EOCIS

EARTH OBSERVATION CLIMATE INFORMATION SERVICE

Quick Start Guide

RAL Infrared and Microwave Sounder (IMS) Products

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Date: 6 March 2025
Version: 0.2

Table of Contents

Table of Contents 2
1. Quick Start: RAL IMS L3 Products 3
1.1 What products are available? 3
1.2 Summary information 5
1.2.1 L3U Summary information 6
1.2.2 L3C Summary information 12
1.3 What can these products be used for? 15
1.4 Where to find these products for download 15
1.5 Using downloaded data 16
1.5.1 Import and plot L3U data 16
1.5.2 Quality control and temporal averaging of L3U data 18
1.5.3 Plotting total and vertically resolved ozone in Dobson units 22
1.5.4 Simple plot of height-resolved water vapour on level. 25
1.5.5 Methane from L3C 26
1.6 Interactive visualisation / data access 30
1.7 Your obligations when using these products 30
1.8 Further Information 30
History of modifications / Change Log 31
Related Documents / Reference Documents 31
Acronyms and/or Abbreviations 31
General definitions 31

1. Quick Start: RAL IMS L3 Products

The following is intended to provide the user with sufficient information to quickly get to grips with the RAL Infrared and Microwave Sounder (IMS) Level 3 (L3) product and to gain some familiarity with the information available.

The IMS retrieval scheme is run in two stages to generate L2 data:

1) IMS-extended retrieval: Temperature, water vapour, ozone surface emissivity, cloud, aerosol and some minor gas species are retrieved from a combination of measurements from the sounders on either the Metop platforms (IASI, AMSU-A, MHS) [Ref:Metop] or NOAA NPOESS sensors (CrIS and ATMS) [Ref:NPOESS}. This scheme is described in [RD1: CCI H2O ATBD]
2) IMS-methane retrieval: For Metop only, methane is retrieved in a second step from IASI spectra in the 8 micron spectral range with temperature and surface spectral emissivity from step 1. This scheme is described in [RD2: Methane+ ATBD].

Products from both schemes are available in a similar format.

Here we specifically cover L3 data produced through UK EOCIS, NCEO, ESA and Eumetsat programmes. .

1.1 What products are available?

The main product types are listed in Table 1. There are separate files for each main retrieved variable (water vapour, methane, cloud fraction etc), and for each satellite platform (Metop A, Metop B, Metop C, Suomi-NPP, NOAA-20).

Filenames are constructed as follows, using “-“ (dash) as the primary field separator. Underscore is used within the primary fields to modify their meaning in some way:

ral-[L3 type]-[Variable ID]-[Platform]-[Retrieval scheme]-[Date]-[Version].nc

Where

- **[L3 type]**: The type of L3 file: “l3u”, “l3c”, “l3c_rm” as described below.
- **[Variable ID]**: Identifies the main physical quantity in the file. This can be one of the following: "cfr", "cfr", "ch3oh", "ch4", "co", "ctp", "ctp", "d_alh", "d_aod", "dt1000", "dt2", "emis", "h2o", "hcooh" (Metop platforms only), "hdo", "hno3", "i13ch4", “isoprene” (NPOESS platforms only), "k_index", "lifted_index", "nh3", "o3", "s_aod", "so2", "t", "tpw", "tsk". Specific contents of each of these file types is given in Table 3.
- **[Platform]**: The satellite used: “metopa”, “metopb”, “metopc”, “npp” (Suomi-NPP), “jpss1” (JPSS-1 also known as NOAA-20).
- [Retrieval scheme]: “ims” or “imch4”.
- **[Date]**: For L3U this specifies the year (YYYY), month (MM), day (DD) in form YYYYMMDD; for L3C this specifies the year and month, followed by either “_day” or “_night” to indicate

whether the averages include data on the ascending or descending node of the orbit. Labels "day" and "night" are used based on the whether the given node is predominantly in daytime or nighttime. For Metop platforms, the descending node is in daytime; for NPOESS platforms, the ascending node is daytime.

- **[Version]**: Version identifier for the L3 files.

Product name and acronym	Filename example	Version
L3U (daily, hourly sampled products on a 0.25x0.25 degree latitude, longitude grid)	ral-l3u-h2o-metopb-ims-20180615-v0001.nc	0.1
L3C (monthly files, separating data for day and night, on a 1x1 degree latitude, longitude grid)	ral-l3c-h2o-metopb-ims-201806_day-v0001.nc	0.1
L3C_rm (monthly averages over IPCC reference regions)	ral-l3c_rm-h2o-metopb-ims-201806_day-v0001.nc	0.1

Table 1 Dataset Products covered in this document

1.2 Summary information

	IMS L3 products
Main observed variables	Water vapour, surface and atmospheric temperature, ozone, surface emissivity, carbon monoxide, methane, minor trace gases (e.g. ammonia, sulfur dioxide), sulfate and dust aerosol optical depth, cloud fraction, cloud height.
Geographical range of dataset	Global
Temporal range of dataset	2007 to present
Spatial resolution / gridding	L3U: 0.25 x 0.25 degree latitude, longitude. L3C: 1x1 degree latitude, longitude L3C_rm: Averages over 61 spatial regions (58 IPCC reference regions + UK, Mediterranean Sea and global ocean between 60S to 60N)
Temporal sampling characteristics	L3U: Each file spans a day, with hourly sampling within the day L3C and L3C_rm: Each file contains averages for a calendar month, separate files are produced for data on the satellite ascending or descending node.
Level of processing	L3 gridded data
Main auxiliary content	L3U: Uncertainties, sensing time, flags identifying certain conditions (cloud affected, dust affected, high uncertainty, orbit in day/night node, whether contains the centre of satellite footprint) L3C and L3C_rm : Mean, median, percentiles and standard deviation of the main variable ; mean uncertainty, estimated standard error in the mean, number of samples, mean and standard deviation of the time of day in each grid cell, flag identifying which days of the month are included in each grid cell.
Dataset citation	TBD
Dataset journal reference	[Various to be added]

Table 2 Summary Information for the L3 products

1.2.1 L3U Summary information

Table 3 summarises the main variables within each of the L3U (daily) files. The left-hand column indicates either "Common" for variables present in most/all files or the specific filename variable ID. In most cases each file contains the main physical variable together with its estimated random uncertainty, together with common variables defining the grid and providing quality information.

In all cases the main physical variables have dimensions of **time** (of which there are 24 hourly samples), **latitude** and **longitude** (or **time** and **region** index in the case of L3C_rm files). Coordinate variables defining these are given in the file, together with corresponding cell boundaries. Some variables also have one of the following additional dimensions (these are only defined in relevant files):

- **level**: Water vapour (h2o) and temperature (t) profiles are defined on a subset of the hybrid sigma model levels used by ERA5 (L137 grid). In this case the file will also contain the surface pressure field (in Pa, usually taken from ERA5 [REF:era5]) and corresponding (time and space invariant) parameters **hya** and **hyb** for each level. These can be used to construct the pressure profile (in Pa) for every grid cell via

  pressure_profile = **hya** + **hyb** * **surface_pressure**

  The levels used are defined in Table 4.
- **layer**: Ozone (o3), methane (ch4) and carbon monoxide (co) are provided as total column average volume mixing ratio (variables with "**_tcol**" in the name) and as sub-column averages integrated between specific layers defined by surface pressure (as the absolute lower bound) or a fixed pressure level in the atmosphere. Variable "**layer_bnds**" givens the bounding layer pressures and "layer" gives the midpoints. Note that wherever layer_bnds is equal to 1000 hPa, this indicates the surface pressure is used to define the layer (**surface_pressure** variable will also be in these files). Layers used are defined in table Table 5. Note that other minor gases (e.g. ammonia (nh3), sulfur dioxide (so2), nitric acid (hno3)) are *only* given as total column averages, in separate files, without any "_tcol" suffix used in the variable name.
- **wavelength**: Surface emissivity is defined for a subset of spectral points: 23.8 GHz, 89.0 GHz, 190 GHz, 15.1 microns, 13.5 microns, 10.4 microns, 8.80 microns, 8.13 microns, 7.73 microns, 4.92 microns, 4.62 microns, 4.59 microns.

To reduce data volume, most variables are stored as integers with **scale_factor** and **add_offset**, which must be applied to convert the stored data type to physical values. This may be done automatically by the tool used to read the files (as is the case for the examples provided below). In particular, uncertainty values are stored as a scaled byte value. If the byte value is 254 or 1 it implies the L2 error has under/over-flowed this form of storage and the L2 value was larger or smaller, respectively.

L3U files contain almost all L2 retrieved values (minimal quality control is applied to the values stored in the files). ***However, it is strongly recommended to apply further quality control to subset data***, based on the following variables in the file.

- **qa_value**: This stores a simple quality value in the range 0-1 (after applying the defined scale_factor).
    - Values should be ignored where qa_value < 0.5. (NB qa_value is stored as a byte in range 0-100; data should be ignored where unscaled qa_value < 50.)
- **status_flags**: For more detailed analysis, this is a bit mask (see flag_names and flag_meanings attributes) which contains more detailed information regarding the data quality.
    - The main variable has attributes **default_status_flag_mask** and **default_status_flag_value** which define the recommended test to be applied to the status_flags in order to select "good" data:
    - Only scenes for which the bit-wise-logical-and of status_flags and default_status_flag_mask is equal to default_status_flag_value should be used. Note that scenes recommended to be excluded in this way will also be flagged with qa_value < 0.5, so it should not always be necessary to use the status_flags if qa_value is checked.

    Examples of using the qa_value and status_flags are given in section 1.5.

Data is gridded under the assumption that individual L1 samples represent a quadrilateral area with corners defined as the mid-points between neighbouring samples in the swath. This full quadrilateral area is mapped to the L3U grid, meaning that data appears contiguous (where valid). However, it should be noted that the instrument only really samples within an elliptical footprint inside this area (of approximately 12km diameter at nadir). The 0.25 degree grid resolution is chosen as it closely matches the L1 sampling of IASI near nadir: For IASI, there will generally be a single L1 sample within each 0.25 degree grid boxes which fall within the swath, however the same L1 sample may appear in multiple (neighbouring) grid boxes towards the edge of the swath and near the poles. CrIS has about twice the spatial sampling density of IASI (9 samples an area of ~50x50kmfor CrIS vs 4 for IASI), resulting in typically 2 or 3 spatial samples per L3U cell.

One of the bits in status_flags indicates whether a given cell contains the centre of an individual L1 sample. This can be used to exclude cells which contained repeated L1 samples, which becomes appropriate when further spatially averaging the data. An example of using the status flags to do this is given in section 1.5.2.

Another of the bits in status_flags indicates when the satellite is in the night-time or day-time node. I.e. the ascending or descending node which is mostly in day-time or night-time for the particular platform. This can therefore be used to separate data into "day" and "night" averages over the whole 24 hour period (though bear in mind this is not strictly separating data into sun-lit/dark scenes).

Note that the time of the observations in a given cell can be known quite precisely (to within about 15s) using the variable **time_in_hour** which stores the time in seconds since the start of the hour. The start of the hour is defined in the **time_bnds** coordinate variable (in s relative to the **time_reference** defined in the global attributes).

Filename variable ID	Variable name	Description	Dimensions	Units
Common	Time	reference time of data	time	seconds since 2000-01-01T00:00:00Z
Common	time_bnds	Time cell boundaries. Contains the start and end times for the time period the data represent.	bnds time	as time
Common	Latitude	Latitude	latitude	degrees_north
Common	latitude_bnds	Latitude cell boundaries. Contains the northern and southern boundaries of the grid cells.	bnds latitude	as latitude
Common	Longitude	Longitude	longitude	degrees_east
Common	longitude_bnds	Longitude cell boundaries. Contains the eastern and western boundaries of the grid cells.	bnds longitude	as longitude
Common	[variable]_uncertainty	Uncertainty estimate for the main variable (e.g. h2o,o3,d_aod etc)	longitude latitude time	1
Common	N	Number of samples in grid cell	longitude latitude time	1
Common	status_flag	Flags indicating conditions that affect the quality of the retrieval: Bit 0: cloud_affected; Bit 1:dust_affected; Bit 2: high_error; Bit 3: poor_thermal_contrast; Bit 4: night_time_node; Bit 5: footprint_centre_in_bin	longitude latitude time	
Common	time_in_hour	Mean observing time. Defines seconds since lower time_bnd of each time interval (i.e. seconds since the start of each hour)	longitude latitude time	seconds
Common	qa_value	data quality value. A continuous quality descriptor, varying between 0 (no data) and 1 (full quality data). Recommend to ignore data with qa_value less than 0.5	longitude latitude time	1
Common	surface_pressure	Surface pressure	longitude latitude time	Pa
Common	layer	Mean pressure of atmospheric layer	layer	Pa
Common	layer_bnds	Pressure of atmospheric layer boundaries	bnds layer	as layer
Common	ctp	Cloud pressure	longitude latitude time	Pa

Common	level	hybrid sigma level	level	
Common	hya	hybrid sigma level parameter a	level	Pa
Common	hyb	hybrid sigma level parameter b	level	1
cfr	cfr	Cloud fraction	longitude latitude time	1
ch3oh	ch3oh	Methanol column averaged volume mixing ratio	longitude latitude time	1
co	co	Carbon monoxide sub-column averaged volume mixing ratio	longitude latitude layer time	1
co	co_tcol	Carbon monoxide total column averaged volume mixing ratio	longitude latitude time	1
d_alh	d_alh	Aerosol layer pressure	longitude latitude time	Pa
d_aod	d_aod	Dust/mineral aerosol infra-red optical depth	longitude latitude time	1
dt1000	dt1000	Surface - 1km air temperature	longitude latitude time	K
dt2	dt2	Surface - 2m air temperature	longitude latitude time	K
emis	wavelength	Wavelength	wavelength	m
emis	emis	Surface emissivity	longitude latitude wavelength time	1
h2o	h2o	Water vapour volume mixing ratio	longitude latitude level time	ln(re 1 ppmv)
hcooh	hcooh	Formic acid column averaged volume mixing ratio	longitude latitude time	1
hno3	hno3	Nitic acid column averaged volume mixing ratio	longitude latitude time	1
isoprene	isoprene	Isoprene column averaged volume mixing ratio	longitude latitude time	1
k_index	k_index	K index (a stability index)	longitude latitude time	K
lifted_index	lifted_index	Lifted index (a stability index)	longitude latitude time	K
nh3	nh3	Ammonia column averaged volume mixing ratio	longitude latitude time	1
o3	o3	Ozone sub-column averaged volume mixing ratio	longitude latitude layer time	1
o3	o3_tcol	Ozone total column averaged volume mixing ratio	longitude latitude time	1
s_aod	s_aod	Sulfate aerosol infra-red optical depth	longitude latitude time	1

so2	so2	Sulfur dioxide column averaged volume mixing ratio	longitude latitude time	1
t	t	Temperature	longitude latitude level time	K
tpw	tpw	Total precipitable water vapour	longitude latitude time	kg/m2
tsk	tsk	Surface temperature	longitude latitude time	K
ch4	ch4	Methane sub-column averaged volume mixing ratio	longitude latitude layer time	1
ch4	ch4_tcol	Methane total column averaged volume mixing ratio	longitude latitude time	1
hdo	hdo	Isotope ratio of HDO relative to standard reference ratio	longitude latitude time	1
i13ch4	i13ch4	Isotope ratio of 13-CH4 relative to standard reference ratio	longitude latitude time	1

Table 3 Summary information for each variable for L3U products

Variable(s)	ERA-5 L137 hybrid-sigma full level index	Pressure (for surface pressure 1013.25 hPA)	Approximate Altitude
t, h2o	137	Surface	Surface
t	121	930 hPa	0.502 km
t, h2o	114	850 hPa	1.13 km
t, h2o	111	804 hPa	1.52 km
t, h2o	107	733 hPa	2.16 km
t, h2o	105	693 hPa	2.55 km
t, h2o	100	590 hPa	3.67 km
t, h2o	98	548 hPa	4.18 km
t, h2o	94	469 hPa	5.26 km
t, h2o	91	416 hPa	6.1 km
t, h2o	86	337 hPa	7.55 km
t, h2o	84	310 hPa	8.15 km
t, h2o	78	237 hPa	9.99 km
t, h2o	72	180 hPa	11.9 km
t	67	141 hPa	13.6 km
t, h2o	61	104 hPa	15.7 km
t	55	75.2 hPa	18 km
t, h2o	50	56.3 hPa	20 km
t	43	35.1 hPa	23.3 km
t	34	16.5 hPa	28.5 km
t	29	9.82 hPa	32.1 km
t	25	6.04 hPa	35.5 km
t	22	3.98 hPa	38.4 km
t	18	2.1 hPa	42.9 km
t	14	0.972 hPa	48.2 km
t	11	0.489 hPa	53 km
t	10	0.379 hPa	54.7 km

Table 4: Hybrid sigmal levels used for water vapour (h2o) and temperature (t). Water vapour is reported for a subset of the levels used for temperature, as indicated in the first column. Levels are taken from the L137 grid used for the ECMWF ERA5 reanalysis.

Variable (s)	Layer pressure bounds	Approximate altitude bounds
o3, co, ch4	Surface – 450 hPa	Surface - 5.55 km
o3, co, ch4	450 – 170 hPa	5.55 - 12.3 km
o3, co, ch4	170 – 100 hPa	12.3 - 16 km
o3	100 – 50 hPa	16 - 20.8 km
o3	50 – 30 hPa	20.8 - 24.4 km
o3	30 – 20 hPa	24.4 - 27.2 km
o3	20 – 5 hPa	27.2 - 36.8 km
o3	5 – 2 hPa	36.8 - 43.2 km
o3	2 - 0.5 hPa	43.2 - 52.8 km
ch4	100 - 0.01 hPa	16 - 80km

Table 5: Layers used for ozone (o3), carbon monoxide (co) and methane (ch4)

1.2.2 L3C Summary information

Table 6 defines the variables in the L3C files. The L3C files contain monthly averaged data accumulated as follows:

- Daily L3U files are used as input. Only cells which have qa_value >= 0.5 and contain the L1 pixel centres are used (in this way the same L1 sample is only used once).
- Separate files are produced for samples on the day-time and night-time nodes of the orbit.
- L3C is computed on a 1x1 degree latitude longitude grid. For each of these cells, the individual L3U samples (at 0.25x0.25 degree sampling) are identified, and percentiles 2.5, 16 (pc16), 50 (median), 84 (pc84) and 97.5 of these values are computed (and reported in the output file in variables with names ending _pc2, _pc16, _median, _pc84 and _pc98, respectively).
- Further statistics are computed after outliers are removed by applying a “3-sigma” test: Values which are smaller than vmin and vmax are ignored, where
    - vmin = median – (median - pc16)*3
    - vmax = median + (pc84 – median)*3

  Note that for variables with a level (or layer or wavelength) dimension the test is applied at all levels (based on level specific percentiles). If an outlier is identified at *any* level, corresponding values at all levels (for the same L3U sample) are excluded. This means that auxiliary data (e.g. n_total, n_3sigma, etc) remains independent of level.
- The number of remaining values is reported (n_3sigma) and for this subset of variables the following quantities are computed (see table for further description): “**_mean**”, “**_stddev**”, “**_weighted_mean**”, “**_uncertainty_mean**”, “_stderr”.

The following variables are included to retain sampling information within the month (with a view to facilitating model comparisons include the effects of satellite temporal and spatial sampling):

- **i_day**: is a 32-bit integer which has bits set flag which has bits 1-31 set depending on which days of the month are included in the average in each cell.

- **time_of_day mean**: This gives the mean time of day (seconds since midnight) of observations in each cell. Note that since the platforms are in sun-synchronous orbit and L3C separates the data into day-time and night-time node, a given latitude/longitude cell will be sampled systematically at a specific time of day (within ~50mins at latitudes smaller than 60 deg.N/S; larger variations occur a polar latitudes where orbit tracks overlap).
- **time_of_day_stddev**: This gives the standard deviation of the time of day of observations in each cell.

The L3C cloud fraction (cfr) file contains additional variables **cfr_low**, **cfr_mid** and **cfr_high,** which are the mean of the daily cloud fraction for scenes with cloud top pressure (**ctp**) in specific ranges defined for ISCCP [ref:ISCCP]: Low cloud: ctp >= 680 hPa; high cloud: ctp < 440 hPa; Mid-level cloud: 680 hPA > ctp >= 440 hPa. The cfr file also contains mean cloud pressure, which is computed as the mean of daily ctp weighted by the associated cloud fraction.

Note that for dust aerosol layer height (d_alh), the L3U qa_value is set to zero for all scenes with dust optical dept (d_aod) lower than 0.04 (layer height has no meaning if the optical depth is zero, and generally tends to it's *a priori* value if the optical depth is very low). This means that the L3C d_alh products contain far fewer samples than other L3C products – they only include values where a significant dust plume was sampled during the month. In this case the i_day variable could be particularly useful in allowing the day(s) on which the plume was present to be identified from the monthly file.

Note that for the special case of water vapour, the unit used at L3U is the natural logarithm of the volume mixing ratio in parts per million by volume. "ln(re 1 ppmv)" is the UDUNITS convention [Ref: UDUNITS] for this representation. This is used instead of the CF-convention [Ref: CF convention] standard form to allow the variable (which spans a very large dynamic range) to be represented in compact form as a short integer (and thereby reduce the file size). L3C processing is however carried out in volume mixing ratio (not log) and volume mixing ratio (not log) is used as the output variable. This allows the CF-convention standard name to be used in the water vapour L3C files (but not L3U).

Product ID	Variable name	Description	Dimensions	Units
Common	time_of_day_mean	Mean UT time in day	longitude latitude	seconds
Common	n_total	Total number of L3 daily 0.25x25 degree samples	longitude latitude	1
Common	i_day	Bit mask indicating which days of month included	longitude latitude	1
Common	n_day	Number of L3 daily files used	longitude latitude	1
Common	n_3sigma	Number of L3 daily 0.25x25 degree samples after 3-sigma test.	longitude latitude	1
Common	[variable]_mean	Mean of [variable]	longitude latitude	As [variable]
Common	[variable]_stddev	Standard deviation of [variable]	longitude latitude	As [variable]
Common	[variable]_pc02	Percentile 2.5 of [variable]	longitude latitude	As [variable]
Common	[variable]_pc16	Percentile 16 of [variable]	longitude latitude	As [variable]
Common	[variable]_median	Median (Percentile 50) of [variable]	longitude latitude	As [variable]
Common	[variable]_pc84	Percentile 84 of [variable]	longitude latitude	As [variable]
Common	[variable]_pc98	Percentile 97.5 of [variable]	longitude latitude	As [variable]
Common	[variable]_weighted_mean	Weighted mean of [variable], using the inverse uncertainty variance as the weight of each sample.	longitude latitude	As [variable]
Common	[variable]_uncertainty_mean	Mean uncertainty of [variable]	longitude latitude	As [variable]
Common	[variable]_stderr	Standard error in uncertainty-weighted mean of [variable]	longitude latitude	As [variable]
cfr	cfr_low_mean	Mean of low-level cloud fraction (cloud pressure >= 680 hPa)	longitude latitude	1
cfr	cfr_mid_mean	Mean of mid-level cloud fraction (680 hPA > cloud pressure >= 440 hPa)	longitude latitude	1
cfr	cfr_high_mean	Mean of high-level cloud fraction (cloud pressure < 440 hPa)	longitude latitude	1

Table 6 Summary information for each variable for L3C products. "[variable]" indicates a quantity given for each of the main physical variables defined in the L3U files. In general units are the same as the L3U file, with the exception of water vapour profile (see text).

1.3 What can these products be used for?

These Product(s) can be used in scientific studies of atmospheric variability on a range of spatial (~25km – global) and temporal (semi-diurnal - decadal) scales. Their global coverage and homogeneous spatial/temporal sampling is complementary to that of surface-based and airborne observations made in the same time period. Comparisons can be made with global chemical-transport and climate models or analyses/re-analyses, although like-for-like comparisons need to account for vertical smearing intrinsic to satellite soundings. These are therefore best done using the L2 data from which these gridded L3 files were produced, since those files include the necessary vertical “averaging kernels”. .

1.4 Where to find these products for download

To access the dataset products(s) navigate to the following locations using the links below:

- https://gws-access.jasmin.ac.uk/public/rsg_share/transfer/eocis_l3/ims/

  (To be updated with CEDA link when archived)

1.5 Using downloaded data

Examples are given below of use and basic manipulation of the data using python.

1.5.1 Import and plot L3U data

Example Code:

```
import xarray as xr
# Open total precipitable water vapour file:
 filename = 'eocis_l3/ims/l3u/v0001/metopb/2018/06/15/ral-l3u-tpw-metopb-ims-20180615-v0001.nc'

d = xr.open_dataset(filename)
d
```

Illustrative Results:

```
<xarray.Dataset> Size: 622MB
Dimensions:          (time: 24, bnds: 2, latitude: 720, longitude: 1440)
Coordinates:
  * time             (time) datetime64[ns] 192B 2018-06-15T00:30:00 ... 2018-...
  * latitude         (latitude) float32 3kB -89.88 -89.62 -89.38 ... 89.62 89.88
  * longitude        (longitude) float32 6kB -179.9 -179.6 ... 179.6 179.9
Dimensions without coordinates: bnds
Data variables:
    time_bnds        (time, bnds) datetime64[ns] 384B ...
    latitude_bnds    (latitude, bnds) float32 6kB ...
    longitude_bnds   (longitude, bnds) float32 12kB ...
    tpw              (time, latitude, longitude) float32 100MB ...
    tpw_uncertainty  (time, latitude, longitude) float32 100MB ...
    n                (time, latitude, longitude) float32 100MB ...
    status_flag      (time, latitude, longitude) uint8 25MB ...
    time_in_hour     (time, latitude, longitude) timedelta64[ns] 199MB ...
    qa_value         (time, latitude, longitude) float32 100MB ...
Attributes: (12/72)
    Conventions:                    CF-1.8, Unidata Observation Dataset v...
    title:                          RAL IMS L3 data v1.0
    summary:                        RAL infra-red/microwave sounder produ...
    references:                     Siddans, R. et al, Algorithm Theoreti...
    institution:                    RAL
    history:                        Created by eocis_write_l3u 2024-10-27...
    ...                             ...
    creation_date:                  2024-10-27T18:12:33Z
    data_date:                      2018-06-15T12:00:00Z
    filename:                       ral-l3u-tpw-metopb-ims-20180615-v0001.nc
    processing_flags:               AMACC:0; BUFR:0; CRIS:0; DIA:0; E60:7...
    processing_flags_l2:            RET: 1;RAM: 2;RAM2: 0;NRC: 0;AME: 0;R...
    ims_variable_name:              tpw
>>>
```

```
# Plot the water vapour field
import matplotlib.pyplot as plt
# plot data for timestep 1 (including possibly bad data)
ax = d.tpw[1].plot.imshow(vmax=70)
ax.axes.set_aspect('equal')
plt.show()
```

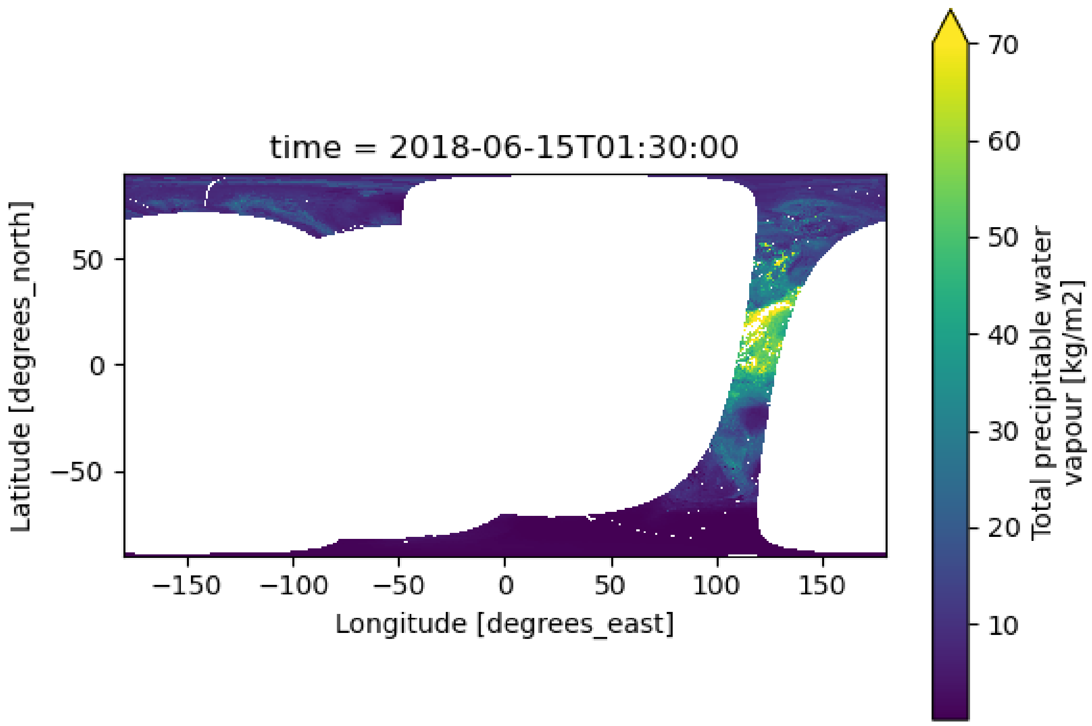

Figure 1: Total precipitable water vapour from the 2nd (index 1) time step of an L3U file, containing 1 hour of data. All samples are included, without use of the qa_value to select "good" data.

1.5.2 Quality control and temporal averaging of L3U data

```
# Apply qa_value, select daytime data, and average over 24 hours, combining
orbits. NB status flag logical and with 16 selects daytime data.
dm = d.tpw[:].where(d.qa_value >= 0.5).where((d.status_flag &
16)==0).mean(dim="time",keep_attrs=True)
ax = dm.plot.imshow(vmax=70)
ax.axes.set_aspect('equal')
plt.show()
```

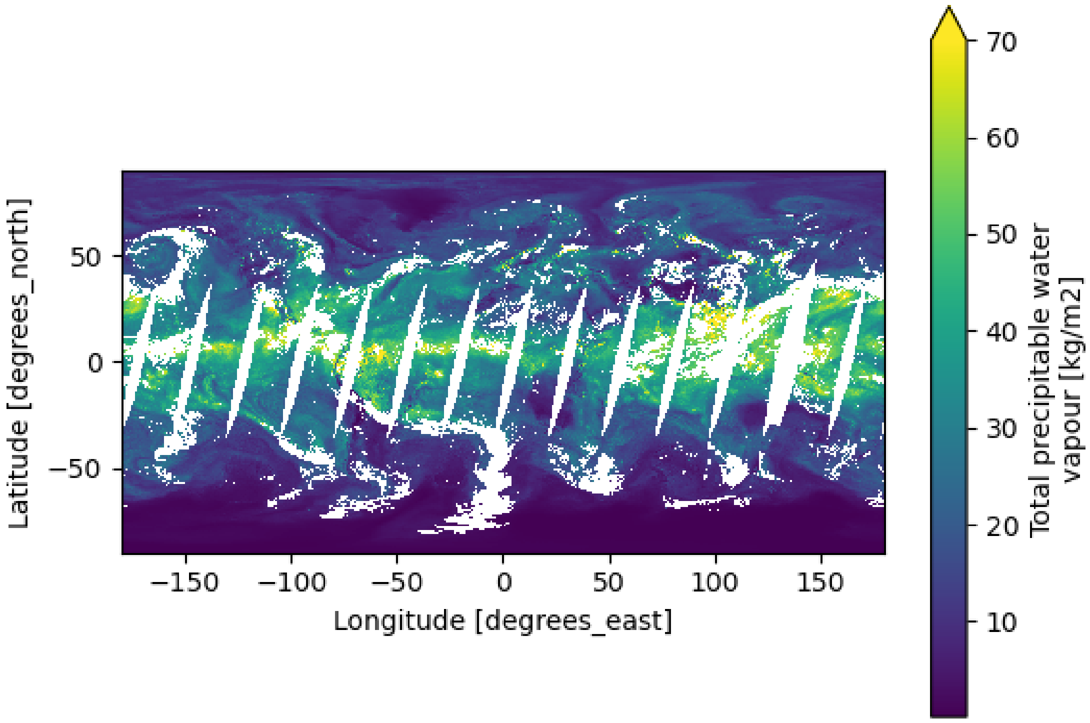

Figure 2: All data on day-time node after applying standard quality control using qa_value.

```
# Apply qa_value, select nighttime data, and average over 24 hours, combining
orbits. NB status flag logical and with 16 selects daytime data.
dm = d.tpw[:].where(d.qa_value >= 0.5).where((d.status_flag &
16)==16).mean(dim="time",keep_attrs=True)
ax = dm.plot.imshow(vmax=70)
ax.axes.set_aspect('equal')
plt.show()
```

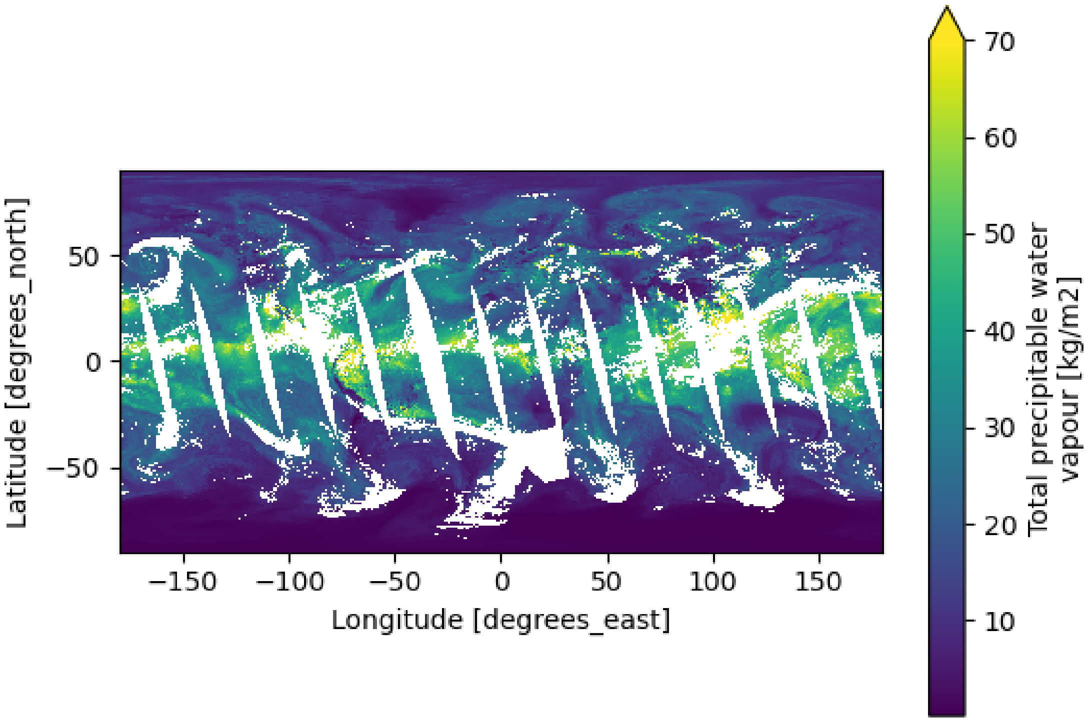

Figure 3: All data on night-time node after applying standard quality control using qa_value.

```
# Apply qa_value and select daytime data, only where footprint centre in bin.
dm = d.tpw[:].where(d.qa_value >= 0.5).where((d.status_flag & 48)==32)
ax = dm.mean(dim="time",keep_attrs=True).plot.imshow(vmax=70)
ax.axes.set_aspect('equal')
plt.show()
```

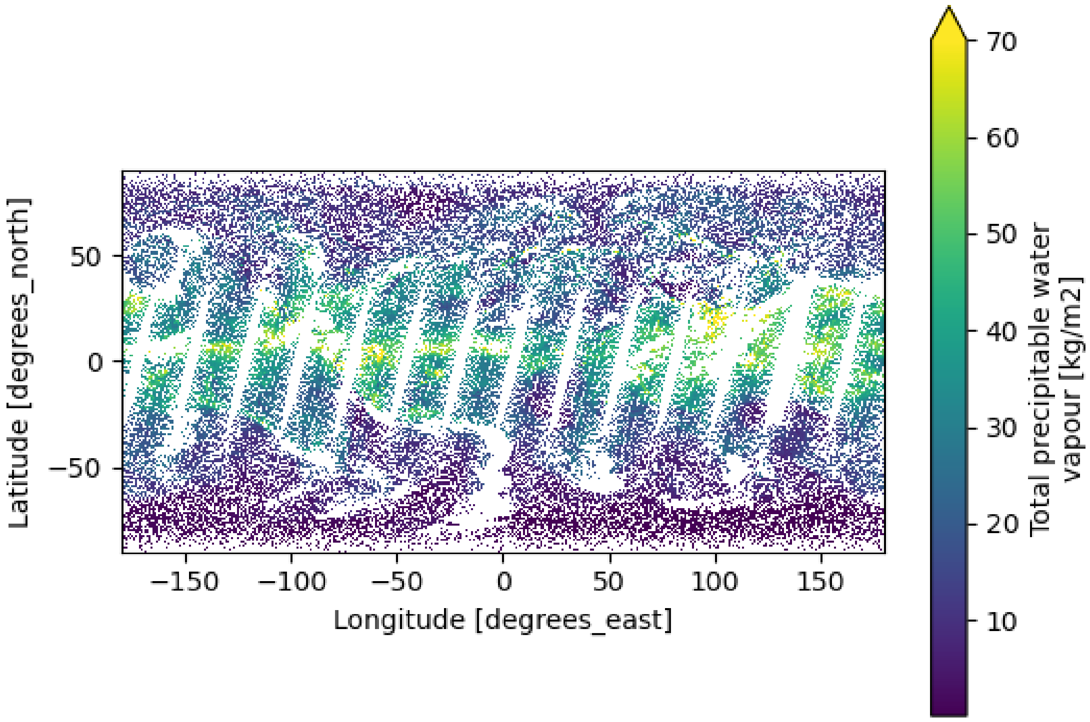

Figure 4: All data on day-time node after applying standard quality control and selecting only cells contain the L1 pixel centre coordinates (i.e. removing repeated L1 samples filling gaps between from neighbouring cells)

```
# Average over time to combine all orbits on the day, then average to 10x10
degrees grid (from original 0.25)
dmm =
dm.mean(dim="time",keep_attrs=True).coarsen(latitude=40,longitude=40).mean()
# Plot the variable
ax = dmm.plot.imshow(vmax=70)
ax.axes.set_aspect('equal')
plt.show()
```

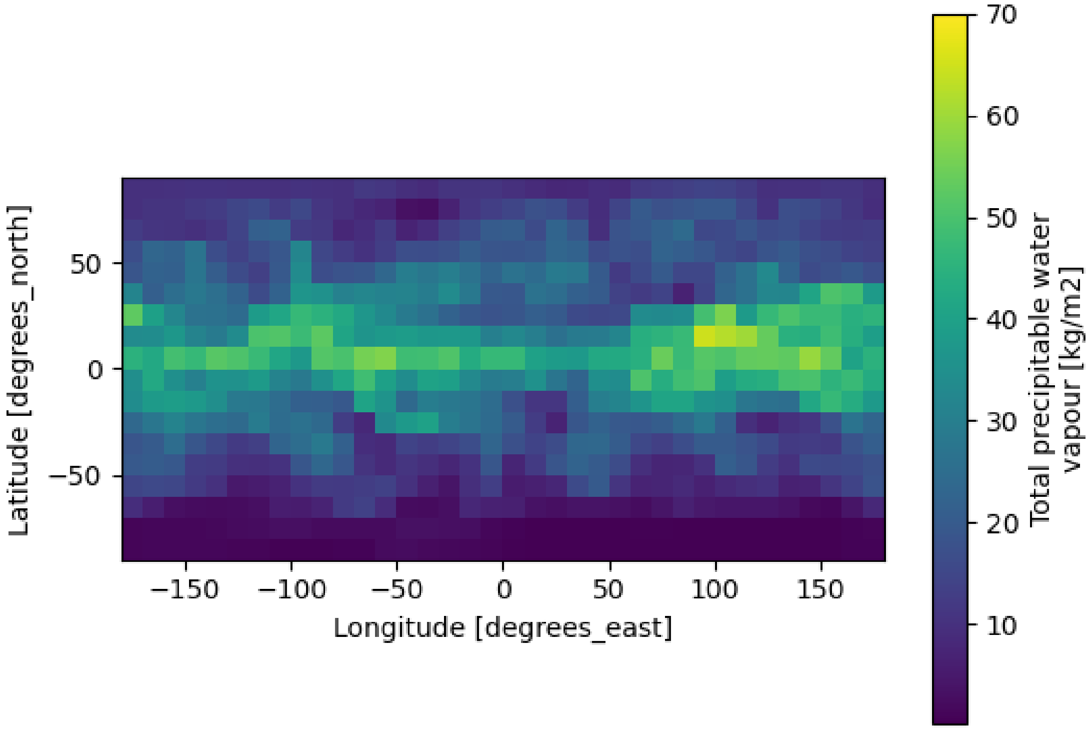

Figure 5: 10x10 degree re-gridded data on day-time node, after applying standard quality control and selecting only cells contain the L1 pixel centre coordinates (i.e. removing repeated L1 samples from neighbouring cells)

1.5.3 Plotting total and vertically resolved ozone in Dobson units

```
# Open ozone file…
filename = 'eocis_l3/ims/l3u/v0001/metopb/2018/06/15/ral-l3u-o3-metopb-ims-20180615-v0001.nc'
d = xr.open_dataset(filename)

# Convert total column average mixing ratio to Dobson units (multiply by constant * surface_pressure)
o3tcol_du=d.o3_tcol*d.surface_pressure*7891.1826
o3tcol_du.assign_attrs(units='DU',long_name=d.o3_tcol.long_name)

# Apply qa_value, select daytime data, and average over 24 hours, combining orbits.
dm = o3tcol_du.where(d.qa_value >= 0.5).where((d.status_flag & 16)==0).mean(dim="time",keep_attrs=True)

ax = dm.plot.imshow()
ax.axes.set_aspect('equal')
plt.show()
```

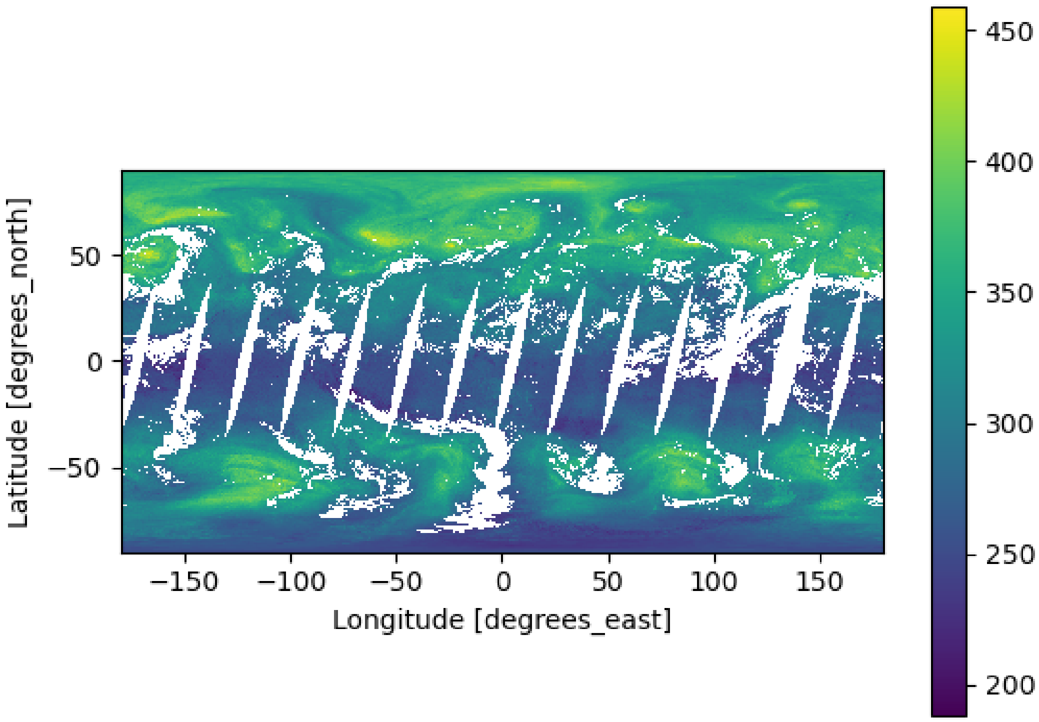

Figure 6: Total ozone day-time average in Dobson units

```
# Convert 0-6km sub-column average mixing ratio to Dobson units (multiply by constant *
layer pressure difference)
du_factor=7891.1826 # factor to convert volume mixing ratio integrated in pressure (Pa)
to Dobson units
o3trop_du=d.o3[:,0]*(d.surface_pressure - d.layer_bnds[0,1])*du_factor

# Add units to the converted dataset
o3trop_du.attrs={'units':'DU','long_name':d.o3.long_name}

# Apply qa_value, select daytime data, and average over 24 hours, combining orbits.
dm = o3trop_du.where(d.qa_value >= 0.5).where((d.status_flag &
16)==0).mean(dim="time",keep_attrs=True)

# Make plot
ax = dm.plot.imshow(vmax=40)
ax.axes.set_aspect('equal')
plt.show()
```

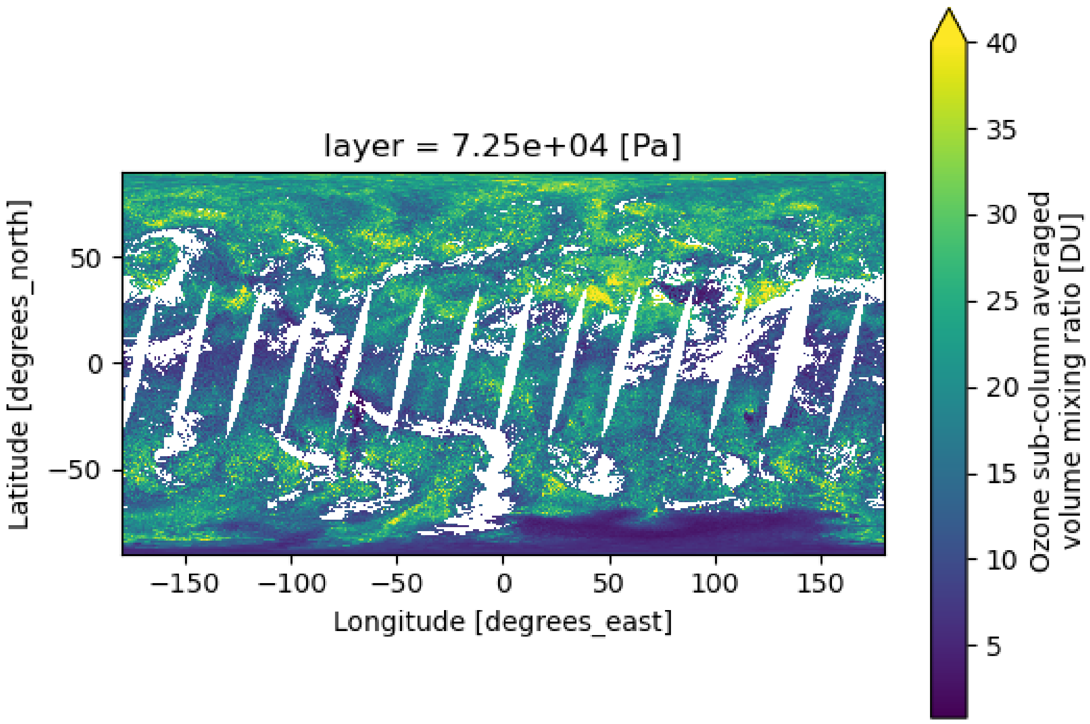

Figure 7: Tropospheric (0-6km) ozone day-time average in Dobson units

```
# Convert 20-24km sub-column average mixing ratio to Dobson units (multiply by constant
* layer pressure difference)
o3strat_du=d.o3[:,4]*(d.layer_bnds[4,0] - d.layer_bnds[4,1])*du_factor
o3strat_du.attrs={'units':'DU','long_name':d.o3.long_name}

# Apply qa_value, select daytime data, and average over 24 hours, combining orbits.
dm = o3strat_du.where(d.qa_value >= 0.5).where((d.status_flag &
16)==0).mean(dim="time",keep_attrs=True)

ax = dm.plot.imshow()
ax.axes.set_aspect('equal')
plt.show()
```

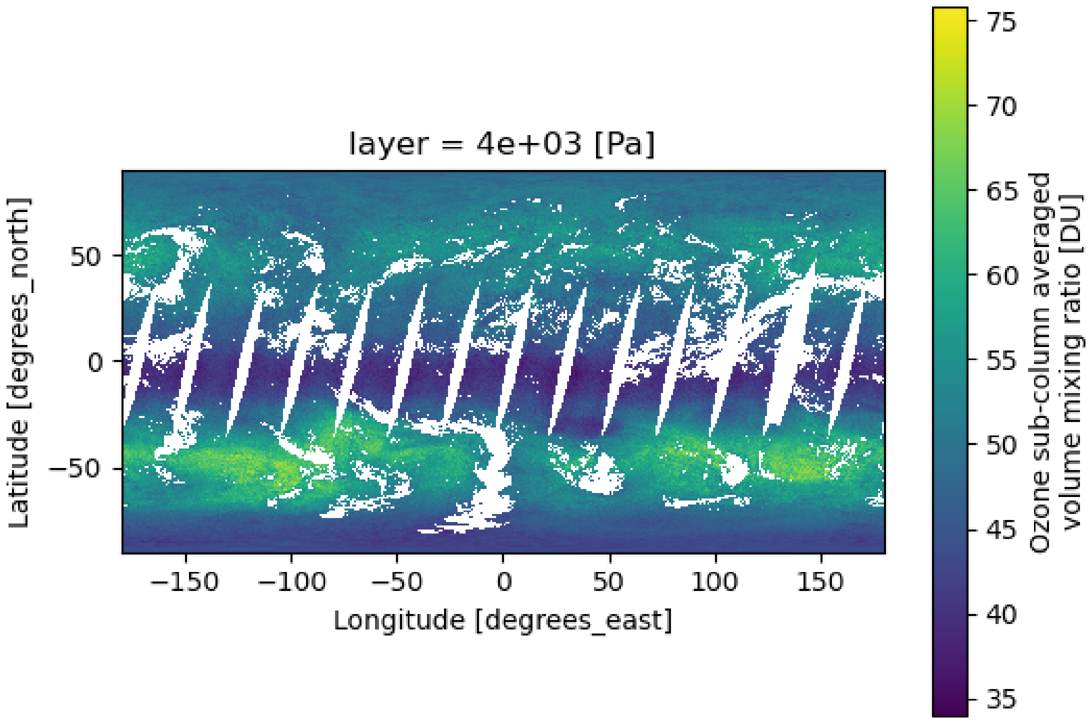

Figure 8: Stratospheric (20-24 km) ozone day-time average in Dobson units

1.5.4 Simple plot of height-resolved water vapour on level.

```
# Open height-resolved water vapour file:
filename = 'eocis_l3/ims/l3u/v0001/metopb/2018/06/15/ral-l3u-h2o-metopb-ims-20180615-
v0001.nc'
d = xr.open_dataset(filename)

ilev=8       # define level index to plot

# For selected vertical level, apply qa_value, select daytime data,  and average over
24 hours, combining orbits.
dm = d.h2o[:,ilev].where(d.qa_value >= 0.5).where((d.status_flag &
16)==0).mean(dim="time",keep_attrs=True)

ax = dm.plot.imshow()
ax.axes.set_aspect('equal')
plt.show()
```

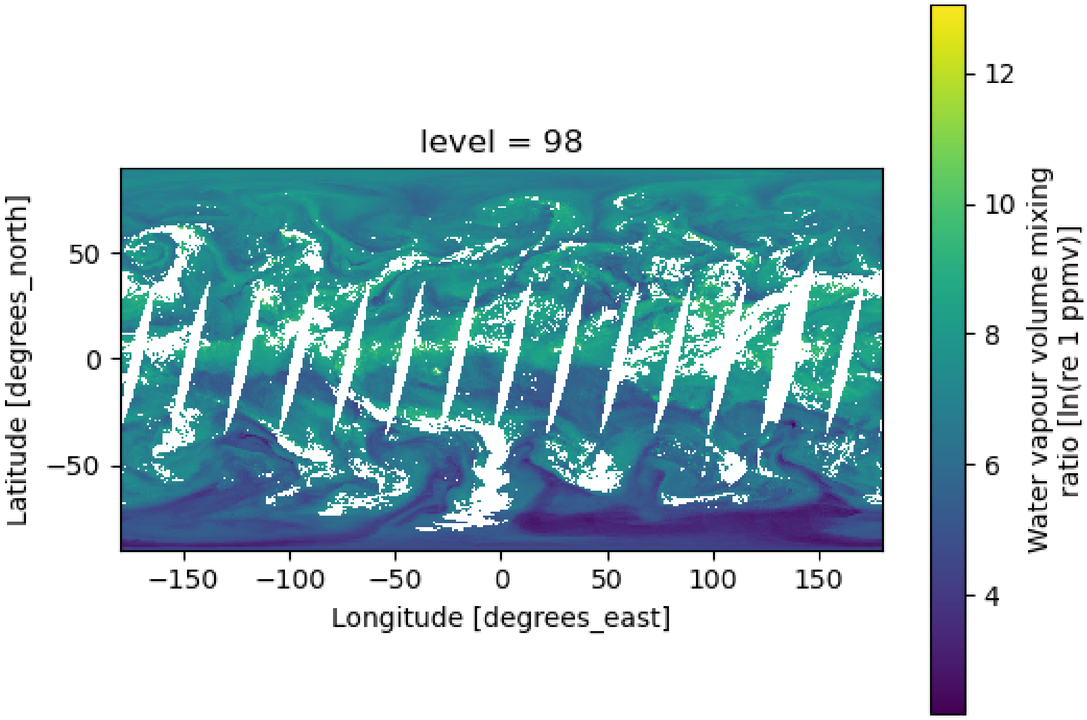

Figure 9: Water vapour mixing ratio on L137 hybrid sigma level 98 (548 hPa ~ 4.2km)

1.5.5 Methane from L3C

```
# Open methane L3C file:
filename =
'/gws/pw/j07/rsg_share/public/transfer/imsch4/eocis_l3/l3c/v0001/metopb/2018/06/ral-l3c-ch4-metopb-imsch4-201806_day-v0001.nc'
d = xr.open_dataset(filename)

# Plot the total column average volume mixing ratio
ax = d.ch4_tcol_mean.plot.imshow()
ax.axes.set_aspect('equal')
plt.show()
```

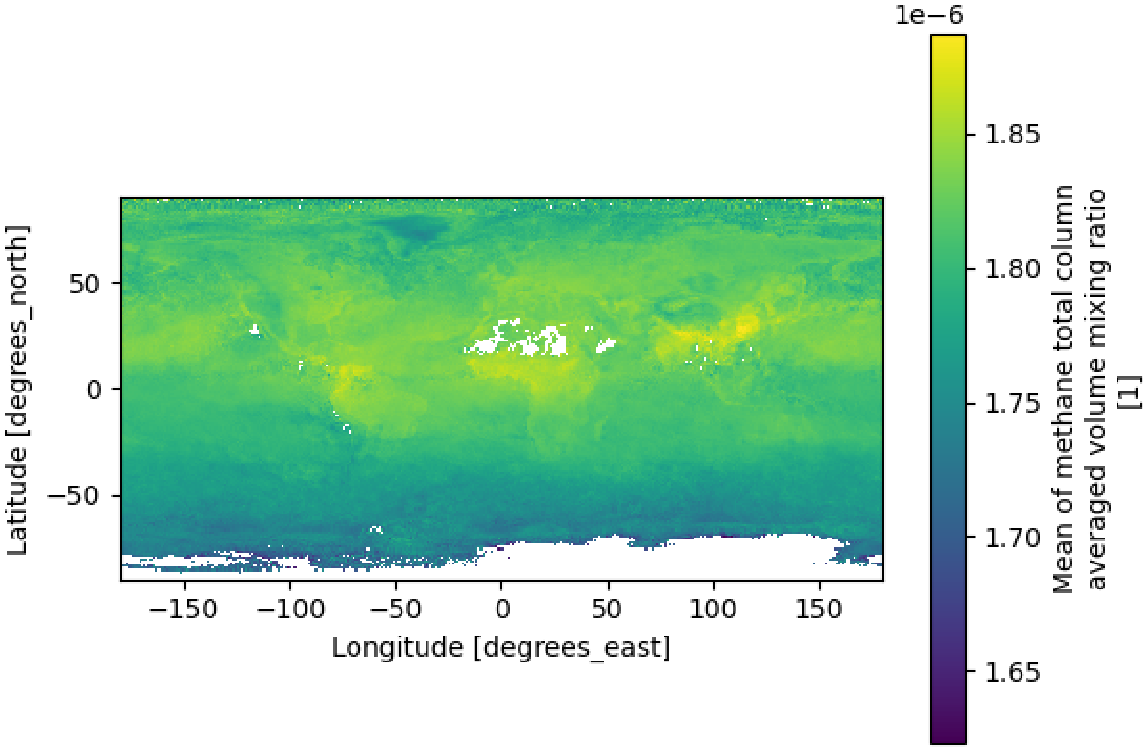

Figure 10: Monthly averaged methane distribution (due to qualiy control at L2 there are regions of persistent missing data over desert and Antarctica).

1.5.6 Methane Hovmöller plot

This example demonstrates using python xarray to access files for multiple months and assemble a timeseries of data in the form of a Hovmöller plot.

```
from netCDF4 import Dataset
import glob
import xarray as xr
import matplotlib.pyplot as plt

#get all metop A L3C methane files
filenames=glob.glob('/home/users/rsiddans/Data/projects/iasi_mhs/nrt/eocis_l3/imsch4/l3
c/v0002/metopa/*/*/ral-l3c-ch4-metopa-imsch4-??????_day-v0002.nc')
#sort files into order (will be in order of time)
filenames.sort()
# open files
d=xr.open_mfdataset(filenames,concat_dim='time',combine='nested')
# make zonal mean and then transpose array
dm = d.ch4_tcol_mean.mean(dim="longitude",keep_attrs=True).T
# make the plot
ax = dm.plot.imshow(aspect=6,size=3)
ax.axes.set_aspect(4)
plt.show()
```

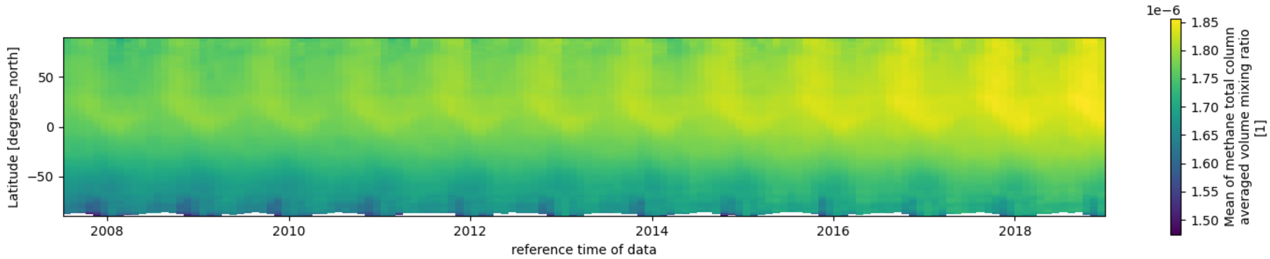

Figure 11: Hovmöller plot showing zonal avergae total column averaged methane as a function of date and latitude.

1.5.7 Methane timeseries for a specific region

This example demonstrates using the regional mean (rm) data together with python xarray to plot a timeseries line plot.

```
from netCDF4 import Dataset
import glob
import xarray as xr
import matplotlib.pyplot as plt

#get all metop A L3C regional mean methane files
filenames=glob.glob('/home/users/rsiddans/Data/projects/iasi_mhs/nrt/eocis_l3/imsch4/l3
c_rm/v0002/metopa/*/*/ral-l3c_rm-ch4-metopa-imsch4-??????_day-v0002.nc')

#sort files into order (will be in order of time)
filenames.sort()

# open files
d=xr.open_mfdataset(filenames,concat_dim='time',combine='nested')

# define a region index to plot and get its name/acronym
# Region index 38 is South-East Asia (SEA)
ireg=38
rname=d.region.attrs['name'].split()[ireg]
racro=d.region.attrs['acronym'].split()[ireg]

# extract the data for this region
dm = d.ch4_tcol_mean.isel(region=ireg)

# plot
ax = dm.plot()
plt.title(rname)
plt.show()
```

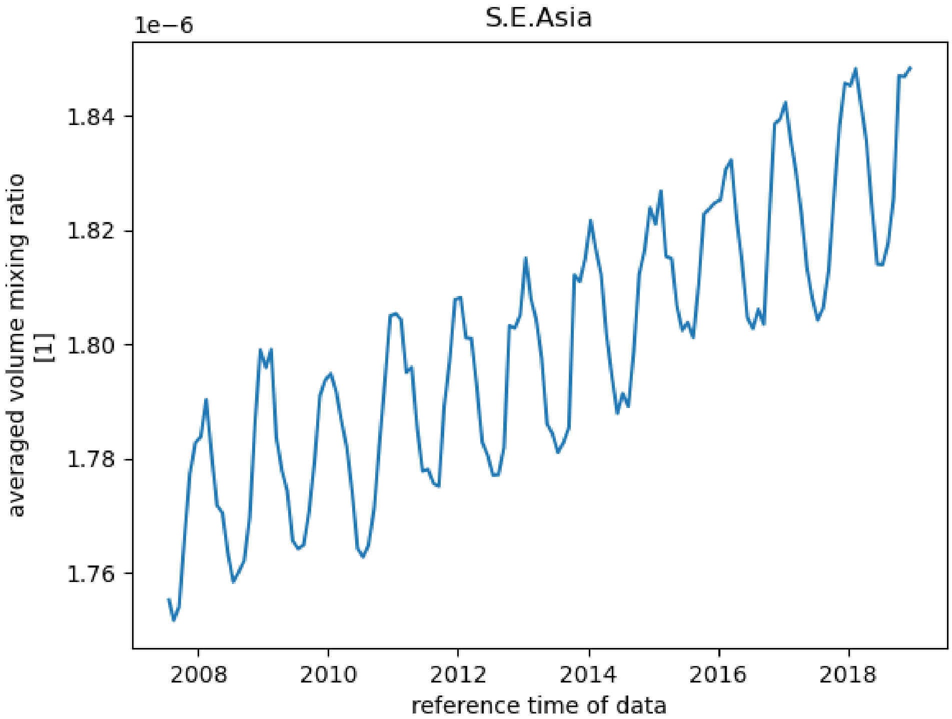

Figure 12: Timeseries of methane column average mixing ratio over the South-East Asia region.

1.6 Interactive visualisation / data access

Data can be visualised using standard netcdf tools such as panoply, ncview etc.

Data can be browsed via this tool ***(username / password currently required – can be provided on request)***:

- https://gws-access.jasmin.ac.uk/public/rsgnceo/web_internal/nrt_webpages/timeseries/show_image2.html
- http://gws-access.jasmin.ac.uk/public/rsg_share/webpages/rsg_data_viewer/

1.7 Your obligations when using these products

By accessing the RAL IMS products, you agree to cite the dataset digital object identifier (doi) and corresponding journal article describing the dataset every time you publish results obtained in whole or in part by use of UK EOCIS products. These citations are given under Summary Information.

The reference to the dataset should mention "created by the UK Earth Observation Climate Information Service". The product name and acronym in Table 1 and should be used to avoid confusion and enable traceability.

1.8 Further Information

History of modifications / Change Log

Version	Date	Changes	Person
0.1	31 October 2024	Initial Draft	R.S.
0.2	6 March 2025	Time series plot added	R.S.

Related Documents / Reference Documents

Document	Author	Reference
Water Vapour CCI: Algorithm Theoretical Basis Document (ATBD) Part 2 - IMS L2 Product **https://climate.esa.int/documents/2497/** **Water_Vapour_CCI_D2.2_ATBD_Part2-IMS_L2_product_v2.0.pdf**	R. Siddans	RD1
RAL Methane Retrieval ATBD's: IASI version 2.1: https://methaneplus.eu/Docs/RAL_IASI_CH4_ATBD_v2p1.pdf	R. Siddans	RD2

Acronyms and/or Abbreviations

Acronym / Abbreviation	Definition
ATBD	Algorithm Theoretical Basis Document
IMS	Infra-red Microwave Sounder retrieval scheme
….	

General definitions

Term	Definition