Met Office
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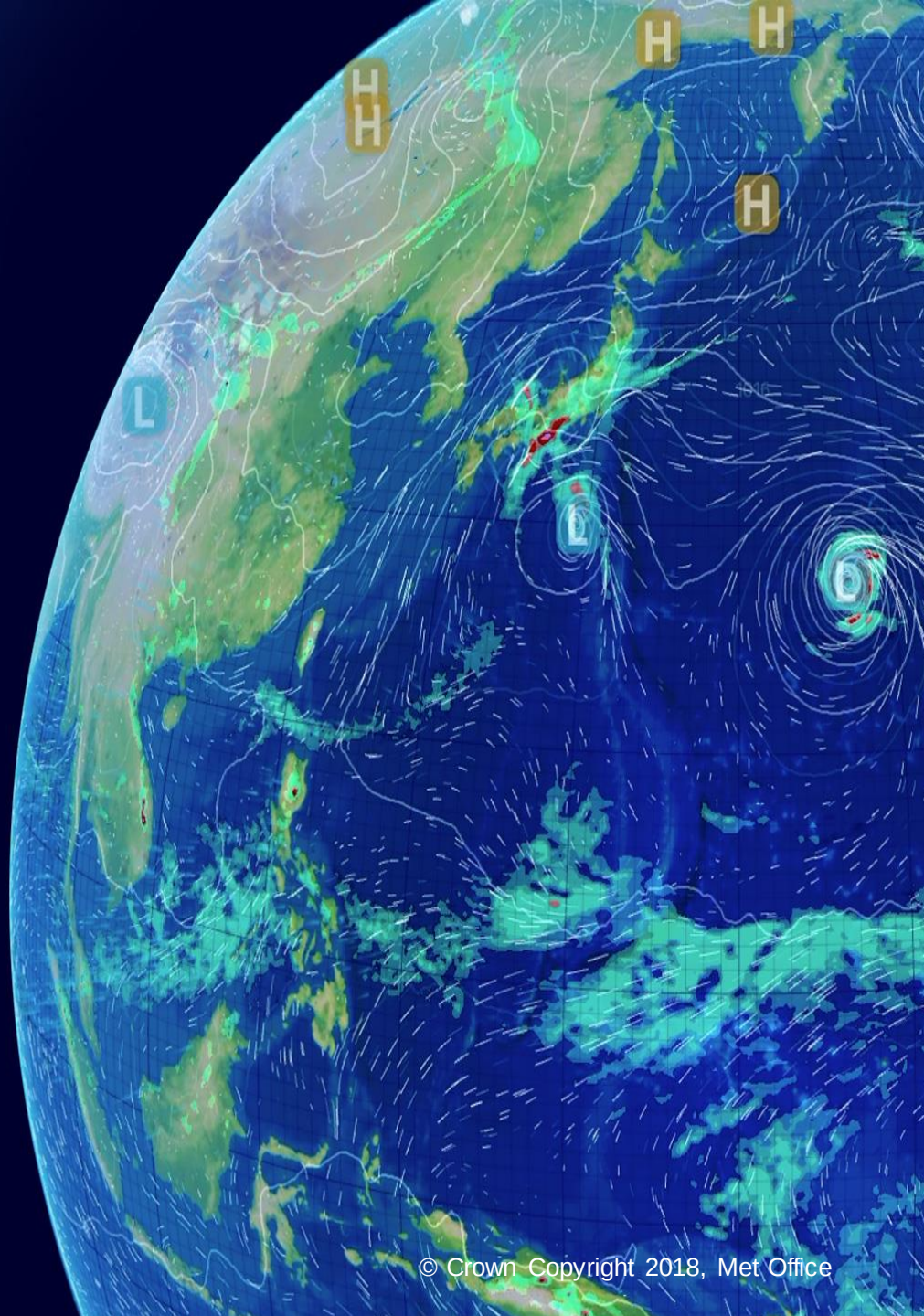
Prologue

Nick Rayner

Head, Climate Monitoring

Met Office Hadley Centre

NCAS/RMetSoc Atmospheric Science Conference, 3-4th July 2018



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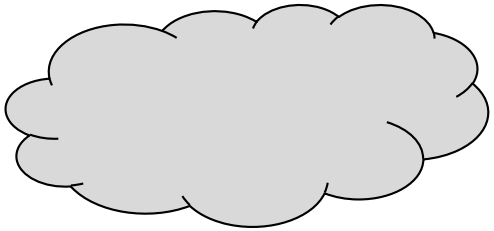
Climate Data Record generation

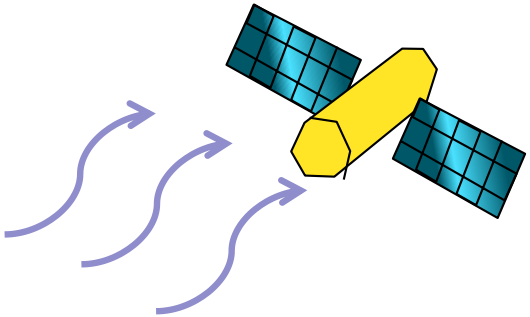
- Step 1: **Understand what is needed** from a particular data set by different end users
- Step 2: **Collect the observations together with metadata** to describe how they were taken, **digitising more measurements** from paper archives whenever possible
- Step 3: Write down the measurement equation for the variable, as measured by each component of the observing system for the variable of interest and **determine an error model**
- Step 4: **Remove obvious outliers** from the measurements and **correct any within-series discontinuities**, propagating uncertainties
- Step 5: **Compare measurements from different components of the observing system** and understand how they relate to one another
  - This could also form part of Step 4, if an independent comparison is needed. Consistently-estimated uncertainty estimates for each component are important here

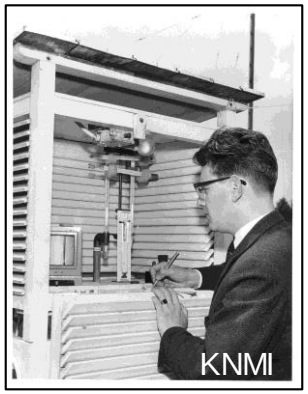
Climate Data Record generation

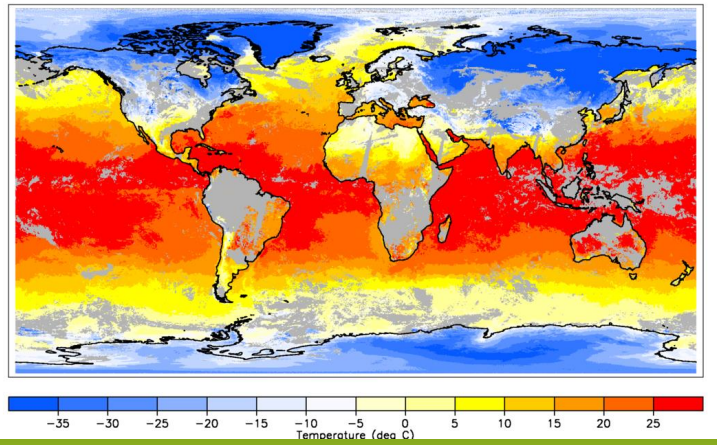
- Step 6: **Produce products relevant to different applications**, e.g.
  - Single observing component data sets
  - Combined measurement types to provide maximum information content
  - Gridded fields or ensembles,
  - Globally- or regionally-complete fields or ensembles,
  - Area averages, etc
- Step 7: **Evaluate the products** by comparison to independent reference data, if possible
- Step 8: Provide these with appropriate metadata, uncertainty components and documentation.

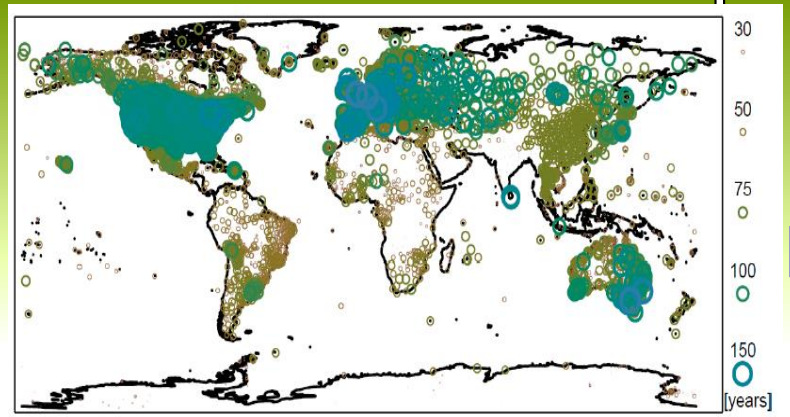
Measuring temperature











EUSTACE

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THE EUSTACE PROJECT: DELIVERING GLOBAL, DAILY INFORMATION ON SURFACE AIR TEMPERATURE

NICK RAYNER, EUSTACE SCIENCE COORDINATOR

NCAS/RMETSOC ATMOSPHERIC SCIENCE CONFERENCE 2018

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material contributed by: Lizzie Good, Yuri Brugnara, Antonello Squintu, Darren Ghent, Karen Veal, Pia Nielsen-Englyst, John Kennedy, Colin Morice, Francesco Capponi and Finn Lindgren

EUSTACE has received funding from the European Union's Horizon 2020 Programme for Research and Innovation, under Grant Agreement no 640171

EUSTACE AIMS

EUSTACE will give publicly available daily estimates of surface air temperature since 1850 across the globe for the first time by combining surface and satellite data using novel statistical techniques. To do this, we need to:

- Identify non-climatic discontinuities in daily weather station data, *so users can trust the changes our records show*
- Produce consistent uncertainty estimates for satellite skin temperature retrievals over all surfaces (land, ocean and ice), *so we know how far to trust the estimates everywhere*
- Understand how surface temperature measured *in situ* and by satellite relates, *to estimate air from skin temperature*
- Estimate values in areas where we have no *in situ* or satellite data, *so users can have daily information here*

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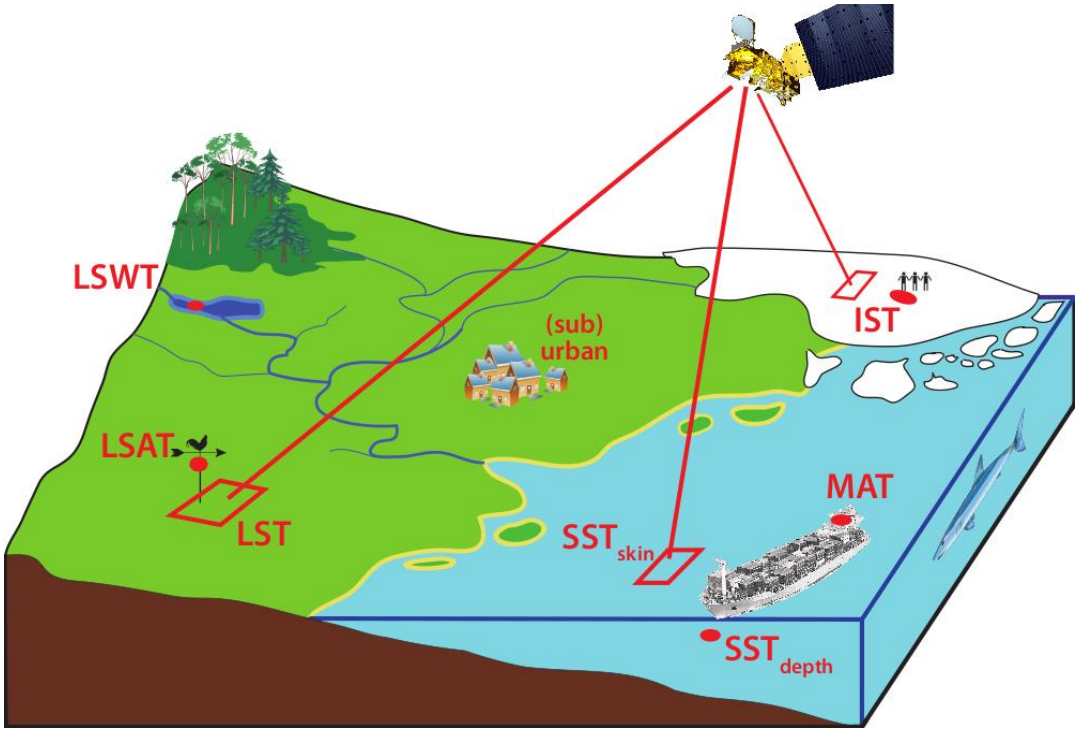
UNDERSTAND RELATIONSHIP BETWEEN AIR AND SKIN TEMPERATURE



From Merchant et al., 2013 community paper and roadmap:
http://www.geosci-instrum-method-data-syst.net/2/305/2013/gi-2-305-2013.html

EarthTemp Network

NERC SCIENCE OF THE ENVIRONMENT

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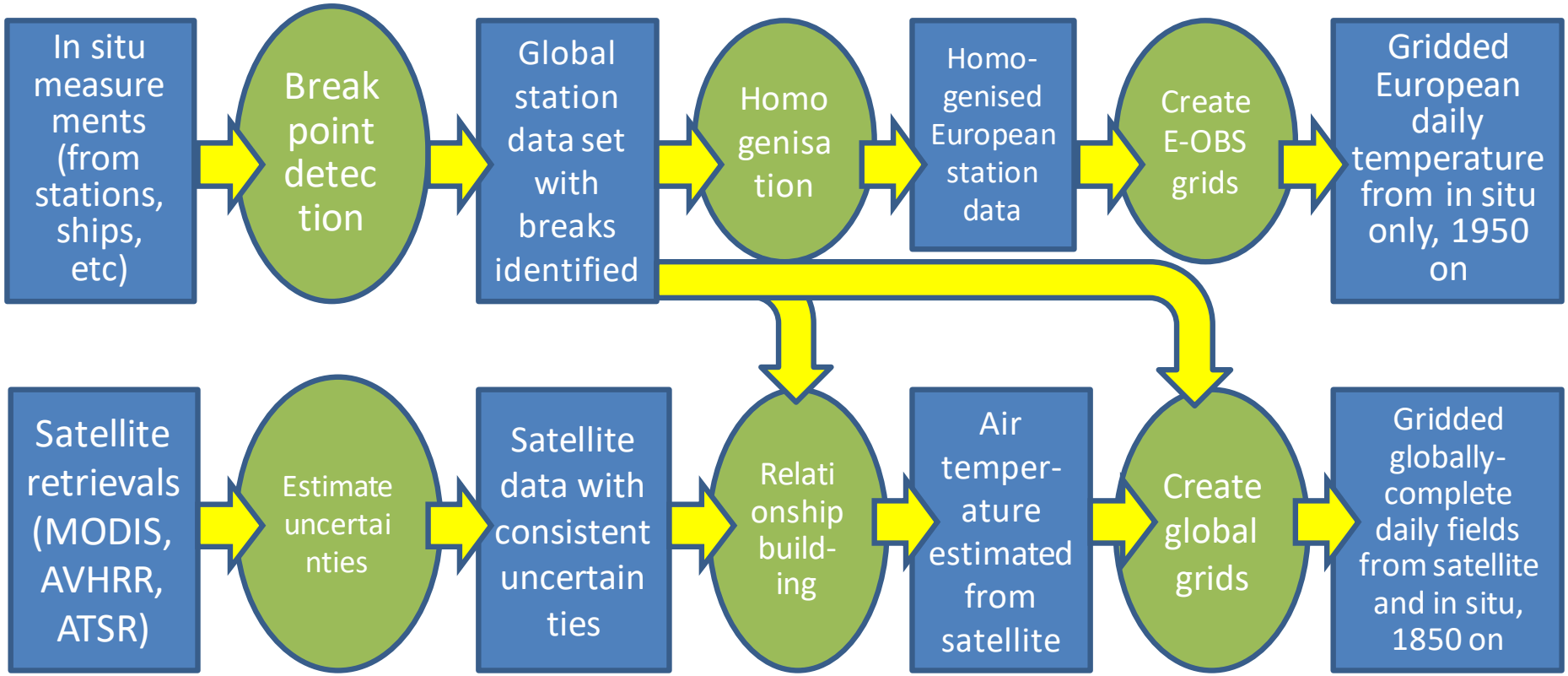
EUSTACE SCHEMATIC



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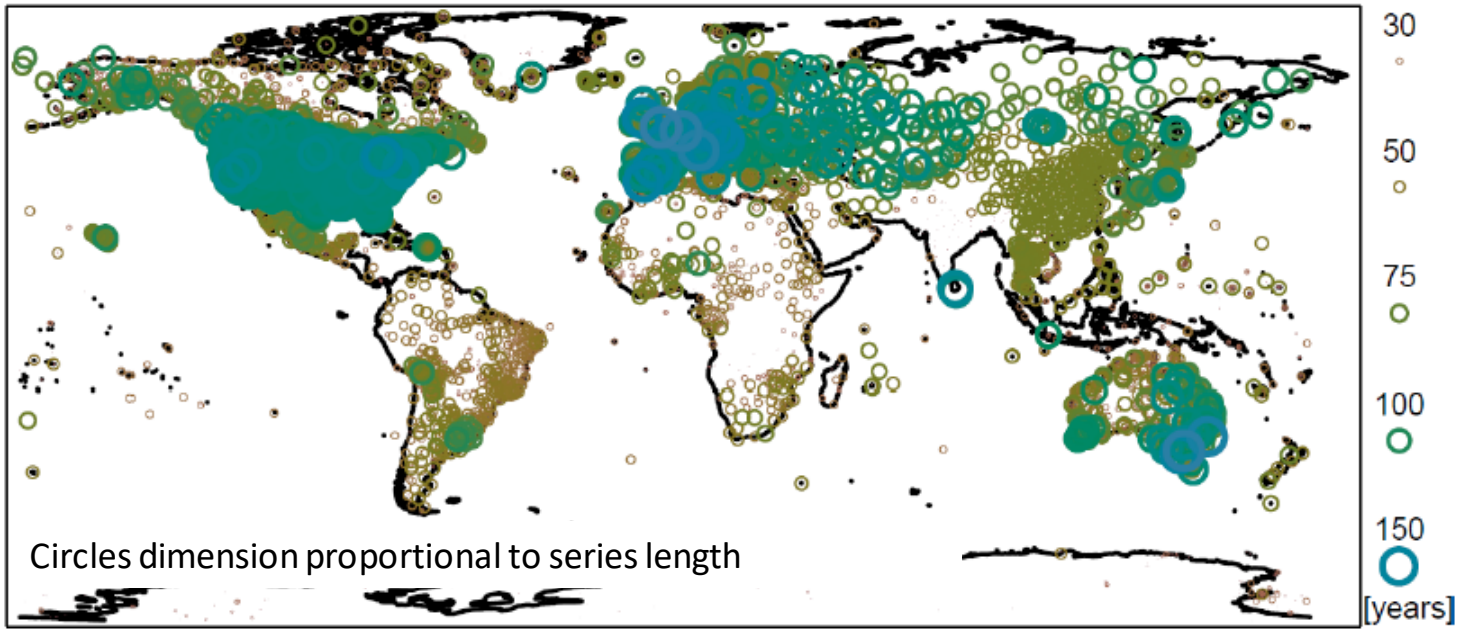
EUSTACE DAILY STATION DATASET



Three different algorithms applied to annual and semi-annual averages of differences between candidate and reference series

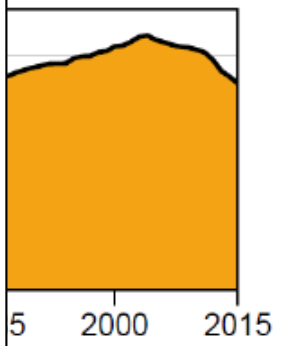
+

Absolute test when reference stations not available or insufficient

Applied to: T_{max}, T_{min}, $T_{avg} = (T_{max} + T_{min}) / 2$ and

$DTR = T_{max} - T_{min}$

Gives: a 48-member break point detection ensemble.



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OESCHGER CENTRE CLIMATE CHANGE RESEARCH

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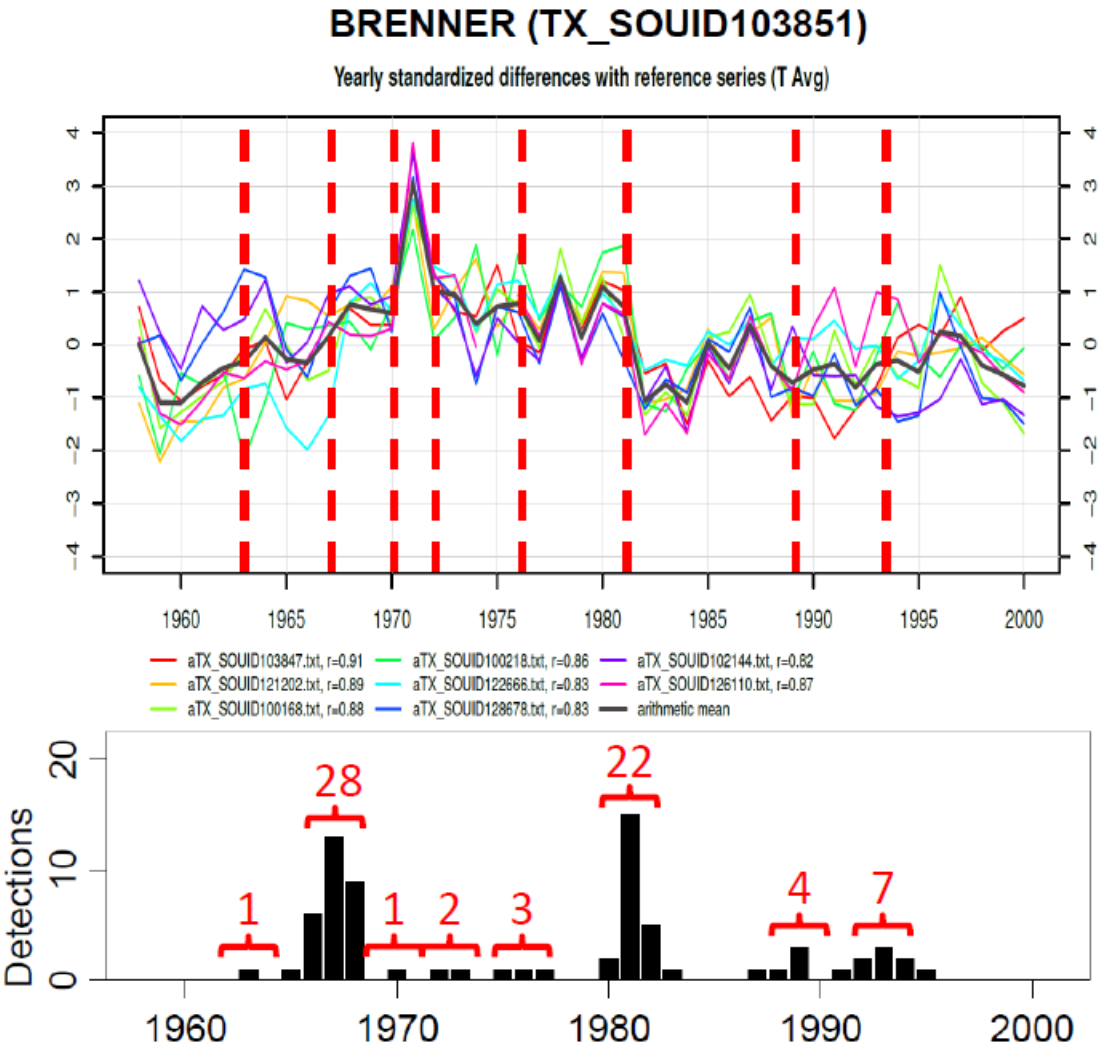
EXAMPLE BREAKPOINT DETECTION

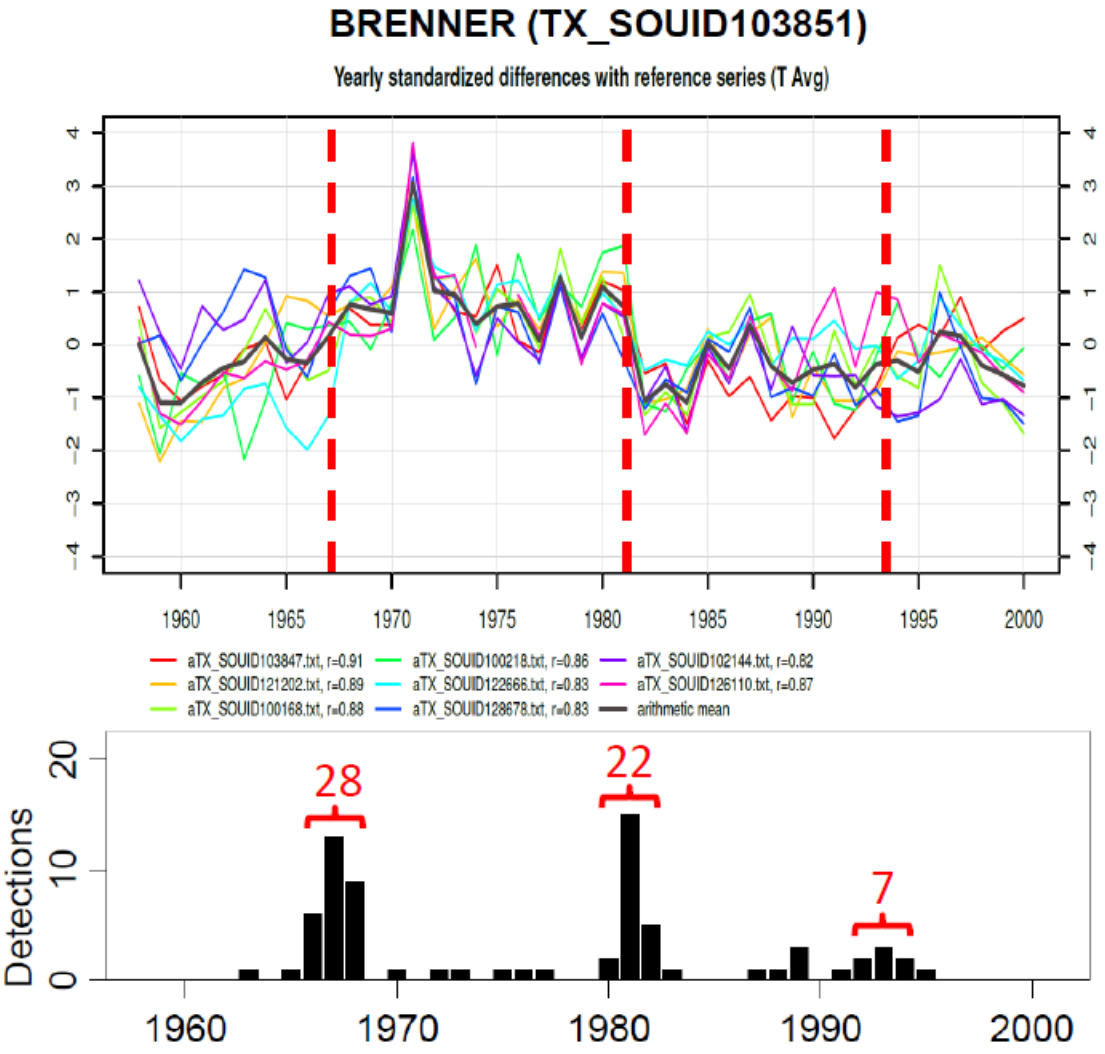
Brugnara et al, 2018, in prep



Likelihood index is created from the ensemble for each detected break

EXAMPLE BREAKPOINT DETECTION

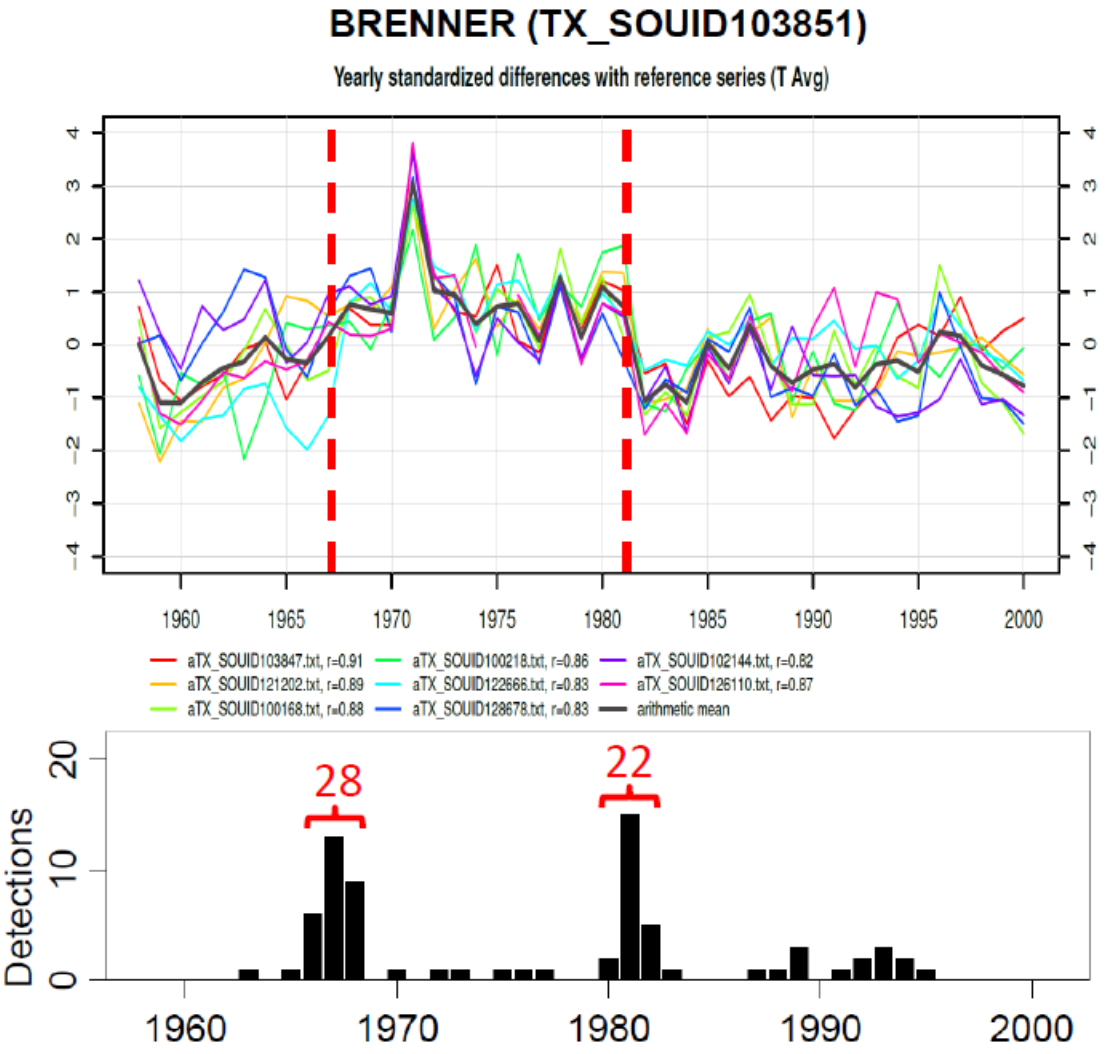
Brugnara et al, 2018, in prep



Likelihood threshold ≥ 5

EXAMPLE BREAKPOINT DETECTION

Brugnara et al, 2018, in prep



Likelihood threshold ≥ 10

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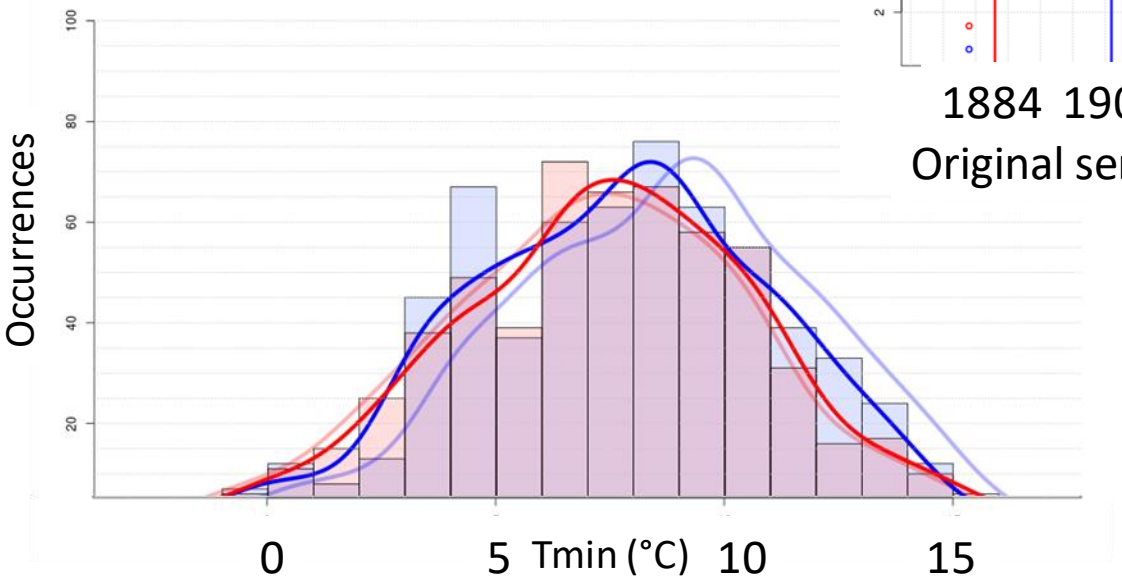
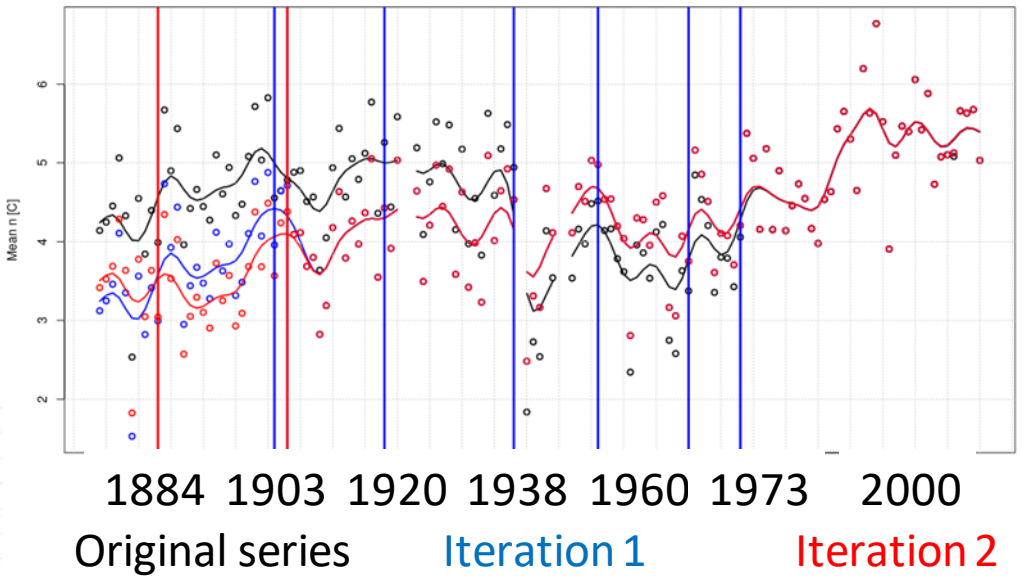
HOMOGENIZATION FOR EUROPE

Squintu et al, 2018, in prep

Pdf of May Tmin for Salzburg in 1918-1937 (light blue: original; blue: homogenised version) and in 1939-1958 (red)



Annual mean Tmin Salzburg, Austria



Annual means of Tmin for Salzburg before (black) and after the homogenisation
Blue: 1st iteration
Red: 2nd iteration

A Quantile Matching procedure is used to adjust for the impact of non-climatic breaks in European station data. Example shows adjustment for a discontinuity in 1938.

Royal Netherlands Meteorological Institute
Ministry of Infrastructure and the Environment

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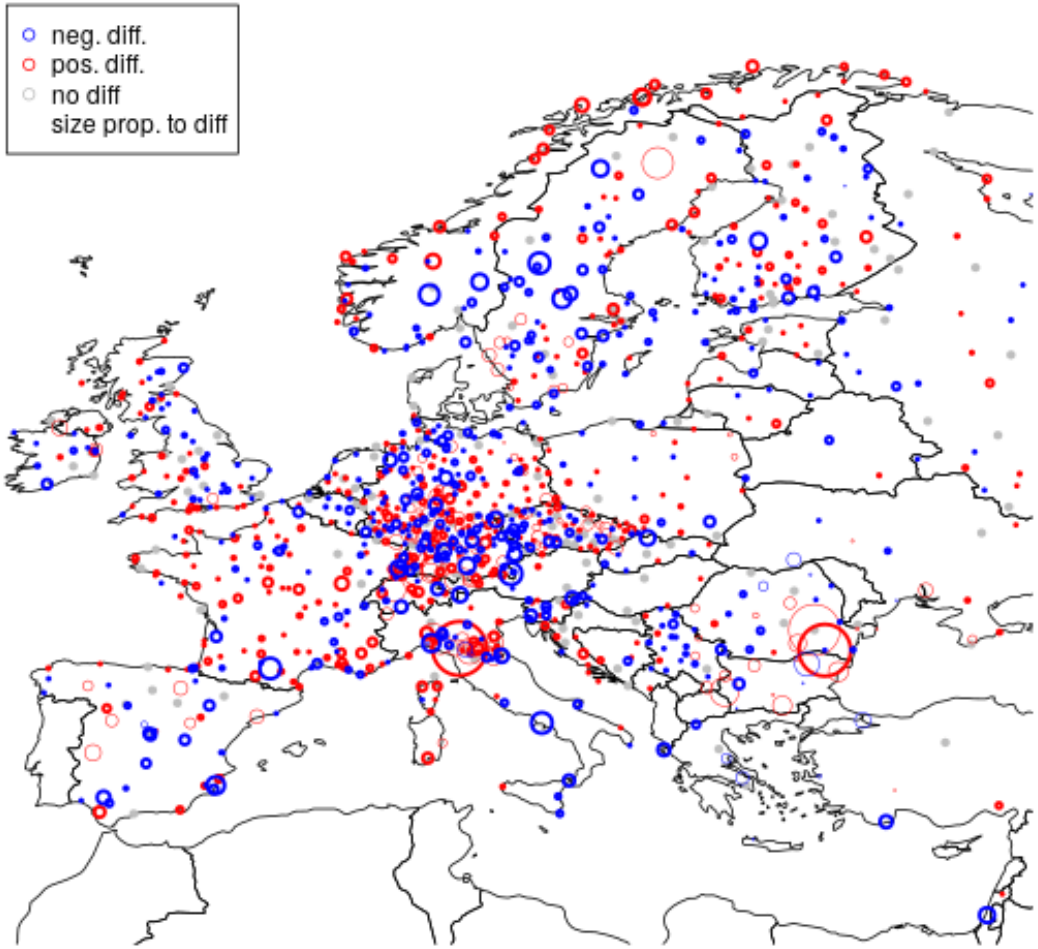
DIFFERENCE IN TRENDS IN TMIN

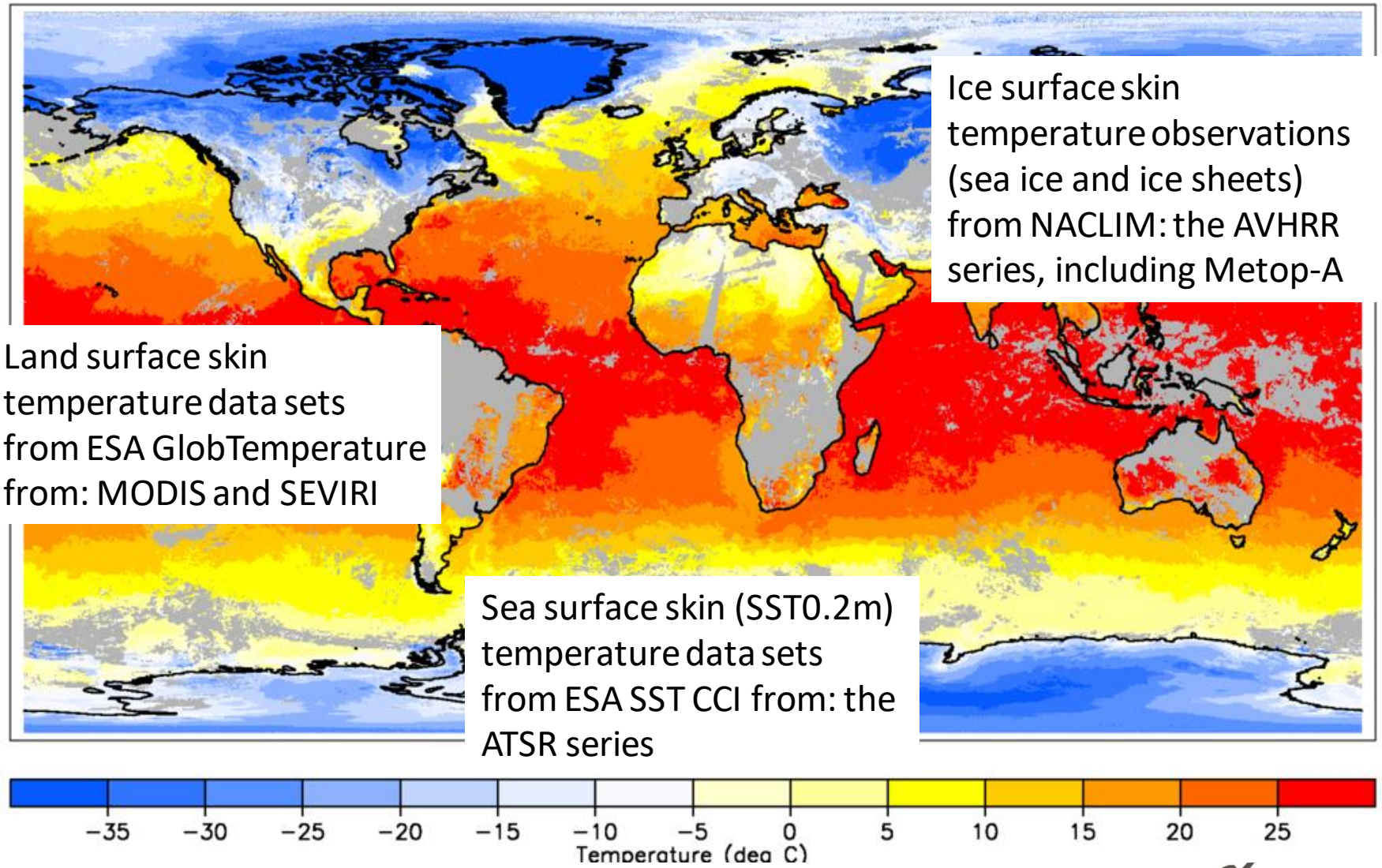
Annual mean Tmin, 1961-2010, difference in trends before and after two iterations of quantile matching



Squintu et al, 2018, in prep

Adjustments can increase or reduce trends. Stations that showed negative trends now show positive trends in most cases

EUSTACE SATELLITE OBSERVATIONS



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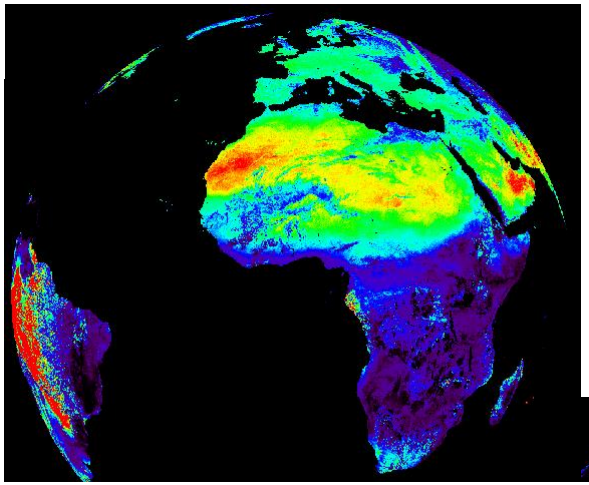
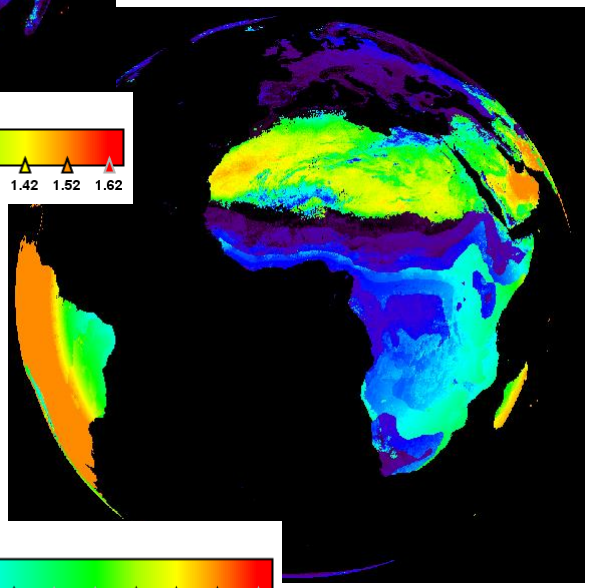
ESTIMATING CONSISTENT UNCERTAINTIES IN SATELLITE RETRIEVALS

- Uncertainties categorised by effects whose errors have distinct correlation properties:
  - ➢ random
  - ➢ locally correlated
  - ➢ (large-scale) correlated
- These are then propagated through the air temperature estimation

Random



Locally correlated



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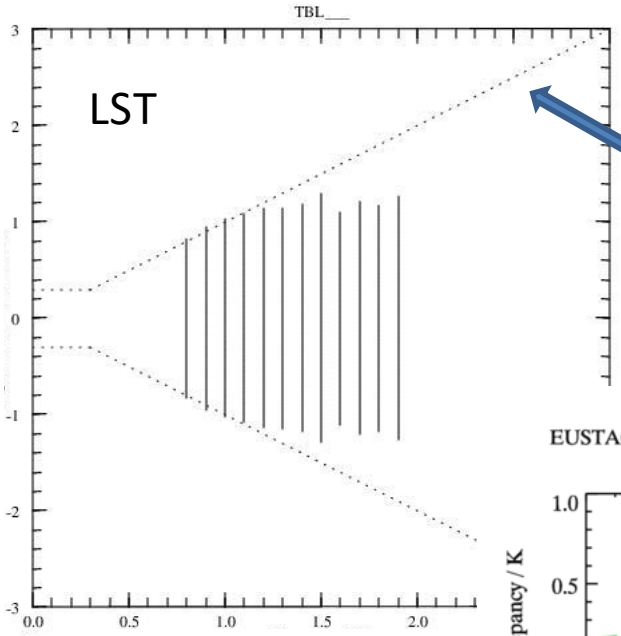
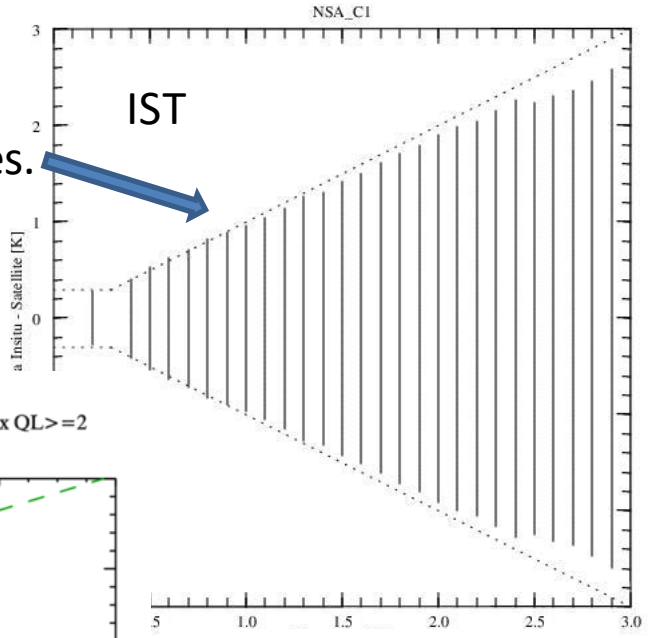
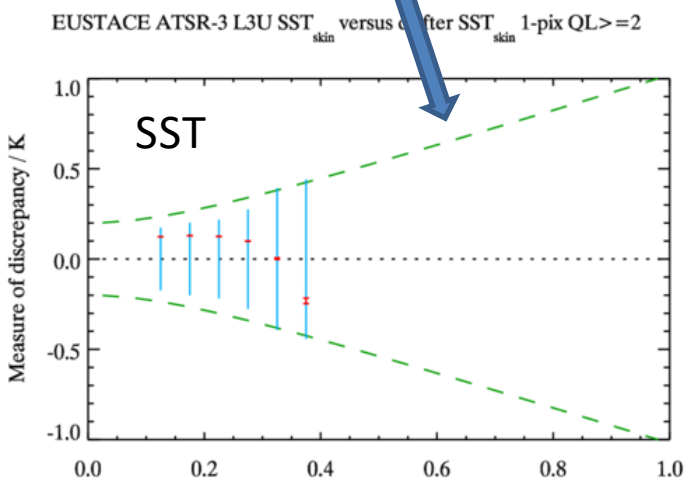
VALIDATION OF LST, IST AND SST UNCERTAINTY ESTIMATES

Temperature difference in situ – satellite (K)



Expected difference envelope defined by uncertainty estimates.





Bars: difference between retrievals and reference measurements, binned by uncertainty estimate

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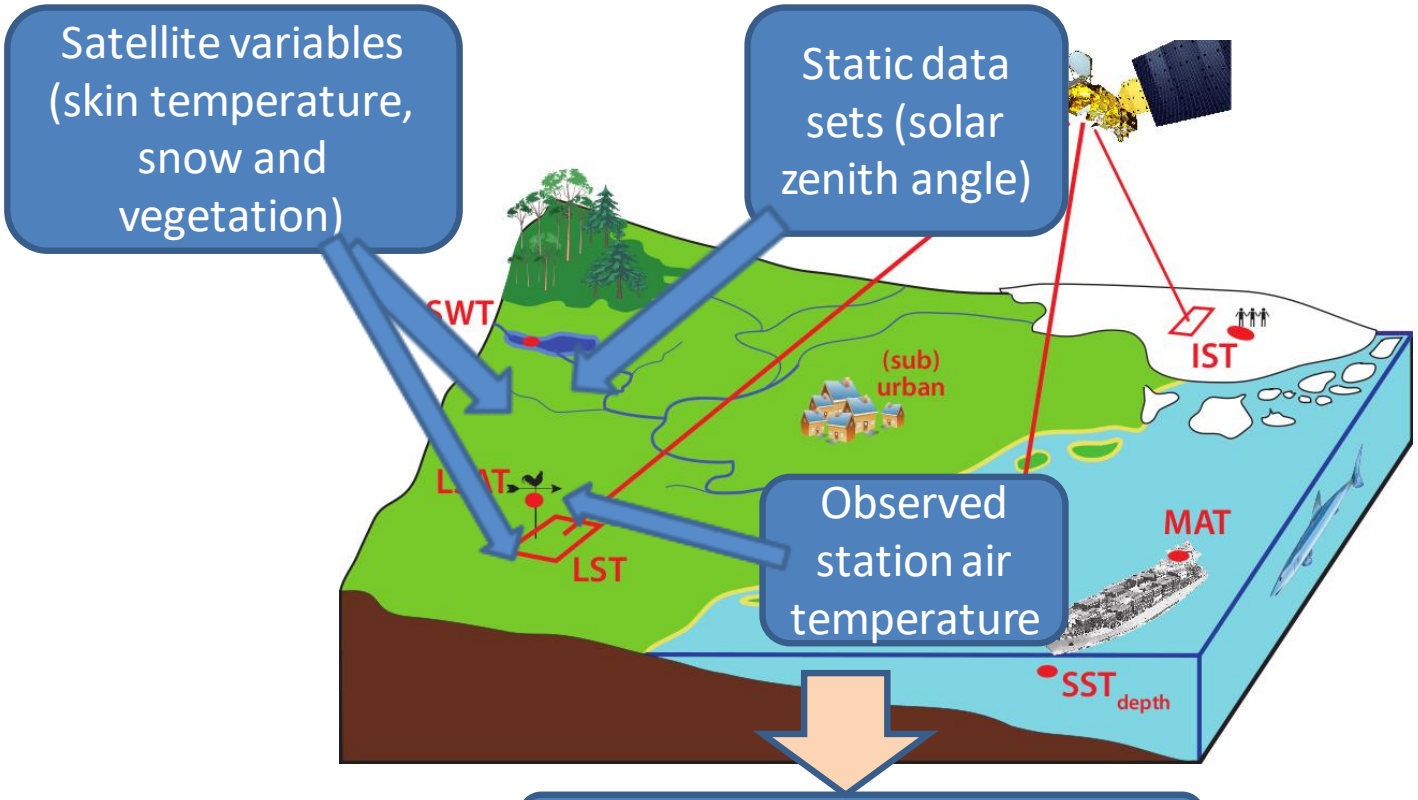
ESTIMATING AIR TEMPERATURE FROM SKIN TEMPERATURE



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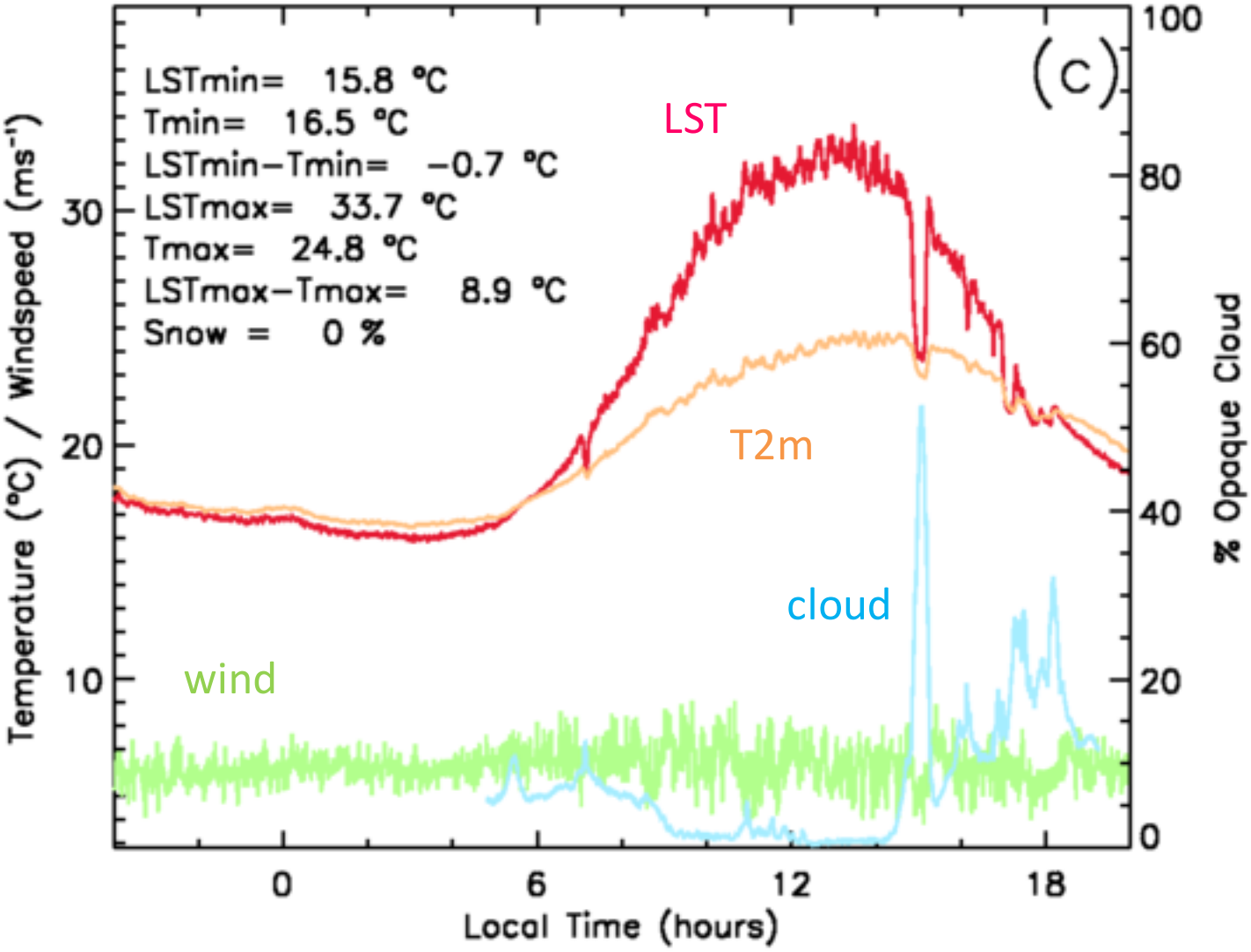
Good (2016), JGR, 121, doi:10.1002/2016JD025318.

LST/TMAX/TMIN

Cape Cod, Massachusetts , 21/06/2013



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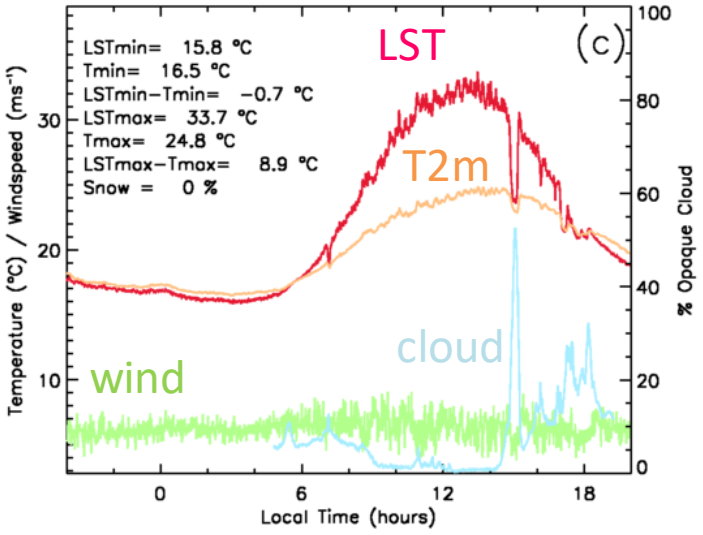
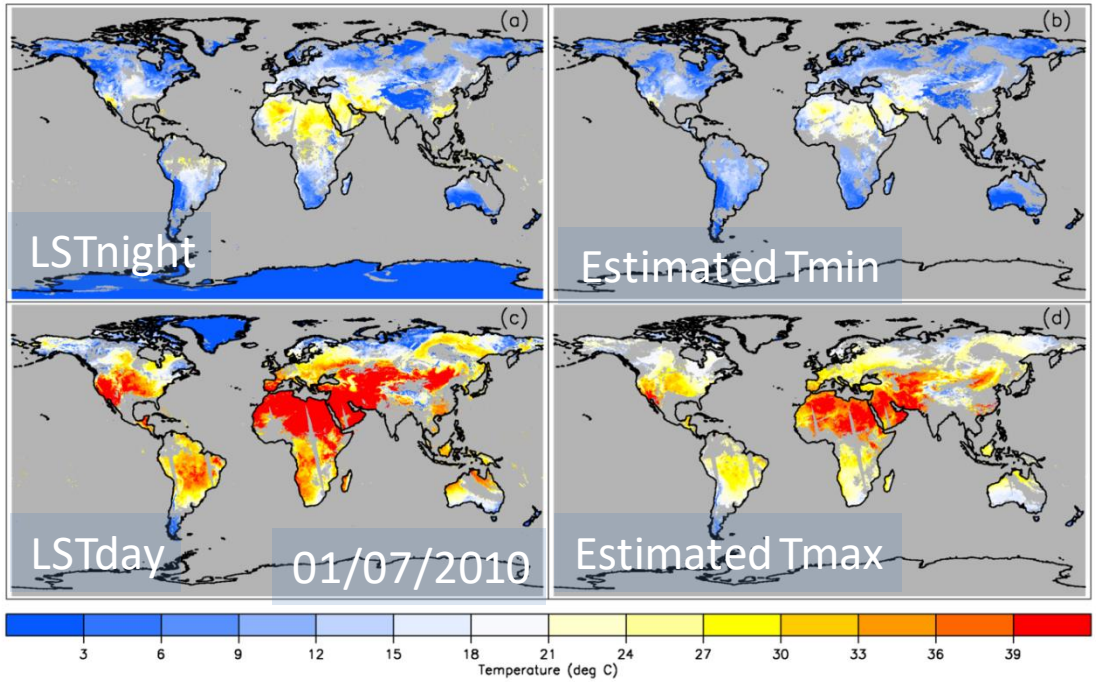
LST/TMAX/TMIN

Cape Cod, Massachusetts , 21/06/2013

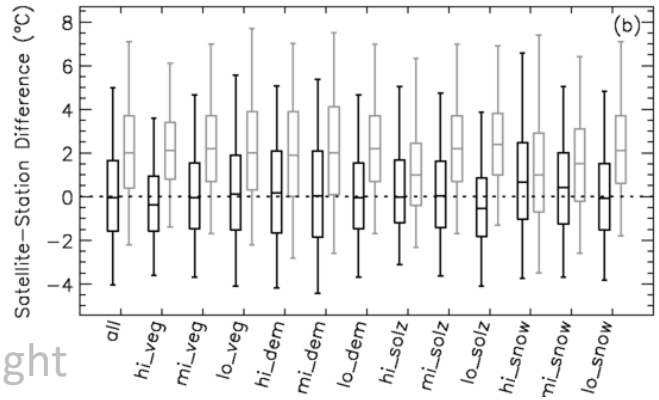




$$T_{max}=\alpha_0+\alpha_1.LST_{day}+\alpha_2.LST_{ngt}+\alpha_3.FVC+\alpha_4.SZA_{noon}+\alpha_5.Snow+\varepsilon_{Tmax}$$

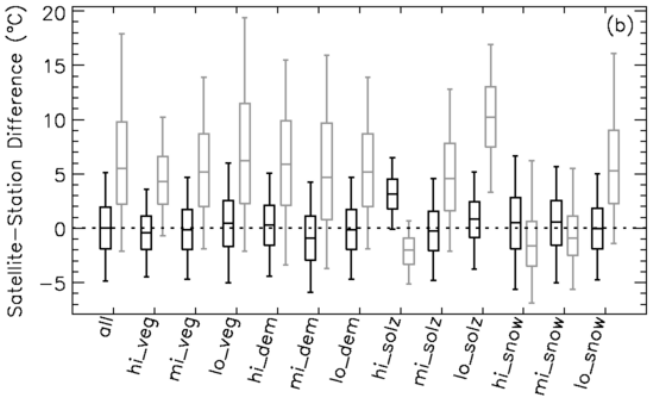
$$T_{min}=\beta_0+\beta_1.LST_{day}+\beta_2.LST_{ngt}+\beta_3.FVC+\beta_4.SZA_{noon}+\beta_5.Snow+\varepsilon_{Tmin}$$

Estimated Tmin vs independent stations



Tmin

LSTnight



Estimated Tmax vs independent stations

Tmax

LSTday

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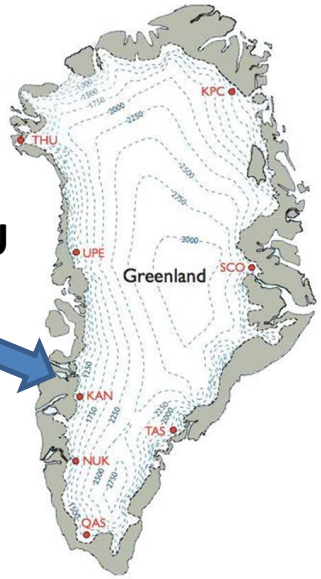
IMPACTS OF CLOUDS

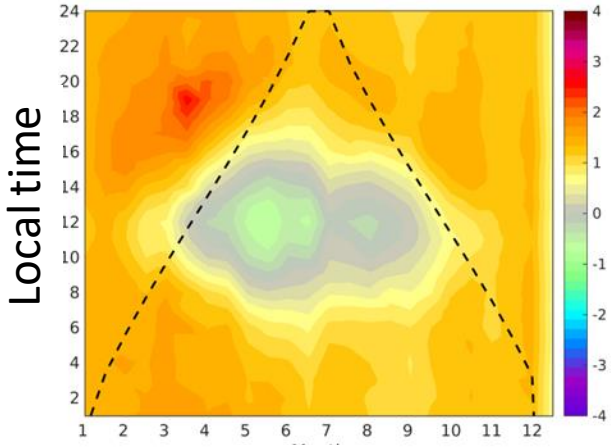


PROMICE - KAN U

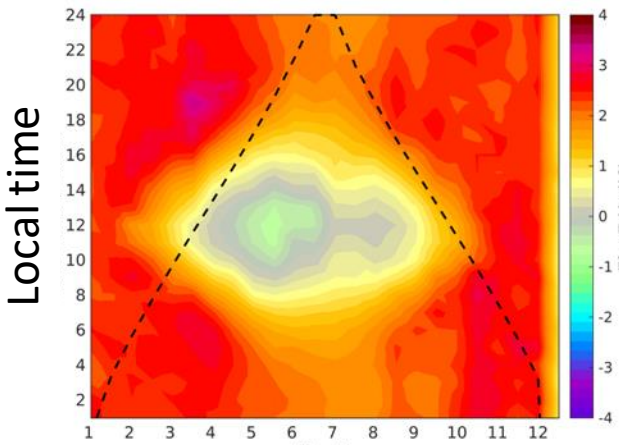
- **Difference between skin temperature and air temperature**
- **Largest differences in clear sky conditions**
- **Seasonal changes**

Dashed lines: total hours of sunlight each month

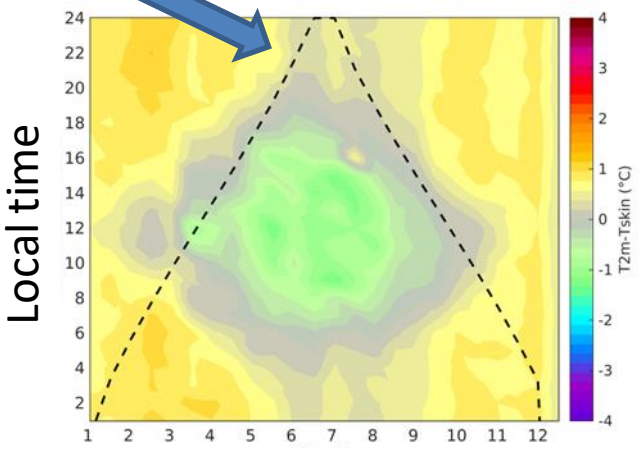
All sky



Clear sky



Overcast



Air temperature – Tskin (^{o}C)

Nielsen-Englyst et al, 2018, in prep

DMI
Danish Meteorological Institute

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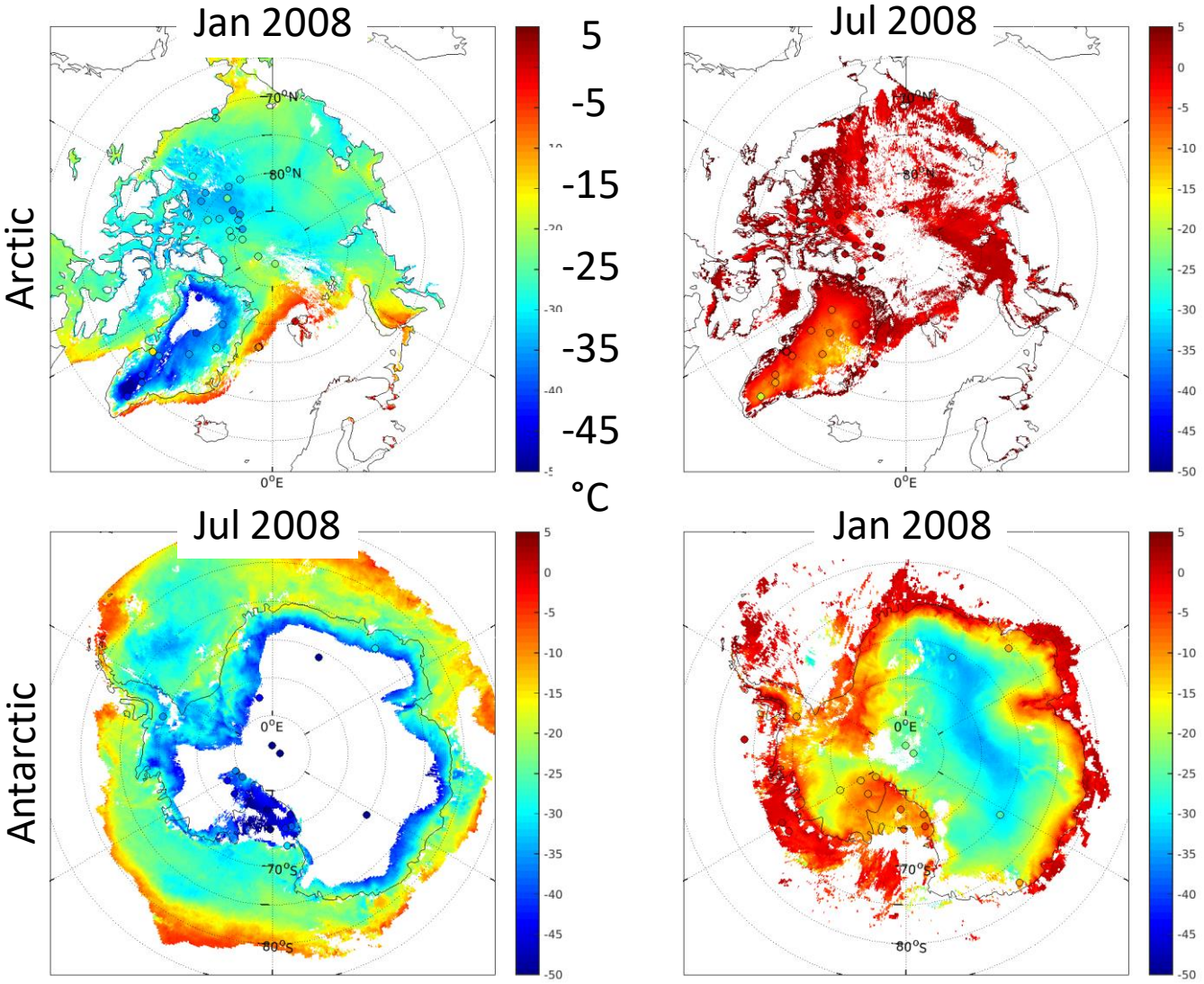
ICE SURFACE AIR TEMPERATURES



Four examples of daily mean surface air temperature over ice, estimated from satellite IST.

Circles show in-situ measurements and white areas indicate missing data, often due to clouds.

DMI
Danish Meteorological Institute

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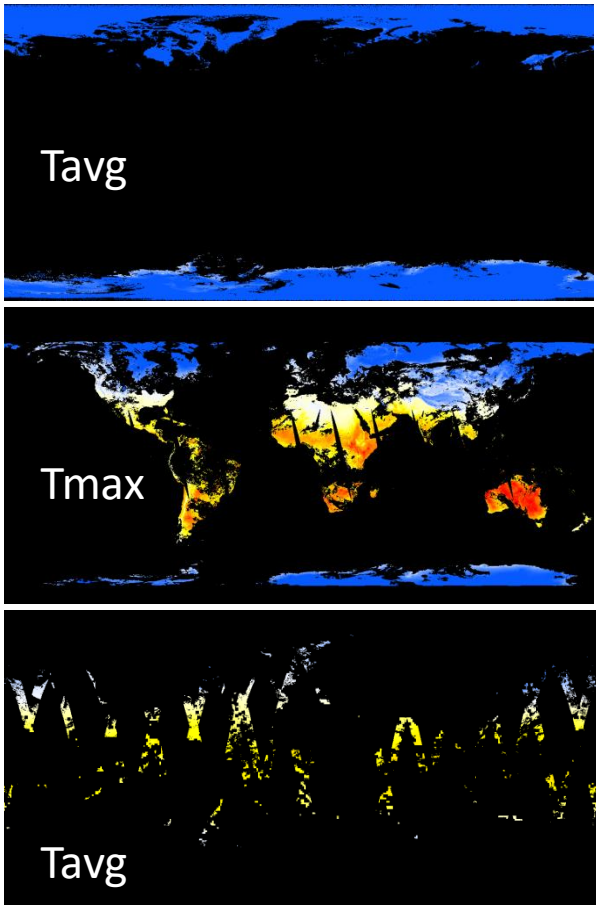
CONSISTENT AIR TEMPERATURE ESTIMATED FROM SATELLITE DATA

- A main surface air temperature file per day per surface type (land, ocean, ice)
- The main files contain total uncertainty budget per grid box and so uncertainty is consistently expressed for all surface types
- There is an ancillary file per day per surface type which contains more detailed uncertainty information. These depend on surface type as uncertainty models differ.



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INFILLED ANALYSIS: AIMS

The desirable properties for analysis depend on the application, and sometimes there is a trade-off between different properties. We are aiming for the following:

Mathematical model for the temperature field should be easy to communicate

Statistical assumptions about the temperature field in the model should be consistent with our knowledge of the physics of the situation

Results for temperature field should have low cross-validation error

Results for uncertainty estimates should also validate well

It should be possible to see where/when temperature estimates are not well constrained by the model

Where uncertainties are difficult to determine, they should overestimate the uncertainty

Output should be in a form that is easy to use even for those without expertise in spatial statistical methods

Output should be in a form that makes it easy to retrieve uncertainty information

Data output formats should work well with commonly available software tools

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TEMPERATURE MODEL

Linear error model

Daily mean air temperatures are decomposed into variability at different scales:

$$y^i = T(\boldsymbol{s}^i, t^i) + \beta^i + \epsilon^i$$

Where β^i is a sum of observational biases affecting observation i and ϵ^i are non-bias related observational errors.

y^i = An air temperature observation index by i

$T(\boldsymbol{s}^i, t^i)$ = Temperature at space/time location $(\boldsymbol{s}^i, t^i)$

β^i = Additive bias associated with observation i

ϵ^i = Error associated with observation i

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TEMPERATURE MODEL

Temperature Process Decomposition

- Temperature variability is decomposed into model sub-components with defined structure in space/time:

$$\boldsymbol{T}(s,t) = \boldsymbol{T}^{\text{clim}}(s,t) + \boldsymbol{T}^{\text{large}}(s,t) + \boldsymbol{T}^{\text{local}}(s,t)$$

$\boldsymbol{T}(s,t)$ = Temperature at space/time location (s,t)

$\boldsymbol{T}^{\text{clim}}(s,t)$ = Climatological temperature

$\boldsymbol{T}^{\text{large}}(s,t)$ = Large spatial/temporal scale component

$\boldsymbol{T}^{\text{local}}(s,t)$ = Daily, short spatial scale component

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ADVANCED STANDARD METHOD

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TEMPERATURE MODEL

Strategy for solution

- Temperature variability is decomposed into model sub-components with defined structure in space/time:

$$\boldsymbol{T}(s,t) = \boldsymbol{T}^{\text{clim}}(s,t) + \boldsymbol{T}^{\text{large}}(s,t) + \boldsymbol{T}^{\text{local}}(s,t)$$

- Each component is a Gaussian linear model (or linearised model).
- Solve each sub-component conditioned on the expected value of other sub-components.
- Refine the solutions to each sub component by iteratively re-estimating each sub-component.

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ADVANCED STANDARD METHOD

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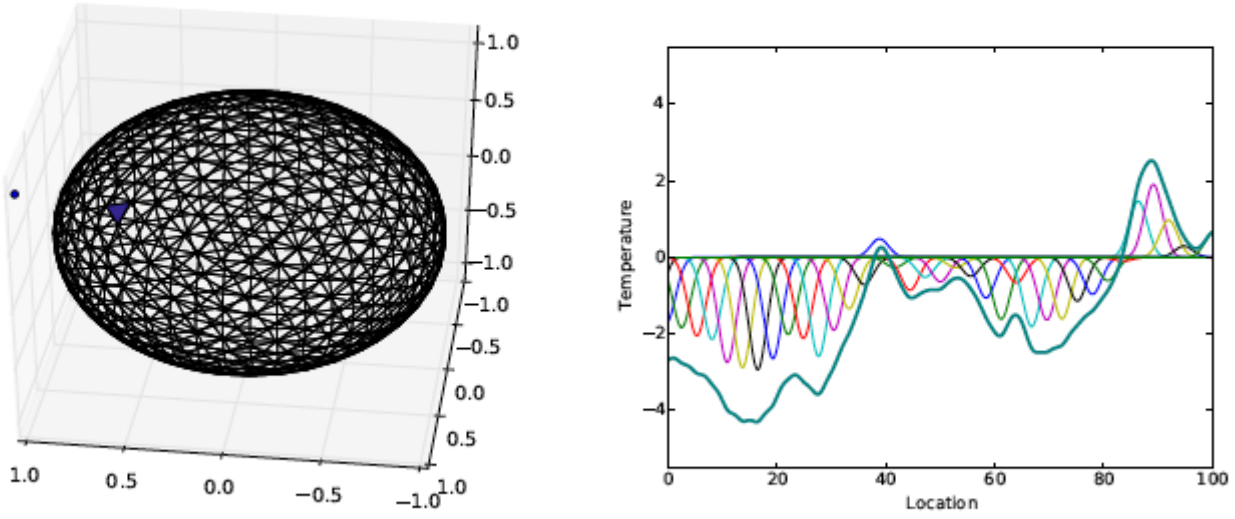
ANALYSIS METHOD

Spatial interpolation based on the SPDE approach (Lindgren et al 2011):

- Temperatures are modelled as weighted sum of local functions.
- A Bayesian method, where variability/smoothness is controlled by a prior distribution for the weights.
- Compute the probability density function of the weights conditioned on the temperature observations.



Lindgren, F., H. Rue, J. Lindström, (2011). An explicit link between Gaussian fields and Gaussian Markov random fields: the stochastic partial differential equation approach, *Journal of the Royal Statistical Society: Series B (Statistical Methodology)*, 73, 4

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ADVANCED
STANDARD METHOD

Performing the analysis

WE NEED A STARTING POINT

A

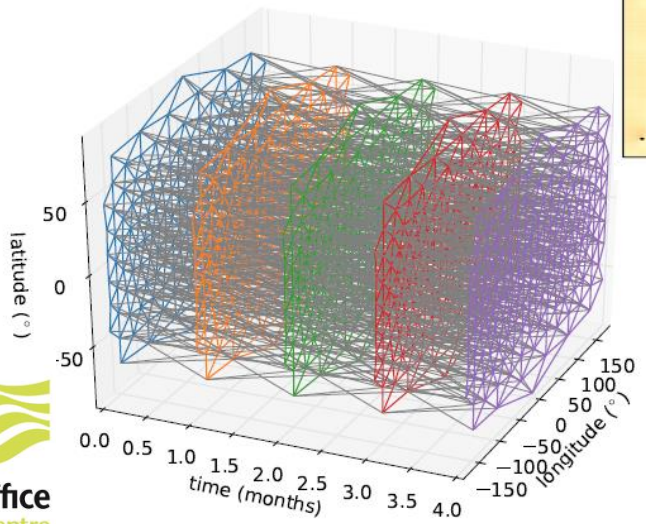
Process observations

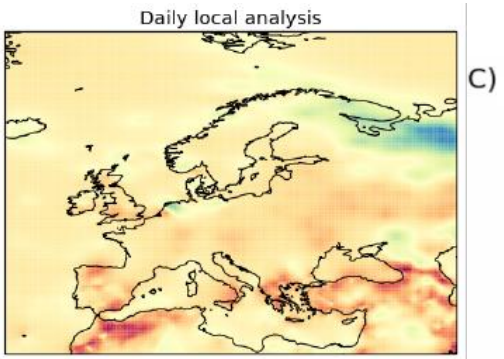
Solve climatology

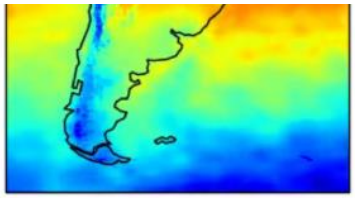
B

Process observations conditioned on A

Solve large scale







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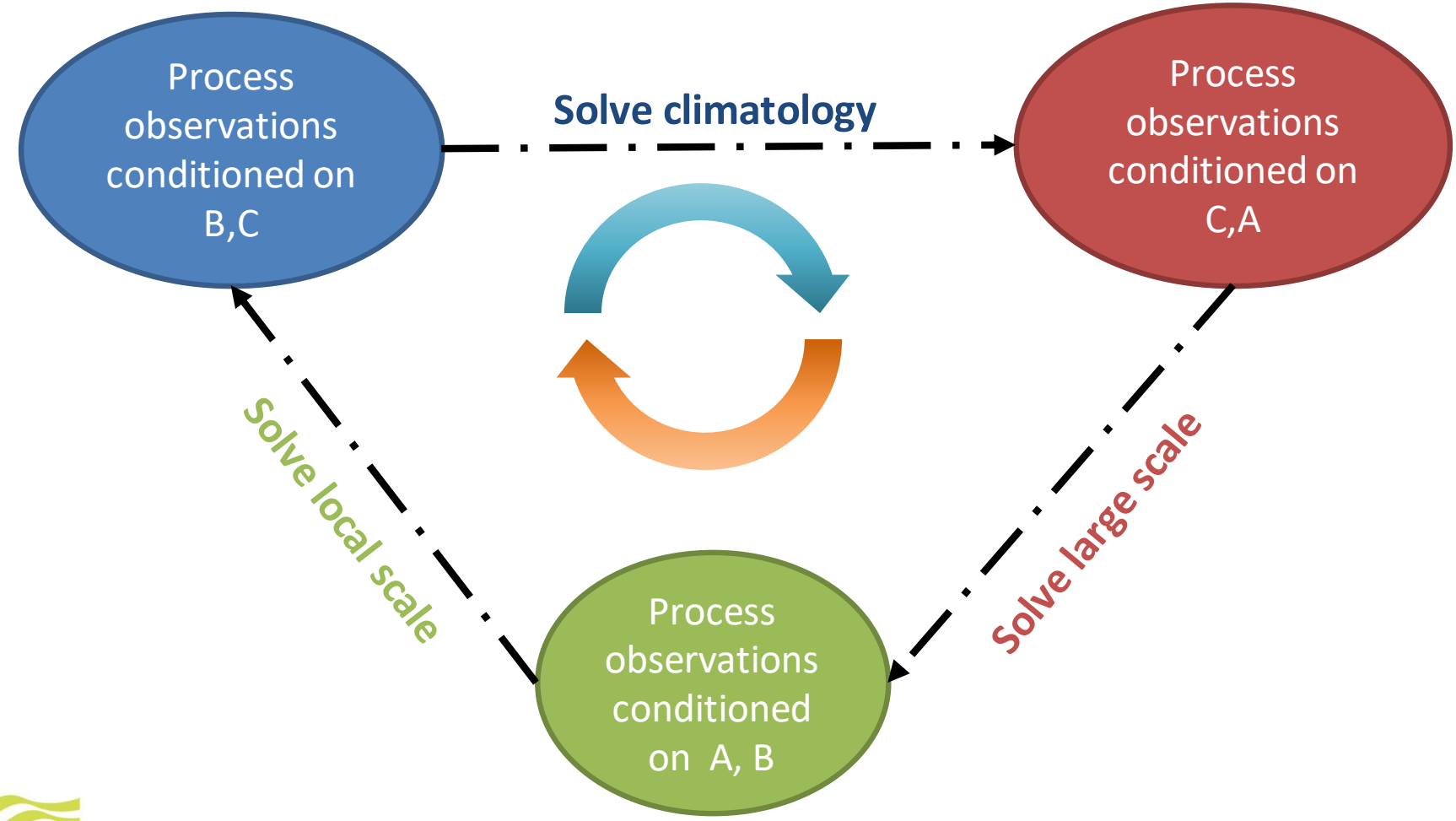
ADVANCED STANDARD METHOD

Performing the analysis



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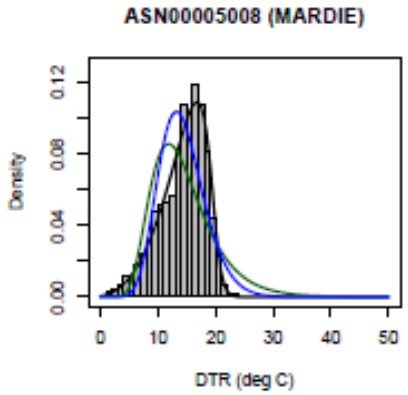
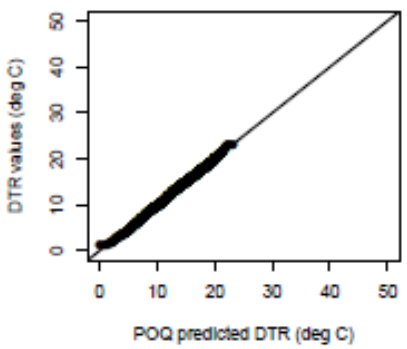
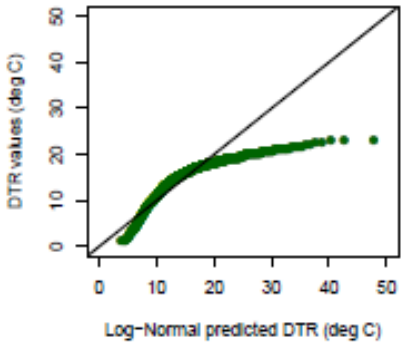
Additionally model Tmax and Tmin via diurnal temperature range



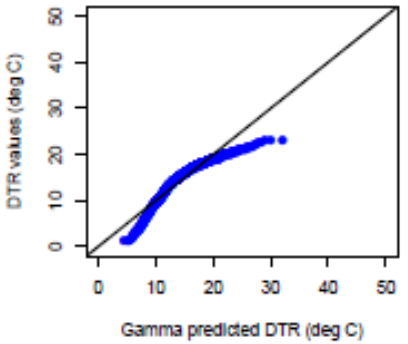
Example station DTR



POQ

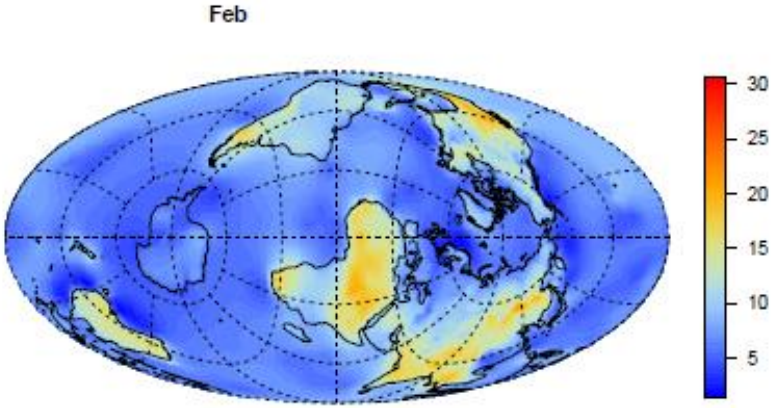


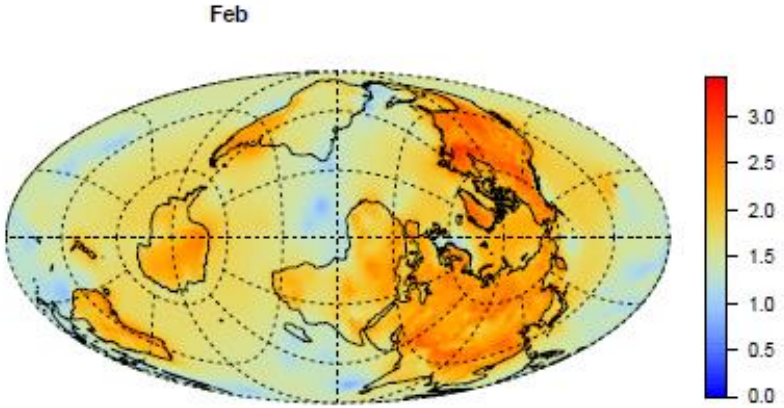
Log normal



Gamma

DTR





AMBITIOUS METHOD

EUSTACE PRODUCTS

Product	Description	Date
Station series and E-OBS update	Global data set of daily weather station air temperature measurements (Tmax and Tmin) with non-climatic breaks identified – Station time series and gridded for Europe	Completed 2017
Satellite skin temperature retrievals	Daily satellite skin temperature estimates for all surfaces of Earth with consistent uncertainty estimates – Gridded or along satellite's track	Release 2018
Skin/air temperature relationships	Understanding of the relationship between surface skin and surface air temperature over all surfaces of Earth and in different seasons – A report on EUSTACE website	Publish 2018
Air temperature estimates from satellites	Gridded daily estimates of surface air temperature from skin temperature retrievals	Complete 2018
Globally complete air temperature fields	Globally-complete daily fields of surface air temperature over all corners of Earth since 1850 – Gridded (0.25° lat/lon) perhaps an ensemble. (Tmax and Tmin over land, Tmean elsewhere.)	Release 2019
Derived products	For example, global means and climatologies	Release 2019

SUMMARY

- EUSTACE is producing global, daily information on surface air temperature by combining measurements made in situ with satellite retrievals
- Non-climatic breaks in global station data have been identified and removed from European station data
- Consistent estimates of uncertainty have been estimated for skin temperature retrievals
- Relationships between skin and air temperature have been used to estimate air temperature from satellite retrievals
- Statistical interpolation methods are being developed to create globally- and regionally-complete fields.
- For further information about EUSTACE, visit https://www.eustaceproject.eu/

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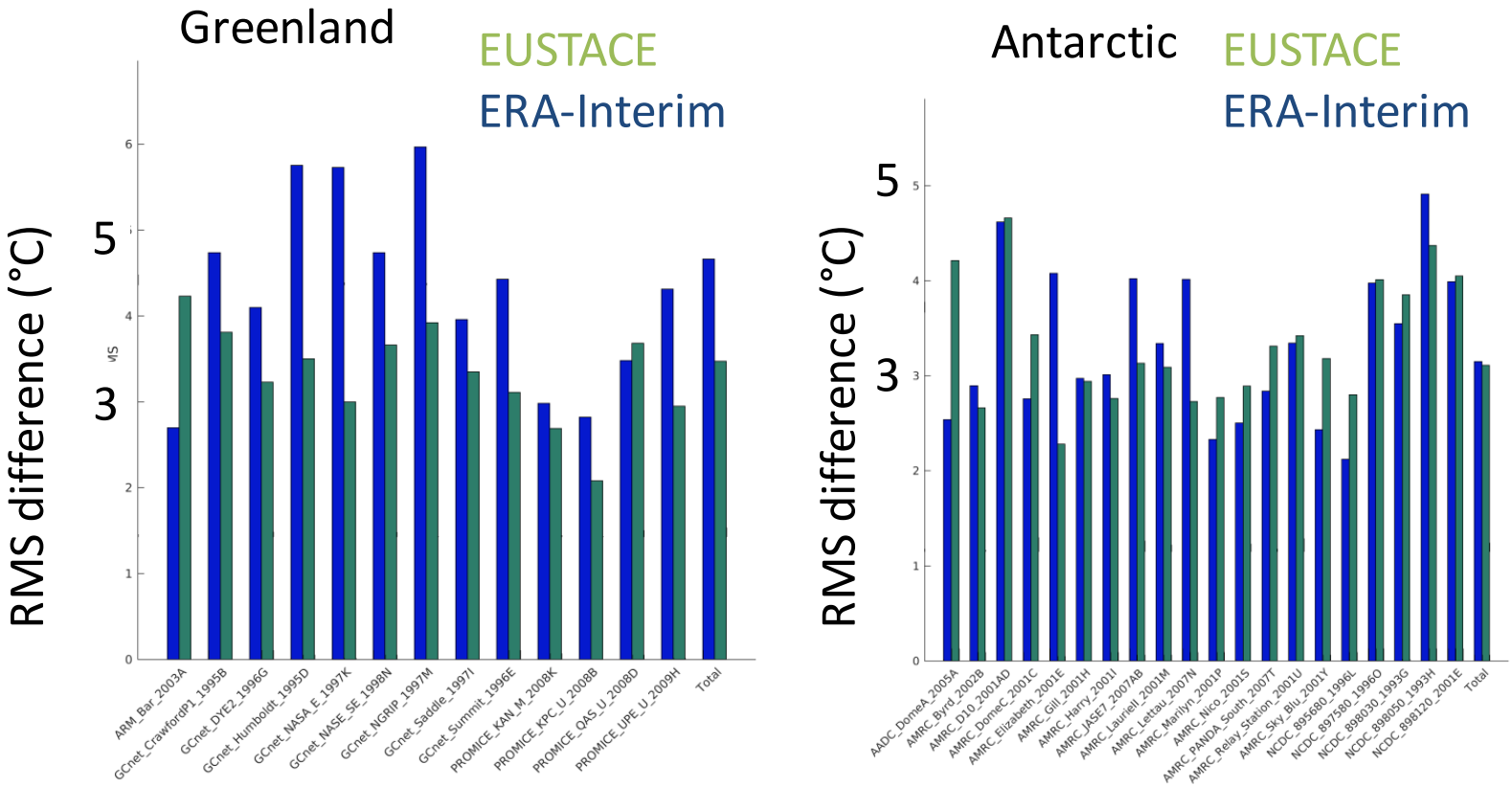
QUESTIONS

EUSTACE has received funding from the European Union's Horizon 2020 Programme for Research and Innovation, under Grant Agreement no 640171

VALIDATION & INTERCOMPARISON

RMS differences (°C) over land ice. Blue: in situ vs ERA-Interim.
Green: in situ vs EUSTACE satellite-derived air temperature.

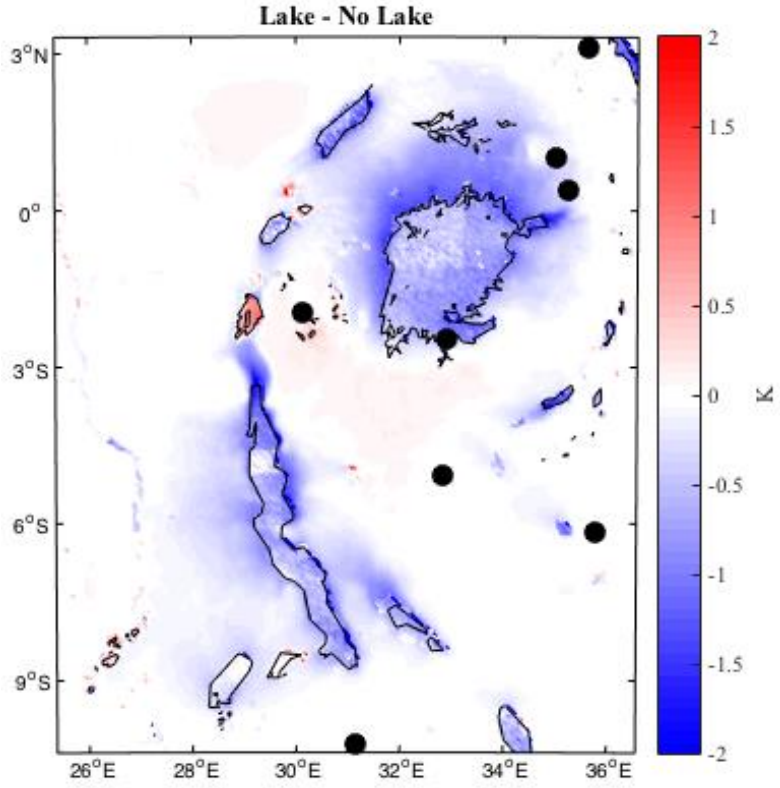


DMI
Danish Meteorological Institute

EUSTACE

FUTURE REFINEMENTS: IMPACT OF LAKES

Experiment: Difference between Regional Climate Model simulation ‘with’ and ‘without’ the presence of lakes, e.g. for Lake Victoria



When we compare the ‘with’ and ‘without’ lake model runs we see a large influence of lakes on nearby T2m

The affected region is not only situated above the lake surface but can also extend more than 100 km from the lake

University of Reading

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