An Assessment of Actual and Potential Building Climate Zone Change and Variability From the Last 30 Years Through 2100 Using NASA's MERRA and CMIP5 Simulations

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Purpose and Importance of Building Climate Zones

- In the US, residential and commercial building infrastructure combined consumes about 40% of total energy usage and emits about 39% of total CO_2 emission (DOE/EIA "Annual Energy Outlook 2013"). Thus, increasing the energy efficiency of buildings is paramount to reducing energy costs and emissions.

- Building codes, as used by local and state enforcement entities are typically tied to the dominant climate within an enforcement jurisdiction, where the dominant climate is based upon a 30-year average of local to regional surface observations.

- Guidelines for these codes, applied to residential and commercial buildings, are developed by Department of Energy (DOE) and ASHRAE (formerly known as the American Society of Hearting, Refrigeration and Air-Conditioning Engineers).

- Based upon surface observations ASHRAE, in partnership with the Department of Energy, have developed climate zone maps for which building codes are developed.

Purpose and Objectives

- A significant shortcoming of the methodology used in constructing such maps is the use of surface observations that
  - may be far removed from or not representative of the construction site of interest (particularly outside the US and Europe)
  - may frequently have periods of missing data that need to be filled by various approximation schemes
  - may be difficult to update, lacking information about variability
- Assimilation data products, such as the Modern-Era Retrospective analysis for Research and Applications (MERRA), provide regular long-term estimates of near-surface conditions including variability.
- This talk explores the value of the use of an atmospheric assimilation system to derive such climate maps.

Climate Zone Definitions

Heating Degree Days:

$$HDD = \sum (T_{base} - < T_i >)^+$$

T_{base} = 18°C (65°F)

Cooling Degree Days:

$$CDD = \sum (< T_i > - T_{base})^+$$

T_{base} = 10°C (50°F)

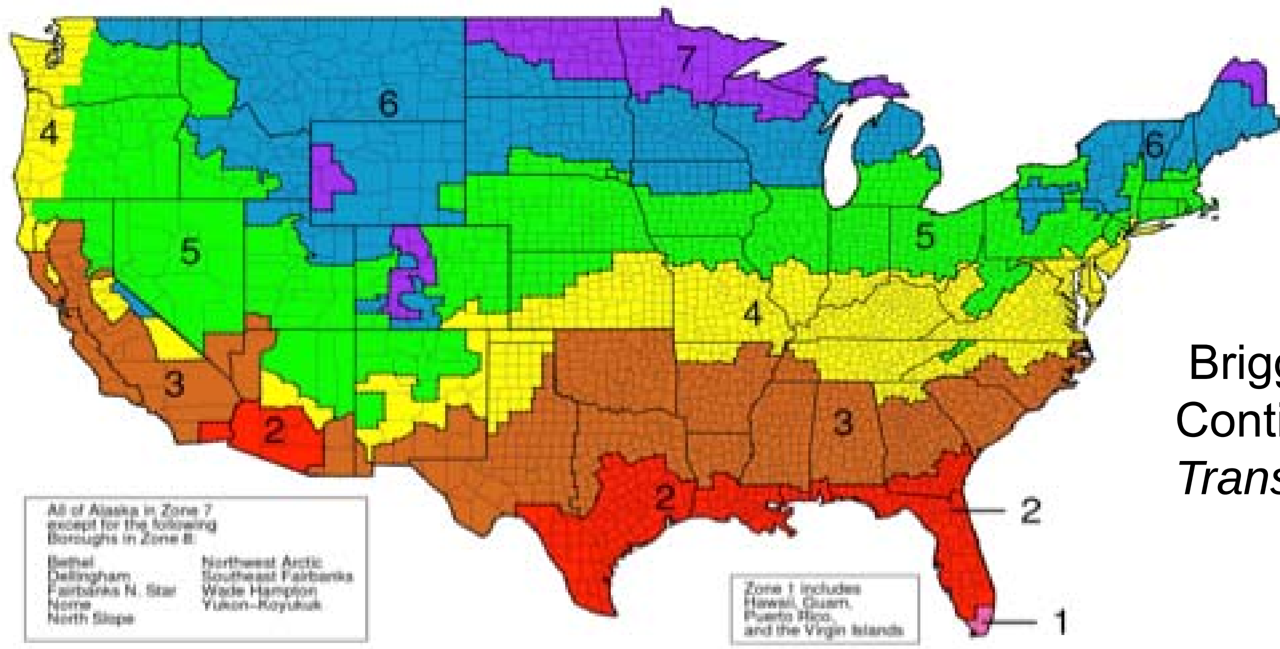
[+]Note that negative values are not included in sum

Table A-3 Climate Zone Definitions (taken from Proposed Addendum b to Standard 169, Climate Data for Building Design Standards).

Thermal Zone	Name	I-P Units	SI Units
0	Extremely Hot – Humid (0A), Dry (0B)	10,800 < CDD50ºF	6000 < CDD10ºC
1	Very Hot – Humid (1A), Dry (1B)	9000 < CDD50ºF ≤ 10,800	5000 < CDD10ºC ≤ 6000
2	Hot – Humid (2A), Dry (2B)	6300 < CDD50ºF ≤ 9000	3500 < CDD10ºC ≤ 5000
3A and 3B	Warm – Humid (3A), Dry (3B)	4500 < CDD50ºF ≤ 6300 AND HDD65ºF ≤ 3600	2500 < CDD10ºC < 3500 AND HDD18ºC ≤ 2000
3C	Warm – Marine (3C)	CDD50ºF ≤ 4500 AND HDD65ºF ≤ 3600	CDD10ºC ≤ 2500 AND HDD18ºC ≤ 2000
4A and 4B	Mixed – Humid (4A), Dry (4B)	2700 < CDD50ºF ≤ 6300 AND 3600 < HDD65ºF ≤ 5400	1500 < CDD10ºC < 3500 AND 2000 < HDD18ºC ≤ 3000
4C	Mixed – Marine	CDD50ºF ≤ 2700 AND 3600 < HDD65ºF ≤ 5400	CDD10ºC ≤ 1500 AND 2000 < HDD18ºC ≤ 3000
5A and 5B	Cool– Humid (5A), Dry (5B)	1800 < CDD50ºF ≤ 6300 AND 5400 < HDD65ºF ≤ 7200	1000 < CDD10ºC ≤ 3500 AND 3000 < HDD18ºC ≤ 4000
5C	Cool – Marine (5C)	CDD50ºF ≤ 1800 AND 5400 < HDD65ºF ≤ 7200	CDD10ºC ≤ 1000 AND 3000 < HDD18ºC ≤ 4000
6A and 6B	Cold – Humid (6A), Dry (6B)	7200 < HDD65ºF ≤ 9000	4000 < HDD18ºC ≤ 5000
7	Very Cold (7)	9000 < HDD65ºF ≤ 12600	5000 < HDD18ºC ≤ 7000
8	Subarctic/Arctic (8)	12600 < HDD65ºF	7000 < HDD18ºC

The criteria for dry and humid are similar but not identical to those enumerated in Table 2B above.

Current DOE/ASHRAE Climate Zones Map



Briggs et al., 2002 of the Continental US (*ASHRAE Transactions*)

Characteristics of Briggs buildings climate zones			
Zone #	**Climate Zone Name and Type**	**Zone #**	**Climate Zone Name and Type**
1A	Very Hot – Humid	4C	Mixed – Marine
1B	Very Hot – Dry	5A	Cool – Humid
2A	Hot – Humid	5B	Cool – Dry
2B	Hot – Dry	5C	Cool – Marine
3A	Warm – Humid	6A	Cold – Humid
3B	Warm – Dry	6B	Cold – Dry
3C	Warm – Marine	7	Very Cold
4A	Mixed – Humid	8	Subarctic
4B	Mixed – Dry		

Key Parameters:

- Heating/Cooling Degree days using Max/Min daily temperatures
- Annual precipitation

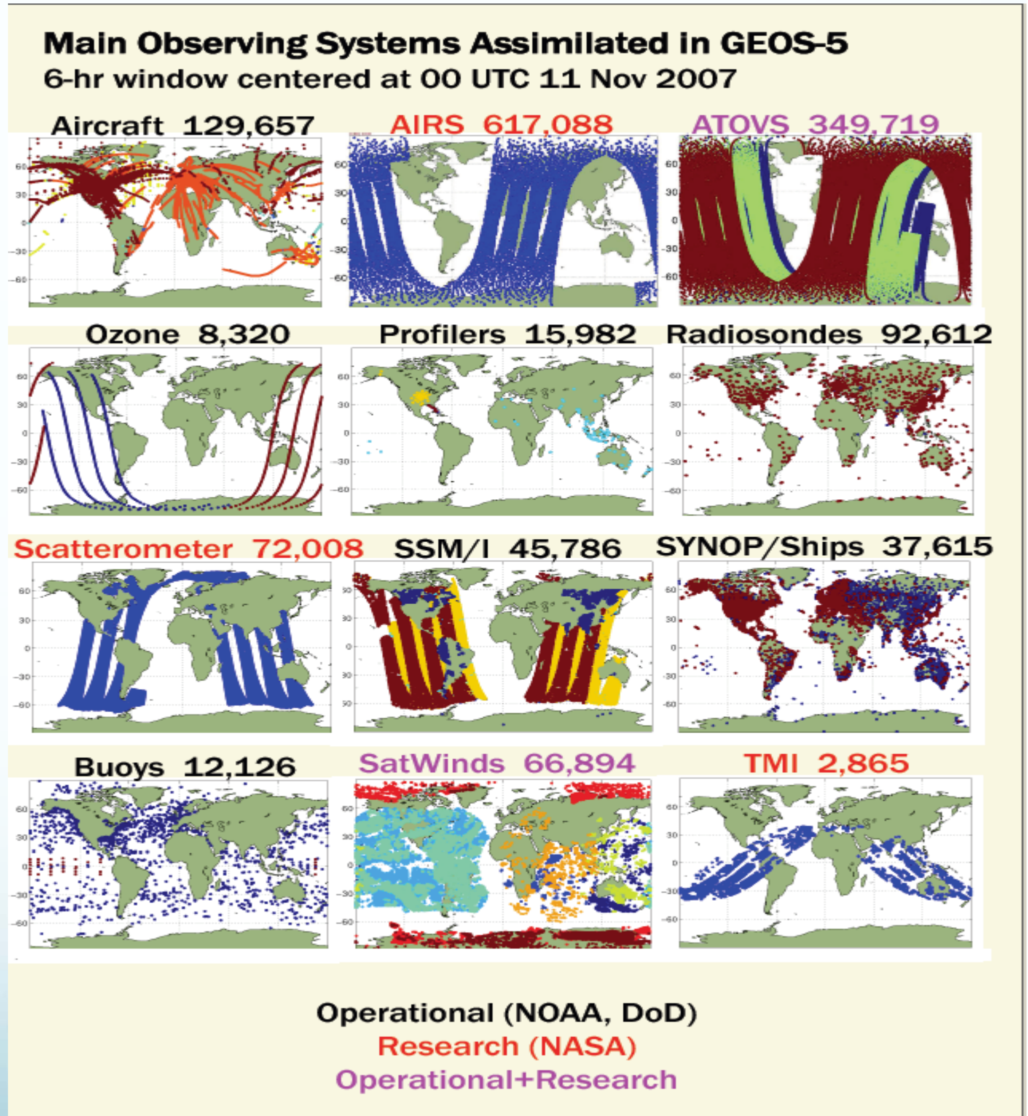
MERRA Overview

- MERRA was generated with version 5.2.0 of the Goddard Earth Observing System (GEOS) atmospheric model and a 3-D data variational assimilation system.

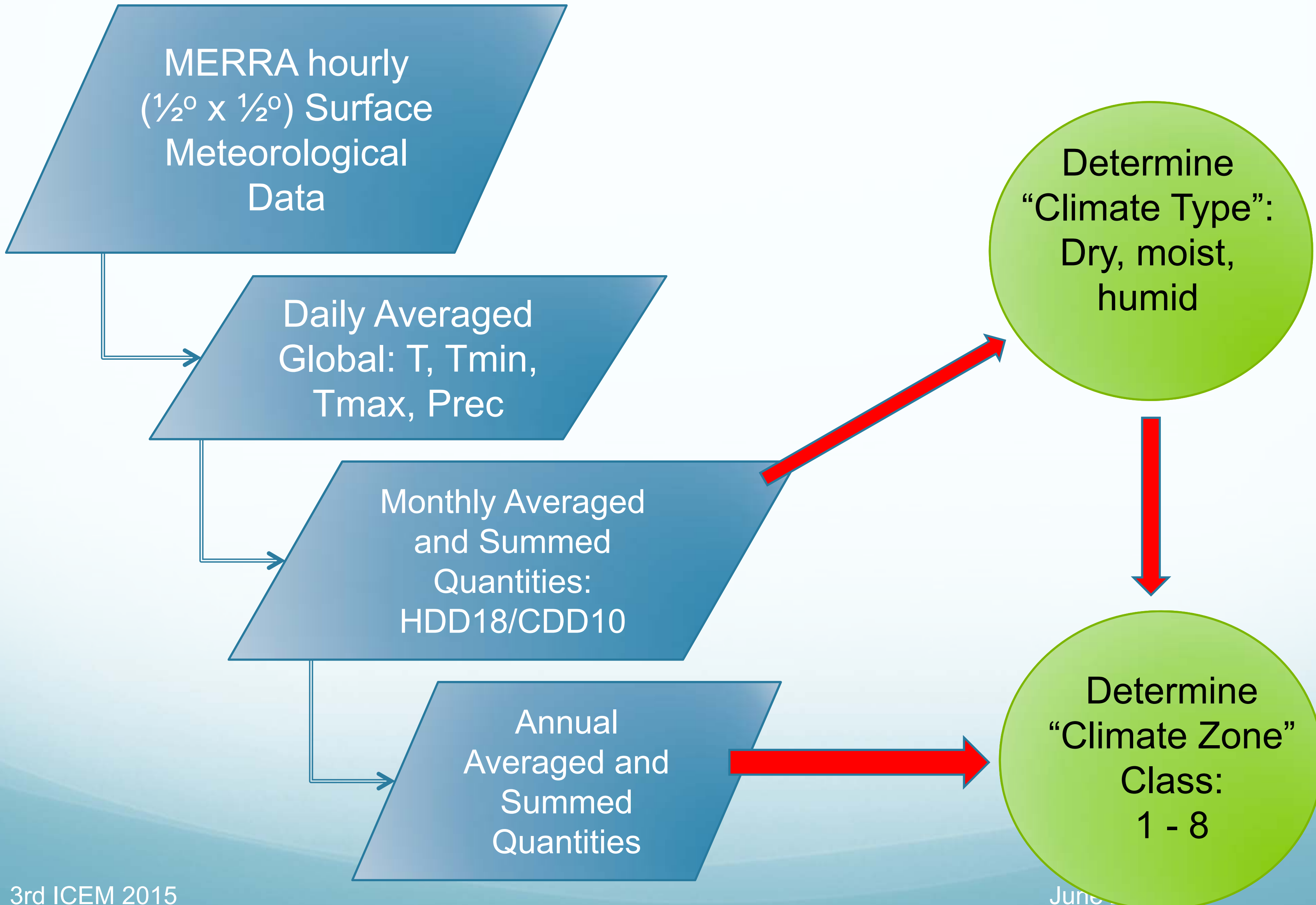
- MERRA assimilates satellite radiances and in situ measure-ments from a large set of sources.

- MERRA provides a complete suite of meteorological parameters at a 1/2^{o} latitude 2/3^{o} longitude with 72 vertical levels, from the surface to 0.01 hPa, spaning from 1979 to near-present

(Rienecker at al 2008, 2011 describe MERRA in detail)

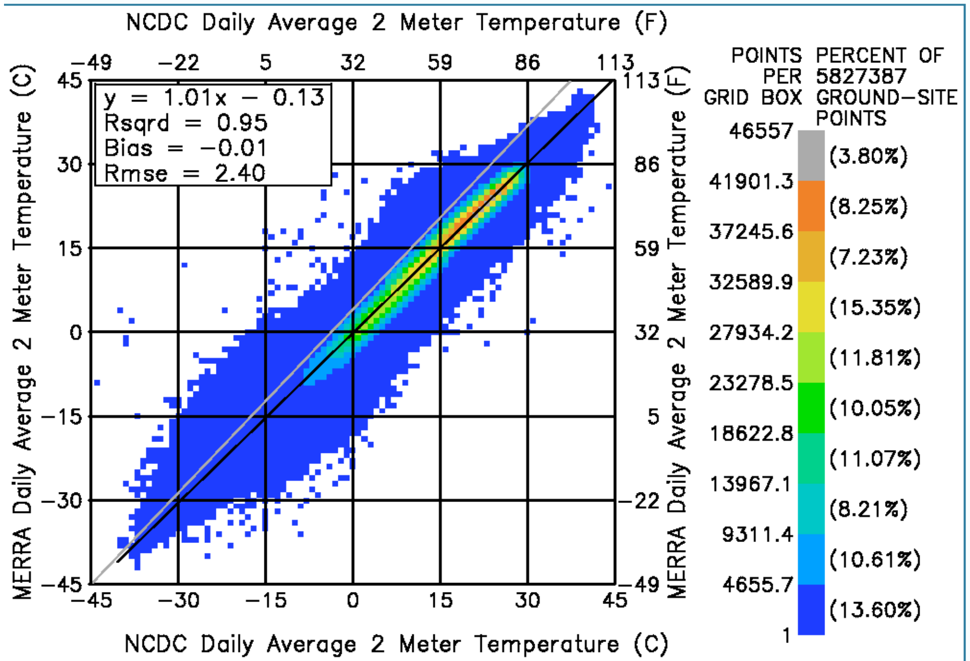


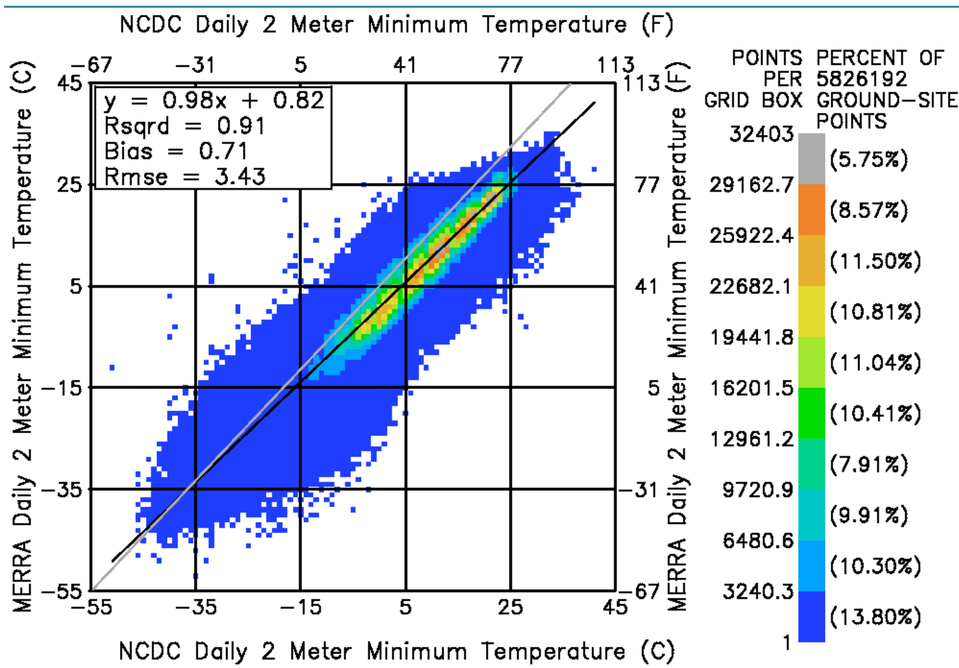
Deriving Building Climate Zones from MERRA

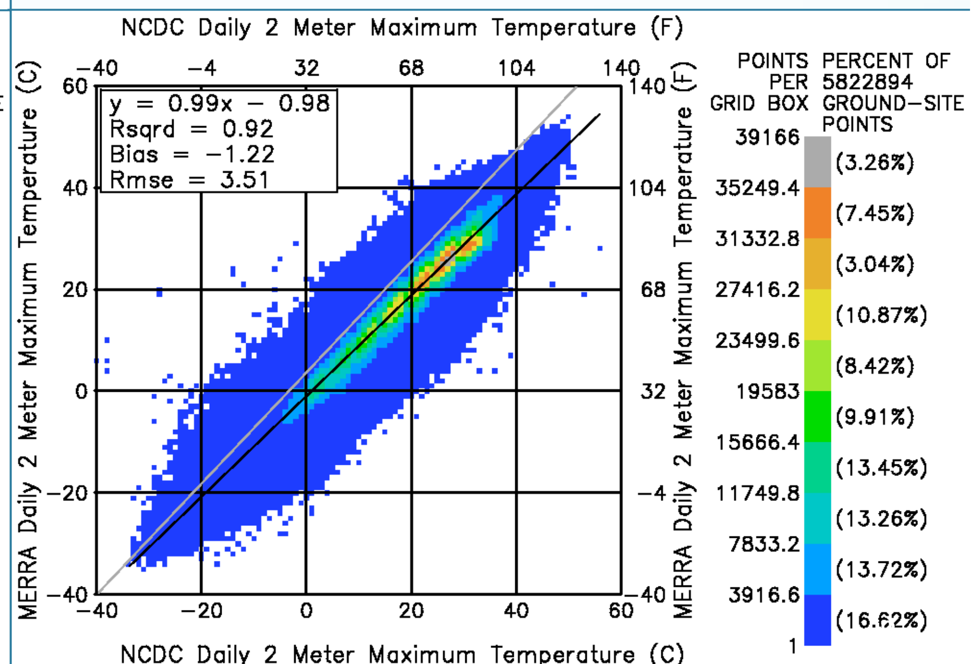


Temperature Validation

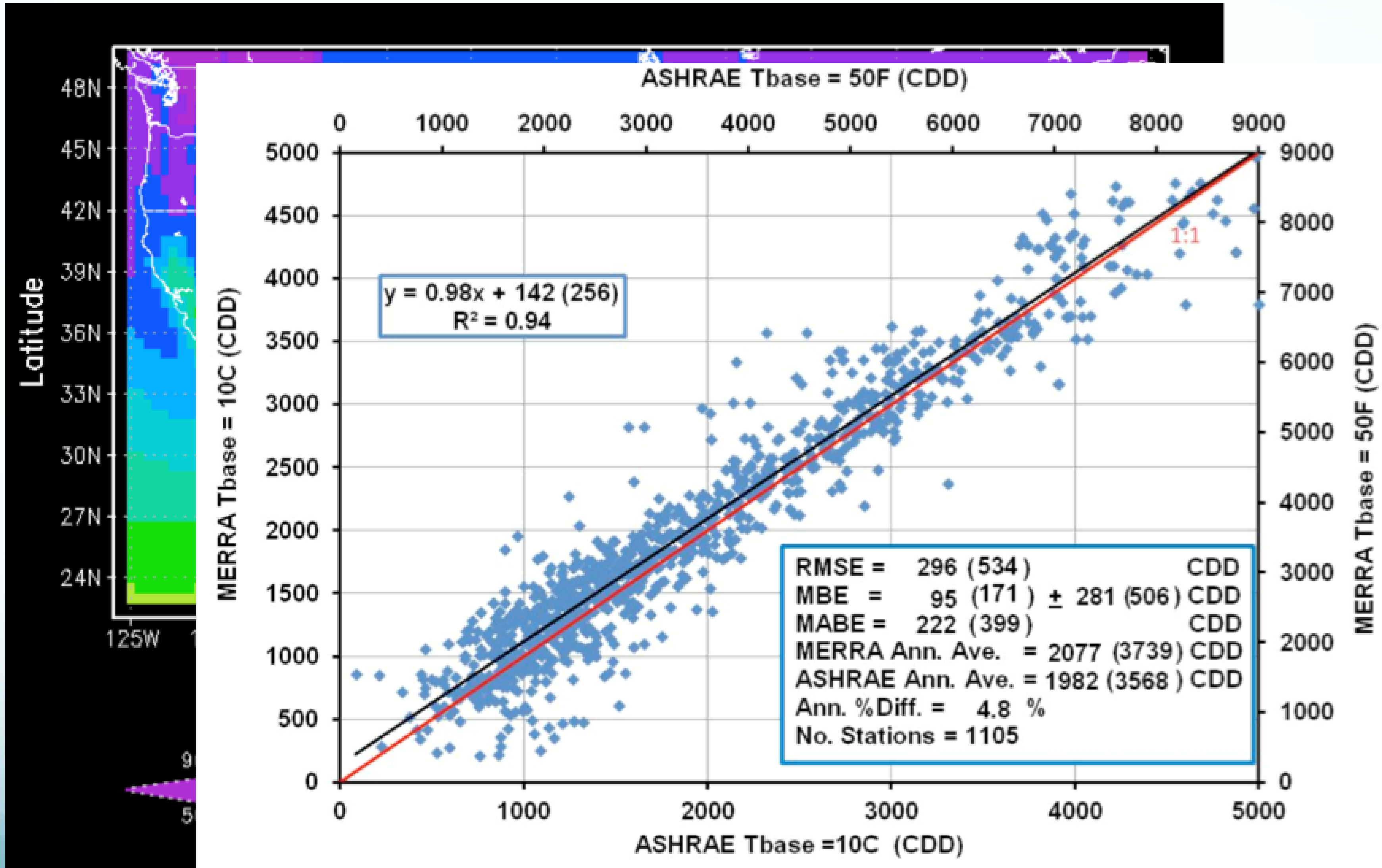
- MERRA temperatures (Tave, Tmax, and Tmin) for 0.5° x 0.5° grid boxes versus observations from NCDC surface stations contained within those MERRA grid boxes.
- The comparison covers 1,116 surface stations in the CONUS study region meeting our 85% selection criteria.



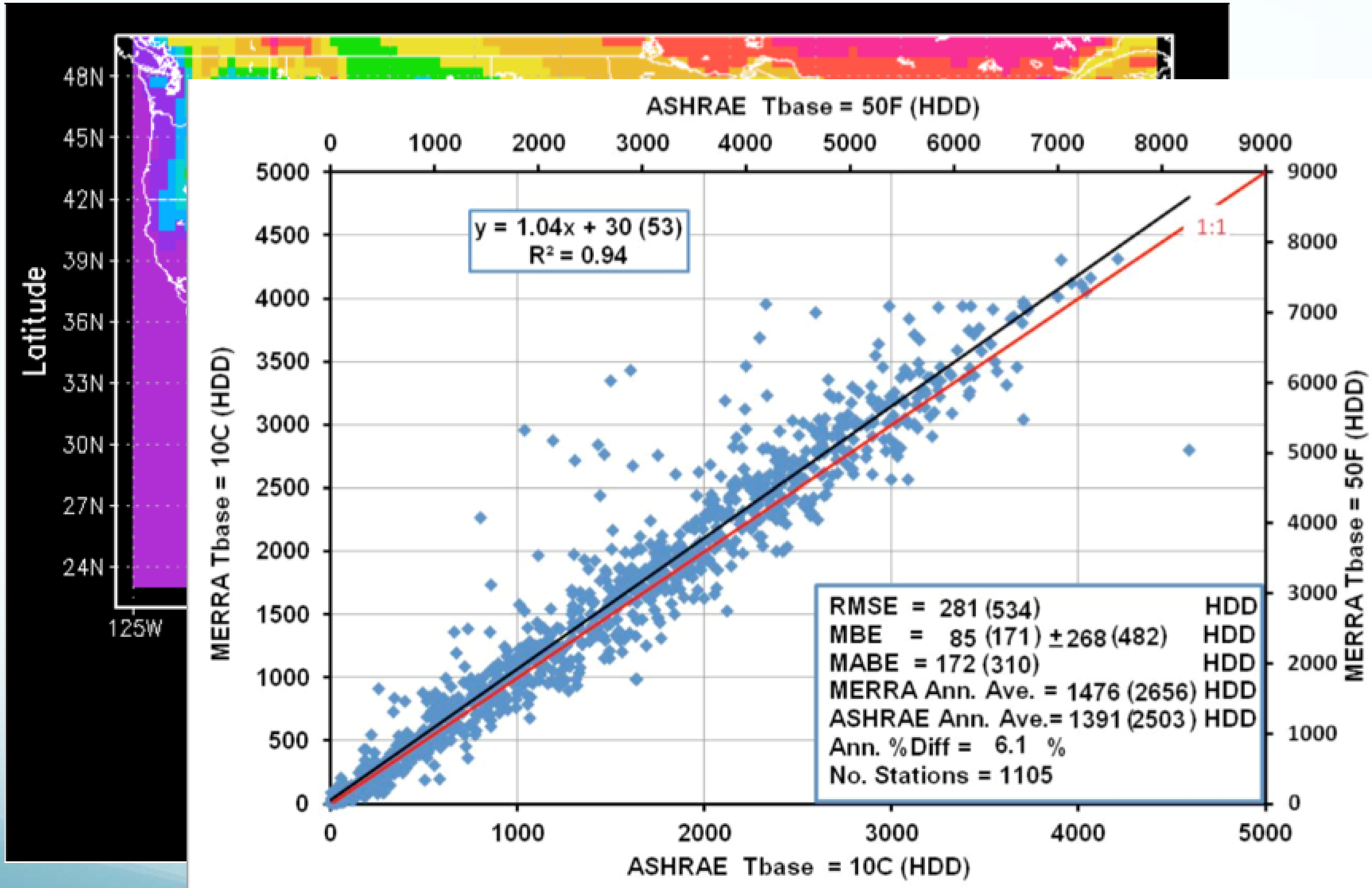




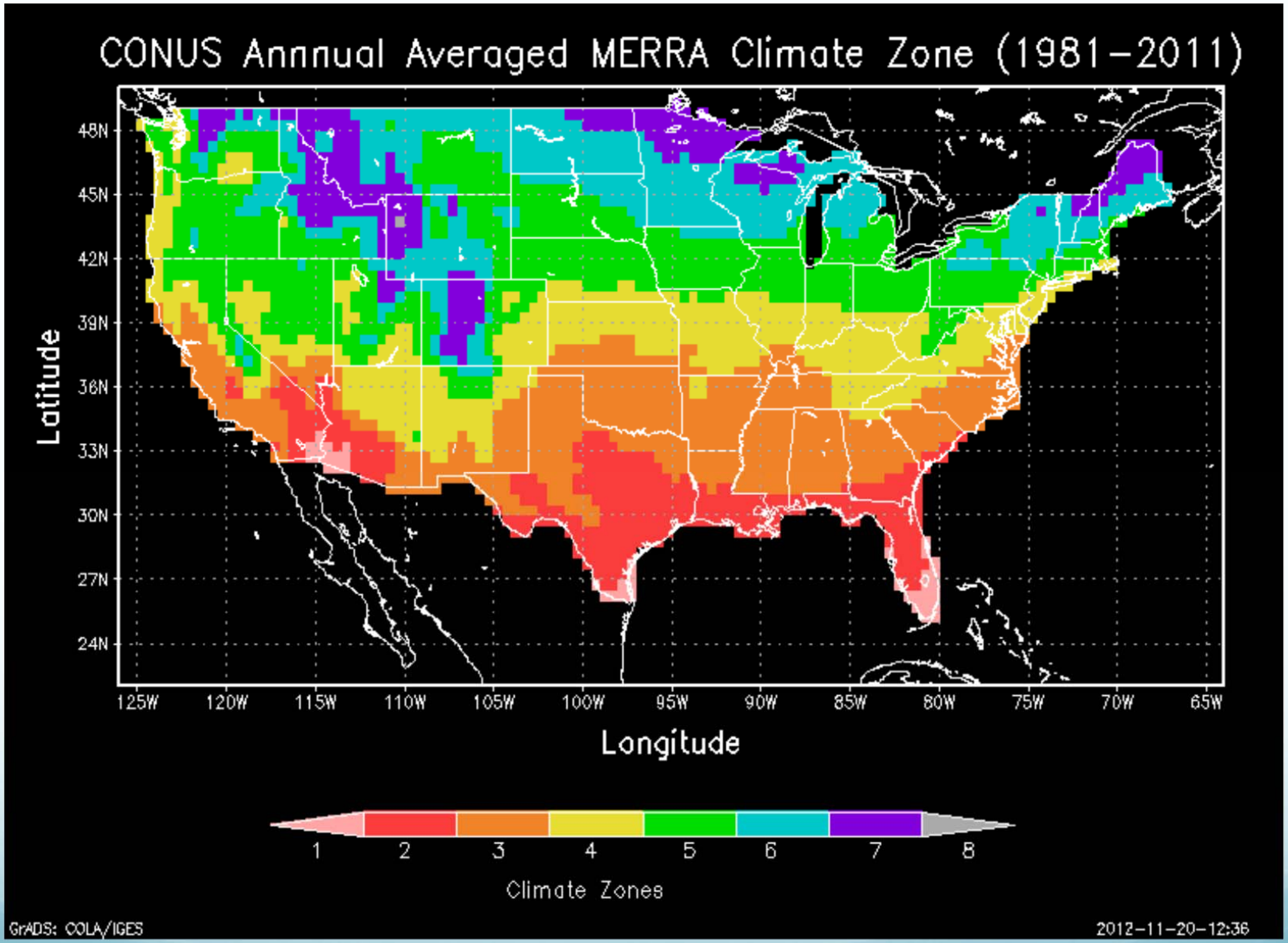
MERRA 30 Year Averaged CDD (10ºC)



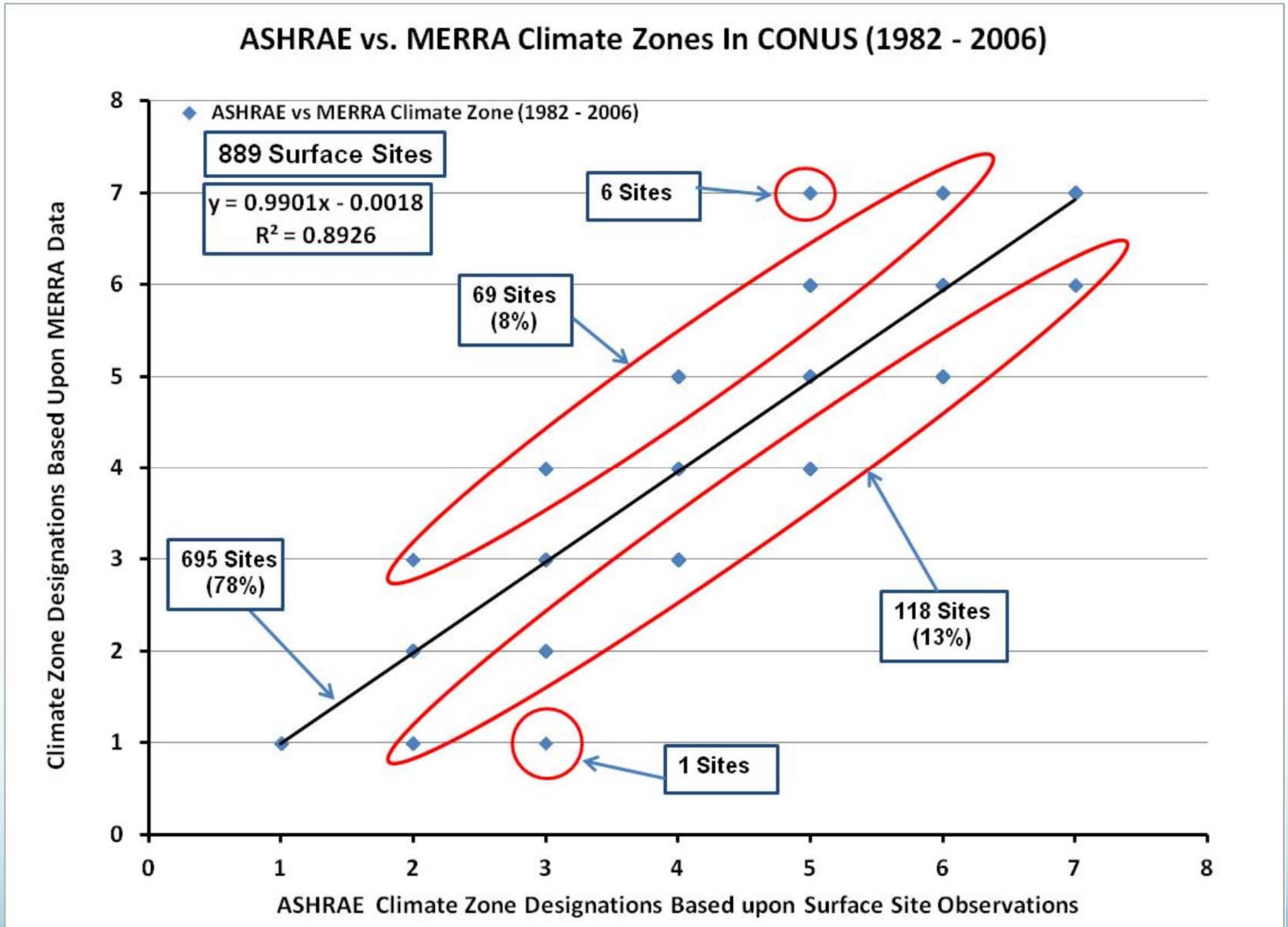
MERRA 30 Year Averaged HDD (10ºC)



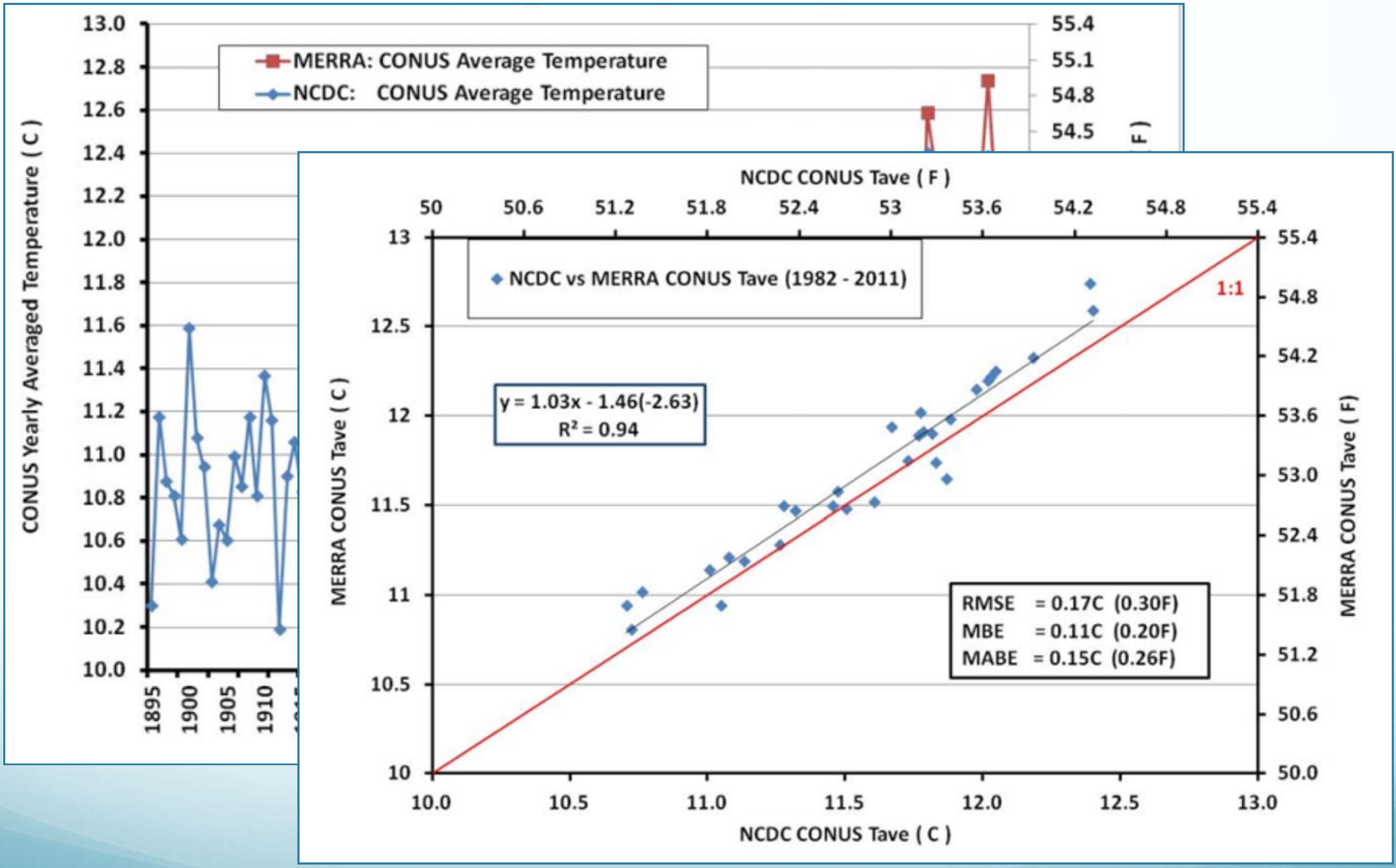
MERRA Based 30 Year Climate Zones for CONUS



MERRA vs DOE/ASHRAE Climate Zone Maps

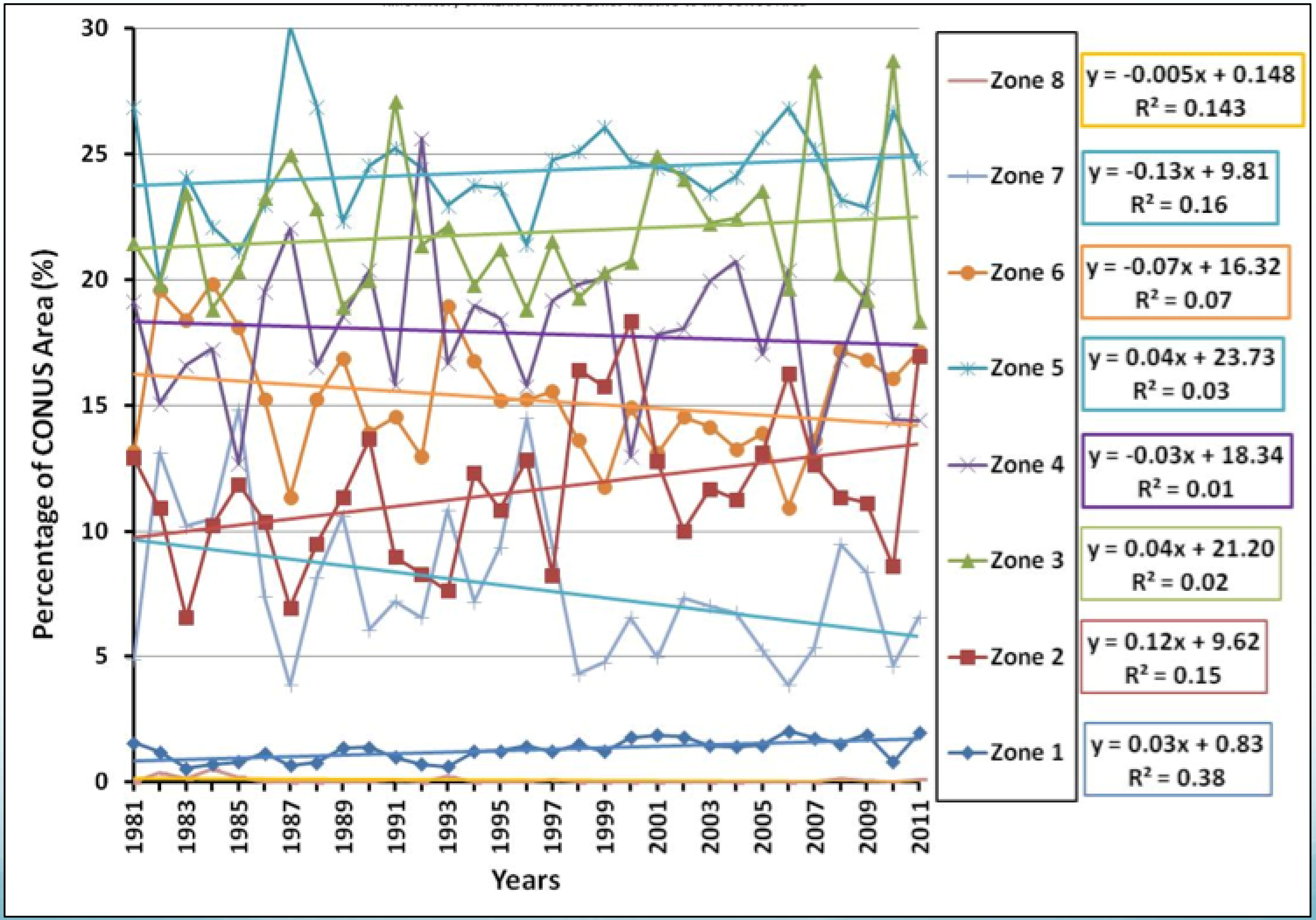


MERRA T_{ave} Variability



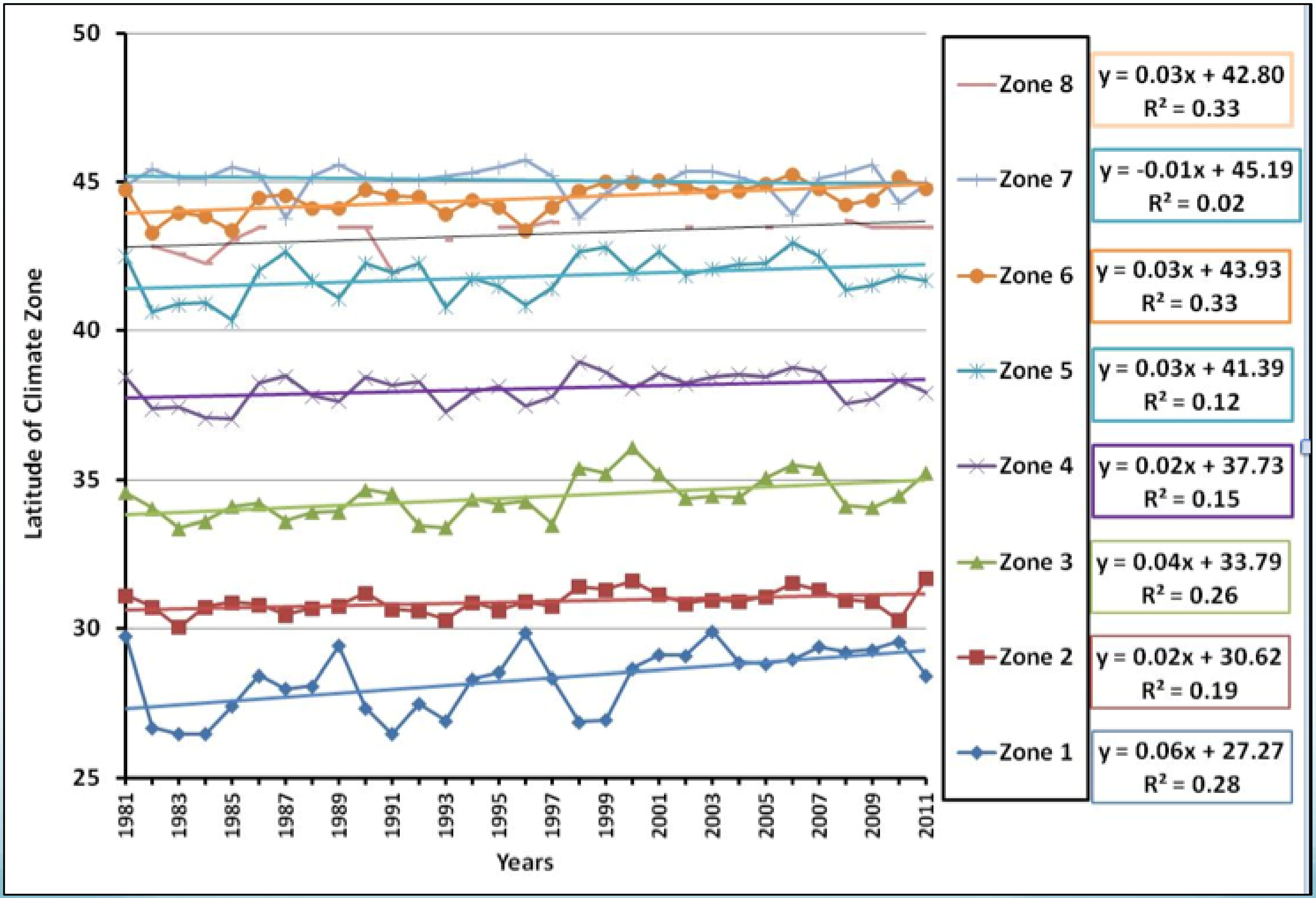
Climate Zone Variability from MERRA

Percent of Climate Zone / CONUS Area Variation



Climate Zone Variability from MERRA

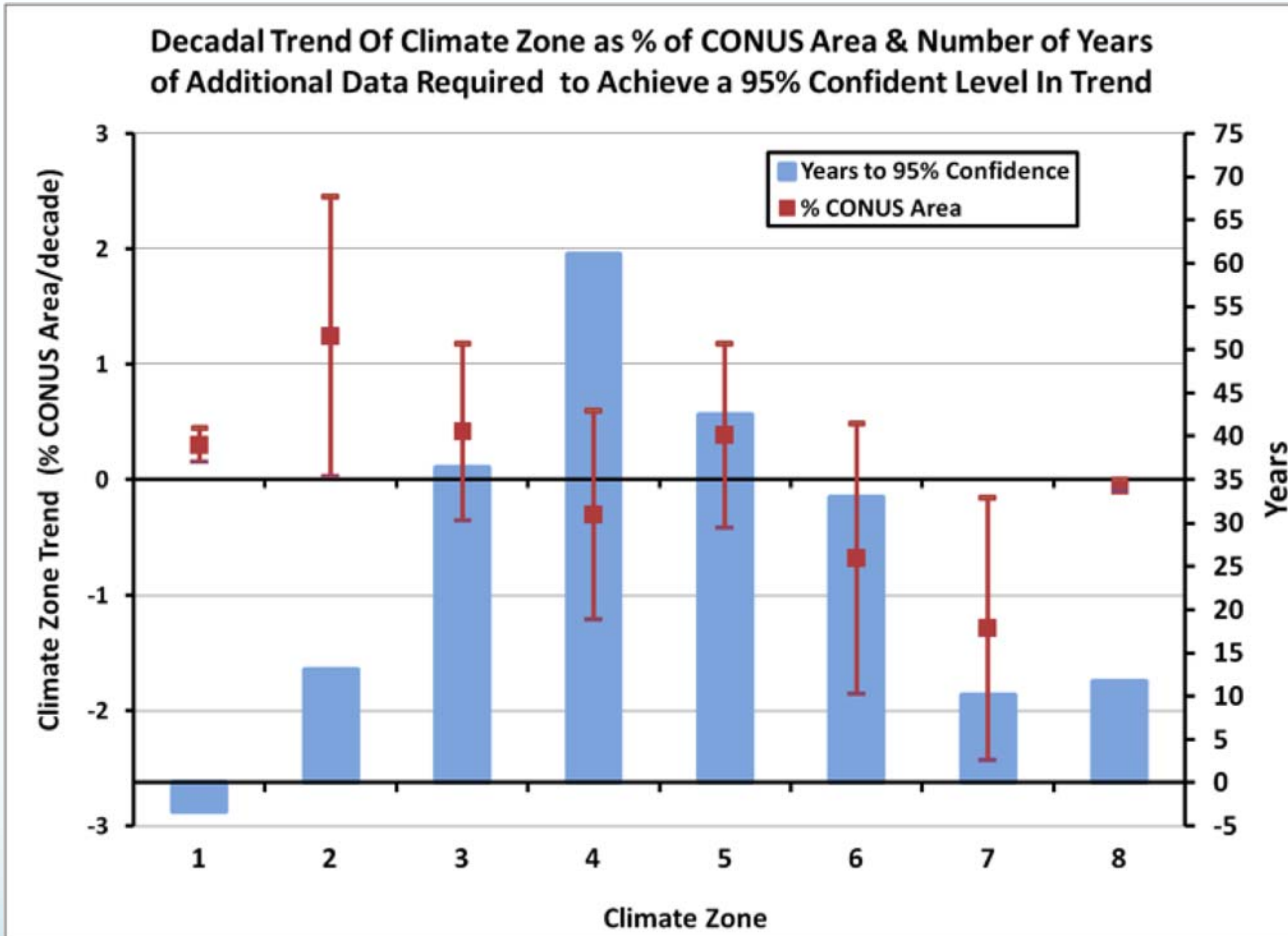
Weighted Mean Zone Latitude Variation



Statistical Significance?

- Used statistical technique of Weatherhead et al (1998) as modified by Hinkelman et al (2009) considers the autocorrelation as part of the time series.

- Determines confidence inteval and estimates # of years until 90% probability is obtained.

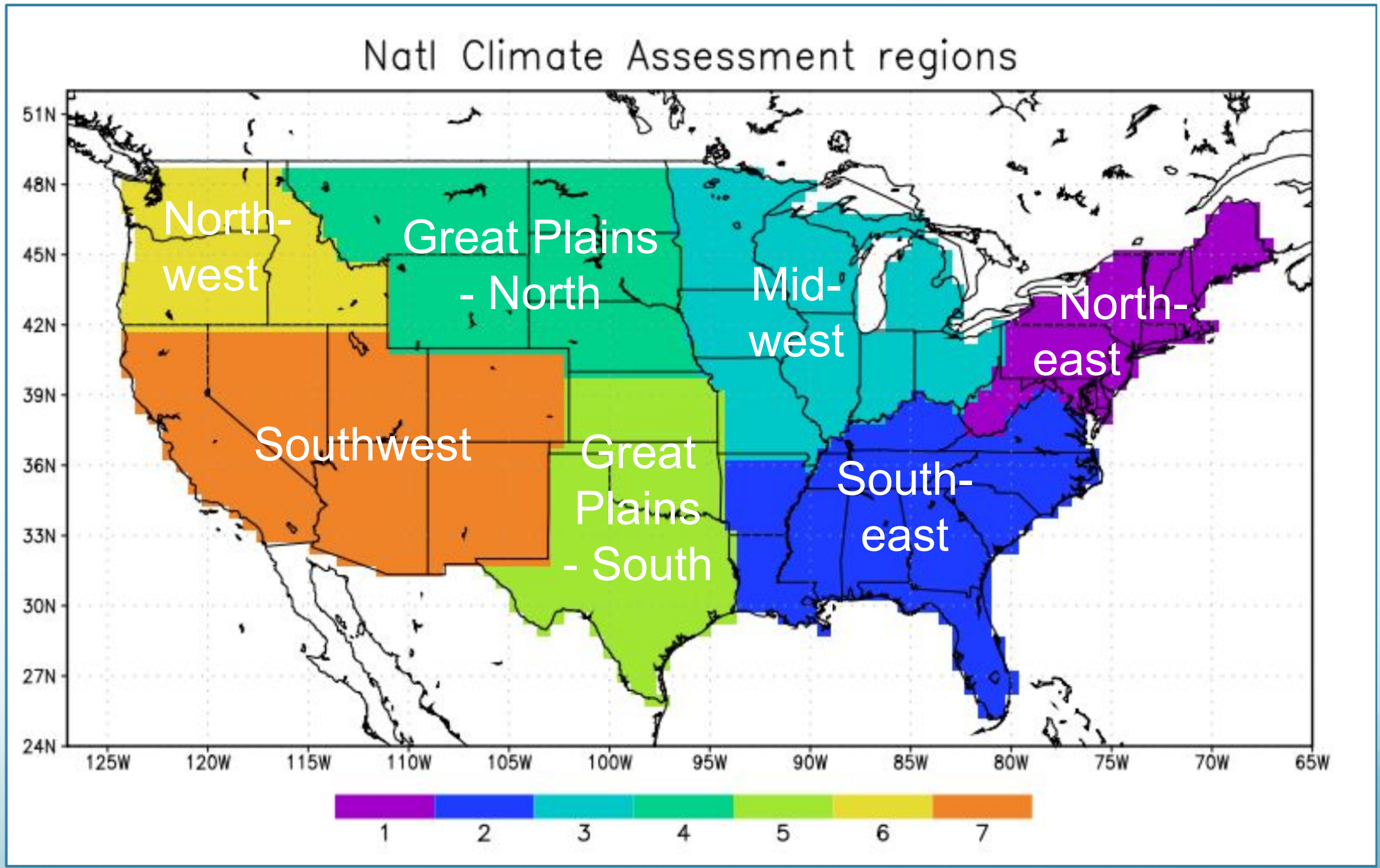


National Climate Assessment Regions

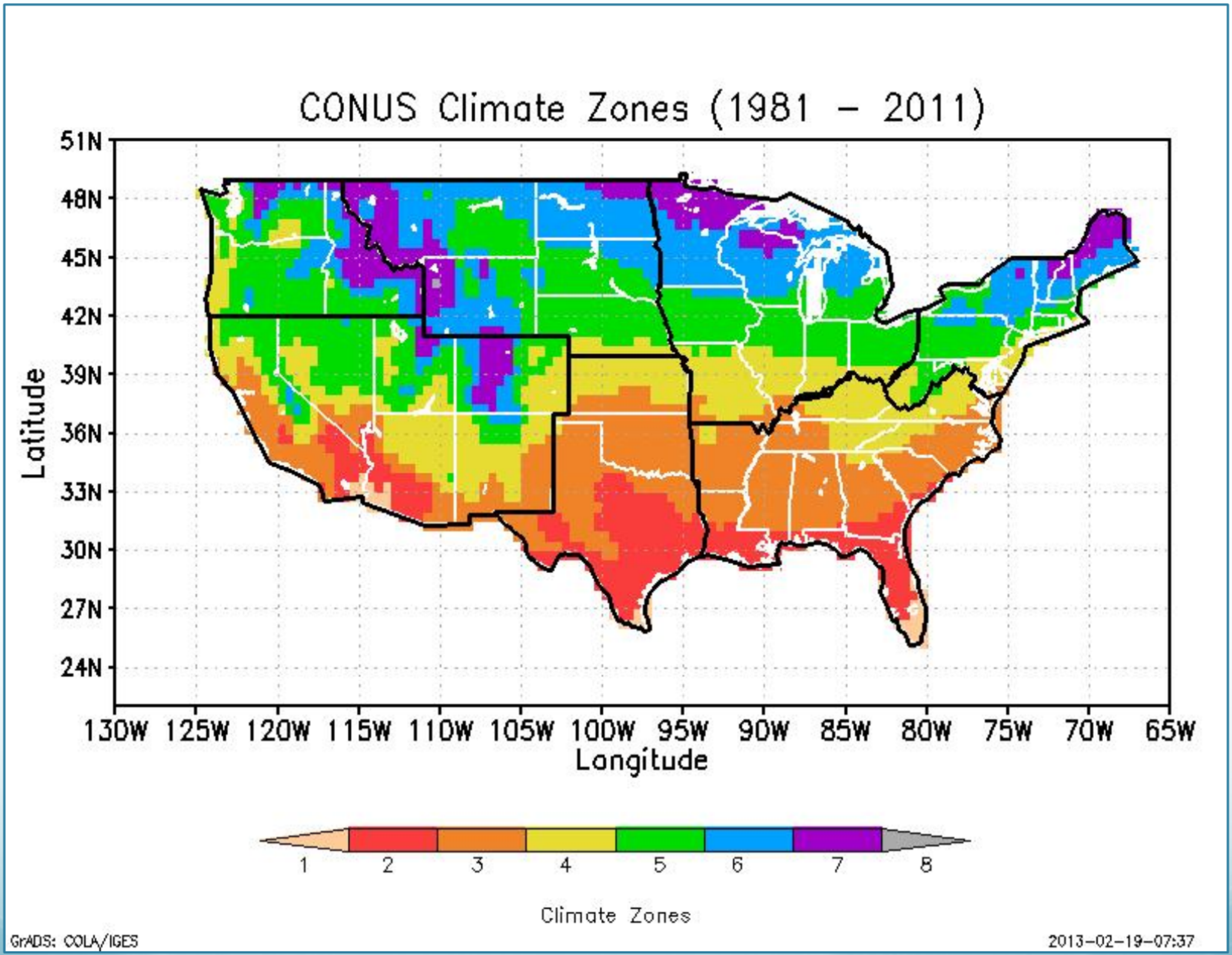
National Climate Assessment was established to provide regular reports on climate science and impacts for the United States.

Using MERRA, we assess changes to building zones over the last 30 years.

Note: we divide Great Plains into 2 regions



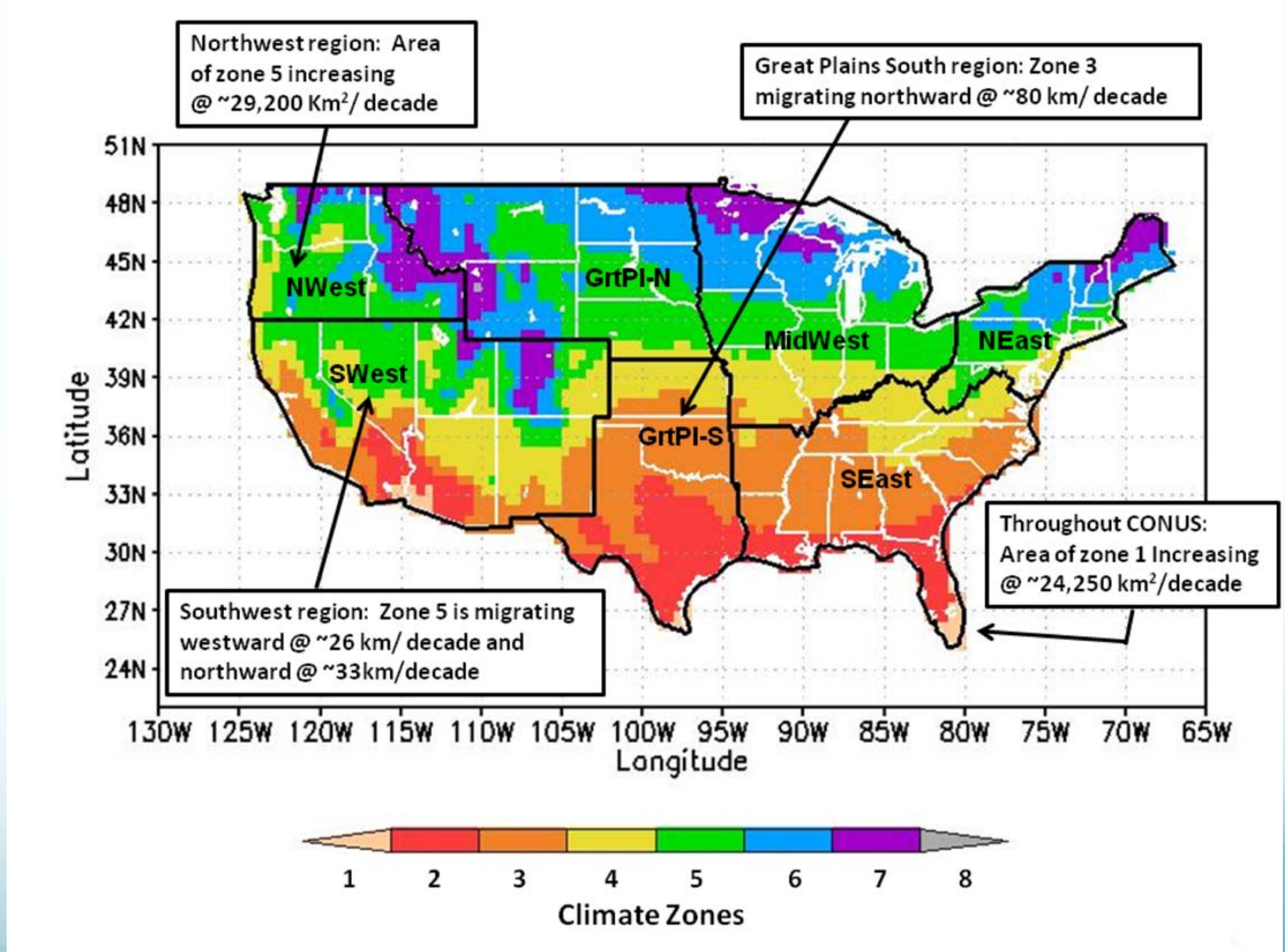
MERRA Climate Zones by NCA Region



MERRA Climate Zones & Variability

Region 2 (7) is in(de)creasing by about 1.2% per decade; change won't be significant to 90% probability unless maintained another 10 years

Trends to 95% Confidence

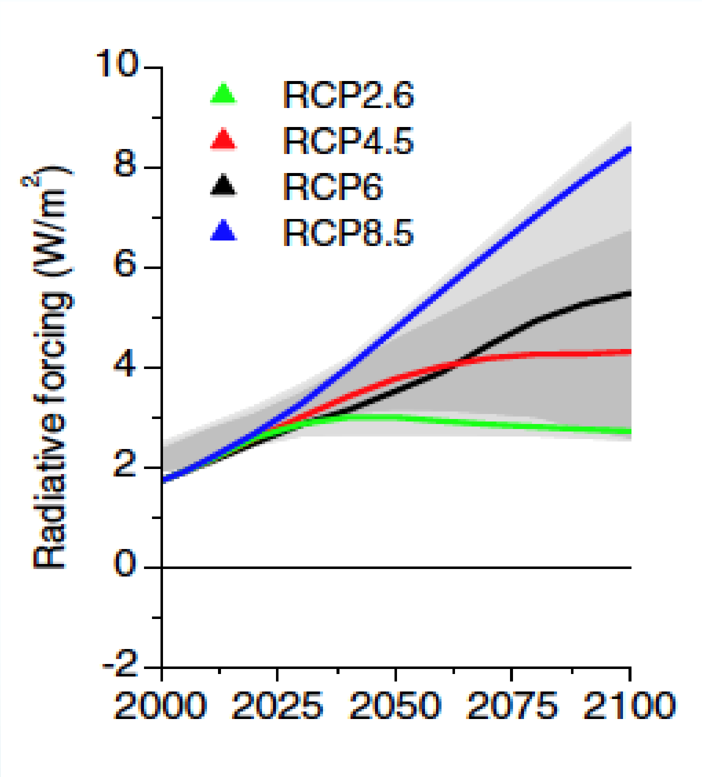


Conclusions from Last 30 Years

- Building Climate zones computed using MERRA HDD/CDD agree well (78% of zones agree; 21 of the zones agree with +/- 1 zone - partly due to elevation differences)
- MERRA assimilation data products provide good agreement with observed surface temperature variability
- MERRA variability of annual climate zones show a general migration of zones northward
- However, statistical significance to 95% level was obtained for the increase of the most extreme warm zone (zone 1) and zone 3 in the Southern Great Plains
- Numerous other zones will reach at least the 90% within the next decade if the currently observed changes continue
- The potential of reanalysis data sets to provide building climate zone information will assist the development building codes in response to climate related changes; potential to compare to long-term climate simulations.

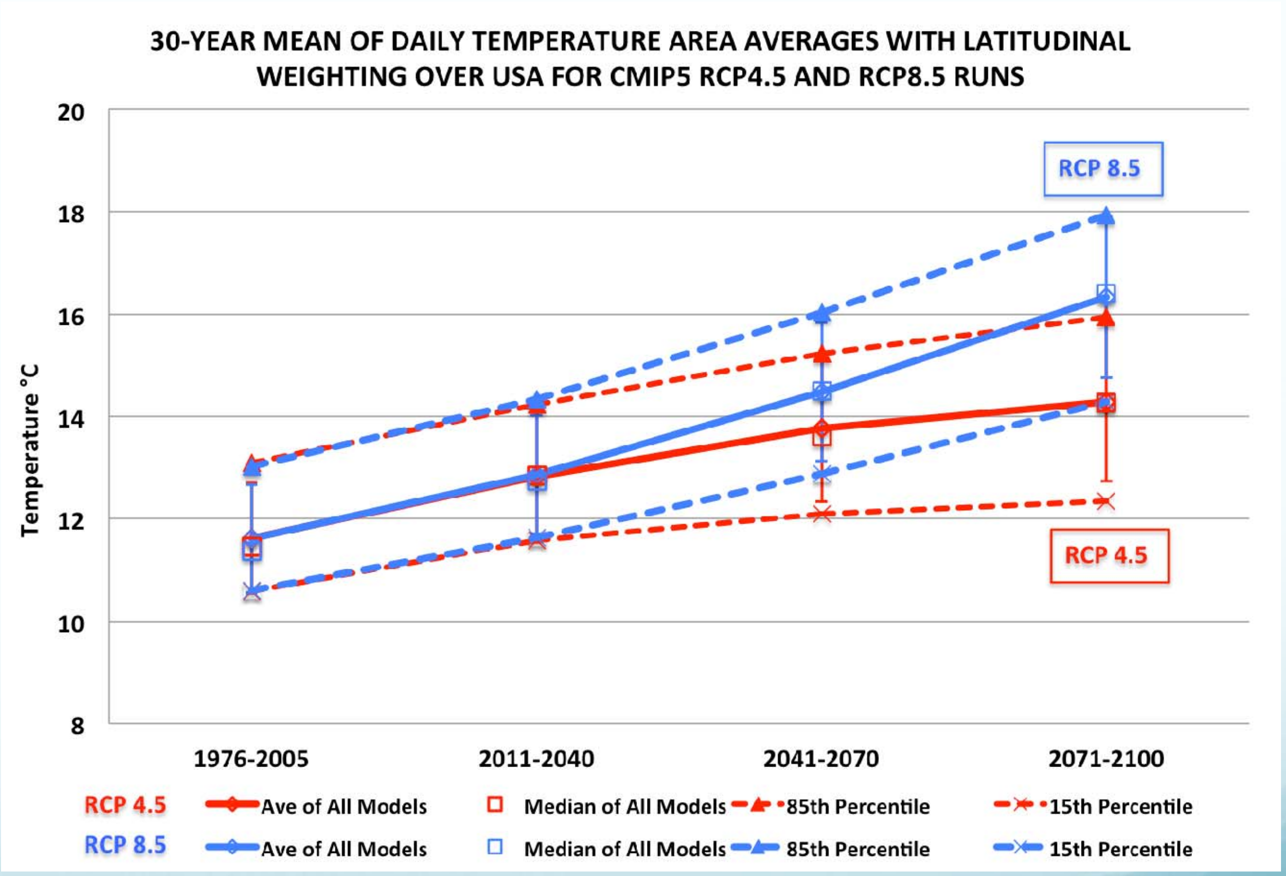
Climate Simulation Analysis: CMIP5

- Building projects require a long-term planning horizon and usually have a multi-decadal lifespan.
- Climate Model Intercomparison Project (CMIP5)
- We explore the future forecasted building climate zones from a multi-model ensemble from the recent CMIP5 climate simulations.
- The projections of climate zones from the RCP4.5 and 8.5 runs (Van Vuuren et al., 2011) for 28 models.



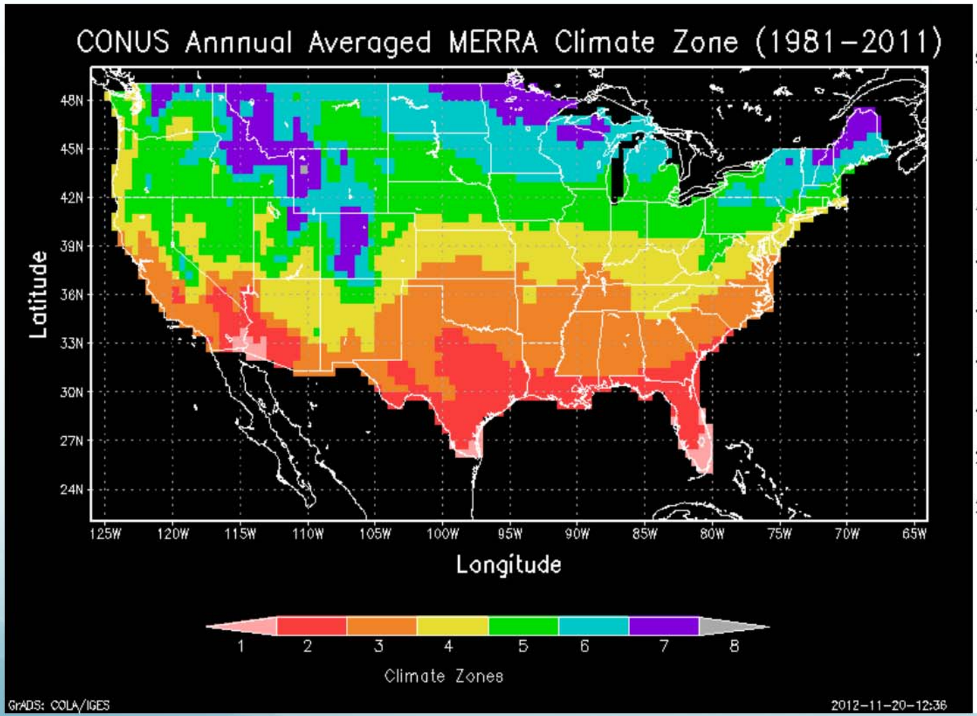
Climate Simulation Analysis: CMIP5

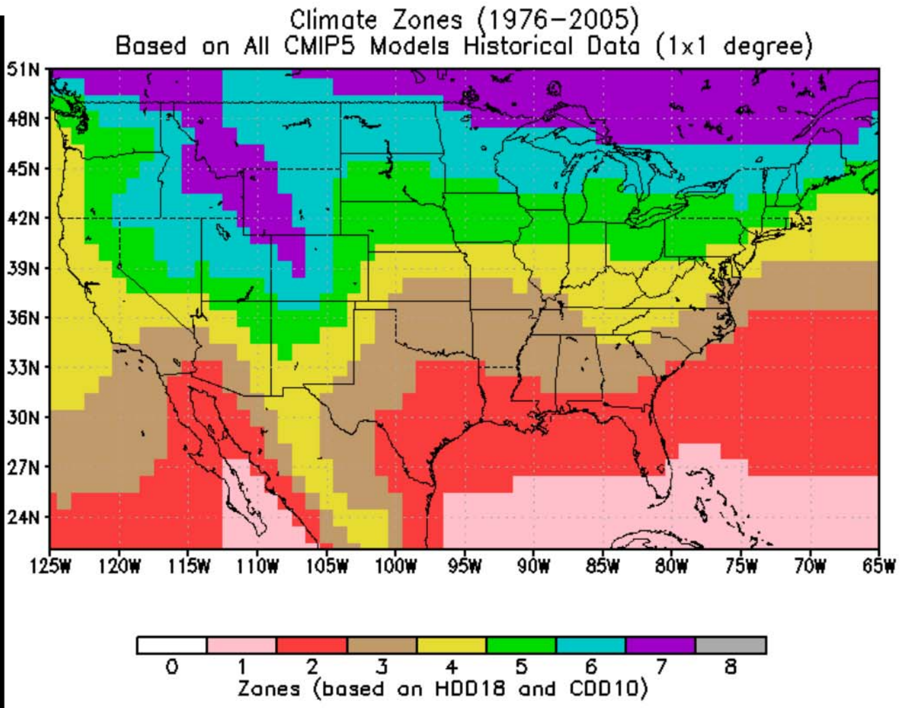
From 28 models evaluating the ensemble model mean, 15% warmest (in red) and 15% coldest (in blue) simulations from each pathway.



MERRA vs. CMIP5 Ensemble

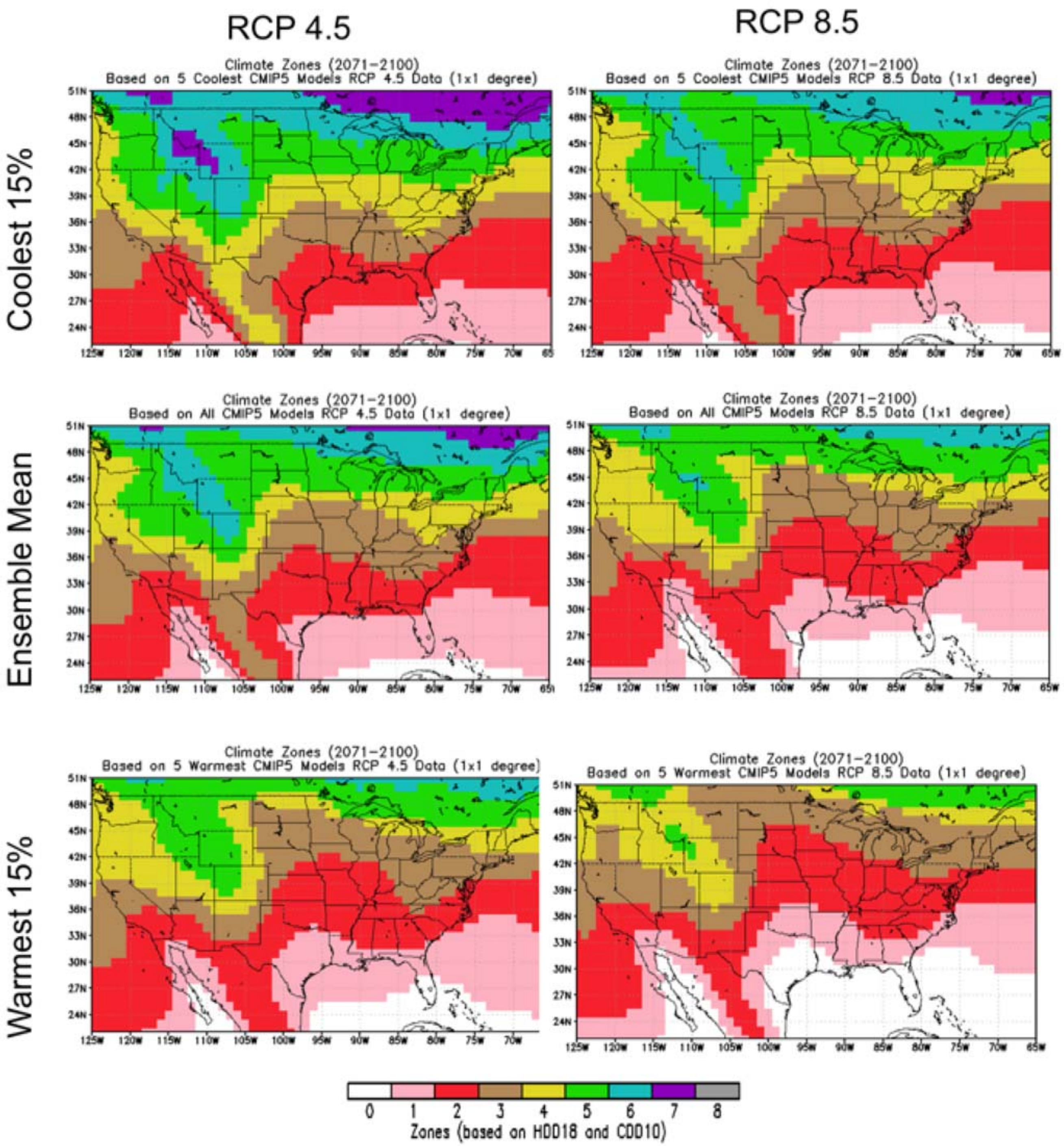
Ensemble base climate zones agree well with MERRA





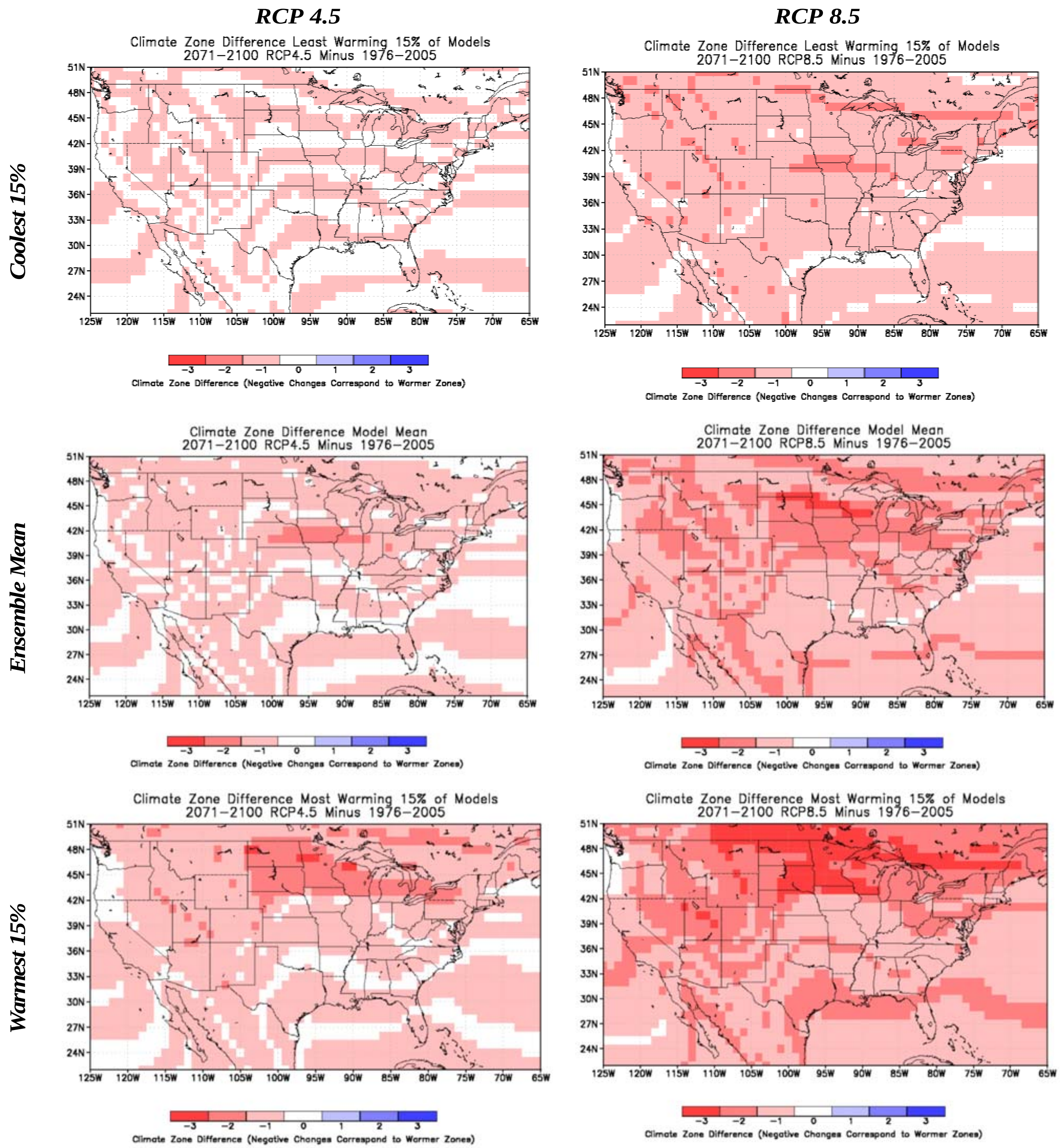
2071-2100 Decadal Results

- Spread of zones shows progressive warming from 15% least sensitive for RCP 4.5, to most sensitive 15% for RCP 8.5
- Notice advent of most extreme tropical zone in SE US and disappearance of coldest zones in northern US.



2071-2100 Decadal Results

- Negative change corresponds to a warmer zones
- Changes in zones first occur along transition zones and then spread.
- Similarly for multiple zone changes.
- Most extreme zone changes in Northern parts of mid-west are 3 zones warmer



Conclusions from CMIP5

- Ensemble base periods from 28 Models used for climate simulations give climate zones relatively consistent with current designations.
- Used an ensemble analysis of 28 models and separated into mean, 15% warmest and 15% coolest for
  - RCPs: 4.5 and 8.5
  - Decades: 2011-2040, 2041-2070, 2071-2100
- Zone vary widely from RCP RCP 4.5 coolest and RCP 8.5 warmest models.
  - Warmest climate zones expand in area; including introduction of newly formed tropical zone in Gulf Coast US
  - Coolest climate zones that represent current climate shrink and disappear depending upon the RCP and model ensemble
- Climate zones changes first occur zone transitions and spread in area.
  - Some changes for RCP 8.5 and warmest models exceed 3 climate zones
  - Most climate areas see a climate zone change of 1 zone in the ensemble mean.
- Determining the probable occurrence of these scenarios represents ongoing work. However, the cost of adapting to these changes from these results can begin to be estimated