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WORLD METEOROLOGICAL ORGANIZATION

INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION

Report of the Twelfth GCOS Reference Upper Air Network Implementation Coordination Meeting (GRUAN ICM-12)

Virtual Session
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GCOS-237

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Chair, Publications Board

World Meteorological Organization (WMO)

7 bis, avenue de la Paix

P.O. Box 2300

CH-1211 Geneva 2, Switzerland

Tel.: +41 (0) 22 730 84 03

Fax: +41 (0) 22 730 80 40

E-mail: Publications@wmo.int

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INTRODUCTION:

Due to the global Covid-19 situation, the ICM-12 meeting was organized as a condensed, virtual meeting during the week of 16-20 November 2020. The meeting was held as a 5-days series of 2-hour video conferences during which only the most essential topics were discussed. The timings of the sessions were rotated in an attempt to evenly spread the burden of unfavourable hours over all participants from various time zones.

The following sections provide a summary paragraph for each of the presentations, as submitted by the author of the presentation (if provided).

All presentations are available for further review from the GRUAN meeting website, at https://www.gruan.org/community/meetings/icm-12.

The meeting agenda is given In Annex 1.

Annex 2 provides a summary on progress of actions from ICM-11 and the list of actions.

Annex 3 lists the agreed outcomes/actions from ICM-12.

PRESENTATION SUMMARY:

SESSION 1 – SITE PRESENTATION

1.1 Overview of network status (Ruud Dirksen, GRUAN LC, DWD Lindenberg)

The network has expanded to 30 sites, with the recent additions being Dakar (first site on the African continent), Hong Kong (HKO), Neumayer (GVN), Ross Island (ROS). Paramaribo will join soon, after the official acceptance letter has been received by WMO. The sites Payerne, Potenza and Sodankyla have been recertified, the certification applications of Tenerife and Ross Island are under review, and the recertification of Cabauw and Beltsville is pending. In total 12 GRUAN sites have been certified. The flow of data to the Lead Centre is steady, although lacking for some sites. The GRUAN archive contains more that 110k radiosoundings. The 100k mark was reached by Beltsville in December 2019.

Development of GRUAN data products is ongoing, currently there are 2 certified GRUAN Data products (Vaisala RS92, Meisei RS-11G) with GNSS-PW to follow suit, and several others are in the making.

Since ICM-11 several GRUAN documents have been published (TD-6, TNs 6, 9, 11) as well as a multitude of papers on GRUAN-related research. Two important publications for the network are on the use of auto-launchers (Madonna et al.) and on the GRUAN-wide approach to the RS92-RS41 transition (Dirksen et al.)

A pressing issue that needs to be resolved is an alternative to the application of R23 as cryogen for CFH/FPH for observations of stratospheric water vapor.

A major task is the comprehensive analysis of the impact of the transition from RS92 to RS41 on the GRUAN data records.

1.2 Update on GRUAN data flow (Michael Sommer, GRUAN LC, DWD Lindenberg)

This presentation was used to show the current state of GRUAN data flow and the content of GRUAN data archive. Main focus was on radiosounding and other balloon-born in-situ instruments. Approximately 114,000 soundings are stored in archive and more than 20,000 were added since last ICM. The dominating radiosonde model is the Vaisala RS41 since several years. Several new sites were included in data flow. Unfortunately, starting of data flow is still pending for several sites, which are GRUAN sites since many years. An overview was given about state of development of GRUAN data products for several radiosonde models. A short notice about increasing the number of sites with a GNSS-PW data flow was made.

Possibilities and tools of monitoring of data flow was shown in second part of this presentation. The GRUAN Lead Centre has developed several internal analysis tools for detailed monitoring. The GRUAN community can use regular updated material on the GRUAN website to get an overview about current status of data flow and data archive. The yearly site reports are going to be created in a yearly rhythm without relation to time schedule of ICMs from now on.

1.3 Update on AirCore flights at Sodankylä (Rigel Kivi, FMI)

AirCore observations have been performed at the Sodankylä GRUAN site since September 2013, using meteorological balloons to lift the instrument package to the altitude of typically 30-35 km. So far more than 50 flights have been performed at Sodankylä, resulting in accurate profiles of CO2, CH4 and CO from stratosphere down to the surface. We have shown that also other trace gases can be measured using the AirCore technique. The flights have been coupled with Vaisala RS92 radiosonde and in some cases also with ECC ozonesonde measurements. Vertical resolution of the measured AirCore profiles has been 5 mb in the stratosphere and 15 mb in the troposphere. The data are directly related to the WMO in situ trace gas measurement scales, providing the opportunity for interesting comparisons using remote sensing techniques. One of the original motivations for our measurements was to provide comparisons with respect to the Fourier transform spectrometer measurements at the Sodankylä TCCON site. The results of the recent flights have been published by Zhou et al. (2019a; 2019b), Sha et al. (2020), Tu et al. (2020), Hooghiem et al. (2020), Karppinen et al. (2020), and Laube et al. (2020). Laube et al. (2020) showed that AirCore technique can be successfully used to measure mixing ratios for CFC-11, CFC-12, H-1211, H-1301, HCFC-22, and SF6. The derived mixing ratios and mean stratospheric residence times, both from the AirCore and aircraft data have enabled the assessment of the performance of meteorological reanalysis packages such as ERA-Interim, JRA-55 and MERRA-2.

1.4 New site introduction for Hong Kong (Olivia Shuk-ming Lee, Hong Kong Observatory)

Hong Kong is a major, highly populated city at the southern coast of China. The only upper-air meteorological station in Hong Kong is located at King’s Park (WMO No. 45004). It is on a small hill in Kowloon, an urban district of Hong Kong. King’s Park is reasonably well exposed with a fairly typical outdoor setting of the city with short grass, trees and buildings in the vicinity. The station was accepted as a GRUAN candidate site in July 2020, with GRUAN name ‘Hong Kong’ and code ‘HKO’.

The station was inaugurated in 1951 and radiosonde launch started since then. You can find the history of the station from the blog – Seeking ground truth at a height at King’s Park (https://www.hko.gov.hk/en/Observatorys-Blog/103423/Seeking-ground-truth-at-a-height-at-King%E2%80%99s-Park). The station is a GUAN station with routine twice daily radiosonde launch (Vaisala RS41-SG carried by Helium inflated TOTEX balloon) at 00 and 12UTC using Vaisala Autosonde. We also conduct weekly ozonesonde launch (SPC 6A-ECC on Vaisala RS41-SG). We started monthly moisture sonde (CFH) launch (EN-SCI CFH) since October 2020. For the ozonesonde and moisture sonde, we introduced manufacturer-independent humidity check by Standard Humidity Chamber (SHC1) and Fluke Pt100 temperature probe since October 2020. As Hong Kong Observatory is also responsible for radiation monitoring of the environment, we conduct radioactivity sonde launch (MEISEI) a few times each year under different weather conditions. Ad-hoc radiosonde launches will be performed when important weather systems are in the vicinity (e.g. tropical cyclone, intense cold front, pressure trough etc.). We hope to finalize the data flow between Hong Kong and Lead Centre and start near real time data submission shortly. We will try using dry ice and ethanol as coolant for CFH sonde and we plan to try launching MEISEI SKYDEW moisture sonde as well.

1.5 New site introduction/update for Trappes and Reunion (Frédéric Marin)

Trappes radiosounding station: The Trappes site is located in the west of Paris, about 25 km away. It is a historical meteorological observatory since the first measurements were made with balloons at the end of the 19th century. The first radiosounding was performed in 1929 from this observatory. The radiosounding was performed with a manual system until April 2015 before being fully automated from that date. The Trappes station performs radiosounding twice a day: at 00 UTC and at 12 UTC using M10 Meteomode's sondes. Since May 2018 the GRUAN procedures are implemented for all radiosoundings. With the implementation of these new procedures, the calibration of the M10 sondes in terms of humidity and temperature has been improved. For the 100% saturation of humidity Meteo-France use a humidity chamber (SCH1).

The radiosounding station on Reunion island: This radiosounding station was automated in April 2018. Before the automation the manual radiosounding was done at the airport of Saint Denis de la Réunion located 3 km away. Now the radiosounding is automated and the system is on the roof of the meteorological center in the city of Saint Denis de la Réunion. In October 2019 we set up the same calibration procedures as for the Trappes station. The data are also sent directly to the IPSL server. Operational radiosoundings are performed twice a day (00 UTC and 12 UTC) during the hurricane season (from mid-Nov to mid-Apr) and once a day the remaining of the year. All radio soundings are performed with Météomodem's M10 sondes and follow the procedure set up for the GRUAN.

1.6 New site introduction for Faa’a (Tahiti) and others (Frédéric Marin)

The Faa'a station is located in French Polynesia in the middle of the South Pacific. French Polynesia has 117 islands in an area the size of Europe. The radiosounding station is located on the largest island in this area (Tahiti island). The radiosounding station is located in the international airport area between the airport runways and the edge of the lagoon. Due to its geographical position, the Polynesian climate is tropical with a humid maritime type. It is characterized by heavy rainfall in the hot season, which often becomes light in the cool season. The rainy season begins in November and ends in April. December and January are the wettest months. Temperatures are warm but not excessive (annual average of 26°C at Faa'a).

Meteo-France started doing the first manual radiosoundings in Faa'a in 1957. The radiosounding station has been automated in October 2018. Two radiosounding per day: 00 UTC and 12 UTC all year round with M10 sondes. There is a GNSS station just a few metres from the radiosounding station which allows us to obtain hourly data from ZTD and to compute the quantities of atmospheric water vapour. The average altitude reached by these radiosondes is 22 km. The advantage of the site is that it is located in an area where there are few observations.

We hope to be able to install the necessary additional calibration procedures for GRUAN by the end of 2021 if the sanitary context allows it.

1.7 Update on ARM Sonde Activities (Evan Keeler)

The Atmospheric Radiation Measurement (ARM) user facility continued its fixed site balloon-borne soundings through 2020. The ARM group maintains three GRUAN sites. Radiosonde operations are managed by a mentor out of the Argonne National Laboratory. Evan Keeler has replaced Donna Holdridge as the radiosonde mentor and liaison to GRUAN. The ARM sites that are currently operating are:

- Southern Great Plains (Lamont, Oklahoma, USA) launching four manual radiosondes a day at regular synoptic intervals. This site is GRUAN certified;
- North Slope of Alaska (Barrow, Alaska, USA) launching four radiosondes a day at regular synoptic intervals with the Vaisala Autosonde platform. This site will be seeking certification in 2021;
- Eastern North Atlantic (Graciosa, Portugal) launching two manual radiosondes a day at regular intervals.

The ARM program is consistently seeking to meet the needs of the research community at these fixed launch locations. Several improvements have been identified and will be proposed in the 2021 calendar year. The ARM program will also be supporting several large campaigns in the coming year. ARM will provide four MW41 sounding platforms for the Tracking Aerosol Convection Interactions Experiment in South East United States (TRACER) campaign and one MW41 sounding platform for the Surface Atmosphere Integrated Field Laboratory (SAIL) campaign. The ARM facility also continues to launch balloons coincident with satellite overpasses for the JPSS and RIVAL field experiments.

SESSION 2 – NEW GRUAN DATA PRODUCTS AND FLASH UPDATES

2.1 GNSS-PW (Galina Dick, GFZ German Research Centre for Geosciences, Potsdam, Germany)

In this presentation an overview of the recent activities within the development of the GDP GNSS-PW at GFZ was given. The main directions of these activities towards certification of PW product are:

- Development of the Operational Data Center (ODC) at GFZ including the data monitoring;
- Establishing an automated hourly GNSS raw data flow and near real-time PW analysis
- Establishing a data flow to LC in Lindenberg;
- Adding of PW uncertainty estimation after Tong Ning algorithm to automated PW processing;
- Validation of ZTDs with different GNSS solutions;
- Validation of PW with RS;
- Monitoring of PW quality at GFZ.

The following links provide access to the results of comparisons with NWM ERA5 for GRUAN stations: ftp://ftp.gfz-potsdam.de/GNSS/products/nrttrop/MONITORING_IFS/ENAO_pic.jpg

The following GRUAN GNSS stations have been included into the automated PW processing chain: Graciosa (ENAO, GNSS equipment has been installed by GFZ in 2019), Tsukuba (TSK2), Neumayer (NMSH), Cabauw (CBW1), Ross Island (SCTB), Potenza (TITO), Lindenberg (LIN0, replacement of LDB0 in October 2020).

The following main points of future work have been presented:

- Interactions with sites on assistance for new instruments, initiation of the data flow and data processing: GFZ continues to support all GRUAN sites;
- GFZ continues negotiations/contacts with: Boulder (USA), Paramaribo (Suriname), Tenerife (Spain). Beltsville (USA) will be installed soon;
- GFZ will contact the new GRUAN sites Hong Kong and Dakar as well as following GNSS sites with GNSS: Trappes-Palaiseau, La Reunion;
- Reprocessing with the new PW uncertainty estimation will be continued for the whole time period 2011-2020, validation with RS and other collocated meteorological (WVR) and geodetic instruments (VLBI) will be performed;
- NetCDF format will be implemented at GFZ.

2.2 M10 GDP status: overview of organization and progress, correction and uncertainty, strategy of validation and results (Jean-Charles Dupont et al)

Since the last ICM11, the M10 GDP L1 and L2 are now in production for the Trappes-Palaiseau (TRP) and Reunion (REU) sites. Both sites use automatic radiosonde launchers (Meteomodem Robotsonde described in the Madonna et al. 2020) under the operation of Meteo France. Before each launch, a standard ground-check procedure is applied with a comparison (1) inside an ambient shelter for relative humidity and temperature, and (2) inside the SHC 100%RH.

Data flux is now organized with automatic transfers from operational sites (TRP and REU) to AERIS (CNRS data center, https://en.aeris-data.fr/?noredirect=en_GB) to convert (1) the 5 raw files into an unique well documented netcdf L1 file and next (2) the L1 files into the optimized M10 GRUAN Data Product (M10GP). Data are produced in netcdf file following the GRUAN Lead Center recommendations. Data files are under review.

Strategy of correction has been defined with Meteomodem Company, it includes radiative correction on temperature defined thanks to experimental results produced at Lindenberg. Tests in the new wind channel setup experiment have been done but results are not taking into account for this version. RH is corrected using time lags and radiative transfer model. Both temperature and RH included an ARL outlet correction, described in the technical document.

Validation of the L2 M10 GDP has been done in comparison with CFH and Maïdo Lidar from the Reunion Island (-21N; 55E). Results show very good consistence with references where differences have been found less than to 2 %RH compared to CFH results over the whole troposphere.

Now, M10 GDP and associate sites meet the six conditions to be GRUAN site in giving elements which are under review by LC.

2.3 Lidar (Thierry Leblanc)

TT-GB oversee the production and integration of ground-based remote sensing techniques MWR, FTIR, and lidar, in compliance with GRUAN best measurement practices. The composition of the new task team has now been finalized for 2021. Besides the co-chairs, it comprises 10 members representing the ground-based lidar, microwave and FTIR techniques (approximately 2 for each technique) at the GRUAN sites of Cabauw, ARM SGP, Boulder, Lindenberg, Potenza, Payerne, Ny-Aalesund, and Tenerife. The TT-GB liaison to the GRUAN LC is Michael Sommer. In 2021, the TT-GB will continue their work efforts to develop a GRUAN lidar and microwave product, and will re-visit potential contributions of the IR technique to GRUAN.

In 2020, the Global Lidar Analysis Software Suite (GLASS) data processor went from a development to a production stage. Test data from the Payerne, Ny-Aalesund, and Cabauw lidars were ingested, complementing many other lidars at non-GRUAN sites. Automated data transfer was set up between Payerne and the processing centre (JPL Table Mountain, CA). There has been no progress in the setup of automated data transfer from Cabauw and Ny-Aalesund. Homogenization of meta data (e.g., through LidarRunClient) requires dedicated manpower, not available at this time. It is planned to foster GRUAN LC involvement in the data production chain for 2021.

2.4 GRUAN Data product for Meisei iMS-100 & RS-11G radiosondes (Shunsuke Hoshino, JMA)

Meisei iMS-100 radiosonde has been used since 2017 at JMA's radiosonde sites including Tateno and Minamitorishima. The TU sensor of iMS-100 is common with former model, Meisei RS-11G radiosonde. But the validation of RS-11G-GDP.1 (Kobayashi et al., 2019) shows some issues especially in relative humidity (RH) observation, so the improvement of GDP processing algorithm for these two models. Major changes are (1) considering difference of time constant of RH sensor in absorption / desorption situation, (2) implementation of formulated hysteresis correction, (3) improvement of TUD (temperature-humidity dependency) correction with laboratory experiments and CFH observations, (4) using the EGM2008 geoid model for calculation geometric altitude instead of coarse iMS-100 original model (for iMS-100) and (5) trimming of profile when long-gap (> 3 minutes) in temperature.

GDP for iMS-100 (hereafter, IMS-100-GDP) are compared with RS92-GDP.2 using 55 dual sounding data since September 2017 to January 2020 at Tateno. The temperature of IMS-100-GDP is about 0.5 K lower than RS92-GDP.2 in stratosphere in daytime. The RH of IMS-100-GDP is about 1.8 %RH higher than RS92-GDP.2 below 200 hPa level and about 1.0 %RH lower above 30 hPa level. The pressure of IMS-100-GDP is 0.4 hPa lower than RS92-GDP.2 in lower troposphere. The geopotential height of IMS-100-GDP get 10 m higher than RS92-GDP.2 above 100 hPa level. The difference of pressure may be caused by difference of pressure at launch height between barometer at ground observation system (used in IMS-100-GDP) and pressure sensor of RS92. The difference of geopotential height above 100 hPa level may be caused by geoid height variance between geoid models.

Revised version of GRUAN-TD-5 and the article about intercomparison between IMS-100 and RS92-GDP.2 are in preparation and will be submitted in near future.

2.5 MWR (Nico Cimini)

Activities towards the establishment of a ground-based microwave radiometer (MWR) product for GRUAN have been resumed with the launch of the Task Team on Ground-Based Remote Sensing Measurements (TT-GB).

Two highly MWR-qualified scientists, new to GRUAN community though related to GRUAN sites, have been invited and agreed to join TT-GB: Maria Cadeddu (ANL, USA), MWR mentor for ARM, and Christine Knist (DWD, DE), responsible for MWR observations at GRUAN LC in Lindenberg.

Recent activities concerning MWR characterization include: (i) quantification of systematic uncertainty of atmospheric absorption models in the 20-30 GHz band (Rosenkranz and Cimini, TGRS, 2020) and 170-200 GHz (Koshelev et al., submitted to JQSRT, 2020), and (ii) continuous calibration monitoring through Observation minus Background (O-B) statistics.

In addition, two opportunities are coming up that should help the establishment of a GRUAN MWR product: (i) a MWR data & calibration center is planned within ACTRIS (Aerosols, Clouds and Trace gases Research Infrastructure), a long-term Research Infrastructure being established in Europe, and (ii) EUMETNET (European Met Service Network) will soon decide on the proposal to include MWR in their profiling programme E-PROFILE.

2.6 Ozone (Richard Querel)

The ASOPOS 2.0 report (Assessment of Standard Operating Procedures for OzoneSondes) will be submitted to WMO in December 2020. This report will form the basis of the GRUAN Ozonesonde data product document. The recommended best-practices and SOPS from the ASOPOS 2.0 report will be fully adopted by GRUAN. Their report includes peer-reviewed results and comprehensive descriptions of required data/metadata parameters and uncertainty budgets. The GRUAN ozonesonde data file format to be created will use a common naming convention aligned with the recommended ASOPOS fields. Some unique aspects of a "GRUAN" ozonesonde could be the recommendation that the site have a manufacturer independent ground-check, i.e. a UV photometer, for generating known amounts of ozone to test the ECC ozonesonde hardware before flight. The GRUAN Lead Centre already receives and stores raw ozonesonde data in its archive. The processing of ozonesonde data will be done by the Lead

Centre. During the upcoming year, a short document with GRUAN-specific content will be written, using the ASOPOS 2.0 report as background reference material.

2.7 Graw (Ruud Dirksen)

As successor to the DFM09, Graw has introduced the DFM17. The DFM09 has been deployed for various years at Singapore, before the site switched to RS41. With support of Graw, a contractor at Lindenberg (Bernd Stiller) is working on the development of a GRUAN data product for both models. Main new feature of the DFM17 is the heated RH sensor, and the absence of a protective cover. The process for developing the GRUAN data product for the Graw radiosondes is similar to that of the RS41 and the RS92, and builds on the experience gained with these. It involves laboratory testing to characterize the measurement errors and uncertainties and twin soundings with other radiosondes. The laboratory testing includes tests in SHC to investigate calibration accuracy of the T- & RH sensors at room temperature, investigation of the radiation induced temperature error in the dedicated radiation test facility, and characterisation of the time lag of the humidity sensor at low temperatures. The results of the characterisation are the basis for the development of correction algorithms for the GRUAN data processing. The laboratory testing has been concluded and analysis is ongoing. Following steps include, correction algorithms, analysis of comparison with RS92 & RS41, documentation. Aim is to have the dataproduct ready in 2021.

2.8 ASOPOS 2.0: Involvement GRUAN together with GAW-NDACC and IOC (Herman Smits)

A presentation was provided on this activity. Any outcomes/actions following the presentation are captured in Annex 2.

SESSION 3 – R-23 REPLACEMENT

3.1 Introduction – overview of situation regarding R-23 (Ruud Dirksen, DWD Lindenberg)

Nine GRUAN sites use R23 to operate CFH/FPH for the required monthly observations of water vapor profiles in the stratosphere. Currently the CFH/FPH is the instrument of choice for stratospheric water vapor observations, although alternatives instruments are in various stages of development (Skydew, PCFH, FLASH-B). The thermodynamic properties of R23 make it an ideal cryogen for chilled mirror instruments (as well as for large scale industrial refrigeration). However, because of its environmental impact (100-year CO2 equivalent of ~15000) its use is restricted or banned in the EU and Japan, and other countries are starting to impose restrictions as well. At this moment, only sites in the USA and Hong Kong are unaffected by restrictions on R23. To ensure continuity of their measurement program, sites have resorted to stockpiling R23. In search for a long-term sustainable solution, sites are testing alternative cooling methods, such as the ethanol/dry-ice mixture, or are even considering switching to instruments that operate without cryogen.

3.2 CFH cooling agent alternatives (Christian Rolf)

The current and future limitations due to national and international environmental regulations for the usage and purchase of cooling agent R23 (CFH-23) requires to find an alternative for the operation of the balloon-borne CFH instrument. The alternative has to be environmentally friendly, low cost, with easy provision, harmless, and good heat conduction (liquid). In our presentation we show our attempts at Forschungszentrum Jülich (Germany). First, we tested a liquid nitrogen (LN2) pressure vessel to operate the CFH instrument with LN2. The second more favourable alternative was found to be a slush out of Ethanol and dry ice (CO2). We tested this solution in a climate chamber and during several balloon flights and found a general good agreement between CFH operated with Ethanol/CO2 and the CFH with R23 (no bias). However, the CFH with Ethanol/CO2 shows a slower response time if strong cooling power is necessary mainly due to general warmer temperature and worse heat conduction in the cooling bath. It was found that there is some improvement necessary to increase heat conduction between CFH mirror and cooling bath. Further tests are necessary to show applicability under very cold conditions like at the tropical tropopause.

3.3 PCFH – Peltier Cooled Frost point Hygrometer (Teresa Jorge/Frank Wienhold, ETH Zurich)

We introduced the characteristics of the PCFH: twin instrument construction with shared electronics and communication with wider intake tubes than the CFH, a double stage Peltier element and cooling provided by ambient air through a heat sink, an optical detection scheme with a reference surface and 4 different temperature measurements with thermocouples per sub-unit besides the mirror temperature. Another novelty is the possibility to program the instrument with different controller schemes. Following, we introduced the different controller schemes used so far: 'characterization steps', 'temperature relay controller', 'reflex relay controller' 'bang-bang' and with 'bias update' and a 'proportional integral controller' (PI).

We then provided a list of the 17 flights performed in total since 2018. The flights started from Lindenberg, Payerne and Ny-Ålesund, for this outcome, we thanked the colleagues from DWD, MeteoSwiss and AWIPEV. Since August 2020, we started three flights from Zürich. As an outcome of all these flights, we concluded the thermal characterization of the PCFH, reached an established design for the double stage Peltier element, copper finger and heat sink. We see reproducibility of characteristic curves and understand the thermal behavior of the instrument.

We also showed results for the optical characterization of the PCFH and compared the frost point temperature measured by the PCFH with the frost point temperature measured by the CFH for two flights from Ny-Ålesund and with the frost point temperature calculated from the relative humidity measured by the I-met for two flight from Zürich. The instruments showed good agreement below 400 hPa. The disagreement above seems due to loss of sensitivity regarding the ice reflectivity on the mirror of the PCFH. Our next steps focus on increasing this sensibility through changes of the controller set point or redesign of the instrument's mirror.

3.4 Report on tests in Lindenberg (Ruud Dirksen)

Lindenberg observatory has been a test-bed in the search for stratospheric water vapor observations without R23, enabling several groups to perform tests soundings with their instruments. These include PCFH, Skydew and FLASH-B.

Testing with FLASH-B has shown that the instrument performs fine from a technical perspective. An unresolved issue is the fact that the instrument's calibration is not stable. A recent flight showed very good qualitative agreement with the CFH profile, but for quantitative agreement a posteriori adjustment of the calibration factor was necessary. In addition, we looked at alternative ways to cool the CFH. The first attempt resulted from a collaboration with the TU Dresden and involved using super-cooled ethanol. The volume of the cryogen container was increased to 700ml in order to augment thermal capacity. A copper-wire mesh was connected to the cold finger to increase the cooling power by improving the thermal contact. For the test-flight an ethanal liquid/ice mixture of -113.5C was used, a R23-operated CFH was flown on the same rig. The ethanol cooling worked up to 17km, above that altitude cooling power was insufficient to maintain the condensate layer. The CFH's PID controller is optimized for operation with R23, so that the ethanol-cooled CFH recorded smoother profiles. Furthermore, it was observed that it took several minutes to rebuild the condensate layer after the second heat pulse. This is attributed to the smaller cooling power of ethanol compared to R23.

Another test involved an ethanol/dry-ice mixture. This mixture has sufficient thermal capacity for ascent + descent. Similar to the super-cooled ethanol case it was observed that the recorded profiles are smoother, and that the recovery of the condensate layer was slower, although not as excessive as with super-cooled ethanol. The CFH's firmware performed additional diagnostic tests leading to deliberate oscillations in the mirror temperature in the stratosphere. In conclusion the test with ethanol/dry-ice looks very promising, but modifications to the CFH (PID controller, thermal conductivity) appear necessary.

3.5 Report on tests in Boulder (Dale Hurst)

Dale Hurst showed the results of a test flight at Boulder back in February 2020 using dry ice + ethanol (instead of R23) as the cryogen for the NOAA FPH. The water vapor mixing ratio profile in the upper troposphere and stratosphere demonstrated sufficient cooling power by the cryogen for the hygrometer mirror to reach frost point temperatures as low as -89°C. Further test flights have not yet been possible in 2020 at Boulder due to COVID-19, but it is planned to perform more tests in 2021, especially at Hilo, Hawaii, where frost point temperatures are even lower than over Boulder.

3.6 Status of the Meisei Skydew instrument (Takuji Sugidachi, Meisei electric co., Japan)

A Peltier-based digitally-controlled chilled-mirror hygrometer, named "SKYDEW", has been developed to measure atmospheric water vapor accurately. The SKYDEW instrument is environmentally-friendly and ease-to-handle in nature because this instrument does not use a cryogenic material to cool the mirror. Since 2011, we have conducted several lab test and test soundings more than 30 times at tropics and mid-latitude sites. During 2019 and 2020, SKYDEW had been improved for better cooling performance. Some test soundings show that the SKYDEW can measure atmospheric water vapor up to 29km without cryogen material. Currently, the data processing for the GRUAN Data Product of SKYDEW is being considered. The chilled-mirror hygrometer also has several uncertainty sources. Some uncertainties such as time lag effect are being investigated.

SESSION 4 – NEW SCIENCE

4.1 Understanding balloon-borne frost point hygrometer measurements after contamination by mixed phase clouds (Teresa Jorge, ETH Zurich)

This presentation addressed CFH contaminated measurements in the StratoClim balloon campaign dataset. This campaign took place during the Asian Summer Monsoon 2016/ 2017 at the southern slopes of the Himalayas in India and Nepal. We identified contamination as anomalously high-water vapor mixing ratios in the stratosphere. This happened in almost 20% of the flights carrying the CFH. We proposed as contamination mechanism the traverse of a mixed-phase cloud in the troposphere. Supercooled water in the cloud freezes on the surfaces of the payload and balloon, especially inside the intake tube. Later the ice layer inside the intake tube sublimates in the warmer and dryer stratosphere contaminating the water vapor measurement.

We focused our analysis on one of the contaminated profiles (NT011). We investigated the mixed-phase cloud in the profile. Although the saturation over water in this cloud is below one, through microphysics modelling, we concluded big super cooled water droplets could still be present. Smaller droplets would have evaporated and fed the ice crystals present. The pendulum motion of the payload below the balloon is a crucial aspect of our analysis. The pendulum motion means the intake tube ascends at an angle to the inlet flow, this angle facilitates the impact of super cooled droplets inside the intake tube. We developed a method to quantify this angle based of the effect of the pendulum motion in the ascent angle and circular movement on the horizontal plane of the payload.

We then used computational fluid dynamic (CFD) methods to evaluate the efficiency of the big droplets impact inside the intake tube, and the expected contamination in the stratosphere from different coverages of the inside of the intake tube with ice. There was agreement with the observed contamination for a 5 cm deep ice coverage inside the intake tube. With CFD methods, we also evaluated the balloon and payload as causes of contamination. We concluded the balloon could be responsible for contamination above 20 hPa, and that the intake tube prevents contamination from the payload.

4.2 Evaluation of Numerical Weather Prediction model uncertainty using the new RS41-GDP (F. Carminati and S. Newman, Met Office)

Numerical Weather Prediction (NWP) model-based validation of satellite instruments, although commonly used, is limited to the extent of the NWP model biases and uncertainties. Their characterisation is an active field of research and can be studied to first order as a function of latitude and height. Taking advantage of the new RS41 GCOS reference upper-air network (GRUAN) data product (beta version), profiles from five sites representative of five latitude bands: northern polar (Sodankylä), mid northern (Lindenberg), tropical (Singapore), mid southern (Lauder), and southern polar (Ross Island) latitudes, have been compared to the Met Office NWP model in radiance space. Top-of-atmosphere radiance simulations have been generated at frequencies used by the future microwave sounder (MWS) and infrared atmospheric sounding interferometer-next generation (IASI-NG) on the next generation of European polar-orbiting satellites Metop-SG A. The mission will provide atmospheric soundings of temperature, moisture and trace gases at unprecedented resolution and with a 0.25K design requirement of absolute radiometric accuracy for IASI-NG and less than 1K for MWS.

Taking GRUAN profiles as the truth and while ignoring the inter-channel correlation error and assuming that the uncertainty is correctly defined, we highlighted biases in the NWP fields particularly affecting the temperature channels at 657.5 and 696 cm-1 in the infrared and between 54.4 and 57.29 GHz in the microwave. At frequencies sensitive to humidity, the profiles are found in statistical agreement owing to the large NWP uncertainty. The statistical overall agreement, accounting for inter-channel correlation, however, shows that the total uncertainty (covariance of the difference NWP minus GRUAN) tends to be underestimated, especially in the tropics. This suggests that some aspect of the total uncertainty have been underestimated and/or overlooked (such as, for example, the uncertainty due to the model scale mismatch or the off-diagonal correlation terms of GRUAN covariance).

In summary, it is unlikely that NWP model will be able to detect small uniform biases within MWS and IASI-NG radiometric accuracy at frequencies sensitive to humidity, although NWP-based validation remains a useful tool to detect biases with geometrical (e.g. scan-dependent bias) or geographical (e.g. day-night bias) origins. For some temperature-sensitive frequencies, biases of the order of the instruments radiometric accuracy should be detectable, noting however that comparison with real satellite observations will bring additional sources of uncertainty driving the total uncertainty closer to the instruments' accuracy requirements.

4.3 Empirical estimation of random uncertainties and error covariance matrices from radiosondes, radio occultations and model forecast. (Joe Nielsen)

Tropospheric humidity is retrieved from refractivity profiles, obtained by GNSS radio occultation measurements. The ROM SAF 1D-Var algorithm used to disentangle temperature and specific humidity in the refractivity signal depends on the refractivity uncertainty and on the vertical uncertainty correlations, expressed in the refractivity error covariance matrix (R). In this presentation it is demonstrated that it is possible to estimate the full R-matrix, by using collocated refractivity profiles from 3 independent datasets, GRUAN RS92, ERA-I and radio occultations from Metop and COSMIC missions. The method used is equivalent to the so called "3-cornered hat" method, which has been generalized here to include correlations. The results confirm that refractivity uncertainty in the lower stratosphere is close to the 0.2%, currently assumed in the ROM SAF 1D-Var configuration. In the troposphere the R-matrix estimate suggests that a considerable deflation of the current R, by a factor 2-3, can be justified.

4.4 Understanding the quality of radiosonde descent data (Bruce Ingleby et al)

Radiosonde descent data can be obtained at little extra cost once the ascent has been made. Radiosonde descent reports (a test product) have been monitored in the operational ECMWF system since June 2019 and in June 2020 ECMWF started assimilating the profiles below 150 hPa from German stations using Vaisala RS41 radiosondes. This follows improvements in understanding the factors affecting the quality of descent data.

At upper levels descent profiles exhibit a warm bias relative to ascent profiles and the forecast model. The descent rate is variable, with a strong association between increased descent rate and an increased temperature bias, probably due to frictional heating. Using parachutes and pressure sensors, the German radiosondes show very similar tropospheric temperature fit to the ECMWF model between ascent and descent. Radiosonde descents without parachutes and pressure sensors show apparent temperature biases of up to about +0.5 K in the troposphere – due to an accumulated bias in the derived pressures during descent. The pressures could be improved using an estimate of the descent temperature biases.

Descent winds show a closer fit to ECMWF model profiles than the ascent winds. For most flights, the raw descent winds show reduced high frequency variability than the ascent winds; this could be mainly due to pendulum motion below the balloon during ascent. The Vaisala processing includes a time filter to remove/reduce pendulum motion, which is currently applied in the same way to descent winds and may over-smooth them.

4.5 Stratospheric Aerosol monitoring (Greg Frost)

A presentation was provided on this activity. Any outcomes/actions following the presentation are captured in Annex 2.

4.6 Uncertainties (Tom Gardiner)

Following a short summary of some of the key metrological methods and terms relevant to atmospheric measurements the talk focussed on a traceability and uncertainty assessment process that has been developed over the last few years. This process provides the current best estimate of uncertainty contributions to a particular measurement product and their associated correlations, as well as identifying gaps in the current knowledge of uncertainties. The outputs from the process provide the underlying information for different options for uncertainty reporting, driven by user needs, but earlier work did not resolve how to report correlation in overall uncertainty.

Recent work has focussed on reporting uncertainty on different timescales as a simple way for different users to identify the most relevant uncertainty for their application. Examples were provided of such an uncertainty assessment for GRUAN RS92 data from Lindenberg. The next steps are to implement the process for the complete GRUAN RS92 dataset (as part of Copernicus Climate Change Service activities) and to prioritise the potential extension to other GDPs.

4.7 Results from the CONCIRTO Balloon campaigns at Maïdo Observatory (Stephanie Evan)

A presentation was provided on this activity. Any outcomes/actions following the presentation are captured in Annex 2.

SESSION 5 – RS41 DATA PRODUCT

5.1 RS41 GRUAN Data product (RS41-GDP) – version 1 (Michael Sommer, GRUAN LC, DWD Lindenberg)

In this presentation, the final state of developed general GRUAN processing system for radiosonde data (GDPS) and the GRUAN data product for the RS41 radiosonde was shown. In the first part the schema of the GDPS was explained and the possibilities and advantages were named. Afterwards the scheme of the specific processing of the RS41-GDP (BETA.1) was shown with some examples, e.g. control of the input data, automatic analysis of ground check data (SHC), GPS uncertainty, radiation correction of temperature, time-lag correction of humidity, uncertainty determinations. Several changes were pointed out which were implemented after release of version BETA.1 and current state of RS41 technical document (TD) was presented. A compact time schedule was defined for the finalization and certification of the RS41-GDP.1. The certification process is planned for second quarter 2021. The current version RS41-GDP-BETA.1 was processed for all GRUAN stations for the period 2019-08-01 until now (2020-11-20), and in addition for all comparison flights with RS92 since 2014.

5.2 Position uncertainties in the RS41 GDP (Tzvetan Simeonov)

The presentation is focused upon a revision of all uncertainties related to positioning of the RS41 radiosonde. The foundation is laid through the experimental determination of the uncertainties of the coordinates of the radiosonde. Based on the horizontal coordinate's uncertainties, the uncertainties for the wind components are determined. The uncertainty of pressure from GPS height is derived from the altitude uncertainty of the radiosonde position. The coordinate uncertainty estimates are also used for the determination of ventilation uncertainties in the radiation corrections, as well as for the estimation of the IWV uncertainty. The methodology for positioning uncertainty derivation is universal and is applicable to any other makes of radiosonde.

5.3 GRUAN radiation correction for RS41 temperature measurements (Christoph von Rohden, GRUAN Lead Centre, Meteorological Observatory Lindenberg, Germany)

A laboratory set-up for measurements of the solar radiation induced temperature bias for the RS41 radiosonde was built. It was designed following the idea to simulate the conditions during a real flight as closely as possible. Light from a source with a sun-like spectrum was applied to the sensing element of a test sonde, and the radiation-induced temperature excess was derived. The structure works according to the principle of a wind tunnel, and the sonde was installed in it such that flight conditions in terms of air flow and illumination were replicated. Pressure, air speed, radiance, and incident angle of light were systematically changed to simulate height, ventilation, solar radiation, and sun elevation angle in real soundings. To account for orientation changes that are connected with the sonde spinning, the test unit was continuously rotated, and the temperature response evaluated as temporal average over these rotations. In conjunction with radiation profiles that were simulated for each sounding using a radiation transfer model, a point-by-point temperature correction was derived from the experimental results including uncertainty estimates, which was integrated into the operational GRUAN data processing for the RS41 radiosonde.

5.4 Accuracy of Vaisala RS41 and RS92 upper tropospheric humidity compared to satellite hyperspectral infrared measurements (Bomin Sun – IMSG at NOAA/NESDIS/Center for Applications and Research (STAR), College Park, Maryland, USA)

This study assesses RS41 and RS92 upper tropospheric humidity (UTH) accuracy by comparing with Infrared Atmospheric Sounding Interferometer (IASI) upper tropospheric water vapor absorption spectrum measurements. Using RS41 and RS92 soundings at GRUAN and DOE Atmospheric Radiation Measurement (ARM) sites, collocated with cloud-free IASI radiances (OBS), we compute Line-by-Line Radiative Transfer Model radiances for radiosonde profiles (CAL). We analyse OBS-CAL differences from 2015 to 2020, for daytime, night-time, and dusk/dawn separately if data is available, for standard RS92 and RS41 processing, and RS92 GRUAN Data Processing (GDP; RS41 GDP is in development).

We find that daytime RS41 (even without GDP) has ~1% smaller UTH errors than GDP RS92. RS41 may still have a dry bias of 1-1.5% for both daytime and night-time, and a similar error for night-time RS92 GDP, while standard RS92 may have a dry bias of 3-4%. These sondes humidity biases are probably upper limits since "cloud-free" scenes could still be cloud contaminated. Relative differences between RS41 STD and RS92 GDP obtained from the radiance analysis, are consistent with their differences obtained directly from the RH measurements.

5.5 NOAA Products Validation System (NPROVS) feedback on GRUAN Uncertainty (RS92 to RS41) and RIVAL (Tony Reale)

This report focused on the recently concluded joint NOAA / DOE-ARM / GRUAN Radiosonde Inter-comparison and VALidation (RIVAL) campaign providing dual Vaisala RS92/RS41 radiosonde targeted with NOAA-20 satellite overpass and included the storage of satellite sensor (SDR) data along with derived atmospheric soundings. RIVAL compiled over 150 collocations from the three ARM sites over the 2-year (Feb 2018-Feb 2020) campaign and final dataset preparation and delivery (LC) are underway. A remaining activity is to replace the RS41 vendor version with the recently available RS41 GRAUN data product (Beta).

Samples of RS41 (Beta) uncertainty parameter vertical plots were also shown including comparisons against dual RS92 uncertainties. Results included a tendency/concern that GRUAN uncertainty estimates (for RS92) appear elevated at ARM sites. The RIVAL campaign initiated routine (NPROVS) procedures to append SDR for all GRUAN radiosondes within 1 to 2 hours of a MetOp or NOAA polar satellite overpass with consideration to target GNSS (GRAS and COSMIC-2 …). Procedures to routinely target polar and GNSS at GRUAN sites was promoted as desirable particularly in a Global Space-based Inter-Calibration System (GSICS) context of satellite sensor (and RT model) monitoring. The report concluded with a summary of balloon burst heights typically achieved across GRUAN, currently about 30% reach 10 hPa and benefits (for RT models calculations) of achieving up to 50% at 5 hPa.

5.6 Propagation of GDP uncertainties with Data Visualization and Analysis Software (DVAS) (Frederic Voigt, MeteoSwiss, Payerne, Switzerland)

The next Upper-Air Instrument Intercomparison is scheduled to take place at Lindenberg (D) in 2021. For the field campaign, GRUAN Data Products (GDPs) will be used as working measurement standards, such that 3 GDPs will be included in each multi-payload flights. DVAS is an open-source Python software currently under active development at MeteoSwiss. This code, purpose-built to handle the data analysis of intercomparison campaigns, is hosted on Github and is expected to be made-public in Q2 2021. The development of the "data analysis" pillar of DVAS revealed non-trivial challenges related to the statistical combination of GDPs, namely: 1) the poor compatibility of GDP uncertainty schemes, and 2) the correlation of the "uncorrelated" uncertainties for existing GDPs, in the case of dual-flights.

It is a core goal of DVAS to correctly propagate uncertainties throughout the analysis process. However, the fact that existing (and upcoming) GDPs use different uncertainty schemes implies that the "correctness" of error propagation by DVAS, when combining GDPs, will be limited by the GDP(s) providing the least amount of details on its measurement errors. For the "uncorrelated" errors specifically, dual-flights reveal that these error terms are in fact correlated at a significant level in the case of multi-payload flights. This is a direct consequence of the existing error estimation algorithm which is sensitive to real atmospheric fluctuations on timescales of 10-15s. This also implies that uncorrelated uncertainties for the existing GDPs are being significantly overestimated. A careful revisit of the underlying algorithm thus appears warranted to improve the quality of existing (and upcoming) GDPs, also when used as working measurement standards for intercomparison campaigns.

5.7 Calibration of RS41 humidity sensors using upper-air simulator at KRISS (Sang-Wook Lee, Korea)

Calibration of humidity sensors of commercial radiosondes is demonstrated using the upper-air simulator (UAS) at Korea Research Institute of Standards and Science (KRISS). The operation principle of the UAS adopts a two-temperature humidity generation mode in which the temperature of the saturator and the test chamber is independently and automatically controlled. The operation range is -70 °C – 20 °C in temperature, -80 °C – 20 °C in dew/frost-point temperature, and 0 %rh – 100 %rh in relative humidity. The total combined uncertainty of the humidity generation of the UAS is within 1 %rh at the coverage factor k = 2. As a proof of concept, a RS41 humidity sensor is calibrated. Consequently, the maximum difference between RS41 humidity measurement and the UAS reference is about 3 %rh at -67 °C and is gradually decreased to about 1 %rh as the temperature is elevated up to 21 °C. The repeatability of a single RS41 unit and the reproducibility of three different RS41 units are 0.5 %rh and 0.9 %rh, respectively, in terms of standard deviation. The uncertainty of a RS41 humidity sensor is found to be 0.9 %rh – 1.3 %rh (k = 2) at -67 °C.

5.8 Interpolation uncertainty of Vaisala RS41 temperature profiles (Alessandro Fasso)

Although temperature readings made by Vaisala RS41 radiosondes at GRUAN sites (www.gruan.org) are given at 1 s resolution, for various reasons, missing data are spread along the atmospheric profile. Hence, linear interpolation is useful to fill the gaps in GRUAN Data Processing. This presentation considers interpolation uncertainty, using a statistical approach to understand the consequences of substituting missing data with interpolated data.

In particular, a general frame for the computation of interpolation uncertainty based on a Gaussian process set-up and an extensive cross-validation based on the block-bootstrap technique are developed. This gives statistical results about interpolation uncertainty at various GRUAN sites and for various missing gap lengths.

Using the root mean square error, it is found that, for short gaps, with an average length of 5 s, the average uncertainty is less than 0.10 K. It increases up to 0.35 K for an average gap length of 30 s and up to 0.58 K for a gap of 60 s. It is concluded that this approach could be implemented in a future version of the GRUAN data processing.

5.9 First analysis of RS92-RS41 GDP intercomparisons (Ruud Dirksen, DWD Lindenberg)

Data from 945 RS92-RS41 twin soundings from the GRUAN data base were used to compare the GRUAN data product for the RS41 to RS92-GDP and to the manufacturer-processed data (EDT). The data from sites from different climate regions make sure that the range of solar elevation angles is adequately covered. Even for elevation angles close to 90 degrees sufficient measurements are available to enable analysis of the data. First results of the analysis show for Temperature:

- RS92GDP warmer than RS41GDP (up to 0.5K) above 25 km (day)
- RS41GDP warmer than RS41EDT (up to 0.2K) above 15 km (day)

There is some dependence on latitude, but this occurs predominantly in the troposphere. The analysis of the humidity profiles shows that:

- RS41 data are moister than RS92 data, both for GRUAN and manufacturer-processed data.
- Some RS41GDP – RS41EDT differences in UTLS region. This is attributed to differences in the time lag correction.

Other corrections are not applied. A radiation correction for the humidity measurements like that for the RS92 is not necessary, since the temperature of the humidity is directly measured by an integrated temperature sensor. Further analysis will e.g. look at the influence of the solar elevation angle on the temperature differences between the data products. Furthermore, CFH measurements will be used to independently assess the uncertainty of the RH data.

ANNEX 1: AGENDA

Session 1 – Site presentations (Monday 16 November) / Chair(s): Marion Maturilli & Dale Hurst

1-1	State of the network	Ruud Dirksen
1-2	Overview GRUAN data flow	Michael Sommer
1-3	Update on AirCore flights at Sodankylä	Rigel Kivi
1-4	New site introduction for Hong Kong	Olivia Shuk-ming Lee
1-5	New site introduction/update for Trappes and Reunion	Jean-Charles Dupont
1-6	New site introduction for Faa'a (Tahiti) and others	Frédéric Marin
1-7	Update on ARM GRUAN	Evan Keeler
1-8	Key common challenges	Chairs

Session 2 – New GRUAN data products (Tuesday 17 November) / Chair(s): June Wang

2-1	GNSS-PW	Galina Dick
2-2	Modem M10 GDP	Jean-Charles Dupont
2-3	Lidar	Thierry Leblanc
2-4	Meisei IMS-100 (& RS11G)	Shunsuke Hoshino
2-5	MWR	Nico Cimini
2-6	Ozone	Richard Querel
2-7	Graw	Ruud Dirksen
2-8	ASOPOS 2.0: Involvement GRUAN together with GAW-NDACC and IOC	Herman Smits

Session 3 – R-23 replacement (Wednesday 18 November) / Chair(s): Ruud Dirksen

3-1	Introduction – overview of situation regarding	Ruud Dirksen
3-2	Results of CFH test flights with ethanol/dry ice	Christian Rolf
3-3	The development of the Peltier-based CFH (PCFH)	Teresa Jorge/Frank Wienhold
3-4	Report on tests in Lindenberg	Ruud Dirksen
3-5	Report on tests in Boulder	Dale Hurst
3-6	Status of the Meisei Skydew instrument	Takuji Sugidachi

Session 4 – New science (Thursday 19 November) / Chair(s): Peter Thorne

4-1	Understanding balloon-borne frost point hygrometer measurements after contamination by mixed phase clouds	Teresa Jorge
4-2	Evaluation of Numerical Weather Prediction model uncertainty using the new RS41-GDP	Fabien Carminati
4-3	RO (TBC)	Joe Nielsen
4-4	Understanding the quality of radiosonde descent data	Bruce Ingleby
4-5	Stratospheric Aerosol monitoring	Greg Frost
4-6	Uncertainties	Tom Gardiner
4-7	Results from the CONCIRTO Balloon campaigns at Maïdo Observatory	Stephanie Evan

Session 5 – RS41 data product (Friday 20 November) / Chair(s): David Smyth

5-1	RS41 GRUAN Data product – version 1	Michael Sommer
5-2	Position uncertainties in the RS41 GDP	Tzvetan Simeonov
5-3	RS41 solar radiation correction – laboratory experiments and implementation in the GRUAN data product	Christoph von Rohden
5-4	Discussion	
5-5	Accuracy of Vaisala RS41 and RS92 upper tropospheric humidity compared to satellite hyperspectral infrared measurements	Bomin Sun
5-6	NPROVS feedback on GRUAN uncertainty (RS92 vs RS41) using RIVAL	Tony Reale
5-7	DVAS analysis software for radiosonde intercomparisons	Frederic Voigt
5-8	Calibration of RS41 humidity sensors using upper-air simulator at KRISS	Sang-Wook Lee
5-9	Interpolation uncertainty of Vaisala RS41 temperature profiles	Alessandro Fasso
5-10	First analysis of RS92-RS41 GDP intercomparisons	Ruud Dirksen

ANNEX 2: SUMMARY OF PROGRESS ON ACTIONS FROM ICM-11 AND LIST OF ACTIONS

		Completed	In Progress	Unaddressed
Total Actions				
35		**13 (37%)**	**20 (57%)**	**2 (6%)**
- High Priority				
4		**1 (25%)**	**3 (75%)**	
- RS92-RS41				
4		**1 (25%)**	**3 (75%)**	
- New GRUAN Data Products				
7		**1 (14%)**	**5 (72%)**	**1 (14%)**
- Other				
20		**10 (50%)**	**9 (45%)**	**1 (5%)**

No.	Action	Responsibility	Status
High Priority Actions			
HP1	Lead Centre to complete production of first full version of RS41 GDP. Note that LC should reach out for help â€“ 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.	RS41-GDP Beta has been released for testing. Remaining to be done: Complete TD. Current draft includes sections on RH time-lag, radiation experiments and radiation correction. Implement updates in processing (e.g. handling of uncertainties). Additional updates depending on feedback of beta-testers. Release of Version 1 and its certification.
HP2	Finalize first draft of GRUAN radiosonde foundational technical document to cover the general instrument-independent aspects.	TT Radiosondes and Lead Centre	Not much progress, priority given to development of RS41-GDP. Draft to be forwarded to the group at the appropriate time for further feedback. Commence search for potential co-authors (and for individual sub-chapters).

HP3	ARL (Automatic Radiosonde Launcher) 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	Paper published in AMT. Lead Centre need to make recommendation to WG on whether to now release the historical ARL data as an additional data stream. Otherwise the juxtaposition with releasing ARM processed data looks odd now that the paper shows broad equivalence between manual and ARL data - no more distinct than ARM is from other streams.
HP4	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	"Quality Task Force" group created and discussions started. Discussions taking place on how to deal with missing data. Action needs to be carried over.
RS92 to RS41 transition actions			
A1	Community approach 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	Submitted 2019, published Geosci. Instrum. Method. Data Syst. 2020.
A2	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.	Draft TN written. Sample NPROVS dataset for a RIVAL parallel sounding at SGP will be made available for GRUAN to assess. Suggestion is to use this test case to further discussions on how to move forward. Suggestions for making the sounding data available and easily acquirable for the community are being discussed. Also, how to treat redundant satellite data and let users know which dual soundings are associated with satellite overpass and / or GNSS-RO occultations.

A3	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	Updates received. Presentations on some of these aspects were given at ICM-12.
A4	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)	Alessandro and Tony liaising to perform a synthesis assessment of the differences between the two manufacturer processed versions. Bomin leading this; status uncertain.
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)	JMA and Meisei colleagues have decided the details of GDPv2, and have started writing the updated TD for it. LC to follow up on IMS-100.
B2	Take steps necessary to further develop the Modem product (TD completion, uncertainty characterisation, papers); update to be given at ICM-12.	TT Radiosondes (Modem)	Modem have visited LC and a draft is prepared and a paper published. TD needs to be discussed.
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	All necessary steps completed. LC have recommended certification.

B4	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	ASOPOS 2.0 (Assessment of Standard Operating Procedures for Ozone-Sondes) published. Ozonesonde GDP being considered in this context. Potential options: (1) providing ASOPOS to make it GRUAN-quality? (2) collaborating with ASOPOS to develop our own product?
B5	TT-AM to further progress the MWR product and present on progress at ICM-12.	TT-AM	New TT reported some progress at 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	Progress outlined at ICM-12 but as yet still no data stream owing to resource and covid-19 related issues.
B7	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	No update. Most effort has been on the R23 replacement issue understandably which is more pressing. Needs to be carried over to ICM-12 action items list.

Remaining Actions			
C1	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 split into TT-GB (Thierry and Nico) and TT-SAT (Lori and Axel). TORs (including members) need to be finalised. ToRs can be seen as BaU activity so no need to raise as an ICM-12 action.
C2	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	TN-9 published. Generic password being used. https://www.gruan.org/documentation/gruan/tn/gruan-tn-9. Not all GRUAN sites have yet uploaded their site photos. Action about sites uploading photos to be carried to ICM-12 action item list.
C3	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.	WG Chairs; Lead Centre	Stations due now: Cabauw; Beltsville Target stations status: Tenerife - application with Tenerife, to respond to LC queries. Nudge Miguel Hernandez. Macquarie Island - status needed (and of Australian sites in general) Additional: Barrow - package sent. Nudge Martin Stuefer. Carry over as new action item?
C4	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	Investigation started into the possibilities to use PANGAEA as a data repository for GRUAN. GRUAN data are now publicly available in the Copernicus Climate Data Store (CDS) with all the documentation needed to support the data usage: https://cds.climate.copernicus.eu/cdsapp#!/dataset/insitu-observations-gruan-reference-network?tab=overview Further dedicated discussion to occur on this topic.

C5	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	Progress has been made in installing hardware at additional sites and starting data flow. GFZ has been working with sites.
C6	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	Synthesis of results from sites survey (e.g. obtaining cryogen, balloon burst height, concerns over payload weight, etc.) sent to LC for evaluation. Subsequently circulated to TT-Sites and some aspects were discussed at ICM-12.
C7	Progress to finalization of an explicit strategy regarding which data can be released to whom and get signed off by sites and WG.	LC, TT Sites, WG	First draft TN-10 circulated to WG co-chairs. Need to finalise the strategy regarding which data can be released to whom (e.g. for alpha / beta etc releases) means this should be carried over as an ICM-12 action and possibly revised.
C8	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	Service is up and running. Next step - get RO predictions from non-EUMETSAT satellites. Discussion of this topic has been initiated by Axel von Engeln.

C9	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	Completed. Full GRUAN file archive (raw data + data products of all levels) have been backed-up, and an operational (daily) backup process has started.
C10	Develop a white paper on uncertainty quantification and presentation options for possible submission for publication.	TT-Scheduling	Update presented at ICM-12, Thursday 19 November (new science session). Next steps: Planning to implement for the complete GRUAN RS92 dataset under C3S. Discuss potential extension to other GDPs. Write up for potential publication Carry over action to ICM-12 action items list?
C11	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	Writing outline of paper initially, to circulate to Ruud and Richard in the first instance. Inputs received from Ruud and Richard (& Peter).
C12	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	This is covered by existing LC preparation of the certification package for GNSS-PW. Develop into a journal paper in e.g. AMT. Jonathan Jones: Consider writing up comparison/analysis; to bring up in the GNSS TT. Follow-up action required?

C13	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)	We may also need to include TT Sites and LC on this (as operational sites & operational radiosonde software packages usually have been collecting this type of information for many years)? Need to carry over to ICM-12 actions and clarify?
C14	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	LC checking with Sterling, they have a lot of experience with different rig types. Need to recast and retain or does this get dropped?
C15	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	Presented at ICM-12: "Understanding the quality of radiosonde descent data". Working on publication. Is there any follow-on action required here?

C16	TT radiosondes to progress an analysis of the various benefits of high-altitude attainment 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	Discussions within the wider WG taking place. By early January 2021 produce a draft which can be reviewed internally by GRUAN-related colleagues. New action on possible TD or paper required?
C17	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 ICM12.	TT radiosondes, LC	Descent and ascent winds discussed at ICM-12 as part of presentation "Understanding the quality of radiosonde descent data" (Bruce Ingleby). Uncertainty in winds amongst the issues presented as LC update for RS41 product.
C18	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 accessibility 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	Garnered more details on parallel soundings, such as types, X-X, X-Y. Several such flights are now available via LC but still a concern they may not be entirely complete.

C19	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	Presentation at ICM-12 on RS41 solar radiation correction: laboratory experiments and implementation in the GRUAN data product. Very preliminary first draft of the paper "INRiM-Potenza on the lab characterization of RS41-92" on hold until lab entry is permitted. Follow on action required?
C20	Review and refresh generic power point, create generic poster, encourage presentations at relevant conferences.	David Smyth, WG, LC	Material is currently very radiosonde-oriented; other techniques are only represented with photos (lidar, gnss, mwr, wind profiler). Balancing content is key, as well as addressing text. Powerpoint and poster being addressed in the first instance. Action to be carried over.

ANNEX 3: ACTIONS FROM ICM-12

High priority:

	Description	Activity (s)	Responsibility	Date
HP1 (a)	**Development of RS41-GDP.1**	Milestone in the development of the first full version of RS41 GDP, which is to be certified by working group June 2021. Release of version BETA.2	Lead Centre	Dec 2020
HP1 (b)	**Development of RS41-GDP.1**	Milestone in the development of the first full version of RS41 GDP, which is to be certified by working group June 2021. Submit paper (describing radiation temperature correction)	Lead Centre	Mar 2021
HP1 (c)	**Development of RS41-GDP.1**	Milestone in the development of the first full version of RS41 GDP, which is to be certified by working group June 2021. Finalize TD (for review)	Lead Centre TT-Radiosondes (review)	Mar 2021
HP2	**Radiosonde fundamental documentation**	Finalize first draft of GRUAN radiosonde foundational technical document to cover the general instrument-independent aspects. Including dual or complex ascents guidance.	Ch von Rohden (LC) TT Radiosondes Lead Centre	By ICM-13
HP3	**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.	Tzvetan Simeonov (LC) + Ad-hoc group members (QTF)	TN by ICM-13

RS92-RS41 transition items:

	Description	Activity (s)	Responsibility	Date
A1	**Parallel soundings database augmentation with ancillary data**	Augment parallel soundings of RS92-RS41 with 'ancillary' measurements (CFH, FPH, lidar, MWR, cloud observations (incl. BSRN) within +/-2 hours).	TT-GB; TT Sites; WG Chairs; Lead Centre.	TN completed Feb 2021 Data submissions from sites by ICM-13
A2	**Satellite data collocations with RS92/41 pairs**	TT-SAT to provide collocations with the historical RS92-RS41 payload ascents for a range of relevant polar orbiter and radio occultation measurements.	TT-SAT; Lead Centre	LC to provide list of target locations / times by Feb 2021 Data to be provided to LC by TT-SAT by ICM-13

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-13. Reports to be made available a month prior. Consideration of submission of reports as peer-reviewed literature.	RIVAL team; WG Chairs; ad-hoc members; Lead Centre	Presentations at ICM-13

New GRUAN data products:

	Description	Activity (s)	Responsibility	Date
B1	**Maintain status of GDPs**	LC to revised the status of GDPs under development https://www.gruan.org/data/data-products/development-status add a column "Actions"), maintain in a timely fashion and report on this at ICM-13. Update quarterly, make accessible via website.	Lead Centre; GDP development leads	Report at ICM-13 Initial site available by March 2021 and updated quarterly thereafter
B2 (a)	**Development of Meisei Data product**	Milestone in the development of the GRUAN Dataproducts for RS-11G (v2) and iMS-100 (v2), which is to be certified by the Working Group by June 2021. Data stream in Beta mode.	JMA; Meisei; TT-Radiosondes	Jan 2021
B2 (b)	**Development of Meisei Data product**	Milestone in the development of the GRUAN Dataproducts for RS-11G (v2) and iMS-100 (v2), which is to be certified by the Working Group by June 2021. Complete TD for review.	JMA; Meisei; TT-Radiosondes	Mar 2021
B2 (c)	**Development of Meisei Data product**	Milestone in the development of the GRUAN Dataproducts for RS-11G (v2) and iMS-100 (v2), which is to be certified by the Working Group by June 2021. Submit paper.	JMA; Meisei; TT-Radiosondes	Apr 2021
B3 (a)	**Development of M10 Data product**	Milestone in the development of the GRUAN Dataproducts for Modem M10 Data stream in Beta mode.	IPSL; Modem; TT-Radiosondes	Feb 2021
B3 (b)	**Development of M10 Data product**	Milestone in the development of the GRUAN Dataproducts for Modem M10 **Finalize** the TD for review.	IPSL; Modem; TT-Radiosondes	May 2021
B3 (c)	**Development of M10 Data product**	Milestone in the development of the GRUAN Dataproducts for Modem M10 Complete comparisons of Modem-M10 to **RS92**/41.	IPSL; Modem; TT-Radiosondes	Jun 2021
B4	**Ozonesondes GDP progression**	A short document with GRUAN-specific content will be written, using the ASOPOS 2.0 report as background reference material.	Richard Querel; WG Chairs	By ICM-13

B5	**Microwave Radiometer GDP progression**	Review status of MWR GDP TD by new TT GB members. Update MWR GDP TD and make progresses on MWR GDP.	TT GB; Nico; Maria; Christine; Fabio; Gianni	Update at ICM-13
B6	**Lidar GDP progression**	Report on beta testing outcomes and progress of a v1 data stream at ICM-13. If beta testing shows no issue, then aim to have finalized TD and be in a position to certify one or more initial lidar data streams.	Thierry Leblanc; Arnoud Apituley; Fabio Madonna; TT-GB	Update at ICM-13
B7	**Frostpoint hygrometer GDP progression**	Provision of update on progress towards a GDP for frostpoint hygrometers covering at a minimum: 1. whether a single statistical approach can be applied to all frostpoint models, especially for uncertainties 2. questions around the vertical averaging and uncertainty analyses of Voemel et al raised at ICM-11.	Dale Hurst; Ruud Dirksen; Takuji Sugidachi	Update at ICM-13

Other Actions:

	Description	Activity (s)	Responsibility	Date
C1	**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. LC: Continue reminding sites to upload quarterly (including those who have already)	TT Sites; Lead Centre; GCOS Secretariat	All sites to have uploaded at least initial set of photos by end of March 2021
C2	**Usage of GRUAN data**	Further develop ideas around the appropriate usage and citation metrics of GRUAN data including appropriate acknowledgment to sites and research institutions. (CDS only acknowledges GRUAN, not research institutes / stations).	WG; TT sites	Instigate measures as per discussions and further update progress at ICM-13.

C3	**Data Policy**	Progress to finalization an explicit strategy regarding which data can be released to whom and get signed off by sites and WG.	Lead Centre; TT Sites; WG	TN completed, reviewed by WG and TT sites and published by May 2021
C4	**Uncertainty terminology and presentation in GRUAN products**	Develop a white paper on uncertainty quantification and presentation options for possible submission for publication. Next steps: • Planning to implement for the complete GRUAN RS92 dataset under C3S. • Discuss potential extension to other GDPs. Write up for potential publication.	TT-Scheduling	Draft paper available for review by March 2021
C5 (a)	**Standard Humidity Chamber**	Paper to justify the use of the SHC in terms of the data quality and the benefits and including need for standardization of operating procedures. TN to describe procedural requirements (e.g. operational procedure; quality of the applied references in the SHC).	Richard Querel; David Smyth; TT-sites; Lead Centre	First draft outline of paper Q2 2021
C5 (b)	**Manufacturer-independent ground-check**	Define how to treat the results of the manufacturer-independent ground check in the GRUAN data processing and the subsequent QA/QC of the GDP. Relevant parameters: RH, Temperature, pressure (if available).	Lead Centre; QTF; TT-radiosonde	TN by ICM-13

C6	**Standardizing cloud observations / reporting**	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 and the results of the survey into site issues identified (ICM-11 Action C6, closed).	TT-Radiosonde; TT Sites; TT SAT; Lead Centre	Update at ICM-13
C7	**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.	TT Radiosondes; IPET-OSDE	Draft report Feb 2021
C8	**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 accessibility 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).	Audit of sites parallel measurements completed March 2021 Available parallel launches submitted to LC by ICM-13
C9	**Refresh of presentation materials**	Review and refresh generic power-point, create generic poster, encourage presentations at relevant conferences.	David Smyth; WG; Lead Centre	Available by ICM-13

C10	**Silent stations**	WG, LC and secretariat to propose a review mechanism for retention of sites which remain silent and never progress to certification. What would be the criteria and process by which eventual removal as candidate sites may occur? How could they be encouraged?	WG-GRUAN; Lead Centre; GCOS Secretariat	Proposal available by ICM-13 for further discussion, talk at ICM-13
C11	**GNSS GDP format**	GFZ to progress provision of a netCDF format version of the GNSS GDP.	TT GNSS-PW; Lead Centre (review)	Jun 2021
C12	**Metrological closure of GNSS-IWV and radiosondes**	For GRUAN sites that perform both GNSS-IWV measurements and radiosoundings, analyse the comparison of the GRUAN data products (and their respective uncertainties) for these data streams to establish whether metrological closure is attained. Further results to be presented at ICM-13 and written up in a paper.	GNSS-IWV; TT- radiosonde	ICM-13: presentation & preparation of manuscript

GCOS Secretariat
Global Climate Observing System
c/o World Meteorological Organization
***7 bis,* Avenue de la Paix**
P.O. Box No. 2300
CH-1211 Geneva 2, Switzerland
Tel: +41 22 730 8567/8067
Fax: +41 22 730 8181
Email: gcos@wmo.int