

Authors' Response to Anonymous Referee #1, RC1 (21 Jul 2021):

In this authors' response, the text (normal style) answers point by point to the comment of the anonymous Referee #1 (text in bold). The text in blue corresponds to the authors' change in the manuscript.

Editor decision (by Matthias Themessl): Publish subject to technical corrections

Comments to the author:

Dear authors,

Thank you for your detailed responses to the referees comments as well as in the interactive discussion. The inputs were highly appreciated.

As the project's name is "EUNADICS-AV" I would finally strongly suggest to use the correct name throughout the entire manuscript in order to avoid any confusion. Please adapt the manuscript accordingly.

The correct name throughout the entire manuscript is now used (EUNADICS-AV instead of EUNADICS).

For your information, Saskia Wagenaar has changed of position (from KNMI to NewMotion).

Her email address is the following: saskiawagenaar@gmail.com

Her affiliation is: NewMotion, Amsterdam, The Netherlands.

After the answer to the comment CC1, we realised that 2 co-authors from INGV-EO were missing (Simona Scollo and Giuseppe Salerno)

simona.scollo@ingv.it

giuseppe.salerno@ingv.it

Text modified and co-authors added, are included in the new manuscript.

Note that we have removed the colour in the tables.

Thank you very much for your comments. Best regards,

Hugues Brenot and co-authors

Authors' Response to Anonymous Referee #1, RC1 (21 Jul 2021):

In this authors' response, the text (normal style) answers point by point to the comment of the anonymous Referee #1 (text in bold). The text in blue corresponds to the authors' change in the manuscript.

RC1 from the anonymous Referee #1:

General comments

This study describes European Natural Airborne Disaster Information and Coordination System for Aviation (EUNADICS-AV) Early Warning System (EWS). The EUNADICS EWS greatly extends the existing Support to Aviation Control System (SACS) automatic alert system for airborne volcanic sulfur dioxide SO₂ and ash to include other airborne hazards (dust, smoke and radionuclide clouds) with creation of multiple new alert products (email and web pages with NRT maps, data files) and convenient formats (NetCDF). These new data are provided by EUNADICS partners and external data sources. The EUNADICS system further combines satellite data with the European ground-based networks (lidar and passive) and regional measurements from volcanic observatories in Iceland and Sicily.

EUNADICS serves European users, primarily Volcanic Ash Advisory Centers (VAACs) in London and Toulouse that have operational responsibility for volcanic ash advisories and forecasts. New message formats (NetCDF alert data products) will facilitate using the alerts to initialize plume dispersion models.

There is room for English and punctuation improvements, which would make paper easier to read. Many sentences need re-wording and/or clarification. Specific suggestions are mentioned below.

I found the paper informative and suitable for publication after language and syntax improvements.

OK thank you, this will be addressed.

Specific comments

The aviation hazards satellite data sources are comprehensive, except for direct readout data for Iceland and Europe from Satellite Measurements from Polar Orbit (SAMPO) service (<https://sampo.fmi.fi/products>). Using SAMPO data would help reducing alert latency time and geographical coverage of the EUNADICS system.

Thank you for highlighting this aspect. FMI is partner of EUNADICS. Note that we use Very Fast Delivery from FMI (i.e., over Europe) and GINA (i.e., over Alaska). The following text has been added in section 4.1.1:

Note that a very fast delivery of OMI and OMPS data retrievals (time delivery of ~45 min for northern region, i.e. near Europe and Alaska) is provided by the Finnish Meteorological Institute (FMI) and the Geographic Information Network of Alaska (GINA), as satellite data are received at Sodankylä, Finland, and Fairbanks, Alaska (see <https://sampo.fmi.fi>).

Abbreviations should be explained when first used.

OK, thank you. Done

Consider removing abbreviation from the title.

The only acronym of the title is EUNADICS, which is the name of the system. We would prefer keeping this acronym in the title. As mentioned in the technical corrections, the abbreviation is now explained in the first line of the abstract.

Technical corrections

Abstract is not clear to a general reader, not familiar with the EUNADICS project. I suggest explanation of the abbreviation “EUNADICS” in the abstract. OK done in the first line of the abstract.

45 ATM – explain abbreviation done

47 have shown significant OK thx

48 satellite[s] done

51 e.g.[,] done

55 service[s] done

57 to proceed – consider changing this verb we change by: the interest of implementing

58 ... highlighting the capability of operating early warnings ... - consider re-wording done:

EUNADICS EWS has also shown the need to implement a future relay of radiological data (gamma dose rate and radionuclides concentrations in ground-level air) in case of nuclear accident. This highlights the interest of operating early warnings with the use of homogenised dataset

75 implication in meteorological processing... – clarify done:

Due to atmospheric transport, airborne particle cloud may also travel to area several thousand kilometres apart from the source. Such airborne particles can impact atmospheric dynamics, bringing difficulties to understand meteorological process (Knippertz and Todd, 2012). It can also cause worrying implication and damage for the aviation (Casadevall...).

80 particles done

81 satellite [data] done

84 It makes it possible as it can to provide information We think we can leave the text as it is: It makes it possible as it can provide information

94 <https://meteoalarm.org> done, thx for this updated web link

149 The results - objectives? replacement done

153 Copernicus Atmosphere [Monitoring] Service (CAM5) done

165-166 ... specialization [in] atmospheric transport modelling done

Figure 1: SAMPO service We don't think we should include SAMPO service in Figure 1 (in the list of the existing service used by EUNADICS EWS) as technically we don't use it. We get data from GINA and FMI, not from SAMPO. If a better Very Fast Delivery (VFD) can be obtained than the one already provided by GINA and FMI, this is something we should consider in the future activity of EUNADICS. Note that we added a reference to the VFD from FMI and GINA, and we mentioned SAMPO in section 4.1.1.

186 boards done

195 i.e., done

207 were done

217 possibility -> discussion with ? replacement done

218 Tables 1 and 2 -> 2 and 3? Thx, done

227 overpass done

243 particulate matter (PM) as the abbreviation PM is not used in the manuscript, there is no need to put (PM). Particle matter has been replaced by particulate matter

243 volcanic ash total column [number or mass density] done, using mass density

245 averaging kernel done

250 We reviewed ... done

252 products done

253 section 2.2? The requirements for data integration is in section 2.3 and the inventories of observations in section 2.2, as mentioned in the text:

Requirements for the data integration (section 2.3) have been considered to define a list of data product candidates (Tab. 1 and 2) from inventories of satellite, in-situ and ground-based observations (section 2.2).

276, 277 .. Observatory which operates ... done

281 e.g., done

296 e.g., done, note that a coma after e.g. has been added in all the manuscript

308 at NOAA done

312 MWOs – explain abbreviation done

316 aim at -> with the goal of supporting ... done

317 satellites done

345 use ground observations done

404 when done

405 up to the lower stratosphere – why not in the middle and upper stratosphere? Thank you, we replace lower stratosphere by upper stratosphere (even this is rare and extreme events)

405 Eight? satellites sensors ... Thank you, done

407 Yang et al., [2007] - OMI product has been replaced with conceptually new OMI SO₂ product: Li et al., New-generation NASA Aura Ozone Monitoring Instrument (OMI) volcanic SO₂ dataset: Algorithm description, initial results, and continuation with the Suomi-NPP Ozone Mapping and Profiler Suite (OMPS), Atmos. Meas. Tech., 10, 445-458, doi:10.5194/amt-10-445-2017, 2017. Thank you, you are right, I removed Yang et al. 2007 in the reference. I also added Li in the references (it as missing)

415 between 3 and 21 km, - why is the upper limit 21km? The upper limit was chosen after careful examination of several eruptions, as a lot of false detections above 21 km were observed. This is actually expected as the sensitivity to altitude, which relies on H₂O-SO₂ spectral interferences decreases with altitude (as there is less and less water vapour).

421 e.g., done

423 expressed in Kelvin degree (K) done

432 missing reference: Virtanen et al., (2014) done

438 to define done

443 illustrates done

447 a fast? ash detection done

448 i.e., done, note that a coma after i.e. has been added in all the manuscript

469 presented done

470 is based done

487 is obtained ? OK done

503 triggered we put triggers

Figure 13, left map: should the white box show station Finokalia (Crete), shown on the right? Done, Finokalia, already shown "Fi", is now highlighted by an arrow and the name Finokalia has been added.

549 ash advections have not been observed done

555 networks done

560, 561, 566: e.g., done

608 ZAMG and STUK – explain abbreviations done

609 ZAMG done

610 remove "have been designed" done

613 delete "proceeding". ... is implemented? Done, the text now is:

[Both data sources are ultimately released by STUK after filtering of the EURDEP data is implemented and collecting the EMERCON information](#)

643 new alert products done

644 creates done

667-670 repeat of 645-650 OK thank you, these lines have deleted

683 quantity product – just use product done

715 nuclear central - plant? done

749 remove "thanks to" done

751 explain TRL done, this text has been added:

[In case of a future operationalisation of EUNADICS activity for TRL \(Technology Readiness Levels; see H2020, Annex G of the General Annexes\) of 5 and higher, i.e., system prototype demonstration in operational environment, all the NRT observations will be visible on the EUNADICS data portal.](#)

753 i.e., done

757 allows consultation -> visualization? OK, done

763 burst -> cloud done

801 remove “same” done

814 consider done

839 is operated -> is implemented ? OK, done

855 NCAP fiel -> file? OK, done

857 details done

P36 868 possible done

870 link not found done. We don't know why the link in the pdf was corrupt. Anyway, now this should work. The link has been simplified and the text is the following:

https://sacs.aeronomie.be/alert/SO2_202102241052_202102281322_LNK_TROPOMI.nc is the link to the NCAP provided in the alert webpage (Fig. 25) of the notification (Fig. 24) result of the paroxysm at Etna on 28 February 2021.

873 MWOs – explain done, abbreviation (Meteorological Watch Offices) is now already explained in section 3.1 of this manuscript

890-891 was designed with the goal of ... done

891 passed done

895 obtained -> has been demonstrated? done

899 satellites done

906 has developed done

907 notifications done

908 include done, concern has been replaced by include

913 better spatial resolution – better than what? ‘better’ has been replaced by ‘high’:

[the use of polar orbiting NRT measurements with high spatial resolution \(under 10 km\)](#)

916 Only one aspect done

919 interest -> usefulness? done

920 of using EUNADICS system in done

921 activity about -> utility for ... done

925,930 in the framework of ... done

The following text:

EUNADICS consortium will now target an operationalisation of its activity, in the frame of SESAR H2020, with the objective of completing TRL 6 (demonstration in a relevant environment). EUNADICS EWS passes with success the performance verification.

has been modified to

EUNADICS consortium will now target an operationalisation of its activity with the objective of completing TRL 5 (validation in a relevant environment) and TRL 6 (demonstration in a relevant environment) in the framework of further SESAR developments. EUNADICS EWS passes with success the performance verification in a limited environment (TRL4).

928 proceeding -> implementing done

958 the alert done

971 details done

972 provided done

991 e.g., done

We hope this document answers properly to the specific comments addressed by Referee #1. We are very grateful for this review and all the technical corrections. We apply all of them and hope this will make the paper easier to read.

Thank you very much for this review. Best regards,

Hugues Brenot and co-authors

Authors' Response to Tatjana Bolic, Referee #2, RC2 (02 Aug 2021):

In this authors' response, the text (normal style) answers point by point to the comment of the Referee #2 (text in bold). The text in blue corresponds to the authors' change in the manuscript.

RC2 from Tatjana Bolic (Referee #2):

The paper describes the results of the EUNADICS AV project, which developed different natural hazards observation and notification products, with the goal to support aviation in the cases of airborne natural hazards. My expertise is in aviation, so I cannot judge the background scientific quality, even though it seems impressive to me - the number of different tools, observations and notifications.

I do have several comments, that would require minor text revisions:

1. In the abstract the authors say "All the ATM stakeholders (e.g. pilots, airlines and passengers) can access and benefit of these alert products through this free channel." I find this a bit strong as a statement. Any member of public can access these products, that is true, but it is unclear how they can benefit, as there is no explanation of the meaning of any of the products - one would need to be a scientist to understand what they are looking at. This is true even for graphical products where different colors are set for different concentrations (or similar), but there is no explanation what it means for layman - even for aviation stakeholder - what is red zone? Can I fly through it or not? If not, how far should I keep? All this to say that these products have great value for aviation, but they are still missing an important part which is the "translation" of its meaning for aviation stakeholders that are not meteorologists or atmospheric scientist (if this is a good term at all).

Thank you for this clarification and your advices. We totally agree with this and will do our best to apply this advice in the future. Hopefully this will help us to improve EUNADICS service. We have removed the term 'benefit' at the end of the abstract. The text is now the following:

All the ATM stakeholders (e.g., pilots, airlines and passengers) can access these alert products through this free channel.

2. In section 5 the authors say "EUNADICS is a SESAR (Single European Sky ATM Research; <https://www.sesarju.eu>) enabling project with regard to the definitions provided in the SESAR 2020 Programme Execution Framework, delivering SESAR Technological Solutions." I would strongly suggest to rephrase this sentence, as the project itself is not even connected to SESAR, and the products developed are not "enabling" in the sense that is used in SESAR (enabling in SESAR means a technology that is a necessary building block of an ATM infrastructure - in a sense that without it, there is no new ATM infrastructure. I would suggest to rephrase into "supporting" or similar wording. Thank you again for this clarification. The text has been modified:

EUNADICS is supporting SESAR (Single European Sky ATM Research; <https://www.sesarju.eu>). The development, verification and validation of products, and the EWS were designed with the goal of potential future deployment.

3. Next, the authors say: "EUNADICS pass maturity phase V2 with regard to the 7-phase concept as introduced by the European Operational Concept Validation Methodology (E-OCVM, 2010)..." E-OCVM presents guidance for V1-V3 of the 8 phases of ATM products life-cycle. However, I don't think that EUNADICS can claim V2 maturity level according to EOCVM, as human factors, safety, business, environmental and standards cases were not performed for any of the products. The point of the cases is to assess the impact of the solution on a wide set of matters in the ATM. These cases are requirements that need to be passed, in order for a solution/product to mature from V1 to V2 or from V2 to V3. The EUNADICS project could easily claim TRLs 2,3 or even 4, of the H2020 technology levels, but not V2 of EOCVM. mainly because the EOCVM requires the assessment of how the products can be implemented in ATM and what would the impact be, and that was not done (the various cases) in the project, nor was that the point of the project). Thank you again for this clarification. The following text:

EUNADICS passed maturity phase V2 with regard to the 7-phase concept as introduced by the European Operational Concept Validation Methodology (E-OCVM, 2010), which shows the feasibility of EUNADICS prototype service. EUNADICS EWS has developed a concept for starting V3 validation (i.e., pre-industrial development & integration). With regard to the alert products developed, a verification of requirements has been performed and a verification of EUNADICS EWS performance has been demonstrated (Fig. 27). A validation of the global concept of EUNADICS and its potential benefits, has also been demonstrated during the EUNADICS exercise (Hirtl et al., 2020a), showing the benefits in a limited framework.

has been replaced by:

EUNADICS passed the maturity phase V1, and we can now target the maturity phase V2 with regard to the 7-phase concept as introduced by the European Operational Concept Validation Methodology (E-OCVM, 2010). Tests with human factors, safety, business, environmental and standards cases are still required for EUNADICS products to reach the maturity phase V2 and show the feasibility of EUNADICS prototype service, according to E-OCVM. EUNADICS EWS has developed some work of validation of the alert products (TRL 4), as shown in Fig. 27. A validation of the global concept of EUNADICS and its potential benefits, has also been demonstrated during the EUNADICS exercise (Hirtl et al., 2020a), showing the benefits in a limited framework.

4. In line 925, what do you mean by "environment). EUNADICS EWS passes with success the performance verification."? As highlighted in comment 3., the environment is the one of E-OCVM, with tests of human factors, safety, business, environmental and standards cases. The following text (line 925-927):

EUNADICS consortium will now target an operationalisation of its activity, in the frame of SESAR H2020, with the objective of completing TRL 6 (demonstration in a relevant environment). EUNADICS EWS passes with success the performance verification.

has been changed to

EUNADICS consortium will now target an operationalisation of its activity with the objective of completing TRL 5 (validation in a relevant environment) and TRL 6 (demonstration in a relevant environment) in the framework of further SESAR developments. EUNADICS EWS passes with success the performance verification in a limited environment (TRL4).

5. **Finally, a suggestion to authors regarding the TRL levels of their products, in aviation setting. A product can be deemed operational in aviation if intended end-users can access the information, understand it and make decisions based on the understood information. If the presented information is not understandable by the end-user (e.g. pilot, air traffic controller), the product will not be used, even if it is completely accurate, and reliable. That is the reason for having various cases in the EOCVM methodology - to make new technology not only work, but to be understood. Some of the next steps, in my opinion should be identification of the end-users, and tailoring of the product for their use. If the end-users are only national meteorological providers, VAACs and similar, then the TRL of EUNADICS products is very high, and probably close to operational. But, if the products should be shared with other, non-scientific types of end-users, there is still a lot of work to reach high TRL levels, and that work is mainly on making the information understandable to these users.**

Thanks a lot for this advice we will definitely consider in the future activity of EUNADICS

With respect to TRL, section 4.6.1 has been modified:

In case of a future operationalisation of EUNADICS activity for TRL (Technology Readiness Levels; see H2020, Annex G of the General Annexes) of 5 and higher, i.e., system prototype validation and demonstration in operational environment, all the NRT observations will be visible on the EUNADICS data portal.

6. **Please review the paper for English proofing. It is overall of good quality, but there are typos and some non-English phrases that make reading slightly harder.** Done, see answer to RC1

We hope this document answers properly to the specific comments addressed by Tatjana Bolic, Referee #2. We are very grateful for this review and all the advices provided. We apply all them, and will do our best to improve the quality of our service in the future. We also improved the text of the manuscript to make the paper easier to read.

Thank you very much for this review. Best regards,

Hugues Brenot and co-authors

Author's Response to Mariana Adam, CC1 (05 May 2021):

In this author's response, the text (normal style) answers point by point to the comment of Mariana Adam (text in bold). The text in blue corresponds to the authors' change in the manuscript.

CC1 from Mariana Adam:

I have several observations and it would be very nice if there will be some clarifications. Regarding Table 5, it will be very useful to have the numerical values of the thresholds given.

Issuing alert can require the use of several criteria. Table 5 provides an indicator of the type of criteria used, e.g. "Threshold", "Triggered" or "Relay". With respect to "Threshold", this doesn't always mean the use of a single threshold/value. To clarify this, we added superscripts to guide the reader for finding more explanation about the criteria used. Whenever possible, thresholds have been added.

See this new Table 5 below

Table 5: Overview of EUNADICS alert products from ground-based [GB], satellite [SAT] and in situ [IS] instruments.

Quantity	Instrument			Responsible institute	Source alert	Alert criteria	Access
	[GB]	[SAT]	[IS]				
High resol. lidar data (att. backscatter, vol. depolarization ratio)				EARLINET / ACTRIS - CNR	Volcano / Dust	⁽¹⁾ Threshold on particle backscatter coeff. and particle depolarization ratio	Off-line
Backscatterig power				INGV-OE / OPGC	Volcano	Manual analysis (volcanologist on duty check the increase of the echo power in respect to the background)	Off-line
Backscatterig power				IMO	Volcano	General threshold at -20 dBz (but specific volcano dependent thresholds are also set: -31/-30 dBz)	NRT
Plume height				IMO	Volcano	Triggered by backscatt. power	NRT
Thermal images				INGV-OE	Volcano	⁽²⁾ Dynamical threshold (no fixed threshold)	NRT
SO ₂ profiles				INGV-OE	Volcano	SO ₂ thresholds are 1000-2000 tons/day (low), 2000-4000 tons/day (medium) and >4000 tons/day (high)	NRT
SO ₂ column amount				IMO	Volcano	SO ₂ threshold depends on a variety of factors (type of sensors, its orientation): currently 100 pmm-m and 200 ppm-m are set as reference thresholds for DOAS in Hekla and in Fagradaslfjall.	NRT
Plume height				INGV-OE	Volcano	⁽³⁾ Intensity contrast pixels (estimation of the column height is made qualitatively by an operator, i.e., the volcanologist on duty)	NRT
Plume height				IMO	Volcano	Manual analysis (identification of specific features); plume height obtained using a graphical interface	NRT

Ash index	AQUA / AIRS	ULB	Volcano	⁽⁴⁾ NOP required	NRT
SO ₂ VCD	AQUA / AIRS	AIRES / BIRA	Volcano	⁽⁵⁾ Threshold (SO ₂ > 3 DU), coeff.	NRT
SO ₂ VCD	AURA / OMI	NASA	Volcano	⁽⁵⁾ Threshold (SO ₂ > 1.25 DU), nb. pixels	NRT
SO ₂ VCD	MetOp-A&B / GOME-2	DLR	Volcano	⁽⁵⁾ Threshold (SO ₂ > 1.45 DU), nb. pixels	NRT
AOD (dusts)	MetOp-A&B / IASI	ULB	Dust	Threshold (AOD > 0.5)	NRT
Ash index	MetOp-A&B / IASI	ULB	Volcano	⁽⁴⁾ NOP required	NRT
SO ₂ BT index	MetOp-A&B / IASI	ULB	Volcano	⁽⁵⁾ Threshold (BT < 2.9K)	NRT
SO ₂ VCD	MetOp-A&B / IASI	ULB	Volcano	Triggerred by BT	NRT
SO ₂ plume height	MetOp-A&B / IASI	ULB	Volcano	Triggerred by BT	NRT
Ash mask	MSG / SEVIRI	DLR	Volcano	Threshold	NRT
Ash column load	MSG / SEVIRI	DLR	Volcano	Triggerred by Ash mask	NRT
Ash top height	MSG / SEVIRI	DLR	Volcano	Triggerred by Ash mask	NRT
SO ₂ VCD	S5P / TROPOMI	BIRA / DLR	Volcano	⁽⁵⁾ Threshold (SO ₂ > 0.5 DU), nb. pixels	NRT
SO ₂ VCD	Suomi-NPP / OMPS	NASA	Volcano	⁽⁵⁾ Threshold (SO ₂ > 0.75 DU), nb. pixels	NRT
Aerosol index	Sentinel-3A&B / SLSTR	FMI	Volcano / Dust	Thres. Ash index (BT < -3K)	NRT
Aerosol top height	Sentinel-3A&B / SLSTR	FMI	Volcano / Dust	Triggerred by Ash index	NRT
Thermal anomaly	Terra & Aqua / MODIS	NASA - FIRMS	Fire	Relay (through FIRMS)	NRT
Thermal anomaly	Suomi-NPP / VIIRS	NASA - FIRMS	Fire	Relay (through FIRMS)	NRT
Seismicity	SIL seismic network	IMO	Volcano	Relay (through VONA)	NRT
Volcanic tremor	Seismic stations	INGV-OE	Volcano	⁽⁶⁾ Relay (through reports)	NRT
Gamma radiation	Network of detectors	EURDEP / ZAMG	Nuclear	Relay (through EURDEP)	NRT

⁽¹⁾ See Papagiannopoulos et al. (2020) for more details.

⁽²⁾ See Behncke et al. (2009) for more details.

⁽³⁾ The uncertainty due to a different operator is less than 2% (Scollo et al., 2019). The uncertainty in the column height is instead ± 0.5 km (see Scollo et al. 2014; 2019).

⁽⁴⁾ Number of medium or high LOC (Level of Confidence) pixels in the area in the threshold radius; see See Brenot et al. (2014) for more details.

⁽⁵⁾ See Brenot et al. (2014) for more details.

⁽⁶⁾ Reports are sent to the Italian Civil Protection during the volcanic crisis and available at the INGV-OE web-site

(<https://www.ct.ingv.it/index.php/monitoraggio-e-sorveglianza/prodotti-del-monitoraggio/comunicati-attivita-vulcanica>); see Agostino et al. (2013) for more details about alert of volcanic tremor based on RMS amplitude.

The line of Table 5 related to alert from Attenuated Backscattered Coefficient (from E-PROFILE) has been removed (see explanation below), as quicklooks should not be considered as alert.

Why don't you use particles extinction and backscatter coefficients from lidars (as mentioned in Table 3)? Moreover, the example from Fig. 13 uses particle backscatter coefficient.

Fig. 13 shows 3 graphs (particle backscatter coefficient at 532 nm, particle depolarization ratio at 532 nm, and alert for aviation). The alert for aviation uses threshold criteria on the particle backscatter coefficient at 532 nm and the particle depolarization ratio at 532 nm. See Papagiannopoulos et al. (2020) for more details. Table 5 has been updated accordingly.

Does the example given in Fig. 14 represent a hazard? I see it just as an illustration of the Eprofile capability. Please mention if you have any criteria for attenuated backscatter from which you can set a warning.

The event shown there does not directly present a hazard, the smoke concentrations involved are far too low to cause any issues to aviation, but are nevertheless well detected by the ALC network so that this case can illustrate what can be achieved with E-PROFILE. Cases with large scale presence of high concentrations of hazardous aerosols are rare (but have very high socio-economic impact as we all know), so that the E-PROFILE network did not yet have the chance to capture such an event due to its young age.

No threshold of attenuated backscatter for issuing warnings has been defined up to now. Only quicklooks (and data) are available. Therefore we have decided to remove the line related to E-PROFILE in Table 5. For issuing alert using attenuated backscatter, a synergy with information on aerosol typing is required and would be judicious (unless the event is extremely strong). For the time being, we rather consider the E-PROFILE network as a tool for precisely determining the 4D (lat, lon, altitude, arrival and dissipation time) presence of aerosols, once their type has been identified by other means.

What do you mean by 'Range of att. backscatter' in Table 5? To me, what is of interest is the pollution layer geometry (layer altitude and depth).

We agree that attenuated backscatter is very well suited to track lat/lon/altitude/depth/timing of pollution. The line related to E-PROFILE and range of att. Backscatter has been removed from Table 5. We could define a range where we would for sure issue a warning, but this would suffer from large uncertainty (either a high false alarm rate or a lot of missed events depending on tuning), due to the impossibility to do aerosol typing with the single-wavelength elastic lidars. Therefore, we would argue that a high aerosol attenuated backscatter should best be used in combination with some typing information in order to issue a warning, hence some synergy in the EWS would need to be exploited. The big advantage of automatic lidars and ceilometers is that in contrast to EARLINET they are up and running 24/7 with very high timeliness and their spatial distribution is dense, the disadvantage, of course, is that they cannot do typing.

Please mention the timeliness for EWS, i.e., when the warning will be issued after the event (hours).

Information about timeliness for EWS is presented in Table 6 (i.e. Time delivery and resolution). It is not our goal to provide the time delay of the alert with respect to the start of the event. Our objective is to provide situational awareness of an event and alert data product. However about the time delay of observations, we provide:

- The time delivery, i.e. the time delay between the time of measurement and the NRT availability of data retrievals.
- The time resolution, i.e. the time delay between 2 consecutive observations of the same region. For the instruments onboard polar orbiting satellites, it depends on the latitude and the type of sensors, e.g. UV-vis or IR.

I am a bit confused about Fig. 13. You mention that the alert uses mass concentration based on backscatter coefficients thresholds. According to Papagiannopoulos et al. (2020), the thresholds are for particle backscatter coefficients, based on given mass concentrations (eq. 9). Please correct and cite the reference. Please comment on uncertainty.

Correct. The text has been updated accordingly. The particle backscatter coefficient is retrieved following Di Girolamo et al. (1999) with an overall error of no more than 50 %. For the estimation of the alert thresholds, the methodology employs the POLIPHON method (Ansmann et al. 2012) with known uncertainty of 20-30%. Uncertainties are discussed in detail in Ansmann et al. (2019) and Papagiannopoulos et al. (2020). The text of section 4.2.1 has been modified:

A tailored alerting product from the European Aerosol Research Lidar Network (EARLINET; <https://www.earlinet.org>) has been developed during the EUNADICS project (Papagiannopoulos et al., 2020). It has been designed for NRT EWS applications. Using a stand-alone lidar-based method for detecting airborne hazards (volcanic ash and desert dust; no discrimination), this product is based on the EARLINET Single Calculus Chain (version 5.1),—and that provides temporally high-resolved, calibrated attenuated backscatter and volume depolarisation ratio (at 532 nm), and cloud mask. The vertical resolution is 7.5 m, and the temporal resolution is 30 s. From these calibrated data, further particle-like products (particle-like backscatter coefficient and particle depolarisation ratio) can be retrieved that act as the basis of the tailored product. The final product (to be used by EUNADICS EWS) is the aviation alert for desert dust/volcanic ash with a three colour-codes. This alert product uses particle mass concentrations (pmc) based on backscatter coefficient thresholds. High level detection appears in red (almost certain detection of ash or dust aerosol with $\text{pmc} \geq 4 \text{ mg/m}^3$), Medium level in orange ($4 \text{ mg/m}^3 > \text{pmc} \geq 2 \text{ mg/m}^3$). Low level is in yellow ($2 \text{ mg/m}^3 > \text{pmc} \geq 0.2 \text{ mg/m}^3$). An example of alert from EARLINET is shown in Fig. 13. On 21-22 March 2018, the eastern Mediterranean, in particular Crete island, was under extreme effects of warm southerly winds pushing enormous amounts of Saharan dust – and hot air – northwards. The desert dust storm caused the closure of Heraklion airport (Crete, Greece) on 22 March 2018, and was, in particular, detected by the ground-based LIDAR from EARLINET.

Please comment on plumes heights. So far, you give examples for ash top height and SO₂ plume height estimated from satellites (Figs. 3 and 5). How this information corroborates with the total SO₂ concentration (threshold of mass loading of 5 kt, page 38).

At the moment, only SO₂ and ash plume height is tackled by the alert data products of our EWS. SO₂ column and height are simultaneously retrieved by IASI and provided in our alert data products. A threshold of 5 kt is used to determine the level of an SO₂ notification (i.e., HIGH versus LOW).

On the other hand, why no lidar or ALC system is used to determine the plumes geometry?

This is a good point about the interest of using lidar and ALC to determine the plume geometry. We plan to use such information and create alert data products in the future. For the time being, it needs more investigations, as mentioned previously, to include plume height information from lidar and ALC in this study. Note however that quicklooks (provided in NRT) are already good for providing situational awareness related to the plume geometry.

Why the lidars are not used for smoke identification? There are many papers on aerosol type, mostly based on lidar ratio and extinction Angstrom exponent. Again, why is just volume depolarization ratio used? Moreover, why not particle linear depolarization ratio?

Here, we applied the methodology introduced in Papagiannopoulos et al. (2020) that focuses on irregular-shaped particles such volcanic ash and desert dust. Their methodology is based on a single-wavelength depolarization lidar with no spectral information; thus, smoke plumes would be challenging to identify following their approach. The methodology uses particle depolarization ratio for the estimation of the EWS.

We hope this answer clarifies the point addressed by your observations.

Thank you for these comments and your interest for our study. Best regards,

Hugues Brenot and co-authors.