GRUAN

An overview of the GCOS Reference Upper-Air Network (GRUAN) and links to the radio occultation community

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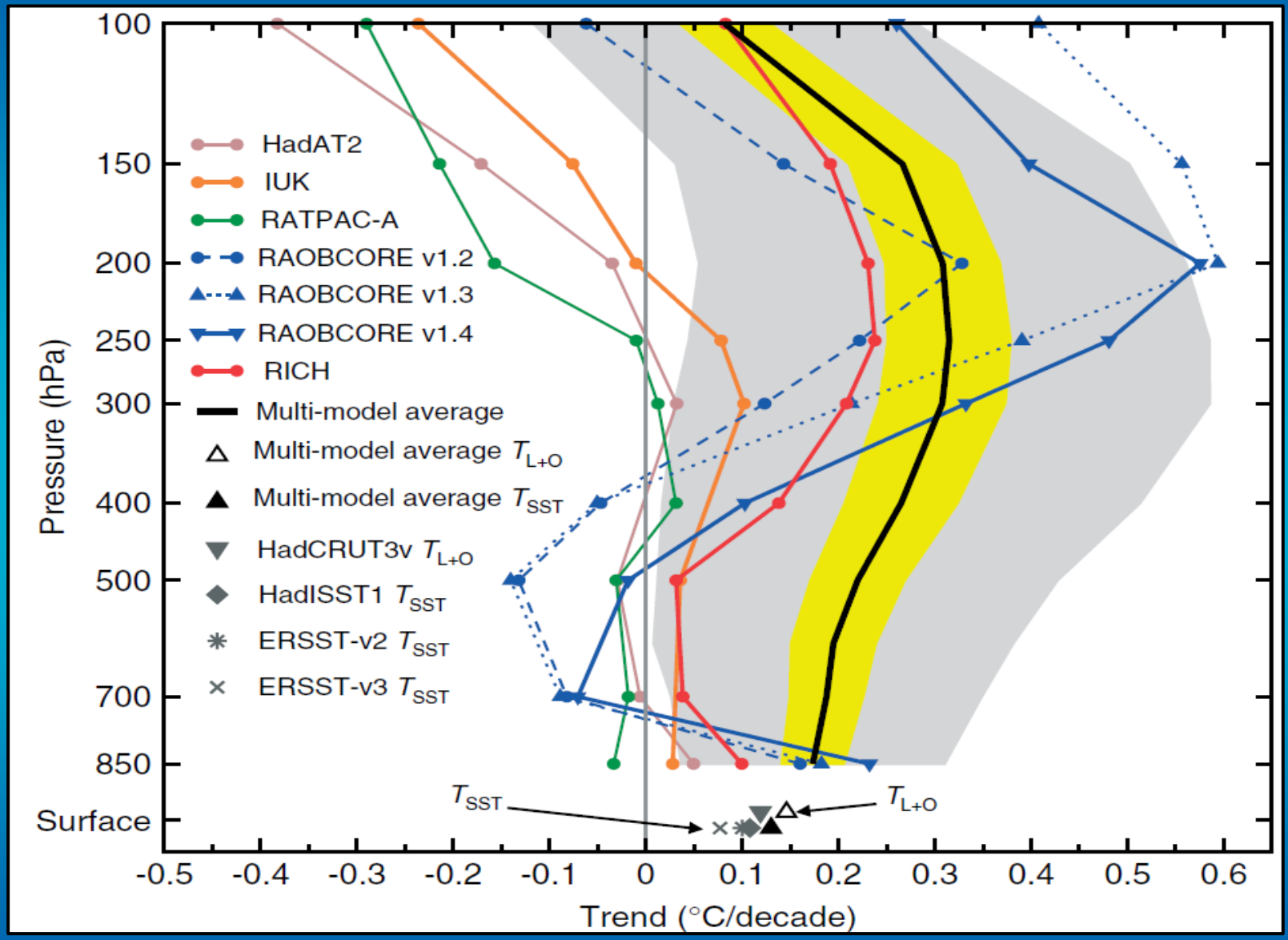
Overview

- First something about GCOS
- What brought GRUAN into existence?
- The goals of GRUAN
- GRUAN governance
- The definition of a reference observation
- Establishing reference quality
- Uncertainty, redundancy and consistency
- Data products currently available
- Research partners and links to the RO community
- Another interesting use for RO temperature data

GCOS – the Global Climate Observing System

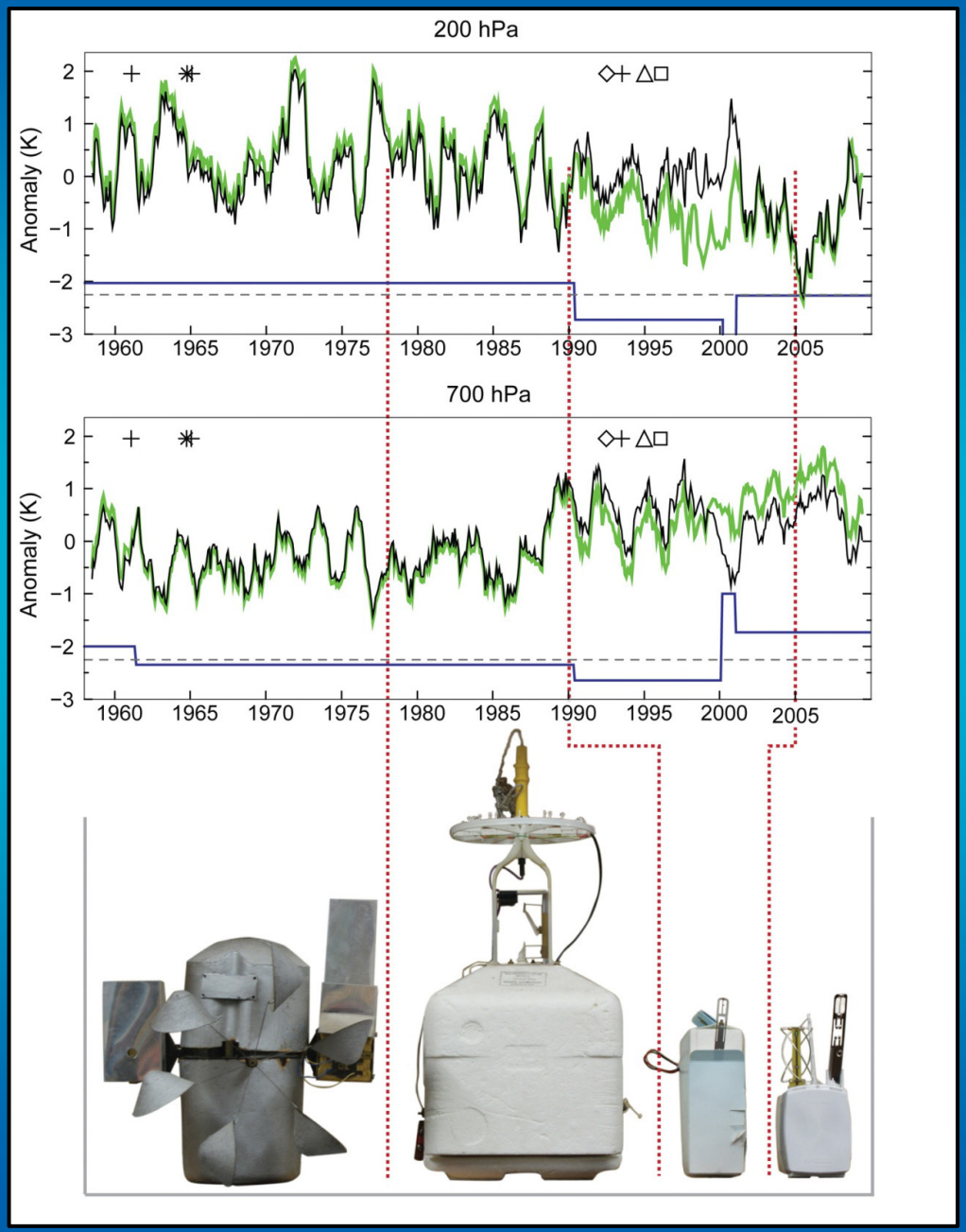
- Joint undertaking of the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission (IOC), the United Nations Environment Programme (UNEP) and the International Council for Science (ICSU).
- GCOS's goals: provide comprehensive information on the total climate system. Consider the full range of physical, chemical and biological properties of the system. Consider all atmospheric, oceanic, hydrological, cryospheric and terrestrial processes.
- Includes both in situ and remote sensing components. Space-based components coordinated by the Committee on Earth Observation Satellites and the Coordination Group for Meteorological Satellites.
- Intended to meet the full range of national and international requirements for climate and climate-related observations.

The problem



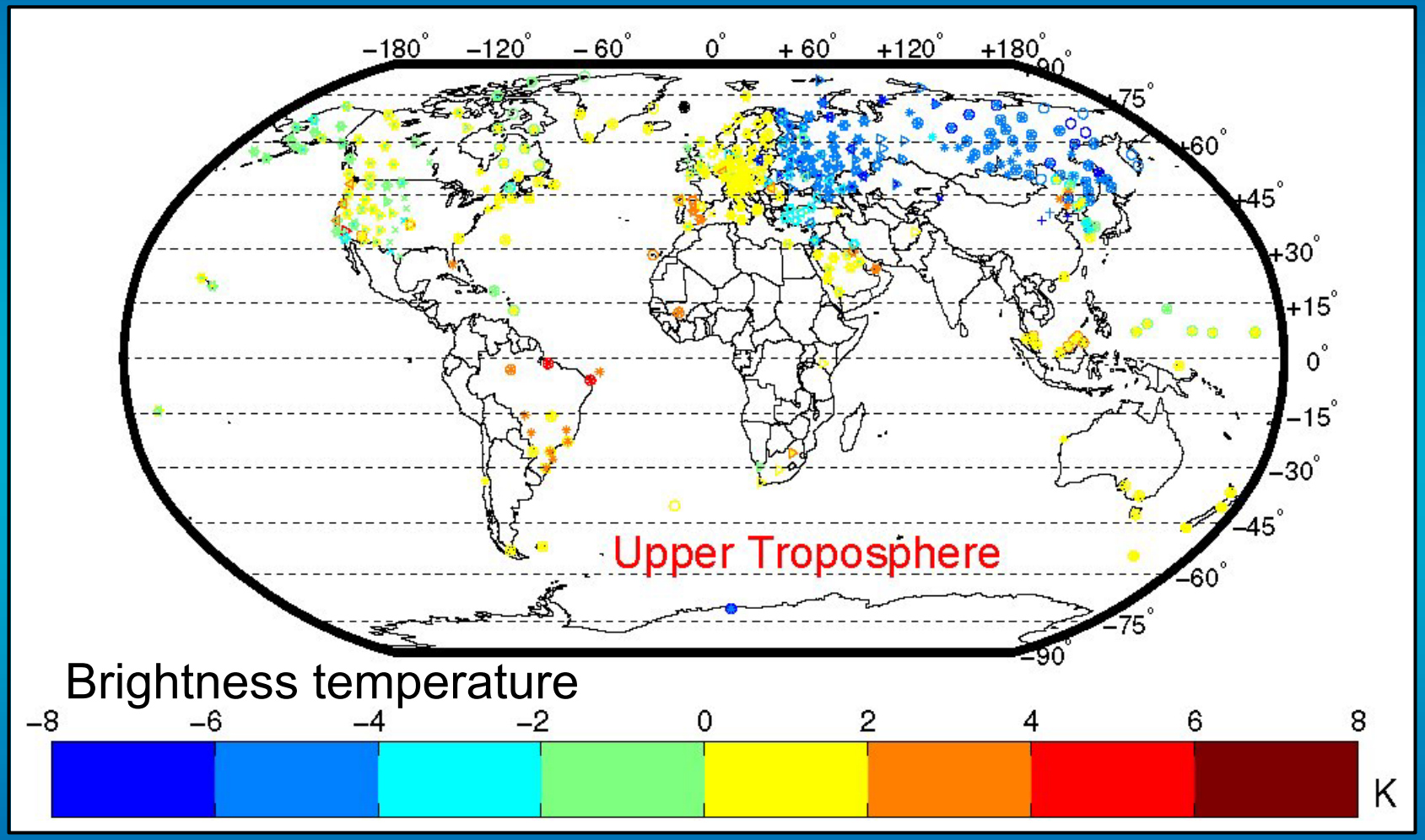
From: Santer et al., Consistency of modelled and observed temperature trends in the tropical troposphere, International Journal of Climatology, DOI: 10.1002/joc.1756, 2008.

What caused the problem



- Historical observations made primarily for operational monitoring purposes.
- Ubiquitous change – impacts very rarely adequately quantified for climate trend determination.
- Ambiguity in the rate and details of climatic changes.
- Significant impediment to understanding climate change and its causes.

Upper tropospheric humidity measurements
Radiosonde minus satellite



Moradi, I.; Soden, B.; Ferraro, R.; Arkin, P. and Vömel, H., Assessing the quality of humidity measurements from global operational radiosonde sensors, *Journal of Geophysical Research: Atmospheres, 118, 8040-8053, 2013.*

The solution - GRUAN

- GCOS Reference Upper-Air Network (GCOS=Global Climate Observing System)
- Network for ground-based reference observations for climate in the free atmosphere in the frame of GCOS.

The purpose of GRUAN

- Provide long-term high quality climate records;
- Constrain and calibrate data from more spatially-comprehensive global observing systems (including satellites and current radiosonde networks); and
- Fully characterize the properties of the atmospheric column.

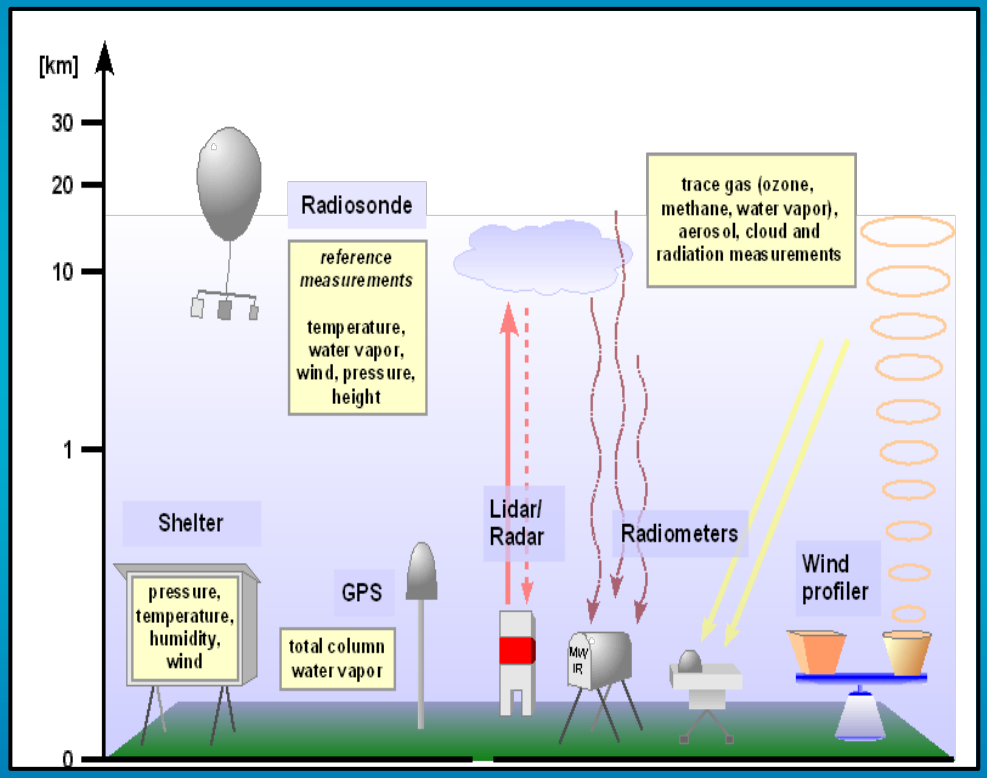
Four key user groups of GRUAN data products are identified:

- The climate detection and attribution community.
- The satellite community.
- The atmospheric process studies community.
- The numerical weather prediction (NWP) community.

More about goals of GRUAN

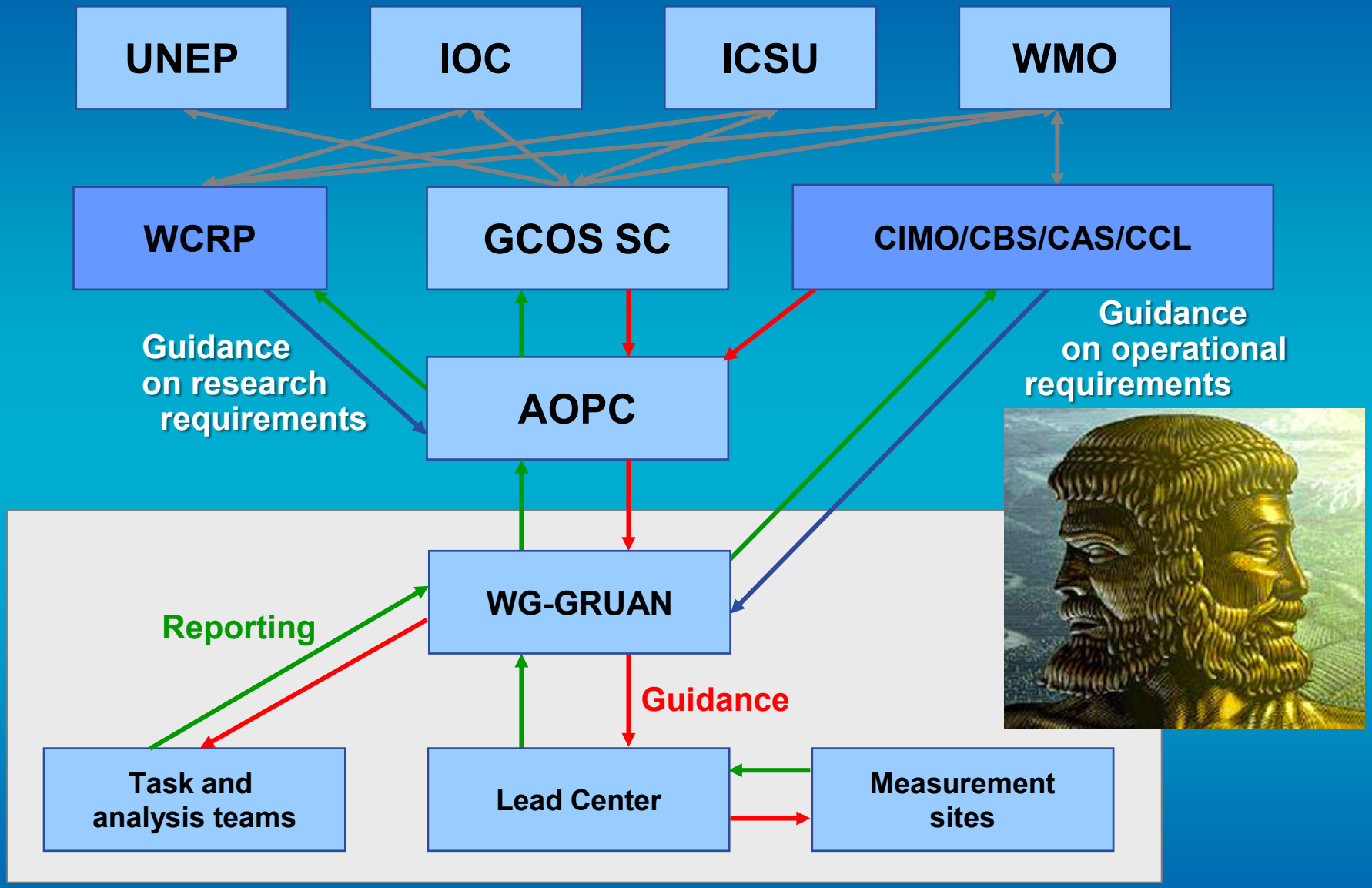
- Multi-decade measurement programmes.
- Characterize observational biases.
- Robust, traceable estimates of measurement uncertainty.
- Ensure traceability through comprehensive meta-data collection and documentation.
- Ensure long-term stability by managing measurement system changes.
- Tie measurements to SI units or internationally accepted standards.

Priority 1: Temperature, pressure, water vapour
Priority 2: Ozone, methane …



- Measure a large suite of co-related climate variables with deliberate measurement redundancy

GRUAN Governance



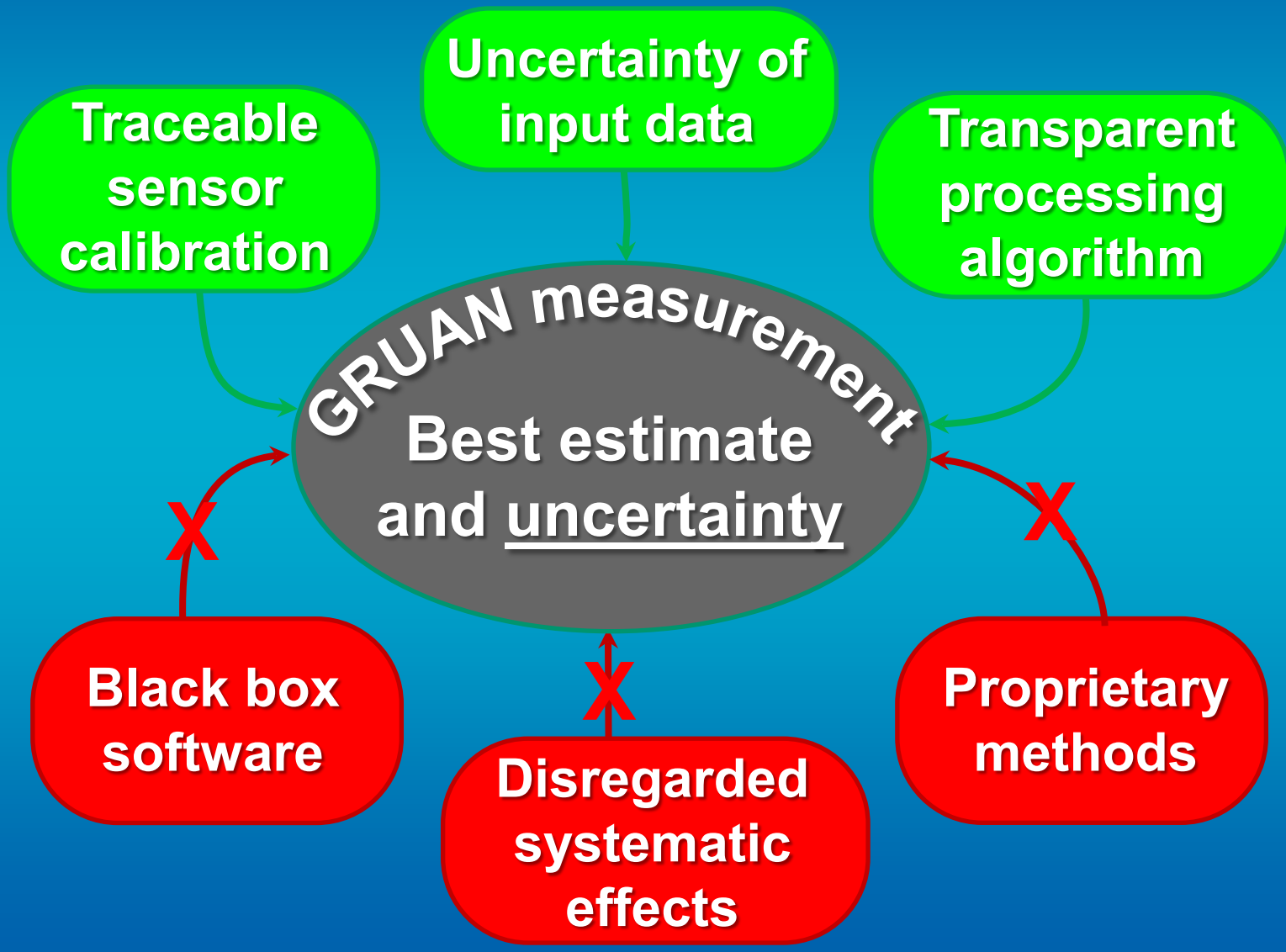
See www.gruan.org for further information

Reference Observation

A GRUAN reference observation:

- ✓ Is traceable to an SI unit or an accepted standard
- ✓ Provides a comprehensive uncertainty analysis
- ✓ Maintains all raw data
- ✓ Includes complete meta data description
- ✓ Is documented in accessible literature
- ✓ Is validated (e.g. by intercomparison or redundant observations)

Establishing reference quality



Establishing uncertainty

- Error is replaced by uncertainty
  - Important to distinguish contributions from systematic biases and random uncertainties.
- A measurement is described by a range of values
  - m is corrected for systematic biases
  - u is random uncertainty
  - generally expressed by $m \pm u$

Literature:

- Guide to the expression of uncertainty in measurement (GUM, 1980)
- Guide to Meteorological Instruments and Methods of Observation, WMO 2006, (CIMO Guide)
- Reference Quality Upper-Air Measurements: Guidance for developing GRUAN data products, Immler et al. (2010), Atmos. Meas. Techn.

Uncertainty, redundancy and consistency

- GRUAN stations should provide redundant measurements.
- Redundant measurements should be consistent i.e.

$$|m_1 - m_2| < k\sqrt{u_1^2 + u_2^2}$$

  - No meaningful consistency analysis possible without uncertainties.
  - if m_2 has no uncertainties use u_2 = 0 ("agreement within error bars").

$\lvert m_1 - m_2\rvert < k\sqrt{u_1^2 + u_2^2}$	True	False	Significance level
k=1	Consistent	Suspicious	32%
k=2	In agreement	Significantly different	4.5%
K=3	-	Inconsistent	0.27%

Uncertainty, redundancy and consistency

Understand the uncertainties:

- Describe/Analyze sources - identify, which sources of measurement uncertainty are systematic (calibration, radiation errors), and which are random (noise, production variability …). Document this.

Quantify/Synthesize best uncertainty estimate:

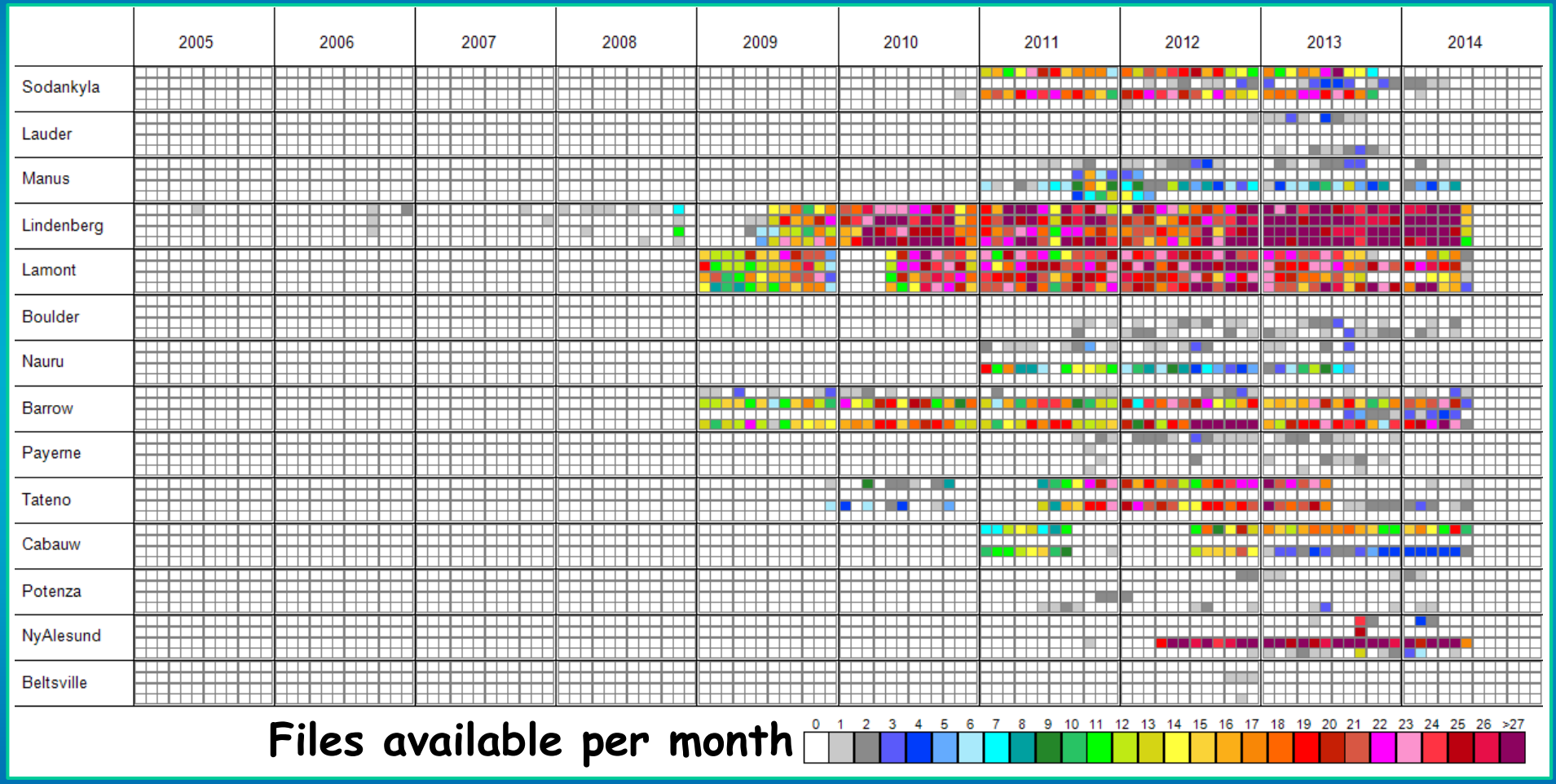
- Uncertainties for every data point, i.e. vertically resolved

Use redundant observations to verify that the evaluated net uncertainty is in agreement with the required target uncertainty. Also use redundant observations to:

- to manage change
- to maintain homogeneity of observations across network
- to continuously identify deficiencies

GRUAN RS92 radiosonde data availability

Currently the Vaisala RS92 radiosonde data product is the only GRUAN data product in routine production.



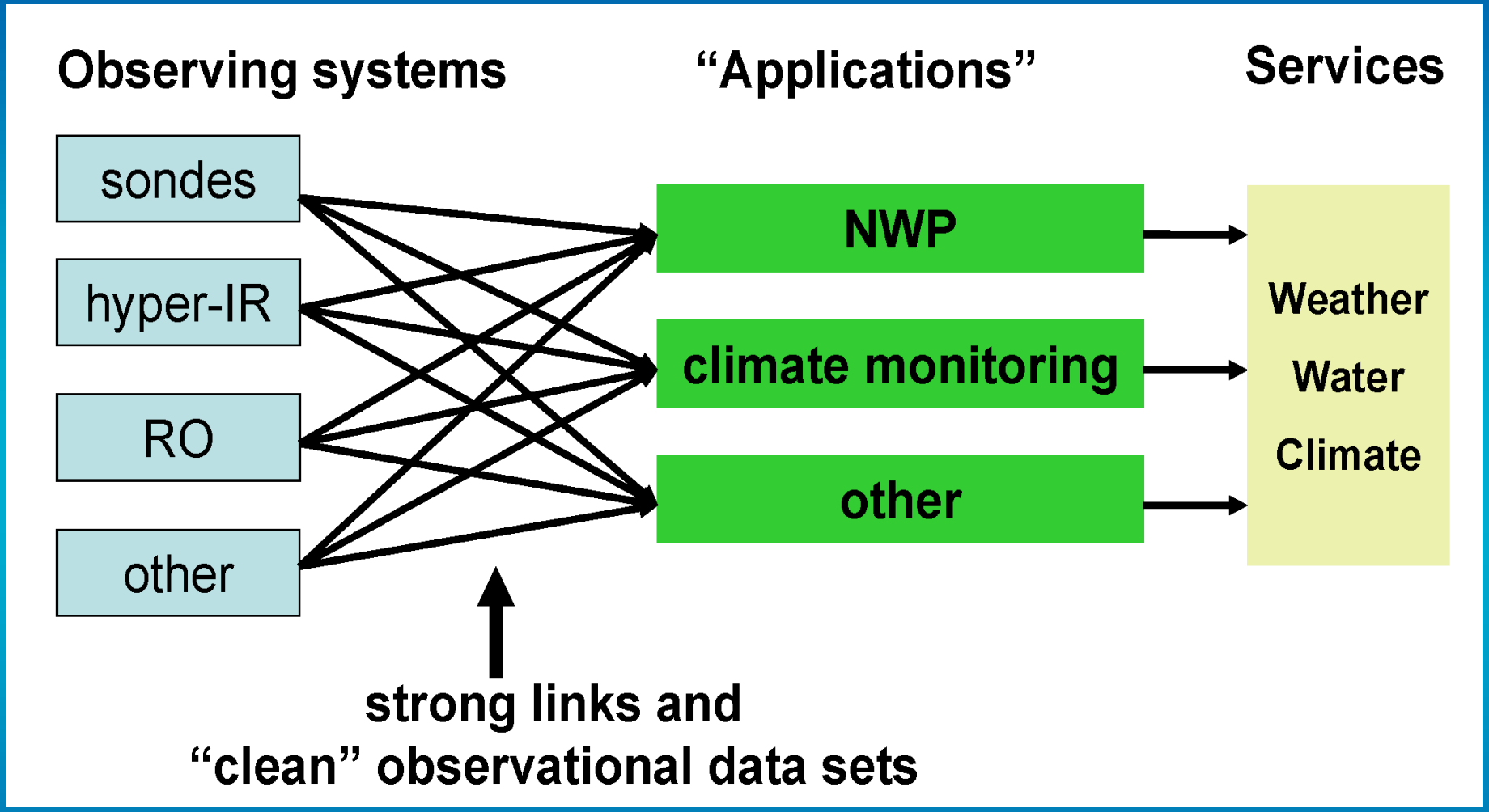
Additional products in development including non-RS92 radiosondes, GNSS-PW, FTIR, lidar, ozonesonde, microwave radiometer.

Research partners and links to the RO community

- GRUAN-GSICS-GNSSRO WIGOS Workshop on Upper-Air Observing System Integration and Application (Geneva, 6-8 May 2014). Objectives:
  - Identify measures to better connect GRUAN with the satellite community
  - Compare methods of measurement uncertainty estimation
  - Provide guidance for how the various observing systems and datasets can better serve meteorological and climate applications
  - Develop recommendations for future observing system design
- Workshop framed as a WIGOS "case study" in this regard; benefited from WIGOS Project Office funding
- Outputs: 20 recommendations at strategic and technical level. Workshop report:

  http://www.wmo.int/pages/prog/www/WIGOS-WIS/reports/3G-WIGOS-WS2014.pdf

Links between GRUAN and RO communities



"Integration" in the sense of the WMO Vision for 2015 means strong links between observing systems and application communities.

Links between GRUAN and RO communities

- GRUAN best practices in using uncertainty terminology have been circulated with other communities.
- Prediction tool for availability of RO profiles in space/time useful for dedicated observations/launches.
- Intercomparison of methods to estimate collocation uncertainties based on data from "3G", NWP fields, SASBEs over 4 GRUAN sites.
- Study has been commissioned on characterizing radiosonde temperature biases and errors using RO measurements and NWP background fields (EUMETSAT ROM SAF Visiting Scientist, Jordis Tradowsky).
- Use of RO data for in-flight calibration of Google Loon temperature measurements. Connection to Dan Bowen at Google.

Conclusions

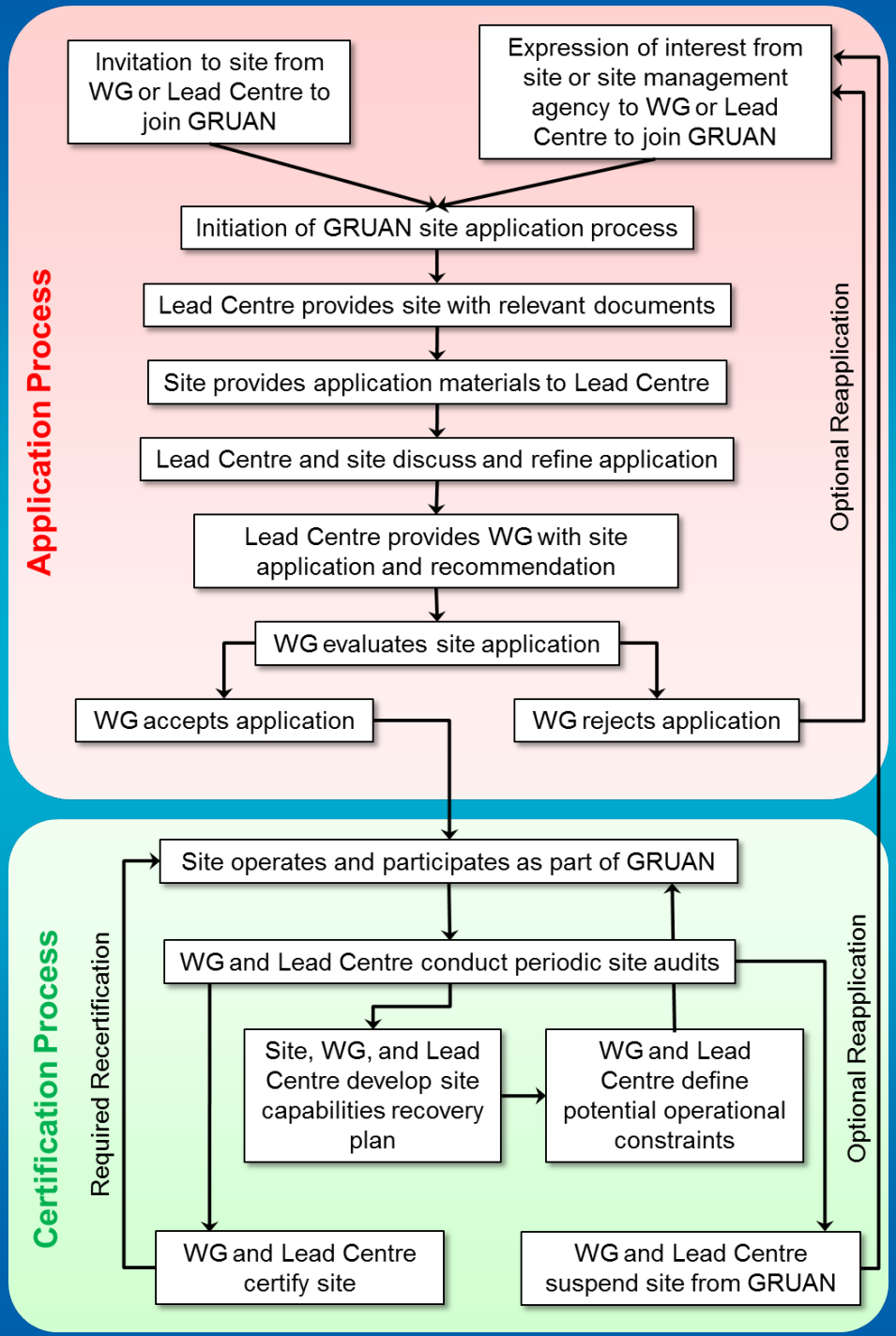
- GRUAN is a new approach to long term observations of upper air essential climate variables
- Focus on *reference* observations.
- Understand the uncertainties.
- Data are flowing and are being used. GRUAN data observations are already being compared with RO data.
- New data products are in development.
- New sites are being identified and are being invited to join GRUAN.
- Comprehensive implementation plan is in place.
- GRUAN Manual and Guide have been written.
- We need to work closely with the RO community to ensure that we are following best practice and to identify co-benefits.

GCOS Climate Monitoring Principles

- Impact of new systems or changes to existing systems should be assessed prior to implementation.
- Importance of collecting and archiving meta data.
- Quality and homogeneity of data should be regularly assessed.
- Operation of historically-uninterrupted stations and observing systems should be maintained.
- Good geographical coverage especially in regions where changes are occurring or are expected to occur.
- Long-term requirements should be specified to network designers, operators and instrument engineers at the outset of system design and implementation.
- Suitable period of overlap for new and old systems should be ensured to determine inter-system biases.

The importance of monitoring for the long term

- The atmosphere has never been in steady state.
- Our knowledge of the system is incomplete.
  - We do not fully understand the impacts of what we may do (e.g. CFCs).
  - We do not fully understand how different aspects of the system may co-vary, particularly locally/regionally.
- Unless we monitor, analyze, reanalyze and question on a sustained basis there are risks. Therefore it is not sufficient solely to fund observations.
  - Failure of the discovery of the ozone hole due to automated screening of incoming data.
- As anthropogenic climate change effects increase the economic implications will increase.
  - Providing the best adaptation and mitigation advice is compromised if the observational basis is too uncertain



Site assessment and certification

- Quality of GRUAN sites assured through rigorous site assessment and certification process.
- GRUAN more than a collection of measurements made at individual sites → benefit accrues from homogeneity across the network.
- Shortfall in maintaining quality at one site reduces users' confidence in measurements made across the network.