

# ICON Data Product 1: Calibrated EUV Brightness Profiles

This document describes the data product for ICON EUV Level 1 Calibrated Flux and Error altitude profiles Software Version = 3.2.0, which is in NetCDF4 format.

ICON is a NASA low-Earth-orbit (~586 km) satellite dedicated to the study of the Earth's ionosphere. Its four instruments are designed to measure the temperature, velocity, and ion density of the atmosphere along vertical profiles from 100 to 600 km. The typical observation cadence is one exposure every 12 s. Orbital precession ensures rapid coverage of all available ranges of latitude, longitude, and local time-of-day.

This document describes the ICON Extreme Ultraviolet Imaging Spectrograph (EUV) Level 1 (L1) science products which are the emission line radiances required for the altitude-profile ion density inversion modeling (Level 2 products, Stephan et al. 2017, DOI: 10.1007/s11214-017-0385-1). Inputs are the raw Level 0 products which are 2D Altitude Profile Region (APR) images in units of counts (with the horizontal axis representing wavelength, and the vertical axis tangent altitude). Outputs are intensities as a function of altitude bin in units of flux (Rayleighs) along with the corresponding random and systematic errors for twelve emission lines. The profiles are 108 elements long [0:107] with the active EUV Field-of-View spanning 99 elements [5:103]. In addition to the essential flux and error variables, several other L1 vector and scalar variables are provided that are used in the flux calculations. For each emission line profile the vector variables are: the raw number of counts, the number of background counts, and the ratio of the source-count area to background-count area. The scalar variable is the detector dead-time that is applied to the L0 exposure time variable.

The following L1 variables are provided for convenience: a vector of the 12 emission line center wavelengths, a vector containing the integrated counts (i.e. a spectrum) of the entire detector, a scalar which is an estimate of the total number of Solar Stray Light counts, and an image (same dimensions as the input Counts image) in flux units (Rayleighs per pixel). This image is flat-fielded, but not background subtracted. It may prove useful to future investigators who wish to do more sophisticated modeling of background, stray light, blended features etc...

All the L0 variables are passed along to the L1 products unchanged (except for the Counts Image which is replaced with the Flux Image). To create the Level 2 products from the Level 1 products, additional information is required concerning the satellite's position and orientation as a function of time. This information is provided for every L1 file in Ancillary NetCDFs (one file per day). Note that the Ancillary data is not used in creating EUV Level 1 products. Written by Martin M. Sirk and Eric Korpela. See Sirk et al 2017 (doi:10.1007/s11214-017-0384-2) for more information about EUV, and Immel et al 2017 for the ICON mission (doi:10.1007/s11214-017-0449-2)

## History

Notes for Version 2.0.21 2020 April 3

0) In the beginning there were Photons, and they were good. Then the slaughter began ...

1) Added 5 emission lines (i.e. 5 new Region Masks)

2) Updated Stim Fiducial Average positions

3) Background is fit with a 2nd order polynomial to reduce Poisson noise.

For exposures with very low background (< 25 counts in Background region)

the background is set to a constant (mean of the counts/pixel)

4) Get\_flux does better small and large scale flat-fielding before

extracting lines. Errors for pixels with small or negative counts are now correct. Errors for out-of-FOV pixels are set to 99999.9

Fractional Poisson error in the Flat Field is now added in Quadrature (with factor of 2 applied to denominator) to the Random fractional flux error

5) Solid angles are now correct for flight image scale. Look Angles of FOV are now centered on pixel 51.5, not 54. A text file containing pixel #, look angle, solid angle, and mean tangent altitude is now part of the calibration files for user convenience.

6) If significant SAA counts are detected in the region where there are no emission features (pixels [48:104,64:107]), then perform SAA subtraction by scaling a pure SAA calibration image by the appropriate amount.

7) QEs for all lines are based on the QE model curve scaled to the SSL measurements (at 584, 616, and 834). Since the two emission lines at the extreme edges of the spectral range are known to be blended and vignetted as well as contaminated by detector edge effects (and SAA counts), the systematic error was arbitrarily increased by a factor of 1.5.

Notes for Version 2.1.0 2020 Aug 19

1) Fixed conceptual error in Deadtime Correction. Now only uses the observed number of Stimulsor events to determine detector deadtime.

2) Calculates the loss in gain for He 584 and O 834 based on slope of gain loss curves determined from Lunar Calibrations.

3) Interpolated Flat Field is determined as a function of EPOCH from a single program that loads all the flatfields into a data cube.

4) Added a new variable to the L1 product that is an estimate of Solar Stray Light (caused by pointing too close to the Sun). L2 products can use this variable and set a threshold of around 450 counts. Solar light changes significantly as a function of viewing geometry, so this threshold is likely

to change with the seasons.

5) Center of EUV FOV is now at Pixel 51.91 +/- 0.14. This is the number used for the EUV L1 Ancillary products.

Notes for Version 2.1.1 2020 Sep 17

1) Trivial edits to History Attribute, and Software Version number strings

Version\_3-0-0\_notes.txt M.M.Sirk April 30 2021

1) Adjusted slopes in GAIN\_LOSS\_CORRECTION.PRO to better correct O 834 and He 584 fluxes

2) Modified ISPY.PRO to skip very first file of each day in case it happens to have the HV ramping up

3) Shifted the vector of solid angles in DOMEGA.PRO by 1/2 pixel to center the value on the middle of pixel, not the edge

4) The L1 COUNTS (line counts vector) variable returned by GET\_FLUX.PRO is now the raw counts, not background subtracted counts

Version\_3-2-0\_notes.txt M.M.Sirk Sept 21 2021

1) Re-Adjusted slopes in GAIN\_LOSS\_CORRECTION.PRO to better correct O 834 and He 584 fluxes. Now, the first year is fit with a second order polynomial and then a straight line for most of 2021.

2) Modified ISPY.PRO to check for valid time intervals. If Bad, skip the file and say so in the error log.

3) Modified the way background counts are estimated to account for regions of high gain loss where the background counts are lower.

4) Fixed a conceptual error in the way the Flat Fields are determined. Now the average gain loss across each line profile is determined for each altitude bin. The flats are normalized to the Average number of counts in the line, not the Median.

## Dimensions

NetCDF files contain **variables** and the **dimensions** over which those variables are defined. First, the dimensions are defined, then all variables in the file are described.

The dimensions used by the variables in this file are given below, along with nominal sizes. Note that the size may vary from file to file. For example, the "Epoch" dimension, which describes the number of time samples contained in this file, will have a varying size.

<b>Dimension Name</b>	<b>Nominal Size</b>
Epoch	1
Vertical	108
Horizontal	169
ICON_L0_EUV_SR_SumCnt	16
ICON_L0_EUV_PulseHH	64
ICON_L1_EUV_Lines	12

# Variables

Variables in this file are listed below. First, "data" variables are described, followed by the "support\_data" variables, and finally the "metadata" variables. The variables classified as "ignore\_data" are not shown.

## data

Variable Name	Description	Units	Dimensions
Epoch	<p>Exposure epoch, midpoint of exposure. Number of msec since Jan 1, 1970.</p> <p>Exposure epoch, midpoint of exposure. Number of msec since Jan 1, 1970. This variable contains the time corresponding to the wind profile reported in this file. It is evaluated at the midpoint of the exposure time. It is in UTC and has units of milliseconds since Jan 1, 1970. A human-readable version of the time can be found in the global attributes Date_Start and Date_Stop.</p>	milliseconds	Epoch
ICON_L1_EUV_Deadc	<p><b>Deadtime Correction</b></p> <p>Exposure time correction factor due to detector deadtime. Calculate deadtime correction based on the exposure time, and the known Stimulsor rate, and the observed Stimulsor counts. Calculate the ratio of observed (NStim) to expected stim counts (this is the electronics deadtime). If routine fails, Set DEADCOR=1.0 and set stim warning flag.</p>		Epoch
ICON_L1_EUV_BackRatio	<p><b>Ratio of background to total counts</b></p> <p>Ratio of background region counts to total image counts. This ratio can be used to quickly identify observations with high background such as SAA. If greater than 0.25 then a warning flag is set. This flag is often set at night since the lines fluxes are low, and, thus, the background relatively high. The ratio is for convenience and non-essential.</p>		Epoch
ICON_L1_EUV_Lines	<p><b>Wavelengths of Science Lines</b></p> <p>Wavelengths of Science Lines. Counts are extracted from the counts image using the REGIONS_MASK variable, and fluxes and their errors are calculated for these wavelengths</p>	nanometers	Epoch, ICON_L1_EUV_Lines
ICON_L1_EUV_Spectrum	<p><b>Integrated Spectrum in Raw Counts</b></p> <p>Integrated Spectrum of entire APR in Raw Counts. Useful for assessing general spectrum quality, background level etc. Provided as a non-essential convenience</p>	Counts	Epoch, Horizontal

Variable Name	Description	Units	Dimensions
ICON_L1_EUV_Flux	<p>Line Fluxes in Rayleighs</p> <p>Flux in Rayleighs for the extracted lines.</p> <p>This is the primary L1 product. For every science line the flux is determined for each altitude bin. Converting from raw image counts to Rayleighs is as follows</p> <p>Corrected_Counts = Region_Mask * (APR_Image - Background) / Flatfield</p> <p>Flux = Corrected_Counts / (ExposureTime * DeadCor * QE * GeoArea * Omega)</p> <p>GeoArea is the area of the slit in cm<sup>2</sup>, and Omega is the solid angle (in radians) subtended by each altitude bin.</p> <p>The same math is applied to the random and systematic errors in the flux.</p>	Rayleighs	Epoch, Vertical, ICON_L1_EUV_Lines

Variable Name	Description	Units	Dimensions
ICON_L1_EUV_RandomError	<p>Poisson errors in Rayleighs</p> <p>Random Error in Flux in Rayleighs for the extracted lines            Random errors are determined based on the *observed* number of counts in the source region and the background region prior to any of the corrections outlined above using this scheme:</p> <p>S = source counts</p> <p>B = background counts</p> <p>SA = source area</p> <p>BA = background area</p> <p><math>R = SA/SB</math></p> <p><math>Net = S - R*B</math></p> <p><math>\sigma_S = \sqrt{S}</math></p> <p><math>\sigma_B = \sqrt{B}*R</math></p> <p><math>\sigma_{Net}^2 = \sigma_S^2 + \sigma_B^2</math></p> <p><math>\sigma_{Net} = \sqrt{S + (B * R^2)}</math></p> <p><math>Flux\_error = flux * \sigma_{net}/Net</math></p> <p>Additionally, the fractional error in the Flat Field is added in Quadrature to the Random Error.</p>	Rayleighs	Epoch, Vertical, ICON_L1_EUV_Lines

Variable Name	Description	Units	Dimensions
ICON_L1_EUV_SystematicErr	<p>Systematic errors in Rayleighs</p> <p>Systematic Error in Flux in Rayleighs for the extracted lines The systematic error was determined during ground calibration at three wavelengths (834, 584, and 616 Ang) and represents a multiplicative uncertainty in the instrument throughput, not a lack of knowledge in the Zero Point. The absolute QE of ICON EUV was measured with a calibrated NIST photodiode, and was cross-checked by a MCP detector that was calibrated against a second NIST photodiode. The two methods agreed to within 11% (the two photodiodes were measured at SSL side by side and agree to within 5%). The uncertainty in the absolute photometric sensitivity quoted by NIST for the diodes is 7%. Thus, combining in quadrature</p> $\text{Sys Error} = \text{Sqrt}(0.11^2 + 0.07^2) = 13\%$ <p>For other wavelengths we used interpolated values of the grating and detector efficiency curves. For these wavelengths we add another 5% in quadrature to get 14%. For the two lines at the extreme edges of the detector, He 537 and O 878, we add another 7% since the first line is vignetted, and the second often shows scattered Lyman Alpha.</p>	Rayleighs	Epoch, Vertical, ICON_L1_EUV_Lines
ICON_L1_EUV_Backgrounds	<p>Backgrounds in Rayleighs</p> <p>Backgrounds in Rayleighs for each extracted line</p>	Rayleighs	Epoch, Vertical, ICON_L1_EUV_Lines
ICON_L1_EUV_Counts	<p>Raw Counts</p> <p>Raw counts for each extracted line per altitude pixel</p>	counts	Epoch, Vertical, ICON_L1_EUV_Lines
ICON_L1_EUV_Background_Counts	<p>Raw Background Counts</p> <p>Raw Background Counts for each line per altitude bin</p>	counts	Epoch, Vertical, ICON_L1_EUV_Lines

support\_data



<b>Variable Name</b>	<b>Description</b>	<b>Units</b>	<b>Dimensions</b>
ICON_L0_EUV_TimeGPS	Calculated number of GPS milliseconds since 1980 January 06 00:00:00 UTC to center of image integration.	milliseconds	Epoch
ICON_L0_EUV_TimeUTC_Start	UTC milliseconds since 1970 January 01 00:00:00 to beginning of image integration.	milliseconds	Epoch
ICON_L0_EUV_TimeUTC_Stop	UTC milliseconds since 1970 January 01 00:00:00 to end of image integration.	milliseconds	Epoch
ICON_L0_EUV_TimeIntegration	Time to integrate EUV buffer (transmitted as N where time is $10 \times (N+1)$ ms).	milliseconds	Epoch
ICON_L0_EUV_SecondsGPS	Reported GPS seconds.	seconds	Epoch
ICON_L0_EUV_50_NanosecondOffsetGPS	Reported flight clock GPS offset in 50ns increments (always less than 2 seconds worth).	count	Epoch
ICON_L0_EUV_CountPulseFEC	Number of FEC pulses during integration. Number of Fast Event Counter pulses during integration	count	Epoch
ICON_L0_EUV_APR_BinsX	X (column) dimension of the APR image (X maximum - X minimum + 1).	count	Epoch
ICON_L0_EUV_APR_BinsY	Y (row) dimension of the APR image (Y maximum - Y minimum + 1).	count	Epoch
ICON_L0_EUV_APR_ErrorFlag	Indicates processing error in APR (some photons in region were ignored) when set.	flag	Epoch
ICON_L0_EUV_APR_MaximumX	APR maximum X value in region of interest.		Epoch
ICON_L0_EUV_APR_MaximumY	APR maximum Y value in region of interest.		Epoch
ICON_L0_EUV_APR_MinimumX	APR minimum X value in region of interest.		Epoch
ICON_L0_EUV_APR_MinimumY	APR minimum Y value in region of interest.		Epoch
ICON_L0_EUV_APR_PhotonCount	Altitude profile region photons collected during integration.	count	Epoch
ICON_L0_EUV_APR_ShiftRightX	Number of bits each APR X value has been right shifted.	bits	Epoch
ICON_L0_EUV_APR_ShiftRightY	Number of bits each APR Y value has been right shifted.	bits	Epoch
ICON_L0_EUV_CompressionErrorFlag	Data transmitted via delta-compression mode contained errors during compression if set.	flag	Epoch

Variable Name	Description	Units	Dimensions
ICON_L0_EUV_CompressionFlag	Data transmitted via delta-compression mode.	flag	Epoch
ICON_L0_EUV_DiagnosticPhotonCount	Total number of photons received on EUV interface by DCB FPGA before ROI filtering during integration.	count	Epoch
ICON_L0_EUV_HV_ActiveFlag	HV power supply activity flag (0=OFF, 1=ON).	flag	Epoch
ICON_L0_EUV_HV_DAC_Day	DAC HV count / level programmed for EUV day mode.	count	Epoch
ICON_L0_EUV_HV_DAC_Night	DAC HV count / level programmed for EUV night mode.	count	Epoch
ICON_L0_EUV_HV_DAC_Safe	DAC HV count / level programmed for EUV safe mode.	count	Epoch
ICON_L0_EUV_ModeSelect	Currently selected EUV mode (0=SAFE, 1=?, 2=DAY, 3=NIGHT).	flag	Epoch
ICON_L0_EUV_Q_Maximum	Maximum charge/pulse height (q) (higher q photons not histogrammed).		Epoch
ICON_L0_EUV_Q_Minimum	Minimum charge/pulse height (q) (lower q photons not histogrammed).		Epoch
ICON_L0_EUV_SR_ErrorFlag	Indicates processing error in SR (some photons in region were ignored) when set.	flag	Epoch
ICON_L0_EUV_SR_PhotonCount	Stimulation region (1 and 2) photons collected during integration.	count	Epoch
ICON_L0_EUV_SR1_MinimumX	SR 1 minimum X value (always of size 128 x 128 prior to binning).		Epoch
ICON_L0_EUV_SR1_MinimumY	SR 1 minimum Y value (always of size 128 x 128 prior to binning).		Epoch
ICON_L0_EUV_SR2_MinimumX	SR 2 minimum X value (always of size 128 x 128 prior to binning).		Epoch
ICON_L0_EUV_SR2_MinimumY	SR 2 minimum Y value (always of size 128 x 128 prior to binning).		Epoch
ICON_L0_EUV_PulseHeightHistogram	Pulse height / charge histogram bin for Q.		Epoch, ICON_L0_EUV_PulseHH
ICON_L0_EUV_SR1_SumColumn	Sum of stimulation region 1 binned column photon counts.	count	Epoch, ICON_L0_EUV_SR_SumCnt
ICON_L0_EUV_SR1_SumRow	Sum of stimulation region 1 binned row photon counts.	count	Epoch, ICON_L0_EUV_SR_SumCnt

Variable Name	Description	Units	Dimensions
ICON_L0_EUV_SR2_Sum Column	Sum of stimulation region 2 binned column photon counts.	count	Epoch, ICON_L0_EUV_SR_SumCnt
ICON_L0_EUV_SR2_Sum Row	Sum of stimulation region 2 binned row photon counts.	count	Epoch, ICON_L0_EUV_SR_SumCnt
ICON_L1_EUV_Max_Stim_Shift	<p>Maximum observed shift of Stim Pulsors</p> <p>Maximum observed shift of Stimulsors. StimPulsors are current pulses injected directly into the micro-channel plate (MCP) anode and are processed by detector electronics. They are used to track positional drifts of photon events and changes in plate-scale of the MCP. If this number exceeds 0.65 pixels then the Flatfield and Regions Mask will be warped to match the APR Image. If this number ever exceeds 2 pixels there is probably something wrong, e.g. not enough stim counts to determine a good centroid, or bad SAA contamination.</p>	Pixels	Epoch
ICON_L1_EUV_Error_bit_field	<p>Warning Bit-field</p> <p>Non-fatal Warning bit field Warnings:1 = Invalid Deadtime correction, 2 = Stimulsor counts saturated, 4 = High Background warning, 8 = Stim shift (in pixels) GT Stim_Shift_Limit</p>		Epoch
ICON_L1_EUV_Version	<p>Pipeline Version Number</p> <p>ICON EUV L0 to L1 Pipeline Software Version Number</p>		Epoch
ICON_L1_EUV_Solar_Counts	<p>Total Raw Solar Counts</p> <p>Total Raw Solar Counts. Stray Solar counts are not subtracted from the raw data, thus, line fluxes will be contaminated if this number is larger than ~ 450 counts).</p>	counts	Epoch
ICON_L1_EUV_Source_to_Back_ratio	<p>Area Ratio of line region to background region</p> <p>Area Ratio of each line region to background region This ratio is used in the random error calculation</p>		Epoch, Vertical, ICON_L1_EUV_Lines
ICON_L1_EUV_Flux_Image	<p>Flux Image in Rayleighs per pixel</p> <p>Flux Image in units of Rayleighs per Pixel. This image is NOT background subtracted. This image IS Flat Fielded. This image is not needed for creating L2 products but may be useful to future users who may wish to do additional analysis.</p>	Rayleighs	Epoch, Vertical, Horizontal

## metadata

Variable Name	Description	Units	Dimensions
ICON_L0_EUV_TimeUTC	UTC ISO 8601 timestamp at middle of image integration.		Epoch
ICON_L1_EUV_Feng_Shui_Index	<p>Feng Shui Index</p> <p>Feng Shui Index  Feng Shui is important. ICONs Pa Kua # is 3 and flies East, and EUV looks North  which corresponds to Growth and Health, Both Good!</p>		Epoch

## Acknowledgement

This is a data product from the NASA Ionospheric Connection Explorer mission, an Explorer launched at 21:59:45 EDT on October 10, 2019, from Cape Canaveral AFB in the USA. Guidelines for the use of this product are described in the ICON Rules of the Road (<http://icon.ssl.berkeley.edu/Data>).

Responsibility for the mission science falls to the Principal Investigator, Dr. Thomas Immel at UC Berkeley: Immel, T.J., England, S.L., Mende, S.B. et al. Space Sci Rev (2018) 214: 13. <https://doi.org/10.1007/s11214-017-0449-2>

Responsibility for the validation of the L1 data products falls to the instrument lead investigators/scientists.

- \* EUV: Dr. Eric Korpela : <https://doi.org/10.1007/s11214-017-0384-2>
- \* FUV: Dr. Harald Frey : <https://doi.org/10.1007/s11214-017-0386-0>
- \* MIGHTI: Dr. Christoph Englert : <https://doi.org/10.1007/s11214-017-0358-4>, and <https://doi.org/10.1007/s11214-017-0374-4>
- \* IVM: Dr. Roderick Heelis : <https://doi.org/10.1007/s11214-017-0383-3>

Responsibility for the validation of the L2 data products falls to those scientists responsible for those products.

- \* Daytime O and N2 profiles: Dr. Andrew Stephan : <https://doi.org/10.1007/s11214-018-0477-6>
- \* Daytime (EUV) O+ profiles: Dr. Andrew Stephan : <https://doi.org/10.1007/s11214-017-0385-1>
- \* Nighttime (FUV) O+ profiles: Dr. Farzad Kamalabadi : <https://doi.org/10.1007/s11214-018-0502-9>
- \* Neutral Wind profiles: Dr. Jonathan Makela : <https://doi.org/10.1007/s11214-017-0359-3>
- \* Neutral Temperature profiles: Dr. Christoph Englert : <https://doi.org/10.1007/s11214-017-0434-9>
- \* Ion Velocity Measurements : Dr. Russell Stoneback : <https://doi.org/10.1007/s11214-017-0383-3>

Responsibility for Level 4 products falls to those scientists responsible for those products.

- \* Hough Modes : Dr. Chihoko Yamashita : <https://doi.org/10.1007/s11214-017-0401-5>
- \* TIEGCM : Dr. Astrid Maute : <https://doi.org/10.1007/s11214-017-0330-3>
- \* SAMI3 : Dr. Joseph Huba : <https://doi.org/10.1007/s11214-017-0415-z>

Pre-production versions of all above papers are available on the ICON website.  
<http://icon.ssl.berkeley.edu/Publications>

Overall validation of the products is overseen by the ICON Project Scientist, Dr. Scott England.

NASA oversight for all products is provided by the Mission Scientist, Dr. Jeffrey Klenzing.

Users of these data should contact and acknowledge the Principal Investigator Dr. Immel and the party directly responsible for the data product (noted above) and acknowledge NASA funding for the collection of the data used in the research with the following statement : "ICON is supported by NASA's Explorers Program through contracts NNG12FA45C and NNG12FA42I".

These data are openly available as described in the ICON Data Management Plan available on the ICON website (<http://icon.ssl.berkeley.edu/Data>).

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