ICON Data Product 2.1: Line-of-sight Wind Profiles

This document describes the data product for ICON MIGHTI Line-of-sight Winds (DP 2.1), which is in NetCDF4 format.

This data product contains altitude profiles of the line-of-sight winds (inverted wind profiles in the direction of the sensor's line of sight) for 24 hours of data taken by MIGHTI. In addition to the line-of-sight wind data and the corresponding ancillary data, such as time and location, this product contains supporting data, such as fringe amplitude profiles and relative volume emission rate profiles. Absolute calibration and MIGHTI-A/B cross calibration of these data is not necessary to obtain the wind data, and therefore any direct analysis of these supporting data requires caution.

There is one file for each sensor (A or B), for each color (red or green) and for each day. The profile spans from an altitude of ~90 km (for green) or ~150 km (for red) to ~300 km, though altitudes with low signal levels are masked out. This data product is generated from the Level 1 MIGHTI product, which comprises calibrated interference fringe amplitudes and phases. The effect of spacecraft velocity is removed from the interferogram phase, then (optionally) the data are binned from their native altitude sampling (~2.5 km) to improve statistics. An onion-peeling inversion is performed to remove the effect of the line-of-sight integration. After the inversion, each row (i.e., altitude) is analyzed to extract the phase, and thus the line-of-sight wind. Level 2.1 files from MIGHTI-A and MIGHTI-B are combined during the Level 2.2 processing (not discussed here). See Harding et al. [2017, doi:10.1007/s11214-017-0359-3] for more details of the inversion algorithm. Further discussion of the calibration and performance of MIGHTI after launch can be found in a forthcoming paper in Space Science Reviews [Englert et al., 2022, in preparation].

Known issues with the v05 data release are listed below. Work is in progress to resolve or mitigate these issues in future data releases.

Known issues with v05:
* When ICON is in the South Atlantic Anomaly (SAA), radiation effects on the detector cause poor data quality. The quality control algorithm adequately flags and masks most of the affected samples, but some outliers remain, especially near the edge of the SAA. Other uncaught outliers are rare but can occur due to cosmic rays, stars in the field of view, moonlight, etc.
* The bottom row of data (corresponding to an altitude of ~88 km) is masked out as the signal is rarely strong enough to permit a wind estimate, and calibrations have large uncertainties. It is unlikely but possible that this altitude will be reported in future releases, pending further investigation.
* Airglow brightness observations are not a required mission product, and no effort was yet made to absolutely calibrate the brightness observations for MIGHTI-A and MIGHTI-B, and thus the Relative_VER variable should be treated with caution. In v05, MIGHTI-A and B are cross-calibrated using a conversion factor derived from on-orbit data. However, there are some indications that this cross-calibration may be changing with time, which is not accounted for in v05.
* As discussed in the variable notes below, a new zero wind phase determination has been implemented in v05. However, during the period from 2021 Apr 26 to Aug 14, data gaps and one period of southward ("Reverse LVLH") pointing cause errors in this determination. The accuracy is estimated to be degraded by a factor of two. See the *_Accuracy variable.
* During the one orbit per day when the calibration lamp is on, the wind data can be noisier and have a slight bias. Although this issue is much improved since v04, for the sake of conservatism, these orbits are still labeled with quality=0.5 (i.e., caution).
* Some data gaps appear on days when the sun passes near MIGHTI's field of view. Most of these gaps are located near the terminator, but some are longer lasting.
* In some cases, there are indications that the *_Precision_1_Sample variables are underestimating the true sample-to-sample noise, suggesting that, in addition to shot noise, there is a second source of noise. It is recommend that any quantitative use of the reported error estimates (i.e., precision and accuracy) should treat those estimates as uncertain. It is believed that most error estimates are correct to within a factor of 2. The largest problems with error reporting occur where the airglow signal is weakest.
* Imperfect daily calibration data lead to small discontinuities in the zero wind phase at the boundaries between days (i.e., between 23:59:59 and 00:00:00 UT), which are not accounted for by the reported error variables.

This was estimated to be a 2-5 m/s (root-mean-square) error early in the mission, but is growing over time, possibly reaching 5-10 m/s by mid-2022.
* A signal-dependent phase shift is seen in atmospheric and calibration lamp fringes, possibly caused by a charge trapping effect in the CCD. This is the subject of ongoing investigation, but a first-order correction is implemented in the v05 dataset. The correction increases linearly with time to match the effect seen in on-orbit calibration data. The variable *_Precision_Low_Signal_Effect is an estimate of the remaining uncertainty due to an imperfect correction. Where this uncertainty is large, caution is recommended. For example, for winds in the core science region (90-105 km altitude, away from the terminator), the magnitude of the correction is small or zero, but data in the red channel during the night and twilight are subject to a large correction (many tens of m/s) and the uncertainty is correspondingly large. A goal for future releases is to characterize and correct this effect more accurately.
* Data near the solar terminators are subject to a variety of errors, including those described above and others related to the rapidly varying illumination. Not all errors near the terminator are accounted for by the reported error. Users are encouraged to use extra caution with these data.
See the documentation below for more information.

History

v1.0: First release of MIGHTI L2.1/L2.2 software, B. J. Harding, 05 Mar 2018

v2.0: First run of on-orbit data, using external zero wind reference and smooth daily-averaged profiles, B. J. Harding, 01 May 2020

v3.0: Correction for long-term mechanical drift, B. J. Harding, 04 Jun 2020

v4.0: Updated correction for long-term mechanical drift to handle settling after ~May 2020 and precession cycle variation. LoS winds have changed by a bulk offset of up to 30 m/s. Studies using only perturbations from the mean (e.g., non-migrating tidal retrievals) are unlikely to be affected. B. J. Harding, 21 Oct 2020

v5.0: The ad-hoc, HWM-based correction for the zero wind phase has been replaced with a self-calibration based on comparing data from the ascending and descending orbits (see the notes for the wind variables below for details). Long-term trends in the zero wind phase degraded the accuracy of version 4 over time, and the accuracy of version 4 data was tied to the accuracy of HWM. In version 5, errors on these long time scales (>100-150 days) are now accounted for, improving the accuracy to 10-25 m/s (see the "Accuracy" variable for more details) and removing the dependence on external models. A long window of data is required to implement this self-calibration, so v05 data are processed at least 100 days behind real time. For errors on precession-cycle time scales (48 days), the previous ad-hoc correction using initial red-vs-green comparisons has been replaced with a more comprehensive red-green cross-calibration (165-185 km altitude during the day) that accounts for the time-dependence of mechanical drifts of the optics. This result is consistent with a first-principles analysis of the fiducial notch positions (see Marr et al., 2020 and subsequent publications). A mission-average fiducial notch analysis is also used to correct mechanical drifts on an orbital time scale (97 minutes, or 24 hours of local time), which could affect migrating tide estimates. The RMS difference due to this effect is estimated at 5-10 m/s (root mean square). Analysis of waves with periods that do not coincide with these new corrections are not likely to be different than in version 4 (e.g., nonmigrating tides, planetary waves, and gravity waves). New variables related to error (i.e., uncertainty) estimates from various sources are now included, whereas version 4 error estimates only included the effects of shot, read, and dark noise. MIGHTI-A and MIGHTI-B variables related to emission brightness are now cross-calibrated, though not absolutely calibrated. Exposures affected by solar and lunar stray light are now flagged. Some data during periods in May and July 2020 when the sun approached the MIGHTI field of view was marked as unavailable in v04, but is now available in v05 with the exception of a few days. The data from the second row in the green channel (~91 km) is now available when the signal strength permits a wind estimate. An error in the local time calculation has been corrected, which changes the local time by up to 20 min. A new algorithm to identify cosmic ray spikes has been implemented, improving precision. A preliminary algorithm has been implemented to to correct a wind bias associated with low signal levels, and associated uncertainties are estimated (see the "Precision_Low_Signal_Effect" variable for more details). Finally, various quality control parameters have been optimized. More description is provided in the notes below. A full history of software changes can be found on

Github: https://github.com/bharding512/airglowrsss/commits/master/Python/modules/MIGHTI_L2.py B. J. Harding 08 Sep 2022

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.

Dimension Name	Nominal Size
`Epoch`	unlimited
`Altitude`	82
`Vector`	3
`Start_Mid_Stop`	3
`N_Flags`	12
`Row`	82

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
ICON_L21_Line_of_Sight_Wind	Line-of-sight horizontal wind profile. A positive wind is towards MIGHTI. The wind is the primary data product in this file. This variable contains the projection of the horizontal wind (at the tangent point) onto the line of sight direction. An entire altitude profile is observed simultaneously. An onion-peeling inversion is used on the raw observations to remove the effects of the integration along the line of sight. The line-of-sight wind is defined such that a positive value indicates motion towards the spacecraft. This direction is given by the Line_of_Sight_Azimuth variable. It is assumed that the vertical wind is zero, but even large vertical winds (~100 m/s) do not significantly affect this data product, since the line of sight is nearly horizontal everywhere. It should be noted that while this measurement is ascribed to a particular latitude, longitude and altitude, it is actually an average over many hundreds of kilometers horizontally, and 2.5-30 kilometers vertically (depending on the binning). See Harding et al. [2017, doi:10.1007/s11214-017-0359-3] for a more complete discussion of the inversion algorithm. Knowledge of the "zero wind phase" is needed for any instrument using Doppler shifts to determine winds. The zero wind phase is defined as the measured interference fringe phase that corresponds to the rest wavelength of the emission. For the v05 data release, the zero wind phase has been determined by considering a window of LoS wind data spanning two precession cycles (96 days). Assuming that on average the real zonal and meridional winds do not depend on the aspect angle with which MIGHTI observes the atmosphere (an angle which is significantly different between the ascending and descending portions of the orbit), a matrix equation can be constructed which combines data from both MIGHTI-A and MIGHTI-B and both the ascending and descending orbits. This equation is solved for the average zonal and meridional wind, and the zero wind phase for MIGHTI-A and MIGHTI-B. This window is moved in time to determine the appropriate zero wind phase for each date. The value of the zero wind phase depends on emission color (red or green), aperture mode (day or night), calibration lamp status (on or off) and row (i.e., altitude). An additional zero-mean signal is added to this result to ensure that 48-day (i.e., 1 precession cycle) average winds are smooth in altitude. Adjustments are smaller than the reported accuracy, so this adjustment is not expected to change any scientific conclusions, although it does ensure more realistic wind profiles. This is a less restrictive assumption than the smoothness criterion used in v04, which relied on the Horizontal Wind Model 2014 and also enforced smoothness on 1-day averages. It is thus expected that the amplitude of tidal structures in the lower thermosphere are subject to less suppression in v05+ than in v04. This version of the MIGHTI zero wind phase is independent of any external data or models (such as the Horizontal Wind Model 2014, which was used in v04 and earlier versions). The zero wind phase used for each wind sample is saved in the _Zero_Wind_Phase variable below. The 1-sigma uncertainty in the winds incurred by the inaccuracy in the zero wind phase is estimated and reported in the *_Wind_Accuracy variable below.	m/s	Epoch, Altitude

Variable Name	Description	Units	Dimensions
ICON_L21_Line_of_Sight_Wind_Precision_1_Sample	Line-of-sight wind precision (1 sample) Various sources of error in MIGHTI winds are quantified with 1-sigma estimates and organized by their temporal persistence. These error sources are nearly uncorrelated with each other and can thus be added in quadrature. Users are encouraged to contact the MIGHTI team for assistance with error propagation. The "1 sample" error variable quantifies errors that are uncorrelated from one exposure to the next, dominated by shot and dark noise in the detectors. The correlation time of this error source is 30-60 seconds (i.e., the measurement cadence). The reported error is estimated from the fringe intensity and background. This is the recommended variable to use for analyses of wind fluctuations within a single day and a single altitude (e.g., gravity waves). Because the Level 2.2 data include interpolation of Level 2.1 data, some correlation remains between consecutive samples. Errors are slightly correlated across small altitude gaps as a result of the inversion.	m/s	Epoch, Altitude
ICON_L21_Line_of_Sight_Wind_Precision_1_Day	Line-of-sight wind precision (1 day) Various sources of error in MIGHTI winds are quantified with 1-sigma estimates and organized by their temporal persistence. These error sources are nearly uncorrelated with each other and can thus be added in quadrature. Users are encouraged to contact the MIGHTI team for assistance with error propagation. The "1 Day" error variable quantifies the error introduced by daily calibrations, which is correlated for an entire 24-hour period (00:00 - 23:59 UT). This is estimated from the magnitude of fluctuations in the daily-averaged phase, propagated through the inversion. Errors in day mode and night mode are nearly uncorrelated. For studies pertaining to atmospheric tidal modes that combine data from many days, this error can be treated as uncorrelated across time.	m/s	Epoch, Altitude

Variable Name	Description	Units	Dimensions
ICON_L21_Line_of_Sight_Wind_Precision_Low_Signal_Effect	Line-of-sight wind precision (from low signal effect) Various sources of error in MIGHTI winds are quantified with 1-sigma estimates and organized by their temporal persistence. These error sources are nearly uncorrelated with each other and can thus be added in quadrature. Users are encouraged to contact the MIGHTI team for assistance with error propagation. The "Low Signal Effect" error variable quantifies the error introduced by the imperfect correction for the signal-dependent phase shift, which is an effect seen in atmospheric and calibration-lamp fringes where the phase of the fringes is biased at very low signal levels. This is under investigation but could be caused by a charge trapping effect in the CCD. A correction has been implemented based upon the empirical relationship between measured phase and signal level of the calibration lamps for the first ~30 months of the mission. However, especially for cases with low signal levels, this correction is uncertain. The uncertainty in the resulting winds is estimated from the signal level and reported in this variable. It is likely to be correlated across samples nearby in time and space, but the correlation between different channels (red and green), sensors (MIGHTI-A and MIGHTI-B), and operating modes (Day and Night) is not known. Depending on the analysis being used, it could be treated as a systematic error or as a statistical error. Where this uncertainty is large, caution is recommended. For example, for winds in the core science region (90-105 km altitude), the magnitude of the correction is small or zero, but data in the red channel during the night and twilight are subject to a large correction (many tens of m/s) and the uncertainty is correspondingly large. A goal for future releases is to characterize and correct this effect more accurately.	m/s	Epoch, Altitude
ICON_L21_Line_of_Sight_Wind_Accuracy	Line-of-sight wind accuracy Various sources of error in MIGHTI winds are quantified with 1-sigma estimates and organized by their temporal persistence. These error sources are nearly uncorrelated with each other and can thus be added in quadrature. Users are encouraged to contact the MIGHTI team for assistance with error propagation. The "Accuracy" variable quantifies the error introduced by the zero-wind phase estimate. It is strongly correlated across time lags of days to weeks and becomes increasingly decorrelated for time lags longer than 2 precession cycles (96 days). This error is estimated from the discrepancy between various techniques of determining the zero-wind phase. This error source is irrelevant for most users studying perturbations from the mean (e.g., tides, waves), but may be important for studies of zonal mean winds, point comparisons with other data sets, and seasonal/long-term trends thereof. Errors are moderately correlated across small altitude gaps. Errors in day mode and night mode are nearly uncorrelated, implying there could be different offsets for day mode and night mode. This could be important for error propagation of odd-numbered migrating tides (e.g., DW1).	m/s	Epoch, Altitude

Variable Name	Description	Units	Dimensions
ICON_L21_Line_of_Sight_Wind_Error	Line-of-sight horizontal wind error profile For robust error propagation, users are encouraged to consider the individual error variables: "Precision_1_Sample," "Precision_1_Day," and "Accuracy." The "Wind_Error" variable is included for backwards compatibility and is equal to the quadrature sum of the "1 Sample" error and the "1 Day" error. This is the recommended uncertainty to use for analyses that collect data from several weeks and compute perturbations from the mean (e.g., for estimating tides and planetary waves). This error is uncorrelated across time lags larger than 24 hours. Errors are slightly correlated across small altitude gaps. Errors in day mode and night mode are nearly uncorrelated.	m/s	Epoch, Altitude
ICON_L21_Wind_Quality	A quantification of the wind quality, from 0 (Bad) to 1 (Good) A quantification of the overall quality of the wind data. While the intent is that the variable ICON_...Line_of_Sight_Wind_Error accurately characterizes the statistical error in the wind data, it is possible that systematic errors are present, or that the statistical error estimation is not accurate. If it is suspected that this is the case, the quality will be less than 1.0. If the data are definitely unusable, the quality will be 0.0 and the sample will be masked. Users should exercise caution when the quality is less than 1.0. This parameter can currently take 3 values: 0.0 (Bad), 0.5 (Caution), 1.0 (Good)		Epoch, Altitude
ICON_L21_Fringe_Amplitude	Fringe amplitude profile An approximate volume emission rate (VER) profile in arbitrary units. Technically this a profile of the amplitude of the fringes, which has a dependence on thermospheric temperature and background emission. Thus, it does not truly represent volume emission rate. However, it is a useful proxy. The units are arbitrary, but an attempt has been made to cross-calibrate MIGHTI-A with MIGHTI-B. In contrast to the wind inversion, which is nonlinear due to the phase extraction step, the amplitude inversion is purely linear. The Level 1 interferogram is analyzed to obtain a single brightness value per zenith angle, and this is inverted with the distance matrix to obtain a value of the amplitude per altitude.	arb	Epoch, Altitude
ICON_L21_Fringe_Amplitude_Error	Fringe amplitude error profile The statistical (1-sigma) error in the fringe amplitude. As with the wind, systematic errors are not included, but can arise from sources such as horizontal gradients and inaccurate calibration.	arb	Epoch, Altitude

Variable Name	Description	Units	Dimensions
ICON_L21_Relative_VER	Relative volume emission rate profile The volume emission rate (VER) obtained by scaling the fringe amplitude by a calibration factor. Pre-flight calibrations and on-orbit comparisons with ground-based instruments are used to determine the best possible calibration. The fringe amplitude has a dependence on temperature, which is corrected using the MSIS model. Because the on-orbit calibration is uncertain, and because the MSIS temperature correction is not perfect, caution should be exercised when absolute calibration is required, or when comparisons are being made between samples at different temperatures. Please contact the MIGHTI team before performing any studies that require absolute calibration. The statistical (1-sigma) error for this variable is provided in the variable ICON_..._Relative_VER_Error, though it is expected that systematic calibration errors dominate the total error. See the Fringe_Amplitude variable for a discussion of the inversion.	ph/cm^3/s	Epoch, Altitude
ICON_L21_Relative_VER_Error	Relative volume emission rate error profile The statistical (1-sigma) error in the relative VER estimate. This error arises mostly from shot noise. Importantly, it is expected that systematic errors (e.g., calibration errors) dominate the total error, but they are not included in this variable.	ph/cm^3/s	Epoch, Altitude
ICON_L21_VER_Quality	A quantification of the VER quality, from 0 (Bad) to 1 (Good) A quantification of the overall quality of the VER data. While the intent is that the variable VER_Error accurately characterizes the statistical error in the wind data, it is possible that systematic errors are present, or that the statistical error estimation is not accurate. If it is suspected that this is the case, the quality will be less than 1.0. If the data are definitely unusable, the the quality will be 0.0 and the sample will be masked. Users should exercise caution when the quality is less than 1.0. This parameter can currently take 3 values: 0.0 (Bad), 0.5 (Caution), 1.0 (Good)		Epoch, Altitude

support_data

Variable Name	Description	Units	Dimensions
Epoch	Sample time, midpoint of exposure. Number of msec since Jan 1, 1970. This variable contains the time corresponding to the wind profiles reported in this file, taken 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 variable ICON_..._UTC_Time	ms	Epoch
ICON_L21_Time	Sample time at start, mid, stop of exposure. Number of msec since Jan 1, 1970. This variable is the same as Epoch, except it has another dimension which holds the start time, middle time, and stop time of each exposure.	ms	Epoch, Start_Mid_Stop

Variable Name	Description	Units	Dimensions
ICON_L21_UTC_Time	Sample time, midpoint of exposure. This variable is the same as Epoch but is formatted as a human-readable string.		Epoch
ICON_L21_Altitude	WGS84 altitude of each wind sample The altitudes of each point in the wind profile, evaluated using the WGS84 ellipsoid. If the variable Integration_Order=0 (which is the default value), then these altitudes are one half sample above the tangent altitudes of each pixel's line of sight (consistent with the assumption implicit in the inversion that the wind and emission rate are constant within the layer between tangent altitudes). If Integration_Order=1, this variable contains the tangent altitudes.	km	Epoch, Altitude
ICON_L21_Latitude	WGS84 latitude of each wind sample The latitudes of each point in the wind profile, evaluated using the WGS84 ellipsoid. The latitude only varies by several degrees from the bottom of the profile to the top. It should be noted that while a single latitude value (the tangent latitude) is given for each point, the observation is inherently a horizontal average over many hundreds of kilometers.	deg	Epoch, Altitude
ICON_L21_Longitude	WGS84 longitude of each wind sample The longitudes (0-360) of each point in the wind profile, evaluated using the WGS84 ellipsoid. The longitude only varies by several degrees from the bottom of the profile to the top. It should be noted that while a single longitude value (the tangent longitude) is given for each point, the observation is inherently a horizontal average over many hundreds of kilometers.	deg	Epoch, Altitude
ICON_L21_Magnetic_Latitude	Magnetic quasi-dipole latitude of each wind sample A two-dimensional array defining the magnetic quasi-dipole latitude of the two-dimensional data grid. The latitude varies only slightly (a few deg) with altitude, but this variation is included. It should be noted that while a single latitude value is given for each point, the observation is inherently a horizontal average over many hundreds of kilometers. Quasi-dipole latitude and longitude are calculated using the fast implementation developed by Emmert et al. (2010, doi:10.1029/2010JA015326) and the Python wrapper apexpy (doi.org/10.5281/zenodo.1214207).	deg	Epoch, Altitude
ICON_L21_Magnetic_Longitude	Magnetic quasi-dipole longitude of each wind sample A two-dimensional array defining the magnetic quasi-dipole longitude of the two-dimensional data grid. The longitude varies only slightly (a few deg) with altitude, but this variation is included. It should be noted that while a single longitude value is given for each point, the observation is inherently a horizontal average over many hundreds of kilometers. Quasi-dipole latitude and longitude are calculated using the fast implementation developed by Emmert et al. (2010, doi:10.1029/2010JA015326) and the Python wrapper apexpy (doi.org/10.5281/zenodo.1214207). Quasi-dipole longitude is defined such that zero occurs where the geodetic longitude is near 285 deg east (depending on latitude).	deg	Epoch, Altitude

Variable Name	Description	Units	Dimensions
ICON_L21_Line_of_Sight_Azimuth	Azimuth angle of the line of sight at the tangent point. Deg East of North. Consider the vector pointing from the spacecraft to the tangent point (i.e., the line of sight). At the tangent point, this vector is parallel to the ground. This variable contains the azimuth angle of this vector, evaluated at the tangent point. It follows the typical geophysical convention of degrees East of North (North=0, East=90, South=180, West=270). It can vary by a few degrees from the top of the profile to the bottom, so one value is reported per altitude. MIGHTI-A and MIGHTI-B will have values approximately 90 degrees apart.	deg	Epoch, Altitude
ICON_L21_Low_Signal_Effect_Correction	Correction for low-signal effect This is the correction used for the "low signal effect" in the lower-level processing. This correction has already been applied to the data, but is included here for reference. It was taken directly from the Level 1 file but has been converted from rad to m/s. For the red channel, it has also been binned to match the data. It has not been modified by the inversion. The uncertainty of this correction is captured by the Line_of_Sight_Wind_Precision_Low_Signal_Effect variable. See the notes for that variable for more information.	m/s	Epoch, Altitude
ICON_L21_Solar_Zenith_Angle	Solar zenith angle of each wind sample Angle between the vectors towards the sun and towards zenith, at the location of each wind sample.	deg	Epoch, Altitude
ICON_L21_Local_Solar_Time	Local solar time of each wind sample Local solar time at the location and time of each wind sample, calculated using the equation of time.	hour	Epoch, Altitude

metadata

Variable Name	Description	Units	Dimensions
ICON_L21_Exposure_Time	The exposure time for each profile The exposure time (i.e., integration time) for each sample. Nominally this is 30 seconds during the day and 60 seconds at night.	s	Epoch
ICON_L21_Chi2	Variance of the phase in each (unwrapped) row: (std of phase)^2 In consolidating each row of the unwrapped interferogram into a single phase value, the variance of the phase is saved in this variable. Ideally this should provide no new information beyond what is provided by the wind uncertainty, but it is a useful diagnostic.	rad^2	Epoch, Altitude

Variable Name	Description	Units	Dimensions
ICON_L21_Observatory_Velocity_Vector	ICON S/C velocity vector in Earth-centered, Earth-fixed coordinates At each time, this is a length-3 vector [vx,vy,vz] of the ICON spacecraft's velocity in Earth-centered Earth-fixed (ECEF) coordinates at the midpoint time of the observation. The effect of spacecraft velocity has already been removed from the ICON_..._Line_of_Sight_Wind variable.	m/s	Epoch, Vector
ICON_L21_Observatory_Latitude	The WGS84 latitude of the ICON S/C The latitude of the ICON spacecraft at the midpoint time of the observation, using the WGS84 ellipsoid.	deg	Epoch
ICON_L21_Observatory_Longitude	The WGS84 longitude of the ICON S/C The longitude (0-360) of the ICON spacecraft at the midpoint time of the observation, using the WGS84 ellipsoid.	deg	Epoch
ICON_L21_Observatory_Altitude	The WGS84 altitude of the ICON S/C The altitude of the ICON spacecraft at the midpoint time of the observation, using the WGS84 ellipsoid.	km	Epoch
ICON_L21_Line_of_Sight_Vector	The look direction of each MIGHTI line of sight, as a vector in ECEF The vector from the spacecraft to the tangent point (i.e., along MIGHTI's line of sight), as a unit vector in Earth-centered Earth-fixed (ECEF) coordinates. A vector is provided for each tangent point for each time. If this vector is transformed to an azimuth and zenith angle at the tangent point, the zenith angle will be 90 deg, and the azimuth angle will be the same as the ICON_..._Line_of_Sight_Azimuth variable.		Epoch, Altitude, Vector
ICON_L21_Orbit_Number	Orbit Number Integer ICON orbit number		Epoch
ICON_L21_Orbit_Node	Orbit Ascending/Descending Node Flag Orbit Ascending/Descending Node Flag. 0 = Latitude of ICON is increasing. 1 = Latitude of ICON is decreasing.		Epoch
ICON_L21_Bin_Size	How many raw samples were binned vertically for each reported sample To improve statistics, adjacent rows of the interferogram can be averaged together before the inversion. This improves precision at the cost of vertical resolution. If no binning is performed, this value will be 1, corresponding to ~2.5 km sampling. A value of 2 corresponds to ~5 km sampling, etc.		

Variable Name	Description	Units	Dimensions
ICON_L21_Integration_Order	Order used to discretize the integral for inversion: 0=Riemann, 1=Trapezoidal In formulating the inversion, an assumption must be made regarding the choice of basis functions, which can be thought of as an assumption regarding the behavior of the wind and fringe amplitude (airglow volume emission rate) within each altitude layer. The most basic assumption is that these quantities are constant within each altitude layer, which corresponds to Integration_Order=0. However, if it is assumed that the variation within each layer is linear, Integration_Order=1. This sacrifices precision to improve vertical resolution.		Epoch
ICON_L21_Top_Layer_Model	How the top altitudinal layer is handled in the inversion: "exp" or "thin" In formulating the inversion, an assumption must be made about the shape of the emission rate profile above the top measured altitude, since this shape is not measured. It can be assumed to go to zero (Top_Layer_Model="thin") or assumed to fall off exponentially with a scale height of 26 km, a value extracted from running a variety of airglow models (Top_Layer_Model="exp"). Usually this choice will not affect the inversion significantly. In cases where it does, the quality variable will be decreased.		Epoch
ICON_L21_Attitude_LVLH_Normal	Attitude status bit 0: LVLH Normal LVLH Normal pointing. This variable is taken from bit 0 of the Level 1 variable ICON_L1_MIGHTI_X_SC_Attitude_Control_Register. 0=False, 1=True		Epoch
ICON_L21_Attitude_LVLH_Reverse	Attitude status bit 1: LVLH Reverse LVLH Reverse pointing. This variable is taken from bit 1 of the Level 1 variable ICON_L1_MIGHTI_X_SC_Attitude_Control_Register. 0=False, 1=True		Epoch
ICON_L21_Attitude_Limb_Pointing	Attitude status bit 2: Earth Limb Pointing Earth limb pointing. This variable is taken from bit 2 of the Level 1 variable ICON_L1_MIGHTI_X_SC_Attitude_Control_Register. 0=False, 1=True		Epoch
ICON_L21_Attitude_Conjugate_Maneuver	Attitude status bit 6: Conjugate Maneuver Conjugate Maneuver. This variable is taken from bit 6 of the Level 1 variable ICON_L1_MIGHTI_X_SC_Attitude_Control_Register. 0=False, 1=True. If it is 1, then the S/C is performing a conjugate maneuver during this exposure.		Epoch
ICON_L21_Attitude_Zero_Wind_Maneuver	Attitude status bit 10: Zero Wind Maneuver Zero Wind Maneuver. This variable is taken from bit 10 of the Level 1 variable ICON_L1_MIGHTI_X_SC_Attitude_Control_Register. 0=False, 1=True. If it is 1, then the S/C is performing a zero wind maneuver during this exposure.		Epoch

Variable Name	Description	Units	Dimensions
ICON_L21_Quality_Flags	Quality flags This variable provides information on why the Wind_Quality and VER_Quality variables are reduced from 1.0. Many quality flags can exist for each grid point, each either 0 or 1. More than one flag can be raised per point. This variable is a two-dimensional array with dimensions of altitude and number of flags. 0 : (From L1) SNR too low to reliably perform L1 processing 1 : (From L1) Proximity to South Atlantic Anomaly 2 : (From L1) Bad calibration 3 : (From L1) Calibration lamps are on 4 : (From L1) Solar/lunar contamination 5 : Not enough valid points in profile 6 : SNR is very low after inversion 7 : Significant airglow above 300 km 8 : Line of sight crosses the terminator 9 : Thermal drift correction is uncertain 10: S/C pointing is not stable 11: SNR is low after inversion, but maybe still usable		Epoch, Altitude, N_Flags
ICON_L21_Relative_VER_DC	Relative volume emission rate profile derived from DC value The MIGHTI team recommends that users utilize the Relative_VER variable instead of this variable. This is the same as Relative_VER, except it is derived from the DC value of the interferogram rather than the fringe amplitude. The DC value is susceptible to contamination by stray light and background emission, but is not sensitive to atmospheric temperature like the fringe amplitude.	ph/cm^3/s	Epoch, Altitude
ICON_L21_Zero_Wind_Phase	The phase subtracted from Level 1 data See notes for _Line_of_Sight_Wind above. This variable is reported as a function of Row (Level 1 coordinates) instead of Altitude (Level 2 coordinates).	rad	Epoch, Row

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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