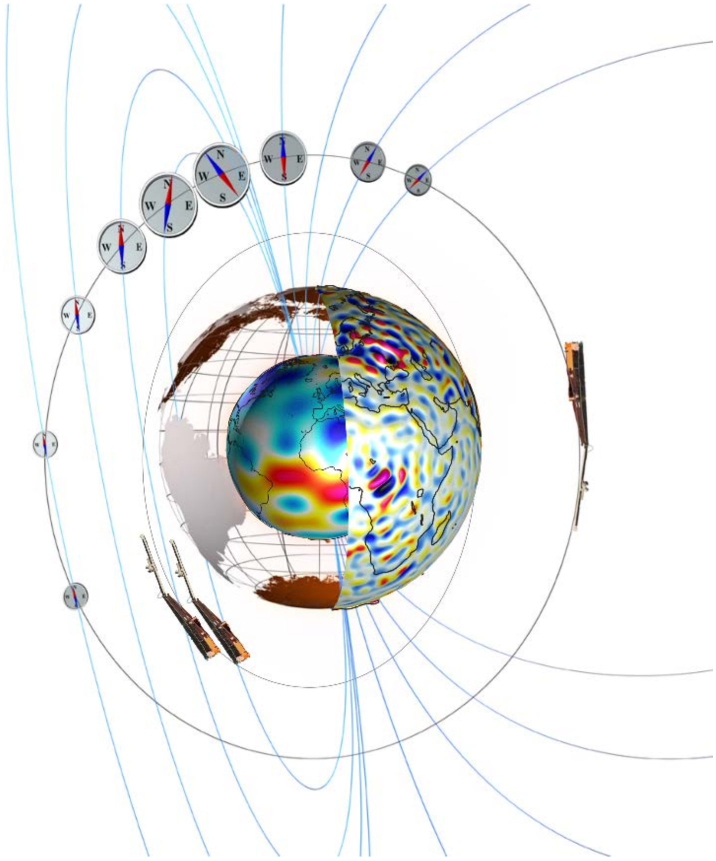
Data, Innovation, and Science Cluster

Swarm Ion Temperature Estimate Product Definition



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Prepared:

Levan Lomidze Date 15 Apr 2021

Project Scientist

Approved:

Johnathan Burchill Date 15 Apr 2021

Project Manager

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1 Introduction

The document describes the Swarm Ion temperature data product.

1.1 Scope and applicability

This document is a deliverable of the Swarm Ion Temperature Estimation project [AD-1].

2 Applicable and Reference Documentation

2.1 Applicable Documents

The following documents are applicable to the definitions within this document.

[AD-1] SW-CO-DTU-GS-123, Rev: 1A 2019-10-08, Subcontract SITE 2.3.

2.2 Reference Documents

The following documents contain supporting and background information to be taken into account during the activities specified within this document.

[RD-1] Schunk (1996), STEP: Handbook of Ionospheric Models, Utah State Univ., Logan, Utah.

[RD-2] Huba, J.D., G. Joyce, and J.A. Fedder (2000), Sami2 is Another Model of the Ionosphere (SAMI2): A new low-latitude ionosphere model, J. Geophys. Res., 105, 23,035.

[RD-3] SW-RN-IRF-GS-005, Extended Set of Swarm Langmuir Probe Data

[RD-4] Lomidze, L., Knudsen, D. J., Burchill, J., Kouznetsov, A., & Buchert, S. C. (2018). Calibration and validation of Swarm plasma densities and electron temperatures using ground-based radars and satellite radio occultation measurements. Radio Science, 53.

[RD-5] Picone, J. M., Hedin, A. E., Drob, D. P., & Aikin, A. C. (2002). NRLMSISE-00 empirical model of the atmos-phere: Statistical comparisons and scientific issues. Journal of Geophysical Research, 107(A12), 1468.

[RD-6] Drob, D. P., et al. (2015), An update to the Horizontal Wind Model (HWM): The quiet time thermosphere, Earth and Space Science, 2, doi:10.1002/2014EA000089.

[RD-7] SW-RN-UoC-GS-004, EFI TII Cross-Track Flow Data Release Notes

[RD-8] Weimer, D. R. (2005). Improved ionospheric electrodynamic models and application to calculating Joule heating rates. Journal of Geophysical Research, 110, A05306.

[RD-9] SW-TN-UoC-GS-002, Input data and model validation

2.3 Abbreviations

A list of acronyms and abbreviations used by Swarm partners can be found here. Any acronyms or abbreviations not found on the online list but used in this document can be found below.

Acronym ***or abbreviation***	***Description***
NRLMSISE	Naval Research Laboratory Mass Spectrometer and Incoherent Scatter Radar Extended

HWM	Horizontal Wind Model
UoC	University of Calgary
SITE	Swarm Ion Temperature Estimation

3 Product Description

3.1 Outline

Ionospheric ion temperature is one of the key parameters for understanding many physical processes in the ionosphere-thermosphere system. The Swarm ion temperature product is an ion temperature estimate in the upper F region ionosphere along the orbits of Swarm satellites. Because O^+ is the major ion species at Swarm altitudes, the ion temperature here refers to the temperature of O^+ ions. The temperature estimation is performed using a data-driven model of the ion energy balance. At low and middle latitudes the model assumes a thermal electron gas to be the main heat source, transferring heat to ions through elastic Coulomb collisions. The O^+ Ion cooling occurs via resonant charge transfer collisions with the parent O and H, and by elastic collisions with other atoms and molecules. At high latitudes, an ion frictional heating is also taken into account.

3.2 Approach

The ion temperature model uses a simplified version of ion energy equation:

$$Q_{ie} + F_{in} = L_{in} \quad (1).$$

The terms retained from the complete ion temperature equation [RD-1, RD-2] are electron-ion and ion-neutral heat transfers, and ion frictional heating. The model assumes steady-state conditions, and the heating/cooling processes due to thermal conduction, heat advection, and heat convection, as well as ion-ion heat exchange are omitted.

$$Q_{ie} = \frac{7.7\times10^{-6} n_e n_i}{A_i T_e^{1.5}} (T_e - T_i) \quad \text{eV cm}^{-3}\ \text{sec}^{-1}$$

$$L_{in} = \sum_q \frac{3k_B n_i m_i}{m_i + m_q} \nu_{iq} \left(T_i - T_q\right) \quad \text{eV cm}^{-3}\ \text{sec}^{-1}$$

$$F_{in} = \sum_q \frac{n_i m_i}{m_i + m_q} \nu_{iq} m_q \left(\mathbf{v}_i - \mathbf{v}_q\right)^2 \quad \text{eV cm}^{-3}\ \text{sec}^{-1}$$

where q and j denote summations over neutrals and ions, respectively. T_i and n_i are the temperature and density of ion type "i", $\mathbf{v}_i$ is the ion velocity, Q_{ie} and L_{in} are the ion heating/cooling rates due to collisions between ions and electrons and ions and neutrals, respectively, F_{in} is the ion frictional heating due to the motion of ions relative to the neutrals. $\nu_{iq} = \nu_{iq}\left(n_q, T_q, T_i\right)$ denotes ion-neutral collision frequency and depends on the corresponding neutral density, and for O^+-O and O^+-H collisions also on neutral and ion temperatures. $\mathbf{v}_q$ is the neutral wind velocity, and A_i is the mass of ion "i" in atomic mass units.

Schematically, the Swarm ion temperature estimation (SITE) concept employed in the model is shown in Figure 1.

3.3 Inputs

The ion temperature model inputs are Swarm LP observations of electron density and temperature [RD-3, RD-4], and neutral composition and temperature, which are calculated using the NRLMSISE-00 model [RD-5]. At high magnetic latitudes (≥44°) the ion frictional heating term is also included. The horizontal components of neutral wind velocity are computed using the HWM14 empirical wind model [RD-6]. The high-latitude ion drifts are obtained from the Swarm TII measurements [RD-7] when such data are available. An alternative ion temperature product, based on the Weimer 2005 empirical convection electric field model [RD-8], is also provided in order to expand the temperature coverage outside the TII operations. The two estimates are identical at low and middle latitudes.

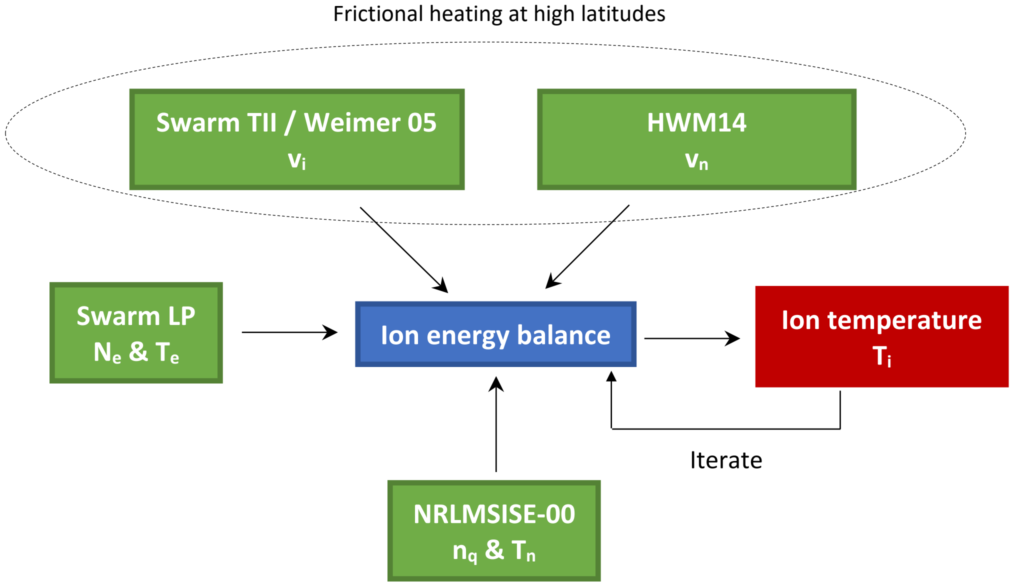

Figure 1: Schematic view of the ion temperature estimation approach.

3.4 File format

Daily data of Ion temperature estimates are provided in Common Data Format files (CDF) at 2Hz resolution with the following naming convention:

SW_OPER_EFIxTIE_2__yyyymmddThhmmss_YYYYMMDDTHHMMSS

where

- X is the satellite letter, one of A, B or C;
- YYYYMMDDTHHMMSS marks the beginning of the interval;
- yyyymmddThhmmss marks the end of the interval.

Table 1. Swarm ion temperature product definition

Product Identifier	SW_OPER_EFIxTIE
Definition	Estimated ion temperatures along the Swarm satellite orbits
Input Data	SW_EXTD_EFIX_LP, SW_EXPT_EFIX_TCT02, empirical models: NRLMSISE-00, HWM14, Weimer 2005
Input Time Span	1 day
Spatial representation	Estimates along the Swarm satellite's orbit
Time representation	Time series in every 0.5 seconds
Units	Kelvin
Resolution	1 K
Uncertainty	~ 20 %
Quality Indicator	Flagbit number
Data Volume	~8 MB (daily file)
Data Format	CDF
Output Data	CDF file with time series
Output Time Span	1 day
Update Rate	two months
Latency	6 minutes
Notes	

The data fields are as follows:

Table 2. Swarm Ion temperature CDF fields

Variable	CDF Type	Unit	Note
Timestamp	CDF_EPOCH	ms	Milliseconds since Jan 1, UTC
Latitude	CDF_REAL8	deg	Geodetic latitude
Longitude	CDF_REAL8	deg	Geodetic longitude
Radius	CDF_REAL8	m	Geocentric radius
Height	CDF_REAL8	m	Height above WGS84 reference ellipsoid
QDLatitude	CDF_REAL8	deg	Quasi-dipole magnetic latitude
MLT	CDF_REAL8	hour	Magnetic local time
Ti_meas_drift	CDF_REAL8	K	Ion temperature estimated using Swarm TII drift at high latitudes
Ti_model_drift	CDF_REAL8	K	Ion temperature estimated using Weimer 2005 model drifts at high latitudes
Te_adj_LP	CDF_REAL8	K	Corrected Swarm LP electron temperature
Tn_msis	CDF_REAL8	K	Neutral temperature from NRLMSISE-00 model
Flag_ti_meas	CDF_UINT1	N/A	Bitwise flag for 'Ti_meas_drift' identifying included inputs and processes, see Section 3.5
Flag_ti_model	CDF_UINT1	N/A	Bitwise flag for 'Ti_model_drift' identifying included inputs and processes, see Section 3.5

3.5 Data field description

Two versions of the ion temperature are included in the CDF files. Their values are identical at low and middle latitudes, and differ only at high magnetic latitudes (≥44°). '*Ti_meas_drift*' is an ion temperature where at high latitudes the ion frictional heating is calculated using Swarm TII ion drift measurements. In '*Ti_model_drift'* the frictional heating is computed using the Weimer 2005 model.

The negative values (equal to -9999) of ion temperature indicate that it could not be determined either because of unavailability of key model input data or the resulting temperature value was unphysical, such as cases inconsistent with the assumptions in the ion energy balance equation.

‘*Te_adj_LP*’ is the corrected Swarm LP electron temperature [RD-4], typically from the high-gain probe. When the high-gain probe data are not available or usable in the SITE model, the low-gain probe is used if possible. The data flag identifies the used probe.

‘*Flag_ti_meas*’ and ‘*Flag_ti_model*’ identify inclusion (Bit0 = 1) or omission (Bit0 = 0) of high-latitude frictional heating, and identify the use of high-gain (Bit1=0) or low-gain (Bit1=1) probe data of electron temperature. Bit2 specifies whether the ion temperature data are available (Bit2=1) or set to -9999 (Bit2=0).

Table 3. Description of flags: *Flag_ti_meas* and *Flag_ti_mode*

Bit number	Value	Description
0	0/1	High-latitude frictional heating omitted/included
1	0/1	Used is high-gain/low-gain LP T_e
2	0/1	Estimated ion temperature not available(= −9999)/available

3.6 Validation

For input data and model validation refer to RD-9.