Estimation and Extrapolation of Climate Normals and Climatic Trends

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Outline

- Motivation: Rapid Climate Change and the Irrelevance of WMO Normals
- Take-Away Messages
- Existing Approaches and their Relative Accuracies (using contributions by Konstantine Vinnikov, Marina Timofeyeva, and Richard Tinker)
- New and Hybrid Approaches
- Concluding Remarks

How well can we describe the current climate?

- As a practical matter, we don't know with sufficient accuracy or confidence what regional or local climates are today!

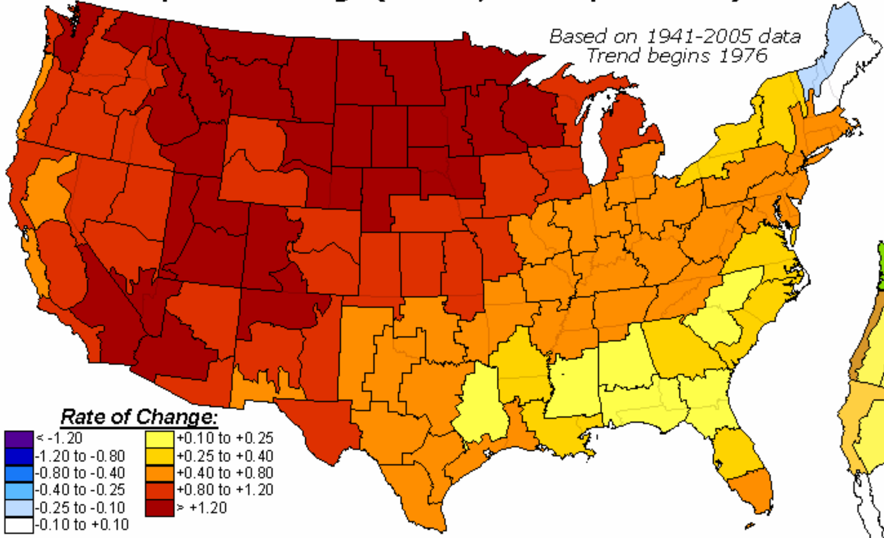
- This is because
  - the climate is changing rapidly,
  - we don't have dynamical models that can credibly replicate the statistics of the current climate at spatial and seasonal resolutions important to users
  - we have been slow to improve on the inadequate empirical approaches (which include linear-trend fits and the Optimum Climate Normal, OCN) currently used to estimate trends and track the changing climate.

Take-Away Messages

- The United States has undergone dramatic climate change over the last 30 years or so and change is likely to continue.
- These changes need to be taken into account in all activities that rely on knowledge of climate normals, risks, and other climate statistics. This requires better estimates of today's climate and methods for extrapolation.
- Alternatives to operational approaches for improved estimation and extrapolation of climate normals are available now. In the near term they are our best opportunity for substantial improvements to climate change related services.
- We need to alert the user community to the problem and its solutions.

U.S. Trends

Rate of Long-Term Trend Temperature Change (top; °F per decade)
& Precipitation Change (bottom; inches per decade) – JFM



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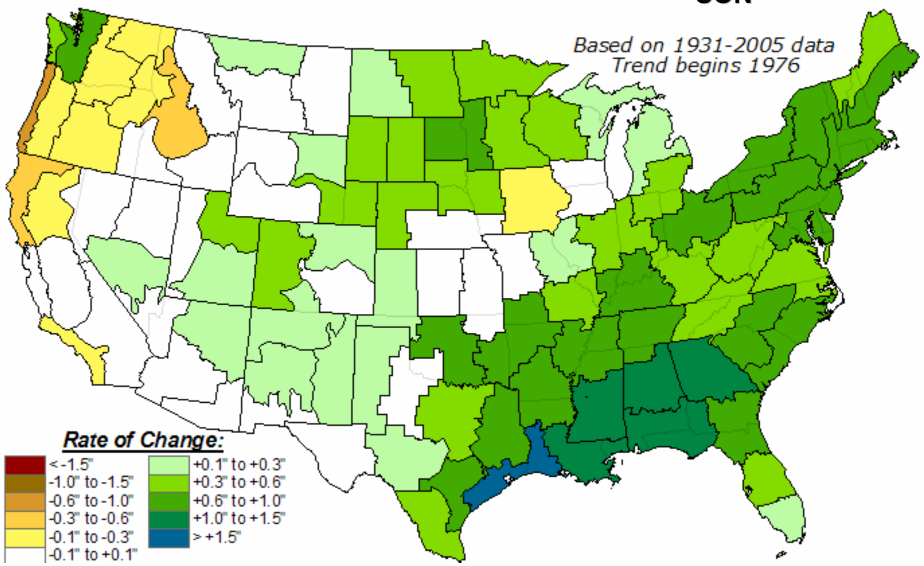
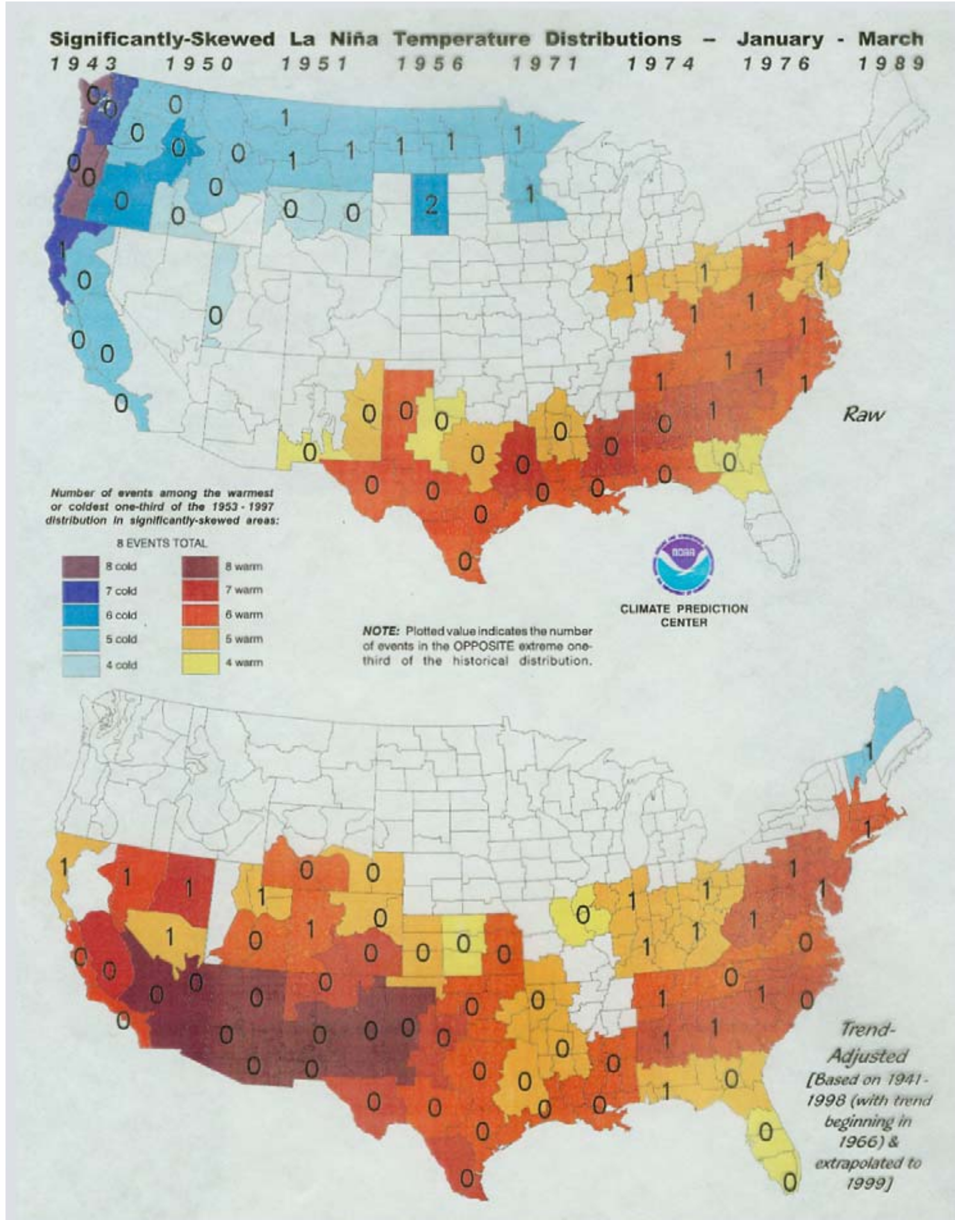


Complete set at http://www.cpc.ncep.noaa.gov/trndtext.shtml

JFM



Significantly-Skewed La Niña Temperature Distributions – January - March
1943 1950 1951 1956 1971 1974 1976 1989
Raw
Number of events among the warmest or coldest one-third of the 1953 - 1997 distribution in significantly-skewed areas:
8 EVENTS TOTAL
8 cold
7 cold
6 cold
5 cold
4 cold
8 warm
7 warm
6 warm
5 warm
4 warm
NOTE: Plotted value indicates the number of events in the OPPOSITE extreme one-third of the historical distribution.
CLIMATE PREDICTION CENTER
Trend-Adjusted [Based on 1941-1998 (with trend beginning in 1966) & extrapolated to 1999]

Common Methods for Estimating and Extrapolating Climate Normals

- 30-year normal, updated every 10 years, available in 3rd year, persistence constitutes the forecast.

- Optimum climate normal (OCN), average of previous 10-years (temp) and 15-years (precip), updated annually, persistence constitutes the forecast (CPC operational methodology).

- Least-squares linear trend fit, extrapolation of fitted trend constitutes the forecast.

- Intuition suggests that if the climate is changing rapidly and the change is dominantly linear, each successive method above will outperform the others. Livezey, *et. al.* (2007) have attempted to quantify this relative performance.

Error in Estimates of Current and Extrapolated Normals

- Assume the time series of a particular monthly or seasonal average can be well represented by trend plus climate noise (year to year variability), where

  σ the standard deviation of the climate noise with zero mean,

  g is the year to year persistence in the climate noise,

  τ years from the end of the averaging or estimation period, *i.e.* the forecast lead, and

  $\beta = b/\sigma$ the scaled trend (per year).

- Let $\eta(t)$ be the expected mean squared scaled (by σ) error of Y(t). As a reference, let an acceptable RMSE be 0.5σ, or $\eta(t) = 0.25$

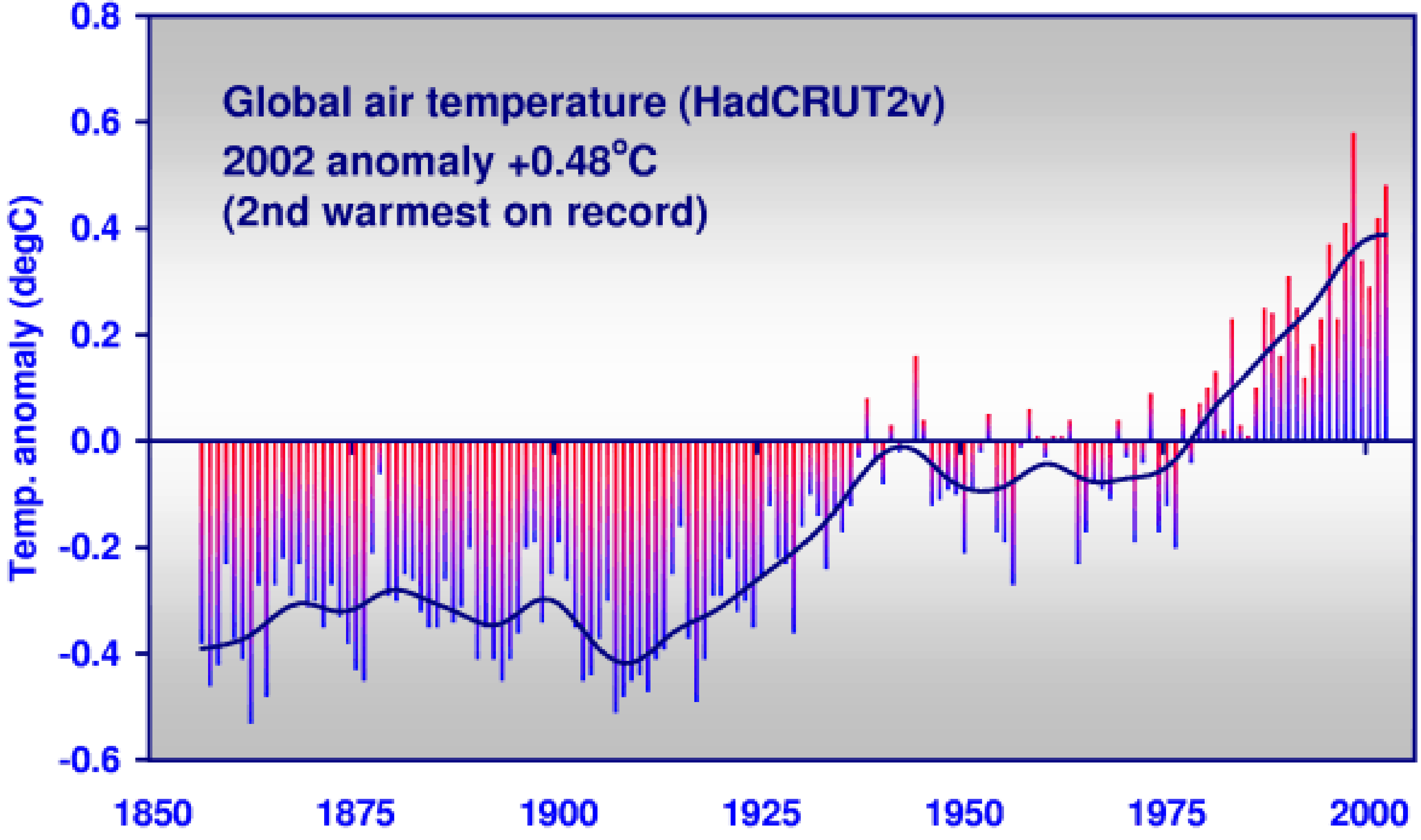
Errors with Use of 30-Year Normals, OCN, and Linear Trend Fits

- 30-Year Normals: Except for weak trends error is already unacceptable at release, and by next release ($\tau > 10$) grossly in error!
- OCN: Big improvement over 30-year normals but error still not acceptable beyond moderate trends ($\beta = 0.05$) with weak residual redness.
- The linear fit outperforms the OCN for moderate to strong trends, but not weak ones.

Notes on Fitting Linear Trends

- A linear trend fit should never be fit to a whole time series or a segment arbitrarily.
- At a minimum the scatter diagram should be examined to confirm that the trend is not obviously non-linear.
- Optimally the functional form of the trend should be based on additional considerations.
- Linear trend fits are very sensitive to endpoints.
- Very large-scale trends associated with global warming are approximately linear over the last 30-years but decidedly not over the last 40 to 70 years.

Notes on Fitting Linear Trends



From Trenberth (2004) Presentation

A Hinge Fit for U.S. Trends

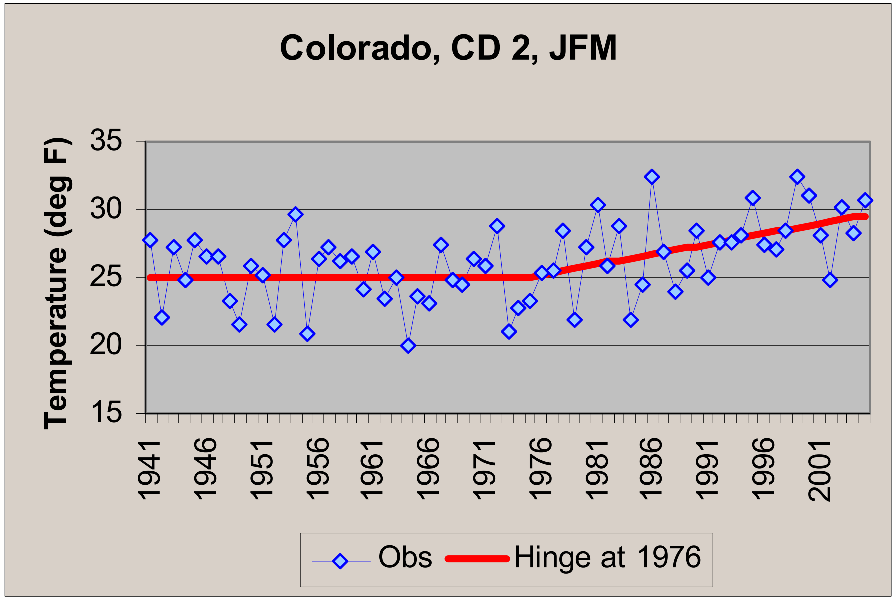
- **Piecewise continuous with no change from 1940-1976 and linear change thereafter.**

- **An appropriate trend model for strong trends since the mid-1970s related to global warming.**

- **Sampling variability is substantially smaller than a linear fit to the last three decades.**

- **Thus it will outperform the linear fit if the underlying trend is dominantly linear.**

- **β = 0.06, g = -0.1 in this example.**



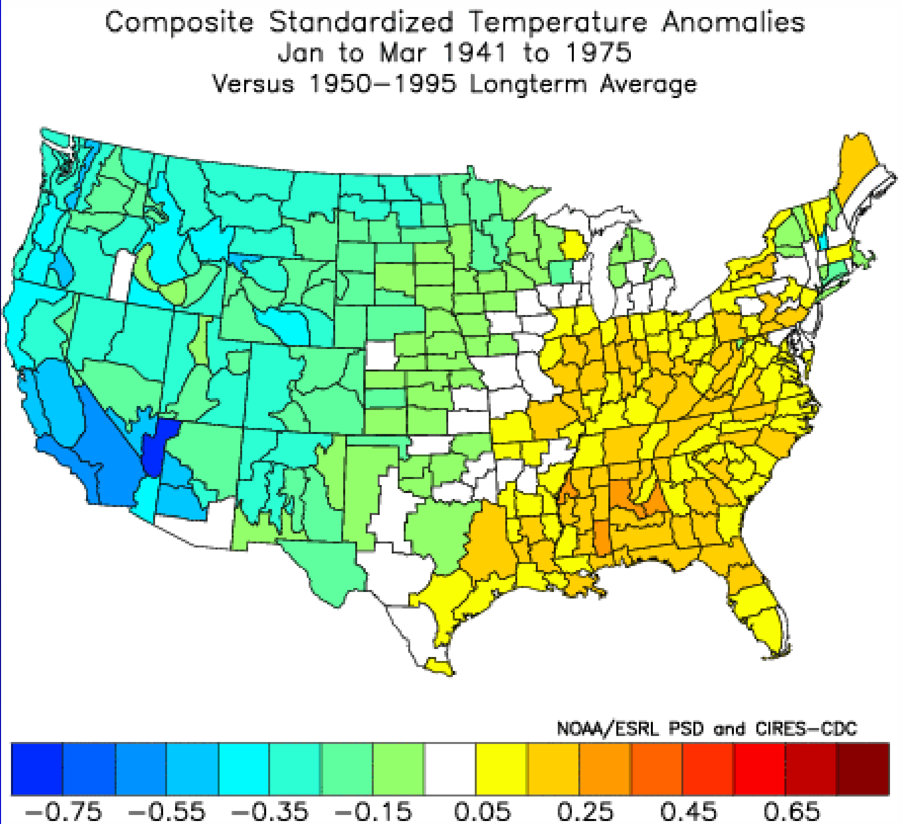
A Hinge Fit for U.S. Trends

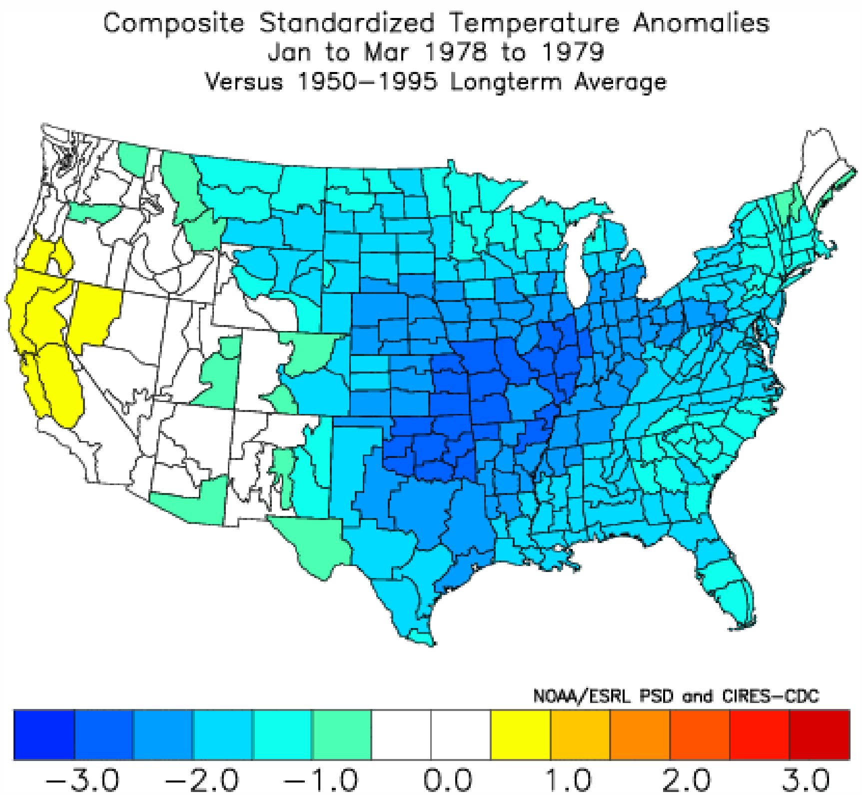
τ_{max}				
g	**Hinge Fit (N = 65 yrs)**	**Linear Fit (N = 30 yrs)**	**OCN (β = 0.03)**	**OCN (β = 0.05)**
0.0	14	7	8	3
0.1	10	5	7	2
0.2	7	3	6	2
0.3	4	1	5	1
0.5	--	--	2	--

- For any β, the table shows the error threshold expressed as the maximum τ with acceptable error.

- The hinge fit outperforms OCN for all but the smallest trends.

A Hinge Fit for U.S. Trends





The mid- to late 1970s were unrepresentative of the post-1940 climate, so linear trend fits from then give a distorted view of modern trend pattern.

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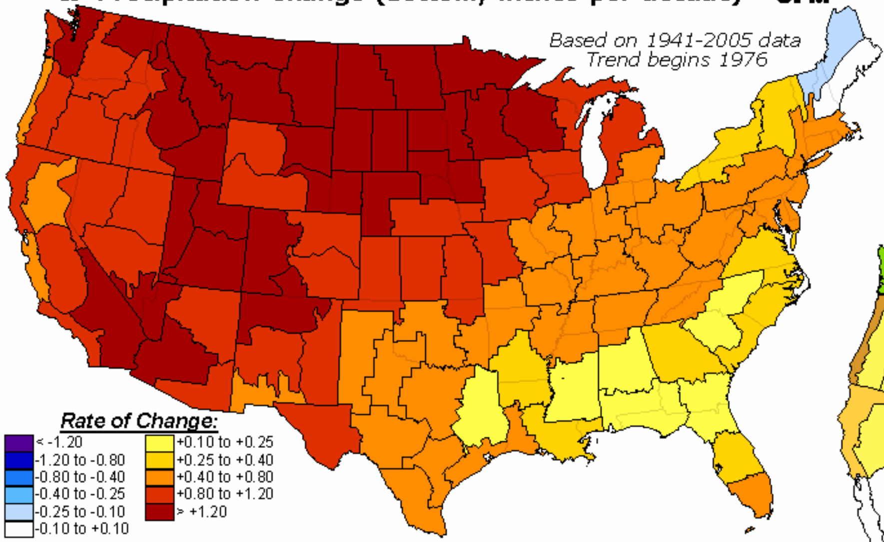

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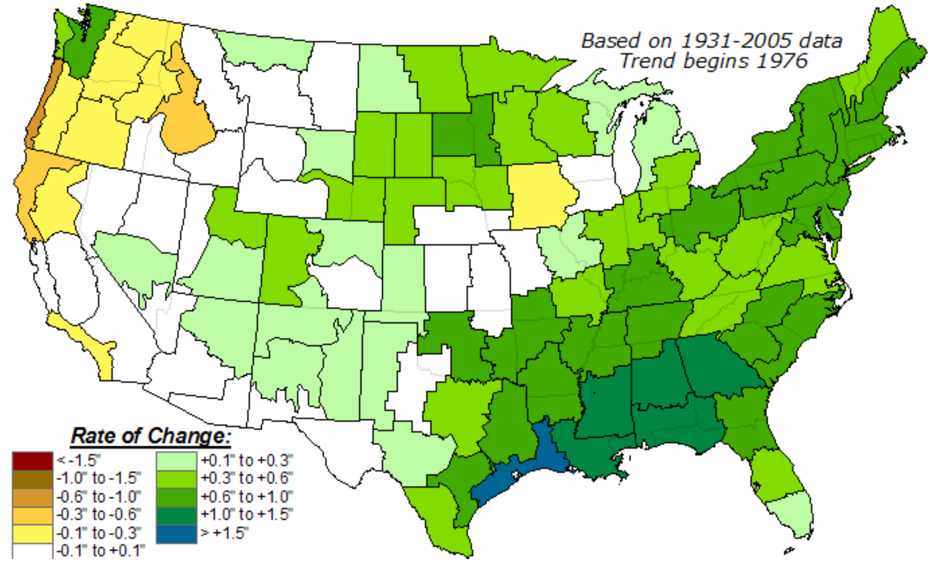

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- Alternatives to operational approaches for improved estimation and extrapolation of climate normals are available now.

- We need to alert the user community to the problem and its solutions: OCN where trends are small and the hinge fit where trends are moderate to large.

- See Livezey, Vinnikov, Timofeyeva, Tinker, and Van den Dool, 2007: Estimation and extrapolation of climate normals and climatic trends. *Journal of Applied Meteorology and Climatology.* In press.