How much has China warmed?

Photo: F. Zwiers (Lijiang countryside)

Sun Yat-Sen University
6 April 2016

中山大學
SUN YAT-SEN UNIVERSITY

Francis Zwiers, Pacific Climate Impacts Consortium
University of Victoria, Victoria, Canada

Outline

- Introduction
- Urban warming effect
- Previous estimates
- Detection and attribution
- Application to quantifying urban warming
- Conclusions

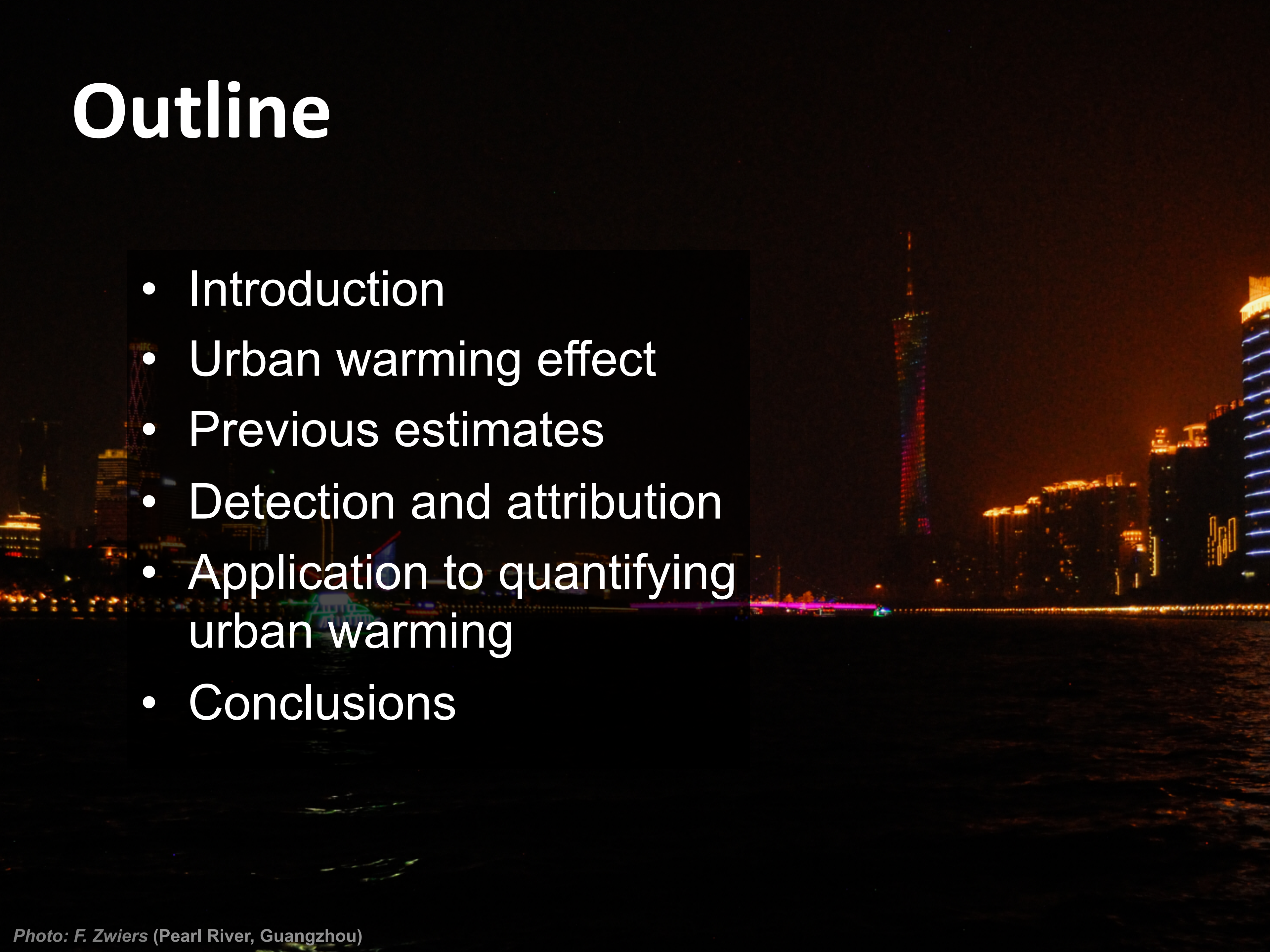


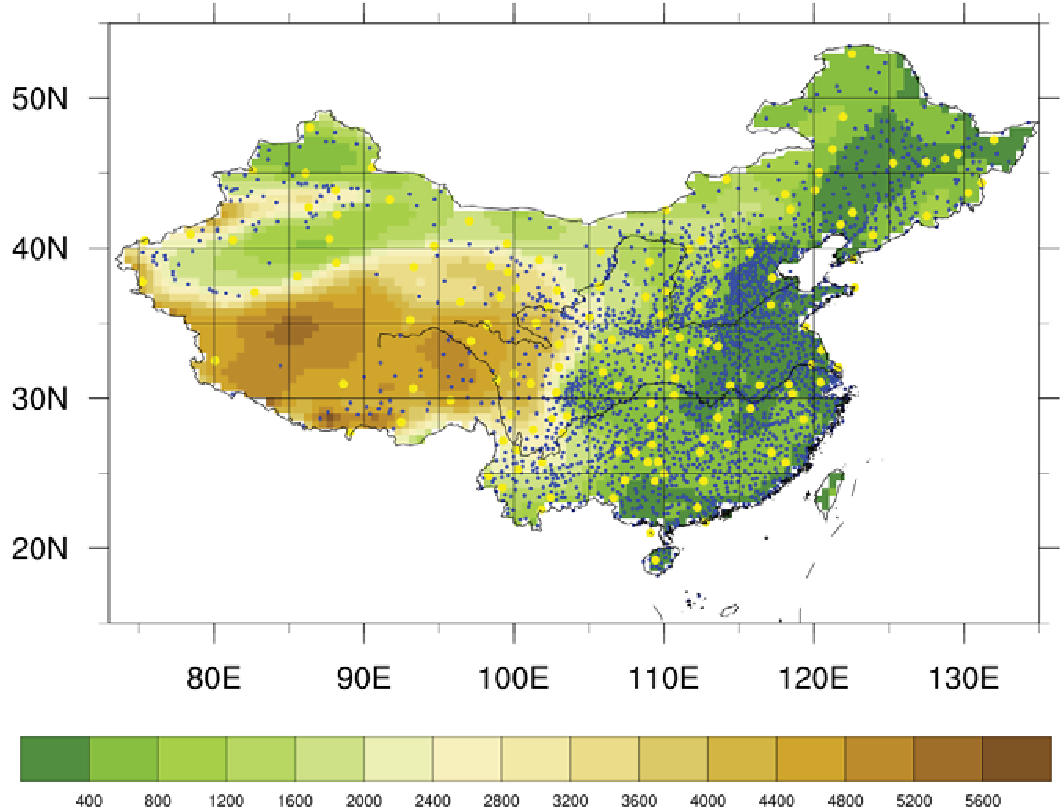
Photo: F. Zwiers **(Pearl River, Guangzhou)**

Introduction

- China's surface temperature record indicates 1.44°C (90% confidence interval [1.22-1.66°C]) of warming over 1961-2013 (53 years)
- The global mean land temperatures warmed 1.09°C [0.86-1.31°C] over 1951-2010 (60 years)
- Why did China warm so much more quickly?
- One possibility is that the Chinese temperature record might be contaminated by the expansion of urban heat islands over this period
- This would lead an over-estimate of the average amount of warming across China

Introduction

- Urban areas cover <1% of China’s land mass
- But most observing stations subject to some kind of urban influence
- China’s National Meteorological Information Centre provides 2419 homogenized stations (blue) for 1951-2013
- Ren et al (2015) identify 143 “rural” reference stations (yellow)



- Usual approach, which compares rural stations with all stations is uncertain and possibly biased low

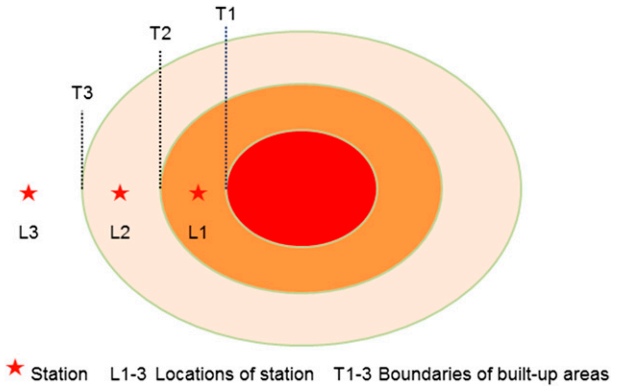
How much did China really warm, and why?

Urban warming effect

Photo: F. Zwiers (Lanzhou)

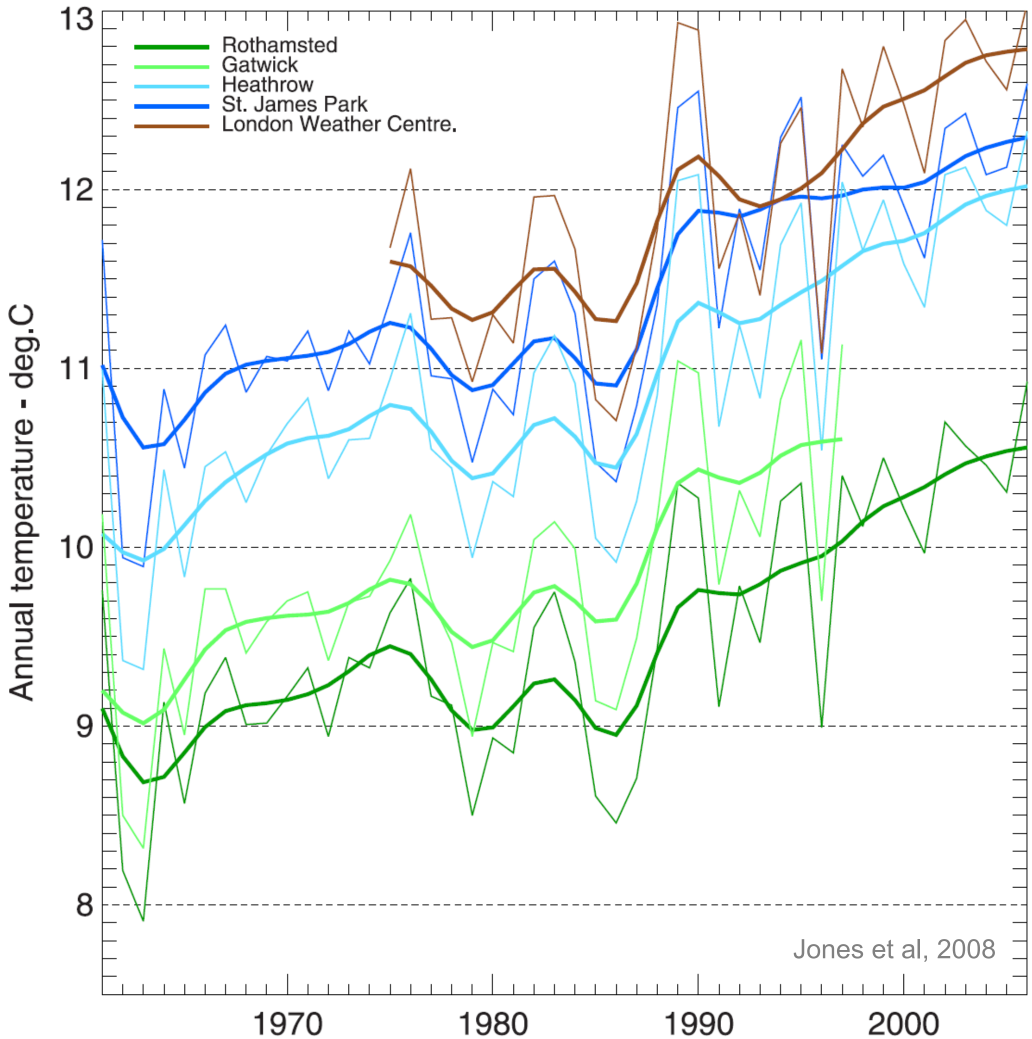
Urban heat island effects

- Long-recognized effect (e.g., Howard,1833)
- Location and history dependent
- London (Jones et al, 2008)
  - trends similar in urban and rural areas
  - urban region about 1.5-2.0°C warmer.



- New York City (Gaffin et al, 2008)
  - perhaps cause of 1/3 of warming in NYC since 1900
  - suggest skyline development may have played a role
- China (Jones et al, 2008)
  - rapidly developing
  - perhaps more than half of warming since 1954
  - very difficult to isolate UHI intensification from available data (very little rural data available)

Urban warming – London, UK

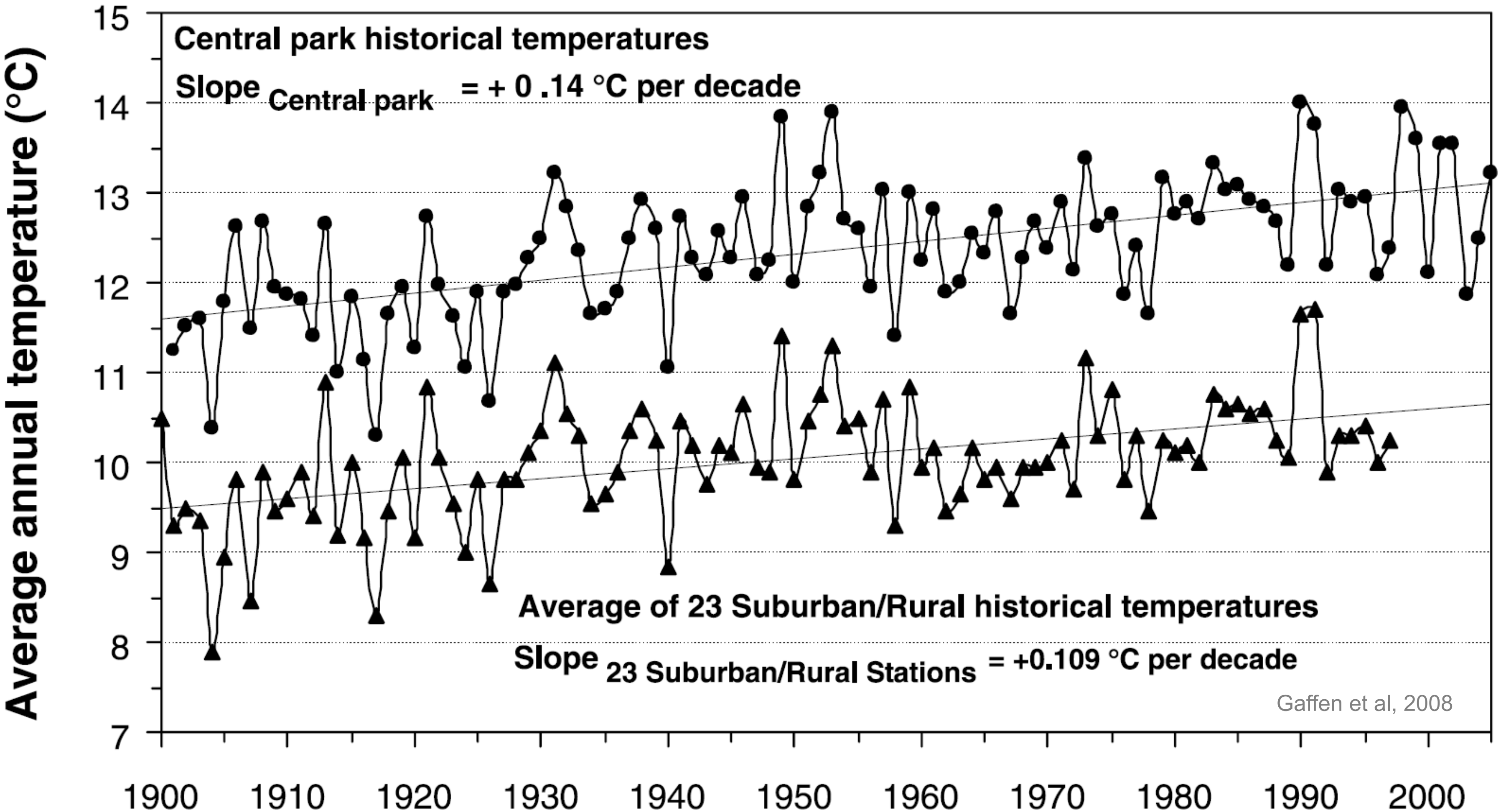


London Weather Centre
St. James Park
Heathrow Airport

Gatwick Airport
Rothamsted

- Rural, suburban and urban trends similar
- Notice also the common variability

Urban warming - NYC



Previous estimates of urban warming influence on China's temperature record

Photo: F. Zwiers (Cordova Bay Sunrise)

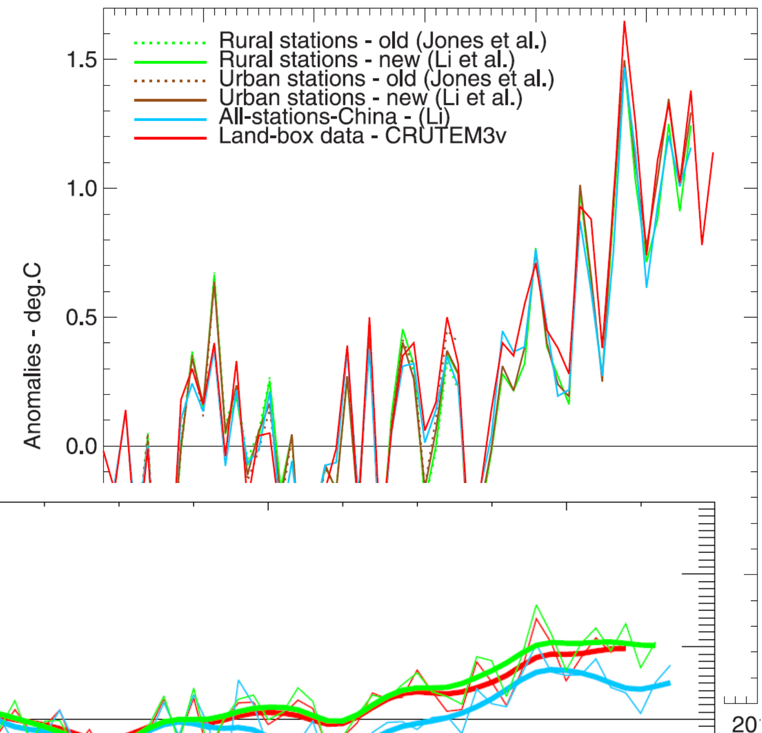
Urban warming effects on Chinese data

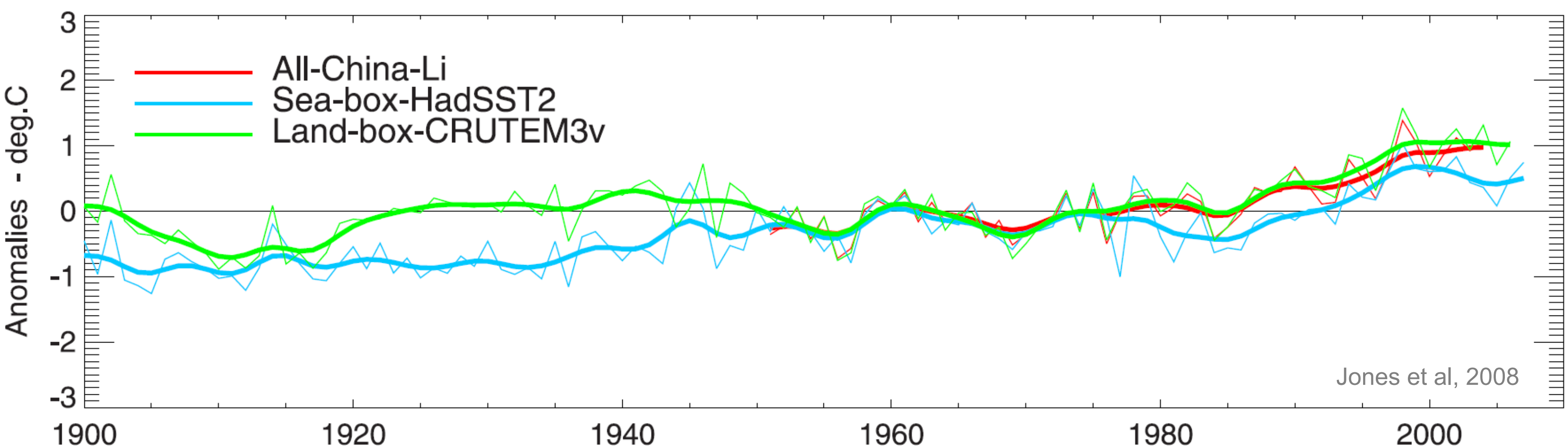
- Jones et al (2008) compare land temperatures with SSTs

- Land temperatures warmed 1.19°C to 1.35°C over 1951-2004 (depending on dataset used)
- Nearby SSTs warmed 0.76°C
- Jones et al suggest difference is due to urbanization effect (~0.5°C, or ~40% of recorded warming)

China annual average

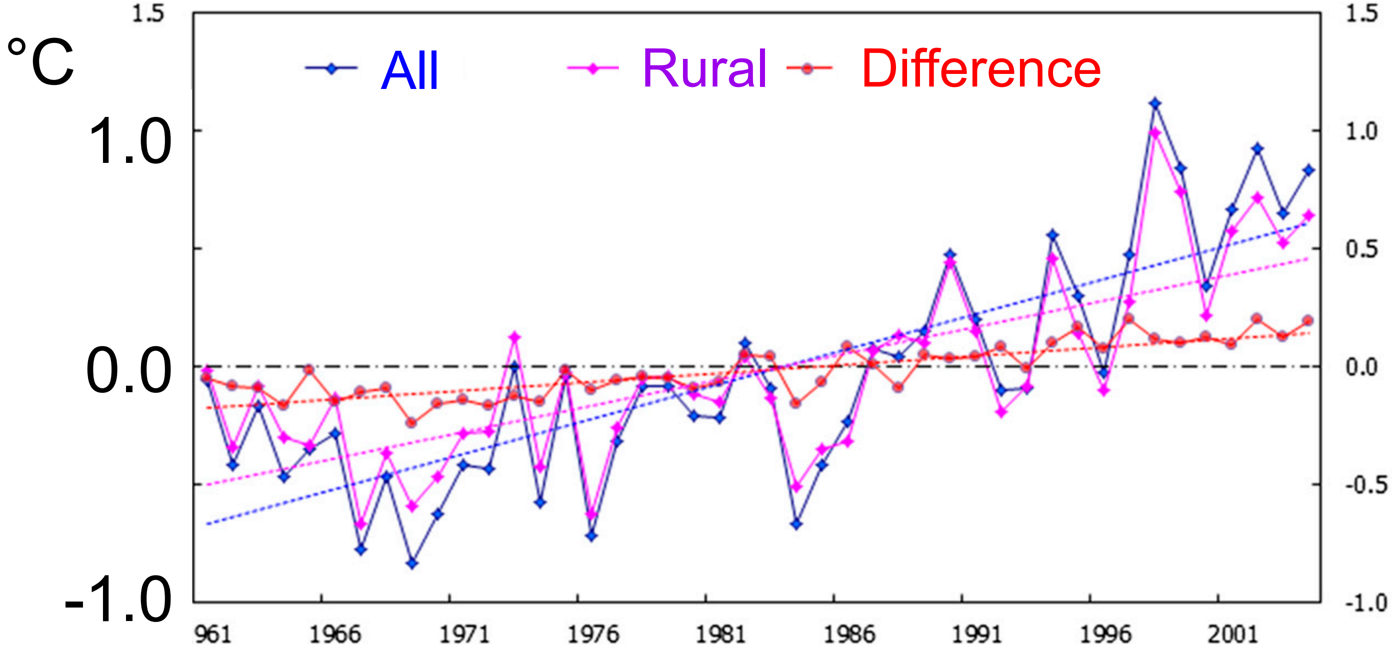
(relative to 1954-1983)





Urban warming effects on Chinese data

- Ren et al. (2015) compare rural reference stations with all stations (reference climate network and basic meteorological network) combined



- Difference ≈25% of recorded warming over 1961-2004 (0.32°C of 1.28°C)

Detection and attribution of Long Term Climate Change

Photo: F. Zwiers (Ring-Necked Duck, Victoria)

Some definitions

- *Detection* of change is the process of demonstrating that the climate or a system affected by the climate has changed in some defined statistical sense

- *Attribution* is the process of evaluating the relative contributions of multiple causal factors to a change or event with an assignment of statistical confidence

- Casual factors refer to *external influences*
  - Climate: *anthropogenic* and/or *natural*
  - Systems affect by climate: *climate change*

IPCC Good Practice Guidance Paper on Detection and Attribution, 2010

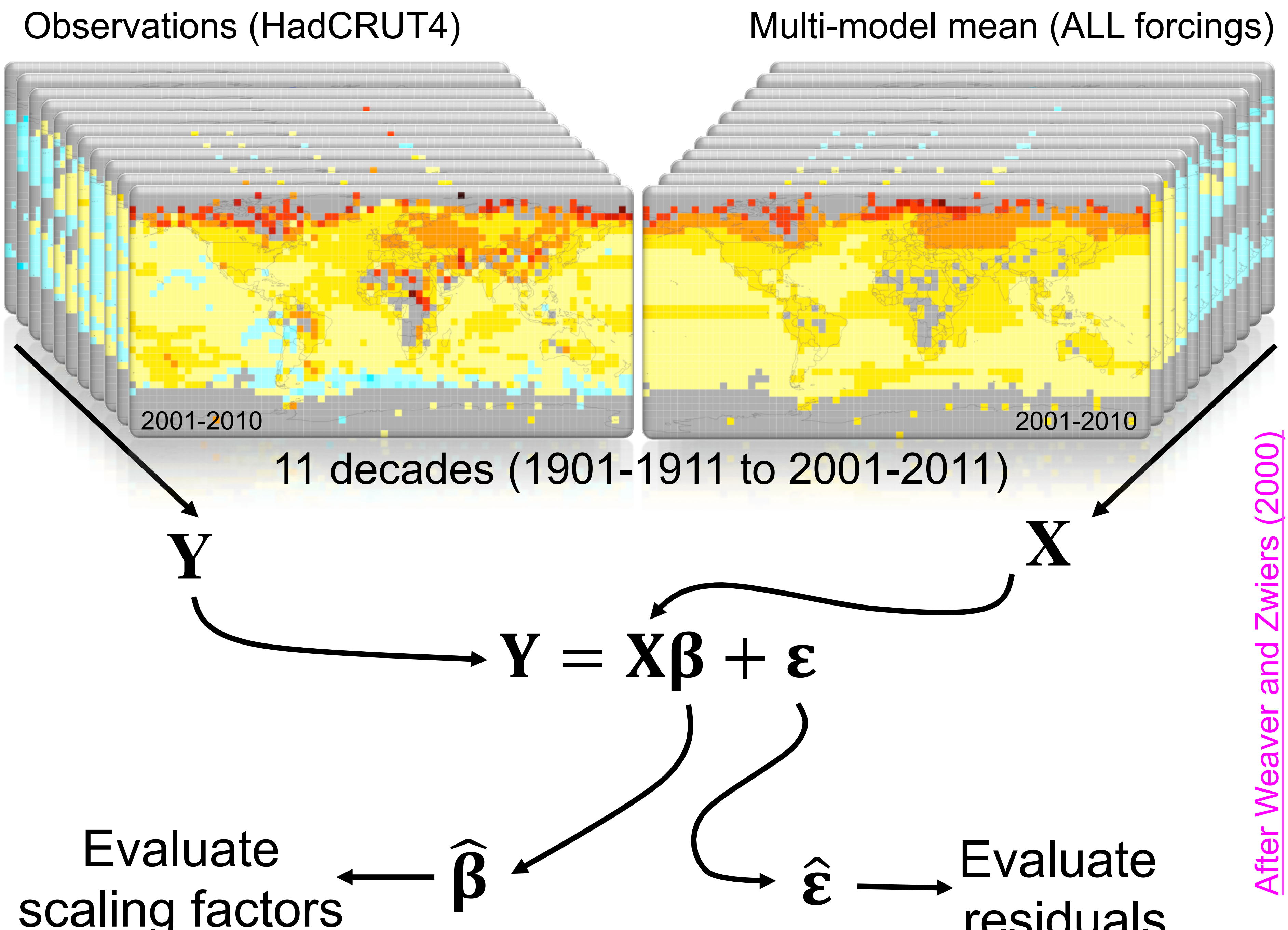
Methods

- Involve simple statistical models
- Complex implementation due to data volumes (which are both small and large)

Usual assumptions

- Key forcings have been identified
- Signals and noise are additive
- Model simulation of large-scale forcing response patterns ok, but signal amplitude is uncertain

→ leads to a regression formulation


Observations (HadCRUT4)
Multi-model mean (ALL forcings)
2001-2010
2001-2010
11 decades (1901-1911 to 2001-2011)
Y
X
Y = Xβ + ε
β̂
ε̂
Evaluate scaling factors
Evaluate residuals
After Weaver and Zwiers (2000)

That formulation has been evolving

$$\mathbf{Y} = \sum_{i=1}^{s} \beta_i \mathbf{X}_i + \boldsymbol{\varepsilon}$$

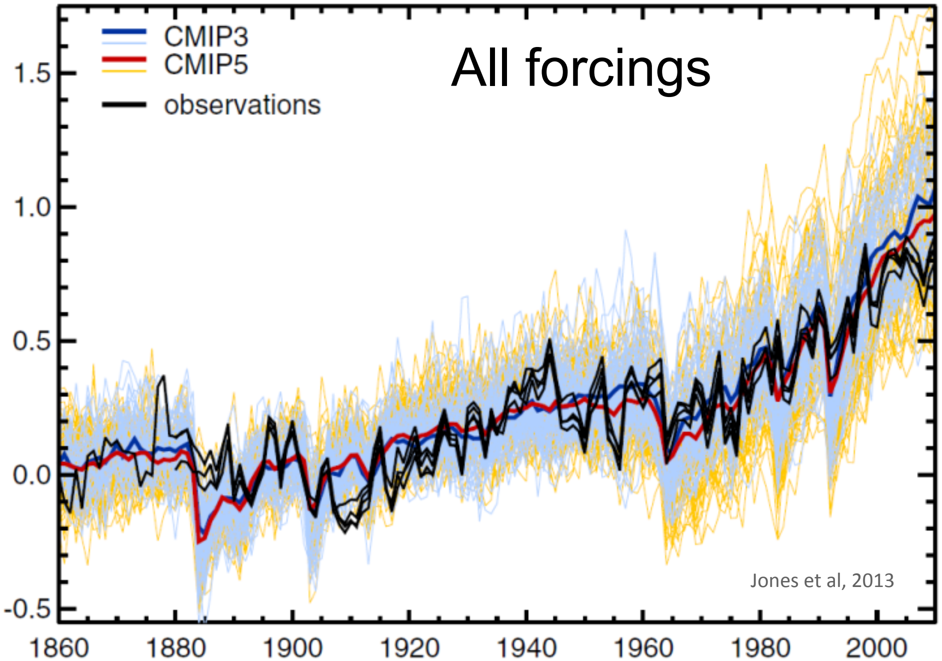
$$\mathbf{Y} = \mathbf{Y}^* + \boldsymbol{\varepsilon}_y$$
$$\mathbf{X}_i = \mathbf{X}_i^* + \boldsymbol{\varepsilon}_{x_i}$$
$$\mathbf{Y}^* = \sum_{i=1}^{s} \beta_i \mathbf{X}_i^*$$

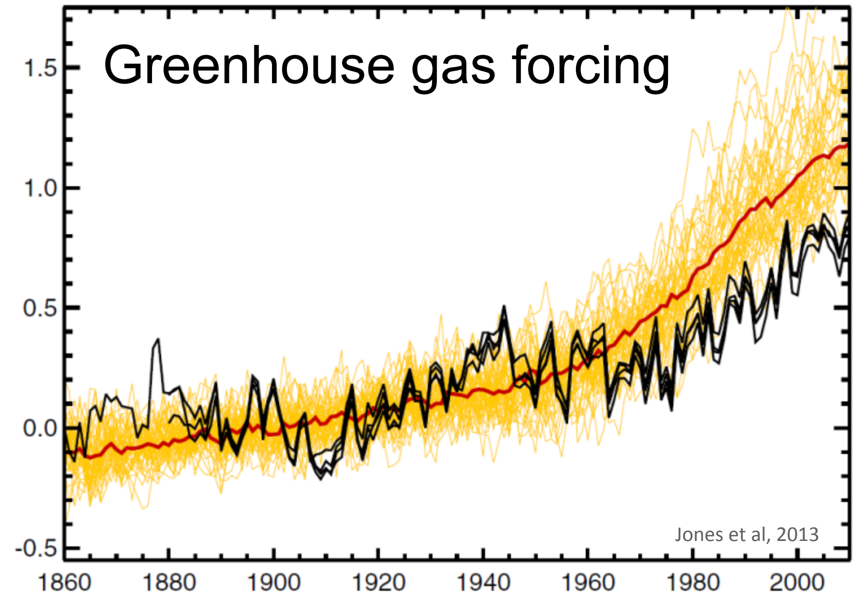
$$\mathbf{Y} = \mathbf{Y}^* + \boldsymbol{\varepsilon}_y$$
$$\mathbf{X}_i = \mathbf{X}_i^* + \boldsymbol{\varepsilon}_{x_i}$$
$$\mathbf{Y}^* = \sum_{i=1}^{s} \mathbf{X}_i^*$$

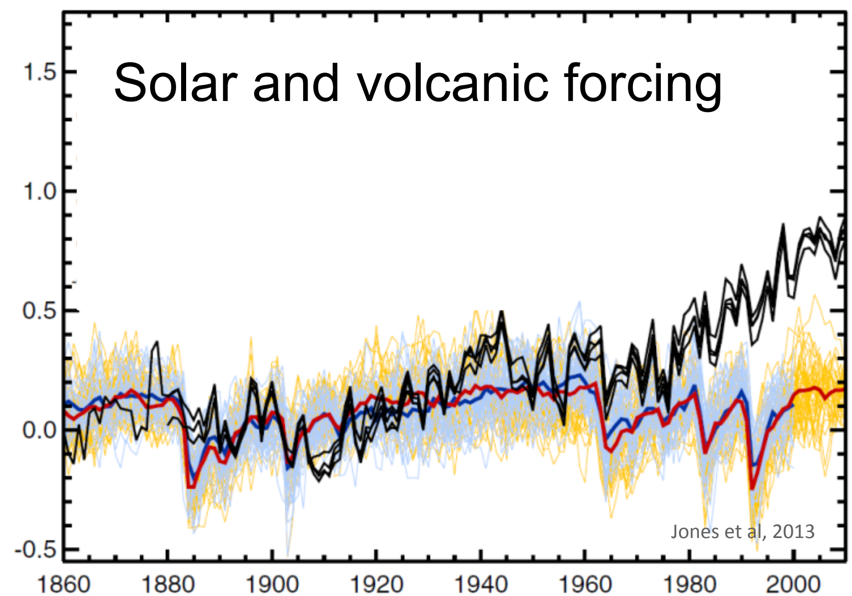
- Hasselmann (1979, 1993)
- Hegerl et al (1996, 1997)
- Tett et al (1999)
- Allan and Stott (2003)
- Huntingford et al (2006)
- Hegerl and Zwiers (2011)
- Ribes et al (2013a, 2013b)
- Hannart et al (2014)
- Hannart (2015, accepted)

- Ribes et al (in review)

Global mean temperature anomaly







It is ***extremely likely*** that human influence has been the dominant cause of the observed warming since the mid-20th century.

See also Figure 10.1, IPCC WG1 AR5

Mechanics of the attribution process

- Gather observations Y
- Estimate signals X_i, $i=1,\ldots,s$
- Fit the regression model
- Evaluate residuals and β_i, $i=1,\ldots,s$
- Calculate trends in $\beta_i X_i^*$

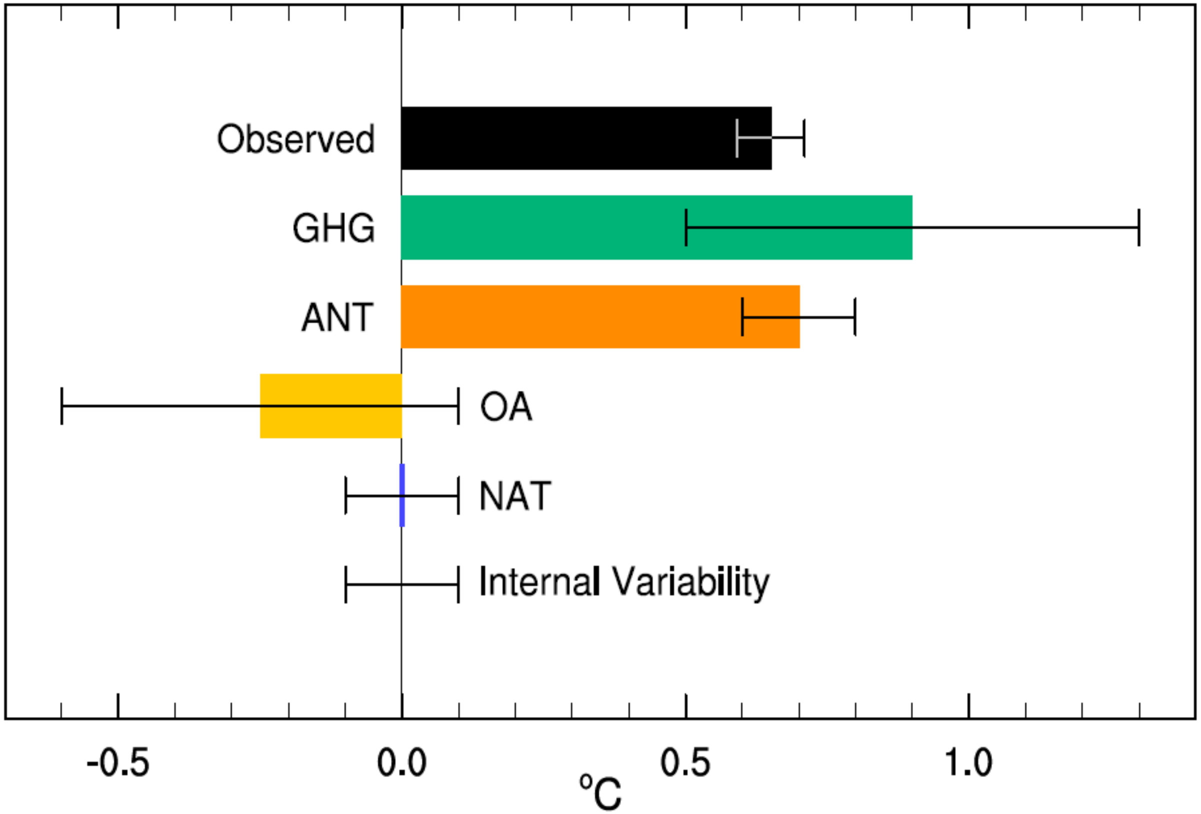
$$\mathbf{Y} = \mathbf{Y}^* + \boldsymbol{\varepsilon}_y$$

$$\mathbf{X}_i = \mathbf{X}_i^* + \boldsymbol{\varepsilon}_{x_i}$$

$$\mathbf{Y}^* = \sum_{i=1}^{s} \beta_i \mathbf{X}_i^*$$

Observed warming trend and 5-95% uncertainty range using HadCRUT4 (black).

Attributed warming trends with assessed *likely* ranges (colours) using CMIP5 historical and control simulations



IPCC WG1 AR5, Fig 10.5

Decomposing China’s temperature record

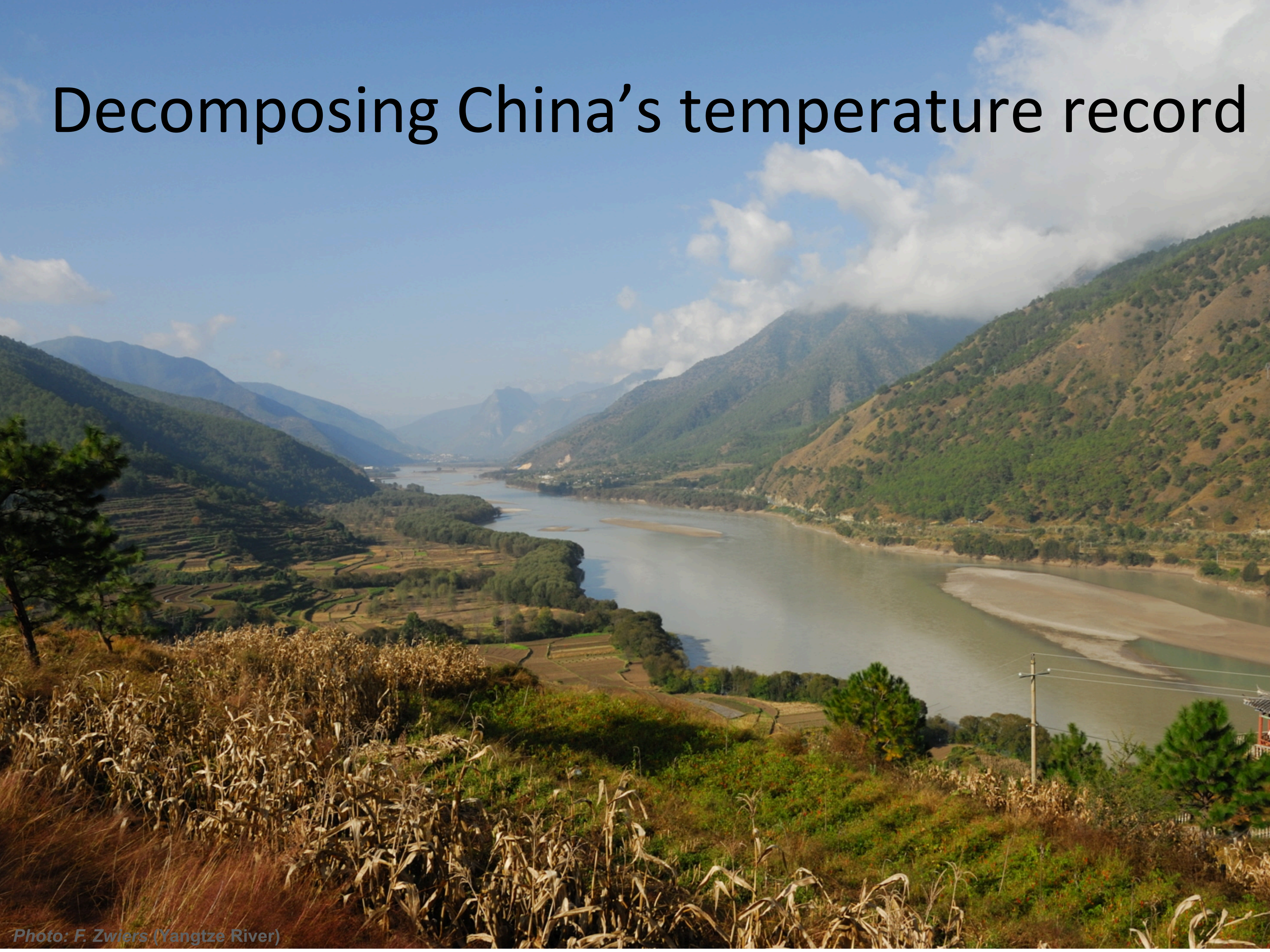


Photo: F. Zwiers (Yangtze River)

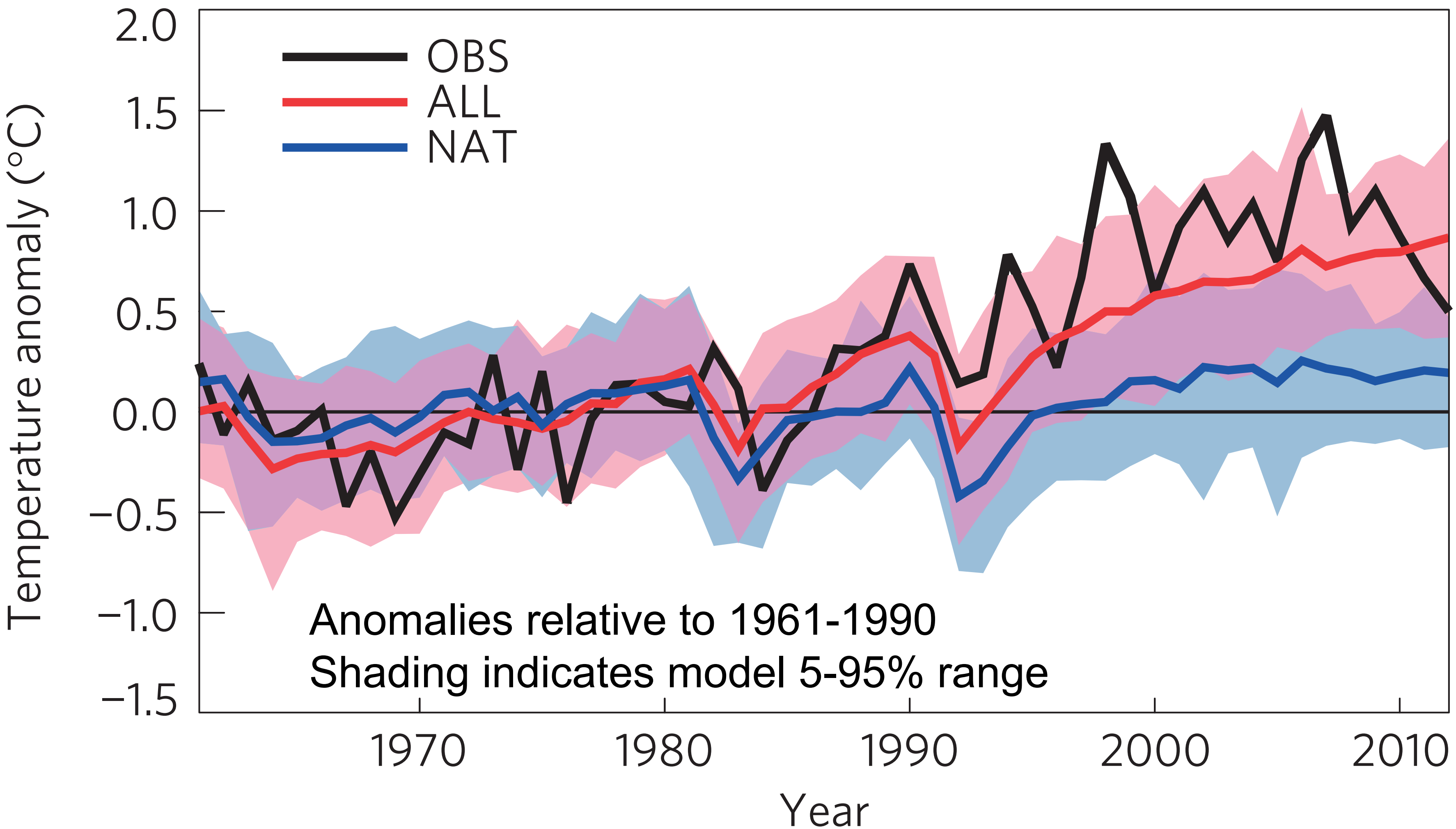
Idea

- Recorded warming is the result of
  - Response to external forcing
    - Greenhouse gas increases (GHG)
    - Other Anthropogenic influences (OANT)
    - Solar and volcanic influences (NAT)
  - Effect of urbanization (URB)
  - Internal variability (noise)
- Use a detection and attribution method to decompose the observed temperature record into
  - 2 components + noise
    - ALL (GHG+OANT+NAT combined)
    - URB
  - 4 components + noise

Implementation

- Construct observational vector Y
  - Consider the period 1961-2012 (52 years)
  - Divide China into two parts (east and west)
  - Calculate 3-year mean temperature anomalies for each region (17 values for each region, ending with 2009-2011)
  - Append the 2012 anomaly as an 18^{th} value to complete the record
  - Total length of Y is 2x18=36
- Estimate the ALL, GHG and NAT signals (X_{ALL}, X_{GHG}, X_{NAT}) from CMIP5 simulations
  - ALL: 23 models, 108 simulations
  - GHG: 7 models, 33 simulations
  - NAT: 8 models, 36 simulations
- Estimate internal variability
  - Control simulations (41 models, 346 chunks) and within-ensemble differences

Observed and simulated mean temperature change in China



What about the URB signal?

- Use sigmoid functions (continuous, positive, with 0 and 1 as left and right asymptotes)
- 3-parameter logistic function

$$f(t) = L/(1 + e^{-k(t-t_0)}),$$

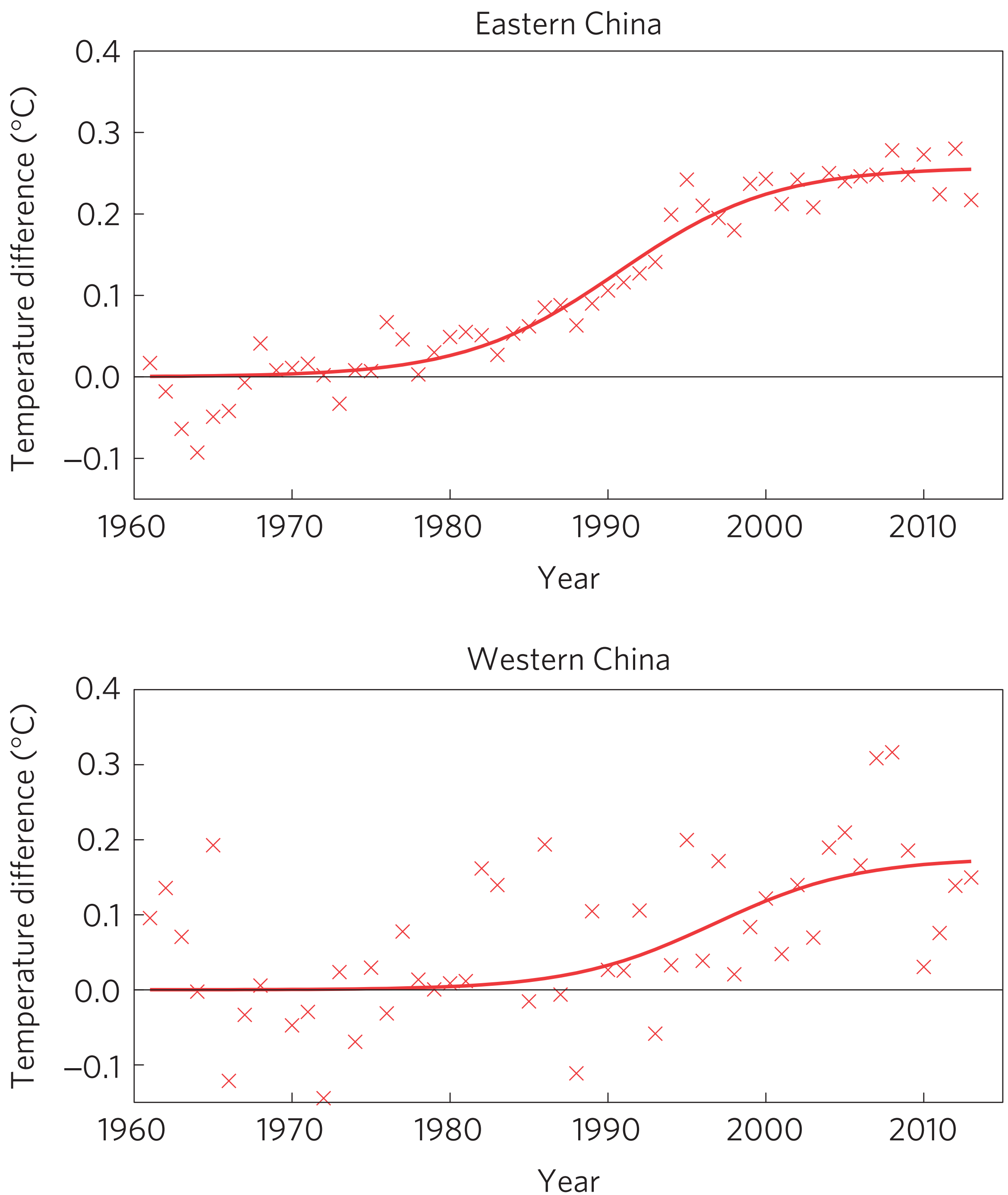
  - t_0 is the midpoint
  - L is the maximum
  - k is the steepness
- Fit these functions to urban - rural temperature differences
- Separate functions for east and west China

Why sigmoid functions?

- The urbanization effect is unlikely to be reversed
  - The URB signal should be monotone increasing
- The urbanization effect does not increase temperatures indefinitely
  - The URB signal should asymptote at some level after the urban heat island is established
- The urbanization effect is established slowly as an urban center expands; we assume minimal urbanization effects during the 1960's and 1970's
- The regional URB signal in eastern China will be different from that in western China.

URB signal estimates

Area weighted combined urban-rural warming is about 0.27°C

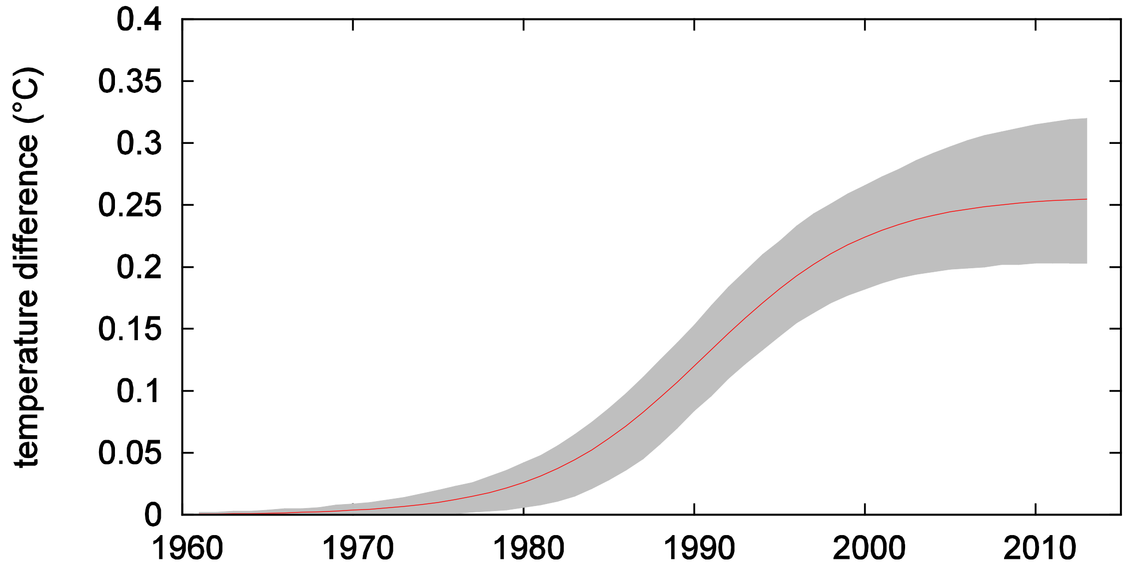


URB signal uncertainty

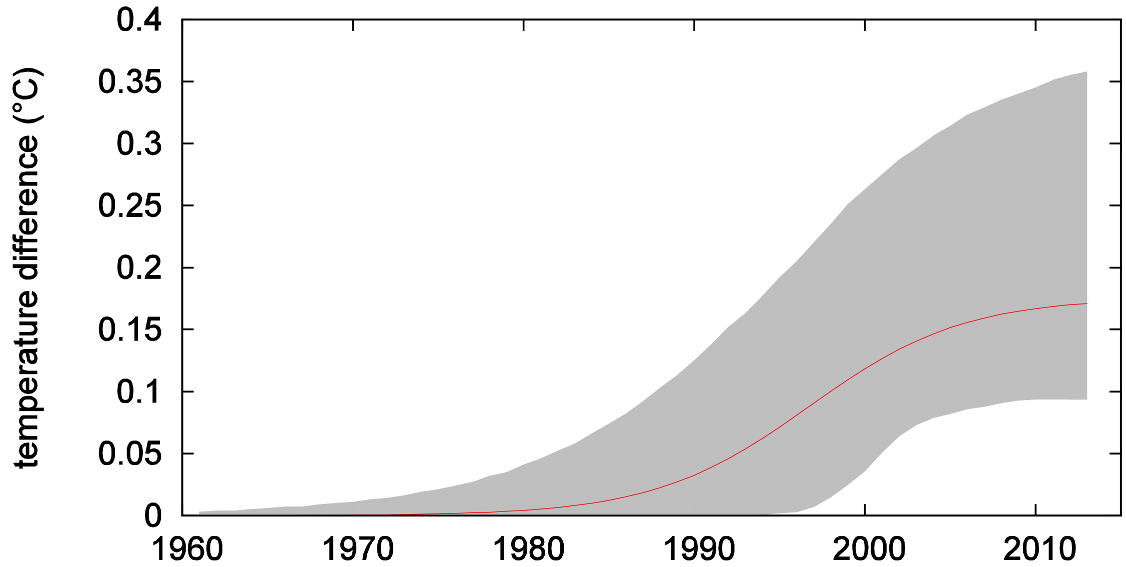
Based on a bootstrapping approach

Shading indicates 5-95% amongst 1000 bootstrap samples

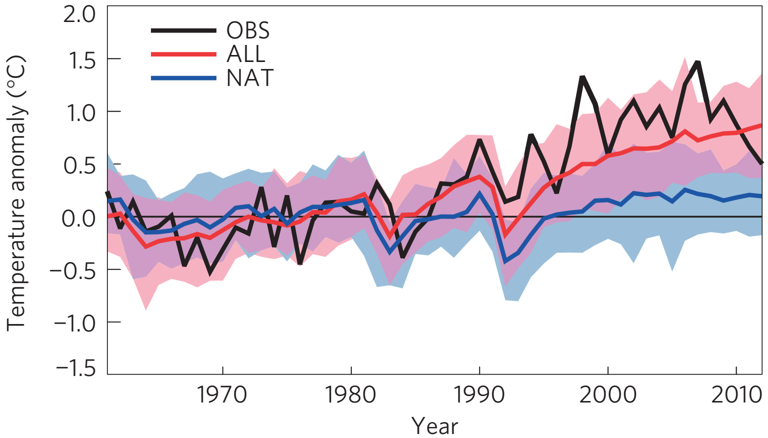
a) Eastern China

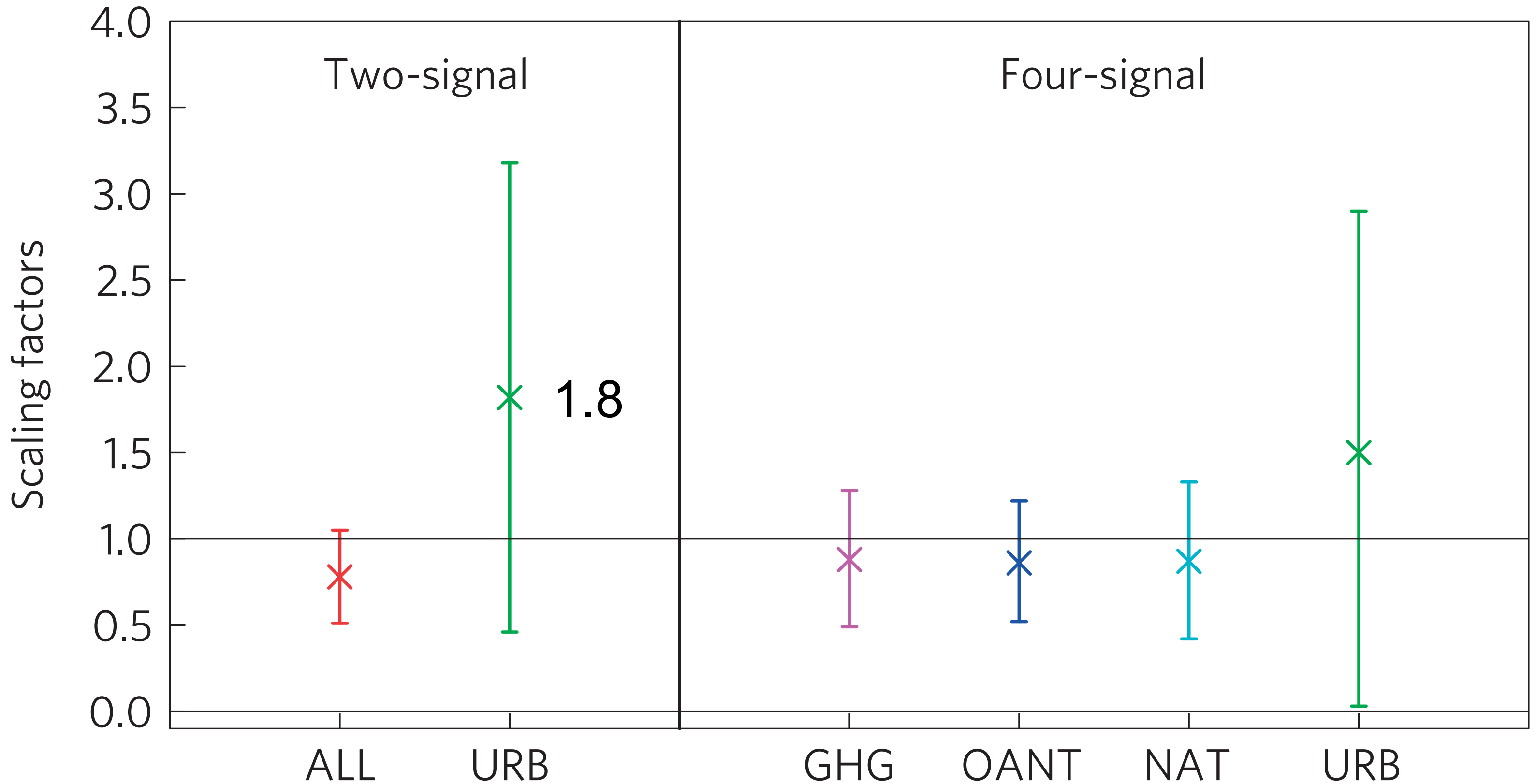


b) Western China



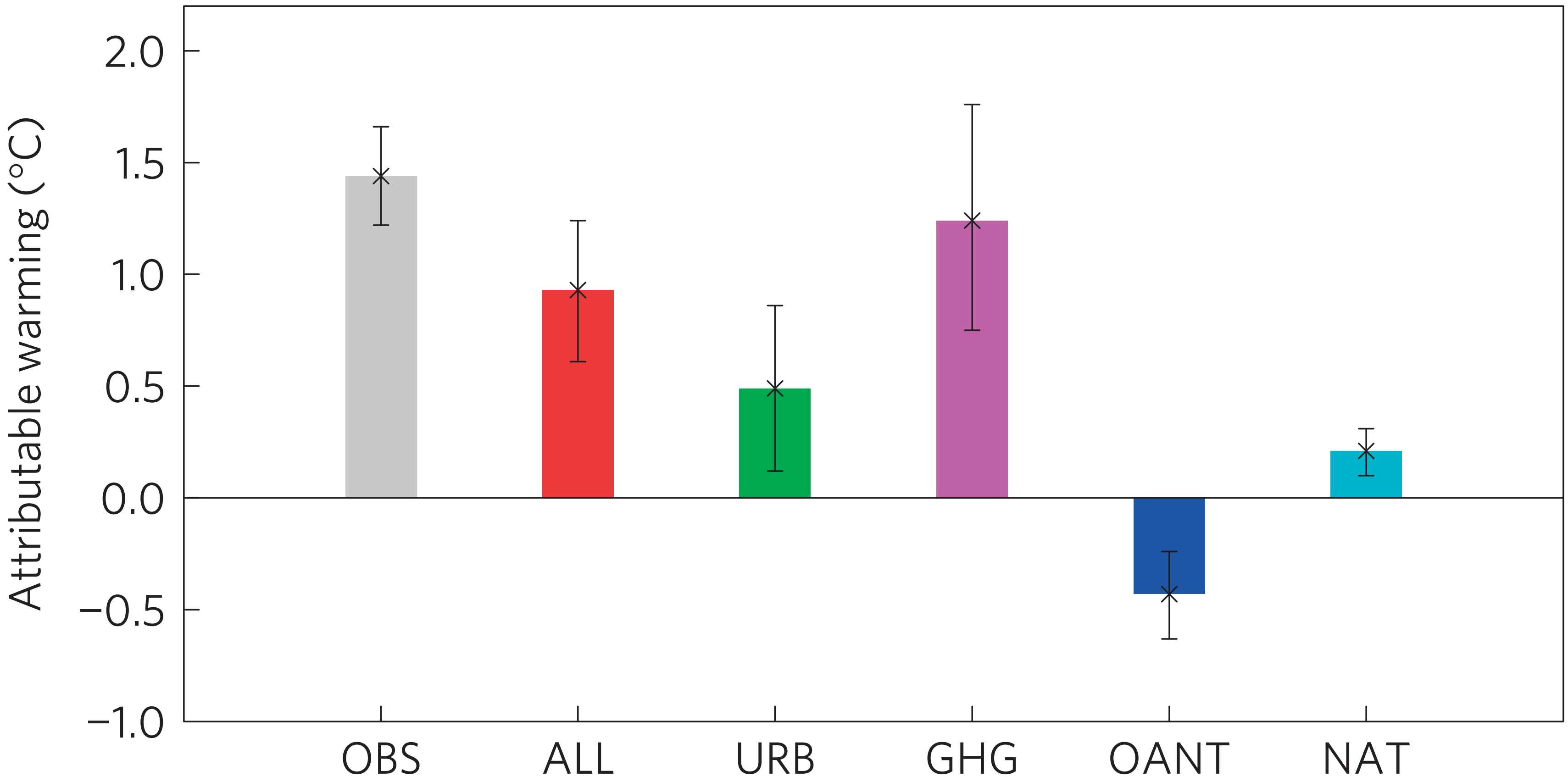
Results – scaling factors





URB detection is robust to URB signal uncertainty

Results – warming contributions



1.44°C [1.22-1.66]

0.93°C [0.61-1.24]

0.49°C [0.12-0.86]

1.24°C [0.75-1.76]

0.43°C [0.24-0.63]

0.21°C [0.10-0.30]

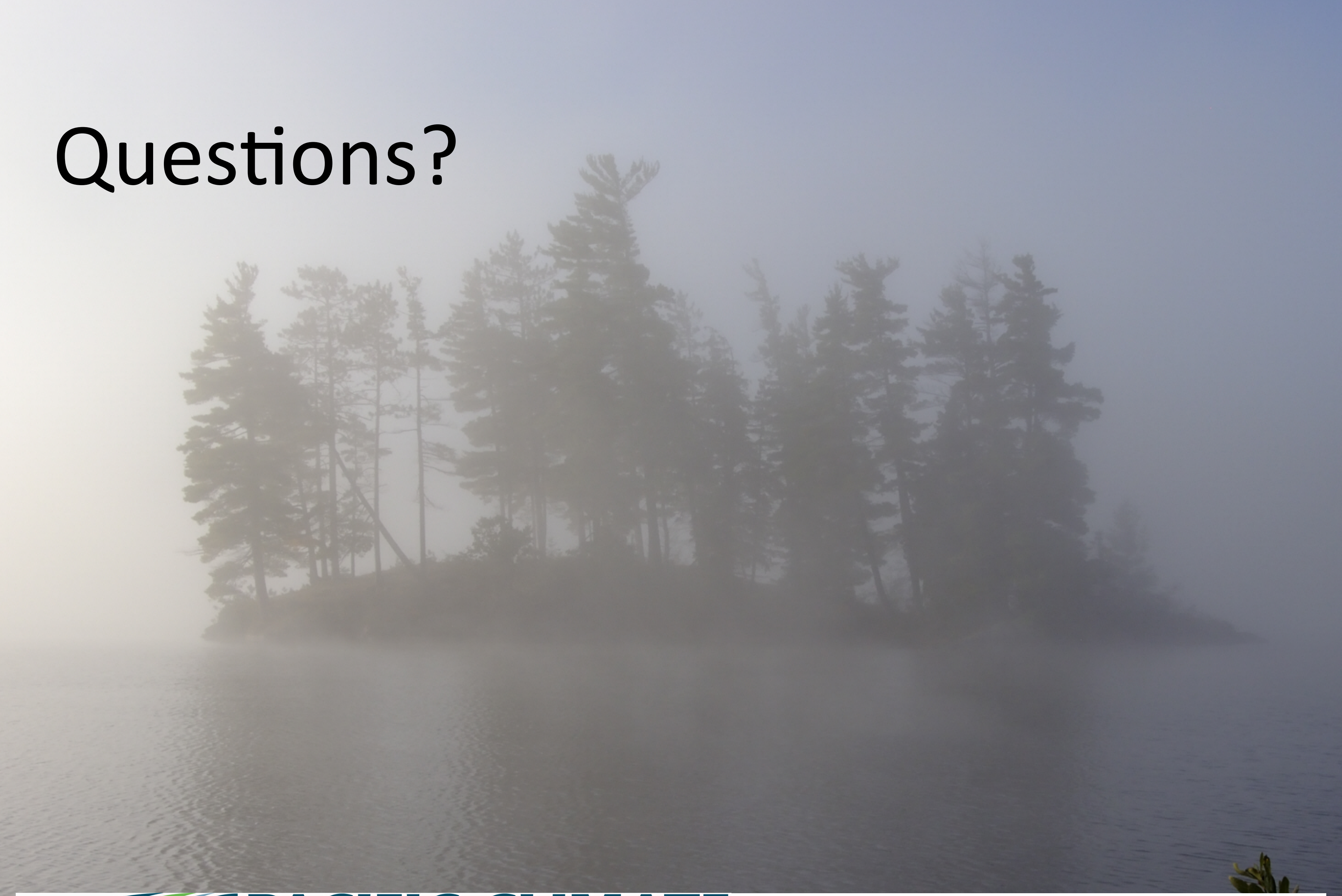
Conclusions

Photo: F. Zwiers (Emlyn Cove)

Conclusions

- China's observing system records temperatures that are broadly influenced by urban warming
- Thus the warming of the Chinese land-mass is likely overestimated
- Comparison between urban and rural stations appears to lead to an underestimate of the strength of the urbanization influence
- A detection and attribution formalism allows decomposition of China's temperature record into externally forced, urbanization induced and internal variability induced components of change
- Results suggest about 1/3rd of the recorded warming is due to urbanization
- Anthropogenic and natural external forcing combined are estimated to have caused 0.93°C [0.61-1.24], consistent with the observed global land mean warming 1.09°C [0.86-1.31]

Questions?



PACIFIC CLIMATE IMPACTS CONSORTIUM www.pacificclimate.org

Photo: F. Zwiers (Big Trout Lake, Algonquin Park)