ICON Data Product 4.3: TIEGCM

This document describes the TIEGCM output files.

Note that there are three types of TIEGCM output files

1. **tidal HME forcing at its lower boundary (naming convention ICON_L4-3_TIEGCM_*YYYY-MM-DD*_v*XX*r*ZZZ*.NC)**
2. **without tidal forcing (naming convention ICON_L4-3_TIEGCM-NOHME_*YYYY-MM-DD*_v*XX*r*ZZZ*.NC).**
3. **with constant geophysical forcing and tidal HME forcing at its lower boundary (naming convention ICON_L4-3_TIEGCM-CONGEOPHYS_*YYYY-MM-DD*_v*XX*r*ZZZ*.NC).**

For the TIEGCM output with tidal forcing at its lower boundary:
The TIEGCM is forced by the HME-TIEGCM data product L4.1 at the TIEGCM lower boundary. The HME-TIEGCM product defines the tidal perturbations in the zonal wind, meridional wind, temperature, and geopotential height based on ICON-MIGHTI observations. We refer to the documentation of data product L4.1 for details of the HME-TIEGCM product.

For the TIEGCM output with and without tidal forcing at its lower boundary:
The TIEGCM-ICON is based on TIEGCM2.0 release with descriptions of the model by *Qian et al. [2014]* and *Richmond and Maute (2013)*. The source code for the TIEGCM-ICON is available at the High Altitude Observatory (HAO) TIEGCM website [1]. A draft TIEGCM model description [2] is available at the HAO TIEGCM website but for an updated description of the TIEGCM-ICON and the differences to TIEGCM2.0 it is referred to *Maute* [2017] Section 2.2. The main differences to TIEGCM2.0 are briefly summarized below:

1. the soft X-Ray fluxes in the 8-40A wavelength range were increased by a factor of 4.4 following *Fang et al. (2008)* to better match E-region plasma density from IRI model (this is a source code change in TIEGCM-ICON from TIEGCM2.0).
2. at the TIEGCM lower boundary the background atmosphere (zonal and diurnal mean) is defined by HWM07 and MSISE00 as published by *Jones Jr. et al (2014)* (name list* read variable BGRDDATA=hwm07_97km_msise00_plev_zonalmean_fields_v3.nc). This is used for TIEGCM output with and without HME tidal forcing at the lower boundary.
3. The HME-TIEGCM files with hourly gridded perturbations can be used at the TIEGCM lower boundary. For TIEGCM with HME tidal forcing at its lower boundary the name list* read variable HME_NCFILES are set to L4.1 file names. For TIEGCM without HME tidal forcing at its lower boundary the name list* read variable HME_NCFILES is not used.

In the case of TIEGCM with HME tidal forcing the lower boundary includes the added values of the background (item 2 above) and the tidal forcing (item 3 above), while for the TIEGCM without HME the lower boundary includes only the background (item 2 above).

*Name list read variable refer to variables/parameters defined at run time in an input script.

For the TIEGCM output with constant geophysical forcing:
The TIEGCM is forced by the HME-TIEGCM data product L4.1 at the TIEGCM lower boundary. The solar flux is held constant with daily and 81-day average F10.7=71., solar wind velocity v_{sw} = 400 km/s, density den_{sw}= 4 1/cm^3, IMF B_y=0nT & B_z=1nT, and hemispheric power is 12 GW. The same convection and auroral models are uses as for the other two simulations.

Run time parameters
The simulations use a timestep size of 30 secs (STEP=30). Helium is included as a major species (CALC_HELIUM=1) following Sutton et al. (2015). This needs to be considered in the mean mass calculation and existing processors should be checked for including Helium. Gravity and plasma pressure gradient driven ionospheric current (CURRENT_PG=1) are included in the ionospheric electrodynamic equation but the influence on the ExB drift is mainly limited to the dawn and dusk sector (*Maute & Richmond, 2017*). The Joule heating is increased by 50% which is the default in the TIEGCM (JOULEFAC=1.5) to account for the effect of small-scale electric field variability not captured by the TIEGCM. The *Weimer (2005)* ion convection patterns are employed driven by 5-min Interplanetary Magnetic Field (IMF) By and Bz magnitudes and solar wind velocity and density. The high latitude energy input associated with auroral particle precipitation is based on the analytical auroral model (Roble and Ridley 1987) and its parametrization to align with the ion convection model (Emery et al., 2012). The solar radio flux is used with a daily (F107d) value and a 81-day averaged solar flux (F107a). The 81day average value of a day is averaged over 7 days after the day and 73 days before the day. If the name list variable GPI_NCFILE uses "ICON_Ancillary_GPI" a 7-73 day averaging in F107a is used otherwise the averaging is centered on the day. The resolution of the simulation is 2.5^{o}x2.5^o in geographic latitude and longitude with a ¼ scale height resolution in altitude. The geomagnetic grid is regular in longitude (4.5^o) and irregular in magnetic latitude varying between 0.34^o to 3.07^o from the magnetic equator to the magnetic pole at 90km altitude.

UPDATE (2025.07.25)
Simulations for year 2020-2021- TIEGCM-NOHME v1r000 and TIEGCM v2r000 use adjusted daily F10.7 and non-centered averaged F10.7 from "ICON_Ancillary_GPI"
Simulations for 2022 -TIEGCM-NOHME v1r000 for 2022, TIEGCM v2r000 from doy 34 onward, TIEGCM v2r001, all these simulations use observed daily F10.7 and 81-day (centered) averaged F10.7 (see Figure at end of document)

We refer to the TIEGCM2.0 user guide (https://www.hao.ucar.edu/modeling/tgcm/tiegcm2.0/userguide/html/) and draft model description (https://www.hao.ucar.edu/modeling/tgcm/doc/description/model_description.pdf) for details.

History of the document
Version 01; product v1r000 initial release with HME-V02; 2022-03-14
Version 02; product v2r000 updated LB with HME-V03; 2023-10-20

Version 03; product v2r000 added constant geophysical forcing simulation with HME-V03; 2024-02-26
Version 04; product v2r001 updated solar forcing for TIEGCM-V2 with HME-V03 (see UPDATE under Run Time Parameters); 2025-07-26

Dimensions

NetCDF files contain coordinates (variable name is the same as the dimension), and variables with dimensions over which those variables are defined. The dimensions are given below, along with nominal sizes.

Dimension name	size	description
time	unlimited	Number of time steps on file (for L4.3 this is 24)
lon	144	Geographic longitudes
lat	72	Geographic latitudes
lev	57	Midpoint pressure coordinate
ilev	57	Interface pressure coordinate
mlon	81	Magnetic longitude
mlat	97	Magnetic latitude
mlev	63	Pressure coordinate (like ilev but downward and one level upward extended)
mtimedim	3	Model time dimension for (day,ut,min)
latlon	2	Dimension for NH and SH magnetic pole
dtidedim	2	Dimension of diurnal Hough mode (1,1) (Amplitude, Phase) NOT used for TIEGCM-ICON L4.3
sdtidedim	10	Dimension of five semidiurnal Hough mode (Amplitude, Phase) NOT used for TIEGCM-ICON L4.3
datelen	24	For written date
filelen	1024	Max. length for filename output

Variables

In the following we describe the variables we consider as important or not described in the user guide. We do not include the coordinate variables which are described by their dimensions in the table above. For a list of variables we refer to the user guide please see https://www.hao.ucar.edu/modeling/tgcm/tiegcm2.0/userguide/html/output.html#netcdf-history-output-files and https://www.hao.ucar.edu/modeling/tgcm/tiegcm2.0/userguide/html/diags.html#table-of-available-diagnostics.

Variable Name	Description	unit	dimension

time	Minutes since initial start date & time, start date & time are given as variable attributes (for easy access of time use variable mtime)	Minutes since initial start date & time	unlimited
mtime	Model time (integer)	(day of year, ut, minute)	(time,mtimedim)
year	Calendar year	year	time
ut	Universal time (from mtime)	hour	time
day	Day of year	day	time
timestep	Timestep size	sec	time
Calendar_advance	calendar advance flag (1 if advancing calendar time as for L4.3 product)		time
f107d	Daily F10.7 radio flux	1.e-22 W/m2/Hz	time
f107a	81-day average F10.7 solar radio flux (note for L4.3 average might not be centered see variable gpi_ncfile	1.e-22 W/m2/Hz	time
hpower	Hemispheric power (parametrized)	GW	time
ctpoten	Cross polar cap potential drop (for L4.3 from Weimer model)	kV	time
Kp	Kp index (for L4.3 not used)		time
byimf	IMF By component from imf_ncfile	nT	time
bzimf	IMF By component from imf_ncfile	nT	time
swvel	Solar wind velocity from imf_ncfile	km/s	time
swden	Solar wind density from imf_ncfile	1/cm3	time
gpi_ncfile	Path & name of gpi file contains (Kp,F107d,F107a, ap, ap3) (For L4.3 F10.7 values are used, see comment under run time parameter)		time
imf_ncfile	Path & name of imf file contains (Bx,By,Bz,Swvel,Swden) (used for L4.3)		time
hme_ncfile	HME file name and path used for lower boundary perturbation (used for L4.3 with HME at LB; not used for L4.3 without HME at LB)		time
bgrddata_ncfile	background lbc data file (for L4.3 based on HWM07 & MSISE00)		time
e1	Peak energy flux in noon sector of aurora	ergs/cm^2/s	time
e2	Peak energy flux in midnight sector of aurora	ergs/cm^2/s	time
h1	Gaussian half-width of the noon auroral oval	degrees	time
h2	Gaussian half-width of the midnight auroral oval	degrees	time

alfac	Characteristic Maxwellian energy of polar cusp electrons	keV	time
ec	Column energy input of polar cusp electron	ergs/cm^2/s	time
alfad	characteristic Maxwellian energy of drizzle electrons	keV	time
ed	Column energy input of drizzle electrons	ergs/cm^2/s	time
crit1	Magnetic colatitude for electrodynamics (poleward of crit1 the high latitude potential is prescribed)	degree	time
crit2	Magnetic colatitude for electrodynamics (equatorward of crit2 pure wind dynamo & gravity and plasma pressure gradient current forcing is applied)	degree	time
mag	geog. lat & lon coordinates of S,N magnetic poles (note that the magnetic main field is set up once per simulation)		Latlon,latlon
p0	Reference pressure (to convert to hPa)	millibars	
p0_model	Reference pressure (as used by the model) (to convert to hPa see global attribute for formula)	microbars	
grav	gravitational acceleration (constant with altitude see global attribute for formula)	cm/s^2	
TN	Neutral temperature	K	time,lev,lat,lon
UN	Zonal neutral wind	cm/s	time,lev,lat,lon
VN	Meridional neutral wind	cm/s	time,lev,lat,lon
WN	Upward neutral wind (note that the vertical dimension is using ilev)	cm/s	time,ilev,lat,lon
O2	Molecular oxygen	Mass mixing ration (mmr)	time,lev,lat,lon
O1	Atomic oxygen	mmr	time,lev,lat,lon
N2	Molecular nitrogen	mmr	time,lev,lat,lon
NO	Nitric oxide	mmr	time,lev,lat,lon
N4S	N(^{4}S)	mmr	time,lev,lat,lon
HE	Helium	mmr	time,lev,lat,lon
NE	Electron density (note that the vertical dimension is ilev)	1/cm^3	time,ilev,lat,lon
TE	Electron temperature	K	time,lev,lat,lon
TI	Ion temperature	K	time,lev,lat,lon
O2P	O^{2+} ion	1/cm^3	time,lev,lat,lon

OP	O^+ ion	$1/cm^3$	time,lev,lat,lon
POTEN	Electric potential (on geographic grid)	V	time,ilev,lat,lon
UI_ExB	Zonal ExB velocity (geog.eastward)	cm/s	time, ilev, lat, lon
VI_ExB	Meridional (geog. northward) ExB velocity	cm/s	time, ilev, lat, lon
WI_ExB	Vertical (geog. Upward) ExB velocity	cm/s	time, ilev, lat, lon
Z	Geopotential height (used in the code with constant gravity)	cm	time, ilev, lat, lon
ZG	Geometric height (just postprocessing with variable gravity)	cm	time, ilev, lat, lon
PHIM2D	Electric potential at 90 km on magnetic grid	V	time,mlat,mlon
ED12D	E_{d1} see *Richmond (1995)* at 90km (magnetic eastward direction)	V/m	time,mlat,mlon
ED22D	E_{d2} see *Richmond (1995)* at 90km (down-/equatorward direction)	V/m	time,mlat,mlon
SIGMA_PED	Pedersen Conductivity	S/m	time, lev, lat, lon
SIGMA_HAL	Hall Conductivity	S/m	time, lev, lat, lon
EEX	Geog. eastward electric field on geog. grid	V/cm	time, lev, lat, lon
EEY	Geog. northward electric field on geog. grid	V/cm	time, lev, lat, lon
EEZ	Geog. upward electric field on geog. grid	V/cm	time, lev, lat, lon
QJOULE	Joule heating	erg/g/s	time, lev, lat, lon
QJOULE_INTEG	Height integrated Joule heating	$erg/cm^2/s$	time, lev, lat, lon
QAURORA	Aurora ionization rate	$1/(cm^3\ s)$	time, lev, lat, lon
PHIMW	Prescribed high latitude potential (for L4.3 Weimer potential)	V	time,mlat,mlon
JE1PG_DYN	Magnetic eastward gravity and plasma pressure gradient driven current density (used in electrodynamo if CALC_JPG=1, used in L4.3)	A/m^2	time, lev, lat, lon
JE2PG_DYN	Magnetic down-/equatorward gravity and plasma pressure gradient driven current density (used in electrodynamo if CALC_JPG=1, used in L4.3)	A/m^2	time, lev, lat, lon
ZMAG	Geopotential height (constant gravity) on magnetic grid	cm	time, imlev, mlat, mlon
TLBC	Lower boundary of TN (background and perturbation)	K	time, lat, lon

ULBC	Lower boundary of UN (background and perturbation)	cm/s	time, lat, lon
VLBC	Lower boundary of VN (background and perturbation)	cm/s	time, lat, lon

Global Attributes

In the following we mention a few global attributes which might be helpful for a user

Potential_model	Describes which prescribed high latitude potential model was used (Weimer for L4.3 TIEGCM-ICON)
lev_to_hPa_method1	Formula to convert from pressure level lev to hPa
lev_to_hPa_method2	Alternative formula to convert from pressure level lev to hPa
contents	Content time range yyddd day hour min to yyddd day hour min by delta_mins
Version	Version number of the L4.3 product
Description	Describes ICON product
lowerBoundary_type	For TIEGCM with HME at LB: HME with version number for L4.3 For TIEGCM without HME "noHME" specified

References

[1] https://www.hao.ucar.edu/modeling/tgcm/tie.php

[2] https://www.hao.ucar.edu/modeling/tgcm/tiegcm2.0/userguide/userguide.pdf

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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/N2 ratio: Dr. Robert Meier: 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. Roderick Heelis: https://doi.org/10.1007/s11214-017-0383-3

Additional theoretical work in support of these products was supported by Dr. Robert Meier
Daytime O/N2 product https://doi.org/10.1029/2020JA029059
Daytime (EUV) O+ profiles: https://doi. org/10.1029/2023JA031533

Responsibility for Level 4 products falls to those scientists responsible for those products.
* Hough Modes: Dr. Chihoko Cullens: 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 (2018-2022) and Dr. Ruth Lieberman (2022-present).

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 NASAs 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).

Figure
Information about TIEGCM with HME-V3 v2r001 changes (date 2025.07.26)

With the update (v2r001) solar forcing of the simulation with HME V3 (red line) and wo HME (green line) are identical (on top of each other in plot to the right).
1. Updated simulation is doy 1-33, 2022 with HME-V3 (v2r001).
2. With the update for 2022, the solar forcing is consistent between the simulation with and without HME- both using observed daily F10.7 and 81-day average F10.7.
3. For 2020-2021, both simulations with and without HME use solar forcing from “ICON_Ancillary_GPI” (adjusted F10.7 and 7 (future)-73 (past) day average F10.7a).