

1 Changes to the Joule heating calculation

These changes were done by Art Richmond and Astrid Maute.

Changes were included in tiegcm1-8tune2 (July 29 2005).

References:

1. general textbook or e.g. Lu et al. JGR Vol. 100, No, A10, pp. 19,643.
2. Schunk and Nagy; Ionospheres Physics, Plasma Physics, and Chemistry; Cambridge University Press; 2000.

The calculation of the Joule heating was corrected. Therefore, the following four files were modified: dynamics.F, fields.F, lamdas.F, and qjoule.F.

In the source file dynamics.F the call to calculate ion drag (call lamdas), and the calls to calculate joule heating (call qjoule_tn and qjoule_ti) were modified. The field λ_1 (lam1) was added to the source file fields.F, and is calculated in subroutine lamdas.

The joule heatin (qjoule.F) g is calculated by

$$\mathbf{J}_\perp \cdot \mathbf{E}' = \sigma_P \mathbf{E}'^2 = \sigma_P (\mathbf{E} + \mathbf{u} \times \mathbf{B})^2 \quad (1)$$

with \mathbf{J}_\perp is the component of the current perpendicular to the geomagnetic field \mathbf{B} . We assume that the energy transfer $\mathbf{J} \cdot \mathbf{E}$ is almost equal to $\mathbf{J}_\perp \cdot \mathbf{E}$ since the electric field along the geomagnetic field \mathbf{B} is much smaller than the perpendicular component. The electric field in the frame of neutral winds \mathbf{u} is \mathbf{E}' . The Pedersen conductivity is denoted by σ_P .

The square of the electric field \mathbf{E}' can be written as

$$\mathbf{E}'^2 = B^2 \left(\frac{\mathbf{E} \times \mathbf{B}}{B^2} - \mathbf{u}_\perp \right)^2 \quad (2)$$

Therefore, the Joule heating in eq. 1 can be written as

$$\mathbf{J}_\perp \cdot \mathbf{E}' = \sigma_P B^2 \left(\frac{\mathbf{E} \times \mathbf{B}}{B^2} - \mathbf{u}_\perp \right)^2 = \sigma_P B^2 (\mathbf{u}_{E \times B} - \mathbf{u}_\perp)^2 \quad (3)$$

with $\frac{\mathbf{E} \times \mathbf{B}}{B^2}$ drift velocity substituted by $\mathbf{u}_{E \times B}$. In the TI(M)EGCM source code the three components of $\mathbf{u}_{E \times B}$ are called ui, vi and wi. The ion drag coefficient λ_1 is calculated in subroutine lamdas (lamdas.F)

$$\lambda_1 = \frac{\sigma_P B^2}{\rho} \quad (4)$$

with ρ the mass density. A reference to the above derivation can be found in many textbook or e.g. Lu et al.; JGR; Vol. 100; No, A10; pp. 19,643.

The Joule heating is then added to the calculation of the ion T_i (seti.F) and neutral T_n (dt.F) temperature. For this part, we refer to the book of Schunk and Nagy; Ionospheres Physics, Plasma Physics, and Chemistry; Cambridge University Press; 2000, although there might be a better reference, but we didn't do an intensive search. Eq. (5.48d) of Schunk and Nagy, which will be repeated here, is part of the transport equations.

$$0 = \sum_n \frac{\nu_{in}}{m_i + m_n} [3k(T_n - T_i) + m_n(\mathbf{u}_i - \mathbf{u})^2] \quad (5)$$

This equation assumes that we have monotomic particles, such that we only have kinetic energy and no rotational energy. In the above equation the collision frequency ν_{in} is used instead of the ion drag coefficients in eq. 3, since it also uses the velocity difference $\mathbf{u}_i - \mathbf{u}_n$ instead of the $\mathbf{E} \times \mathbf{B}$ drift velocity. Note that \mathbf{u}_i is the ion drift velocity and not the $\mathbf{E} \times \mathbf{B}$ drift velocity. In the heat equation for the neutrals there is no explicit term for the energy transfer from ions to neutrals, therefore the whole term of the Joule heating $Q_j(T_n)$ is included.

$$Q_j(T_n) = \lambda_1(\mathbf{u}_{E \times B} - \mathbf{u}_\perp)^2 \quad (6)$$

According to the equation in Schunk and Nagy, only a part of the energy contributes to the ion temperature T_i .

$$Q_j(T_i) = \frac{m_n}{m_i + m_n} \lambda_1(\mathbf{u}_{E \times B} - \mathbf{u}_\perp)^2 \quad (7)$$

with m_n and m_i the mean molecular weight of neutrals and ions. Eq. 7 is valid above 100 km where the contribution from the electron neutral collisions to the Pedersen conductivity σ_P is small. Only at around 75 km we would have to consider also the Joule heating part which goes into the electron temperature. However, since the contribution from the electrons is small, we can justify using the λ_1 which is based on the Pedersen conductivity σ_P including the electron neutral collision contribution.

The values calculated in TIEGCM are actually energy rates per unit mass, e.g. with the units [ergs/s/g].

Note that we also include the vertical velocity component from the neutral wind and the $\mathbf{E} \times \mathbf{B}$ drift velocity.