COST Action
Final Achievement Report

ES1303: Towards operational ground based profiling with ceilometers, doppler lidars and microwave radiometers for improving weather forecasts (TOPROF)

(22/10/2013 to 21/10/2017)

The Action was approved by the Committee of Senior Officials (CSO) on 16-5-2013 and has the MoU reference COST 012/13.

This report shows the data entered into e-COST to enable the Action Chair to verify the completeness and accuracy of the report with the MC prior to submitting the report via e-COST in fulfilment of the rules for COST Action Management, Monitoring and Final Assessment.

COST Association AISBL | Avenue Louise 149 | 1050 Brussels, Belgium
T +32 (0)2 533 3800 | F +32 (0)2 533 3890 | office@cost.eu | www.cost.eu

Funded by the Horizon 2020 Framework Programme of the European Union

Action leadership and participants

Leadership Positions

Position	Name	Contact details	Country of work affiliation
Chair	Prof Anthony Illingworth	A.J.Illingworth@reading.ac.uk +441183786508	UK

Position	Name	Contact details	Country of Nomination
Vice Chair	Dr Dominique Ruffieux	dominique.ruffieux@meteoswiss.ch +41266626247	CH

Working Groups

#	WG Title	# of participants	WG Leader	Country of nomination
1	Ceilometers	30	Dr Martial Haeffelin martial.haeffelin@ipsl.polytechnique.fr	FR
2	Doppler Lidars	20	Dr Ewan O'Connor e.j.oconnor@reading.ac.uk	FI
3	Microwave radiometers	25	Dr Domenico CIMINI domenico.cimini@imaa.cnr.it	IT
4	Use of the new data in NWP	25	Prof Roland Potthast roland.potthast@dwd.de	DE

Participants

COST Members having accepted the MoU

AT	20/07/2013	**BE**	06/08/2013	**BG**	08/08/2013	**DK**	07/10/2013	**FI**	30/09/2013
FR	05/07/2013	**DE**	19/06/2013	**EL**	27/11/2013	**HU**	28/08/2013	**IS**	10/02/2015
IE	26/09/2013	**IL**	10/02/2015	**IT**	09/07/2013	**NL**	10/04/2014	**NO**	21/08/2013
PL	27/09/2013	**PT**	16/09/2013	**RO**	25/06/2013	**ES**	06/06/2013	**CH**	03/07/2013
TR	30/10/2013	**UK**	31/05/2013						

Other Participants

Institution Name	Country

Summary

Main aim/ objective

The main objective of the Action is to co-ordinate the operation of the many ceilometers, Doppler lidars and microwave radiometers installed across Europe, so they can be networked and provide quality controlled observations to National Meteorological and Hydrological Services (NMHSs) in near real time.

The Action addressed this as described below.

TOPROF has successfully implemented procedures so that observations from three previously under-exploited instruments are now suitable for use by European NMHSs to validate their new generation of high resolution numerical weather prediction (NWP) models. Ultimately the aim is to assimilate the data into the NWP model to improve forecasts of hazardous weather. TOPROF has developed the algorithms to convert the new observations into variables used in the NWP models and tested routines to ensure that the data are calibrated, in a standard format, and quality controlled.

Automatic Lidar Ceilometers (ALC) measure aerosol and cloud backscatter profiles. WG1 has developed the routines for identifying aerosols, volcanic ash, fog, cloud phase, depth and density from the ALC profiles. At present observations from 155 ALCs in 14 countries are being distributed in near-real time to European NMHSs; this should rise to several hundreds within a couple of years. The deployment and near-real time data exchange of the ALCs in Europe is the responsibility of NMHSs via the EUMETNET 'E-PROFILE'. The real-time data can be viewed at http://eumetnet.eu/alc-network. Volcanic dust and fog can cause major transport disruption. On-going trials of ALCs fog forecasting at Paris, Munich and Vienna airports are organised by WG1 (http://www.lmd.polytechnique.fr/~madrouin/parafog).

Doppler Wind Lidars (DWL) sense the movement of aerosol particles and so measure wind and turbulence. WG2 has developed DWL algorithms for characterising boundary layer winds, low level jets, turbulence, wind gustiness, and distorted airflow around isolated islands. FMI (Finnish Meteorological Institute) is studying their application for improving forecasts in an operational environment, and other stations have implemented these algorithms to display products in real-time (see http://macehead.nuigalway.ie/rt/lidar.html). E-PROFILE is distributing data from a few DWLs in Germany on an experimental basis; in 2018 this will be extended and become operational.

Microwave radiometers (MWR) provide temperature and humidity profiles together with column integrated liquid cloud water. Two TOPROF measurement campaigns allowed WG3 to draft and distribute recommendations for common calibration and uncertainty characterization. Common data exchange formats were defined and implemented. A fast forward model and a one-dimensional variational retrieval code were developed to allow data assimilation into NWP. WG3 published a long-term analysis of observation minus NWP model background statistics for 6 prototype network nodes, showing that the network is ready to operate. The inclusion of MWR to E-PROFILE has been proposed to EUMETNET.

WG4 has investigated the impact of these new observations on improving weather forecast. Preliminary studies have been made at ECMWF of assimilating ALC data on smoke from Canadian forest fires. An analysis of MWR observations has shown a potential impact in improving the forecasts of heavy rainfall events in the Mediterranean.

Six joint MC/WG meetings have been held in CH, DK, ES, FR, BG and IE, with attendance (55 in average) from 22 countries, 16 NMHSs and 6 European instrument manufacturers. There have been 24 STSMs and 12 special WG meetings (reports on the TOPROF website). 16 refereed open literature papers acknowledge TOPROF and the contribution of COST.

Action website

http://www.toprof.imaa.cnr.it

Achievement of MoU objectives, deliverables and additional outputs/ achievements

MoU objectives

Please self-assess and describe the level of achievement of each MoU objective. For any MoU objectives that were less than 76% achieved please provide justification.

Please provide proof to enable the Action Rapporteur to confirm the level of achievement.

Mou objective	To implement a harmonized ceilometer network reporting quality-controlled calibrated attenuated backscatter profiles of aerosols and clouds in near real time across Europe.		
Type of objective	1.b Coordination of information seeking, identification, collection and/or data curation 1.f Achievement of a specific tangible output that cannot be achieved without international coordination (e.g. due to practical issues such as database availability, language barriers, availability of infrastructure or know-how, etc.) 2.d Acting as a stakeholder platform or trans-national practice community, pertaining to a certain area of socio-economical or societal application, or to a certain market sector		
Level of achievement of MoU objective	76 - 100%	**Dependence of achievement on the action networking**	High
Proof of achievement of MoU objective	At present observations from 155 ceilometers in 14 countries are being distributed operationally to European NMHSs; this should rise to several hundreds within a couple of years. The calibration procedures, retrieval algorithms, quality assurance and data formats have been the responsibility of TOPROF. The deployment and near-real time data exchange of the ALCs in Europe is the responsibility of NMHSs via the EUMETNET 'E-PROFILE'. The real-time data can be viewed at http://eumetnet.eu/alc-network. Plans are to extend the European network to 250 systems. This has been achieved by the following activities within Work Group 1: A new version of the RAW2L1 (python language) converting tool to put all ALC data in a common data format has been developed (available since autumn 2015) and delivered to E-PROFILE. The RAW2L1 can be accessed from the French Renater research forge https://sourcesup.renater.fr/projects/sirta-raw2l1/ WG1 developed ALC calibration software and recommend specific calibration techniques dependent on ALC detection technology (Rayleigh calibration technique for photon-counting detection and cloud calibration technique for analog detection). Software delivered to E-PROFILE. Implementation at E-PROFILE Hub on-going (MetOffice). http://www.toprof.imaa.cnr.it/index.php/short-term-scientific-mission/8-1-short-term-scientific-mission ALC measurement uncertainties have been assessed. Instrument issues have been raised and partially solved through discussions with manufacturers. WG1 produced several documents making recommendations on ALC configurations, operations, and uncertainties. See for example Kotthaus et al. 2016 (http://www.atmos-meas-tech-discuss.net/amt-2016-87/) and Hervo et al. 2016 (http://www.atmos-meas-tech-discuss.net/amt-2016-30/) An ALC intercomparison campaign was organized by Working Group 1 for 3 months (June-Aug 2015) at the DWD Lindenberg observatory, where 12 instruments have been compared. This unprecedented dataset is currently used for investigations concerning calibration, uncertainty estimates, cloud detection, and aerosol retrievals and it is available through http://ceilinex2015.de/		

Mou objective	To evaluate the backscatter profiles predicted by the prognostic aerosol schemes within the next generation of European forecast models for forecasting air quality as exemplified by the EU-FP7 MACC model at European Centre for Medium-Range Weather Forecasts (ECMWF).

Type of objective	1.f Achievement of a specific tangible output that cannot be achieved without international coordination (e.g. due to practical issues such as database availability, language barriers, availability of infrastructure or know-how, etc.)		
Level of achievement of MoU objective	51 - 75%	**Dependence of achievement on the action networking**	High
Proof of achievement of MoU objective	Two Tasks to support this objective: Coordinated developments based on the 4 Tasks described above has lead to the provision of a dataset of calibrated attenuated backscatter profiles based on 10 stations (E-PROFILE Testbed) covering a 3-month period (June-Aug 2015). This first dataset was provided to WG4 in October 2015. WG1 supports the development of ALC forward operators by WG4. A special working group meeting dedicated to this issue was organized in 27-28 July in Reading (http://www.toprof.imaa.cnr.it/images/toprof/sub_working_group/SWG_Scientific_Report_Meeting_final_AI2.pdf). Attenuated backscatter profiles simulated from ECMWF CAMS forecasts will be compared to ALC measurements (O-B comparisons) based on the 3-month dataset described above. Results were presented at the SWG meeting held in Paris in December 2016 (http://www.toprof.imaa.cnr.it/images/toprof/sub_working_group/Scientific_Report_ABL_Paris2017.pdf).		
Please provide a justification(s) for any MoU objectives that were less than 76% achieved.	Evaluation of the forecast models has not been possible as the distribution of real time ceilometer data to European forecasting centres has only been implemented during the past six months.		

Mou objective	To set up a system to monitor the spatial distribution, height and density of aerosol plumes (e.g. volcanic ash, mineral dust, biomass burning, or industrial accidents) over Europe, which are key information for air traffic safety, and to monitor the depth through which surface emitted species are mixed or trapped over Europe, a key factor for pollutant concentration predictions.		
Type of objective	1.a Development of a common understanding/definition of the subject matter 1.d Comparison and/or performance assessment of a theory, model, methodology, technology or technique		
Level of achievement of MoU objective	76 - 100%	**Dependence of achievement on the action networking**	High
Proof of achievement of MoU objective	A system to monitor in real time these characteristics of aerosols derived from ceilometer profiles has been set up as described in objective 1. This has been achieved by the following activities: fog prediction using ALC profiles to trace aerosol activation processes. See publication: Haeffelin et al. 2016 (http://www.atmos-meas-tech-discuss.net/amt-2016-182/) Several algorithms have been developed, tested, adapted (e.g. STRAT+, Pathfinder+, Manufacturer algorithms) to estimate mixing height from ALC data. Discussions about mixing height retrieval between TOPROF and ICOS were organized on multiple occasions. WG1 to harmonize TOPROF and ACTRIS definitions and recommendations regarding mixing layer height retrievals. Investigations to derived mass concentration profiles from ALC calibrated attenuated backscatter are carried out by several groups. Instrument-to-instrument variability is investigated using Ceilinex data.		

Mou objective	To establish the operational procedures for the new Doppler lidars by defining suitable scan strategies which combine zenith viewing operation to sense vertical wind structure and turbulence with azimuth scanning operation to provide accurate and representative high resolution profiles of horizontal winds.
Type of objective	1.a Development of a common understanding/definition of the subject matter 1.b Coordination of information seeking, identification, collection and/or data curation

	2.b Building a community around a new or emerging field of research		
Level of achievement of MoU objective	76 - 100%	**Dependence of achievement on the action networking**	High
Proof of achievement of MoU objective	The operational procedures for the Doppler lidars have been established and are currently being tested by EUMETNET. Data from one Doppler lidar is being distributed experimentally in near real-time to European NMHSs. Within 12 months this should be extended to 20 Doppler lidars. This has been achieved by the following activities: WG2 has assessed instrument performance, and is establishing operational procedures for generating quality-controlled wind and turbulence profiles at high spatial and temporal resolution from Doppler lidar across Europe. Instrument measurement uncertainties were assessed in three STSMs, with issues reported to and discussed with manufacturers. Post-processing procedures to enable reliable uncertainty estimates have been developed, see publication: Manninen et al., 2016 (http://www.atmos-meas-tech.net/9/817/2016/amt-9-817-2016.pdf) Special Working Group meetings (11-12 Sep, 2014, Fuerstenwalde; 2-3 Mar, 2015, Helsinki; 4-6 April 2017, Helsinki) were devoted to defining operational procedures for retrieving profiles of horizontal wind from different instruments, and instrument configurations; and for methods for retrieving turbulent properties from different instruments and instrument configurations. The SWG Scientific reports are available on the TOPROF website. The ability of Doppler wind lidars to retrieve wind gust measurements (vital for forecasting) has been assessed in three STSMs. See publication: Suomi et al., 2017 (http://onlinelibrary.wiley.com/doi/10.1002/qj.3059/full) Objective detection of low-level jets and associated turbulence was demonstrated. See publication: Tuononen et al., 2017 (http://journals.ametsoc.org/doi/pdf/10.1175/JAMC-D-16-0411.1)		

Mou objective	To investigate the ability of the Doppler lidars to identify the various boundary layer states, such as, stable, unstable, coupled and decoupled, so that boundary layer classification and parameterization schemes implicit in NWP models can be evaluated.		
Type of objective	1.a Development of a common understanding/definition of the subject matter 1.d Comparison and/or performance assessment of a theory, model, methodology, technology or technique 2.b Building a community around a new or emerging field of research		
Level of achievement of MoU objective	76 - 100%	**Dependence of achievement on the action networking**	High
Proof of achievement of MoU objective	TOPROF has investigated the ability of Doppler lidars to retrieve properties of the boundary layer as described below. New turbulent retrievals (e.g. http://www.atmos-meas-tech.net/8/1875/2015/amt-8-1875-2015.html) allow the diagnosis of various aspects of the dynamical boundary layer, including type and height, and identifying the presence and source of mixing. An STSM was dedicated to developing a classification method and a report is available on the TOPROF website. An STSM investigated synergy with MWRs, combining thermodynamic and turbulent profile information. Improvements and updates to the standard classical picture of the boundary layer, prompted by the new Doppler lidar observations, continue to be evaluated.		

Mou objective	To establish the operational procedures for the microwave radiometers by defining protocols for calibration procedures, scanning strategies, and maintenance.

Type of objective	1.b Coordination of information seeking, identification, collection and/or data curation 1.d Comparison and/or performance assessment of a theory, model, methodology, technology or technique 1.h Input for future market applications (including cooperation with private enterprises)		
Level of achievement of MoU objective	76 - 100%	**Dependence of achievement on the action networking**	High
Proof of achievement of MoU objective	WG3 has organised Special Working Group (SWG) meetings, including two field campaigns (Joint microwave CALibration experiment, J-CAL 1 (August 2014) and 2 (September 2015)) to develop recommendations for microwave radiometer absolute calibration procedures using liquid nitrogen and well as the sky-tipping approach; this was carried out for instruments from the two common, commercial manufacturers. Additionally, a common set-up of measurements was derived to provide a better characterization on the absolute accuracy as well as on the uncertainty of microwave radiometer observations. The SWG scientific reports of J-CAL 1 and 2 are available on the TOPROF website, as well as the following “Recommendations for operation and calibration of MWR within a network” (http://www.toprof.imaa.cnr.it/images/toprof/pubs/TOPROF_MWR_recommendations_20160315.pdf). During a further SWG on "Improved MWR data flow - from instrument to user” (March 2016) a document containing a guideline for users during the calibration and operation procedure was completed and afterwards circulated among all European MWR users. It is also available via the TOPROF website. Software requirements needed to improve the uncertainty characterization of the measurements were drafted, which are currently iterated with the manufacturers. In addition, improved calibration approaches were presented. Based on the J-CAL activities, one major MWR manufacturer renewed its absolute calibration approach with liquid nitrogen. An absolute accuracy down to 0.1 K in brightness temperature measurement is now possible, stating an improvement of almost a factor of 10 compared to prior calibration approaches. In addition, a future system for automatic, uninterrupted live monitoring of all relevant MWR data and meta data streams within a future operational network was discussed and is currently being conceptualized in close cooperation with one of the MWR manufacturers.		

Mou objective	To foster the utilization of disparate microwave radiometer observations by implementing a harmonized microwave radiometer data processing chain to provide quality-controlled calibrated multiple frequency radiances (for direct data assimilation into forecast models) and accurate profiles of temperature and humidity as well as cloud liquid water path in a near real time monitoring network.		
Type of objective	1.b Coordination of information seeking, identification, collection and/or data curation		
Level of achievement of MoU objective	76 - 100%	**Dependence of achievement on the action networking**	High
Proof of achievement of MoU objective	There has been extensive collaboration between TOPROF scientists and members of national weather services through several STSMs to advance the use of microwave radiometers. A harmonized microwave radiometer data processing chain (mwr_pro), providing quality-controlled level 1 (calibrated radiances for direct NWP DA) and level 2 (temperature and humidity profile retrievals) has been developed. The processing chain has been tested on 6 prototype network nodes off-line. mwr_pro is freely available for download (ftp://gop.meteo.unikoeln.de/pub/loehnert/mwr_data_flow/). The operators of MWR at these 6 nodes agreed to commit to a continuous, harmonized and quality-controlled data flow to a central data server. The near real time processing is planned among the activities following up the TOPROF action.		

Mou objective	To investigate optimized means of using downwelling radiance observed with the microwave radiometer network to derive profiles of temperature with highest accuracy

	in the boundary layer, lower resolution humidity profiles and the integrated water vapour and cloud liquid water path in the observed column.		
Type of objective	1.f Achievement of a specific tangible output that cannot be achieved without international coordination (e.g. due to practical issues such as database availability, language barriers, availability of infrastructure or know-how, etc.) 1.j Dissemination of research results to stakeholders (excluding specific input in view of knowledge application)		
Level of achievement of MoU objective	76 - 100%	**Dependence of achievement on the action networking**	High
Proof of achievement of MoU objective	A fast forward model to simulate MWR observations from NWP data output has been developed (RTTOV-gb), building on the heritage of tools developed for satellite observation DA. RTTOV-gb will be distributed freely from the EUMETSAT NWP SAF (https://www.nwpsaf.eu/site/software/rttov/). A network-suitable 1-dimentional Variational (1DVAR) code exploiting RTTOV-gb and microwave radiometer observations for the retrieval of temperature, water vapour, and cloud liquid water path has been developed. The 1DVAR code has been tested on data from MWR of different types located in 6 prototype network nodes (http://www.toprof.imaa.cnr.it/images/toprof/short_term_scientific_mission/STSM_Scientific_Report_Martinet.pdf).		

Mou objective	To collaborate with researchers running NWP models in NMHSs to ensure that the quality controlled data from the remote sensing networks of ceilometers, Doppler lidars and microwave radiometers meets their requirements.		
Type of objective	1.f Achievement of a specific tangible output that cannot be achieved without international coordination (e.g. due to practical issues such as database availability, language barriers, availability of infrastructure or know-how, etc.)		
Level of achievement of MoU objective	76 - 100%	**Dependence of achievement on the action networking**	High
Proof of achievement of MoU objective	During TOPROF there has been extensive collaboration with NWP modellers from the 16 NMHSs that are participating in TOPROF as described below. Preparation of common formats for the ALCs, DWLs and MWRs to enable comparison with NWP models. A special working group meeting on forward operators for ALCs was carried out end of July 2015. Close collaboration with Meteo France, MeteoSwiss, and DWD exists to demonstrate the positive impact of MWR observations on updating model output within data assimilation experiments. For MWR, O-B statistics have been analysed for a 1-year dataset at 6 prototype network nodes. During an SWG at DWD, Offenbach (December 2016), it was agreed to continue a cooperation (DWD, MeteoFrance, University of Cologne, University of L'Aquila) with the objective to run an OSSE (Observation System Simulation Experiment) for characterizing the impact of microwave radiometer and DIfferential Absorption Lidar (DIAL) observations on the quality short term weather forecasts. At this SWG - in coordination with E-PROFILE representatives - it was decided to evaluate MWR for the 2nd phase of E-PROFILE (2019-2023). The scientific report is available on the TOPROF website (http://www.toprof.imaa.cnr.it/images/toprof/sub_working_group/Scientific_Report_SWG3.7_Offenbach.pdf)		

Mou objective	To discuss with climate modellers their precise requirements for long term data sets acquired COST 012/13 12 TECHNICAL ANNEX EN by these ground based networks and their use in evaluating the parameterisation schemes in climate models run in forecast mode. If the climate models are based on sound physical principles rather than empirically tuned parameterization schemes, then there will be greater confidence in their ability to predict climate change.
Type of objective	1.b Coordination of information seeking, identification, collection and/or data curation

	1.g Input to stakeholders (e.g. standardization body, policy-makers, regulators, users), excluding commercial applications		
Level of achievement of MoU objective	76 - 100%	**Dependence of achievement on the action networking**	Medium
Proof of achievement of MoU objective	The considered ground-based remote sensing instruments are gaining consideration in the climate monitoring community, especially for characterizing boundary layer schemes and cloud-aerosol interaction. The Global Climate Observing System (GCOS) Reference Upper-Air Network (GRUAN) has evolved in the last decade from aspiration to reality and it is now delivering reference-quality measurement of Essential Climate Variables. In addition to radiosonde observations, ground-based remote sensing products are planned in GRUAN, including from remote sensing instruments such as MWR. The Action's WGs have engaged the information exchange with GRUAN management, e.g. WG3 provided the expertise to draft the GRUAN MWR products guidelines.		

Deliverables

This section covers only deliverables that were foreseen for the Action, not additional outputs that were generated during the Action (these additional outputs will be added in the following section). Please select and comment on the level of achievement of each deliverable as well as the extent to which the achievement was dependant on the Action networking.

For deliverables that are:

- Delivered, please provide proof to enable the Action Rapporteur to confirm the delivery
- Not delivered but delivery is foreseen within 2 years please explain how the delivery will be achieved
- Not foreseen to be delivered please explain why not

Deliverable	Standardised techniques for calibrating, maintaining and operating ceilometers, Doppler lidars, microwave radiometers so that the products derived from them are quality controlled and accompanied by quantified errors.		
Level of achievement of deliverable	Delivered	**Dependence of achievement on the action networking**	High
Proof of achievement of deliverable	http://www.toprof.imaa.cnr.it/index.php/deliverable-1		

Deliverable	Standardised formats and data protocols, so that observations can be exchanged in near real time between the various NMHSs across Europe.		
Level of achievement of deliverable	Delivered	**Dependence of achievement on the action networking**	High
Proof of achievement of deliverable	http://www.toprof.imaa.cnr.it/index.php/deliverable-2		

Deliverable	Standardised retrieval algorithms for ceilometers, Doppler lidars and MWRs so that key atmospheric properties (clouds, humidity, temperature, aerosol, and winds) can be derived together with their errors.		
Level of achievement of deliverable	Delivered	**Dependence of achievement on the action networking**	High
Proof of achievement of deliverable	http://www.toprof.imaa.cnr.it/index.php/deliverable-3		

Deliverable	Forward models and metrics for model evaluation.		
Level of achievement of deliverable	Delivered	**Dependence of achievement on the action networking**	High
Proof of achievement of deliverable	http://www.toprof.imaa.cnr.it/index.php/deliverable-4		

Additional outputs / achievements

Co-authored Action publications

Please enter below ONLY publications (including publications that are submitted but not yet accepted):

- that are on the topic of the Action, and
- that are co-authored by at least two Action participants from two countries participating in the Action, and
- for which the Action networking was necessary.

Please pay special attention to representatives of Inclusiveness Target Countries (ITCs) in each publication. If there are more than 20 you *may* choose to enter only the most 20 significant (in terms of Inclusiveness, Excellence and the MoU objectives).

	Bibliographic data	Countries participating in the Action among authors	Open Access	COST cited?	COST funds?	Relevance to H2020 Societal challenge	Peer Reviewed?
1	Illingworth, A. J., D. Cimini, C. Gaffard, M. Haeffelin, V. Lehmann, U. Loehnert, E. J. O'Connor, D. Ruffieux, Exploiting Existing Ground-Based Remote Sensing Networks To Improve High Resolution Weather Forecasts, Bull. Amer. Meteor. Soc. doi: 10.1175/BAMS-D-13-00283.1, February, 2015 10.1175/BAMS-D-13-00283.1	FI, FR, DE, IT, CH, UK	Y	Y	Y	Climate action, environment, resource efficiency and raw materials	Y
2	Cimini, D., Nelson, M., Güldner, J., and Ware, R.: Forecast indices from a ground-based microwave radiometer for operational meteorology, Atmos. Meas. Tech., 8, 315-333, doi:10.5194/amt-8-315-2015, 2015. 10.5194/amt-8-315-2015	DE, IT	Y	Y	N	Climate action, environment, resource efficiency and raw materials	Y
3	Schween, J. H., Hirsikko, A., Löhnert, U., and Crewell, S., 2014: Mixing layer height retrieval with ceilometer and Doppler lidar: from case studies to long-term assessment, Atmos. Meas. Tech., 7, 3685-3704, http://dx.doi.org/10.5194/amt-7-3685-2014 10.5194/amt-7-3685-2014	FI, DE	Y	N	N	Climate action, environment, resource efficiency and raw materials	Y
4	Vakkari, V., O'Connor, E. J., Nisantzi, A., Mamouri, R. E., and Hadjimitsis, D. G.: Low-level mixing height detection in coastal locations with a scanning Doppler lidar, Atmos. Meas. Tech., 8, 1875-1885, doi:10.5194/amt-8-1875-2015, 2015.	FI, UK	Y	N	N	Climate action, environment, resource efficiency and raw materials	Y

10.5194/amt-8-1875-2015

5	Manninen , A. J., O'Connor, E. J., Vakkari, V. and Petäjä, T.: A generalised background correction algorithm for a Halo Doppler lidar and its application to data from Finland. Atmos. Meas. Tech., 9, 817–827, doi:10.5194/amt-9-817-2016, 2016 10.5194/amt-9-817-2016	FI, UK	Y	N	N	Climate action, environment, resource efficiency and raw materials	Y
6	Gryning, S.E., Floors, R., Peña, A., Batchvarova, E., and Brümmer, B.: Weibull wind-speed distribution parameters derived from a combination of wind-lidar and tall-mast measurements over land, coastal and marine sites, Boundary-Layer Meteorol. 159, 329–348, doi:10.1007/s10546-015-0113-x, 2016. 10.1007/s10546-015-0113-x	BG, DK	Y	Y	N	Climate action, environment, resource efficiency and raw materials	Y
7	Caumont O., D. Cimini, U. Löhnert, L. Alados-Arboledas, R. Bleisch, F. Buffa, M. E. Ferrario, A. Haefele, T. Huet, F. Madonna, G. Pace, Assimilation of humidity and temperature observations retrieved from ground-based microwave radiometers into a convective-scale model, Quart. Jour. Roy. Met. Soc., Volume 142, Issue 700, 2692–2704, October 2016 10.1002/qj.2860	FR, DE, IT, ES, CH	Y	Y	Y	Climate action, environment, resource efficiency and raw materials	Y
8	Kotthaus, S., O'Connor, E., Münkel, C., Charlton-Perez, C., Gabey, A. M., Grimmond, C. S. B., and Haeffelin M.: Recommendations for processing atmospheric attenuated backscatter profiles from Vaisala CL31 Ceilometers, Atmos. Meas. Tech., doi: 10.5194/amt-9-3769-2016, 9, 3769-379, 2016. 10.5194/amt-9-3769-2016	FI, FR, DE, UK	Y	Y	Y	Climate action, environment, resource efficiency and raw materials	Y
9	De Angelis, F., Cimini, D., Hocking, J., Martinet, P., and Kneifel, S.: RTTOV-gb – Adapting the fast radiative transfer model RTTOV for the assimilation of ground-based microwave radiometer observations, Geosci. Model Dev., 9, 2721-2739, 2016 10.5194/gmd-9-2721-2016	FR, IT, UK	Y	Y	Y	Climate action, environment, resource efficiency and raw materials	Y
10	Haeffelin, M., Laffineur, Q., Bravo-Aranda, J.-A., Drouin, M.-A., Casquero-Vera, J.-A., Dupont, J.-C., and De Backer, H.: Radiation fog formation alerts using attenuated backscatter power from automatic Lidars and ceilometers, Atmos. Meas. Tech., 9, 5347-5365, 2016. 10.5194/amt-9-5347-2016	BE, FR, ES	Y	Y	Y	Smart, green and integrated transport	Y
11	Hervo, M., Poltera, Y., and Haefele, A.: An empirical method to correct for temperature dependent variations in the overlap function of CHM15k ceilometers, Atmos. Meas. Tech., 9, 2947-2959, 2016	FR, CH	Y	Y	Y	Climate action, environment, resource efficiency and raw	Y

	10.5194/amt-9-2947-2016					materials	
12	Martinet, P., Cimini, D., De Angelis, F., Canut, G., Unger, V., Guillot, R., Tzanos, D., and Paci, A.: Combining ground-based microwave radiometer and the AROME convective scale model through 1DVAR retrievals in complex terrain: an Alpine valley case study, Atmos. Meas. Tech., 10, 3385-3402, https://doi.org/10.5194/amt-10-3385-2017, 2017 10.5194/amt-10-3385-2017	FR, IT	Y	Y	Y	Climate action, environment, resource efficiency and raw materials	Y
13	De Angelis, F., Cimini, D., Löhnert, U., Caumont, O., Haefele, A., Pospichal, B., Martinet, P., Navas-Guzmán, F., Klein-Baltink, H., Dupont, J.-C., and Hocking, J.: Long-term observations minus background monitoring of ground-based brightness temperatures from a microwave radiometer network, Atmos. Meas. Tech., 10, 3947-3961, https://doi.org/10.5194/amt-10-3947-2017, 2017 10.5194/amt-10-3947-2017	FR, DE, IT, NL, CH, UK	Y	Y	Y	Climate action, environment, resource efficiency and raw materials	Y
14	Suomi, I., Gryning, S.-E., O'Connor, E. J. and Vihma, T.: Methodology for obtaining wind gusts using Doppler lidar. Q.J.R. Meteorol. Soc., 143: 2061–2072. doi:10.1002/qj.3059, 2017. 10.1002/qj.3059	DK, FI, UK	Y	Y	N	Climate action, environment, resource efficiency and raw materials	Y

Projects resulting from Action activities

Please enter below all the projects on the topic of the Action resulting from Action activities, involving at least one Action participant, and for which the Action networking was necessary.

The Action reported 2 project(s) and 0 proposal(s) resulting from the Action networking.

Key details of the projects are shown below.

#	Title	Countries participating in the Action among proposers	Main proposer name	Funder	Amount	Call identifier	Relevance to H2020 Soc challenge
1	GAIA-CLIM	FR, DE, IT	Peter Thorne	H2020	6000000 €	H2020-EO-3-2014	Climate action, environment,

							resource efficiency and raw materials
2	ACTRIS-2	FI, FR, PT, RO, ES, UK	Gelsomina Pappalardo	H2020	500000 €	H2020-INFRAIA-2014-2015	Climate action, environment, resource efficiency and raw materials

Other outputs / achievements

Please enter below any additional outputs/ achievements on the topic of the Action that contribute to the COST mission: “COST enables break-through scientific developments leading to new concepts and products and thereby contributes to strengthen Europe’s research and innovation capacities", and for which the Action networking was necessary (e.g. a patent, standards, white paper).

Output / achievement description	Dependence of achievement on the Action networking
The four European manufacturers of ALCs are member of the action, as are the two manufacturers of Doppler Wind Lidars, and the only European Manufacturer of Microwave Radiometers. This is a field where European manufacturers are currently dominating the market.	High
TOPROF activities have led to a modification of ALC firmware by European manufacturer to enable qualitative exploitation of attenuated backscatter profiles provided by the instruments	Medium
TOPROF activities have led to a significant adaptation of the common MWR liquid nitrogen calibration method as well as modification of MWR firmware and software of the leading European manufacturer.	Medium
TOPROF activities have shown that Doppler wind lidars can provide wind gust estimates.	Medium

Impacts

Please describe the impacts (the short- to long-term scientific, technological, and / or socioeconomic changes produced by a COST Action, directly or indirectly, intended or unintended) that have resulted, or might result, from the Action in the following table (one impact per line).

Description of the impact, i.e. what will change, and for whom, as a result of what the Action achieved	Type of impact	Timing of impact
TOPROF has been involved with defining the ISO standard for Doppler wind lidars.	• Economic	Achieved
TOPROF scientists from NMHSs are leading the installation of the European ceilometer network	• Economic	Achieved
Fog forecasting at airports – large economic implications. Experimental implementation at Paris, Munich, Vienna airports	• Economic • Societal	Achieved
The Bulletin of American Meteorological Society (BAMS) has agreed to host a paper summarizing the achievements of TOPROF in their journal. BAMS is a highly reputed journal reaching a wide scientific community as well as decision makers	• Scientific / Technological	Achieved
The major impact has been the setting up via EUMETNET of a system for distributing in near real time the data from ceilometers to NMHSs. Currently observations from 155 ceilometers are being distributed, and one Doppler lidar. Next year this will be extended to many hundreds of ceilometers, and 20 Doppler lidars. EUMETNET is considering distributing Microwave Radiometers data starting in 2019. The impact of this activity will be the assimilation of these new data streams which should improve the accuracy and reliability of forecasts of pollution events, fog, volcanic ash. The cloud profile data from ceilometers should improve forecasts of precipitation and consequent flooding.	• Scientific / Technological • Economic • Societal	Foreseen within 2 years
Volcanic ash monitoring/forecasting – large economic implications	• Economic • Societal	Foreseen within 2 years
MWR has been proposed as part of the Global Climate Observing System Reference Upper Air Network (GRUAN) - through providing high-temporal-resolution observations in the atmospheric boundary layer, MWR observation are expected to improve short-term weather forecasts once implemented	• Scientific / Technological	Foreseen within 2 years
High density ceilometer network over Europe for monitoring of aerosol and volcanic ash feeding data in near-real time directly to national weather forecasting centres.	• Economic • Societal	Foreseen within 2 years
Doppler lidars to provide the missing winds in the boundary layer to complement the existing operational wind profilers in E-PROFILE.	• Scientific / Technological	Foreseen 2-5 years
MWR have been proposed and are currently being evaluated for the E-PROFILE 2nd phase (2019-2023). A positive evaluation would make a centralized network observation approach possible and make data available to NMHSs in real-time.	• Scientific / Technological	Foreseen 2-5 years

Please describe how the Action has advanced careers, skills and network of researchers, including Early Career Investigators (for example: joint supervision of graduate and PhD students, research exchanges not funded by the action, collaborations, Training Schools with ECTS accreditation, joint projects, internship and job prospects.

Networking between scientists, NMHS staff, and instrument manufacturers has led to: - instrument firmware and

hardware improvements, increasing the competitiveness of European companies in the remote sensing instrument market - pioneer studies on the data assimilation of ground-based remote sensing instrumentation. The Action has also allowed: - collaborations between research bodies and application services (NMHSs) - joint supervision of graduate and PhD students (e.g. De Angelis by Martinet, Saeed by Cimini).

The career benefits were mainly to researchers with the following amount of experience after their PhD: ≤ 8 years

Which of the stakeholders described in the “Plan for involving the most relevant stakeholders” in the Action’s MoU have been engaged and how? What additional stakeholders have been, or will be, engaged and how? This information will not be included in the Action Report that is made publicly available (on the website).

Stakeholder from European NMHS have been engaged through: - a dedicated session at the European Meteorological Society (EMS) annual meeting - a training school organised back-to-back with the EMS Annual meeting Stakeholder from International NMHS have been involved through: - solicited representatives from USA and Japan invited to attend the TOPROF dedicated session at the EMS annual meeting

Dissemination and exploitation of Action results (other than co-authored Action publications listed previously)

Please describe the Action's dissemination and exploitation approach as well as all activities undertaken to ensure dissemination and exploitation of the Action results and the effectiveness of these activities.

Dissemination and exploitation approach of the Action

The Action’s dissemination and exploitation approach included: 1. presentations of activities and results at topical conferences 2. organization of special sessions at major conferences 3. publication of main results on scientific open-access journals 4. presentation of action review at major global Symposium (e.g. WMO) 5. training school focusing on the Action's deliverables to foster their exploitation

Dissemination meetings funded by the Action

Title of Dissemination meeting	Meeting date	Meeting country	Action participant	Event name and hyperlink to the website	Title of presentation	Description of added value to the Action
WMO Symposium on Data Assimilation	01-01-1970 to 01-01-1970	Brazil	Dr Ulrich Löhnert	7th International Symposium on Data Assimilation organized by WMO (World Meteorological Organization)	Oral	Dissemination of main results concerning the use of TOPROF instruments in data assimilation to an international audience.

Other dissemination activities

E.g. participation to non-Action meetings, e.g. EU Parliament, meetings with policy makers, experts in the field, regional authorities.

Item/activity	Target audience	Outcome	Hyperlink
Participation in the World Weather Conference. 16-20 Aug 2014, Montreal, Canada	Members of Natioanl Met Services, research centers, universities, and also Media	Presentations by WG chairs and MC v-chairs of WG2, WG4 & WG3 activites	http://wwosc2014.org/pdf/20140825-WWOSC-FinalBookofAbstracts.pdf
European Meteorological Society Annual Meeting, Sept 2015, Bulgaria	Members of National Met Services & Universities	Presentation by chair of WG2	http://www.emetsoc.org/meetings-events/ems-annual-meetings
Presentations at ITARS summer school	ITARS PhD students	TOPROF activities have been presented to	http://tinyurl.com/ITARS-talk-TOPROF-

2014 (EU-Marie-Curie ITN)		ITARS students. Cooperation with ITARS was started and three ITARS PhD students from NL, D and I made presentation to MC3 meeting Roskilde, DK, Nov, 2014.	Roskilde-pdf
Participation in 6th WMO Workshop on the Impact of Various Observing Systems on NWP. 13-16 May 2016 Shanghai, China	Members of Nat Met Services & all major NWP centres	Presentations by WG2/3/4 representative	https://www.wmo.int/pages/prog/www/WIGOS-WIS/meetings/NWP-6_May2016_Shanghai/WMO-NWP-6_Programme_2016-05-12.pdf
Special TOPROF session at International Symposium of Advancements in Boundary layer Research (ISARS). 6-9 June 2016, Varna, Bulgaria.	Members of National Met Services & Universities	The Conference Chair is on TOPROF MC. Facilitated participation by ITC participants and students.	http://isars2016.org/isars/sites/storm.cfd.meteo.bg.isars/files/Programme30May2016Monday.pdf
Participation in ICAP meeting 12-14 July 2016	International science community predicting aerosol loading.	Presentation on the potential near real time data source from ceilometers.	http://icap.atmos.und.edu
Special TOPROF session at European Meteorological Society (EMS) Annual Meeting. 5 September 2017 Dublin, Ireland.	Members of National Met Services & Universities	Dissemination of main results to a broader audience	http://meetingorganizer.copernicus.org/EMS2017/orals/25521

Exploitation activities

Please describe below any activities undertaken to ensure exploitation (use, in particular in a commercial context) of the Action's achievements.

Item/activity	Target audience	Outcome
Training School at EMS, Dublin, 3 September, 2017	Trainees from PhD programs, NMHS, industry	Dissemination of main results and deliverables to 47 delegates: PhD students, industry and mostly NMHS staff

Action Success(es)

Taking into account the achievements, impacts and policy implementation of the Action described in the preceding sections, please describe below the two most significant successes of the Action.

Description of the success	Ceilometers, Doppler radars and Microwave radiometers were present in many European countries but operating independently and not networked. As their name implies, ceilometers were just measuring cloud base, but it was found that they can also detect aerosol, pollution, smoke and volcanic ash. TOPROF has implemented a system whereby the data are now calibrated, using a standard format with common quality control and retrieval algorithms, so that EUMETNET (via their E-PROFILE initiative) are now sending data in near-real time from 150 ceilometers to a central hub where it is distributed to National Weather Services. This number will increase to many hundreds in the next two years. Assimilation of these data in real-time into weather forecast models should improve predictions of high impact weather such as pollution episodes, fog, volcanic ash, and episodes of heavy rainfall leading to severe flooding. The real-time data can be viewed at http://eumetnet.eu/alc-network . In addition, TOPROF has developed a ceilometer based algorithm for improved forecasting fog and has organised trials of this fog forecasting algorithm which are currently being carried out at Paris, Munich and Vienna airports (http://www.lmd.polytechnique.fr/~madrouin/parafog). Fog is a major cause of delays at airports; improved forecasts would lead to considerable financial savings.
Dimensions of the success	• Scientific breakthrough • Technological breakthrough • Breakthrough in socio-economic or societal applications

Description of the success	TOPROF has developed algorithms that use Doppler lidar data to characterise the wind and turbulence in the boundary layer; this boundary layer airflow is responsible for the build-up and dispersal of polluting gases in the air close to the ground. TOPROF has lead first time demonstration of ground-based profiling instrument network data assimilation into numerical weather prediction (NWP). The tools developed within TOPROF will be used in the future for operational NWP data assimilation of ground-based profiling instruments.
Dimensions of the success	• Scientific breakthrough • Technological breakthrough • Breakthrough in socio-economic or societal applications

Other matters

This section is confidential to the Management Committee, the Action Rapporteur and the COST Association, and is not included in the version of the report that is published on the COST website.

Difficulties in implementing the Action

If any difficulties were experienced in the implementation of the Action (e.g. imbalances of participation across the Working Groups, inactive country representatives) please described these below. Please also describe the efforts made by the MC to address these.

It was pointed out that for some representatives from ITC it was difficult to advance the expenses and get reimbursed weeks if not months later. The MC tried to give preference to ITC hosts for the MC/WG meeting, whenever there was more than one candidate country.

Suggestions for improvements to COST framework/ procedures

The mandate of the Scientific Committee includes providing advice to the COST Committee of Senior Officials on possible improvements to the COST framework. Please describe below any improvements that you believe should be made to the COST framework.

The electronic voting system (used to approve the annual work plan) could be extended to all the decisions that require MC approval.

Sustaining the network beyond the Action

Are there any plans to sustain the network beyond the end of the Action?	YES

Please describe how the network will be sustained beyond the end of the Action.

The two H2020 projects linked to TOPROF are still on going.
A proposal for a new, more focused, COST action has been submitted.

Emerging topics/ developments in the field of the Action

Please describe any emerging topics or potentially important future developments identified during the Action and that could potentially be addressed by future COST activities such as Actions S&T Conferences or Exploratory Workshops.

During the Action it emerged that the atmospheric boundary layer is the most important under-sampled part of the Atmosphere. This observation gap affects many societal aspects, including but not limited to weather forecast, aviation meteorology, wind and solar energy, air quality. To bridge this observation gap, an interdisciplinary effort should be organized to network scientists, instrument experts, operational agencies, and end-users.

Annex 1: Types of objectives

1 - Coordination of scientific and technological activities at a European level

1.a - Development of a common understanding/definition of the subject matter

1.b - Coordination of information seeking, identification, collection and/or data curation

1.c - Coordination of experimentation or testing

1.d - Comparison and/or performance assessment of a theory, model, methodology, technology or technique

1.e - Development of knowledge needing international coordination, pertaining to a new or improved theory, model, methodology, technology or technique

1.f - Achievement of a specific tangible output that cannot be achieved without international coordination (e.g. due to practical issues such as database availability, language barriers, availability of infrastructure or know-how, etc.)

1.g - Input to stakeholders (e.g. standardization body, policy-makers, regulators, users), excluding commercial applications

1.h - Input for future market applications (including cooperation with private enterprises)

1.i - Dissemination of research results to the general public

1.j - Dissemination of research results to stakeholders (excluding specific input in view of knowledge application)

2 - Community building

2.a - Building a community around a topic of scientific and/or socio-economic relevance, allowing for knowledge exchange and the development of a joint research agenda

2.b - Building a community around a new or emerging field of research

2.c - Bridging separate fields of science/disciplines to achieve breakthroughs that require an interdisciplinary approach

2.d - Acting as a stakeholder platform or trans-national practice community, pertaining to a certain area of socio-economical or societal application, or to a certain market sector

2.e - Building capacity in the demographic inclusiveness of networks in science and technology, including representation of newly established research groups, Early-Career Investigators, the under-represented gender and teams from countries/regions with less capacity in the field of the Action

Annex 2: Dimensions of successes

1 - Breakthroughs

- 1.a - Scientific breakthrough
- 1.b - Technological breakthrough
- 1.c - Breakthrough in socio-economic or societal applications

2 - Policy contribution

- 2.a - Contribution to regulatory policy
- 2.b - Contribution to environmental, infrastructural or agricultural policy
- 2.c - Contribution to economic or socio-economic policy
- 2.d - Contribution to social, cultural or legal policy

3 - Capacity building

- 3.a - Building capacity in an existing field of science and technology
- 3.b - Building capacity in bridging separate fields of science and technology
- 3.c - Building capacity in a new or emerging field of science and technology
- 3.d - Building capacity in valorising and implementing advances and applications in science and technology
- 3.e - Building capacity in the demographic inclusiveness of networks in science and technology, including representation of newly established research groups, Early-Career Investigators, the under-represented gender and teams from countries/regions with less capacity in the field of the Action