WORLD METEOROLOGICAL ORGANIZATION

INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION

Report of the Eleventh GCOS Reference Upper Air Network Implementation Coordination Meeting (GRUAN ICM-11)

Singapore
20-24 May 2019

GCOS-230

UNITED NATIONS ENVIRONMENT PROGRAMME

INTERNATIONAL SCIENCE COUNCIL

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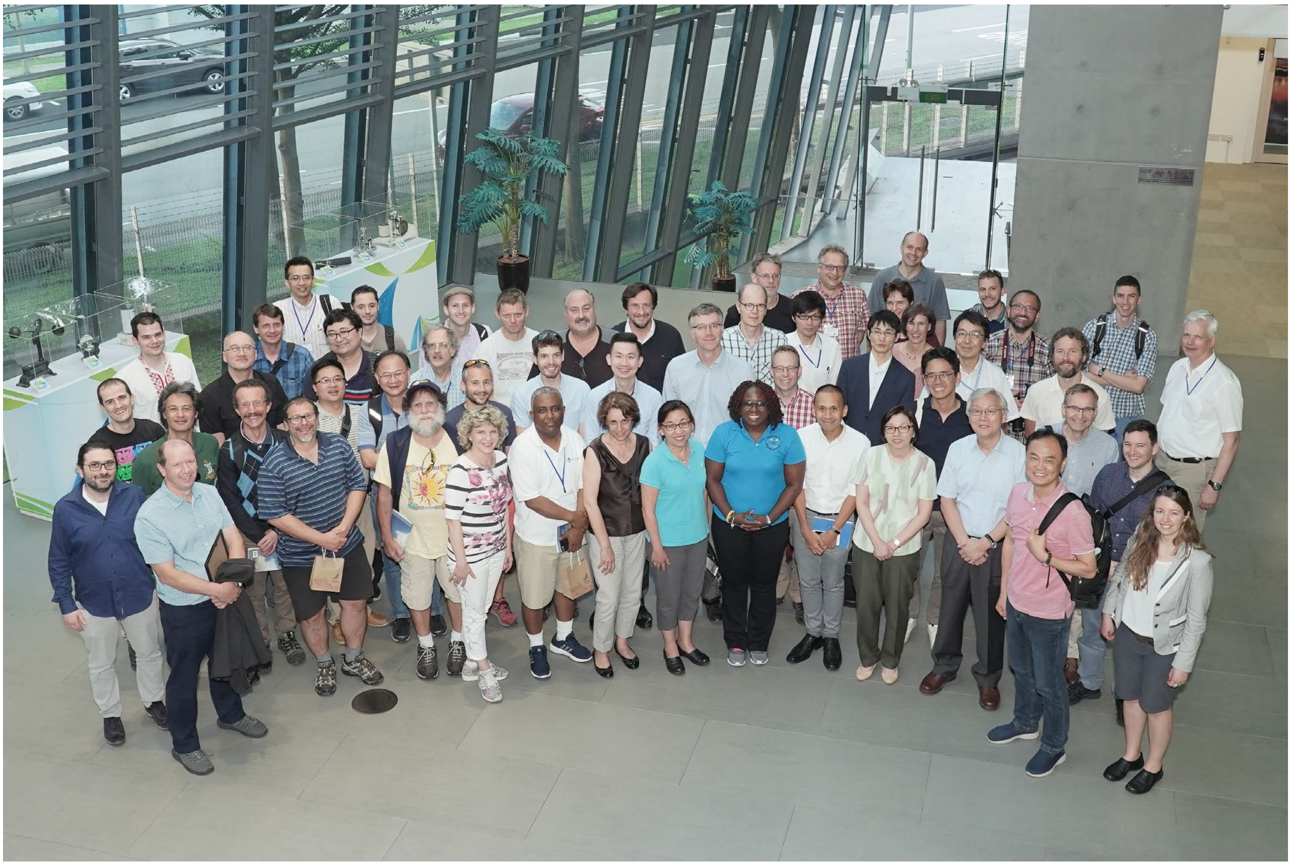

1. OPENING OF THE MEETING

1.1 Introductions

The meeting opened with a welcome to all participants from the Global Climate Observing System (GCOS) Reference Upper Air Network (GRUAN) co-chair, June Wang. The participants introduced themselves. The goal of the meeting was to review progress and address identified issues with the implementation of GRUAN. The overarching theme of the meeting was thus "New data products, Operational concerns and Change management". The list of participants can be found in Annex 1.

1.2 Official opening

Patricia Ee, Director of the Meteorological Service Singapore (MSS) Weather Services Department, gave an official welcome and an introductory message on behalf of the hosts. She underlined the importance of meteorological observations that underpin all aspects of their work. She explained that Singapore is located in the tropics and therefore is being affected by severe and extreme weather that is challenging to forecast. Singapore is also subject to the effects of climate change and the Climate Research Singapore centre was set up in 2013 with the mission to advance scientific understanding of tropical weather and climate variability and change. In terms of upper-air observations, the MSS launches radiosondes twice daily and has been contributing to GRUAN since 2015. Ms Patricia Ee concluded her welcome speech wishing the participants a successful meeting and a pleasant stay in Singapore.

1.3 GRUAN Fundamentals – Ruud Dirksen

Ruud Dirksen, head of the Lead Centre (LC), explained the GRUAN basics and the motivation for GRUAN. GRUAN is a ground-based network for upper air observations that was established in response to the need identified by WMO and GCOS for highest accuracy data possible. GRUAN's goals include long-term consistent data records, validation of satellite systems, process studies and Numerical Weather Prediction (NWP). The requirements for a GRUAN data product are traceability, uncertainty analysis, inclusion of raw data and metadata, proper documentation and validation. At the moment, priority variables are temperature, water vapour and pressure, with the development of data products for other variables, such as ozone, following in a second phase. GRUAN comprises 26 sites with the aim to expand to 30-40 sites.

1.4 Presentation of GRUAN certification to ARM-SGP

The presentation of GRUAN certification to ARM-SGP was postponed as there were no representatives of the site at the meeting.

2. REVIEW OF PROGRESS

2.1 Welcome, local logistics, outline of events and adoption of agenda

June Wang, co-chair of GRUAN, thanked the local host for hosting the meeting. The logistics of the meeting were explained. Peter Thorne, co-chair of GRUAN, underlined the need to focus on having more data streams and to manage the transition from the RS92 to the RS41. He also explained that, following a survey held last year after ICM-10, changes had be included in the agenda, allowing more time for discussion as requested by the participants previous year. The agenda was adopted and can be found in Annex 2.

2.2 Remarks from GCOS including relevant AOPC outcomes – Caterina Tassone

Caterina Tassone, from GCOS Secretariat, presented the activities of GCOS and of the Atmospheric Observations Panel for Climate (AOPC) during the prior year. She presented the concept for the Global Basic Observing Network (GBON), which was developed by WMO with the aim of improving the exchange of observational data for global NWP and that meets threshold requirements for NWP and Global Climate Monitoring Analysis according to WMO Rolling Review of Requirements. She also presented the outcome of the Joint Panels Meeting of the three GCOS panels, and the outcome from the three AOPC task teams, the radar for climate task team, the lightning observations for climate task team, and the task team for the instigation of a GCOS Surface Reference Network (GSRN). The latter is of particular interest to GRUAN. The GSRN will support WMO Integrated Global Observing System (WIGOS) aiming to meet the "goal" requirements in the WMO OSCAR requirements database. It is proposed that the GSRN will be sponsored by WMO and the Bureau International des Poids et Mesures (BIPM). Next required steps will be the approval of the proposed GSRN by relevant WMO programmes, the GCOS programme and other sponsors, an offer to host and staff appropriately a Lead Centre and offers of suitable sites for an initial GSRN. Finally, she reminded the participants that two actions from the GCOS Implementation Plan (GCOS-200) require progress from GRUAN, and in particular action A19 calls for an increase in the number of sites contributing reference-quality data-streams for archive and analysis and in the number of data streams with metrological traceability and uncertainty characterisation.

2.3 Lead Centre progress report – Ruud Dirksen

Ruud Dirksen presented the Lead Centre progress report. GRUAN has now 26 sites of which 12 are certified. Regarding the transition from RS92 to RS41, laboratory experiments for the radiation correction and for calibration are ongoing. All RS92 sites have now switched to RS41 and there are 800 GRUAN-wide dual soundings with RS41/RS92. Main achievements this year have been the publication of two technical reports, the release of RS41 GRUAN data product Alpha version, and the certification of the Meisei RS-11G GRUAN data product. New data products under development include Vaisala RS41, Modem M10 Radiosonde, Lidar, Microwave Radiometer, and GNSS. The development of the website is progressing and Ruud Dirksen again solicited contributions from the community, especially from instrument experts. He presented the work plan for the Lead Centre which includes:

- Completion of the development of a new GRUAN data processor.
- Finishing development of GRUAN data product for RS41 (RS41-GDP.1).
- Developing a new version of the data product for RS92 (RS92-GDP.3).
- Completing the GRUAN radiosonde omnibus.
- Preparing for WMO-CIMO Radiosonde intercomparison campaign.
- Continuing development of alternative, non-R23 based, cooling mechanisms for frostpoint hygrometers.
- Further coordinating RS92-RS41 transition activities within GRUAN.
- (Re)certifying sites.
- Further development of the GRUAN website.
- Operationalize the processing of Cryogenic Frostpoint Hygrometer (CFH) data.

In the discussion that followed the presentation, it was noted that knowledge of the clouds during the radiosonde flight is very important. It was decided to develop a proposal on how to take cloud observations in order to support the radiosonde profiles and how to include that information in the data files (**Action C13**).

2.4 Assessment of progress against action items arising from ICM-10 - Peter Thorne

Peter Thorne presented the actions from ICM-10 (see annex 3).
Out of 30 agreed actions arising from the previous ICM hosted by The Deutsche GeoForschungsZentrum (GFZ), 15 are assessed as completed, 14 are in progress and 1 has not been addressed yet. Many of the remaining open actions are part of the agenda of the meeting and were therefore to be revisited at the end of the meeting together with the need

for any new actions. Resulting actions arising from ICM-11 can be found in Annex 4. For action A3 from ICM-10 on the parallel soundings database augmentation with satellite/ancillary, very limited progress to date has been recorded and it is suggested that the GRUAN Working Group (WG) Chairs and LC provide guidance to the sites. This is reflected in **Action A2** from ICM-11. During the discussion, it was decided that there is a need for one or more scientific papers explaining the benefits of the radiosondes reaching 10hPa. This is reflected in **Action C16** of ICM-11. Finally, in terms of GRUAN data products, it was noted that winds need to be introduced as GRUAN products. These could also help justifying the radiosondes getting to 10hPa. Winds are measured but the uncertainty for wind data is not described. **Action C17** of ICM-11 asks for evaluating and improving radiosonde wind uncertainty.

3. DISCUSSION OF TOPICS RAISED BY TASK TEAM REPORTS

3.1 Radiosonde Task Team – Masatomo Fujiwara

There are currently 12 members including two new members. The current main tasks are: the autolauncher assessment task which would have a breakout session and summary talk later during the meeting; and the multiple-payload launch configuration task, where the Technical Document (TD) No. 7 has been published and the next step is to encourage evaluation studies. There are other related tasks that are led by LC or others. The task on BUFR to transmit uncertainties has been given low priority at ICM-10.

3.2 Discussion on points arising

Following the presentation, it was discussed whether the task on BUFR to transmit uncertainty should be completely removed from the task list or should be expanded to more general task on radiosonde GRUAN Data Product (GDP) uncertainty, e.g., investigating uncertainty data usage. However, it was pointed out that the transmission of uncertainty in the BUFR had been requested at previous meetings by the Commission of Basic Systems (CBS) representative and before removing this task, the impact on the wider networks should be considered. Regarding the multiple-payload task, it was pointed out that the length of the main string needs attention as sites use different lengths of string and this can have an impact. Scientific studies on rig-configuration evaluations are needed in order to provide recommendations. It was also suggested to publish a peer reviewed paper. DWD and MeteoSwiss are hosting the CIMO intercomparison campaign, so they should formally be invited to consider running parallel multi-payload configuration to try to minimize the impacts of multi-versus single payload (**Action C14**). There was also a discussion on how to proceed with the radiosonde descent data, that need to be well understood before using them operationally. Several NWP groups are trying to evaluate the value of the descent data as this would double the number of observations. It was therefore suggested to revisit the potential use and value of operational radiosonde descent data with GRUAN (**Action C15**).

3.3 Sites Task Team – Dale Hurst

Changes in the membership of TT Sites since ICM-10 included the addition of two new site representatives, one each for Japanese sites Syowa (Antarctica) and Minamitorishima (Western Pacific region), and personnel changes for Tateno, Payerne and Paris. A brief review of progress on action items for which TT Sites is involved was given.

3.4 Discussion on points arising

The site photos report is now ready. The sites were asked to upload a first set of photos commensurate with the new site photos guidance. The LC was asked to work with sites through their Permanent Representatives to share these with the OSCAR Surface database (**Action C2**).

3.5 Scheduling Task Team – Tom Gardiner

A short presentation outlined the aims and membership of the Measurement Scheduling and Combination Task Team with its focus on optimally combining measurements of Essential Climate Variables (ECVs) from multiple instruments to meet all GRUAN objectives. Recent activities of the TT were highlighted including work on Site Atmospheric State Best Estimates (SASBEs) and uncertainty assessment activities under the Copernicus Climate Change Service programme.

3.6 Discussion on points arising

The future focus for TT activities and the need to define specific tasks and timelines for these were discussed. It was agreed that a Task Team breakout meeting would be held later in the ICM.

3.7 Ancillary Measurements Task Team – Thierry Leblanc

The GRUAN Task Team on Ancillary Measurements oversees the production and integration of ground-based Microwave, FTIR, and lidar in compliance with GRUAN best measurement practices, and coordinate the use of satellite data for GRUAN-related tasks. The composition of the task team has not changed since ICM-10. It is suggested to invite Nico Cimini as a "third" Task Team co-chair to represent and coordinate the activities pertaining to Microwave measurements and GRUAN products.

The GRUAN Lidar Data Stream, under development for the past several years, is progressing slowly. Raw data from 14 lidars (GRUAN, NDACC, TOLNet) are now processed by the mature data processor GLASS. A GRUAN Lidar Data Stream exists, but not through the normal GRUAN pathway. Instead, raw data are being transferred to the data processing center located at JPL-Table Mountain Facility. In 2019, systematic analysis using several Lidars at GRUAN sites focus on measurements coincident with radiosonde launches. The results from these analyses will serve as a validation basis for the first version of the GRUAN Lidar Data Product (GLDP1). Work to finalize LidarRunClient is still ongoing, which when completed, will provide closure to the GRUAN Lidar data stream. Full documentation (TD) is in preparation, to be released together with GRUAN Lidar Data Product version 1 (GLDP1).

An intercomparison campaign involving ancillary measurements, radiosonde and Frost-point hygrometers is planned for May 2020 at the JPL Table Mountain Facility. The campaign will follow the operation principles of the MOHAVE 2009 NDACC campaign, with a two-fold science and technical focus (UTLS variability, and sonde, hygrometer, and lidar intercomparison).

On the satellite side, dual radiosonde soundings (RS92 & RS41 on the same balloon) synchronized with NOAA-20 overpass were performed "weekly" since February 2018 in the frame of the Radiosonde Intercomparison and VALidation (RIVAL). The campaign supports the RS92-to-RS41 transition management, ensuring continuity of ARM radiosonde record. Updated analysis, including distinctions in rigging and ancillary measurements, will be presented at ICM-12, with the reports also to be considered for submission as peer-reviewed literature **(Action A3)**.

3.8 Discussion on points arising

It was suggested to divide the task team in two. The first one would concentrate on the satellite/NWP applications and validation of GRUAN and the second one on the development of ground-based measurements techniques (**Action C1**). Peter Thorne will check whether AOPC endorsement is required. There were questions about how to proceed with the cloud reports for satellite validation, as the information needs to be standardized and included in the CDF file. It was decided that the first step would be to survey the sites for the current approach. This is part of **Action C6**.

3.9 GNSS Precipitable Water (PW) Task Team – Kalev Rannat

A short overview about TT members and their affiliation with a short report about the status of GNSS PW TT tasks listed in ICM Action Items (as at ICM-10) was given.

- The GNSS PW Technical document (Omnibus) – the manuscript is finished, is accepted and awaiting publication.

- GNSS-PW GDP data flow and certification (deadline ICM-11) – Work continues on improving the GRUAN GNSS data flow and GNSS data processing.

The sites currently delivering GNSS data (continuous processing chain) are: Lindenberg (LBD0, LBD2), Payern (PAYE), Lauder (LDRZ), Sodankyla (SODF), NyAlesund (NYA2), Barrow (UTQI), Lamont (SPGO) and Singapore (MSS1) - since May 2019. Meteorological data flow is missing from some of the GNSS sites (technical issues that should get resolved soon).
The status of Boulder and Tateno GNSS sites and the situation of new upcoming sites was presented. A more detailed overview and the status of the GNSS data product was given by Galina Dick (on Tuesday, presentation 4.8).

- Uncertainty terminology and presentation in GRUAN products (deadline Feb 2019) – not completed, it was proposed to shift until after ICM-11.

3.10 Discussion on points arising

A question about representation of GNSS-PW GDP was arisen for discussions and future work. It was asked for GNSS-PW data flow to be set up for additional sites prior to ICM-12 **(Action C5)**. GFZ can put the hardware at additional sites and start the data flow. A brief discussion touched upon the terminology for IWV (Integrated Water Vapor) to be used instead of PW (Precipitable Water). The task team will decide about the best name to be used.

3.11 Report from GRUAN science coordinator – Tom Gardiner

The range of GRUAN-related scientific activities was highlighted with a particular focus on the two priority areas that were identified in the Science Coordinator-led review of science needs within the network: the RS92/RS41 change over, and the development of SASBE's.

3.12 Discussion on points arising

The ongoing need and purpose of the Science Coordinator role were discussed. This discussion highlighted a number of areas where the Science Coordinator could take a leading role including: championing the scientific outputs from the network, helping ensure common treatment of uncertainties across the network, acting as a central point of contact for potential collaborative funding opportunities, and coordinating scientific outreach activities. The key challenge is how to prioritise the wide range of potential activities given the limited resource available. It was agreed to continue this discussion within the WG and review the terms of reference for the Science Coordinator role.

3.13 WG meeting to discuss WG and Task Team rotation – lead by June Wang

According to the new Term of References for the Working Group (2018), members need to be rotated every 4 years. The Co-chairs will ask for 2-3 long-serving WG member volunteers before ICM-12 for rotation. It was noted that co-chairs will also need to rotate and succession planning needed to start prior to ICM-12 to find a successor for Peter Thorne.

4. ADVANCES IN THE DEVELOPMENT OF NEW GRUAN DATA PRODUCTS

4.1 Steps needed for a GRUAN Data Product – Ruud Dirksen

Ruud Dirksen described the steps needed for a GDP. The guidelines on requirements for the initial development of a GDP are described in the GRUAN Technical Note (TN) 4. The requirements are the following:

- A GRUAN Technical Document describing, measurement principles, measurement technique specifications, uncertainty quantification, correction algorithms and metadata
- A peer reviewed paper (submitted/published) that describes the scientific foundation for the data product with emphasis on the uncertainty quantification
- A central data processing facility at either the LC or an external facility
- Measurement system (ready to be) adopted at one GRUAN site, and potentially deployed at other sites.
- Data stream (beta release) for a limited period while it is validated.

4.2 Progress to an RS41 product - Michael Sommer and Christoph von Rohden

Part 1: Operational processing system - Data processor and Alpha 2 – Michael Sommer
In this presentation the current state of development of a general GRUAN processing system for radiosonde data (GDPS) and the GRUAN data product for the RS41 radiosonde was shown. In the first part the schematics of the GDPS was explained and the possibilities and advantages were outlined. After that the scheme of the specific processing of the RS41-GDP (version Alpha.2) was shown with many examples, e.g. control of the input data, automatic determination of launch point and burst point, automatic analysis of ground check data (SHC), pendulum analysis and calculation of ventilation, wind smoothing, estimation of radiation, radiation correction of temperature, time-lag correction of humidity, and uncertainty determinations. An overview of unresolved issues was given and a schedule for the completion of the RS41-GDP.1 was presented. The current version of the dataproduct, RS41-GDP-ALPHA.2, was processed for all GRUAN sites for the period 2018-01-01 until 2019-05-21.

Part 2: Radiation tests and humidity sensor time-lag - Christoph von Rohden
I) The heating of the temperature sensor by solar radiation is the dominant error for temperature measurements from daytime upper-air soundings with radiosondes. The method to estimate the solar radiation error in order to derive a correction is to irradiate the sensor with sunlight, or an artificial light source, and measure the resulting temperature increase. These tests need to be done at lowered pressure and need to include active ventilation to imitate the conditions during a real radiosounding.

Previously, such experiments were undertaken at Lindenberg Observatory in a simple test chamber where the sensor booms of the radiosondes were fixed and irradiated perpendicularly through a quartz window. The radiative effect was determined from the temperature difference between the irradiated and non-irradiated situations after thermal equilibrium was established. However, the spinning of the radiosonde during an ascent results in changing orientation of the sensor boom relative to the sun and the radiation environment. This leads to a continuously changing heatload on the sensor element. The recorded temperature is the result of several – sometimes competing- factors, of which the most important are the direct solar irradiance, the convective heat exchange with ambient air, and conduction along the boom. Each factor has a different magnitude and varies on a different timescale.

To better account for these dynamical effects, an improved laboratory setup (an evacuable wind tunnel) was developed. This new setup allows to rotate the sonde along its vertical axis to mimic the sonde's spinning during ascent. A well-defined air flow ventilates the sensor boom, which is mounted at an angle to the airflow similar to real ascents. The solar elevation angle is simulated by changing the incident angle of the light source. The basic idea is to measure the effective (time-averaged over various rotation periods) radiative sensor heating as a function of pressure, ventilation, irradiance, and incident angle (solar elevation). Analysis of the measurement data yields a parameterization of the radiation correction. Contrary to the old set up, no assumptions regarding sonde rotation and orientation need to be made.

First results for the Vaisala RS41 radiosonde show smooth and well-reproducible dependencies of the radiation error on pressure, ventilation, and radiation incident angle. At 5 hPa and 1081 W·m−1, measured values range from ~0.95 K to ~1.6 K for ventilation speeds of 4 m·s−1 to 1 m·s−1, quickly decreasing with higher pressure or ventilation speeds.

II) Existing experimental data on the response time of the RS41 humidity sensor, measured at Lindenberg Observatory, were re-evaluated to form the basis for a correction of the temperature-dependent time-lag of the humidity sensor. The evaluation takes into account that the RS41 humidity sensor is heated to ~5 K above ambient. That is, the time-lag was evaluated for that 'internal' relative humidity and temperature. Hence, the correction applied in the GRUAN processing of measured profiles (GDP) relies to the same conditions. The corrected humidity is afterwards reconverted to the 'true' relative humidity of the air. The new parameterization leads to significantly more reliable relative humidity measurements as well as smaller uncertainties, especially in the tropopause region where extremely low temperatures may necessitate large corrections. The new time-lag correction will be implemented in the GRUAN data product for the RS41 radiosonde.

The first full version of RS41 GDP has to be completed and the product certified and publicly available by ICM-12. A schedule for the completion is reflected in **Action HP1**.

4.3 Quality control and assessment for radiosonde data products - Michael Sommer and Christoph von Rohden

This presentation was used to demonstrate once again the importance of a general quality control and assessment for radiosonde data products in GRUAN. With the help of several examples, specific cases were presented where an assessment of the data quality is necessary (e.g. ground check, data gaps, very large uncertainties, contamination). Currently no clear guidelines exist how to deal with this. Many questions were raised in the presentation and a scheme was proposed, which can serve as a first draft for a discussion of this topic. It was suggested to create a task force to address the questions and issues raised in the presentation.

It was pointed out that data is still potentially valuable even with a large uncertainty, as long as the uncertainty is documented. Among the questions that need to be answered is whether the quality stamp applies to the individual data points or to the entire profile, which can be more controversial. During the discussion it was suggested that rather than giving a single number to the assessment it would be better to assess the data against the application areas so it would become clear whether that observation is fit to use. This issue was discussed further at a special breakout session. At the end of the discussion it was decided that an ad hoc group on QC/QA flagging will develop a strategy and rationale as a technical note (**Action HP4**).

4.4 Status update of GRUAN data products for Meisei RS-11G and iMS-100 radiosondes – Shunsuke Hoshino

The status and the evaluations of Meisei RS-11G and iMS-100 were reported. Both types show daytime temperature observations that are 0.5 K cooler than RS92. They also show drier characteristics in lower troposphere and wetter characteristics in middle and upper troposphere than RS92 and CFH. The development team plans to address these issues and develop new versions of Meisei GDPs.

It was decided that for IMS-100 the TD needs to be completed, the data stream produced in beta mode and the peer-reviewed paper submitted before ICM-12 (**Action B1**).

4.5 Presentation of GRUAN certification for RS-11G – Ruud Dirksen

As all the requirements were fulfilled for RS11G, the data product for Mesei RS-11G was certified. Ruud Dirksen presented a certificate to Shunsuke Hoshino.

4.6 Calibration of a Radiosonde Humidity Sensor using the low-temperature low pressure humidity chamber at KRISS – Sang-Wook Lee

In this presentation, the calibration of radiosonde humidity sensors at low-temperature and low-pressure is demonstrated using a newly developed humidity generator at the Korea Research Institute of Standards and Science (KRISS). First, the operation principle of the humidity generator and the validation of the generated humidity at low temperature and low pressure are introduced. The humidity generator is a two-temperature and two-pressure (2T2P) type in which a saturator and a test chamber are immersed in separate baths. The saturation performance of the saturator is evaluated at low temperature at atmospheric pressure. Then, a chilled-mirror hygrometer directly connected to the saturator is calibrated at low-pressures for the compensation of the drop in the frost-point temperature from the reference. A compensation formula for low-pressure effects on the chilled-mirror hygrometer is obtained

and is applied for the validation of humidity generation in the test chamber at low temperature and low pressure. A representative humidity generation at low temperature and low pressure and its validation by the hygrometer are demonstrated in the test chamber at a fixed temperature (-70 °C) and at two different pressures (46 hPa and 200 hPa). In these conditions, uncertainty budgets on relative humidity in the test chamber, in which a radiosonde humidity sensor is located, are less than 2 %rh at the coverage factor, k = 2.
Based on the humidity generator, the calibration of a radiosonde humidity sensor is demonstrated by varying relative humidity in the test chamber at the temperature range from -70 °C to 20 °C and the pressure range from 50 hPa to 1000 hPa. The thin-film humidity sensor shows a temperature dependency in the sensing capability in which the sensor indicates significantly lower humidity than the reference humidity by the generator at low temperatures. However, the sensing capability of the humidity sensor is not affected by the surrounding pressure. A calibration formula for the correction of the relative humidity measured by the humidity sensor is obtained. The uncertainty of the humidity sensor is analysed (usensor ~ 3.8 %rh at k = 2) by considering the uncertainty due to the humidity generator, sensor stability, hysteresis, reproducibility, pressure effect, and correction formula. The new humidity generator provides the traceability to International System of Units (SI) in the calibration of radiosonde humidity sensors. The humidity measurement by calibrated radiosonde humidity sensors will also be SI-traceable even at low temperature and low pressure upper air environment.

4.7 A study on the solar correction for the RS41 using the Upper Air simulator at KRISS – Yong-Gyoo Kim

Solar irradiance testing for the Vaisala RS41 was conducted in the stratospheric region using the KRISS Upper Air Simulator (UAS). UAS can control many upper air parameters such as temperature, pressure, air ventilation and solar irradiance, simultaneously, with a high stability. Temperature and pressure were changed from -70 °C to 20 °C and 7 hPa to 100 hPa under solar irradiance of 900 W/m2 and air ventilation speed of 4 to 6.5 m/s, respectively. As pressure decreases, the effects of solar heating become larger. It was suggested that stronger air convection at higher pressure may reduce the temperature rising. At low pressure of 7 hPa, solar heating increases as temperature decreases. However, at higher pressure of 100 hPa, there were no clear temperature effects. This temperature behaviour may be related to the change of long wave radiation from the sensor with temperature (Erad = seT4) under low influence of convection. It was shown experimentally that ambient temperature has to be taken into account to get a precise solar correction value. It was possible to create a solar radiation correction formula from the measured data, and solar correction data from UAS for RS41 were in good agreement with CoreTemp 2017 data in the stratosphere region. With UAS, it will be able to calibrate all types of radiosondes with traceability to international measurement standards.

4.8 Review of progress of Data Product GNSS PW – Galina Dick

This presentation gave an overview of achieved progress at GFZ in deriving the GNSS Precipitable Water (PW) data product for GRUAN.
The first part of the presentation described GFZ and its activities in automatic processing of GNSS data for retrieval of tropospheric products. Operational GNSS data processing at GFZ is done with GFZ EPOS.P8 software and provides all kinds of tropospheric products: zenith total delays, converted precipitable water vapor, slant total delays and tropospheric gradients both in near-real time and in reprocessing mode.

The second part of the talk described the operational GNSS PW processing for GRUAN at GFZ including uncertainty estimation. The estimation of GNSS PW uncertainties after the Tong Ning algorithm (T. Ning et al., AMT, 2016) was added to the automated processing chain in April

2019. The GRUAN PW products are available both in COST716 and TRO-SINEX formats at GFZ ftp. All products are also delivered to the GRUAN LC at Lindenberg.

GNSS stations in automated PW processing for GRUAN at GFZ are presently: Lindenberg, Ny-Alesund, Sodankyla, Lauder and Barrow. Boulder GNSS station TMS3 was closed in October 2018. New GNSS stations under installation since ICM-10 are: Payerne, Lamont, Singapore, Tateno and Scott Base in Antarctica, close to Arrival Heights. Validation of GNSS PW with NWP output of ECMWF shows a very good agreement for all GRUAN stations in PW processing.
Planned GNSS sites in operational processing: Boulder, Beltsville, Graciosa Island, Paramaribo, Cabauw, Potenza and Dolgoprudny.

The GNSS PW is very close to having fulfilled the requirements for certification. The peer-reviewed paper has already been published. The LC was asked to prepare the certification package and send it to the WG-Chairs. The Technical Document is to be submitted and published and the product certified by November 2019 (**Action B3**).

Discussion on whether there is metrological closure between GNSS-IWV and radiosondes led to **Action C12**. Sites that perform both GNSS-IWV and a GRUAN qualified radiosonde were asked to perform an analysis as to whether metrological closure is attained and present the initial results at ICM-12.

4.9 Update on GRAW DFM-09 (and RS92) – Ruud Dirksen

Ruud Dirksen presented an update on GRAW DFM-09. He explained that the radiation correction of the temperature sensor and the time-lag correction of humidity sensor still need to be addressed. It was suggested by the chairs to postpone any work on this topic until the GDP for RS41 is completed.

4.10 Intermet iMET-4 radiosonde: development history and steps towards GRUAN qualification – Mark Benoit

The iMet-4 radiosonde from InterMet Systems has been in production for a couple of years now. InterMet has a long history with the research community and would like to continue this collaboration to produce a GRUAN data product for the instrument. Testing has been done with the RS41, but full quantification of the data uncertainties must be done with laboratory tests and evaluations. After making some final modifications to our radiosonde, we hope to work with our partners to fully characterize radiosonde uncertainties and publish a technical document and a peer-reviewed document.
It was suggested to cooperate with South Africa as they also use this kind of radiosonde and there is a geographical need of covering this region. Mark Benoit confirmed that they are already in contact.

4.11 Current status of lidar GDP - Thierry Leblanc

Version 1.1 of the GRUAN Lidar Analysis Software Suite (GLASS) has now reached a mature stage. The software can analyse large amounts of lidar raw signals from 14 ozone, water vapour, aerosol, and temperature lidar instruments belonging to 3 networks, (GRUAN, NDACC and TOLNet). The GLASS ingests more than 120 parameters, covering all aspects of the data processing, including instrument configuration, raw data pre-processing options, and species-specific retrieval options. All parameters are instrument-dependent and time-dependent, making processing and re-processing quick and versatile. Automated raw data transfer has been implemented for the GRUAN site of Payerne, and is under development for the GRUAN sites of Ny-Alesund and Cabauw. Later in 2019, it is planned to analyse a large amount of coincident lidar-radiosonde profiles from the Payerne, Cabauw and Ny Aalesund sites, with the objective of producing the first GRUAN Lidar Product before ICM-12 (**Action B6**).

4.12 Operational and GRUAN radiosounding validation of PRR temperature data retrieved by the Raman Lidar for Meteorological Observations (RALMO) at Payerne – Gianni Martucci

The RAman Lidar for Meteorological Observations (RALMO) is operated at the meteorological station of MeteoSwiss in Payerne and provides, amongst other products, continuous measurements of temperature since 2010. The temperature profiles are retrieved from the pure rotational Raman (PRR) signals detected around the 355-nm Cabannes line. The transmitter-receiver system of RALMO is described in detail and the reception and acquisition units of the PRR channels are thoroughly characterized. The FastCom P7888 card used to acquire the PRR signals, the calculation of its dead-time and the procedure to desaturate the PRR channels are presented. The temperature profiles retrieved from RALMO during July 2017 to October 2018 have been calibrated and then validated against two reference radiosounding systems (RS) co-located with RALMO, the Meteolabor SRS-C50 and the Vaisala RS41. The mean temperature deviation (bias) of RALMO temperature with respect to the RS and the root mean square error (RMSE) are used in this study to characterize the accuracy and the precision of RALMO temperature retrievals. The overall bias and RMSE of the daytime comparisons RALMO vs RS averaged along the troposphere are −0.67K and 1.32 K. The night-time comparisons showed a much smaller bias (−0.08K) with also smaller RMSE (1.15 K). The temporal stability of the calibration factor obtained by comparison of the RALMO temperature with the RS temperature has also been analysed. In order to investigate better the possible sources of systematic and total uncertainty, the T_RAL−T_RS dataset has been split into seasons to assess the possible temporal dependence of bias and RMSE. The results show that spring data suffer a much larger (cold) bias and RMSE that affect the overall statistics. Finally, the validated PRR temperature has been used with the humidity profiles retrieved from RALMO to calculate the relative humidity and to perform a qualitative study of the supersaturation occurring in liquid stratus clouds.

4.13 Current status of MWR GRUAN Data Products – Fabio Madonna

Fabio Madonna presented on behalf of Domenico Cimini the progress achieved since ICM-10 towards a GRUAN data product for microwave radiometer (MWR). Progress is mainly related to: the implementation of online calibration monitoring and their test at two EU sites; extension of calculation of absorption model uncertainty to 150 GHz; and improvements to systematic uncertainty estimation from absorption model which is the main systematic contribution to the uncertainty budget. Despite the additional achievements described in the talk, to provide a GRUAN product for MWR still three aspects must be improved: the implementation of MW transfer standard calibration targets, the National Institute of Standards and Technology (NIST) is working on this development; the release of certified internal temperature sensors for each MWR, though manufacturers may provide certifications; solve the issue that uncertainties on *a priori* model background and radiative transfer model are not SI-traceable. A proposal to start providing microwave brightness temperatures will be considered.

The Task Team on Ancillary Measurements was asked to further progress the MWR product and present progress at ICM-12 (**Action B5**).

4.14 Strategy for developing GRUAN data products for frostpoint hygrometers – Dale Hurst

The first step in developing a GDP for frost point hygrometers (FPs) is to evaluate a previously-published methodology for vertically averaging FP measurements and calculating their uncertainties. An overview of this methodology was presented, and some components thought to be somewhat subjective were indicated. Uncertainties in the water vapour mixing ratios and relative humidity values determined from FP measurements must also include the uncertainties of simultaneous pressure and temperature measurements by radiosondes. A small team of FP

experts has been assembled to assess the suitability of the existing methodology for different models of FPs, and to decide if a single GDP can be developed for them.
The team will provide an update on progress toward a single GDP and answer the questions around the Voemel et al. (AMT, 2016) analysis raised at ICM-11 (**Action B7**).

4.15 Update on the ozonesonde data product - Richard Querel

The ozonesonde expert group is working on defining best practice standard operating procedures for within the ozonesonde community. They are also working to improve representation of uncertainties in the measurements. GRUAN will work with the ozonesonde community to determine how the GRUAN ozonesonde data product can add value. A key differentiating feature between a GRUAN ozonesonde and a community ozonesonde will be the use of a manufacturer independent ground-check (i.e. measuring a known 100 ppb ozone source during the ozonesonde preparation and calibration process). The GRUAN ozonesonde technical document has been completed and gone out to reviewers. Three reviews have come back. The writing team has since changed with two key driving people no longer involved. The new team will revisit the existing technical document and aim to split it into two or more documents, e.g. remove discussion of homogenization and back-processing as they needn't be in the forward-looking GRUAN document.
An update on progress towards an Ozonesonde GDP will be presented at the ICM-12, including consideration of TD issues raised at ICM-11 and outcome of further discussion with the community (**Action B4**).

4.16 Use of Standard Humidity Chamber - Richard Querel

The Standard Humidity Chamber (SHC) is recommended for GRUAN sites, however there is no Standard Operational Procedure (SOP) defining correct usage of the SHC. Sites are all doing different things: length of time in chamber; orientation of sensor; whether or not to also log temperature and humidity within the chamber, etc. These should all be specifically recommended by the Lead Centre and by way of an SOP. A peer-reviewed publication demonstrating the scientific value resulting from the SHC ground-check is essential to help justify SHC use within GRUAN and will also help in encouraging its use into the wider community (**Action C11**). Once the GRUAN SHC SOP are defined, these need to be included into WMO regulatory material.

4.17 Status of GRUAN data product development for Modem – Damien Vignelles

Damien Vignelles introduced himself as the new researcher at Meteomodem in charge of estimating M10 uncertainties in the frame of the GRUAN certification. He presented the current organization of GRUAN France, with Frédéric Marin as MétéoFrance representative for the GRUAN France operational part and Jean-Charles Dupont, from IPSL, as representative of scientific activities and data processing.
Main updates are: the Trappes site near Paris operated by Météo-France, (part of SIRTA observatory candidate to GRUAN), has been using GRUAN procedures for more than 1 year including the use of SHC SPRH100 and a comparison with a calibrated sensor in outdoor ambient conditions, and a Meteomodem Robotsonde for 2 measurements per day. The GRUAN data stream is almost complete and the last part concerning the NetCDF files transfer to the Lead Centre will be soon operational. The M10 characteristics are under review (Dupont et al. 2019) according to the methods described in Dirksen et al. 2014. New laboratory experiments will be scheduled in Lindenberg by the end of the year. Finally, the La Réunion Island site will soon be operational as a GRUAN autolauncher site, and the Faa'a site, in French Polynesia could be soon a candidate for the third French GRUAN site.

It was decided to take the necessary steps to further develop the Modem product, including producing the Technical Document, the uncertainty characterization and the peer-reviewed paper. An update will be given at ICM-12 (**Action B2**).

4.18 Uncertainty terminology and presentation in GRUAN products – Tom Gardiner

A combined talk on uncertainty issues was given covering two main aspects – the first part on the basic concepts and terminology for uncertainty evaluation and the second part on the issue of how to assess and report uncertainties that are correlated over different timescales. A set of uncertainty descriptors were proposed for individual uncertainty sources: Random; Structured Random; Quasi-systematic; Systematic. Individual sources could then be combined with combined uncertainties reported over different timescales. The next step is to see how such a scheme could be implemented for GRUAN products, taking RS92 as an initial case study.
It was decided to develop a white paper on uncertainty quantification and presentation options for possible submission for publication (**Action C10**).

4.19 How to deal with correlated uncertainties when processing long data series? - Tom Gardiner

This agenda item was combined with 4.18.

4.20 Progress on the Use of Uncertainty in Operational Sounding Products Assessment - Tony Reale

Strategy and results were presented using the "Guidelines for Uncertainty Measurements" principles to estimate uncertainty for suites of satellite based atmospheric sounding products and NWP forecasts based on collocated GRUAN processed (Vaisala RS92, version2) radiosonde and satellite (and NWP) observations. Results focused at the ARM / GRUAN site at SGP, USA. Overall, the results appear consistent with expectations. However, the strategy and results are met with some scepticism as they suggest possible misrepresentations in the GRUAN uncertainties for RH in the lower atmosphere associated with high moisture contents. The results suggest the uncertainties in these situations are perhaps too "large" even though they appear to conform with expected RH uncertainties under such conditions; RH uncertainty is converted to water vapour mixing ratio to be consistent with the primary satellite derived product. Uncertainties for water vapour at other atmospheric levels (with reduced moisture content) and for temperature, overall, do not show such problems. Further analysis of the strategy with support from GRUAN members is underway, for example, the independence of GRUAN and respective satellite (and NWP) profiles may be a concern. The strategy does confirm known "concerns" with GRUAN uncertainties associated with radiation induced errors (daytime). The potential value to be able to estimate expected satellite sounding product uncertainties is high given their utility to assist weather forecaster to more optimally utilize NOAA Unique Combined Atmospheric Processing System (NUCAPS) soundings in the relatively clear sky, pre-convective environments commonly encountered at the SGP site. The report emphasizes the unique value of GRUAN observations (available at SGP) in the context of NOAA Cal/Val program for soundings. Future work is planned to update these results using GRUAN processed Vaisala RS41 and as available reprocessed GRUAN RS92 using version 3. Publication of the presented results is planned.

4.21 GRUAN Data Policy – Ruud Dirksen

Ruud Dirksen addressed the issue that the GRUAN data base contains a wide variety of data, and that only a small fraction of it are publicly available, since at ICM-9 it was decided only to publish GRUAN data products. Another issue is that sites want to be able to control the distribution of data from additional instruments (e.g. ozone sonde). A table was presented with access privileges for internal and external users to the various kinds of (intermediate) data.

Discussion following the presentation pointed out that beta release data should be advertised and made free available for the broader community to give them the opportunity to feedback on the usability. Making this data open to the world is an opportunity to have the data revised prior to its certification.

It was agreed that the task team on sites should work together with the LC and define a strategy regarding the data policy, including which data should be released to whom, that then will be reviewed by the WG (**Action C7**).

5. INTERMEDIATE OPERATIONAL CONCERNS

5.1 Availability of cryogen for CFH/FPH – Ruud Dirksen

Regulations on reduction of f-gases in the European Union call for a ban on R23 starting in 2020. The (upcoming) sale ban in Europe and Japan has led to a reduced availability and increased costs. This has repercussions for the GRUAN sites performing measurements requiring R23. Even though stockpiling is a possibility, GRUAN is a long-term programme, so the problems arising from the new regulations should be looked at critically. Alternative solutions are therefore needed that utilize an alternative cooling method. At the moment, the LC is cooperating with the Technical University in Dresden, to develop an alternative cooling method. Ensci, the CFH-manufacturer reportedly is doing the same. Alternative instruments are the Skydew and the Peltier Cooled Frostpoint Hygrometer (PCFH) along with other alternatives, which were presented in Session 8.

5.2 Issue with availability of Helium, viability of Hydrogen – Arnoud Apituley

Due to the strategic importance of Helium, and since the main supply of the gas is as a by-product of natural gas production (and therefore limited and only from a small number of sources), the supply price of Helium can fluctuate considerably in case of discontinuities in supply for political or technical reasons. In late 2018 a period of short supply occurred and the agencies relying on Helium for balloon launches sometimes had to wait longer than expected and pay more than expected for new supply of helium, which in some cases resulted in a reduced number of launches.

A more secure and cheaper source of filling gas for balloons is hydrogen. Sites depending on helium may consider switching to hydrogen. Issues to be considered in the transition are 1. the local safety rules for handling hydrogen, which include precautionary measures to the infrastructure (i.e. filling hut properties) as well as personal protective measures and 2. the supply source of hydrogen that can be in bottles, electrolytic local production or chemical local production.

Considering the different local conditions regarding regulations and logistics, each of the helium dependent sites need to make a cost-benefit analysis for themselves and decide if a transition should be made for their site. The GRUAN community is asked to share information on the implementation issues – with questions on the one hand and from experience on the other hand. Sites will be surveyed for helium/Hydrogen issues and strategies. This is part of **Action C6**.

5.3 Premature balloon bursts because of low temperatures - Shwei Lin Wong/Marion Maturilli

There is an issue of balloons bursting early in tropics. Based on our analysis at Singapore, 33% of evening flights (12 UTC) failed to reach 10 hPa or higher, while 8.6% of morning flights (00 UTC) failed to reach the required height. Thus MSS seeks to identify possible indicators that

caused the balloons to burst earlier. A possible significant indicator is the presence of significant low cloud cover (based on input ground conditions), where 41.1% and 13.3% of evening and morning flights burst earlier, when two or more oktas of low clouds were observed. We will thus perform comparison trials with dual layer balloons and single layer balloons under such conditions. Pending the outcome of the trial, we will incorporate this in our decision cycle to try to improve the burst heights.
Following up, Marion Maturilli presented the balloon treatment that is applied at GRUAN site Ny-Alesund once the stratospheric temperatures drop below -75°C, introducing the composition of the liquid used for balloon dipping and illustrating the procedure with documentary photos.
Sites will be surveyed for current strategies on ensuring burst height attainment. This is part of **Action C6**.

5.4 Stand up sites presentations about operational concerns- Belay Demoz

Several "concerns" were expressed. These include (i) the lack of a GRUAN Ozone product and plan on how to get there as well as a clear decision on whether to bring historical ozone sonde data into the GRUAN data archive; (ii) the fact that the CFH operation is becoming costly and the availability of the cryogen (R23) is getting harder and restricted for some sites. This requires a concerted GRUAN plan and change management plan; (iii) a clear guidance on the RS92 to RS41 transition and knowing when a site has enough data. Other concerns raised were GRUAN data usage and acknowledgment as regards to the sites. The sites bear the cost for collecting all the data so there must be a way to point to the data usage which may be important for auditing and justification to funding agencies. Further, an update on US-NWS activities and sonde evaluation campaign was presented and the continued collaboration and work that is ongoing in the GRUAN Mid-Atlantic Consortium (GMAC) was mentioned.
Regarding the usage of GRUAN data, it was decided to further develop ideas around the appropriate usage and citation metrics of GRUAN data, including appropriate acknowledgement to sites (**Action C4**).

5.5 Breakout session (TT ancillary/Autolaunchers/Satellite applications)

Breakout sessions on the task team on ancillary measurements and on autolaunchers were chaired by Thierry LeBlanc, Fabio Madonna, Giovanni Martucci and Christoph von Rohden. A breakout session on satellite applications was chaired by Jordis Tradowsky. The output of the breakout session on autolaunchers is summarized in section 9.1.

Summary of the breakout session on the task team on ancillary measurements - Thierry LeBlanc

Part 1: Discussion on GRUAN Lidar Data Processing (GLASS)
The release of the first GRUAN Lidar product was discussed. Table Mountain (TMF), Beltsville, Lauder, Cabauw, Lindenberg, Ny-Alesund, Payerne, La Reunion, Sirta (Paris) are the stations with lidar operation and represent a good critical mass for GRUAN.
In phase 1, data will be analyzed at JPL-TMF, for Lauder, Cabauw, Ny-Ålesund, Payerne, and TMF, with focus on the profiles coinciding with radiosonde, for the purpose of validation. Results will be sent out to Fabio Madonna for a neutral, "referee-type" evaluation. Once phase 1 is complete, phase 2 will consist of sending out a "frozen version" of GLASS to be used by individual sites.
The output data files will come with several ascii files to document which meta data parameters have been used for the processing. The meaning of meta data as well as version number were discussed.
It was followed by a discussion on how to define the different lidar products: i) atmospheric processes (high-res., short time), ii) climatology and trends (longer integration time, lower

altitude resolution), iii) calval (overpass product in coordination with satellite), iv) for GRUAN also a product in parallel to radiosondes.
Currently, there is an issue with the raw data transfer from GRUAN site to TMF: need to set up automated FTP for Cabauw, Lindenberg and Ny-Ålesund. Michael Sommer (LC) asked that raw data are first transferred to LC, from there go to processing center; Storage space at LC need to be checked first. There will be a back-up at Table Mountain.

Part 2: Discussion on Splitting TT Ancillary Measurements
Two options discussed:

- Option 1:

The remote sensing would include lidar and MWR; once GNSS-PW has finished its task to develop a GRUAN product, it will be included to this Task Team

- Option 2:

Remote Sensing is further separated to one Task Team Lidar and one Task Team MWR, with the existing GNSS TT unchanged.

Summary of the breakout session on satellite applications – Jordis Tradowsky

During ICM-11 a breakout session was organised for participants that are interested in the overlap between GRUAN and the satellite community. The session discussed matters such as how to get cloud information for the time and location of a GRUAN profile. Should there be any guidance from GRUAN of where this cloud information could come from? As many GRUAN sites have a variety of other instruments available at the same location, the data from these instruments may provide information about the cloud cover. It was concluded, that, while it is unlikely that GRUAN will provide information about the cloud cover in radiosonde profiles within the near-term future, having a list of other instruments available at every GRUAN site, would be helpful. Such a list of instruments could be hosted on the GRUAN website for every site individually. Even if no GRUAN product is available, researchers could then contact the site contact to find out where to get the data if they are not yet a GRUAN data product.
Regarding guidance about how to best detect cloud when comparing satellite data with GRUAN data, the satellite community itself has expert knowledge and it may be that there is no consensus on how to achieve this best. Thus, it is out of scope for GRUAN to provide the guidance about this topic.

It was further discussed, that it would be very helpful for the satellite community to get error covariance matrices of the GRUAN profiles. During the discussion it became clear that clarification about what would be required is needed. Thus, a proposed first step to progress the discussion about error covariances would be to clearly define what is required. Some members of the group volunteered to be available for these discussions. This will be followed up and should ideally lead to a short (about 2 page) description of what is required, including a definition of the term 'error covariance' as applied here.

6. RS92-RS41 CHANGEOVER AND PARALLEL SOUNDINGS

6.1 Parallel soundings database augmentation update – Michael Sommer

The aim of this talk was to show the current status of the data set for the RS92-RS41 comparison flights. Currently more than 1000 comparison flights are included in the dataset. Additional measurements from other instruments are partly available (e.g. CFH) but are not yet part of the data set, or are not yet available (e.g. satellite data). The GRUAN archive also contains many comparative flights between other radiosonde models. It was suggested to extend the dataset in such a way that it will be a generally applicable dataset for all comparison flights in GRUAN in the future.

This is one of the largest dataset ever for intercomparison. Therefore, it was suggested that the dataset should be made available to the community. This is reflected in **Action C18**.

6.2 RIVAL campaign status and GRUAN/GSICS coordination – Tony Reale

Plans, status and preliminary results for the Radiosonde Inter-comparison and VALidation (RIVAL) program and coordinated activities with the Global Satellite Inter-Comparison System (GSICS) were presented. RIVAL is approximately 2/3rds through its planned 2-year program and overall on track toward successful completion early next year. The various datasets including the GRUAN profiles and associated satellite based geophysical profile and sensor measurement observations were delineated with overall concurrence that they meet the original RIVAL program requirements. It was noted that RIVAL data collection from the ARM NSA site has met with some technical issues that may reduce the amount of data ultimately received. Examples of the combined sets of dual RS41 and RS92 observations including those from a series of sequential launches (at SGP) combining both vendor and GRUAN processed (including version Alpha 2 for RS41) observations were shown. The status of ongoing coordinated activities between GSICS and GRUAN were summarized, outlining separate actions to utilize GRUAN in respective IR and MW sensor monitoring and highlighting the potential unique value of GRUAN to ascertain absolute satellite sensor accuracy. Preliminary (and encouraging) results showing the consistency between GRUAN (geophysical) and GSICS (AMSU, CDR) derived trends in the vicinity of 90 hPa at the GRUAN sites at Barrow, Alaska and Lindenberg, Germany were presented. The presentation concluded with recommendations commensurate with a proposal from EUMETSAT to initiate a dedicated radiosonde program at MetOp satellite overpass. GRUAN sites at Lindenberg, Beltsville, SGP and Lauder were identified as good locations for such a program.

6.3 RS41-RS92 intercomparison at Darwin – Matt Tully

Comparison of forty-one dual Vaisala RS92/RS41 soundings performed in a month-long intercomparison campaign in Darwin (12.4°S, 130.9°E) were presented, using vendor-processing of the data. In terms of mean bias, the RS41 showed lower temperature than the RS92 from 2-30 km, with both the difference and the spread increasing with height, to reach -0.5 ±0.5 K at 30 km. The differences were much greater for day-time compared to night-time. For relative humidity, the RS41 value was on average 2 % higher through the troposphere. Examination of individual profiles showed the RS41 gave higher values both in high RH and low RH regions of the profile, but no wet-bulb effect could be detected in either temperature or humidity. In the upper troposphere the RS41 showed much higher humidity than the RS92, (typically 10-20 % higher RH) and then a much quicker decrease once above the cloud layer, however in this regard it should be noted improvements to the Vaisala RS92 algorithm following the 2010 WMO radiosonde intercomparison in China were not applied in the analysis.

Some results from a small series of dual RS92/RS41 ozone-soundings conducted at Broadmeadows were also presented, where it was found the small differences in current measured by the OIF411 and OIF921 interface cards obeyed a linear relationship with respect to current. The value of the fit derived from sounding data matched very closely the values reported by Vaisala from laboratory measurements.

6.4 On the accuracy of Vaisala RS41 humidity observations in both radiance and geophysical spaces – Bomin Sun

This work is in support of the RS92-to-RS41 transition in GRUAN. The Vaisala RS92 and RS41 humidity observations were assessed in the upper tropospheric water vapor absorption spectrums (1400 – 900 cm^{-1}). This was achieved through comparing the radiance computed from the radiosonde profiles using radiative transfer modelling (RTM) with collocated MetOp-B IASI measurements, reference sensor measurements in the Global Space-based Inter-

Calibration System (GSCIS). Major results obtained from this work were summarized. Manufacture-RS41 appears to suffer a slight dry bias (~ 1.5% in absolute terms of relative humidity, RH) during daytime in the upper troposphere, but shows improvement over GRUAN RS92 (by ~ 1% in RH). Manufacture-RS41 is consistent with IASI especially during nighttime provided the uncertainties of radiosonde and satellite observations, RTM, and collocation mismatch. Future work will include the assessment of GRUAN RS41 data when they are available.

6.5 Intercomparison of RS92 and RS41 using climatic chambers and wind tunnel: update on the data analysis – Marco Rosoldi

In a joint experimentation from Italian National Research Council's Institute of Methodologies for Environmental Analysis (CNR-IMAA) and National Institute for Metrological Research (INRiM), temperature stability and calibration error of RS92 and RS41, as well as their temperature bias, have been assessed at different controlled temperature, humidity, pressure and wind speed conditions, inside climatic chambers and using reference sensors traceable to SI standards.

In a first experiment, both sondes were tested in a climatic chamber (Kambic KK-105 CHLT) at 3 temperatures (-40°C, -20°C, 0°C) and 6 different combinations of humidity (20%, 40% , 98%) and temperature (20 °C, 40 °C). Data analysis reveals that RS41 is more stable and accurate than RS92 in all the Kambic points, with instability less than 0.06°C and 0.1°C for RS41 and RS92, respectively. The calibration error, quantified as the mean difference between each sonde sensor and a reference co-located thermometer, is estimated in the range [-0.05°C, 0.08°C] and [-0.31°C, -0.08°C] for RS41 and RS92, respectively, while the temperature bias between RS92 and RS41 in the range [-0.36°C, -0.1°C].

In a second experiment, both sondes were tested before and after fast temperature transitions, by moving them very quickly (≈ 10s) between two different climatic chambers set at different temperatures, in order to study the effects of these transitions on sondes' performances and their temperature bias. Transitions from -40°C to 20°C, from 20°C to -30°C, as well as repeated transitions from -30°C to 30°C, from 0°C to 20°C and vice versa were considered. Data analysis reveals that RS41 is more stable than RS92 before and after all the transitions, and these increase sonde instability, up to 0.4°C and 0.8°C for RS41 and RS92, respectively. Moreover, temperature rise and drop stronger (50-60°C) transitions increase the calibration error of RS41 up to ±0.4°C and don't change significantly the calibration error of RS92, while temperature drop smaller (20°C) transitions increase the calibration error of RS92 up to -0.3°C and do not change significantly the calibration error of RS41. The temperature bias between RS92 and RS41 is increased up to ±0.4°C by stronger transitions, but does not change significantly as a result of smaller transitions.

In a third experiment, both sondes were tested in the INRiM's climatic chamber/wind tunnel at different combinations of temperature (-20°C, -10°C, 0°C, 15°C, 30°C), wind speed (2 m/s, 5m/s, 8m/s, 15 m/s) and atmospheric pressures (laboratory, 800 hPa, 500 hPa, 350 hPa). A first data analysis at laboratory atmospheric pressure reveals that RS41 is more stable than RS92, with instability higher than that observed in the first experiment, less than 0.3°C and 0.5°C for RS41 and RS92, respectively. RS41 is more accurate than RS92 at low wind speeds (2m/s) and low temperatures (-10°C), with RS92 calibration error significantly higher than that observed in the first experiment, up to less than -1°C; on the other side, RS41 is less accurate than RS92 at low wind speeds, high temperatures (15°C, 30°C) and at high wind speed (8m/s, 15m/s), low temperatures (-10°C, 0°C), with RS41 calibration error significantly higher than that observed in the first experiment, up to more/less than +/-0.5°C. Finally, the temperature bias between RS92 and RS41 is significantly higher than that observed in the first experiment, ranging from less than -0.5°C up to more than 1°C.

The next steps of this work will consist of continuing and consolidating the analysis of measurements in the wind tunnel at atmospheric pressures lower than that of the laboratory, as well as in obtaining more general results, representative of the two sonde types, by repeating the experimentation with multiple pairs of sondes.

Following the presentation, it was decided that the LC and CNR will begin to integrate laboratory characterization results as part of the database to characterize instruments starting with RS-41 (**Action C19**).

6.6 Met Office RS92-RS41 transition results – David Edwards

The Met Office has been migrating from the RS92-SGPA to the RS41-SG, starting with a tender intercomparison in 2015, a site acceptance test in 2016, a series of climate trials from 2017-19 and most recently a test of the soft-shell variant. In total, more than 250 comparison RS92-RS41 flights have been flown. The RS41 has compared very well with the RS92, producing more repeatable temperature and RH measurements, with comparable winds and GPS derived altitudes and pressures. The RS41 exhibits a wet-bias in the troposphere compared with the RS92 and a dry bias in the stratosphere, but showed closer agreement with the Met Office's NWP for RH. The soft-shell tests showed no difference for T, winds, or GPS derived altitudes and pressures, and showed an indication of a slight dry-bias for the soft-shell variant, although it is not conclusive if this result is due to random chance or was systematic; Vaisala's analysis of the data showed a smaller effect and their other tests have not shown the same difference - further study is required for a conclusive answer. The RS41 has been accepted by its customers within the Met Office, who are generally very pleased with the sonde and software.

6.7 Analysis of RS91-RS41 transition results – Alessandro Fasso

Introduction: this report is an update of the previous report presented at ICM10, both being based on the GRUAN Dual Launches Database (DLD) as updated on May 20, 2019. The main difference is related to the fact that at ICM-10 the "best" available products were presented, while here the two sensors ceteris paribus are compared. In particular, at ICM10, since RS41-GDP was still to be developed, RS41-EDT.1 and RS92-GDP.2 were considered. Instead here, since RS41-GDP is not extensively available in the GRUAN, RS92-EDT.1 and RS41-EDT.1 are compared. Unfortunately, at the time of writing RIVAL twin-launches dataset is not available in the GRUAN-DLD.
All the numeric and graphical results are available on the GRUAN website at www.gruan.org.

Data analysis considered temperature and relative humidity for the following dual launches:

Site		Twin launches			
		ALL	Night	Outliers	Update
BEL	Beltsville	105	49	3	02/03/19
SGP	Lamont	19	7	1	08/06/14
LAU	Lauder	53		2	17/11/16
LIN	Lindenberg	388	146	12	07/05/19
NYA	NyAlesund	120	16	4	27/03/18
PAY	Payerne	107	54	3	12/12/17
TAT	Tateno	10	5		16/10/17
		806	277	25	

It can be observed that, due to station high latitude, Ny-Alesund has a very unbalanced Day/Night sampling. Also, Lamont and Tateno have a very limited number of DS's, so the related statistics have high uncertainty. For these reasons, in the sequel "generally" will refer to DSD excluded Ny-Alesund and Tateno.

Methods: for both T and q, the DS bias, which is the long-term DS difference = RS41-RS92, has been modelled as a smooth function of Solar Elevation Angle SEA and altitude:
DS bias = f(SEA,altitude).
In particular, local polynomial least squares model have been used.

Results:
Temperature: As expected, total co-location uncertainty is lower nighttime, genrally <03K, and higher in the upper atmosphere, generally <0.4K all data and <0.2K nighttime. Ignoring Tateno, Ny Alysund shows the most extreme differences but this may be influenced by the low rate of night soundings. Considering bias, RS41 seems to be cooler both in the upper and lower atmosphere. Generally, bias is <0.1K except in Ny-Alesund and Tateno, where bias is about 0.3K in the upper atmosphere. This bias is probably related to solar radiation, in fact, night time it is very small, generally <0.05K. Seasonal effect is quite limited night time.

Humidity: As expected total co-location uncertainty is lower in upper atmosphere, generally smaller than 0.03 and 0.01 respectively. Solar radiation effect has been found almost negligible. Considering bias, RS41 is wetter in lower atmosphere daytime with limited difference night time.

Comparison is at the moment possible only with the manufactures data. However, a synthesis assessment of the differences between the two manufacturer processed versions would be very beneficial and could be then used by other communities, such as the NHMSs. A paper about the comparison will be produced during the coming year (**Action A4**).

7. SITES PRESENTATIONS

7.1 Do ozonesonde records support the reported continuing decline in lower stratospheric ozone? – Dale Hurst

A recent paper shows that decreasing trends in lower stratospheric (LS) ozone have continued over non-polar regions since 1998, based on composite satellite measurement records. In this work, high-resolution in situ ozone measurements by ECC ozonesondes are analyzed for similar trends. The study exposes a flaw in the recent paper where large amounts of ozone-poor upper tropospheric air are included in the LS ozone columns during summer months, and does not fully support the conclusion of continued decreasing trends. Raising the lower column limits to reduce this flaw invokes other problems. The implementation of tropopause-relative coordinates substantially increases trend uncertainties; only statistically insignificant trends are determine the first 6-7 km above the tropopause.

7.2 Drone-based AirCore measurements at Sodankyla – Rigel Kivi

A new drone-based AirCore system was recently developed at the Finnish Meteorological Institute (FMI) Sodankylä site. The drone based AirCore uses an active sampling method, while in general the sampling is similar to the passive AirCore. The gas samples are collected during a drone flight and the gas analysis is performed by Picarro analyser located in the vicinity of the field experiment site. Thus analysis can be performed within a short time after taking the samples. During July-August 2018 more than 20 flights were performed at the Sodankyla site. The measured profiles overlap with balloon-borne AirCore measurements. Thus they can be used to reduce profile uncertainties in the lowermost layer. The new drone based measurements have been used to contribute to the validation of FTS based retrievals and secondly to study wetland methane emissions. At Sodankylä also other drone-based experiments have been in progress, including a new measurement program to retrieve sun induced chlorophyll fluorescence using a drone borne spectrometer.

7.3 New instruments and data transmission at Tateno, Minamitorishima and Syowa – Shunsuke Hoshino

The current status of Tateno, Minamitorishima and Syowa were reported. These three sites plan to use GSI's GNSS data. JMA tested Meisei SKYDEW as replacement for CFH.

7.4 DWD radiation sonde results – Tzvetan Simeonov

Currently Lindenberg is the only radiosounding station, where routine irradiance sounding is being performed. 30 flights have been performed since 2015 on a monthly to bi-monthly basis, 19 of which were performed in overcast or cloudy conditions in order to estimate the cloud radiative effect. The radiosonde is calibrated using the Baseline Surface Radiation Network (BSRN). The data from this radiosounding technique will be included in the GRUAN database from 2020 or shortly thereafter. Responsible person for the irradiance sounding in Lindenberg is Ralf Becker (ralf.becker@dwd.de).

This technique could be useful for Action A28 of the GCOS Implementation Plan (GCOS-200), which calls for "in situ profile and radiation: to understand the vertical profile of radiation requires development and deployment of technologies to measure in-situ profiles." It was decided that as such this is an important topic and should be discussed at ICM every year.

7.5 Updates on the Inter-Programme Expert Team on the Observing System Design and Evolution (IPET-OSDE) of WMO/CBS - Erik Andersson

The talk presented some of the main drivers of change in the Global Observing System and in the observation requirements for the Global NWP and Climate Monitoring application areas. The Earth System approach to NWP requires initialisation of the atmosphere, ocean, land and ice, and hence aligns very well with the goals of WIGOS.
The talk also provided an overview of the WMO RRR process, i.e. the Rolling Requirements Review, including its Application Areas and its integration in the OSCAR data bases (requirements, surface and space). https://www.wmo-sat.info/oscar/
GRUAN was acknowledged for improving the quality of radiosondes generally, for providing key reference data for calibration of satellite data in NWP and temperature trend analyses in climate monitoring.

7.6 RS41 descent/ascent data comparison – Bruce Ingleby

Bruce Ingleby compared RS41 descent and ascent data from Germany, UK and Finland with ECMWF background (short range forecast) fields. For temperature and relative humidity the standard deviation of O-B was generally similar for ascent and descent data. However, the descent temperatures are somewhat higher in the stratosphere. There is a question of whether the bias is entirely in the descent data or if the balloon wake effects cool the ascent temperatures. For faster falling radiosondes (notably the Finnish ones which don't have a parachute) the descent temperatures are also slightly warm in the troposphere. The descent winds are smoother than ascent winds and the background better – they appear superior because they are much less subject to pendulum motion effects.

8. SUBSTANTIVE DISCUSSIONS ON UTLS WATER VAPOUR MEASUREMENT

8.1 Progress report on the Peltier-Cooled Frostpoint Hygrometer (PCFH); and FLASH-B and TDL-based spectrometer – Yann Poltera

We reported the progress on the Peltier Cooled Frostpoint Hygrometer (PCFH) in development at ETHZ (CH) and on the Quantum Cascade Laser Absorption Spectroscopy Instrument (QCLAS) in development at EMPA (CH). Both instruments are in the late development phase. For the PCFH, five test flights have been performed at Lindenberg in 2018. One of the instruments' versions tested, based on a double-stage Peltier element and an improved thermal management, showed satisfying results and will be further optimized. A working instrument is expected for spring 2020. For the QCLAS instrument, first test flights are planned for 2019/2020. Finally, the Lyman-alpha FLASH-B instrument, a stratospheric water vapor instrument that is in use in some sites and in research campaigns, was presented.

8.2 Assessment of alternatives to R23 by TU-Dresden - Ruud Dirksen

Ruud Dirksen presented the results of a study by the TU-Dresden into possible alternatives to R23 as cryogen for frostpoint hygrometers.
In the first part of the study liquids were assessed on their thermodynamic properties. A short list of liquids satisfying the criteria for heat capacity, boiling point and triple pressure was found, but unfortunately these are all unsuitable because of toxicity, flammability, or for being a greenhouse gas.
Another possible mechanism is the use of a frozen liquid/gas with an embedded wire mesh for increased heat conductivity.
Finally, designs for a miniature pressurized container for liquid nitrogen was presented. Flow of the liquid nitrogen is controlled by capillaries, while a pressure relieve valve prevents the build-up of too high pressures.
Plan for the coming year is to continue the cooperation and to test two approaches: frozen ethanol with a wire-mesh and to devise a prototype of the miniature nitrogen Dewar. Results will be reported at ICM-12.
During the discussion the potential safety issues of the nitrogen Dewar were addressed.

8.3 Meisei Skydew instrument: analysis of results from Lindenberg campaign – Takuji Sugidachi

The comparison soundings of chilled-mirror hygrometers, SKYDEW and CFH, have been conducted at Lindenberg, Tateno, and Kototabang (Indonesia). SKYDEW is a Peltier-based chilled-mirror hygrometer. These results show that the SKYDEW can measure dewpoint/frostpoint up to 25 km at nighttime, and up to 15-25 km at daytime. The dual sounding with two SKYDEWs shows good agreement. The difference between the measured frost point temperatures is generally less than +/-0.2K. The comparison between SKYDEW and CFH shows good agreement throughout the troposphere, but SKYDEW has slight bias as compared with CFH at the stratosphere. The cause of this bias is still under investigation.

8.4 Performance of RS41 in the UTLS (improved time-lag and bias correction) – Yann Poltera

We reported on the performance of the Vaisala RS41 humidity product after analyzing the balloon sounding data from the StratoClim 2016 and 2017 campaigns. We found the RS41 to be in general good agreement with the reference instrument, the CFH. However, time-lag and possibly bias issues at cold temperatures were detected. This motivated the development of an approach to derive new sensor time-constants for RS41, based on the comparison of RS41 raw profiles with the CFH profiles. We also used the technique to derive the time-constants apparently used by the manufacturer. At temperatures larger than 205 K, the time constants we derived were smaller by up to a factor 3 than the ones apparently applied by the manufacturer (which are similar to the time constants of the RS92). At colder temperatures however, the time constants were similar or larger. Unrelated to time-lag, similar to RS92, it is also necessary to correct for biases at low temperatures. Applying our time-lag and bias correction provided more reliable data up to 4 km above the tropopause. While the new formulation yields on average tangible improvements of RS41 in the UTLS, individual soundings still show unexplained relative errors larger than 20 % with respect to CFH.

Following the presentation it was discussed that from the NWP point of view, it is preferable to have the raw data not corrected and then add the time-lag correction, which differs for each type of radiosonde. However, other users might prefer to have the data already with the correction applied.

8.5 Discussion

The high cost of the instruments is a problem for the sites. The presented approaches are not going to result in lowering the cost for the sites. The best way to drop the cost would be to recover the instrument, such for example using drones, but this is problematic due to aviation regulations. Sites and manufacturers were encouraged to continue working on the development of an instrument for humidity in the UTLS.

9. AUTOLAUNCHERS AND RS DOCUMENTATION

9.1 Progress update, including conclusions from breakout session – Fabio Madonna/Masatomo Fujiwara

Fabio Madonna presented an update on the task which aims at demonstrating the advantages and disadvantages of manual vs. Automatic Radiosonde Launchers (ARLs) written up and submitted to the peer reviewed literature and in finding a way to get GRUAN certification for radiosonde data products taken with ARL.

Current activities are mainly related to: writing of a manuscript to submit to peer-reviewed literature to initially assess the performance of ARLs; collection of sites' experience with autolaunchers; providing ideas for possible experiments to improve autosonde "traceability" (i.e. using independent ground check). Details related to each of these activities have been presented and the current status of the manuscript has been presented and though some of the attendees recommended to wait a longer time for the manuscript publication, most of the attendees suggested the manuscript publication be taken forward. It was decided to complete and submit the draft paper on ARL effects and to make recommendations on next steps needed to certify the ARL data (**Action HP3**).

Fabio Madonna then presented the conclusions from the breakout session on autolaunchers (agenda item 5.5).
There were 16 participants: Masatomo Fujiwara, Rigel Kivi , Fabio Madonna, Damien Vignelles, Christoph von Rohden , Matt Tully, Takuji Sugidachi, Shunsuke Hoshino, Mark Benoit, David Edwards, Gonzague Romanens, Bruce Ingleby, Hannu Jauhieinen, Petteri Survo, June Wang, Ruud Dirksen.
Conclusions from the break-out session are the following:

- The main message of the manuscript currently provided to the radiosonde TT is that there are no substantive differences in temperature and humidity data quality between manually launched and autolauncher data.

- In this first paper, all three systems available on the market will be covered. In spite of data availability from the RS41 not being sufficient yet, we cannot wait for e.g. another year to collect additional data.
- State-of-the-art radiosondes (RS41) will be included at least considering the GC comparison (ARLs vs manual). Examples have been already provided by MeteoSwiss.
- Results on the implementation of manufacturer independent ground check must be discussed in a follow-on GRUAN-wide community paper.
- JMA results on the balloon burst altitudes and re-launches may or may not directly be related to the autolaunching system itself. In this sense, Meisei manufacturer may want to check the text and the entire manuscript as well.

Moreover, the identified issues that need to be solved toward a GDP (with publication of the required documentation) are:

- Launch detection issue (reported by M. Sommer in his talk).
- Traceability.
- Change management: not only for radiosonde type and software, but also for autolauncher type and software.

JMA and Modem have proposed potential solutions for the implementation of an independent GC. Several issues surrounding the adoption of a manufacturer-independent GC have be raised and preliminary discussions been undertaken.

9.2 Radiosonde fundamental documentation (RS omnibus) – Christoph von Rohden

The GRUAN Radiosonde fundamental document is intended to offer comprehensive technical information, guidance, and also background knowledge in the field of in-situ measurements of different atmospheric quantities in vertical profiles using balloon-borne ascents of radiosondes. This includes necessary and useful knowledge for all phases of the work with radiosondes and the related data management for GRUAN and other applications. The document is intended to be of a general nature to the extent that it does not relate to specific sonde models. This will be done in further GRUAN Technical Documents. Currently, 10 chapters are planned, including fundamentals about magnitudes to be measured and sensor technologies, measurement practice, reference quality, GRUAN data products, data management, quality assessment, and instrument change management. The chapters are currently distributed to 5 co-authors, and in different stages of progress. The GRUAN LC is responsible for the editorial work and parts of the content. A conversion to a new online document processing platform (Overleaf) is in progress to enable improved joint document creation.
Little progress has been made during the last year, due to the fact that higher priority was given to the RS41 GDP. The team working on the RS omnibus was asked to finalize the first draft (**Action HP2**).
It was also proposed to assign as DOI to technical notes and documents as this would make it easier to cite the document. The LC is going to consider this idea and make a decision.

9.3 Visit at the Center for Climate Research Singapore (CCRS).

On Thursday 23 May, a visit to the Gardens by the bay was organized by the host, followed by a visit at the Center for Climate Research Singapore (CCRS). After a welcome by the DG Ms Wong Chin Ling, Dr Bertrand Timbal gave an overview of CCRS and gave a talk on the homogenization and trends of Singapore’s monthly upper-air temperature on behalf of Dr Muhammad Eeqmal Hassim. Singapore GRUAN site was certified and the MSS was presented with a certificate. GCOS awarded a certificate of recognition for the operation of the center with GUAN.

10. FUTURE PLANS: NEW SITES, PROPOSALS, PRODUCTS, MEASUREMENT PROGRAMS

10.1 Decadal review (2009-2019) of GRUAN journal articles – June Wang

June Wang presented the decadal review of GRUAN journal articles. There have been 87 papers published, many of them on field and intercomparison campaigns, on satellite validation and algorithm development and on GRUAN product development. Other topics include network design, operational developments, validation for ground-based instruments, assessment of the measurement records and model evaluation and calibration. Identified gaps are in climate trends and processing studies and NWP.
One of the noted issues was that there has to be clarity on whether papers referring to GRUAN are actually using GRUAN data and not only mentioning GRUAN.

10.2 Funding opportunities: LC-SPACE-19-EO-2020 and others - Peter Thorne

Peter Thorne talked about fund opportunities for GRUAN, noting that often relevant funding call go uncompleted and that so far GRUAN has been successful with GAIA-CLIM and the Copernicus Climate Change Service (C3S) 311a Lot2. He presented an upcoming opportunity H2020 LC-SPACE-19-EO-2020, a new concept for an innovative and holistic solution for Sentinels calibration & validation. The project should also propose recommendations and establish a roadmap to develop this innovative "Sentinels cal/val concept" with specific reference to the "Copernicus supersite(s)" definition and their distribution, including considerations on data quality check, harmonization, traceability, distribution and conservation process of related information. The call will close later in 2019 and GRUAN should consider being involved. Fabio Madonna, Alessandro Fasso, FMI and KMNI were interested to be involved in the consortium.

10.3 EUMETSAT RO processing: Reprocessing, Occultation predictions, Metop-C Update – Axel von Engeln

The talk gave an overview of the recently launched Metop-C satellite, with a focus on the on-board GRAS radio occultation (RO) instrument, focused primarily on the occultation prediction product for GRAS Metop RO data, and finished with a brief introduction of ongoing and planned RO reprocessing campaigns.
With the launch of Metop-C, there are now 3 RO GRAS instruments in orbit, all at/near a 09:30 local solar time. The instruments show very similar performances and all 3 are now included in the occultation prediction product.
Several improvements are going to be introduced for this prediction product, among them an indication that rising occultations are slightly more likely to be missed by a GRAS instrument. Other improvements focused on e.g. occultations affected by Metop maneuvers, or the location where they are located on the GRAS occultation antenna. With these additional information,

+90% of occultations are correctly predicted - if no GPS maneuver was present. Including these will be the focus of future work.
Regarding the reprocessing campaigns, a first Release is just being prepared. This covers Metop-A data from 2006 to 2016 and was also used for a climate data set release of the ROM SAF. An update, which included Metop-B and data up to 2017 is just undergoing validation and will be available end 2019/early 2020. More releases will follow in 2020, including Metop-C and 3rd Party missions like COSMIC.

10.4 Uncertainty validation of EUMETSAT Radio Occultation Meteorology Satellite Application Facility (ROM SAF) tropospheric specific humidity profiles using collocated GRUAN radiosondes – Johannes Nielsen

GRUAN RS92-GDP.2 relative humidity has been used to evaluate the uncertainty of the ROM SAF CDR1 tropospheric specific humidity product. The comparison is based on more than 15000 collocations. The specific humidity error standard deviation is found to be very consistent with the combined stochastic uncertainty estimates of sondes and radio occultations in the middle troposphere. The comparison also shows a significant RO dry nighttime bias of 2-3% in the troposphere.

10.5 The ongoing collaboration between GRUAN and the Radio Occultation community – Jordis Tradowsky and Fabien Carminati

Jordis Tradowsky summarised the ongoing exchange which developed between the GRUAN community and the radio occultation community following the "3G" Meeting (GRUAN-GSICS-GNSSRO WIGOS Workshop on Upper-Air Observing System Integration and Application) held in 2014. Following this meeting some projects were initiated that facilitated the exchange between the two communities and members of the radio occultation community are taking part in the yearly GRUAN meeting. As the GRUAN-radio occultation liaison Jordis Tradowsky is joining the International Radio Occultation Working Group Meeting since 2016 to promote GRUAN data products and activities within GRUAN.

As part of a recent visiting scientist project within the EUMETSAT Radio Occultation Meteorology Satellite Application Facility (ROM SAF, http://www.romsaf.org/) radio occultation measurements have been compared to GRUAN data from the Vaisala RS92. The uncertainty propagation for the GRUAN profiles is discussed in the presentation on the example for Lindenberg. Per value uncertainties given in the GRUAN data product version 002 for the Vaisala RS92 include random, as well as correlated uncertainties. While random uncertainties decrease with the sample size when averaged, this is not the case for uncertainties which are correlated in time or vertically. Thus, when propagating the uncertainties, the random component is treated differently and becomes very small when averaging data over one year. The correlated uncertainties, however, do not decrease in this way through averaging. The method is described in more detail in the ROM SAF Visiting Scientist report 37 which will soon become available online (http://www.romsaf.org/visiting_scientist.php).

Fabien Carminati presented an analysis of the estimation of model fields bias and uncertainty in radiance space. Bias and uncertainty in NWP temperature and humidity fields mapped to radiance space have been estimated from comparisons with radiosondes of the Global Climate Observing System (GCOS) Reference Upper-Air Network (GRUAN). Top-of-atmosphere brightness temperatures simulated from over 25000 GRUAN profiles of temperature, humidity, and pressure - and their associated uncertainties - from 11 sites in 4 geographic areas (northern latitudes, northern mid-latitudes, norther sub-tropical Atlantic, and tropical west Pacific) obtained over the period 2011-2017 and collocated NWP fields from both the Met Office and ECMWF global models have been compared at key frequencies spanning both the microwave and infrared spectrums through a selection of AMSU-A, MHS, ATMS, HIRS, CrIS and IASI channels. Although providing an incomplete picture due to the lack of GRUAN stations in the southern hemisphere, this analysis offers the most details and robust estimation of model fields bias and uncertainty in radiance space to date and takes NWP models a step closer to a traceable characterisation to SI standard.

10.6 New sites discussion

Paramaribo station is a potential GRUAN site. The GCOS Secretariat will send a formal invitation to the SURINAME Permanent Representative to invite the site to become a GRUAN candidate. Tahiti and Barbados need further work before becoming GRUAN candidate sites. Arrival Heights has now accepted to become a GRUAN candidate site.

10.7 Discussion on protocols for TD/TN/GRUAN Guide reviews/re-issues – David Smith

The GCOS 171 GRUAN GUIDE states that instrument programs and sites have to be audited and re-certified every 3-4 years. There is no mention however of the frequency with which GCOS documents, Technical Documents, Technical Notes and support material should be updated.

Currently, the relevant GCOS GRUAN documents have not been revised since initial publication; and two out of five TDs and three out of seven TNs are more than five years old. The conclusion is that all documentation and support material published more than four years ago should be reviewed within the next six months and then every 3-4 years subsequently. Reference quality documentation and support material should support a reference quality network.

10.8 WMO-CIMO Radiosonde intercomparison campaign 2021 – Ruud Dirksen

Ruud Dirksen presented the plan for the radiosonde intercomparison campaign in Lindenberg, which is co-organized by DWD and MeteoSwiss.

The goals of the campaign are:

- To bring all the major radiosonde manufacturers of all the different regions of the world together.
- To characterize the individual radiosondes with respect to their Reproducibility and to determine the Uncertainty of the different measured parameters.
- To compare the different radiosonde systems to a "Radiosonde Reference" (mean of three chosen Traveling Standard Systems).
- To include remote sensing instruments for the benefit of upper air measurements as a whole.

Furthermore, some GRUAN elements will be adopted, such as a pre-launch check in the SHC before every sounding and laboratory characterisation of the participating radiosondes.

Innovations with respect to the previous campaign (Yangjiang 2010) are a separate laboratory campaign to assess calibration, time lag and radiation error as well as the fact that the soundings will be performed by independent operators.

10.9 Update on WMO/CIMO Expert team on Upper Air Measurements – June Wang

New CIMO working structure for 2019-2022 was adopted at the Seventeenth Session of the Commission for Instruments and Methods of Observation (CIMO-17, Amsterdam, the 10.10 Netherlands, 12-16 0ctober 2018). Bruce Forgan and Bruce Hartley were elected as CIMO president and vice-president, respectively. Five expert teams and five task teams were formed. June Wang was selected as the chairperson of the Expert Team on Upper Air Measurements (ET-UAM). Three of 11 core members of the ET-UAM are involved in GRUAN. Given the overlap in membership, expertise and common interests between the ET-UAM and

GRUAN, the two groups can benefit from each other. GRUAN can influence the broader community through CIMO ET-UAM. The two communities can collaborate on new developments on all aspects regarding upper air measurements.

10.10 Use of GRUAN measurements and data processing to improve the quality of global radiosounding observing capabilities – Fabio Madonna

Fabio Madonna presented the status of the C3S activities aiming at the homogenization of GRUAN measurements and data processing to improve the quality of global radiosounding observing capabilities. Long and homogeneously observed time series are an essential source to diagnose the three-dimensional pattern of climate change. Within C3S an approach named Radiosonde HARMonization (RHARM) has been implemented largely exploiting GRUAN data processing and data products. The presenter showed how the use of adjustments inferred by GDP and GRUAN data is a solution to improve the quality of baseline radiosoundings. Using other "golden" datasets like WMO intercomparisons allows to extend the adjustment to other radiosonde types. Finally in RHARM, Reference data can be also used to tune uncertainty models for historical data. New data GRUAN products will be likely used to adjust different sonde types in future. A peer-reviewed paper is in advanced preparation stage and will be submitted in a few weeks.
The discussion that followed pointed out the importance of showing the improvement in NWP due to research and data from GRUAN. Improvement to instruments by manufacturers as the result of GRUAN is also important, as this will reflect on NWP.

10.11 Use of GRUAN data: Discussion on metrics to support sites in making the case for continued GRUAN participation – David Smyth

The GCOS 171 GRUAN GUIDE states that year‐to‐year traceability of GRUAN's impact within the climate community should be provided. There are several mechanisms outlined to facilitate this, one of which is GRUAN data usage. There is an issue however in that data usage is currently largely untrackable and citations are thus hard to verify. Allocating a doi is seen as the preferred option to enable GRUAN data usage tracking.
Several repository options were examined: the Data Citation Index; NCAR's Research Data Archive; and Pangaea. The issues are that the Data Citation Index has cost implications; the NCAR archive is not fully mature; and Pangaea is hosted by AWI, which may introduce client conflict. As such, work is ongoing to provide a suitable metric with which to monitor GRUAN data usage.

11. GOVERNANCE ISSUES

11.1 Naming conventions for GRUAN-processed data from non-GRUAN sites

More clarity is needed in the definition about what GRUAN data is and a sentence should be prepared for authors of papers to use when referring to GRUAN data.

The WG-GRUAN and LC were asked to ensure that certification and auditing of sites follow an agreed time schedule (**Action C3**). The stations to certify are Tenerife, Arrival Heights, Macquarie Islands, the ones to be recertified are Payerne, who already submitted the necessary paperwork, and Potenza.

The need to have a failsafe back-up of raw data was also discussed. The LC and CNR will proceed with the preparation of a mirroring of raw data holdings and report on progress at next ICM (**Action C9**).

It was also decided to review generic power points, create general posters and encourage presentations at relevant conferences (**Action C20**).

11.2 Agreed ACTIONS – Peter Thorne

Peter Thorne presented a list of actions from the meeting (Annex 4) that were agreed with minor changes. **Action C7** on further generalization of overpass information and **Action A1** on a community approach paper describing the GRUAN change management replacement strategy were briefly discussed and carried over from ICM-10 actions.

11.3 Closing remarks – Peter Thorne

The GRUAN Chairs, the GCOS Secretariat and the participants expressed their sincere gratitude to Shwei Lin Wong and the MSS for the great facilities, the Thursday dinner and the help throughout the week, as well as for the great tour of the Gardens at the Bay and the visit of the CCRS on Thursday.

Next meeting will take place in La Reunion, in the first or second week of November 2020. Dates will be announced at a later time.

ANNEX 1: LIST OF PARTICIPANTS

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Sommer	Michael	GRUAN Lead Centre, German Meteorological Service (DWD), Meteorological Observatory Lindenberg, Am Observatorium 12, 15848 Tauche, DE
Sugidachi	Takuji	Meisei electric co., ltd., JP
Sun	Bomin	STAR / SMCD / OPDB - NOAA Products Validation System (NPROVS), NSOF Building at the Suitland Federal Center, 4321 Suitland Road, Suitland, MD 20746-4304, US
Survo	Petteri	Vaisala,Vaisala Oyj, Vanha Nurmijärventie 21, 01670 Vantaa, FI
Tassone	Caterina	GCOS Secretariat, c/o World Meteorological Organization, 7 bis, avenue de la Paix, P.O. Box 2300, 1211 Geneva 2, CH
Thorne	Peter	Maynooth University Department of Geography, Maynooth, Co. Kildare, IE
Tradowski	Jordis	Bodeker Scientific, 42 Young Lane RD1, Alexandra,9391, Central Otago, NZ
Tully	Matt	Bureau of Meteorology, GPO Box 1289 Melbourne VIC 3001, 700 Collins Street, Docklands VIC 3008, AU
Vignelles	Damien	Meteomodem, F
von Engeln	Axel	EUMETSAT, Am Kavalleriesand 31, D-64295 Darmstadt, DE
von Rohden	Christoph	GRUAN Lead Centre, German Meteorological Service (DWD), Meteorological Observatory Lindenberg, Am Observatorium 12, 15848 Tauche, DE
Wang	June	Department of Atmospheric & Environmental Sciences, University at Albany, SUNY, 1400 Washington Ave., Albany, NY 12222, US
YANG	Rongkang	CMA, China Meteorological Administration, Xi Lin Guo Le Weather Bureau, No.11#, 10th Group, Er Deng Mu Teng street, Xilinhot, CN

ANNEX 2: ICM-11 AGENDA – 20-24 MAY 2019

Monday 20 May 2019			
Day Chair: June Wang			
Session 1- Opening			
08:45-09:00	1.1	Introductions	June Wang
09:00-09:25	1.2	Official opening	Patricia Ee – Director of MSS Weather Service Department
09:25-09:40	1.3	GRUAN Fundamentals	Ruud Dirksen
09:40-09:45	1.4	Presentation of GRUAN certification to ARM-SGP	Ruud Dirksen
09:45-10:15	**Coffee**		
Session 2 – Review of progress			
10:15-10:25	2.1	Welcome, logistics, outline of events, adoption of agenda	Local hosts and WG chairs
10:25-10:45	2.2	Remarks from GCOS including relevant AOPC outcomes	Caterina Tassone
10:45-11:15	2.3	Lead Centre progress report	Ruud Dirksen
11:15-12:00	2.4	Assessment of progress against action items arising from ICM-10	Peter Thorne/June Wang
12:00-13:00	**Lunch**		
Session 3 – Discussion of topics raised by Task Team reports			
13:00-13:10	3.1	Radiosonde TT: brief summary	Masatomo Fujiwara
13:10-13:25	3.2	Discussion on points arising	Led by day chair
13:25-13:35	3.3	Sites TT: brief summary	Dale Hurst/Belay Demoz
13:35-13:50	3.4	Discussion on points arising	Led by day chair
13:50-14:00	3.5	Scheduling TT: brief summary	Tom Gardiner
14:00-14:15	3.6	Discussion on points arising	Led by day chair
14:15-14:25	3.7	Ancillary Measurements TT: brief summary	Thierry Leblond
14:25-14:40	3.8	Discussion on points arising	Led by day chair
14:40-15:05	**Coffee**		
15:05-15:15	3.9	GNSS-PW TT: brief summary	Kalev Rannat
15:15-15:30	3.10	Discussion on points arising	Led by day chair
15:30-15:55	3.11	Report from GRUAN science coordinator	Tom Gardiner
15:55-16:15	3.12	Discussion on points arising from task teams/science coordinator	Led by day chair
16:15-16:30	**Session break**		
16:30-17:15	3.13	WG meeting to discuss WG and TT rotation	WG led by June Wang
End of day			

Tuesday 21 May 2019			
Day Chair: Peter Thorne			
Session 4 – Advances in the development of new GRUAN data products			
09:00-09:10	4.1	Steps needed for a GRUAN GDP	Ruud Dirksen
09:10-09:50	4.2	Progress to an RS41 product: Operational processing system Radiation tests and humidity time-lag	Michael Sommer/Christoph von Roden
09:50-10:05	4.3	QA/QC procedures for radiosonde data products	Michael Sommer/Christoph von Roden
10:05-10:25	4.4	Status update of GRUAN data products for Meisei RS-11G and iMSD-100 radiosondes	Shunsuke Hoshino
10:25-10:30	4.5	Presentation of GRUAN certification for RS-11G	Ruud Dirksen
10:30-11:00	**Coffee**		
11:00-11:15	4.6	Calibration of a Radiosonde Humidity Sensor using the low-temperature low pressure humidity chamber at KRISS	Sang-Wook Lee
11:15-11:30	4.7	A study on the solar correction for the RS41 using the Upper Air Simulator at KRISS	Yong-Gyoo Kim
11:30-12:00	4.8	Review of progress of data product: GNSS PW	Galina Dick
12:00-13:00	**Lunch**		
13:00-13:15	4.9	Update on GRAW DFM-09 (and RS92)	Ruud Dirksen
13:15-13:25	4.10	Intermet iMet-4 radiosonde: development history and steps towards GRUAN qualification	Mark Benoit
13:25-13:40	4.11	Current status of lidar GRUAN data products	Thierry Leblanc
13:40-14:00	4.12	Operational and GRUAN radiosoundung validation of PRR temperature data retrieved by Raman Lidar for Meterological Observations (RALMO) at Payerne	Gianni Martucci
14:00-14:15	4.13	Current status of MWR GRUAN data products	Fabio Madonna
14:15-14:30	4.14	Strategy for developing GRUAN data products for frostpoint hygrometers	Ruud Dirksen/Dale Hurst
14:30-15:00	**Coffee**		
15:00-15:15	4.15	Update on the ozonesonde data product	Richard Querel
15:15-15:30	4.16	Use of Standard Humidity Chamber	Richard Querel
15:30-15:45	4.17	Status of GRUAN data product development for Modem	Damien Vignelles
15:45-16:00	4.18	Uncertainty terminology and presentation in GRUAN products	Tom Gardiner
16:00-16:15	4.19	How to deal with correlated uncertainties when processing long data series?	Tom Gardiner
16:15-16:30	4.20	Progress on the use of GRUAN uncertainty in operational sounding products	Tony Reale
16:30-16:45	4.21	GRUAN data policy	Ruud Dirksen

Wednesday 22 May 2019			
Day Chair: David Smyth			
Session 5 – Immediate operational concerns			
09:00-09:10	5.1	Availability of cryogen for CFH/FPH	Ruud Dirksen
09:10-09:25	5.2	Issues with availability of Helium; viability of hydrogen	Arnoud Apituley
09:25-09:40	5.3	Premature balloon bursts because of low temperatures (relevant for Arctic and tropical sites)	Shwei Lin Wong/Marion Maturilli
09:40-10:00	5.4	Stand-up sites presentations about operational concerns	Belay Demoz and others
10:00-10:30	**Coffee**		
10:30-12:00	5.5	Brealout session (TT ancillary/Autolaunchers)	Thierry Leblanc/Fabio Madonna and Giovanni Martucci/Christoph von Roden
12:00-13:00	**Lunch**		
Session 6 - RS92-RS41 changeover and parallel soundings			
13:00-13:15	6.1	Parallel soundings database augmentation update: how many soundings; all sondes in; satellites; remote sensing	Michael Sommer
13:15-13:30	6.2	RIVAL campaign status and GRUAN/GSICS coordination	Tony Reale
13:30-13:45	6.3	RS41-RS92 intercomparison campaign at Darwin (plus some RS41-RS92 dual ozonesonde flights)	Matt Tully
13:45-14:00	6.4	On the accuracy of Vaisala RS41 humidity observations in both radiance and geophysical spaces	Bomin Sun
14:00-14:15	6.5	Intercomparison of RS91 and RS41 using climatic chambers and wind tunnel: update on the data analysis	Marco Rosoldi
14:15-14:30	6.6	Met Office RS92-RS41 transition results	David Edwards
14:30-14:45	6.7	Analysis of RS92-RS41 twin soundings	Alessandro Fasso
14:45-15:15	**Coffee**		
Session 7 – Sites presentations – New results, updates, opportunities, measurements			
15:15-15:30	7.1	Do ozonesonde records support the reported continuing decline in lower stratospheric ozone?	Dale Hurst
15:30-15:45	7.2	Drone-based AirCore measurements at Sodankyla	Rigel Kiwi
15:45-16:00	7.3	New instruments and data transmission at Tateno, Minamitorishima and Syowa	Shunsuke Hoshino
16:00-16:15	7.4	DWD radiation sonde results	Tzvetan Simeonov
16:15-16:30	7.5	Update on the Inter-Programme Expert Team on Observing System Design and Evolution (IPET-OSDE) of WMO/CBS	Erik Andersson
16:30-16:45	7.6	RS41 descent/ascent data comparison	Bruce Ingleby

Thursday 23 may 2019			
Day chair: Jordis Tradowsky			
Session 8 – Substantive discussions on UTLS water vapour measurement			
09:00-09:20	8.1	Progress report on: the Peltier-cooled frostpoint hygrometer (PCFH); and Flash-B and TDL-based spectrometer	Yann Poltera
09:20-09:40	8.2	Assessment of alternatives to R23 by TU-Dresden	Ruud Dirksen
09:40-10:00	8.3	Meisei Skydew instrument: analysis of results from Lindenberg campaign	Takuji Sugidachi
10:00-10:20	8.4	Performance of RS41 in the UTLS (Improved time-lag and bias correction)	Yann Poltera
10:20-10:30	8.5	Discussion	
10:30-11:00	**Coffee**		
Session 9 – Autolaunchers and RS documentation			
11:00-11:30	9.1	Autolaunchers: progress update, including conclusions from breakout session	Fabio Madonna/Masatomo Fujiwara
11:30-12:00	9.2	Radiosonde fundamental documentation (RS omnibus)	Christoph von Roden
12:00-13:00	**Lunch**		
13:00-18:00	**Site visit:** • Gardens by the Bay:Cloud Dome and Garden Dome tour • CCRS: group photo and tea break • DG address:Ms Wong Chin Ling • GRUAN certificate presentation • CCRS presentations: ○ Dr Bertrand Timbal: CCRS- An Overview ○ Dr. Muhammad Eeqmal Hassim: Homogenization and trends of Singapore's monthly upper-air temperature observations		
18:00-18:45	UAO operations and radiosonde launch		
18:45-22:00	Conference Dinner		

Friday 24 May 2019			
Day chair: Ruud Dirksen			
Session 10 – Future plans: new sites, proposal, products, measurement programs			
09:00-09:15	10.1	Decadal review (2009-2019) of GRUAN journal articles	June Wang
09:00-09:25	10.2	Funding opportunities: LC-SPACE-19-EO-2020 and others	Peter Thorne
09:25-09:40	10.3	EUMETSAT RO Processing: Reprocessing, Occultation Predictions, Metop-C Update	Axel von Engeln
09:40-09:55	10.4	Uncertainty validation of ROM SAF tropospheric specific humidity profiles using collocated GRUAN radiosondes	Johannes Nielsen
09:55-10:10	10.5	The ongoing collaborations between GRUAN and the Radio Occultation community	Jordis Tradowsky
10:10-10:50	10.6	New sites discussion: 1. Paramaribo 2. Tahiti 3. Barbados 4. Arrival Heights	Ankie Piters/Damien Vignelles/David Ferrell/Richard Querel
10:50-11:00	10.7	Discussion on protocols for TD/TN/GRUAN Guide review/re-issues	David Smyth
11:00-11:30	**Coffee**		
11:30-11:45	10.8	WMO-CIMO Radiosonde intercomparison campaign 2021	Ruud Dirksen
11:45-11:50	10.9	Update on WMO/CIMO Expert Team on Upper Air Measurements	June Wang
11:50-12:05	10.10	Use of GRUAN measurements and data processing to improve the quality of global radiosounding observing capabilities	Fabio Madonna
12:05-12:15	10.11	Usage of GRUAN data: discussion on metrics to support sites in making the case for continued GRUAN	David Smyth
12:15-13:15	**Lunch**		
Session 11 – Governance issues			
13:15-13:30	11.1	Naming conventions for GRUAN-processed data from non-GRUAN sites	Ruud Dirksen/LC
13:30-15:30	11.2	Agree Actions	WG co-chairs
15:30-16:00	11.3	Closing remarks/ICM-12 location announcement	WG co-chairs
End of meeting			

ANNEX 3: ACTIONS FROM ICM-10

N.	Actions	Responsibility	Deadline	Progress since ICM-10
HIGHEST PRIORITY				
HP1	**First full version of RS41 GDP:** Lead Centre to complete production of RS41 GDP before ICM-11 and be at worst under active consideration by WG for certification. Product to make use of traceability diagram and effects table approach of GAIA-CLIM and aim to have a radiosonde TD annex and a paper describing the product submitted.	Lead Centre; TT Radiosondes.	**March 2019** Intermediate checkpoints: Update on radiation measurements to WG: **9/18** Beta version of product available to TT and WG: **1/19**	In progress
HP2	**Radiosonde fundamental documentation:** Develop first draft of GRUAN radiosonde foundational technical document to cover the general instrument-independent aspects. Available for review.	Lead Centre; TT Radiosondes.	**January 2019**	In progress
HP3	**Auto-launchers:** (1) An assessment of the advantages and disadvantages of manual vs. auto launches written up and submitted to the peer reviewed literature and/or a technical document. (2) Find a way to get GRUAN certification for radiosonde data products taken with auto launcher systems.	Masatomo Fujiwara (Coordinator) ; Rigel Kivi; Fabio Madonna; Members: Relevant sites; manufacturers; and Lead Centre.	**August 2018** to define small set of well posed questions to be addressed. **December 2018** to submit manuscript. **Discussion regarding GRUAN certification at ICM-11.**	In progress

	(First collect the information/experiences/concerns from various groups, and define the critical questions to answer which would appear to be at least: i) Can we create a GDP?; ii) Is there a bias between manual and auto-launched sondes?; iii) Does the random uncertainty change?; iv) impact of lifetime in launcher (quality, SHC repeatability, and height attained); v) how to make manufacturer-independent ground check.)			
RS92 to RS41 transition actions				
A1	**Community approach paper:** Paper describing the GRUAN change management replacement strategy submitted to peer-reviewed journal (GI) to increase visibility of effort and get broad community buy-in.	Lead Centre; TT Radiosondes; WG-GRUAN	**May 2018**	In progress
A2	**Ensuring all sondes on multi-payloads in archive:** Lead Centre to advise each site of current archive status of muti-rig launches in the database. Sites who have launched more complex set-ups with additional non-Vaisala sondes on their rigs not currently archived to advise Lead Centre and where possible provide that additional data to the Lead Centre. Lead Centre to ensure these additional data associated with such launches. Known cases: Payerne, Modem multi-payload launches	TT Sites; Lead Centre	**September 2018 (then ongoing)**	Completed

A3	**Parallel soundings database augmentation with satellite/ancillary:** Augment parallel soundings of RS92-RS41 with satellite co-locations and 'ancillary' measurements (CFH, FPH, lidar, MWR, satellites, cloud observations (incl. BSRN) within +/-2 hours). • Sites to identify instrument streams available within +/- 2 hours of existing and planned parallel launches • TT ancillary to provide advice on suitability and also provide satellite matchúps (closest pixels?) • WG Chair to coordinate • Lead Centre to receive and archive	TT Ancillary measurements; TT Sites (co-led); WG Chair; Lead Centre.	**Oct 2018 (RIVAL soundings)** **Apr 2019 (all sites)**	Unaddressed
A4	**UKMO/BAS ascents inclusion:** Arrange for the inclusion of Met Office and BAS parallel soundings data in the RS92-RS41 transition. Particular interest in St. Helena given paucity of tropical locations.	Tim Oakley; Lead Centre.	May 2018	Completed
A5	**Scheduling by conditions:** Lead Centre to work with sites to fill the low solar elevation angle 'hole' in the current set of dual launches with a lack of dawn / dusk ascents.	Lead Centre; TT sites	**ICM-11**	Completed
A6	**Updated analysis of dual launch holdings:** Presentations on updated analysis, including accounting for distinctions in rigging and ancillary measurements to be presented at ICM-11. Reports to be made available a month prior. Consideration of submission of reports as peer-reviewed literature	RIVAL team; ad hoc TT; WG Chair; Lead Centre	**ICM-11**	In progress

A7	**Hard to soft casing:** Lead Centre to undertake a number of RS-41 dual launches between hard and soft casing and archive as part of the dual soundings archive. Other sites that wish to ascertain the impact to also submit to the archive.	Lead Centre; TT sites	**ICM-11**	Completed
New GRUAN data products				
B1	**Keeping track of new data stream developments and progress:** WG to define and agree table entries for a quick check table on progress against data stream requirements (per summary given by Tom Gardiner). Lead Centre to host this on an appropriate area of the GRUAN website. WG to regularly review this table on calls.	Lead Centre; TT sites	**October 2019**	Completed
B2	**Meisei GDP product certification:** WG Chair to intiate data stream certification as soon as a discussion version of a paper describing the product is available. Lead Centre to provide a package of materials and data necessary. WG members and TT radiosondes members to undertake a review and advise a decision.	WG Chair; Lead Centrel; Working Group; TT Radiosondes	**Within 4 months of discussion paper availability**	Completed
B3	**GNSS-PW GDP data flow and certification:** Certify the GNSS-PW data stream by ICM-11. WG Chair to work with TT-GNSS-PW to ensure review and finalisation of TD. GFZ to advance a data stream with full uncertainties (considering how to ensure as much information as possible expressed). Lead Centre to prepare a package of materials to enable certification by WG to proceed.	TT GNSS-PW; WG Chair; GFZ; Lead Centre; WG	**ICM-11**	In progress

B4	**Ozonesondes GDP:** WG Chair to discuss with relevant parties (Richard Querel, Jacquie Witte, Greg Bodeker, Lead Centre) remaining challenges in instigating an Ozonesonde product and revert to WG with an update. Challenges are: Peer reviewed paper, data processing.	WG Chair	**October 2018**	In progress
B5	**Modem sonde GDP:** Further update on the Modem product development to be given at ICM-11. Special attention paid to completing documentation steps and laboratory test results.	CNRS; Lead Centre; TT Radiosondes	**ICM-11**	Completed
B6	**Microwave Radiometer GDP:** WG-Chair and Lead Centre to discuss with Nico Cimini and explore potential processing centre options for an MWR product stream and outline potential options. Presentation to be given at ICM-11.	WG Chair; Lead Centre	**ICM-11**	In progress
B7	**Lidar GDP:** Report on beta testing outcomes and progress of a v1 data stream at ICM-11. If beta testing shows no issues then aim to have finalised TD and be in a position to certify one or more initial lidar data streams.	TT Ancillary measurements; Fabio Madonna	**ICM-11**	In progress
B8	**Frostpoint hygrometer roadmap:** Prepare a strategy document (2-sides max) to address the remaining steps required for instigation of a general frostpoint hygrometers GDP (to cover at least FPH and CFH) for presentation and discussion at ICM-11.	Dale; Ruud	**ICM-11**	Completed
Remaining actions				

C1	**Sites photos:** Technical note on guidance on site survey photos and upload instructions. Current site photo surveys to be uploaded to appropriate area of website. GCOS Secretariat to then discuss with WIGOS inclusion into OSCAR Surface metadata database. Lead Centre to instigate mechanism to remind sites to submit new photos. Included here is ensuring that all GRUAN sites have WIGOS identifiers and metadata within OSCAR Surface.	WG Chair; TT Sites; Lead Centre; GCOS Secretariat	**June 2018**	Completed
C2	**Failsafe back-up:** Lead Centre and CNR to instigate a mirror of the raw data holdings from the GRUAN archive.	Fabio Madonna; Michael Sommer	**July 2018**	In progress
C3	**Generalisation of overpass information:** Augment the current golden overpass emails so they show in addition appropriately polar orbiter overpasses information to enable sites to also be able to target these overpass times should they wish to do so.	TT ancillary measures; Fabio Madonna, Tony Reale; Lead Centre; TT Sites; Axel	**August 2018**	In progress
C4	**Certification and auditing:** WG-GRUAN and Lead Centre to ensure certification and auditing of sites on the agreed upon timetables and verify against these targets at ICM-11.	Peter Thorne; Lead Centre	**ICM-11**	Completed
C5	**Annually based reporting:** Lead Centre to provide automated reports on annual performance no later than 20 January of each year. Sites to append site report no later than 15 February to inform the ICM. WG-GRUAN members to read site reports prior to ICM.	TT Sites; Lead Centre; WG-GRUAN	**February 2019**, and then at the same time each year	Completed
C6	**Letters on behalf of sites:** WG-GRUAN chair to review site reports and	WG Chair; TT Sites;	**June 2019**	Completed

	initiate letters from appropriate parties accordingly. TT sites to advise any additional requests as they arise.	Lead Centre; GCOS Secretariat		
C7	**Uncertainty terminology and presentation in GRUAN products:** Brief (max. 8 pages) discussion document to be produced on issues surrounding uncertainty terminology and presentation to users in GDPs including a review of heterogeneity in current approaches in certified and candidate streams to form basis for discussion at ICM-11	Tom Gardiner; WG Chair; Lead Centre; TT-AM; TT-GNSS-PW; TT radiosondes	**February 2018**	In progress
C8	**Vertical radiation profile sounding:** With a view to the GCOS IP action Lindenberg (via LC) to provide an update on their radiation measurement program including inter-alia: costs, practical deployment considerations, understanding of traceability, assessment of required launch frequency	Lindenberg site	**ICM-11**	Completed
C9	**New sites:** Lead Centre to follow up with French sites over potential site in Faa'a, Tahiti as proposed in Modem product update talk.	Lead Centre	**July 2018**	Completed
C10	**Clarification on NRT transmission when launching dual sondes:** Lead Centre to draft letter with John Eyre to sites undertaking dual launches to clarify preference to transmit the operational sonde in NRT.	Lead Centre; John Eyre	**May 2018**	Completed
C11	**Standard Humidity Chamber:** If funding secured for WG Chair support role undertake a viability assessment of writing a paper that justifies the use of the SHC in terms of the data quality using data arising from the Lead Centre.	WG Chair	**ICM-11**	In progress

C12	**Usage of GRUAN data** Investigate and instigate appropriate usage metrics to support sites in making the case for continued GRUAN participation.	WG Chair, TT sites	**ICM-11 session** Intermediate deliverables: May 2018 updated bibliography of GRUAN use in literature October 2018 – brief discussion document on additional potential ways to monitor usage	In progress

ANNEX 4: GRUAN ACTIONS FOLLOWING ICM-11

Note:

- All unremedied actions from prior ICM by default to be carried forwards.
- New actions proposed based upon meeting discussions
- Next ICM planned for November 2020, therefore many of the actions have intermediate deadlines

N	Action	Responsibility	Timeline
		High Priority Actions	
HP1	**First full version of RS41 GDP**: Lead Centre to complete production of first full version of RS41 GDP. Note that LC should reach out for help – e.g. Tom Gardiner can provide PTU diagram and other aspects? Product to be certified and publicly available prior to ICM-12	Lead Centre, TT Radiosondes.	**Product to be certified and publicly available prior to ICM-12** Beta version data product available December 2019 TD complete February 2020 Certified by working group by September 2020
HP2	**Radiosonde fundamental documentation:** Finalize first draft of GRUAN radiosonde foundational technical document to cover the general instrument-independent aspects.	TT Radiosondes and Lead Centre	Draft submitted to WG by **ICM-12**
HP3	**ARL:** Complete and submit the draft paper on ARL effects. Make recommendations on next steps to certify the ARL data.	WG-GRUAN, TT radiosonde, Sodankyla, Potenza, Modem, Meisei	Manuscript submitted **September 2019** Further steps available in advance of and then discussed at ICM-12
HP4	**QC/QA flagging and presentation in data files:** Ad hoc group on QC/QA flagging to develop a strategy and rationale as a technical note. Work to include inter-alia: which profiles to present to users; use of multiple fields (good, questionable, bad); and use of interpolated values or otherwise.	Ad hoc group members	TN draft available for WG-review **Aug 2020** Presentation at **ICM-12**

RS92 to RS41 transition actions			
A1	**Community approach paper:** Paper describing the GRUAN change management replacement strategy submitted to peer-reviewed journal (GI) to increase visibility of effort and get broad community buy-in.	Lead Centre, TT Radiosondes, WG-GRUAN	**June 2019**
A2	**Parallel soundings database augmentation with satellite/ancillary:** Augment parallel soundings of RS92-RS41 with satellite co-locations and 'ancillary' measurements (CFH, FPH, lidar, MWR, satellites, cloud observations (incl. BSRN) within +/-2 hours).	TT Ancillary measurements; TT Sites; WG Chair; Lead Centre.	WG Chairs, LC to prepare TN guiding sites on what site data requested for such parallel measurements and how to upload **Sept 2019** Satellite co-locations within reasonable match provided by NOAA STAR **Nov 2019** Sites to respond with planned submissions **Dec 2019** Data submissions received and integrated **May 2020**
A3	**Updated analysis of dual launch holdings:** Presentations on updated analysis, including accounting for distinctions in rigging and ancillary measurements to be presented at ICM-12. Reports to be made available a month prior. Consideration of submission of reports as peer-reviewed literature.	RIVAL team; ad hoc TT; WG Chairs; Lead Centre	**ICM-12**
A4	**Paper on manufacturer processed differences:** Perform a synthesis assessment of the differences between the two manufacturer processed versions using a number of approaches as shown at ICM-11 in the parallel soundings session.	Alessandro, Bomin, Tony, participating sites, MO, Dave (to coordinate)	**March 2020**

Progressing new GRUAN data products			
B1	**Meisei IMS GDP product:** TD completed, data stream in beta mode and paper submitted by time of ICM-12	TT Radiosondes (Meisei)	**ICM-12**
B2	**Modem sonde GDP progression:** Take steps necessary to further develop the Modem product (TD completion, uncertainty characterisation, papers); update to be given at ICM-12.	TT Radiosondes (Modem)	**ICM-12**
B3	**GNSS-IWV GDP certification:** TD finalized and the product certified and flowing from all qualified sites by year end	TT GNSS-PW; GFZ; Lead Centre; WG	TD resubmitted by TT and published **July 2019** Certification package prepared by LC and sent to WG-Chairs **Sept 2019** Certified product **Nov 2019**
B4	**Ozonesondes GDP progression:** Update on progress towards an Ozonesonde GDP to be given at ICM-12 including consideration of TD issues raised at ICM-11 and outcomes of further discussions with the community.	Richard Querel, WG Chairs	**ICM-12**
B5	**Microwave Radiometer GDP progression:** TT-AM to further progress the MWR product and present on progress at ICM-12	TT-AM	**ICM-12**
B6	**Lidar GDP progression:** Report on beta testing outcomes and progress of a v1 data stream at ICM-12. If beta testing shows no issues then aim to have finalised TD and be in a position to certify one or more initial lidar data streams.	TT-AM Thierry, Arnoud, Fabio	**ICM-12**

B7	**Frostpoint hygrometer GDP progression:** Provision of update on progress towards a GDP for frostpoints covering at a minimum: 1. whether a single version can be applied to all frostpoint techniques; 2. questions around the Voemel et al analysis raised at ICM-11	Frostpoint hygrometers ad hoc team	**ICM-12**
		Remaining Actions	
C1	**Split TT-AM into two (or more) teams:** TT-AM to propose splitting into two (or more) teams. The first on satellite/NWP applications of GRUAN and validation of GRUAN, the second on development of ground-based measurement techniques.	TT-AM, LC, WG chairs	TT-AM to propose and agree with LC and WG two ToRs and original membership **Oct 2019**. Split following AOPC endorsement thereafter
C2	**Sites photos:** Sites to upload first set of photos commensurate with the new site photos TN. Lead Centre to work with sites through their PRs to share these with the OSCAR Surface database.	TT Sites; Lead Centre; GCOS Secretariat	**Oct 2019** sites photos uploaded **Feb 2020** photos shared with OSCAR Surface database
C3	**Certification and auditing:** WG-GRUAN and Lead Centre to ensure certification and auditing of sites on the agreed upon timetables and verify against these targets at ICM-12. Target stations to certify: Tenerife, Arrival Heights, Macquarie Island Target stations to recertify: Payerne, Potenza	WG Chairs; Lead Centre	**ICM-12**
C4	**Usage of GRUAN data:** Further develop ideas around the appropriate usage and citation metrics of GRUAN data including appropriate acknowledgment to sites. Instigate measures as possible and further update progress at ICM-12	WG, TT sites	**ICM-12**

C5	Augment GNSS-IWV data flow: GNSS-IWV Data flow to be set up for additional sites prior to ICM-12. Progress to be made in installing hardware at additional sites and starting data flow	GFZ, TT sites members, TT GNSS-IWV	Report on progress at **ICM-12**
C6	**Survey of site approaches vis-à-vis variety of radiosonde issues:** Sites to be surveyed for current approaches / issues identified as of import at ICM-11: 1. How cloud observations are made and reported in RsLaunchclient 2. Current strategies on ensuring burst height attainment 3. Helium / Hydrogen issues and strategies	TT Sites, WG, LC	Define and agree survey with LC and WG **July 2019** Returned surveys **Oct 2019**
C7	Data Policy: Progress to finalization an explicit strategy regarding which data can be released to whom and get signed off by sites and WG.	LC, TT Sites, WG	Lead Centre proposal completed by **Jul 2019** TT sites review completed **Nov 2019** WG review completed **Mar 2020**
C8	**Further generalization of overpass information:** Further augment the current golden overpass emails so they show in addition non-EUMETSAT polar orbiter overpasses information to enable sites to also be able to target these overpass times should they wish to do so.	TT-AM; Tony Reale; Lead Centre; TT Sites; Axel von Engeln, Lori Borg	**October 2019**
C9	**Failsafe back-up of raw data:** Lead Centre and CNR to further the preparation of a mirroring of raw data holdings and report on progress via a presentation at ICM-12	CNR, Lead Centre	**ICM-12**

C10	**Uncertainty terminology and presentation in GRUAN products:** Develop a white paper on uncertainty quantification and presentation options for possible submission for publication.	TT-Scheduling	**February 2020**
C11	**Standard Humidity Chamber:** Paper to justify the use of the SHC in terms of the data quality and the benefits and including need for standardisation of operating procedures. TN to describe procedural requirements.	Richard Querel, David Smyth, TT-sites, Lead Centre	**April 2020**
C12	**Metrological closure of GNSS-IWV and radiosondes:** For those sites which perform both GNSS-IWV and a GRUAN qualified radiosonde perform an analysis as to whether metrological closure is attained or otherwise. Initial results to be presented at ICM-12 and discussed.	GNSS-IWV and radiosonde TTs	**ICM-12**
C13	**Standardizing cloud treatment:** Develop a proposal on how cloud observations should be taken to support the radiosonde profiles including how that information should be included in the data files. Strategy to be cognizant of existing practices (see linked action)	TT Radiosondes and TT AM (satellites)	**ICM-12** presentation
C14	**Multi-payload configurations:** DWD and MeteoSwiss to consider running parallel multi-payload configurations to try to minimize the impacts of multi-versus single (operational) payload with a view to minimizing impacts in GRUAN but also upcoming CIMO intercomparison.	DWD and Meteoswiss	Update talk at **ICM-12**

C15	**Use of descent data:** Revisit the potential use and value of operational radiosonde descent data within GRUAN. Are the data good enough to use? What would be involved? Is there any demonstrable value? Present update at ICM-12	TT Radiosondes	**ICM-12**
C16	**Justification for high ascent attainment:** TT radiosondes to progress an analysis of the additional benefits of high altitude attainment (10hPa compared to 30hPa) with a view to arising one or more papers. Criteria to include NWP impact, seasonal predictability, importance of monitoring LS winds etc. Present update at ICM-12	TT Radiosondes, IPET-OSDE	**ICM-12**
C17	**Radiosonde wind uncertainty estimate:** Evaluate and improve radiosonde wind uncertainty estimates. Meisei has done detailed uncertainty estimate for Meisei wind measurements. LC to consider whether this can be done for RS41 and RS92 v3 and report at ICM-12	TT radiosondes, LC	Report at **ICM-12**
C18	**Generalise parallel soundings database:** Lead Centre to make all parallel soundings (all pairs or sets either model1-model2 or model1-model1) in the archive explicitly available via the parallel soundings archive facility to increase accessability and usability. Parallel soundings archive to be made more externally accessible. TT sites to ensure all sites have uploaded all parallel measurements (not just RS92/41 pairs)	Lead Centre, TT sites	Initial survey of sites – **Aug 2019** Data uploaded to LC - **Oct 2019**

C19	**Addition of laboratory characterization results of instruments:** Lead Centre and CNR to begin to integrate laboratory characterization results as part of the database to characterize instruments starting with RS-41. Progress to be updated at ICM-12	Lead Centre, CNR	**ICM-12**
C20	**Refresh of presentation materials:** Review and refresh generic power point, create generic poster, encourage presentations at relevant conferences.	David Smyth, WG, LC	**October 2019**

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