ENVRIplus DERIVERABLE

D2.1
Report on traceability and standards in Environmental RIs

WORK PACKAGE 2 – Metrology, Quality and harmonisation

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ABSTRACT

This document is a report on metrology standards and practices at use in research infrastructures participating in ENVRIplus. It also identifies metrology needs, providing relevant concrete test cases where metrology developments are being made. First, a network of metrology contact point was established within the project (see Annex 1). This document is based on the expertise brought by this network. Section 1 identified the list of parameters common to at least 3 RIs to focus the gap analysis in terms of metrology needs on these parameters. Section 2 describes metrology practices on core parameters measured by the research infrastructures that can serve as a basis for exchange of good practices across ENVRIplus. The associated quality assessment and quality control procedures are also detailed. Each RI section ends with a short gap analysis in terms of metrological needs. Section 3 gives a panorama of the existing institutional metrology: BIPM at the global international level, EURAMET in Europe and new initiative in the frame of WMO called the GCOS Surface Reference Network (GSRN). The section ends with a general assessment of the traceability to standards in the RIs of ENVRIplus. Based on the gap analysis made in the project and funding opportunity, several concrete testcases, described in section 4, were initiated or further promoted, where metrology improvement relevant to ENVRIplus RIs are being developed via dedicated projects. Finally, section 5 describes the development of a metrology lab in the arctic, a fundamental observation area for climate change evaluation.

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Content

Introduction

This document is a report on metrology at use in research infrastructures participating in ENVRIplus (cf annex 3 and 4). The different research infrastructures don't have the same level of contribution into this report.

ENVRIplus is a Horizon 2020 project bringing together Environmental and Earth System Research Infrastructures, projects and networks together with technical specialist partners to create a more coherent, interdisciplinary and interoperable cluster of Environmental Research Infrastructures across Europe. It is driven by three overarching goals: 1) promoting cross-fertilization between infrastructures, 2) implementing innovative concepts and devices across RIs, and 3) facilitating research and innovation in the field of environment for an increasing number of users outside the RIs. The project ENVRIplus lasting from 2015 to 2019 is organized in the following six themes

T1 Technical Innovation
T2 Data for Science
T3 Access to Research Infrastructures
T4 Societal Relevance and Understanding
T5 Knowledge Transfer
T6 Communication and Dissemination

The present deliverable is part of WP2 of Theme 1.

General description and main goal of Theme 1:

Scientific observations and the related technologies are the foundation of many Environmental Research Infrastructures. The diverse community contributing to ENVRIplus uses a large variety of technologies, measuring parameters ranging from atmospheric concentration of trace gases through metabolomics to detect biodiversity and deep ocean salinity to Earth crust motions. However, the numerous technologies available rely on a few fundamental physical principles and have several technical aspects in common. Ample opportunity for collaborative work across disciplines exists. The goal of Theme 1 is to ensure common development and application efforts and generate innovation that is not possibly achieved by single Research Infrastructure.

Description of WP2 of Theme1:

Delayed or real time observations performed by networks of instruments are generally used in conjunction with other data, including data from other observatories, in situ or from space, or from long time series. Introducing heterogeneous data that are not directly comparable with each other commonly generate biases in the results of scientific users. Harmonization serves the fundamental purpose of enabling the unbiased usage of data. Data flowing from observation networks has to be harmonized in a scientific and metrological sense. There is a crucial need to improve comparability between Research Infrastructure networks and traceability to standard (SI) units and metrological norms. In addition, all Research Infrastructures are facing difficulties with using long time-series lacking harmonized calibration and change in instrumentation. The WP2 also addresses strategies to cope with existing non-harmonized data sets, in particular regarding the issue of satellite validation. The objective of WP2 is to:

1) Address the needs for standardization of measurements and methods across the Research Infrastructures,

2) Develop new services to promote use of heterogeneous time series produced by Research Infrastructures,

3) Develop new services to meet requirements for using heterogeneous networks for satellite validation.

This report addresses the point 1 above related to measurements and methods across the Research Infrastructures that is metrology in a general sense The document both aims at identifying gaps in metrology needs across ENVRIplus RIs but also share advance expertise in metrology where it exists among the participating RIs.

Activities in this task are devoted to make the assessment of key measured parameters within environmental research infrastructures (RIs) and underline the commonalities of these measured parameters in-between different RIs. An insight to the availability of metrology data for these parameters is provided.

This report was established making use of the expertise of various RIs in ENVRIplus.

Section 1: Infrastructures measurement parameter matrix

The ENVRIplus research infrastructures were asked for their list of measured parameters. We obtained a list for the following 11 domain infrastructures: IAGOS, ACTRIS, EISCAT 3D, ICOS-ATM, ICOS-ECO, ICOS-OCEAN, EURO-ARGO, EMSO, EURO-GOOS, FIXO3, JERICO

The following figure gives the number of reported variables for each infrastructure.

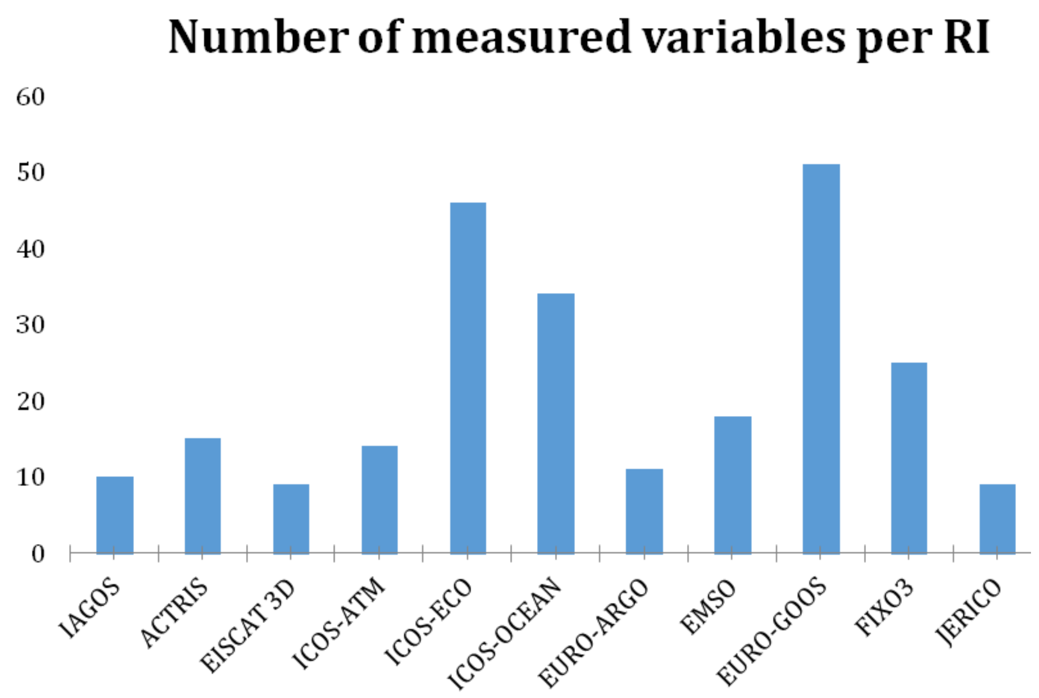

Figure 1 – Number of measured variables for the different infrastructures

It is to be noted that not all parameters reported here are at the same level of maturity in terms of actual measurements some are even aspirational parameters not yet collected. Actual core parameters from the infrastructures are described in section 2.

Analysis of the RI/parameter matrix show that a list of 15 parameters are common to at least 3 RIs and are given in the table below

Cross RIs parameters	
CH4 concentration	Nitrogen Oxides (NOx)
Chlorophyll-a	Pressure (air, sea)
CO concentration	Sea salinity
CO2 concentration	Temperature (air, sea)
Conductivity (salinity)	Total high accuracy precipitation
Dissolved Oxygen	Total odd nitrogen (NOy)
H2O fluxes	Wind speed and wind direction
Humidity	

Table 1 - List of measured parameters common to several research infrastructures

One third of these cross RIs parameters correspond to meteorological parameters (Humidity, pressure, temperature, precipitation, wind (speed, direction), while more than another third refers to concentration of minor elements in atmosphere.

Section 2: RIs metrology practices on their core parameters, quality assurance

This section is organized by infrastructure where best practices linked to metrology are put forward to be shared across the project. For each infrastructure, dedicated expert interviews were conducted with the following questions being addressed:

1. Which measured parameters are linked to SI units?
2. How do you assure Quality Assessment and Quality Control of the measured parameters?
3. How do you assure that the QA and QC are stable over time?
4. What are the needed precision ranges of the measured variables?
5. How do you assure the calibration?
6. Is there a standard instrument used for the measurement?
7. What are the instruments used?

ICOS

The key measurements (parameters) for ICOS (Integrated Carbon Observation System) Atmosphere are measurements of greenhouse gases (GHG): CO_2, CH_4, N_2O and CO as a tracer; acquired both on a continuous and discrete time basis. During the continuous measurements, the raw data is received with a period of a few seconds (2 to 5 seconds), depending on the instrument. Non-continuous or discrete measurements are performed using flasks that are filled with outside air once per week. The aim of the discrete measurements is to analyze the parameters that are hard to measure in continuous mode such as SF_6 and isotopes, esp. ^{14}C on CO_2. Moreover, flask measurements are done using a technique different from the one used for continuous measurements. This allows flask measurements to serve as quality control in duplicating the measurements. Continuous measurements of key parameters are done using infra-red absorption spectroscopy. Technical requirements are based on WMO recommendation. ICOS Atmosphere qualified a few instruments that met these requirements together with being operational enough to be deployed in the field allowing operation by non-expert users. The instrument most used is based on cavity ring down spectroscopy. This technique utilizes high-reflective optical cavity which allows to perform precise and stable measurements.
Enforced criteria exist for compatibility and comparability of results obtained from any ICOS station. The table with the precision requirements is presented in the document "ICOS atmospheric station specifications", Laurent et al., 2017 (https://icos-atc.lsce.ipsl.fr/node/99/27248)

ICOS Atmosphere concentration raw data goes through a calibration process during the data treatment. This calibration step ensures that the measurement results are linked to the international scale (WMO scale) for GHG. In ICOS the calibration gas tanks are fabricated in the ICOS CAL, a dedicated laboratory based in ICOS Germany. The ICOS CAL prepares the calibration scale for the entire ICOS network based on the WMO scale. The calibration is done every two to three weeks depending on the stability of the instrument. In the beginning of the life cycle of the station, the behavior of the station is assessed for the best calibration frequency. In addition to the calibration, ICOS applies a data processing step to correct for the water vapor and report the concentration of the GHG in mixing ratio of dry air. The correction accounts for the dilution effect due to the presence of water vapor in air but also spectroscopic effects (shape of absorption spectral bands) linked to the presence of water vapor. An open research question related to this water correction has to do with the stability over time of this correction.

To limit the influence of water vapor on the measurements, one can also dry the air sample prior to the measurements. On method is to use a Nafion membrane (NAFION method). Even though one dries the air before the actual measurement by the instrument, one still has to perform a water vapor correction if the dew point is not low enough.

In ICOS, the instruments are tested before the deployment in a dedicated metrology lab based in ICOS Atmosphere Thematic Center in France. During this test, the optimal water vapor correction is determined for each instrument..

After the calibration and water vapor steps, further quality assessment steps are applied. With these steps, one estimates the associated uncertainty of the measurements. This is done through the measurement of a so called target gas that is calibrated and measured typically every twelve hours. Further QA/QC test are also performed, e.g. test the sampling system for air leaks (lines, filters, distribution valves, etc.) once or twice per year.

ICOS is recognized to provide high precision GHG measurements. One remaining room for improvement has to do with the water vapor correction over time. Another improvement is needed to have an effective procedure to calibrate meteorological (p,T, winds, humidity) sensors over time.

EISCAT 3D

EISCAT (European Incoherent Scatter Scientific Association) is an infrastructure aiming at fundamental studies of the ionosphere, like Aurora Borealis, and other atmospheric phenomena. EISCAT is measuring two spectral components, the ion line and the plasma line, which is centered at the plasma frequency. The plasma frequency is directly related to electron density at a certain height. From the shape of ion line a number of further parameters can be extracted.

EISCAT is performing the radar measurements of the atmosphere and ionosphere, including several physical parameters. Among them are reflectivity, electron and ion densities (electrons, ions per cubic meter) and temperatures (in K) and local electric fields. These parameters are measured as a function of the height from the surface of radar and can be measured on the heights from 50 to 1000 kilometers.

Principle of measurement and quality control procedure.

The radio pulse (several megawatts, approx. 1ms) is sent toward the area of interest and the scattered signal is received back. The information about the parameters of interest is provided in the raw form of spectra, which is afterwards fitted to the theoretical spectra by means of least-square process. This fitting provides good estimates of uncertainties of the parameters as well as overall residuals, keeping in mind that the incoherent scatter theory is analytically very exact. After the fitting, the information about the parameters of interest is provided in SI units.

In fact, the fitting of obtained data to the theoretical spectra acts as a quality control tool. The recorded spectrum is divided into two regions, namely ion line, which is set around zero frequency, and 2 plasma lines that are far offset. The plasma lines are very narrow in terms of frequency, which provide very accurate measurements. Plasma lines are obtained from one height in the atmosphere and the values of frequency are compared to the integrated power of ion lines. This is the procedure of the quality control in Eiscat 3D, which is done on a weekly basis or as often as plasma lines are received.

All measurements are continuously calibrated by injecting a signal from controlled noise source into the antenna frontend. The power of this signal is very constant over time, and in reality, the plasma line process defined above is calibrating this noise power level.

Calibration of the signal.

There are satellites with known scattering mechanisms, called “flying spheres”. By sending the signal to the satellite and by receiving it back it is possible to calibrate the radar instrument. The calibrations are performed once or twice per lifetime of the radar, meaning the period of several decades (30 years.) The specifications of the radar signal are provided by URSI, International Organization of Radio Science.

Signal quality.

The signal quality depends on the signal power and the radar aperture, measured in the units of surface area (up to 10000 m^2). The bigger the aperture the higher the signal quality. Electron density is measured in number of electrons per cubic meter, temperature is measured in Kelvins, velocity of ions in meters per second. Among those ions are those found in the atmosphere, such as O^+, H^+ He^+, metallic ions, etc.

The uncertainties of the parameters are derived on a statistical basis using fitting procedure. The incoherent scatter signal is noise-like and need averages of some thousand individual estimates of the spectral components, and make thus a good statistical ground for variance calculations of the input data to the fitting process. The accuracy of the final parameters is thus estimated on very good grounds on statistical theory.

Possible improvements.

EISCAT 3D would like to improve the measurements of space weather and space debris. They cooperate with ARISE in detecting particles dust and aerosols at certain heights in the atmosphere. One main complementarity of EISCAT 3D with other RIs is to make measurements higher up in altitudes.

EISCAT 3D is looking to acquire new radar systems and computing clusters for better analysis methods to include more types of radio wave scattering mechanisms. It would also be beneficial to develop better analysis methods for isotropic and anisotropic parameters, better methods for (automatic) real-time decisions of operation modes, better interoperational standards between communities.

ACTRIS

The main parameters measured in ACTRIS (Aerosol, Clouds and Trace Gases Research Infrastructure) are:

- Lidar aerosol extinction coefficient
- Sun photometer aerosol optical depth
- Near-surface measurement of particle size distribution
- Near-surface measurements of NOx
- Near surface measurement of VOCs

Measurement principles of all parameters:

Lidar aerosol extinction coefficient is measured using RAMAN Lidar techniques. There is a possibility to perform measurements at different wavelengths. Aerosol optical depth is measured using sun photometers (through the measurement of radiance and different wavelengths). Particle size distribution measurements are performed using different instruments (in-situ stations) represented by different instrument models and techniques. NOx and VOCs are measured through the comparison of measured values with the laboratory standards.

Scientific question:

The intention is to provide quantitative database of aerosol measurements with uncertainties over long term periods, to access the influence of aerosols on the cloud formation processes and climate parameters. Another important aim is to establish the relationship of aerosol properties with air quality. These parameters are related to the processes that affect directly the health and life quality of European citizens.

Precision:

Aerosol extinction coefficient is measured in (1/m). Precision depends on the levels of product (devices) maturity and on the current state of atmosphere. The uncertainty is calculated as a standard deviation of the Poisson distribution, related to counting, i.e a number of photons counted by the system. This means that larger amount of counted photons gives better precision.
Aerosol optical depth is an integrated parameter over the vertical column, therefore it is unitless. There is no full assessment of uncertainty budget for the measurements of this parameter. However, the estimation of uncertainty is provided within 0.02-0.03 units (unitless). There is a similar situation for **near-surface measurements of particle size distribution**: there is no assessment of uncertainty budget. The precision is taken as one provided by the manufacturer of the instrument. In case obtained further on, the information will be shared among the participants of the community.
VOCs are measured in moles (SI). Uncertainty is estimated to be within 2-5%.
NOx are measured in moles (SI). No precise estimation of uncertainty budge exists**.** The main driving force for the precision of the instruments is comparability of the data between the measurement stations. In that sense, there are large similarities with ICOS.

Data processing:

Step one: in case of **Lidar aerosol extinction coefficient** the signal that is collected during measurements is light. Therefore, the raw measurements are represented by voltage/ number of counting of photons. This information is converted in the form that can be processed, into so-called range corrected signal.

In case of **aerosol optical depth measurements**, the steps described in step one are also valid, but besides that, several corrections are applied to account for the absorption of different gases.

Step two: application of the retrieval algorithm. The number of degrees of freedom depends on the type of the algorithm.

In case of **near-surface aerosol and gas measurements**: there are calibration, retrieval and quality assurance processes that are applied to the raw data.

Calibration and quality assurance.

Calibration means that there is a standard that could be an SI standard or a standard, acknowledged by the community as robust enough. The measurements of the instrument are compared to the data provided by the standard. Thus, the data obtained from **light based techniques** is referred to the light of certain intensity and wavelength. **VOCs concentrations** are compared to the laboratory standards. In case of **Lidar measurements**, currently there is no standard, because the remote measurement is performed in the atmosphere, thus a separate standard for each altitude would be needed. Therefore, the data obtained from these measurements is compared to such profile of the radiation of molecules in the atmosphere as if the aerosol would be missing. In other words, the signal from the clean atmosphere is compared to the experimental signal. Strictly speaking, this procedure cannot be considered as an SI standard, but it is widely used by the community and therefor accepted.

Quality assurance program of ACTRIS is quite wide. For the **Lidar measurements**, ACTRIS provides particle extinction coefficients at two wavelengths in order to check if the wavelength dependency is compatible to the type of observed aerosol and if the values are in the reliable range. In case of **aerosol optical depth** measurements quality assurance is done in a different way. The instrument carries out the measurements for the period of 12-15 months. Than it returns to the calibration facility and the calibration decay is checked. Based on the results the post-fit calibration applied to the data. There are also other less abundant checks, such as "cloud screening", made to avoid cloud observation together with aerosol observations as well as many others.

Areas of improvements

Probably one of the main difficulties associated with certain measurements is the possibility to assess uncertainty contributions. Cloud measurements products are currently least reliable because the calibrations for radars and ceilometers are not robust enough. Sun photometers are not reliable. Aerosol chemical composition techniques need advances in metrology as well.

ACTRIS is collaborating with other RIs, however not on a systematic basis. It cooperates with METEOMET, which is an RI of NMIs working with several atmospheric parameters. ACTRIS and METEOMET collaborate in the implementation of some GRUAN sites which is the GCOS Reference Upper-Air network. ACTRIS has a clear overlap with GRUAN in Europe.

IAGOS

In-Service Aircraft for a Global Observing System is measuring key climate-change- and air-quality-relevant parameters. IAGOS data are being used by researchers world-wide for process studies, trend analysis, validation of climate and air quality models, and the validation of space borne data retrievals.

The key measurement parameters in IAGOS to this date are relative humidity (RH), carbon monoxide (CO) and ozone (O_3). The measurements are performed on the base of eight commercial aircrafts which make several flights per day, which results in about four thousand flights per year. Relative Humidity is measured as a value, relative to the saturation pressure and thus it is unitless. Measurements of gases are performed as volume mixing ratios (usually ppb).

Measurement principle

Relative Humidity is measured with the help of Capacitive RH sensor (Humicap-H, Vaisala, Finland) plus a PT100-sensor: Based on thin-film technology the RH-sensor consists of a hydro-active polymer film as dielectric between two electrodes applied on a glass substrate. The sensor responds to changes of relative humidity rather than absolute humidity in the surrounding air. The additional measurement of temperature with the PT100 thermistor enable to derive the absolute humidity using the measured air pressure provided by the aircraft avionics. The time resolution is 4 seconds.

Carbon monoxide is measured through specific adsorption measurements. CO measurements are improved IR correlation, as described in Nedelec et al., 2003 (https://doi.org/10.5194/acp-3-1551-2003). CO measurements are performed by IR correlation at 4.6 µm, with an optimized IR detector cooled to -30°C. O3 and H2O are filtered prior to the measurements to prevent any interference with CO absorption. Periodic zeroing (10 to 20 minutes) of the instrument is made by passing air on Sofnocat filter to remove the CO.

O3 measurements are performed by classic UV absorption at 254 nm as described in Thouret et al., 1998 (doi: 10.1029/98JD02243*)*. Two cells are used, one for ambient air containing O3, the other one with zero O3 air (removed by MnO3 filter). Each 4 seconds, the cells are switched.

Requirements in terms of precision of the instrument.

At the current stage of precision, the satisfactory values are: RH: ±1 % RHL, SAT: ±0.1 K; Ozone: 2ppb or 2%; CO: 5 ppb or 5%. In case of humidity, precision is limited by the size of the instrument, since the larger and more precise instruments cannot be installed to the aircraft. The fact that instruments are installed on the aircraft also limits the available periods to work with the instruments in the laboratory. Thus, it is possible to physically work with the instruments only once in 3 months. Instruments have to be autonomous, which in turn makes them less precise compared to the laboratory instruments. At the current stage the precision range is a good compromise between the measurement and installation needs.

Another point for the measurements of relative humidity is that in cold conditions the instrument works slower, thus, the integration time period gets to values of more than 4 seconds in the tropopause region. There is room here for metrological improvements.

QA/QC and data processing.

For the near real time measurements of all three parameters there are automatic checks and QC.

For the scientific (Level 2) data pre-flight and post-flight calibrations (similar procedures) are performed and the calibration factors are determined based on the difference between these two calibrations. For the case of RH measurements in the period when the aircraft enters the stratosphere the zero value for the RH is recorded, providing the in-flight calibration. Based on this value, the calibration offset factor determined from pre- and post- flight calibrations can be adjusted step-wise to fit correctly to the obtained zero value. In general, the entire dataset of flight period (2-3 months) has to be evaluated to decide upon corrections. In real life the flight period can be prolonged up to 12 months and depends on the good will and capacity of airlines to provide the exchange of the sensors.

Calibrations and standards

RH: In 2016, the reference instruments in the calibration chamber were extended with a cryogenic dew/frost point hygrometer. The instrument will be annually calibrated against a transfer standard at MBW-Calibration (Switzerland) that is traceable to primary calibration standards at National Measurement Institutes including PTB (Germany) and NIST (USA).

In order to achieve also traceability of the temperature it is planned to calibrate in the future the temperature sensor against a reference which is traceable to a primary standard (MBW-Calibration (Switzerland)).

O3: Package1 is calibrated in O3 by comparison with a reference instrument Thermo Env. Model 49PS, at several levels of O3 to also check the linearity of the instrument within 1% : 0, 50, 100, 200, 300, 500 and 800 ppb. According to EMEP procedures, this reference instrument is sent twice a year to French Laboratoire National d'Essais (LNE) for comparison with a NIST standard instrument. Pressure sensor on the O3 cells is also controlled via a reference pressure sensor.

CO: Package1 is calibrated in CO using NIST referenced CO cylinders (CO in N2, 500 ppm) and a dilution system. Calibration is done at several levels of CO to also check the linearity of the instrument within 2-5% : 0, 250, 500, 750, 1000 and 1500 ppb. Dilution system is sent twice a year to French Laboratoire National d'Essais (LNE) for flow meters' controls.

Associated Uncertainties

1. The uncertainty of RH is a composite of the following contributions:

a. Uncertainty of uncorrected RH, which is approximately 0.1% RH

b. Uncertainties of the pre- and post-flight calibrations against the Lyman-Alpha and Dew/Frostpoint hygrometer which is approximately 5 % of the measured RH reference values

c. Half of the absolute values of the differences between the pre- and post-flight calibration coefficients, a and b (Eq.(7-A) and Eq.(7-B)).

2. The uncertainties of the temperatures

a. Detector recovery temperature DRT (equal to ±0.25°C)

b. Total Air Temperature TAT (equal to ±0.30°C), derived from DRT (Eq.2), whereby the uncertainty of the recovery factor η of the Rosemount probe housing (Fig. 3 right panel) have been included

c. Static air temperature SAT (equal to ±0.5°C), derived from TAT and M (Eq.1). The contribution of the uncertainty of the aircraft air speed measurement to determination is less than ±0.01°C so this source of uncertainty is negligible

O_3 measurements:

Total uncertainty (4sec.) : ± 2 ppb ± 2%, which is the sum of :

- Thermo Model 49 : ± 2 ppb ± 1%

- Calibration Thermo Model 49PS : ± 1%

CO measurements:

Total uncertainty (30 sec.) : ± 5 ppb ± 5%, which is the sum of :

- CO zero noise over 30 seconds : ± 5 ppb
- CO NIST traceable bottle 500 ppm : ± 2%
- dilution system : ± 2%
- Pressure regulator : ± 1%

Needs in terms of metrology improvement

All measurements / parameters shall be related to the primary standards. Currently the temperature measurements are not related yet to the primary standard (plan to relate in Jan. 2019). Since the measurements are aircraft based, it is not easy to cooperate with other RIs, however IAGOS collaborates with ICOS and ACTRIS. In terms of metrology IAGOS mainly refers to WMO standards.

EUROGOOS

Eurogoos (European Global Ocean Observing System) performs real-time measurements of ocean parameters. The three key parameters of EUROGOOS are temperature, pressure and salinity. Pressure serves as an indication of depth under ocean surface. Salinity controls sea dynamics by changing the density of water masses and thus generating convective currents.

Only few metrology labs in Europe exist to properly calibrate the devices that are used in EUROGOOS. Therefore, users typically send their devices back to the manufacturers for the calibration. As a result, only few documents are dedicated to the calibration of instruments for these parameters within EUROGOOS.

Measurement frequency

The measurements are as far as possible continuous measurements in real time. Devices are attached to a fixed platform or a floating line. Real time means as fast as possible after a minimum of scientific validation, meaning that data packages are sent every hour containing several measurements. Data is transmitted in packages, the slowest data assimilation is setting the sending time of the overall package. Sensor type and speed are the limiting factor for the speed of transmission.

At least once a year calibration is done for the temperature and pressure parameters and twice a year for salinity.

Parameter units:

Pressure is measured in Hectopascal or Decibar while instruments are calibrated in Pascal. Temperature is measured in Celsius, instruments calibrated in Celsius, Celsius is related to kelvin through the ITS-90 fixed points.

Salinity is measured using practical salinity (ratio). Calibration is based on practical salinity and then related to the absolute salinity through the ITS-90 fixed points.

The absolute salinity is a new definition of salinity that links salinity to SI units. Until now, measurements were conducted in practical salinity, which is unitless since it is a percent.

Metrology need:

The relationship between practical and absolute salinity is still not very satisfactory. Ultimately, the reason salinity is measured is to know the density. The absolute salinity is related to density; however, the practical salinity is not because it is an electrical measurement.

There are still theoretical questions related to the equation of the state of seawater itself. Understanding the exact relationship between the salinity as we measure it and the absolute salinity, which is the definition, is an active research area.

For pressure, one calibrates against a pressure balance, same method as for industrial pressure sensors. For Temperature, same as for industrial applications, ITS-90 fixed points is used. For Salinity, OSIL standards of sea surface water provides samples of certified seawater for density and salinity for the calibration of the salinometers.

Uncertainty:

For marine work, in order to quantify long-term changes, you need:

temperature: better than 0.002

practical salinity: 0.002/0.003

pressure: 0.002 (depending on the type of sensor and the depth you are measuring)

0.01 is the target for the overall uncertainty in order to be able to measure small long-term changes

The quality control is ensured by the manufacturer themselves for Salintiy. Temperature sensors are controlled every six months. For pressure, our sensors don't show any significant drifts.

New measurements in EUROGOOS

New biological measurements envisioned in EUROGOOS are challenging; coming up with a proper definition is sometimes still an issue. Working groups are establishing new metrology aspects and standards for those new parameters. Main issues are, how can you translate metrological principles into the field? How can you assure it is working in the same way during operation? How can you assure the way it is working?

Link to other RIs

Eurogoos is a consortium of RIs from different countries; they work together in international projects, European projects, etc. There are tasks where the different RIs work together in joint workshops, or on the level of single research, as well as at the level of the different institutes.

Reports for workshops that have been done from Eurogoos projects, are for example Jerico and Jerico next. Those can be found on the Eurogoos website.

EMSO

Essential oceanic variables in EMSO (European Multidisciplinary Seafloor and water column Observatory) discussed here are sea temperature (Celsius degree), measured with the frequency 5 to 10 minutes by means of thermistor sensor, salinity (conductivity) (PSU), measured with the frequency 5 to 10 min by electrode sensor and Dissolved oxygen, measured in ml/l or µmol/kg, with the frequency 30 min (optode sensor). There are no units for measuring the salinity. PSU is a Practical Salinity Unit, which is based on the international scale TEOS10 (thermodynamic Equation for the Sea Water 2010) and acknowledged by the international community. Dissolved oxygen is measured in the intermediate and deep water. EMSO ERIC owns several calibration labs in Europe providing the calibrations for the measurements of T, S and O2 and other variables including those for others ERICs (EURO-ARGO) like total chlorophyll and nitrate.

From these variables, EMSO aims to study transport phenomena in sea water masses, such as deep convection (vertical mixing) and ventilation (enrichment of water with the gases) processes during winter period as well as the mixed layer (homogeneous layer) deepening influencing the nutrients supply and the biomass bloom starts. Besides that Oxygen Minimum Zone expansion and intensity in the context of the global warming is also investigated.

The most common electronics used in the sensors to measure temperature, salinity and dissolved O2 are thermistors, electrodes and optodes (optical sensor). In optode, quenching method is widely applied. In this method, oxygen is passing through the sensitive membrane and is measured at 2 different wavelengths, one measurement acting as a reference and the other being used as an actual measurement. The main providers of sensors for measurement of all three parameters are such companies as Seabird, Aanderaa and RBR.

Very often, these producers also determine the requirements for the precision of the instruments. Thus T and conductivity (salinity) sensors precision is determined by the largest producer of sensors, Seabird (USA). For oxygen, in open ocean regions the precision we are looking for is 1 µmol/kg (Gruber et al., 2007)

On the way from the raw data to the data provided to final users the data passes several additional steps. Oceanographic data from mooring are collected once a year. Delayed mode data are passing through quality-control steps and adjustment to provide correct a dataset. Usually, time series at different pressure level are proposed to end users.

QA procedures:
Regular calibration of the sensors by manufacturer or qualified metrology lab.
QC procedures:
Search of outliers in dataset, when possible comparison of sensor measurements with standards. For oxygen, comparison with reference measurement (Winkler); for salinity with salinometer checked every day during the campaign with IAPSO standard.

Metrology tree to SI units for each measured key parameter:

Temperature: Sensors are calibrated in temperature regulated bath and compared to reference temperature measurements (Standard Platinum Resistance Thermometer, DC comparator resistance bridge, standard resistor 10ohms). SPRT are related to the SI units by 2 fixed points: the triple point of Water and the melting point of Gallium.

Dissolved Oxygen: Sensors are calibrated in temperature regulated bath and compared to Winkler titration that is recognized as reference method by the oceanography community and standardization too (ISO5813:1983(F)).

However, the sampling associated to this Winkler reference method needs experienced staff to proceed correctly, thus reducing errors and variabilities of measurements. Eventually, though the reference method exists it is not sufficient to ensure the quality and traceability of data to SI. That's why laboratories ensuring the metrology of this parameters participates annually to interlaboratory comparisons to survey the quality of their Winkler reference measurements.

Salinity:

Sensors are calibrated in temperature regulated bath and compared to samples analyzed with reference salinometers (Guildline instruments).

Reference salinometers are calibrated with IAPSO Standard SeaWater (SSW). SSW is a primary reference solution, prepared from natural seawater from the north atlantic and has a conductivity ratio assigned according to procedures defined in PSS-78. These solutions are considered as reference but their replicability over a long timescale is missing. Moreover, they are not considered as certified reference materials (CRM) as no uncertainty estimation is associated to the reference conductivity ratio assigned to the standard.

The definition of salinity is also under reinvestigation as this parameter is dependent to several influence quantities and highly dependent on the technology used to measure it. Several projects addressed this issue in the last decade and studies are still under progress to relate salinity to SI, (eg. an empirical conductivity ratio-density relationship was studied (in the OCEAN project http://www.ptb.de/emrp/705.html).

Uncertainty computation for the key parameter

For temperature:

GUM (Guide to the expression of uncertainty in measurement) calculations combining reference temperature sensors uncertainties, temperature-regulated bath uncertainties and sensors uncertainties.

For oxygen:

GUM (Guide to the expression of uncertainty in measurement) calculations combining the different uncertainties on the variables (volumes, concentrations, masses, etc…) that appears in the equation used to calculate the dissolved oxygen concentration obtained by Winkler titration.

For salinity:

No uncertainties calculated due to lack of information and traceability.

Metrology Needs:

For temperature

We should be able to perform calibrations with global uncertainties of few millidegrees. This is not the case currently mainly due to the size of baths (and thus inhomogeneity in temperature) that are necessary (around 400 to 800 liters) to calibrate large size oceanographic instruments.

For oxygen

Need of certified reference material: in order to detect the possible errors that can be introduced during the sampling or the titration, a CRM would be needed. Indeed, as laboratories tend to homogenize their protocols and equipment (in order to improve results), there is an increasing risk of introducing a common offset for all labs that could not be detected in interlaboratory comparisons. A CRM would solve this issue.

There is also a need to reduce the sources of uncertainty of sensors and Winkler titration to answer properly to oceanographic topics.

For salinity

A clear and stable definition of salinity, should be investigated (especially taking into account the recent progress made in technology).

There's also a need of certified reference materiel (in terms of standard solution) and relation to SI.

Wider metrology needs:

Need of a reference metrology lab in charge of research on these topics and ensuring the quality/authenticity of the calibrations/measurements.

EMSO is in relation with the following NMIs: LNE, PTB, University of Chemistry of Tartu, Syke, NPL, InRIM, SMU, IPQ

Section 3: Link to SI units, BIPM and National Metrology Institutes

The international community as adopted the metric system as the most commonly used system of measurements. An international treaty, first signed in 1875, has created the International Bureau of Weight and measures (BIPM) to represent the world-wide measurement community, to be a centre for scientific and technical collaboration and to be the coordinator of the world-wide measurement system. Individual nations have so called National Metrology Institutes (NMIs) that are coordinated under BIPM. European NMIs are regrouped under the association EURAMET (European Association of National Metrology Institutes)

BIPM

Bureau international des poids et mesures is an international organisation established by the Metre Convention, through which Member States act together on matters related to measurement science and measurement standards. As of 14 November 2018, there are 59 Member State and 42 Associate States and Economies.

Its mission is to work with the NMIs of its Member States and to use its international and impartial status to promote and advance the global comparability of measurements for scientific discovery and innovation, industrial manufacturing and international trade, improving the quality of life and sustaining the global environment.

BIPM liaises with relevant intergovernmental organizations and other international bodies in order to develop opportunities for the application of metrology to global challenges. Organisation aims to be a centre for scientific and technical collaboration between Member States, providing capabilities for international measurement comparisons on a shared-cost basis. It coordinates international comparisons of national measurement standards agreed to be of the highest priority, establishes and maintains appropriate reference standards for use as the basis of key international comparisons at the highest level and provide selected calibrations from them.

Change in SI unit [1]

Related to metrology, one could not have omitted to at least mention, the landmark decision, of the BIPM's Member States voted on 16 November 2018 to revise the International System of Units (SI), changing the world's definition of the kilogram, the ampere, the kelvin and the mole.

The decision, made at the 26th meeting of the General Conference on Weights and Measures (CGPM) in Versailles, France, means that all SI units will now be defined in terms of constants that describe the natural world. This will assure the future stability of the SI and open the opportunity for the use of new technologies, including quantum technologies, to implement the definitions.

In the revised SI four of the SI base units – namely the kilogram, the ampere, the kelvin and the mole – are redefined in terms of constants; the new definitions are based on fixed numerical values of the Planck constant (h), the elementary charge (e), the Boltzmann constant (k), and the Avogadro constant (NA), respectively. Further, the new definitions of all seven base units of the SI are also uniformly expressed using the explicit-constant formulation, and specific mises en pratique will be drawn up to explain the realization of the definitions of each of the base units in a practical way. The new definitions will come into force on 20 May 2019.

For temperature that is one of the parameter the most shared between the different RIs of ENVRI Plus, the definition of the kelvin in force since 1967/68 (13th meeting of the CGPM, Resolution 4) is abrogated. The kelvin is currently defined in terms of an intrinsic property of water that, while being an invariant of nature, in practice depends on the purity and isotopic composition of the water used. The kelvin would be better defined if it were linked to an exact numerical value of the Boltzmann constant k_B. With the new definition, the kelvin, symbol K, is the SI unit of thermodynamic temperature, it is defined by taking the fixed numerical value of the Boltzmann constant k to be $1.380\ 649 \times 10^{-23}$ when expressed in the unit $J\ K^{-1}$, which is equal to $kg\ m^2\ s^{-2}\ K^{-1}$, where the kilogram, metre and second are defined in terms of h, c and $\Delta\nu_{Cs}$.

This definition change will have no immediate effect on temperature measurement practice or on the traceability of temperature measurements, and for most users, it will pass unnoticed. The redefinition lays the foundation for future improvements. A definition free of material and technological constraints enables the development of new and more accurate techniques for making temperature measurements traceable to the SI, especially at

[1] https://www.bipm.org/en/measurement-units/rev-si/

extremes of temperature. After the redefinition, the guidance on the practical realization of the kelvin will support its world-wide dissemination by describing primary methods for measurement of thermodynamic temperature and equally through the defined scales ITS-90 and PLTS-2000.

EURAMET

EURAMET's (European Association of National Metrology Institutes) coordinated research actions focused on research for robust and stable measurement for monitoring the environment and on research into innovative new systems and technologies that precisely assess environmental parameters. In 2010 and 2013, EURAMET's European Metrology Research Programme (EMRP) launched a call for projects in this field with an aim to improve data quality for policy making, underpinning environmental research activities and stimulating technological innovation. The projects focus at the local environmental level on air, water and soil pollution, and at the global level on challenges relating to climate change. Earlier this year, the successor programme EMPIR (European Metrology Programme for Innovation and Research) launched another call for Environment projects.

To foster possible solutions for present and upcoming environmental metrology challenges the EURAMET Task Group on "Metrology for Environment" was established in 2014. The tasks of the group include collaboration with relevant institutions such as the World Meteorological Organisation (WMO) but also environmental protection agencies and manufacturers. The task group supports EURAMET's Technical Committees and acts for the development of standards, measurement methods and measurement structures. It reports to EURAMET on new perspectives, emerging needs and activities related to traceability, quality assurance and calibration procedures for environmental measurements.

Examples include the contributions to EURAMET's Strategic Research Agenda and the input to call scopes within the European Metrology Programme for Innovation and Research (EMPIR). To promote the metrology approach of environmental issues to stakeholder communities the task group has organised a number of events such as the 'Metrology for Meteorology and Climate' conference and 'Metrology for Environment in the Arctic', which is a breakout session at the Arctic Circle, the most important scientific and diplomatic event on Arctic environment. EURAMET has already taken measures to meet a series of metrology needs in that area.

Better measurements in the climate sector will show their real benefit in the coming years or decades. The main effort in detecting climate change and therefore supporting environmental protection, should be focussed on how to harmonise and compare the climate data to some reference. The role of the metrology community is well defined: it's the unique contribution to improving data quality that only metrology can deliver. EURAMET and the associated NMIs should guarantee that such effort is not limited to the life time of joint research projects, but will be an established field of metrology. This should involve the promotion of the coordinated European action performed in the research programmes towards improving measurements for a better knowledge on the state of our environment and climate.

Initiatives in the frame of WMO:

Since 1992, the Global Climate Observing System (GCOS) has been operating to ensure that information needed to address climate-related questions are obtained and made available to all potential users. However, the demands on the climate observing system are increasing. Adaptation to climate change and monitoring the impact of mitigation efforts require local and regional scale information, including forecasts and projections on different timescales that provide a more rigorous assessment of future climate change and variability. It is important that we can monitor climate changes adequately, so as to enable relevant, timely, responses, and to understand the extent to which mitigation strategies are working. The greater the confidence that society has in these measurements, the more impact they will have. As a consequence, it is important that GCOS is adapting in order to fulfil the growing demand for robust climate observations. Adaptation of GCOS need to not only increase spatial and temporal coverage as well as measured parameters, but also provide an answer to inevitable changes arising from technology and observing practices evolvement. Imminent issues include e.g. the replacement of mercury-in-glass thermometers and the use of third party measurements arising from private entities, the general public, and non-National Met Service public sector activities. The observations system that underpins a more rigorous assessment of future climate change should be accurate, and metrologically traceable, with long term stability and well characterised uncertainties.

To meet these needs, the GCOS Atmospheric Observation Panel for Climate (AOPC) during the 22th meeting held in UK in March 2017, agreed on the creation of a dedicated task-team to scope a potential GCOS Surface Reference Network (GSRN). The potential for such a network has been proposed by GCOS AOPC and by the Commission for Climatology. This Task Team is charged with taking this forwards towards practical implementation providing a concrete roadmap as to what would be required and to canvas stakeholders. Working models on which to base deliberations include the GCOS Reference Upper Air Network, US Climate Reference Network, and Global Cryospheric Watch.2

The task team, composed by 11 experts representing all interested components at WMO as well as from BIPM on behalf of metrology community, held a first meeting at the end of 2017[3], and a second one at the end of 2018[4]. A position paper, developed by members of the community and published in the International Journal of Climatology in 2018[5], includes the rationale of the existence of a global surface reference network.

It is not necessary to achieve reference measurements at all sites of the observations system, since a tiered approach can be adopted (Thorne et al., cited paper Figure below). A reference network can provide a sufficient set of long-term, high quality, stable observations to enable an improved understanding of the remainder of the continually evolving global observing system.

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[2] https://gcos.wmo.int/en/task-team-proposed-gcos-surface-reference-network-ttgsrn

[3] https://library.wmo.int/doc_num.php?explnum_id=4468

[4] https://public.wmo.int/en/events/workshops/global-surface-reference-network-gsrn-writing-team

[5] Thorne et al, "Towards a global land surface climate fiducial reference measurements network", DOI: 10.1002/joc.5458

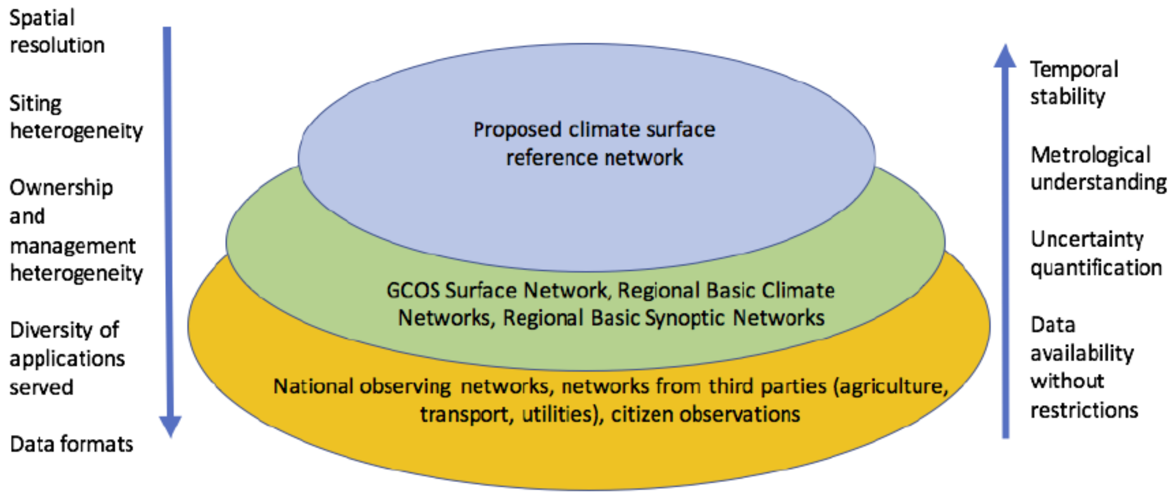

Figure 2 (from Thorne et al, Int J Climatol., **38,** 2760–2774, 2018) - Conceptual outline of how climate observational capabilities map onto a tiered system of systems approach. From top to bottom we have Reference, Baseline and Comprehensive tiers. Arrows report important facets of the measurements that increase moving down or up tiers.

The current global surface meteorological observing network over land, including WMO stations (~11000), and potentially many more observations not currently reported in this manner held by numerous other stakeholders, collectively represent the lowermost 'Comprehensive networks' tier in the figure above. The top tier, at the contrary constitute the Reference network. Between these two tiers lie Baseline networks, the defining characteristics of which are long-term operational commitment and spatial representativeness (Figure middle tier). A set of high-quality long-term fiducial reference measurements of essential climate variables will enable future generations to make rigorous assessments of future climate change and variability, providing society with the best possible information to support future decisions.

Basing their work on this paper, the GSRN Task Team is asked to move forward the concept of a global surface reference network towards the practical implementation of such a network and to provide a concrete roadmap for consideration of the key stakeholders. During 2019, the Task Team will produce a document that will include benefits, requirements, network design, governance and management proposals. This document will be part of the material used to assess the interest in the GSRN from stakeholders and to investigate about possible resources.

General assessment of the traceability to standards in the RIs of ENVRIplus

The question was asked to ENVRIPlus RIs to assess how traceability from Standards to local site measurement is ensured, the so called «Tree of metrology» and determine what is the implication of National Metrology Institutes (NMIs) in the infrastructure. A questionnaire was distributed also intended to identify needs for standardization, NMI involvement, traceability to SI units, plan to adopt an ISO norm (see Annex 3)

The questionnaire was sent to the following ENVRIplus infrastructures: ACTRIS, EMBRC, EMSO, ESONET, EURO-ARGO, EUROGOOS, FIXO3, IAGOS, ICOS, LifeWatch, SIOS.

It appears that approaches to metrology traceability (or tree of metrology) largely varies from one infrastructure to the other and largely depends on measured parameter. For instruments in general it can involve manufacturer certificate, in situ comparison to reference instruments traceable to SI (when possible), calibration at recognized accredited laboratories/sites. For reference material, standards from NMIs are used and sometimes duplicated are used on sites.

For several key environmental parameters there is no recognized traceability to SI. In these cases, reference standards or methods recognized in the community are used.

Also implication and cooperation of NIMs with RIs cover a wide spectrum of conditions. For SIOS, ACTRIS, EURO ARGO, NMIs provide (i) calibration of reference instruments and (ii) contribute to transfer metrology standards on field (improve traceability);
For SIOS, ACTRIS, ICOS ATM, NMIs provide in general gas standards;
EURO ARGO collaborates with NMIs in national or European projects in order to improve these issues in traceability and reduce uncertainties;
For IAGOS, NMIs are indirectly contributing via GAW-WCCs and manufacturer calibrations. Moreover, NMIs are part of an advisory group within the IGAS (IAGOS for GMES Atmospheric Services) follow up project.
The analysis of the questionnaire identified needs for improved standardization for: black carbon, particle absorption, radiation measurements. Needs for reference material or methods/protocols were expressed for 02, CO2, pH, salinity/conductivity, turbidity, fluorescence and eddy covariance. Some of these needs could be picked within WP2 of Theme1 of ENVRIPlus and are detailed in the next section. Need to improve tree of metrology and standardization was also identified for measurement of basic parameters such as temperature and atmospheric relative humidity.

Section 4: Metrology developments: Eddy covariance, CO_2, Sea water acidity, Radon

Based on the gap analysis made in ENVRIplus and funding opportunity, several concrete testcases were initiated or further promoted, where metrology improvement relevant to ENVRIplus Ris are being developed via dedicated projects.

Eddy covariance (EC) measurements: a new WMO standard

Why a standard?
The application of the technique at relatively large temporal and spatial scales and operational systems for longer and longer periods, requires standardization. Particularly in light of the current development activities that focus on integrating carbon and ecological observations transnationally/inter-continentally make this a salient, scientifically and politically urgent issue, e.g., ICOS, NEON, AsiaFlux, CoopEUS (www.coopEUS.eu).

It is critically important that measurements are performed in a standardized manner for their eventual use in GMES services, including use in operational data assimilation systems. We will collaborate with the WMO Technical Commission on meteorology and other international bodies to develop a WMO standard for EC measurements. This requires the production of a standard protocol, including data acquisition, treatment, corrections, error and uncertainty analysis.
To achieve this goal, ICOS and NEON have joined forces to propose to CIMO-ET-NIST the development of an EC standard to be included in the CIMO Guide. The effort was lead by Han Dolman, Vrije Universiteit Amsterdam.

The mission of the Commission for Instruments and Methods of Observation (CIMO) is to promote and facilitate international standardisation and compatibility of instruments and methods of observation used by Members, in particular within the WMO Global Observing System, to improve quality of products and services of Members and meet requirements WMO is a ISO recognised standard setting institution
https://library.wmo.int/opac/doc_num.php?explnum_id=3121

The representatives of major continental networks (ones with governance structures and mandates for sustained observing capability such as ICOS, NEON, AsiaFlux, OzFlux, AmeriFlux) formed a working group that reflects the needed level of international organization and consensus to develop an EC Standard, i.e., its instrumentation type(s) (principles of operation), algorithmic processes, and field deployment/site design.
The expert working group has submitted a draft standard for eddy covariance measurement in March 2018 to be considered as a chapter in the CIMO handbook. The expert working group who benefited from the support of ENVRIplus RIsis now awaiting formal CIMO/CAS review to have final version, with the aim to have this standard published as soon as practicable after that.

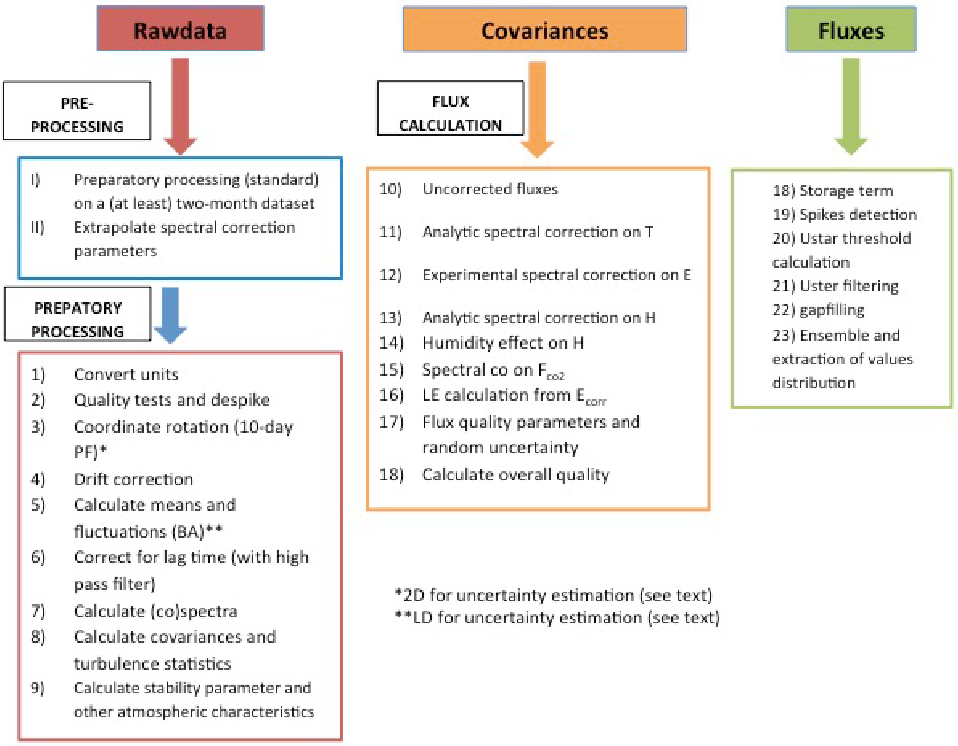

Figure 3 - Conceptual structure: data processing for eddy covariance flux measurements

Standards of carbon dioxide in air

Carbon dioxide (CO_2) is the most important greenhouse gas in terms of radiative forcing which increase is most directly related to anthropogenic emissions. It is therefore important in the context of climate studies to have standards of CO2 in air that are accurately linked to mole SI unit via the kilogram.

WMO has its international standard for CO_2 maintained by NOAA in the US. Recently NMIs came into play extending the offer of reference gases for CO_2 in particular. This was done for example under the EURAMET project HIGHGAS[6]: Metrology for High Impact Greenhouse Gases (June 2014-May 2017)

For CO2, HIGHGAS took especially good care about the isotopic composition of the synthetic air used in the CO2 standards. Indeed, current measurements for greenhouse gases are done spectroscopically, observing the adsorption of certain wavelengths of light that indicate the presence and abundance of different elements. However, this means that if a gas has more than one isotopologue, then if the isotopic composition of the synthetic reference standards differs from that of the ambient atmosphere a systematic bias will result reducing the accuracy of the measurements. Therefore, there is a need to produce synthetic standards with the same isotopic composition as ambient atmosphere, and also to investigate the effect of impurities on spectroscopic measurements.

Seawater acidity

Research in marine science requires an extremely small standard uncertainty in pH measurements (of about 0.004), over a fairly narrow range of pH, and this is far smaller than the differences between many of the operationally defined ‘pH’ quantities, which may be up to 0.2 ‘pH’.

A metrological traceability hierarchy between the conceptual pH value defined in terms of hydrogen ion activity and pH measured in the field by glass electrodes is only established for a few selected calibration procedures in media of low concentration of ionic charges below 0.1 mol/kg. In contrast, seawater has a high concentration of ionic charges (around 0.7 mol/kg for a practical salinity of 35) which causes accuracy problems when using conventional (commercially available) pH calibration standards. Two different methods can be used to measure seawater acidity: the potentiometric method that is based on a voltage measurement of an electrode system providing a pH value, and the spectrophotometric method that is based on an optical measurement of the protons concentration providing a so-denoted pHT value. The potentiometric method is particularly established in metrology to define the pH scale, realised with some defined buffer solutions, while in oceanography mainly the optical method is used.

[6] http://projects.npl.co.uk/highgas/

The Euramet JRP project ENV05 OCEAN[7] (2011- 2014,) lead by P. Spitzer from PTB in Germany addressed this issue. One of the main achievements of the project is the development of primary and reference methods for acidity measurements. As a representative matrix for seawater acidity measurements, artificial seawater with IAPSO approved reference composition (salinity 35) in Tris-Tris·HCl buffer was selected and characterised by a primary pH system (Harned cell), with the aim of determining pH and the pHT value.

Now days, LNE in France, produces reference material TRIS/TRIS-HCl buffers in synthetic seawater reference materials characterised for pHT (RM LNE-MR-S35-pHTXXx) with nominal values between 7.5 and 8.5 and are available on demand with an expanded uncertainty of 0.005. A case study is undergoing with a collaboration with JPI OCEANS for this reference material to be used as QA/QC purpose for spectrophotometric measurements

Last year, EURAMET has established the European Metrology Network on Climate and Ocean Observation (http://www.eoos-ocean.eu/) to provide a single contact point on metrological issues related to climate and ocean observations.

Black Carbon

An EMPIR project running from 2017 to 2020 was accepted with participation of the ACTRIS RI on the subject of Metrology for light absorption by atmospheric aerosols with a special focus on black carbon. The project entitled "Empir Black Carbon" was coordinated by P. Quincey in the UK.

Overview of the project
The measurement of particles in air characterised as black carbon is important both for their role in climate change and as a measure of combustion products associated with health effects. Measurements are made very widely, and compact, precise, real-time, relatively inexpensive instruments are available. Although it is conceptually a simple measure of the light absorbing properties of airborne particles, the metric does not currently have SI traceability, with consequences for the comparability and interpretation of data.

Although black carbon measurement is in principle a simple optical measurement of absorption, characterised by the aerosol light absorption coefficient, traceability is hampered by the fact that routine monitors determine the absorption of particulate matter collected on a fibrous filter. Empirical but non-traceable correction factors are then incorporated into the conversion from light absorption coefficient into the reported particle mass concentration.

The objective of the project is, for the first time, to bring SI traceability to field of black carbon measurements, so that their accuracy and value is greatly increased. The specific objectives are:

[7] http://www.ptb.de/emrp/env05.html

1. To establish a set of well-defined physical parameters, such as aerosol light absorption coefficients and mass absorption coefficients, which together can be used to quantify black carbon mass concentrations with traceability to primary standards.
2. To develop and characterise a black carbon standard reference material (SRM), as a near-black carbon source that is highly relevant for atmospheric aerosols, together with methods for using it to calibrate field black carbon monitors.
3. To develop a traceable, primary method for determining aerosol absorption coefficients at specific wavelengths that are to be defined for the benefit of users. The method should have defined uncertainties and a quantified lowest detection limit.
4. To develop a validated transfer standard for the traceable in-field calibration of established absorption photometers such as multi angle absorption photometers, aethalometers and particle absorption photometers. The transfer standard should make use of the black carbon SRM (developed in objective 2) and associated portable instrumentation characterised by the primary method (from objective 3).
5. To facilitate the take-up of the technology and measurement infrastructure developed in the project by standards developing organisations (CEN, ISO) and end users (e.g., European Environment Agency (EEA), World Meteorological Organisation-Global Atmosphere Watch (WMO-GAW), the ACTRIS (Aerosols, Clouds, and Trace gases Research InfraStructure Network) Project). The current state-of-the-art is that black carbon measurements are being widely made based on a principle that has been used for many decades, with one of several designs of filter-based instrument, such as multi angle absorption photometers, aethalometers and particle absorption photometers. However, robust calibration techniques and traceability to the SI for these instruments are outstanding issues, such that different types of instrument can give results differing by up to 30 %. This project will provide a reference “soot” (black carbon) material for the calibration of those filter-based techniques and will put traceability and calibration mechanisms in place for the first time, enabling measurement of black carbon with a target uncertainty of ±10 % (95 % confidence level).

The technical results that are expected from this project, are as follows:
1. Physical Parameters for traceable quantification of black carbon mass concentrations
The physical properties of aerosols (and the particles within them) that are relevant to black carbon measurements will be clearly defined, in a way that clarifies how traceability to the SI can be established.
2. Black carbon Standard Reference Material
A Standard Reference Material, together with a method for its controlled introduction to black carbon instruments in the field, will be developed and tested.
3. A traceable, primary method for determining aerosol absorption coefficients
A preferred lab-based, SI-traceable, well-characterised method for determining aerosol absorption coefficients at specific wavelengths will be designed and published. This will be selected from options including established techniques such as extinction minus scattering and more novel techniques such as photothermal interferometry. It will be suitable both for calibrating instruments in the laboratory, and for certifying the properties of the Standard Reference Material source of Objective 2.
4. A validated transfer standard for in-field calibration of absorption photometers
A practical and validated protocol for calibrating black carbon instruments in the field will be developed, incorporating a portable Standard Reference Material source. This will be tested in a series of European field trials across a range of ambient concentrations, typically up to 50 Mm-1, to assess the impact of field conditions on instrument accuracy.

The project output is expected to provide the basis for new black carbon standards by European and International standards developing organisations like CEN and ISO. In terms of socio-economic benefits, the project output would potentially lead to revised air quality legislation, based on black carbon, for which reliable measurement methods would be available.

Radon

An EMPIR Potential Research Topic was recently developed under the leadership of A. Rottger from BTB Germany and C. Grossi from UPC, Spain, with the participation of ICOS. It is entitled: Implementation of radon metrology for the analysis for the atmospheric budget of greenhouse gases and radiation protection in the environment.

Environmental radon observations offer support for the quantification of greenhouse gases (GHGs) emissions. Independent techniques for emission estimates, such as the so-called Radon Tracer Method (RTM) make use of radon measurements. This is of direct use by research infrastructures like ICOS where it can also be used for the study of the behaviour of the Planetary Boundary Layer development and in the improvement of Atmospheric Transport Models.

In addition, radon is the main source of natural radiation exposure and its environmental diffusion is important with respect to radiation protection issues.

The overall objective of the EMPIR project is to provide sound and novel metrological tools and relevant data for stakeholders, like ICOS, EURDEP, ALMERA, IAEA, WHO, related with emission reduction strategies of greenhouse gases and radioprotection of general public.

The specific objectives of this project are:

- To establish metrological traceability of outdoor low-level radon activity concentration measurements as input for climate networks and radiation protection networks.
- To support metrological infrastructure for radon flux measurements as input for identification of radon prone areas and for application of radon tracer method. To harmonise different radon flux measurement methods by intercomparison campaigns.
- To validate existing radon flux inventories and models using experimental radon activity concentration data and radon flux data. Including dosimetric and spectrometric data from the radiological early warning networks in Europe.
- To develop standard protocols for radon tracer method to retrieve GHGs fluxes at atmospheric climate stations.
- To provide dynamic radon and radon flux maps for climate change research and radiation protection according COUNCIL DIRECTIVE 2013/59/EURATOM.

To these objectives, a strong improvement of the metrology related with the measurements of really low atmospheric radon concentrations averagely between 1-20 Bq m^{-3} and of continuous and fast radon fluxes is needed especially with respect to traceability.

Also, the European Atlas of Natural Radiation, developed and maintained by the Joint Research Centre of the European Commission, does not yet include radon in the environment (outdoor radon) or neither radon flux maps, due to the metrological challenge of measurement.

Atmospheric ^{222}Rn measurements are currently carried out at tens of worldwide monitoring stations for GHGs and air quality using several measurement principles. However, these different measurements are not yet harmonized between them and no traceability to international standards has been developed so far. On the other hand, radon flux measurements and inventories are still to an early stage. No protocols nor reliable measurements techniques have been confirmed.

Impact

The reference continuous radon monitor and the traceability chain for really low radon concentration (from 1 to 100 Bq m^{-3}) will allow high quality and harmonized atmospheric radon concentration data dynamically mapped for Europe.

Experimental radon flux measurements carried out over Europe within the proposed project will also help in the validation of existing European radon flux models and or inventories in collaboration with EUROPEAN Atlas of Natural Radiation (REMon) from the Joint Research Centre (JRC) of the European Commission in order to obtain on-line real-time European radon flux maps which can be used for climate studies, such as the ones previously reported, or for socially important radioprotection goals like the identification of radon prone areas and their evolution if remediation measures are taken.

The REMon-JRC will get access to reliable data of outdoor radon activity concentrations for the first time. This impact is enforced by the fact that the first digital version of the European Atlas of Natural Radiation is available now through a web portal, as well as the methodology and results for the maps already developed. So far, the digital Atlas contains: an annual cosmic-ray dose map; a map of indoor radon concentration; maps of uranium, thorium and potassium concentration in soil and in bedrock; a terrestrial gamma dose rate map; and a map of soil permeability. With the new data source of radon activity concentration and flux a dynamical mapping of the radon situation in the environment will be possible for the first time. This will significantly help to focus the radiation protection cost efficiently and successful underpin the Council Directive 2013/59/Euratom.

Section 5: Development of a metrology lab in the Arctic

Why a calibration laboratory in the Arctic ?

The Arctic region is a fundamental observation area for climate change evaluation: climate change comes first and comes faster in the arctic. In implementing global as well as regional integrated observing system, attention needs to be devoted to secure metrologically-robust methods and full comparability for Essential Climate Variable (ECV) measurements. The higher accuracy required to quickly capture trends; the extreme range and conditions of sensors exposure; a robust comparability asked by the different measurement networks; the need of dedicated calibration procedures, together with the logistical problems associated with such remote location, motivate the proposal for a joint effort to address metrology experience and activities for Arctic research applications. The Ny-Alesund international research base and community offers a unique infrastructure to directly link metrological traceability to on site polar measurements.

In this super-site, multitudes of measurements in all climate system domains are collected to understand the environment and its evolution. Metrological traceability is fundamental to establish robust comparability among the multitude of observations made in different locations, over time and by different research groups. The comparability is required

- across instrument and measurement types and locations
- across different organizations and different nations
- across generations of researchers
- on climate-change scales
- to fundamental physical models

Direct and shorter chain to higher quality standards improves the overall uncertainty. As an example, the need of 0.1 °C uncertainty in temperature measurements seems ‘‘easy’’ to achieve, but when all the aspects of the calibration and measurement are evaluated and included, starting from a calibration at millikelvin level becomes crucial, to avoid uncertainty degrades quickly well surpassing the target idea, as shown in the following scheme.

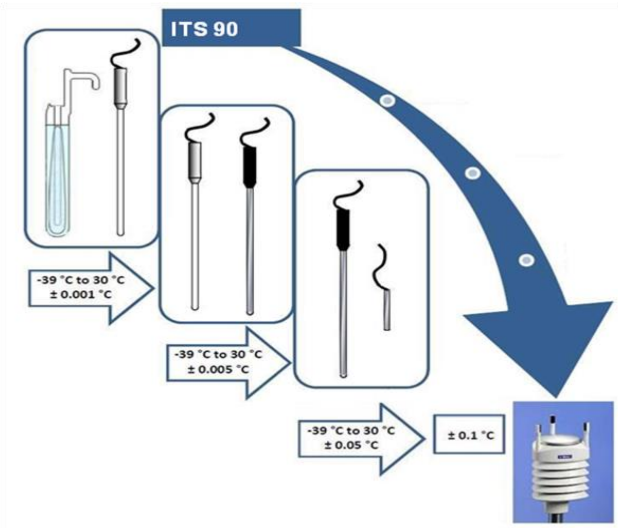

Figure 4 - *An example scheme of calibration traceability for temperature instruments: from the SI standards, the ITS-90 fixed points, to an automatic weather station. How the uncertainty degrades well before even evaluating measurement uncertainty?*

Reducing the length of the metrological chain can be achieved by establishing a permanent Arctic Metrology Facility in a polar research station, to directly link metrological traceability to on site environmental measurements, with the implementation of dedicated devices, specific calibration procedures, and uncertainty evaluations including quantities of influence.

In 2014, part of the MeteoMet project objectives, the ‘‘Arctic Metrology’’ campaign was conducted. A special calibration chamber[8], equipped with pressure and temperature sensors, traceable to primary standards of the International System of Units (SI), was manufactured by the Italian Institute of Metrology and shipped to Ny-Alesund. While the

[8] Meteorol. Appl. **22**, 842–846 (2015)

chamber was available on site, it was also used to calibrate some sensors operated at the Italian Climate Change Tower (CCT) of CNR. Together with absolute calibration, the uncertainty budget generated by the uncertainty in the calibration of the reference standard, the characteristic of the chamber, in terms of temperature uniformity and stability and, the electrical and thermal noise of the sensor under calibration, was computed and integrated as a single uncertainty on the sensors response[9].

NMI involvement was needed as typical calibration accredited laboratories or manufacturers are not in charge to assist research teams in:

1. developing dedicated calibration procedures including mutual analysis of quantities,
3. study of field measurement uncertainty (not approachable by providers and sometimes a hard task for non-experts in metrology researchers).

Towards a metrology laboratory a Ny Alesund

Based on the experience achieved during the ‘‘Arctic Metrology’’ campaign of 2014, A plan to implement a calibration laboratory in one of the structures available in Ny-Alesund was then started. The following steps were identified as necessary to implement a such laboratory:

- acquisition of a commercial climatic chamber and definition of a dedicated set of instruments to adapt such chamber to more specific use and calibration procedures, for air temperature and humidity sensors;
- construction of a special climatic chamber to allow temperature and pressure sensors calibration, including the possibility to evaluate the mutual influences on sensors from both quantities similar to what already used in 2014;
- construction of a specific liquid bath for the calibration of sensors used to measure temperature in sea water, lakes, ice and permafrost;
- survey of target uncertainty in temperature measurements in identified field measurements;
- definition of availability of metrology staff and training of dedicated staff for the first years of implementation of the calibration laboratory;
- identification of logistical requirements and available room in Ny-Alesund to host the calibration laboratory.

The starting structure for a Metrology Laboratory in Ny-Ålesund, was launched in May 2017, organized by the MeteoMet project with the ISAC-CNR. During 2017 field campaign (repeated since than regularly), 4 temperature sensors and one barometer of the CCT were dismantled together with the logger. The instruments were calibrated between -25 °C and + 15 °C, and from 90 kPa to 110 kPa.

[9] Musacchio C et al., Arctic metrology: calibration of radiosondes ground check sensors in Ny-Alesund. Meterol Appl 22:854–860. doi:10.1002/met.1506

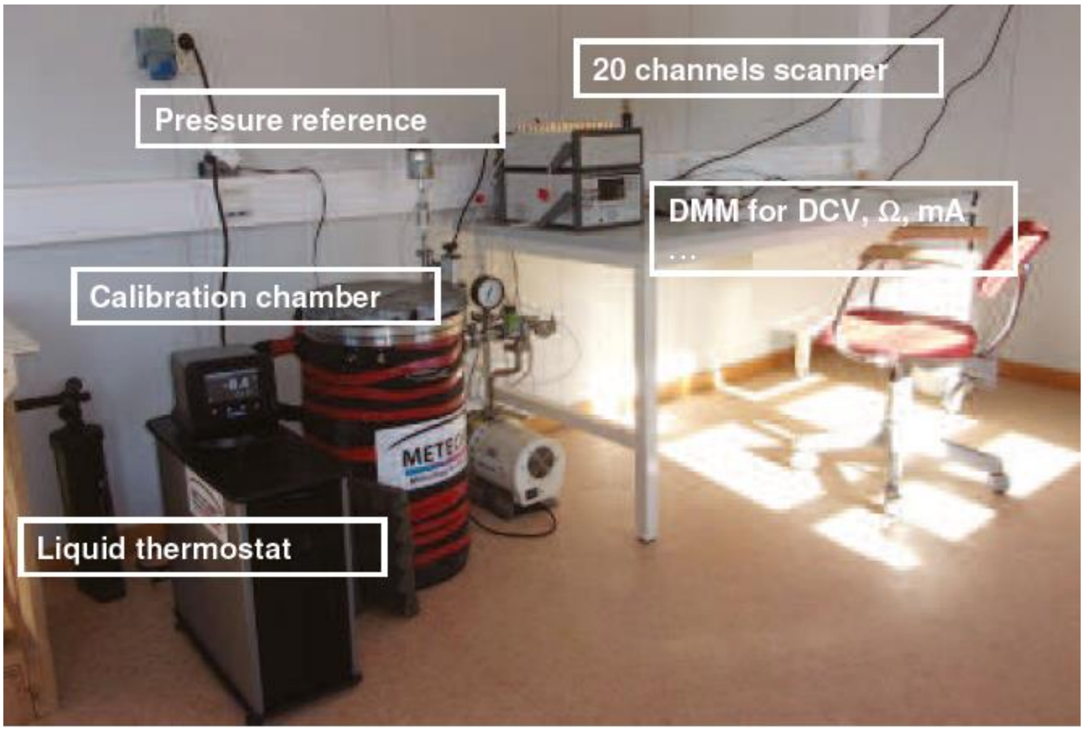

Figure 5 - *The instruments installed in the Vaskeri Lab in May 2017 to establish a first nucleus of the Metrology Laboratory.*

Since 2017, this first nucleus of the Metrology laboratory is now fully operating and allows the calibration of temperature and pressure instruments, the characterisation of sensors dynamics, the evaluation of mutual influences among the quantities. More in details, now available are:

Air temperature		
(PT, PRT, PT100, thermocouples, thermistors)	-35 °C -> +20 °C	u=0.03 °C
Air pressure		
Any kind	5 kPa -> 101.325 kPa	u=40 Pa
Soil, ice, water, permafrost temperature		
(10 cm length max probes)	-40 °C -> +30 °C	u=0.01 °C

Combined calibration of pressure sensors including temperature correction curve

Future implementation plan include:

from the point of view of calibration and traceability

- Extension of the calibration capabilities to further quantities and typologies of instruments: acquisition of a 190 L climatic chamber with extended range for air temperature and humidity, a calibration kit and SPRT, a comparator block, a standard dew point meter, Improved pressure reference, a larger liquid thermostat, to allow multiple calibrations and bigger sensors;
- A permanent calibration service scheduled yearly, with presence of trained staff at the metrology lab (Vaskeri lab)

from the point of view of the evaluation of measurement uncertainties

- Air temperature uncertainty components in field. Setting a test site for evaluating uniformity as a component of uncertainty in representativeness.

- Albedo experiment in arctic conditions (spring season)
- Towards full uncertainty evaluation in permafrost and ice temperature measurements.
- Solar radiation. Temperature and angle effects
- Water temperature. Target uncertainty and capabilities
- Comparability as a source of uncertainty (i.e. CCT)
- Contributing in a proposal to WMO for a standard weather station for arctic/cryosphere observations

Annex 1: List of metrology contacts in ENVRIplus RIs

RI	Metrology contact	email
ACTRIS	Fabio Madonna	Fabio.Madonna@imaa.cnr.it
IAGOS	Susanne Rohs	s.rohs@fz-juelich.de
EMSO	Joaquin Del Rio	joaquin.del.rio@upc.edu
EURO-ARGO	Sylvie Pouliquen	euroargo@ifremer.fr
EUROFLEETS	Valérie Mazauric	Valerie.Mazauric@ifremer.fr
EUROGOOS	Rajesh Nair	rnair@inogs.it
FIXO3	Laurent Coppola	coppola@obs-vlfr.fr
JERICO	Florence Salvetat	Florence.Salvetat@ifremer.fr
ESONET	Ingrid Puillat	Ingrid.Puillat@ifremer.fr
ANAEE	Jacques Roy	Jacques.ROY@cnrs.fr
EPOS	Massimo Cocco	massimo.cocco@ingv.it
ICOS	Samuel Shammer	shammer@iup.uni-heidelberg.de
	Leonard Rivier	leonard.rivier@lsce.ipsl.fr
SIOS	Heikki Lihavainen	director@sios-svalbard.org
EUFAR	Andreas Minikin	Andreas.Minikin@dlr.de
ARISE	Elisabeth Blanc	Elisabeth.BLANC@CEA.FR
CETAF	Ana Casino	ana.casino@cetaf.org
DANUBIUS	Andrew Tyler	a.n.tyler@stir.ac.uk

Annex 2: List of RIs in ENVRIplus

ACTRIS	http://www.actris.eu/
EISCAT 3D	https://eiscat3d.se/
IAGOS	http://www.iagos.org/
EMSO	http://www.emso-eu.org/
EURO ARGO	http://www.euro-argo.eu/
EUROFLEETS2	http://www.eurofleets.eu/np4/home.html
ESONET VI	http://visobservatories.webs.com/
EUROGOOS	http://eurogoos.eu/
FIXO3	http://eurogoos.eu/
JERICO NEXT	http://www.envriplus.eu/wp-content/uploads/2015/08/Jerico-next-logo.jpg
SEADATANET	http://www.seadatanet.org/
EPOS	https://www.epos-ip.org/
ANAEE	http://www.anaee.com/
ELIXIR	https://www.elixir-europe.org/
INTERACT	http://www.eu-interact.org/
LTER	http://www.lter-europe.net/
EMBRC	http://www.embrc.eu/
ICOS	https://www.icos-ri.eu/
IS ENES2	https://verc.enes.org/ISENES2
SIOS	http://www.sios-svalbard.org

Annex 3: Metrology questionnaire

SURVEY Metrology standards & National Metrology Institutes (NMI) ENVRI+ Theme 1 WP2

Why fill this survey?

- Exchange good practices
- Increase scope of existing standards to the benefit of more Research infrastructures RIs
- Harmonization across Ris
- Improve involvement of National Metrology Lab towards our community
- Improve quality assessment in your RI

Who should fill this survey?

A person knowledgeable about metrology procedures in his RI

Thank you to answer the following?

1. Your name, email, affiliated RI, your role in the RI.
2. What standards are used in your RI? (multiple choices allowed)
   Standards can be anything from ISO to internal to your RI
   - ☐ Standard instrument (limiting choice of other instruments)
   - ☐ Standard for measurement protocol
     (physical/chemical/biological quantities, e.g. Atmospheric Co_2 concentration, aerosol composition, CO_2, CH_4 emission by plant, etc.);
   - Standard for reference associated protocols
   - ☐ Standard for Quality Management in general and QualityAssessment/Quality Control in particular
   - ☐ Standard for calibration on site
   - ☐ Standard for calibration in labs
   - ☐ Standards for other lab processes
     (eg lab test to qualify instruments according to given specifications)
   - Other standards?

If one of the previous choice is positive, please add information here.
(One paragraph per positive choice)

3. If you use standards involving reference labs or materials. Please describe the tree of metrology references ie how the traceability is insured from the reference to the actual local site measurement
4. What are the need for standardization in your RI ?
   See example categories from question 2
5. Are NMI implicated in your RI community? if yes how ?
   Calibrating individual instruments
   calibrating network primary instruments
   contributing to transfer metrology standards (improve traceability)
   contributing to develop measurement protocols
   contributing to discover/reduce uncertainties

If one of the previous choice is positive, please add information here.
(One paragraph per positive choice)

6. How could NMIs be active in helping your RI with issues related to metrology standards
7. How can traceability to SI units be improved in your RI?
8. Are you planning to adopt an ISO procedure in your RI?
9. Is there any activity in your RI for which it would be useful to have new standard?
10. Is there in your RI the need to develop metrology standard?

Annex 4: Research infrastructures participating in the ENVRIplus project.

Atmospheric domain

ACTRIS: (Aerosols, Clouds and Trace gases Research Infrastructure) is a pan-European initiative consolidating actions amongst European partners producing high-quality observations of aerosols, clouds and trace gases. Different atmospheric processes are increasingly in the focus of many societal and environmental challenges, such as air quality, health, sustainability and climate change. ACTRIS aims to contribute in the resolving of such challenges by providing a platform for researchers to combine their efforts more effectively, and by providing observational data of aerosols, clouds and trace gases openly to anyone who might want to use them.

EISCAT 3D: (**European Incoherent Scatter Scientific Association**) operates three incoherent scatter radar systems, at 224 MHz, 931 MHz in Northern Scandinavia and one at 500 MHz on Svalbard, used to study the interaction between the Sun and the Earth as revealed by disturbances in the ionosphere and magnetosphere. At the Ramfjordmoen facility (near Tromsø, Norway), it also operates an ionospheric heater facility, similar to HAARP. Additional receiver stations are located in Sodankylä, Finland, and Kiruna, Sweden. The **EISCAT Svalbard radar** (**ESR**) is located in Longyearbyen, Norway. The EISCAT Headquarters are also located in Kiruna.

IAGOS (In-service Aircraft for a Global Observing System) is a European Research Infrastructure for global observations of atmospheric composition from commercial aircraft. IAGOS combines the expertise of scientific institutions with the infrastructure of civil aviation in order to provide essential data on climate change and air quality at a global scale.

Marine domain

EMSO (The European Multidisciplinary Seafloor and water column Observatory)O: aims to explore the oceans, to gain a better understanding of phenomena happening within and below them, and to explain the critical role that these phenomena play in the broader Earth systems. EMSO consists in a system of regional facilities placed at key sites around Europe, from North East to the Atlantic, through the Mediterranean, to the Black Sea. Observatories are platforms equipped with multiple sensors, placed along the the water column and on the seafloor. They constantly measure different biogeochemical and physical parameters, that address natural hazards, climate change and marine ecosystems.

EURO-ARGO: Euro-Argo is the European contribution to the international Argo network comprised of nearly 4000 autonomous floating profilers that record temperature and salinity in real time from the sea surface to depths reaching 2000 m in all the oceans across the globe. Euro-Argo is a European legal entity (European Research Infrastructure Consortium, ERIC) coordinated by France and ensures the continuity and the consolidation of the European contribution to the Argo network.

EUROFLEETS 2 objectives are:

- Promoting a larger integration of European Global/Ocean and Regional RVs as these two types should be addressed separately for most of the strategic and programming issues. In fact in EUROFLEETS2 a higher participation of RVs is expected: 8 Ocean/Global with 4 new ones;
- 14 regional RVs with 6 new ones and 6 mobile equipments normally not made accessible on their usual national support vessel;
- Integrating a common polar vision in the strategic vision of the European marine research fleets;
- Promoting exchanges of movable equipment on board European RVs and in doing so fostering high operational interoperability within Europe;
- Further integrating the European RVs by coordinating multi-vessels experiments (super-integration) for larger and ambitious marine research missions;
- Initiating operational experimental tests demonstrating the higher interoperability of European fleets;
- Enhancing the impact of research infrastructures on innovation by fostering the involvement of industry with specific activities, both as a user (e.g. development and testing of new equipment or deep-sea exploration for new energy or mineral resources) and as a supplier of such facilities.

ESONET-Vi (ESONET the Vision) is a consortium focusing on deep-sea observatories built upon ESONET (European Seafloor Observatory NETwork) activities, in complement to the EMSO (European Multidisciplinary Seafloor Observation) observatories infrastructures.The consortium aims at defining a perennial integration at European level of scientists from numerous laboratories using data collected by deep sea observatories. ESONET-Vi will allow linking geographically scattered complementary research, industrial and governmental elements in Europe in order to rapidly transfer and implement research results into science and industrial applications.

EuroGOOS is an international non-profit association of national governmental agencies and research organisations, committed to European-scale operational oceanography within the context of the intergovernmental Global Ocean Observing System (GOOS). It was founded in 1994 and has today 41 members_from 19 European countries providing operational oceanographic services and carrying out marine research. Since February 2013, EuroGOOS is established as an international non-profit organisation in Belgium (EuroGOOS AISBL).
EuroGOOS operates in five regional sea areas where operational systems have been set up: the Arctic (Arctic ROOS), the Baltic (BOOS), the North West Shelf (NOOS), the Ireland-Biscay-Iberian area (IBI-ROOS) and the Mediterranean (MONGOOS). Strong cooperation within these regions, enabling the involvement of many more regional partners and countries, forms the basis of EuroGOOS work, and is combined with high-level representation at European and Global forums.

FixO3 (The Fixed point Open Ocean Observatory) network seeks to integrate European open ocean fixed point observatories and to improve access to these key installations for the broader community. These will provide multidisciplinary observations in all parts of the oceans from the air-sea interface to the deep seafloor. Coordinated by the National Oceanography Centre, UK, FixO3 will build on the significant advances largely achieved through the FP7 programmes EuroSITES, ESONET and CARBOOCEAN.

Jerico-NEXT. The aim of Jerico-NEXT is to improve and innovate the cooperation in coastal observatories in Europe by implementing the coastal part of a European Ocean Observing System, to cooperate with other European initiatives as ESFRI (EURO-ARGO, EMSO, EMBRC), Integrated Infrastructures (FIXO3, …), OCEAN OF TOMORROW sensors innovation project (SenseNET, NEXOS), the emerging European biological network (EMBRC) and EMODnet to contribute to provide services to the research community and the society.

SeaDataNet is a distributed Marine Data Infrastructure for the management of large and diverse sets of data deriving from in situ of the seas and oceans.

Professional data centres, active in data collection, constitute a Pan-European network providing on-line integrated databases of standardized quality. The on-line access to in-situ data, meta-data and products is provided through a unique portal interconnecting the interoperable node platforms constituted by the SeaDataNet data centres.
The development and adoption of common communication standards and adapted technology ensure the platforms interoperability. The quality, compatibility and coherence of the data issuing from so many sources, is assured by the adoption of standardized methodologies for data checking, by dedicating part of the activities to training and preparation of synthesized regional and global statistical products from the most comprehensive in-situ data sets made available by the SeaDataNet partners.
Data, value added products and dictionaries serve wide uses: e.g. research, model initialisation, industrial projects, teaching, marine environmental assessment

Solid earth domain

EPOS the European Plate Observing System, is a long-term plan to facilitate integrated use of data, data products, and facilities from distributed research infrastructures for solid Earth science in Europe. EPOS will bring together Earth scientists, national research infrastructures, ICT (Information & Communication Technology) experts, decision makers, and public to develop new concepts and tools for accurate, durable, and sustainable answers to societal questions concerning geo-hazards and those geodynamic phenomena (including geo-resources) relevant to the environment and human welfare. EPOS vision is that the integration of the existing national and trans-national research infrastructures will increase access and use of the multidisciplinary data recorded by the solid Earth monitoring networks, acquired in laboratory experiments and/or produced by computational simulations. The establishment of EPOS will foster worldwide interoperability in the Earth sciences and services to a broad community of users. EPOS mission is to integrate the diverse and advanced European Research Infrastructures for solid Earth science, and build on new e-science opportunities to monitor and understand the dynamic and complex solid-Earth System. EPOS will identify existing gaps and promote implementation plans with environmental, marine and space science to help solve the grand challenges facing the Earth and its inhabitants.

Biodiversity/ Ecosystem domain

AnaEE will be a research infrastructure for experimental manipulations of managed and unmanaged terrestrial and aquatic ecosystems. It will strongly support scientists in their analysis, assessment and forecasting of the impact of climate and other global changes on the services that ecosystems provide to society.
AnaEE will support European scientists and policymakers to develop solutions to the challenges of food security and environmental sustainability, with the aim of contributing to a vibrant bioeconomy. AnaEE will accomplish this mission by building substantial links among researchers, science managers, policy makers, public and private sector innovators, and citizens.

ELIXIR is an intergovernmental organisation that brings together life science resources from across Europe. These resources include databases, software tools, training materials, cloud storage and supercomputers.

The goal of ELIXIR is to coordinate these resources so that they form a single infrastructure. This infrastructure makes it easier for scientists to find and share data, exchange expertise, and agree on best practices. Ultimately, it will help them gain new insights into how living organisms work.

INTERACT is an infrastructure project under the auspices of SCANNET, a circumarctic network of currently 82 terrestrial field bases in northern Europe, Russia, US, Canada, Greenland, Iceland, the Faroe Islands and Scotland as well as stations in northern alpine areas. INTERACT specifically seeks to build capacity for research and monitoring in the European Arctic and beyond, and is offering access to numerous research stations through the *Transnational Access* program. The project, which is funded by the EU, has a main objective to build capacity for identifying, understanding, predicting and responding to diverse environmental changes throughout the wide environmental and land-use envelopes of the Arctic. This is necessary because the Arctic is so vast and so sparsely populated that environmental observing capacity is limited compared to most other latitudes. INTERACT is multidisciplinary: together, the stations in INTERACT host thousands of scientists from around the world who work on projects within the fields of glaciology, permafrost, climate, ecology, biodiversity and biogeochemical cycling. The INTERACT stations also host and facilitate many international single-discipline networks and aid training by hosting summer schools.

LTER (Long-Term Ecosystem Research) is an essential component of world-wide efforts to better understand ecosystems and the environment we depend on. Through research and long-term observation of representative sites around the globe, LTER enhances our understanding of the structure and functions of ecosystems, which provide essential services to people. LTER contributes to the knowledge base informing policy and to the development of management options in response to the Grand Challenges under Global Change.

Multidomain

EMBRC-ERIC is a pan-European Research Infrastructure for marine biology and ecology research. With its services, it aims to answer fundamental questions regarding the health of oceanic ecosystems in a changing environment, enable new technologies to further our investigation capabilities, support life-science breakthrough discoveries with the use of marine biological models, and continue long-term marine monitoring efforts. EMBRC-ERIC is a driver in the development of blue biotechnologies, supporting both fundamental and applied research activities for sustainable solutions in the food, health and environmental sectors.

ICOS RI (Integrated Carbon Observation System Research Infrastructure) integrates atmosphere, ecosystem and ocean greenhouse gas observations to provide timely and reliable data for research, policy making, and the general public. ICOS RI brings together high quality European national research communities and measurement stations and, through coordination and support, constitutes a European-wide research infrastructure that serves both scientists and society. ICOS RI consists of a number of researchers and measurement stations, governance bodies and a carbon data portal, collaborating across Europe. ICOS RI has more than 100 measurement stations in twelve European countries.

These stations measure greenhouse gas concentrations in the atmosphere and fluxes over the terrestrial and marine ecosystems. The ICOS stations are run and funded by national funding agencies, institutes and universities, demonstrating an impressive joint effort to enable climate change research. At the moment ICOS Research Infrastructure has more than 100 stations in 12 European countries. The current ICOS Atmosphere and Ecosystem Networks include more than 30 atmospheric and around 70 ecosystem stations located across Europe. The ICOS Ocean Network covers the North Atlantic and European marginal seas. The Ocean Observation System will consist of more than 20 facilities: Voluntary Observatory Ships, fixed stations and research vessels.

EUFAR was established to create a central network for the airborne research community in Europe with the aim to support researchers by granting them access to research infrastructures, not accessible in their home countries, and providing professional support and training.
From in situ measurement of atmospheric properties to remote sensing, the high maneuverability of instrumented aircraft allows researchers to pursue atmospheric phenomena, especially useful in remote locations, follow their evolution and explore their chemistry and physics from small spatial sales up to thousands of kilometers.

ARISE It has been robustly demonstrated that variations in the circulation of the middle atmosphere influence weather and climate throughout the troposphere all the way to the Earth's surface. A key part of the coupling between the troposphere and stratosphere occurs through the propagation and breaking of planetary-scale Rossby waves and gravity waves. Limited observation of the middle atmosphere and these waves in particular limits the ability to faithfully reproduce the dynamics of the middle atmosphere in numerical weather prediction and climate models. ARISE combines for the first time international networks with complementary technologies such as infrasound, lidar, airglow, radar systems, ionospheric observations and satellites. This joint network provides advanced data products used as benchmarks for weather forecast models. The ARISE network also allows enhanced and detailed observations of other extreme events in the Earth system, such as erupting volcanoes, magnetic storms, tornadoes and tropical thunderstorms, for a better understanding of underlying physical processes and future monitoring for civil applications.

LifeWatch-ERIC is the European Infrastructure supplying e-Science research facilities for biodiversity and ecosystems. LifeWatch was born to allow researchers tackling today's big challenges, such as those related to the sustainability of development, conservation of biodiversity and ecosystems, and climate change, by using virtual research environments equipped with cutting-edge ICT tools to share, manage and model data.

DANUBIUS-RI will be a pan-European distributed research infrastructure supporting interdisciplinary research on large river-sea systems. DANUBIUS-RI will fill the gap of fragmented research on European research on river-sea systems, drawing on existing research excellence across Europe, enhancing the impact of European research while maximising the return on investment. It will provide access to a range of European river-sea systems, facilities and expertise; a 'one-stop shop' for knowledge exchange in managing river-sea systems; access to harmonised data; and a platform for interdisciplinary research, inspiration, education and training.

EMPHASIS is a pan-European distributed infrastructure listed on the ESFRI Roadmap for multi-scale plant phenotyping and simulation for food security in a changing climate. EMPHASIS aims at supporting the exploitation of crop genetic diversity required for the enhancement of plant productivity and progress in plant breeding. The infrastructure will enable diverse users to quantify a diversity of plant traits and the analysis of genotype performance in in current and future agro-climatic scenarios.

SIOS SIOS is a regional observing system for long-term measurements in and around Svalbard addressing Earth System Science questions. SIOS integrates the existing distributed observational infrastructure and generates added value for all partners beyond what their individual capacities can provide. SIOS focuses on processes and their interactions between the different spheres, i.e. biosphere, geosphere, atmosphere, cryosphere and hydrosphere. The core observational programme of SIOS provides the research community with systematic observations that are sustained over time, yet dynamic enough to be adapted as new methods and questions from society appear.
The SIOS Knowledge Centre (SIOS-KC) is the central hub of SIOS. It is located in the Svalbard Science Centre in Longyearbyen and offers coordinated services for the international research community. The services offered include:
Integration and optimisation of the observing system, including stimulation and coordination of new observing technology developments (Science Optimization Service).
Access to the research infrastructure
Data management, storing and curating of scientific data
Sharing and use of remote sensing resources
Logistical services
Training and education programmes
Information and outreach
In particular, the Science Optimisation Service creates a platform for interdisciplinary communication and collaboration across institutes and nations. This service makes recommendations on the scientific priorities of SIOS, including defining what constitutes "SIOS core data" and ways to optimise the observing system. The main output of this service will be the annual "State of Environmental Science in Svalbard" (SESS) report, summarising the current state of Earth System Science, highlighting research needs and recommending future priorities in the Observing System.