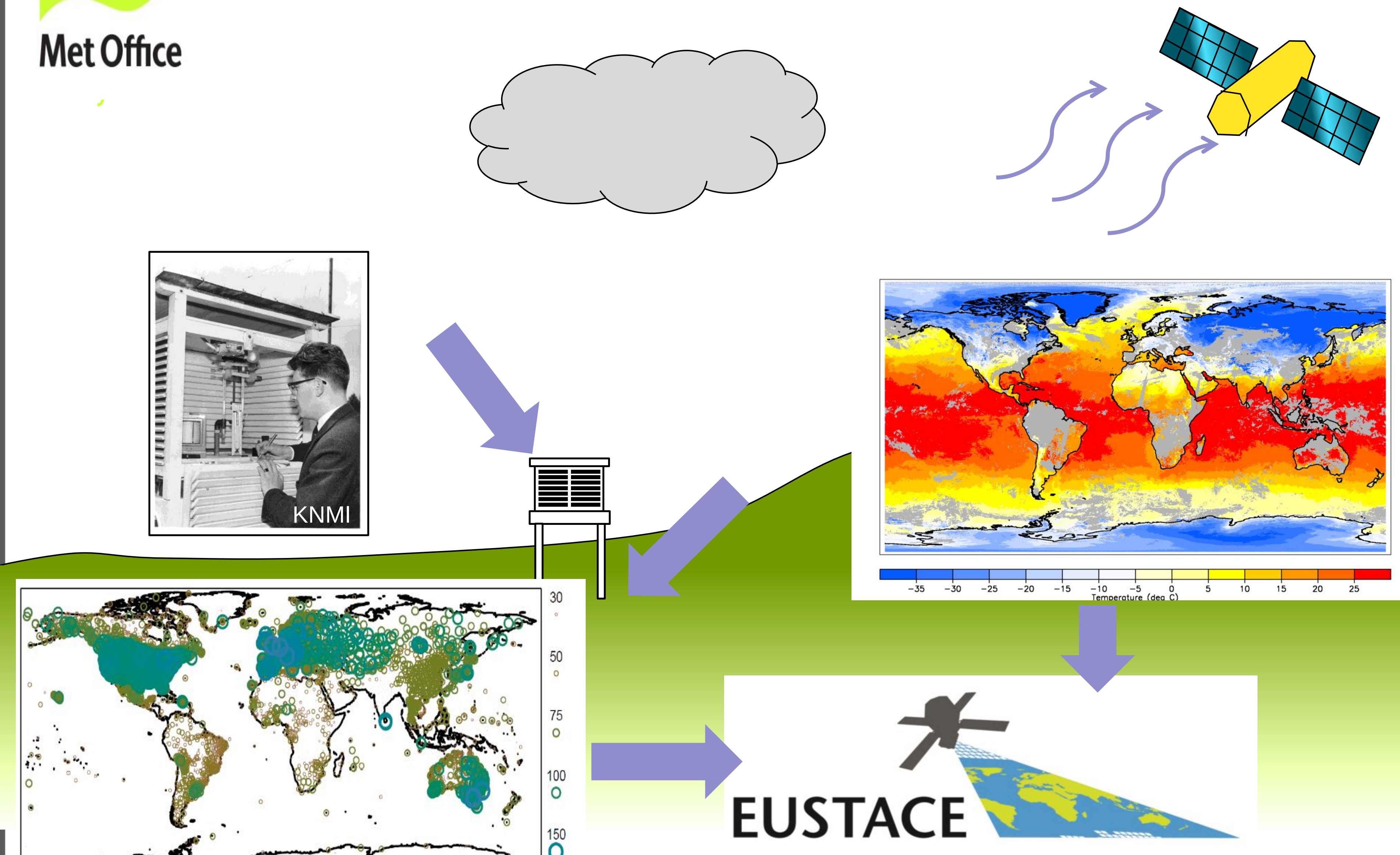
Measuring temperature



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

NICK RAYNER, EUSTACE SCIENCE COORDINATOR

AND THE EUSTACE PROJECT TEAM

EMS CONFERENCE 6TH SEPTEMBER 2018

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material provided by: Lizzie Good, Yuri Brugnara, Antonello Squintu, Darren Ghent, Karen Veal, John Kennedy, Colin Morice, Francesco Capponi and Finn Lindgren

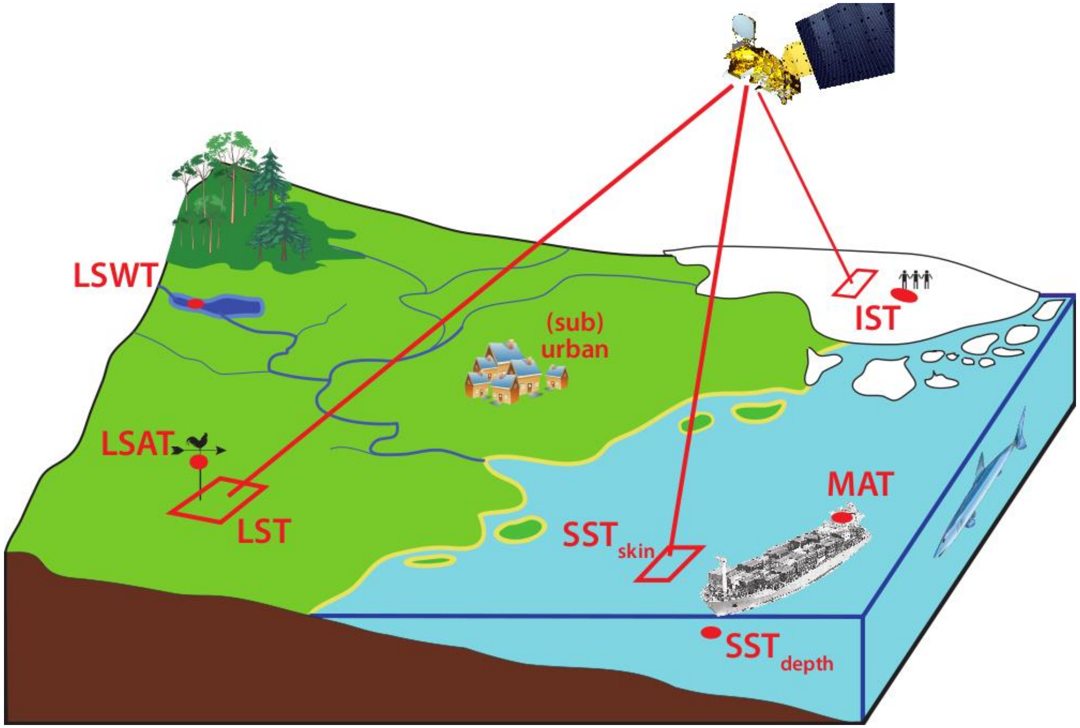
EUSTACE has received funding from the European Union's Horizon 2020 Programme for Research and Innovation, under Grant Agreement no 640171

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:

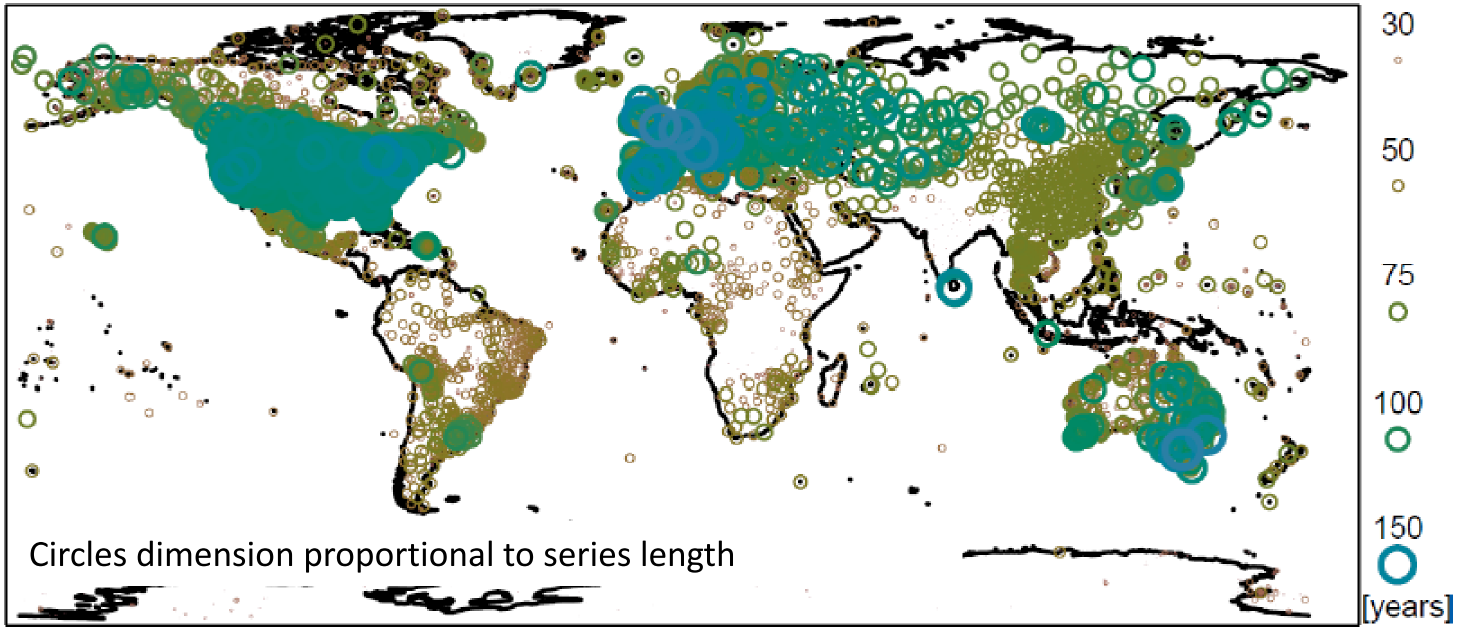
- Identify non-climatic discontinuities in daily weather station data, *so users can trust the changes our records show*
- Produce consistent uncertainty estimates for satellite skin temperature retrievals over all surfaces (land, ocean and ice), *so we know how far to trust the estimates everywhere*
- 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*

UNDERSTAND RELATIONSHIP BETWEEN AIR AND SKIN TEMPERATURE

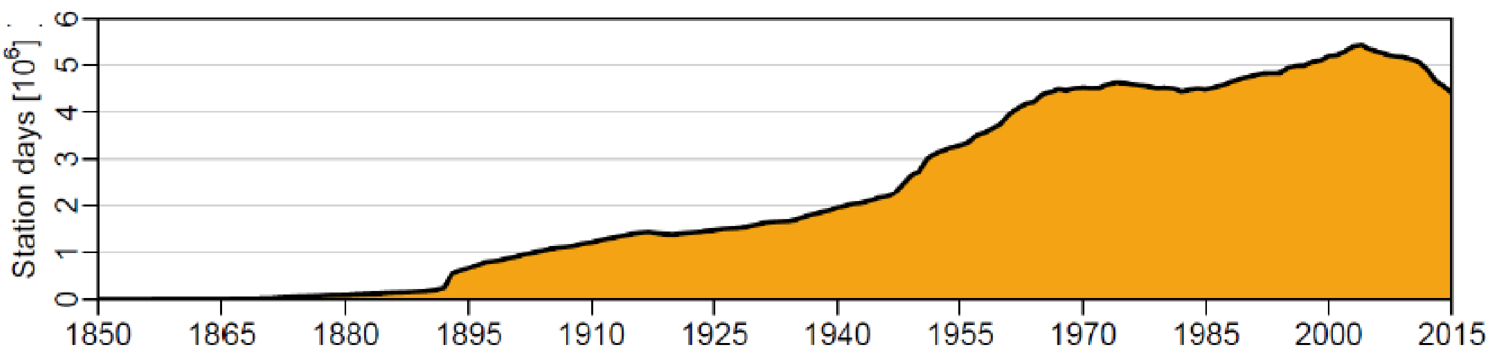


From Merchant et al., 2013 community paper and roadmap:
http://www.geosci-instrum-method-data-syst.net/2/305/2013/gi-2-305-2013.html

EUSTACE DAILY STATION DATASET

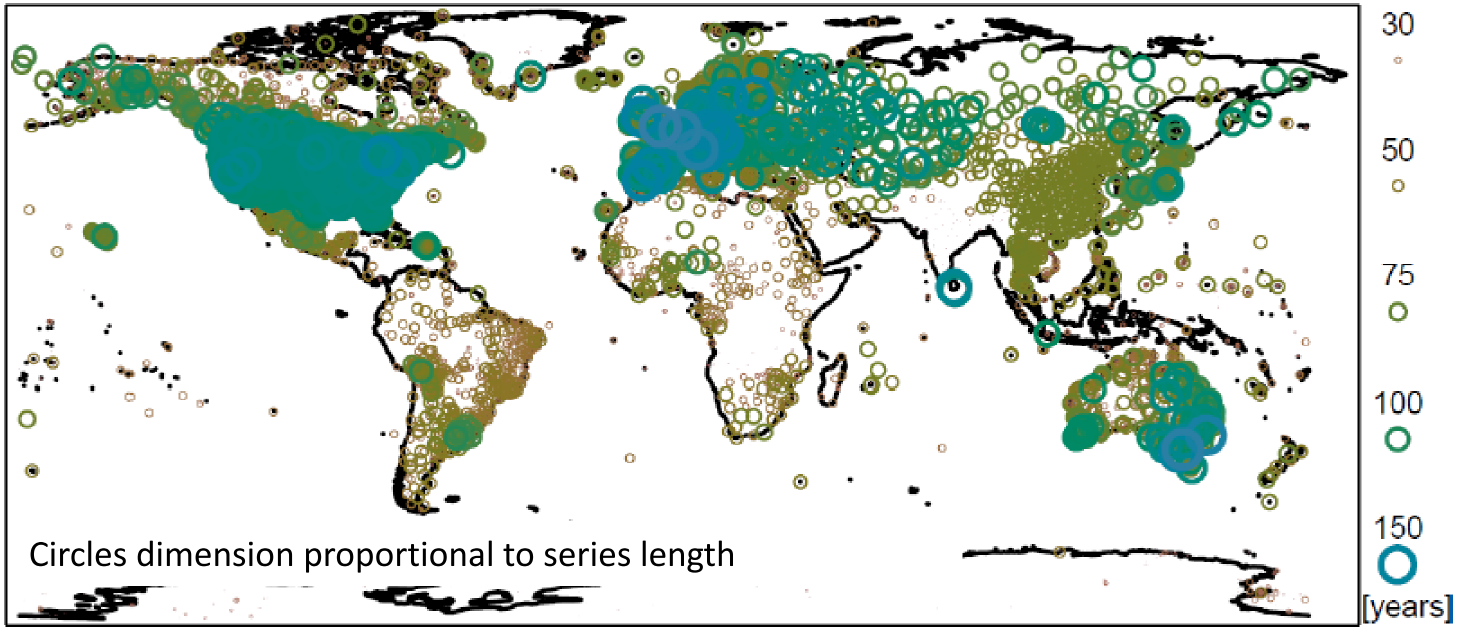


GHCN-D + ECA&D + ISTI + ERA-CLIM + DECADE + UNIBE + SMN



Brugnara et al, 2018, submitted

EUSTACE DAILY STATION DATASET



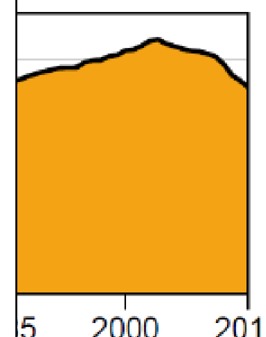
Three different algorithms applied to annual and semi-annual averages of differences between candidate and reference series

+

Absolute test when reference stations not available or insufficient

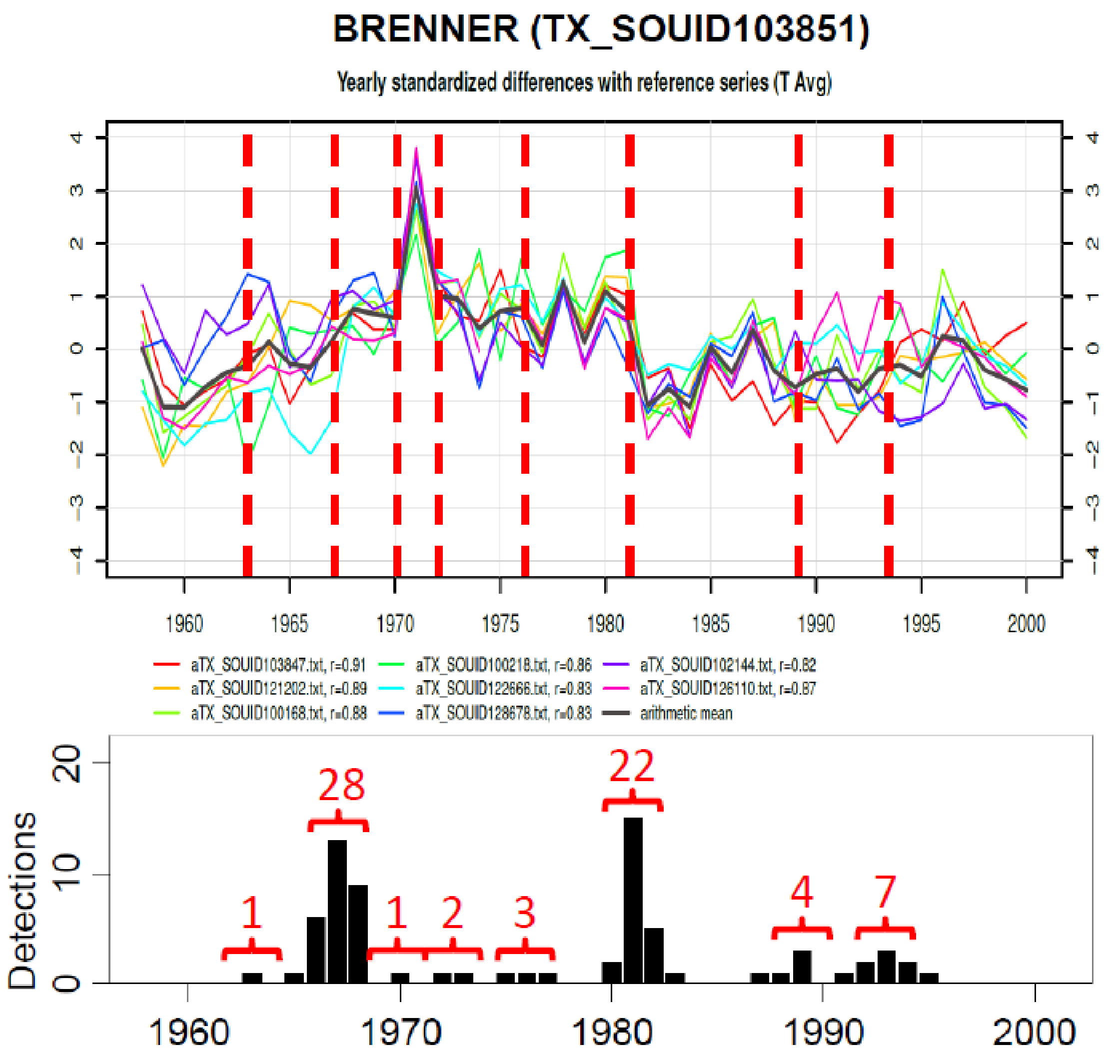
Applied to: T_{max}, T_{min}, $T_{avg} = (T_{max} + T_{min}) / 2$ and $DTR = T_{max} - T_{min}$

Gives: a 48-member break point detection ensemble.



EXAMPLE BREAKPOINT DETECTION

Brugnara et al, 2018, submitted



Likelihood index is created from the ensemble for each detected break

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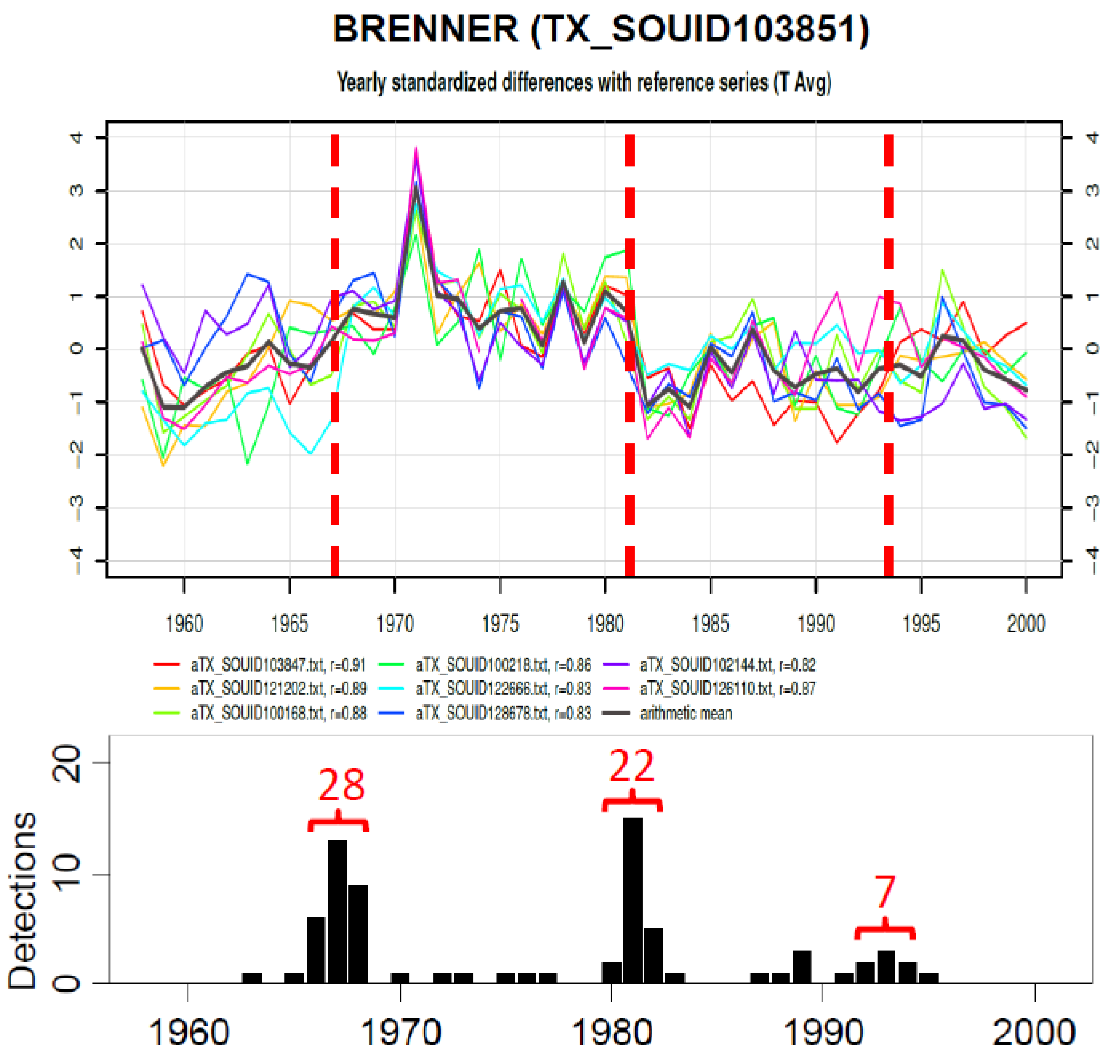
EXAMPLE BREAKPOINT DETECTION

Brugnara et al, 2018, submitted



Likelihood threshold ≥ 5

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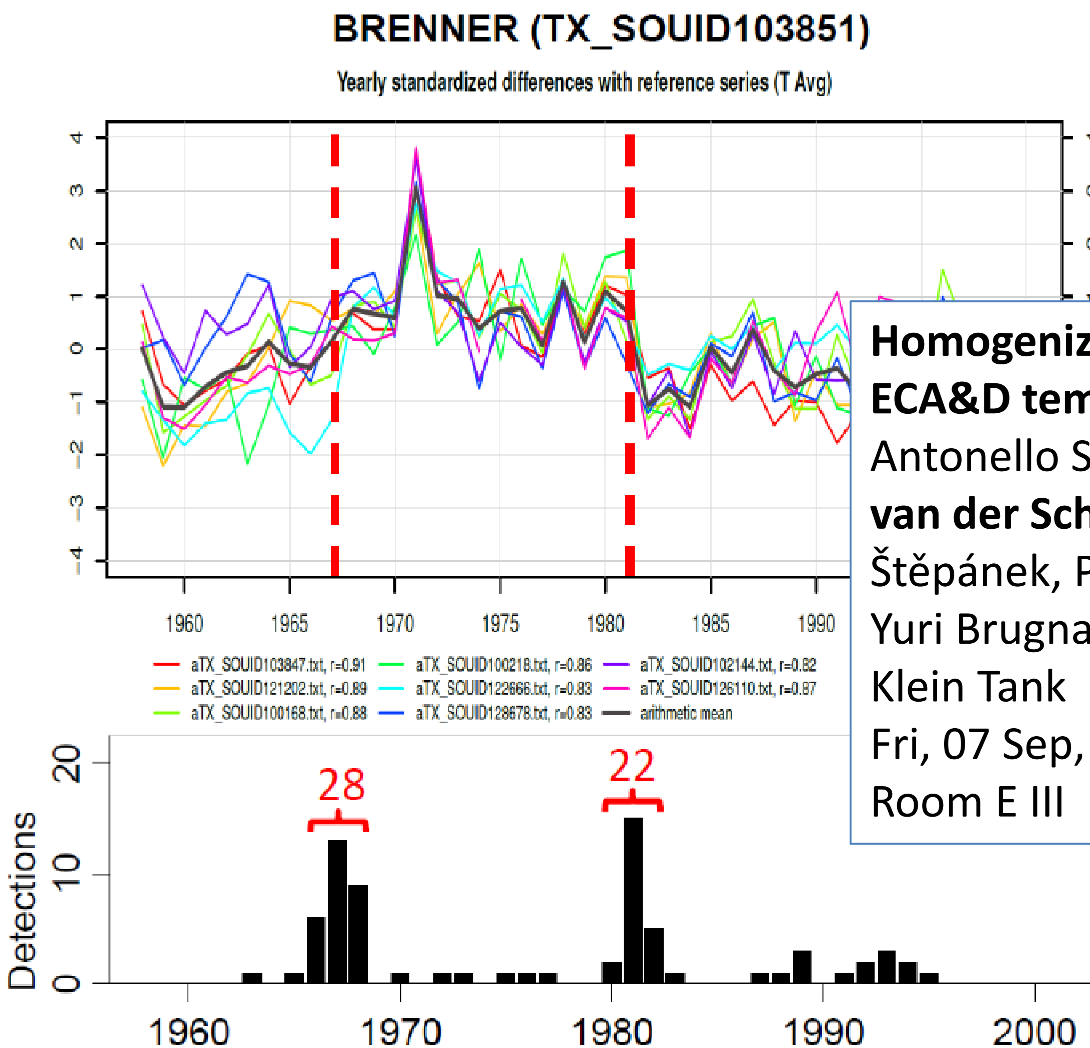
EXAMPLE BREAKPOINT DETECTION

Brugnara et al, 2018, submitted



hold ≥ 10

Homogenization of the ECA&D temperature dataset
Antonello Squintu, **Gerard van der Schrier**, Petr Štěpánek, Pavel Zahradníček, Yuri Brugnara, and Albert Klein Tank
Fri, 07 Sep, 11:45–12:00, Room E III

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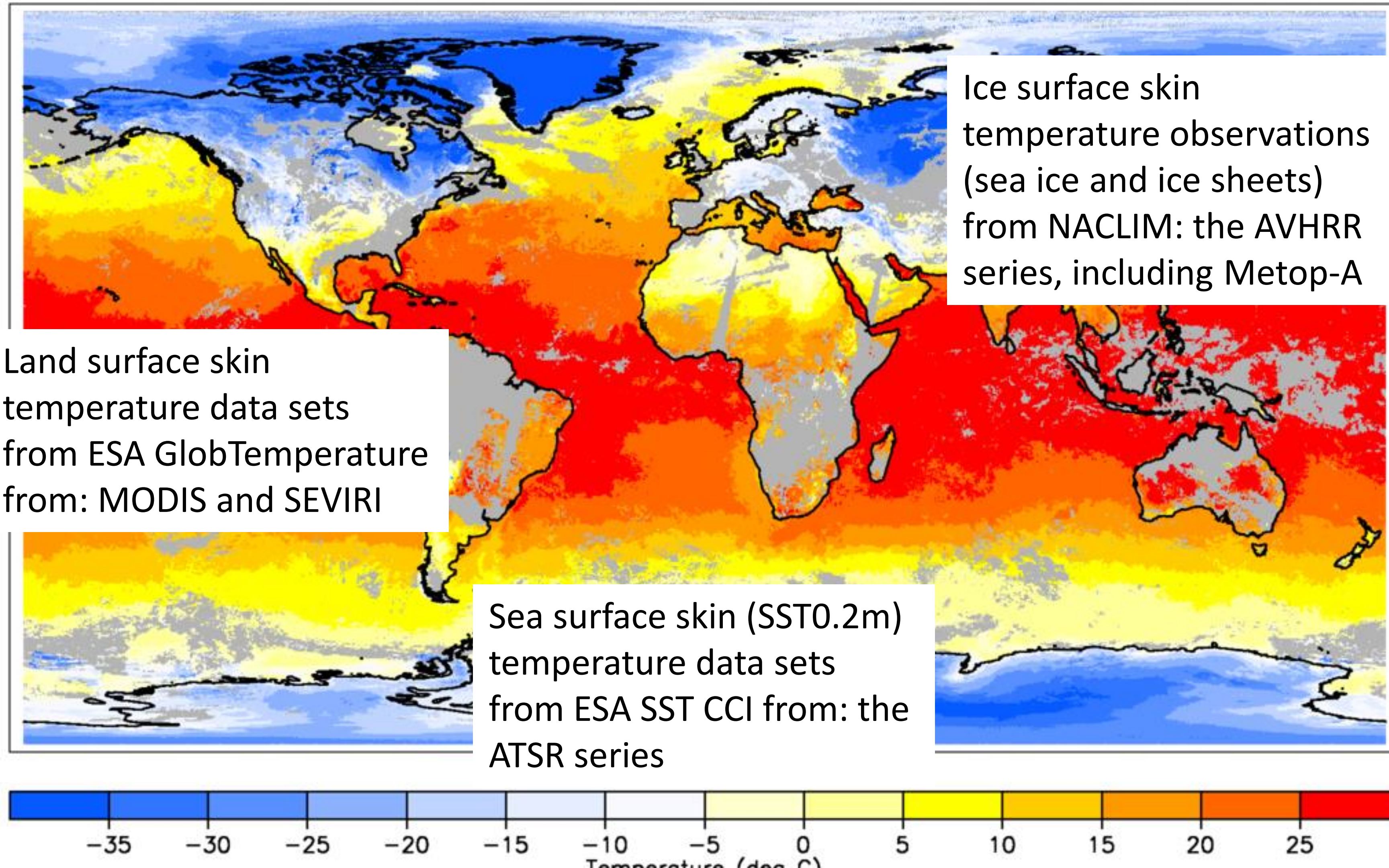
EUSTACE SATELLITE OBSERVATIONS



Ice surface skin temperature observations (sea ice and ice sheets) from NACLIM: the AVHRR series, including Metop-A

Land surface skin temperature data sets from ESA GlobTemperature from: MODIS and SEVIRI

Sea surface skin (SST0.2m) temperature data sets from ESA SST CCI from: the ATSR series

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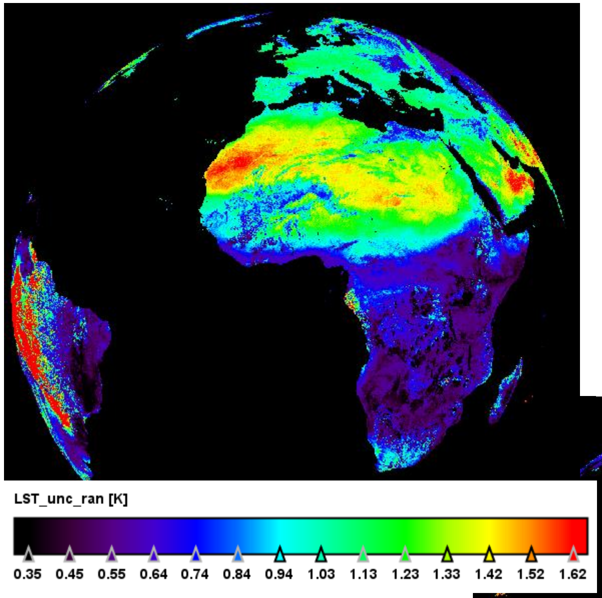
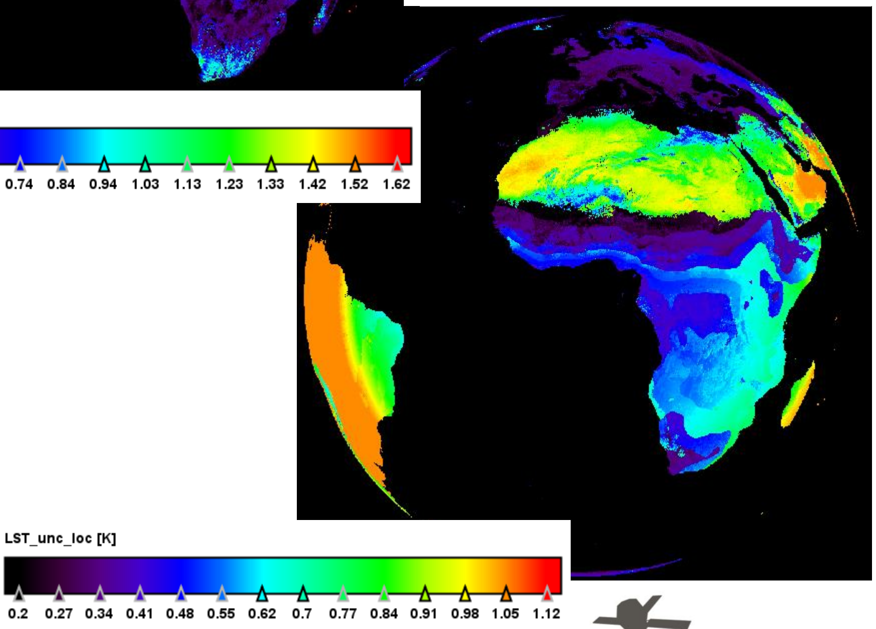
ESTIMATING CONSISTENT UNCERTAINTIES IN SATELLITE RETRIEVALS

Random



- 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

Locally correlated



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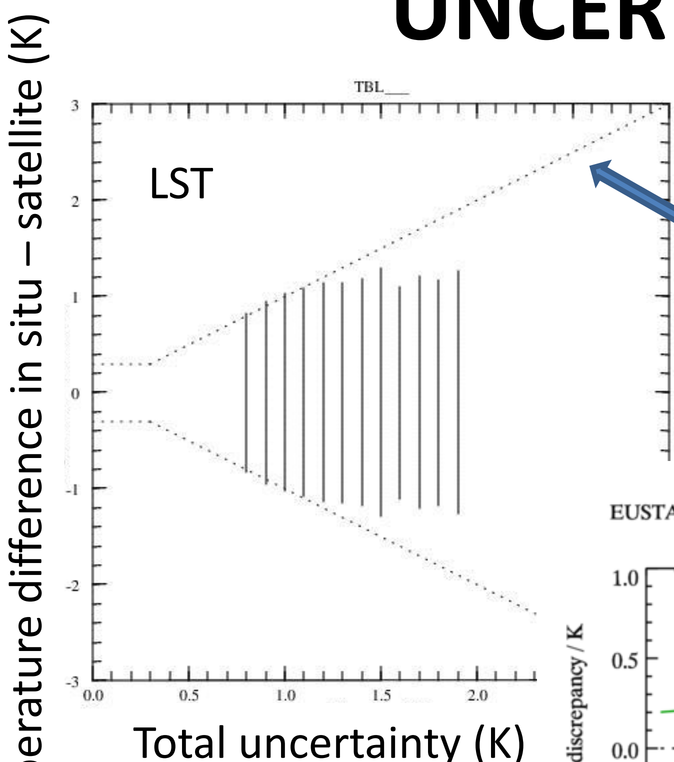
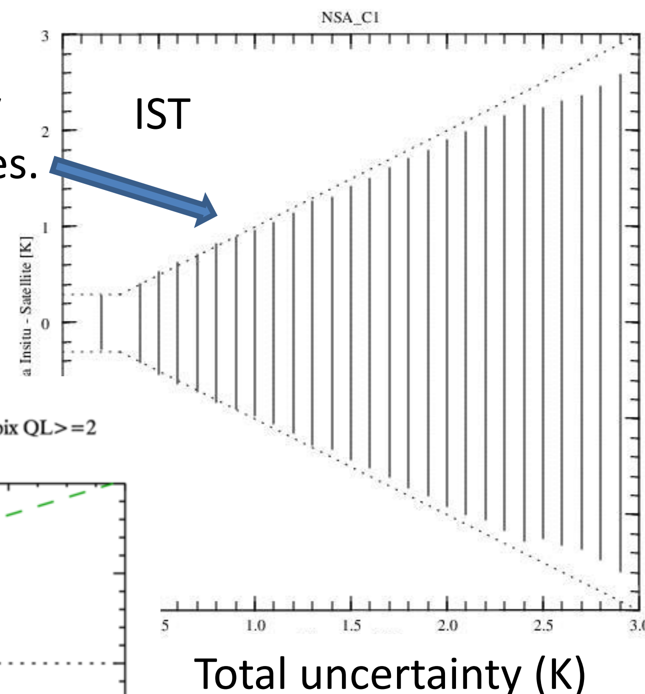
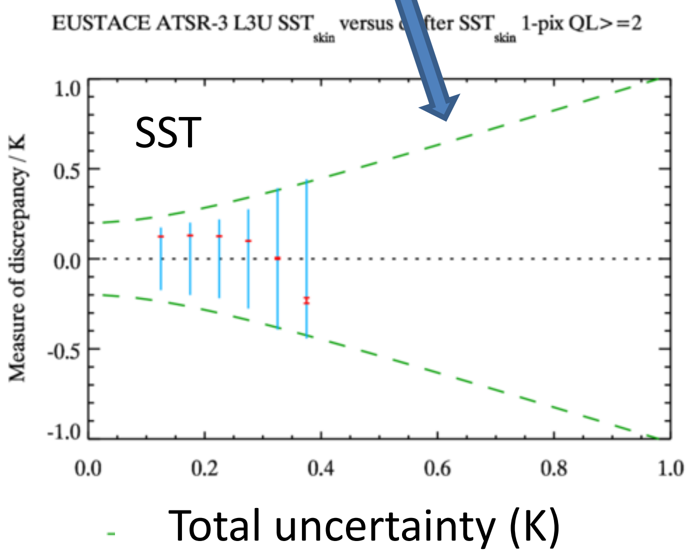
VALIDATION OF LST, IST AND SST UNCERTAINTY ESTIMATES



Expected difference envelope defined by uncertainty estimates.





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

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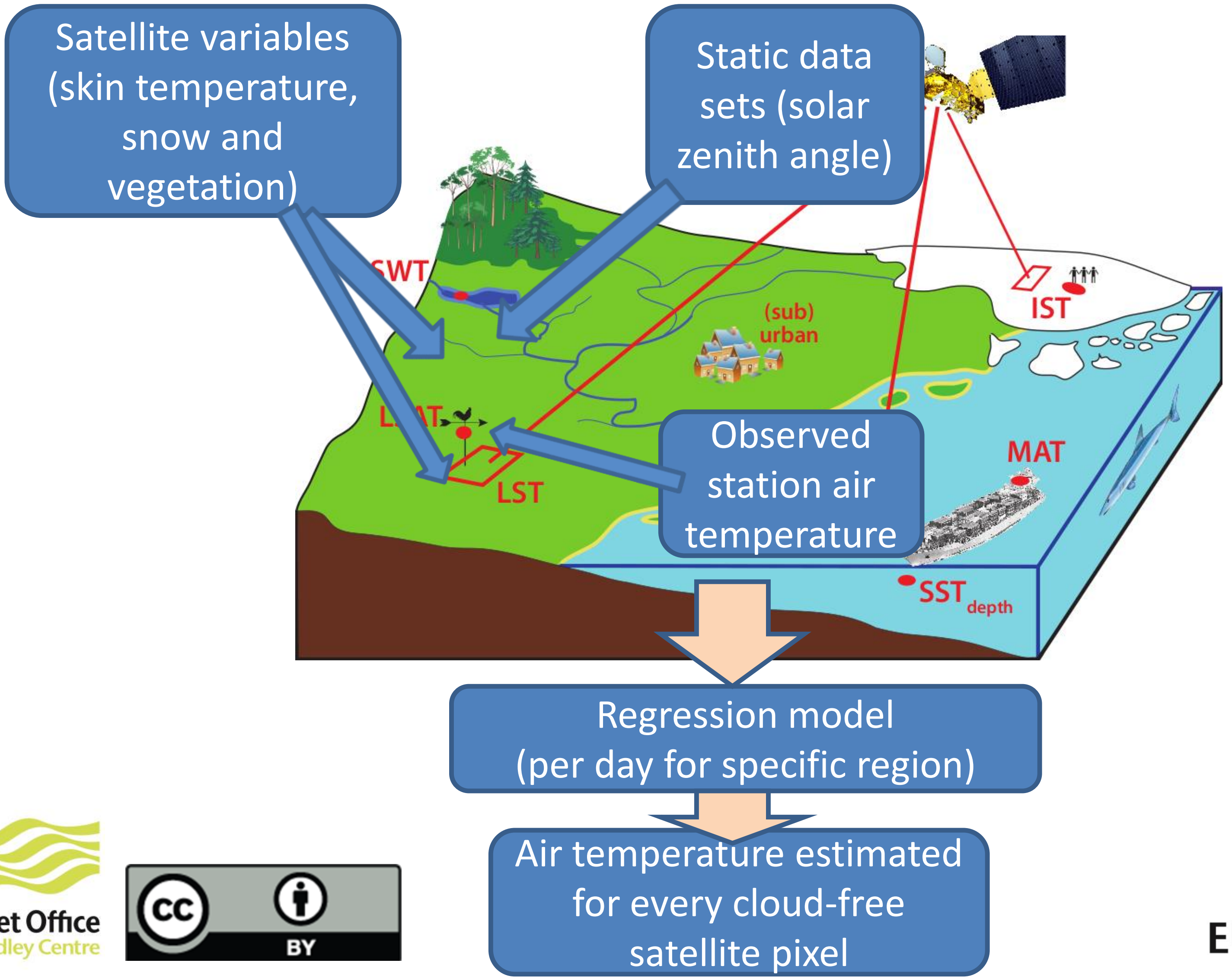
ESTIMATING AIR TEMPERATURE FROM SKIN TEMPERATURE



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

LST/TMAX/TMIN

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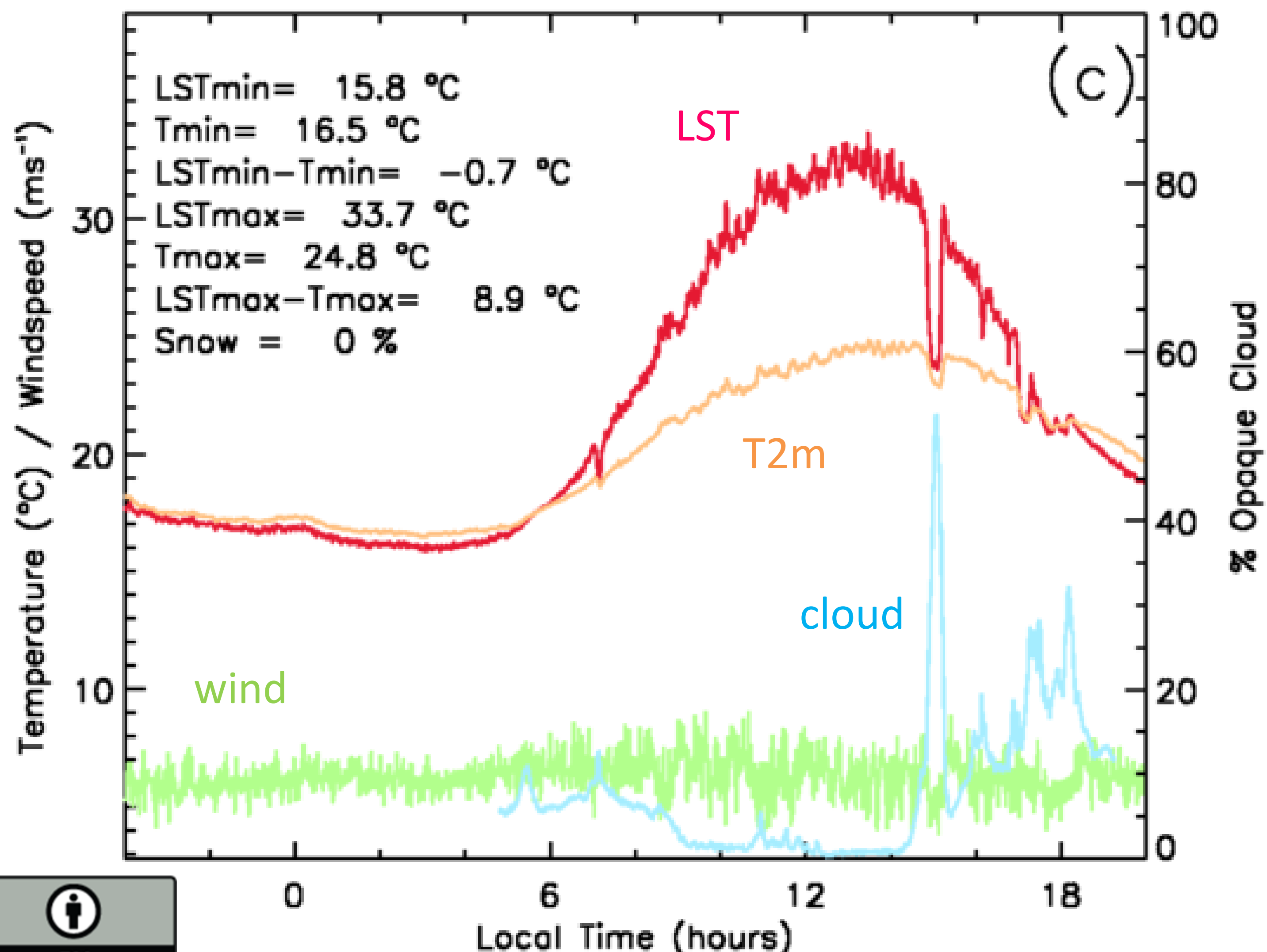
Cape Cod, Massachusetts , 21/06/2013



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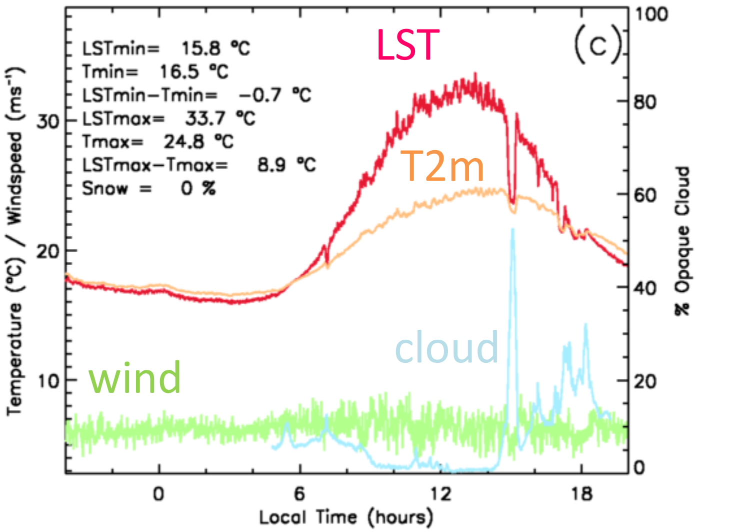
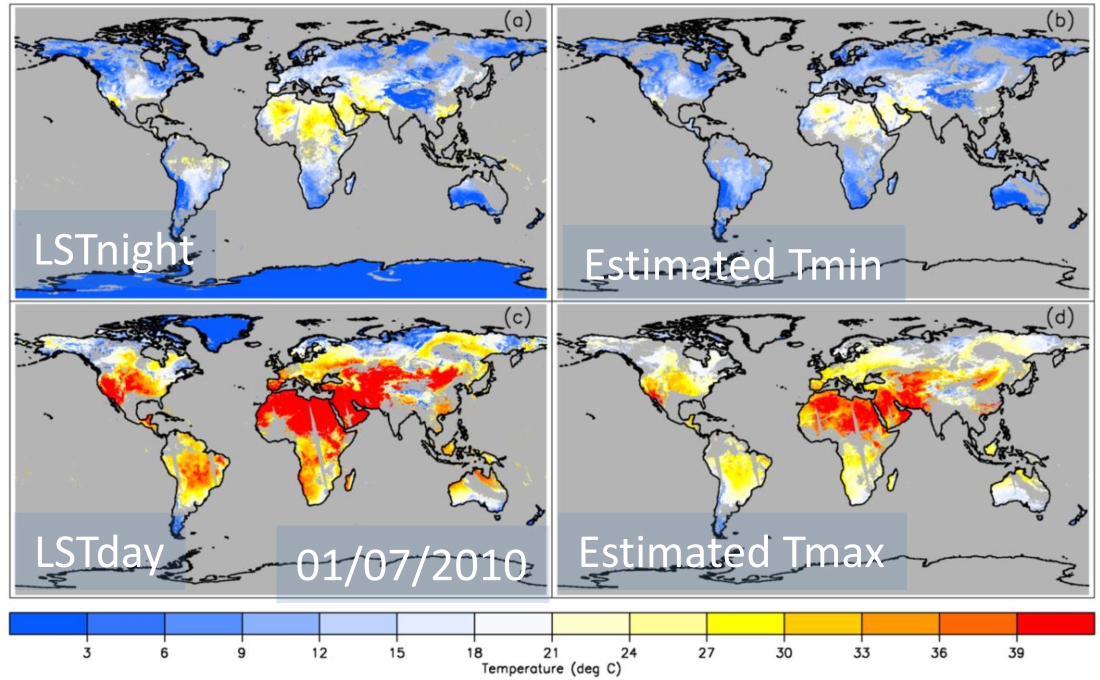
LST/TMAX/TMIN

EUSTACE

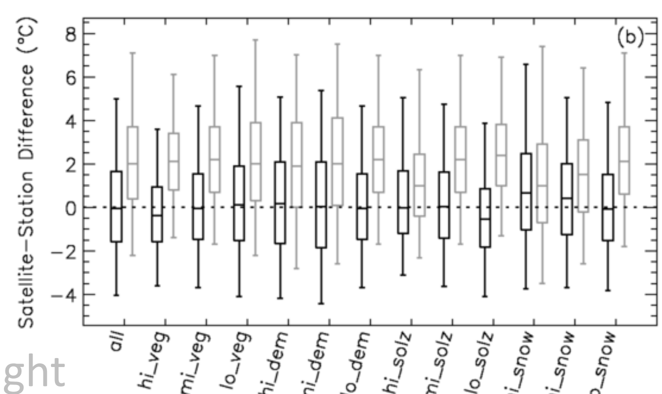
Cape Cod, Massachusetts , 21/06/2013





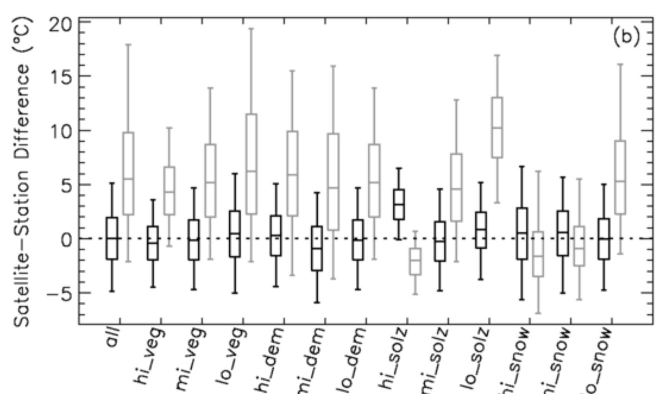
$$T_{max}=\alpha_0+ \alpha_1.LST_{day} + \alpha_2.LST_{ngt}+ \alpha_3.FVC + \alpha_4.SZA_{noon}+ \alpha_5.Snow +\varepsilon_{Tmax}$$
$$T_{min}=\beta_0+ \beta_1.LST_{day} + \beta_2.LST_{ngt}+ \beta_3.FVC + \beta_4.SZA_{noon}+ \beta_5.Snow +\varepsilon_{Tmin}$$

Estimated Tmin vs independent stations



Tmin

LSTnight



Estimated Tmax vs independent stations

Tmax

LSTday

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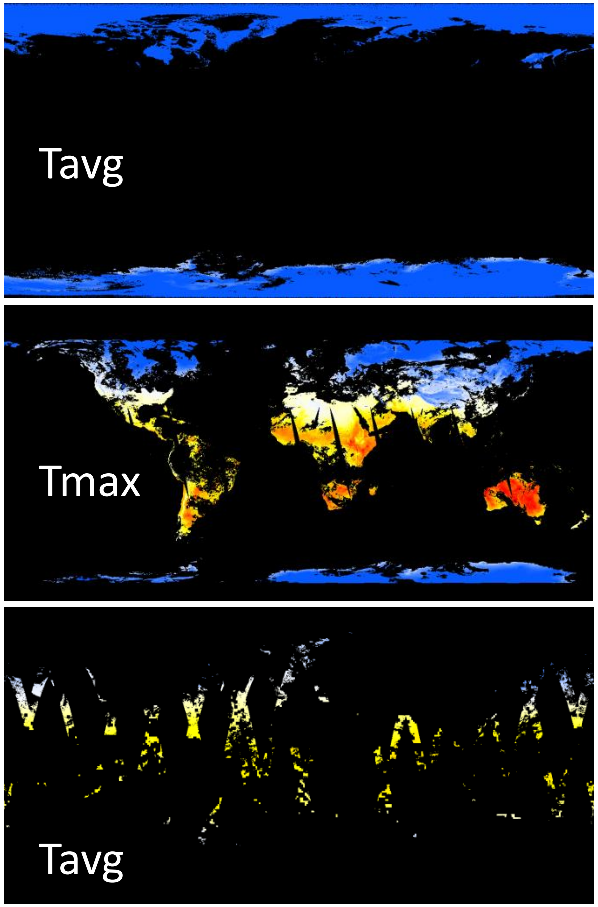
Hadley Centre

GLOBAL ESTIMATES OF AIR TEMPERATURE FROM SATELLITE SKIN TEMPERATURE

- Separate regression estimates over land, ocean and ice - a global picture of air temperature based on the satellite measurements. Files include:
  - A main surface air temperature file per day per surface type (land, ocean, ice)
  - Total uncertainty budget per grid box and so uncertainty is consistently expressed for all surface types
  - Also an ancillary file per day per surface type which contains more detailed uncertainty information.



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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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OBSERVATION 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

TEMPERATURE MODEL

Temperature Process Decomposition

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

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

$T(s,t)$ = Temperature at space/time location (s,t)

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

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

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

TEMPERATURE MODEL

Strategy for solution

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

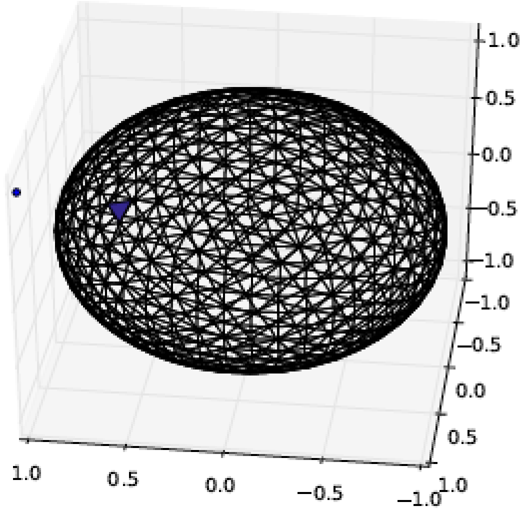
$$T(s,t) = T^{\mathrm{clim}}(s,t) + T^{\mathrm{large}}(s,t) + T^{\mathrm{local}}(s,t)$$

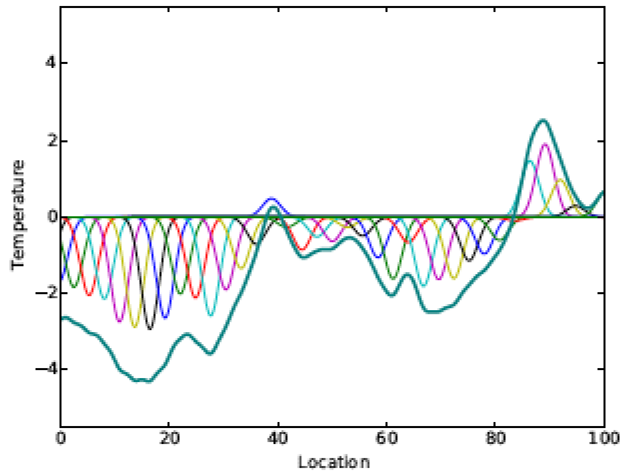
- Each component is a Gaussian linear model (or linearised model).
- Solve each sub-component conditioned on the expected value of other sub-components.
- Refine the solutions to each sub component by iteratively re-estimating each sub-component.

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

Local hyperparameter estimation

Spatial correlation length scale; magnitude of variability

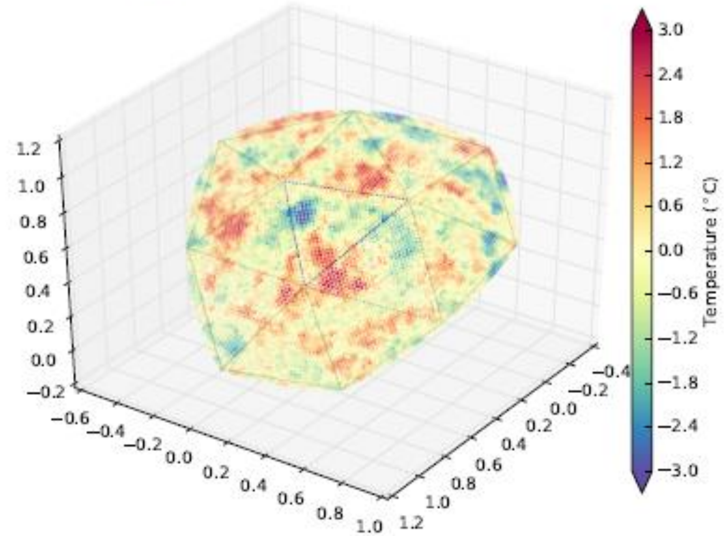
Concept:

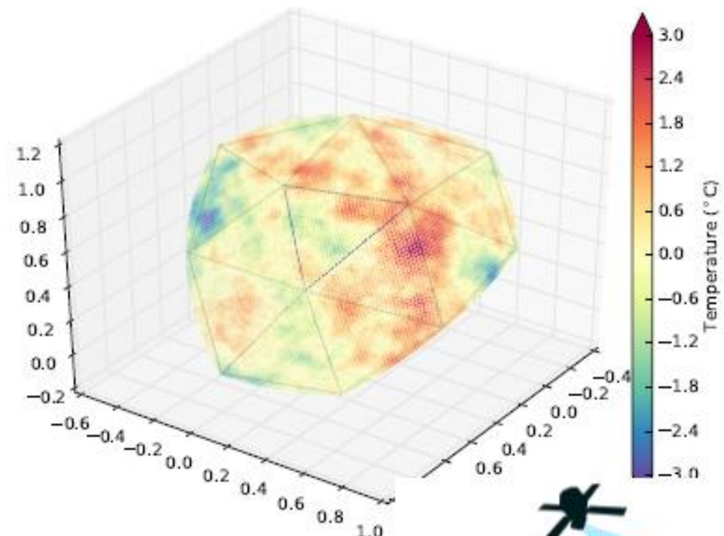
- Nearby locations are correlated;
- Location dependent spatial correlation;
- Location dependent variability amplitude.

Approach:

- Use heirachical triangulation to extract a region;
- Optimise local parameters for region;
- Plug local parameters into the global model for global solve.

Implementation is an upcoming priority.





ADVANCED STANDARD METHOD

Performing the analysis

WE NEED A STARTING POINT

A

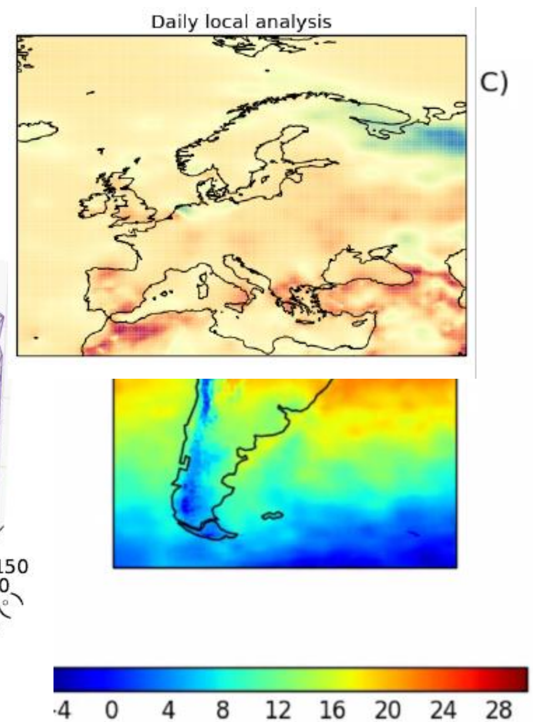
Process observations

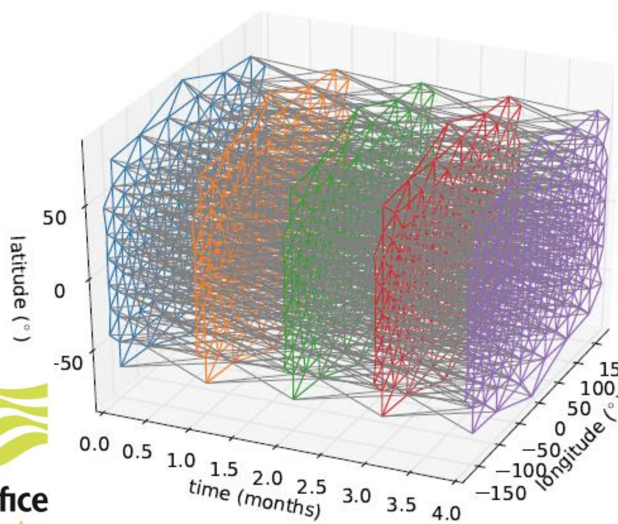
Solve climatology

B

Process observations conditioned on A

Solve large scale





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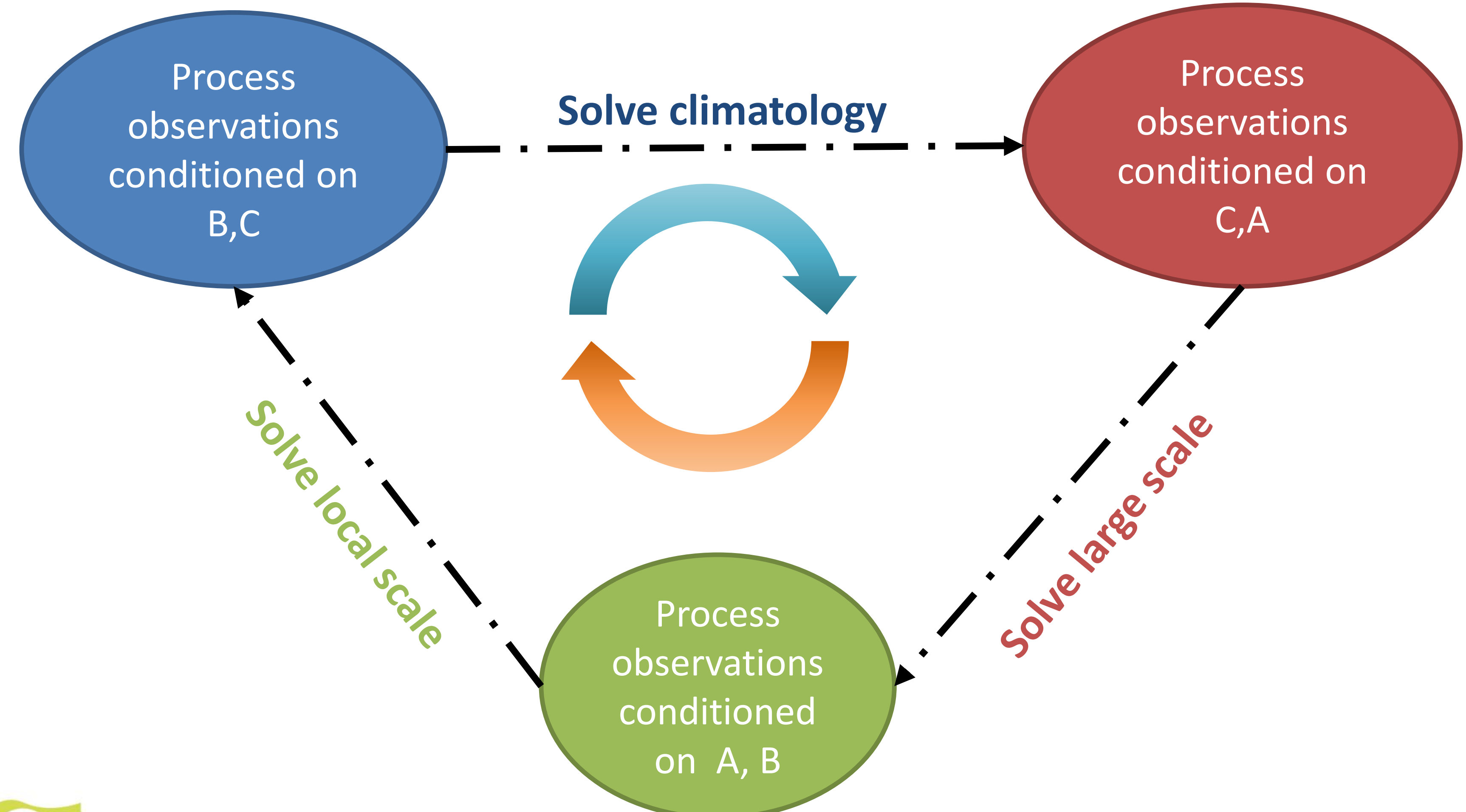
ADVANCED STANDARD METHOD

Performing the analysis



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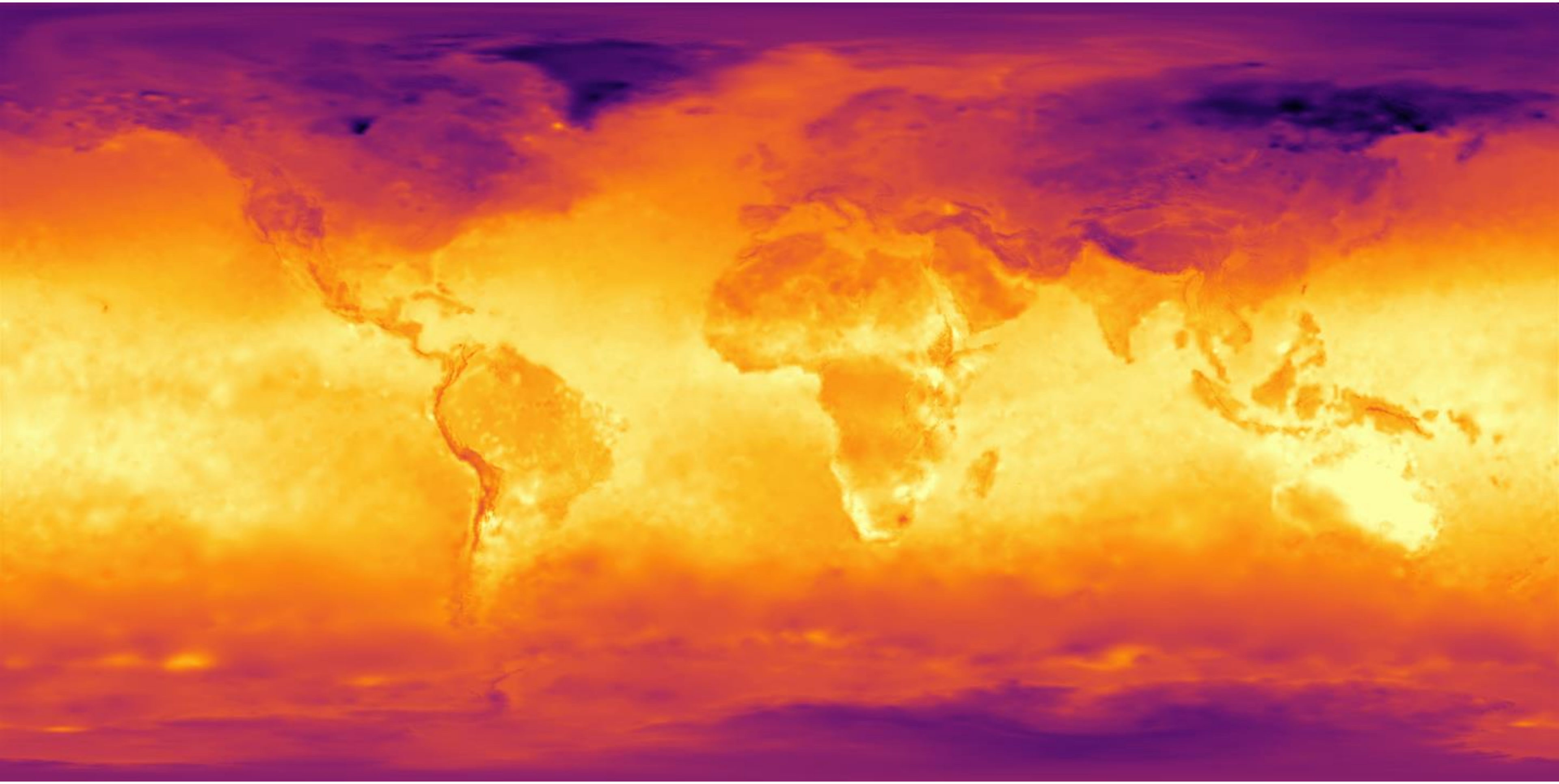
PRELIMINARY ANALYSIS – JAN 1 2006



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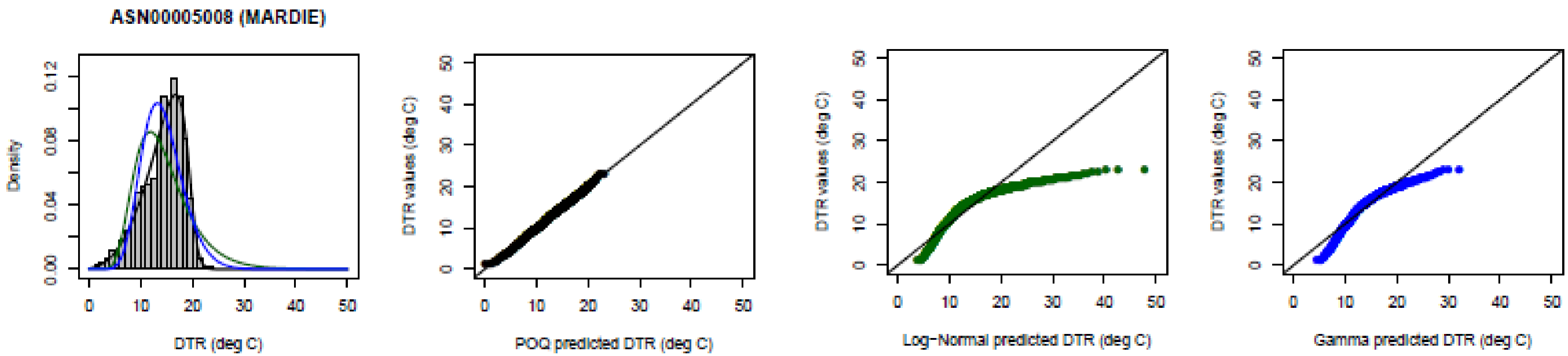
Additionally model Tmax and Tmin via diurnal temperature range



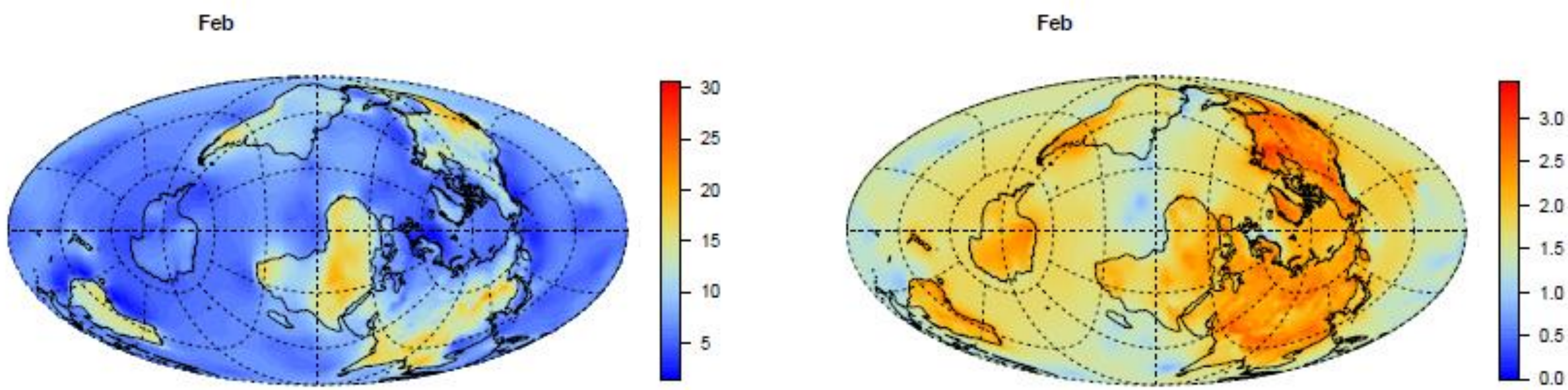
Example station DTR

POQ

Log normal

Gamma

DTR



AMBITIOUS METHOD

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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