This trend continues into 2090, with an overall average predicted to be 1223 mm. Cornerstone B also predicts cooler decadal temperatures than the other Cornerstones by 2060—with an overall average of 19.39° C—for every subregion except the Mid-South. This trend continues into 2090, with Cornerstone B's overall average of 20.14° C, lower than all the others for all subregions.

Cornerstone A predicts warmer decadal temperatures than the other Cornerstones by 2060, with an overall average of 20.83° C for all five southern subregions. This trend continues into 2090, with Cornerstone A's overall average of 21.84° C leading all the others for all subregions.

Comparing these predictions with historical trends in air temperature and precipitation for the 13 southern capital cities from 1960 to 2007 shows a statistically significant increase (total of 0.705° C, average of 0.016° C) in air temperature but no significant change in precipitation (fig. 3.11). These findings are consistent with a trend of significant increases in temperature from 1970 to 2008 reported by Karl and others (2009) (table 3.4), but not after their data from 1901 to 1969 were included.

DISCUSSION AND CONCLUSIONS

GCMs provide some indication of how climate will change across the South in coming decades. Each has been independently developed, often for a specific region, and frequently calibrated to recreate historical climate on the assumption that successful modeling of the past increases the likelihood of accurately forecasting the future. However, the same calibration that allows an accurate recreation of historical climate for one region can result in over- or under-predicting climate change for others.

An example of possible over-predicting is Cornerstone A (MIROC3.2+A1B), which assumes high energy-use and economic-growth and predicts the warmest conditions, with monthly averages sometimes exceeding single-day historical highs (fig. 3.12). Similarly, Cornerstone A's average precipitation is about 20 percent lower (fig. 3.13). For these reasons, it is considered the most severe of the Cornerstones in terms of extreme events as well as annual averages. The other GCMs used in this analysis also predict maximum monthly air temperatures in excess of historically observed conditions, but by a smaller margin. In particular, Cornerstone B (CSIROMK3.5+A1B) predicts increases in average annual precipitation compared to historical averages.

Another caveat is that averaged or summed monthly values are less able to express climate variability (especially extremes) than daily values. Monthly average air temperatures are expected to be much lower than some of the individual daily highs, and higher than some of the individual daily lows. For example, if a maximum monthly air temperature is predicted to be 40° C, then individual daily air temperatures are likely to exceed 45 or even 50° C.

Likewise, monthly average precipitation does not fully represent the number or magnitude of individual events. Although Cornerstone A predicts a reduction in average precipitation, many of its monthly maximums exceed historical highs. Similarly, variations among months may not be captured by monthly averages or annual summaries. For example, 1000 mm of precipitation during a 5-month period in winter and spring would produce a very different impact than if evenly distributed throughout the year or concentrated during growing-season months. And for monthly level predictions, a 100-mm average would mask the water quality and flooding impacts that would result if precipitation were concentrated in one or two major events.

The GCMs also have limited spatial resolution. Their one-twelfth degree by one-twelfth degree resolution is a significant improvement on older model forecasts, but still coarse for predicting precipitation, which can be highly variable with adjacent areas receiving drastically different precipitation amounts from a single event. This variation is also important for localized flood forecasting and in estimating water quality.

Table 3.2—Predicted average precipitation for subregions of the Southern United States as forecasted by four Cornerstone Futures A through D

		Cornerstone[a] prediction of average precipitation (mm)			
Date	Subregion	A	B	C	D
2010	Appalachian-Cumberland	1223	1419	1303	1390
	Coastal Plain	1216	1375	1268	1328
	Mid-South	721	812	663	784
	Mississippi Alluvial Valley	1351	1550	1358	1472
	Piedmont	1263	1484	1285	1379
2020	Appalachian-Cumberland	1257	1376	1371	1307
	Coastal Plain	1210	1313	1289	1257
	Mid-South	677	735	710	659
	Mississippi Alluvial Valley	1427	1397	1462	1348
	Piedmont	1285	1259	1326	1272
2040	Appalachian-Cumberland	1139	1448	1336	1298
	Coastal Plain	1174	1295	1307	1309
	Mid-South	579	837	713	725
	Mississippi Alluvial Valley	1261	1524	1392	1321
	Piedmont	1202	1273	1328	1331
2060	Appalachian-Cumberland	940	1444	1338	1362
	Coastal Plain	1037	1370	1309	1370
	Mid-South	525	729	650	717
	Mississippi Alluvial Valley	1024	1455	1371	1346
	Piedmont	1065	1345	1324	1371
2090	Appalachian-Cumberland	999	1434	1271	1417
	Coastal Plain	1109	1358	1195	1396
	Mid-South	536	884	666	743
	Mississippi Alluvial Valley	1110	1582	1303	1456
	Piedmont	1164	1395	1231	1388

[a]Each Cornerstone represents a general circulation model paired with one of two emission scenarios (A1B represents low-population/high-economic growth, high energy use; B2 represents moderate growth and use): A is MIROC3.2+A1B, B is CSIROMK3.5+A1B, C is CSIROMK2+B2, and D is HadCM3+B2.
Source: Intergovernmental Panel on Climate Change 2007b.

Table 3.3—Predicted average temperature (°C) for subregions of the Southern United States as forecasted by four Cornerstone Futures A through D

		Cornerstone[a] prediction of average temperature (°C)			
Date	Subregion	A	B	C	D
2010	Appalachian-Cumberland	14.02	13.18	14.31	14.01
	Coastal Plain	19.36	18.89	19.49	19.45
	Mid-South	18.60	18.02	18.48	18.59
	Mississippi Alluvial Valley	19.01	18.54	19.36	19.15
	Piedmont	16.16	15.41	16.34	16.24
2020	Appalachian-Cumberland	14.57	13.99	14.67	13.91
	Coastal Plain	19.91	19.24	19.84	19.30
	Mid-South	19.15	18.40	19.01	19.01
	Mississippi Alluvial Valley	19.67	18.95	19.63	19.16
	Piedmont	16.73	16.02	16.72	16.05
2040	Appalachian-Cumberland	15.55	14.68	15.46	14.17
	Coastal Plain	20.61	19.98	20.27	19.80
	Mid-South	19.93	18.91	19.44	19.36
	Mississippi Alluvial Valley	20.38	19.63	20.04	19.75
	Piedmont	17.59	16.77	17.39	16.41
2060	Appalachian-Cumberland	16.87	15.03	15.91	15.16
	Coastal Plain	21.85	20.44	20.80	20.49
	Mid-South	21.34	20.11	19.97	19.97
	Mississippi Alluvial Valley	21.92	20.27	20.68	20.39
	Piedmont	18.79	17.05	17.84	17.26
2090	Appalachian-Cumberland	17.73	15.78	17.29	16.32
	Coastal Plain	22.78	21.30	21.96	21.50
	Mid-South	22.53	20.74	21.01	20.90
	Mississippi Alluvial Valley	22.73	20.94	21.87	21.34
	Piedmont	19.74	17.89	19.12	18.46

[a]Each Cornerstone represents a general circulation model paired with one of two emission scenarios (A1B represents low-population/high-economic growth, high energy use; B2 represents moderate growth and use): A is MIROC3.2+A1B, B is CSIROMK3.5+A1B, C is CSIROMK2+B2, and D is HadCM3+B2.
Source: Intergovernmental Panel on Climate Change 2007b.

Table 3.4—Average change in temperature and precipitation in the Southeastern United States, as recreated from Karl and others (2009)

	Temperature change (°F)			Precipitation change (percent)	
	1901-2008	1970-2008		1901-2008	1970-2008
Annual	0.3	1.6	Annual	6.0	-7.7
Winter	0.2	2.7	Winter	1.2	-9.6
Spring	0.4	1.2	Spring	1.7	-29.2
Summer	0.4	1.6	Summer	-4.0	3.6
Autumn	0.2	1.1	Autumn	27.4	0.1

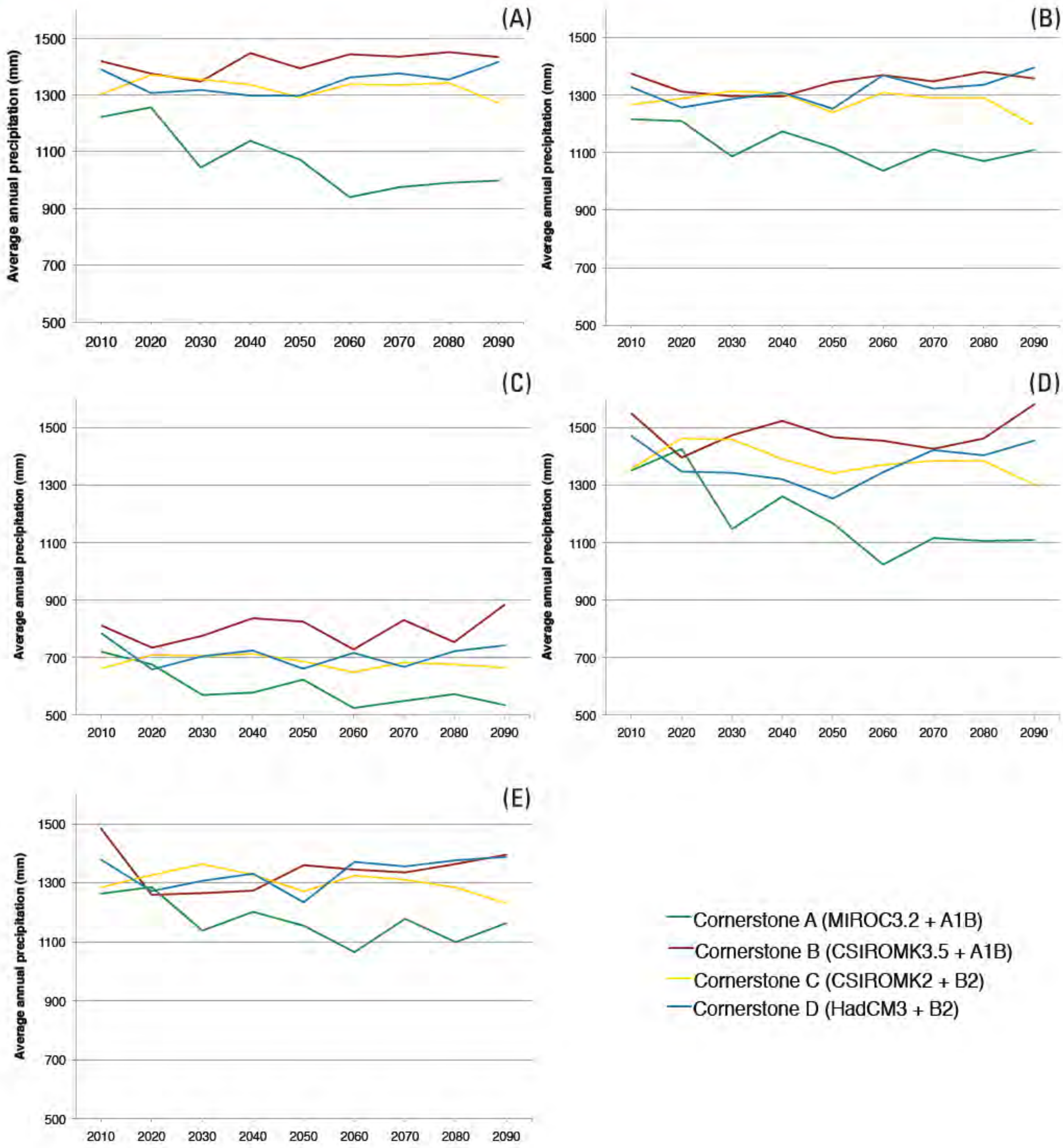

Figure 3.9—Predicted annual precipitation (2010, 2020, 2040, 2060, and 2090) for the (A) Appalachian-Cumberland, (B) Coastal Plain, (C) Mid-South, (D) Mississippi Alluvial Valley, and (E) Piedmont subregions of the Southern United States as forecasted by four Cornerstones Futures (A through D), each of which represents a general circulation model paired with one of two emission scenarios—A1B representing low-population/high-economic growth, high energy use, and B2 representing moderate growth and use. (Source: Intergovernmental Panel on Climate Change 2007b).

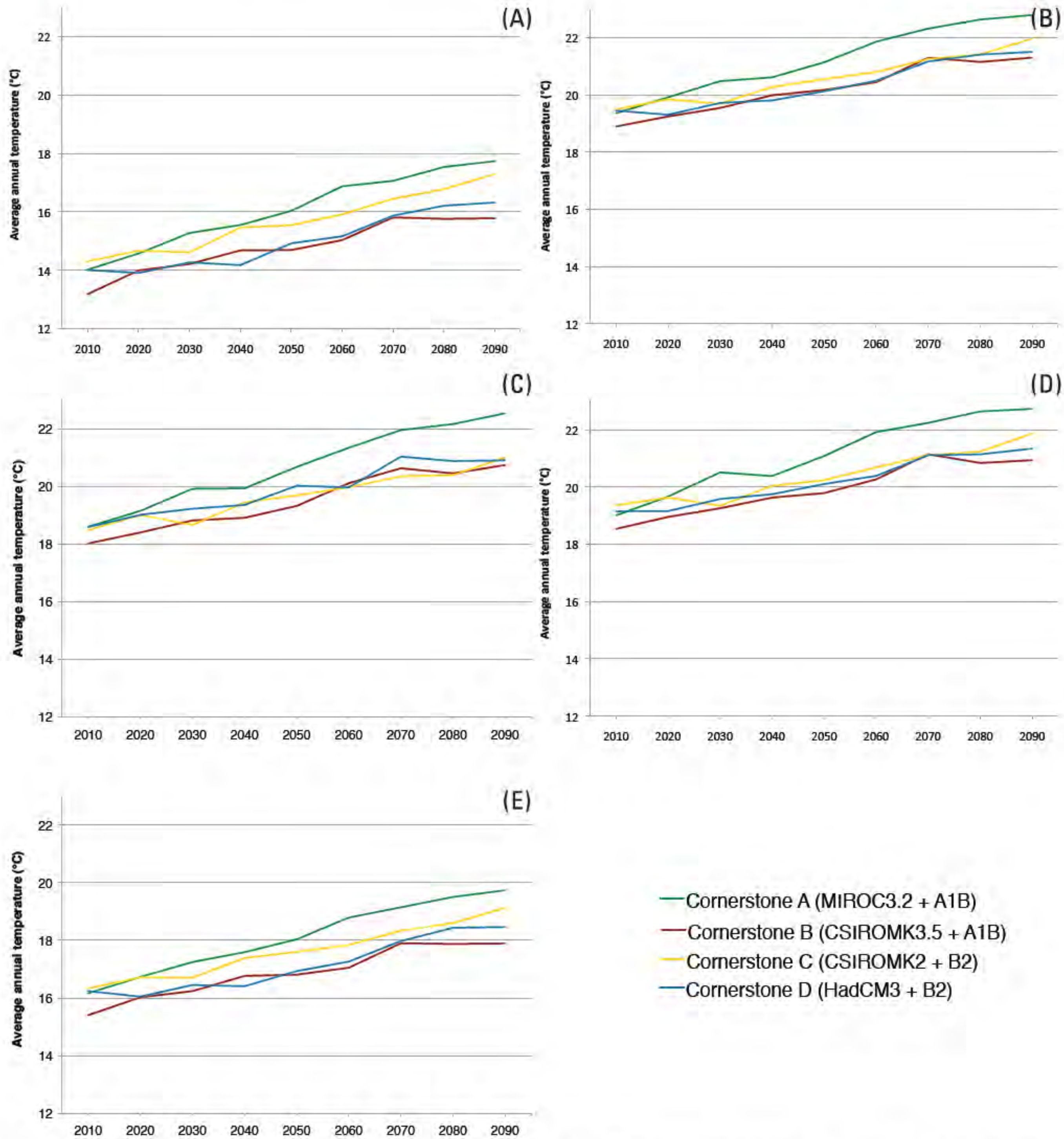

Figure 3.10—Predicted annual air temperature (2010, 2020, 2040, 2060, and 2090) for the (A) Appalachian-Cumberland, (B) Coastal Plain, (C) Mid-South, (D) Mississippi Alluvial Valley, and (E) Piedmont subregions of the Southern United States as forecasted by four Cornerstones Futures (A through D), each of which represents a general circulation model paired with one of two emission scenarios—A1B representing low-population/high-economic growth, high energy use, and B2 representing moderate growth and use. (Source: Intergovernmental Panel on Climate Change 2007b)

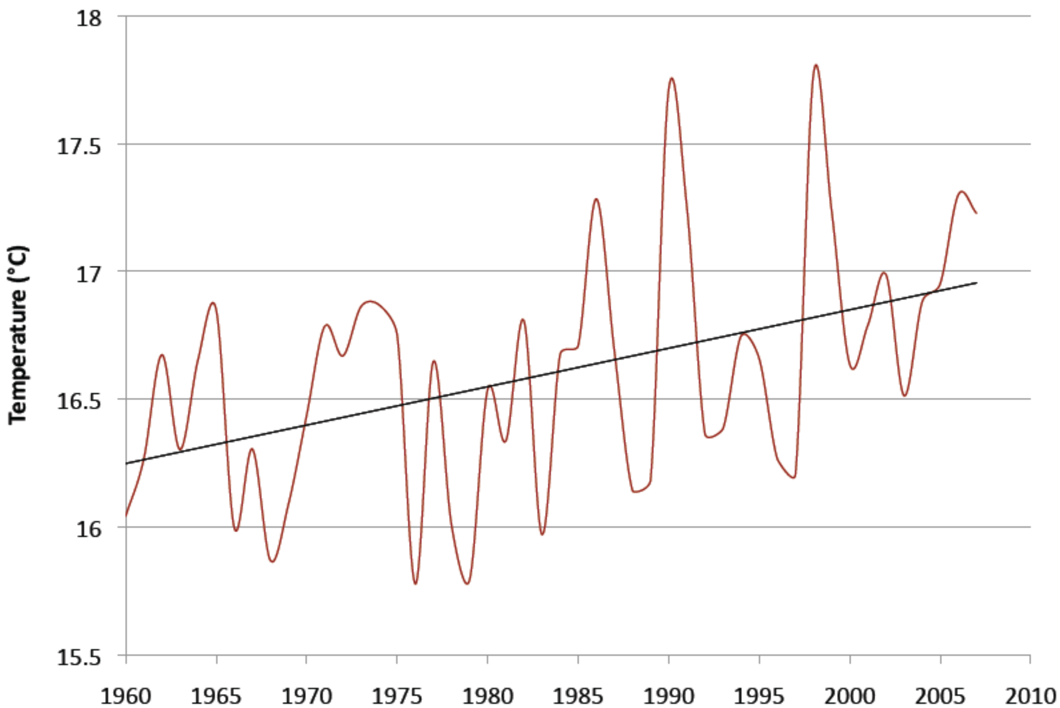

Figure 3.11—Average annual air temperature for the 13 southern capital cities from 1960 to 2007. (Source: Gibson and others 2002)

These factors complicate efforts to develop detailed assessments of climate change for every subregion. For example, even though Cornerstone A predicts a hotter and drier climate for the South, some areas within the region could become wetter (although not likely cooler). Finally, the GCMs were designed to produce decadal, long-term averages for air temperature and precipitation. As with historical climate, any given year could be cooler, hotter, drier, or wetter than the long-term average.

Even with these caveats, several strong trends emerge from the analysis of the climate change predictions. First and foremost, air temperature across the South is forecasted to increase significantly from historical and current levels. None of the models used in this analysis, or any others published by other climate scientists, suggest that air temperatures will remain stable or will cool. The precipitation predictions of these GCMs are in much better agreement than those of previous climate model assessments (NAST 2001). All but Cornerstone A predict relatively little change in precipitation across the region, but as previously discussed, variation could be significant from one subregion to the next.

Changes in precipitation need to be examined in the context of air temperature changes. As temperature increases in an ecosystem, water use also increases. Therefore, temperature increases will likely offset small increases in precipitation, resulting in more frequent water shortages and streamflow reductions. If precipitation remains at historical levels (or less), then water shortage issues will increase.

Although the magnitude and temporal and spatial distribution of climate change is uncertain, all indications suggest that some change is certain. Even the most conservative estimates would produce dramatic changes in ecosystem water use (chapter 13), carbon sequestration (chapter 5), species composition (chapter 5), and human societies (chapter 12).

KNOWLEDGE AND INFORMATION GAPS

The GCMs on which the climate change predictions are based are improving both spatially and temporally as computational power increases and our understanding of atmospheric physics and chemistry interactions improves. Early models had few interactions among terrestrial, ocean, and atmospheric drivers of climate change. Since the passage of the U.S. Global Climate Change Research Act of 1991, billions of dollars have been dedicated to understanding these relationships. Additionally, international contributions to this effort have been significant, producing improvements in understanding and forecasting.

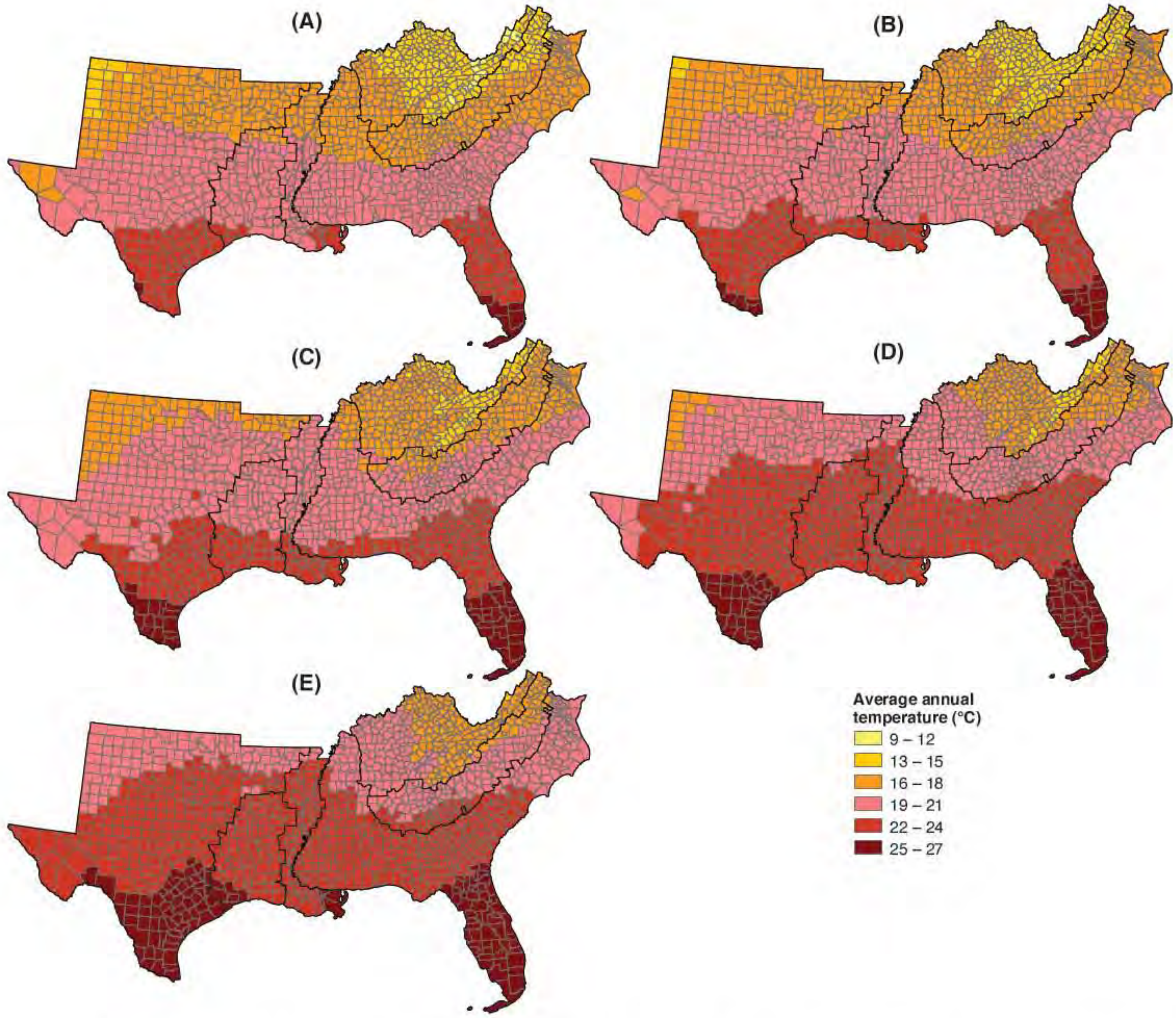

Figure 3.12—Predicted annual average air temperature for selected decades —(A) 2010, (B) 2020, (C) 2040, (D) 2060, (E) 2090—for the Southern United States as forecasted by Cornerstone A, a future representing the MIROC3.2 general circulation model and an emission scenario (A1B) of low-population/high-economic growth and high energy use. (Source: Intergovernmental Panel on Climate Change 2007b)

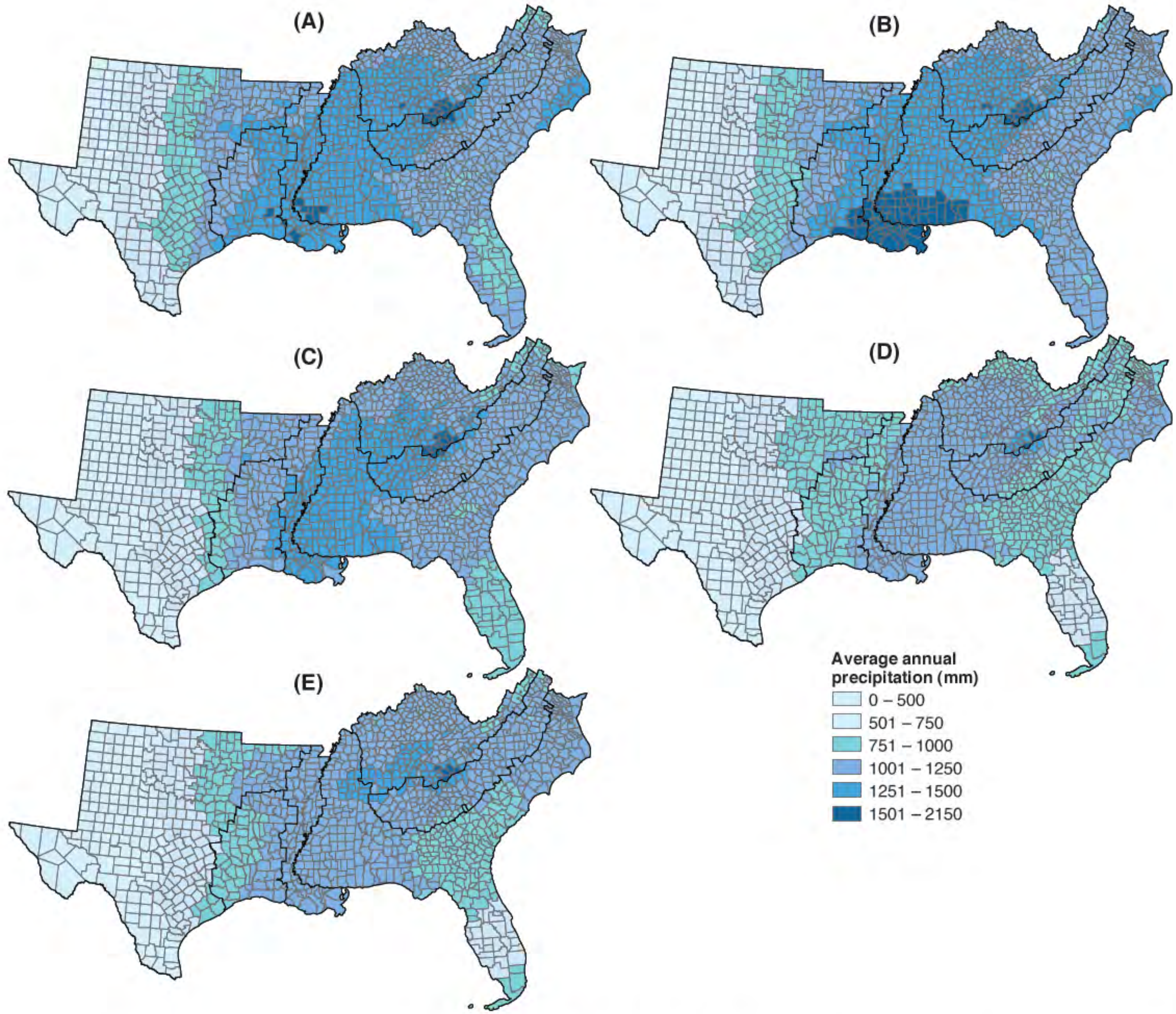

Figure 3.13—Predicted annual average precipitation for selected decades—(A) 2010, (B) 2020, (C) 2040, (D) 2060, (E) 2090—for the Southern United States as forecasted by Cornerstone A, a future representing the MIROC3.2 general circulation model and an emission scenario (A1B) of low-population/high-economic growth and high energy use. (Source: Intergovernmental Panel on Climate Change 2007b)

However, gaps still exist, both in knowledge and its implementation. For example, the GCMs from the most recent assessment incorporate changes in albedo from polar ice cap melting (IPCC 2007b), an improvement over previous assessments (Winton 2008) that can offer more accurate simulations but only if this important feedback is incorporated into new model runs. Additionally, the positive feedback between permafrost melting and subsequent release of carbon dioxide and methane adds important greenhouse gases to the atmosphere that must be included in the global warming predictions (Walter and others 2006).

Just as weather forecasts commonly predict from 7 to 10 days into the future with decreasing accuracy over time, climate forecasts based on existing and developing global ocean and atmospheric circulation patterns currently predict 6 to 12 months into the future. Although additional improvement in the accuracy and forecast length of these seasonal predictions are likely, accurately predicting specific weather events or patterns that may occur years or decades in the future is unlikely anytime soon. The science needed to predict the impacts of doubling atmospheric carbon dioxide on global air temperature and precipitation is very different from the science needed to predict monthly air temperature for a specific city on a specific date. Given these limitations, land managers will need to rely on the climate envelopes (ranges of climatic conditions for specific places and times) as they develop climate change impact assessments and coping strategies.

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