

## Article

# Measurements of UV—A Exposure of Commercial Pilots Using Genesis-UV Dosimeters

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**Abstract:** A number of studies suggest that pilots are at twice the risk of melanoma and keratinocyte skin cancers than the general population, and that they have a raised mortality from melanoma. No conclusive links with in-flight exposure to ionising radiation or circadian rhythm disruption due to the pilots' shift work were found. Possible over-exposure to ultraviolet radiation (UVR) may be implicated as pilots may be exposed to higher UV-A levels at cruise altitude compared with those at ground levels. The direct method of making in-flight spectral measurements has been carried out on a limited number of flights, but this technique is challenging; the use of small wearable sensors may be more appropriate but there are a few issues that should be addressed for their use in cockpit measurements. While the spectral response of sensors for erythema effective values usually closely matches the corresponding weighting function, the response of UV-A sensors may not be spectrally flat, which, if not corrected to account for the transmission of the aircraft windshield, could potentially result in large errors. In this paper, the spectral correction method was applied to the UV-A sensor of the Genesis-UV unit to measure UVR exposure of commercial pilots on 312 flights to a range of destinations from four UK airports from September 2016 to August 2017.

**Keywords:** ultraviolet radiation; UVR exposure; dosimetry; UV-A exposure; pilots; occupational exposure; skin cancers; personal solar UV exposure measurements

## 1. Introduction

Meta-analysis studies have shown that commercial pilots have a two-fold higher risk of melanoma and keratinocyte skin cancers than the general population, and that they have a raised mortality from melanoma [1–4]. No conclusive links between levels of in-flight exposure to ionising radiation and skin cancers have been found [3,5]. Apart from cosmic radiation, pilots are also exposed to solar radiation, and ultraviolet radiation may be significantly higher at flight altitudes than on the ground [6]. The nature of pilots' work also includes shift patterns that can contribute to circadian rhythm disruption, though no evidence has been found associating it with skin cancers [3,5]. UVR, on the other hand, is a well-known risk factor for developing skin cancers [7].

UVR in cockpits has been measured on a limited number of flights using spectroradiometers. Chorley et al. [8,9] carried out spectral measurements on five European short-haul return flights from

London Gatwick and one long-haul transatlantic flight, Schennetten et al. [10] on four long-haul and two short-haul flights from Frankfurt to Japan and Europe, and Meerkötter et al. [11] on a flight from Frankfurt to Spain. The direct method of in-flight spectral measurements is challenging; the use of small wearable sensors may be more appropriate. In the past, erythema effective doses were measured using polysulphone film by Diffey et al. [12]. More recently, Solartech UV Index meters for 280–322nm and 280–400nm spectral ranges were used by Sanlorenzo et al. [13] on two midday flights in the USA, and Cadilhac et al. [14] used the RM12 radiometer (Opsytec Dr. Gröbel GmbH on 14 short and long-haul flights from Paris Charles de Gaulle Airport. The time-stamped UV broadband detectors are often wearable, and the recorded time of the measurements can be correlated with the flight log. While the spectral response of sensors for erythema effective values usually closely matches the corresponding weighting function, the response of UV-A sensors may not be spectrally flat, which, if not corrected to account for the spectral transmittance of the aircraft windshield, could potentially result in large errors.

In this paper, the spectral correction method was applied to the UV-A sensor of the Genesis-UV unit to measure UVR exposure of commercial pilots on 312 flights to a range of destinations from four UK airports from September 2016 to August 2017 [15]. The results were compared with the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guideline [16] for the eyes of 10 kJ/m<sup>2</sup>.

## 2. Experiments

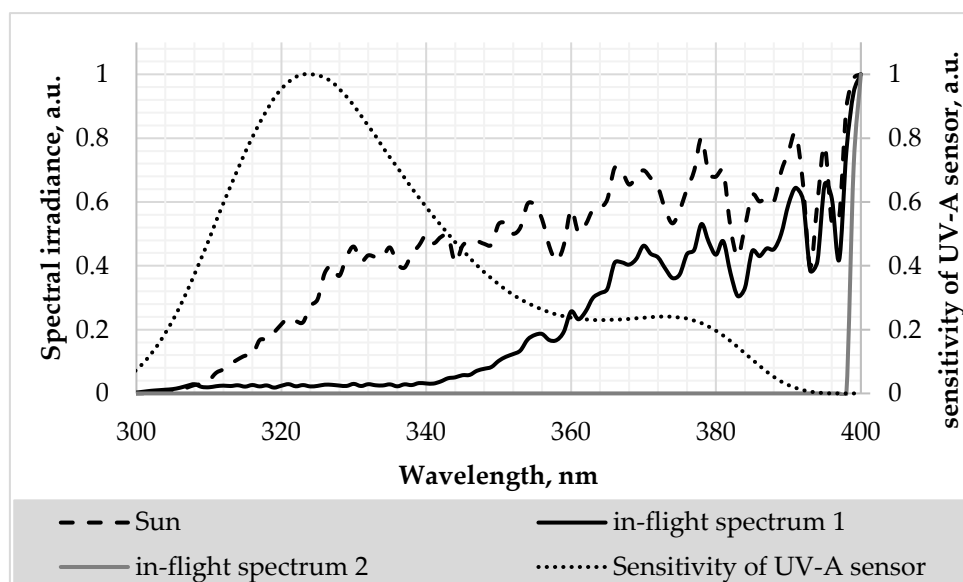
Between September 2016 and August 2017, the in-flight UV exposure of pilots was measured on 312 Monarch Airlines short-haul flights on the Airbus A321-231 and Airbus A320-214 to 31 destinations from 4 UK airports: Manchester (53° 21' N, 2° 16' W), Birmingham (52° 27' N, 1° 45' W), Gatwick (51° 8' N, 0° 11' W) and Leeds-Bradford (53° 52' N, 1° 39' W). Flight times ranged from 1 h 40 min on a flight to Grenoble to 5h on flights to the Canary Islands and Tel Aviv.

GENESIS-UV (GENeration and Extraction System for Individual expoSure) dual-channel electronic data loggers X-2012-10 (Gigahertz-Optik GmbH, Türkenfeld, Germany) with UV-A and erythema effective irradiance sensors were used for measurements inside the cockpits. The sampling interval was set to 15 s to enable long deployments. This system was previously deployed in studies of occupational sun exposure [17,18]. Pilots were recruited for a few weeks to wear the Genesis-UV units clipped to the shirt at chest level, as shown in Figure 1, and to fill in a diary that included date and time of flights, departure and destination airports, aircraft type and registration, and use of visors or sunglasses during flight. Diary records were accurately correlated with data measured by the dosimeters. Data from three return flights when a dosimeter was not worn by the pilot were excluded from the analysis. Ethical approval for this study has been granted by the Institute of Optometry's Research Ethics Committee. The pilots signed consent forms, and they were free to withdraw at any time.



**Figure 1.** Pilot wearing a dosimeter during a flight.

Previous studies [8,10,19] reported that windshields of older aircraft substantially block UVR below ~395 nm and newer windshields transmit UV-A above ~340–360 nm. Examples of spectra measured in these two types of aircraft taken from [8] are presented in Figure 2; spectra are normalised to the value of spectral irradiance at 400 nm. UV-A dose rates of 30 kJ/m<sup>2</sup>/h (spectrum 1) and 0.5 kJ/m<sup>2</sup>/h (spectrum 2) should be expected on these daytime flights.



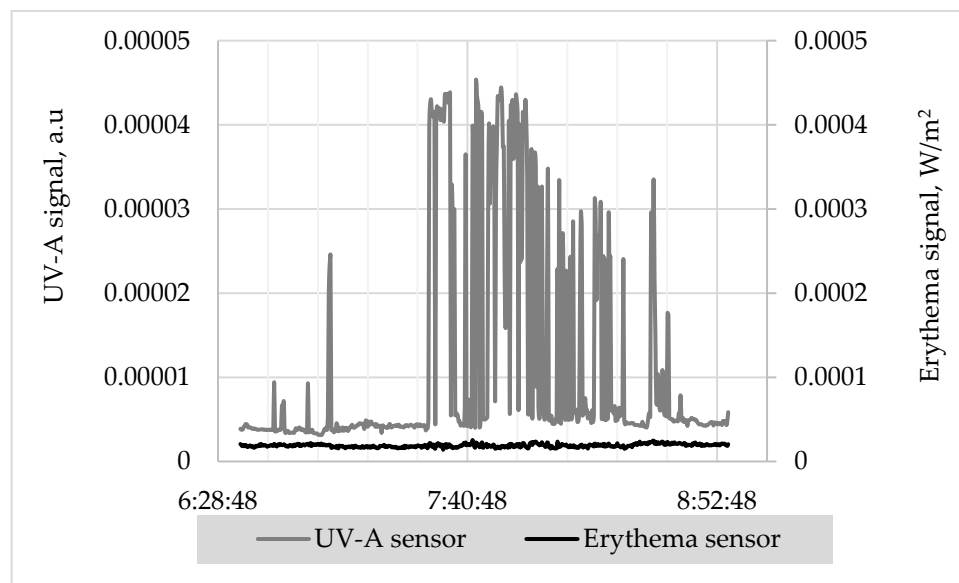
**Figure 2.** Examples of relative solar spectra measured inside cockpits [8] and spectral sensitivity of the UV-A detector (dotted line) shown as relative values (arbitrary units, a.u.).

While the spectral response of the sensors for erythema effective values closely matched the corresponding weighting function, the sensitivity of the UV-A sensor of the Genesis-UV has strong wavelength dependence as shown in Figure 2; it peaks at 325 nm, decreases with increasing wavelengths, and drops below 10% above ~390 nm. This means that results may be highly inaccurate when this instrument is used for the measurements of solar radiation filtered through aircraft windshields if spectral sensitivity is left uncorrected.

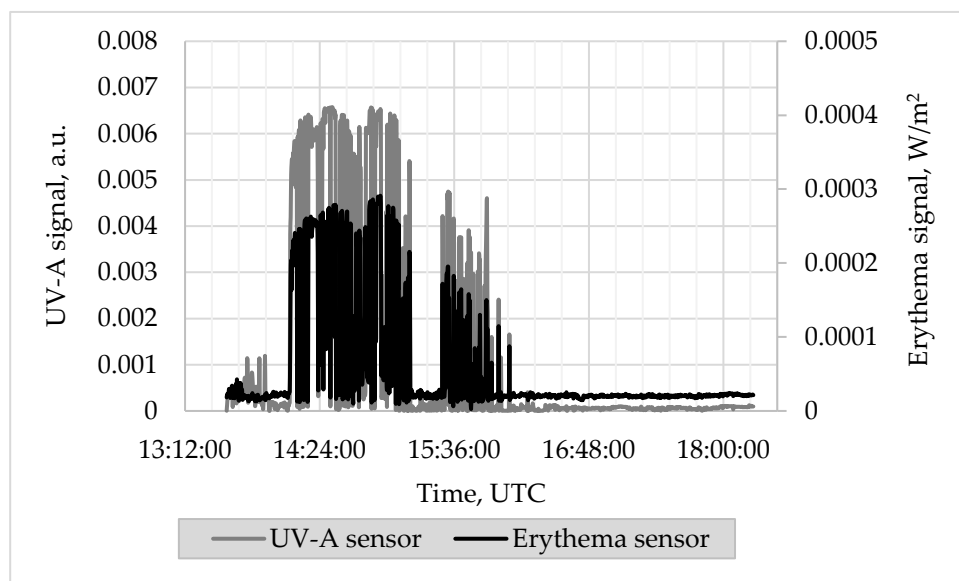
To account for a change in UV-A sensor sensitivity due to windshield attenuation, the Genesis-UV detectors were calibrated using solar radiation filtered through a WG360 filter. Solar spectral irradiance was measured by a co-located D<sup>3</sup> 180 double-grating spectroradiometer (Jobin Yvon, Longjumeau, France). The reference instrument was calibrated using a 1000 W tungsten-halogen lamp, calibrated for spectral irradiance to the Physikalisch-Technische Bundesanstalt (PTB) traceable reference standards. The WG360 filter was chosen in this study as its relative spectral distribution closely matches the transmission of high UV transmitting windshields.

Calibration for high attenuating windshields was not considered necessary as UV-A doses are very low in this case, much lower than the level of biological significance.

It should be noted that UV-A irradiance in the aircraft with good UV attenuation (spectrum 2 in Figure 2) is below 1% of the value in the middle of a sunny day in November in Chilton, UK, and the erythema effective irradiance is below the detection threshold. If measured by the Genesis-UV unit, both erythema effective and UV-A channels will return extremely low signals, below or close to the measurement threshold as illustrated in Figure 3a. It is similar for the flights when visors were deployed.



(a)



(b)

**Figure 3.** Signals from UV-A and erythema effective sensors of the Genesis-UV unit measured during two different flights: (a) morning outbound flight to Barcelona: low ultraviolet radiation may be due to high UV attenuating windshield or use of visors; (b) outbound flight to Tenerife: high UVR, aircraft with high UVR transmitting windshield, no visors.

Contrarily, UV-A irradiance on flights in aircraft with high UV transmitting windshields (spectrum 1 in Figure 2) may be relatively high, and erythema effective irradiance, though very low, may reach a value of  $0.2\text{--}1\text{ mW m}^{-2}$  as illustrated in Figure 3b. If measured by the Genesis-UV unit without sensitivity correction, UV-A may be underestimated by a factor of 6; measurements of erythema effective irradiance are largely unaffected.

This approach will be used to distinguish between two types of windshields for the daytime flights:

- flights with low UV-A signal and erythema effective signal below the measurement threshold (high UV attenuating windshield or when visors are used)
- flights with a range of UV-A signals with erythema effective signal measured (high UV transmitting windshield).

### 3. Results

The following method was used to measure the UVR exposure of commercial pilots on 312 Monarch Airlines flights on the Airbus A321-231 and Airbus A320-214 to 31 destinations, mostly in Europe, from four UK airports from September 2016 to August 2017 [15].

The flights were divided into morning, before 9am UTC, and afternoon, after 12 noon UTC, departure flights from UK airports to the south of Europe, the Canary Islands, and the southeast of Europe and listed in Tables 1 and 2. The flights that were not flown during daylight hours are reported in Table 2 as in dark, a total of 44 flights.

**Table 1.** Summary of the morning departure flights (departure time before 9 am UTC) in August–September 2016, December 2016–January 2017, March–April 2017, and June–July 2017 to the south of Europe (36° 40′–46° 14′) N (7° 58′ W–12° 21′) E, the Canary Islands (28° 2′–32° 42′) N (13° 36′–16° 34′) W, and the southeast of Europe (32° 0′–36° 50′) N (2° 22′ W–34° 53′) E [15].

| Outbound Flight                  |                                  |                          |                                      | Inbound Flight                   |                                  |                          |                                    |
|----------------------------------|----------------------------------|--------------------------|--------------------------------------|----------------------------------|----------------------------------|--------------------------|------------------------------------|
| UV-A Dose, < 1 kJ/m <sup>2</sup> | UV-A Dose, > 1 kJ/m <sup>2</sup> |                          |                                      | UV-A Dose, < 1 kJ/m <sup>2</sup> | UV-A Dose, > 1 kJ/m <sup>2</sup> |                          |                                    |
| Flights                          | Flights                          | Range, kJ/m <sup>2</sup> | Average (STDEV *), kJ/m <sup>2</sup> | Flights                          | Flights                          | Range, kJ/m <sup>2</sup> | Average (STDEV), kJ/m <sup>2</sup> |
| 12                               | 5                                | 3.5–5.7                  | 4.7(0.9)                             | 11                               | 6                                | 3.6–32.2                 | 12.8(9.9)                          |
| 4                                | 2                                | 2.6–13.9                 | 7.8(8.6)                             | 3                                | 3                                | 1.3–4.0                  | 2.3(1.5)                           |
| 4                                | 2                                | 1.8–8.2                  | 5.0(4.5)                             | 5                                | 1                                | 2                        | n/a                                |
| 11                               | 6                                | 1.5–3.0                  | 2.2(0.6)                             | 8                                | 9                                | 1.3–6.1                  | 3(1.3)                             |
| 1                                | 3                                | 2.6–9.0                  | 5.6(3.2)                             | 1                                | 3                                | 5.3–10.8                 | 8.7(3.0)                           |
| 4                                | 1                                | 15.8                     | n/a                                  | 4                                | 1                                | 5.6                      | n/a                                |
| 1                                | 0                                | n/a                      | n/a                                  | 1                                | 0                                | n/a                      | n/a                                |
| 2                                | 0                                | n/a                      | n/a                                  | 2                                | 0                                | n/a                      | n/a                                |
| 0                                | 2                                | 17.3–20.1                | 18.7(2.0)                            | 0                                | 2                                | 3.4–12.3                 | 7.8(6.3)                           |

\* STDEV- standard deviation

**Table 2.** Summary of the afternoon departure flights (departure time after 12 noon UTC) in August–September 2016, December 2016–January 2017, March–April 2017, and June–July 2017 to the south of Europe (36° 9′–47° 15′) N (9° 81′ W–14° 17′) E, the Canary Islands (28° 2′–32° 42′) N (13° 36′–16° 34′) W, and the southeast of Europe (34° 43′–45° 44′) N (16° 41′–33° 37′) E [15].

| Outbound Flight                  |                                  |                          |                                    | Inbound Flight                   |                                  |                          |                                    |
|----------------------------------|----------------------------------|--------------------------|------------------------------------|----------------------------------|----------------------------------|--------------------------|------------------------------------|
| UV-A Dose, < 1 kJ/m <sup>2</sup> | UV-A Dose, > 1 kJ/m <sup>2</sup> |                          |                                    | UV-A Dose, < 1 kJ/m <sup>2</sup> | UV-A Dose, > 1 kJ/m <sup>2</sup> |                          |                                    |
| Flights                          | Flights                          | Range, kJ/m <sup>2</sup> | Average (STDEV), kJ/m <sup>2</sup> | Flights                          | Flights                          | Range, kJ/m <sup>2</sup> | Average (STDEV), kJ/m <sup>2</sup> |
| 10 (2 in dark)                   | 5                                | 2.3–16.9                 | 7.12 (6.4)                         | 15 (5 in dark)                   | 0                                | n/a                      | n/a                                |
| 21 (6 in dark)                   | 0                                | n/a                      | n/a                                | 1 (20 in dark)                   | 0                                | n/a                      | n/a                                |
| 1                                | 1                                | 23.8                     | n/a                                | 2 (1 in dark)                    | 0                                | n/a                      | n/a                                |
| 14                               | 12                               | 1.4–6.2                  | 3.6 (1.4)                          | 26 (4 in dark)                   | 0                                | n/a                      | n/a                                |
| 2                                | 3                                | 1.7–63.5                 | 24.6 (33.9)                        | 5 (1 in dark)                    | 0                                | n/a                      | n/a                                |
| 9                                | 1                                | 1.6                      | n/a                                | 10                               | 0                                | n/a                      | n/a                                |
| 1                                | 1                                | 2.5                      | n/a                                | 2 (1 in dark)                    | 0                                | n/a                      | n/a                                |
| 2                                | 4                                | 1.6–12.7                 | 6.4 (5.1)                          | 6                                | 0                                | n/a                      | n/a                                |
| 7                                | 2                                | 2.2–2.7                  | 2.5 (0.3)                          | 9 (4 in dark)                    | 0                                | n/a                      | n/a                                |

The erythema effective doses were insignificant and did not exceed 0.1 Standard Erythema Doses (SED) on any flight [15], in agreement with published data [9,10,12].

On flights in daylight, the UV-A doses varied. Where the recorded UV-A dose was below 10% of the 10 kJ/m<sup>2</sup> ICNIRP guidance exposure limit, it is reported as < 1 kJ/m<sup>2</sup>. The UV-A exposure doses were below 1 kJ/m<sup>2</sup> in a total of 193 out of 312 flights, including all inbound flights departed from the UK after 12 noon UTC.

On 33 morning departure flights, UV-A exposure was higher than 1 kJ/m<sup>2</sup> but below 10 kJ/m<sup>2</sup>. On four outbound and seven inbound flights, UV-A doses were above 10 kJ/m<sup>2</sup>. The highest values were recorded at 20.1 kJ/m<sup>2</sup> on the 05:18 inbound flight to Dubrovnik and 32.2 kJ/m<sup>2</sup> on the 09:50 outbound flight from Naples. Outbound flights to the southeast of Europe in June–July 2017 resulted in relatively high UV-A doses, though only two flights were flown. No correlation between the time of the morning departures and UV-A doses was found for flights to the south and southwest of Europe ( $p < 0.05$ ) [15].

On 24 afternoon departure flights, UV-A doses were higher than 1 kJ/m<sup>2</sup> but below 10 kJ/m<sup>2</sup>; all outbound flights were either in the dark or resulted in < 1 kJ/m<sup>2</sup> UV-A exposures. On afternoon outbound flights, in five flights UV-A doses were above 10 kJ/m<sup>2</sup>; the highest was recorded at 63.5 kJ/m<sup>2</sup> on the 13:34 flight to Tenerife in summer 2016 [15]. The widest range of 1.7–63.5 kJ/m<sup>2</sup> was recorded on the outbound afternoon flights to the Canary Islands in August–September 2016. This can be explained by differences in the use of visors. This explanation is supported by [20], which showed that visors decrease the UV-A level to below 5% in Airbus cockpits. In some cases, the measured doses were relatively high despite records of visors being used in the participant's diary. This may be due to the visors being used only for part of the flight or that the pilot shielded their eyes from the bright sunlight, leaving the chest-mounted dosimeter fully or partly exposed.

#### 4. Discussion

The presented results show that UV-A exposure is mostly governed by the presence of direct sunlight in the cockpit and depends on the duration of the flight. The highest UV-A dose was recorded on afternoon outbound flights to Tenerife. These flights were also the longest, up to 4 h 45 min, and the UV-A dose was ~12 kJ/m<sup>2</sup> per hour of flight [15].

For interpretation of in-flight ocular exposure to UVR, it is important to treat the presented results with some caution. The position of the dosimeter (chest level) may not accurately represent exposure of pilots' eyes. In addition, use of sunglasses, aircraft visors covering a relatively small area of the windshield [9], or non-standard procedures to control sunlight brightness on the flight deck [21,22] would reduce the irradiance at eye level but may not affect the sunlight level recorded by the dosimeter on the chest. Although uncertainties of these measurements under all flight conditions are difficult to estimate with a high degree of confidence, they should be taken in the context of the potential impact on health outcomes. Pilots' exposure broadly falls into two main categories: very low with negligible potential photobiological impact, and relatively high, often exceeding ICNIRP guidance. While the uncertainty of measurements of very low exposures may be relatively high, it does not have practical importance. High exposures were recorded only in the presence of direct sunlight in a cockpit, e.g., when measurement conditions are close to the calibration conditions.

#### 5. Conclusions

Evidence from meta-analysis studies has shown that commercial pilots have a two-fold higher risk of melanoma and keratinocyte skin cancers than the general population. As UV radiation increases with altitude, possible over-exposure to UVR during flights may be implicated.

The direct method of in-flight spectral measurements is challenging, and the use of small wearable sensors may be more appropriate. However, wearable sensors often cannot be used for measurements of solar radiation filtered through aircraft windshields without correction. In this study, the Genesis-UV dosimeter was used. While the spectral response of its erythema effective sensor closely matches the corresponding weighting function, the response of the UV-A sensor has strong wavelength dependence. To correct for a change in UV-A sensor sensitivity due to windshield attenuation, the Genesis-UV detectors were calibrated with the sunlight filtered through the WG360 filter closely matching the



relative spectral transmittance of the high UV-A transmitting windshield. The main advantage of using the Genesis UV dosimeter for in-flight measurements comes from simultaneous measurements of erythema effective and UV-A irradiances which are crucial to distinguish between high and low transmitting windshields. Sensors also have good cosine response, and the internal temperature variations during the measurement have a negligible effect on their performance.

This method was used to measure UV exposure of commercial pilots on 312 Monarch Airlines flights to 31 European destinations from four UK airports from September 2016 to August 2017.

The erythema (sunburn) doses did not exceed 0.1SED for all flights, in agreement with previously published data. The UV-A exposure doses were below 1 kJ/m<sup>2</sup> in 193 out of 312 flights, including all inbound flights that departed from the UK after 12 noon UTC. On 13 flights out of 312, UV-A exposure could have exceeded the ICNIRP exposure guidance if sunglasses had not been worn or visors had not been deployed. Although some of the UV-A doses exceeded ICNIRP guidance, the average monthly doses were lower than the average UV-A exposures of a sample of UK office workers over a similar period.

**Author Contributions:** K.A.B.: methodology, data analysis, writing the manuscript, reviewing published evidence. M.K.: methodology and editing. M.W.: provision of dosimeters and technical support. A.C.C.: data curation. S.B.: recruitment of pilots and data curation. A.L.: data curation. All authors have read and agreed to the published version of the manuscript.

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