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. One update to this paper is relevant: Zero wind removal is now performed prior to the creation of the Level 1 file, instead of during the L2.1 processing.

Known issues with the initial data release (labeled v03) are listed below. These issues are expected to be resolved in future data releases. In future releases, some data points may change by up to 50 m/s, but most changes are expected to be much smaller. Future updates to the "zero wind phase" (discussed in detail below, in the notes for the wind variable) will change the winds by a bulk offset, but most relative variations in time, latitude, longitude, and from day to day will remain.

Known issues with v03:
* Some artifacts from preliminary calibrations are present (e.g., thermal instrument drift, detector flat field, and fringe visibility correction). These manifest as artificial offsets that affect a single altitude or a single local solar time, persisting for an entire UT day.
* The quality flag indicating contamination by the South Atlantic Anomaly is too conservative, so some high-quality data points are given a lower quality factor.
* The reported wind error includes the effect of dark, read, and shot noise in the observations, but does not include calibration uncertainty. It is likely that a future release will revise the reported error upward by approximately 50%.
* The bottom two rows of data (corresponding to altitudes of ~88 and ~91 km) are masked out pending updated calibrations. These rows are near the edge of the field of view and not all columns are illuminated, which requires special consideration.
* Airglow brightness observations are not a required mission product, and no effort was yet made to absolutely- or cross-calibrate the brightness observations for MIGHTI-A and MIGHTI-B, and thus the Relative_VER variable should be treated with caution.
* A calibration lamp is used for one orbit per day to assess the periodic thermal drift of MIGHTI. This is used to correct all other observations that day. In v03 data, the thermal drift is ascribed entirely to interferometer drift, but some fraction is due to mechanical drift. This will be corrected by using the observed drift of the fiducial notches. The error in the current approach is estimated to be less than 10 m/s.
* During the one orbit per day when the calibration lamp is on, the wind data are noisier and a slight bias is evident. For this release, these orbits have been labeled with quality=0.5 (i.e., caution). Work is underway to remove this restriction.
* The top 3-5 rows of the red channel are experiencing a long-term drift relative to other rows. The error is estimated to be zero on 2020-02-01 and approximately 50 m/s on 2020-05-15, for both MIGHTI-A and MIGHTI-B. Users should use caution with data above 273 km. This artifact has been identified as an uncorrected drift in the phase distortion and will be corrected in a future release.

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.

Dimensions

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
`Start_Mid_Stop`	3
`Epoch`	2120
`Vector`	3
`Altitude`	82
`N_Flags`	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
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 this initial data release, the zero wind phase has been determined by comparing a 60-day average of MIGHTI data to a 60-day average of the empirical Horizontal Wind Model 2014 (HWM14, Drob et al., 2015, doi:10.1002/2014EA000089), which is a fit to decades of previous wind measurements. At each time and location of a MIGHTI measurement, the MIGHTI measurement is simulated by integrating HWM14 along the line of sight, weighted by the observed volume emission rate as determined by the measured fringe amplitude profile. The 60-day-average difference between the measured and simulated phases is taken as the zero wind phase. This is done separately for each sensor (A and B), for each color (red and green), for each mode (day and night), and for each row (i.e., each altitude). This approach to determining the zero wind phase is analogous to the approach taken for the UARS/HRDI instrument (Hays et al., 1992, doi:10.1016/0032-0633(92)90119-9), which assumed that a long-term average of the meridional wind is zero. Although the long-term average altitude profile is constrained to match HWM14 in this initial MIGHTI data release, measured variations in time, latitude, longitude, and from day to day are retained using this approach. A future data release will leverage ICON's unique "zero wind maneuver" to determine an independent zero wind phase.	m/s	Epoch, Altitude

Variable Name	Description	Units	Dimensions
ICON_L21_Line_of_Sight_Wind_Error	Line-of-sight horizontal wind error profile The statistical (1-sigma) error in the line-of-sight wind. This is usually dominated by shot noise, but also includes the effects of dark and read noise, as well as calibrations errors (e.g., the zero wind calibration), and spacecraft pointing error (which affects the uncertainty in removing the spacecraft velocity from the observed velocity). Other systematic errors or biases may exist (e.g., the effect of gradients along the line of sight) which are not included in this variable. Errors in daily calibrations may create systematic patterns in winds that are constant for an entire 24 hour period (00:00 - 23:59 UT) but change from day to day.	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

Variable Name	Description	Units	Dimensions
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
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

Variable Name	Description	Units	Dimensions
`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`
`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_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`

Variable Name	Description	Units	Dimensions
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
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

Variable Name	Description	Units	Dimensions
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.		
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

Variable Name	Description	Units	Dimensions
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		Epoch
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) Unused 5 : (From L1) Unused 6 : SNR too 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: Unused		Epoch, Altitude, N_Flags

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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