Lake Temperature Trends as Indicators for Climatic Change in Florida

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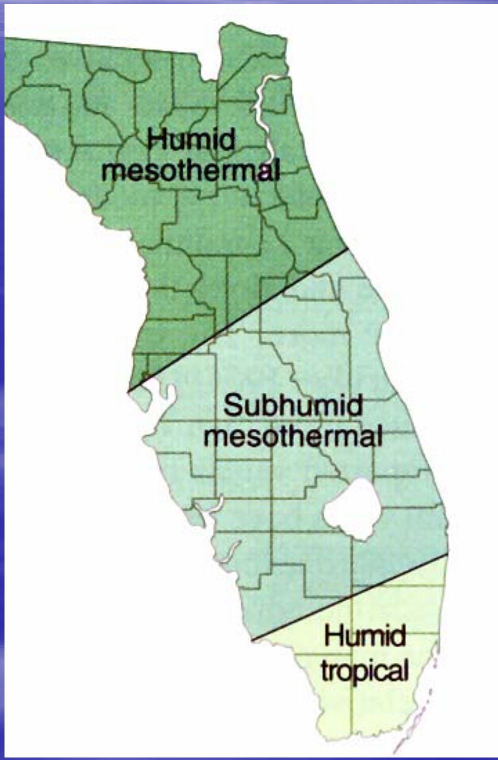
Study Objectives

- Based on analyses of lake sampling data (1968-2004):
  - Evaluate suitability of lake water temperature records for climate research
  - Identify influence of location, morphometric and biological variables on thermal properties of FL lakes
  - Identify interdecadal temperature trends (if any) as potential indicators for recent warming in Florida
  - Identify spatial and temporal patterns of change
  - Discuss possible impacts of climate change on lacustrine ecosystems in FL during the 21st Century

Features of Florida

- Steep climate gradient
  - Temperate-tropical transition over <700km
- Narrow ecological life zones (<300km)
- Substantial human population pressure and land cover modification/fragmentation
- Peninsular shape
- Low topographic relief
- Exposure to tropical cyclones
- Sensitive to drought



Henry 1998

Vegetation and Climatic Zones

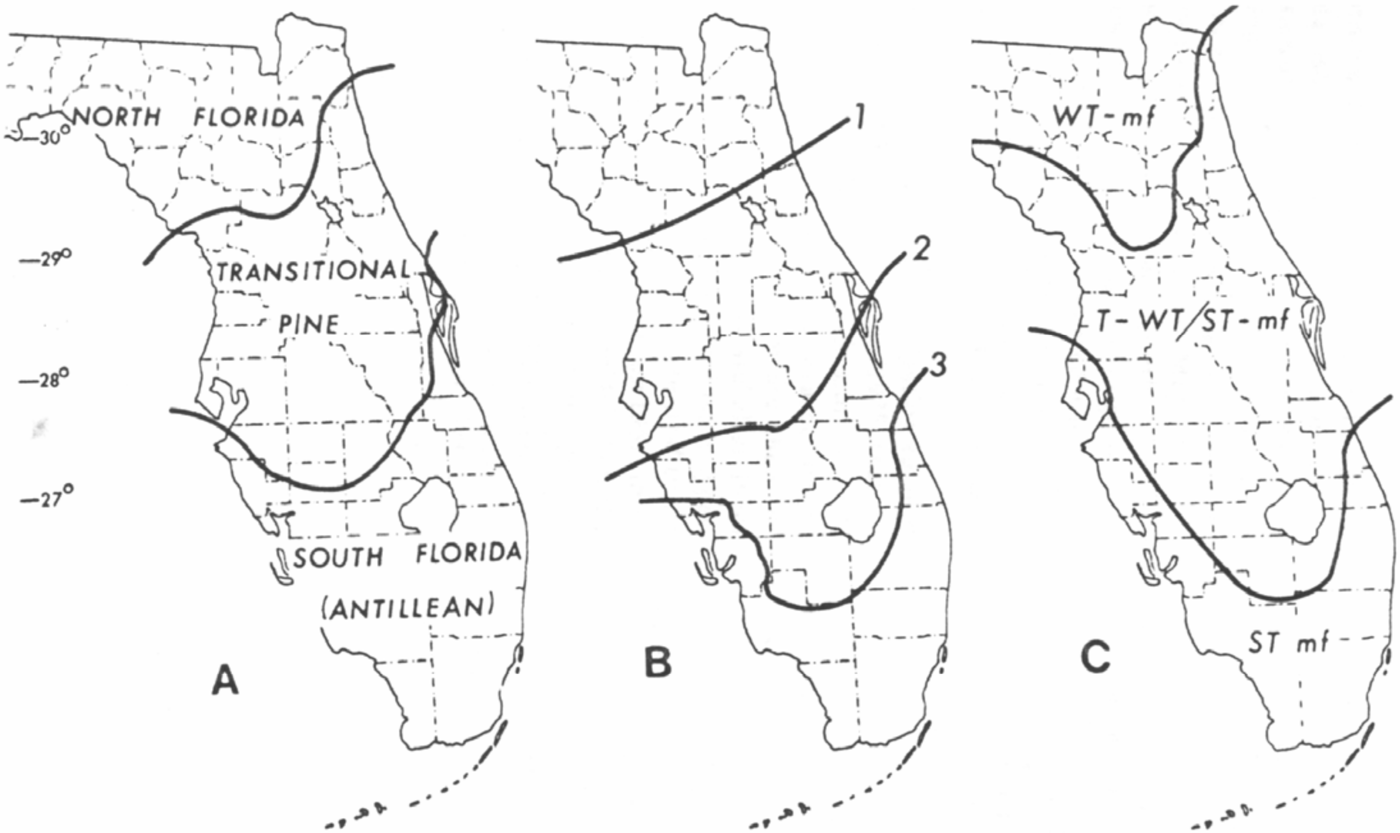


Fig. 5. Vegetation and climatic zones in peninsular Florida: A) major forest regions, Brown (1909). B) White Oak *(Quercus alba)* line approximating the southern limit of 20 tree species (1), southern Red Oak *(Quercus rubra)* line and the beginning of subtropical vegetation (3), after Dohwender & Harris (1975). (C) Life zones of Florida according to the Holdridge (1967) prediction model after Dohwender & Harris (1975). Zones include warm temperate moist forest (WT-mf), the transition zone between warm temperate and subtropical moist forest (T-WT/ST-mf), and subtropical moist forest (ST-mf).

Beaver et al. 1981

Lake Zones

- Beaver, Crisman & Bays (1981):
  - classified FL lakes into three groups based on thermal properties
  - based on a late 1970s dataset of 24 lakes sampled monthly for one year
  - warm temperate (>29.5º), transitional, subtropical (<28º)
  - Partitions similar to ecological life zones

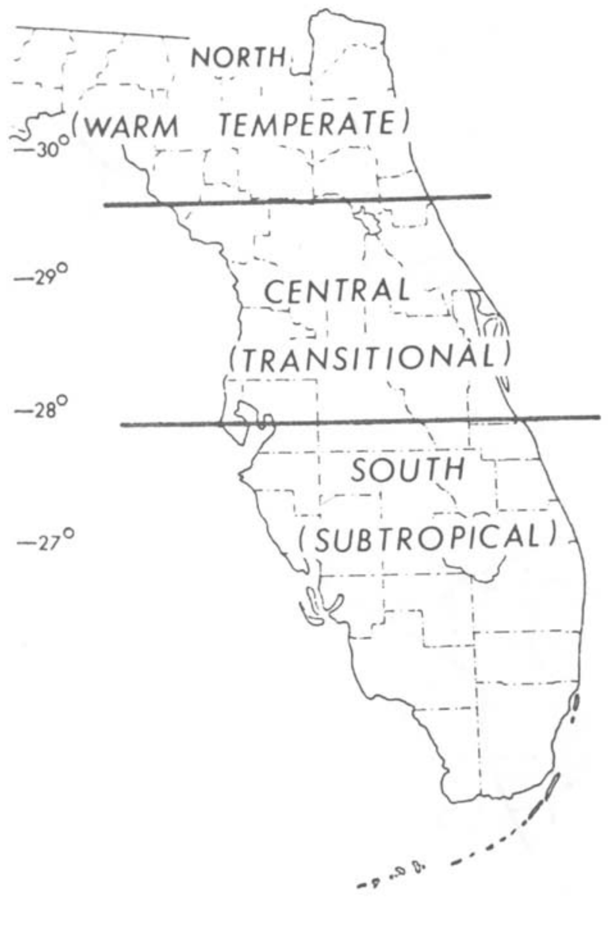


Fig. 4. Statistically defined zonal boundaries for Florida lakes based on monthly mean water column temperatures.

Latitude-Temperature Relationships

- Beaver, Crisman & Bays (1981)

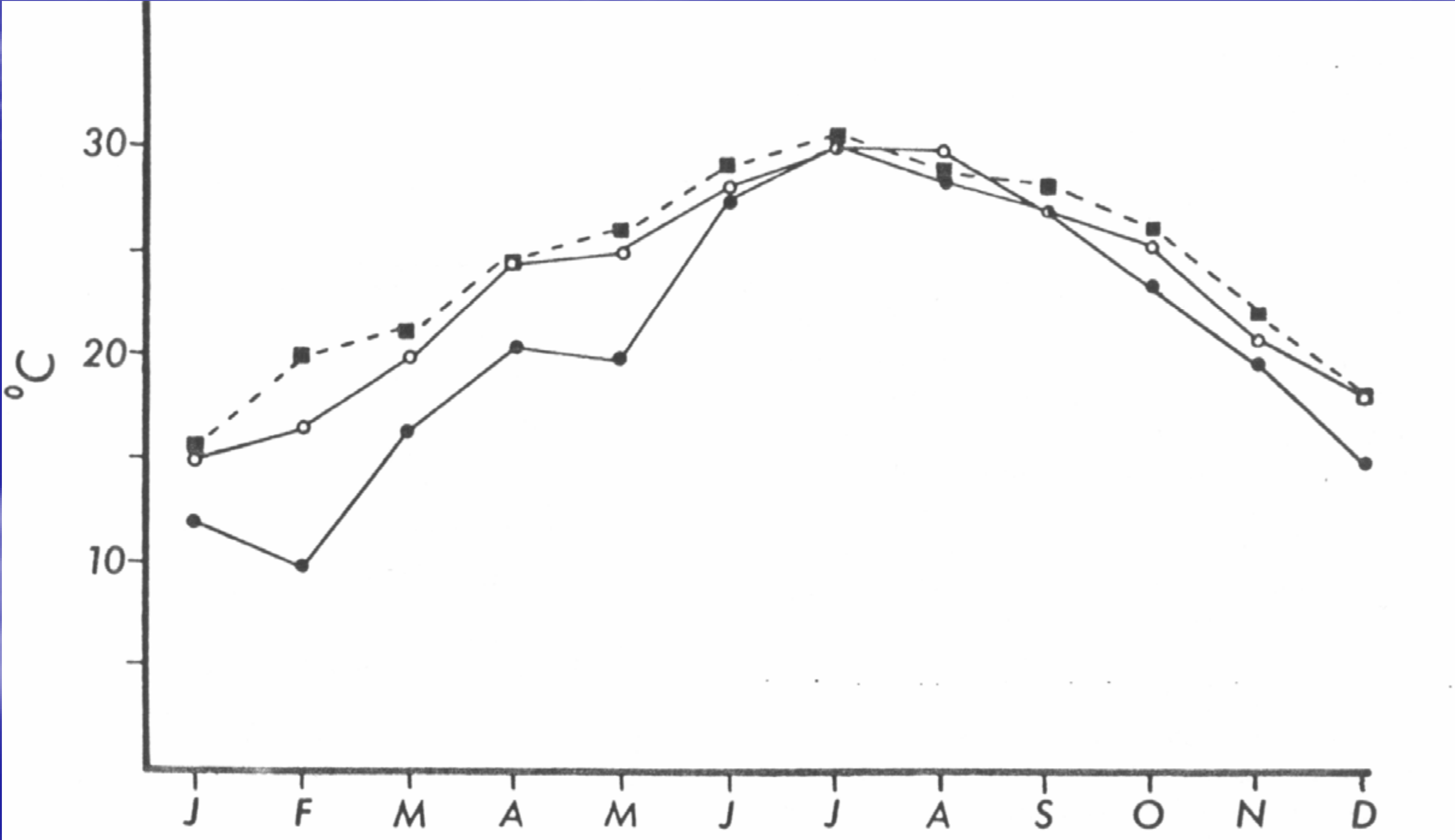


Fig. 3. Mean monthly water column temperatures for northern (closed circles), central (open circles), and southern (squares) Florida lake groups that were defined from hierarchical fusion of temperature data from 24 lakes (Figure 2).

Why Lakes for Climate Study?

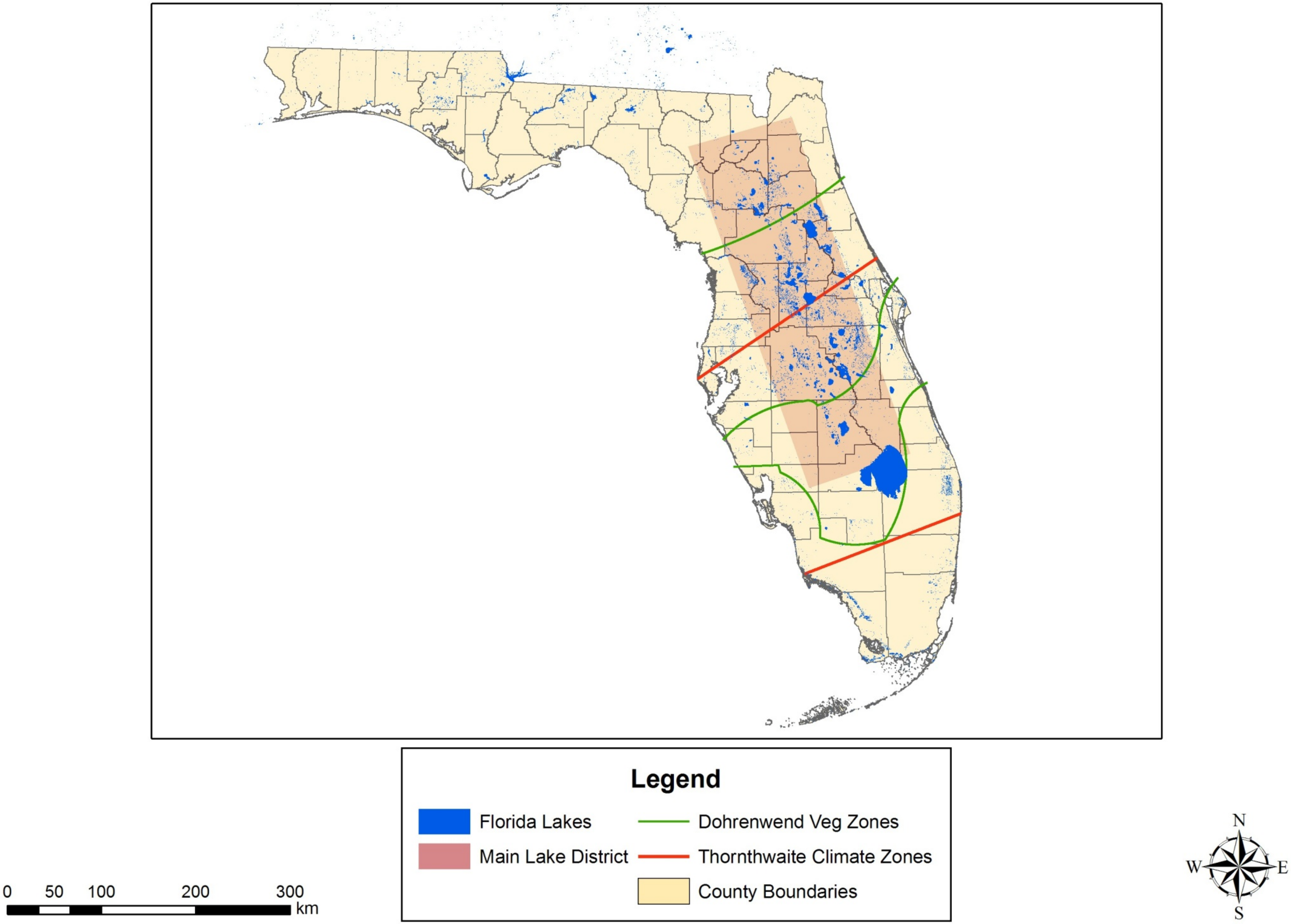
- In Florida, day-night air temperature differences approach or exceed the annual range of daily temperature means.

County	Diurnal Range	Annual Range
Alachua	12.6ºC	13.9ºC
Orange	11.5ºC	11.1ºC
Highlands	15.6ºC	10.5ºC

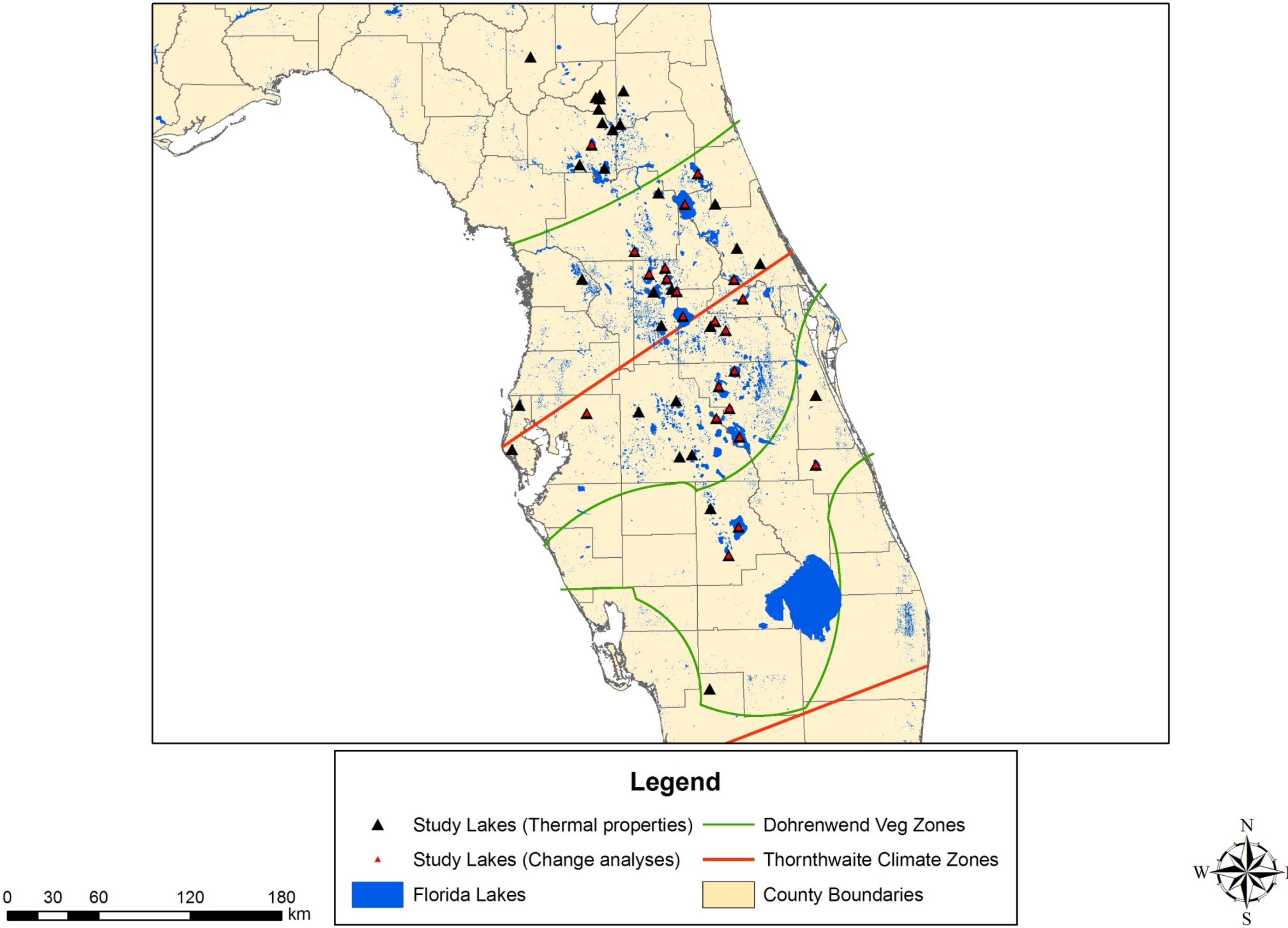
- Lakes exhibit thermal inertia due to the high specific heat of water (4186 J/kg/ºC), naturally “filtering” the diurnal signal and producing clearer medium-long term trends.

Lake	Mean Diurnal Range	Annual Range
Conway, Orange (1977-78)	1.19ºC	18.41ºC

The Peninsular Lake District



Study Sites - Overview



Site Selection

- Constrained primarily by data availability
- Lakes sampled by Canfield (1981) and those listed by Shafer et al. (1986) among the 100 largest lakes in FL formed the database core
- Additional data were obtained directly from the Water Management Districts, Florida Fish and Wildlife Commission, Archbold Biological Station, US Forest Service, and research records from the Center for Wetlands.
- Modern and Legacy EPA STORET databases were queried for each of the above systems to complete the record (Temperature, Chl a, Color)

Site Selection Cont'd

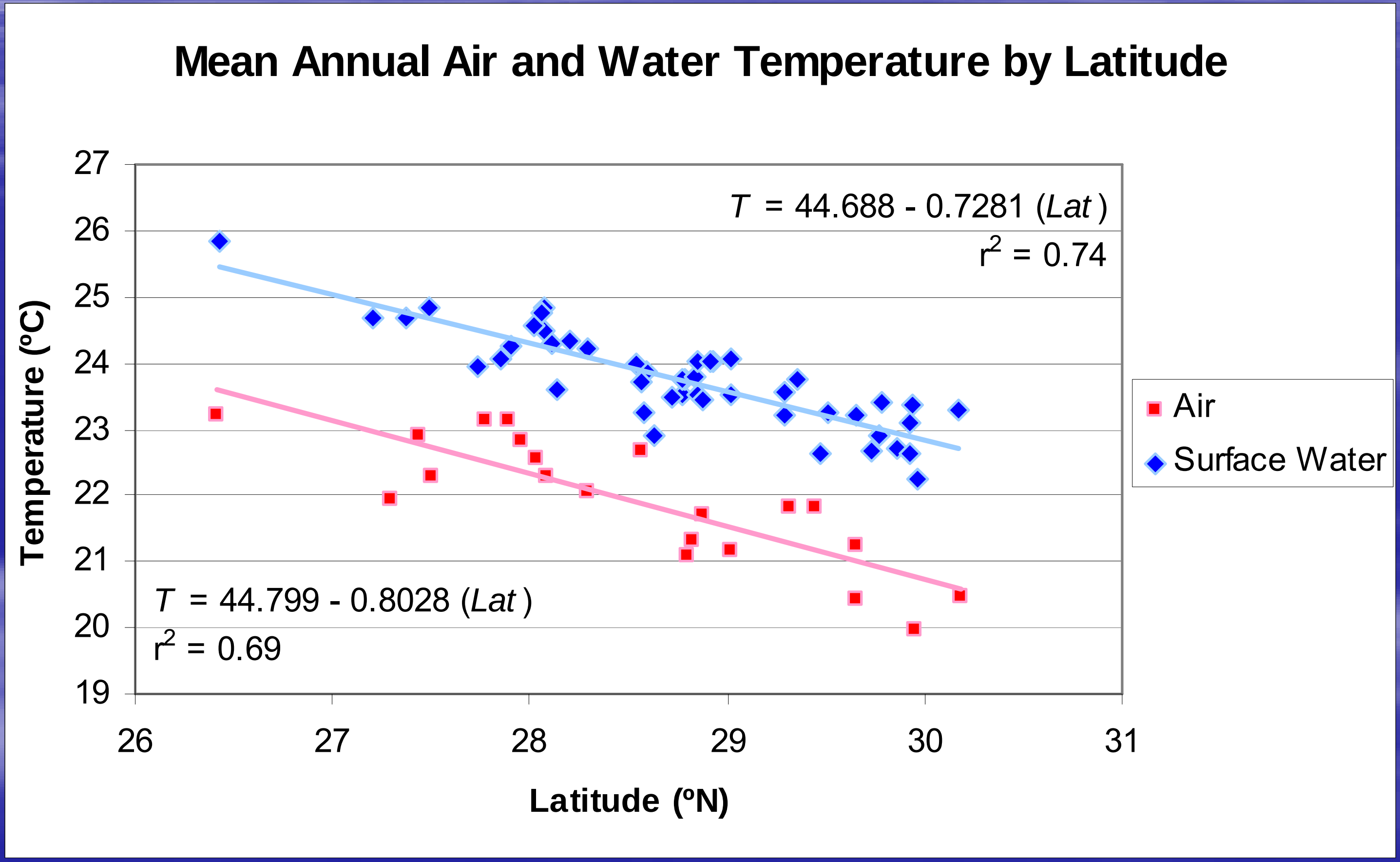
- Known reservoirs and highly astatic lakes were discarded
- 50 systems with the longest temperature records were selected to form the main database for analyses of thermal properties
- Subsets were selected for analyses for temporal change

Perry
Mayo
Lake City
Starke
St. Augustine
Cross City
Trenton
Gainesville
Palatka
Palm Coast
Fruitville
Ocala
Ormond Beach
Daytona Beach
De Land
Deltona
Inverness
Eustis
Leesburg
Sanford
Bushnell
Pine Hills
Orlando
Titusville
Brooksville
Spring Hill
UNITED STATES
Kissimmee
Merritt Island
Palm Harbor
F L O R I D A
Melbourne
Clearwater
Plant City
Lakeland
Palm Bay
Pinellas Park
Tampa
Bartow
St. Petersburg
Avon Park
Wauchula
Sebring
Bradenton
Fort Pierce
Port St. Lucie
Sarasota
Arcadia
Okeechobee
Venice
Port Charlotte
Lake Okeechobee
Cape Coral
Fort Myers
Belle Glade
Immokalee
A t l a
O c

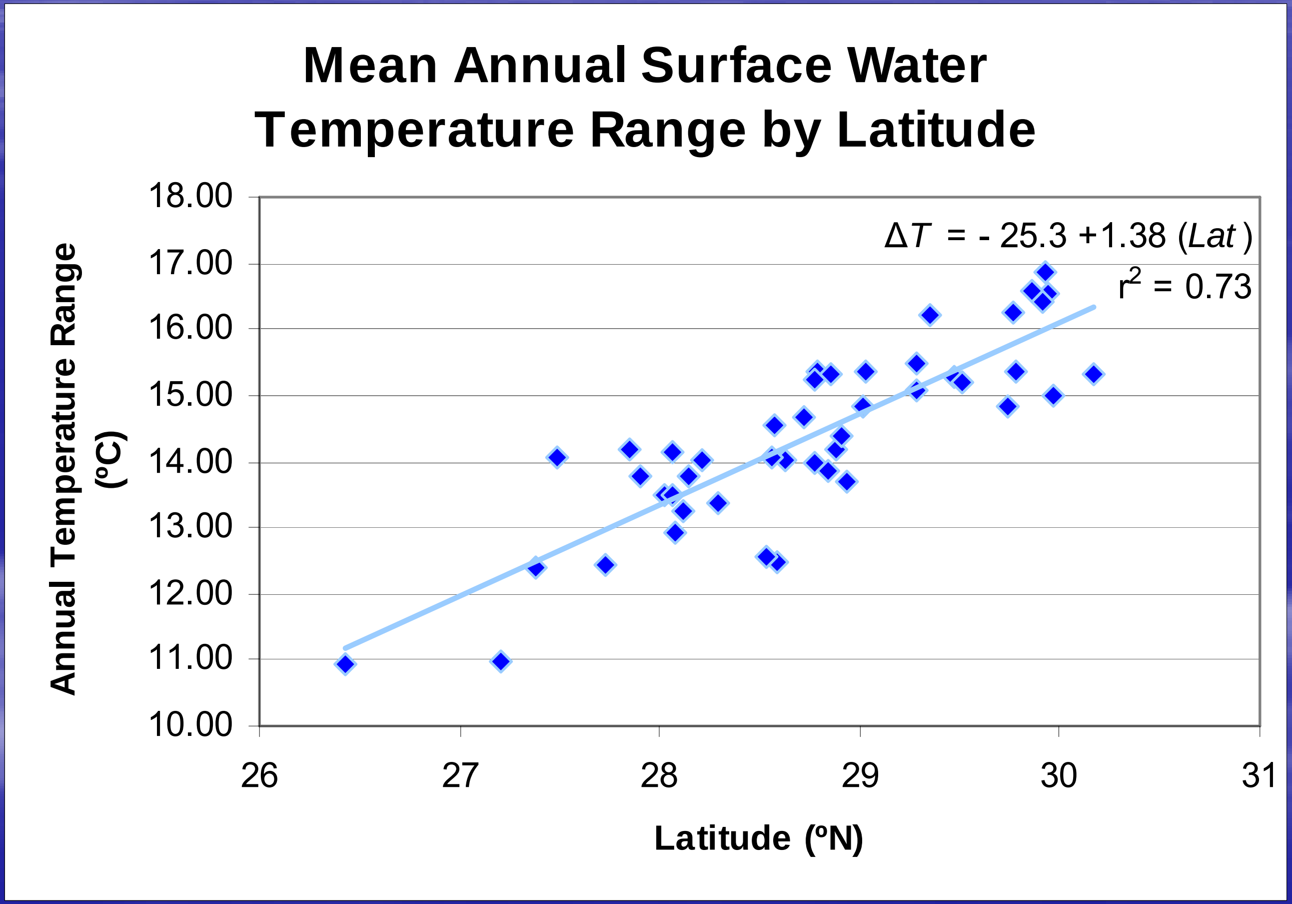
Analysis Approach

- Data Analysis
  - Latitude-Temperature relationships
    - Mean annual temperatures & mean annual temperature range
    - Lake vs. air temperature patterns
    - Simple and multiple regression analyses
  - Lake temperature trends
    - 10-year study interval means, contrasting periods of minimal (Jan-Feb) and maximal (Jul-Aug) surface water temperatures
    - Time series slope analysis
    - (Thermal regime boundary shifts: hierarchical cluster analyses)
- Interpretation of Results & Future Outlook

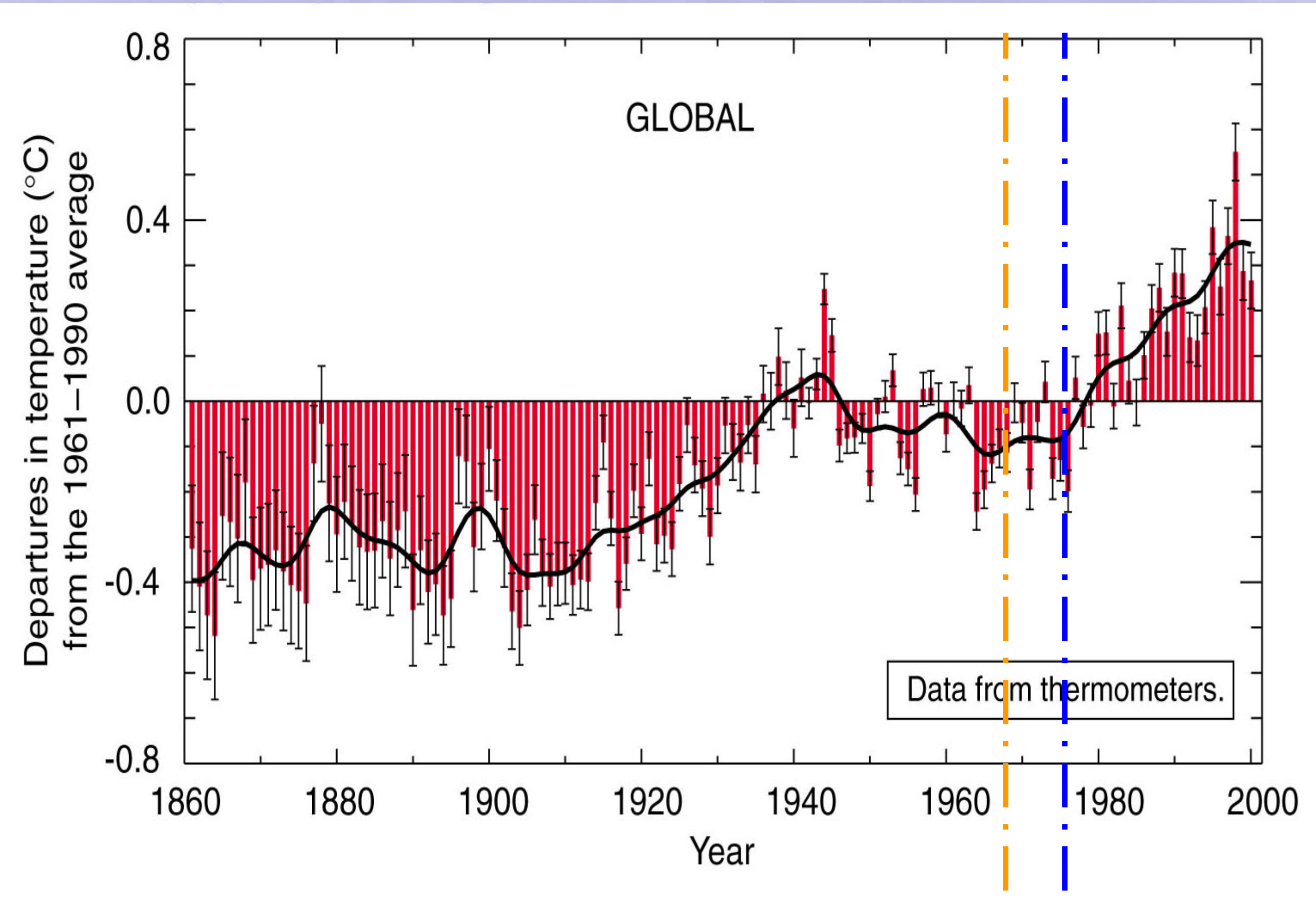
Latitude-Temperature Relationships



Latitude-Temperature Relationships



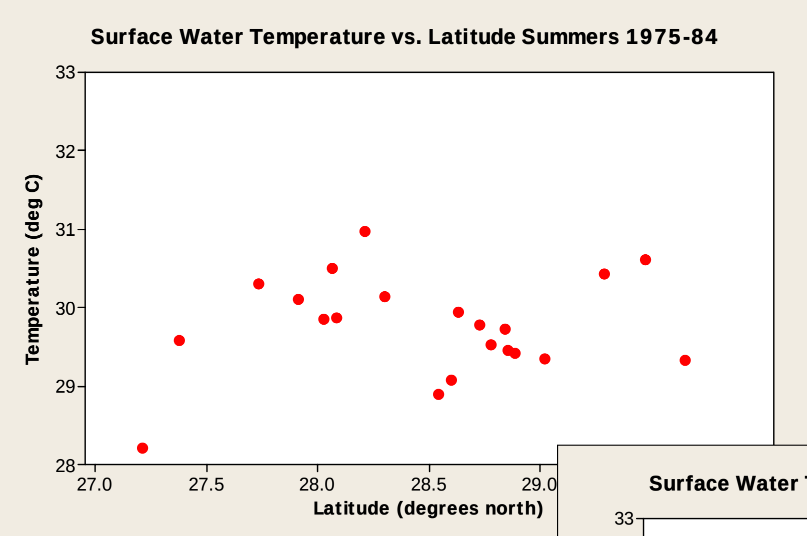
20th Century Warming

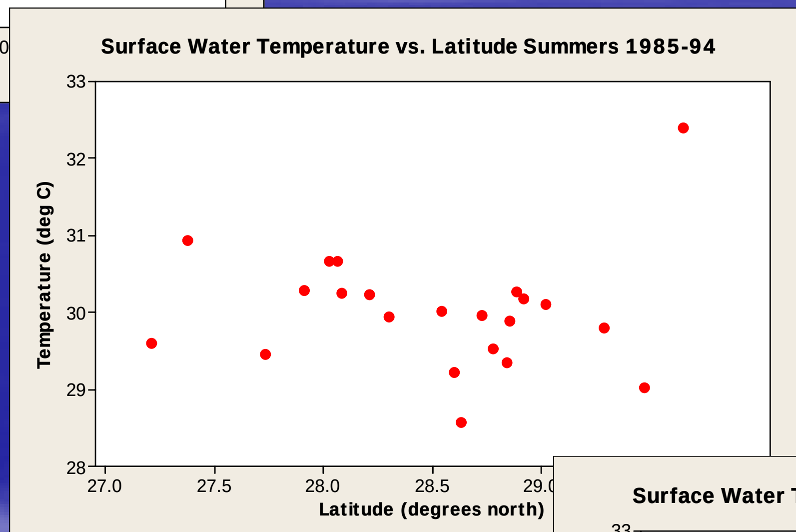


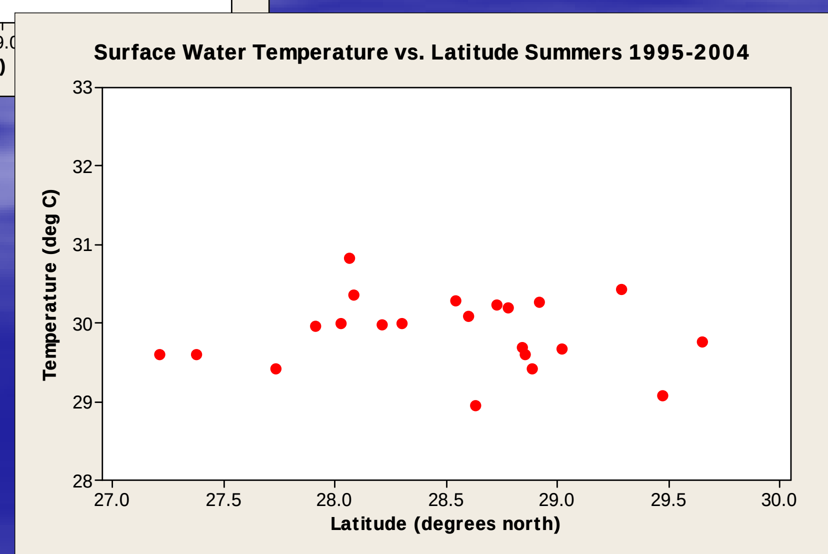
IPCC 2001

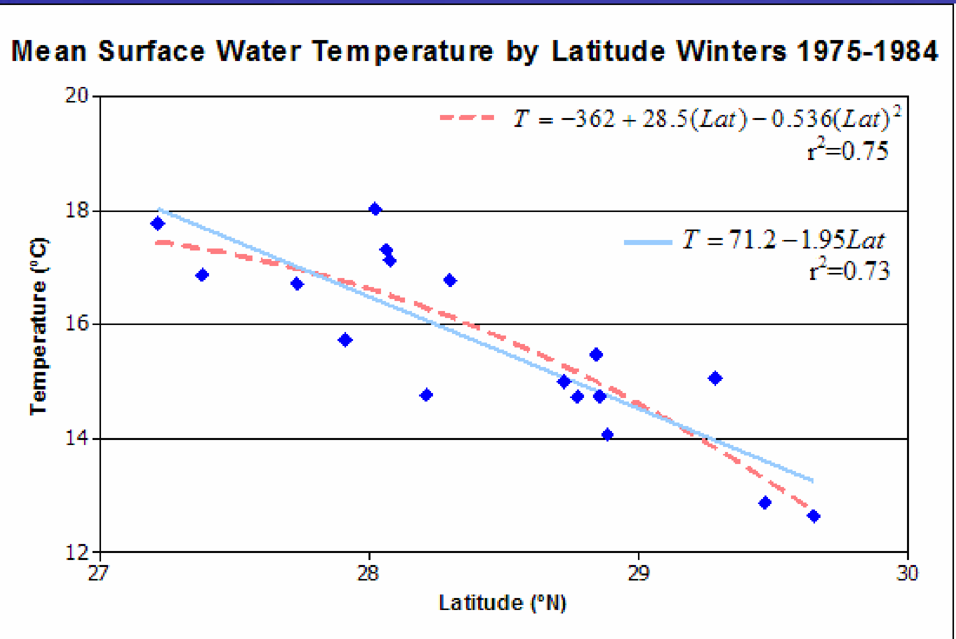
Earliest available data (1968)

Begin of 10-year study intervals (1975)

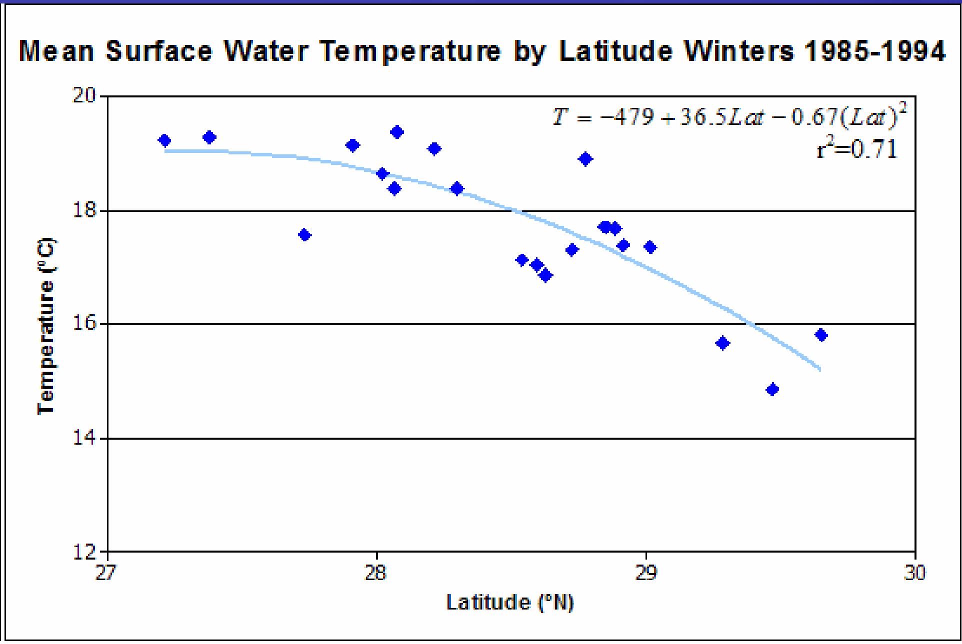

Surface Water Temperature vs. Latitude Summers 1975-84
Temperature (deg C)
28
29
30
31
32
33
27.0
27.5
28.0
28.5
29.0
Latitude (degrees north)


Surface Water Temperature vs. Latitude Summers 1985-94
Temperature (deg C)
28
29
30
31
32
33
27.0
27.5
28.0
28.5
Latitude (degrees north)

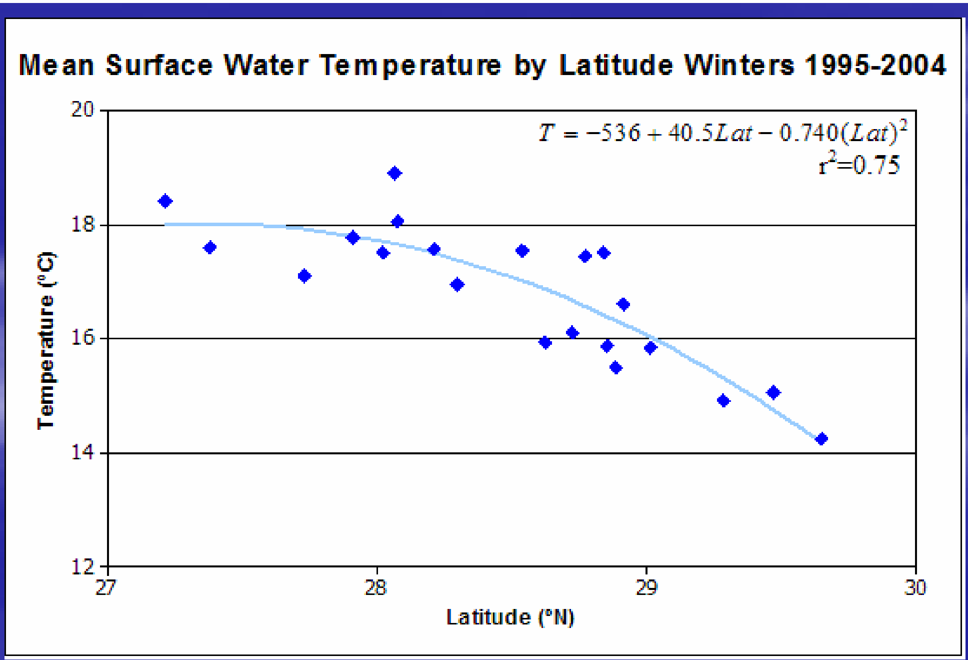

Surface Water Temperature vs. Latitude Summers 1995-2004
Temperature (deg C)
28
29
30
31
32
33
27.0
27.5
28.0
28.5
29.0
29.5
30.0
Latitude (degrees north)



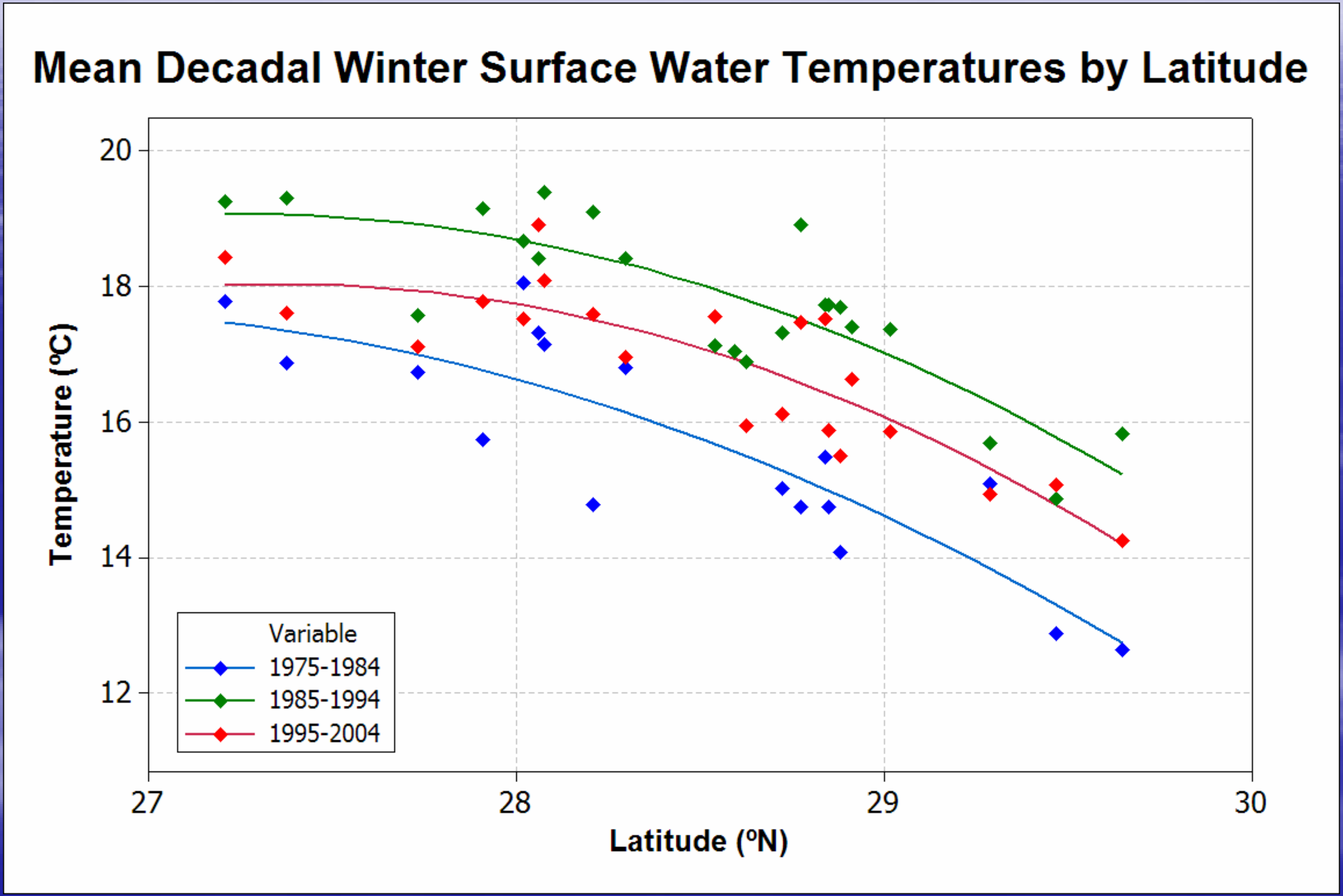
Mean Surface Water Temperature by Latitude Winters 1975-1984
$T = -362 + 28.5(Lat) - 0.536(Lat)^2$
$r^2=0.75$
$T = 71.2 - 1.95Lat$
$r^2=0.73$
Temperature (°C)
Latitude (°N)
20
18
16
14
12
27
28
29
30

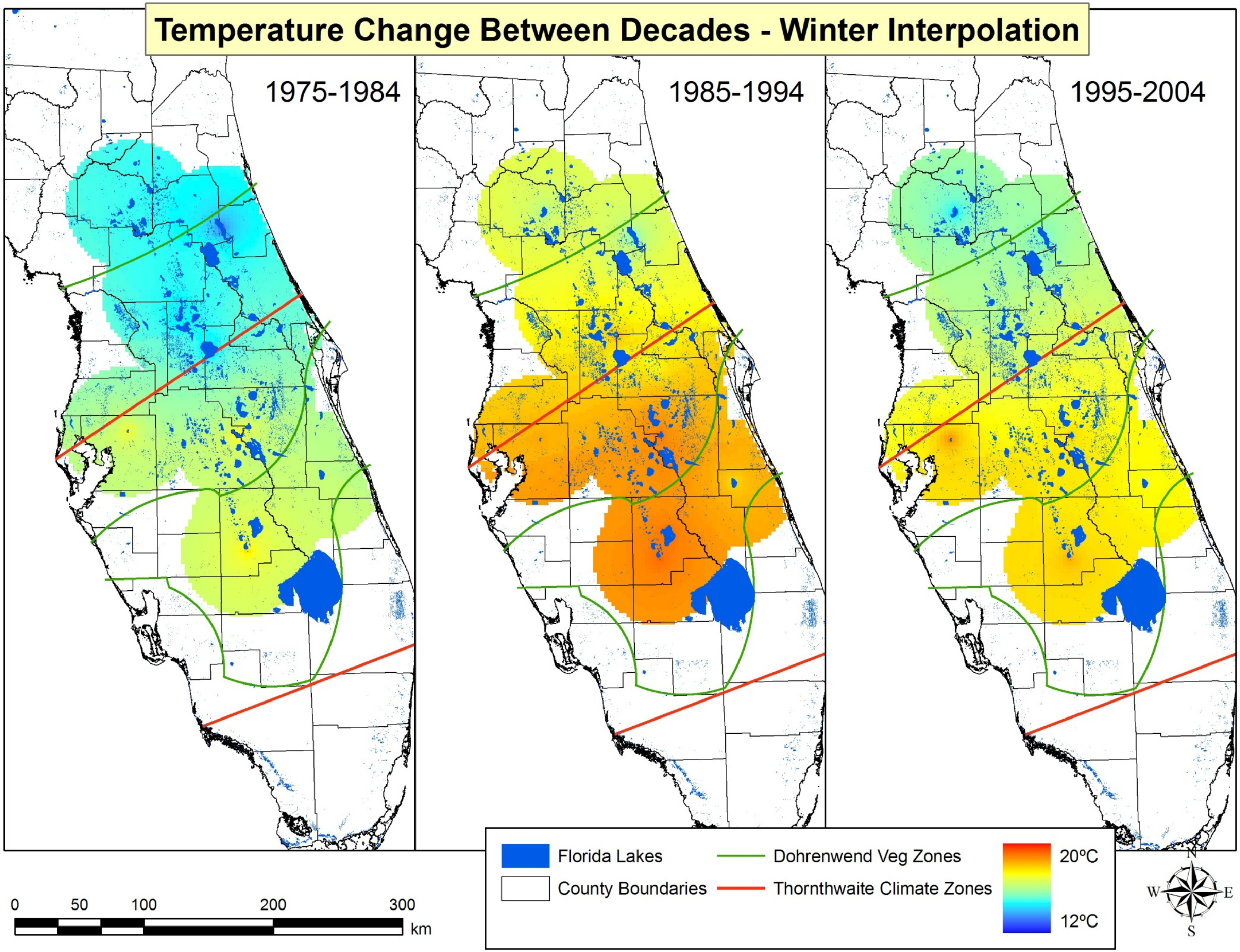


Mean Surface Water Temperature by Latitude Winters 1985-1994
$T = -479 + 36.5Lat - 0.67(Lat)^2$
$r^2=0.71$
Temperature (°C)
Latitude (°N)
20
18
16
14
12
27
28
29
30

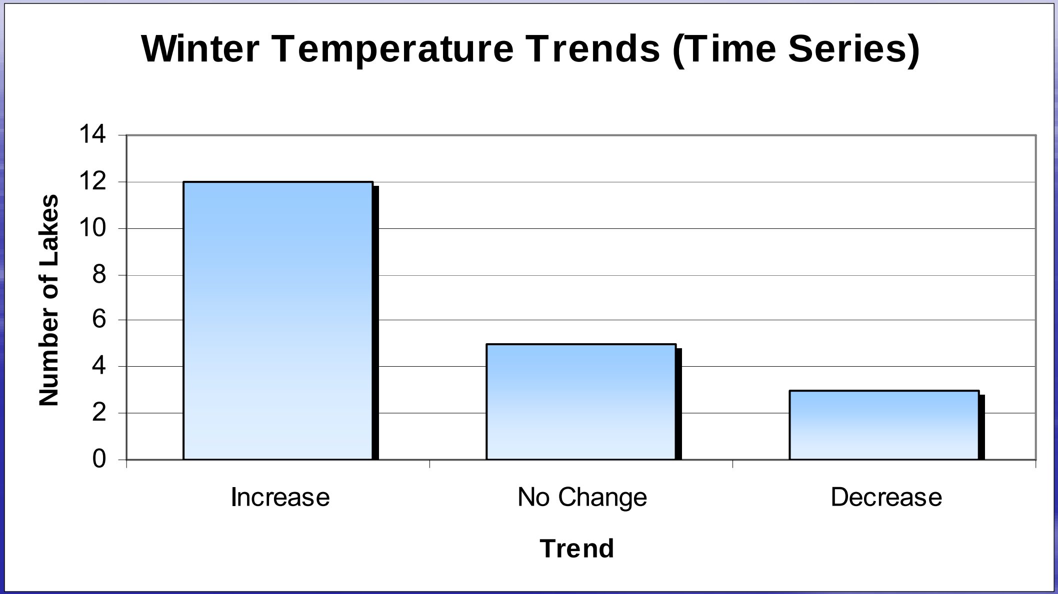


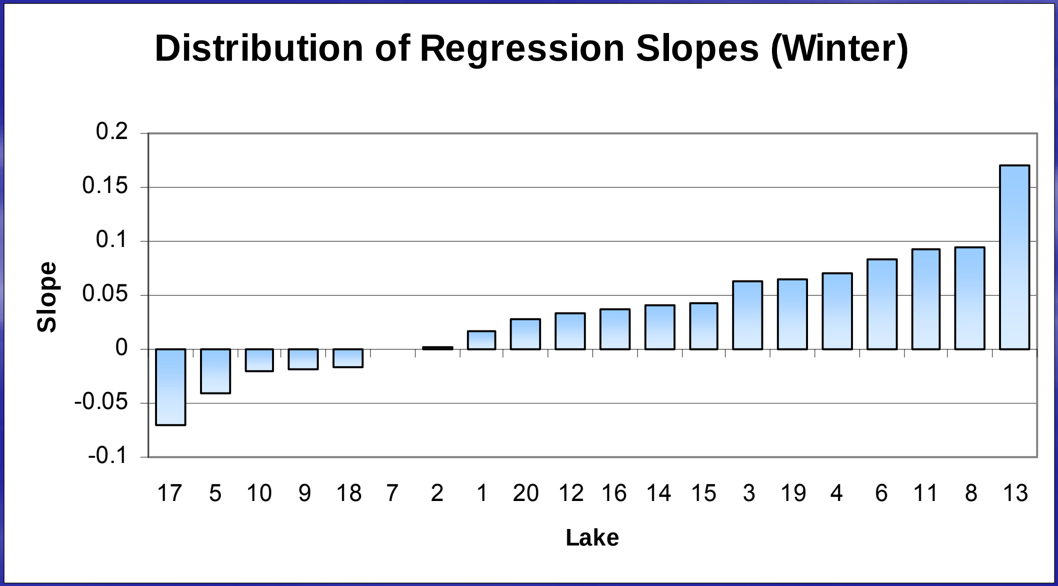
Mean Surface Water Temperature by Latitude Winters 1995-2004
$T = -536 + 40.5Lat - 0.740(Lat)^2$
$r^2=0.75$
Temperature (°C)
Latitude (°N)
20
18
16
14
12
27
28
29
30


Mean Decadal Winter Surface Water Temperatures by Latitude
Temperature (ºC)
20
18
16
14
12
27
28
29
30
Latitude (ºN)
Variable
1975-1984
1985-1994
1995-2004

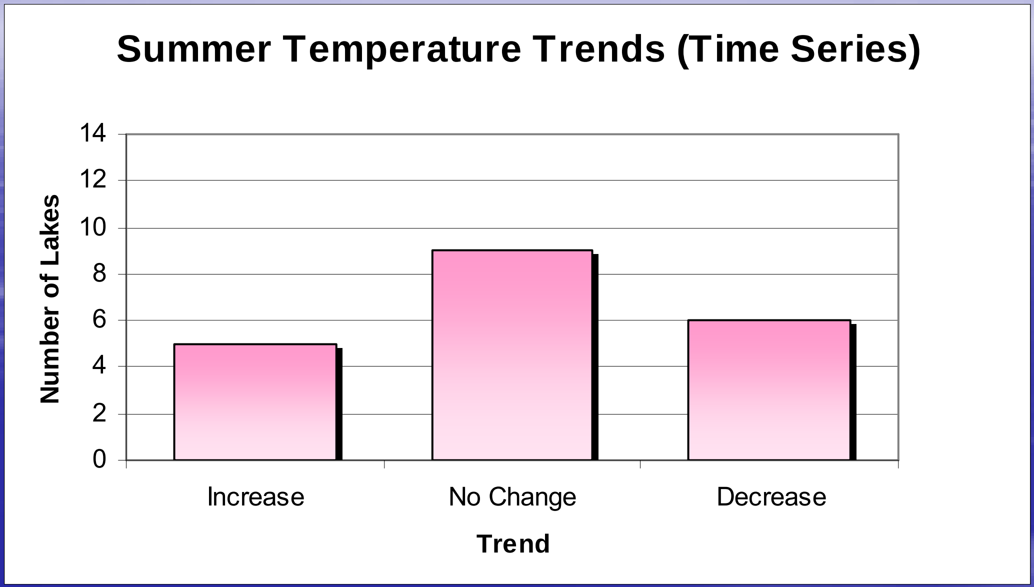

Temperature Change Between Decades - Winter Interpolation
1975-1984
1985-1994
1995-2004
Florida Lakes
County Boundaries
Dohrenwend Veg Zones
Thornthwaite Climate Zones
20ºC
12ºC
0
50
100
200
300
km
N
W
E
S

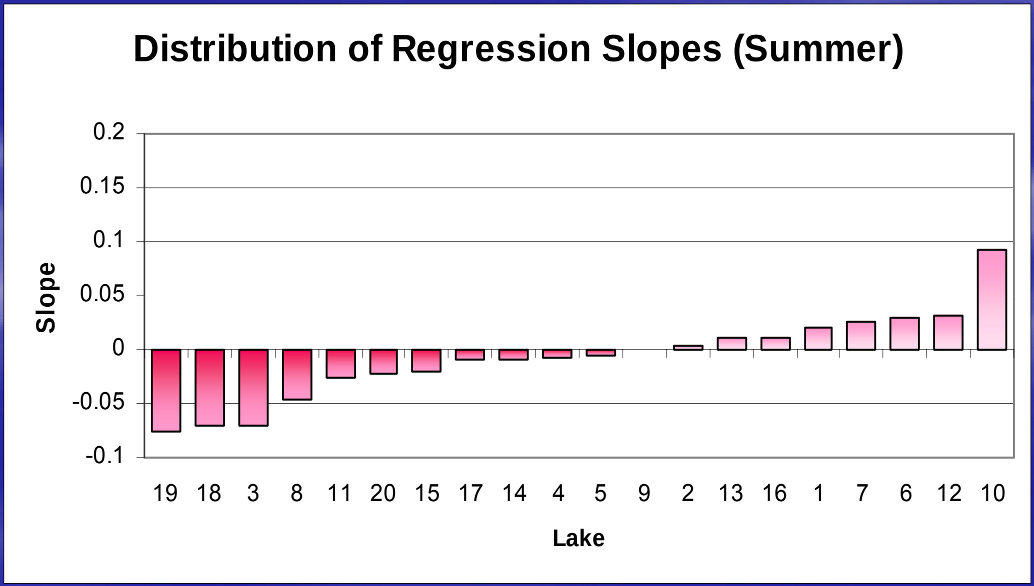
Time Series - Winter





Time Series - Summer





Temperature Trends Summary

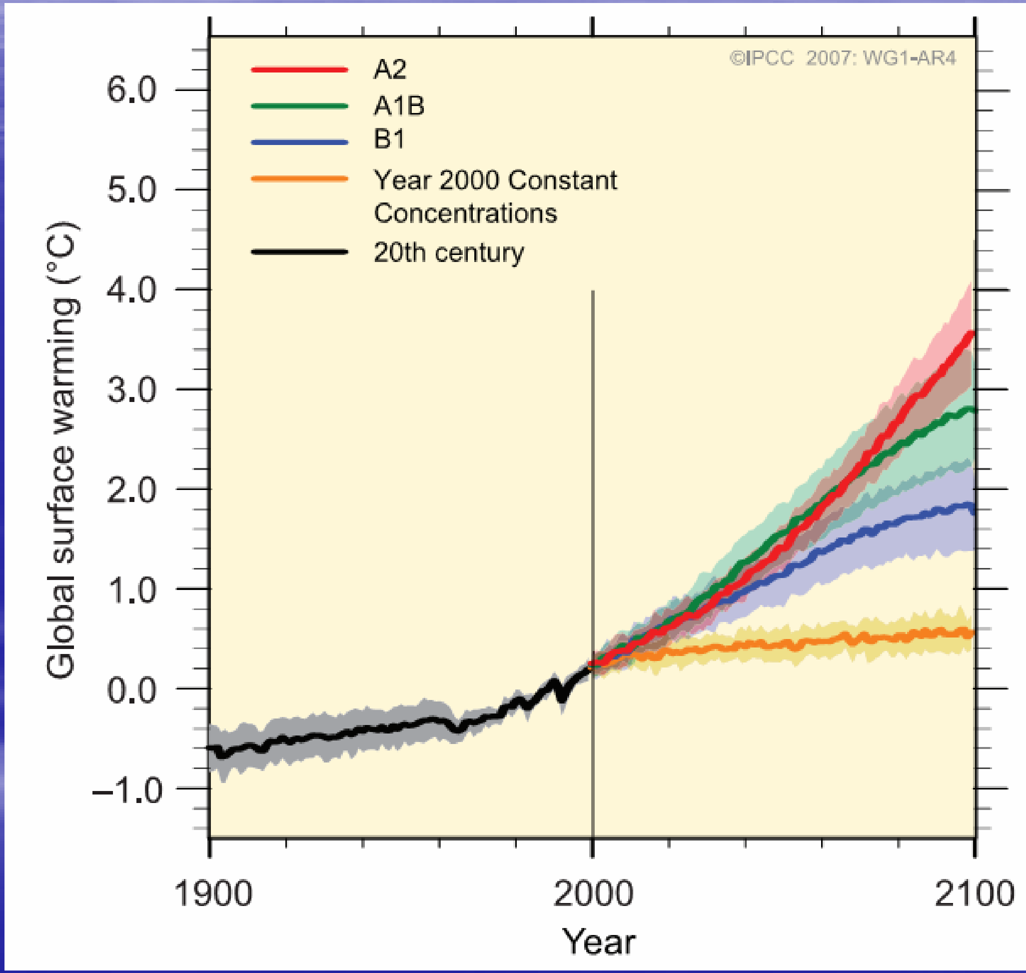
- Winter:
  - Analysis based on time series linear regression slopes suggest a statistically significant ($P<0.01$) water temperature increase of ca. 1.0±0.9°C based on a mean sampling period of 29.15 years.
  - All lakes subjected to the analysis showed a tendency to "mean-revert" during the most recent study interval. This is reflected in slower rates of warming or cooling compared to the previous decade
- Summer:
  - No statistically significant temperature change ($P>0.7$) over a mean sampling period of 26.7 years
  - Unlike winter, no consistent decadal patterns could be identified.

Ecological Implications (to date)

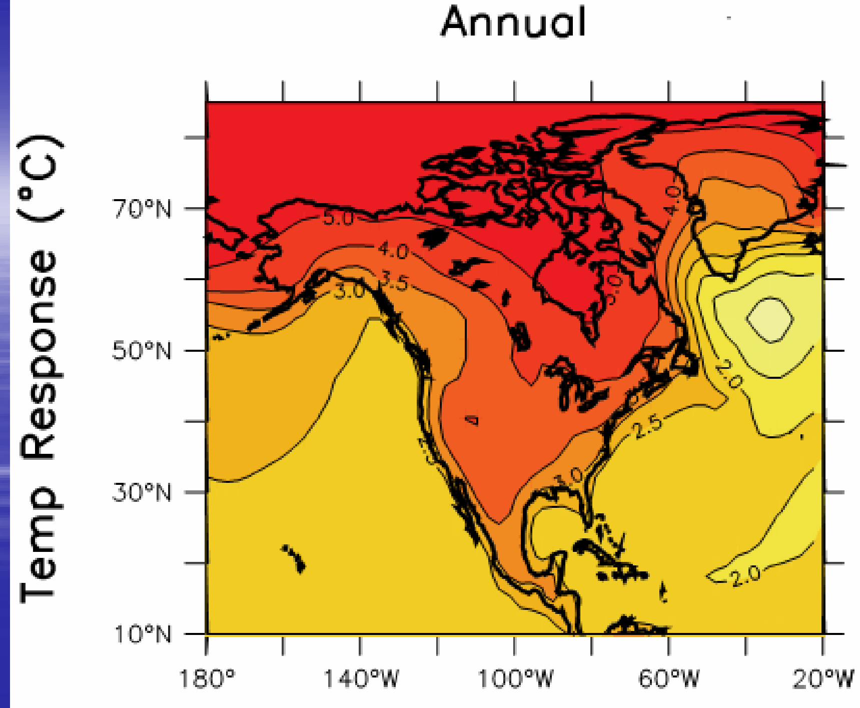
- Thermal tolerance limits
  - no apparent change for warm temperate species
  - warmer winters may have facilitated northward expansion of (sub)tropical species
- Dynamic ecological succession processes along the subtropical-transitional boundary and in the transitional zone
- Novel species interactions resulting in increased competition, ecosystem structure changes
- However, global warming effects on Florida ecosystems have been subtle and are secondary to more acute stresses (e.g. land cover modification)

Future Scenarios

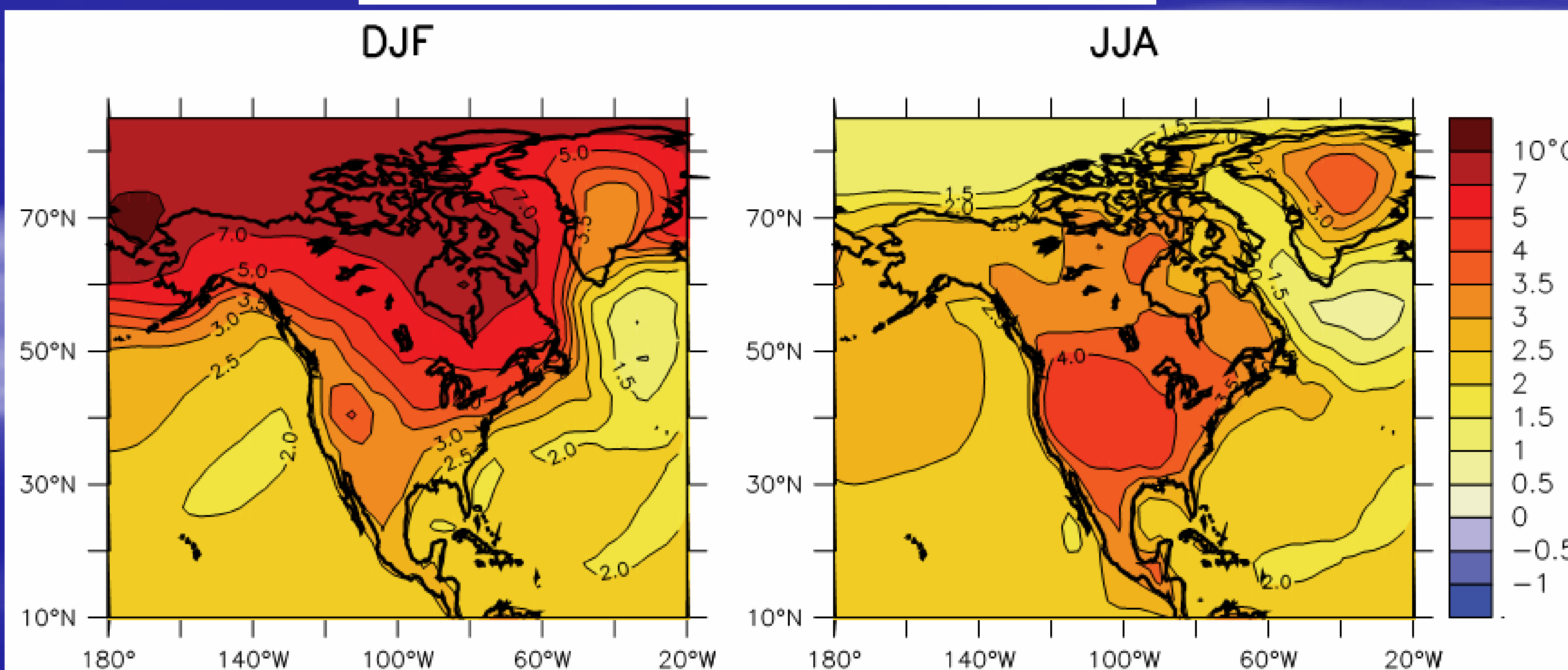
- IPCC WG1 FAR projects mean global temperatures will increase by 1.8-4.0ºC by 2100



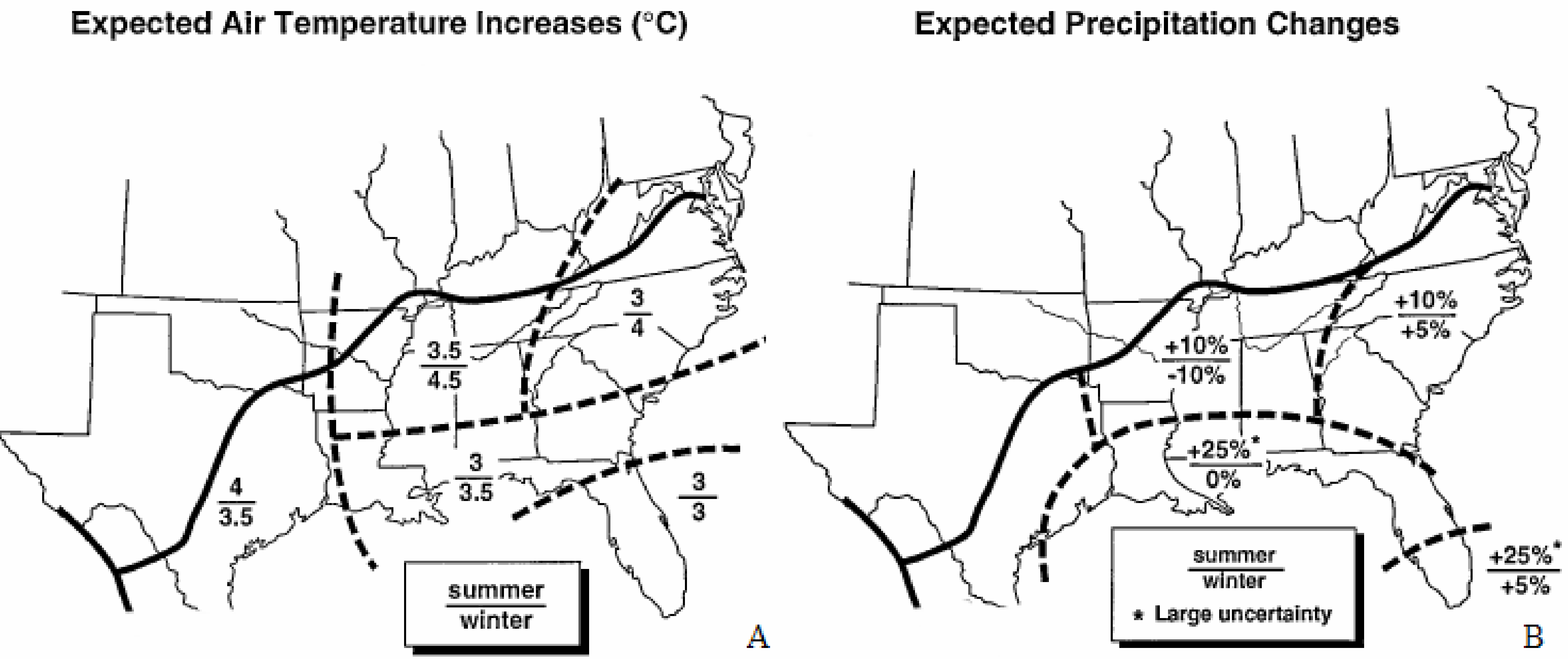
IPCC 2007


Annual
Temp Response (°C)
70°N
50°N
30°N
10°N
180°
140°W
100°W
60°W
20°W

IPCC 2007


DJF
JJA
70°N
50°N
30°N
10°N
180°
140°W
100°W
60°W
20°W
10°C
7
5
4
3.5
3
2.5
2
1.5
1
0.5
0
−0.5
−1

Regional Scale Cont'd



2x CO_2

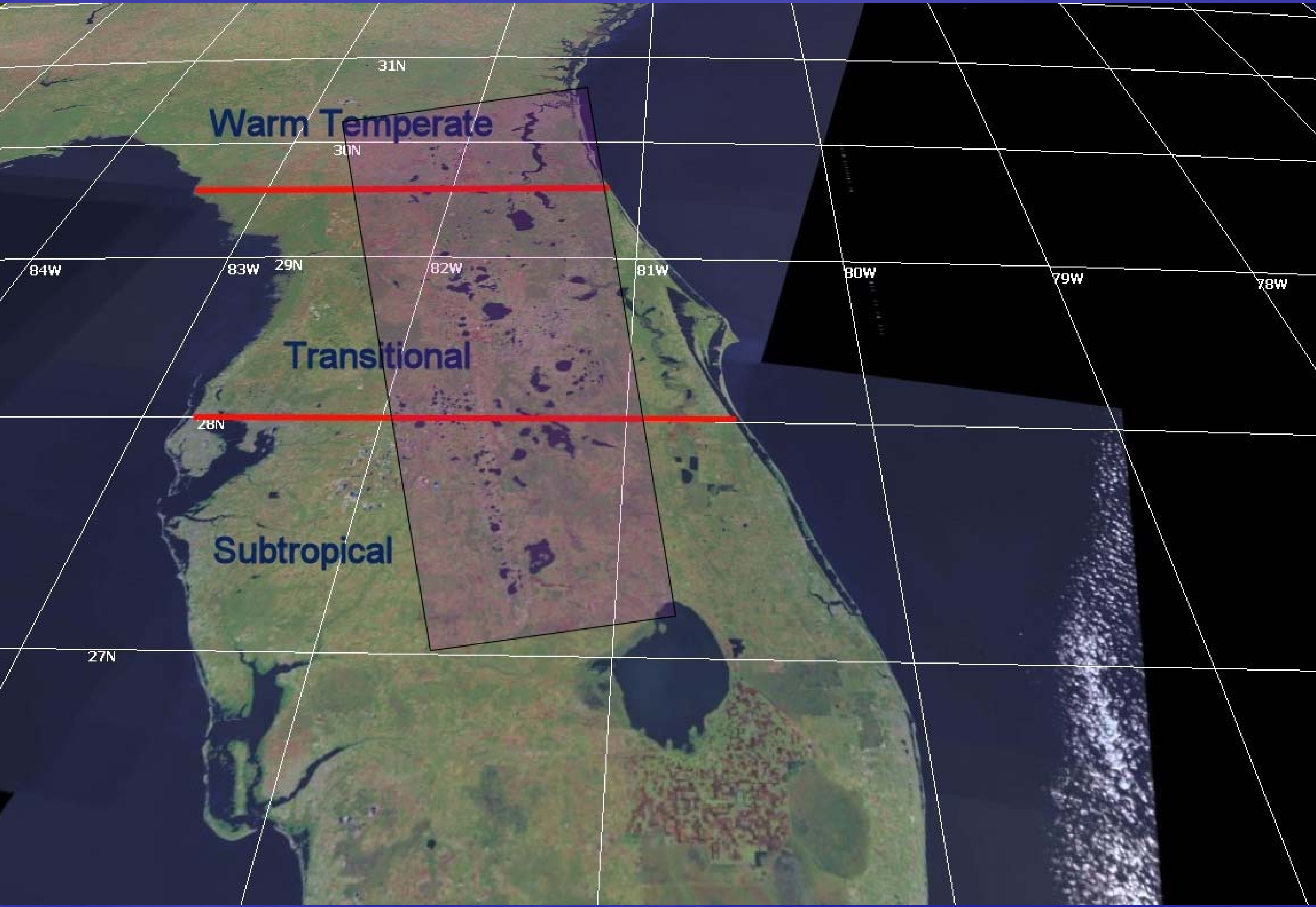
Mulholland et al. (1997) SE-US RCM predicts:

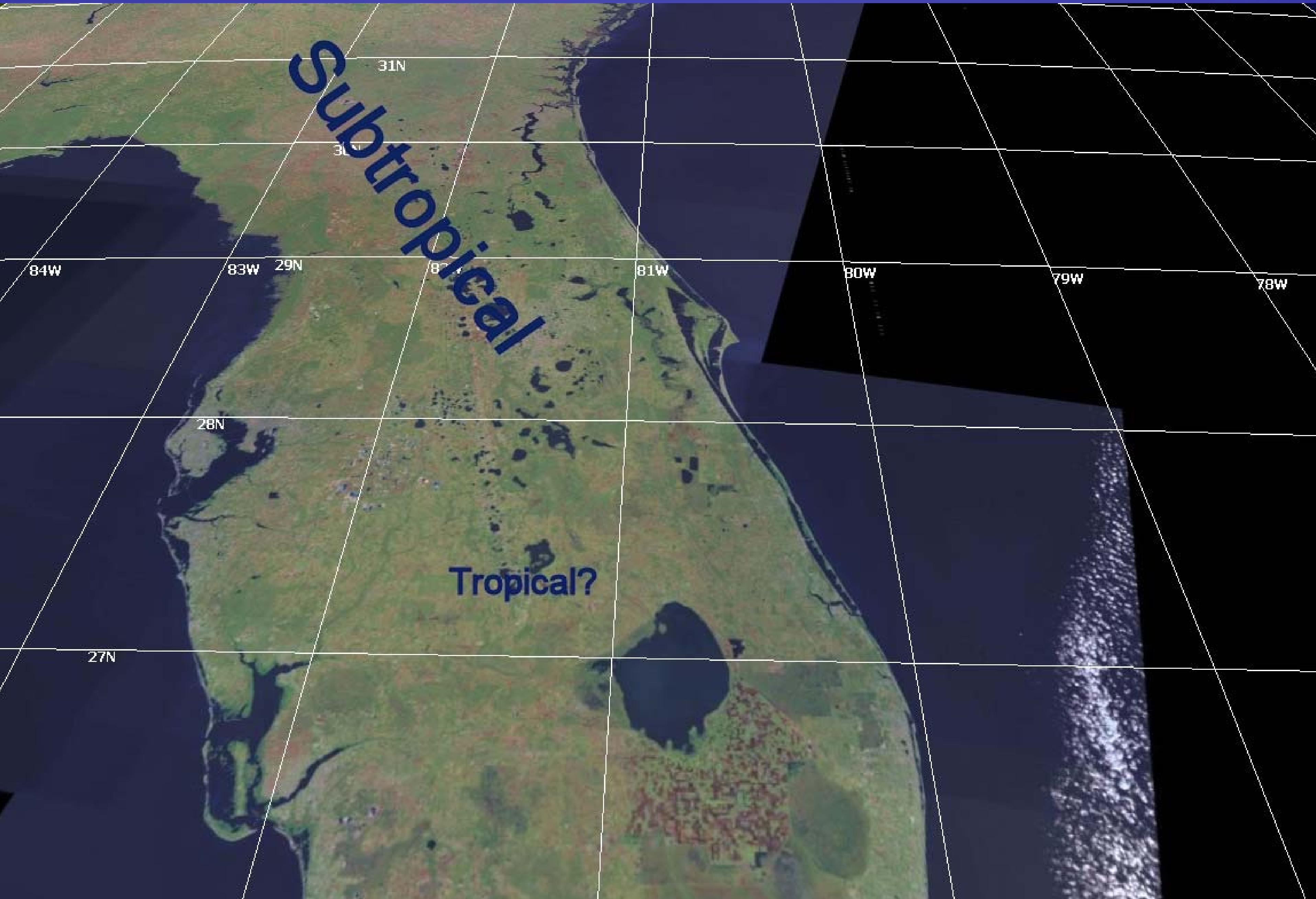
- 3ºC increase for 2x CO_2 (ca. 2050-2100)
- +25% summer precipitation
- +5% winter precipitation

Mulholland et al. 1997

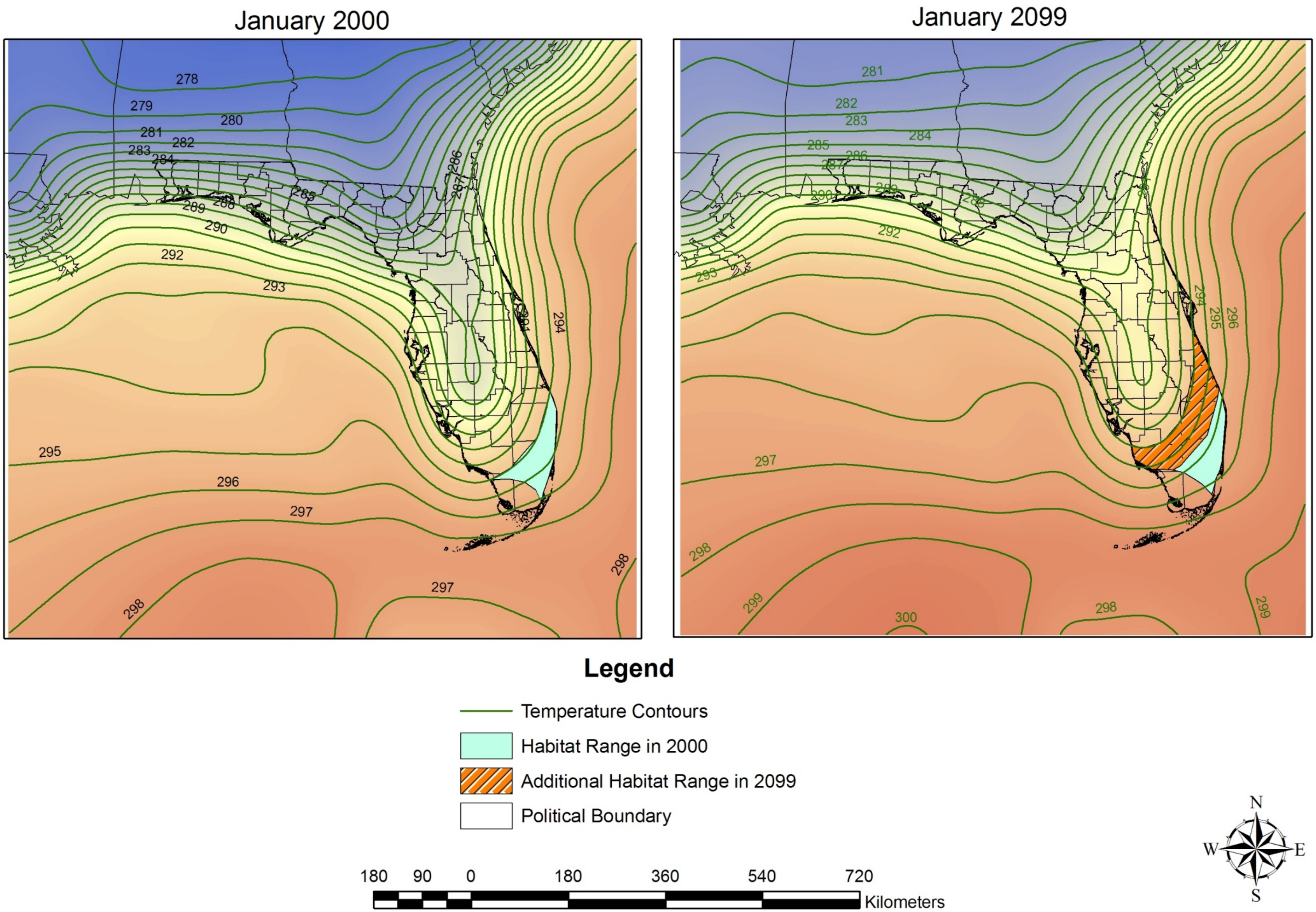
Future Impacts

- 3ºC of warming is estimated to shift isothermal lines northward by up to 450 km in Florida vs. global mean = 300-400 km (Hughes 2000)
- Loss of warm temperate and transitional life zones and lake thermal zones, possible establishment of tropical zone in southern Florida
- Non-synchronous northward expansion of cold-limited subtropical/tropical species
- Loss of habitat for warm temperate species
  - Increased competition from subtropical invasive species
  - exceeding of thermal tolerance limits


31N
Warm Temperate
30N
84W
83W
29N
82W
81W
80W
79W
78W
Transitional
28N
Subtropical
27N


Subtropical
Tropical?
31N
29N
28N
27N
84W
83W
81W
80W
79W
78W

Potential Habitat Expansion for a Hypothetical Cold-Limited Species under SRES Scenario A1B

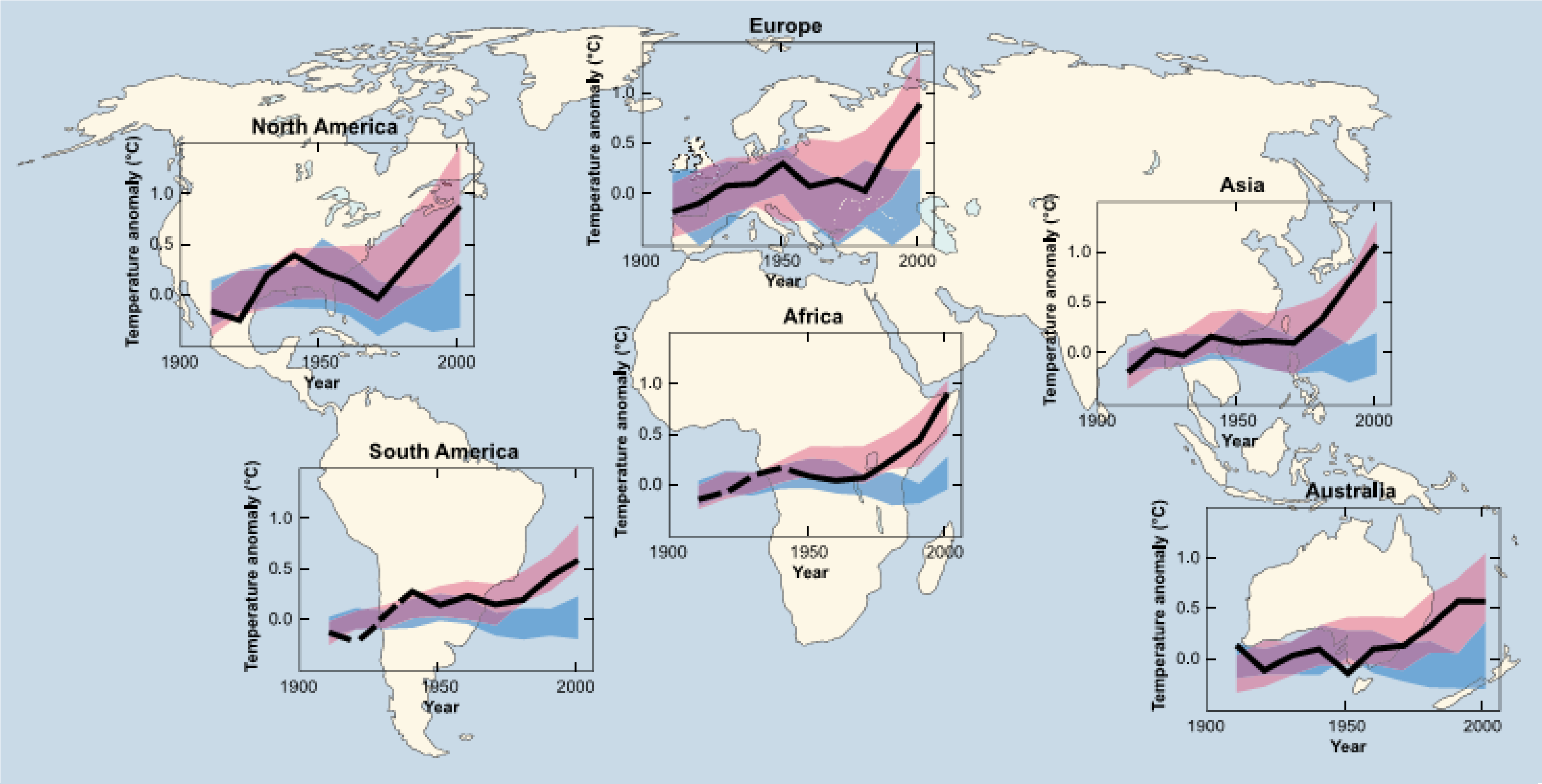


Future Impacts

- Accelerating changes to ecosystem structure
  - Likely dominance of generalists capable of rapid dispersal vs. sedentary specialists
  - Induction of microevolutionary adaptations, particularly in organisms with short generation times
  - Alteration of ecosystem functions, including provision of goods and services
- Lakes
  - Potentially increased primary productivity
  - Reduced dissolved oxygen storage capacity
  - Greater POC, DOC inputs to lakes
  - Reduction in duration of winter mixis in stratified lakes
    - increased potential for hypolimnetic oxygen stress
    - shorter, more intense periods of nutrient cycling

Questions/Comments

Global and Continental Temperature Change



models using only natural forcings

models using both natural and anthropogenic forcings

observations

Figure TS.22. *Comparison of observed continental- and global-scale changes in surface temperature with results simulated by climate models using natural and anthropogenic forcings. Decadal averages of observations are shown for the period 1906 to 2005 (black line) plotted against the centre of the decade and relative to the corresponding average for 1901 to 1950. Lines are dashed where spatial coverage is less than 50%. Blue shaded bands show the 5% to 95% range for 19 simulations from 5 climate models using only the natural forcings due to solar activity and volcanoes. Red shaded bands show the 5% to 95% range for 58 simulations from 14 climate models using both natural and anthropogenic forcings. Data sources and models used are described in Section 9.4, FAQ 9.2, Table 8.1 and the supplementary information for Chapter 9. {FAQ 9.2, Figure 1}*