Understanding climate change in the southeast US from (recent) past, present and future

Acknowledgements:
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Based on:

1) **Recent Past**: [Misra, V., J-P Michael, R. Boyles, E. Chassignet, M. Griffin, and J.J. O'Brien, 2012: Reconciling the spatial distribution of the surface temperature trends in the Southeastern United States. J. Climate, in press: doi:10.1175/JCLI-D-11-00170.1

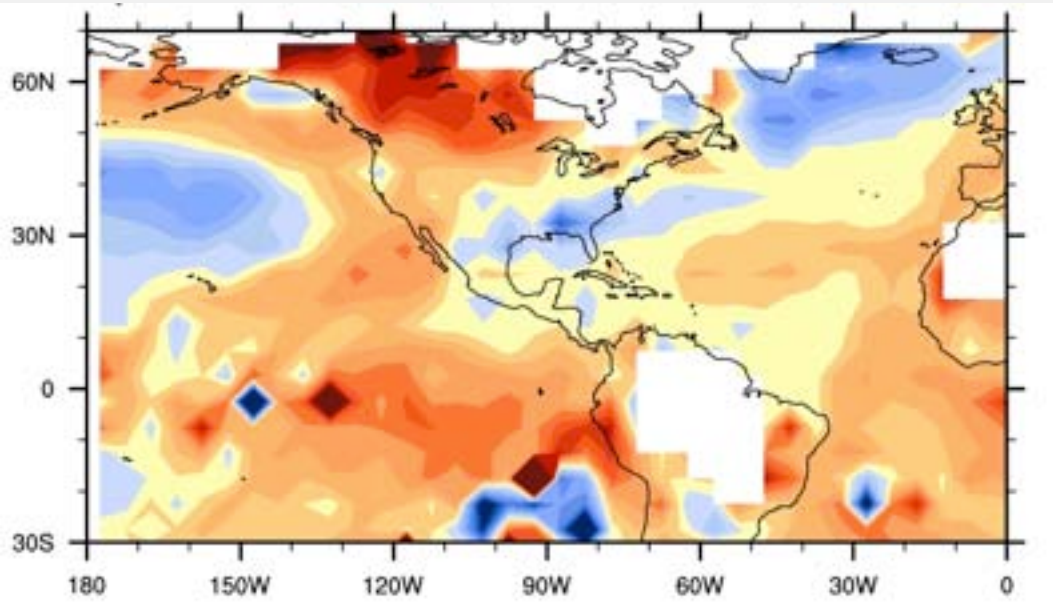
2) **Present**: Observational analysis with some short records of high resolution data

3) **Future**: Climate projection from CMIP3 and CLAREnCE10

V. Misra

Recent Past

Surface temperature trends of annual mean from HADCRUT3



HADCRUT3 is on a 5^0x5^0 grid box and covers a period from 1850 to present (http://www.cru.uea.ac.uk/cru/data/temperature/)

Courtesy: Meehl et al. 2012: Understanding the U. S. east-west differential of heat extremes in terms of record temperatures and the warming hole. J. Climate. In review.

Recent past……..

- The cooling trend is most pronounced in maximum temperature observed in the day and most notable in March-June period of the seasonal cycle

- Conclusive reasoning is still elusive but speculations are
  a) Land cover/use change
  b) Irrigation
  c) Aerosols (volatile organic molecules [e.g. isoprene], secondary organic aerosol)
  d) SST
  e) Internal dynamics (or chaos)

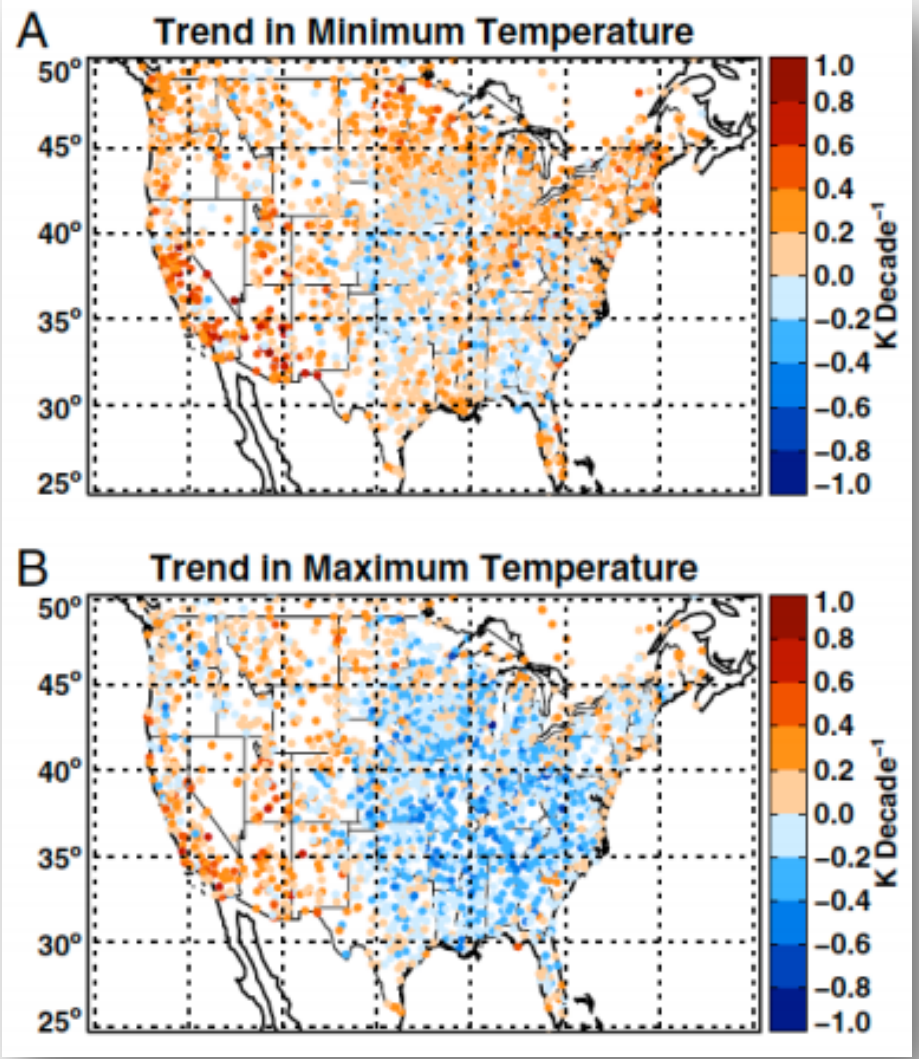


Fig. adapted from Portmann et al. 2009

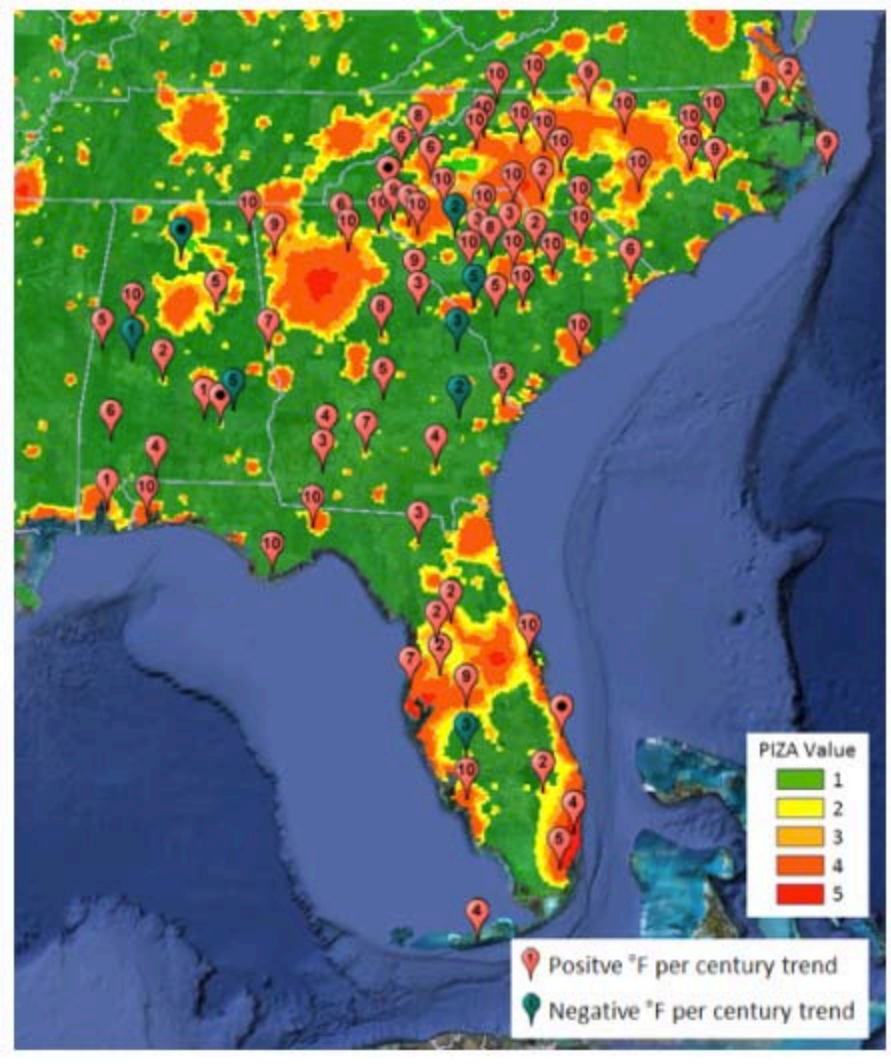
Recent past……..

Urban heat island effect……

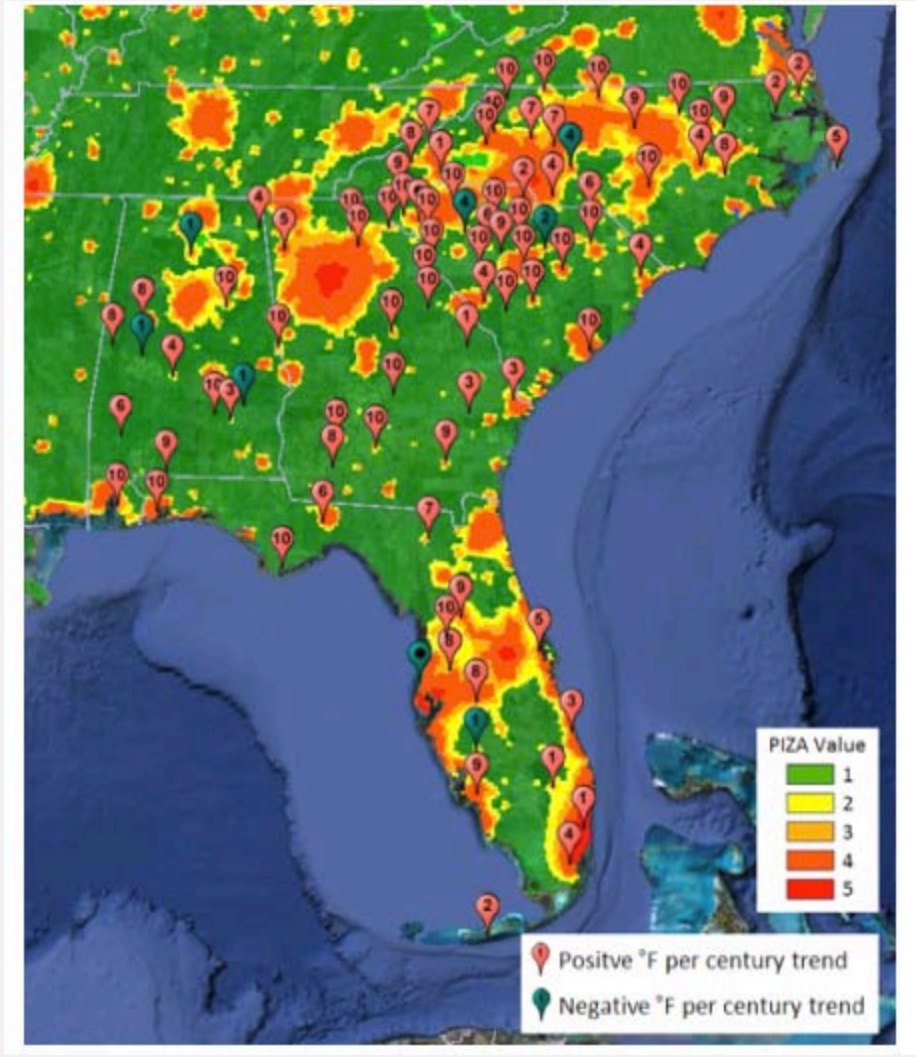
- The heat capacity and conductivity of building and paving materials allow for more heat to be absorbed during day in urban areas which then partially compensate for the radiational cooling at night.
- Sky view factor: trapping of reflected solar radiation by narrow arrangement of buildings
- Additional sources: pollutants, heat from refrigeration and air-conditioning systems and obstruction of rural air flows by the windward surface of built up surfaces

Recent past…..

Using USHCN2+ data



Trends of T_{min} overlaid on PIZA

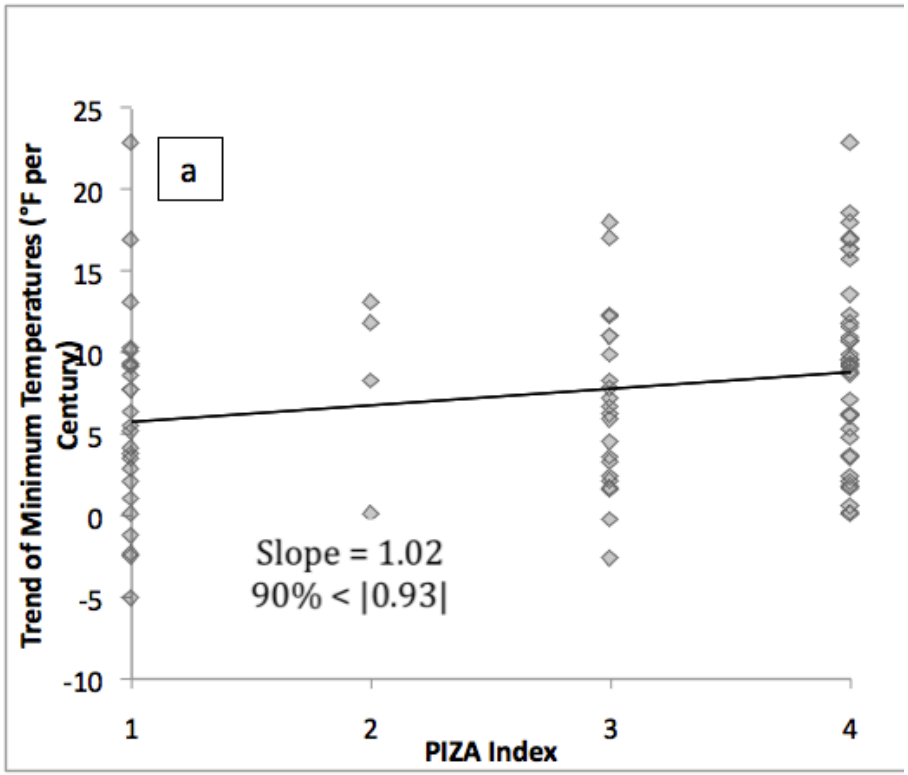


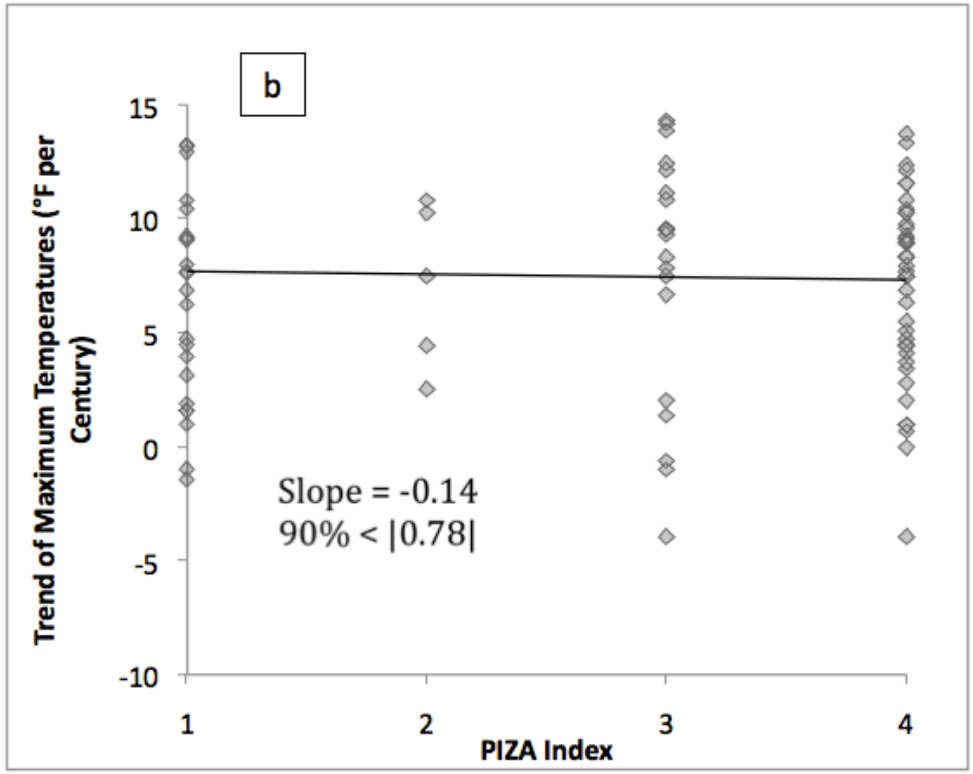
Trends of T_{max} overlaid on PIZA

Population Interaction Zone for Agriculture defined by the USDA ERS which is designed to represent residential, commercial, and industrial urban activities affecting the social and economic environment of agriculture. The data is available at 5km grid resolution.

Recent past…..

Using USHCN2+ data





More urban the land surface higher would be its PIZA index

The relatively stronger linear relationship of PIZA index with T_{min} is suggestive of the urban heat island effect.

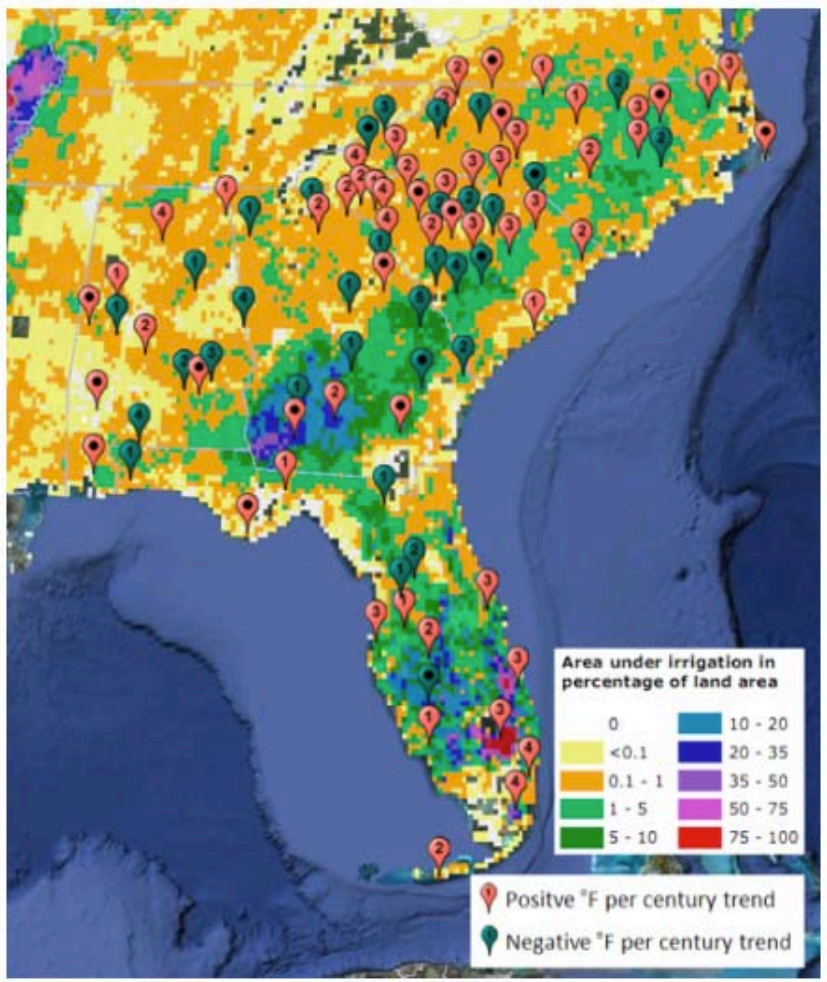
Recent past……..

Influence of irrigation…..

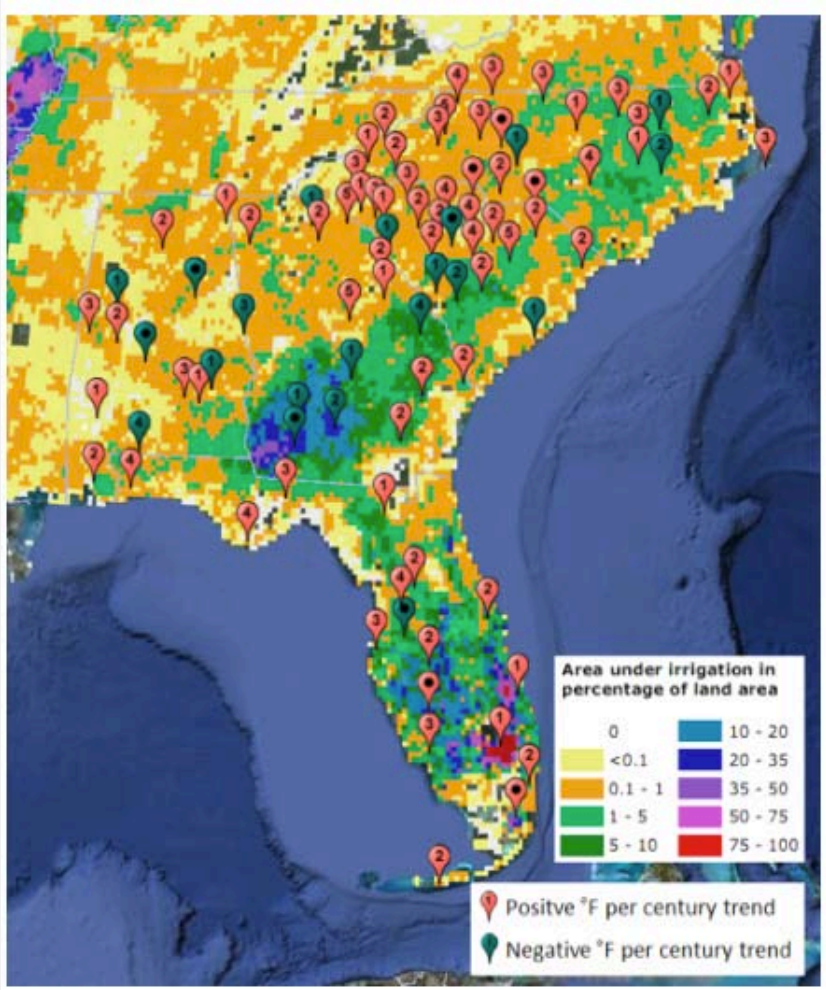
- Irrigation, by way of wetting the soil, raises evaporation during the day and changes the Bowen ratio, which leads to apparent cooling of the surface temperature
- Irrigation raises the heat capacity and conductivity of the soil and, under weak wind conditions (typically at night, when the boundary layer decouples from the rest of the atmosphere), can lead to warming of surface T_{min}

Recent past…..

Using USHCN2+ data



Trends of **JJA** T_{min} overlaid on irrigation density

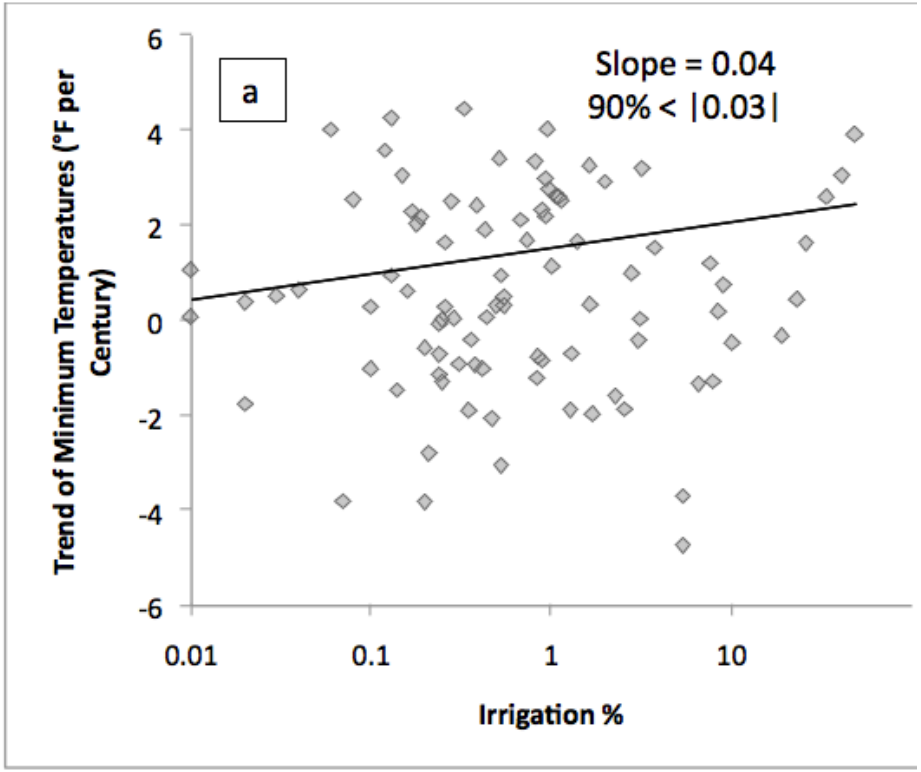


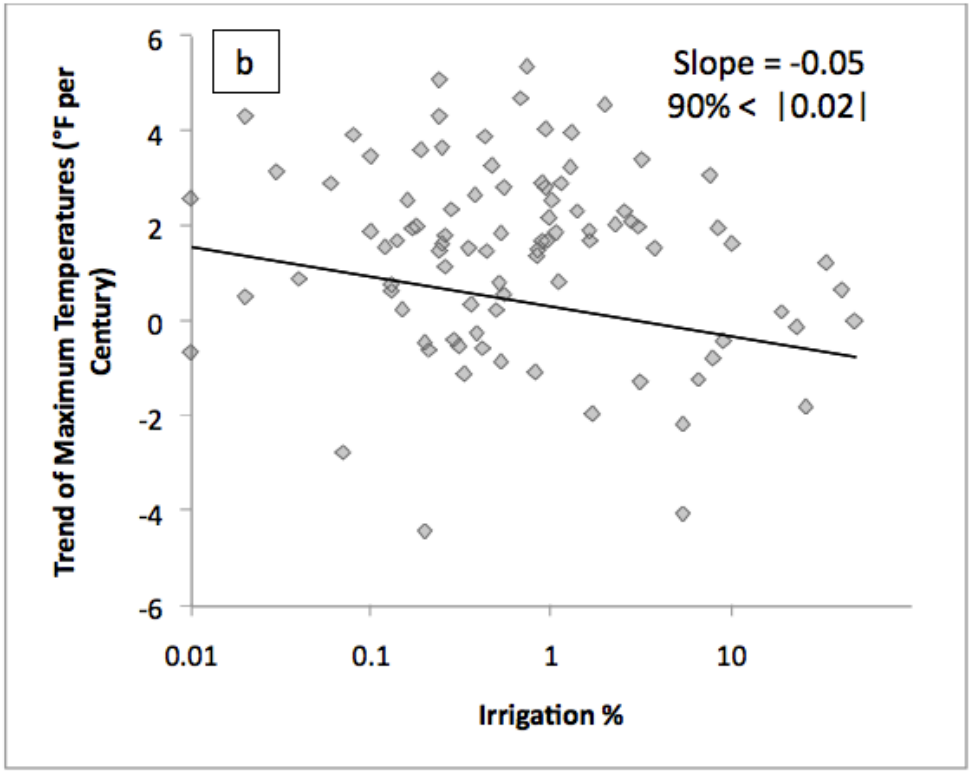
Trends of **JJA** T_{max} overlaid on irrigation density

JJA Surface temperature trends overlaid on irrigation density maps from UN Food and Agriculture Organization available on 5 arc-minute cells. Irrigation density refers to area equipped for irrigation, not amount of irrigation.

Recent past…..

Using USHCN2+ data





Trends of **JJA** T_{min} increase with increase in irrigation

Trends of **JJA** T_{max} decrease with increase in irrigation

In summary…..

- Urbanization has an influence on the temperature trends of the T_{min} in the southeast US: Rural areas have weaker warming (or larger cooling) trends
- Irrigation in the southeast US, especially in summer seems to reduce the warming (or increase the cooling) trends of T_{max}. On the other hand irrigation seems to raise the warming (or reduce the cooling) trends of T_{min}.
- Summer season shows the strongest influence of land cover and irrigation (take my word for it!)
- Change in land cover and irrigation has secondary effect on surface temperature trends: they explain the spatial distribution of the trends but not the trends in itself.

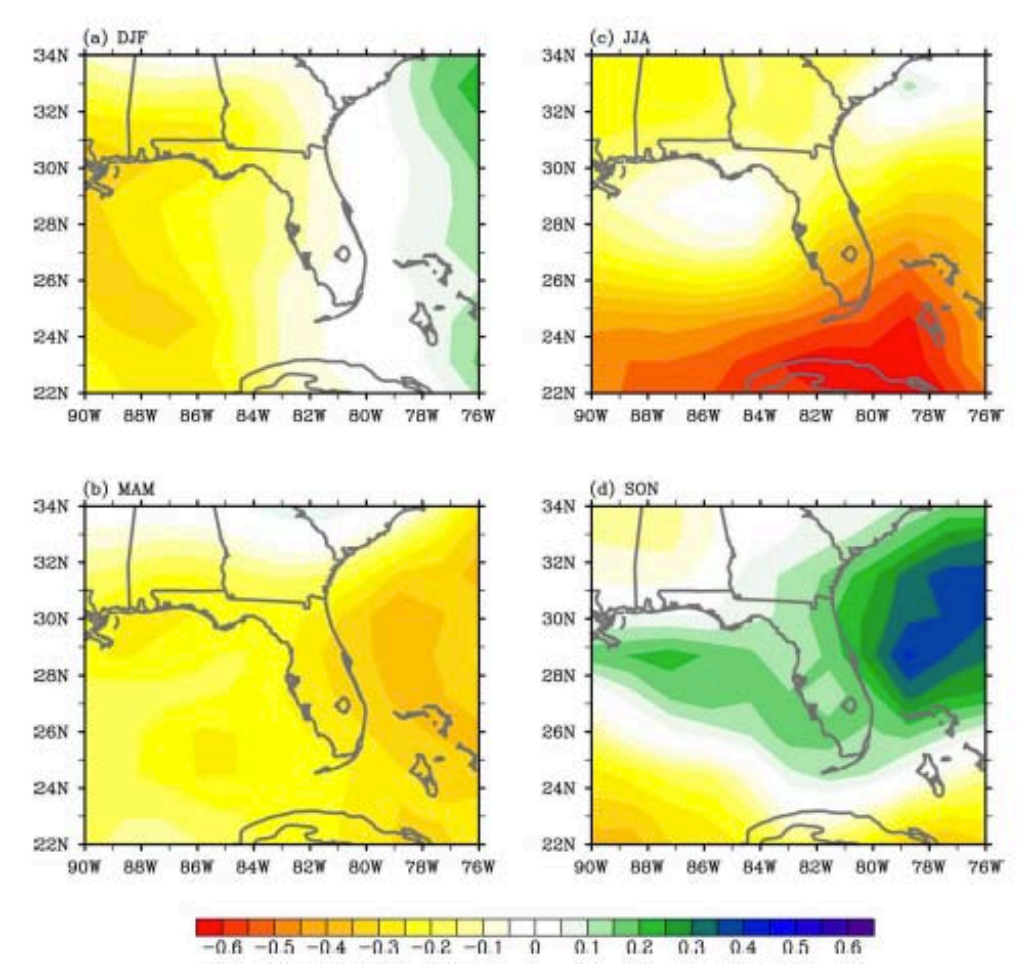
Starting points to get at climate projections

- Late spring/early summer season in the Southeast seems to show the largest response to increasing concentrations of greenhouse gases

- We show from our work that the strongest influence of land cover, irrigation on observed surface temperature trends in the southeast US seems to be in summer

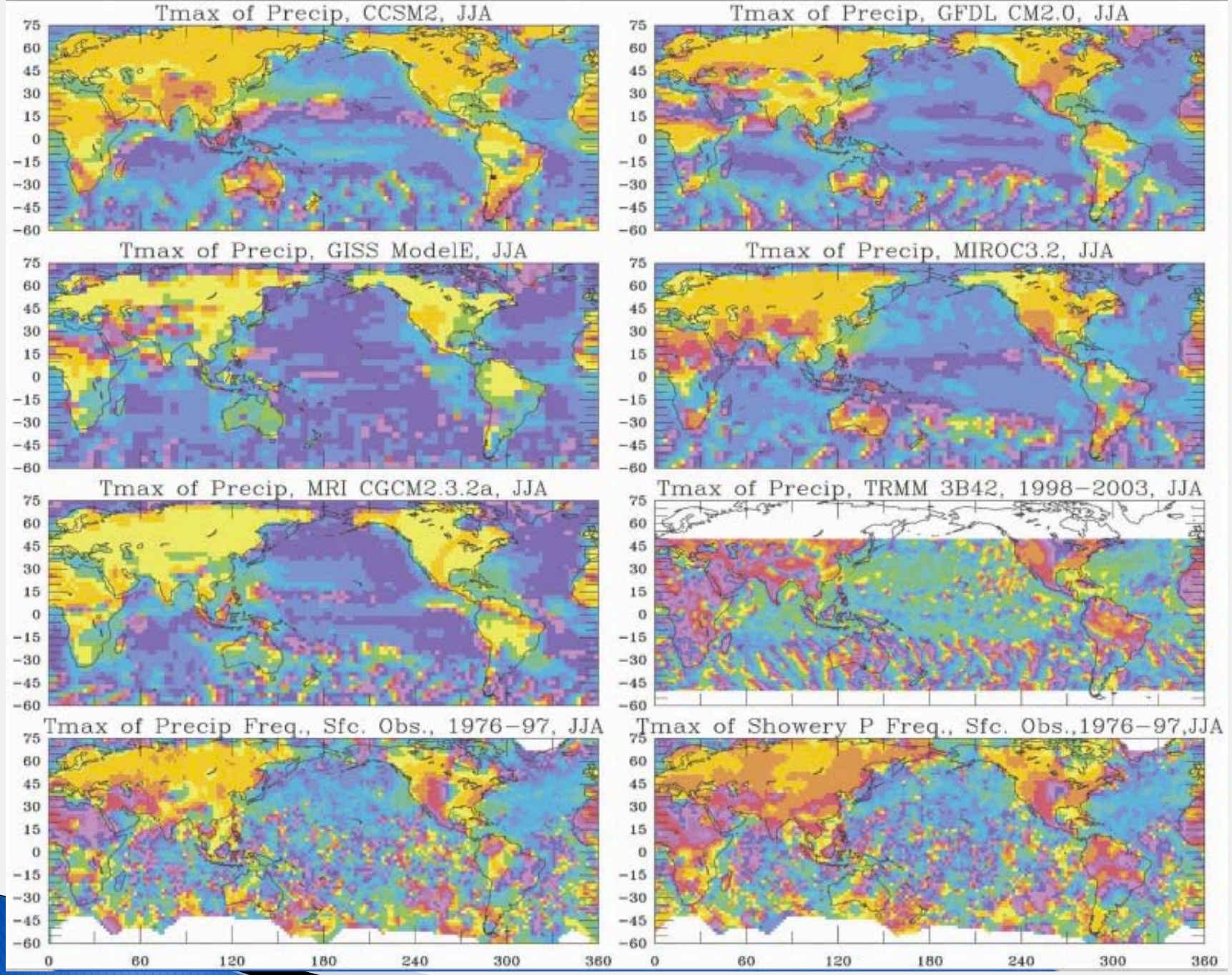
- Most IPCC AR4 models however had a horizontal resolution of ~200km: insufficient to resolve hurricanes, thunderstorms. So what are the rain bearing systems in these models? It is parameterized rain that is supposed to represent statistics of the aggregate of actual rain bearing systems (rain in climate models is some sort of a statistical construct)

Rainfall projections from IPCC AR4/CMIP3 models



Rainfall projection is highly uncertain, but drying over southern Florida is linked to broader drying over the Caribbean region, a robust feature projected across AR4 models.

Adapted from Enfield et al. 2012



Dai 2006

0 2 4 6 8 10 12 14 16 18 20 22 24

Local time

Present……

- “Tropical precipitation patterns from **many new models**, such as the HadGEM1 and CCSM3, **have no substantial improvements** over their previous generations, such as the HadCM3 and Climate System Model (CSM), version 1.”
- “Warm season convection still starts too early in all the new models, and is too frequent at reduced intensity in some models (e.g., CCSM2, MIROC3.2)”

Dai (2006)

Present……

- CMORPH data: CPC MORPHing technique data that combines microwave estimates of precipitation from low orbiting satellite exclusively and the features are propagated using IR data from geostationary satellites.

  Grid resolution: 8km at equator

  Temporal resolution: 30 minutes

  Period of record: 3 December 2002-present

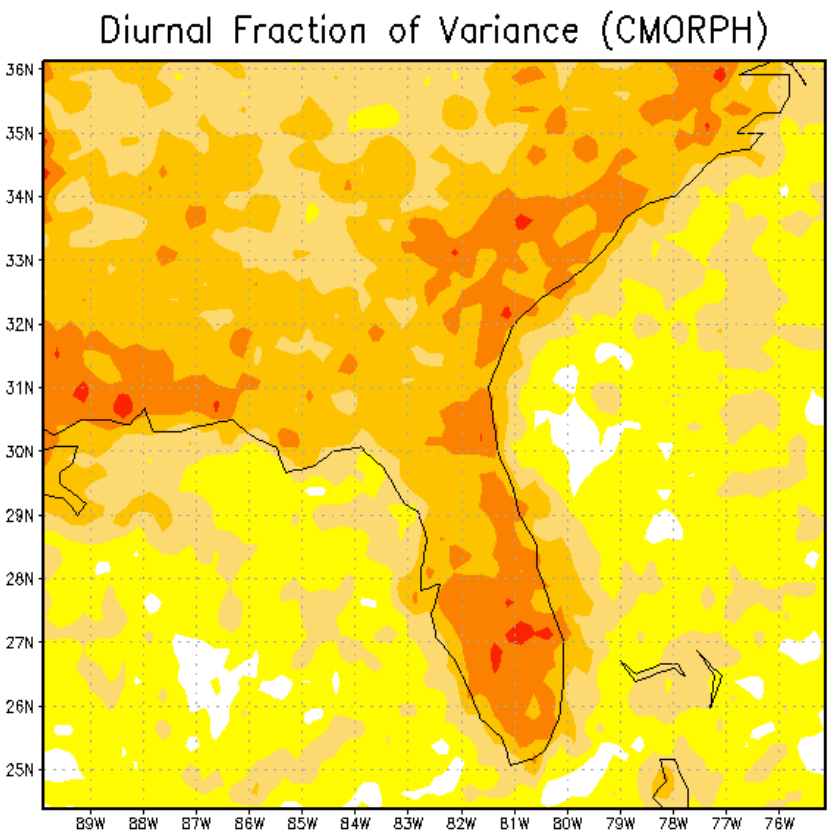
- NCEP StageIV data: It is a multi-sensor (radar + gauges) precipitation analyses produced by the 12 RFC's in the CONUS.

  Grid resolution: 4km

  Temporal resolution: hourly

  Period of record: 1 Jan 2002- present

Present……


Diurnal Fraction of Variance (CMORPH)
36N
35N
34N
33N
32N
31N
30N
29N
28N
27N
26N
25N
89W
88W
87W
86W
85W
84W
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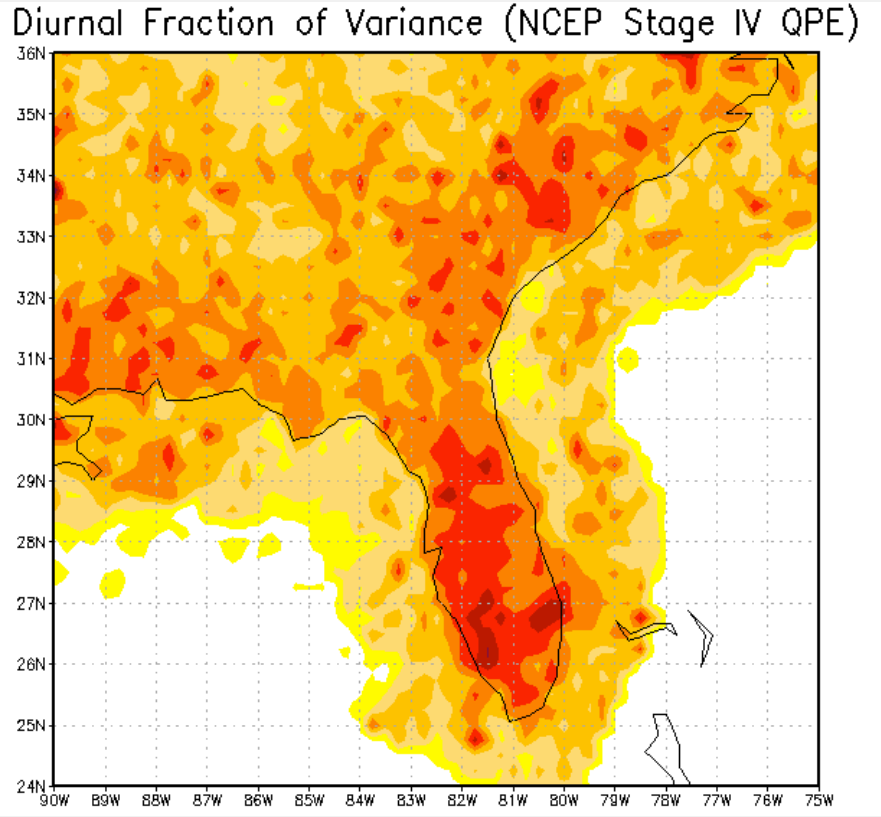
82W
81W
80W
79W
78W
77W
76W


Diurnal Fraction of Variance (NCEP Stage IV QPE)
36N
35N
34N
33N
32N
31N
30N
29N
28N
27N
26N
25N
24N
90W
89W
88W
87W
86W
85W
84W
83W
82W
81W
80W
79W
78W
77W
76W
75W
0.5
0.45
0.4
0.35
0.3
0.25
0.2

Present……

- **Regional Spectral Model (Kanamitsu et al. 2010)**

- **Dynamically downscaled with reanalysis specified forcing at lateral boundaries**
  - **NCEP-DOE (R2) reanalysis (grid resolution 2.5^0)**
  - **ERA reanalysis (grid resolution 2.5^0)**
- **10km horizontal resolution**
- **28 vertical sigma levels**

Present…..

- **Climatology from 21 years!**
- **FCI-FSU RSM does a great job at resolving the diurnal phase of precipitation**

RSM

Time of Maximum precipitation in GMT

Obs

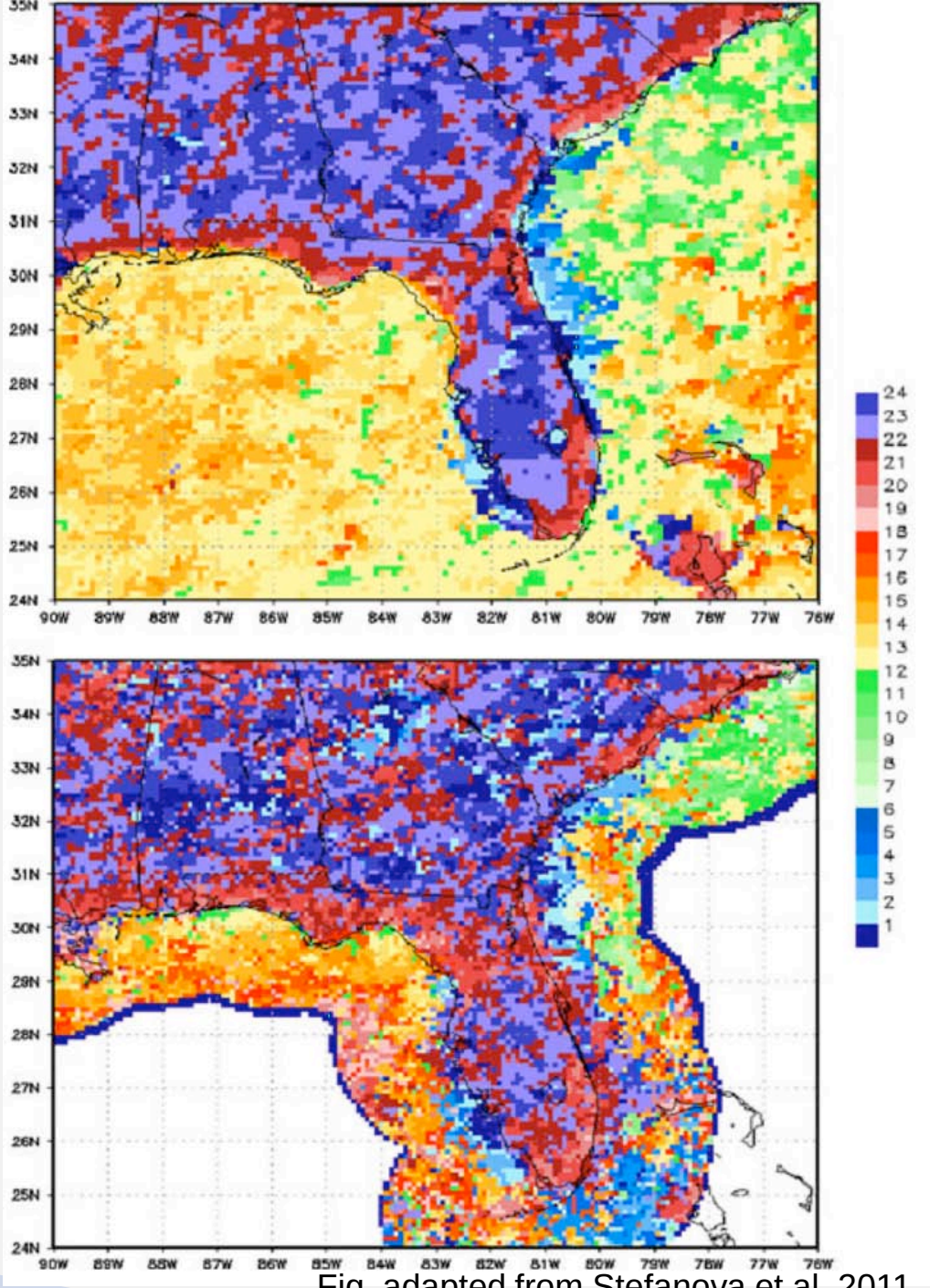
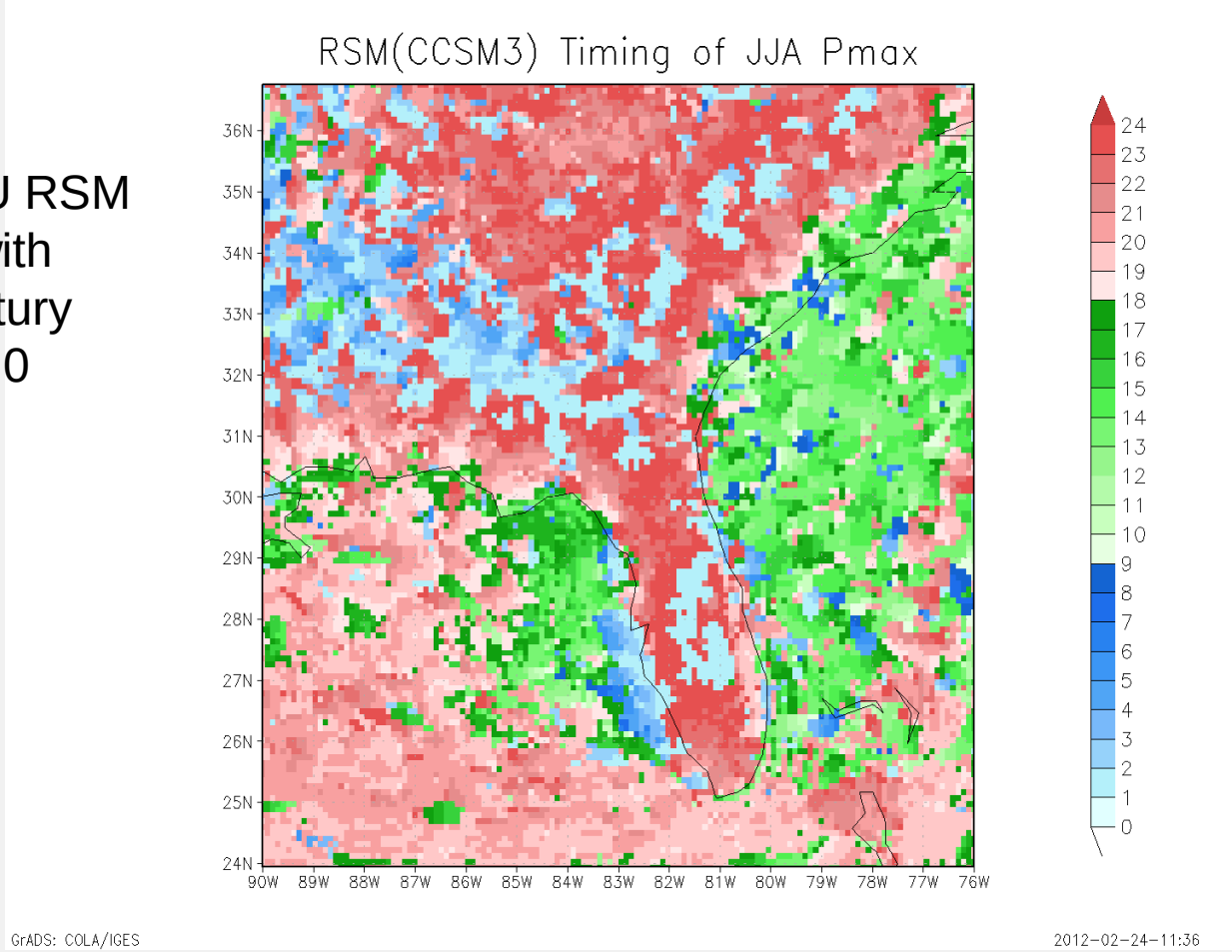
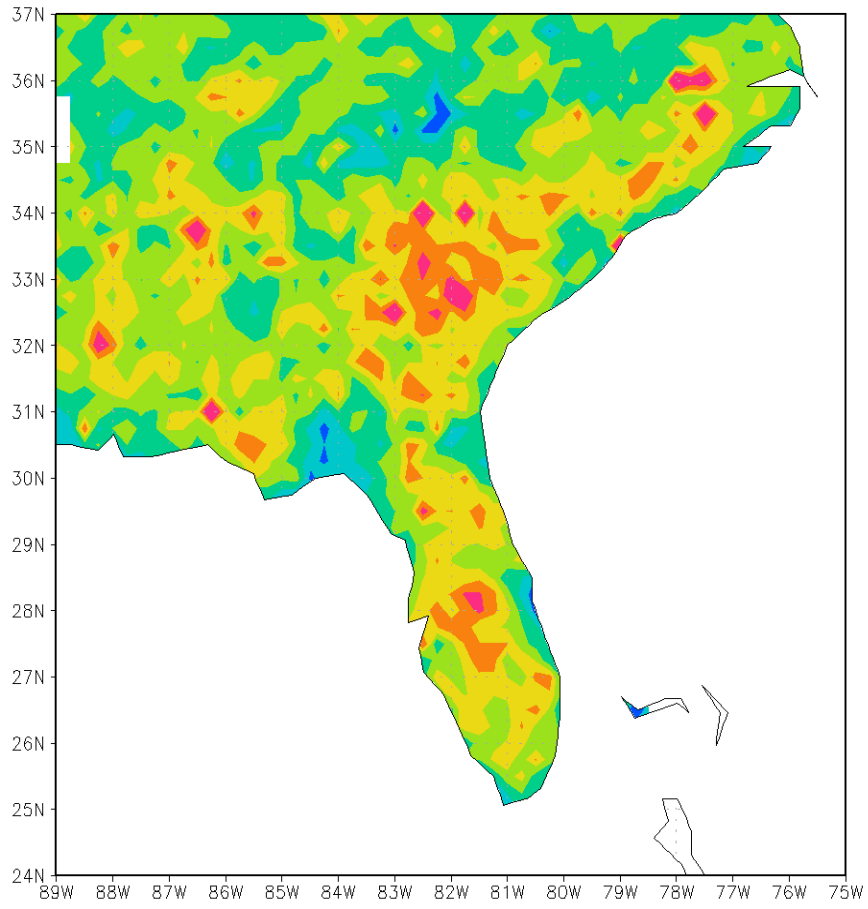


Fig. adapted from Stefanova et al. 2011

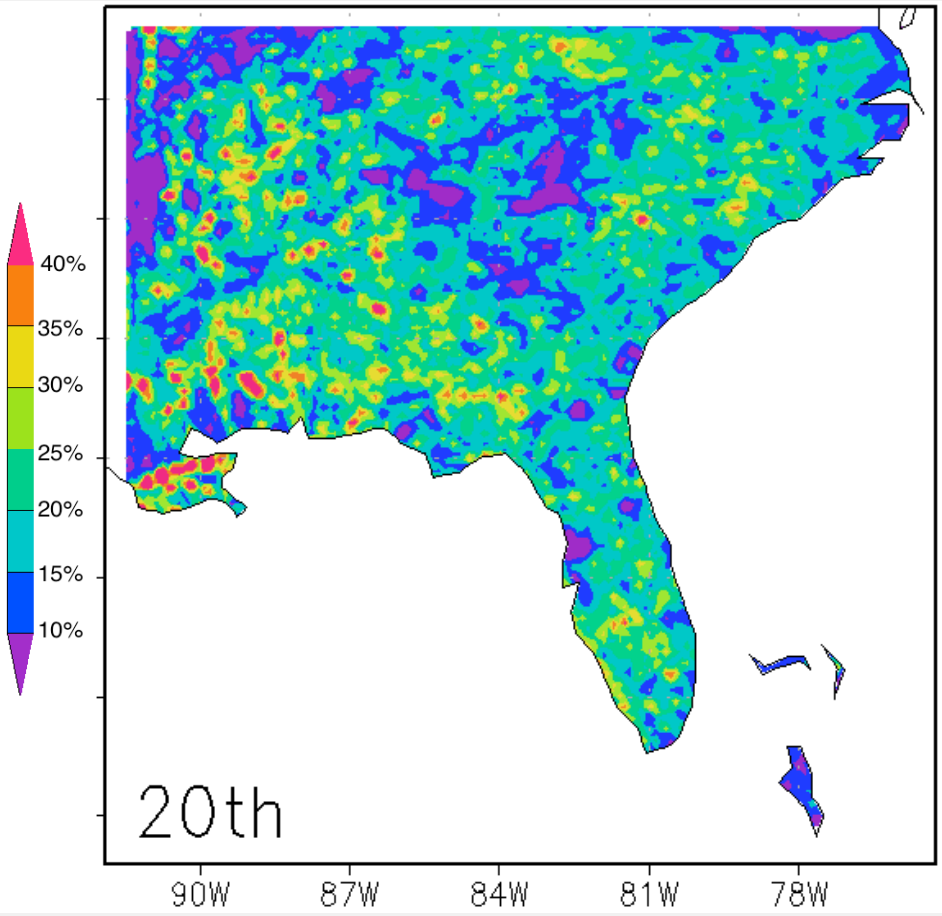
FCI-FSU RSM forced with 20th century CCSM3.0



How does the RSM stack up?

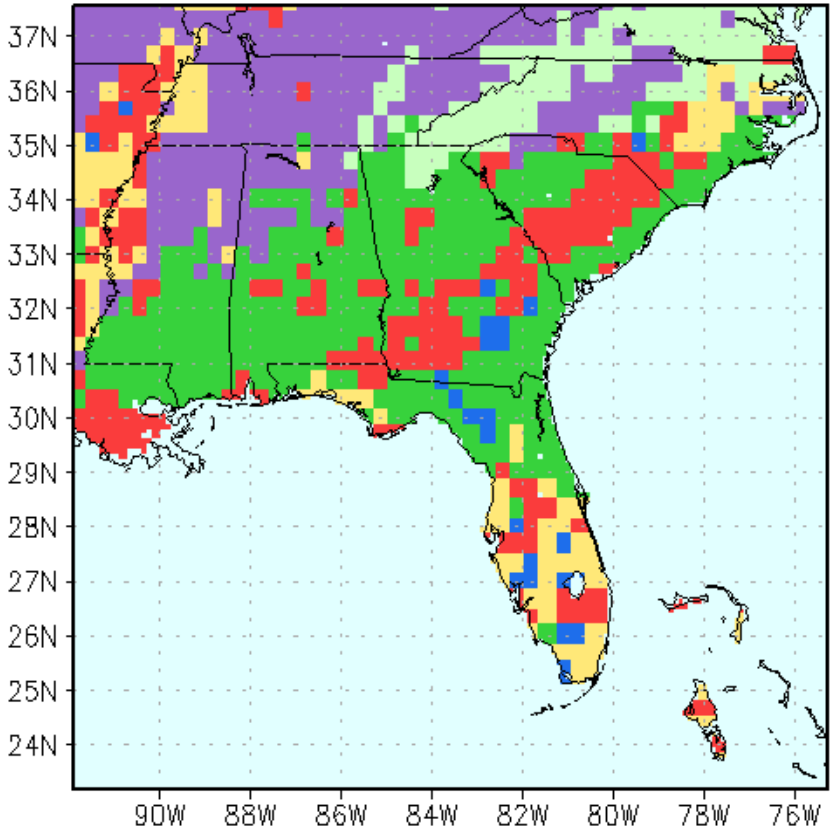


Obs Diurnal Fraction of Variance



RSM Diurnal Fraction of Variance

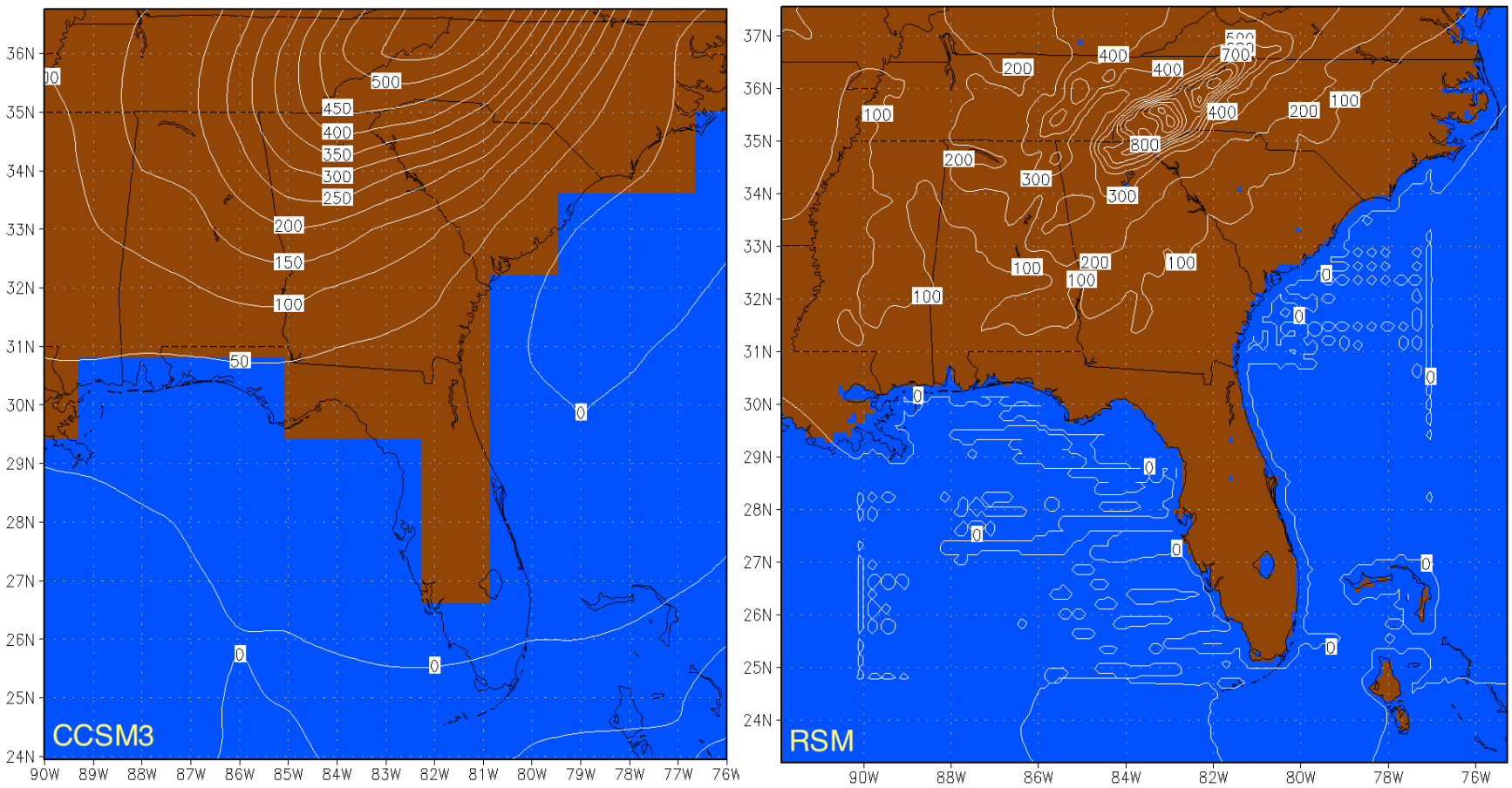
RSM underestimates fractional diurnal variance?



Vegetation Types:

- broadleaf evergreen (tropical)
- broadleaf deciduous
- mixed forest
- needleleaf evergreen
- needleleaf deciduous
- broadleaf with groundcover
- perennial groundcover
- broadleaf shrubs w groundcover
- broadleaf shrubs w bare soil
- tundra
- bare soil
- cultivations

Land/Sea Coverage & Topography

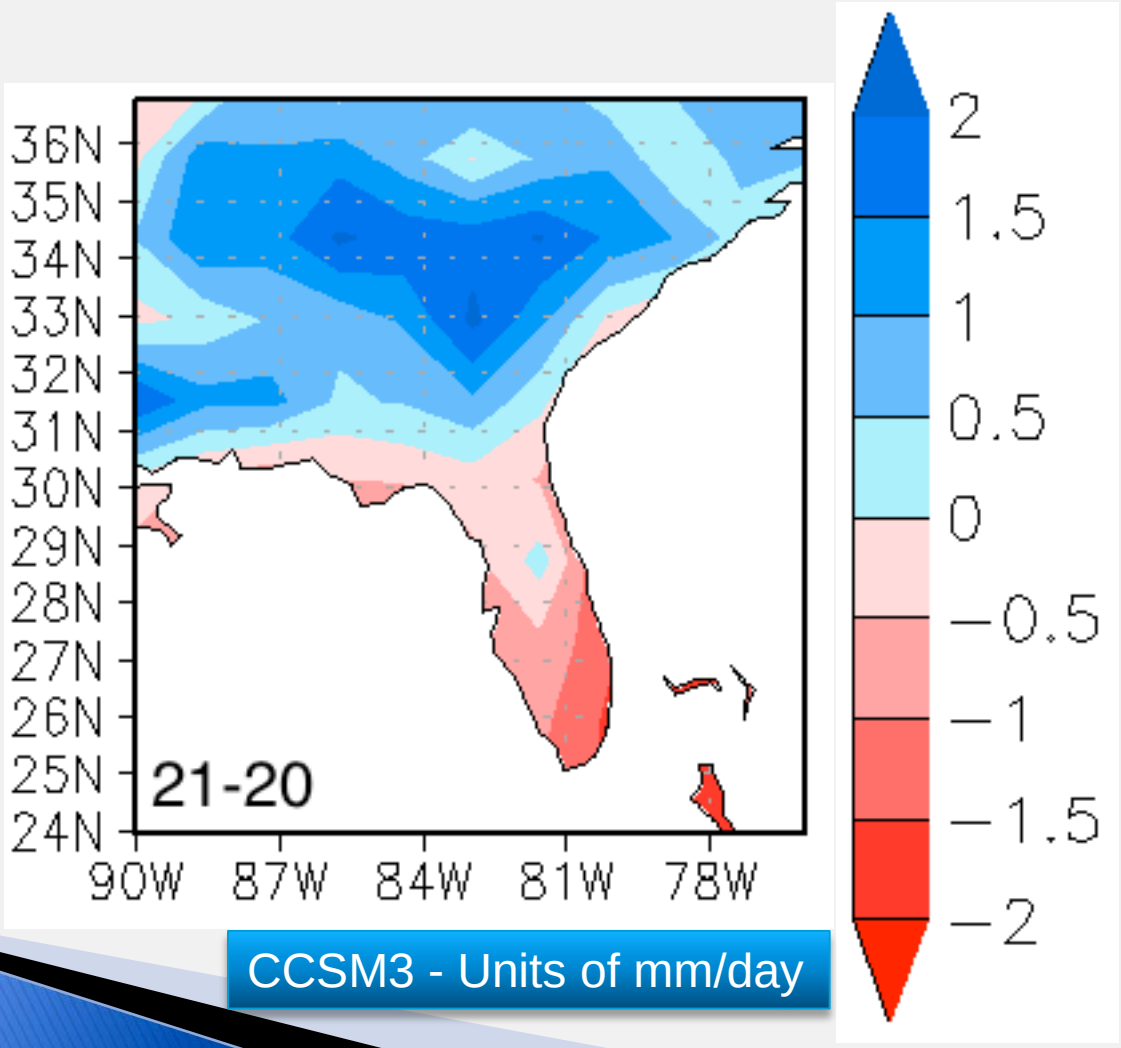


In summary…..

- Diurnal variability is a significant fraction of wet season rainfall over the southeast US
- FCI-RSM does a reasonable rendition of the diurnal variations in the southeast US➔ More than the physics in FCI-RSM (we cannot claim that this model is using a parameterization scheme that is superior to most CMIP3 models). We believe it is the resolution of the local orography, coastlines that matters.

Future…….

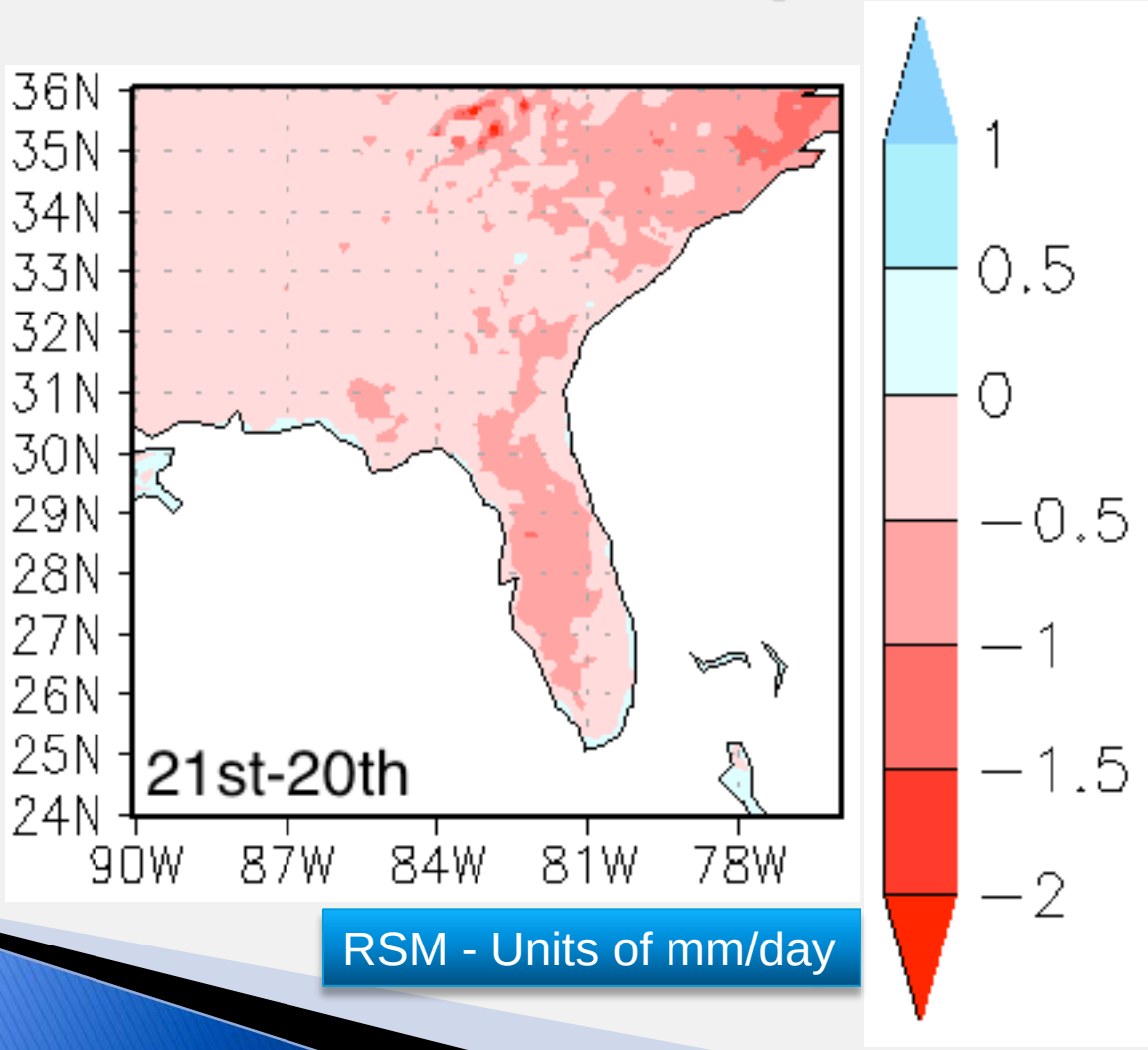
21st century CCSM3 JJA rainfall anomaly



CCSM3 - Units of mm/day

Future…….

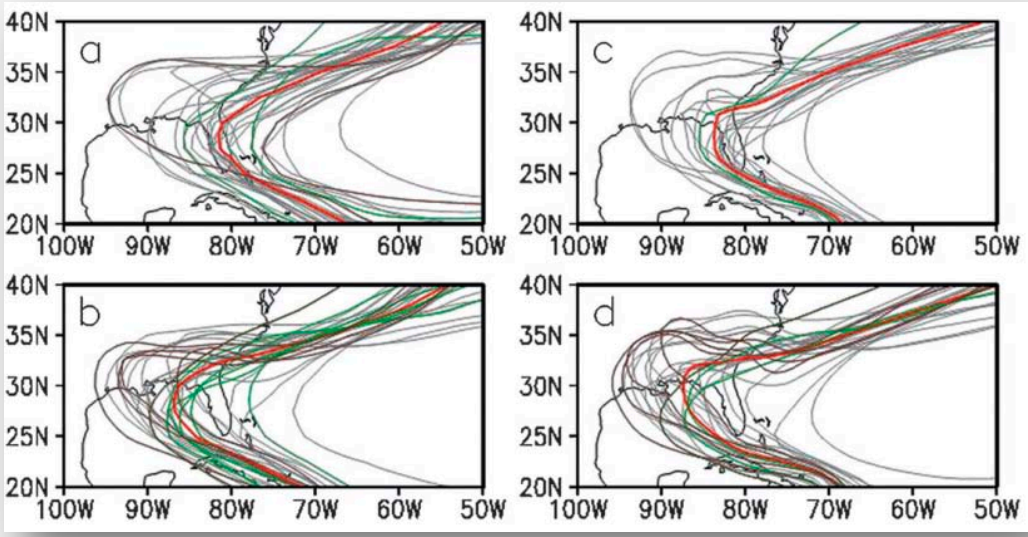
21st century RSM forced with CCSM3 JJA rainfall anomaly



RSM - Units of mm/day

More variation in summer?

- **Expansion of the North Atlantic Subtropical High (NASH)?**
  - **Westward expansion brings higher surface pressures**
  - **The opposite is also true**
  - **Enhanced/reduced subsidence as a result**
  - **Impact of -0.5 to -0.3 mm/day**



(A and B are NCEP reanalysis, C and D are ERA-40 reanalysis. Top row is mid-20th (1958-77) century, bottom row is late 20th to early 21st (1978-2002) century reanalysis data)

Almost 6^0 westward shift in 60 yrs!

Figure adapted from Li et al. 2011

Another hypothesis

•The “upped-ante” mechanism – Increased ABL moisture “ante” required to initiate convection in a warmed troposphere.

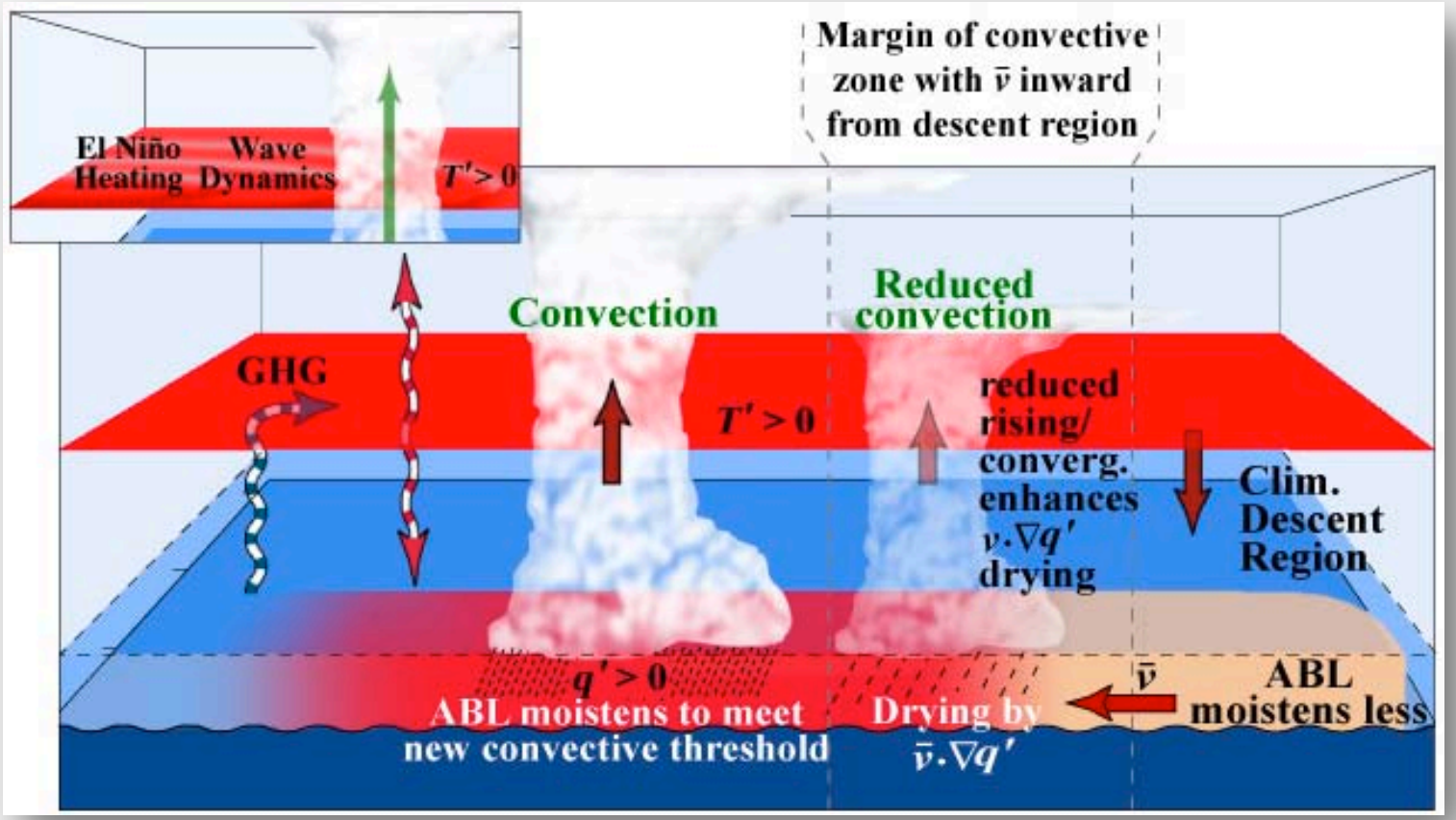
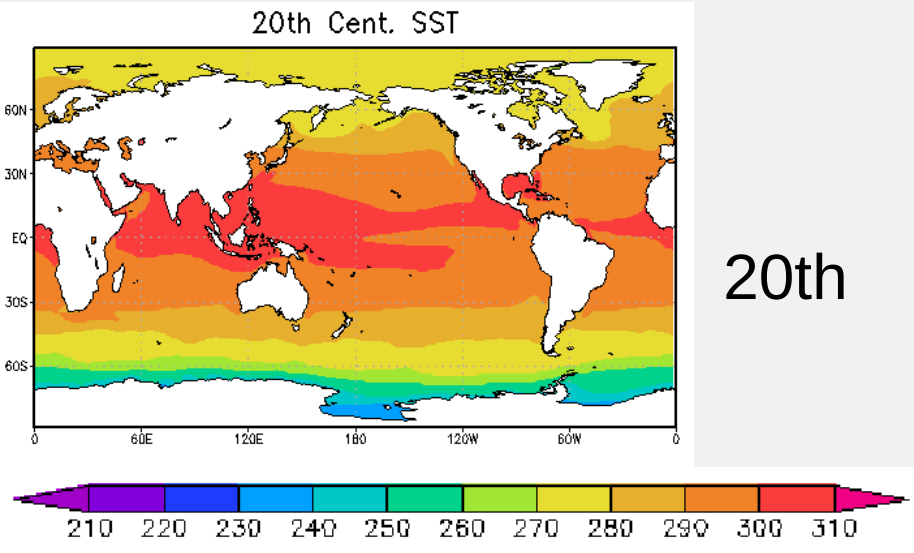


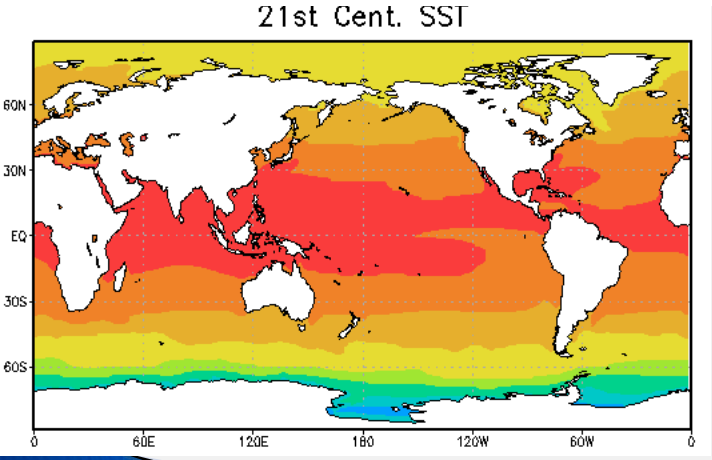
Fig. adapted from Neelin et al. 2003

Future……

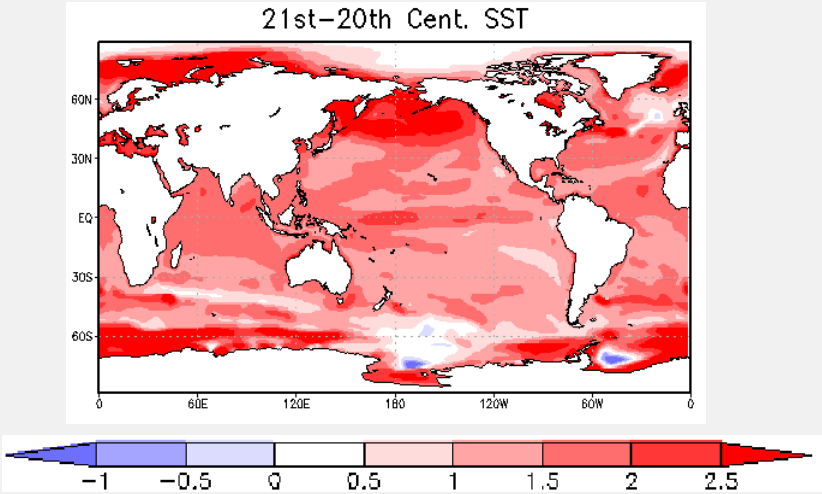
SST



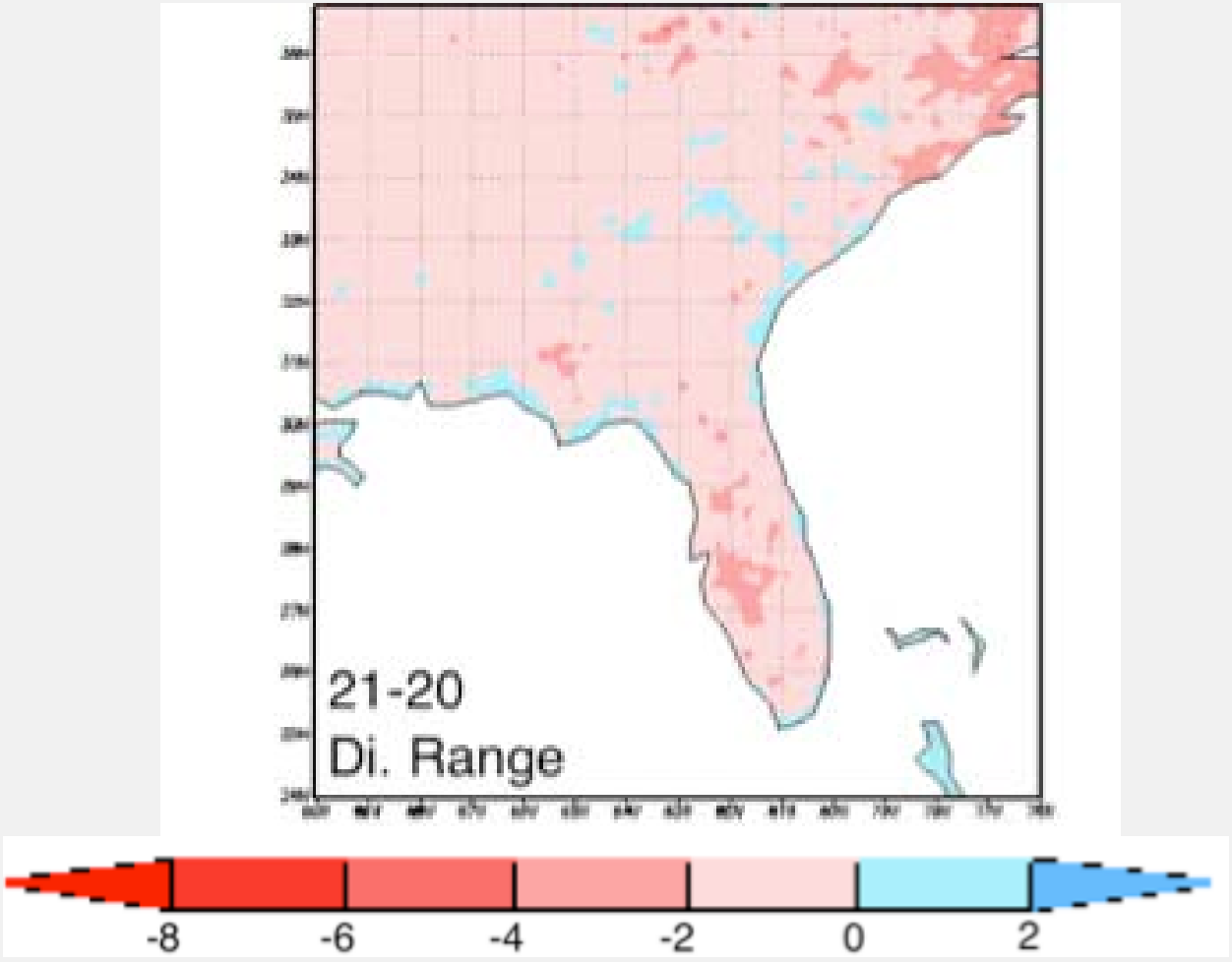
20th

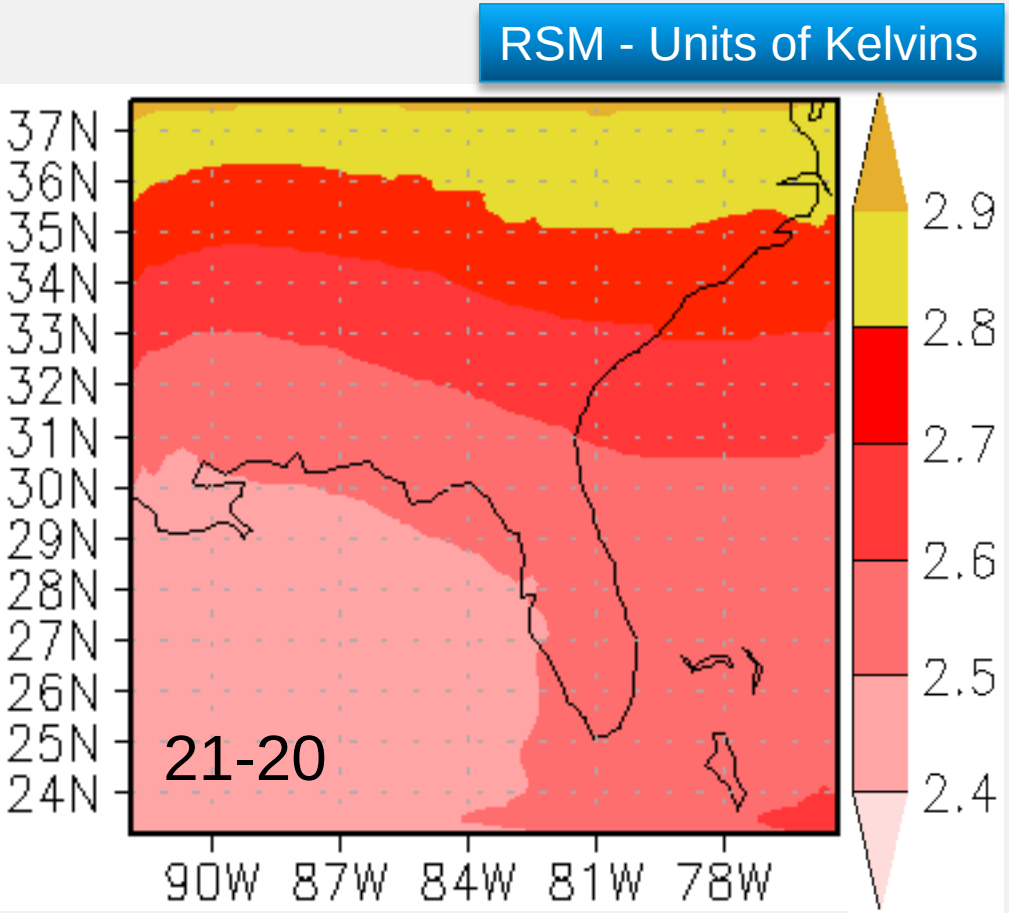


21st



CCSM3 – Units of Kelvins

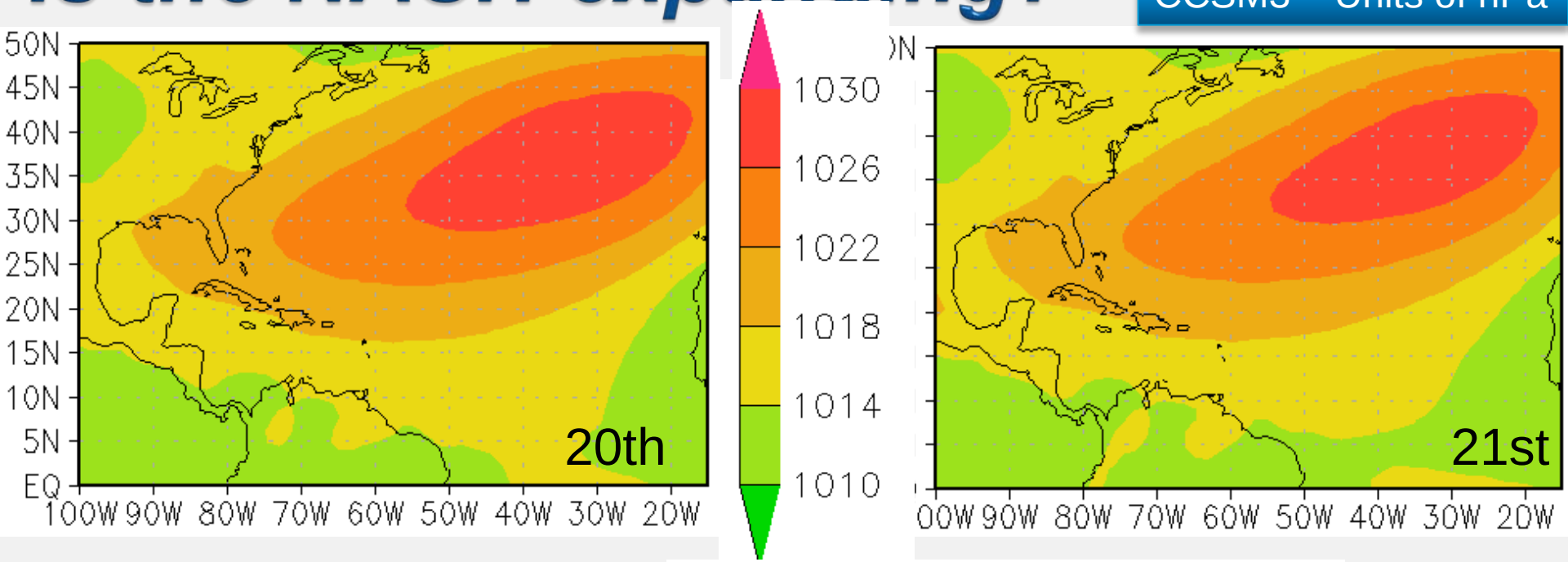

21-20
Di. Range
-8
-6
-4
-2
0
2

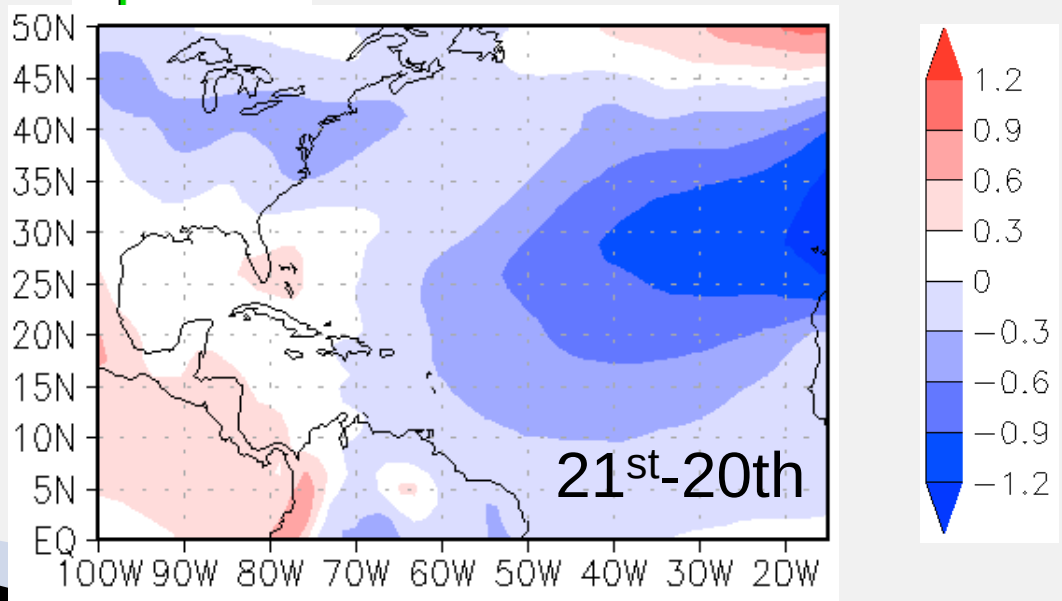


Consistent with the “Upped-ante” mechanism; moist convective region to south, SEUS on convective margin can’t meet “ante,” precipitates less!

Is the NASH expanding?

CCSM3 – Units of hPa





In summary…..

- Summer rainfall in majority of the CMIP3 models in a future A2 scenario (CO_2 doubling its concentration by mid to late 21st century—2040-2070) is projected to be more dry in south Florida and wetter north of it in the southeast US.
- Summer rainfall in the downscaled FCI-FSU-RSM from CCMS3 is uniformly projected to be dry across the southeast US compared to 20th century summer climatology---this is associated with significant reduction in the diurnal variations
- Diurnal variations in southeast US are responding to large-scale changes of tropospheric temperature warming and the westward shift of the weakened Bermuda High

Conclusions

- The physical processes for the observed surface temperature trends in the SEUS is complex--- influence of local surface features (e.g. urbanization, irrigation) is evident.
- Diurnal variability plays a significant role in the warm season rainfall in the SEUS. Examining **one** model projection for **one** scenario provides **anecdotal evidence** for the modulating role of the diurnal variability on the future projection of the SEUS summer climate.