# Relationships Between Excessive Heat and Daily Mortality over the Coterminous United States

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# Objective and Methods

- **Objective: Examine the relationships between heat-related mortality and excessive heat at the daily, county scale**

- **Science Questions:**

- Can heat-related deaths be clearly tied to excessive heat events?
- What time lags are critical for predicting heat-related deaths?
- Which of the many common heat metrics correlates best with heat-related deaths?

- **Methods:**

- Use meteorological reanalysis data to develop measures of extreme heat on a 1/8$^{o}$ (~12 km) grid over the coterminous U.S.
- Aggregate heat measures to county, daily level for coterminous U.S.
- Use heat data to identify 'Extreme Heat Events' (EHEs) based on nine definitions
- Examine the relationship between EHEs and heat-related mortality using CDC's National Center for Health Statistics 'Multiple Causes of Death 1999-2010' data

# Environmental Data:
# North American Land Data Assimilation System (NLDAS)

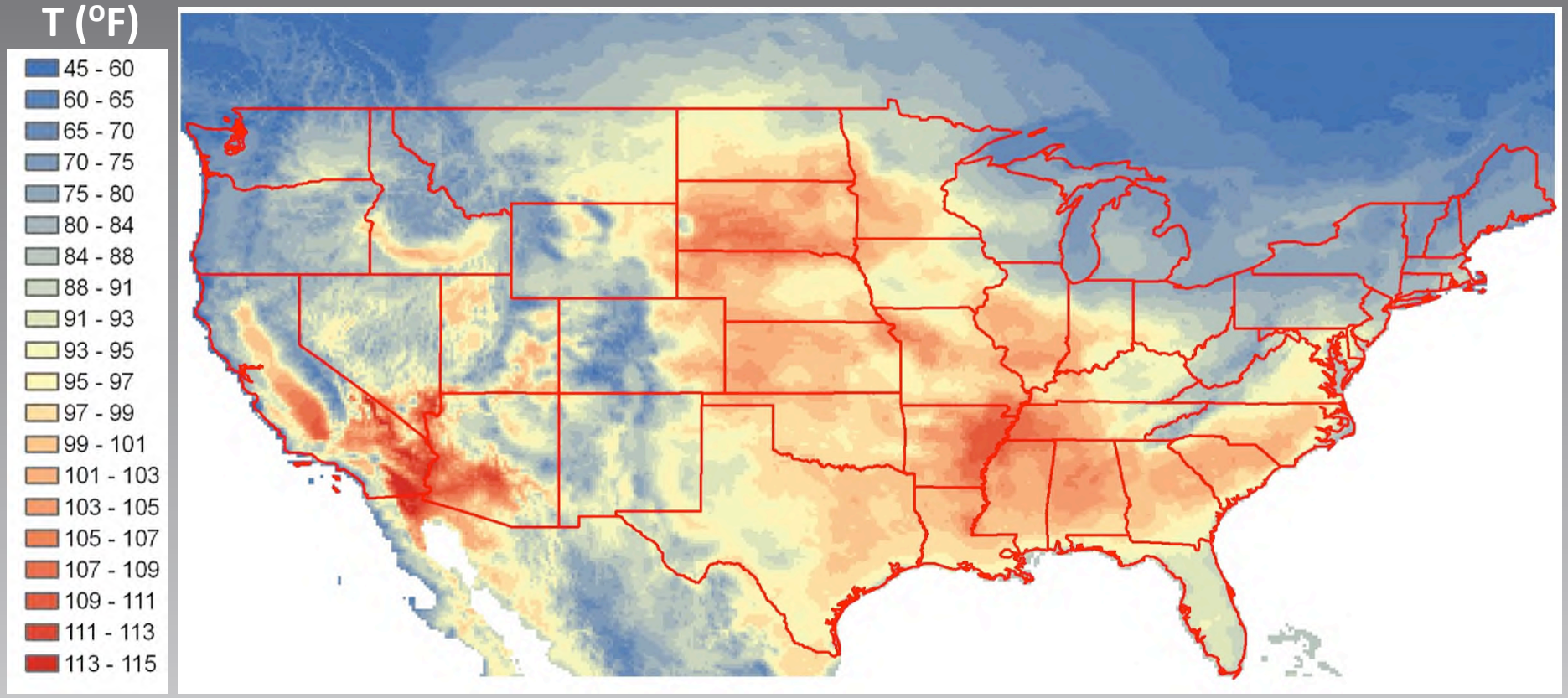
- North American Land Data Assimilation System (NLDAS) combines meteorological data from models with observations from ground stations and satellites for the conterminous U.S.
  - 1/8$^{th}$ degree (about 12 km) spatial resolution
  - Available hourly for 1979-current
  - Available from http://www.emc.ncep.noaa.gov/mmb/nldas/

- Hourly air temperature and humidity data have been used to create grid-level daily maximum and minimum temperatures and other heat-related variables such as Heat Index.

# Metrics of Excessive Heat

## 1. Daily Maximum Air Temperature

➢ Daily maximum air temperature, the highest temperature recorded at an observation site between midnight and midnight local standard time, is a traditional measure of heat, and one with which everyone is familiar.
We used NLDAS hourly data to calculate daily maximum air temperature.




**August 13, 2007**

# Metrics of Excessive Heat

## 2. Heat Index (HI)

Heat Index or 'apparent temperature' combines air temperature and relative humidity (Steadman et al., J. Appl. Met. 1979). As humidity increases, the efficiency with which our bodies lose heat through evaporation of sweat is reduced. Commonly used as a heat stress indicator, HI is the basis for NWS heat warnings:

| | | |
|---|---|---|
| HI ≥ | 90° F | Extreme Caution |
| | 105° F | Danger |
| | 130° F | Extreme Danger |

Advantage over air temperature: Because it incorporates humidity information, HI more closely relates to physiological stress on humans.

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**HI is only calculated when air temperature > 80° F.**

# Metrics of Excessive Heat
## 3. Net Daily Heat Stress (NDHS)

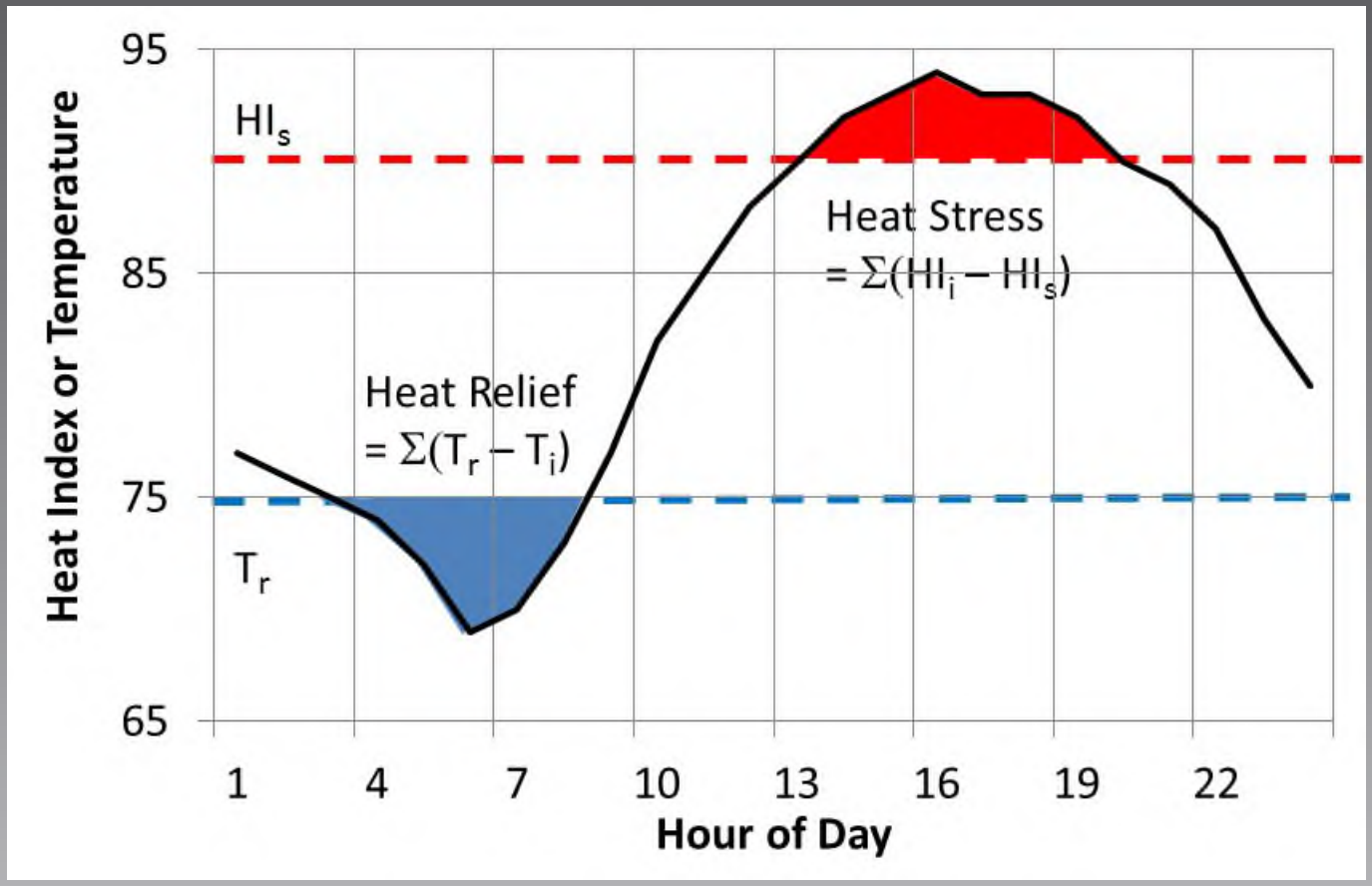
**Net Daily Heat Stress** is a new heat variable that gives an integrated measure of heat stress (and relief) over the course of a day, defined as:

$$NDHS = \underbrace{\Sigma(HI_i - HI_{hot})}_{\text{heat stress}} - \underbrace{\Sigma(T_{cool} - T_i)}_{\text{heat relief}}$$

- Sums are over the hours in a day and include only positive terms. Units are degree-hours.
- The 'heat stress' term is only calculated when $HI_i > HI_{hot}$ , where $HI_{hot}$ is a threshold above which HI is considered a stressor, set to 90° F.
- The 'heat relief' term is only computed when $T_i < T_{cool}$, a temperature below which relief from heat occurs, set to 75° F.
- If heat relief is greater than heat stress, NDHS is set to 0.

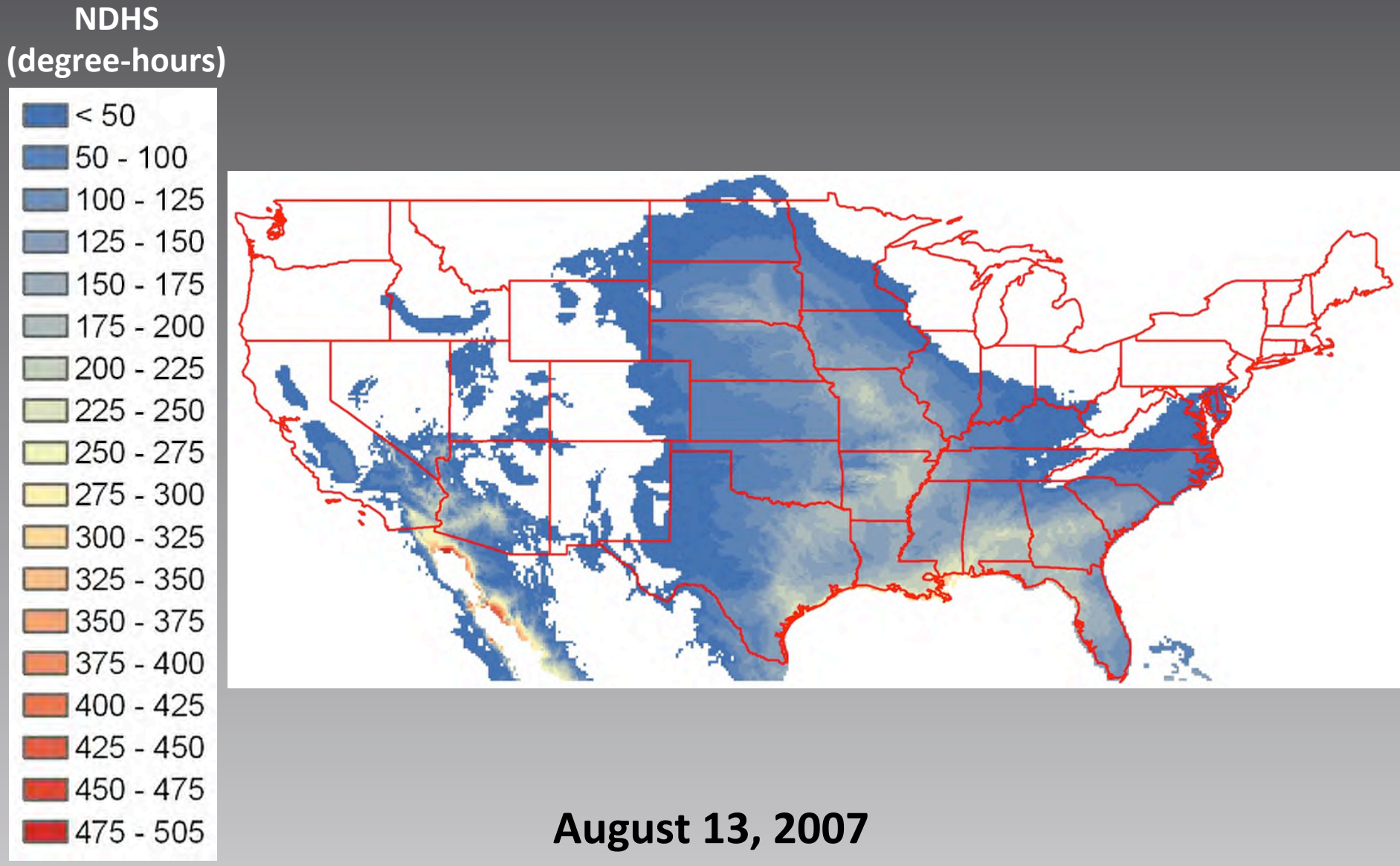
**Advantage over Temperature and Heat Index:**
NDHS may be a more appropriate heat stress measure than HI, an instantaneous variable not well-suited to capture the health impacts of multi-day heat events.

# Metrics of Excessive Heat
## 3. Net Daily Heat Stress (NDHS)




NDHS = Max(0, Red area – blue area)

# Metrics of Excessive Heat
## 3. Net Daily Heat Stress (NDHS)




**August 13, 2007**

# Definitions of Extreme Heat Events

We applied 9 definitions of Extreme Heat Events (EHE) for the 'warm season' of May-September.

For all definitions, the variable must exceed the threshold on two consecutive days.

Percentiles are determined for each county based on 1981-2010 NLDAS data for the warm season.

| | Variable(s) | Percentile | Absolute threshold |
|---|---|---|---|
| 1 | Daily maximum temperature | 95 | |
| 2 | Daily maximum temperature | 95 | 90° F |
| 3 | Daily maximum temperature | 99 | |
| 4 | Daily maximum and minimum temperatures | 95 | |
| 5 | Daily maximum and minimum temperatures | 95 | 90° F for max. temperature |
| 6 | Daily maximum Heat Index | 95 | |
| 7 | Daily maximum Heat Index | 99 | |
| 8 | Net Daily Heat Stress | 95 | |
| 9 | Net Daily Heat Stress | 99 | |

# Mortality Data

Source: CDC's National Center for Health Statistics 'Multiple Causes of Death 1999-2010', which includes:

State and county of decedent's residence and place of death;
Date of death;
Underlying cause of death;
Contributing factors of death;

and many other demographic variables.

In this study, a 'heat-related death' is one for which heat was an underlying or contributing cause.

# Evaluation Statistics

We applied several statistics for 9 regions and for the entire US to evaluate how well each of the EHE definitions indicates heat-related mortality.
Using a 'forecast-outcome' analogy, an 'EHE exposure' is one person exposed to extreme heat for one day – think of this as a forecast of a heat-related death. (We calculate all statistics on a per 1 million exposures basis.)

An 'EHE death' is one heat-related death occurring during an EHE.
A 'non-EHE death' is one heat-related death occurring outside of an EHE.

1. Equitable Threat Score (ETS): Takes into account correct forecasts, 'false alarms' (EHE exposures but no deaths) and missed events (non-EHE deaths) and is designed to avoid a tendency toward poor scores for rare events.

2. Ratio of heat-related deaths on EHE days to heat-related deaths on non-EHE days

ETS and the Ratio are calculated based on total heat-related deaths and exposures over all warm seasons, 1999-2010.

3. Linear correlation coefficient between daily heat-related deaths and number of persons exposed to EHE

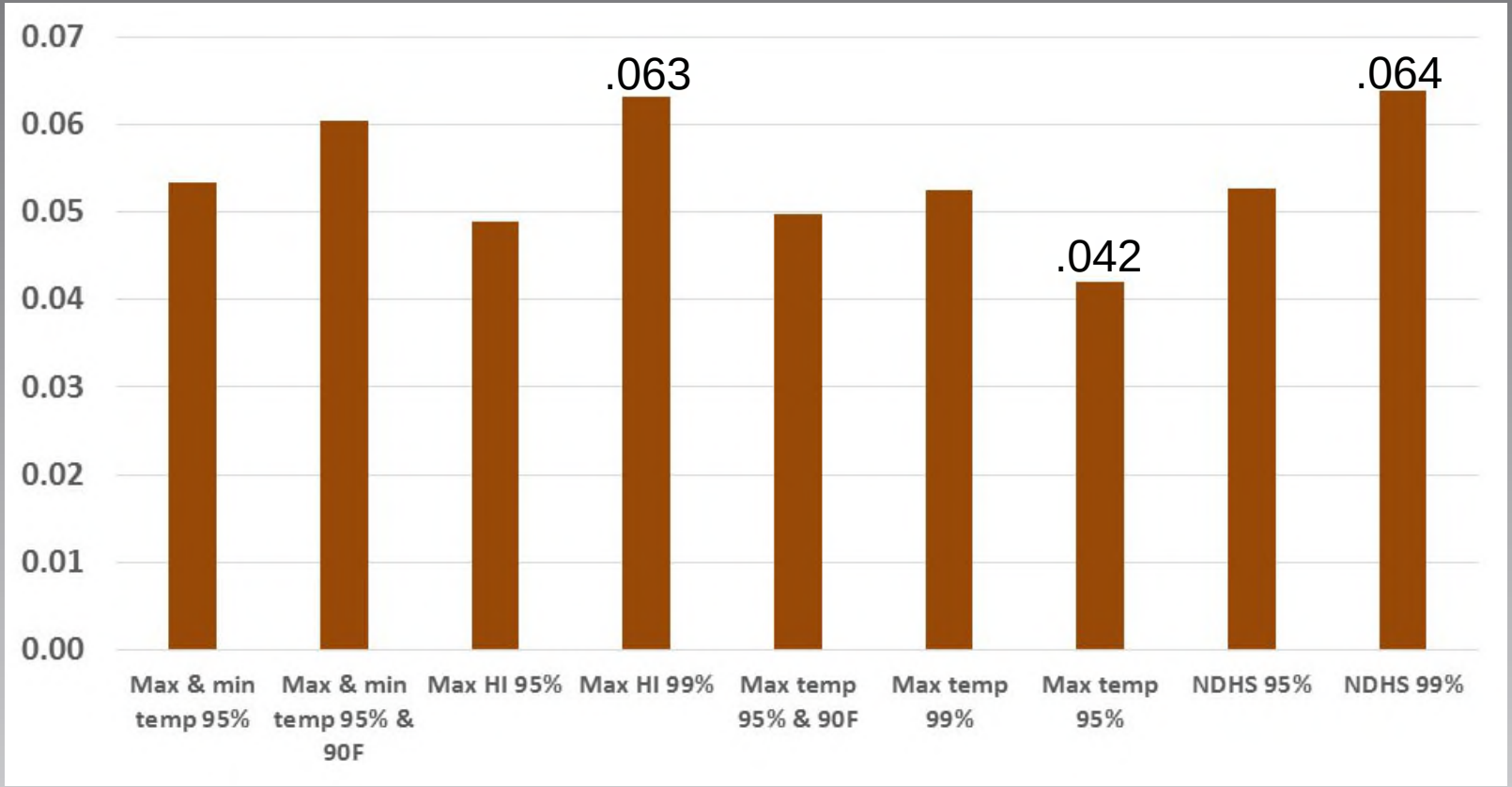
Correlations are calculated based on daily heat-related deaths and exposures.

# Evaluation Statistics – Equitable Threat Score (ETS) Results for Entire US

Results are shown for best temporal lag (usually 1 day).

Best results: NDHS 99$^{th}$ percentile and maximum Heat Index 99$^{th}$ percentile EHE definitions.

Worst results: Maximum temperature 95$^{th}$ percentile EHE definition.

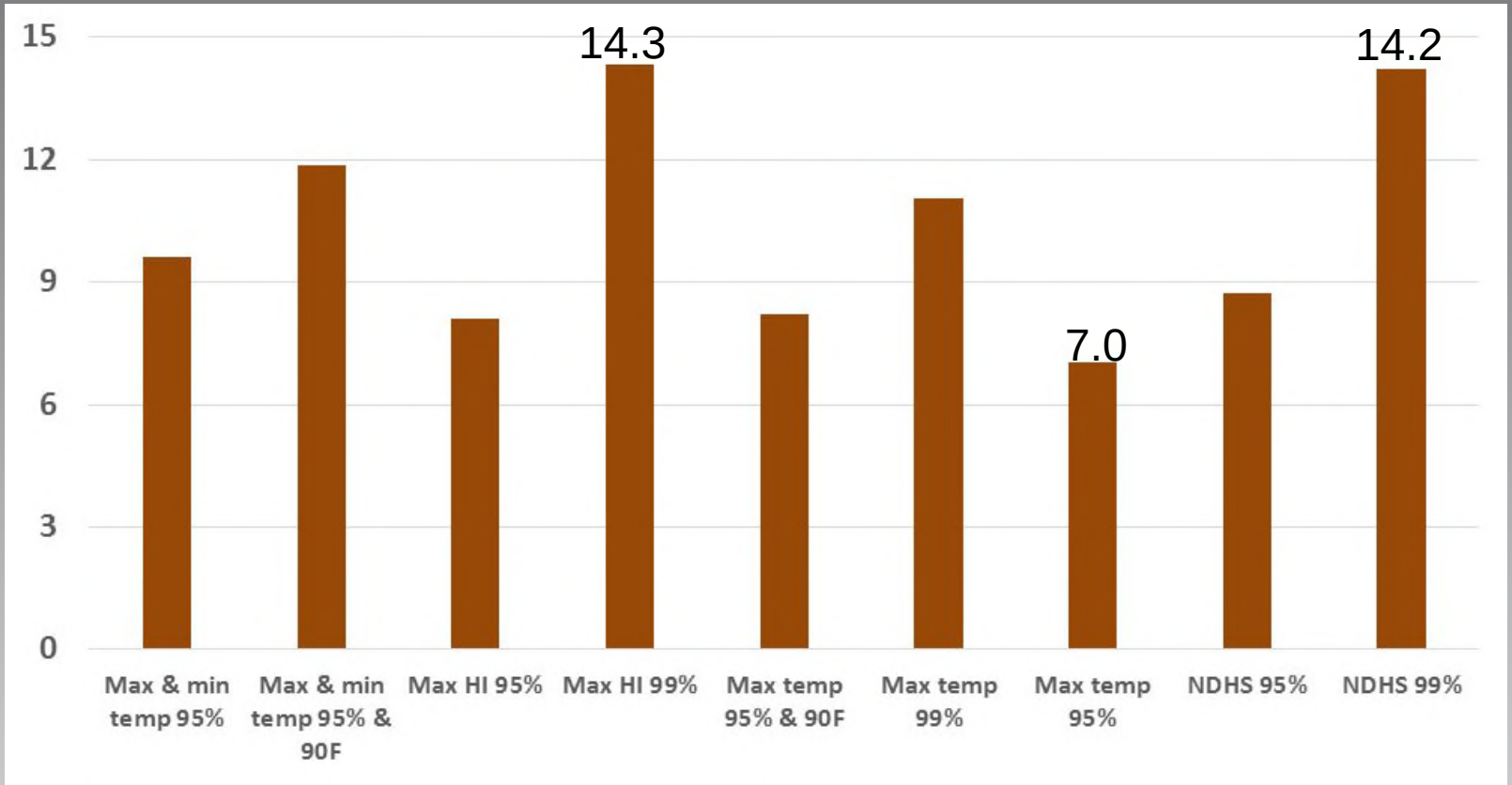


# Evaluation Statistics – Ratio of Death Rates Results for Entire US

Results are shown for best temporal lag (usually 1 day).

Best results: Maximum Heat Index 99th percentile and NDHS 99th percentile EHE definitions.

Worst results: Maximum temperature 95th percentile EHE definition.

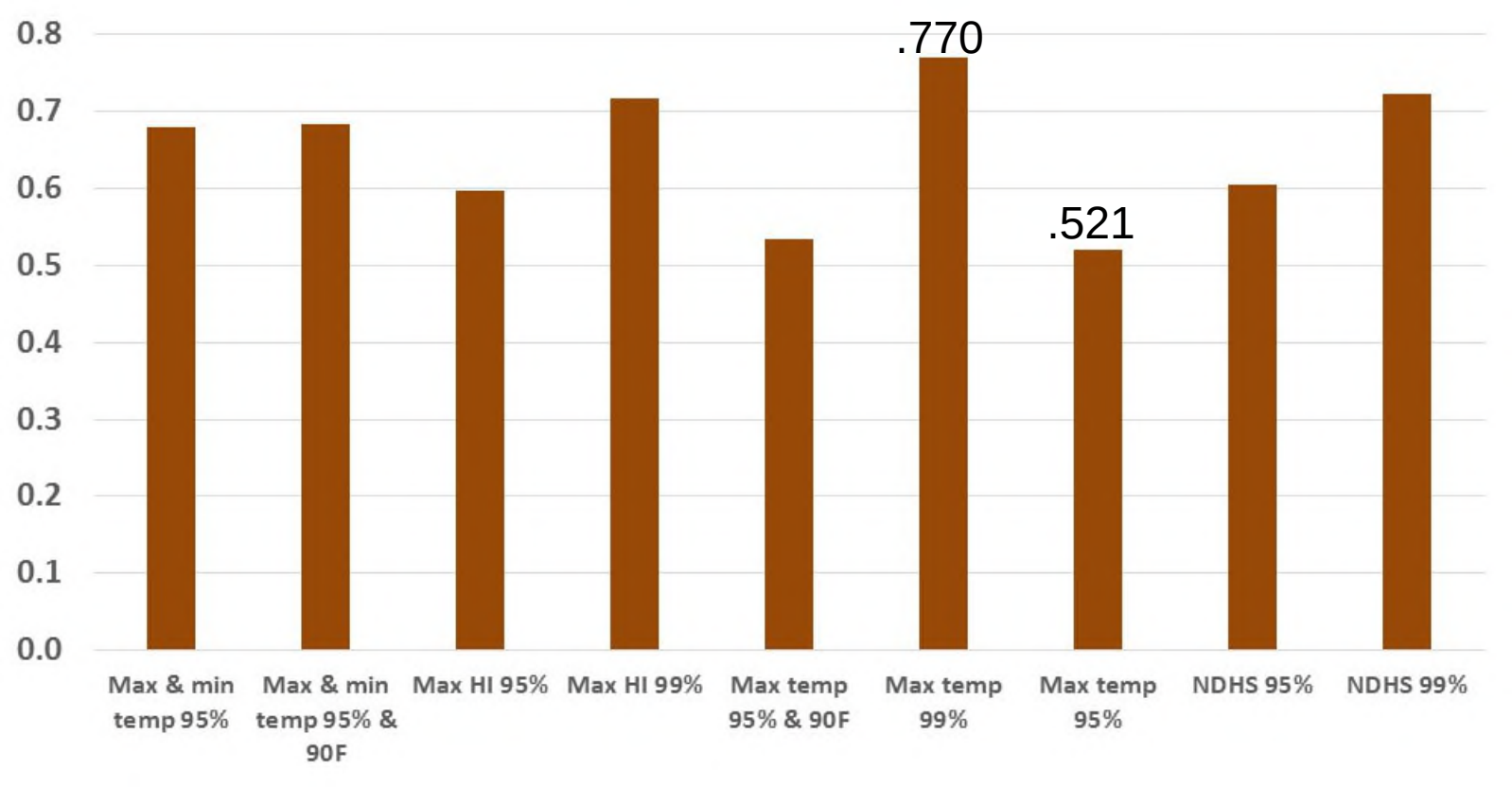


# Evaluation Statistics – Linear Correlation Coefficient Results for Entire US

Results are shown for best temporal lag (usually 1 day).

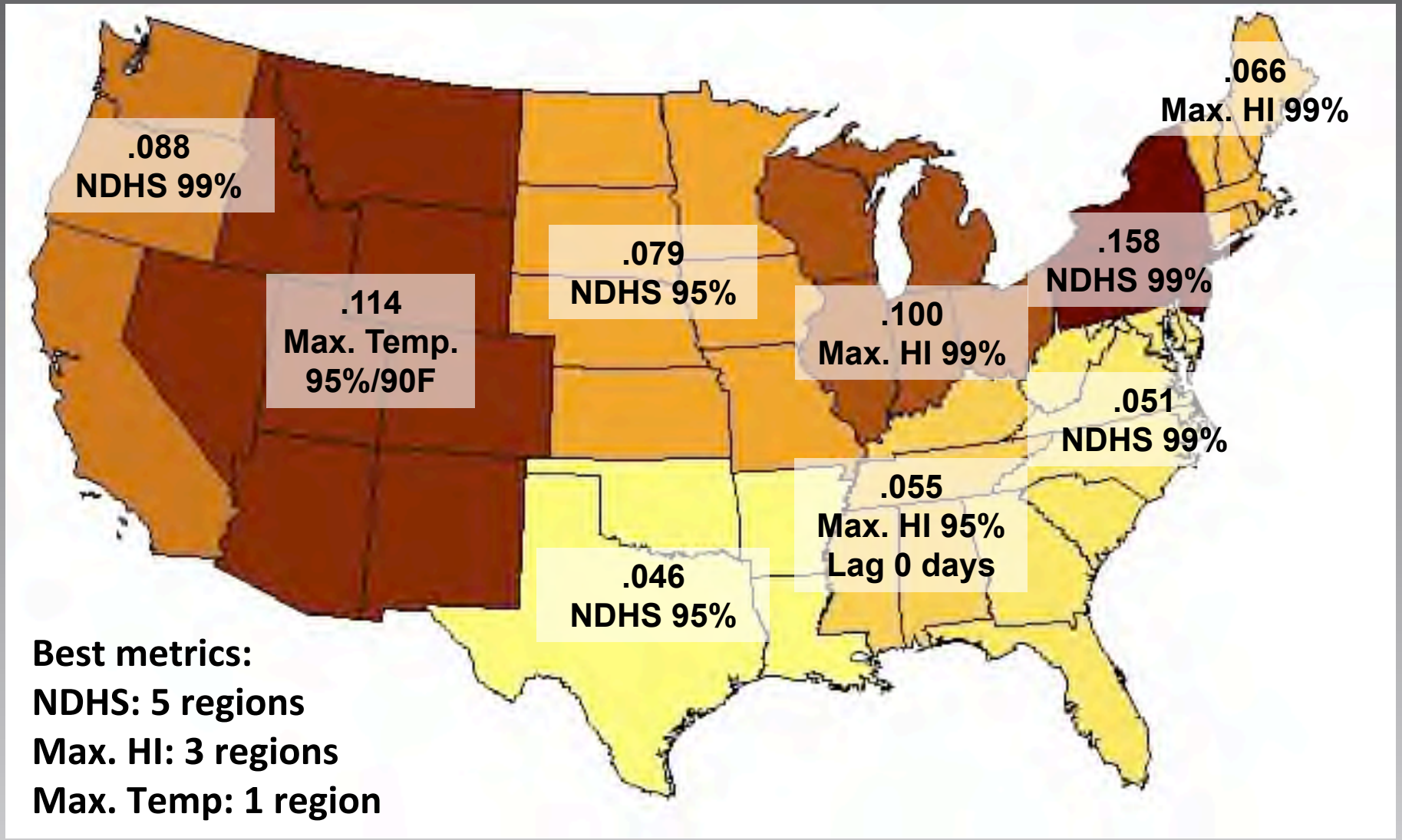
Best results: Maximum temperature 99th percentile EHE definition.

Worst results: Maximum temperature 95th percentile EHE definition.



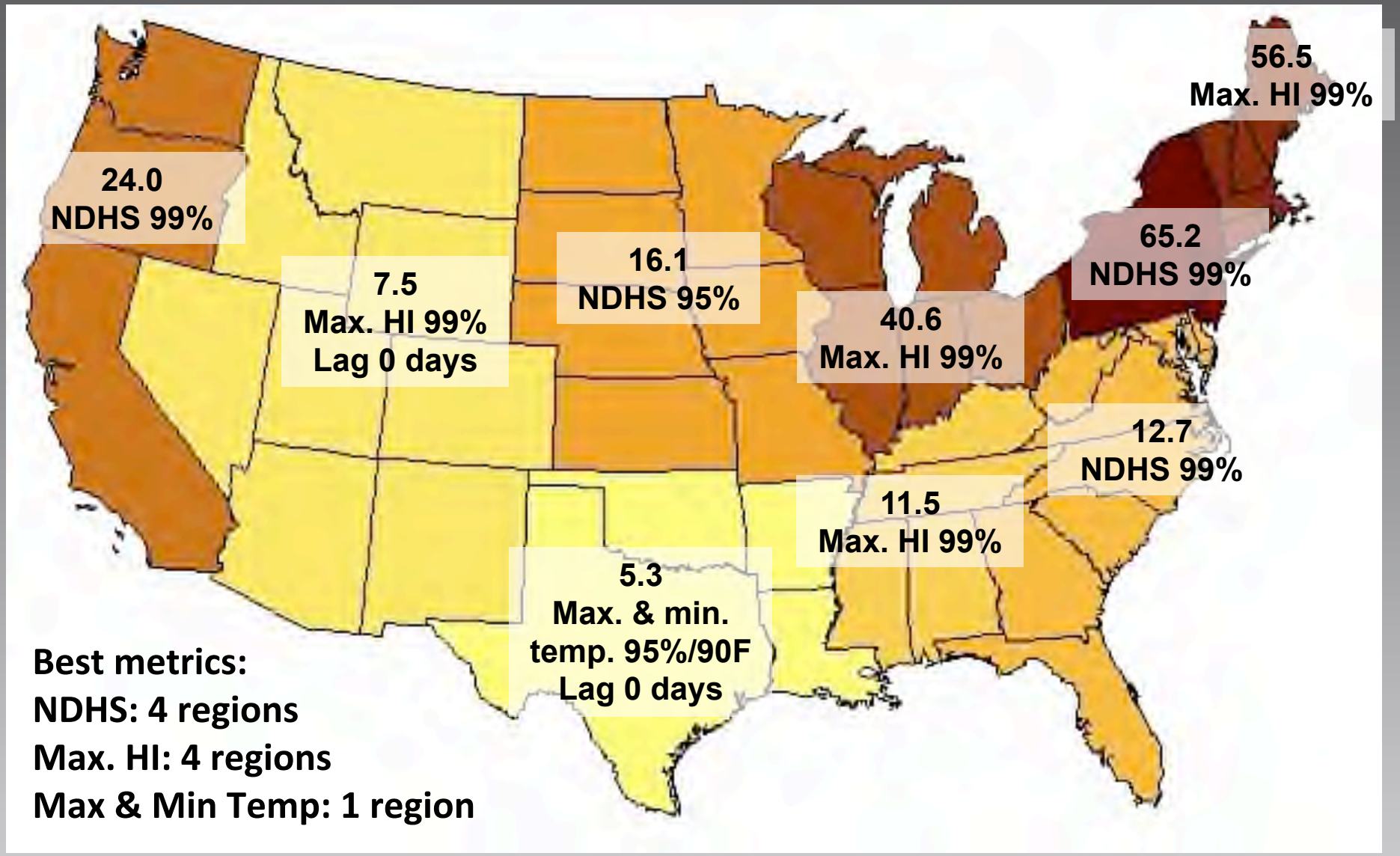
# Evaluation Statistics – Equitable Threat Score

Best results were obtained using a lag of 1 day unless otherwise noted.



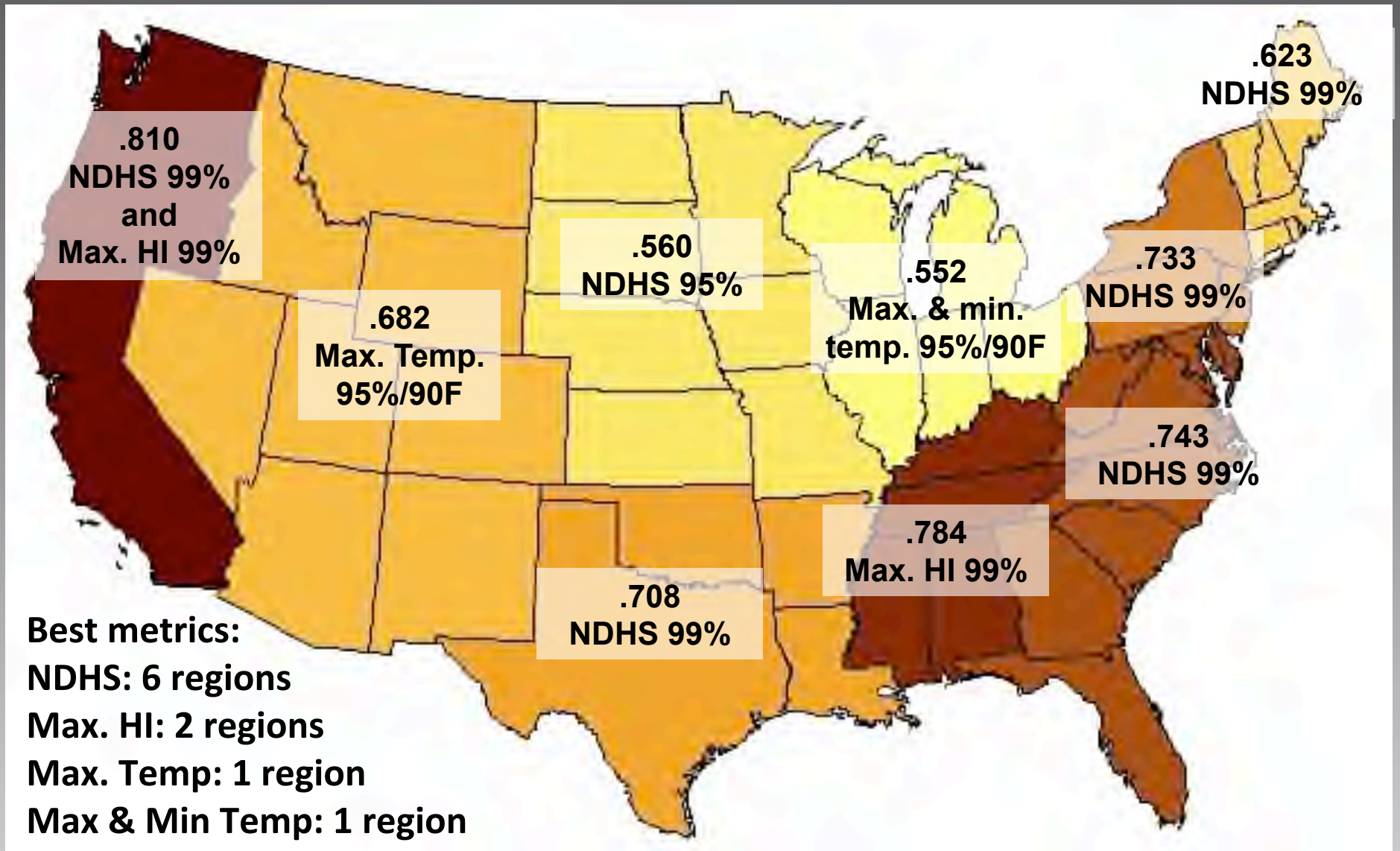
# Evaluation Statistics – Ratio of Death Rates

Best results were obtained using a lag of 1 day unless otherwise noted.



# Evaluation Statistics – Linear Correlation Coefficient

Best results were obtained using a lag of 1 day unless otherwise noted.



# Summary and Conclusions

- We used NLDAS meteorological data to identify all Extreme Heat Events, based on 9 definitions, during 1999-2010 for all US counties.

- We used CDC's 'Multiple Causes of Death, 1999-2010' dataset to compute daily, county-level mortality counts for which heat was the underlying or a contributing cause.

- We used three statistics to evaluate how well the 9 EHE definitions correlate with heat-related mortality within 9 US regions.

- For the US, and for most regions, the Net Daily Heat Stress metric performed best, followed closely by daily maximum Heat Index.

- For each evaluation statistic and each heat metric, EHE definitions using $99^{th}$ percentile performed better than definitions based on $95^{th}$ percentile.

- A temporal lag of 1 day produced the best indicator of mortality in most cases.

# Acknowledgments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