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A Guide to the DST Airglow Database

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ABSTRACT

The Defence Science and Technology (DST) Group performs airglow experiments at wavelengths of 557.7 nm, 572.4 nm, 589.3 nm, 630.0 nm and 777.4 nm in support of the Jindalee Operational Radar Network (JORN): a network of three High Frequency (HF) over-the-horizon Radars located at Longreach, Queensland; Laverton, Western Australia and Alice Springs, Northern Territory which monitor the Northern Australian coastline. This report describes the DST airglow database composed of measurements taken primarily over DST Edinburgh in South Australia from March 2012 to December 2016. The database consists of three components: airglow videos from each night, tables of nightly weather conditions and summary plots created nightly from airglow and environmental sensors. The summary plots allow quick look detection of various ionospheric phenomena such as mesospheric bores, ripples and travelling ionospheric disturbances (TIDs).

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A Guide to the DST Airglow Database

Executive Summary

The contents of this report detail a new publicly available database of DST airglow measurements collected from March 2012 to December 2016 primarily at DST Edinburgh, Adelaide in South Australia (34.7 S, 138.62 E). The database was created to enable long-term airglow studies of ionospheric disturbances related to high-frequency (HF) over-the-horizon radar signal propagation including: travelling ionospheric disturbances (TIDs), thermospheric bubbles, sporadic E, mesospheric bores and ripples as well as meteor studies in conjunction with external collaborators.

The database utilizes data from two airglow imaging systems, three cloud sensors and a sky quality meter which is used to record calibrated ambient light levels. It is composed of tables of nightly weather conditions, multi-wavelength airglow videos and summary plots created nightly from airglow and environmental sensor measurements. A description of the instruments is provided, and the database‘s uses and limitations are discussed.

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Glossary

DST Group	Defence Science and Technology Group
FOV	Field of View
GPS	Global Positioning System
HF	High Frequency
JORN	Jindalee Operational Radar Network
MUTA	Murray Bridge Training Area
NIR	Near Infrared
NSID	National Security and Intelligence, Surveillance and Reconnaissance Division
PortaTRACE	Portable Thermospheric Airglow Correlation Experiment
SQM	Sky Quality Meter
TRACE	Thermospheric Airglow Correlation Experiment

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1. Introduction

The National Security and Intelligence, Surveillance and Reconnaissance (ISR) Division (NSID), Defence Science and Technology (DST) Group supports the Jindalee Operational Radar Network (JORN): a network of three High Frequency (HF) over-the-horizon radars located at Longreach, Queensland; Alice Springs, Northern Territory; and Laverton, Western Australia which monitor Australia's northern coastline. JORN radar signals propagate via two main ionospheric layers: the F layer which lies at an altitude of approximately 250 km and the E layer which lies at an altitude of around 100 km. Density perturbations are common at these altitudes and can affect radar co-ordinate registration and signal strength.

Ionospheric perturbations are measured using a variety of instruments such as HF sounders, GPS monitors and airglow imagers. Airglow is light resulting from chemical reactions in the atmosphere. Airglow emission occurs at different frequencies, depending on the species of ions, atoms and molecules present, the most common being oxygen, hydroxide and sodium. Different species tend to have density peaks at distinct characteristic altitudes in the atmosphere. As airglow intensity is related to atmospheric density, it may be used to map density changes in the atmosphere at the various altitudes where it originates.

The four main airglow emission lines of interest to studies of HF radar propagation are: red 630.0 nm atomic oxygen which originates at altitudes from 200 to 300 km, green 557.7 nm atomic oxygen which originates mainly from a 2 km wide band around 96 km, yellow sodium 589.3 nm doublet emission from a narrow altitude region around 92 km and high altitude (300-400 km) near infrared (NIR) atomic oxygen 777.4 nm emission.

NSID currently operates two airglow imager systems: the Thermospheric Radar Airglow Correlation Experiment (TRACE) and a more portable version of TRACE known as PortaTRACE. These are supported by cloud sensors to record weather conditions, a sky quality meter (SQM) to measure ambient light levels and an all-sky camera which images the sky at all wavelengths. A summary plot of all available measurements and multi-wavelength videos for each camera are created each night. Airglow studies already published from this airglow data include work on travelling ionospheric disturbances (TIDs) [1, 2] and mesospheric bores [3].

Many ionospheric phenomena are best studied through long term data collection. This is particularly true of airglow measurements which are often sporadic due to weather conditions, or moon and sun location. The contents of this report describe a new publicly available database of DST airglow measurements collected from March 2012 to December 2016. The database includes nightly weather tables, airglow videos for each camera and summary plots. Interpretation of the summary plots with corresponding images is also given. The majority of the data originates from DST Edinburgh, Adelaide in South Australia (34.7 S, 138.62 E) but includes a brief PortaTRACE experiment undertaken at Alice Springs in September, 2015.

2. Equipment

Airglow equipment used to create the DST airglow database is described in detail in Unewisse and Cool [4]. It is divided into two imaging systems with associated ancillary sensors: the Thermospheric Airglow Correlation Experiment (TRACE) and PortaTRACE.

2.1 Airglow Filters

Airglow emission is sampled by both TRACE and PortaTRACE imagers using 2 nm bandwidth filters centred on desired airglow emission wavelengths of 557.7 nm, 589.3 nm, 630.0 nm and 777.4 nm with typical exposure times of two minutes. A control filter is used to measure intensity at 572.4 nm where there is no known airglow emission.

The filter names, central wavelength (λc), species and altitude of origin are summarised in Table 1. The table reflects some details of the airglow emission components detected by each filter with minor components denoted by square brackets. Green 557.7 nm atomic oxygen emission detected by the OXY1 filter, for example, originates mainly from a 2 km wide band around 96 km but also contains a small component from atomic oxygen at 250 km. For information on oxygen airglow production mechanisms see Kubota, Ishi [5].

Sodium emission detected by the NA1 filter is actually a sodium doublet emission with two lines at wavelengths of 589.0 nm and 589.6 nm. Measurements with the sodium filter at the DST Edinburgh site did not detect airglow due to local light pollution at this frequency. In 2017, TRACE was moved to a new dark site outside Murray Bridge, South Australia approximately 70 km south east of DST Edinburgh and preliminary results show that sodium airglow detection is possible at this site. This data is not included in the current database.

The OXY3 filter, designed to detect 777.4 nm emission from oxygen ions around 300-400 km in altitude, also detects a 777.3 nm hydroxyl molecule (OH) airglow emission line from an altitude of around 87 km due to the 2 nm filter bandwidth. When large density perturbations are present at altitudes of 80-100 km, features seen in the 557.7 nm airglow images are often seen in reverse light/dark intensity in OH emission detected in the OXY3 filter images.

Table 1. Airglow filter definitions

Filter name	λc (nm)	Species	Altitude (km)
OXY1	557.7	Oxygen atoms O(1S)+ [Oxygen atoms O(1D)]	96 [250]
OXY2	630.0	Oxygen atoms O(1D)	200-300
OXY3	777.4	Oxygen ions (O^+) + [Hydroxyl molecules (OH)]	300-400 [87]
NA1	589.3	Sodium atoms (Na) doublet	92
CONTROL	572.4	No Airglow	-
EMPTY	-	No filter – all wavelengths	-

2.2 TRACE

The TRACE airglow imager (Figure 1) consists of a Keo Sentry camera [6] with a six slot, temperature controlled filter wheel containing five 2 nm bandwidth filters centred on 557.7 nm, 572.5 nm, 589.3, 630.0 nm and 777.4 nm and an empty slot. The 777.4 nm measurements tend to suffer from a fringing interference pattern known as etaloning which may be mitigated during image processing [7]. The Sentry uses a 16 Bit Princeton Instruments Acton backlit Pixis 1024B CCD camera with a pixel size of 13.3 µm x 13.3 µm and has a 180° field of view (FOV), 24 mm / F4.0, achromatic Mamiya fisheye lens. The dark current measured by the Pixis camera's CCD at -70 °C is typically 0.001 e-/pixel/sec [8] although it regularly operates at -80 °C. The imager is housed in a 20 ft shipping container and is mounted on a retractable pier which lowers the camera during the day to protect the lens from UV damage.

Figure 1. The TRACE airglow imager

TRACE is supported by a Unihedron Sky Quality Meter [9] which records calibrated light readings every minute and a Boltwood cloud sensor [10] which monitors environmental conditions such as temperature, cloud coverage, rain, humidity, wind speed and light every 2.06 seconds. As well as monitoring current weather conditions, the cloud sensor output provides a trigger for pier retraction when conditions are too light, rainy, too cloudy or too windy. Recently, a cheaper Aurora cloud sensor has been added to the sensor suite which measures light, cloud and rain but not wind.

2.3 PortaTRACE

PortaTRACE is a smaller version of the TRACE experiment which consists of two single filter Keo Sentinel [11] imagers with 150° FOV placed a meter apart in a 800 mm x 1200 mm x 1200 mm IP66 rated outdoor enclosure. The Sentinel uses a Kodak KAI 04022 2048 x 2048 16 bit CCD with a pixel size 7.4 µm x 7.4 µm [11]. There are four available 3 inch, removable 2 nm bandwidth filters centred on: 557.7 nm, 572.4 nm, 589.3 nm and 630.0 nm although only two may be used at any one time – one in each camera – due to the lack of a filter wheel.

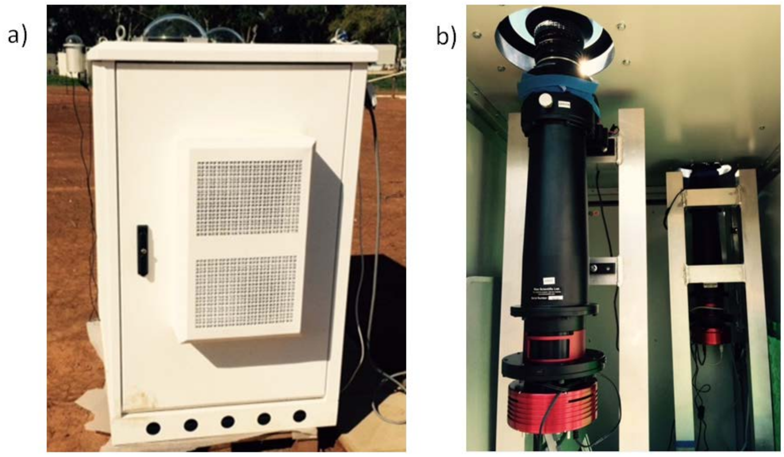

Figure 2. The PortaTRACE imager

The PortaTRACE imagers may be Peltier cooled down to a maximum of -40 °C below ambient but are typically run at -15 °C given a pre-set air conditioned ambient temperature of 15 °C. Typical dark current noise is 0.01 electrons/pix/sec at -20 °C.

PortaTRACE is supported by an Aurora cloud sensor [19] to determine weather conditions, an internal temperature and humidity sensor and an Oculus all-sky camera [20].

3. The Database

The DST group database consists of three components: weather and filter tables, summary plots and airglow videos. The airglow videos are divided into Sentry videos from TRACE and a limited number of Sentinel videos from PortaTRACE.

3.1 Boltwood Weather and TRACE Filter Tables

The weather and filter tables summarise nightly weather conditions reported by the Boltwood cloud sensor and list the number of images taken with each TRACE filter. Note the Boltwood 'cloud' designation may not always be reliable, especially for thin cloud. When the sensor determines conditions are very cloudy, rainy or very windy, it will trigger an 'emergency close' causing the pier to retract the camera until conditions improve. A detailed study of the Boltwood cloud sensor performance may be found in Marchant, Smith and Steele [12].

An example weather/filter file table is shown in Table 2. The columns are: year (YYYY), month (MM) and day (DD) in Universal Time (UT), percentage of night designated clear (CLR) or cloudy (CLD) by the Boltwood cloud sensor, the number of emergency closes flagged due to excessive wind, cloud or rain (CLS), the number of dark hours from the first to the last image (DRK) and the number of images taken with each filter in the order OXY1, CONTROL, NA1, OXY3, EMPTY and OXY3 as defined in Table 1.

Table 2. An example of a weather/filter table

YYYY	MM	DD	CLR	CLD	CLS	DRK	OX1	CON	NA1	OX2	EMP	OX3
2013	12	01	43	57	0	9	47	46	0	47	0	46
2013	12	02	29	71	0	9	48	47	0	47	0	47
2013	12	03	2	98	0	8	47	47	0	47	0	47
2013	12	04	5	95	42	4	43	43	0	43	0	43
2013	12	05	5	95	13	9	19	18	0	18	0	18
2013	12	06	15	85	0	8	31	29	0	31	0	31
2013	12	07	84	16	0	9	26	25	0	25	0	25
2013	12	08	0	100	4	9	21	20	0	21	0	20
2013	12	09	30	70	0	9	17	16	0	16	0	16
2013	12	10	0	100	2	8	12	11	0	12	0	12

3.2 Airglow Videos

The airglow images from each camera and filter undergo basic image processing including dark subtraction and correction for lens distortion, atmosphere and line of sight [3, 13]. Each image is then rotated so that North is at the top of the image. Processing does not include conversion from pixels to kilometres or star subtraction, but such data is available on request.

Movies created from processed images for each filter are then combined into a single multi-pane video for each night and camera as shown in Figure 3. The order of the videos on the screen depends on the order in which they were imaged on the night. In general, airglow measurements are collected when the sun is lower than 18 degrees below the horizon, although PortaTRACE measurements are sometimes longer.

Individual filter video titles contain date, camera, image processing, and location e.g. ‘09 Jan 2014 Sentry_SUB_DARK_VRJ_FLAT Edinburgh’ indicates videos from the Sentry camera taken at Edinburgh on 9 January 2014 with normal processing sequence as described above. Note that 777.4 nm airglow images suffer from etaloning interference which is more apparent on 2 minute exposures than 4 minute exposures. An extra processing step is included for 777.4 nm images to minimise this interference.

Each filter video has a separate title which gives the image time in UT, filter wavelength and image exposure length for example, a 2 minutes OXY1 video image taken at 14:37:17 UT will be labelled: ’14:37:17 UT 557.7 nm exp 2 mins’.

TRACE Sentry videos, as shown in Figure 4, consist of a maximum of four 1024 x 1024 pixel videos. The videos generally contain images from 557.7 nm (OXY1), 630.0 nm (OXY2), 589.3 nm (NA1) and 572.4 nm (CONTROL) filters but if one of these is missing (usually NA1), 777.4 nm (OXY3) will be inserted if available.

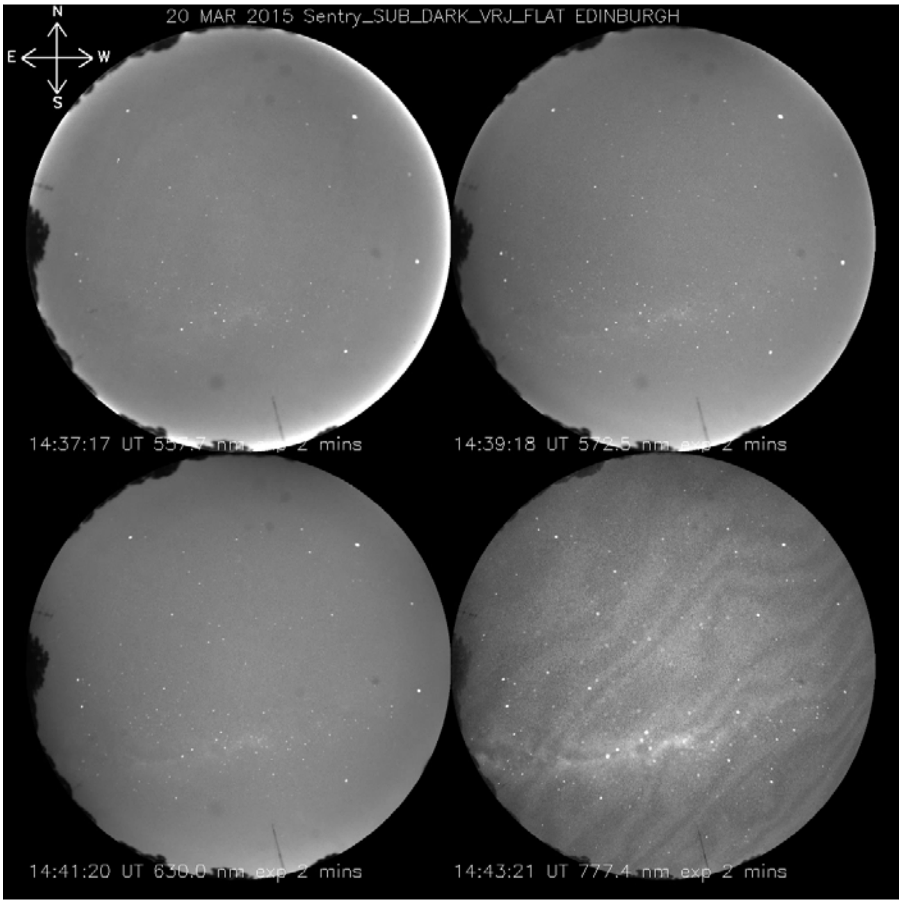

Figure 3. An example of TRACE Sentry videos

PortaTRACE videos are presented as a maximum of two 2048 x 2048 pixel videos per night as shown in Figure 4. It can be difficult to distinguish between cloud and airglow in Sentinel images without experience especially on days when only one camera was operational. Checking the weather tables and any Sentry data taken on the same night provides guidance. PortaTRACE data is only available on limited days from May 2015.

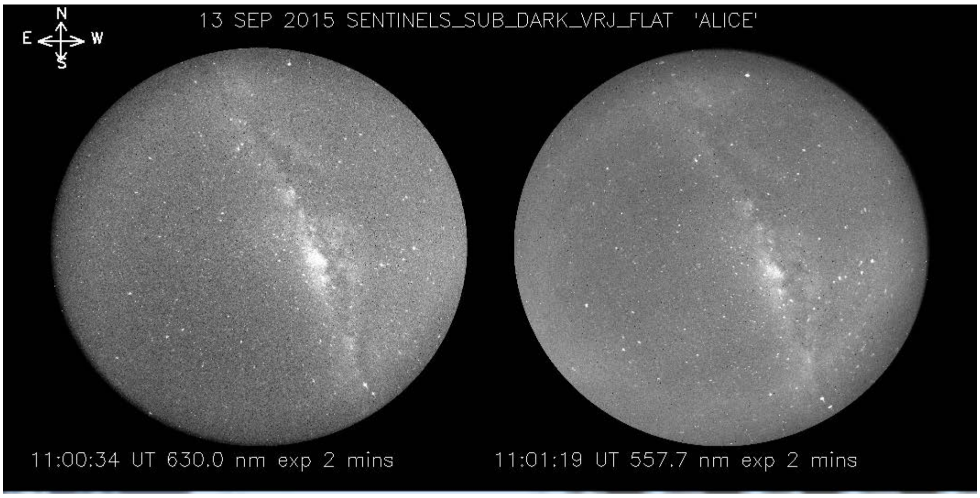

Figure 4. An example of PortaTRACE Sentinel videos

The video library has been edited to remove nights where data suffers from overwhelming cloud cover, camera malfunction etc. Edinburgh, South Australia enjoys a southern hemisphere Mediterranean climate hence most cloud and rain occurs in mid-year winter months. A summary of the percentage usable TRACE Sentry data (usable data/all data acquired) over the five years by month is shown in Figure 5.

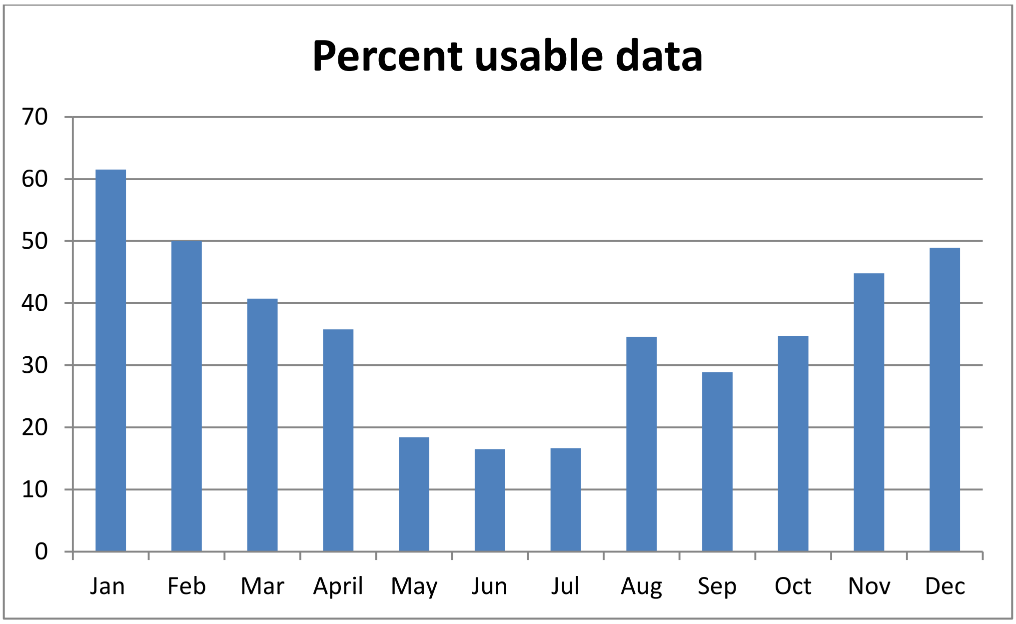

Figure 5. Percentage of usable images per month

3.3 Nightly Summary Plots

An example of a nightly summary plot is given in Figure 6. The plots contain a summary of airglow camera, cloud sensor and sky quality meter (SQM) measurements made during the night as well as a calculated plot of the moon position to indicate if it is above or below the horizon. Moon glow can be expected to impinge on images when the moon reaches 12 degrees below the horizon. A key on the top left hand side of the summary plot gives the name of each file used to construct the plot as well as the darkest SQM light reading and the percentage of moon illumination. Except for the PortaTRACE Aurora cloud sensor, all sensors are co-located with TRACE.

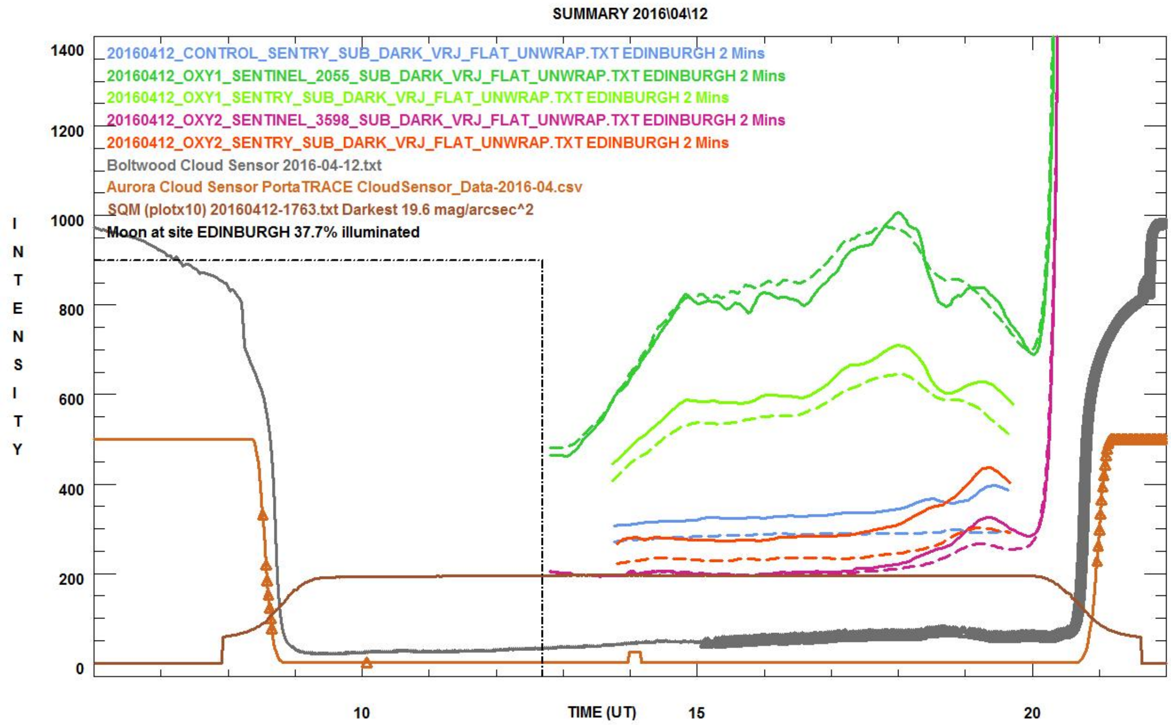

Figure 6. An example of a nightly summary plot

The night’s airglow information is represented by the calculation of two values per processed image: the median of the central 10 x 10 pixels (solid line) and the median intensity of an inscribed square in the circular airglow image to represent the background (dashed line). This is illustrated in Figure 7.

The airglow median values are colour coded according to camera and wavelength with line colour chosen to reflect the filter colour where appropriate – for example: red, yellow and green. The key provides the location and exposure time of the airglow data and the specific file used. The name is in the form yyyymmdd_filter_camera_processing where yyyymmdd is the year, month and day in UT, ‘filter’ is the filter label (Table 1), ‘camera’ is the camera used and ‘processing’ is the processing steps.

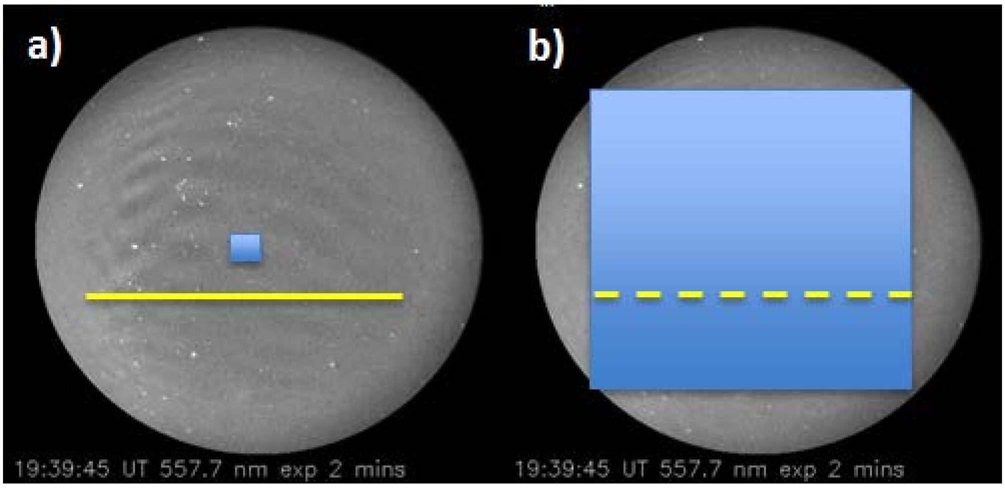

Figure 7. Calculating the airglow median over a) the central region and b) the background. The dotted and solid lines show the appearance of the median on the summary plots.

TRACE Boltwood cloud sensor and TRACE and PortaTRACE Aurora cloud sensor light measurements are plotted on the summary plots in arbitrary units. Triangle symbols in the sensor line colour are used to denote cloud or rain detection.

Smoothed SQM calibrated light measurements (Magnitudes per square arcsecond) are included on the summary plots where available but values have been scaled by a factor of 10 for easier viewing so that a value of 200 is actually 20.0 mag/arcsec^2. The key denotes the file used as well as the darkest light reading over the night.

3.4 Interpretation of Summary Plots

Airglow summary plots may be used as a 'quick look' estimation of airglow, moon and cloud activity. This section covers some of the more common non-airglow features seen in the plots and the associated airglow images. Interpretation of summary plots airglow features will be covered in a future publication.

3.4.1 TRACE Camera Retracted

Figure 8 shows an example of the summary plot and a typical corresponding airglow image when the TRACE camera is in the retracted position. The background median time series (dashed lines) for all TRACE filters form a constant background. This can occur if the Boltwood cloud sensor detects very light, very cloudy, rainy or very windy conditions.

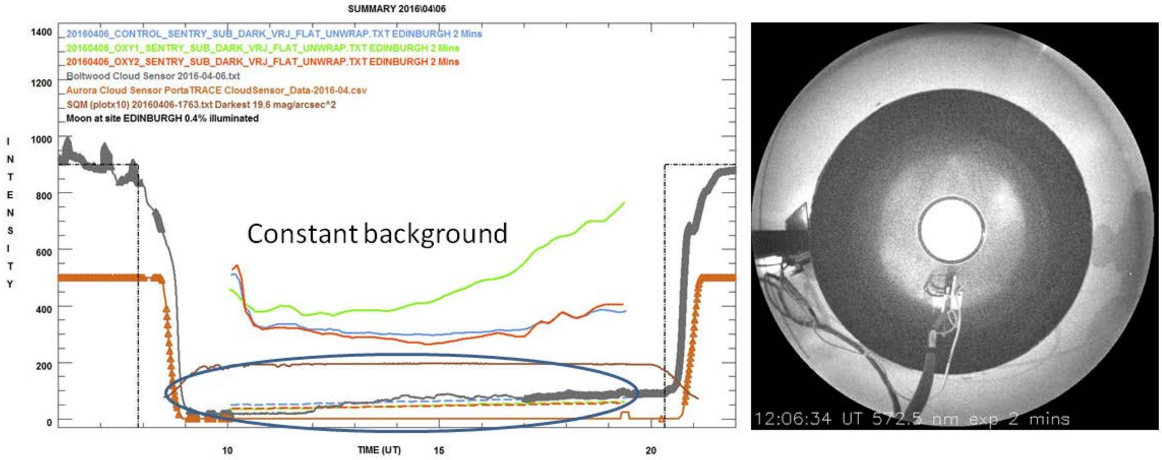

Figure 8. Example of summary plot when the TRACE camera is down

3.4.2 Moon in View

Originally, the TRACE camera was not run when the moon was higher than 18 degrees below the horizon. Later, this criteria was relaxed as it became apparent that some airglow was still visible even when the moon above the horizon. Figure 9 shows an example summary plot and image when the moon is in view of the camera. A characteristic rise in airglow intensity is apparent for all filters but not in cloud sensor or SQM intensity. The calculated moon position and illumination is a recent addition and acts as a sanity check. The image shows the moon in the image and a column of over exposed pixels which have been rotated in the processing step to place North at the top of the image.

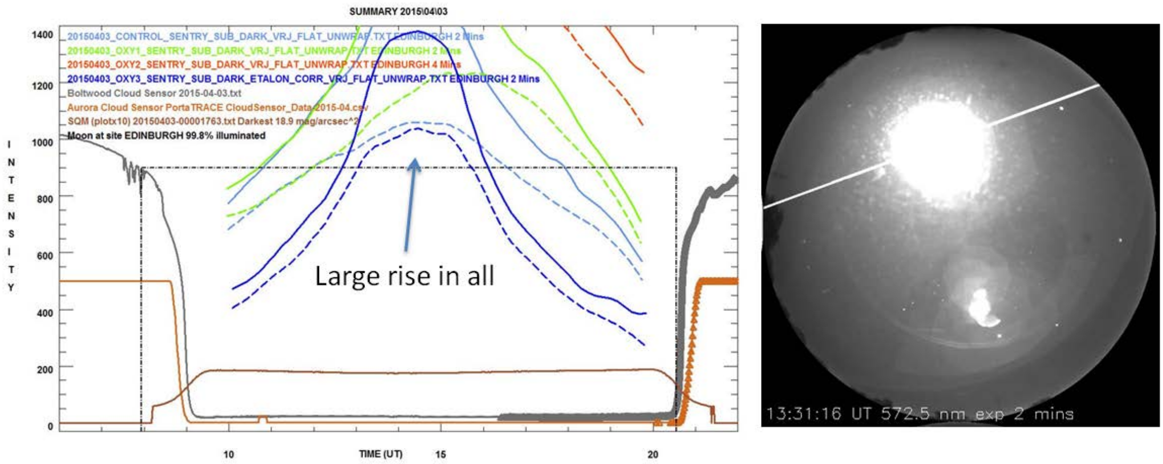

Figure 9. An example summary plot of the moon in view

3.4.3 Impulsive Light Signals

As DST Edinburgh is a secure defence site, security patrols often pass the cameras causing impulse light signals in the summary plots. These impulsive peaks are usually removed from the summary plots using a simple smoothing algorithm, but they may still be apparent in single frames of airglow videos. An example of impulsive light interference in a summary plot before removal is shown in Figure 10 along with the corresponding TRACE and PortaTRACE airglow images.

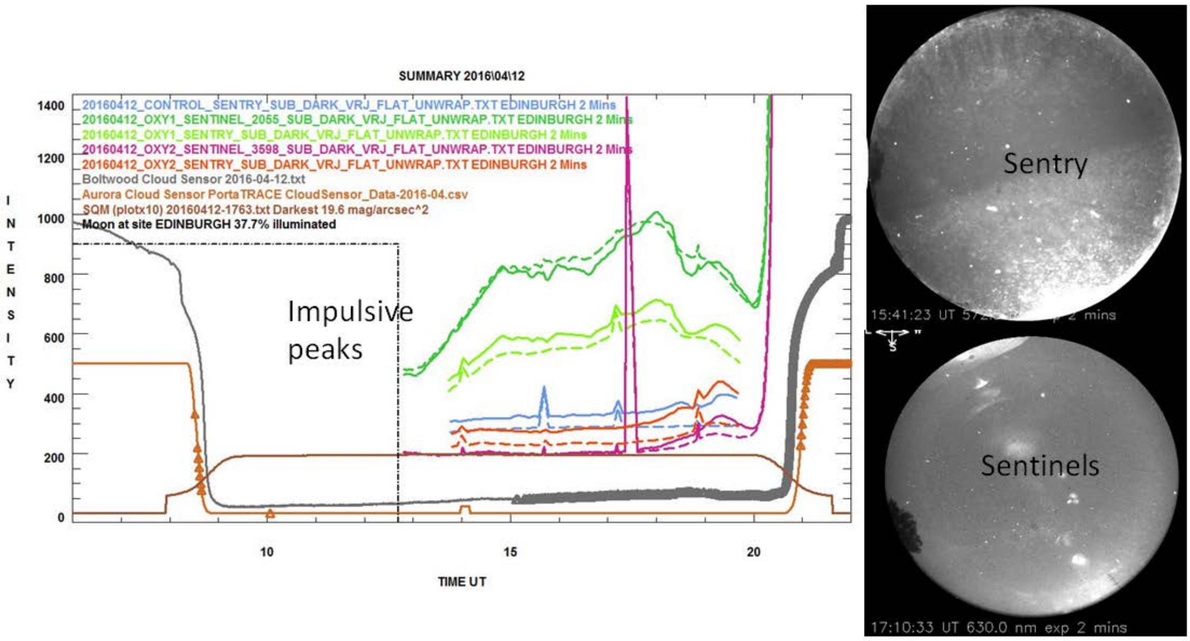

Figure 10. Impulsive light spikes and their appearance in the TRACE and PortaTRACE cameras. Peaks should have been removed from summary plots but may still be apparent.

3.4.4 Cloud Cover

Examples of cloud response in the summary plots during intermittent cloud cover and heavy cloud are shown in Figure 11 and Figure 12 respectively. Note the cloud sensors report cloud throughout most of the night in Figure 11 but a visual inspection of the images reveals many stars implying that any cloud cover was very thin. Conversely, the cloud sensors report no cloud cover in Figure 12 even though it was cloudy enough to affect airglow measurements. Two cloud sensor independent methods of detecting cloud which affects airglow measurements are looking for sharp intensity rises in the control filter time series, and looking for simultaneous sharp intensity rises in the time series of all filters.

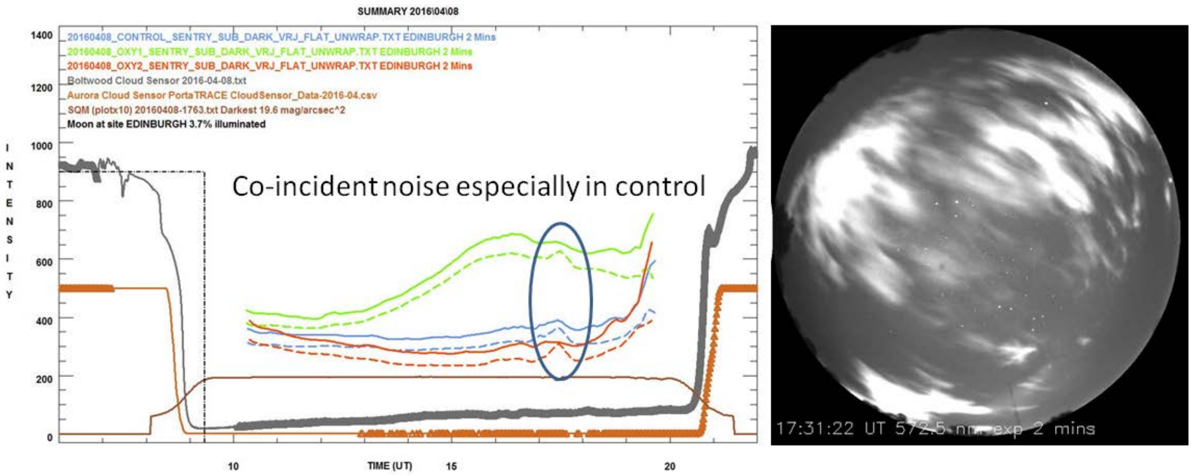

Figure 11. An example of a summary plot and corresponding image during intermittent cloud

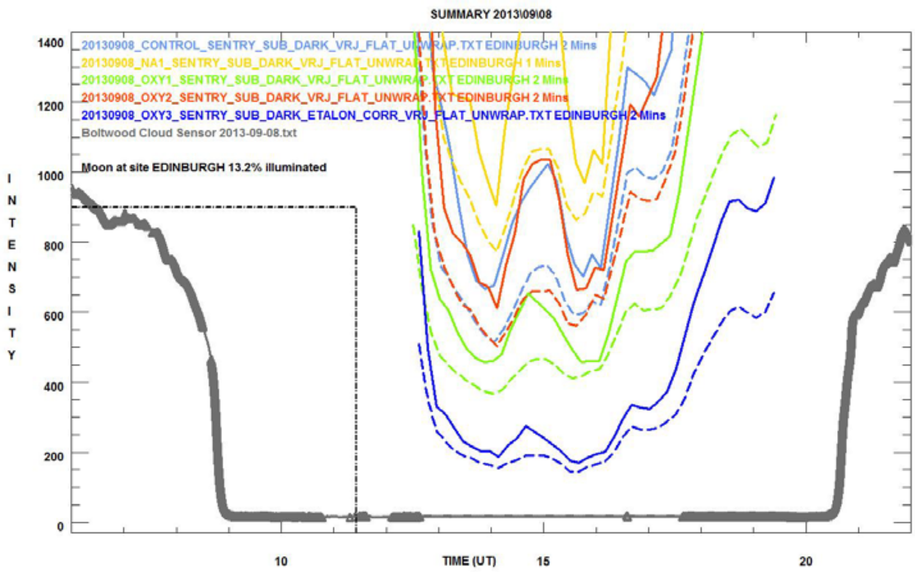

Figure 12. An example of a summary plot and corresponding image during intermittent cloud

4. Conclusion

The contents of this report describe the DST Group airglow database and discuss limitations in the data. The database is a compilation of almost five years of nightly airglow, weather and sky quality measurements taken primarily over DST Edinburgh in South Australia (34.7 S, 138.62 E). It includes summary plots to compare sensor information obtained during each night, tables of weather information and filters used as well as videos of airglow images taken with different filters each night. This database will be useful for studies of such ionospheric phenomenon as travelling ionospheric disturbances, mesospheric bores, meteors and sky quality.

The airglow experiment has now relocated to the Murray Bridge Training Area (MUTA). It is expected that current airglow data obtained at MUTA will be added to the existing database sometime in the future. This recent work focuses on the relation between sodium airglow and sporadic E using the sodium airglow filter and a co-located HF sounder.

5. Acknowledgments

Please add the following acknowledgement to any published material which contains results obtained using this database: "The results published in this paper were obtained using the TRACE airglow database, created by Dr Anne Unewisse and Mr Andrew Cool, Defence Science and Technology Group, Australia."

6. Disclaimer

The TRACE airglow database is a ‘scientific research’ database. It is not recommended for operational purposes and should be regarded "use at own risk".

7. References

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19. ABSTRACT

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