FINAL PUBLISHABLE REPORT

Grant Agreement number	17SIP02
Project short name	SimpleMeteoU
Project full title	Simple expression of uncertainty for meteorological observations

Project start date and duration:	01 May 2018 33 Months	
Coordinator: Stephanie Bell, NPL Project website address: www.meteomet.org	Tel: +44 20 8942 6402	E-mail: stephanie.bell@npl.co.uk
Primary Supporter: Mike Molyneux, Met Office		
Internal Funded Partners: 1. NPL, UK	External Funded Partners:	Unfunded Partners: 2. MO, UK

TABLE OF CONTENTS

1 Overview

For users of weather and climate information, confidence in the observational data is key. Many factors, however, can affect meteorological observations, from weather station location to the type of measurement equipment used. This project addressed a widely recognised need for a simple way to attribute uncertainty in these meteorological observations. The project's primary supporter, the UK Met Office (MO), sought an approach to doing this by refining existing metrology knowledge, including that from EMRP JRP ENV58 MeteoMet2, to form a simplified system of expressing measurement uncertainty.

This project developed proposals for rule-based systems that could be applied to meteorological data, to give simplified expression of uncertainty based on influences such as siting location and current weather conditions. It offered recommendations on how best to present this uncertainty information. The resulting approach to expressing uncertainty could in future be used to improve numerical weather prediction leading to more accurate weather forecasts.

2 Need

Weather affects a vast range of human endeavours, and its importance ranges from convenience and comfort to matters of safety, environmental and economic impact. Despite ever-improving techniques, there is always some uncertainty in weather forecasts. Users at all levels (such as meteorologists, infrastructure operators, businesses, and individuals) needed uncertainty information, so that they could assess weather-related risks. In addition, the large class of users of commercially supplied weather services needed uncertainty as a differentiator of quality in order to select between sources. However, this uncertainty information was generally not available, or was not provided in an easy-to use format.

In addition, MO itself had particular needs for simplified expression of uncertainty for observations. MO needed to use more widely sourced data in order to meet its ambition of improving the resolution of numerical weather prediction from 500 m, previously, towards 100 m, with a rapid turnaround of 2 hours from data to forecast. In order to achieve a higher resolution, a wider source of data was required, including data from third parties such as public or private organisations. Such data would be of mixed quality and could not have uncertainty evaluation case by case: a simple and fast system was needed. In order to provide this, a simplified system to express the uncertainty of meteorological data in an easily understandable form was required.

3 Objectives

The overall aim of the project was to demonstrate a system of expressing uncertainty in a simplified way, for meteorological observations. The specific objectives of this work were:

1. To develop a system (methodology and visual representation) for simplified expression of uncertainty for meteorological data, suitable for observations of varying sources and quality from both MO and third parties, and for use by non-experts, demonstrated in a worked example for air temperature.

2. To communicate, consult and agree the approach for the simplified expression of uncertainty with the World Meteorological Organisation (WMO) Commission for Instruments and Methods of Observation (CIMO) Expert Teams on Operational In Situ Technologies and Operational Metrology and with other selected stakeholders, and propose how this could be implemented across a range of variables and for a range of audiences including non-experts.

4 Results

The overall objective of the project was to demonstrate a system of expressing uncertainty in a simplified way, for meteorological observations.

Objective 1. To develop a system (methodology and visual representation) for simplified expression of uncertainty for meteorological data, suitable for observations of varying sources and quality from

both MO and third parties and for use by non-experts, demonstrated in a worked example for air temperature.

In weather-station observations, there are many causes of uncertainty including those due to influences of siting and conditions. Although some influences have been characterized by workers in the field, it is common that uncertainty is not rigorously evaluated for the observations as a whole. There is a need for evaluation and reporting of uncertainty and for this to extend beyond conventional weather networks to increasingly widely sourced observations of varied quality. This includes a need for options to evaluate uncertainty in a simplified way wherever detailed calculations cannot be used.

The project has produced a report proposing approaches to simplified evaluation and expression of uncertainty, together with a worked example, diagrams, tables and visualizations, and including precautions for using such simplifications. This draws on outputs of EMRP ENV58 MeteoMet2 *Metrology for Essential Climate Variables*, particularly a set of studies to evaluate the influences in observed temperature.

The produced document first outlines the principles of uncertainty of measurement because this subject is challenging for some of the target readership. This can also benefit even many readers familiar with uncertainty evaluation. Next, the work proposes some suitable ways of simplifying the evaluation of uncertainty by approximation, which is a valuable step in two ways. Firstly, this may offer a resolution to the problem of evaluating uncertainty at all, for some classes of meteorological observation, since this continues to be seen as challenging and it is not widely carried out. Secondly, this system of approximation is potentially appliable to a wide class of observations from many sources. This offers the further prospect that, if suitable metadata are available, it may be possible to develop automatic (machine actionable) attribution of approximate uncertainty for meteorological observations. Some ways of visualizing uncertainty are shown, to support the understanding of uncertainty concepts and their communication to audiences at various levels.

The main parts of the work for Objective 1 were:

- Information gathering by NPL from work delivered in previous project EMRP ENV58 MeteoMet2 Metrology for Essential Climate Variables, and from other relevant literature
- Drafting of a report by NPL, with input from MO, containing the development of ideas for approximating uncertainty in the context of meteorology

MO contributed to this objective by:

- providing details of meteorology practices in general
- clarifying the needs of stakeholders in meteorology
- clarifying the state of the art in meteorology regarding the evaluation of uncertainty in observations, especially the gaps in this
- helping to define the outline content of the document
- drafting text for parts of the report
- identifying a useful published model for communicating uncertainty on a scale from qualitative to quantitative
- providing literature research on relevant past studies in meteorology
- identifying the need to detail assumptions and caveats in the report
- reading and advising on text written by NPL.

Collaboration between the partners has produced added value because neither partner alone could have developed the material produced in the project. MO contributed substantial background knowledge of meteorology practices, forthcoming developments in widely sourced observations, and the needs of stakeholders. NPL contributed expertise in evaluation and communication of measurement uncertainty, as well as bringing to the project the outputs of EMPR ENV58 MeteoMet2 and analyzing these. In addition, the collaboration has had additional benefits which go beyond the project, leading already to data sharing for another project, nomination of NPL for a committee position in the field of meteorology, and to plans for further collaborative research.

In summary, Objective 1 was achieved by the creation of a draft document outlining a system (methodology and visual representation) for simplified expression of uncertainty for meteorological data, for non-experts in uncertainty evaluation. This was illustrated using a worked example for a temperature observation. The draft was non-final and therefore was not required to be complete. However, it already contained early elements of Objective 2: namely details on how a simplified approach might apply to a range of variables, plus some proposed material about communication of uncertainty to general readers. Overall, it is considered that Objective 1 was fully achieved.

Objective 2. To communicate, consult and agree the approach for the simplified expression of uncertainty with WMO CIMO Expert Teams on Operational In Situ Technologies and Operational Metrology and other selected stakeholders, and propose how this could be implemented across a range of variables and for a range of audiences including non-experts.

The work contributed to Objective 2 by testing the proposed ideas with stakeholders including experts with familiarity in both uncertainty and specific areas of meteorology. The communication and consultation stage was relevant to the project's need because it ensured that the document under development took account of user requirements. It ensured that the document was accurate in its reflections of meteorology practices and that it was tailored to the needs of the target readership. It identified areas where there was risk of ambiguity for readers, leading to clarifications. It generated suggestions for additional areas of applicability or special precautions, for example in marine observations. Consultation gave the document early exposure, promoting awareness. The early engagement of reviewers to input to the document will have encouraged buy-in from potential users and promoters of the uncertainty approach developed.

The main work undertaken for Objective 2 was:

- circulation of the draft report by NPL to a number of stakeholders for comment and incorporating the many points of detailed feedback received.
- refinement of the report and addition of further material by NPL to produce a completed version suitable for publication.

The consultation stage consisted of circulations of the draft to a list of readers. The recipients were specialists in meteorology or uncertainty evaluation, or both. These were reviewers proposed by MO, shortlisted to a set of the most relevant. This included chairs of three Expert Teams within the WMO committee structure, plus several other Expert team members. NPL formatted the document for distribution, sending it with a covering email and instructions for how to comment. NPL then collated the comments, reviewed them all, and made changes to the documents. Some 250 areas of the text were revised in response to the comments.

MO contributed to this objective by

- identifying useful variables to illustrate how the approach could be implemented more widely. The variables singled out were relative humidity, and wind speed and direction.
- suggesting reviewers to comment on the draft
- reviewing and advising on the document at several stages.

Collaboration between the partners added value beyond the contributions of individual partners by bringing together expertise in two disciplines: metrology and measurement uncertainty. The collaboration enabled the identification of reviewers in both fields (meteorology and metrological uncertainty). It guided the choice of variables as illustrations to explain how the approach could be applied more widely. Towards the end of the project, the collaboration enabled the fine tuning of the document for it to come across correctly to readers from either discipline.

In Objective 2, two particular WMO CIMO Expert Teams on Operational In Situ Technologies (OIST) and Operational Metrology (OM) were identified. However, the WMO committee structure underwent restructuring the during the period of the project. This was foreseen and identified in the risk analysis. In the new structure, Chairs of three Expert teams with similar relevance to the original ones were consulted: Expert Team on Surface and Sub-surface Measurement (ET-SSM), Expert Team on Quality, Traceability and Calibration (ET-QTC) and Expert Team on Measurement Uncertainty (ET-MU). Two of these chairmen were the original chairs of the earlier named expert teams (OIST and OM)

Overall, Objective 2 was fully achieved in a document describing approaches for simplified expression of uncertainty and communicated through a consultation process by distributing a draft for comment. This consultation included Chairs of three WMO CIMO Expert Teams plus other selected stakeholders. Feedback was incorporated, and a final version of the document contained proposals for further work including how this could be implemented across a range of variables and for communication to a range of audiences including non-experts.

5 Impact

Details of the project been disseminated through a number of events and personal interactions from 2018 to 2021. These engagements spanned subject areas of meteorology and climate, temperature and humidity, and engagements with more general audiences.

Meteorology- and climate-specific engagements included an NPL seminar on H2020 GaiaClim/Fiduceo project work; a seminar meeting on awareness of uncertainty treatment in the Copernicus Climate Change Service; presentations to WMO CIMO TECO 2018 International conference, a site visit to Teddington Bushy Park weather station; and participation in the kick-off meeting of the European Metrology Network on Climate and Ocean.

Engagement with the metrology community included meetings of EURAMET Technical Committee on Thermometry (2019 and 2021) and BIPM CCT Working Group for Humidity (2019, 2020), and presentations at TEMPMEKO and TEMPBEIJING with MMC 2019 international conference.

Engagement with wider audiences included presentations to NPL Programme (External) Expert Groups, and participation in “Improving reproducibility in research” public technical meeting on uses of machine-actionable data and metadata.

Early impact

The project has been of early benefit to MO at several levels. It was useful to them that the project initially collected the findings of research literature on effects of siting and conditions on metrological temperature observations, including those from work in EMRP ENV58 MeteoMet2 whose quantitative results had not previously been summarised. MO also benefited from the production of a worked example of a full evaluation of uncertainty for a temperature observation, to reinforce understanding of conventional uncertainty evaluation. The project identified, for this application, the key sources of uncertainty and outlined how to take a simplified approach by focusing on these main sources. For the simplified approach, the project report documented a number assumptions and qualifications of the approach, at the request of the MO in order for them to take into account any limitations of the approach. The project report also provided several visualisations of the analysis of uncertainty which are available to MO to support communication of the ideas in the report, and for communication about uncertainty analysis generally. In addition, the identification of next steps in developing and making use of the simplified approach provided MO with indications for possible future work.

A wider immediate benefit of the work was to promote discussion of uncertainty evaluation in meteorology, among experts in the target readership (such as specialist in meteorology and in measurement uncertainty). Awareness has been raised of approaches to reporting meteorological uncertainty, both rigorously and by approximation, as an improvement to the current state of the art. The process of sharing the project document for comment with a number of influential readers (such as individuals with leading roles in WMO activities) has also increased awareness of the earlier MeteoMet2 work.

This work has brought together and applied some outputs of EMRP ENV58 MeteoMet2. That project had delivered several studies of the effects of siting and conditions on meteorological observations of temperature. Within 17SIP02 SimpleMeteoU, the quantitative findings of the MeteoMet2 studies have been collected, together along with those of some other relevant studies in the field. For the collected findings, the magnitude of the influence on temperature observations has been examined to consider how such effects can be taken into account individually or in combination, to evaluate uncertainty. This has been analysed in the project alongside the system of siting classifications previously established on a consensus basis by the World Meteorological Organization Commission on Instruments and Methods of Observation (WMO CIMO). The quantitative summary of MeteoMet2 outputs provides material to support possible future review of the CIMO attributed uncertainties associated with siting.

The project was publicised at CIMO TECO conference in 2018 and also by networking and short presentations at meetings on low-cost sensor networks, reproducibility in research, and others.

Following on from joint working in the project, MO nominated NPL to the expert list for selection for the newly re-formed committee structure of WMO CIMO. Consequently, NPL accepted an invitation to join the Expert Team on Quality, Traceability and Calibration within the WMO Standing Committee on Measurements, Instrumentation and Traceability. In addition, NPL was invited to Join a newly-formed Task Group on Air Temperature, within the BIPM CCT WG-Env, as well as participating in a research intercomparison of air temperature calibrations among members of EURAMET TC-T.

Longer term impact and wider benefits

The processes developed in this project, of assimilating uncertainty in observations from different sources into a simplified expression of uncertainty, will support MO towards using weather observations from an increased range of widespread sources of differing quality - sources including infrastructure (roads, airports), industrial premises and amateur observations. This will support attribution of uncertainty to observations in cases where uncertainty was not previously reported. This can ultimately contribute to the use of more third-party observations in numerical weather models, using weightings according to quality (uncertainty). Such third-party data can ultimately contribute to forecasts with finer resolution than at present. Using available metadata, as illustrated in the project, there is potential for this type of approach to be made machine-actionable to be applied on the rapid timescale needed for timely forecasting.

The simple approach to expressing uncertainty, once implemented by MO, can improve user understanding and confidence in weather information. The illustrations and visualisations available from the project will support understanding by non-experts in uncertainty, including meteorology specialists and consumers of meteorology services.

For users purchasing commercial meteorological services, improved expression of uncertainty will ultimately provide a basis for selecting according to the quality (uncertainty) of weather data. Clearly expressed uncertainty can increase user understanding and trust of weather forecasts and can enable decisions based on awareness of risk. In the longer term, the developments in the project, for simplified calculation and for communication of uncertainty, will allow MO's customers (including transport sector, utilities, agriculture, large-scale construction, defence and management of civil emergencies) to better consider weather risks and to improve their risk mitigation strategies associated with weather. Overall, weather risk management can have benefits such as: optimised safe running of transport infrastructure; energy-efficient operation of building management systems and of utility networks; and protection of citizens across spheres of business, health, and leisure.

In addition, the engagement of WMO CIMO Expert Teams, which establish best practice in meteorology worldwide, will provide a route for further exploitation of the project outputs to influence practices globally.

6 List of publications

n/a

7 Contact details

n/a