Estimating the Role of Natural Variability in Climate Change Using Observations

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results drawing from:

- Thompson et al. (submitted to Journal of Climate)

see www.atmos.colostate.edu/~davet
Time series of near surface temperature from the NCAR CCSM3 40-member ensemble.

Ticks at 1 deg.

See also Deser et al. 2012
Range of trends from all 40 ensemble members during October-March.
• What determines the range of trends indicated by the large ensemble?

• Can the range in climate trends be accurately estimated from a control simulation?

• Can the range in the trends be accurately estimated from observations?
An analytic expression for the margins of error in a Gaussian process.

Consider a time series $x(t)$ with mean zero and linear least-squares trend $b$.

The confidence interval on the trend in $x(t)$ can be expressed as:

$$CI = b \pm e$$

Where $e$ is the margin of error on the trend.
If the distribution of the deviations in $x(t)$ about its linear trend is Gaussian, then the margin of error on the trend in $x(t)$ is:

$$e = t_c s_b$$

where $e$ is the margin of error on the trend.

The trend, its confidence interval and its margin of error are all expressed in units $\Delta x / n_t \Delta t$,

where $n_t$ is the number of time steps and $\Delta t$ is the time step.

For example, if $x(t)$ corresponds to 50 years of wintertime mean temperature data, then $n_t = 50$, $\Delta t = 1 \text{ year}$, and the temperature trend in $x(t)$ is expressed in units degrees Celsius/50 years.

If the distribution of the deviations in $x(t)$ about its linear trend (i.e., the residuals of the regression) is Gaussian, then the margin of error on the trend in $x(t)$ is:

1) $e = t_c s_b$
2) $s_b = n_t \sum (i_i - i_i)^2 / n_t$

$s_b$ is the standard error of the trend, $n_t$ is the number of time steps, and the factor $n_t$ is included so that the standard error is given in units $\Delta x / n_t \Delta t$.

Equations 1 and 2 are widely used to assess the significance of a trend in climate science.

Regarding the standard deviation of the time axis: The denominator in Eq. 2 can be expanded as:

- desired confidence level
- standard error of the trend.
If the distribution of the deviations in \(x(t)\) about its linear trend is Gaussian, then the margin of error on the trend in \(x(t)\) is:

\[
e = t_c s_b
\]

where:

- \(e\) is the margin of error on the trend.
- \(t_c\) is the desired confidence level.
- \(s_b\) is the standard error of the trend.

\[
s_b = \frac{n_t s_e}{\sqrt{\sum_{i=1}^{n_t} (i - \bar{i})^2}}
\]

where:

- \(n_t\) is the number of time steps.
- \(s_e\) is the standard error of the residuals.
- \(\bar{i}\) is the mean of the time steps. 

The trend in \(x(t)\) is expressed in units about its mean \(\overline{x(t)}\).
After some algebra...

\[ e = t_c \cdot n_t \cdot \sigma \cdot \gamma(n_t, r_1) \cdot g(n_t) \]

- **length of the record**
- **scaling factor** to account for autocorrelation
- **standard deviation of the residuals**
- **arises from variance of the time axis**

\[ \gamma(n_t, r_1) = \left( \frac{[n_t - 2]}{n_t \left( \frac{1 - r_1}{1 + r_1} \right) - 2} \right)^{1/2} \]

\[ g(n_t) = \sqrt{\frac{12}{n_t^3 - n_t}} \]
The margin of error on a trend in a Gaussian process is a function of three statistics:

1) the standard deviation of the internal (unforced) variability.

2) the lag-one autocorrelation of the internal (unforced) variability.

3) the number of time steps in the time series.
If the residuals are serially uncorrelated and the trend is 50 time steps, then:

$$e_{95\%} \sim \sigma \ (\text{for } n_t = 50 \text{ and } r_1 \sim 0)$$
… testing the analytic model in the NCAR CCSM3 large ensemble

"Actual" 95% margin of error on trends (from 40 ensemble members)

50 year trends in Oct-March surface temperature

From Thompson et al. 2015
... testing the analytic model in the NCAR CCSM3 large ensemble

“Actual” 95% margin of error on trends (from 40 ensemble members)

“Predicted” 95% margin of error (from interannual standard deviation of control run)

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... testing the analytic model in the NCAR CCSM3 large ensemble

b) “Actual” 95% margin of error on trends
   (from 40 ensemble members)

c) “Predicted” 95% margin of error
   (from interannual standard deviation of control run)

50 year trends in Oct-March precipitation

From Thompson et al. 2015
… testing the analytic model in the NCAR CCSM3 large ensemble

50 year trends in Oct-March precipitation
50 year trends in Oct-March precipitation
... applying the analytic model to observations

“Predicted” 95% margin of error
(from interannual standard deviation of observations)

Predicted uncertainty in Oct-March surface temperature trends

Observations from CRU

From Thompson et al. 2015
... applying the analytic model to observations

“Predicted” 95% margin of error
(from interannual standard deviation of observations)

“Predicted” 95% margin of error
(from interannual standard deviation of control run)

Predicted uncertainty in Oct-March surface temperature trends
... applying the analytic model to observations

"Predicted" 95% margin of error
(from interannual standard deviation of control run)

"Predicted" 95% margin of error
(from interannual standard deviation of observations)

Predicted uncertainty in Oct-March surface temperature trends
... applying the analytic model to observations

Predicted uncertainty in Oct-March precipitation trends

From Thompson et al. 2015
... applying the analytic model to observations.

“Predicted” 95% margin of error
(from interannual standard deviation of observations)

Observations from GPCP

Control simulation

Predicted uncertainty in Oct-March precipitation trends
... applying the analytic model to observations

"Predicted" 95% margin of error
(from interannual standard deviation of observations)

Observations from GPCP

Predicted uncertainty in Oct-March precipitation trends
Time of emergence / when is a trend significant?

set $e = bn_t$ and solve for $n_t$

for seasonal-mean data and $n_t \approx 10$:

$$n_t = 12^{1/3} \left( \frac{t_c \sigma}{b} \right)^{2/3}$$
• $bn_t$ is the ensemble mean trend (the forced response)
• $e$ is the uncertainty predicted by control
Chicago wintertime

\[ n_t = 12^{1/3} \left( \frac{t_c \sigma}{b} \right)^{2/3} \]

\( n_t \) denotes the time step when 95% of the ensemble members (i.e., realizations of the real world) exceed a trend of 0.
$n_t = 12^{1/3} \left( \frac{t_c \sigma}{b} \right)^{2/3}$

$n_t$ denotes the time step when 95% of the ensemble members (i.e., realizations of the real world) exceed a trend of 0.
the “time of emergence” given by an individual ensemble member does not:
1) correspond to the time step when the forced signal is significant
2) account for the uncertainty in the trend due to natural variability
The analytic model provides a zeroth order estimate of the uncertainty in future trends in any **Gaussian** process with **stationary** variance.

E.g., the atmospheric circulation at middle latitudes, precipitation averaged over a specific watershed, surface temperature averaged over a broad agricultural region, and global-mean temperature.
Large-ensembles provide seemingly little information on the role of internal variability in future climate that can not be inferred from a relatively short, unforced climate simulation.

(Multiple ensembles are required to estimate the forced response)
Arguably… the role of internal variability in future climate change is best estimated not from a climate model (which inevitably exhibits biases), but from the statistics of the observed climate.

(Decadal variability accounts for a relatively small fraction of the standard deviation on regional scales).

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