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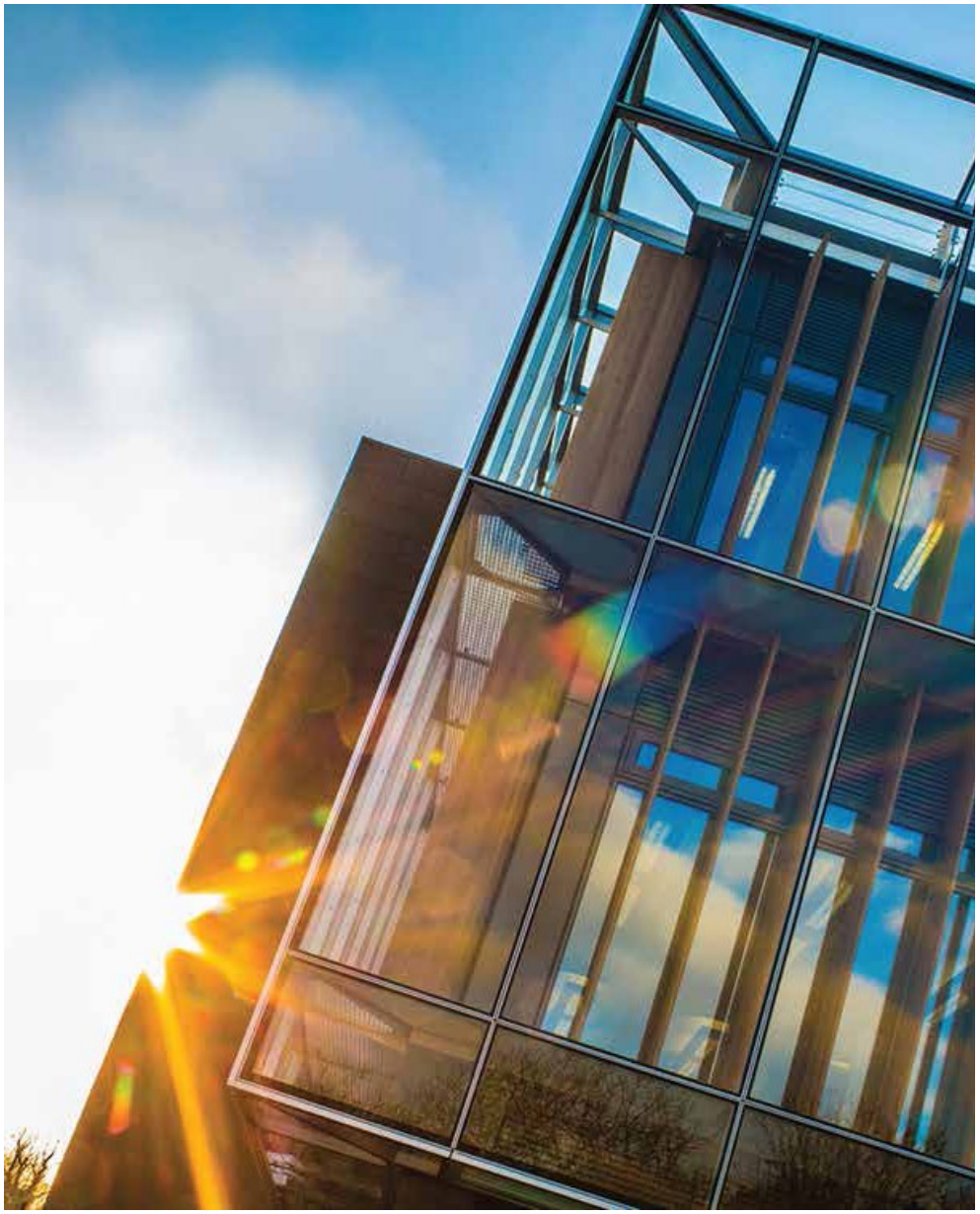
Potential roles of GNSS-RO in climate activities

Peter Thorne



Climate change is unequivocal

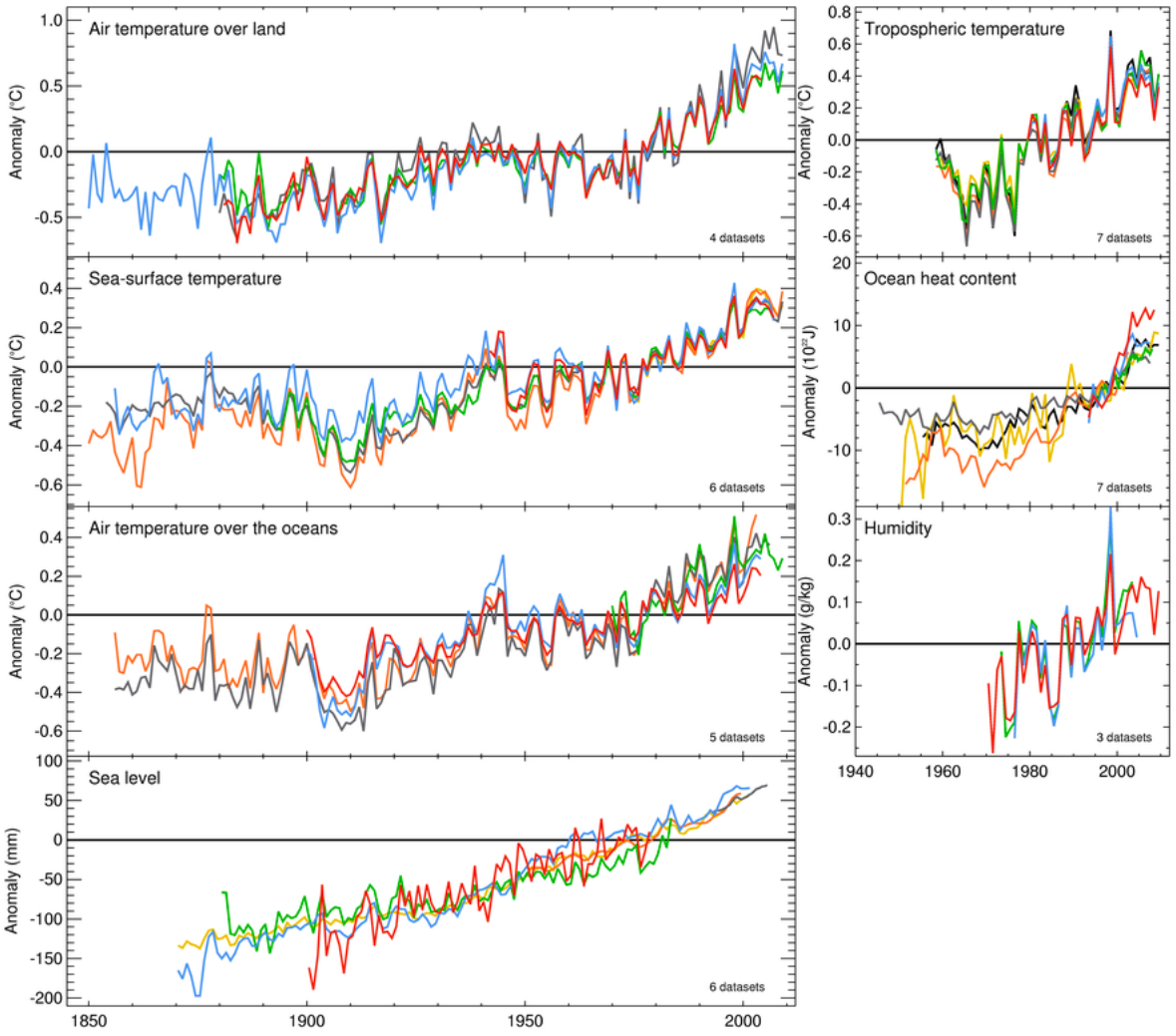
A range of indicators are all changing in a manner consistent with a warming world

Multiple indicators

Multiple analyses

Multiple distinct types of underlying data

Source: https://www.metoffice.gov.uk/hadobs/indicators/11keyindicators.html



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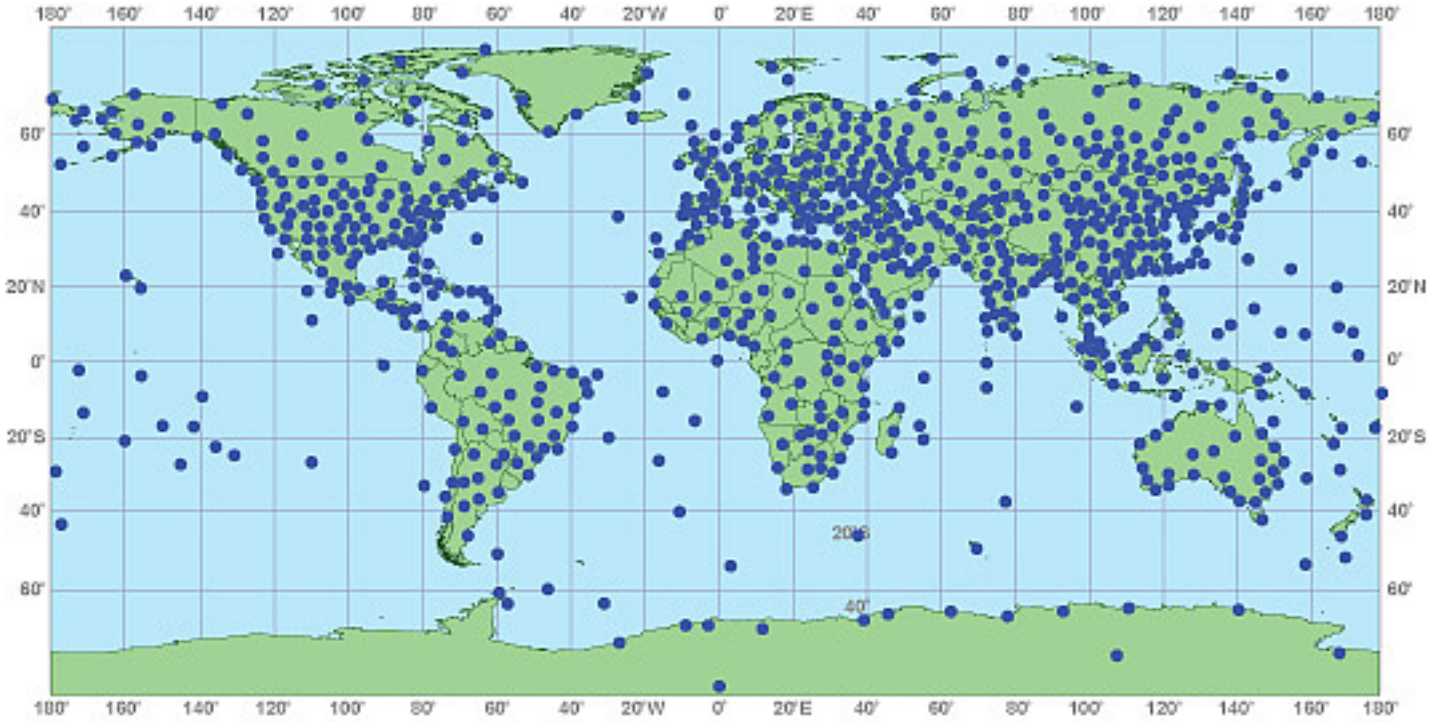
Job done?

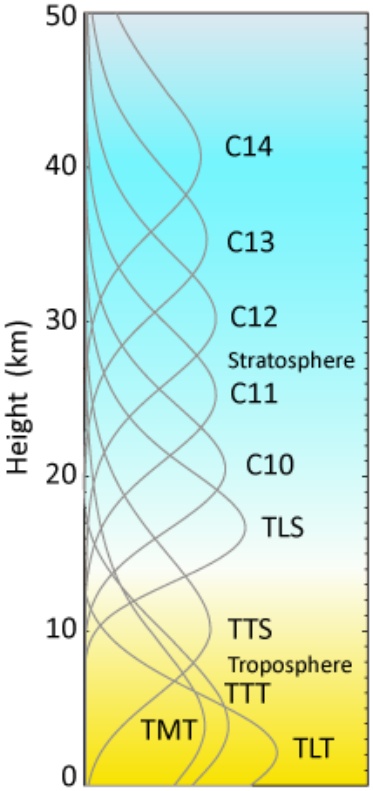
- Not by a long way.
- Underlying data are:
  - Spatio-temporally sparse for in-situ data
  - Generally thick layer averages for satellite
  - Generally lacking in fundamental SI traceability
  - Subject to frequent changes which may impart systematic and random effects into the series

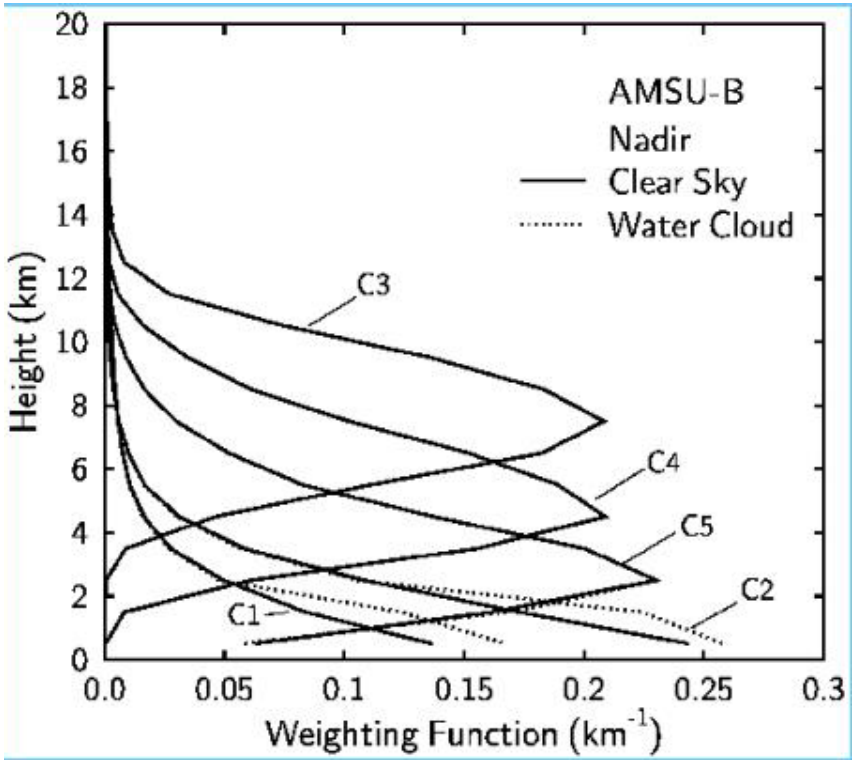
Sparsity



Current global radiosonde network – not all sites here fly regularly. Flights are generally once or twice daily at 00 or 12 UTC.

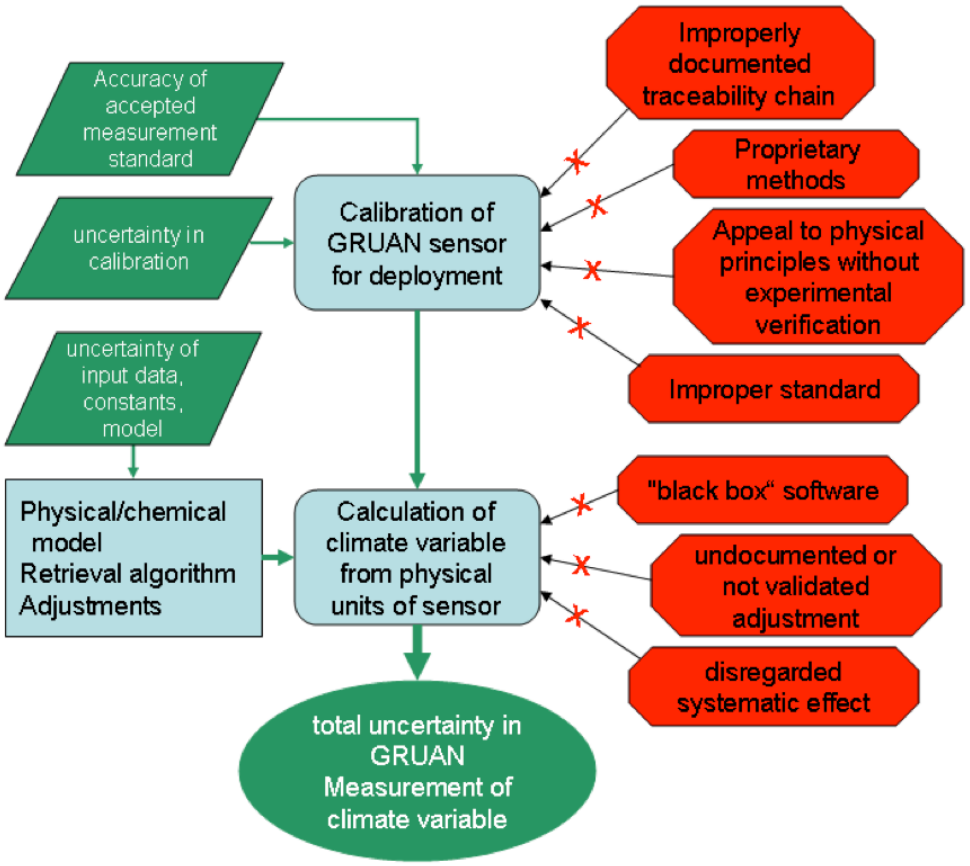
Layer integrals





AMSU-A (temperature, left) and AMSU-B (humidity, above) weighting functions

General lack of traceability



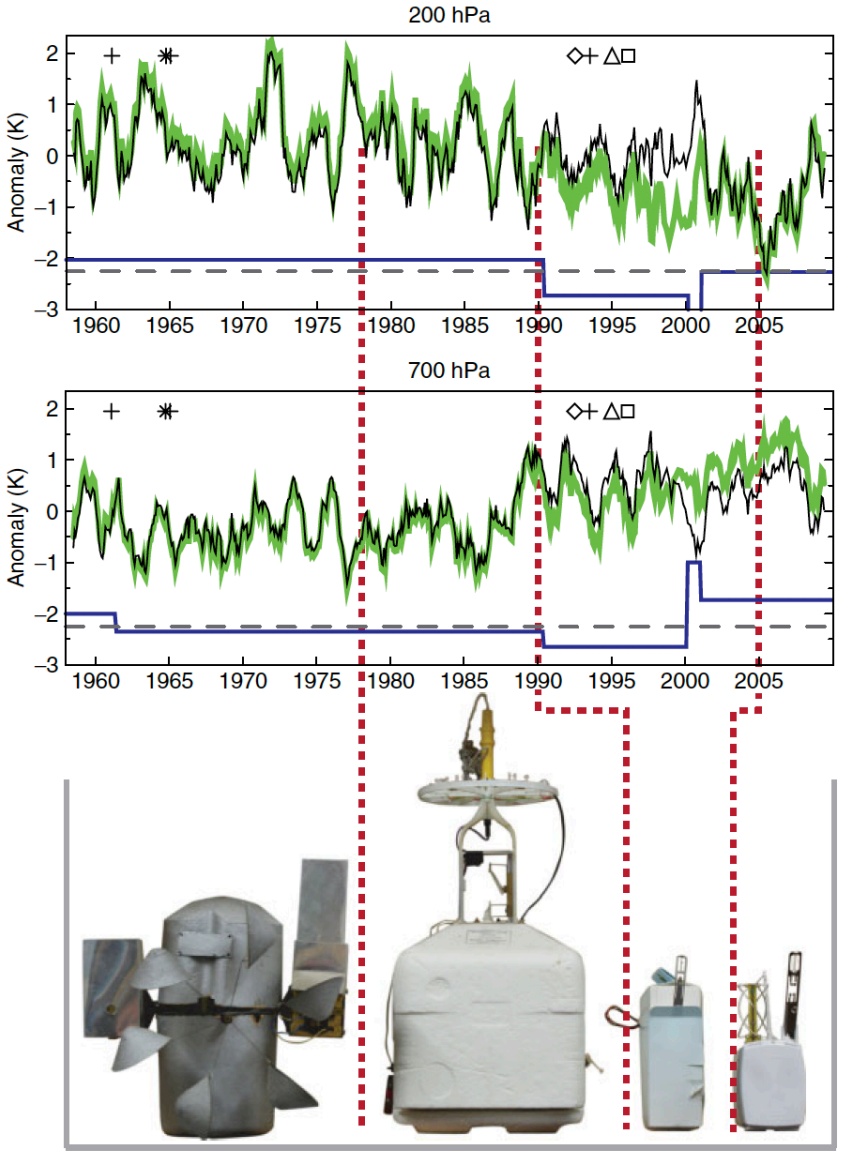
Ascertaining and maintaining full traceability for in-situ measurements is hard and possible only at subset of sites (www.gruan.org)

There is no sustained absolutely traceable measurement for non-RO techniques yet from space (although several missions are now committed)

Ubiquitous change

Change across both in-situ techniques and satellites has been ubiquitous

Changes frequently are associated with breakpoints detected in the series.



Potential of GNSS-RO for climate monitoring

- The base measurement of a time delay is fundamentally SI Traceable
- The measurement technique is to first order comparable across sensors
- The derived parameter estimates are vertically resolved to a resolution bettered only by balloon-borne techniques
- The full processing chain is ‘open’ and thus the uncertainties are in principle calculable
- Measurements in principle can be obtained for many decades to come in a consistent manner assuring long-term comparability and robust trend estimates

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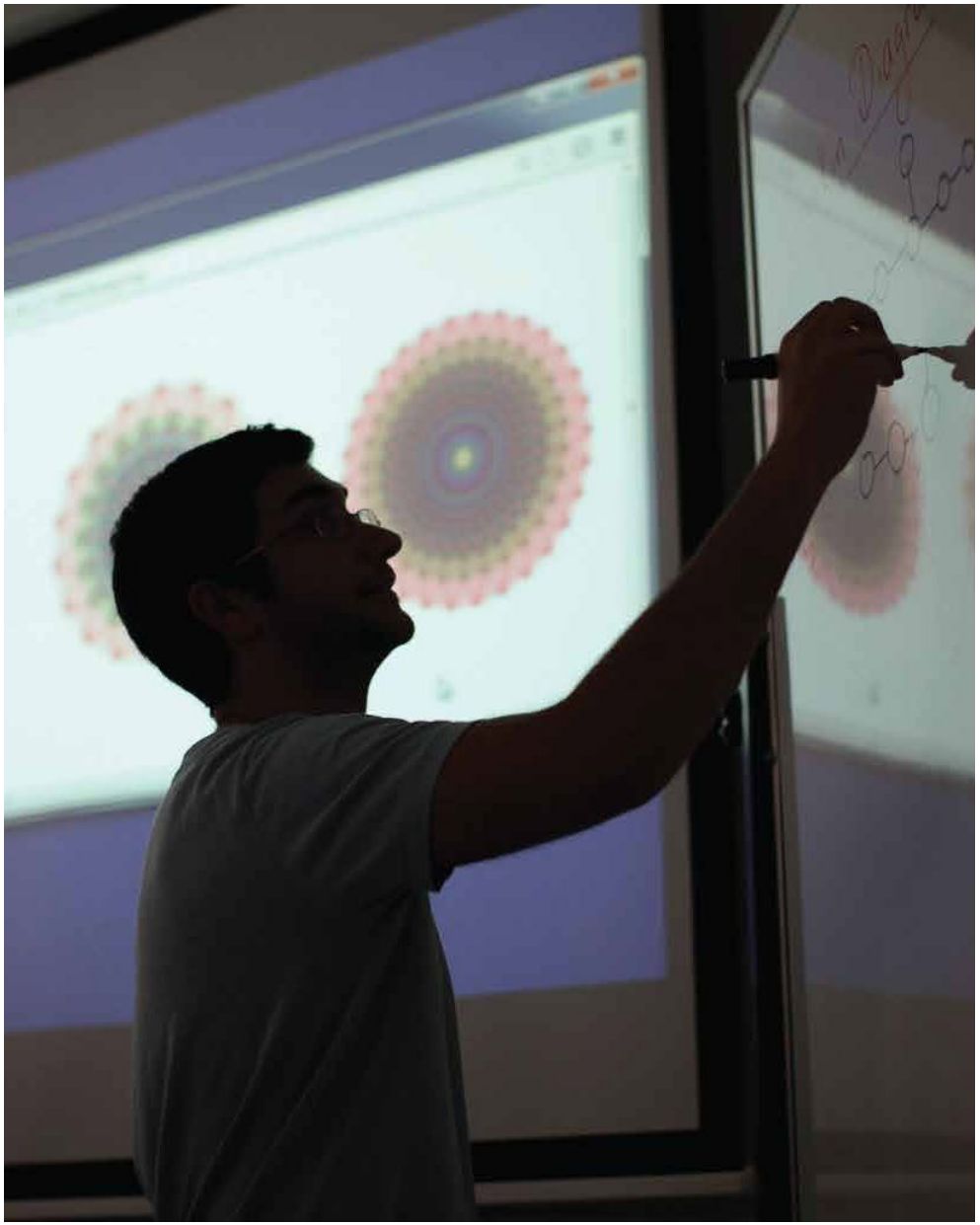
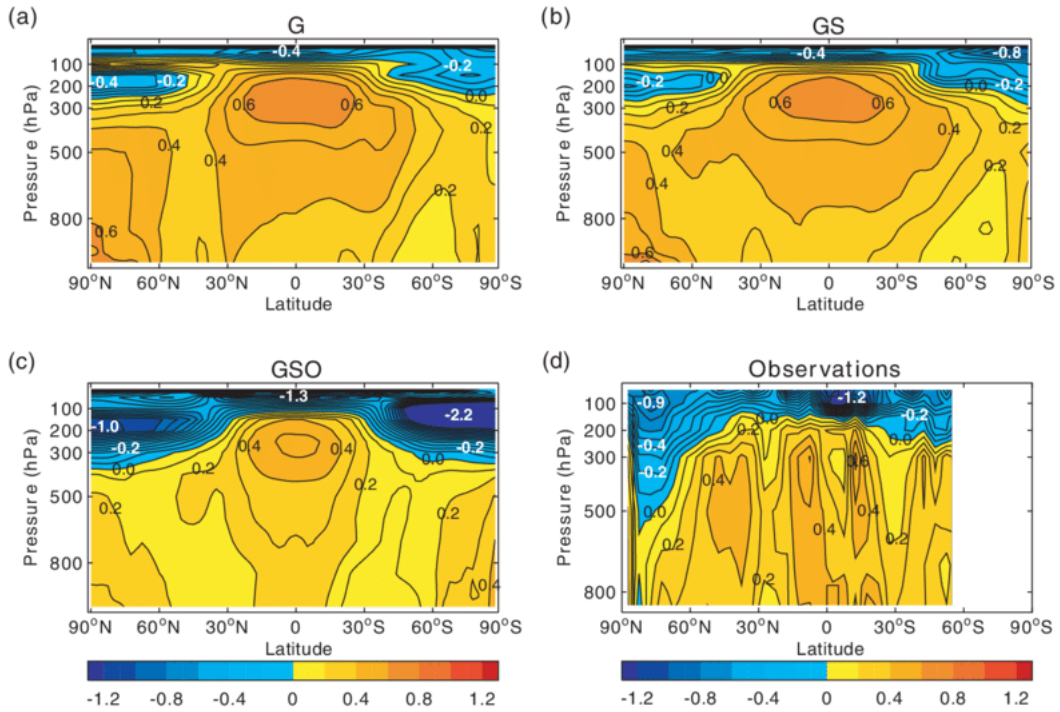
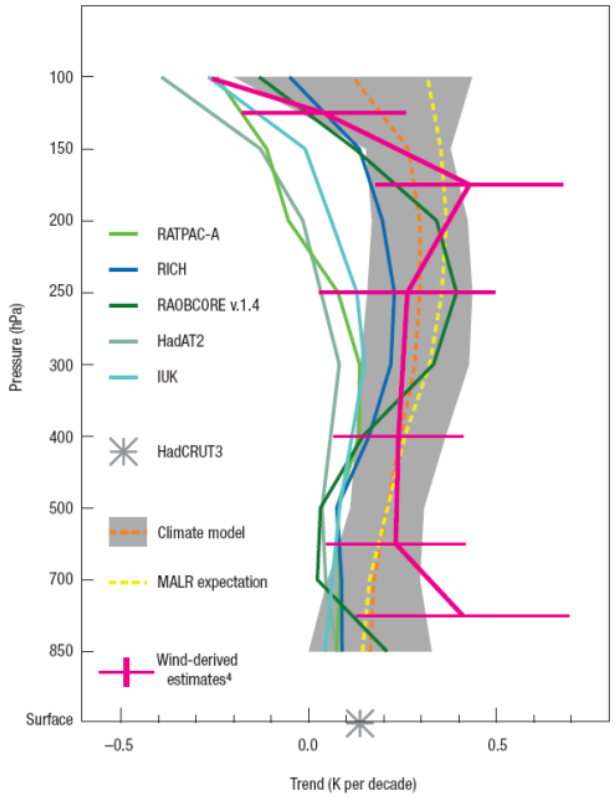
Tropical upper tropospheric temperatures and model validation



Tropical troposphere dominated by convective adjustment

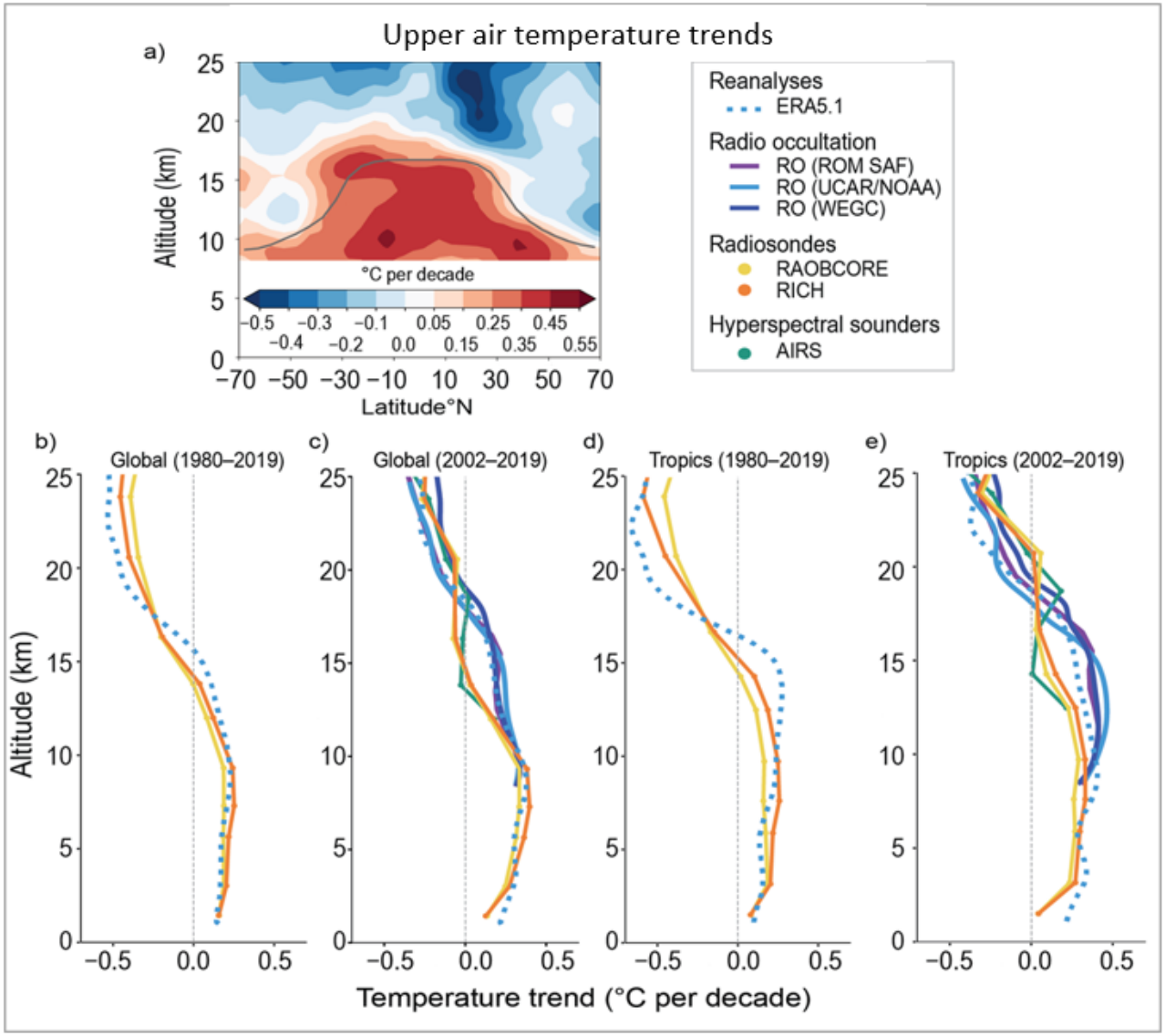


Ambiguity in whether models and observations agree



Important considerations

- Check the constrained behavior – amplification – rather than comparing absolute trends
- Need for sufficiently vertically resolved measurements (hard from passive remote sensing)
- Need for sufficient observations (hard from sparse radiosonde network)
- Need for high-quality observations (hard for radiosondes – solar effects)
- Role for GNSS-RO – dense sampling, vertically resolved



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UTLS humidity

Water vapour most important high up

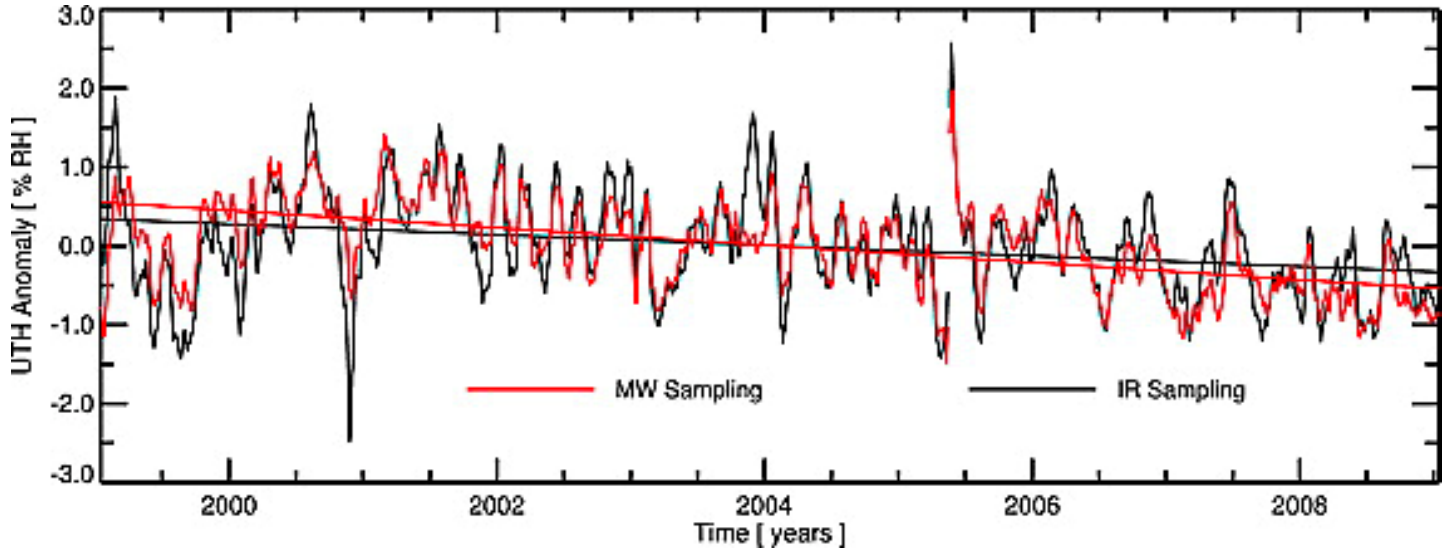
- In the Boundary Layer and lower troposphere the water vapour bands are pretty much saturated everywhere
- In the UTLS absolute WV concentrations are small and the bands are not saturated
- If we care about the TCR and ECS metrics what matters is the UTLS water vapour as this determines the strength of the positive feedback
- Is UTLS water vapour changing and if so how?

Frostpoint hygrometer measures

- Water vapour absolute concentrations vary over several orders of magnitude over the column
- Commercial sondes cannot quantify water vapour above the mid-upper troposphere
- Frostpoint hygrometer measurements are:
  - very expensive,
  - made infrequently
  - available from only a limited number of locations
  - A source of long-lived GHG R23 with huge GWP (the active refrigerant)

Passive sensors challenges

- Again, all data are from broad weighting functions
- IR sensors suffer from clear-sky sampling biases



Source: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2010JD015355

Limb sounder continuity and relative sparsity

- Limb sounder techniques offer reasonably vertically constrained estimates
- But fewer estimates than RO
- Continuity is assessed as at significant risk

Humidity from RO

- Most unambiguous in the UTLS region where most needed
- More frequent sampling than frostpoint hygrometers or limb sounders
- High vertical resolution

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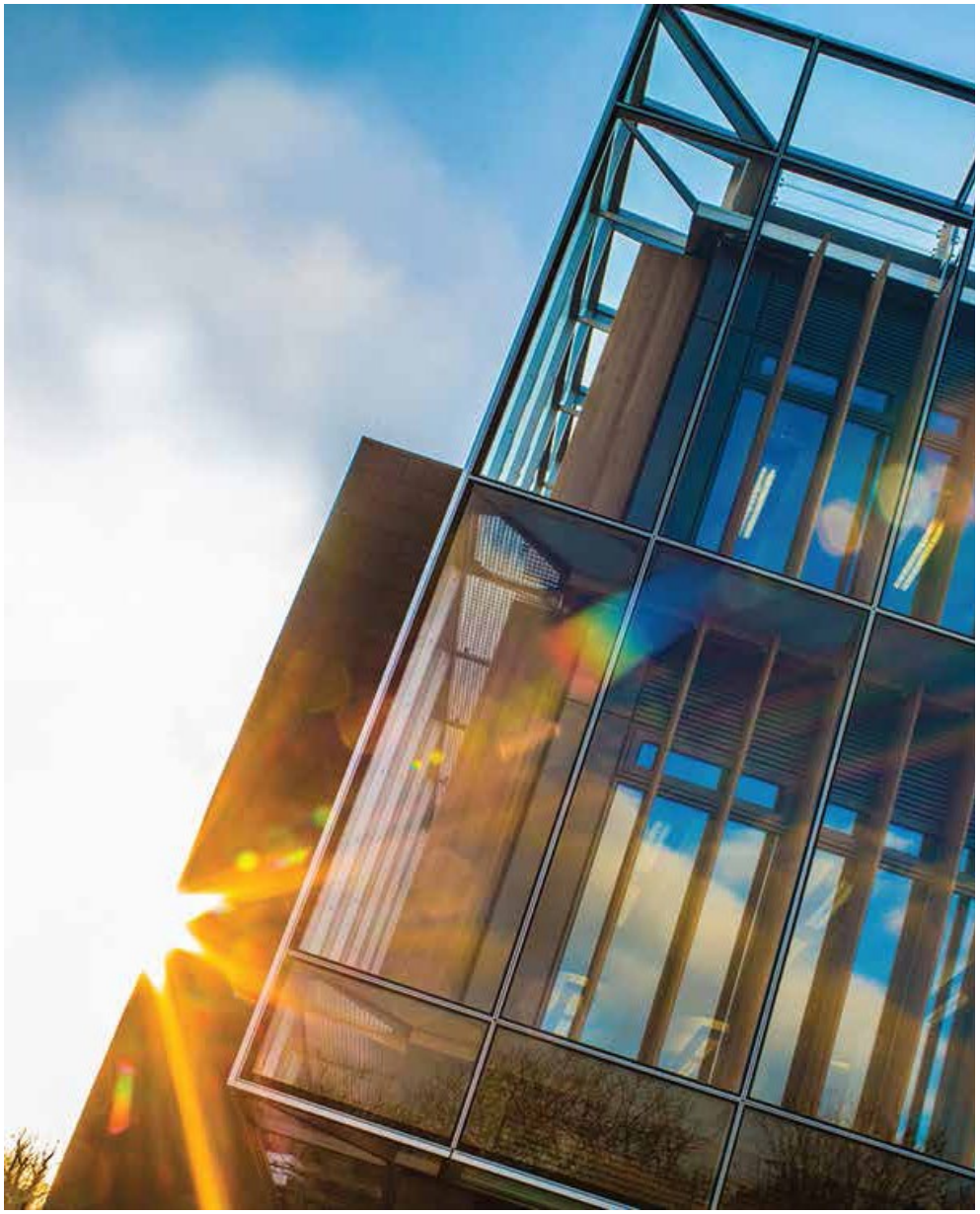
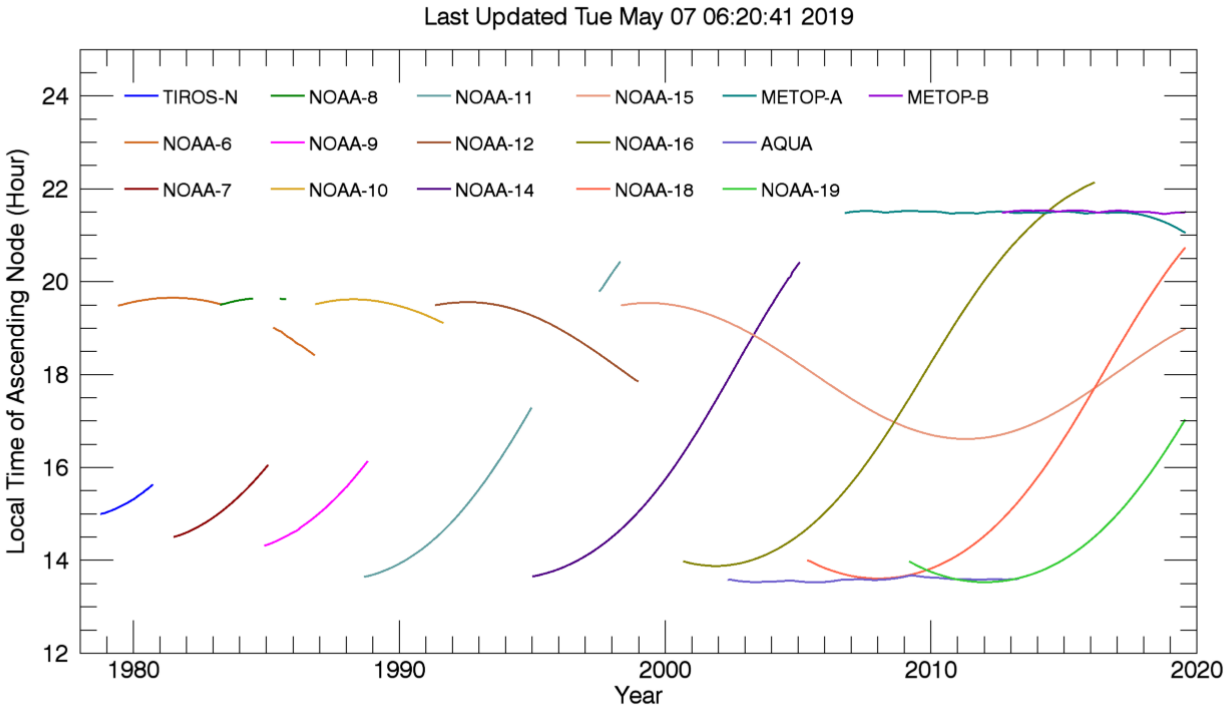
Diurnal cycle of temperature and humidity



Historical polar orbiter station keeping issues



Ambiguity in MSU/AMSU/ATMS records

- Largest when satellites were drifting rapidly as alias in diurnal effects
- Largest in tropics where repeat frequency is 3 days
- No robust estimate of the diurnal cycle
  - For lowermost channels need estimate of skin surface cycle
  - Most radiosondes at 00 and / or 12Z
  - Reanalyses will suffer from this
  - Climate models are imperfect

RO (increasingly) samples the diurnal cycle

- As the number of GNSS satellites and RO receiver platforms increases (particularly with commercial smallsats) we get more and more samples across a broader range of timezones
- Sufficient samples to determine diurnal and semi-diurnal and even higher order moments seasonally?

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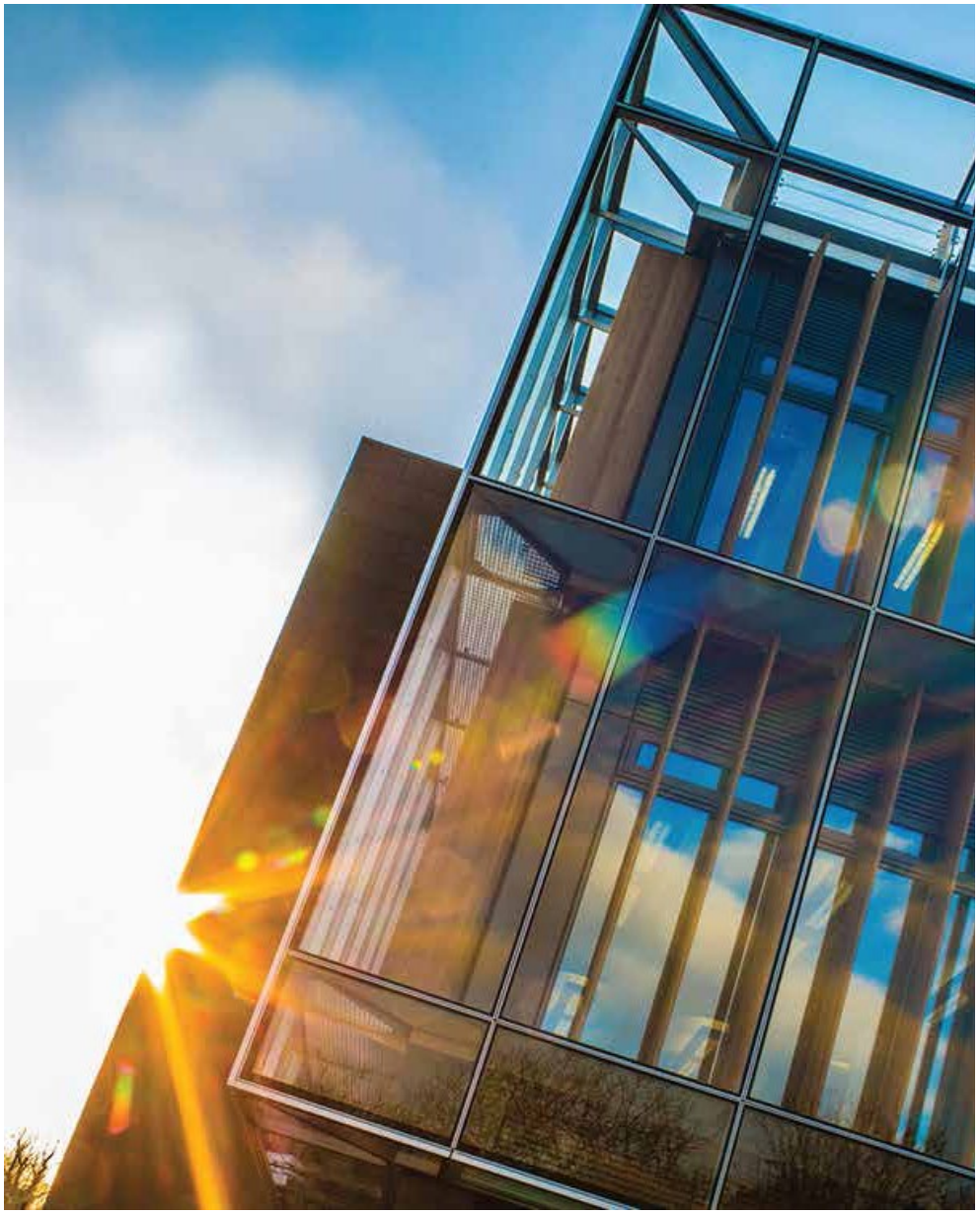
Constraining reanalyses



Arctic warming structure controversy

- Gravesen et al., 2008 (https://www.nature.com/articles/nature06502) noted rapid tropospheric Arctic warming in ERA-40
  - No fewer than 3 critical responses
- ERA-40 vertical structure changed substantially at poles and tropics when RO came in
- Reanalyses in the absence of radiosondes had over-fitting issue to broad satellite weighting functions
- RO provides high vertical resolution constraint that is globally representative (unlike radiosonde network)

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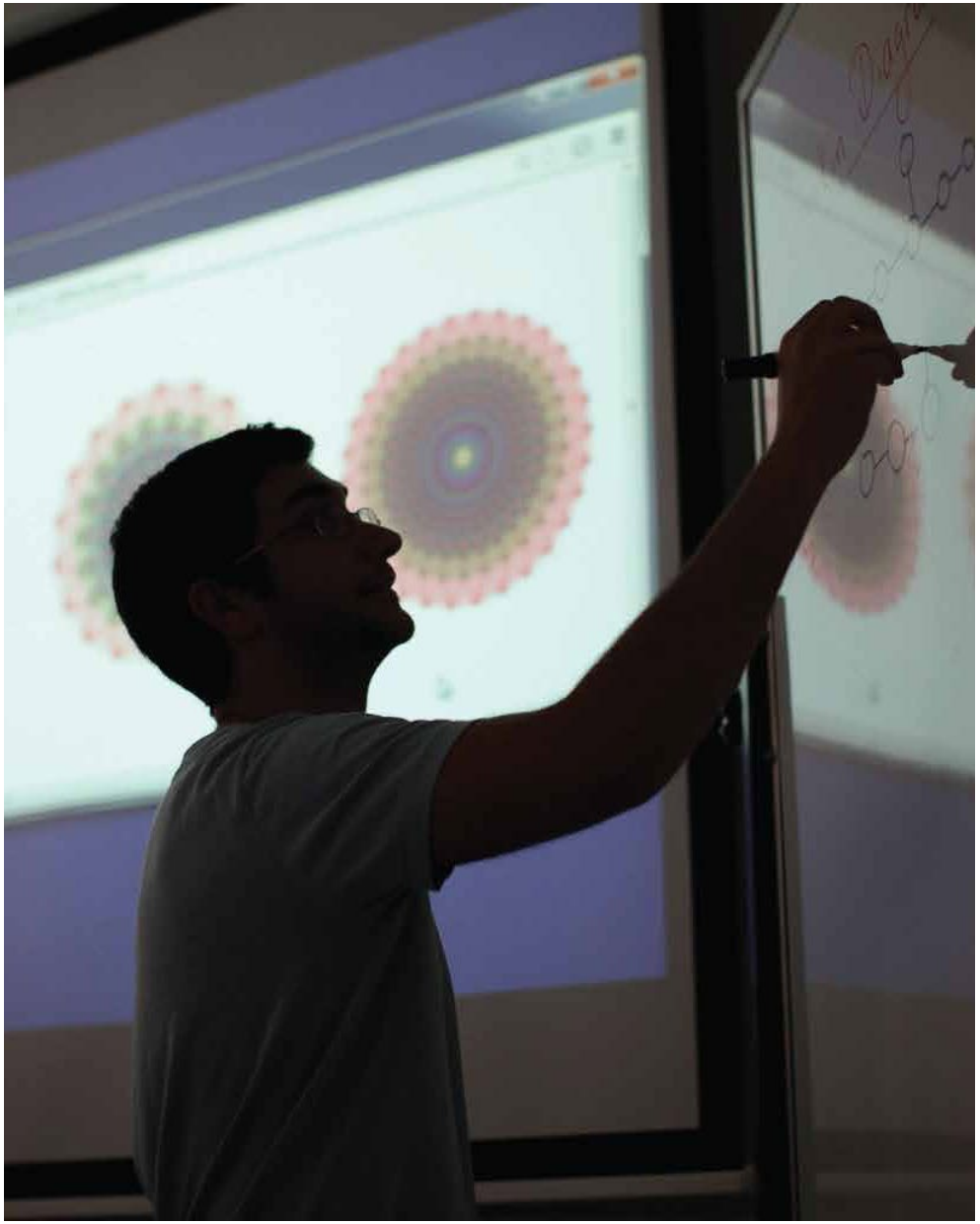
Conclusion



Summary

- There remain important questions which require measurements of:
  - High fidelity
  - Vertically resolved
  - Long-term sustained
  - Measuring the seasonal and diurnal cycles and any changes therein
  - Of temperature and humidity through the troposphere and stratosphere
- And their analysis…!
- The GNSS-RO record can be of great utility