Title: Metrology for pressure, temperature, humidity and airspeed in the atmosphere

Abstract

Climate modelling critically relies on precise and reliable measurements of physical parameters such as pressure, temperature, humidity and airspeed. Air humidity is a crucial parameter due to the enormous heat capacity of gaseous water and its key role in atmospheric processes. Traceable measurements of air humidity from near the earth surface up to the stratosphere are required. Due to the very low relative humidity in the stratosphere, the response of conventional capacitive sensors is poor and their traceable calibration especially difficult. Temperature is a key quantity that has been measured widely with a long historical record. However, published historical data often lacks a clear statement on the measurement technique, uncertainty budget and linkage to the international temperature scale ITS-90.

This Topic aims to contribute to improvements in climate modelling through improved traceability and reduced uncertainties for these key measurements.

Conformity with the Work Programme

This Call for JRPs conforms to the EMRP 2008, section on "*Grand Challenges"* related to *Industry & Environment* on:

Page 9: "..validated and traceable measurement techniques, sensors and measurement standards related to: detecting change and monitoring climate; measuring flow and concentration of species under regulations such as the Kyoto protocol"

Page 24: "Activities performed across the EU to detect changes in the environment and to monitor the climate depend on the availability of a robust and stable measurement infrastructure. The EMRP will address the needs for:

- Novel sensors and underpinning measurements for global surface and ocean temperatures and stable long-term trends in the composition of the ocean and atmosphere.
- Provision of a distributed system capable of providing traceability for measurement data from global ground and satellite-based networks."

Keywords

Climate change, environmental measurements, meteorological climate modelling, Atmospheric parameters, air temperature, air-speed, water vapour, vapour pressure equation, optical spectrometer, dew-point hygrometer, LIDAR, frost-point hygrometer, stratospheric balloons, radiosondes, meteorology, weather forecast, traceability, ITS-90, small temperature differences.

Background to the Metrological Challenges

Climate change is a huge challenge to mankind, and is monitored by a network of national meteorological institutes according to local procedures. A historical investigation of the data across countries will enable better understanding of the real situation of the climate change.

The development of new methods and standards for climate monitoring offers the possibility to accurately measure small temperature differences and to establish a traceability chain suitable for climate monitoring and correcting historical data. At a regional level, NMIs (in cooperation with meteorological institutes) can seek to validate data-logging software for in situ weather stations

Much climate measurement is undertaken by Radiosonde weather balloon observations. These instruments are vital for studies of upper-air climate change and extremely high stability is required in the systematic errors of their measurements. Radiosonde manufacturers produce systems that need to operate over an extremely wide range of meteorological conditions: 1050 hPa to 5 hPa for pressure, 50 °C to – 90 °C for temperature, 100 % to 1 % for relative humidity, with the systems being able to sustain continuous reliable operation when operating in heavy rain, in the vicinity of thunderstorms, and in severe icing conditions. A compromise is then necessary between the reliability and the accuracy of the measuring instruments, their robustness and their cost.

Pressure

For pressure measurements, at pressures higher than about 30 hPa, radiosonde measurement errors are about twice the stated optimum performance limit. At pressures lower than 30 hPa, the errors in older radiosonde types increase rapidly with decreasing pressure. The propsed JRP could seek to improve these measurments.

Temperature

Atmospheric temperature measurements are used for monitoring global temperature changes, for clarifying links between atmospheric parameters and climatic behaviour and to validate global models of the atmosphere. These measurements are required locally or globally, for input to numerical weather prediction models. Measurements of temperature may be required as continuous records or may be sampled at different time intervals.

Most modern radiosonde systems measure temperature in the troposphere with a standard error of between 0.1 K and 0.5 K. Unfortunately, standard errors larger than 1 K are still found in some radiosonde networks in tropical regions.

Humidity

Water vapour is the most important gas in the atmosphere due to its substantial heat capacity and thus a key player in climate change. Knowledge of the exact amount of atmospheric water vapour and its vertical distribution is essential. In a recently published study e.g. it has been shown that ‘a rise in water vapour in the atmosphere fuelled 30 per cent of the global warming that took place during the 1990s’ [1]. The quality of the air humidity data entered into climate models substantially affects the modelling outcome, e.g. inferred trends which directly impinges e.g. on mitigation strategies. In the very low relative humidity in the stratosphere, the response of conventional capacitive sensors is poor and their traceable calibration is difficult.

Modern radiosonde relative humidity measurements (using capacitive polymer sensors) are at least a factor of two or three larger than the optimum performance limit for high relative humidity. The lastest climate models require Radiosondes that resolve to 1 % of saturated water vapour pressures from 46 hPa at 30 °C down to at least 0.06 hPa at –50 °C. This implies the development of new humidity standards and instruments and improvements in the knowledge of saturation curve. To improve the situation new devices like chilled mirror hygrometers or laser diode spectrometers should be developed and tested. Traceability through calibrations is essential for reliable measurements. Cheap construction is needed due to a high loss rate of the equipment. The feasibility of calibrations should be advanced by providing new calibration methods for field measurements.

Calibration of current capacitive humidity sensors at water vapour fraction levels of 10^{-6} takes typically several days because of the low diffusion and adsorption/desorption rate of water molecules, which makes calibrations difficult to apply to large number of instruments. A faster method is urgently required.

Tuneable diode laser absorption spectrometers (TDLAS) especially in the near infrared (NIR) spectral region have generated some interest in the atmospheric community. Due to significant improvements in NIR laser technology and TDLAS capabilities it seems possible to design a new generation of very robust, airborne NIR-TDL hygrometers with improved sensitivity suitable for stratospheric measurements while still being more compact and light-weight than previous 1.4 µm NIR TDL instruments. These need to be proven and have suitable calibration techniques developed.

Air speed

Measurements of atmospheric winds may be used either as inputs for climate forecasting models or in order to study global changes. Upper winds measurements are essential for operational weather forecasting on all scales and at all latitudes, and are usually used in conjunction with measurements of mass field (temperature and relative humidity). They are essential to the safety and economy of aircraft operations and accurate upper wind and vertical wind shear measurements are critical for the launching of space vehicles. In the boundary layer, upper winds with reliable measurements of vertical wind shear are essential for environmental pollution forecasting.

Scientific and Technological Objectives

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them, in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the JRP protocol.

The proposed JRP should address the development of metrological tools and methods underpinning climate models, considering the quantities air pressure, temperature, humidity and airspeed in the atmosphere up to stratospheric heights.

The aim of your JRP should be to provide validated and reliable measurements/methods with traceability wherever it is practicable to do so for :

1. Development and testing of novel instruments for the measurement of air humidity. Optical laser diagnostic as well as small open-path chilled mirror hygrometers are to be deployed for the humidity measurements up to stratospheric level. This may include instruments suitable to monitor air humidity in the range between 0.1 % (polar regions) and 4 % (the tropics) in the troposphere and below 1 g water vapour per kg air mass (polar regions) and 30 g (the tropics) in the upper troposphere and values below 10 ppm in the stratosphere
2. Generation of data to improve the water vapour formulae
3. Assessment of the historical temperature measurement data with respect to uncertainties and to the used techniques and temperature scales, and recalculation of the data where appropriate in order to establish comparability through traceability to the international temperature scale ITS-90.
4. Development of traceable measurement methods and protocols for temperature, humidity, pressure and airspeed measurements needed for climate studies and meteorological long-term and wide-scale observations. Possible applications are ground-based measurements, aircraft measurements, radiosonde measurements, balloon measurements – such as traceability for LIDAR systems, improvement of anemometer calibration in wind tunnel.

Proposers shall give priority to work that meets documented stakeholder needs and may include measures to facilitate the development of European standards and Directives.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the “end user” community. This may be through the inclusion of unfunded JRP partners or collaborators, or by including links to industrial/policy advisory committees, standards committees or other bodies. Evidence of support from the “end user” community (eg letters of support) is encouraged.

Where a European Directive is referenced in the proposal, the relevant paragraphs of the Directive identifying the need for the project should be quoted and referenced. It is not sufficient to quote the entire Directive per se as the rationale for the metrology need. Proposals must also clearly link the identified need in the Directive with the expected outputs from the project.

You should also detail other Impacts of your proposed JRP as detailed in the document “Guidance for writing a JRP”

You should detail how your JRP results are going to:

- feed into the development of urgent standards through appropriate standards bodies
- transfer knowledge to the climate modelling and weather prediction sectors.

You should also detail how your approach to realising the objectives will further the aim of the EMRP to develop a coherent approach at the European level in the field of metrology. Specifically the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards
- the metrology capacity of Member States and countries associated with the Seventh Framework Programme whose metrology programmes are at an early stage of development to be increased
- outside researchers & research organisations other than NMIs and DIs to be involved in the work

Time-scale

The project should be of 3 years duration.

Additional Information

The references were provided by PRT submitters; proposers should therefore establish the relevance of any references.

1. WMO-No. 1050, Report of the Commission for Atmospheric Sciences Fifteenth session, 18–25 November 2009
2. Guide to meteorological instruments and methods of observation (WMO-No.8)
3. Climate change 2007 – Synthesis report, a report of the intergovernmental panel on climate change
4. Raino Heino , Statement of guidance for climate, report of WMO from Commission for Climatology
5. S. Solomon, K. Rosenlof, R. Portmann, J. Daniel, S. Davis,T. Sanford, G.-K. Plattner. Contributions of Stratospheric Water Vapour to Decadal Changes in the Rate of Global Warming. Science DOI: 10.1126/science.1182488 Feb. 2010
6. German Government. German strategy for adaptation to climate change. Dec. 2008. http://www.bmu.de/files/english/pdf/application/pdf/das_gesamt_en_bf.pdf