Innovations in in-situ surface temperature data products

29th Session of the GCOS/WCRP Atmospheric Observation Panel for Climate (AOPC-29)

NOAA NCEI
Asheville, United States
17-20 September 2024

Colin Morice, Met Office Hadley Centre, UK

Recent innovations in data products

Global data set	Land data source	Marine data source
HadCRUT.5.0.2.0	CRUTEM.5.0.2.0 (LSAT)	HadSST.4.0.1.0 (SST)
GISTEMP v4	GHCNm v4 (LSAT)	ERSST v5 (SST)
NOAAGlobalTemp v6	GHCNm v4 (LSAT)	ERSST v5 (SST)
Berkeley Earth	Berkeley Earth land record (LSAT)	HadSST.4.0.1.0 (SST)
Kadow et al. (2020)	CRUTEM.5.0.2.0 via HadCRUT5 (LSAT)	HadSST.4.0.1.0 via HadCRUT5 (SST)
CMST 2.0	C-LSAT 2.0 (LSAT)	ERSST v5 (SST)
DCENT v1.0	DCLSAT v1.0 (LSAT)	DCSST v1.0 (SST)
Calvert (2024)	CRUTEM.5.0.2.0 via HadCRUT5 (LSAT)	HadSST.4.0.1.0 via HadCRUT5 (SST)
GloSATref.1.0.0.0	GloSATLAT_5.0.1.3 [from CRUTEM.5.0.1.0] (LSAT)	GloSATMAT_2.4.0.0 (MAT)

Method updates

New data sets

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Data sources: CRUTEM/HadSST/HadCRUT, GHCN/ERSST, Berkeley, C-LSAT, DCENT, GloSAT MAT

Method updates

NOAAGlobalTemp

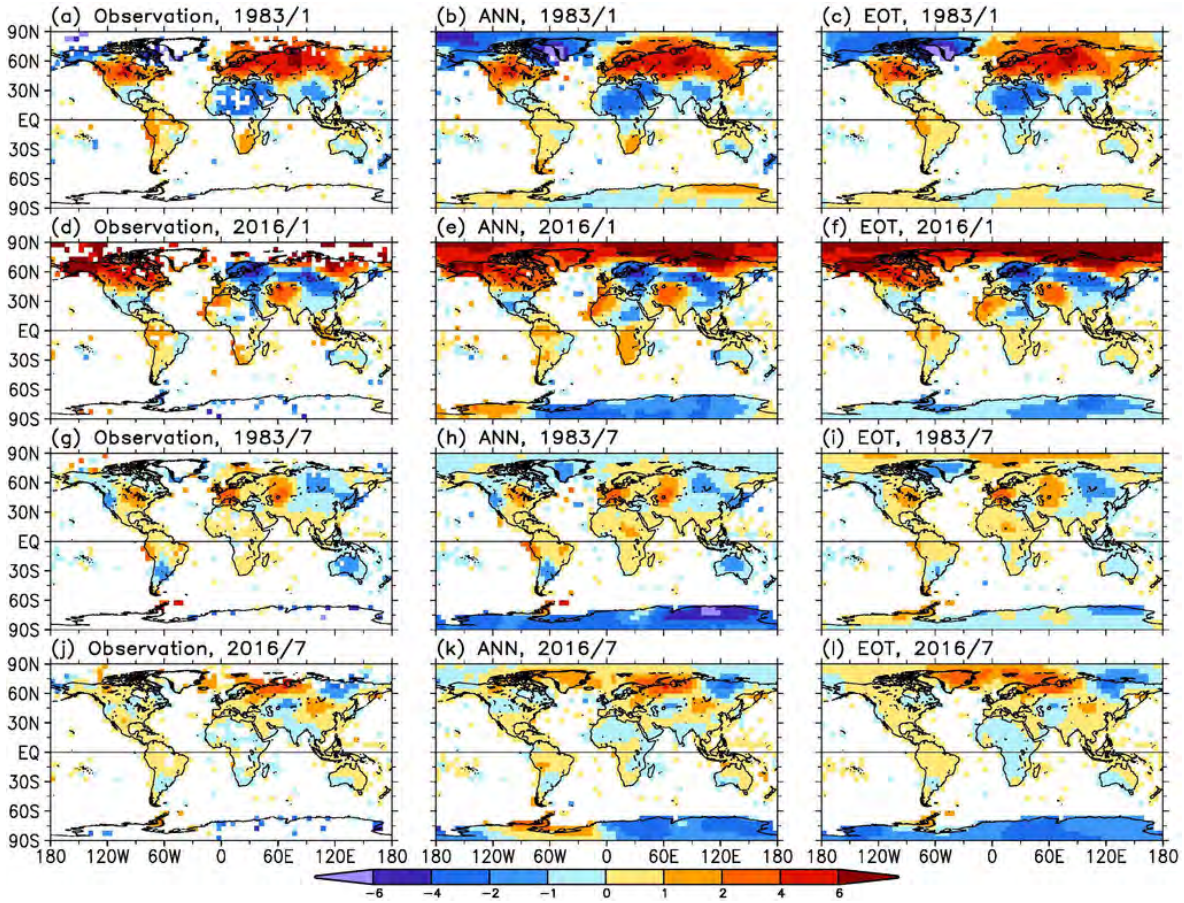
New neural network land surface air temperature gridding method

NASA GISTEMP

New ensemble uncertainty estimates

1. NOAAGlobalTemp v6

- Adopted the neural network infilling approach of Huang et al. (2022) for LSAT:
  - Retains low frequency smoothing of previous version.
  - High frequency EOT reconstruction replaced by 3-layer neural network.
  - Trained and validated using ERA5 fields.
- Improves local reconstruction statistics compared to previous EOT method.
- Minimal impact on long term trends with unchanged low frequency reconstruction
- SST data remains ERSSTv5 using the EOT method.



Huang, B., X. Yin, M. J. Menne, R. Vose, and H. Zhang, 2022: Improvements to the Land Surface Air Temperature Reconstruction in NOAAGlobalTemp: An Artificial Neural Network Approach. *Artif. Intell. Earth Syst.*, **1**, e220032, https://doi.org/10.1175/AIES-D-22-0032.1.

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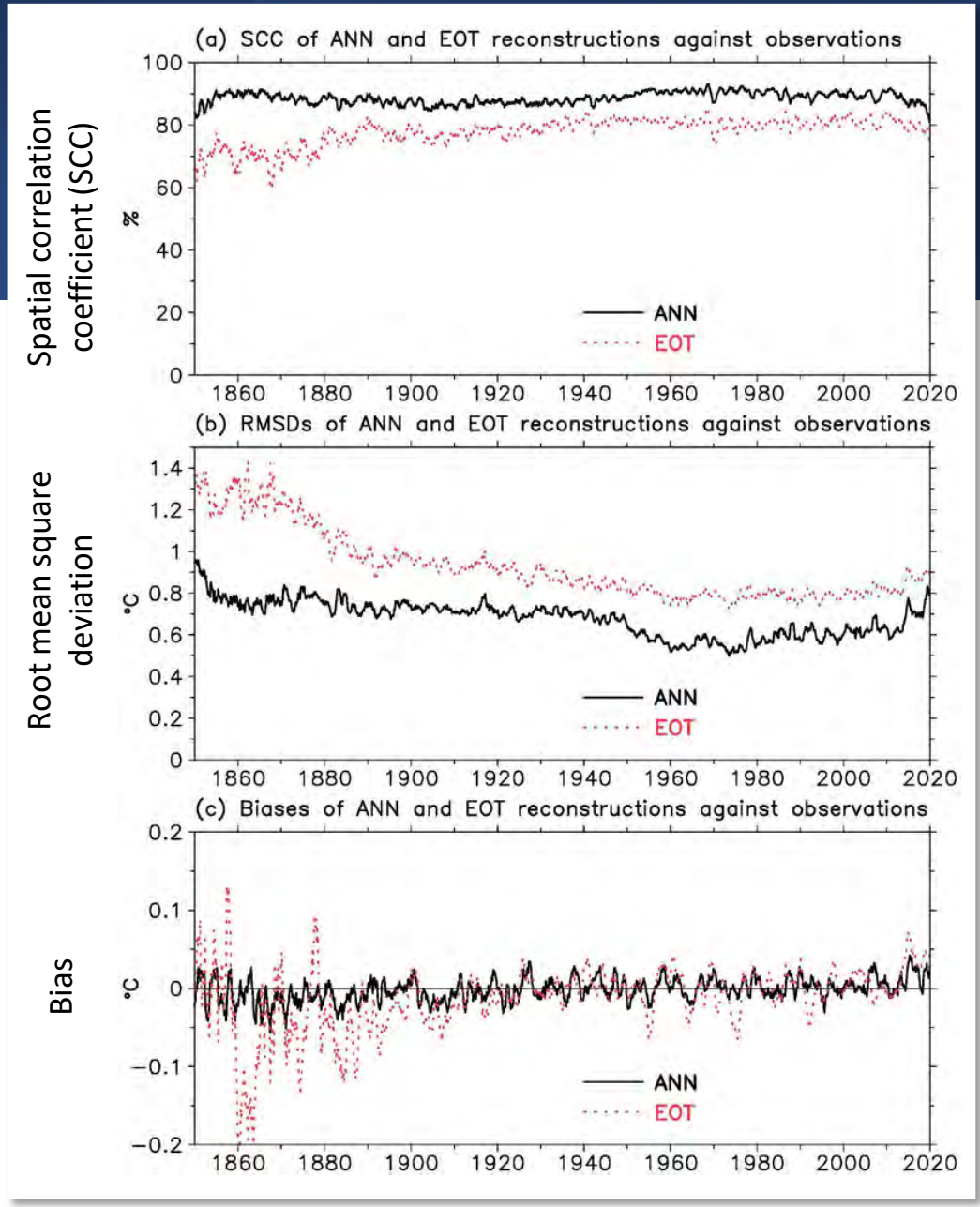

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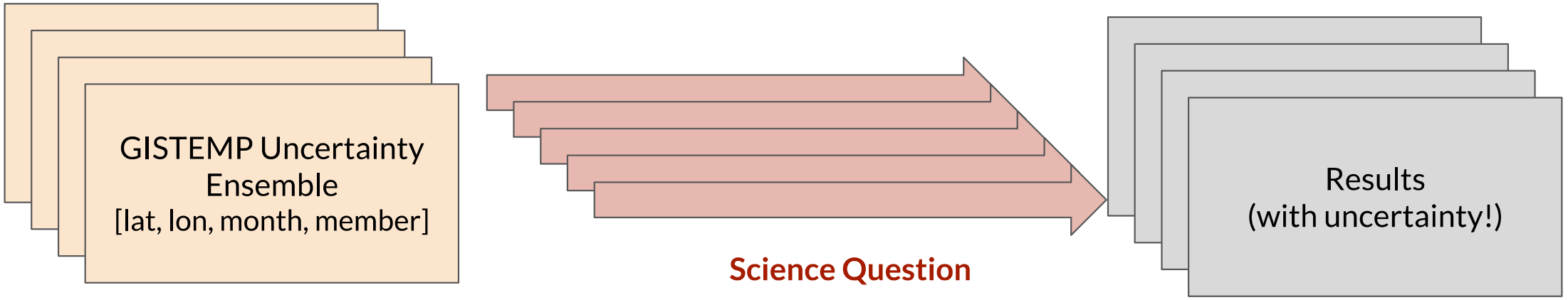
2. GISTEMPv4 Observational Ensemble

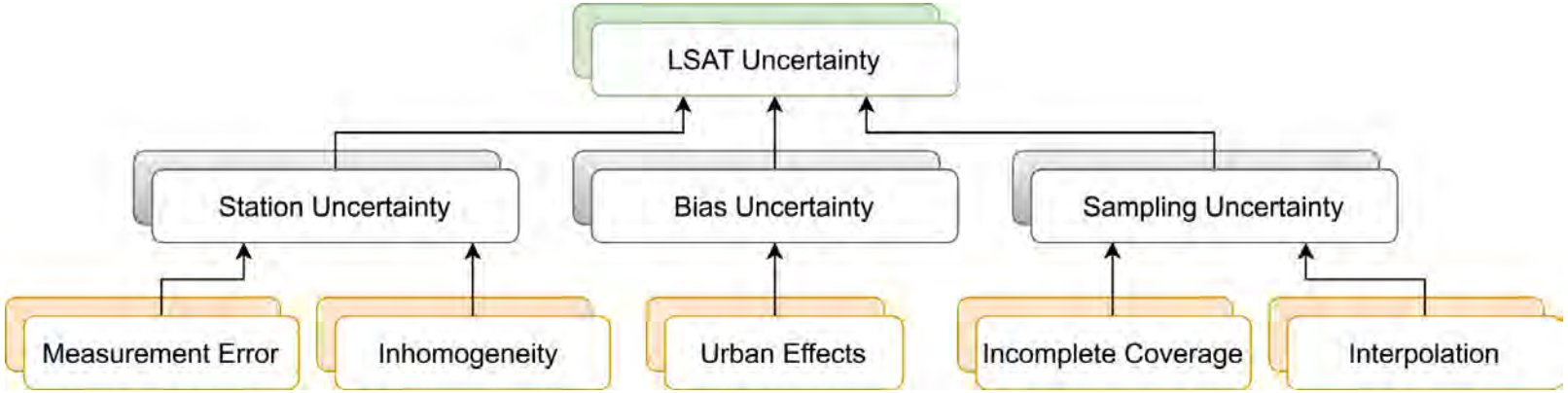
A 200-member, gridded, monthly ensemble at 2°x 2° resolution that samples all sources of uncertainty in LSAT and SST reconstruction

- Analogous to the 200-member HadCRUT5 ensemble
- Should be used in addition to the HadCRUT5 ensemble when possible
- Currently 1880-2020, will extend back to 1850 and make operational



Slide provided by Nathan Lenssen, Colorado School of Mines / NCAR

2. GISTEMPv4 Observational Ensemble



- The GHCN-ERSST-GISTEMP ensemble is generated by running the production GISTEMPv4 code-base with source data from the GHCN and ERSST uncertainty ensembles
- Sampling uncertainty is quantified by simulation of errors applying GISTEMP interpolation to masked ERA5 data

Lenssen, N., Schmidt, G. A., Hendrickson, M., Jacobs, P., Menne, M. J., & Ruedy, R. (2024). A NASA GISTEMPv4 observational uncertainty ensemble. *Journal of Geophysical Research: Atmospheres*, 129, e2023JD040179. https://doi.org/10.1029/2023JD040179

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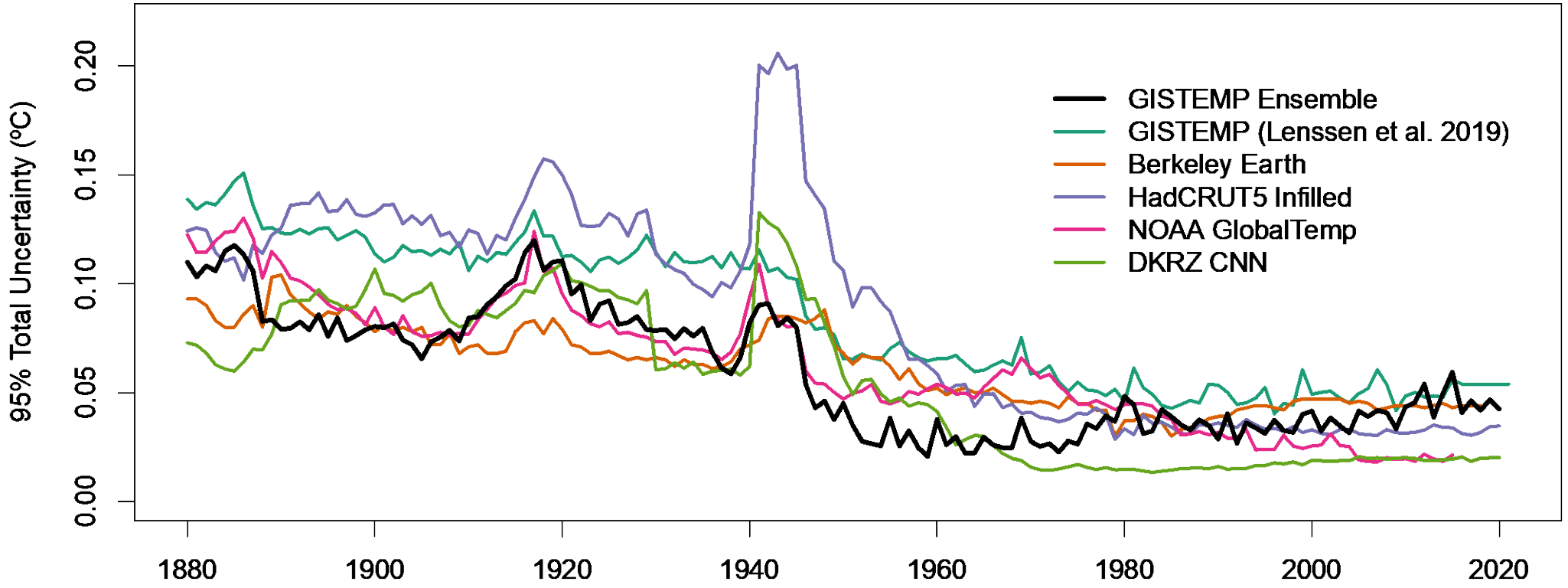


Annual global mean uncertainty is similar to other estimates

Slide provided by Nathan Lenssen, Colorado School of Mines / NCAR

2. A GISTEMPv4 Observational Ensemble

GISTEMP has greater uncertainty in sparsely sampled regions due to a more general assumption of non-stationarity in the LSAT spatial model.

Slide provided by Nathan Lenssen, Colorado School of Mines / NCAR

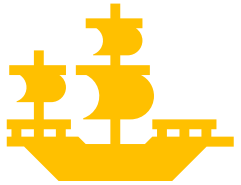
New data sets

DCENT

New processing chain. New LSAT and SST bias adjustments. Not yet infilled.

Calvert 2024

Reprocessing of HadCRUT5 using space-time interpolation and climatology bias adjustment for sea ice loss.



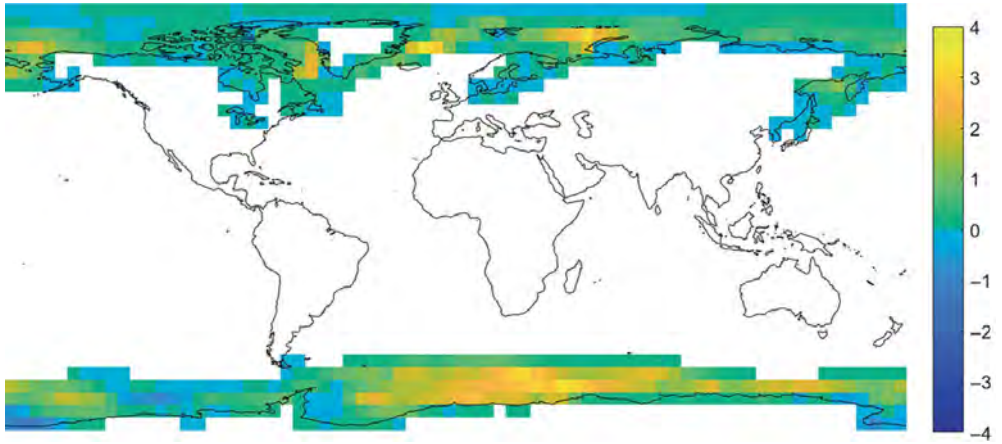
GloSATref

Upcoming product with (1) all-hours marine air temperature rather than SST and (2) new bias adjustments of early record LSAT

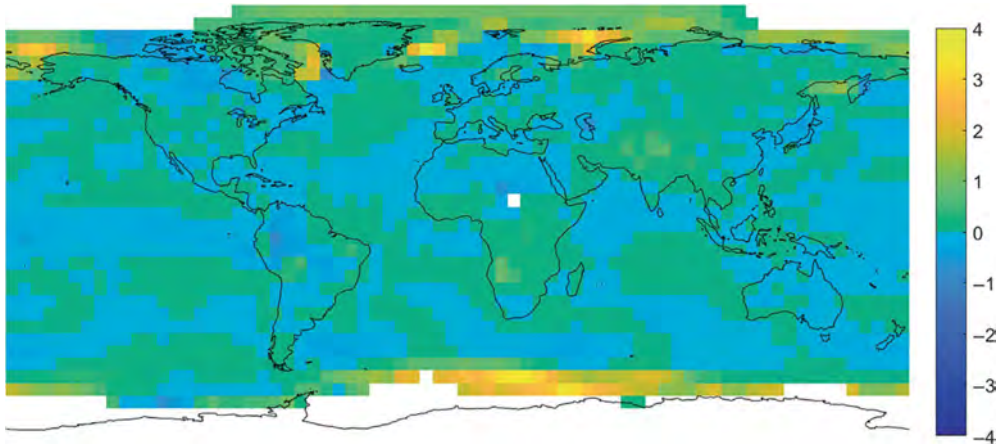
3. HadCRUT5_MLE (Calvert, 2024)

- A new data set that reprocesses HadCRUT5 non-infilled grids
- Replaces HadCRUT5 spatial infilling:
  - space-time kriging with regional trend modelling
- Adds new climatology bias adjustment:
  - accounts for transition from LSAT over sea ice to open water SST.
- Greater warming trend than HadCRUT5
  - primarily from ice climatology bias adjustment

Estimated impact of change in sea ice concentrations



Difference from HadCRUT5



Difference from the late 19th century to 2023 (°C)

Calvert, B.T.T. (2024) Improving global temperature datasets to better account for non-uniform warming. *Quarterly Journal of the Royal Meteorological Society*, 1–31. Available from: https://doi.org/10.1002/qj.4791

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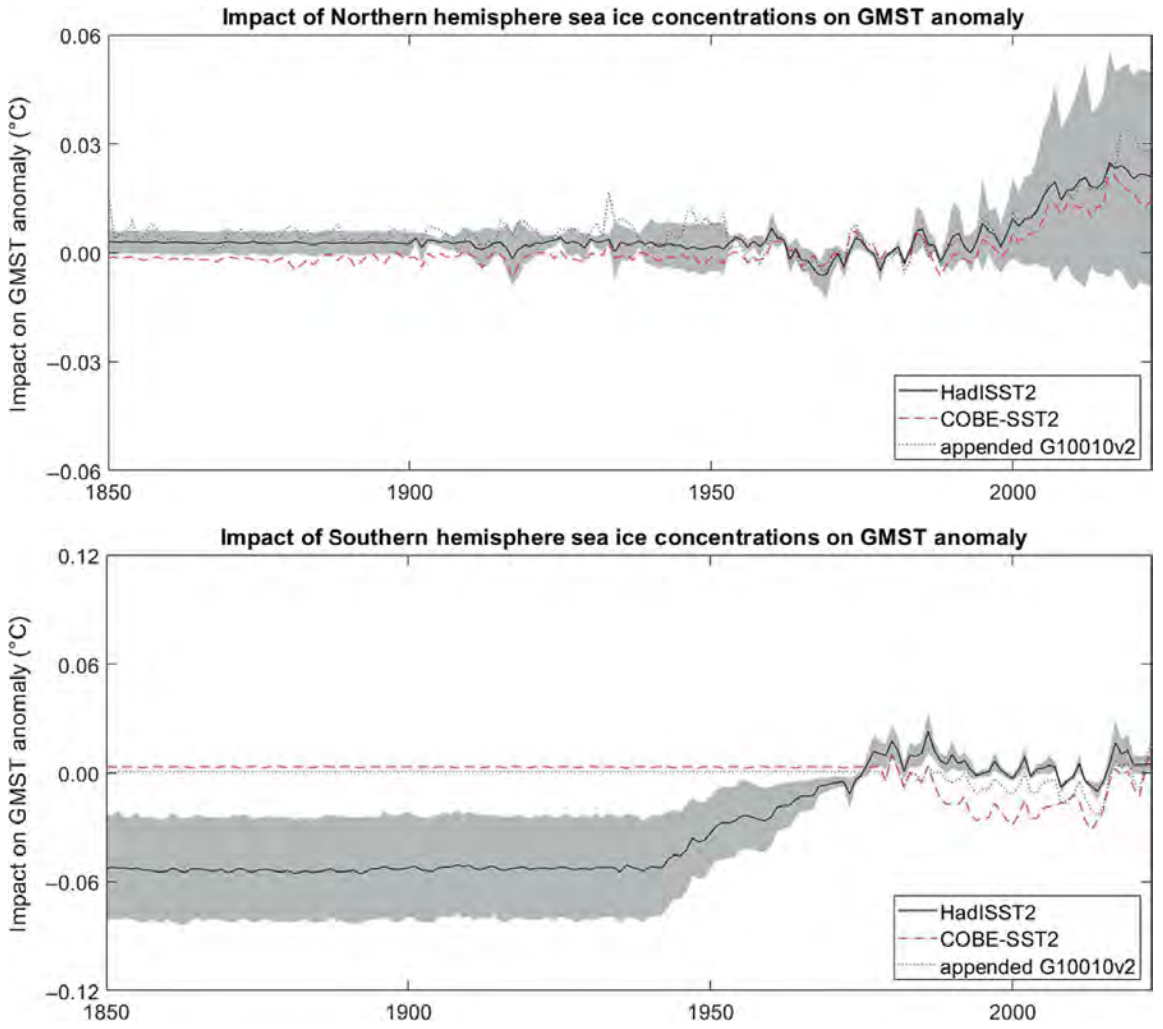

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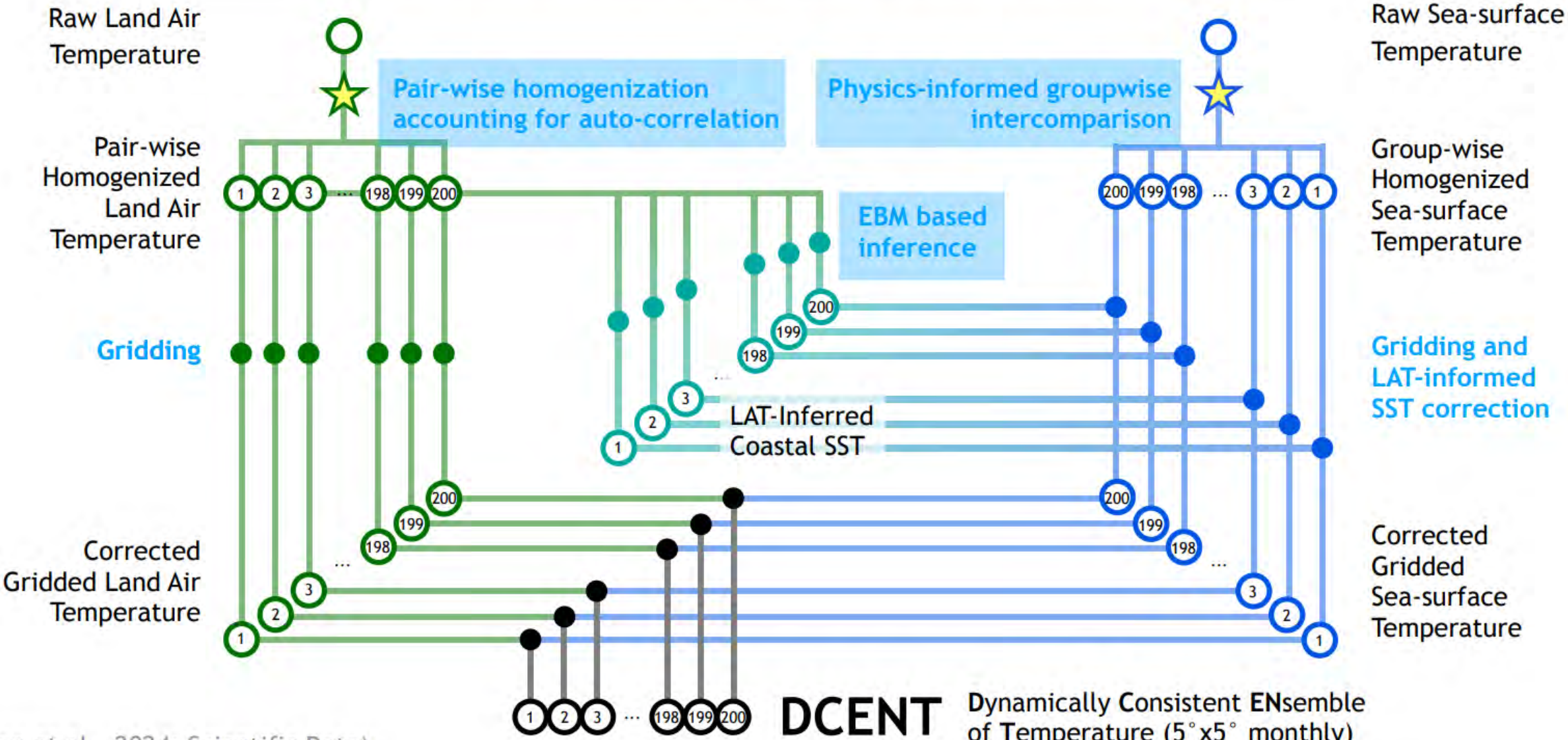
DCENT has improved data homogenization within and across land and ocean temperature archives



(Chan et al., 2024; Scientific Data)

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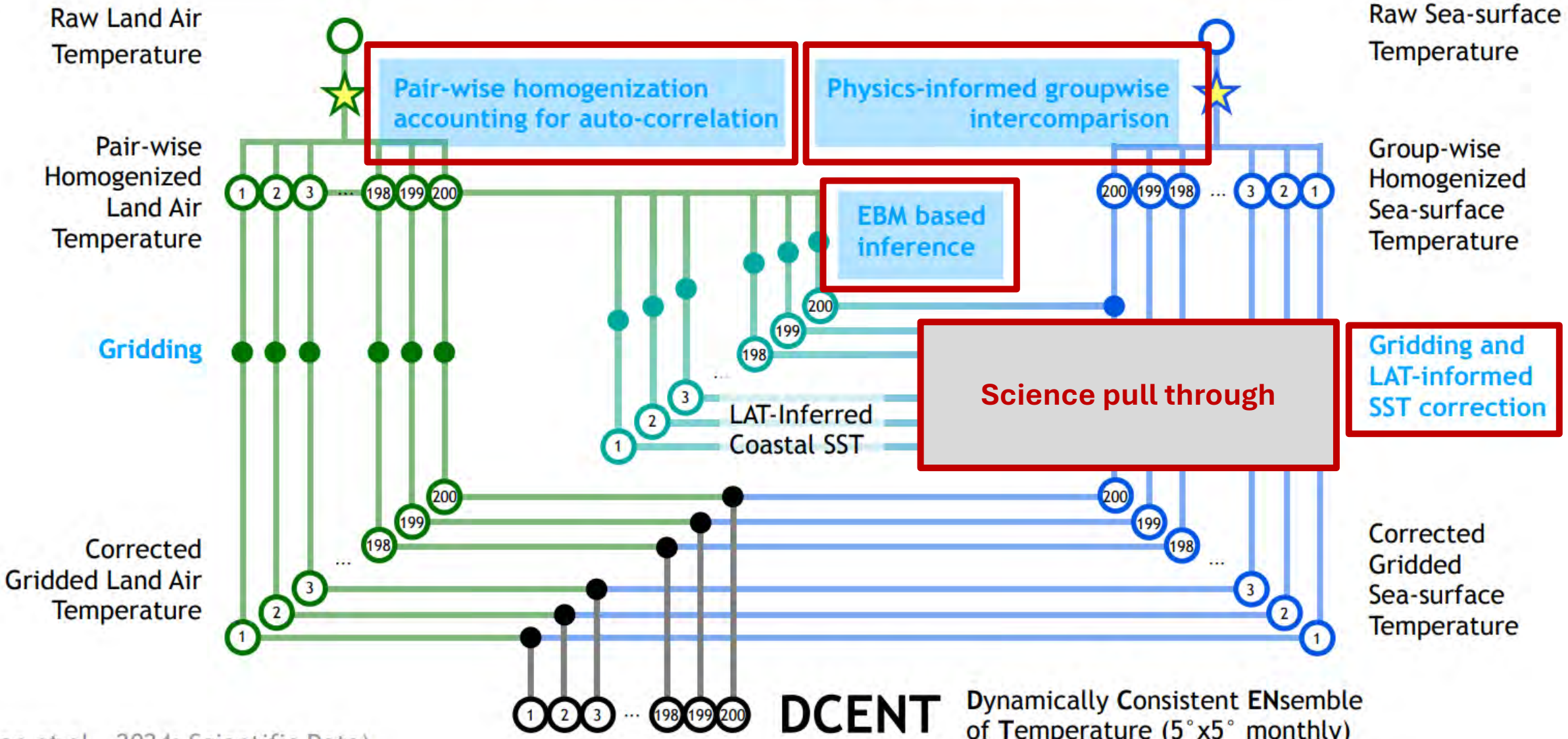
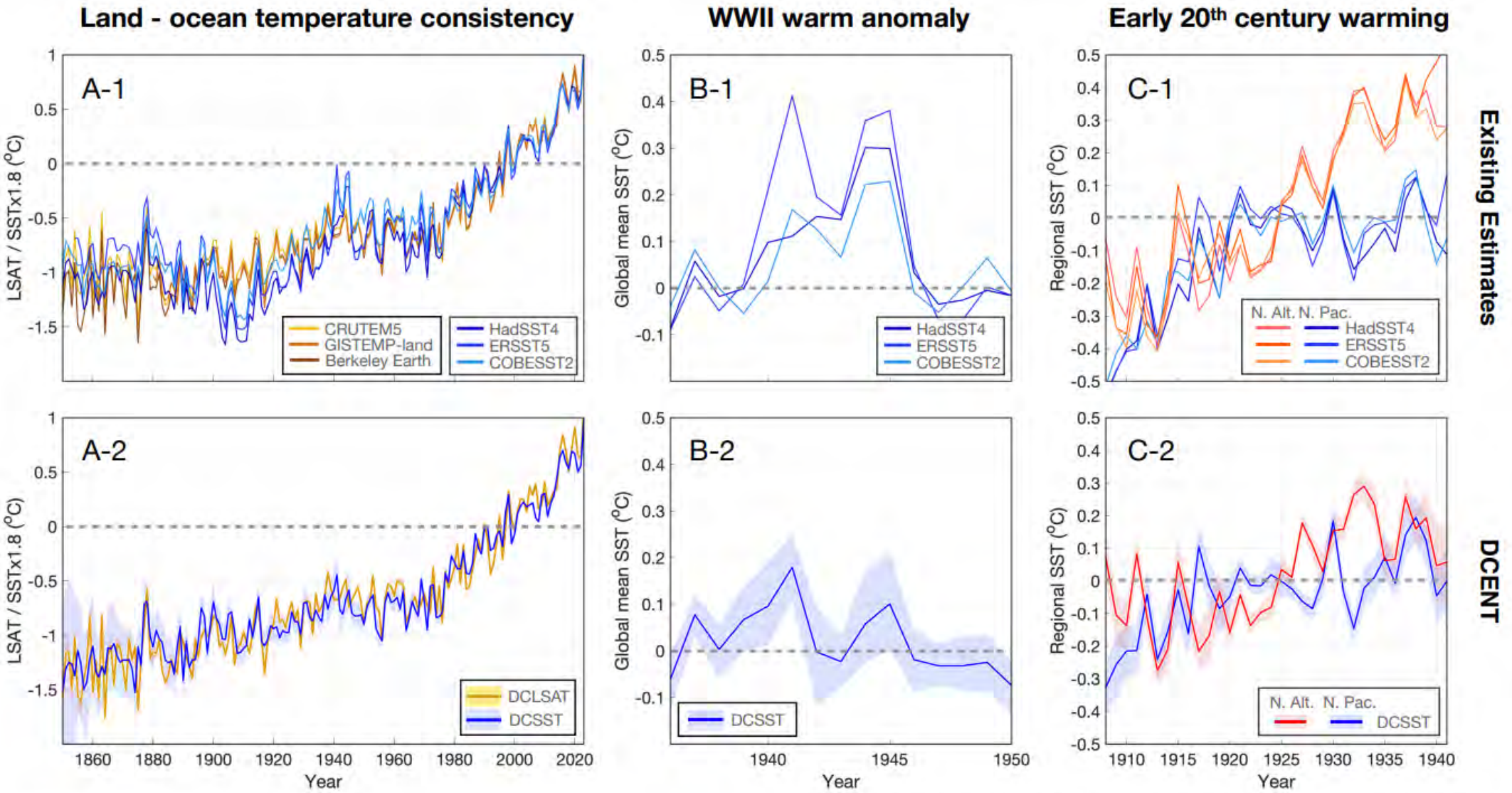


(Chan et al., 2024; Scientific Data)

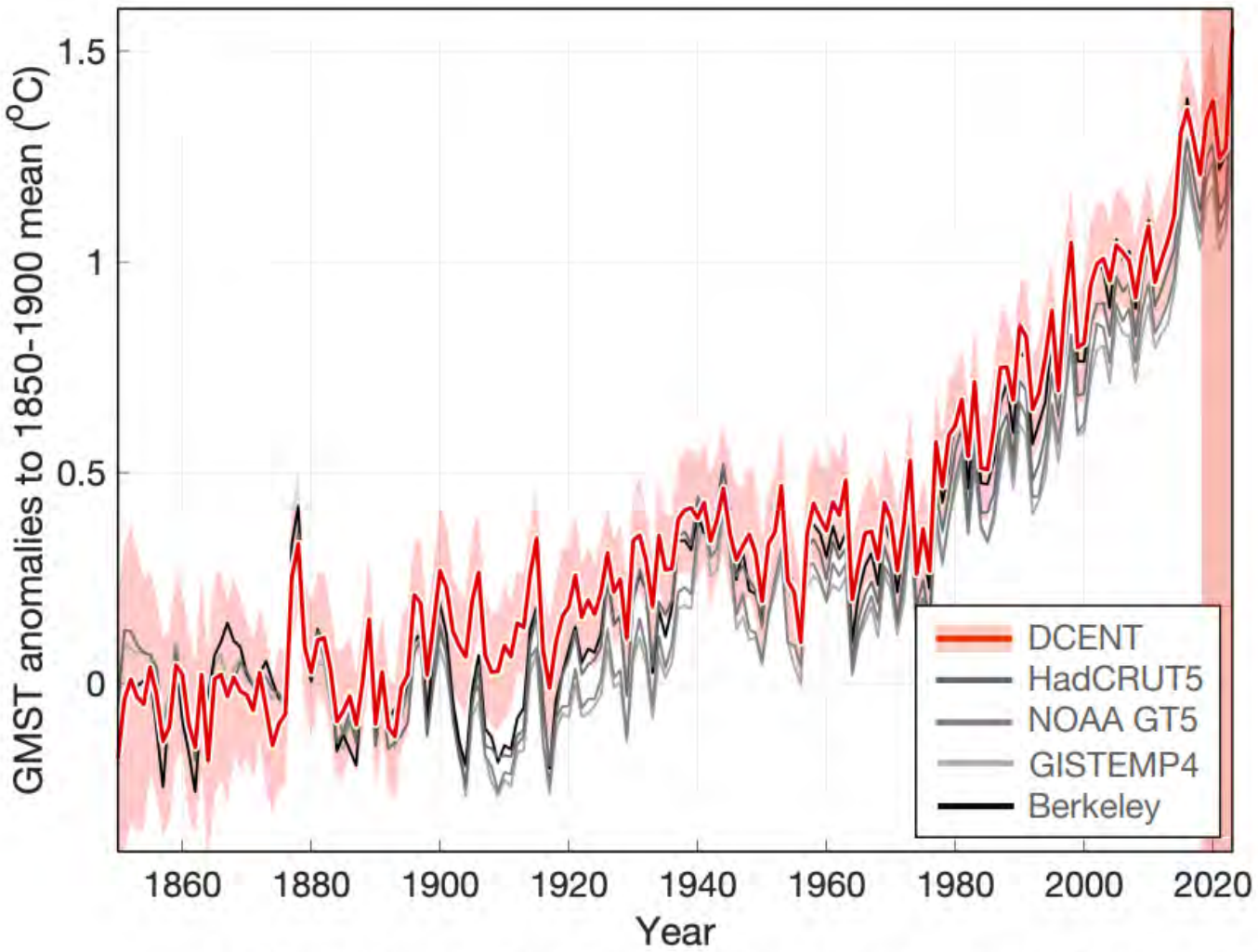
DCENT reveals climate variability without artifacts at global and regional scales

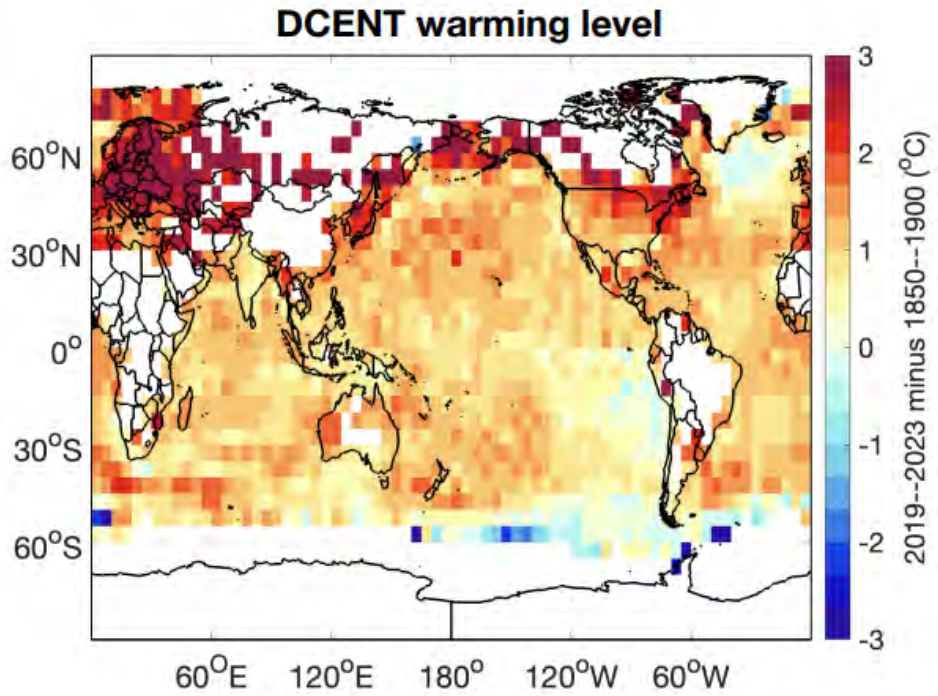


(Chan 2024; NCAR climate data guide)

* Shown time series are averages of data masked by the least common coverage across data sets

DCENT suggests a steadier and faster historical warming since 1850





* Shown time series have sampling uncertainties inferred

(Chan 2024; NCAR climate data guide)

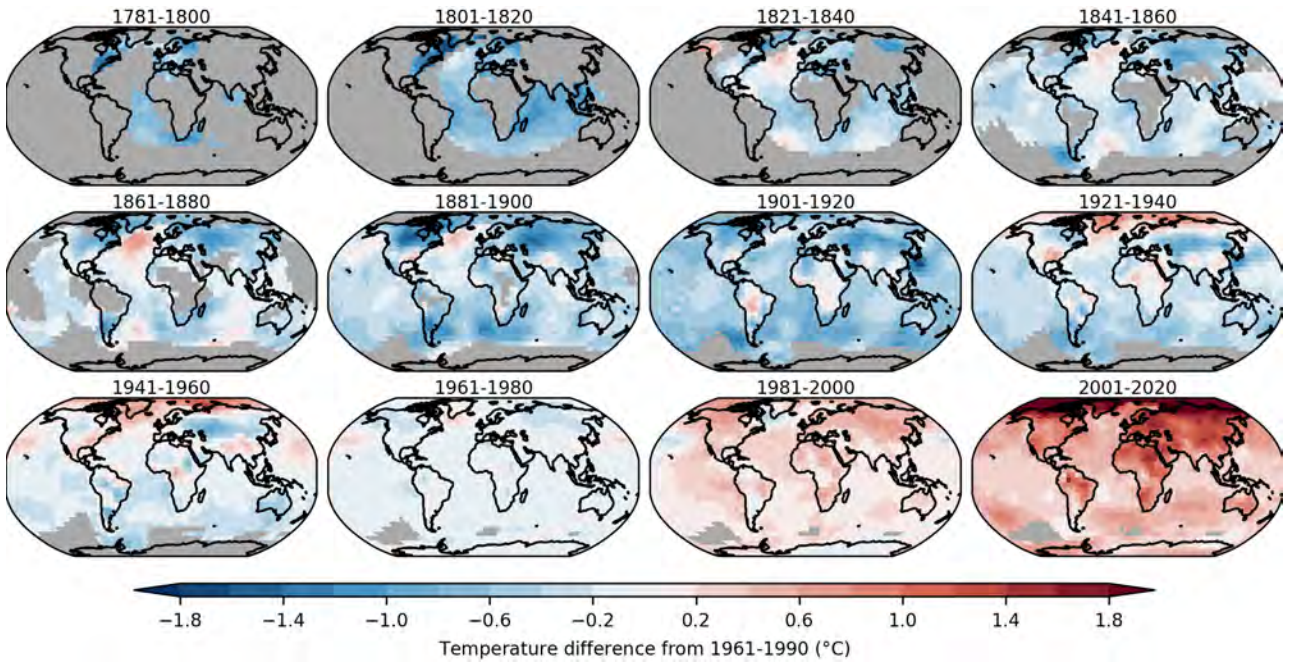
5. The GloSAT reference analysis

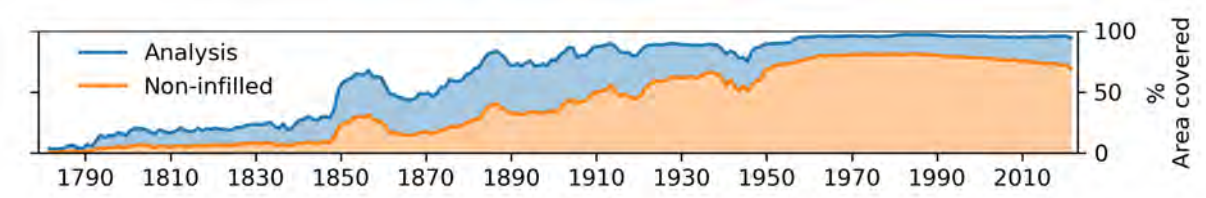
A data set of Global Surface Air Temperature (GSAT) change since the late 18th century:

- Marine Air Temperature (MAT) observations over ocean;
- Near Surface Air Temperature observations over land (LSAT).

Differs from traditional Global Mean Surface Temperature (GMST) datasets that use Sea-Surface Temperature (SST).

- Daytime MAT heating biases estimated, allowing extension back to the 18th century (Cropper et al., 2023)
- Corrections for early-record thermometer enclosures (Wallis et al., 2024)
- Gaps in station normals inferred from station neighbours to allow short station records to be used (Taylor et al., in prep).
- 200-member ensemble analysis using HadCRUT5 processing chain propagating LSAT/MAT uncertainties



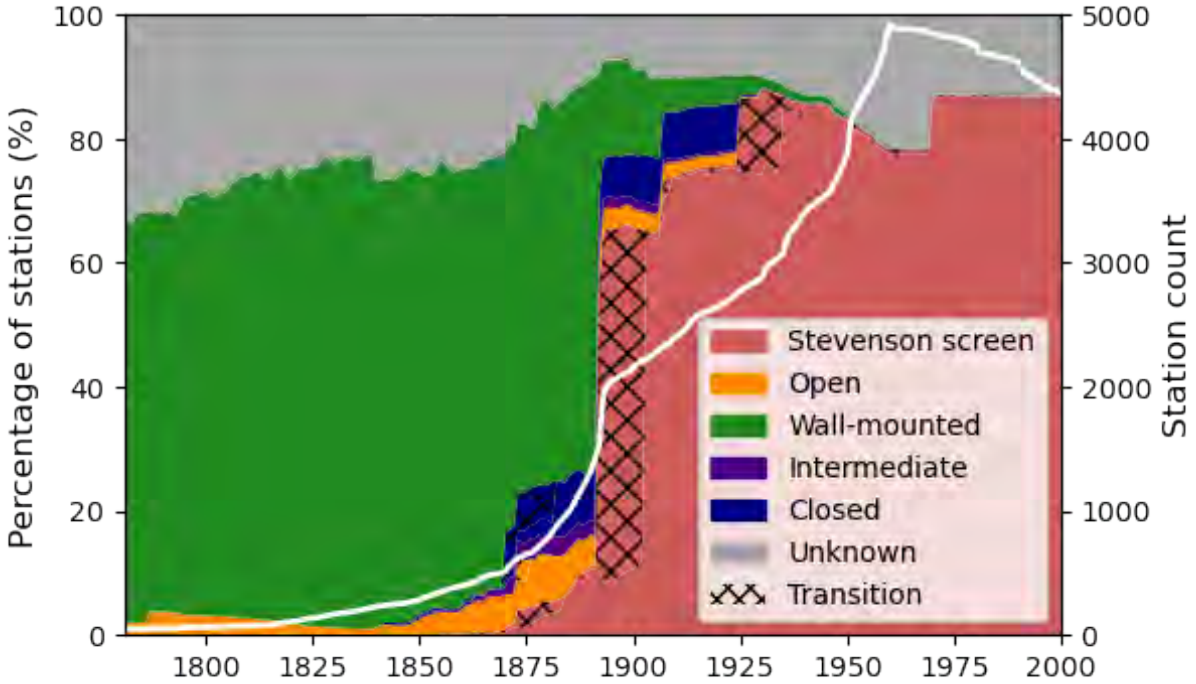


Met Office Hadley Centre

GloSAT Global Surface Air Temperature

5. The GloSAT reference analysis: Exposure biases

THE PROBLEM



The transition from non-standard thermometer exposures to Stevenson screens introduced biases into the land surface temperature record

OUR APPROACH TO ADDRESS THE BIAS

1. **Define the characteristics of the exposure bias** based on an empirical analysis of 54 parallel measurement series

2. **Develop models to estimate the bias** based on the relationship between the identified bias (1) and solar radiation/temperature

3. **Identify the bias-effected stations and months** by compiling exposure metadata for stations within CRUTEM5

4. **Estimate the bias present in CRUTEM5** by applying the models (2) to the bias-effected stations/months (3)

5. **Adjust the individual bias-effected stations**/months based on the biases predicted in (4)

Wallis, E. J., Osborn, T. J., Taylor, M., Jones, P. D., Joshi, M., & Hawkins, E. (2024). Quantifying exposure biases in early instrumental land surface air temperature observations. *International Journal of Climatology*, 44(5), 1611–1635. https://doi.org/10.1002/joc.8401

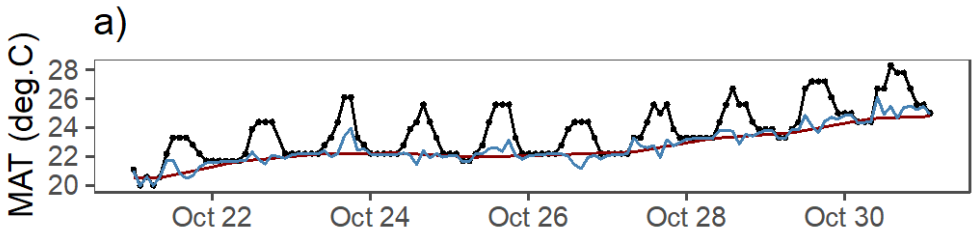
University of East Anglia

GloSAT Global Surface Air Temperature

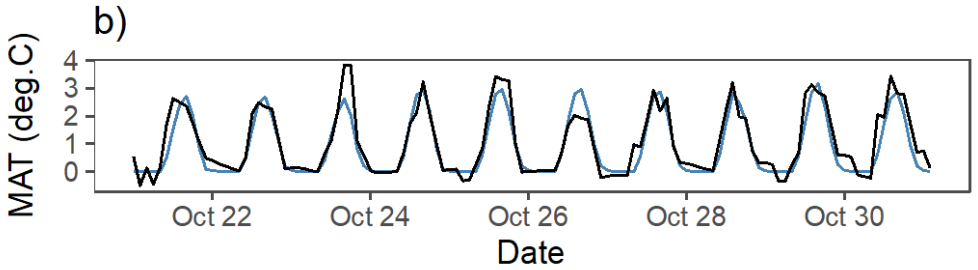
5. The GloSAT reference analysis: Marine Air Temperature Adjustments

MAT diurnal heating adjustments

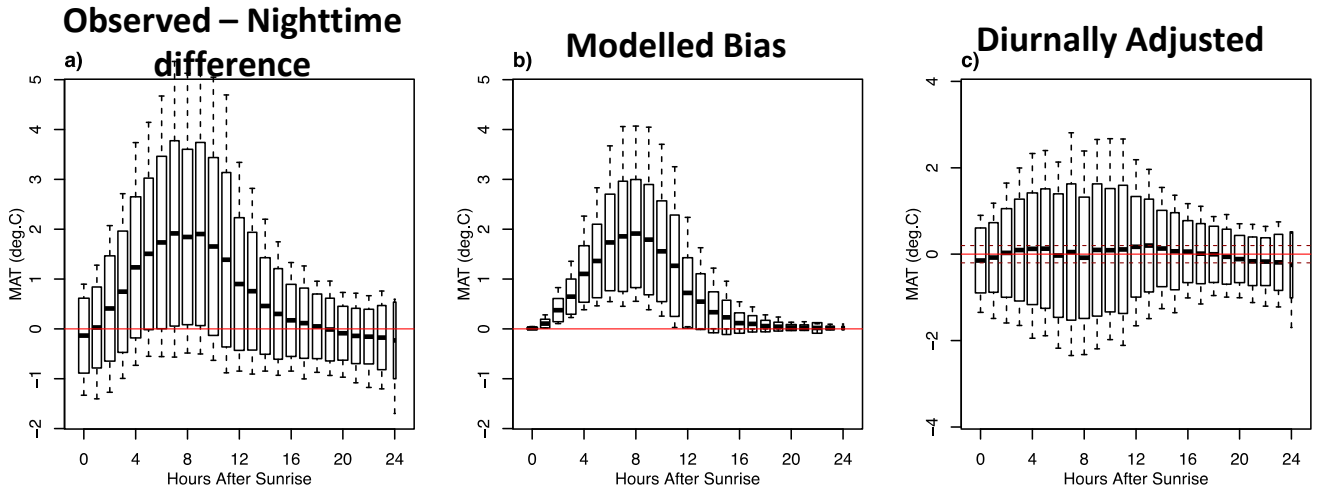
- MAT datasets start in 1880/1900 (CLASSNMAT / UAHNMAT).
- Daytime heating bias – limits potential starting point to ~1850.
- Cropper et al. (2023) – implementation of heat budget model to remove daytime heating bias.
- Applied on a ship-by-ship basis (differing biases per ship).
- Pseudo-NMAT dataset created with daytime heating bias removed.



Unadjusted MAT (Black)
Underlying Nighttime mean trend (Red)
Adjusted MAT (Blue) (Unadjusted MAT minus model estimated error from panel b)

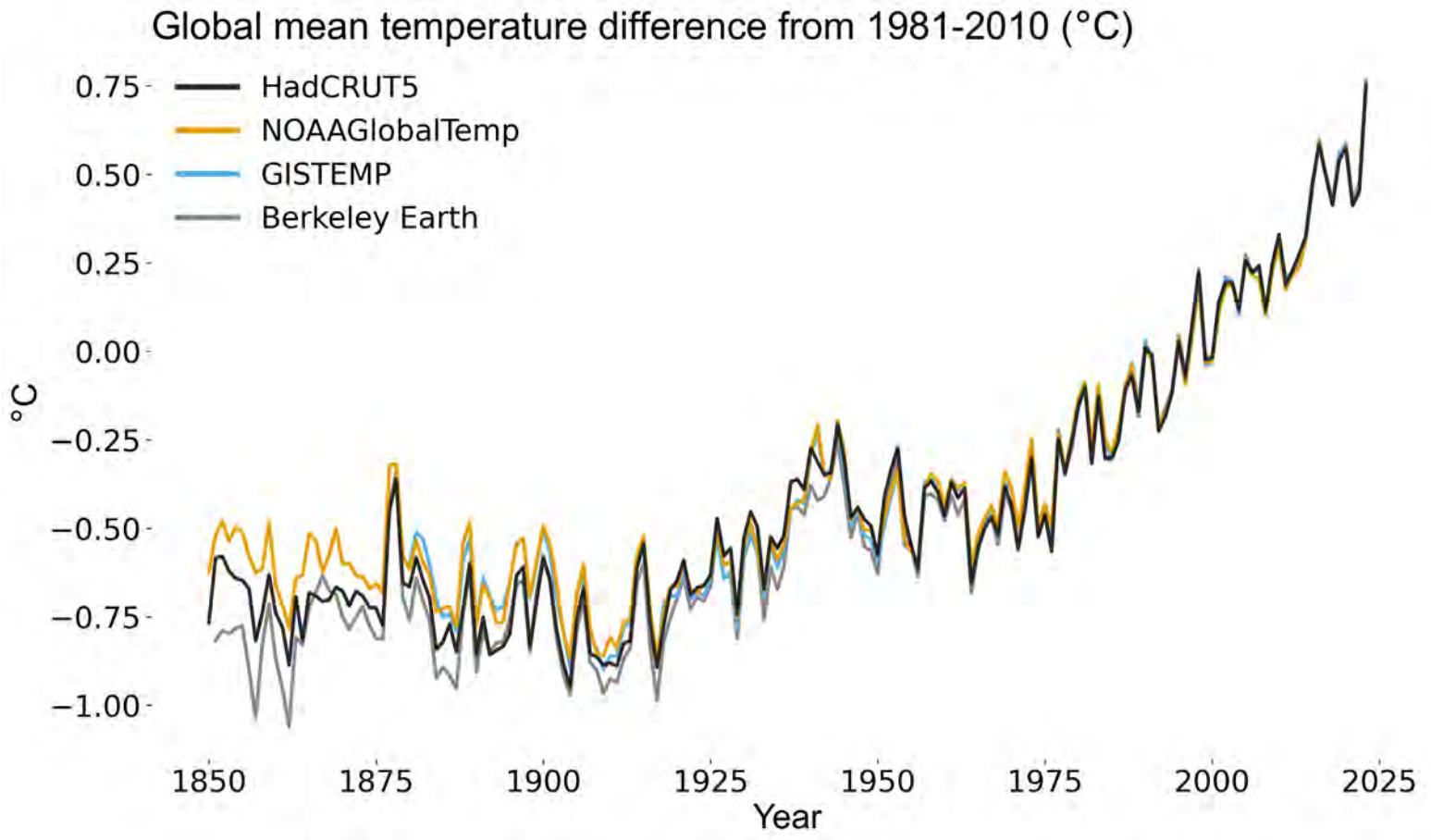


MAT Error Estimate (Unadjusted MAT minus the Nighttime mean trend) Model Estimated Error (Blue)

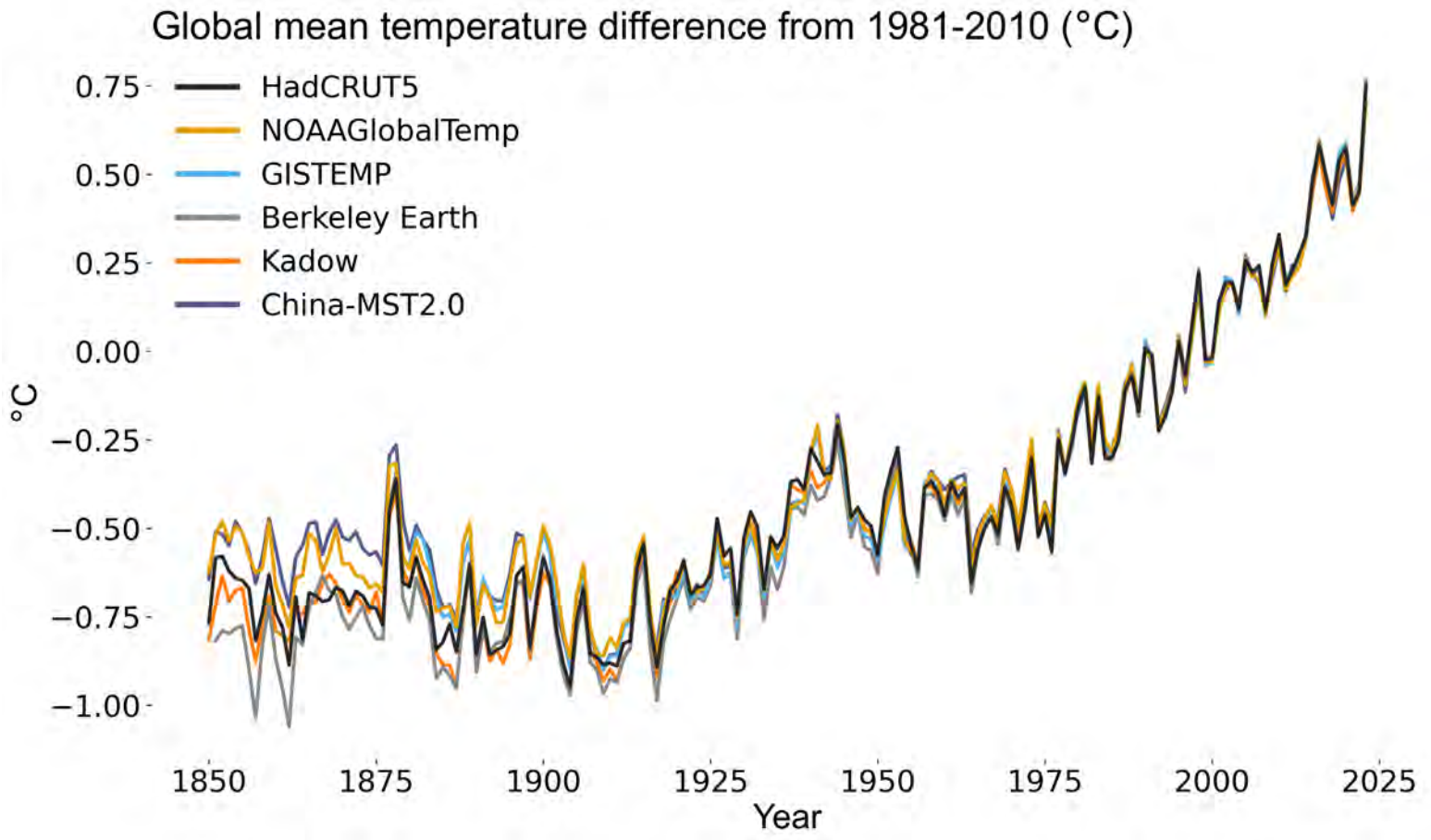


Cropper, T. E., D. I. Berry, R. C. Cornes, and E. C. Kent, 2023: Quantifying Daytime Heating Biases in Marine Air Temperature Observations from Ships. *J. Atmos. Oceanic Technol.*, **40**, 427–438, https://doi.org/10.1175/JTECH-D-22-0080.1.

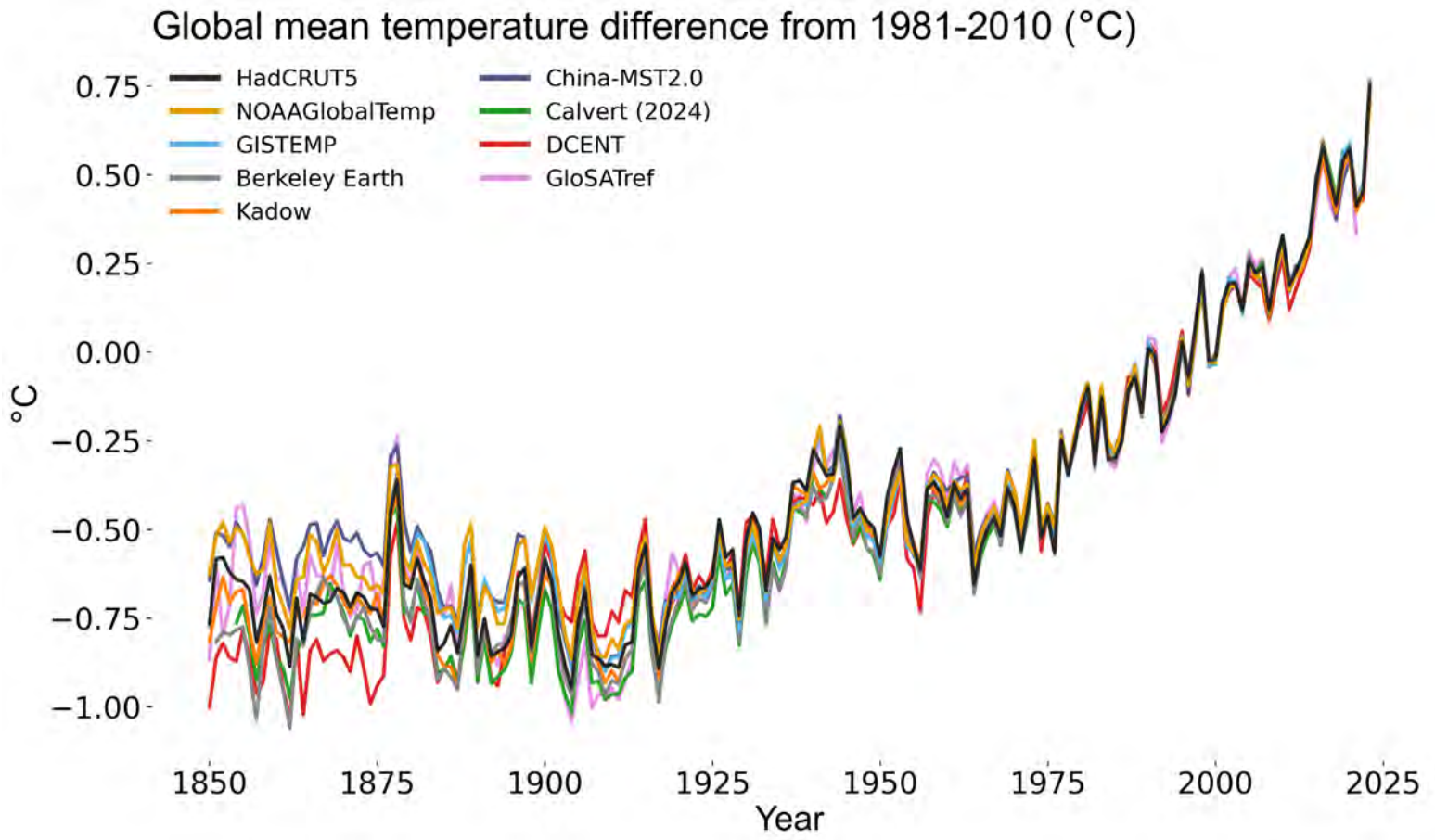
In-situ global temperature series: operational products



In-situ global temperature series: operational + recent products



In-situ global temperature series: all products



Summary

- Developments of existing data sets:
  - GISTEMP – uncertainty ensemble improvements
  - NOAAGlobalTemp - new AI based grid infilling
- New data sets:
  - DCENT - new processing chain and bias adjustments
  - Calvert (2024) - space/time infilling with new ice climatology bias adjustment
  - GloSATref – use marine air temperatures and early station exposure adjustments
- New additions:
  - Increase degree of freedom in data sources and processing
  - Increase ensemble spread highlighting structure uncertainties in data set construction

C3: General Improvements to in situ Data Products for all ECVs

- C3.1: 1. Periodically reprocess in situ data products to account for new knowledge, new techniques and improved access to historical data holdings.
  - NOAAGlobalTemp, DCENT, GloSAT
- C3.2: Improve uncertainty quantification of in situ-based products.
  - GISTEMP - ensemble improvements
  - DCENT - new processing chain and bias adjustments
- C3.3: Undertake efforts to account for spatio-temporal sparsity of in situ measurements via interpolation.
  - NOAAGlobalTemp - new ML based grid infilling
  - Calvert (2024) - space/time infilling with new ice climatology bias adjustment
  - DCENT – published version is not infilled
- C3.4. Ensure adequate sampling of the structural uncertainty inherent in in situ product development via supporting the development of multiple methodologically distinct products and their intercomparison.
  - Three new data sets: DCENT, Calvert and GloSATref.

Things not discussed

- Situation improved but method degrees of freedom small
- Data sets contingent on:
  - underlying monitoring networks and databases, data sharing.
  - Data rescue for historical data into shared archives.
  - Data licencing and usage restrictions.
- Use of reanalysis to develop uncertainty estimates and train statistical/ML models
- Low spatial resolution, monthly.
- Regional products not discussed
- Over ice observations not used
  - Statistical infilling from land/sea
- Research takes time to make its way into products
- Update of “research” data sets
- Typically, anomalies not actuals
- Data and meta data format standards

Agenda: Task C3

- Introductory presentation on innovations in surface temperatures
- Review activities from AOPC 28 relating to IP Action C3: general improvements to in situ data products for all ECVs
- Review progress on Activity C3.1 and C3.3.
- Review position on Activity C3.2 and C3.4.
- Agree timeline and way forward for Activity C3.1 and C3.3.