

Supplementary Material

1 SUPPLEMENTARY TABLES

1.1 Package daedalusmase_derived_products

1.1.1 Module mod_heating_sources

mod_heating_sources		
	sub_heating_rates	
Routine Name	Description	
joule	joule heating rate calculation	
ohmic	ohmic heating rate calculation	
frictional	frictional heating rate calculation	
convection_heat	convection heating rate calculation	
wind_heat	wind heating rate calculation	
ohmic_per_mass	ohmic heating per neutral mass	
sub_heat_transfer_rates		
heat_transfer_ie	heat transfer between electrons and ions	
heat_transfer_in	heat transfer between ions and neutrals	
heat_transfer_ne_elastic	heat transfer between electorns and neutrals [eslastic]	
heat_transfer_ne_elastic _rees	heat transfer between electorns and neutrals [eslastic]	
sı	lb_frictional_heating_rates	
frictional_ie	frictional heating between electrons and ions	
frictional_ii	frictional heating between ion species	
frictional_nopn	frictional heating between NO^+ and neutrals	
frictional_opn	frictional heating between O^+ and neutrals	
frictional_o2pn	frictional heating between O_2^+ and neutrals	
frictional_npn	frictional heating between N^+ and neutrals	
sub_cooling_rates		
N2_rot	N_2 rotational excitation	
N2_vib	N_2 vibrational excitation	
O2_rot	O_2 rotational excitation	
O2_vib	O ₂ vibrational excitation	
O_fine	O fine structure	

Table S1: Routines of the mod_heating_sources module.

1.1.2 Module mod_collision_freqs_cross_sections

mod_collision_freqs_cross_sections	
sub_collision_frequencies	
Routine Name	Description
i_n_collision_freqs	ion-neutral collision frequencies
i_n_collision_sangalli _freqs	ion-neutral collision frequencies (Sangalli et al., 2009)
i_e_collision_freqs	ion-electron collision frequencies
i_i_collision_freqs	ion-ion collision frequencies
e_n_collision_freqs	electron-neutral collision frequencies
sub_cross_sections	
i_n_cross_sections	ion-neutral cross sections
Table S2: Routines of the mod_collision_freqs_cross_sections	

module.

1.1.3 Module mod_conductivities

Description
Pedersen conductivity
Hall conductivity
Parallel conductivity

Table S3: Routines of the mod_conductivities module.

1.1.4 Module mod_currents_magnetic_forcing

mod_currents_magnetic_forcing	
Routine Name	Description
current_pedersen	Pedersen current
current_hall	Hall current
JxB_forcing	JxB forcing
mechanical_power	mechanical power

Table S4: Routines of the mod_currents_magnetic_forcing module.

1.1.5 Module mod_height_integration

mod_height_integration	
Routine Name	Description
regrid	Regrid TIEGCM output from pressure to altitude defined
	grid
integration_height	Perform height integration
integration	Perform integration in a 3D region
integration_limits	Define integration limits for 3D integration

Table S5: Routines of the mod_height_integration module.

1.1.6 Module mod_tiegcm_utils

mod_tiegcm_utils	
Routine Name	Description
ion_velocities	Ion velocities from momentum equation
e_velocities	Electron velocities from momentum equation
vi_ve_relative	Electron-Ion relative velocities
vi_vi_relative	Ion-Ion relative velocities
igrf_B	IGRF geomagnetic field
electric_field	Electric field from ion ExB drifts
gyro_frequencies	Electron and ion gyro-frequencies
electric_field	Electric field from ion ExB drifts
read_tiegcm	Read TIEGCM NetCDF file
convert_mmr	Convert densities from mmr to cm^{-3}
const	Define constants
allocations	Define empty arrays for the notebook outputs

Table S6: Routines of the mod_tiegcm_utils module.

1.1.7 Module mod_plot_utils

mod_plot_utils	
Routine Name	Description
plot_conductivities	Plot conductivity profiles
plot_currents	Plot electric currents profiles
plot_densities	Plot ion and neutral densities profiles
plot_frequencies	Plot collision frequencies profiles
plot_heatings	Plot heating rates profiles
plot_velocities	Plot ion and neutral velocities profiles
plot_temperatures	Plot ion, electron and neutral temperatures profiles
plot_map_2d	Plot quantities in latitude-longitude map
plot_polar_north	Plot quantities in polar map [north]
plot_polar_south	Plot quantities in polar map [south]
plot_quiver	Plot vector quantities in polar map
plot_ortho	Plot quantities in global orthographic map
plot_lat_alt	Plot quantities in latitude-altitude map

Table S7: Routines of the mod_plot_utils module.

1.2 Package daedalusmase_collision_frequencies

daeda	lusmase_collision_frequencies
	mod_collision_freqs
Routine Name	Description
vin_banks	Ion-neutral collision frequencies (Banks, 1966)
vin_schunk_and_walker	Ion-neutral collision frequencies (Schunk and Walker, 1973)
vin_schunk_and_nagy	Ion-neutral collision frequencies (Schunk and Nagy, 2009)
vin_richmondr	Ion-neutral collision frequencies (Richmond, 2017)
vin_ieda	Ion-neutral collision frequencies (Ieda, 2020)
op_o_cols	$O^+ - O$ collision frequencies
op_o_temps	Temperature dependence of $O^+ - O$ collision frequencies
ven_coll_freq	Electron-neutral collision frequencies
pedersen	Pedersen conductivity
hall	Hall conductivity
	mod_utils
run_igrf	Run IGRF model
run_iri	Run IRI model
run_msis	Run MSIS model
const	Define constants
allocations	Define empty arrays for the notebook outputs
	mod_plot_utils
plot_pedersen_vin	Plot Pedersen conductivity for different vin models
plot_hall_vin	Plot Hall conductivity for different vin models
plot_pedersen_contributions	Ion contributions to Pedersen conductivity
plot_hall_contributions	Ion contributions to Hall conductivity
plot_vin	Ion-neutral collision frequencies from different models
plot_vNOpO	NO^+ -neutral collision frequencies from different models
plot_vO2pO	O_2^+ -neutral collision frequencies from different models
plot_vOpO	O^+ -neutral collision frequencies from different models
plot_oplus_freq_altitude	$O^+ - O$ collision frequencies per altitude
plot_oplus_freq_temperature	$O^+ - O$ collision frequencies per temperature
plot_densities	Ion and neutral densities from IRI and MSIS

Table S8: Routines of the daedalusmase_collision_frequencies module.

1.3 Package daedalusmase_error_propagation

daedalusmase_error_propagation	
	product_derivation
Routine Name	Description
model_input	Read TIE-GCM input file and execute the IGRF
products	Calculates LTI products
	support_functions
enu_ecef	Convert ENU to ECEF
	error_propagation
error Error propagation and error contribution on LTI products	
	Plots
mapla_collisions_plot	Plot collision Frequencies [Lat-Alt]
mapla_collisions_rel_error_plot	Plot collision frequencies Relative error [Lat-Alt]
mapla_conductivities_plot	Plot conductivities frequencies [Lat-Alt]
mapla_conductivities_rel_error_plot	Plot conductivities Relative error [Lat-Alt]
mapla_cross_section_plot	Plot cross sections [Lat-Alt]
mapla_cross_section_rel_error_plot	Plot cross sections relative error [Lat-Alt]
mapla_currents_plot	Plot currents [Lat-Alt]
mapla_currents_rel_error_plot	Plot currents relative error [Lat-Alt]
mapla_heating_rates_plot	Plot heating rates [Lat-Alt]
mapla_heating_rates_rel_error_plot	Plot heating rates relative error [Lat-Alt]
mapll_collisions_plot	Plot collision frequencies over the Earth's map
mapll_collisions_rel_error_plot	Plot collision frequencies relative error over the Earth's map
mapll_conductivities_plot	Plot conductivities over the Earth's map
mapll_conductivities_rel_error_plot	Plot conductivities relative error over the Earth's map
mapll_csection_plot	Plot cross sections over the Earth's map
mapll_csection_rel_error_plot	Plot cross sections relative error over the Earth's map
mapll_currents_plot	Plot currents over the Earth's map
mapll_currents_rel_error_plot	Plot currents relative error over the Earth's map
mapll_heating_rates_plot	Plot heating rates over the Earth's map
mapll_heating_rates_rel_error_plot	Plot heating rates relative error over the Earth's map
plot_collisions	Plot collission frequencies vertical profile
plot_collisions_contr	Plot contribution of error of each variable to collision
	frequencies calculation in vertical profile
plot_collisions_error	Plot collission frequencies error vertical profile
plot_collisions_plus_error	Plot collission frequencies vertical profile, including error
plot_collisions_rel_error	Plot collission frequencies vertical profile, relative Error
plot_conductivities	Plot conductivities vertical profile
plot_conductivities_contr	Plot contribution of error of each variable to conductivities
	calculation in vertical profile
plot_conductivities_error	Plot conductivities error vertical profile
plot_conductivities_plus_error	Plot conductivities vertical profile, including error
plot_conductivities_rel_error	Plot conductivities vertical profile, relative Error

plot_cross_sections	Plot cross sections vertical profile
plot_csections_contr	Plot contribution of error of each variable to cross sections
	calculation in vertical profile
plot_csections_error	Plot cross sections error vertical profile
plot_csections_plus_error	Plot cross sections vertical profile, including error
plot_csections_rel_error	Plot cross sections vertical profile, relative Error
plot_currents	Plot currents vertical profile
plot_currents_contr	Plot contribution of error of each variable to currents
	calculation in vertical profile
plot_currents_error	Plot currents error vertical profile
plot_currents_plus_error	Plot currents vertical profile, including error
plot_currents_rel_error	Plot currents vertical profile, relative Error
plot_heating_rates	Plot heating rates vertical profile
plot_heating_rates_contr	Plot contribution of error of each variable to heating rates
	calculation in vertical profile
plot_heating_rates_error	Plot heating rates error vertical profile
plot_heating_rates_plus_error	Plot heating rates vertical profile, including error
plot_heating_rates_rel_error	Plot heating rates vertical profile, relative Error

Table S9: Routines of the daedalusmase_error_propagation

1.4 Package daedalusmase_interpolation

daedalusmase_interpolation	
	inout
Routine Name	Description
write	Function to save interpolation results to netCDF output file
model	Model class handles basic IO of the Model Data extracting
	grid quantities and variables as selected by the user to be
	used in the interpolation.
model.readVar	readVar is model class function used to read variable for
	interpolation of TIEGCM input
model.readGrid	readGrid is model class function used to read grid definition
	variables of TIEGCM grid
orbit	Orbit class handles basic IO of Daedalus' orbit allocating
	arrays for the spatial components
orbit.createorbit	Orbit class function reads the orbit definition variables
	supportfunctions
first_order_drivative	Function to calculate first order Derivative
second_order_mixed_derivative	Function to calculate second order mixed derivative
third_order_mixed_derivative	Function to calculate second order mixed derivative
euclidian_distance	to calculate EuclidianDistace between two points in geodetic
	coordinates
geod_lat2geo_lat	Calculate geocentric latitude from geodetic latitude
	according to WGS84
local	Find the local neighbors of a specific component in a non
	equally spaced array such as the pressure levels in the
	TIEGCM
interpolationmase_mainfunc	
runinterpolator	This function begins the execution of the selected
	interpolation scheme
trilinearinterpolation	This function performs Trilinear interpolation
tricubicsplineInterpolation	This function performs Tricubic interpolation
idwinterpolation	This function performs Inverse Distanse Weight interpolation

Table S10: Routines of the daedalusmase_interpolation

1.5 Package daedalusmase_coverage_calculator

daedalusmase_coverage_calculator	
Routine Name	Description
AddMagneticCoordinates	Adds magnetic coordinates information to a csv orbit file.
set_OrbitFilesPath	Defines another path than the default
	"//Sample_Data/orbital_data/"
set_CoverageResultsFilesPath	Defines another path than the default
	"//Sample_Data/tiegcm_data/"
set_GeomagneticIndicesFilesPath	Defines another path than the default
	"//Sample_Data/geomagnetic_indices/"
readGeomagneticIndices	Reads the Geomagnetic kp Indices from text files and stores
	them in a dictionary.
CreateNewBin	Defines a new Bin according to the specified ranges.
CalculateCoverage	Reads an CSV orbit-file and for each position of the satellite
	calculates how much time the satellite spends inside each bin.
	These coverage-results are stored in a file for later usage.
LoadCoverageResults	Loads a coverage-results file and stores the information in
	the Bins.
PlotCoverage_Bars	Plots the Bins as vertical bars. The altitude is at the Vertical
	Axis. Kp index and Magnetic Local Time is at the Horizontal
	Axis. The Bins are colored and labeled according to the
	time the satellite spends inside them. One plot per Magnetic
	Latitude range is created.
PlotCoverage_Bars_GroupedByRegio	Plots the Bins as vertical bars grouped by user-specified
	regions. The altitude is at the Vertical Axis. Kp index and
	Magnetic Local Time is at the Horizontal Axis. The Bins
	are colored and labeled according to the time the satellite
	spends inside them. One plot per Magnetic Latitude range is
DistCovers on DalarChart	Created.
PlotCoverage_PolarChart	Magnetic Letitude and the Area represent Magnetic Lecel
	Time
PlotOrbit KnSpottor	Plots all satellite positions as points colored by Kn index
1 10101011_XpScatter	The Magnetic Latitude is at Vertical Axis and Magnetic
	Local Time is at the Horizontal Axis
PlotOrbit Heatman	Plots the satellite positions as heatman. Altitude is at the
r lotoron_reatinap	Vertical Axis and Magnetic I atitude at the Horizontal Axis
	The color represents the time spent at each area
	The color represents the time spent at each area.

Table S11: Routines of the daedalusmase_coverage_calculator

1.6 Package daedalusmase_global_statistics

daedalusmase_global_statistics	
Routine Name	Description
calc_stats_for_orbit	Reads the orbit files and fills the Bins with values for each
	variable. It stores the result in a netCDF file.
calc_stats_for_tiegcm	Reads the TIEGCM files and fills the Bins with values for
	each variable. It stores the result in netCDF files.
load_results	Reads the calculation results and fills with data the
	corresponding Bins.
plot_variable	Creates plots of a variable in relation to Magnetic coordinates
	and Altitude.
plot_variable_KpSeparated	Creates plots of a variable in relation to Magnetic coordinates
	and Altitude, with sub-plots for low and high Kp.
plot_ColorSpread_KpSeparated	Creates several sub-plots, according to Kp-index and
	Altitude. Each sub-plot is a colored surface of Magnetic
	Latitude against Magnetic Local Time. Color represents the
	values of the variable.
plot_distributions	Plots the distribution of the values of the Variable. The
	function also tries to find a curve to fit the distribution.
plot_comparison	Loads two result-files and plots a bar-chart comparing mean
	values of each bin. Useful for comparing the results of an
	orbit to those of tiegcm.
plot_PDFperSubBin	Loads two result-files and plots Probability Densities of a
	variable at the same chart.
execute_stat_test	Loads two result-files and executes several statistical tests (Z-
	test, Wilcoxon, scipy-ranksums, mannwhitneyu) in order to
	compare them. The results are printed as text on the screen.

Table S12: Routines of the daedalusmase_global_statistics

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