W O R L D   M E T E O R O L O G I C A L   O R G A N I Z A T I O N

COMMISSION FOR INSTRUMENTS
AND METHODS OF OBSERVATION

EXPERT TEAM ON NEW IN-SITU TECHNOLOGIES

First session

Geneva, Switzerland
10-13 September 2013

FINAL REPORT

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EXECUTIVE SUMMARY

This first session of the CIMO Expert Team on New In-Situ Technologies was held from 10 to 13 September 2013 at the WMO Headquarters in Geneva, Switzerland.

The session reviewed a draft report on recent developments by hydrological and meteorological instrument manufacturers and provided suggestions for completion of the report.

The session reviewed a report on the survey of manufacturers and Members on AWS algorithms used around the world, and agreed that the second part of this activity should focus on gathering detailed information on cloud amount and layer algorithms and how these observations are reported by automated systems. The session agreed to recommend to HMEI that manufacturers include quality information in observational reports from automated instrumentation where possible.

A draft report on the installation and operation of instruments to withstand severe weather was reviewed by the session and suggestions given to the authors on how to adapt the document to provide draft text on the subject for inclusion in the CIMO Guide.

The session was informed of recent developments in the measurement of solar and terrestrial irradiance, such that changes to the WRR and WISG should now be contemplated. The session agreed to recommend to CIMO-MG the formation of a special Task Team during CIMO-XVI to determine and manage the changes required before CIMO-XVII.

The session received presentations on the Trans-African Hydro-Meteorological Observatory (TAHMO) project in eastern Africa, in which cheap sensors are being developed for deployment at up to 20,000 locations, to enhance the observations network there. TAHMO is hoping that WMO will endorse the project once they have ensured that traceabiity of the observations can be assured and their administrative arrangements are acceptable to WMO.

The session also received a presentation on the measurement of eddy covariance and its importance, and agreed that the CIMO Guide is as appropriate place for an agreed global standard for data processing algorithms, once the standard has been drafted by experts from the eddy covariance community.

The session then updated its plan of work for the remainder of this inter-sessional period, and agreed on priority tasks to be pursued in the new inter-sessional period, after CIMO-XVI.

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GENERAL SUMMARY

1. ORGANIZATION OF THE SESSION

1.1 Opening of the Session

1.1.1 The first session of the CIMO Expert Team (ET) on New In-Situ Technologies (NIST) was opened on Tuesday 10 September 2013 at 9:00, by Dr Steven Oncley, Chairman of ET-NIST.

1.1.2 The list of participants is given in Annex I.

1.2 Adoption of the Agenda

The meeting adopted the Agenda as reproduced at the beginning of this report.

1.3 Working Arrangements for the Session

The working hours and tentative timetable for the meeting were agreed upon.

2. REPORT OF THE CHAIRPERSON

2.1 Dr Oncley presented a summary of the activities of the CIMO ET-NIST since October 2012, when the Work Plan of the team was last refined and agreed at an ad-hoc meeting of the Expert Team in Brussels, Belgium during CIMO TECO 2012. He highlighted the progress and problems in each individual topic. He stressed the importance of the contribution of ET-NIST to the implementation of WIGOS and requested the session to keep this in mind during the week to follow.

2.2 Dr Oncley advised the session that he will be providing a report on the activities of ET-NIST to the OPAG Chair, Dr van der Muelen in time for the next scheduled CIMO Management Group meeting. That report will need to provided by the end of January 2014, will include an account of the work achieved by the ET during the inter-sessional period, and suggestions for future work of the ET. Hence the majority of the ET's work should be completed and documented by (mid) December 2013, only 3 months away. There will be much to do in a short time.

2.3 Dr Oncley also noted an additional need to submit material for the CIMO Guide to the CIMO Guide Editorial Board in time for its meeting in November 2013, so those materials submitted for consideration in this next version must be provided by the end of September. This deadline requires that action be taken immediately on any such sections.

2.4 Dr Oncley advised that this session would comprise a presentation on progress and discussion on each of the tasks outlined in the Work Plan. He notes that summaries are provided at the beginning of each of the meeting documents. In general, significant action has been taken on each task and most are nearing completion. In addition, reports on the TAHMO project to augment instrumentation in Africa and an effort to create a standard for Eddy-Covariance calculations would be presented.

2.5 In closing, Dr Oncley suggested that time would be made available during the session to discuss ideas for future progress on measurement issues that could be presented to the CIMO MG in the ET's final report. In particular, two items that came up during TECO 2012 were a need to compare AWOS and manual observations as NMHSs transition to automation, and to consider retaining of the WRR radiometer standard or transitioning to a new standard.

3. WIGOS FRAMEWORK IMPLEMENTATION – UPDATE ON PROGRESS

3.1 The meeting was informed about the status of development of WIGOS, one of the priority activities of WMO.

3.2 New technologies tend to be associated with increasingly expensive instrumentation, which are not always easy to put into operational use as they require personnel with relatively high qualifications to operate and maintain them. However, the meeting recognized that it could play an important role in providing information on simpler and cheaper new instrumentation that can be easily used and maintained, and decided to address this when reviewing its workplan.

3.3 The meeting noted that some countries had made positive progress with integration, while others were struggling with various operators applying totally different standards, or no standards, for example, for the siting of instruments. It noted that sharing “success stories” on integration would be very valuable to motivate various entities to adhere to the WIGOS principles and recommended that such experience be published in relevant WIGOS outreach documents so that they could be easily accessible and shared.

3.4 Mr Hut advised the session that the TAHMO field experience in Africa is that many network operators are reluctant to install observing stations if the instrumentation does not fully satisfy the quality criteria laid out in the CIMO Guide: perhaps the CIMO Guide should make it clearer that it can still be worthwhile to install stations even if they do not meet all the requirements of the CIMO Guide, though one cannot overstress the importance in these cases of providing adequate metadata describing any discrepancies.

3.5 The session then discussed its activity under Task 6 of the Work Plan: Contribute to the implementation of WIGOS and provide relevant advice and support to the CIMO-MG. It noted that most of its activity, by the very nature of the Terms of Reference for this Expert Team, contributes directly to WIGOS. In particular, its activities tend to contribute to development of regulatory material (itself a standardization activity) through the ET’s contributions to the CIMO Guide and to the development of standards, to development of standardized observing procedures and instrument configurations, and to Capacity Development by its development of guidance material on new observing technologies and techniques.

3.6 The session agreed that, in developing recommendations for CIMO-MG-11 on tasks for the ET to pursue in the next inter-sessional period, attention should be given to ensuring that these tasks are prioritized according to their direct contribution to WIGOS, and are phrased carefully to ensure a WIGOS focus is maintained during the performance of the work.

4. PERFORMANCE OF NEW IN-SITU TECHNOLOGIES

4.1 Mr Hartley advised the session on the comprehensive review of recent (the past 4 years) and proposed future (the next 2 years) developments by hydrological and meteorological instrument manufacturers that has been performed under this task of the Work Plan. He presented to the session the survey response statistics, a table of survey responses that included new technology and/or techniques complete with technical information, and a summary identifying items considered significant new developments. The supplier address list (and sources), email requests, survey form were included in the report for completeness.

4.2 Supporting documentation from manufacturers in the form of brochures or manuals or other statements that were supplied in electronic format were made available to the meeting but these were not reviewed.

4.3 The session then considered additional candidates that might be included in the table. It was suggested that the USA NWS has found that the "Earth Networks, PulseRad – Radar Alternative Based on Total Lightning: January 2012" has a relatively good success rate with text message warnings produced by the system. It was suggested that IBM are designing a similar platform to PulsRad that should be identified, though no further details of this system were available. Electric IMP was identified as another form of remote wireless technology, however the system is WiFi only and therefore is not suitable for low power applications. Crowd sourcing of road weather data from car sensors (precipitation data from wiper speed, air temp from engine control system) were identified as potential future data sources. It was also suggested that KNMI has performed research on sky condition that may be relevant to the new sky condition sensors identified in the report. Additional developments identified by the meeting that should be considered included Neutrino use for moisture in partitions in layers (http://hydroinnova.com/ps_soil.html). It was also suggested that some ceilometers are now capable of provide mixing layer height.

4.4 With regard to future work under this topic, Mr Hartley was requested to investigate the IBM system similar to PulsRad that is purported to be under development and report back to ET-NIST, and Dr Wauben was requested to obtain more details of the KNMI research on sky condition sensing, and include the information in the final report of ET-NIST to the OPAG Chair.

4.5 Mr Hartley was requested to consider the performance of the most promising items identified in the summary table and report to ET-NIST on these in more detail, in particular with respect to how 'operational' the new sky scanning instruments now are. It was also suggested that ET-NIST recommend to CIMO-MG in its final report that the newly identified sky condition sensors should be included, should there be a future inter-comparison of sky condition instruments (including ceilometers).

4.6 Mr Hartley was requested to enquire with manufacturers of ceilometers to ascertain whether their sensors are capable of provide mixing layer height and to provide a statement on these findings for inclusion in the final report of ET-NIST. Mr Pevny and Mr Islander agreed to assist in contacting HMEI members on behalf of HMEI, if further information is needed. Mr Hartley was also asked to review the appropriate sections of the CIMO Guide and check if any of the most promising new technology items should be included, and provide appropriate text where applicable describing the technique, and how and where it may be used.

4.7 It was noted that as well as ascertaining the measurement uncertainties that can be achieved with new instruments, it is also important to explore the maintenance requirements, how well these instruments can perform under operational conditions, etc. Ms Guo suggested that WMO Members might be consulted for information regarding their experience with these new instruments and how well they perform.

5. STANDARDIZATION OF AWS ALGORITHMS

Algorithms

5.1 The approach and results of the review on AWOS algorithms was presented by Dr Wauben. In this first stage 32 WMO Members and 4 HMEI manufacturers responded. Although the number of respondents is rather small, the willingness to share information is large. This concluded the first stage of the task (although clarifications by respondents are still coming in).

5.2 Due to the amount of work involved is was decided to focus in the next stage directly on cloud and weather algorithms since for these elements information on algorithms is mostly lacking in the CIMO guide. In order to stimulate the participation of Members and manufacturers it was agreed that the review will be performed on a general level involving only the basic principles/essentials of these algorithms. Furthermore the results will be presented anonymously.

5.3 Clouds algorithms will be restricted to the processing of ceilometer cloud base height data into cloud cover and cloud layer height information; an essential consideration is e.g. the time window considered; the results of this will for example be presented as mean and range of values used.

5.4 Concerning weather, the various instruments/principle will be listed and the manner in which the information provided by these instruments is combined and translated into weather codes will be summarized.

5.5 It was agreed that, during the remainder of the inter-sessional period leading up to CIMO-XVI it would only be feasible to start gathering the information on cloud and weather and to decide whether the information that has been made available is sufficient to continue this task in the next inter-sessional period. The information on clouds and weather will be requested from respondents to the questionnaire, but also from other Members/manufacturers that did not answer the stage 1 questionnaire. The feedback will be analyzed and reported.

5.6 The session decided that the team responsible for this task should provide an overview of performance of weather measurements, although it was originally not part of the task. All ET members were asked to provide documentation and available information on observer/sensor comparisons from their own institutes and others to the task leader. After the available information is gathered the task members will be asked to contact the respective institutes to obtain further performance details or review the documentation in order to be able to make summary of the performance. Next the task leader will make a report on the performance of weather measurements.

5.7 It was also agreed that the task team should scan the CIMO guide, particularly Parts 2 and 3, to identify gaps in algorithm documentation.

5.8 Finally it was suggested that users would be able to make better use of automated observations if quality information was included in the sensor output where possible. For example, not only is it important for a present weather sensor to report the correct precipitation type, but also to provide information on the likelihood that the type has been misclassified: e.g. to provide a list of other types of precipitation that might be being experienced (rather than that identified as the most likely) with an estimate of the likelihood of each type. So ET-NIST should recommend to HMEI that manufacturers include quality information in sensor output where possible.

6. INSTALLATION AND OPERATION OF INSTRUMENTS TO WITHSTAND SEVERE WEATHER

6.1 Dr Oncley reminded the session that this task was concerned with assembling and reviewing guidance material about:

- Making instruments more resilient to extreme weather conditions.
- Developing of instruments with increased measurement range
- Investigating performance of instruments in extreme climates.
- Sustaining AWS operations in extreme climate conditions.

Clearly this guidance is quite important for WMO Members to maintain high-quality meteorological data. It is especially important to quantify extreme events.

6.2 Dr Oncley described how the task team had gathered candidate material by web search, their own experience, and word-of-mouth contact, which yielded limited results. He noted that no material had been obtained on development of instruments with increased measurement range, despite the efforts of the task team. The resultant material had been organized into a short report with guidance on instruments, infrastructure, and deployment strategies, with these latter aspects included to address the topic of sustaining AWS operations in extreme conditions. Dr Oncley noted that the document required further development before it would be ready for publication as a IOM report.

6.3 It was suggested that the document needed to contain more guidance material before it would be suitable for publication and that perhaps a different search method might help, or perhaps there is simply little information available on this subject. The session agreed that enough material had been gathered to provide a few pertinent paragraphs for the CIMO Guide. Dr Oncley agreed to draft a few paragraphs accordingly, in time for submission at the end of September for consideration at the next meeting of the CIMO Guide Editorial Board.

6.4 Following useful discussion, the task team also agreed to try to gather more guidance material using electronic communication methods:

- A posting to an existing micrometeorologist mailing list [Oncley]
- A posting to the EuMetNet bulletin board [Waas]
- An item in the Chinese Meteorological Administration newsletter [Guo]
- An item in the report on this meeting in the HMEI newsletter [Pevny]
- Other internal communication methods by the ET members' home institution

It was also suggested that, since two previous ETs have attempted this same task, it would be useful to retrieve and examine any material they may have gathered.

6.5 If sufficient new material is received, the existing report will be edited to include this new material. The report also will be reorganized to increase its utility and rewritten in a style to minimize direct quotations.

6.6 It was suggested that the CIMO Secretariat consider establishment of a new, or utilization of an existing, electronic communication method (bulletin board, email list, Wiki, etc.) for gathering similar material for other CIMO ETs and Task Teams.

7. DEVELOPMENT OF NEW RADIATION REFERENCE INSTRUMENTS

7.1 Dr Groebner summarized his activity under this task of the Work Plan and noted that each sub-task has now essentially been completed. He noted the importance of distinguishing between ‘solar and terrestrial’ radiation, and ‘visible and infrared’ radiation.

7.2 Dr Groebner recounted to the session how the radiation community has recently detected a likely error in the World Radiation Reference (WRR). He noted that preliminary measurements from the new SI-traceable Cryogenic Solar Absolute Radiometer (CSAR) during IPC-XI at Davos, Switzerland in 2010 have indicated a lower solar irradiance value (0.3%) than the WRR, suggesting that the solar irradiance scale may need to be adapted if subsequent measurements confirm the disagreement and that it may be appropriate for CIMO to form a Task Team to address this matter.

7.3 Dr Groebner next recounted to the session how two new infrared radiometers have been developed that provide longwave radiation measurements that are traceable to SI: one is an Infrared Integrating Sphere Radiometer (IRIS) developed by PMOD/WRC, the other an absolute cavity pyrgeometer. Preliminary intercomparison of the two instruments during February 2013 shows that the two instruments agree with each other within their respective uncertainties. Corroborative evidence from follow-up intercomparisons will enable the means to calibrate the World Infrared Standard Group (WISG) relative to these reference instruments. Dr Groebner suggested that this is likely to be another change management challenge that can be addressed by the same Task Team that examines the WRR matter.

7.4 Dr Groebner tabled two documents to be submitted for publication as IOM reports: the first a report on the Davos pyrgeometer intercomparison of February 2013, the second a report describing the technique used for pyrgeometer calibration at PMOD/WRC-IRS. The session approved the latter report (at Annex II) and requested the Secretariat to arrange external review and subsequent publication as an IOM report.

7.5 Finally, Dr Groebner informed the session that he had, as agreed, completed and submitted an update to Part I, Chapter 7 of the CIMO Guide, which he tabled at the session.

7.6 The session agreed that, noting the advice delivered by Dr Groebner in regard to the WRR and the WISG, ET-NIST should recommend to CIMO that a Task Team be formed (at CIMO-XVI) for the next inter-sessional period to address the change management issues in regard to the WRR and the WISG and report back to CIMO-XVII. It was noted that this is consistent, but delays the work somewhat, and expands the scope of 4.1.13 of CIMO MG-10, 2012, by including consideration of the WISG as well as the WRR. Suggested Terms of Reference for such a Task Team area as follows:

To address implications of proposed changes to the solar and terrestrial radiation references, by:

1) *Reviewing and assessing developments of reference instruments of solar and terrestrial radiation with regard to observed differences to working reference,*
2) *Assessing consequences of a change in solar/terrestrial reference scales with regard to Stakeholder needs,*

3) *Making recommendation for a modification of the current references (Implementation plan) and propose methods on how to deal with old data ,*

4) *Providing a status report and recommendations for CIMO-XVII (2018).*

7.7 The session suggested that the membership of the Task Team should comprise representatives of Stakeholder Groups and at least one representative of the World Radiation Center. Stakeholder Groups include:

- BSRN
- Solar power / photovoltaic Industry
- Climate Scientists – IPCC
- World Radiation Data Center

7.8 Dr van der Meulen noted that BIPM has procedures on how to move from one reference to another. It would be important to ensure that the Task Team worked closely with BIPM, following their procedure for changing a reference.

7.9 Dr Groebner advised the session that follow-on work under this task would include:

- Finalization of a recommendation to CIMO-XVI on formation of the WRR-WISG Task Team.
- Submit the report on the pyrgeometer intercomparison to the Secretariat for publication as a IOM report.
- Submit the CIMO Guide update to Secretariat.
- Contribute updated UV material for CIMO Guide Ch 7, once it becomes available in mid-2014 (via ARE Department).

8. ICING

8.1 Dr Wauben provided his report on the status of activity under this task of the Work Plan.

8.2 The joint publication of the COST 727 final report on icing by COST and WMO is still awaiting formal approval by COST. The publication itself is ready, but the COST Office has been unresponsive to a series of communications regarding their agreement to a joint copyright statement, which must be obtained before the document can be published in the IOM series.

8.3 Dr Wauben went on to inform the session that there is an ISO standard describing how to measure icing (with a suspended vertical rod, monitoring its change of mass). However, icing sensors have problems at the high end (extreme icing) and the low end (onset of icing). Although there are some data on performance in the COST report, no specification of requirements has been received from users with regard to data on resolution, uncertainty, etc., so it is premature to really enter the details into the CIMO Guide.

8.4 However the report contains some useful results. There are two chapters of the CIMO Guide that mention icing: the chapters on precipitation and present weather. There are gaps in these chapters which could be addressed, so these chapters should be updated with the information that is available.

8.5 After some discussion, the session agreed that:

- This task only deals with the measurement of icing:
- The information provided by the COST action is not sufficient to include icing (detection, accretion rate, load) in its own chapter in the CIMO guide because specifications and requirements are lacking;
- An update should be made to the icing information contained in the current CIMO guide based on the information in the COST report;
- The proposed changes to the CIMO guide will be made by the task team, after which a review by icing experts will be sought;
- The draft upgraded CIMO document on icing should be prepared by mid-October.

- 3 icing experts should be selected from different backgrounds who are willing to review the revised text, including one from HMEI.

8.6 Finally, the session discussed how CIMO should proceed on the subject of icing. Clearly there is a need in many countries for icing measurements. The requirements should however be specified by the users. CBS through DRR will be asked to clarify this need for icing measurements and to provide guidance on the requirements.

9. OTHER ACTIVITIES OF THE EXPERT TEAM

9.1 No topics were raised for discussion concerning other activities of the Expert Team, but the Chair suggested the session take some time to consider suggestions for activities of the Expert Team that should be undertaken during the coming inter-sessional period, so that the Chair might include these in his final report to the OPAG Chair for discussion at CIMO-MG-11.

Suggestions for On-going Work of the ET, 2014-2018

9.2 Draft guidance material for the CIMO Guide on the advantages and disadvantages of transitioning to automated technology, in particular AWS. In most cases, supporting the more advanced equipment requires significant increases in technical ability to maintain and repair equipment, with related training costs, and the cost of spare parts for automated equipment can be considerably higher than for manually operated alternatives. So for some countries, particularly some of the least developed countries, this can introduce new problems and it would be appropriate to warn Members of this in the guidance material.

9.3 Investigate and report on advances in snow pack measurements (include guidance material in next CIMO guide). There are many new developments that have occurred recently, including laser snow depth, dielectric snow ice/water content, wood plates for measuring snow depth are being replaced by rough plastic plates, drifting snow measurements. (The SPICE report may provide useful input.)

9.4 Draft appropriate guidance material on volcanic ash detection and vertical profiles of concentration/phase using lidar and/or ceilometer. (The E-Profile project may provide useful input).

9.5 Review surface characterization sensors (whether cover is dry/wet/frozen/frost). These can be difficult to differentiate. A possible WIGOS-targeted activity.

9.6 PAR (photosynthetically active radiation) has not been dealt with by the radiation community up until now, but perhaps as a WIGOS activity it is now appropriate for CIMO to consider this. Fundamentally, it is not new, but a standardized definition may be useful. This is important for the ecological community though they often have low accuracy requirements.

9.7 It was suggested that it might be worthwhile drafting guidance material for the CIMO Guide on the range of communication techniques that can be used to report data and their advantages and disadvantages (cost, reliability), since data communications is often a significant issue in ensuring continued reporting from stations in some developing countries. There are various types of communications in use, but no standard techniques.

9.8 Investigate and report on the performance of automated cloud reporting. For example, KNMI is investigating the use of ceilometers pointed by cloud cameras. With many countries transitioning to automated observations, cloud observation remains a challenge for automation.

9.9 Investigate and report on transmissometer performance. Transmissometers perform well at low visibility (<2km), but perform poorly at high visibility.

10. ANY OTHER BUSINESS

10.1 *The Trans-African Hydro-Meteorological Observatory*

10.1.1 Mr Rolf Hut, an expert from the Technical University (TU) of Delft, was invited to attend the session to appraise the members of the work being done in Africa to develop the **Trans-African Hydro-Meteorological Observatory** (TAHMO). Mr Hutt provided a detailed briefing on the work, focusing on the technology being used to set up a network of cheap observing sites at educational institutions in Kenya, Senegal, Ghana and South Africa. (See Annex III for further details)

10.1.2 Mr Hut described how farmers in these parts of Africa take out insurance on precipitation amounts over the coming season: if drought occurs and their crops fail, they receive an insurance payment, so they can make long-term investments on their lands. The insurance companies involved benefit from rainfall data with which to verify insurance claims, so install rainfall stations. They would prefer TAHMO to manage the stations. TAHMO envisages designing and selling cheap instruments to schools and/or farmers, which would then maintain the instruments and send the data back to TAHMO for payment. TAHMO would on-sell the data to the insurance companies and possibly others, while making it freely available to educational and government institutions.

10.1.3 TAHMO is currently deploying a small network of 11 stations in Kenya as pilots. At present the main cost of the stations is the price of the electronics, which are produced in small quantities. If 10’000 stations could be produced, then the price would be much cheaper, perhaps below $100. He noted that the data uncertainty is approximately 10% and that the sensors are unreliable at quantifying light rain: in these situations they can detect rain or no rain, but not the intensity. Their main current problem is real-time referencing or calibration in the field.

10.1.4 The session raised the potential issues that WMO may have in affiliating itself with such an arrangement if it were seen to be counter to Resolution 40/25 and this aspect may require further consideration. The session also advised that, from a WMO perspective it would be very important for TAHMO to consult beforehand with a country’s NMHS regarding any plans TAHMO might wish to make in regard to the establishment of sites in that country, and that the best result would be if TAHMO could collaborate with the NMHS in setting up and operating the network, since this may also provide a data communications solution.

10.1.5 It was noted that this TAHMO activity, situated in eastern Africa, overlaps with EGAN-HYCOS and some of these stations could potentially become part of the list of stations approved by the Region as part of WIGOS.

10.1.6 The session noted that it was not in a position to assess the quality of the instruments or of the data, and recommended that, to advance its project further, TAHMO first demonstrate the performance of the sensors. The session noted that the development timescale for such instruments to achieve an operational status and to meet the requirements of the CIMO Guide can be long, and that sensor calibration is critically important. Mr Hut agreed that these instruments should not be used to replace the sensors at existing meteorological stations equipped with high quality instruments, but that these new sensors could be tested by installation alongside, and side-by-side comparison with, the recognized instrumentation.

10.2 *The Measurement of Eddy Covariance.*

10.2.1 Prof Han Dolman, an invited expert from the VU University Amsterdam, next provided a presentation on the measurement of eddy covariance and a current European project in which a network of reference stations is being developed in Europe (NEON).

10.2.2 Prof Dolman commenced his presentation with a detailed explanation of the importance of eddy covariance measurements and described the theory behind these measurements. (See Annex IV).

10.2.3 Prof Dolman noted that, while the types of processes involved in the derivation of data are widely accepted internationally, standardization of the algorithmic approaches is required, and is, in part, where NEON could benefit from WMO's collaboration.

10.2.4 The 2010 updated GCOS IP with action T3 calls for the establishment of a set of reference sites. These are required to:

- ensure "that a representative set of biomes are properly and consistently documented over long periods of time (decades or more). This will allow the details of natural vegetation changes and carbon stocks, including fluxes, to be carefully monitored at key locations;
- measure key meteorological ECVs to support interpretation of changes recorded at such sites;
- optimize the joint use of these terrestrial reference sites with a set of sites delivering essential ground data for the validation of satellite-derived products that provide extensive geographical coverage for these."

The ecological and atmospheric observatories that use eddy covariance (EC) are part of this reference network. EC is the key methodology employed at these reference and other observational sites.

Maturity

10.2.5 The technique was first developed in the 1960s and reached maturity through field campaigns in the middle 1990s. Towards the end of the 1990s, a series of long term monitoring stations was established world-wide, some of which have been operating continuously and have a record of almost 20 years. First coordinated by continental networks such Ameriflux and Euroflux in the 90s and later by a suite of regional networks worldwide, a global volunteer network has now developed. This research community has initiated algorithm comparisons, later multi-site comparisons (i.e. Fluxnet Activities, www.fluxnet.org). Currently, there are over 400 sites globally under various continental scale organizations that have a mandate for sustained long term observations: Asiaflux, Chinaflux, ICOS, NEON Ameriflux. This calls for the establishment of a global standard that can be adopted and sustained by these collective organizations and their associated governance structures.

10.2.6 Initially, the use of EC was focused on understanding site-specific ecosystem processes and their drivers. Since its inception in the 1990s, this technique has provided robust data to; scale among sites, scale to whole continents, parameterize ecosystem-to-global models, decompose within ecosystem processes, parameterize atmospheric inversion approaches and Bayesian techniques, etc. The full potential of the EC technique may not have been fully realized. These EC-based data and synthetic uses are what is being called for in establishing large-scale, transnational datasets to address societal benefits by entities such as; Group on Earth System of Systems (GOESS), Office of Science Technology and Policy (US Government Executive Branch), US President's Council of Advisors on Science and Technology (PCAST), and many other position papers (full list available).

Path to a standard

10.2.7 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 trans-nationally/inter-continentally make this a salient, scientifically and politically urgent issue, e.g., ICOS, NEON, AsiaFlux, CoopEUS (www.coopEUS.eu). To achieve this goal, ICOS and NEON have joined forces to propose to CIMO-ET-NIST[1] the development of an EC standard to be included in the CIMO Guide.

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[1] NEON and ICOS have also engaged in efforts to broadly develop the interoperability of all methodologies through the establishment of a signed MOU and through the efforts of CoopEUS (FP7 and NSF-SAVI supported interoperability efforts).

10.2.8 After some discussion, the session agreed that:

- ***Development of an EC standard has high utility and would be useful, and CIMO is the appropriate entity to manage the standard once it has been drafted by a group of experts drawn from the global EC community;***

- The representatives of major continental networks (ones with governance structures and mandates for sustained observing capability such as ICOS, NEON, AsiaFlux, OzFlux, AmeriFlux) should ***form a working group*** that reflects the needed level of international organisation and consensus to develop an EC Standard, i.e., its instrumentation type(s) (principles of operation), algorithmic processes, and field deployment/site design;

- This working group is to submit ***a draft outline for a EC Standard*** by the end of 2013 for consideration by CIMO ET-NIST, in collaboration with relevant experts from CAS, which will then make a recommendation to CIMO MG on the appropriateness of CIMO/CAS involvement in the proposed standard, and whether to publish the standard in the CIMO Guide or using an alternative mechanism;

- Assuming a positive response from CIMO and CAS to ET-NIST's recommendation, the working group will draft the document and vet its content with the broader user community (formal community review process), track and incorporate comments, and submit a final version for CIMO/CAS review;

- Formal CIMO/CAS review of the final version should then follow, with the aim to have this standard published as soon as practicable after that.

11. REVIEW OF TERMS OF REFERENCE AND REFINEMENT OF WORK PLAN

11.1 The meeting reviewed its Terms of Reference and revised its Work Plan to incorporate the decisions taken during this meeting, as provided in Annex IV.

12. CLOSURE OF THE SESSION

12.1 Having agreed on a tentative teleconference, if required, at 0800 UTC on 29 January 2014 to finalize the report to the OPAG Chair for CIMO-MG-11 (with members to email their contributions to the Chair by mid-January), the session was closed on Friday 13 September 2013 at 16:15 hours.

ANNEX I

LIST OF PARTICIPANTS

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ANNEX II

Pyrgeometer Calibration Procedure at the PMOD/WRC-IRS

Julian Gröbner and Stefan Wacker

Davos, 1 May, 2012

Introduction

Pyrgeometers measure longwave radiation, defined as radiation emitted by the atmosphere (downwelling) or the Earth surface (upwelling) in the wavelength range between 3 and 100 ìm [WMO, 2008]. At the Infrared Radiometry Section of the World Radiation Center, Pyrgeometers are calibrated for downwelling longwave irradiance relative to the World Infrared Standard Group (WISG) of pyrgeometers. The WISG consists of four pyrgeometers, two modified Eppley PIRs 31463F3 and 31464F3, and two Kipp&Zonen CG4 FT004 and CG4 010535. A fifth Pyrgeometer, Kipp&Zonen CG4 030669, is running continuously besides the WISG since February 2008 but is not used for the calibration of test pyrgeometers.
Currently, the calibration coefficients of the WISG are those retrieved during the IPASRC-I measurement campaign [Philipona et al., 2001b], relative to the Absolute Sky Scanning Radiometer (ASR) [Philipona, 2001a] and have not been changed since. Recently, a new transfer standard radiometer, the Infrared Integrating Sphere (IRIS) Radiometer, has been developed to allow traceability of longwave radiation to reference blackbody cavities [Gröbner, 2012].
While it is the goal to eventually calibrate the WISG relative to a group of transfer standard radiometers, comprised of IRIS radiometers and possibly additional radiometers, the aim of this report is to describe the current pyrgeometer calibration procedure adopted at the WRC-IRS and to propose suitable changes to improve the reproducibility and uncertainty in the pyrgeometer calibrations in view of recent findings.

Pyrgeometer Calibration Procedure at WRC-IRS

Test Pyrgeometers are calibrated at the WRC-IRS based on the following radiometric equation, first proposed by Albrecht et al., 1974 and endorsed by the BSRN [see BSRN Manual V2.1, McArthur, 2004]:

$$E = \frac{U}{C}\left(1 + k_1 \sigma T_B^3\right) + k_2 \sigma T_B^4 - k_3 \sigma \left(T_D^4 - T_B^4\right)$$

Where U is the electrical output of the thermopile, C the sensitivity, T_B and T_D the pyrgeometer body and dome temperatures respectively, and k_i instrument constants.
The instrument constants k_i are determined in the laboratory by placing the test pyrgeometer at the aperture of a blackbody cavity and taking measurements at several combinations of cavity and pyrgeometer temperatures. The measurements are taken only when both the cavity and the pyrgeometer temperatures have stabilized (e.g. static conditions). In case of Eppley PIRs, the dome coefficient k_3 is obtained by differentially heating the dome of the pyrgeometer by a copper ring to produce a positive temperature difference of about 1 K between dome and body. In all other cases, the dome coefficient is set to 0.
Following the laboratory characterization to retrieve the instrument constants k_i, the test pyrgeometer is mounted in a ventilated unit with a heated airflow to the instrument dome (VHS-PMOD) on a shaded solar tracker beside the WISG pyrgeometers on the measurement platform of WRC-IRS. Measurements of downwelling longwave irradiance are stored as one-minute averages for a period lasting between a few days to several months, depending on customer demand and weather conditions. The sensitivity C of the test pyrgeometer is retrieved relative to the WISG average from a subset of nighttime measurements applying the following criteria:

1. Outliers are removed (U>0.001 V, U<-20 mV, $|T_D|$>40 °C, $|T_B|$>40 °C)
2. Any night containing rain is excluded (limit of 0.2 mm/10 min)
3. Stable atmospheric conditions, defined by the standard deviation of the WISG <2 Wm^{-2}

4. Net radiation measured by the WISG < -70 Wm^{-2}
5. Measurements from one night are used if there are at least 80% valid measurement points
6. Night is defined when the solar zenith angle is larger than 95°
7. Relative standard deviation of the test pyrgeometer signal <3%

The aim is to obtain sufficient measurements during cloud-free nights to determine the sensitivity C with adequate statistical significance (no quantitative criterion is currently defined when this is reached). Specifically, criteria 3, 4, and 7 are used to select stable atmospheric conditions with a large signal at the thermopile which usually correspond to clear sky nights.
The calibration uncertainty of the test pyrgeometer is obtained by taking into account the following uncertainty components (expressed as expanded uncertainty, 95% coverage interval):

- Uncertainty of the WISG based on the ASR and its internal variability, typically ±2.6 Wm^{-2}
- Uncertainty of the thermopile signal, ±1 ìV
- Uncertainty of the temperature measurements of ± 0.02 K
- Uncertainty of the instrument constants [k_1,k_2,k_3] =[0.03 0.0008 0.2]
- Standard deviation of the retrieved sensitivities C

Stability of the WISG

The WISG is operated continuously on the outdoor platform of the WRC-IRS. Its stability is monitored by internal consistency checks of the four pyrgeometers comprising the WISG. As can be seen in Figure 1, the pyrgeometers of the WISG typically agree to within ±1 Wm^{-2}, with minor seasonal variations between the WISG pyrgeometers. While the absolute level of this reference group is important for radiation and energy budget studies, its long-term stability is relevant for long-term trend investigations, which, as is shown here, can be demonstrated to better than ±1 Wm^{-2}.

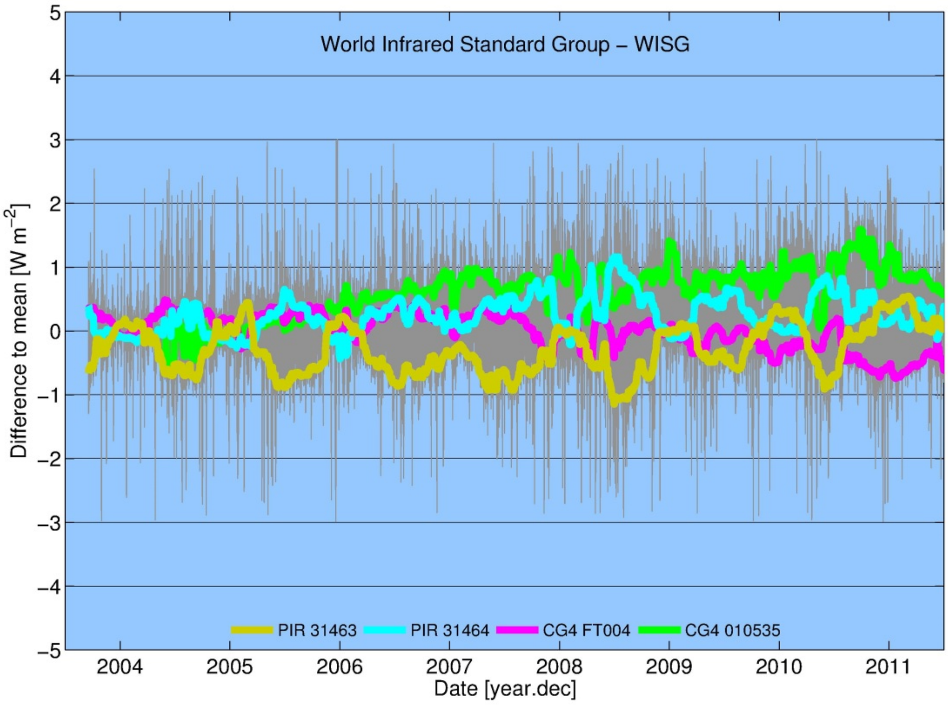


Figure 1 Night average differences of longwave irradiance measurements between the WISG pyrgeometers relative to their average. The thick lines represent a monthly running average.

Calibration of a test pyrgeometer (retrieval of the sensitivity C)

As mentioned previously, a test pyrgeometer is calibrated relative to the average of the WISG and its sensitivity C is retrieved by minimizing the residuals. As an example, Figure 2 shows the residuals of a test pyrgeometer (Eppley PIR) relative to the WISG.

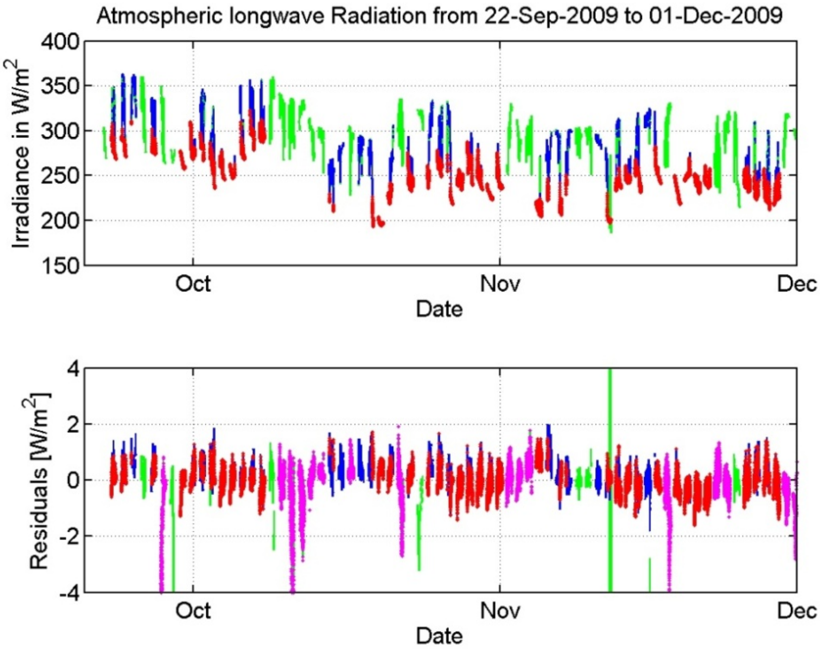


Figure 2 Atmospheric downwelling longwave irradiance measurements by a test pyrgeometer (Eppley PIR) and the WISG (one minute averages). The upper figure shows the actual measurements, while the lower figure shows the residuals relative to the WISG. The red dots represent the measurements used for the retrieval of C, the blue dots correspond to the measurements fulfilling all criteria but with net radiation also higher than -70 Wm^{-2}, while the pink dots correspond to measurements excluded due to precipitation.

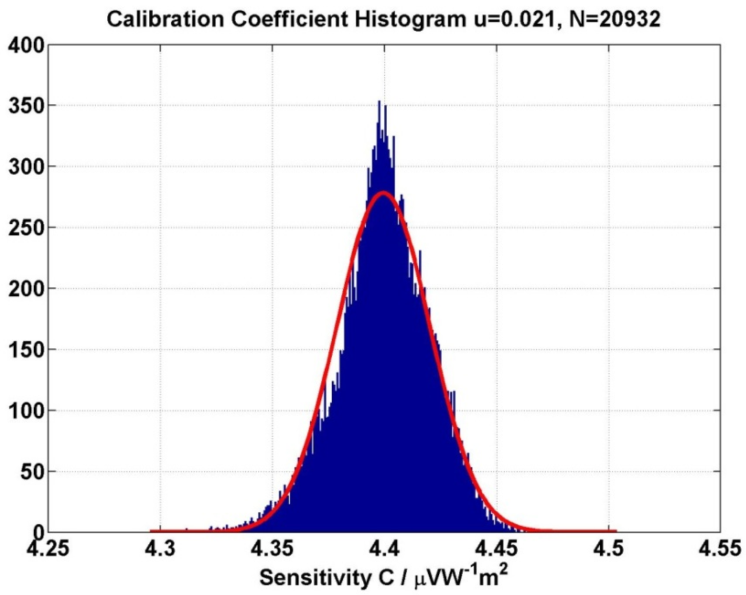


Figure 3 Histogram of the sensitivities C retrieved from the measurements shown in Figure 2 for a test pyrgeometer. The red curve corresponds to the best fit of a normal distribution with a standard deviation of 0.021 ìVW^{-1}m^{2}.

The histogram of the sensitivities C retrieved from the measurements displayed in Figure 2 is shown in Figure 3 and demonstrates that for this particular instrument the residuals follow closely a normal distribution with a standard deviation of 0.45%. The corresponding standard deviation of the residuals in terms of atmospheric longwave radiation is 0.4 Wm^{-2}.

The residuals can be correlated to a variety of parameters, such as thermopile signal, pyrgeometer body temperature, etc… to check for systematic dependencies to these parameters. In this particular example, no significant correlations can be observed. A particularly interesting parameter is the integrated atmospheric water vapour (IWV), obtained from GPS time delay measurements determined at PMOD/WRC by the automatic GNSS-network of Switzerland (AGNES). Figure 4 shows the residuals and the sensitivities C with respect to this parameter.

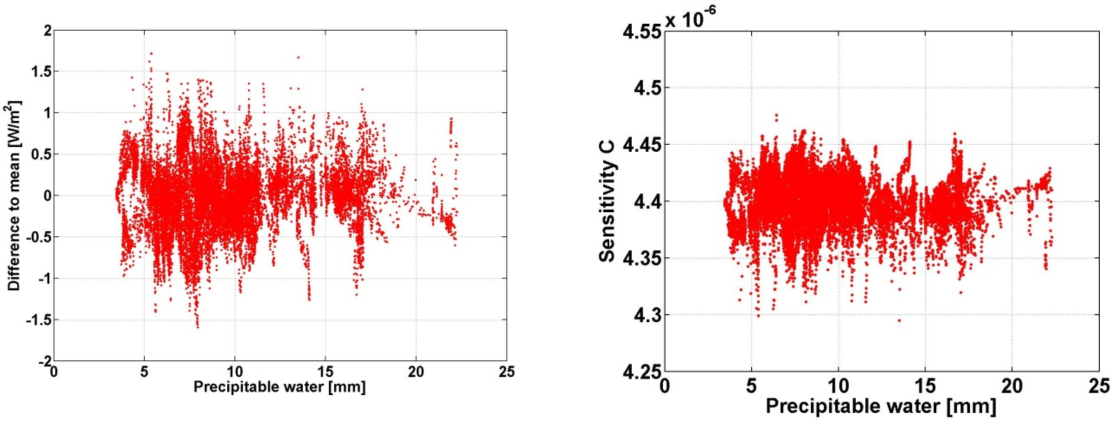


Figure 4 The left figure shows the residuals versus the integrated water vapour while the right figure shows the sensitivities C retrieved relative to the WISG versus the integrated water vapour.

In this particular example, the sensitivity C and the corresponding expanded uncertainty (applying a coverage factor k=2, which for a normal distribution corresponds to a coverage probability of approximately 95%) retrieved by comparison to the WISG are:

$C = 4.40 \pm 0.15 \mu V W^{-1} m^2$.

While the calibration relative to the WISG can be obtained with a relative expanded uncertainty (with a 95% coverage probability) of only 0.9% (see Figure 3 above), the expanded uncertainty of the WISG of ±2.7 Wm^{-2} is mainly responsible for the large uncertainty of the calibration. Therefore, a calibration with respect to the WISG has an uncertainty of typically less than 1%, while the absolute uncertainty is limited by the traceability of the WISG to the SI.

Calibration of Kipp&Zonen CG4 pyrgeometers

Since 2001, Kipp&Zonen CG4 pyrgeometers have increasingly been calibrated at WRC-IRS, becoming the second largest group of pyrgeometers after the Eppley PIR. While only 1 CG4 and 11 PIR were calibrated in 2001, near parity was reached in 2010 with calibrations of 15 CG4 and 16 PIR. While the calibration procedure was not modified with the advent of the CG4 pyrgeometer, apart from the absence of a dome thermistor, some systematic variabilities between certain CG4 pyrgeometers and the WISG have been observed, especially during cold weather conditions at Davos.

The modified pyrgeometer CG4 FT006 with Dome 030669

At PMOD, the domes of CG4 FT006 and of CG4 030669 (instruments manufactured in 2001 and 2003 respectively) were exchanged and mounted on the respective thermopile bodies of each CG4 (see Gröbner, 2010). In the following section the results of CG4 FT006 before and after the modification will be analysed. For simplicity reasons, the modified pyrgeometer CG4 FT006 with the dome of 030669 will be renamed CG4 030669 in the remaining document. The original and modified pyrgeometer was compared to the WISG during two subsequent years, the residuals of which are shown in Figure 5. When investigating the best correlation of the residuals with atmospheric or instrumental parameters, the best correlation was obtained with respect to integrated water vapour.

Unmodified CG4 FT006 (Aug 2007 - Feb 2008) **Modified CG4 030669 (Feb 2008 - Feb 2009)**

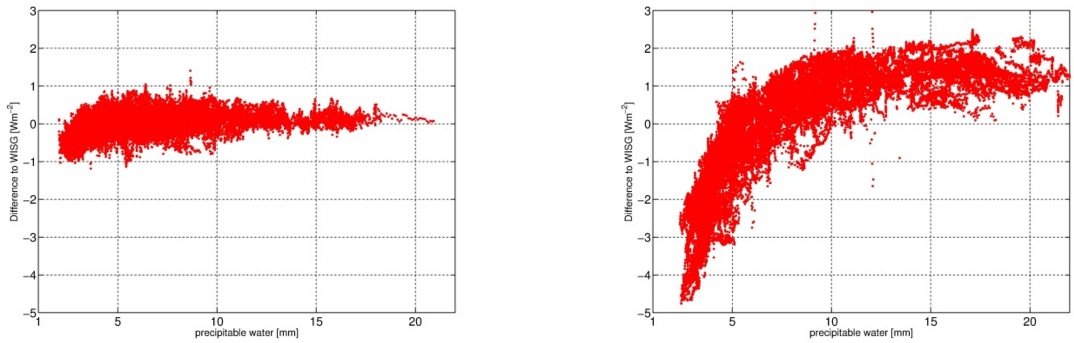


Figure 5 The left figure shows the residuals of the unmodified CG4 FT006 with respect to the WISG while the right figure shows the residuals of the modified pyrgeometer with the dome of CG4 030669 with respect to the WISG. The residuals are displayed with respect to the IWV as this is the parameter showing the best correlation.

The resulting dependence of the residuals between the pyrgeometer and the WISG with respect to the IWV is striking and obviously due to the exchange of the domes. The reason for the observed deviations with respect to IWV could not be ascertained so far; it is likely that spectral differences between these domes (especially the solar blind coating) are responsible for this behaviour, since the spectrum of downwelling longwave irradiance below an IWV of 10 mm differs significantly from spectra with larger IWV, especially in the wavelength range of the second atmospheric window, between 18 and 25 ìm.

Similarly to the example shown in Figure 2 for an Eppley PIR, Figures 6 and 7 show the residuals of CG4 030669 with respect to the WISG for the same period from September to December 2009:

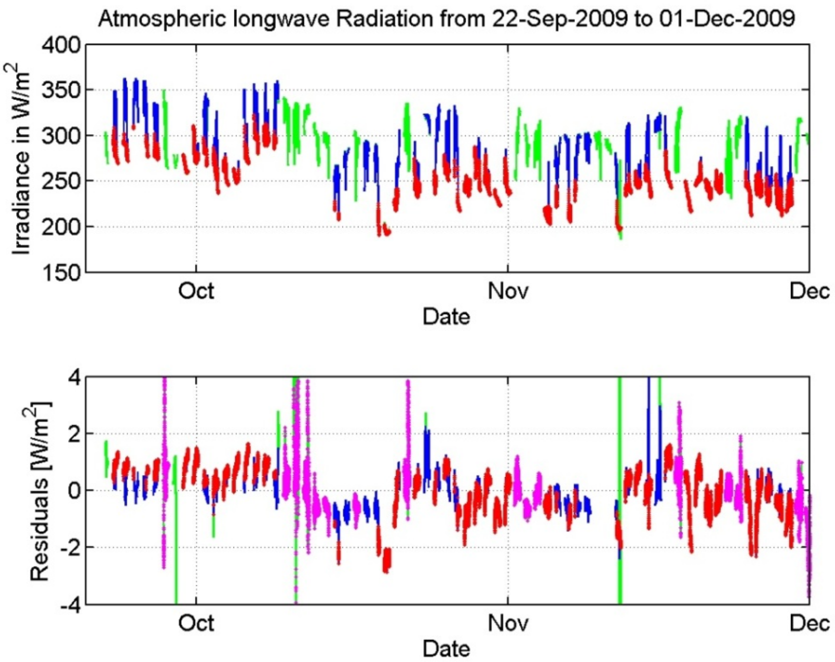


Figure 6 Atmospheric downwelling longwave irradiance measurements by a CG4 pyrgeometer (CG4 030669) and the WISG (one minute averages). The upper figure shows the actual measurements, while the lower figure shows the residuals relative to the WISG. The red dots represent the measurements used for the retrieval of C, the blue dots correspond to the measurements fulfilling all criteria but with net radiation also higher than -70 Wm^{-2}, while the pink dots correspond to measurements excluded due to precipitation.

As can be seen in the figure, the residuals of this CG4 with respect to the WISG show large deviations of up to -3 Wm^{-2} for certain periods. The histogram of the sensitivities C retrieved from the measurements displayed in Figure 6 is shown in Figure 7 below and shows that this pyrgeometer behaves differently to the Eppley PIR shown previously.

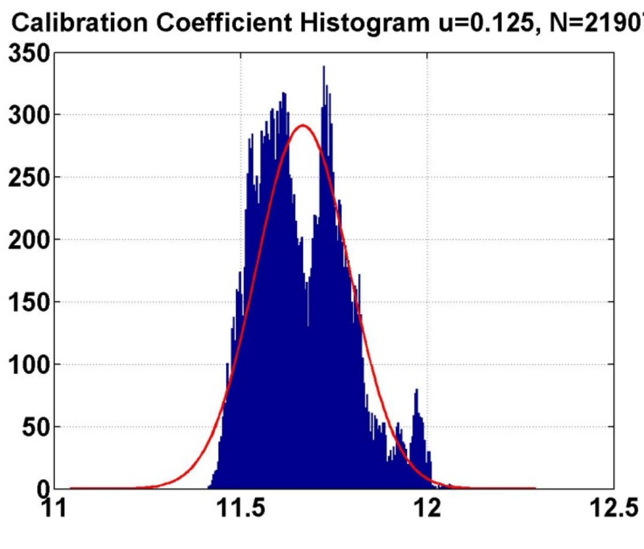


Figure 7 Histogram of the sensitivities C retrieved from the measurements shown in Figure 6 for the CG4 030669 pyrgeometer. The red curve corresponds to the best fit of a normal distribution with a standard deviation of 0.125 ìVW^{-1}m^{2}.

In contrast to the Eppley PIR for the same period, the corresponding standard deviation of the residuals in terms of atmospheric longwave radiation is 0.9 Wm^{-2}, e.g. about two times larger than the Eppley PIR.

When investigating the best correlation of the residuals with atmospheric or instrumental parameters, the best correlation is obtained with respect to integrated water vapour as shown in the figures below:

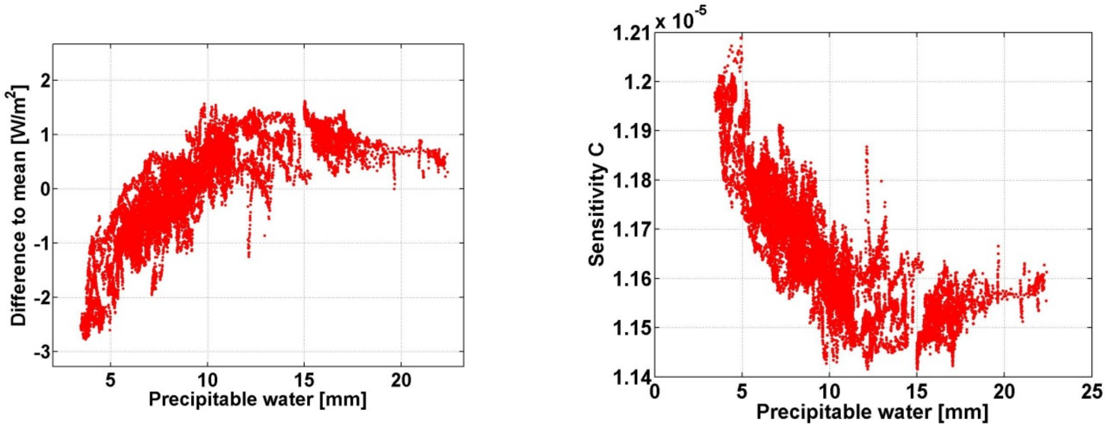


Figure 8 The left figure shows the residuals versus the integrated water vapour while the right figure shows the sensitivities C retrieved relative to the WISG versus the integrated water vapour.

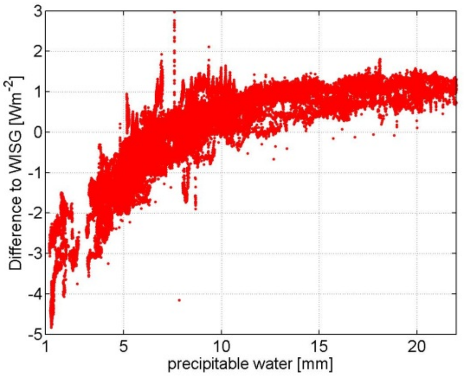
The residuals show a clear correlation with IWV, decreasing significantly below approximately 10 mm. In this particular example, residuals of up to 3 Wm^{-2} are observed between this CG4 and the WISG. The relative change in the retrieved sensitivity between very dry (<5 mm) and standard atmospheric water vapour conditions (around 20 mm) is larger than 4%. With respect to the WISG, this pyrgeometer underestimates atmospheric longwave irradiances under conditions with very little precipitable water vapour. In the remaining report, CG4 030669 is used with a sensitivity of 11.55 ìVW^{-1}m^{2} retrieved by a calibration relative to the WISG for conditions with IWV larger than 10 mm, as shown in the right figure of Figure 8.

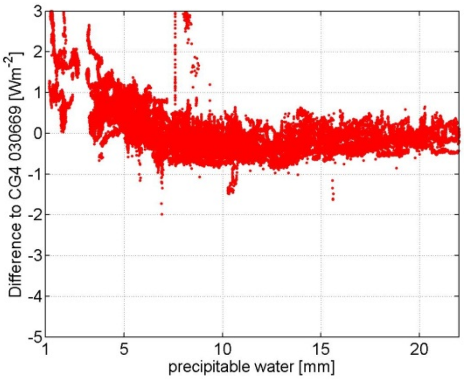
CG4 Pyrgeometers versus WISG and CG4 030669

Interestingly, similar deviations with respect to the WISG are seen between all investigated CG4's manufactured after about 2003 (judging by the first two digits of the instrument serial number). The following table shows the residuals between several CG4 (or CGR4) calibrated at PMOD/WRC relative to the WISG, with respect to the IWV in the left column, while the same data is shown with respect to CG4_030669 in the right column (this pyrgeometer belongs to the PMOD/WRC and is operated continuously besides the WISG).

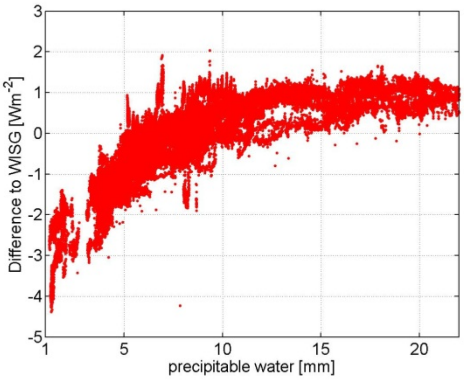
Table 1 The left figures show the residuals of several CG4 or CGR4 pyrgeometers with respect to the WISG while the right figures show the same measurement data relative to CG4 030669. The residuals of each dataset are obtained from fitting the measurement data to the pyrgeometer equation using either the WISG or CG4 030669 as reference.

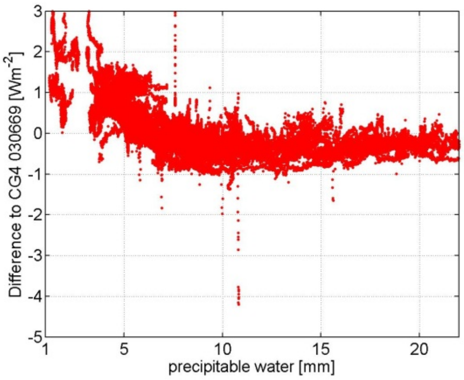
CGR4 110350 (Sep 2011-Feb 2012)



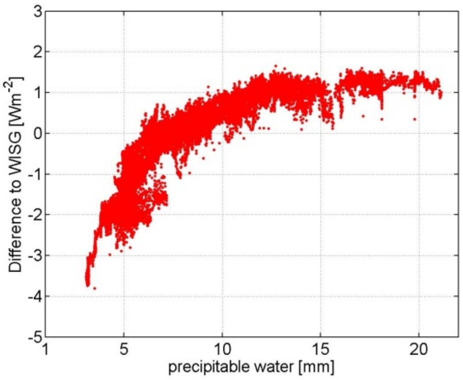


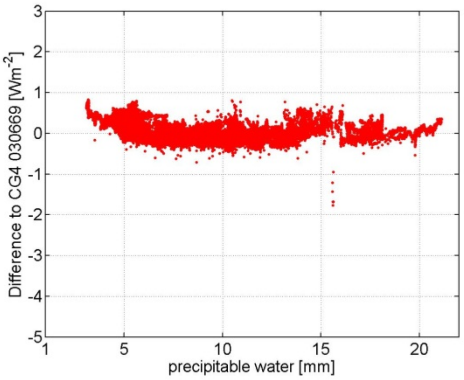
CGR4 110349 (Sep 2011-Feb 2012)



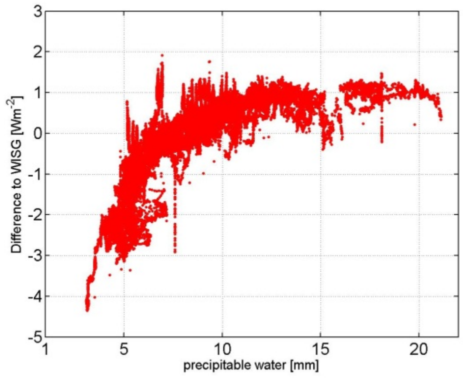


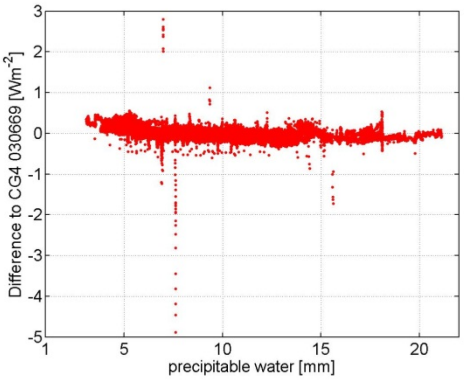
CGR4 070038 (Sep-Dec 2011)



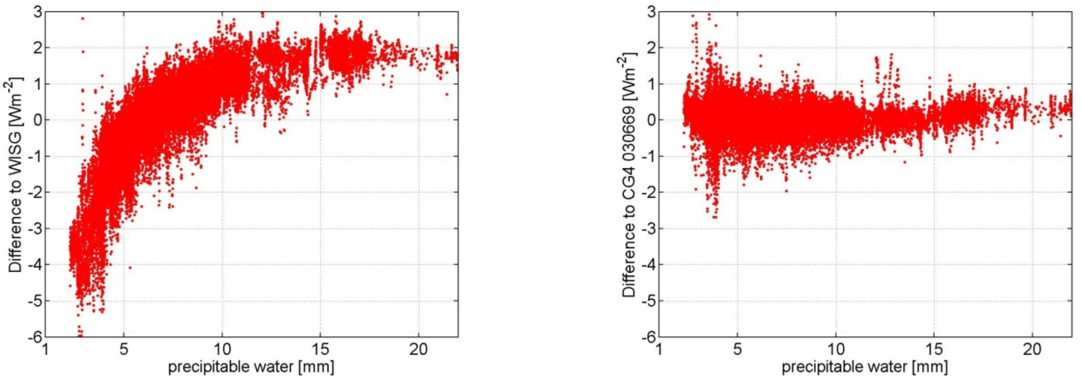


CG4 010536 (new dome since 2005) (Sep-Dec 2011)

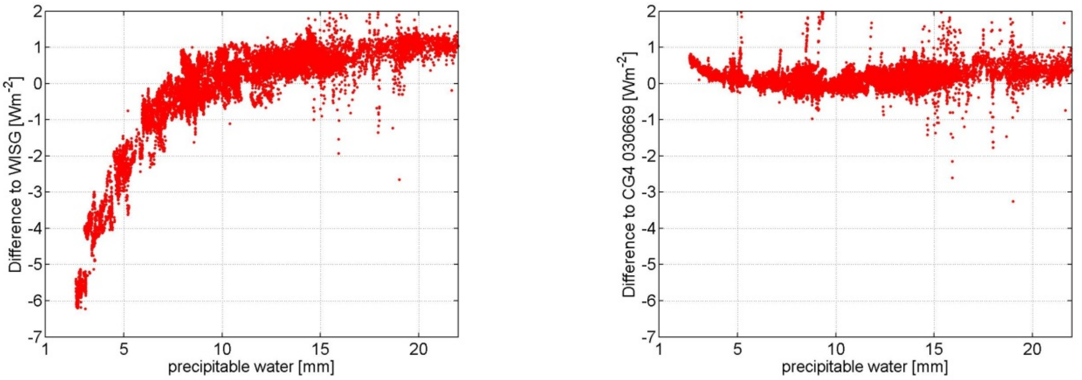




CG4 060881 (Sep 2009 to Jan 2010)



CG4 070039 (Sep 2009 to Jan 2010)



As can be seen in the figures, all CG4 (CGR4) pyrgeometers show significant deviations with respect to the WISG for IWV lower than 10 mm. These deviations are instrument dependent and under-estimate atmospheric longwave irradiances by as much as 6 Wm^{-2} for IWV amounts as low as 2 mm. One should note that two pyrgeometers of the WISG are CG4 type pyrgeometers, built before 2000, which do agree with the overall WISG group of pyrgeometers and do not show these increasing discrepancies with decreasing IWV.

However as can be seen on the right hand side of the table, the CG4 pyrgeometer group agrees remarkably well between each other, showing deviations of less than ±2 Wm^{-2} for the whole sampled IWV range.

Comparison to the IRIS Radiometers

The previous section has shown that deviations between the WISG group of pyrgeometers and CG4 (CGR4) pyrgeometers have been observed with respect to the atmospheric IWV. However from these measurements alone it is not possible to decide which group of instruments is responsible for these deviations.

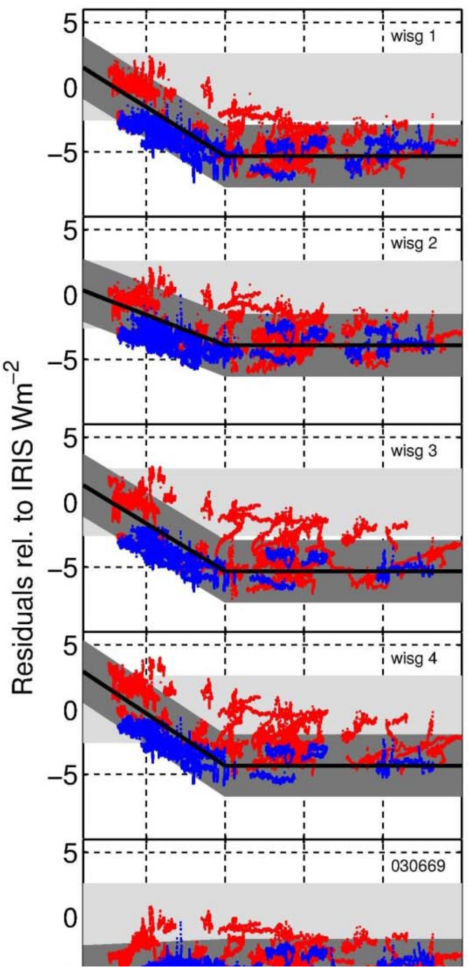


Figure 9 Residuals of the WISG and CG4 030669 pyrgeometers to IRIS#2 and IRIS#4 with respect to integrated water vapour. The thick black line represents a linear fit to the combined residuals for 2010 and 2011. The slope is determined for IWV smaller than 10 mm, while it is set to a constant value at larger IWV. The light grey area corresponds to the estimated uncertainty of the WISG based on the ASR, ±2.6 Wm^{-2}, while the dark grey area corresponds to the estimated uncertainty of the IRIS radiometer, ±2.4 Wm^{-2}.

The new IRIS Radiometer has been designed to measure atmospheric downwelling longwave irradiance without spectral windows using a novel integrating sphere design with a pyroelectric detector. The instrument has been in operation since 2009 and several instruments were constructed, of which currently four are in operation, two of which at PMOD/WRC. Optimal measurement conditions are encountered during clear sky conditions at nighttime. Figure 9 shows the comparison of downwelling longwave irradiance measurements between the WISG and IRIS radiometers #2 and #4 from respectively 73 nights in 2010 (red dots) and 59 nights in 2011 (blue dots). The residuals are plotted against the integrated water vapour in order to demonstrate the systematic dependence on this atmospheric parameter. The thick black lines are linear fits to the residuals for the two IWV ranges above and below 10 mm. The light gray area corresponds to the uncertainty of the WISG of ±2.6 Wm^{-2}, based on the ASR uncertainty [Philipona, 2001a] while the dark gray area represents the uncertainty of the IRIS radiometers of ±2.4 Wm^{-2} [Gröbner, 2012] applied to the linear fit average.

Two distinct regimes can be observed : During relatively warm and humid conditions (IWV larger than 10 mm), the difference between the WISG and IRIS radiometers is constant, with IRIS measuring larger irradiances; during cold and dry conditions (IWV smaller than 10 mm), the difference between the WISG and IRIS gradually decreases. The specific offset and slope for each WISG radiometer is summarised in Table 2.

Table 2 Observed differences between WISG pyrgeometers and CG4 030669 with IRIS#2 (2010) and IRIS#4 (2011). The linear fit is used for IWV smaller than 10mm, while for larger IWV, the difference between pyrgeometer and IRIS is constant and equal to the offset. The standard deviation of the residuals is based on 18458 (73 nights) and 18925 (59 nights) 1 minute measurements for 2010 and 2011, respectively.

Instrument	Linear Fit		Standard Deviation of Residuals in Wm^{-2}	
	Offset at IWV ≥10 mm [Wm^{-2}]	Slope [$Wm^{-2}mm_{IWV}^{-1}$]	2010	2011
WISG1	-5.3	-0.76	1.70	1.12
WISG2	-3.9	-0.47	1.54	1.02
WISG3	-5.3	-0.74	1.85	1.04
WISG4	-4.3	-0.81	1.87	0.98
Average WISG	-4.6	-0.69	---	---
CG4 030669	-4.1	0.04	1.25	0.76

The average offset between the IRIS and WISG is 4.6 Wm^{-2} which remains within the respective estimated uncertainties of the WISG and IRIS. While a constant offset between the WISG and IRIS would be only a matter of implementing a scale change, the observed variability with IWV between the WISG and the IRIS radiometer necessitates a more thorough analysis:

- The variability with respect to IWV implies a spectral mismatch between the IRIS and WISG radiometers. Since the IRIS radiometers are windowless and use pyroelectric detectors with an organic black coating having a spectrally flat responsivity, the spectral mismatch is attributed to the domes of the WISG pyrgeometers, and, as shown in Table 2, variable between different instruments.
- As noted previously [Gröbner, 2010], the calibration of PIR pyrgeometers, when combining the results from the IPASRC-I and –II campaigns, implicitly showed that these pyrgeometers measured higher irradiances during the IPASRC-II campaign with respect to the ASR than during the IPASRC-I campaign. For example the discrepancy of the WISG1 radiometer was +4.1 Wm^{-2}, consistent with the observed change of +4.6 Wm^{-2} between the warm and cold conditions encountered in Davos.
- As mentioned previously, the exchange of the dome of CG4 FT006 with the one of CG4 030669 showed that the observed variability with IWV could be attributed to the dome of the pyrgeometer and not to the thermopile and electrical circuitry.

Conclusion

1) There exists two groups of commercial pyrgeometers, the Eppley PIR and CG4 (CGR4) pyrgeometers manufactured since 2003, showing significant deviations between each other with respect to integrated water vapour at IWV amounts below approximately 10 mm.
2) The atmospheric longwave irradiance measurements of the WISG pyrgeometers have a systematic dependence on IWV when it is below about 10 mm. This corresponds to the cold and dry conditions encountered in winter in Davos.

-

3) Pyrgeometer calibrations at the WRC-IRS are based on the WISG. To improve the consistency of the pyrgeometer calibrations performed at the WRC-IRS, the following actions are suggested:
    - Routine calibrations are only performed at IWV above 10 mm. This restricts the calibration season at Davos from March to November.

- Specific cold season calibrations should span the IWV range between at least 3 and 15 mm in order to determine the dependency on IWV of the pyrgeometer due to its spectral mismatch.
- Eventually, the WISG measurements should be corrected with the correction functions derived with respect to the IRIS radiometers and shown in Table 2.

4) The observed average offset of 4.6 Wm^{-2} between the IRIS and WISG (IRIS measuring higher than WISG) needs to be confirmed by independent measurements such as [Reda, 2012] before updating the WISG calibration coefficients.

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ANNEX III

TRANS-AFRICAN HYDRO-METEOROLOGICAL OBSERVATORY

Understanding current climate conditions and future trends is essential to managing food production, disease, and land resources, especially in Africa where rain-fed agriculture is highly vulnerable, dependent on a few critical weeks of annual rainfall and other climate variables. There is insufficient hydro-meteorological data monitoring across the African continent -- with estimates that Africa has the lowest density of weather-monitoring stations of any continent, *with only one weather station per 260,000 km^2*. Key obstacles to weather monitoring in Africa include: measurement hardware poorly suited to environmental challenges; high cost of equipment; lack of technical infrastructure to maintain stations; and complex obstacles to collection and dissemination of environmental data. Yet, the opportunities have never been greater, due to broad access to mobile communication, radical decreases in sensor costs, and renewed donor commitment to continental-scale issues in Africa.

The **Trans-African Hydro-Meteorological Observatory** (TAHMO) aims to establish a network of 20,000 cell-phone enabled weather stations across Africa to provide greatly needed rainfall, temperature, humidity and other data to governments, the private sector, NGOs and other stakeholders. TAHMO data will provide micro-insurance companies, governments and other agencies assisting farmers with more timely, reliable and locally relevant weather information to help farmers improve on-farm practices, increase agricultural productivity and better adapt to climate change.

By 2022, TAHMO's goals are:

- To install 20,000 self-powered, self-calibrating, weather stations across Sub-Saharan Africa (starting in Kenya, Senegal, South Africa, Ghana and Uganda), with robust sensors and communication technology that provides accurate, real-time hydro-meteorological data;
- To assist smallholder farmers to improve agricultural productivity with more accurate, locally relevant and real-time weather data available to African stakeholders serving farmers;
- To make raw weather data freely available via the Internet for use by scientists, WMO, educators, and African government agencies.

Working closely with African universities and collaborators, TAHMO began in 2012. It has experiments in Kenya, Senegal, Ghana and South Africa, which test the durability of new measurement techniques, communication methods, and measure meteorological and water resource variables. In parallel, it is working with schools to develop a curriculum on weather, climate, environment and computation.

Since 2012, TAHMO activities have included:

- Defining weather station design criteria: Robustness, zero/ low maintenance, no moving parts, no open cavities (insects!), self-calibrating, cross-calibrating
- Testing proto-type stations. (Self powered stations with an integrated solar panel, connected to the Internet via a GSM network, using low bandwidth and smart data compression, which are compact, modular and durable, designed to last 5 years.
- Holding a sensor design competition to identify African-based scientific teams interested in working with TAHMO and designing proto-type weather stations. Teams came from Nigeria, Zimbabwe, Kenya, Uganda and Spain. See http://tahmo.info/sensor-design-competition-0

TAHMO's focus in 2013/2014 will be:

- Providing support for micro-insurance: Many weather-indexed insurance schemes across Africa are beginning to provide insurance products to farmers, but need more accurate, real-time and local weather information to improve the data on which their insurance products are based. TAHMO plans to partner with such companies to provide real-time weather data, enabling them to develop locally relevant micro-insurance packages.

- Science education: Since many TAHMO stations will be located at K-12 schools and universities, TAHMO plans to provide science curriculum materials to accompany the stations.
- Data availability: TAHMO is dedicated to making climatic data from the stations freely available for African scientists and others interested in African weather information. To do that, they are working with several data service providers to make TAHMO's raw, real-time weather data easily accessible via the Internet, for use by scientists, educators, African and international government agencies, and others.

TAHMO is currently organized as a joint project of Delft University of Technology (Netherlands) and Oregon State University (USA). Contact details of key personnel are:

- Dr. John Selker, Oregon State University (USA), Department of Biological & Ecological Engineering, john.selker@oregonstate.edu;
- Dr. Nick van de Giesen, Delft University of Technology (Netherlands), Dept. of Water Management, n.c.vandegiesen@tudelft.nl;
- Rolf Hut, Delft University of Technology, Faculty of Civil Engineering and Geosciences, r.w.hut@tudelft.nl.

TAHMO's aim is to build an agro-hydro station costing less than $500, using open-source hardware, such as wii technologies.

TAHMO is also involved in exploring opportunities for the use of alternative technologies to develop other sensors. TAHMO has attempted to measure tree canopy water loading using strain gauges attached to the tree trunk, which measures the compression of the stem due to the weight of the water. It has also trialed a 'bucket on a stick' arrangement which is equipped with an accelerometer and, by tracking the eigen-frequencies of the system, can estimate the water content as the eigen-frequencies change with mass of the container.

MEASUREMENT OF EDDY COVARIANCE

The exchange of momentum, heat, water vapor, CO_2 and other scalars between the earth's surface and the atmosphere is mainly governed by turbulent transport. Buoyancy forces as well as shear stresses form turbulent motions for most of the day. *The eddy-covariance* (EC) technique directly measures the properties of turbulent motions while at the same time measuring the scalars (CO2, H2O, Temperature, CH4, etc.) being transported by these motions. This makes it the least invasive method currently available for direct, real-time, and continuous observations of the net scalar surface-air exchange, i.e., net ecosystem exchanges, net fluxes. The technique is based on the concept of mass conservation and makes use of the Reynolds decomposition (isolation of mean and fluctuating part) and the simplification of relevant terms in the Navier-Stokes equation. The net flux *F* into or out of an ecosystem can be expressed as the covariance between the vertical wind speed, w and the scalar quantity X:

$$F = \overline{w'X'}$$

Primes denote the turbulent fluctuations, the overbar represents an averaging time (typically 30-min). Wherever possible, auxiliary measurements are used to assess non-turbulent terms such as the storage flux, or to assess the assumptions from the simplification of the Navier-Stokes terms, i.e., advective and divergence terms.

The equipment used to calculate this flux is based on a sonic anemometer (in principle, 1-D vertical speed would be sufficient, but 3-D is preferred to obtain the full 3-D wind field properties), a gas analyser (typically based on infra-red absorption for CO2 and H2O and on laser for other gases) and often a fast repose thermocouple for temperature fluctuations. All sensors typically have to operate at frequencies >10 Hz to capture also the turbulent motions that transport the mass and energy. This set of sensors is usually mounted on a boom, well above the ecosystem canopy to avoid interference of tower structures and to ensure that measurements are taken within a well-developed surface boundary layer.

The raw data are then converted into a flux, by applying a specific sequence of processes such as those based on sensor frequency response, flux angle corrections for the sonic, the distance between the sensors. While the types of processes are widely accepted internationally, standardization in these algorithmic approaches is required. In the more recent advancements of these algorithms in networks such as NEON and ICOS, uncertainties are also calculated along the algorithmic process at various stages (in response to needs articulated by the broader research communities).

ANNEX V

REVISED WORKPLAN

Work Plan of CIMO Expert Team on New In-Situ Technologies (2011-2014)

No.	Task description	Person responsible	Action	Deliverable	Deadline for deliv.	Status [%]	Comments
1.	**Performance of new in-situ technologies**	W. Wauben **B. Hartley** M. Yigit N. Nouni S. Waas	1. Review performance of new surface and upper-air technologies and measurement techniques, including ceilometers, integrated sensor methods to observe mixed-layer height, and cloud base and amount derived from a variety of techniques	1.1 Report on preliminary findings 1.2 Document on findings 1.3 Recommended updated to CIMO Guide	CIMO–MG-10, 2012 Mid-Dec 2013 Mid-Dec 2013	50 50 0	ET ToR 2 Aligns with WIGOS Action 3.1.1 See FP ET-NIST-1
2.	**Review algorithms used in AWOS and make proposal for their standardization as a contribution to WIGOS**	**W. Wauben** M. YİĞİT B. Hartley S. Waas	1. Examine use of algorithms and setup of instrumentation by Members 2. Document algorithms used by automatic observing systems, to enable assessment and review of climate datasets	1.1 Questionnaire to members and HMEI 1.2 Report on Stage I to CIMO-MG 2.1 Preliminary report on cloud and weather, with recommendation for future activity 2.3 Recommendation on update to CIMO Guide	July 2011 CIMO-MG 2014 CIMO-MG-2014 Mid-Dec 2013	100 90 10	CIMO-XV, para 9.30 Aligns with WIGOS Action 6.1.1
3.	**Guidelines to install and operate instruments to withstand severe weather**	S. Oncley J. GUO	1. Identify and review existing guidance material on the optimal use of methods to measure severe hydro-meteorological events.	1.1 List of existing documents 1.2 IOM report on severe weather 1.3 New CIMO Guide chapter on severe weather, if appropriate	Dec. 2011 2012 Dec. 2013	30 20 0	CIMO-XV, para 9.30
4.	**Review development of**	J. Gröbner	1. Assess the development of	1.1 Preliminary report	2012	100	ET-MR&ACM-2, para

No.	Task description	Person responsible	Action	Deliverable	Deadline for deliv.	Status [%]	Comments
	new radiation reference instruments		new reference pyrheliometers including traceability to SI 2. Report on the development of new refererence pyrgeometers and pyrgeometer response equations and propose suitable approaches 3. Examine UV component of CIMO Guide Chapter 7	1.2 IOM document 1.3 Recommended update to CIMO Guide 2.1 Preliminary report 2.2 IOM document 2.3 Recommended update to CIMO Guide 3. Recommended update to CIMO Guide chapter 7	Awaiting outcome of Task Team. 2013 2014	0 0 100 90 90 0	7.2.2 IOM Report in intercomparison Awaiting outcome of EMRP ENV-03
5.	**Icing** (pending publication of COST 727 report)	**W. Wauben** (Jani Poutiainen)	1. Review COST-727 Report 2. Update Guide taking in account findings of COST-727 on icing	1. Document on review 2. Proposed updates to CIMO Guide	2012 2013	100 50	CIMO-XV, para 4.10
6.	**Contribute to the implementation of WIGOS and provide relevant advice and support to the CIMO-MG**	TBD	1. Address relevant items of WIGOS Implementation Strategy approved by Cg-XVI and subsequent WIGOS IP	TBD after Cg-XVI			