The Red Sky: investigating the hurricane Ophelia Saharan dust and biomass burning aerosol event

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Introduction

- Throughout 16th October UK skies began to turn an eerie organey-red colour
- Such optical phenomena can result from high loading of aerosol (e.g. near forest fires), where aerosol scatters shorter – mid wavelengths
- But what cause this in the middle of the day in the UK in autumn?
- Answer: ex-hurricane Ophelia hitting the UK
- Ophelia had captured a mix of particles from across northern Europe and Africa and brought them to the UK
- We used an ensemble of modelling and remote sensing to interrogate this particle matrix and determine its origins

Method

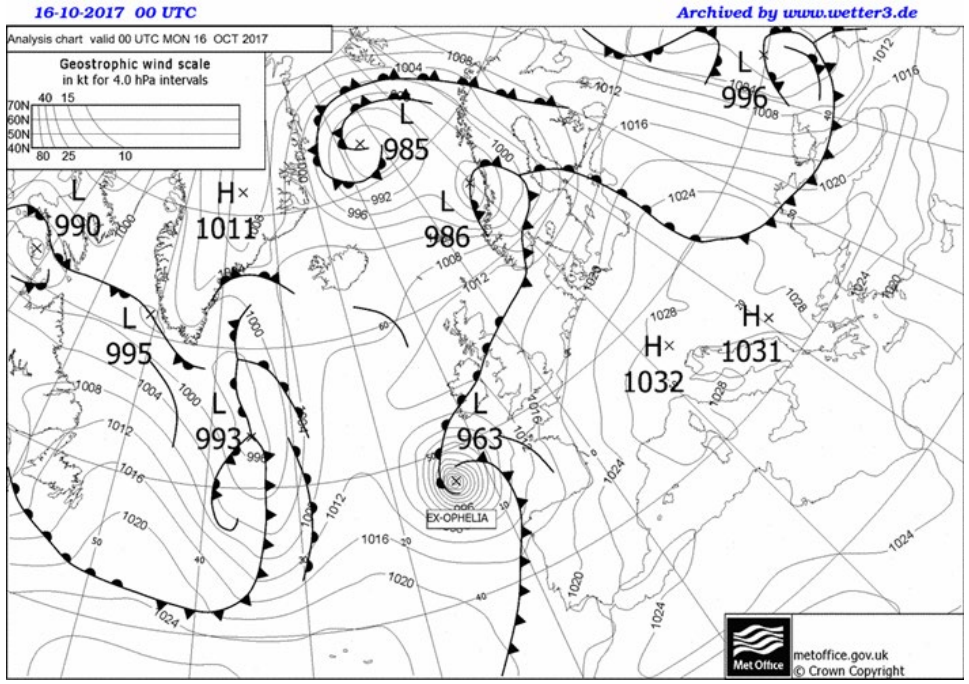
- Mixed method approach: remote sensing from orbital platforms and from ground and also modelling

- **Orbital Instruments**
  - *MODIS (Terra)*: true colour imagery
  - *VIIRS (Suomi)*: true colour imagery, Aerosol Optical Thickness (AOT) and thermal anomalies
  - *AIRS (Aqua)*: Carbon monoxide at 500 hPa
  - *OMI (Aura)*: Aerosol Index (AI)
  - *MSI (Sentinel-2)*: multispectral imaging

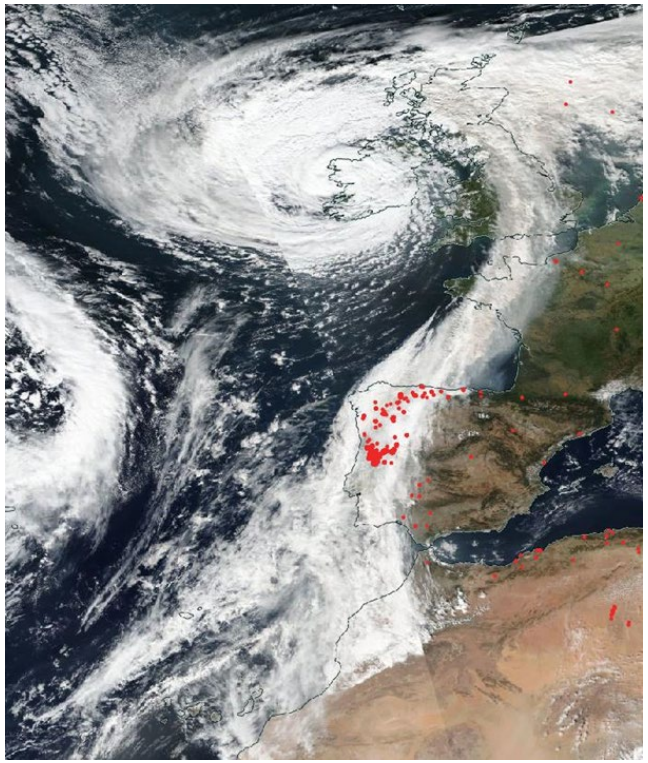
- **Ground Instruments**
  - *Lidar:* Elastic backscatter Mini Micro Pulse Lidar (MiniMPL) (Droplet Measurement Tech., US)

- **Modelling**
  - *HYSPLIT (NOAA)*: Back trajectories

Results: Synoptic Overview

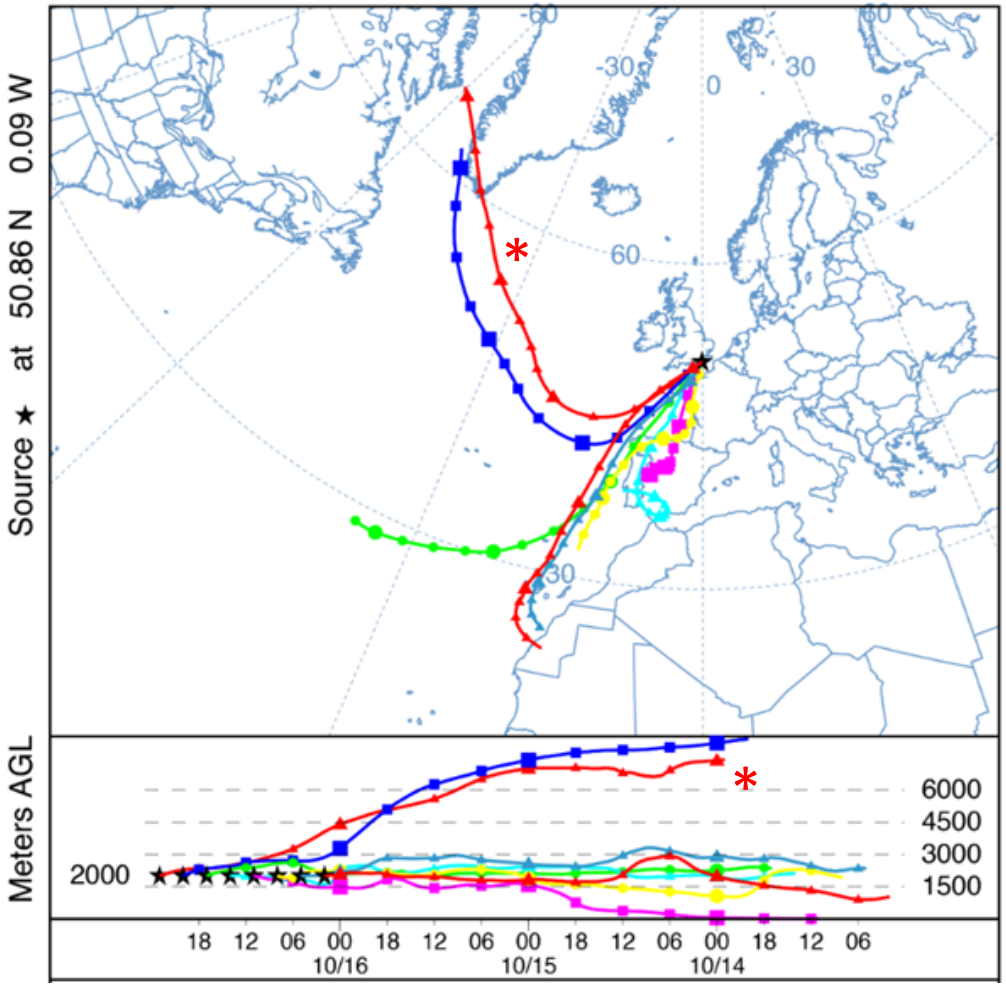


- Synoptic chart for 16th October 2017 at 00:00 UTC
- Landfall along Irish coast in AM; winds reached 155.6 km h^{-1} (record breaking 10-minute av. wind of 114.8 km h^{-1})
- British coast also experienced strong, warm winds within warm sector; these formed warm conveyor belt (WCB)



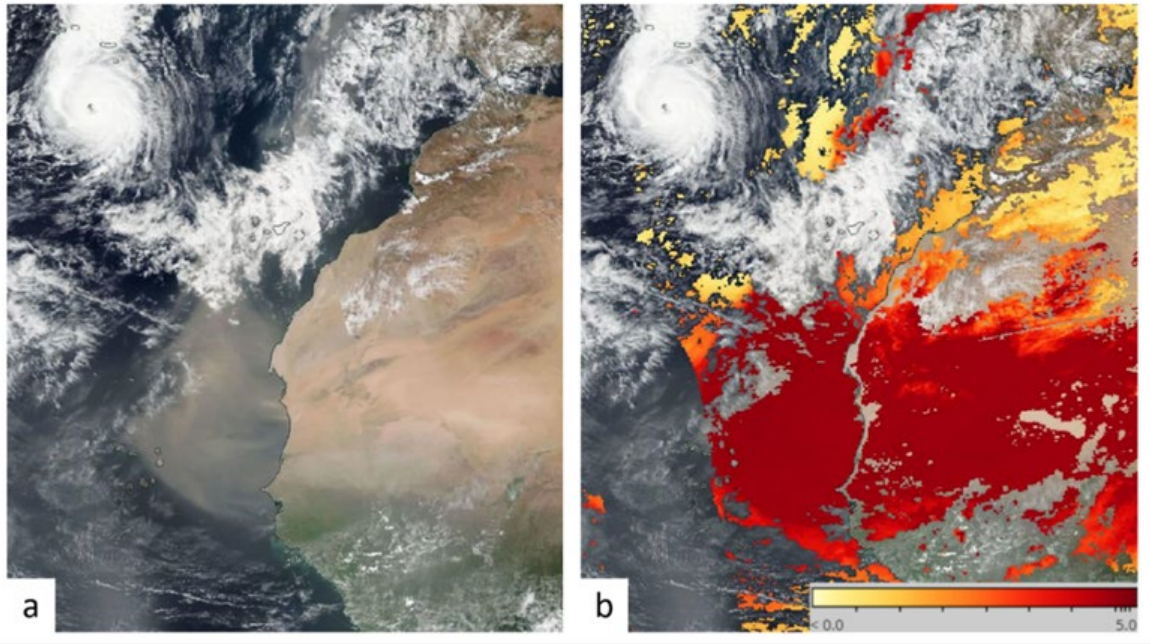
- Composite true colour RGB image of Ophelia
- WCB identified by narrow swath of cloud stretching from Portugal, over north-western France, up to southern England – this contained aerosol mix to redden sky

Results: Back Trajectory Analysis

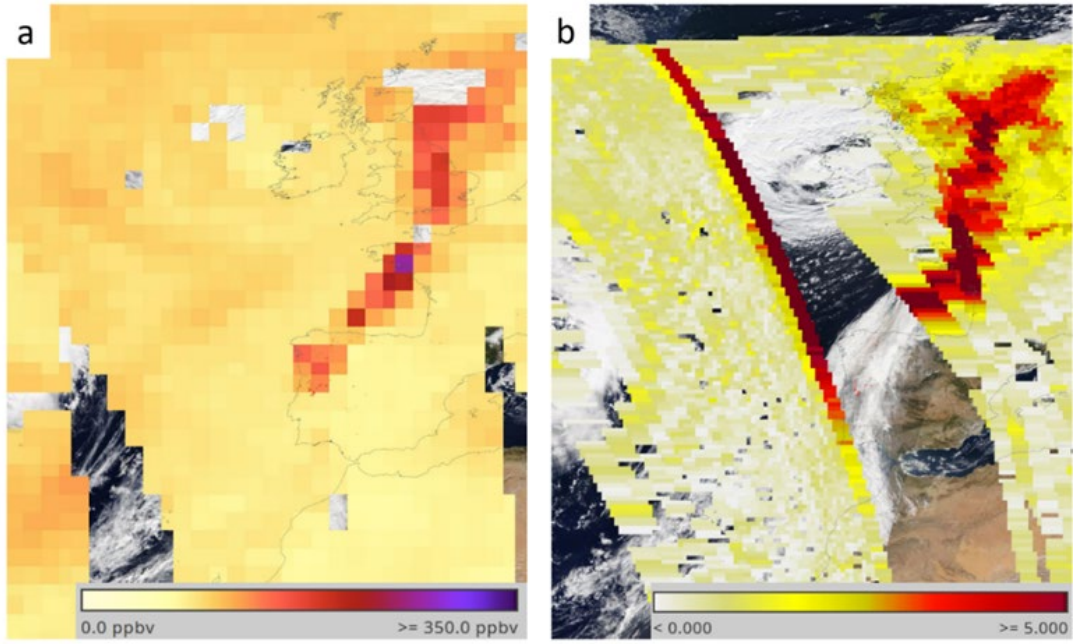


- Brighton back trajectories for air parcels arriving at 2 km between 02:00 and 23:00 UTC on 16th October 2017; time resolution = 3 hours, backcast for 72 hours
- **02:00 (red) - 08:00 (yellow):** air parcels had origins off north-west African and Iberian coasts at heights of ~ 1.5 - 3.0 km
- **11:00 (pink) - 17:00 (green):** the air parcels brought directly from Portugal and northern Spain, at times, from near ground level (11:00, pink); it was during this time the 'red sky' phenomenon was observed
- **20:00 (blue) and 23:00 (red*):** origin changed, air parcels being imported from remote northern areas of Atlantic Ocean towards Greenland and at higher altitudes (*i.e.* > 6.0 km).

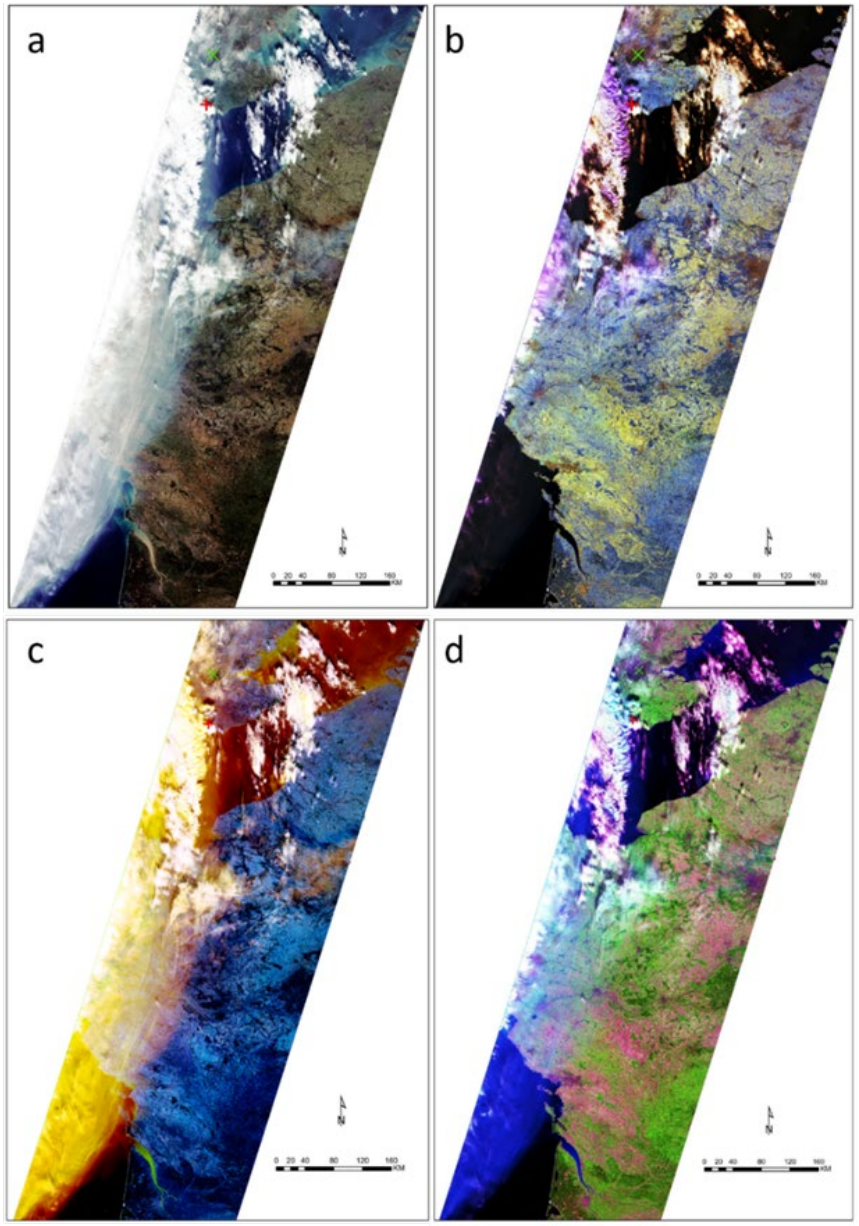
Results: Top-Down Satellite Observations



- (a) True colour corrected reflectance VIIRS imagery recorded on 14th October prior to UK ‘red sky’ event – shows large patches of Saharan dust haze
- (b) VIIRS AOT measurements reached high levels >1.5 indicating a dense, aerosol heavy haze layer

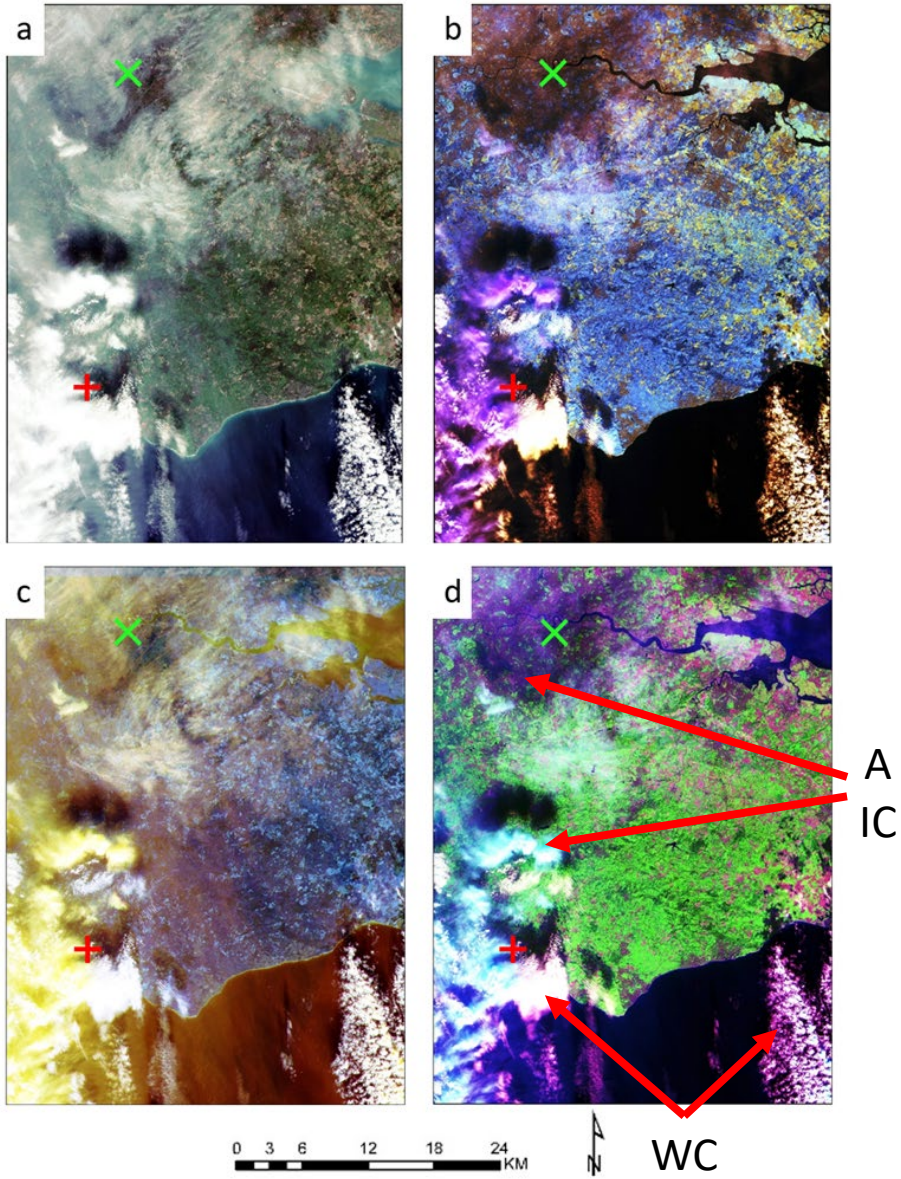


- (a) AIRS CO at 500 hPa recorded (*ca.* 12:00 - 14:00 UTC) on and (b) OMI AI (*ca.* 12:10 - 12:20)
- CO (273 ppbV) and AI (>5) very high in distinct band aligning with Ophelia’s cloud-top, stretching from Portugal to UK



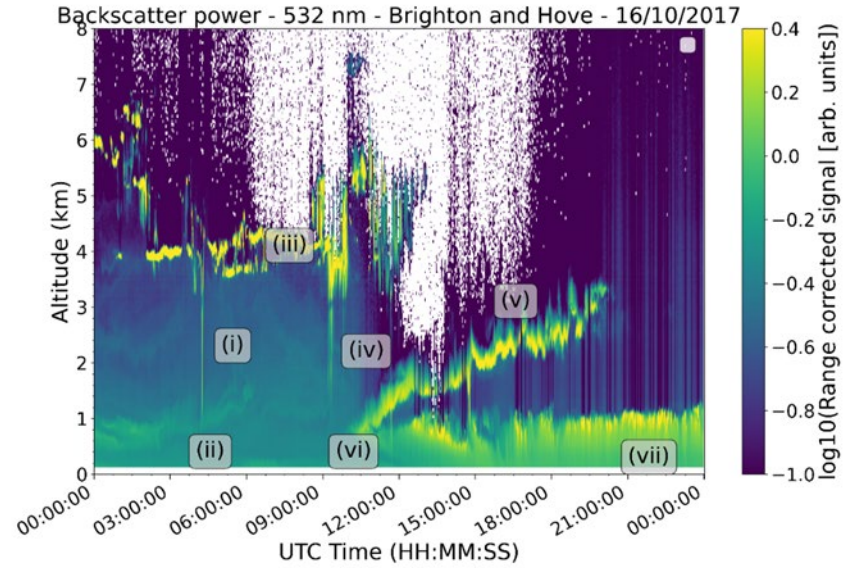
Results: Multispectral Imaging

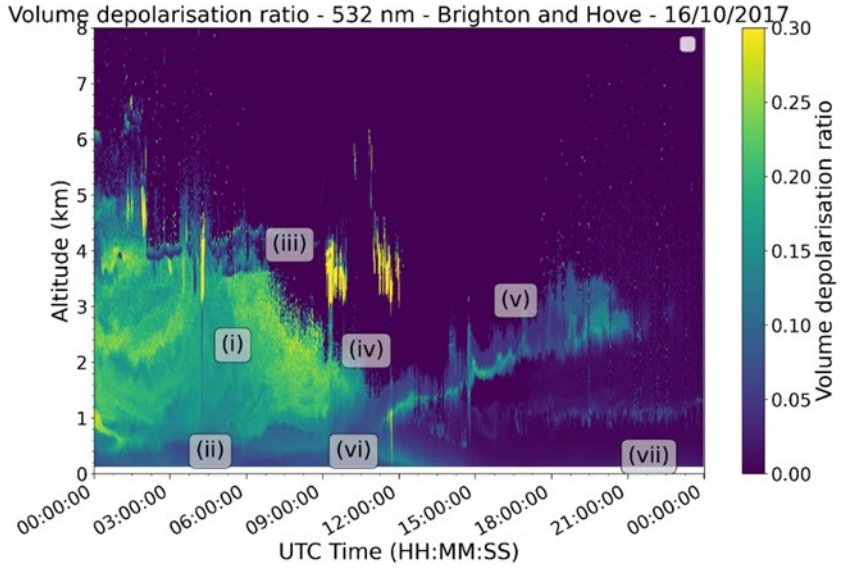
- 60 m resolution (non-atmospherically corrected) Sentinel-2 MSI data on 16th October
- (a) true colour representation of the scene, and (b) – (d) are various different band combinations



Results: Multispectral Imaging

- 60 m resolution (non-atmospherically corrected) Sentinel-2 MSI data on 16th October
- (a) true colour representation of the scene, and (b) – (d) are various different band combinations
- Close up over Brighton gives the cloud above the lidar
- Can make out three different types of cloud, plus areas of mixing
- *E.g.* in (d):
  - Water cloud = white (purple edges)
  - Ice cloud = cyan (white where thicker)
  - Aerosol (smoke/dust) = faded royal blue (with blue/white hue)
- To the west and north of the image we can see the mixing





Results: Bottom-Up Lidar Observations

- Ground-based lidar - detailed, high time-resolution data; backscatter power of parallel signal (top), volume depolarisation ratio (VDR) (bottom). Event split into two time phases, *i.e.* 00:00 - 10:00 UTC and 10:00 - 22:00 UTC
- **Before 10 am**
  - 0.5 – 5km (i): deep aerosol layer; high VDR (15 – 25 %) = non-spherical aerosol, *e.g.* Saharan/mineral dust
  - 0 – 0.5 km (ii): lower VDR (6 – 10 %) = mixture of dust and anthropogenic aerosol
- **After 10 am**
  - 10:00 – 21:00 UTC (v): strongly absorbing layer; lidar only able to penetrate layer ca. 10:00 – 12:00 and 18:00+
  - 12:00 – 18:00 UTC: higher VDRs (8 – 18 %) = mix of spherical and non-spherical particles, here biomass burning particles and mineral dust