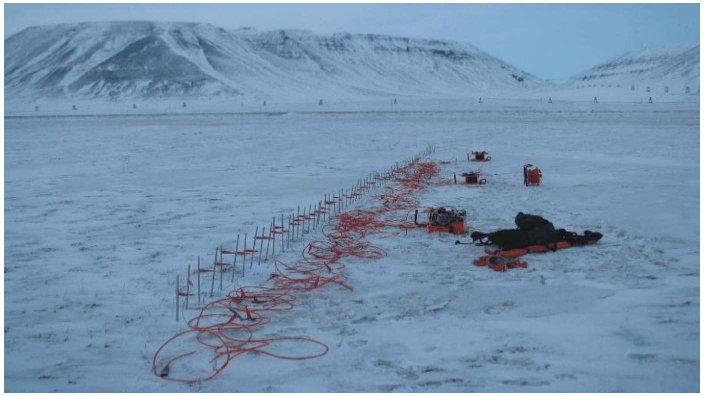
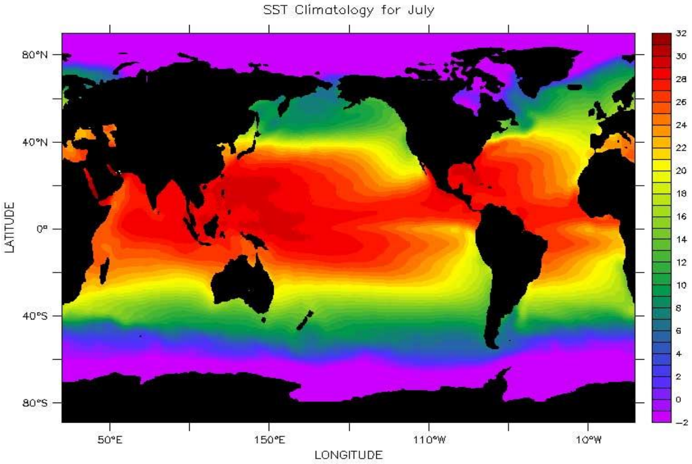
THERMAL METROLOGY FOR METEOROLOGY AND CLIMATE

Andrea Merlone

Temperature and humidity measurements of air, deep ocean and sea surface, ice and permafrost soil, together with the determination of their thermophysical properties are needed as input to numerical weather prediction models, for hydrological and agricultural purposes and as indicator of the climatic variability.

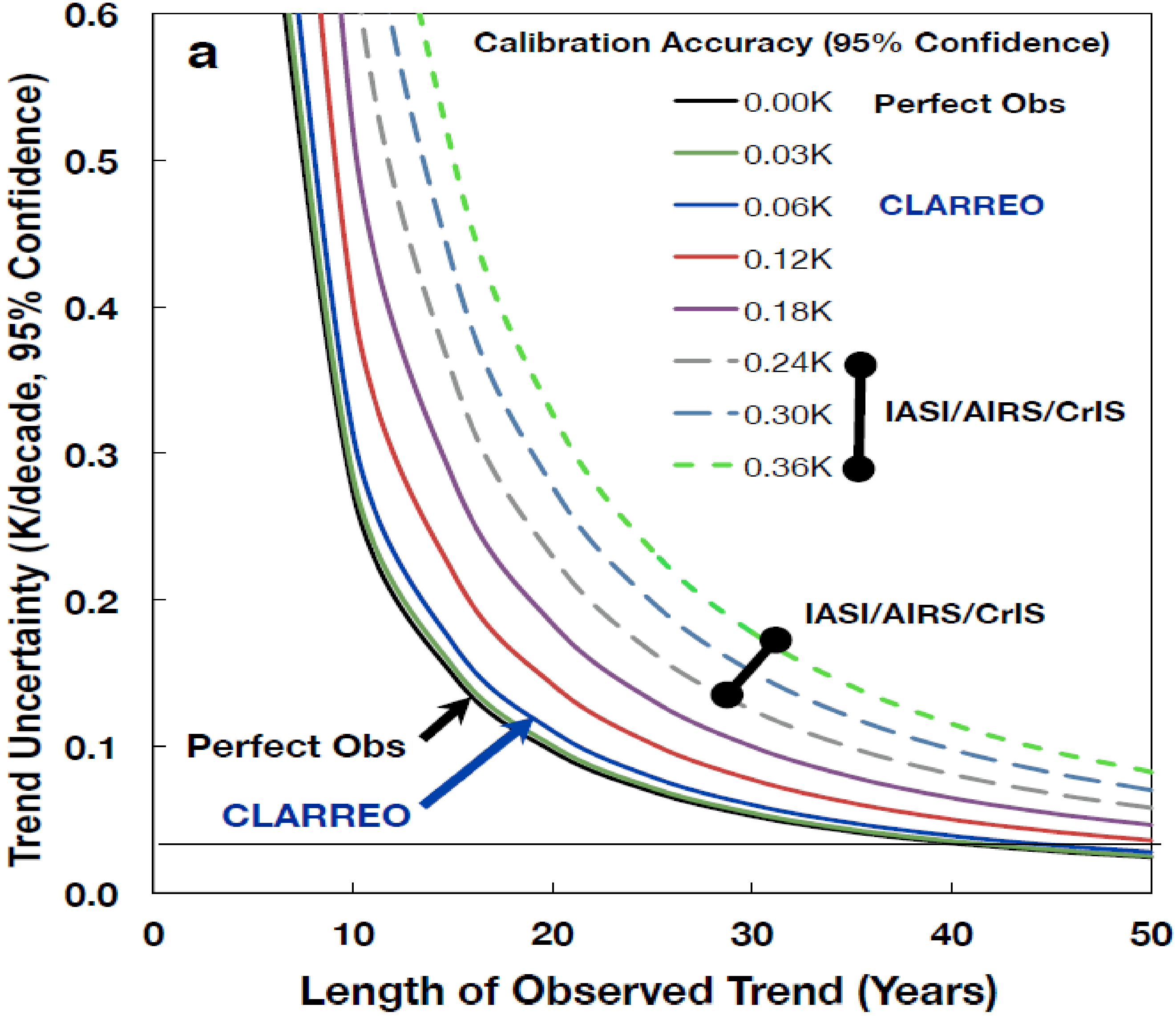




Date file from National Meteorological Center and the Optimal Interpolation based on both satellite observations and ship and buoy observations

Time Sep. 4, 1997

Accurate Measurements Reduce the Time Necessary to Capture a Trend



Wielicki et al. 2

GCOS

GLOBAL CLIMATE OBSERVING SYSTEM

WMO IOC UNEP ICSU International Council for Science

WORLD METEOROLOGICAL ORGANIZATION

INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION

GCOS is intended to be a long-term, user-driven operational system capable of providing the comprehensive observations required for:

- **Monitoring the climate system,**
- **Detecting and attributing climate change,**
- **Assessing impacts of, and supporting adaptation to, climate variability and change,**
- **Improving understanding, modelling and prediction of the climate system.**

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OCEANOGRAPHIC COMMISSION

GCOS Defines 50 Essential Climate Variables

All ECVs are technically and economically feasible for systematic observation.

It is these variables for which international exchange is required for both current and historical observations.

Domain	GCOS Essential Climate Variables
Atmospheric (over land, sea and ice)	**Surface:** Air temperature, Wind speed and direction, Water vapour, Pressure, Precipitation, Surface radiation budget. **Upper-air:** Temperature, Wind speed and direction, Water vapour, Cloud properties, Earth radiation budget (including solar irradiance). **Composition:** Carbon dioxide, Methane, and other long-lived greenhouse gases[3], Ozone and Aerosol, supported by their precursors[4].
Oceanic	**Surface:** Sea-surface temperature, Sea-surface salinity, Sea level, Sea state, Sea ice, Surface current, Ocean colour, Carbon dioxide partial pressure, Ocean acidity, Phytoplankton. **Sub-surface:** Temperature, Salinity, Current, Nutrients, Carbon dioxide partial pressure, Ocean acidity, Oxygen, Tracers.
Terrestrial	River discharge, Water use, Groundwater, Lakes, Snow cover, Glaciers and ice caps, Ice sheets, Permafrost, Albedo, Land cover (including vegetation type), Fraction of absorbed photosynthetically active radiation (FAPAR), Leaf area index (LAI), Above-ground biomass, Soil carbon, Fire disturbance, Soil moisture.

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GCOS Defines 50 Essential Climate Variables

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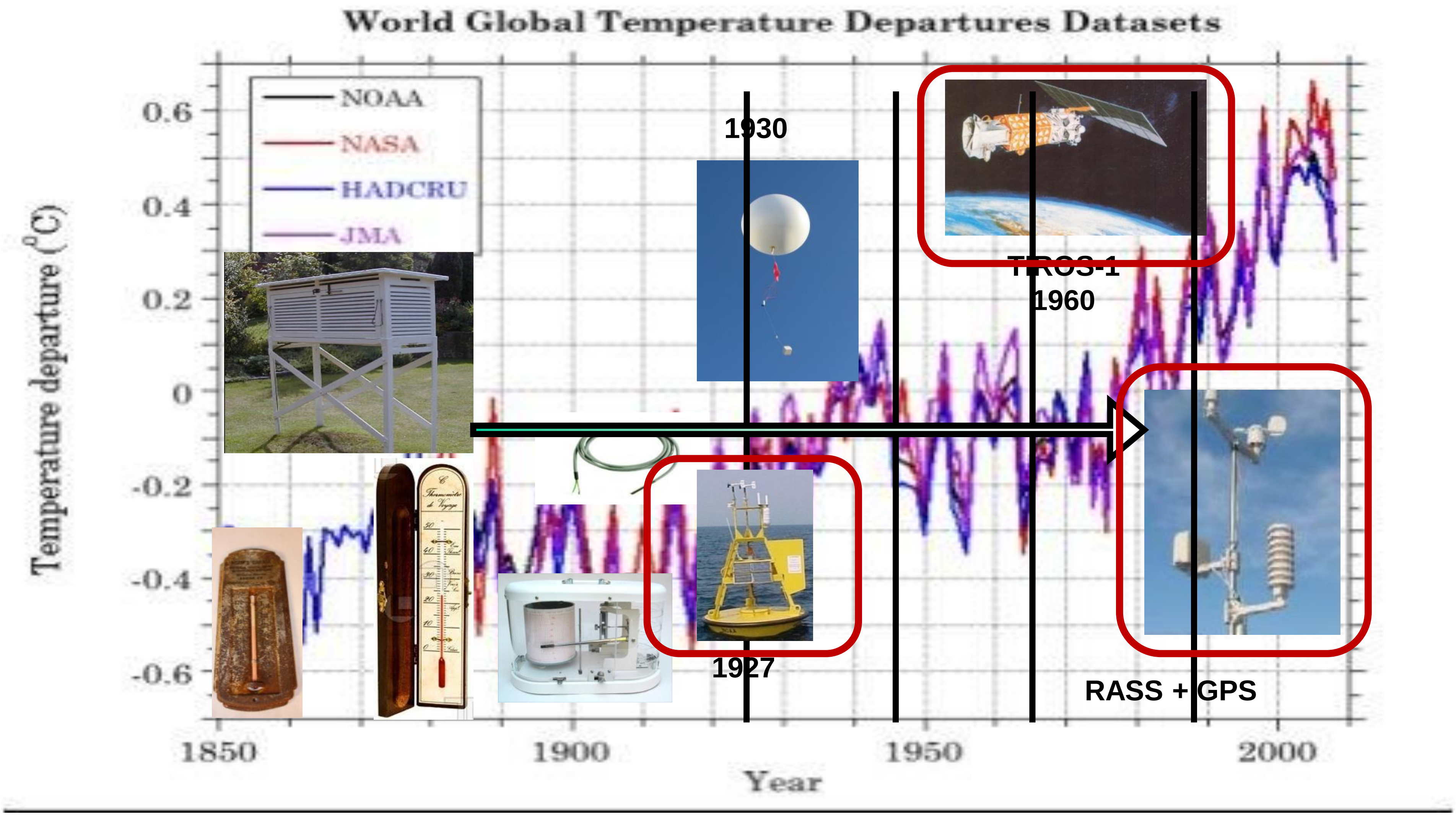
Observation is based on **measurement** results.

Reliable measurement must be based on **traceability** and a consistent measurement **uncertainty** calculation, which needs a complete knowledge of the measurement system, starting with its intrinsic behavior, including the instrument characteristics and **calibration**, the influence of different quantities and parameters, including the state of the place.

A key example:

Historic Earth air temperature records are almost universally used as the basis for climate trend analysis.

Do homogenization processes, algorithms and software take into account type B uncertainties on measurements or at least the instrumental uncertainties achievable over the years?


World Global Temperature Departures Datasets
NOAA
NASA
HADCRU
JMA
Temperature departure (^{0}C)
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
1930
TIROS-1
1960
1927
RASS + GPS
1850
1900
1950
2000
Year

International Surface Temperature Initiative

The International Surface Temperature Initiative was instigated in 2010, to create a suite of new and more scientifically robust estimates of surface temperature changes and variability from meteorological stations around the globe. The initiative borrows heavily from metrological best practices in formulating the framework for advancing its work.

ISTI is a massive scientific challenge that requires international collaboration.

ISTI and the thermal metrology community are collaborating since 2011 and, beside historical series, MeteoMet provided software for including the change in the scales along the year in historical data and is working to approximate the evaluation of type B instrumental uncertainties from metadata, where available.

Measurements have been made by instruments on the surface since around 1850. All meteorological measurements until about the 1970s originated from manual instruments such as Stevenson screens and liquid-in-glass thermometers.

Errors originate from how the instruments are operated, exposed, maintained and calibrated.

These factors have the potential to give a misleading indication of climate but the evaluation of the associated uncertainty is far from simple.

Open issues and research opportunities

Siting

The CIMO-XV/Doc. 4 establishes a classification to help determine the ground based observation site's representativeness on a small scale. This classification associates a discrete uncertainty value/level to temperature measurements carried out in sites where exposure rules are not fully met.

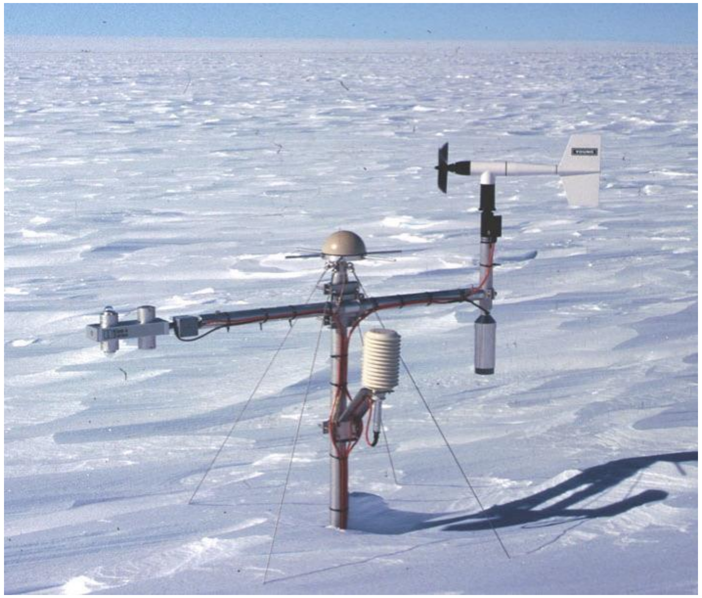
Thermal metrology studies are needed to evaluate quantitatively uncertainty for some of the influences of some siting parameters on temperature measurements (closeness to trees, buildings, and asphalt roads).

The metrological assessment of these in field tests and uncertainty evaluation methods will allow obtaining more robust and comparable data.

Albedo effect on temperature data

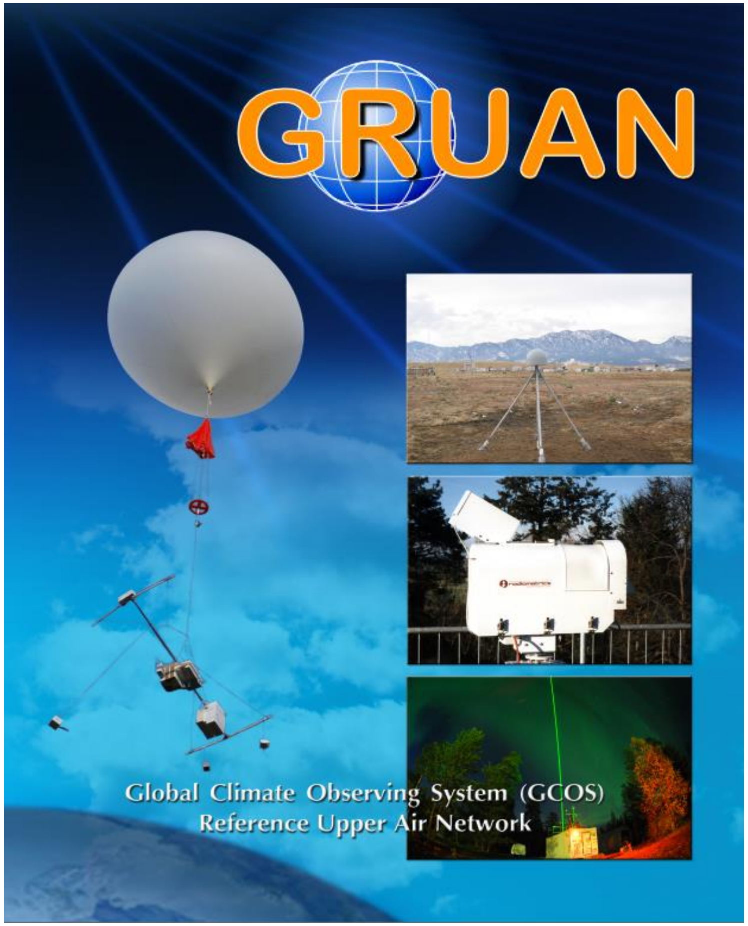
Up to now, the influence of the albedo on air temperature measurements using AWSs in high mountain sites has not been measured following metrology considerations, thus evaluation correction curves and/or uncertainty components to the air temperature data.

This influence needs to be studied by performing traceable measurements of the albedo and determining reliable uncertainty calculations.



Upper air

The Working Group on the GCOS Reference Upper Air Network (GRUAN) was established in recognition of the importance of initiating reference-quality observations of atmospheric column properties, in particular temperature and water vapor, from the surface into the stratosphere to enhance the monitoring and understanding of climate variability and change



The GRUAN WG hosts two metrologists and since 2011 is working to fully adopt the GUM in its guides and manual.

2012 – March 5-9
Tokyo - Japan

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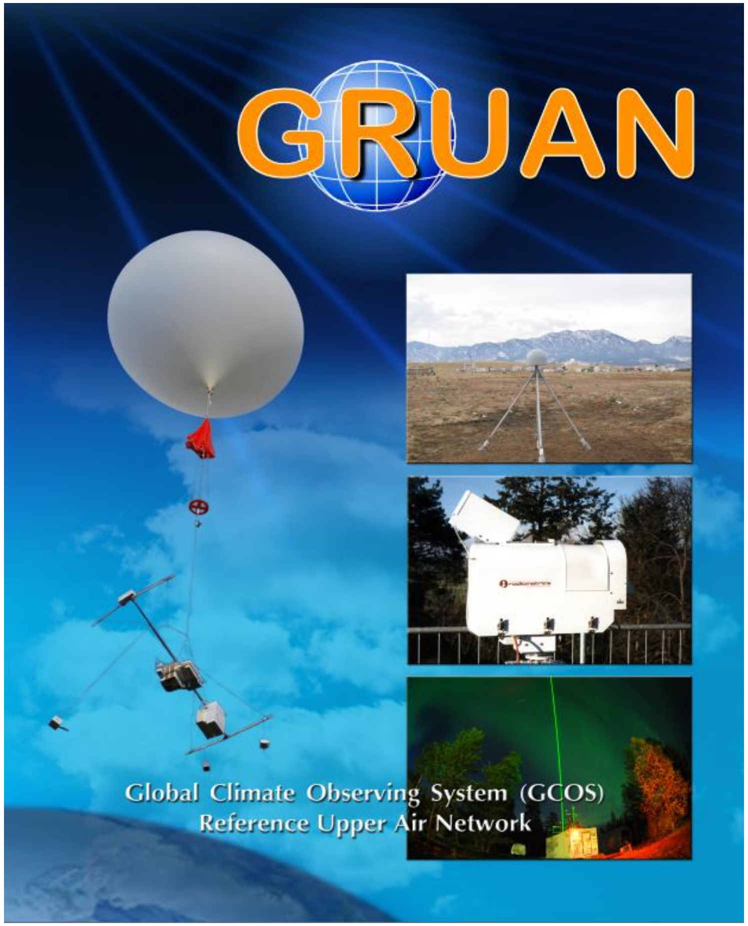


A long lasting cooperation is being established aiming at fully define uncertainty components in atmospheric temperature and humidity profiles, together with improved instruments calibration procedures.

Humidity…

A wide measurement range with a factor of more than 10 000 **from tropical conditions at sea level to upper air below -80 ° C and 1 kPa sets a challenge for the reliability of the measurements, in the extensive meteorological sensor networks and for long time series . Calibration procedures must guarantee full traceability all over the range, starting from the ppm.**

Moreover, reliable measurements of atmospheric humidity require **sensitive** and **fast response** time sensors able to quantify continuous and dynamic changes.

From the GRUAN Guide:
Standard radiosonde humidity sensors have generally a very poor response at the low temperatures (<-50 ºC), pressures, and water vapour concentrations of the UT/LS. No operational radiosonde can be expected to measure with sufficient accuracy in the lower stratosphere for climatological purposes.

Knowledge about the enhancement factor is essential for the correction of the water vapour pressure for humidity calculations. The enhancement factor for water in air above 0 ºC are well known, but further experimental data to ensure the theoretical models for the enhancement factor below 0 ºC are necessary

…and moisture

Soil moisture measurements are essential to understanding water vapour interchange between land and air (heat and mass transfer) affecting fields of meteorology, earth observation, hydrology, agriculture and management of flood risk.

Soil moisture instruments are diverse: some affected by variations in soil composition, especially the presence of salts, and have limited discrimination between surface water and depth profile (calibrations even less so).

Research is needed to develop new proposals for valid calibration approaches and methods to quantify the uncertainty of soil moisture measurements.

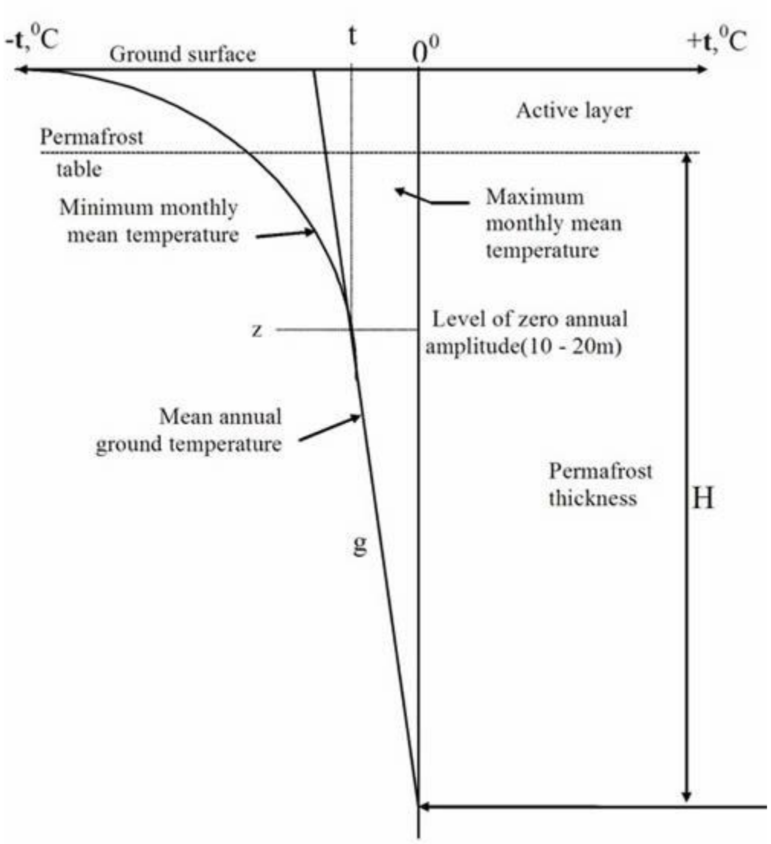
Permafrost

- Permafrost thermal data is a key component for validating hydroclimatic models, land surface models, and climatic change models.
- Permafrost is among the few measurable **paleo-climatic** elements.
- The boreholes drilled in the permafrost soil need to be equipped with thermal probes to permanently measure temperature at different depths along the well with measurements uncertainty better of 0.05 ºC and less close to the surface layer.

.

Permafrost

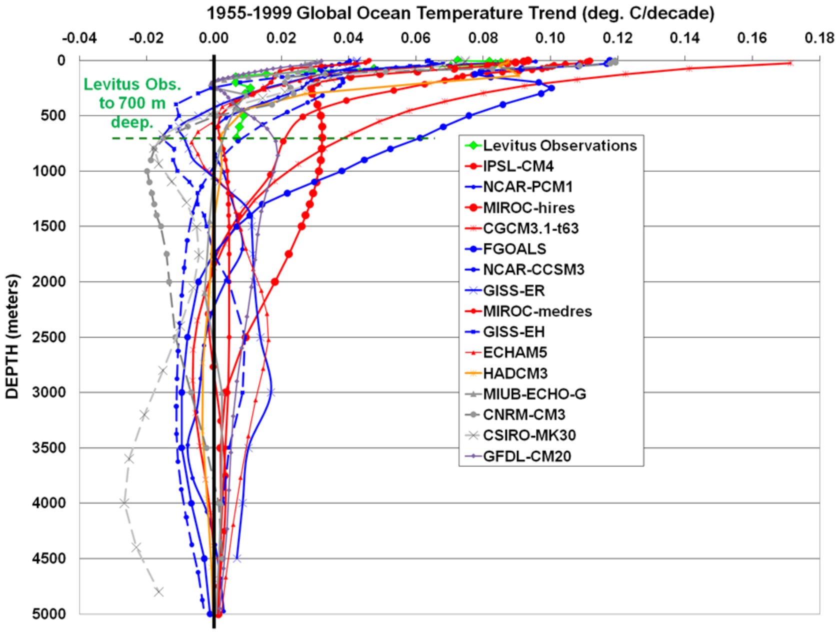
- Acquisition accuracy needs to remain stable especially in the range closely above-below 0 ºC to evaluate thermal cycle occurrence and frequency.
- Periodic recalibration of temperature probes is required possibly on the field.
- Quantify effects of unfrozen water near melting/freezing temperature.
- Buried thermometers or in pipe thermometers procedures both need careful measurement uncertainty evaluation.



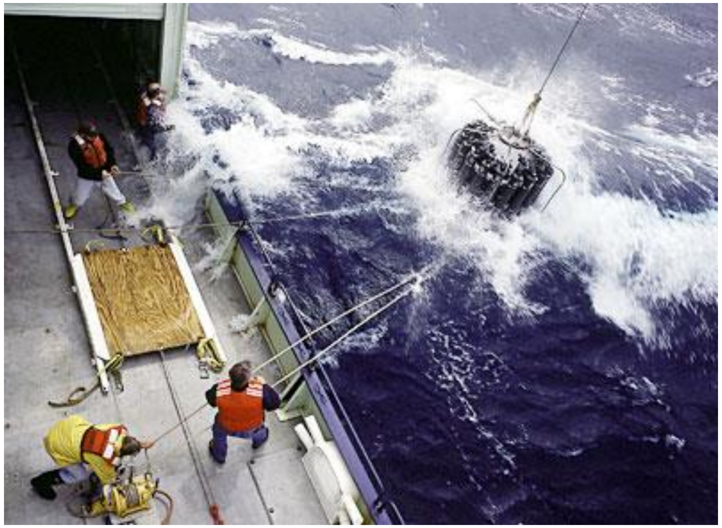
Sea temperature

The target uncertainty set by the World Ocean Circulation Experiment (WOCE) Hydrographic Program (WHP) on deep ocean temperature measurements is 2 mK, since recent studies have reported an increase of 5 mK per decade in the North Pacific Ocean.

However, deep-ocean *in situ* temperature measurements may suffer of larger uncertainties, especially because of the effect of water pressure on thermometers, which may introduce deviations of several millikelvins at pressures up to 60 MPa.



Sea temperature



In addition, considering that the most widespread deep-ocean thermometers are based on thermistors, there is a need of **metrological validation of the temperature-resistance linearization equation** adopted – especially on high-grade deep-sea reference thermometers. The only laboratories able to reach such uncertainty levels are NMIs.

Another key issue in thermodynamic models of the oceans is the measurement of **absolute salinity** of seawater. The recent definition of the Thermodynamic Equation of Seawater TEOS-10 focuses on the absolute salinity assessment.

To make the development progressing and to perform accurate metrological characterization, the study of the effect of water pressure and temperature on refractive-index absolute salinometers is needed.

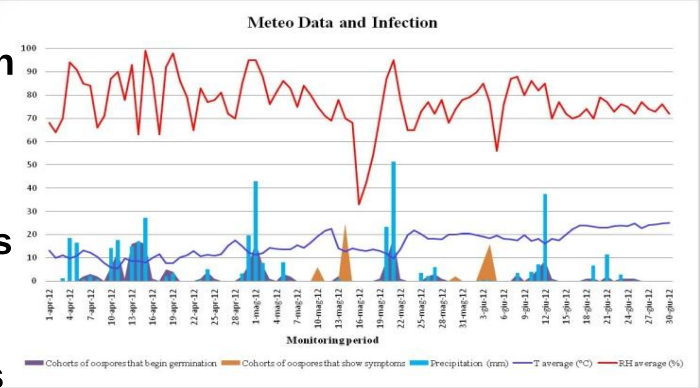
Emerging needs in agricolture and food production

High quality traceable data of meteorological parameters are necessary for more accurate estimation, forecasting and decision support system on treatment planning.

Accurate measurement of soil moisture and soil temperature to better support irrigation

Measurement of air temperature, air relative humidity, precipitation for plant management disease. Uncertainty evaluation improves decision on treatment plans.

Measurement of solar radiation as influence on the productivity and quality of plant growth and final product. Accurate measurements for deciding cultivar areas and studies on green houses materials


Meteo Data and Infection

Meteorological data as input values in forecasting model for plant infection. Accuracy = economy

Establishing a methodology for the characterization of the temperature and humidity in underground wine cellars

GOBIERNO DE ESPAÑA

MINISTERIO DE DEFENSA

INTA

VSL, 13th March 2014

Instrument comparison protocols

CEM INTA

GOBIERNO DE ESPAÑA

MINISTERIO DE AGRICULTURA, ALIMENTACIÓN Y MEDIO AMBIENTE

AEMet Agencia Estatal de Meteorología

INRiM ISTITUTO NAZIONALE DI RICERCA METROLOGICA

b.1. Calibration of *T* & *H.R*. sensors in liquid stirred baths (in progress).

b.2. Calibration of *p* sensors (in progress)

Characterization the CEM climate chamber (already done)
***V* = 335 l, control of *T* and *H.R*.**
***T* : (10, 95) ºC, *H.R.* (10, 98)%**

b.3. Calibration of *p*, *T* & *H.R*. sensors in the climate chamber

b.4. Calibration of T&H sensors with the radiation shield in climate chamber

b.5. Calibration of the set sensor + radiation shield + data logger in climate chamber

VAISALA

Lufft a passion for precision

Thies CLIMA

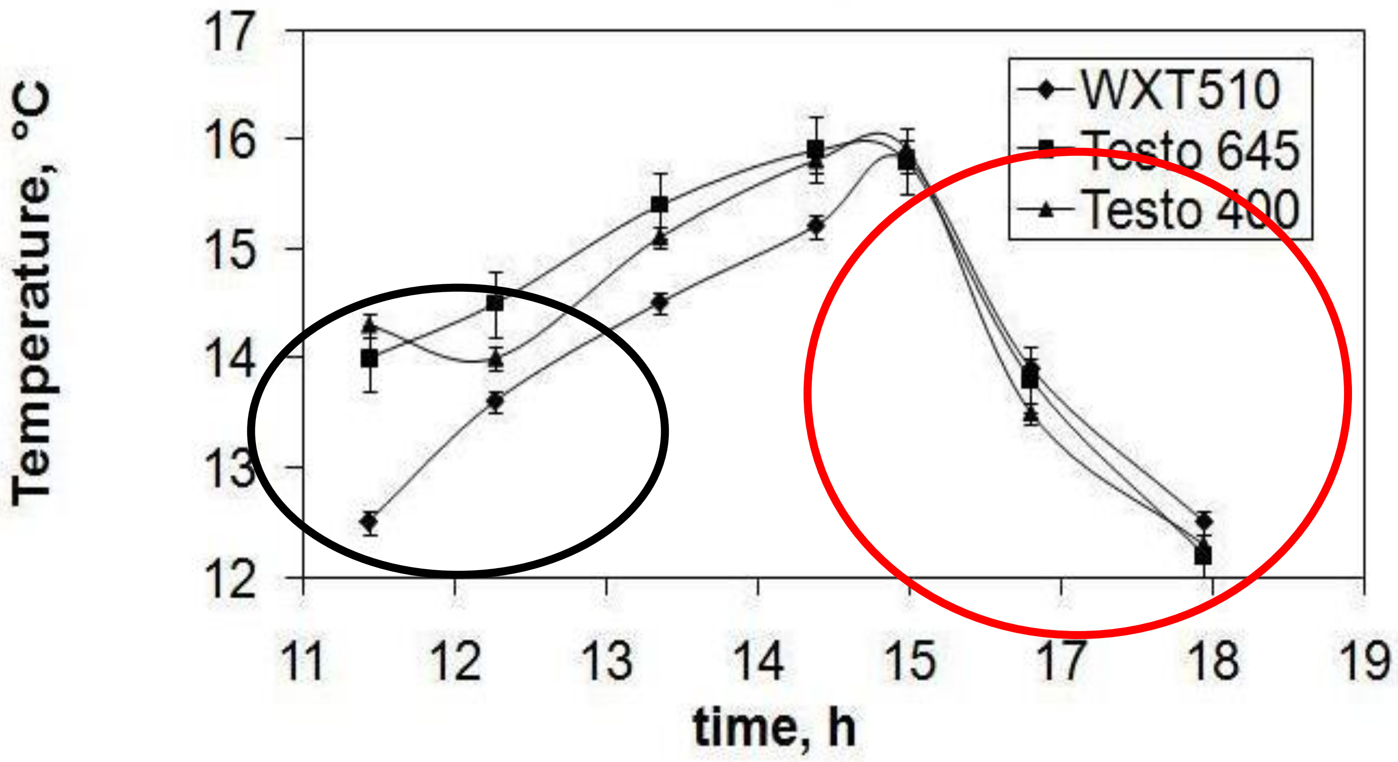
seac

rotronic MEASUREMENT SOLUTIONS

setra SENSING SOLUTIONS

CAE

Instrument comparison protocols



World Meteorological Organization
Working together in weather, climate and water

MRA

BIPM

Michel Jarraud, Secretary General of the WMO, signed the Arrangement on behalf of the WMO. The signing ceremony took place on *1 April 2010*

Left to right: Len Barrie (WMO), Andrew Wallard (Director BIPM), Michel Jarraud (Secretary General WMO), Ernst Göbel (President CIPM), Wenjie Zhang (WMO)

WMO CIMO says:

World Meteorological Organization
Working together in weather, climate and water

There is a Critical and Urgent Need for:

- **Improved Traceability**
- **Reduced Uncertainty**

To achieve greater confidence in climate change analyses and predictions.

The thermal metrology community can address these needs through several key initiatives, most of which are common to CIMO's mission.

2010 May 4-7.
XXV Comité Consultatif de Thermométrie (CCT) meets and prepares a significant reccomendations for the CIPM.

CCT-WG2 New Terms of reference

European Association of National Metrology Institutes

EURAMET
2020 Strategy

Issued: 15-09-2011
Version: 1

Maximum impact can be achieved if the research agendas are used to target long-term objectives.

…to enable and stimulate related investments in facilities and equipment…

…and pooling of metrological resources across national boundaries to tackle key societal challenges.

EMRP 2009 – 2013 calls schedule

2009	Energy	projects running
2010	**Environment**	projects ending
	Metrology for Industry	
2011	Health	projects running
	SI broader scope	
	New Technologies	
2012	Metrology for Industry	projects running
	SI broader scope	
	Open excellence call	
2013	Energy	projects negotiating
	Environment	

MeteoMet 2011 – 2014

MeteoMet2 2014 - 2017

The EMPIR committee supports means to facilitate long-term, large-scale approaches exploiting the unique opportunities under EMPIR.

EMPIR new ENV calls planned for

2016 …

2019…

EURAMET

European Association of National Metrology Institutes

EURAMET
2020 Strategy

Issued: 15-09-2011
Version: 1

Maximum impact can be achieved if the research agendas are used to target long-term objectives.

…to enable and stimulate related investments in facilities and equipment…

…and pooling of metrological resources across national boundaries to tackle key societal challenges.

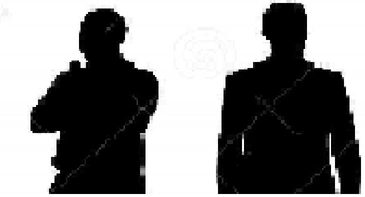
2014
EURAMET starts the new Task Group on Environment

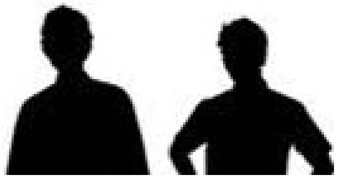
EURAMET TG-ENV members come from involved TCs and the stakeholders communities

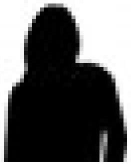
TC-MC
Metrology in Chemistry
EURAMET Technical Committee

TC-IR
Ionising Radiation
EURAMET Technical Committee

TC-PR
Photometry and Radiometry
EURAMET Technical Committee



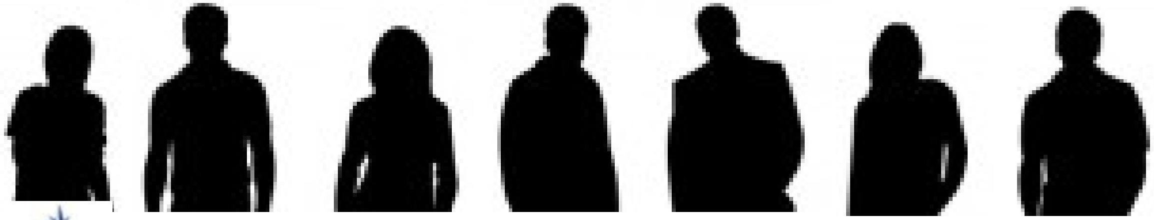




TC-T
Thermometry
EURAMET Technical Committee

TC-AUV
Acoustics, Ultrasound and Vibration
EURAMET Technical Committee

TC-F
Flow
EURAMET Technical Committee



World Meteorological Organization

GAW

APMP

GCOS
GLOBAL CLIMATE OBSERVING SYSTEM

IAPWS

GRUAN

Metrology for Meteorology and Climate international workshop - MMC 2014

15-18 September 2014 – Brdo – Slovenia.

Scientific committee

MMC Slovenija 2014

METROLOGY FOR METEOROLOGY AND CLIMATE

Stephanie Bell (NPL, Great Briitain), CCT-WG6 Chair

Rainer Feistel (IAPWS, Germany)

Carmen Garcia Izquierdo (CEM, Spain)

Drago Groselj (WMO-CIMO, ARSO, Slovenia)

Martti Heinonen (MIKES, Finland)

Rodica Nitu (WMO-CIMO, Canada)

Susanne Picard (BIPM, Sèvres)

Michela Sega (TC-MC Chair person – Italy)

Fernando Sparasci (CNAM, France)

Peter Thorne, GRUAN Chairperson

Yong-Gyoo Kim (KRISS, Korea), APMP TCT chair

Davor Zvizdić (IMEKO TC12 chair, HMI-FSB, Croatia)

TC-T Thermometry EURAMET Technical Committee

International Surface Temperature Initiative

World Meteorological Organization

IAPWS

GCOS

GRUAN

IMEKO TC12

APMP

Open issues and research opportunities

Open issues and research opportunities

AIR. (GRUAN-oriented activities)

- **Improving the representativeness of radiosonde calibrations to actual measurement conditions, including boundary conditions**
- **Enhancement factor up to stratospheric range**
- **Requirements for airborne traceability of humidity measurements**
- **Metrology for fast changing quantities in upper air – sensors dynamics**
- **Uncertainty for air temperature measurements evaluation (u < 0.1 K)**

Water

- **Quantities of influence on deep-sea sensors**
- **Thermodynamic characterization of oceanographic reference thermometers**
- **Characterisation of deep-sea thermometers**
- **Buoys and fibre optics**
- **Target uncertainty for deep see temperature records u < 2mK**

Open issues and research opportunities

Land

- **Metrological requirements for traceable measurements of soil moisture**
- **Air temperature sensors characteristics**
- **Comparison protocols**
- **Air humidity sensors characteristics**
- **High mountains observations: albedo as uncertainty component**
- **Siting related uncertainty**
- **Uncertainty for air temperature measurements evaluation (u < 0.1 K)**
- **Permafrost temperature measurements (u ~ 0.01 K) and procedures**
- **Novel in field calibration devices (TDLAS – CRDS – Permafrost chain)**

Link with other tecniques different from thermal metrology Liaisons with other TCs – CCs -… Start multidisciplinary projects

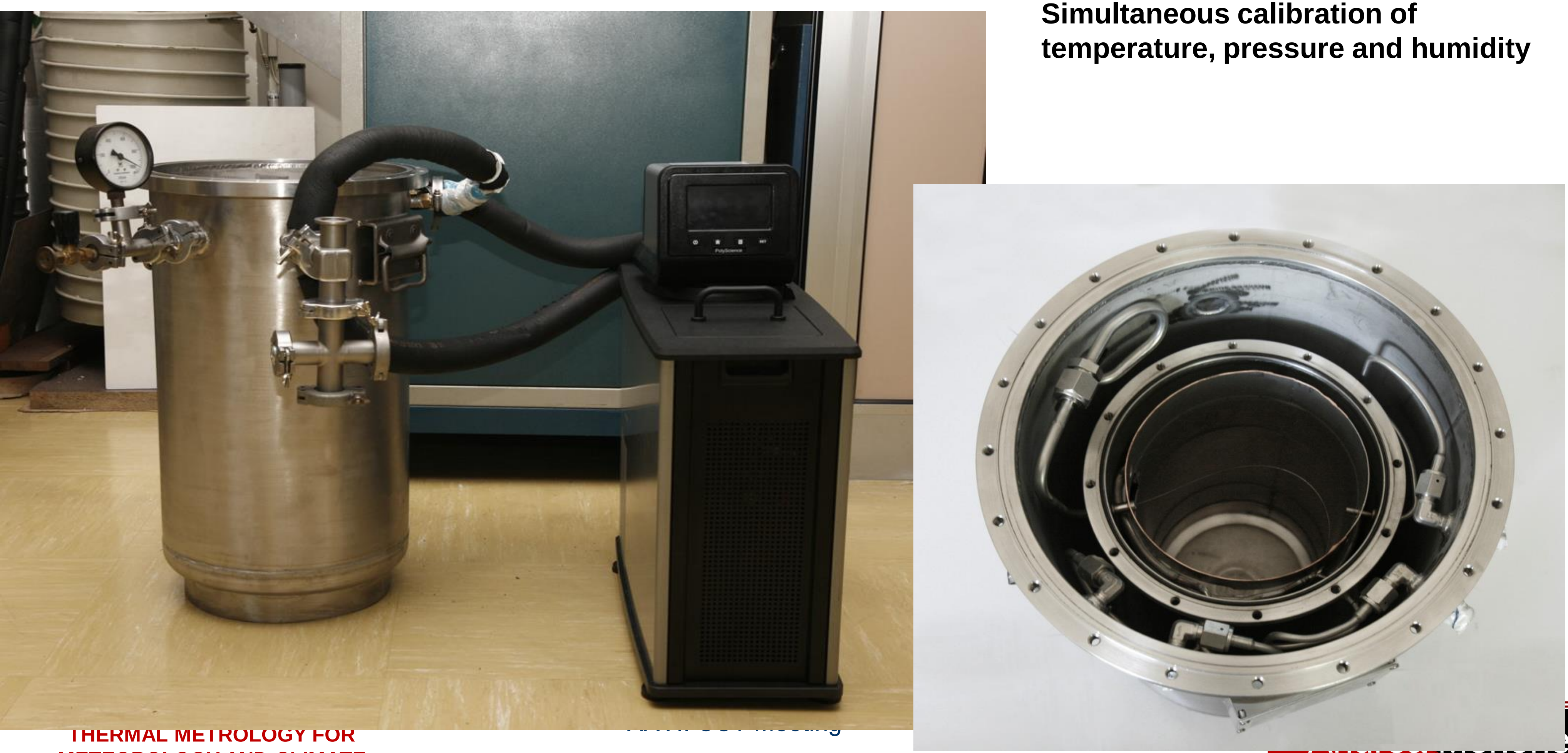
- Environmental sciences
- Food production
- Temperature as a quantity of influence in air quality measuring station (chemistry TC-MC - CCQM)
- New EURAMET TG on environment
- Radiometry and thermal metrology
- Salinity measurements and electrical and chemical metrology
- Networking techniques
- Joint projects for implementing single sites calibration laboratories for multiple quantities. Also for remote areas (i.e. Everest Pyramid, Ny Alesund – Svalbard, South Pole…)

Task 3.5

The New portable facility carried out at INRiM

EDIE-1

Simultaneous calibration of temperature, pressure and humidity




METEOMET
Metrology for Meteorology

EvK2CNR

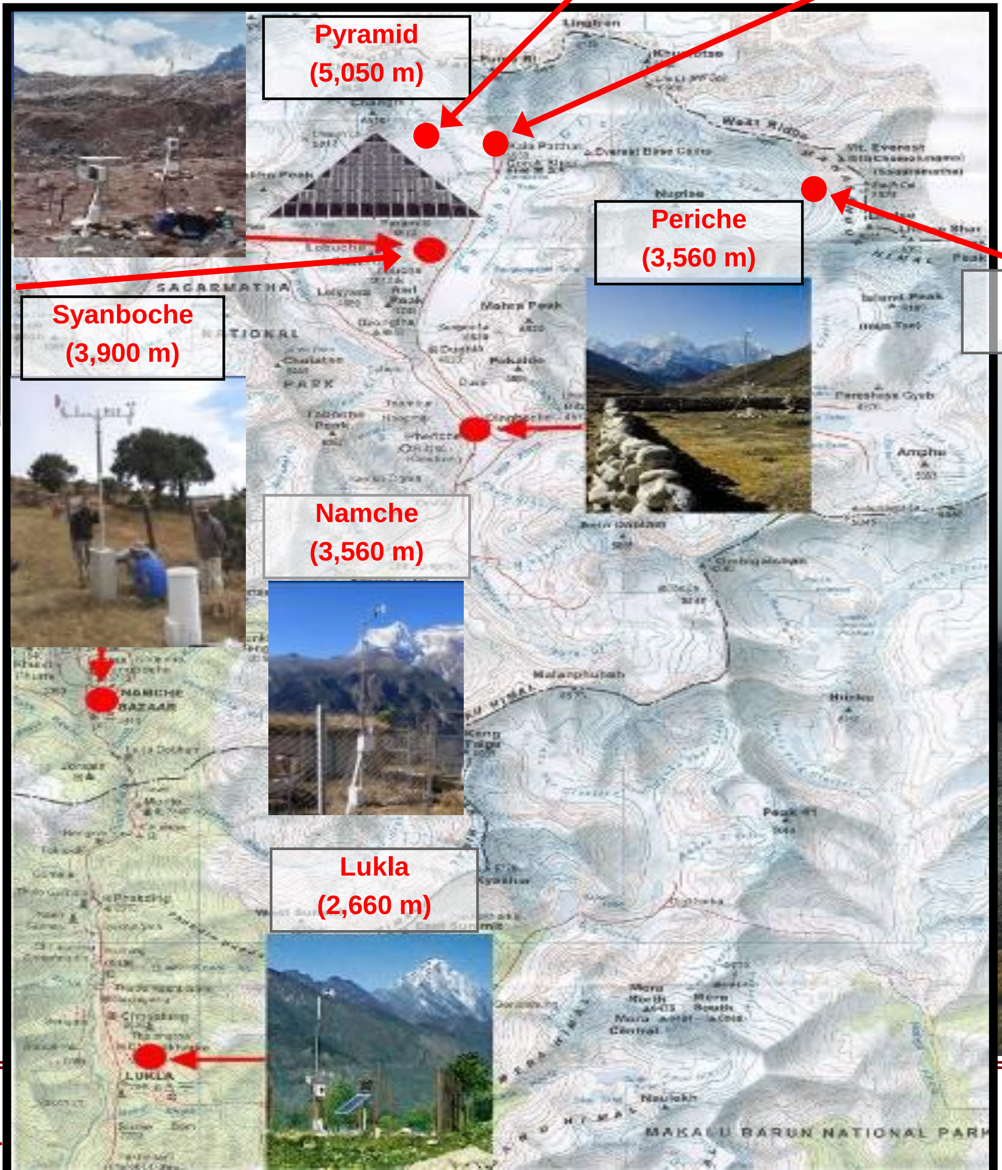
SHARE
Stations at High Altitude for Research on the Environment

METEOMET
Metrology for Meteorology

Changri Nup
(5,750 m)

Kala Patthar
(5,550 m)

NCOP-P
(5,079 m)



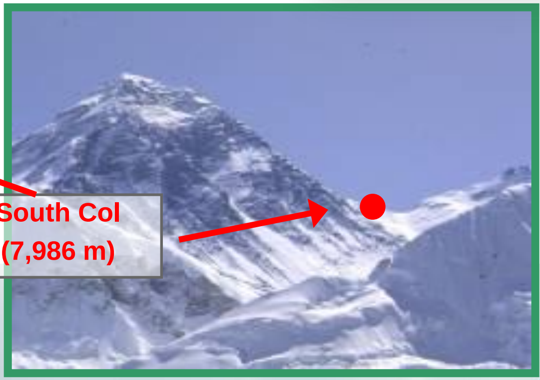
Pyramid
(5,050 m)

Syanboche
(3,900 m)

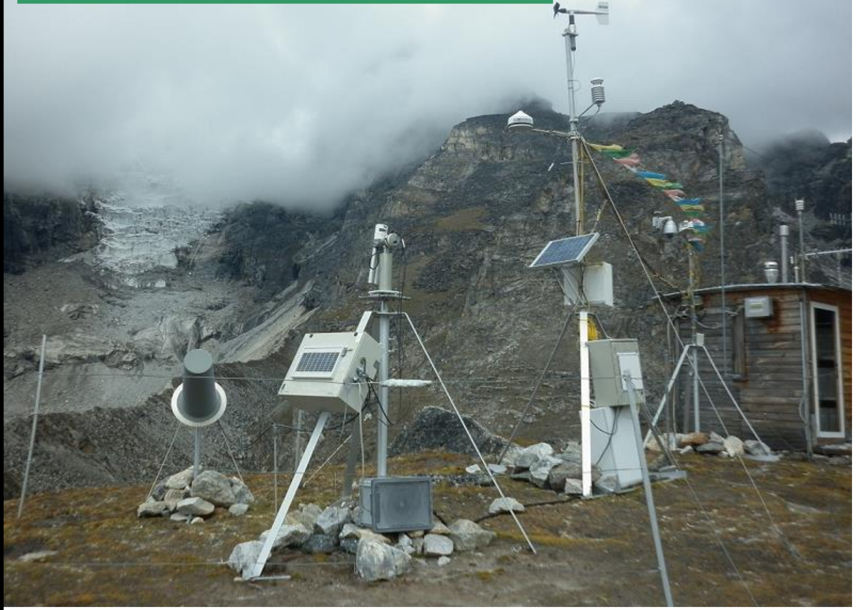
Periche
(3,560 m)

Namche
(3,560 m)

Lukla
(2,660 m)



South Col
(7,986 m)



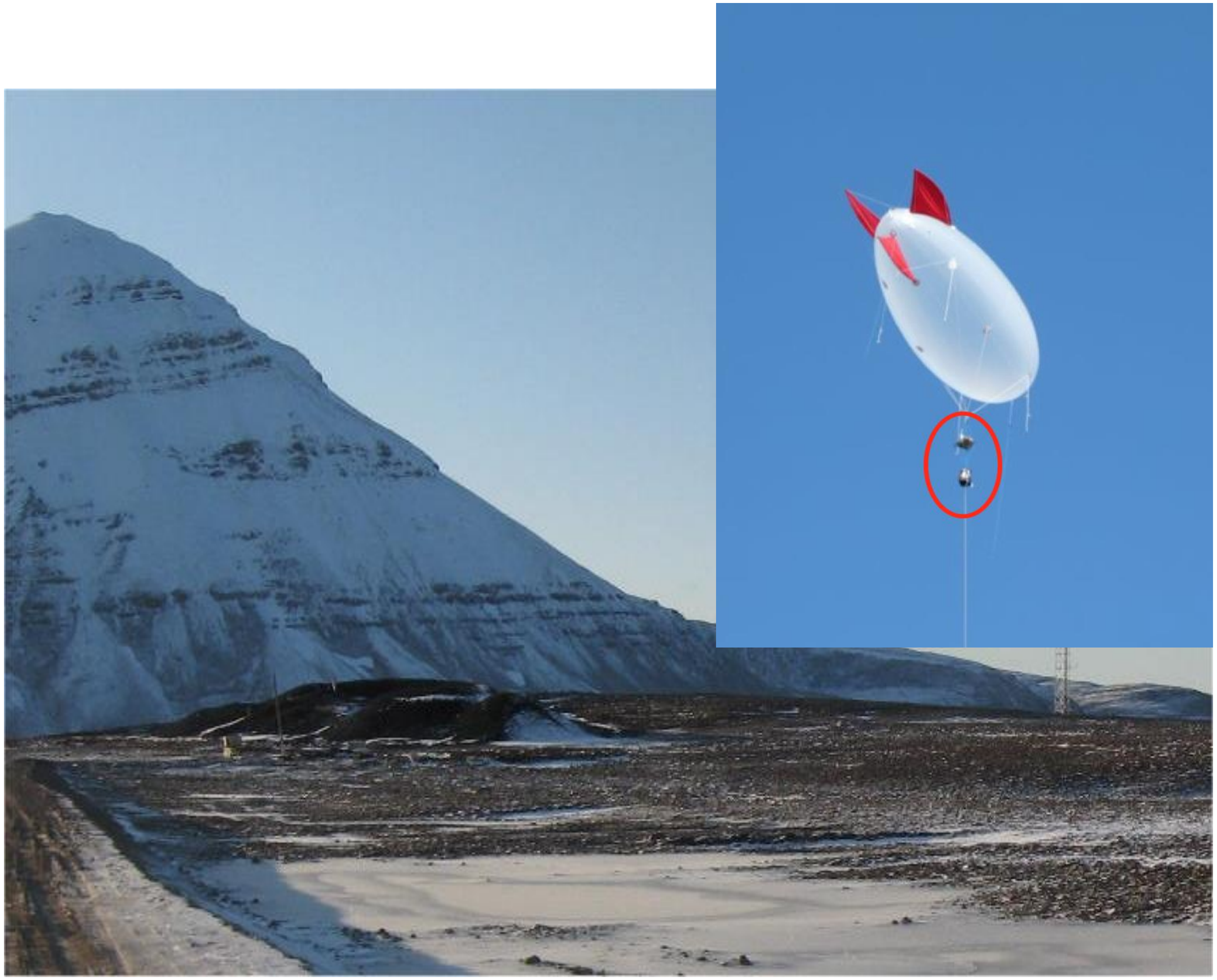
“MeteoMet North Pole 2014”

June 2014 Ny Alesund - Svalbard

An EDIE chamber will be shipped from INRiM to Ny Alesund. Three INRiM operators will reach the polar base and perform the calibration of the GRUAN instruments operating there.

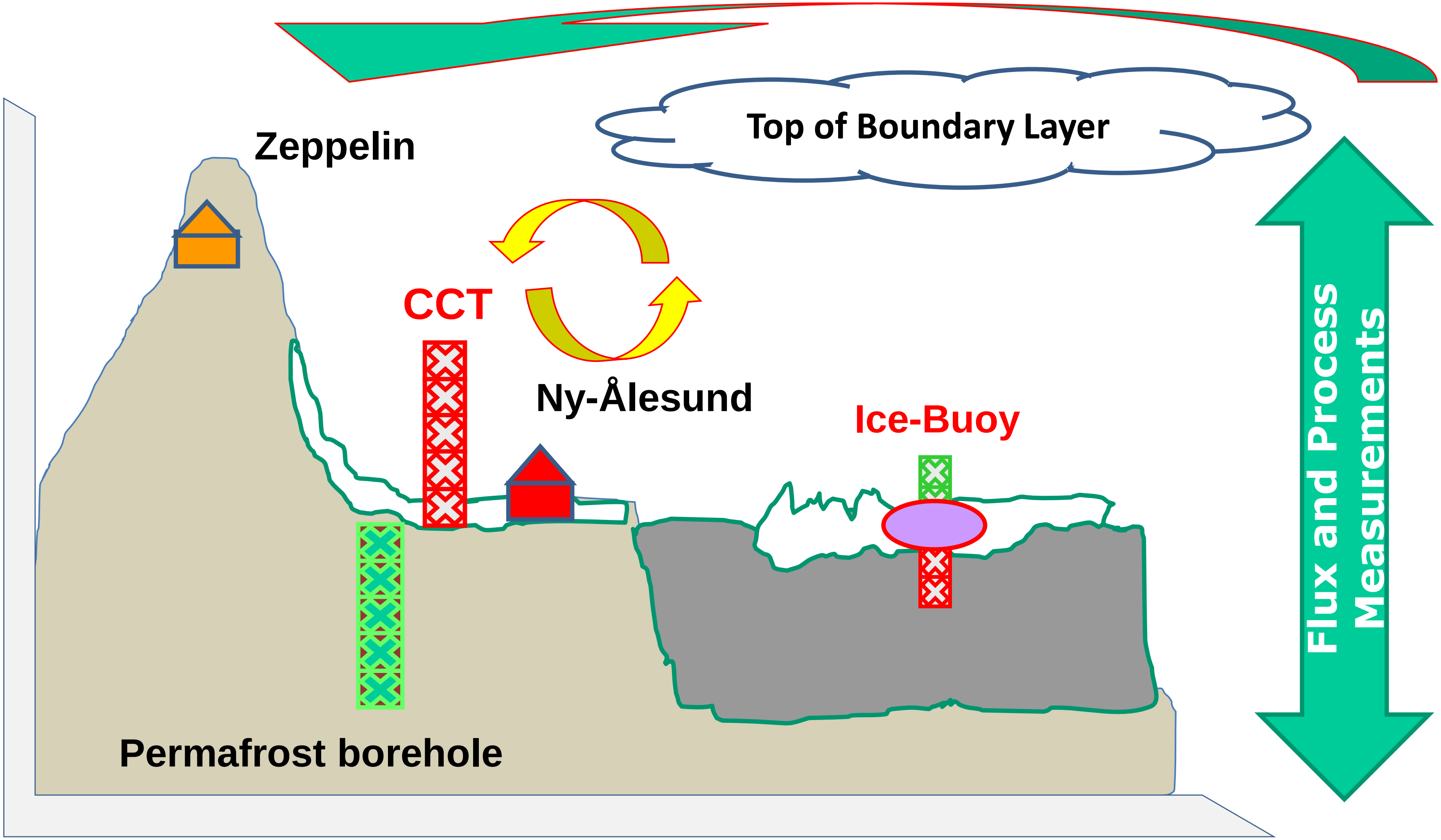
This will prepare the basis to study the feasibility of a laboratory for metrology in Ny Alesund 79° N.

Amundsen-Nobile Climate Change Tower



http://www.isac.cnr.it/~radiclim/CCTower/

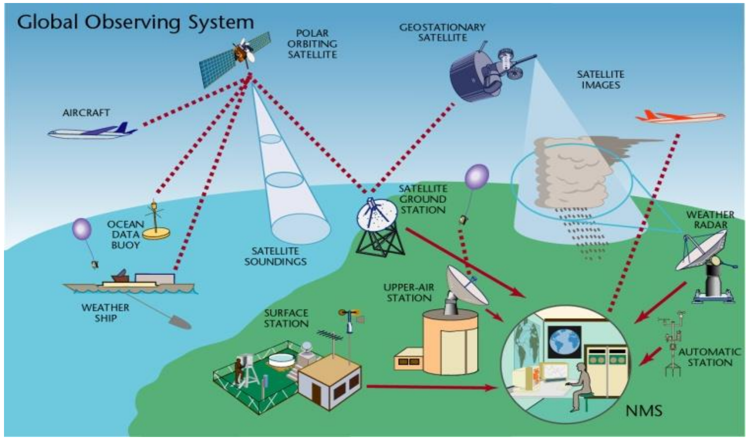
The Climate Change Tower Integrated Project (CCT- IP)

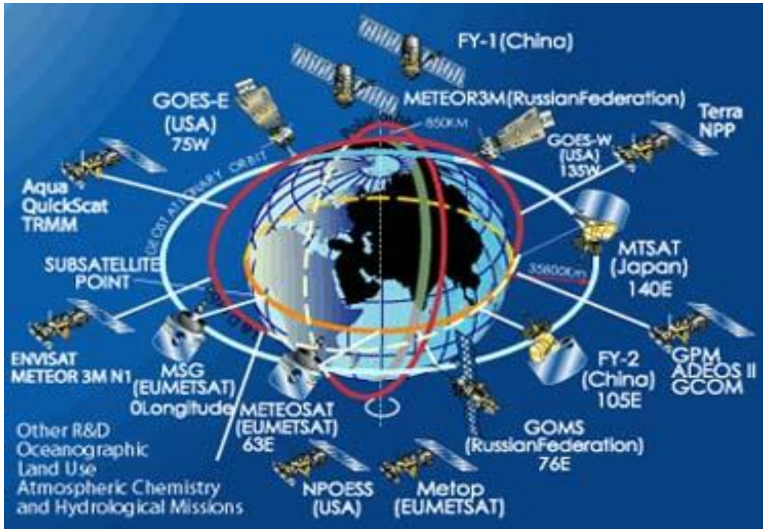


http://www.isac.cnr.it/~radiclim/CCTower

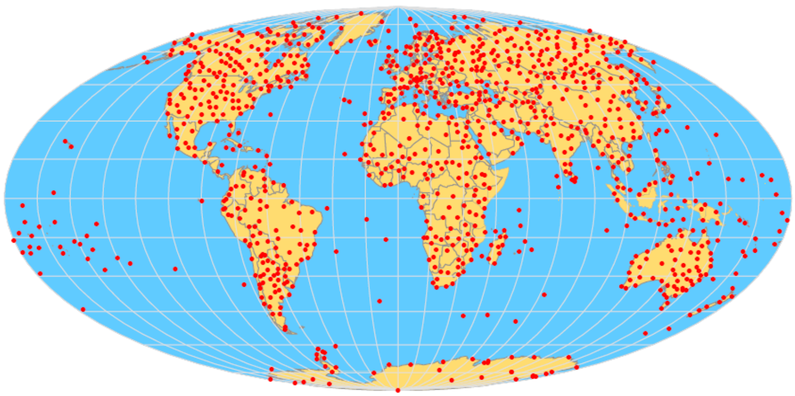
Uncertainties evaluations to reach full comparability

- **Comparability on climate-change scales**
- **Comparability to fundamental physical models**
- **Comparability across generations**
- **Comparability across borders & organizations**
- **Comparability across instrument/measurement types**





(1016 Stations)



GCOS Secretariat, 1 January 2007

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Atmospheric (over land, sea and ice)	**Surface:** Air temperature, Wind speed and direction, Water vapour, Pressure, Precipitation, Surface radiation budget. **Upper-air:** Temperature, Wind speed and direction, Water vapour, Cloud properties, Earth radiation budget (including solar irradiance). **Composition:** Carbon dioxide, Methane, and other long-lived greenhouse gases[3], Ozone and Aerosol, supported by their precursors[4].
Oceanic	**Surface:** Sea-surface temperature, Sea-surface salinity, Sea level, Sea state, Sea ice, Surface current, Ocean colour, Carbon dioxide partial pressure, Ocean acidity, Phytoplankton. **Sub-surface:** Temperature, Salinity, Current, Nutrients, Carbon dioxide partial pressure, Ocean acidity, Oxygen, Tracers.
Terrestrial	River discharge, Water use, Groundwater, Lakes, Snow cover, Glaciers and ice caps, Ice sheets, Permafrost, Albedo, Land cover (including vegetation type), Fraction of absorbed photosynthetically active radiation (FAPAR), Leaf area index (LAI), Above-ground biomass, Soil carbon, Fire disturbance, Soil moisture.

The vision

Establish a permanent cooperation

between the

Metrology and Meteorology communities

- A coordinated system of systems approach that recognizes the intrinsic value both of a suite of ground-station-based sensing capabilities and space-based remote sensing capabilities provides for a resilient observing system architecture
- High-quality profile information from lidars, microwave radiometers, FTIR and other instruments might give substantive benefits if assimilated.
- Ground based validation of satellite measurements are of fundamental importance for the remote sensing data quality.

Two methods are used to check the records for ‘homogeneity’ (or being free from non-climatic influences). The first, ‘absolute homogeneity’, uses the station’s metadata (records kept about changes at a site) as a guide for likely errors. The second, ‘relative homogeneity’, looks for inconsistencies between neighbouring stations. In fact the latter is usually the only possibility since most stations lack any metadata. While the relative method can detect large sudden errors, it cannot tell if slowly-changing differences are errors or a real change in climate at one station. Questionable records are rejected even though they might be correct.

Measurements have been made by instruments on the surface since around 1850. For the last 50 years. All meteorological measurements until about the 1970s originated from manual instruments such as Stevenson screens and liquid-in-glass thermometers.

Even today, many instruments operated by the world's National Meteorological Services are still of this type. Errors originate from how the instruments are operated, exposed, maintained and calibrated. The microclimate they operate in will change over time, as may the surrounding country. All of these factors have the potential to give a misleading indication of climate but the evaluation of the associated uncertainty is far from simple.

But 71% of the globe is ocean-covered. While Marine Air Temperature (MAT) is measured aboard ships, it is not used widely because it is unreliable. Instead, Sea Surface Temperature (SST) is measured, using buckets to collect the water. More recently the temperature of the engine-room intake water and hull temperatures have been measured. Moored and drifting buoys have also now been introduced. The lack of a need for thermometer screens, the homogeneity of the oceans and minimal human presence, avoids most of the problems encountered in measuring air temperature over the land, making SST a potentially more accurate record.

The calibration uncertainty is significantly reduced, since probes for those measurements are calibrated in baths.

It would be disingenuous to argue, as some do, that the records of temperature are so unreliable (or even that they have been intentionally falsified) as to make them worthless. Although there is inevitably some uncertainty over their accuracy, they contain a wealth of valuable information.

Trends results are obtained by homogenizing relative values.

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Calculating global averages

Because in climate studies we are interested in temperature changes, ‘anomalies’ are used rather than simple averages. Temperature measurements from land instruments are first converted into daily, monthly and yearly averages. The average of each average is then calculated over a 30-year period, currently 1961-1990. The anomaly is derived by subtracting each daily, monthly and annual average from its 30-year average. But we are more interested in anomalies over an area, so these point anomalies are next converted into anomalies over a ‘grid’, typically of 5º x 5º latitude by longitude. To calculate the average anomaly for each grid, the anomalies from all the stations in each grid are simply averaged.

But this procedure may contain flaws. Is it legitimate, for example, to average anomalies from different climates without some adjustment? Should anomalies not be ‘weighted’, for example to allow for differences in the amount of available free water, or of WV in the atmosphere, which will affect the division of incoming energy into sensible and latent heat fluxes? This is not done, but probably should be.

Over the oceans, the conversion of spot readings of SST into average anomalies is calculated in the same way as with LAT. Because the oceans are homogeneous, however, it seems more legitimate to average anomalies within a grid without weighting them, but whether this holds true up to the hemispheric scale is doubtful since the processes in tropical and polar oceans are very different.

Other uncertainties arise; for example, should LAT be merged with SST, given their extremely different natures, processes and speed of change? And again, does one average figure for the whole globe - land and sea and both hemispheres combined - have any useful meaning? Such gross figures hide all the differences between hemispheres, latitudes and seasons that could help explain why temperature changes occurred. The main use that one figure probably has is for the media, public and politicians who want simple answers; but there aren’t any.

Although WV feedback is potentially a real phenomenon, it is clearly also complex and not always inevitable.

There is a further uncertainty involving WV. Under warmer conditions, the additional WV would take its extra latent heat up into the troposphere and release it as it condensed into cloud droplets, thereby warming the upper atmosphere. This reduces the lapse rate making the atmosphere where the photons escape warmer, thereby reducing the GHE (the lapse-rate feedback). This effect works in the opposite direction to the WV feedback and the balance between them is unknown.

Resolving WV uncertainties is important because climate models include a substantial WV positive feedback.

Humidity

While water vapor in atmosphere is the most powerful GHG, climate models treat it only as a feedback because its amount varies greatly and its 'residence time' is short. The argument goes that an increase in temperature, due to anthropogenic increases in CO2, would increase evaporation and the extra WV, being a GHG, would then 'amplify' the warming - perhaps resulting in 'runaway' warming. It is this amplification that produces model projections of future temperatures higher than that due to CO2 alone. Accurate measurements of water vapour will then increase in importance for climate change modelling and predictions.

A wide measurement range from tropical conditions at sea level to upper air conditions at below -80 °C and 10 hPa sets a difficult challenge for the reliability of the measurements. Also ensuring the reliability and traceability of humidity measurements in the extensive meteorological sensor networks and for long time series is very challenging.

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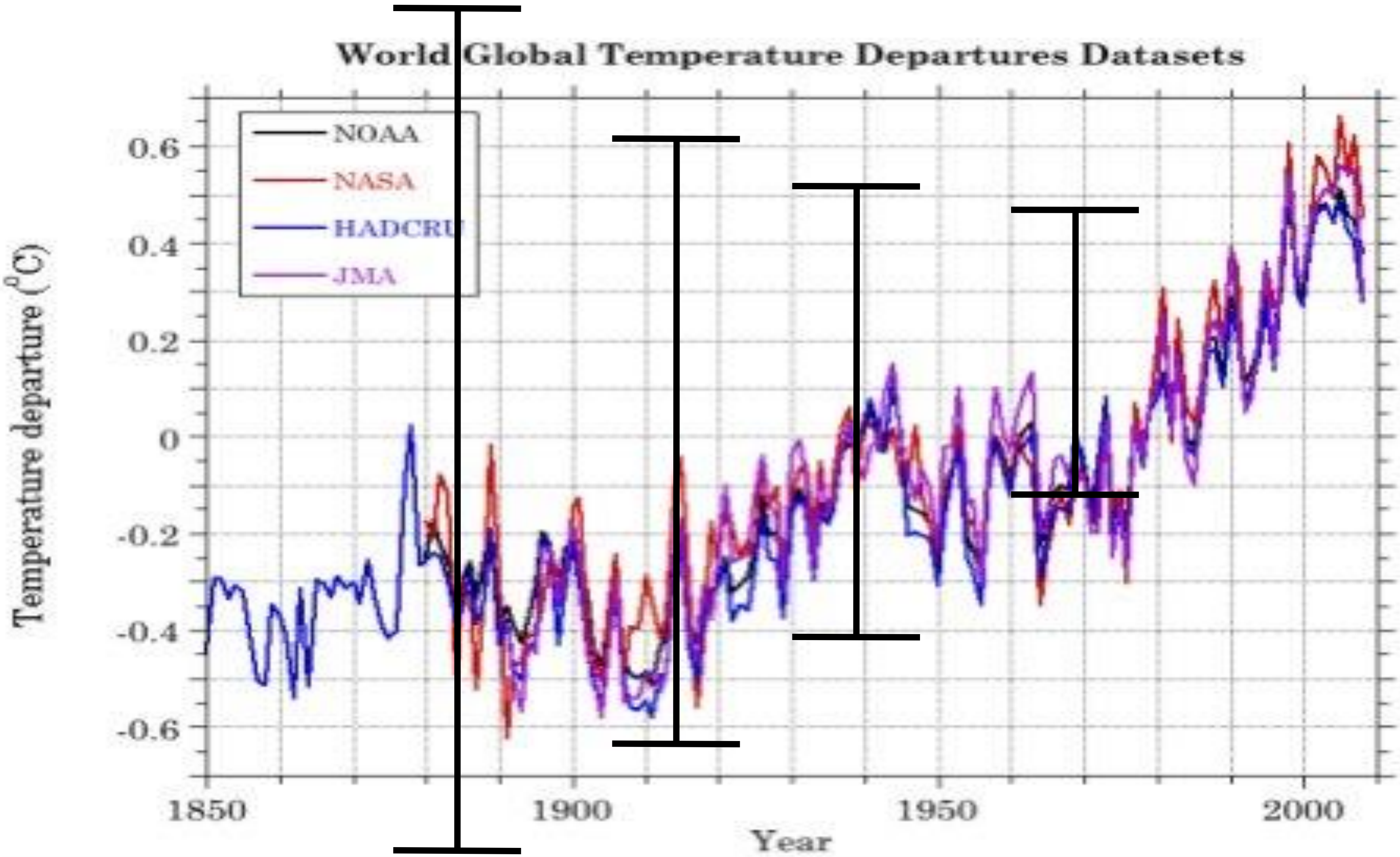
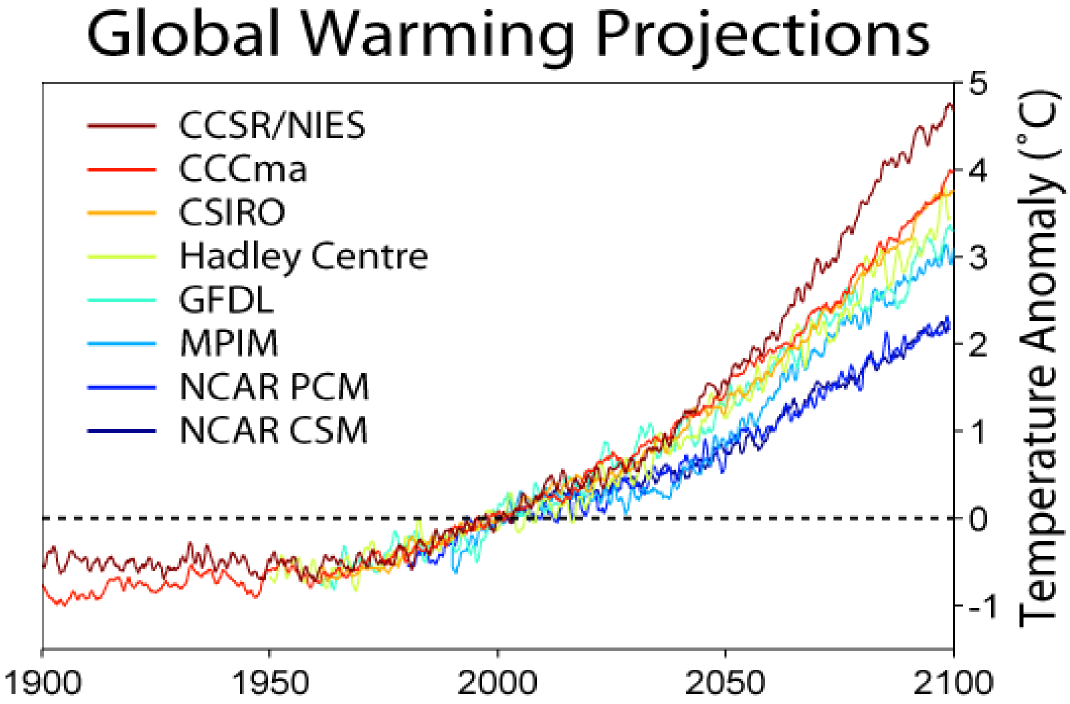

World Global Temperature Departures Datasets
NOAA
NASA
HADCRU
JMA
Temperature departure (°C)
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
1850
1900
1950
2000
Year

Claim: Climate is Done. Accurate Measurements are No Longer Necessary.

- **How much and how fast?**
- **What is the impact?**
- **What are the global vs. regional differences and consequences?**
- **Is there a mitigation strategy?**
- **Is mitigation working?**
- **Are there unexpected new anthropogenic environmental threats?**



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