

NIST Surface Air Temperature Measurements

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DISCLAIMER: Mention of any commercial products identified in this talk does not constitute endorsement by NIST

Acknowledgements

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THE SMART SENSORS COMPANY



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Surface Air Temperature Measurement

- Traditionally measured with thermometer shielded from direct sunlight but exposed to good airflow, in double-louvered wooden box (*Stevenson screen*), with thermometer 1.2–2.0 meter above ground level
 - WMO Requirements
 - Maximum: 0.2 K max. error, calibration from -25 °C to 40 °C
 - Minimum : 0.3 K max. error, calibration from -30 °C to 30 °C



World Meteorological Organization

Instruments and Methods of Observation

<http://www.wmo.int/pages/prog/www/IMOP/IMOP-home.html>

Surface Air Temperature Measurement

- **GOALS**

- Characterize sources of measurement uncertainty
- Evaluate performance of analog thermometer measurements made by National Weather Service, United States Historical Climatology Network (USHCN), and antecedents
 - Uncertainty claims ranging from 0.7 mK to 0.2 °C
- Compare analog and **digital** readings
- Determine best estimator of mean daily temperature based on daily maximum and minimum



Measurement Systems

Historical Temperature Measurement System

- **Analog Thermometers**

- *Maximum thermometers* – Mercury in glass
- *Minimum thermometers* – Organic in glass
- Calibration required to establish traceability
 - Analog thermometers when used un-calibrated are only accurate to one scale division
- Limitations
 - 0.5 °C scale division
 - Require daily physical observations
 - 0.25 °C eyeball resolution
 - Captures only two data points / day



Measurement Systems

- Mobile sensor / communications package to track temperature-sensitive cargo developed for FedEx
- Measurement uncertainty 0.02 °C, operates for 30 days autonomously, sending temperature values and GPS location via cell phone



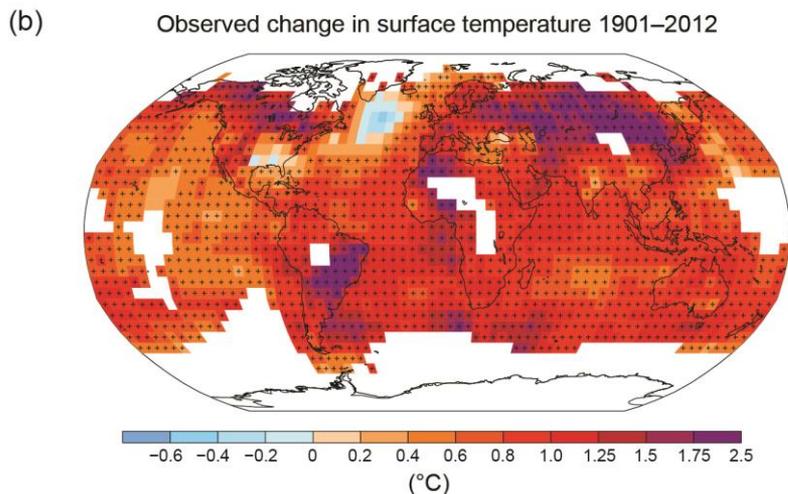
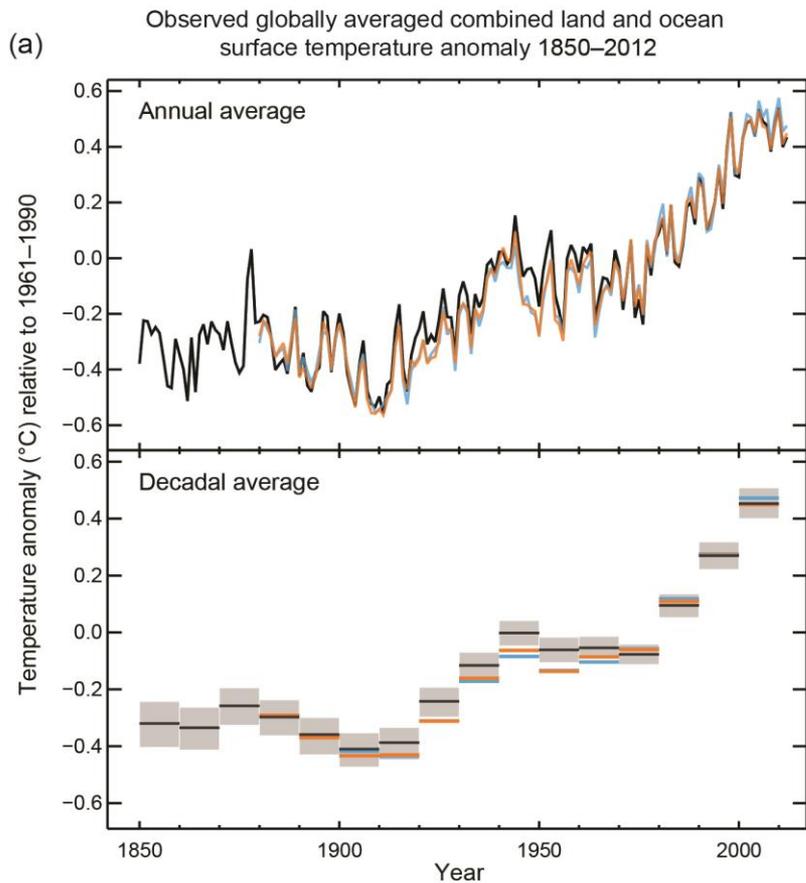
Uncertainties

- Digital
 - Laboratory 0.02 °C
 - Field 0.05 °C
 - **$U_D(k=2)$ 0.1 °C**

- Analog
 - Laboratory 0.1 °C
 - Field 0.25 °C
 - **$U_A(k=2)$ 0.5 °C**



- Analog “Daily Mean” relative to digital daily average = 1.6 °C
- Measurement uncertainties are larger than literature, manufacturer values, and WMO guidelines



Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. In the Northern Hemisphere, 1983–2012 was *likely the warmest 30-year period of the last 1400 years (medium confidence)*.

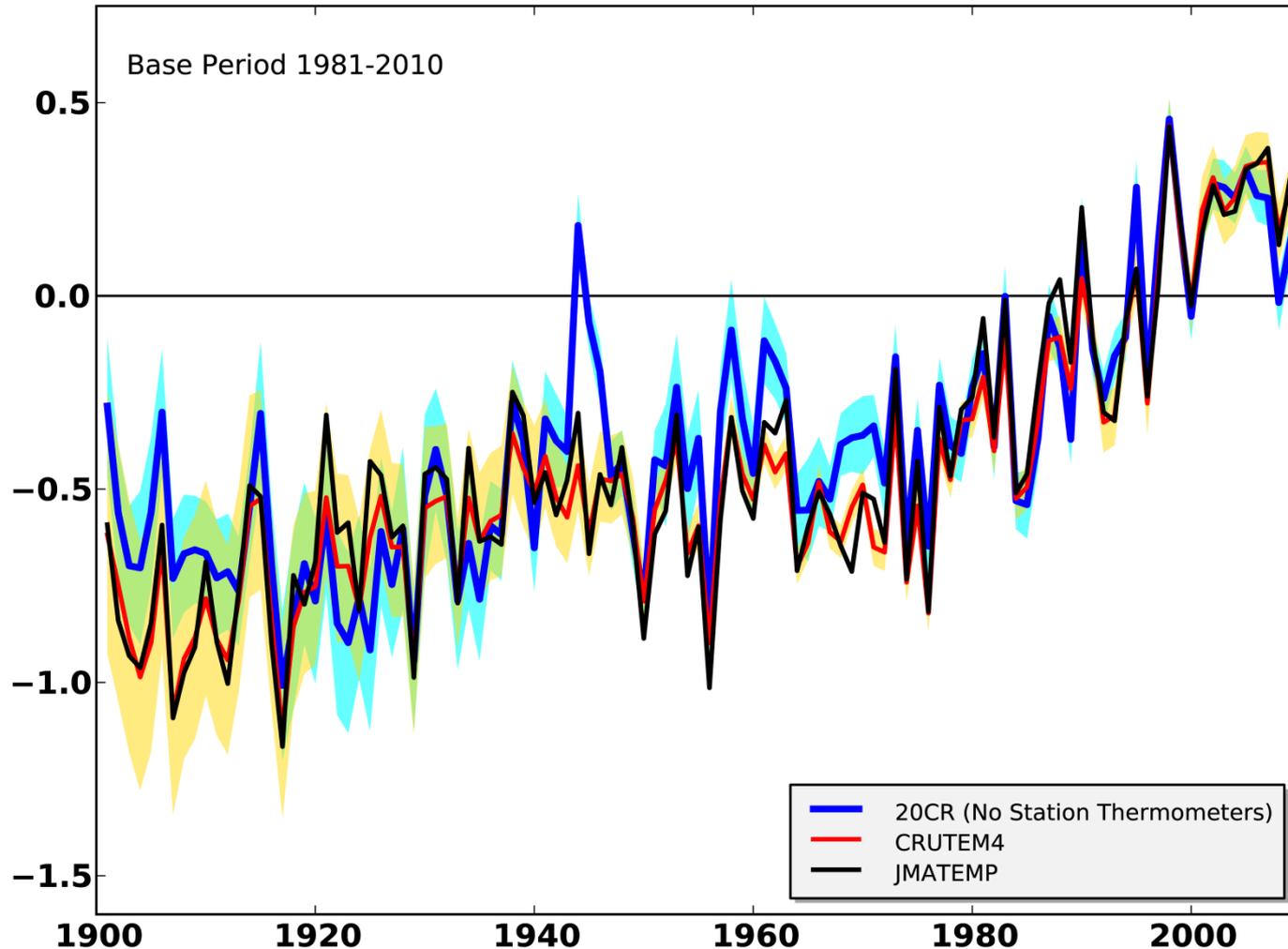
Climate Change 2013: The Physical Science Basis — IPCC Summary For Policymakers

Near-surface air temperature over land

Compo *et al.* (2013) Independent confirmation of global land warming without the use of station temperatures
Geophys. Res. Lett., 40, 3170–3174

- CO₂, solar, and volcanic radiative forcing agents
- Monthly averaged sea surface temperature
- Monthly averaged sea-ice concentration
- Hourly barometric pressure observations
(International Surface Pressure Databank)

Near-surface air temperature over land



20CR

Re-analysis (Sea surface temperature and Barometric Pressure)

CRUTEM4

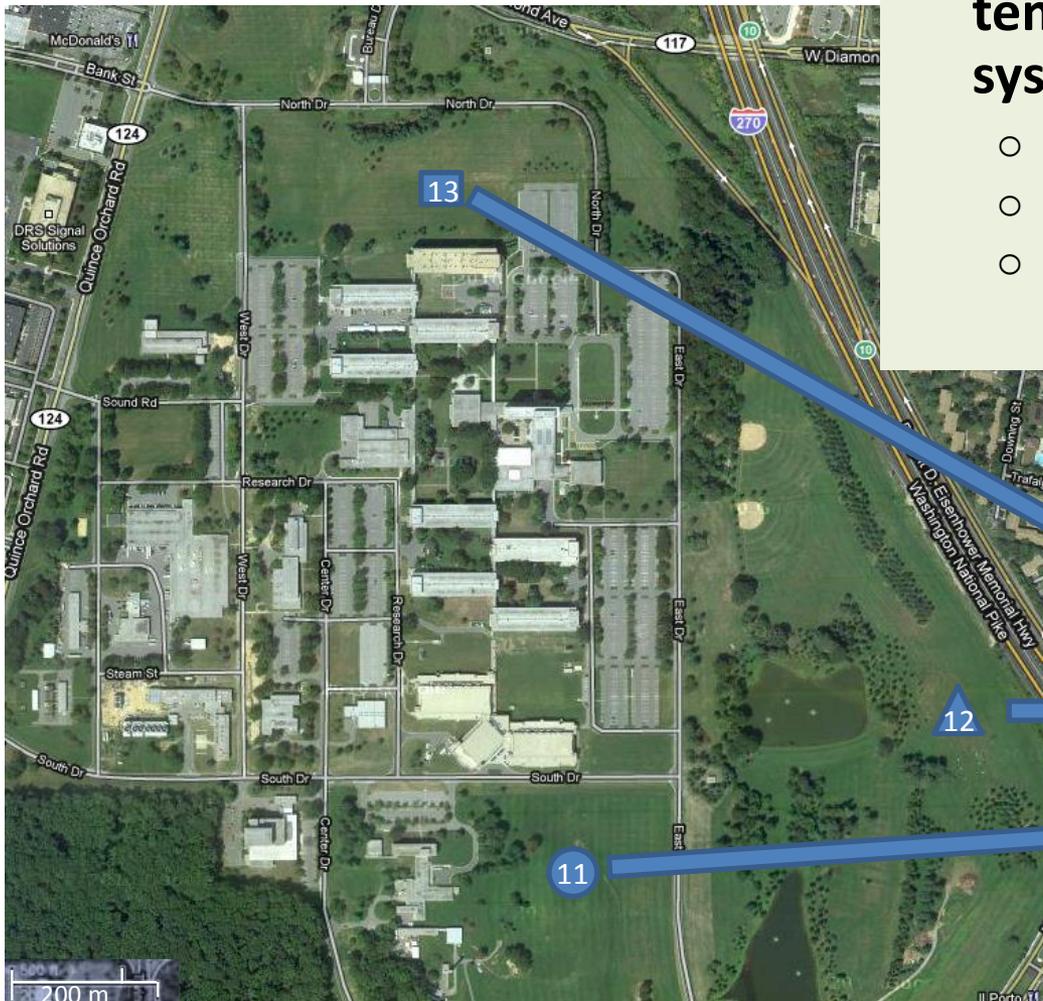
Climatic Research Unit (Univ. East Anglia), UK Met Office Hadley Centre

JMATEMP

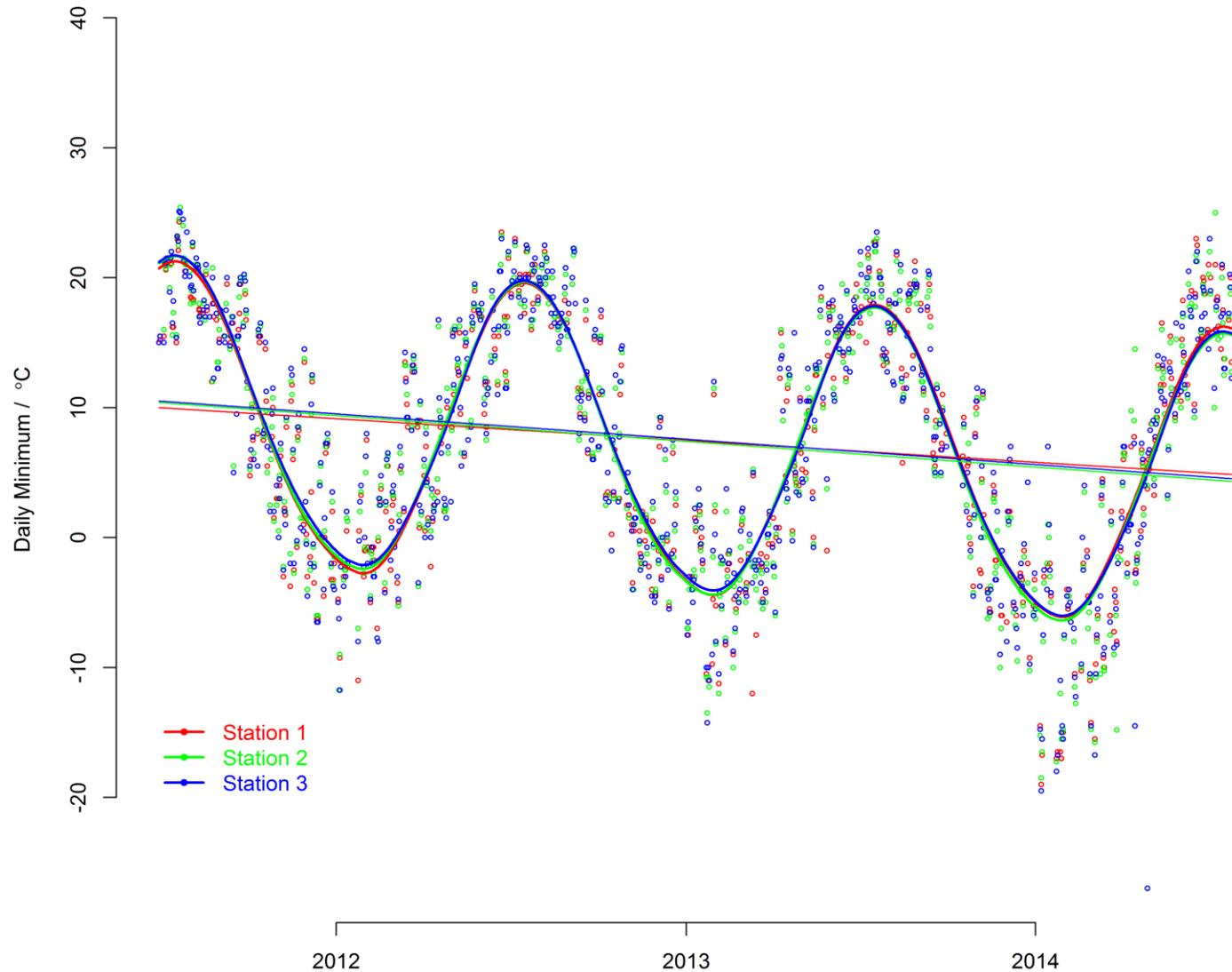
Japan Meteorological Agency

NIST Surface Air Temperature Stations

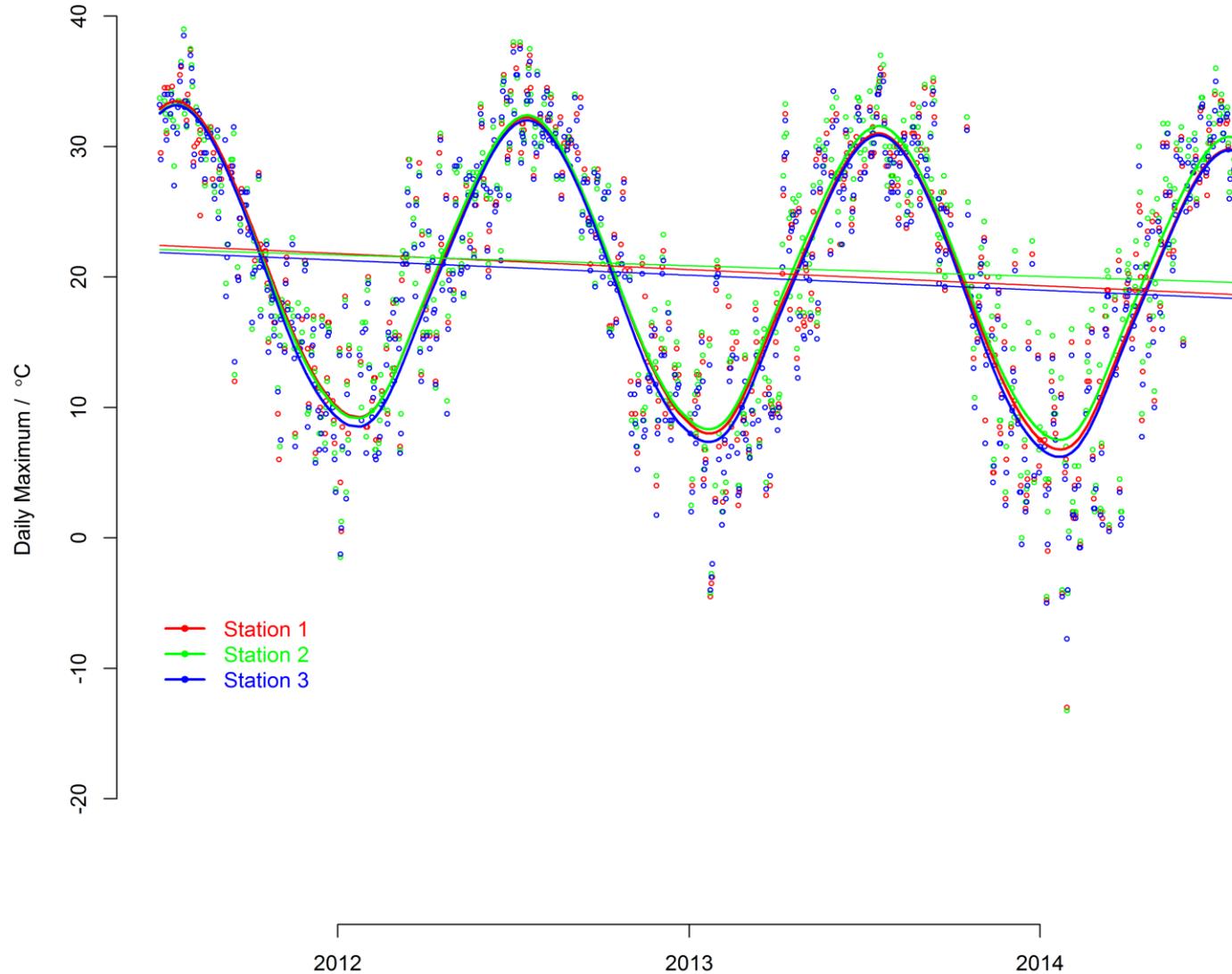
- Compare analog and digital temperature measurement systems over a 1 km² area
 - Uncertainty of analog vs digital
 - Seasonal influences
 - Station placement
 - *WMO Guidelines – Class 1 (A)*



NIST Gaithersburg Weather Stations



NIST Gaithersburg Weather Stations

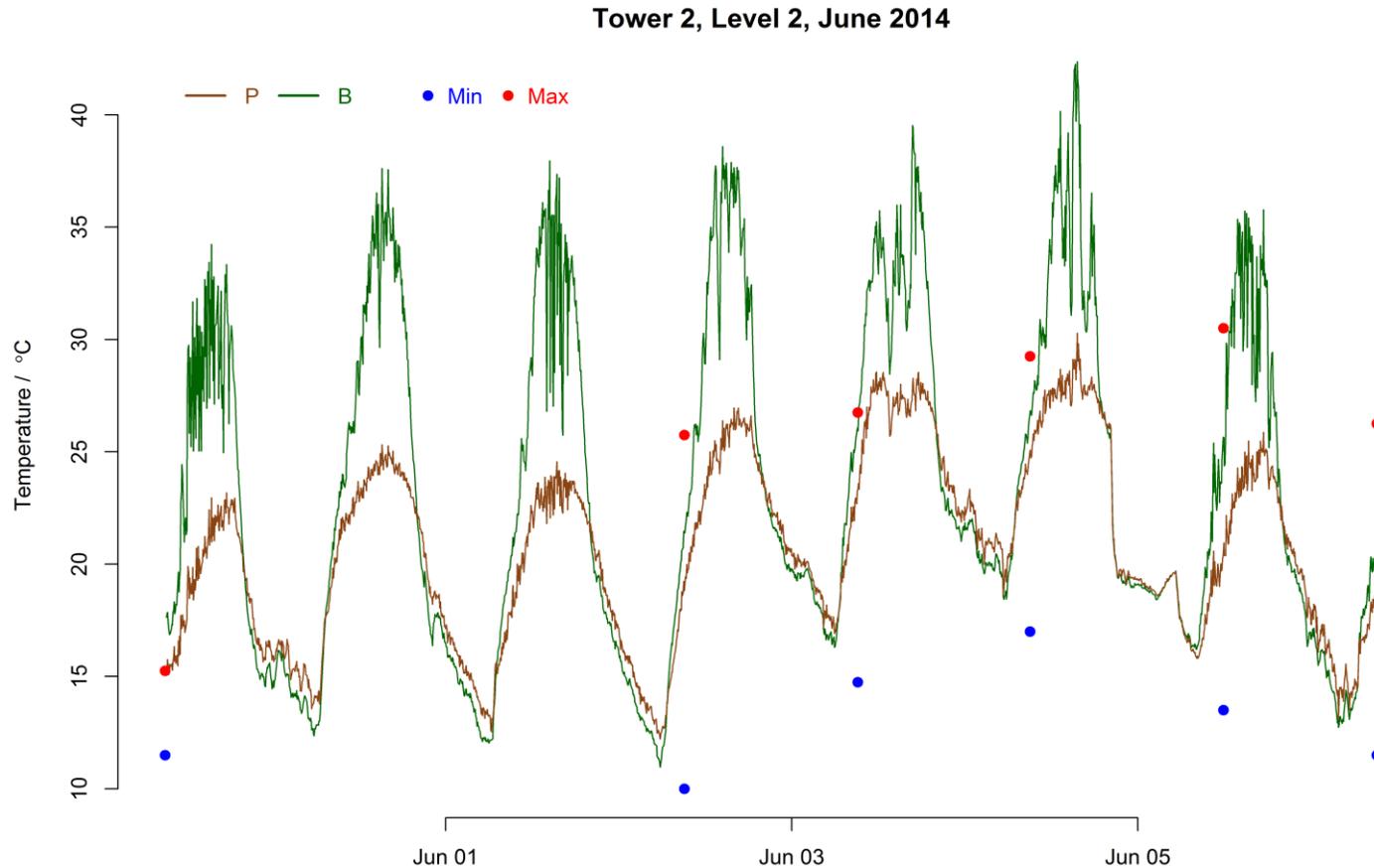


Future Work

- Build optimal predictor of *mean daily temperature* that is a function of analog daily min and max temperatures
 - May be non-linear function of TMIN and TMAX
 - May depend on time of year
- Compare *parallel measurements* (analog/digital) with similar records at Basel (Switzerland)
- Characterize *vertical temperature gradient* in neighborhood of Stevenson shelters
- Develop empirical *model for energy balance* in screen that takes into account
 - Screen / sensor geometry
 - Incident radiation (including from ground) upon screen
 - Changes to sensible heat flux between screen and sensor resulting from changes in wind speed



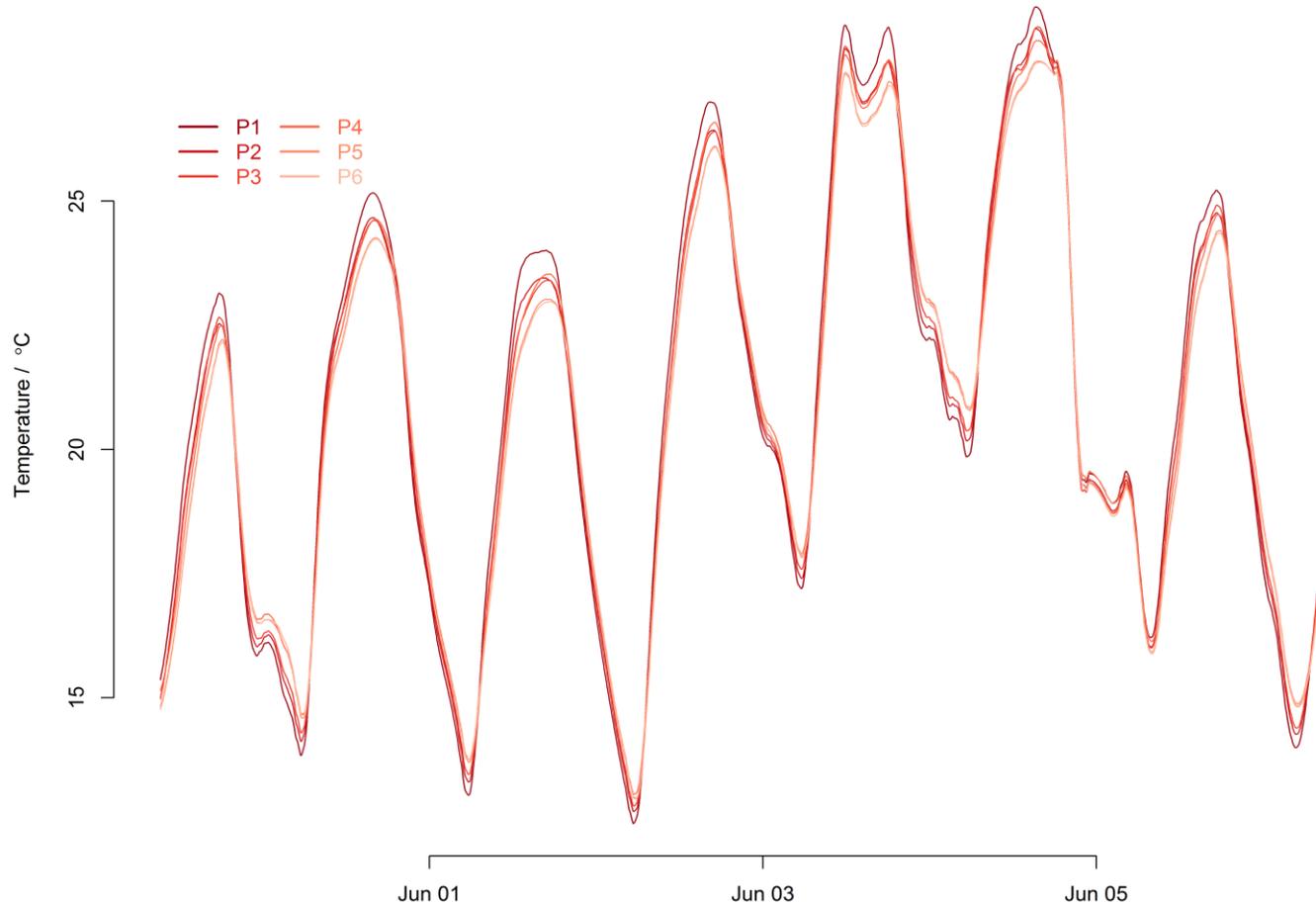
Tower 2 — First Look



- **B**ulbs have insufficient ventilation — act as little greenhouses
- **P**agodas more in line with **Max** and **Min** from nearby LIG thermometers

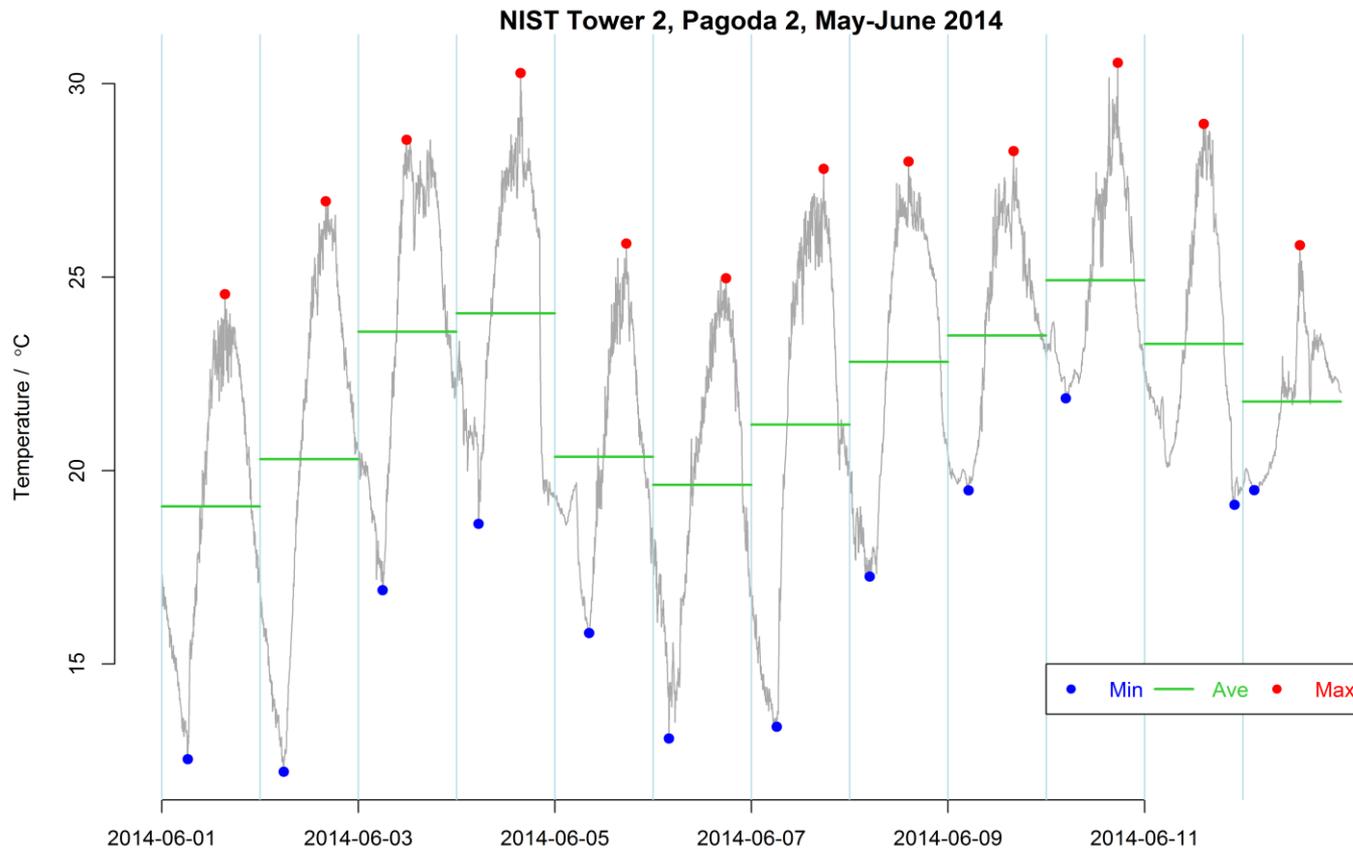
Tower 2 — Second Look

Tower 2, Levels P1-P6, June 2014



- Smoothed readings from thermocouples in **P**agodas
- **P1, ..., P6** at increasing heights above ground

Predict Ave. Daily Temp. from Max-Min



- $T_{AVE} = \varphi(T_{MIN}, T_{MAX})$
- φ may be linear or non-linear

Predict Ave. Daily Temp. from Max-Min

- **NAÏVE** $T_{AVE} = (T_{MIN} + T_{MAX})/2$
- **LM** $T_{AVE} = a + bT_{MIN} + cT_{MAX}$
- **GAM** $T_{AVE} = \tau(T_{MIN}, T_{MAX})$
 - τ Thin plate regression spline

