GAIA-CLIM Report

Gap Analysis for Integrated Atmospheric ECV CLImate Monitoring:

Report from Workshop held at the 2017 International TOVS Study Conference to disseminate the findings of WP4

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Introduction

GAIA-CLIM (Gap Analysis for Integrated Atmospheric ECV CLImate Monitoring) is a project undertaken to assess and develop our capability for the calibration/validation of long-term Earth Observation (EO) data sets using non-satellite reference measurements. The long-term environmental monitoring of Essential Climate Variables (ECVs) from space relies on traceable uncertainty estimates for the reference, an understanding of the additional uncertainties that result from spatial and temporal mismatches in location and scale, as well as the comparison process itself.

Work Package 4 of the project focuses on developing the use of Numerical Weather Prediction (NWP) as a comprehensive reference and aims to establish traceability for the model fields through comparisons with high quality (though sparse) comparator data, such as selected radiosondes, e.g. from the Global Climate Observing System (GCOS) Reference Upper-Air Network (GRUAN). The "GRUAN processor" [1] has been developed as a collocation- and radiance-simulation tool that quantifies differences between NWP fields and radiosonde profiles in both observation and radiance space. Known GRUAN uncertainties are propagated into the radiative transfer calculation. NWP-GRUAN differences are helping to inform our knowledge of the uncertainty in NWP fields.

A number of new satellite missions have undergone assessments within the NWP framework by comparing observed with simulated Top-Of-Atmosphere (TOA) brightness temperatures. The instrument-state and geophysical-state dependence of observed minus model background ("O-B") departures has been investigated for AMSR2,[2] FY-3C MWHS-2/MWRI,[3] GMI and MTVZA-GY[4] instruments. For example, these assessments have revealed instrument-related artefacts such as differences between ascending and descending node data, which we attribute to instrument-calibration instabilities around the satellite orbit.

The aforementioned studies have focused on the primary target ECVs of atmospheric sounders for meteorology, i.e. temperature and water vapour. As the capability of NWP and reanalysis models improves, there is the potential to extend the NWP data validation approach to a wider set of ECVs, including potentially in the terrestrial, cryospheric and oceanic domains.[5] Unfulfilled user needs ("gaps") in the availability of reference-quality measurements to support ECV monitoring are documented in the Gaps Assessment and Impacts Document (GAID), while a recommendations document aims to distill the findings into a set of high level proposals for tackling the gaps[6]. Based on the experience of WP4 during GAIA-CLIM, a number of gaps impacting on the utility of NWP systems for EO validation have been identified.

It was envisaged towards the end of GAIA-CLIM to arrange a workshop to engage the satellite remote sensing and NWP communities with WP4 activities and publicise project outcomes. This workshop served to disseminate the findings of WP4 and offered training material and practical sessions to induct future training providers. This report describes and summarises the workshop, which was held on 30 November 2017 during the 21st International TOVS Study Conference in Darmstadt, Germany.

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[1] WP4 Deliverable D4.4 describes the GRUAN processor and web-based monitoring. GAIA-CLIM deliverable reports are available online at http://www.gaia-clim.eu/page/deliverables.

[2] WP4 Deliverable D4.2 on evaluation of AMSR2.

[3] WP4 Deliverable D4.5 on evaluation of MWHS-2 and MWRI.

[4] WP4 Deliverable D4.6 on evaluation of GMI and MTVZA-GY.

[5] WP4 Deliverable D4.7 will expand on the prospects of NWP-based assessments for a broader range of ECVs.

[6] The GAID is available at http://www.gaia-clim.eu/page/gaid while the recommendations document can be found at http://www.gaia-clim.eu/page/recommendations.

1. Description of WP4 representation at ITSC-21

The workshop was organised to be held as an integral part of the International TOVS Study Conference XXI (ITSC-21)[7]. ITSC is organised by the International TOVS Working Group (ITWG) with part of its role to provide high-level recommendations for consideration by the Coordination Group for Meteorological Satellites (CGMS). The meeting is held approximately every 18 months and is the foremost meeting of experts in the EO community to exchange scientific advances in the development, characterisation and utilisation of EO data in myriad applications. ITSC-21 was hosted by EUMETSAT and held in the Darmstadtium conference centre in Darmstadt, Germany between 29 November and 5 December 2017. The GAIA-CLIM WP4 representation at ITSC-21 had three strands:

(i) Oral and poster presentations on GAIA-CLIM topics. ITSC sessions are held in plenary rather than parallel and provide wide exposure of presentations to attendees.

(ii) Participation by WP4 in the Climate Working Sub-Group (CWSG) and input to group's recommendations.

(iii) A dedicated workshop focusing on outcomes from GAIA-CLIM WP4.

There were a number of presentations showcasing GAIA-CLIM project activities on the opening two days of the conference:[8]

- **Poster 2p.07 Emma Turner**: Quantification of line-by-line parameter errors in the 183.31 GHz water vapour line
- **Poster 2p.09 Heather Lawrence**: Uncertainties in the dielectric constant model for seawater used in FASTEM and implications for the calibration/validation of new microwave sounding and imaging instruments
- **Talk 3.03 Fabien Carminati**: Characterisation of numerical weather prediction model biases for improved satellite cal/val
- **Talk 3.05 Stuart Newman**: An assessment of Meteor-M N2 MTVZA imager/sounder data at the Met Office and ECMWF for GAIA-CLIM
- **Poster 3p.01 Stuart Newman**: The GAIA-CLIM project
- **Poster 3p.02 Stefano Migliorini**: Robust quantification of uncertainty on short-range model forecasts in radiance space based on reference sonde data
- **Poster 3p.03 Brett Candy**: Assessment and assimilation of microwave imager observations in NWP global models
- **Poster 3p.04 Heather Lawrence**: Assimilation of FY-3C MWHS-2 at ECMWF and evaluation of the microwave imager FY-3C MWRI at ECMWF and the Met Office
- **Interactive exhibit by Stéphanie Guedj:** The "Virtual Observatory" developed by WP5 was shown as a live demonstration on a laptop during the poster sessions

[7] Conference website: http://cimss.ssec.wisc.edu/itwg/itsc/itsc21/

[8] At the time of writing these presentations are not yet available online. It is expected they will be linked from the conference website in due course.

These presentations preceded the workshop session on 30 November 2017 and therefore primed conference attendees on the aims and scope of GAIA-CLIM.

The Climate Working Sub-Group met on 2 December 2017. The co-chairs of the group (Nathalie Selbach and Cheng-Zhi Zou) have circulated a draft report and associated recommendations. The report explicitly notes the recommendations produced by GAIA-CLIM to address gaps in the current capability for cal/val of Earth observations for a wide set of ECVs. Following a discussion in the group, two related recommendations were made:

> Recommendation Climate-7 to satellite agencies: *Traceable ground calibration and characterization is a necessary (but not sufficient) condition for traceable, low uncertainty, observations on orbit. All space agencies are encouraged to aim to support/develop "ground" calibration strategies which aim at traceability accuracy for all pre-launch characterization and on-orbit calibration - with the aim of reducing radiometric biases over the long term for sounding observations.*
>
> Recommendation Climate-8 from ITSC 21: *The Climate WG supports free and open data policy and recommends satellite agencies to follow this policy. Satellite agencies should promote / integrate reference in-situ observation from programs such as GRUAN for cal/val activities. The group recommends relevant countries to retain calibration sites even after cal/val campaigns.*

The following sections describe the format of the dedicated WP4 workshop itself and participants' interaction/feedback.

2. WP4 workshop agenda and presentations

WP4 partners, Met Office and ECMWF, led the workshop by presenting the following topics:

1. Stuart Newman (Met Office) gave an introduction to GAIA-CLIM and the specific aims of Work Package 4 investigating the role of NWP for characterising EO data.

   This presentation was designed as an overview of GAIA-CLIM and WP4 for those not familiar with the project. The key advantages of NWP as a tool for characterising satellite data were described (fields are spatially continuous, with their evolution constrained by knowledge of atmospheric physics/dynamics, and data assimilation provides an optimal way of blending information from the model and observation sources). Examples from WP4 assessments of new satellite missions were shown (Figure 1) with the ability to diagnose instrument-state and geophysical-state dependence of detected biases. The GAID and recommendations document were advertised as mature resources on unfulfilled user needs for reference quality measurements to support ECV monitoring. The complementary aims of GAIA-CLIM and FIDUCEO were compared (FIDUCEO's role in quantifying satellite instrument uncertainties, GAIA-CLIM's role focusing on non-satellite reference data for EO validation).

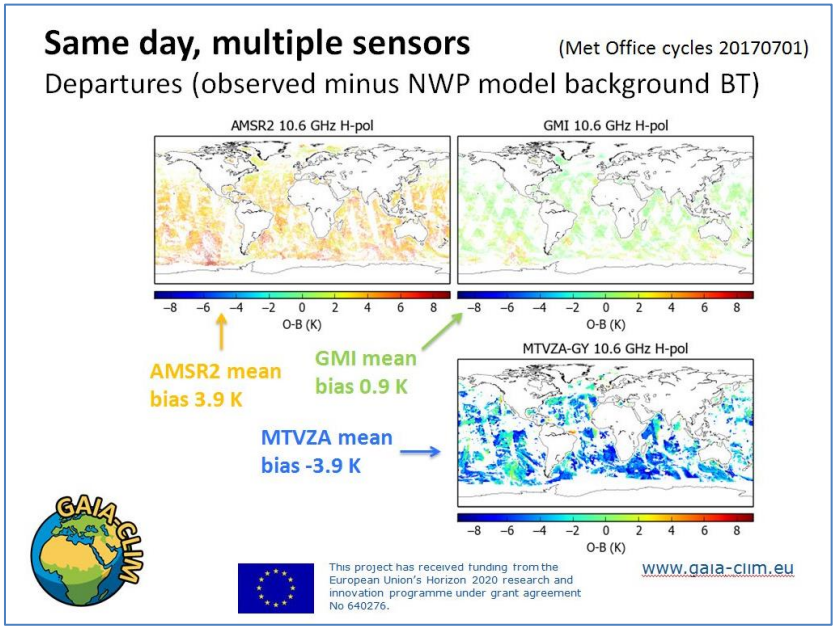

Figure 1. Slide from presentation 1, comparing O-B departures for three satellite instruments with the same (10.6 GHz horizontally polarized) channel. This illustrates how NWP provides a *stable* reference, identifying inter-instrument biases, but with bias characteristics that remain to be quantified with tools such as the GRUAN processor.

2. Fabien Carminati (Met Office) described the GRUAN processor (Figure 2) and gave a demonstration training session of the software.

The top-level design of the processor was outlined and examples of the processor output in geophysical and radiance space were shown. Fabien ran a live demonstration of the processor on a laptop, which served to illustrate how quickly the underlying radiance simulator runs and the format and structure of input/output files. The final slide of the presentation explored the future development of the processor, with the aim of: extending processing of GRUAN profiles and model fields to other NWP centres; semi-automatic monitoring of NWP-GRUAN differences; estimating channel-by-channel NWP uncertainty for selected instruments; contributing to MHS uncertainty closure collaboration with FIDUCEO.

Figure 2. Fabien presents the GRUAN processor to the ITSC workshop participants.

3. Bill Bell (ECMWF) outlined how the NWP cal/val approach, demonstrated during GAIA-CLIM for temperature and humidity sensors, could be generalised to encompass a wider set of ECVs.

   The presentation contended that the NWP framework is particularly well suited to the validation of temperature sounding radiances where NWP uncertainties are thought to be small, of magnitude 0.1-0.5 K in terms of TOA brightness temperatures. Similarly, the model uncertainty for humidity sounding channels is estimated to be of magnitude 1 K, whereas for surface sensitive channels 2-5 K uncertainties are to be expected. With continuous development and improvement of data assimilation systems, and greater sophistication in the treatment of model processes, we expect the role of NWP for validating a wider range of ECVs to grow. Bill suggested the necessary components in a global analysis system for this purpose are: a comprehensive observing system; a mature data assimilation system; a well developed forecast model; operational continuity; and the availability of reference observing

networks. The presentation concluded with some illustrative examples, such as a comparison of satellite total column ozone estimates with CAMS reanalysis fields (Figure 3).

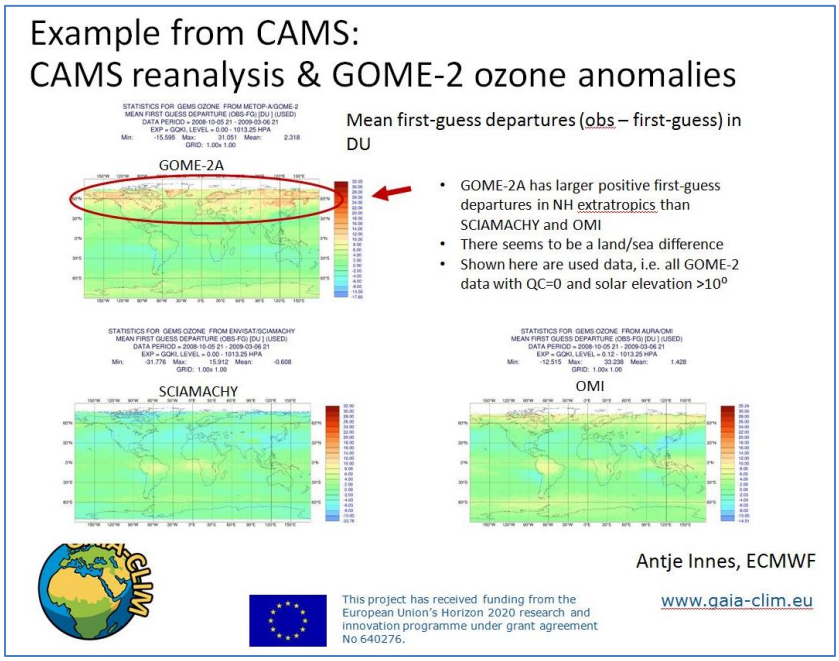

Figure 3. Slide from presentation 3, comparing departures of satellite column ozone retrievals with respect to Copernicus Atmosphere Monitoring Service (CAMS) reanalysis fields. Anomalies are seen for GOME-2A departures in the Northern Hemisphere extratropics which are not seen for SCIAMACHY or OMI.

4. Heather Lawrence (ECMWF) reviewed the outcomes of WP4 activities during GAIA-CLIM

The set of satellite instruments critically assessed within the NWP framework was outlined, with channels sensitive to temperature and water vapour in the 10-183 GHz range. Heather described the data selection method developed during GAIA-CLIM which is designed to screen out scenes where the radiative transfer modelling is uncertain (cloudy scenes and situations such as high surface wind speed). Results for several instruments were shown, such as for MWHS-2 where instrument calibration instabilities can be detected in O-B time series. The contributions to the uncertainty budget for NWP-simulated brightness temperatures were explored, comprising uncertainties in NWP model fields; in radiative transfer modelling; due to residual cloud; due to vertical interpolation effects; and due to scale mismatch. Heather summarised remaining areas of work identified during WP4 (Figure 4), such as the need for a reference microwave ocean emissivity model and the requirement for a better understanding of uncertainties in key spectroscopic parameters.

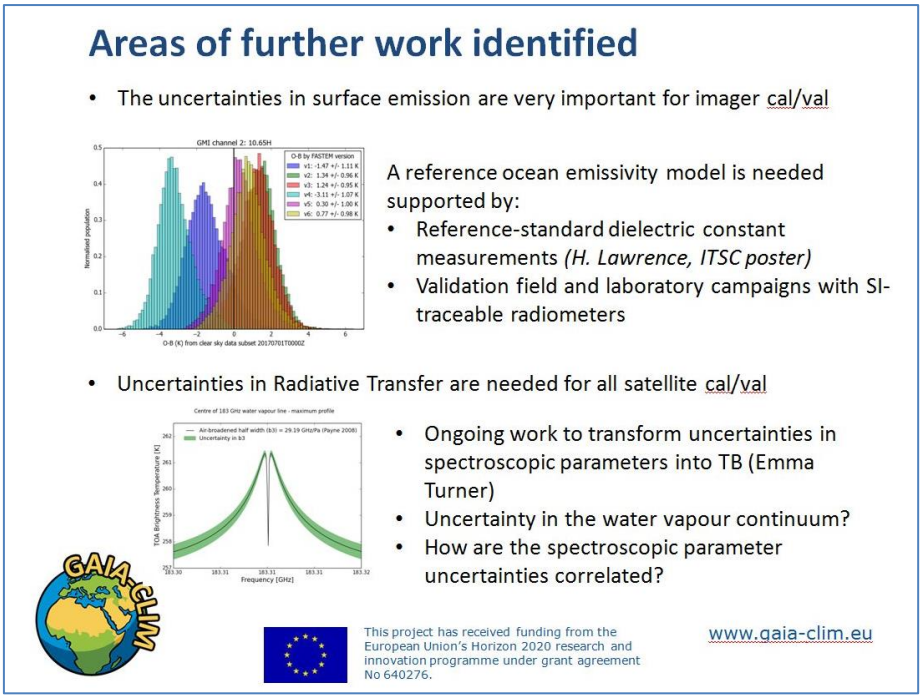

Figure 4. Slide from presentation 4, discussing areas of further work identified in WP4.

3. Detail of workshop participants' contributions

There were twenty-eight workshop attendees from a broad cross-section of the ITSC community. Their names and affiliations are provided in the Annex (Section 5).

The workshop participants were proactive in making interjections, which encouraged a lively discussion. A summary of questions and discussion points follows.

Treatment of uncertainties

There were several comments related to the uncertainty equation (Immler et al., 2010)[9]:

$$\left|m_1 - m_2\right| < k\sqrt{\sigma^2 + u_1^2 + u_2^2}$$

1. *How are mean (systematic) and random uncertainties accounted for by this equation?*

   John Eyre expressed the view that the separation of these terms is important (and customary in data assimilation). Bill pointed out that systematic uncertainties can be difficult to estimate, although the GRUAN processor is a tool that allows such uncertainties to be estimated in principle for NWP fields.

[9] Immler, F. J., Dykema, J., Gardiner, T., Whiteman, D. N., Thorne, P. W., and Vömel, H.: Reference Quality Upper-Air Measurements: guidance for developing GRUAN data products, Atmos. Meas. Tech., 3, 1217-1231, https://doi.org/10.5194/amt-3-1217-2010, 2010.

2. *What is the significance of σ in the case of NWP observed minus calculated radiances?*

   As a mismatch uncertainty between the satellite and reference measurements, the NWP community considers representativeness uncertainty as that, which arises from differing spatial scales of the NWP model and satellite footprint.

3. *How can scale mismatch be estimated practically?*

   The WP4 approach has been to degrade/smooth high spatial resolution NWP fields to gauge the effects of differing fields of regard between satellite and model.

4. *Do m_1 and m_2 have correlated uncertainties?*

   Most participants thought such correlations are small enough to be ignored.

GRUAN processor

5. *How reliable are NWP-GRUAN statistics for surface-sensitive channels?*

   Fabien explained that the surface-skin temperature is not available in GRUAN data and it is generally advisable to look at channels sensitive to the troposphere or UTLS region.

6. *Could CRTM be used as an alternative to RTTOV in the processor?*

   The response from WP4 presenters was that it is feasible but would require some significant work to implement.

7. *How are GRUAN uncertainties treated? If the uncertainties are assumed to be correlated throughout the profile, doesn't this overestimate the final uncertainty in TOA radiance?*

   Yes. Reliable correlated uncertainties are not yet available from GRUAN. WP4 will attempt in the final months of the project to obtain estimates of vertical correlations e.g. through use of Desroziers statistics in data assimilation.

8. *The GRUAN processor netCDF output includes `rttov_rmse`, `rttov_bias` per channel, how are these defined?*

   These are RMSE and mean bias of RTTOV minus line-by-line for a set of diverse profiles.

   So, this doesn't include spectroscopy uncertainties?

   Indeed not. It was noted that spectroscopy errors should largely cancel in the difference NWP-GRUAN.

9. *Do different GRUAN stations have distinct uncertainties and NWP-GRUAN statistics?*

   This needs to be investigated and will be addressed in a future publication.

10. *Several participants noted the very large humidity uncertainties for GRUAN sondes (as any other radiosondes) for pressures less than 100 hPa, caused by the huge range of water vapour concentration and the technical limitations of such instruments.*

    This means the user needs to exercise care when interpreting the processor output, and be advised to concentrate on channels with weighting functions having little sensitivity to the upper atmosphere.

11. *Mitch Goldberg suggested a rather controversial approach where sounders such as IASI and CrIS have rather small radiometric uncertainty for upper tropospheric channels and so could be used to validate GRUAN sondes.*

    This is contrary to the GAIA-CLIM philosophy; nevertheless, there was some serious discussion during ITSC-21 about identifying high-peaking channels with known (small) spectroscopic uncertainty for model evaluation.

12. *For hyperspectral instruments, such as IASI, only a subset of channels are processed. Could the user select a different/wider channel set?*

    Yes, the input namelists allow channels to be selected for output. One participant felt that labelling channels by frequency rather than index would be more useful when interpreting plots.

13. *What about trace gases? Doesn't this result in forward -model errors for channels sensitive to minor species?*

    This is a legitimate point; RTTOV includes trace gases with approximate standard profiles but does not account for local variability. Similarly, a participant asked about the impact of clouds: the radiative transfer simulations are assumed clear sky for both NWP profiles and GRUAN.

14. *Is the drift of radiosondes with prevailing winds accounted for?*

    Yes: model profiles are interpolated and reconstructed along the path of the sonde.

15. *How is the portion of the atmosphere above the maximum sonde height dealt with?*

    Fabien explained that the only source of information is from the NWP model, which is used to "top up" the GRUAN profile as necessary.

16. *Can the user select their choice of radiative transfer coefficients?*

    Yes, in principle a different coefficient file can be selected.

17. *The GRUAN processor webpage output[10] is formatted as Encapsulated PostScript figures and text files. Could the data be available as netCDF for the user?*

    Yes, if there is a need from the user base.

Extension of WP4 approach to other ECVs

18. *Are NWP fields sufficiently accurate to act as a reliable reference when assessing EO data?*

    Bill suggested it may be useful to think of NWP and reanalysis fields as 'sensitive' rather than 'accurate', i.e. need to demonstrate that observation minus model differences are sensitive to the presence of instrument dependent and model state dependent biases of a certain magnitude. The WP4 satellite instrument assessments have showcased this. Efforts will continue to estimate the size of model biases where these exist.

[10] https://nwpsaf.eu/GProc_test/ins.shtml

19. *What are prospects for bringing Argo float data into WP4 for assessments of ocean temperature and salinity?*

    Ocean ECVs will be considered as part of the ECMWF effort, but there may not be time left in the project for a full study.

WP4 satellite mission assessments

20. *Do assessments show the same patterns of O-B for different (but related) channels? E.g. for MWRI the reflector emission should be the same for multiple channels so are biases correlated?*

    WP4 studies have indeed revealed common bias characteristics for sets of channels. [Plots are available, see e.g. Fig. 5 of WP4 Deliverable D4.5.]

21. *For ATMS is the antenna temperature (Temperature Data Record, TDR) or the conversion to brightness temperature (Sensor Data Record, SDR) used?*

    There was some confusion on this point. ECMWF participants thought that their use of ATMS data differed from other centres.

Spectroscopic uncertainties

22. *There was support in the room for investment in fundamental spectroscopic measurements needed for remote -sensing applications.*

23. *Steve English pointed out that several posters at ITSC-21 dealt with spectroscopic uncertainty and useful knowledge is "out there" in specialist communities.*

24. *Are uncertainties related to definition of line shapes and continuum contributions being considered by WP4?*

    Not the former, but the latter is being addressed as part of the MHS uncertainty budget study.)

25. *Do we need to attach uncertainty estimates to uncertainties*? *E.g. HITRAN provides some spectroscopic uncertainty information*, *but it is sometimes of unclear provenance.*

Finally, participants were asked for their overall impressions of WP4 outcomes. Views expressed were (i) supportive of the potential for NWP-based assessments of new satellite missions, with the caveat that a limited number of centres have the expertise to carry these out; (ii) constructively critical of the proposed means of estimating uncertainties in NWP fields and propagating these to TOA radiances; (iii) showing general interest in GRUAN processor coupled with concern that it may cease to be maintained beyond the lifetime of GAIA-CLIM.

4. In conclusion

This deliverable is presented as an official report on the workshop organised to disseminate the outcomes of GAIA-CLIM Work Package 4. The workshop was held as a dedicated session during the 21st International TOVS Study Conference on 30 November 2017. Twenty-eight conference attendees participated in the workshop and engaged in a wide discussion of WP4 activities. The workshop raised the profile of GAIA-CLIM with representatives of national meteorological services, academic institutions, and space agencies. Together with other presentations during the conference, e.g. on the WMO Global Space-Based Inter-Calibration System (GSICS) and the NOAA Products Validation System (NPROVS), the principles of traceable calibration and robust validation of satellite observations were well debated. Workshop participants expressed broad support for NWP-based assessments of new satellite missions as part of the "toolkit" for validation alongside dedicated field campaigns and use of simultaneous nadir overpasses. There was genuine interest in the GRUAN processor, which was seen as a novel tool for monitoring NWP-GRUAN biases and visualising the results. With a busy schedule of new satellite missions planned over the next five years (Meteosat Third Generation, EPS Second Generation, Joint Polar Satellite System, Feng-Yun satellite programme, and others), the methods developed in WP4 will continue to be relevant for future satellite data quality assessments. Means to continue to support and further develop these approaches should be pursued.

5. Annex: list of workshop participants

Presenter list

Stuart Newman	Met Office
Fabien Carminati	Met Office
Bill Bell	ECMWF
Heather Lawrence	ECMWF

Attendee list

Oleksandr Bobryshev	Uiversität Hamburg
Stephan Bojinski	WMO
Xavier Calbet	AEMET
Claude Camy-Peyret	Institut Pierre-Simon Laplace (IPSL)
Olivier Coopman	Météo France
Mohamed Dahoui	ECMWF
Stephen English	ECMWF
John Eyre	Met Office
Vincent Guidard	Météo France
Wei Han	NWPC/CMA
Chawn Harlow	Met Office
Stephan Havemann	Met Office
Gerrit Holl	University of Reading
Viju John	EUMETSAT
Masahiro Kazumori	JMA
Jun Li	SSEC
Qifeng Lu	CMA/NSMC
Marco Matricardi	ECMWF
Yasutaka Murakami	JMA
Seonki Park	Ewha Womans University, South Korea
Marc Prange	Meteorological Institute Hamburg
Indira Rani	NCMRWF
Nathalie Selbach	DWD
Sanjeev Kumar Singh	NCMRWF
Christoforos Tsamalis	Met Office Hadley Centre
Fuzhong Weng	EMDO
Peter Weston	ECMWF
Peng Zhang	NSMC/CMA