HARMONIA
International network for harmonization of atmospheric aerosol retrievals from ground based photometers

HARMONIA CA21119

Deliverable 5.3a

Annual review of progress/achievements towards deliverables during MC meetings

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cost EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

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1. Introduction

It is the overall objective of the WG5 to establish mechanisms to disseminate the outcomes of the HARMONIA COST Action (CA21119) WG1-4 activities towards measurement improvement, new techniques and measurement approaches to aerosol scientists and instrument users (inside and outside the HARMONIA consortium). The main targets are:

-Present HARMONIA results to various structures dealing with aerosol measurements, including aspects of the entire processing chain; from measurement to end-user products.

-Disseminate and communicate scientific results and end user aerosol related activities towards different audiences (scientists, public, industry, government bodies).

-Exchange and combine software and hardware user tools among partners towards retrieval improvements.

-Publish scientific results of HARMONIA collaboration to peer reviewed journals, conferences, and reports.

This deliverable describes the progress, the achievements and all the networking activities towards the three deliverables of the first year of the action, based on the discussions during the MC and the corresponding WG meetings. The three deliverables of the first year of the Harmonia action came from WG1, WG2 and WG3 and are respectively:

D1.1: Create a list of existing and foreseen campaigns or experiments needed for night and day aerosol measurements and report on the data collection and analysis of the data/measurements.

D2.1: Report on synergistic approaches towards better quality products

D3.1a: Share the recordings and the presentations of the first Workshop that was organized, with potential users from different interested communities, dealing with climate effects of aerosols, aerosol forecasting, air quality, renewable energy availability, and urban environments, from academia and operational agencies. The

deliverable D3.1a concerns the report for the first of the two workshops and has to be submitted at the end of the first year of the COST action.

2. Annual review for 1st years deliverables

2.1 Deliverable D1.1

The main objective of the WG1 is the homogenization and harmonization of global aerosol measurements and retrievals. To achieve this goal networking is a key aspect since different instruments/networks and related algorithms have to be unified. The cooperation and the knowledge exchange inside the HARMONIA and specifically inside the WG1 aims to create a scientific roadmap on worldwide homogenization of aerosol properties' measurements including calibration, standard operation, quality assurance and control procedures and post processing.

Field campaigns and experiences of aerosol measurements are a unique source of information from different instruments, including different data collection methods and analysis. Hence, the first deliverable of WG1 (D1.1) was:

Deliverable D1.1: "Create a list of existing and foreseen campaigns or experiments needed for night and day aerosol measurements and report on the data collection and analysis of the data/measurements."

In the first WG1 meeting (online, Mar. 2023) a set of six main past campaigns were presented and discussed, and it was decided (also in the first WG2 meeting, online Mar. 2023) that campaigns are both WG1 and WG2 topic (many WG members are in both WG1 and WG2). After the second WG1 and WG2 meetings and the second MC meeting in Davos (May 2023) the decision was made to have a WG1 & WG2 common task "campaigns", which fills the exigences of MoU D1.1 (WG1 /Deliverable 1) as well as of task T2.1 (WG2, Task 1):

Task: T2.1: "Create a list of existing field campaigns or experiments including daytime, night-time aerosol retrievals and low-cost sensors and a database with data from existing networks (GAW, Aeronet, Skynet and Pandonia) and other independent instruments more suitable for performing intercomparison."

So, under the common task "campaigns" of WG1 and WG2, two different subtasks have been distinguished, which finally formulated the deliverable D1.1. The first one (D11A) was the creation of an open list of the campaigns/ experiments using different instrumentation. This was a spreadsheet that all WG1 and WG2 members were asked to fill out with campaigns or experiments in case they have organized or hosted such at their station. Those have to fulfill the criteria that have been defined at MC2 meeting in Davos (May 2023):

- Campaigns where WG members attended or have contact for data access.
- The Campaigns must have at least one photometer (sun, lunar, star or Sky camera) co-located (ground-based aerosol retrievals from sunphotometers).
- Not only Campaigns, but also long-term measurements
- Ancillary measurements (laboratory and model user) can be listed.

Additionally, if WG1&2 Members do not have done such campaigns/experience but have some suggestions for future campaigns, they should report them "future suggestion" of the spreadsheet.

The second subtask (D11B) was the overview of the six campaigns selected as "main campaigns". Five campaigns of the recent years: Izaña 2017, ANNAC 2020, SCILLA 2020, QUATRAM I/II/III 2018-2021, and WMO FRC-V 2021 were selected. This is an overview of the main results of these campaigns, differences-similarities in the results, with interpretation (campaign's place environment, season, etc.). The results of this subtask were also presented at EMS 2023 (Sept. 4-8) in Bratislava by the WG1 leader (Lionel Doppler et al.). The first author (Lionel Doppler) contacted co-authors / PIs / Main actors of these campaigns to ask for results, graphics, etc. and many WG1 and WG2 members also contributed. A first work basis were the presentations during the first WG1 and WG2 meetings (online, March 2023).

2.2 Deliverable D2.1

The objective of the WG2 is to improve aerosol measurements using solar-, lunar- and star photometry, breaking new grounds for aerosol retrieval techniques including calibration improvement (via S.I. traceable related standardization results), hardware and software improvement actions. The exchange of knowledge

and experience among manufacturers, calibration and data processing related scientists and users by establishing a network through HARMONIA, are the foundations for those improvements. The exploitation of existing measurement experimental data for different aerosol environments is one of the main sources of information for investigating and suggesting improvements of aerosol photometry measurement.

The exploitation of synergistic approaches with solar-, lunar- and star photometry is one way to improve aerosol measurements. This is the first deliverable of the WG2:

Deliverable D2.1: "Report on synergistic approaches towards better quality products."

After the WG1 and 2 meetings and the second MC meeting in Davos (May 2023) it was decided that the improvements of aerosol measurements by using synergistic approaches (D21) could be achieved by using synergy of measurements (as subtask D21A) and synergy of algorithms (as subtask D21B).

Concerning D21A, a census of campaigns, long term measurements and permanent observatories was done. All WG1 and WG2 members involved in the management of stations or campaigns (or in the processing of the dataset) were asked to fill in a spreadsheet. This information can be shared for both WG2 and WG1. For every permanent station the requested information to be filled was the availability of specific instruments. The geographical location of those instruments will be part of the deliverable, along with a table presenting an overview of the stations and the available equipment.

Concerning D21B the synergy of algorithms was explored. In fact, different platforms measuring aerosol properties simultaneously require the development of synergistic approaches among the various algorithms that typically manage a multi-instrument database. The approaches to improve the quality and synergy of the algorithms include: 1) development of algorithms; 2) inter-comparison and validation of inversion algorithm products; 3) combined use of algorithms.

2.3 Deliverable D3.1a

The objective of the WG3 is to increase the applicability for aerosol optical properties for different scientific fields. HARMONIA network and specifically WG3 aims to link the accuracy and uncertainty of aerosol optical properties to the objectives and needs of the climate and atmospheric related scientific community and relevant structures (e.g. WMO, GCOS, satellite related missions) and to create interacting mechanisms with users (Climate scientists, air quality, solar energy, aviation and others).The expertise of diverse groups in HARMONIA (ground-based aerosol monitoring, satellite monitoring, atmospheric modelling, etc.) and the networking activities are essential in fulfilling those objectives.

The organization of dedicated workshops to bring together users from all communities (e.g., Academia, industry, operational agencies, research structures, EU and WMO research services) is the best way to maximize the use of ground-based aerosol measurements and with this is related the first Deliverable of WG3:

Deliverable D3.1a: "Share the recordings and the presentations of the first Workshop that was organized, with potential users from different interested communities, dealing with climate effects of aerosols, aerosol forecasting, air quality, renewable energy availability, and urban environments, from academia and operational agencies."

During the first WG3 meeting (online Mar. 2023), it was decided to start organizing the first workshop and to contact people from satellite, modelling, solar energy etc. community to join. WG3 Teams were organized, with Team 1 having a task related to workshop organizing: Identification/invitation of communities of potential users: Climate, satellite measurements, modelling, solar energy resource and forecasting, health, and aviation.

At the second MC meeting in Davos (May 2023), it was decided to organize the first workshop in September 2023 in Athens, Greece (Academy of Athens).

A successful Workshop was organized by HARMONIA COST Action for aerosol end user engagement, on September 19, 2023, in Academy of Athens, Athens, Greece (https://harmonia-cost.eu/wp3-workshop-for-aerosol-end-user-engagement-at-athensgr/). More than 40 people participated from different scientific fields. The agenda included talks about aerosol optical properties use and effects on climate,

in numerical weather prediction, satellite community, the aviation and solar energy sector. There were also presentations of aerosol observations from different networks (ACTRIS and Brewer Network). Lessons learnt and experience of aerosol users from InDust COST Actions were also presented and discussed. The workshop closed with a fruitful discussion about aerosol products and their harmonization, and the paths for the exploitation of HARMONIA COST Action's outcomes have been set. Main outcomes of the discussion and recommendations were:

- To try to pick some of the subjects and work more on some of the issues that seem more promising.
- To get involved with communities like Aerocom-Aerosat and participate in their upcoming meeting.
- To try to keep both high-level objectives but also lower level adequate of all countries' scientific expertise.

A summary of the main suggestions and recommendations of the users of ground-based measurements, as emerged from the discussion is provided in Table 1.

Table 1. Main needs of the users of ground-based aerosol observations

Modelers	• Need for harmonized ground-based measurements. • The measurements should be linked to satellite data and modelling. • Pick regional representative sites, not mountains or ships to set up new observational sites. • Provide data at satellite overpass times. • Try to connect with satellite and modelling communities. • Need for AOD and AAOD for fine and coarse mode particles from ground-based measurements. • Expand the measurements of the aerosol properties in the IR. • More observations for SSA.
Assimilation of CAMS products	• AERONET and in situ are very important for verification of the model output but not for assimilation. Satellite information is used for assimilation. • Information for the vertical aerosol profile and type is needed (can be provided from active sensors).

Energy	• There is a need for higher spatial density in zones where it is needed (i.e., Qatar, Morocco), notably in cities (photovoltaic development). • Need for high resolution measurements. • Involve more passive sensors, e.g., fish-eye cameras from the ground, to assess aerosols.
Aviation	• Accurate ground-based measurements near the airports, especially relative to dust. • More information for the aerosol vertical profile. • Main challenge is to translate measurement information to thresholds & constraints.

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Deliverable 5.3b

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1. Introduction

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-Present HARMONIA results to various structures dealing with aerosol measurements, including aspects of the entire processing chain; from measurement to end-user products.

-Disseminate and communicate scientific results and end user aerosol related activities towards different audiences (scientists, public, industry, government bodies).

-Exchange and combine software and hardware user tools among partners towards retrieval improvements.

-Publish scientific results of HARMONIA collaboration to peer reviewed journals, conferences, and reports.

This deliverable describes the progress, the achievements and all the networking activities towards the five deliverables of the second year of the action, based on the discussions during the MC and the corresponding WG meetings. The five deliverables of the second year of the Harmonia action come from WG1, WG2 and WG5 and are respectively:

D1.2: Report on the differences and uncertainties related to standard products provided from already existing analysis algorithms.

D2.2: List of possible improvements on the quality of solar, lunar and stellar photometry instrumentation.

D2.3: Collaborate and report on the links of metrology MAPP project results and measurement accuracy and uncertainty improvements and ML and CC use for data Harmonization.

D5.1: Share the recordings and the presentations of the training School on solar, lunar, stellar radiation-based techniques.

D5.2: Share the recordings and the presentations of the training School to aerosol measurement scientists and operators.

It was decided (MC vote) that the Deliverables D1.3, D3.1b and D4.1a of the second year are transferred to the next year, related to the activities that will take place in the third year of the action.

2. Annual review for 2nd year deliverables

2.1 Deliverable D1.2

The main objective of the WG1 is the homogenization and harmonization of global aerosol measurements and retrievals. To achieve this goal networking is a key aspect since different instruments/networks and related algorithms have to be unified. The cooperation and the knowledge exchange inside the HARMONIA and specifically inside the WG1 aims to create a scientific roadmap on worldwide homogenization of aerosol properties' measurements including calibration, standard operation, quality assurance and control procedures and post processing.

Aiming for the homogenization of aerosol retrievals, it is an important step to identify first the differences among different instruments and networks. Hence, the second deliverable of WG2 (D1.2) is:

Deliverable D1.2: "Report on the differences and uncertainties related to standard products provided from already existing analysis algorithms."

This deliverable deals with the differences between network retrieval methods, cloud screening, etc. and during the third MC meeting in Reykjavik it was presented the modified name of the deliverable, that better fulfils the Action's objectives compared to the one selected at the proposal stage (back in 2021):

Deliverable D1.2: "Differences and harmonization possibilities in AOD retrieval methods."

The first structure of the deliverable was discussed during the first WG1 meeting of the second year (online, Mar. 2024). Two axes were decided, and specifically to give an overview of differences in:

a) retrieval methods

b) and cloud screening methods

among the three main networks: GAW, SkyNet and AERONET. Regarding **retrieval methods**, the differences arise from the different post processing of the measurements, and the measurements itself. This first part will be focused on how from total optical depth the aerosol optical depth (AOD) is retrieved and how different networks deal with ozone (O_3), NO_2, Rayleigh scattering, airmass, etc., and which is the impact on the uncertainty. Regarding **cloud screening**, the overview will be on the different methods applied and the associated error and uncertainty analysis. Two possible directions were decided for this overview: 1) by performing a literature review of the subject or/and 2) work on real data the methodologies.

The working steps for analyzing real data for the task related to the retrieval methods were presented and discussed with the WG1 members:

Step 1: to ask PI of the stations having couples PFR-Cimel or Cimel-Prede or Prede-PFR, how long they have a dataset useful for comparison and if they already started a comparison study.

This information was available from the previous Action's deliverables and the shared spreadsheet with information regarding the stations for synergies (CIMEL – PFR -Prede sheet). The same information for campaigns was available at D1.1.

Step 2: At the stations where comparison is possible, directions to analyze the differences were given.

Step 3: Reprocess again the data of PFR, Cimel or Prede with a common retrieval method (same airmass formula, same Rayleigh formula and pressure value, same O3 amount, same NO2 amount) and look if the differences from the above graphics were artifacts or instrument based. The differences at this stage will be only due to measurement issues such as pointing, FOV, etc.

For the overview of differences in cloud screening methods relevant literature was proposed and WG1 leaders prompted WG1 members to contact them for their ideas. At the end of the meeting, the WG1 leaders proposed relevant STSM or VMs topics which were available at the sheet "PROJECTS" at the "know each other" shared document. The interested WG members could fill the document and apply for the grant. Finaly WG members were prompted to suggest new projects or add any information to the already mentioned projects, that finally could be part of the deliverables.

In the third MC meeting in Reykjavik (May 2024), it was presented what has already been done and which are the next steps in terms of collaborations and related grants (VM, STSM) towards D1.2. It was discussed that several grants from the first two years of the Action could contribute to the D1.2 and during the WG1 meeting in Reykjavik apart from the discussion, the WG1 members expressed their interest in grants directly related to the Action's D1.2.

The possible structure of the D1.2 was presented, including the following three main chapters:

- Comparison Prede-Cimel-PFR regarding retrieval methods
- Cloud-screening/flagging methods
- High spectral resolved AOD/ UV-AOD (Brewer and BTS)

The chapter of the comparison Prede-Cimel-PFR, starts with the section of Lindenberg (DWD/MOL-RAO) long-term (2013-2024) dataset, which is an extension to a long-term time series of the project 2 of the Sky over Berlin school. This was a study with 8 trainees involved and supervisor WG1 leader Lionel Doppler. In this project AOD datasets from the Lindenberg station were utilized from all the three instruments and the differences were analyzed between the three main aerosol photometry networks (Cimel-AERONET, PFR-GAW and Prede-SkyNet). The second section is the same comparison for SCILLA Campaign (Lindenberg 2020) that had both sun and moon photometers. Then, the comparison is extended to other stations with at least two instruments. In this section, results from the STSM of Simone Pulimeno in Valladolid are included. The last section of this chapter is the

impact of air mass, rayleigh scattering and trace gas absorption on AOD and aerosol properties retrievals in sun photometry.

The chapter of cloud screening methods applied to AOD monitoring with photometers, starts with a section which introduces the Cloud screening/flagging methods used in photometer networks (solar) of AERONET, SKYNET and GAW-PFR. Then the Schenziger and Kreuter (2021) cloud screening method (solar) and the STSM of Verena Schenzinger (Innsbruck → Davos 2023) is included. The next section is dedicated to Camera and broadband measurements algorithms for cloud flagging (solar) which is based on the results of the STSM from Claudia Frangipani (CNR Bologna → DWD Lindenberg 2024) for cloud screening at Lindenberg using Camera – Broadband radiation – Photometer instruments. In addition, a section for the Synergy of sun photometer and spectroradiometer for cloud flagging algorithms assessment (solar) is included based on the study of Masoom et al. (2024). At the end of the chapter, a section for the cloud screen at Lunar (PFR, Cimel and Prede) and Stellar photometry is included. Parts of this section are based on the STSM of Gaurav Kumar on lunar photometry and STSM of Sandra Graßl on lunar and star photometry.

Finally, the chapter of the high spectral resolved AOD / UV-AOD has two parts. At the first one the different retrieval methods of UV AOD from Brewer and BTS instruments are described. For the Brewer AOD retrieval methods among others the IOS (International Ozone Services Inc.) and the EUBREWNET (Aemet/Izana) Brewer-AOD methods are described. In addition, AOD measurements with Brewers at different measuring sites are presented. Here, it is included the study for long-term AOD retrievals with Brewers in Slovakia, based on the ITC Conference grant of Peter Hrabčák. The second part is dedicated to the high spectral AOD by giving a review of the existing methods and instruments. There are different sections for describing the methods to retrieve AOD with BTS, with EKO and with PSR and applications on different sites.

2.2 Deliverable D2.2

The objective of the WG2 is to improve aerosol measurements using solar-, lunar- and star photometry, breaking new grounds for aerosol retrieval techniques

including calibration improvement (via S.I. traceable related standardization results), hardware and software improvement actions. The exchange of knowledge and experience among manufacturers, calibration and data processing related scientists and users by establishing a network through HARMONIA, are the foundations for those improvements. The exploitation of existing measurement experimental data for different aerosol environments is one of the main sources of information for investigating and suggesting improvements of aerosol photometry measurement. The second deliverable of the WG2, provides a list of those improvements:

Deliverable D2.2: "List of possible improvements on the quality of solar, lunar and stellar photometry instrumentation."

The first ideas for the deliverable were discussed during the first meeting of WG2 of the second year (online, March 2024). As a first step was proposed to identify existing studies on instrument improvements. Then to perform research regarding the state of the art of the existing measurement systems and list of main "incompatibilities" and "compatibilities" between them, to understand the gaps in order to list possible improvements. The following systems were listed along with the available datasets and interested WG members (people to involve from "know each other" shared document):

- Stellar and lunar photometers measurements
- Aircraft and sun photometry campaigns
- Network photometers and other instruments
- Brewer and photometers
- Pandora and photometers

A repository was created and presented during the meeting to list the possible projects that could be related to a grant, where interested WG members could propose their availability and if they have other ideas. This repository is the second sheet Project proposals of the "know each other" shared document. This sheet had the title of the project proposals, the topic, the duration of the work, if this would be related with a STSM, a VM or it is only a collaboration, the WGs interested, the

deadline for the proposals, the status of the project, the proposers and the interested people. During the meeting, participants expressed their interest in different topics.

During the third MC meeting in Reykjavik (May 2024), the 18 proposed projects were presented, and it was asked by the PIs of the projects to add the status information, if it is started or not. Up then, the collaboration has started for 6 projects and after the WG meeting in Reykjavik new collaborations started. There were also WG members that select a project, and for these projects it was discussed during the WG meeting which are the needs, the different sites that were suggested for the studies, and which may be possible problems that may be encountered.

The final structure of deliverable D2.2 is based on different projects (those listed in the excel file), VMs, STSMs, papers, participations in conferences like the HARMONIA session at EMS2024, or independent analysis that the WG2 leaders considered relevant D2.2.

The first chapter addresses improvements in solar based techniques. It includes the Cimel CE318 sunphotometer, the Prede POM radiometer and a study towards the harmonization of calibration techniques and all of these are based on the results of studies presented at the HARMONIA session of EMS 2024. This chapter also covers studies applying machine learning and cloud computing methods to photometry (VM related study) and for aerosol optical depth retrievals from ground-based solar irradiance measurements. Finally, there are studies dealing with post-processing improvements.

The second chapter covers the improvements on the lunar/stellar based techniques. It starts with the current status of the stellar and lunar techniques. Then the Cimel CE318 and the Prede POM lunar models are presented based on studies presented also in EMS 2024. There is also a section presenting the evaluation of current lunar techniques in Valencia (Spain) site.

The synergies with airborne based techniques are explored in the third chapter. The current status of the airborne-based techniques is reviewed in the beginning. It follows a study investigating the use of UAV-based techniques for the improvement of vertical profiling (results of VM grant). There is also a study that explores the use

of aircraft data for the improvement of AERONET and SKYNET ground-based measurements.

In the fourth chapter, the current efforts on the validation and harmonization of lower-cost techniques (e.g. of multifilter rotating shadowband radiometer (MFRSR) AODs) with established networks. The last chapter of D2.2 details multi-instrumental analyses of long-term aerosol, clouds and radiation trends for deferent sites (in Slovakia, Italy and Spain) and from different instruments.

2.3 Deliverable D2.3

The third deliverable of the WG2 is:

Deliverable D2.3: "Collaborate and report on the links of metrology MAPP project results and measurement accuracy and uncertainty improvements and ML and CC use for data Harmonization."

During the first meeting of WG2 of the second year (online, March 2024) the work plan towards D2.3 was discussed. For the links with the MAPP project Stelios Kazadzis will contribute to this. For the second part of this deliverable two steps were proposed. As a first step, research for the state of the art to be conducted for works already available on the application of Machine Learning (ML) and Cloud Computing (CC) techniques on solar, lunar and stellar photometry. Then, to choose a dataset of at least three years from photometers and apply ML and CC for a) cloud screening, b) filling temporal gaps before long term trends and for c) aerosol classification. Iveta Steinberga expressed her interest for this second part.

Two VM grants contribute to compiling D2.3. The first one was conducted by Stelios Kazadzis and it was to report on the links of metrology (MAPP) project results and Harmonia objectives on calibration and uncertainty. The second one was conducted by Iveta Steinberga and it had to do with the second part of the deliverable related to machine learning techniques applied to photometry.

2.4 Deliverable D5.1& D5.2

The objective of the WG5 is to increase the dissemination of the produced outcomes of the WG1-4 activities of the HARMONIA COST Action, to aerosol scientists,

instrument users and other HARMONA participants inside and outside the HARMONIA consortium, towards measurement improvement, new techniques and measurement approaches, sharing of protocols etc. thus contributing to the objectives of the Action.

The MC of the CA21119 decided to organize in 2024 a training school especially designed for young researchers to better understanding the solar, lunar, stellar radiation-based techniques, along with one dedicated to aerosol measurement scientists and operators. The following deliverables of WG5:

D5.1: "Share the recordings and the presentations of the training School on solar, lunar, stellar radiation-based techniques."

D5.2: "Share the recordings and the presentations of the training School to aerosol measurement scientists and operators."

are dedicated to sharing the recordings and the presentations of these schools. The results of the training schools contribute to the main objective of HARMONIA Action:

"Establish a mechanism in order to: introduce to aerosol scientists and instrument users, the outcome of the homogenization, the SOPs and the new techniques and measurement improvements."

Two VM grants contribute to compiling D5.1 and D5.2. The first one from Anca Nemuc was for the report on the training School on solar, lunar, stellar radiation-based techniques. The second one from Kyriakoula Papachristopoulou was for the report on the training School to aerosol measurement scientists and operators. Both deliverables 5.1 and 5.2 were combined to a common document.

References

Masoom, A., Kouremeti, N., Kazadzis, S., Killian, M., Kreuter, A., and Raptis, I.-P.: Performance analysis and synergistic use of cloud flagging algorithms of ground-based remote sensing instrumentations, EMS Annual Meeting 2024, Barcelona, Spain, 1–6 Sep 2024, EMS2024-365, https://doi.org/10.5194/ems2024-365, 2024.

Schenzinger, V. and Kreuter, A.: Reducing cloud contamination in aerosol optical depth (AOD) measurements, Atmos. Meas. Tech., 14, 2787–2798, https://doi.org/10.5194/amt-14-2787-2021, 2021.

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Deliverable 5.3c

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1. Introduction

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-Present HARMONIA results to various structures dealing with aerosol measurements, including aspects of the entire processing chain; from measurement to end-user products.

-Disseminate and communicate scientific results and end user aerosol related activities towards different audiences (scientists, public, industry, government bodies).

-Exchange and combine software and hardware user tools among partners towards retrieval improvements.

-Publish scientific results of HARMONIA collaboration to peer reviewed journals, conferences, and reports.

This deliverable describes the progress, the achievements and all the networking activities regarding the five deliverables of the third year of the action, based on the discussions during the MC and the corresponding WG meetings. The five deliverables of the third year of the Harmonia action come from WG1, WG2, WG3 and WG4 and are respectively:

D1.3: Report on the cross validation experiments of synergies with co-located solar, lunar and stellar photometers on white and review papers.

D2.4: Report on uncertainties for optimized and homogenized products and suggestions for improving already existing products.

D3.1b: Share the recordings and the presentations of two Workshops that will be organized, with potential users from different interested communities, dealing with climate effects of aerosols, aerosol forecasting, air quality, renewable energy availability, and urban environments, from academia and operational agencies. The

deliverable D3.1b concerns the report for the second of the two workshops in Cyprus and it was transferred at the end of the third year of the COST action.

D3.2: Report on the requirements of different user communities on the accuracy, uncertainty and spatiotemporal resolution of aerosol measurements needed for their activities.

D4.1a: Share the recordings and the presentations of two Workshops that will be organized, with industrial users related with: technological needs and innovation actions. The deliverable D4.1a concerns the report for the first of the two workshops in Davos and it was transferred at the end of the third year of the COST action.

Following an MC vote (**Harmonia MC/WG meeting 25-26 February 2025 Faculty of Science, Sarajevo**), Deliverable D4.1b ("Organize a Workshop with industrial users related with technological needs and innovation proposed actions") was transferred to the fourth year of the Action, when the second WG4 workshop will be organized.

2. Annual review for 3rd year deliverables

2.1 Deliverable D1.3

The main objective of the WG1 is the homogenization and harmonization of global aerosol measurements and retrievals. To achieve this goal networking is a key aspect since different instruments/networks and related algorithms have to be unified. The cooperation and the knowledge exchange inside the HARMONIA and specifically inside the WG1 aims to create a scientific roadmap on worldwide homogenization of aerosol properties' measurements including calibration, standard operation, quality assurance and control procedures and post processing.

D1.3 was originally planned for the second year of the Action and was transferred to the third year. Its official title in the Memorandum of Understanding (MoU) is:

Deliverable D1.3: "Report on the cross validation experiments of synergies with co-located solar, lunar and stellar photometers on white and review papers."

Discussions on D1.3 started at the online WG1 meeting of 10 December 2024. Members, and especially young scientists wishing to promote their work, were invited to propose contributions, and it was agreed that the scope of the deliverable could be broadened to accommodate relevant new topics. It has been also proposed to change the topic a bit to suit the content if needed and hence create an additional deliverable D1.4.

At the same meeting, M. Campanelli (WG2 leader) proposed a joint WG1–WG2 activity on lunar photometry algorithms ("lunar algorithm improvement").

At the fourth MC meeting in Sarajevo, WG1 leaders reported that D1.3 had been rescheduled for submission in autumn 2025 and presented ideas for its content. It was noted that the title selected at the proposal stage no longer fully reflected the Action's objectives, and a modified scope was proposed: in practice, D1.3 would summarize the related activities of HARMONIA members from mid-2024 to mid-2025. The first structure of the deliverable comprised:

- intercomparisons, harmonization initiatives, campaigns and experiments;

- cross-validation experiments, as in the official title, e.g. at Lindenberg, during measurement campaigns, other dual cross-validations, and at stellar photometry sites.

L. Doppler then outlined the topics to be discussed and worked on, which formed the basis for the separate WG discussions in the afternoon of the MC meeting:

- **Comparisons**: Prede/Cimel, Cimel/PFR and PFR/Prede at stations hosting pairs of these instruments, together with a common strategy for analysing the differences.
- **Synergies**: vertical/columnar (lidar, radiosondes) and lunar/solar/stellar.
- **Common HARMONIA retrieval**: reprocessing PFR, Cimel or Prede data with a common retrieval method (same air-mass and Rayleigh formulas and pressure value, same O_3 and NO_2 amounts).
- **Spectral / UV AOD**.
- **Grants**: STSM and VM topics proposed by the WG1 leaders, listed in the shared "PROJECTS" sheet.

Many members took part in the WG1 breakout session. L. Doppler presented its outcomes in the plenary, summarized below:

1. **Intercomparisons**

a) ***Prede–PFR–Cimel***: comparison strategies were discussed (including dual comparisons, e.g. PFR–Cimel, time matching, filtering and cloud flagging), together with the selection of sites and participants. A shared online document collects expressions of interest.

b) ***Solar–lunar–stellar***: this topic overlaps with WG2 and more contributors are needed; a shared online document is also available.

2. **Spectral / UV AOD**

a) ***High spectral resolution AOD in the VIS–NIR***: instruments and sites were discussed; the method still needs to be defined, building on Gröbner et al. (2023). Several members have registered their interest in a shared document.

b) ***UV AOD***: from different instruments, building on the work done so far; possible sites were discussed and interested members registered in a shared document.

3. Synergies

a) ***Stellar/lunar–solar (and possibly all-sky cameras)***: examining how the datasets complement each other.

b) ***Vertical (lidar, ceilometer, radiosonde):*** previous studies were reviewed and members were encouraged to contribute.

Applications of all kinds of grants were encouraged e.g. the VM of Yeser Aslanoglou using the Lindenberg dataset to compare AERONET lunar and solar AOD and to track events with HYSPLIT trajectories.

The topic of air masses, Rayleigh scattering and gas absorption was not covered, and interested members were encouraged to express their interest.

Outcome: given the breadth of the topics, D1.3 was moved, together with D1.4, to the fourth year of the Action.

2.2 Deliverable D2.4

The objective of the WG2 is to improve aerosol measurements using solar-, lunar- and star photometry, breaking new grounds for aerosol retrieval techniques including calibration improvement (via S.I. traceable related standardization results), hardware and software improvement actions. The exchange of knowledge and experience among manufacturers, calibration and data processing related scientists and users by establishing a network through HARMONIA, are the foundations for those improvements. The exploitation of existing measurement experimental data for different aerosol environments is one of the main sources of information for investigating and suggesting improvements of aerosol photometry measurement. The fourth deliverable of the WG2 is:

Deliverable D2.4: "Report on uncertainties for optimized and homogenized products and suggestions for improving already existing products."

Preparation of D2.4 started after the online WG1 (10 December 2024) and WG2 (17 December 2024) meetings. Following the WG2 meeting of 17 December 2024, the WG2 leader e-mailed WG1 and WG2 members on 28 January 2025 proposing a review of the state of the art in lunar photometry, covering both data-analysis algorithms and calibration methods. Although much work has been done on this topic, the different methods have never been compared, and there is a strong need for harmonization for which the HARMONIA community is ideally placed. This work was also identified as preparatory to Deliverable D2.4. Members were invited to:

1. read a shared online document in which each section names the expert PIs who will mentor newcomers or coordinate contributors already active in the field;
2. add their name and e-mail address to the document if interested;
3. join a dedicated meeting of the interested members during the MC meeting in Sarajevo.

At the MC meeting in Sarajevo, WG2 presented its plans. The list of available projects (STSM and VM topics) remained open in a shared spreadsheet; some projects needed updating, which was addressed in the afternoon WG sessions.

Two actions were defined for D2.4:

1. a joint WG2–WG1 meeting dedicated to the improvement of the lunar photometer algorithm, with the date set through a Doodle poll among the interested members;
2. a comparison of climatologies from the AERONET, SKYNET and PFR networks, building on point 5 of Deliverable D2.2 (comparison of AERONET and SKYNET retrievals under different conditions in Rome, Italy).

Outcome: D2.4 was moved to the fourth year of the Action.

2.3 Deliverable D3.1b

The objective of the WG3 is to increase the applicability for aerosol optical properties for different scientific fields. HARMONIA network and specifically WG3 aims to link the accuracy and uncertainty of aerosol optical properties to the objectives and

needs of the climate and atmospheric related scientific community and relevant structures (e.g. WMO, GCOS, satellite related missions) and to create interacting mechanisms with users (Climate scientists, air quality, solar energy, aviation and others).The expertise of diverse groups in HARMONIA (ground-based aerosol monitoring, satellite monitoring, atmospheric modelling, etc.) and the networking activities are essential in fulfilling those objectives.

The organization of dedicated workshops to bring together users from all communities (e.g., Academia, industry, operational agencies, research structures, EU and WMO research services) is the best way to maximize the use of ground-based aerosol measurements and with this is related the second Deliverable of WG3:

D3.1b: ”Share the recordings and the presentations of two Workshops that will be organized, with potential users from different interested communities, dealing with climate effects of aerosols, aerosol forecasting, air quality, renewable energy availability, and urban environments, from academia and operational agencies.”

At the MC meeting in Sarajevo, it was decided to organize the second WG3 workshop in June 2025 in Limassol, Cyprus, and to start preparations, including the choice of speakers and the exact dates. As another workshop was taking place at the same time, S. Kazadzis suggested dedicating one day to HARMONIA and combining the two events so that HARMONIA members could join both.

During the WG3 session, the WG3 leaders noted that much work was still ongoing and decided to announce VM grants to combine the material from the first WG3 workshop (Athens) and the second (Cyprus) with the outputs of the WG3-related VMs, and to compile the reports due in October 2025. All the material was available and needed to be compiled.

The HARMONIA workshop “Aerosol data users and applications” was held successfully on 16–17 June 2025 at the ERATOSTHENES Centre of Excellence in Limassol, Cyprus, with more than 30 participants from different scientific fields. The VM grant of Florica Toanca contributed to compiling the report.

Outcome: D3.1b has been delivered and is available at https://harmonia-cost.eu/wp-content/uploads/2025/10/Harmonia_D3.1b_final.pdf.

2.4 Deliverable D3.2

The second deliverable of WG3 addresses the requirements of the user communities:

D3.2: "Report on the requirements of different user communities on the accuracy, uncertainty and spatiotemporal resolution of aerosol measurements needed for their activities."

At the online WG3 meeting in November 2024, the WG leaders proposed VM grants for this deliverable. Material from completed grants was already available and was presented, and a contributor was needed to compile it. Two VMs completed in autumn 2024 provided input:

- **Sophie Vandenbussche,** *"Link to AeroCom and AeroSAT communities"* (15/09/2024–25/10/2024). The VM linked HARMONIA with the AeroCom and AeroSAT communities, both end users of ground-based photometer observations and therefore targets of WG3 (end-user engagement towards maximizing aerosol measurement use). Interaction with these communities provides relevant information for D3.2 and D3.3 (white paper on sun-photometric aerosol accuracy and uncertainty for different applications), and established contacts with potential speakers for the second WG3 workshop.
- **Panagiotis Fountoukidis,** *"Assessing the accuracy, uncertainty and spatiotemporal resolution of space-borne aerosol index products on geostationary and polar orbits"* (09/09/2024–15/10/2024).

At the MC meeting in Sarajevo, two further VMs were ongoing, with their reports pending:

- **Maja Kuzmanovski:** *"Bibliographical review: the role of aerosol optical properties uncertainties in the modelling of solar radiation and solar energy"*
- **Nikos Papadimitriou:** *"Assessment of aerosol related uncertainties in solar energy modelling"*

Ideas for preparing D3.2 on the basis of the available VM studies were presented, and members were invited to become actively involved through the two related VMs. As for D3.1b, it was decided to announce VM grants to combine the material from the two WG3 workshops and the WG3-related VMs into the report, due in October 2025. The VM grant of Florica Toanca contributed to compiling the report.

Outcome: D3.2 has been delivered and is available at https://harmonia-cost.eu/wp-content/uploads/2026/02/D32.pdf.

2.5 Deliverable D4.1a

WG4 addresses the challenge: how can scientists improve aerosol measurement quality and future measurement capabilities, including low-cost sensors? Its approach (Objective 4) is to establish an interdisciplinary team of scientists dealing with aerosol measurements and their use, together with industrial instrument developers, in order to report on the current status of measurement uncertainty and on future technical needs, and to suggest innovative ideas for the future of aerosol remote sensing sensors and retrieval methods.

The first deliverable of WG4 relates to the first WG4 workshop:

D4.1a: ”Share the recordings and the presentations of two Workshops that will be organized, with industrial users related with: technological needs and innovation actions.”

At the MC meeting in Sarajevo, the WG4 meeting and first WG4 workshop were announced for 8–9 October 2025 in Davos, alongside the sixth Filter Radiometer Comparison (FRC-VI); manufacturers of sky cameras and handheld photometers were to be invited.

The first WG4 workshop was held at the Physikalisch-Meteorologisches Observatorium Davos / World Radiation Center (PMOD/WRC) on 8 October 2025. It brought together more than 20 participants, most of whom attended in person. The VM grant of Miguel Huerta Gómez contributed to compiling D4.1a which is available at this link https://harmonia-cost.eu/wp-content/uploads/2026/02/Harmonia_VM_WG4_davos.pdf.

References

Gröbner, J., Kouremeti, N., Hülsen, G., Zuber, R., Ribnitzky, M., Nevas, S., Sperfeld, P., Schwind, K., Schneider, P., Kazadzis, S., Barreto, Á., Gardiner, T., Mottungan, K., Medland, D., and Coleman, M.: Spectral aerosol optical depth from SI-traceable spectral solar irradiance measurements, Atmos. Meas. Tech., 16, 4667–4680, https://doi.org/10.5194/amt-16-4667-2023, 2023.

HARMONIA
International network for harmonization of atmospheric aerosol retrievals from ground based photometers

HARMONIA CA21119

Deliverable 5.3d

Annual review of progress/achievements towards deliverables during MC meetings

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1. Introduction

It is the overall objective of the WG5 to establish mechanisms to disseminate the outcomes of the HARMONIA COST Action (CA21119) WG1-4 activities towards measurement improvement, new techniques and measurement approaches to aerosol scientists and instrument users (inside and outside the HARMONIA consortium). The main targets are:

-Present HARMONIA results to various structures dealing with aerosol measurements, including aspects of the entire processing chain; from measurement to end-user products.

-Disseminate and communicate scientific results and end user aerosol related activities towards different audiences (scientists, public, industry, government bodies).

-Exchange and combine software and hardware user tools among partners towards retrieval improvements.

-Publish scientific results of HARMONIA collaboration to peer reviewed journals, conferences, and reports.

This deliverable describes the progress, the achievements and all the networking activities towards the eight deliverables of the third year of the action, based on the discussions during the MC and the corresponding WG meetings. The eight deliverables of the fourth year of the Harmonia action come from all working groups and are respectively:

D1.3 Harmonised AOD Retrievals & AOD Comparisons

D1.4 Spectral AOD and AOD in the UV

D1.5 Photometry from day to night in Europe: solar, lunar and stellar. Historical approach new methods and synergies

D2.4: Report on uncertainties for optimized and homogenized products and suggestions for improving already existing products.

D3.3: Publish a white paper on sun-photometric aerosol accuracy and uncertainty for different applications.

D4.1b: Share the recordings and the presentations of two Workshops that will be organized, with industrial users related with: technological needs and innovation actions. The deliverable D4.1a concerns the report for the first of the two workshops in Davos and it was transferred at the end of the third year of the COST action.

D4.2: Report on hardware and software evolution needs according to WG3 results.

D5.4: Report on the dissemination of HARMONIA results to major stakeholder conferences.

In the Memorandum of Understanding (MoU), WG1 originally had a single deliverable for this period, D1.3 ("Report on the cross validation experiments of synergies with co-located solar, lunar and stellar photometers on white and review papers"). On the proposal of the WG1 leaders, it was split into the three deliverables D1.3, D1.4 and D1.5 listed above.

2. Annual review for 4th year deliverables

2.1 Deliverables D1.3, D1.4, D1.5 (-initially D1.3)

The main objective of the WG1 is the homogenization and harmonization of global aerosol measurements and retrievals. To achieve this goal networking is a key aspect since different instruments/networks and related algorithms have to be unified. The cooperation and the knowledge exchange inside the HARMONIA and specifically inside the WG1 aims to create a scientific roadmap on worldwide homogenization of aerosol properties' measurements including calibration, standard operation, quality assurance and control procedures and post processing.

As decided during the third year, D1.3 was moved to the fourth year and split into three deliverables:

Deliverable D1.3: "Harmonised AOD Retrievals & AOD Comparisons"

Deliverable D1.4: "Spectral AOD and AOD in the UV"

Deliverable D1.5: "Photometry from day to night in Europe: solar, lunar and stellar. Historical approach new methods and synergies"

A joint online WG1–WG2 meeting was held on 12 December 2025 to discuss the deliverables of both WGs and their common topics. For WG1, the focus was on D1.3 and D1.4

At the HARMONIA workshop in Astypalea, Greece (6-7/7/2026), it was announced that two Virtual Mobility (VM) grants would be requested for D1.3 and D1.4, for Angelos Karanikolas and Lionel Doppler, to speed up their preparation. The links to the shared online working documents were circulated and the content of each deliverable was discussed.

For D1.5 (solar/lunar/stellar synergy), the initial idea was to provide an overview of all studies combining stellar and lunar, or solar and lunar, photometry. As this is already largely covered by WG2 Deliverable D2.2, "List of possible improvements on the quality of solar, lunar and stellar photometry" (123 pages), it was proposed to

extend D1.5 to recent work on AOD retrievals from all-sky cameras, also carried out by members of the HARMONIA core group and WGs.

At the Helsinki MC meeting, the WG1 leaders (now including Angelos Karanikolas) said work on D1.3, D1.4 and D1.5 was progressing very actively. The VM grants for Angelos Karanikolas and Lionel Doppler were still pending, the content so far was presented, and members were invited to contribute.

2.2 Deliverable D2.4

The objective of the WG2 is to improve aerosol measurements using solar-, lunar- and star photometry, breaking new grounds for aerosol retrieval techniques including calibration improvement (via S.I. traceable related standardization results), hardware and software improvement actions. The exchange of knowledge and experience among manufacturers, calibration and data processing related scientists and users by establishing a network through HARMONIA, are the foundations for those improvements. The exploitation of existing measurement experimental data for different aerosol environments is one of the main sources of information for investigating and suggesting improvements of aerosol photometry measurement. The fourth deliverable of the WG2 is:

Deliverable D2.4: "Report on uncertainties for optimized and homogenized products and suggestions for improving already existing products."

The joint online WG1–WG2 meeting of 12 December 2025 discussed the topics feeding the deliverables of both WGs, some of which are common.

At the Astypalea workshop, the D2.4 template was shared as an online document with a suggested structure for the content, and members were invited to add their contributions. Work related to D2.4 was also presented during the meeting.

At the Helsinki MC meeting the D2.4 document in progress was presented and members were again invited to add contributions. Work for D2.4 was also presented, along with results from two recent VMs that will be part of the deliverable.

2.3 Deliverable D3.3

The objective of the WG3 is to increase the applicability for aerosol optical properties for different scientific fields. HARMONIA network and specifically WG3 aims to link the accuracy and uncertainty of aerosol optical properties to the objectives and needs of the climate and atmospheric related scientific community and relevant structures (e.g. WMO, GCOS, satellite related missions) and to create interacting mechanisms with users (Climate scientists, air quality, solar energy, aviation and others).The expertise of diverse groups in HARMONIA (ground-based aerosol monitoring, satellite monitoring, atmospheric modelling, etc.) and the networking activities are essential in fulfilling those objectives. The third deliverable of the WG3 is:

D3.3: ” Publish a white paper on sun-photometric aerosol accuracy and uncertainty for different applications.”

After the MC meeting in February 2026, the WG3 leaders e-mailed the HARMONIA WG members asking for contributions to D3.3. As experts in different topics related to the use of radiometric aerosol measurements, members were asked to contribute a couple of paragraphs each, following an indicative assignment in a shared online document. They were also invited to correct the assignments where needed, to recommend people who could help with specific sections or sub-sections, and to involve colleagues. The main goals of the white paper are to:

a) demonstrate the current state of the art of AOD measurements from ground-based instruments, satellites and models (e.g. CAMS, MERRA-2);
b) describe and demonstrate, through a literature review, the use of AOD and other aerosol properties by different communities and applications;
c) identify needs and gaps.

The online document was continuously updated until the final MC meeting in Helsinki (September 2026).
At the final MC meeting in Helsinki (3–4 September 2026), the WG3 leaders presented the status of the white paper. Sections 1 (Introduction) and 2 (Current capabilities) were nearly complete, and most sub-sections of Section 3 (User requirements across disciplines) had been drafted. The following actions remained pending:

- **Section 2 – Current capabilities:** further revision, moving part of the material to a supplement.

- **Section 3 – User requirements across disciplines:**
  - review of Sections 3.1 (Aerosol impacts on solar irradiance) and 3.6 (Aviation);
  - possible shortening of Section 3.2 (Solar energy) and shortening of Section 3.5 (Health);
  - additional contributions to Section 3.3 (Atmospheric composition and climate), particularly on machine-learning techniques, and to Section 3.5 (Health), on complementing PM monitoring;
  - volunteers to draft Section 3.7 (Agriculture, ecosystems and other emerging needs), drawing on material already available in D4.2;
  - upload of a new version and invitation of further contributors and reviewers for specific sections.
- **Section 4 – Gaps and challenges:** to be drafted, reusing material from D4.2 and moving related text from Section 3. Possible topics include geographical coverage (e.g. oceanic and polar regions, developing countries), temporal resolution and diurnal sampling, instrument harmonization and calibration, UV/IR measurements, data latency and dissemination, uncertainty quantification and documentation, and social and geopolitical issues and their impacts.
- **Way forward:** to be added as a short paragraph in Section 4 rather than as a separate section.
- **Overall:** complete the missing information, review the full text and shorten selected sections.

The agreed timeline was:

- **20 September 2026:** finalize Sections 1–3;
- **5 October 2026:** finalize Section 4;
- **15 October 2026:** submit the revised version of the report.

2.4 Deliverable D4.1b

WG4 addresses the challenge: how can scientists improve aerosol measurement quality and future measurement capabilities, including low-cost sensors? Its approach (Objective 4) is to establish an interdisciplinary team of scientists dealing

with aerosol measurements and their use, together with industrial instrument developers, in order to report on the current status of measurement uncertainty and on future technical needs, and to suggest innovative ideas for the future of aerosol remote sensing sensors and retrieval methods.

The second deliverable of WG4 relates to the second WG4 workshop:

D4.1b: "Share the recordings and the presentations of two Workshops that will be organized, with industrial users related with: technological needs and innovation actions."

The second WG4 workshop was held on 30 June 2026 at the Group of Atmospheric Optics of the University of Valladolid (GOA-UVa), Spain, with 18 participants, all attending in person. It focused on low-cost instrumentation and on covering complex regions without measurements. Further details are documented in Deliverable D4.1b.

2.5 Deliverable D4.2

The third deliverable of WG4 is:

D4.2: "Report on hardware and software evolution needs according to WG3 results."

D4.2 was completed (https://harmonia-cost.eu/wp-content/uploads/2026/09/Harmonia_D42.pdf) ahead of the final MC meeting in Helsinki, where the WG4 leaders presented its key points: the highest-priority hardware and software investments, the remaining gaps and strategic recommendations. Its main conclusion is that a measurement ecosystem is needed that combines reference instruments, validated complementary sensors and satellite data.

2.6 Deliverable D5.4

The objective of the WG5 is to increase the dissemination of the produced outcomes of the WG1-4 activities of the HARMONIA COST Action, to aerosol scientists, instrument users and other HARMONA participants inside and outside the HARMONIA consortium, towards measurement improvement, new techniques and

measurement approaches, sharing of protocols etc. thus contributing to the objectives of the Action.

A lot of dissemination activities took place in the 4 years of HARMONIA Cost Action which are reported in the following deliverable:

D5.4: ”Report on the dissemination of HARMONIA results to major stakeholder conferences.

Many dissemination activities took place during the four years of the HARMONIA COST Action; they are reported in D5.4. The deliverable was prepared by Anca Nemuc, WG5 leader, with contributions from the core group and will be published on the website of HARMONIA