Total Ionospheric Conductance: Summation of Sources

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Abstract

Conductivity of the ionosphere allows the complex system of magnetospheric currents to flow through. Conductivity is governed by several factors including electron density and temperature, whose influence is highly dynamic during geomagnetic storm events. Thus, it is a crucial parameter that must be determined for space weather modeling to specify the coupling between the magnetosphere, ionosphere and thermosphere systems. Major sources of ionospheric conductivity are solar EUV and particle precipitation which includes Diffuse (Diff.), Monoenergetic (ME) and Broadband (BB) precipitations. Conductance Σ is the height integrated version of conductivity. Empirically, total ionospheric conductance (Hall and Pedersen) is known to be the root sum square of individual conductance terms [Wallis and Budzinski, 1981], considering that conductivity resulting from different processes are not linearly additive and corresponding ionization rates shall be added at each altitude and then integrated over the desired altitude range. With the inclusion of the less energetic broadband precipitation that was found to cause ionization in the bottom-side F region, the expression for the total ionospheric conductance was modified by the linear addition of the contribution of the broadband precipitation to the total Hall and Pedersen conductance[Zhang et al., 2015].In this study, using a 3-dimensional global physics based model GITM (Global Ionosphere Thermosphere Model), the validity of this combination of vector and linear addition of individual source terms to the total ionospheric conductance is examined and the more accurate expression for the summation of sources contributing to the total conductance is quantified. GITM is employed to calculate the Hall and Pedersen conductance using the average energy, potential and energy flux for each of the sources of conductance. Several scenarios are simulated where the different sources of precipitation are paired with solar EUV radiation, and the total conductance is obtained. Linear and vector summation of conductance resulting from combinations of sources and individual sources indicate that the contribution of broadband precipitation to the total conductance also follows vector addition. To quantify the result that the total conductance is the vector sum of individual sources, error histograms are plotted and a set of metrics including RMSE, mean error, standard deviation, correlation coefficient and fractional error are enumerated for both linear and vector summation of individual sources to produce the total conductance.

Total Ionospheric Conductance: Summation of Sources

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$$\Sigma_{Total} = \sqrt{(\Sigma^2_{\mathrm{EUV}} + \Sigma^2_{\mathrm{Diff.}} + \Sigma^2_{\mathrm{ME}})} + \Sigma_{\mathrm{BB}}$$

OR

$$\Sigma_{Total} = \sqrt{(\Sigma^2_{\mathrm{EUV}} + \Sigma^2_{\mathrm{Diff.}} + \Sigma^2_{\mathrm{ME}}) + \Sigma^2_{\mathrm{BB}}}$$

- ***Conductive ionosphere*** acts as load on the complex system of magnetospheric currents to flow.
- Sources of ionospheric conductivity:
  - Solar EUV
  - Particle Precipitation
    - Diffuse (Diff.)
    - Monoenergetic (ME)
    - Broadband (BB)
- Conductance Σ is height integrated conductivity

$$\Sigma = \int_{h1}^{h2} \sigma dh$$

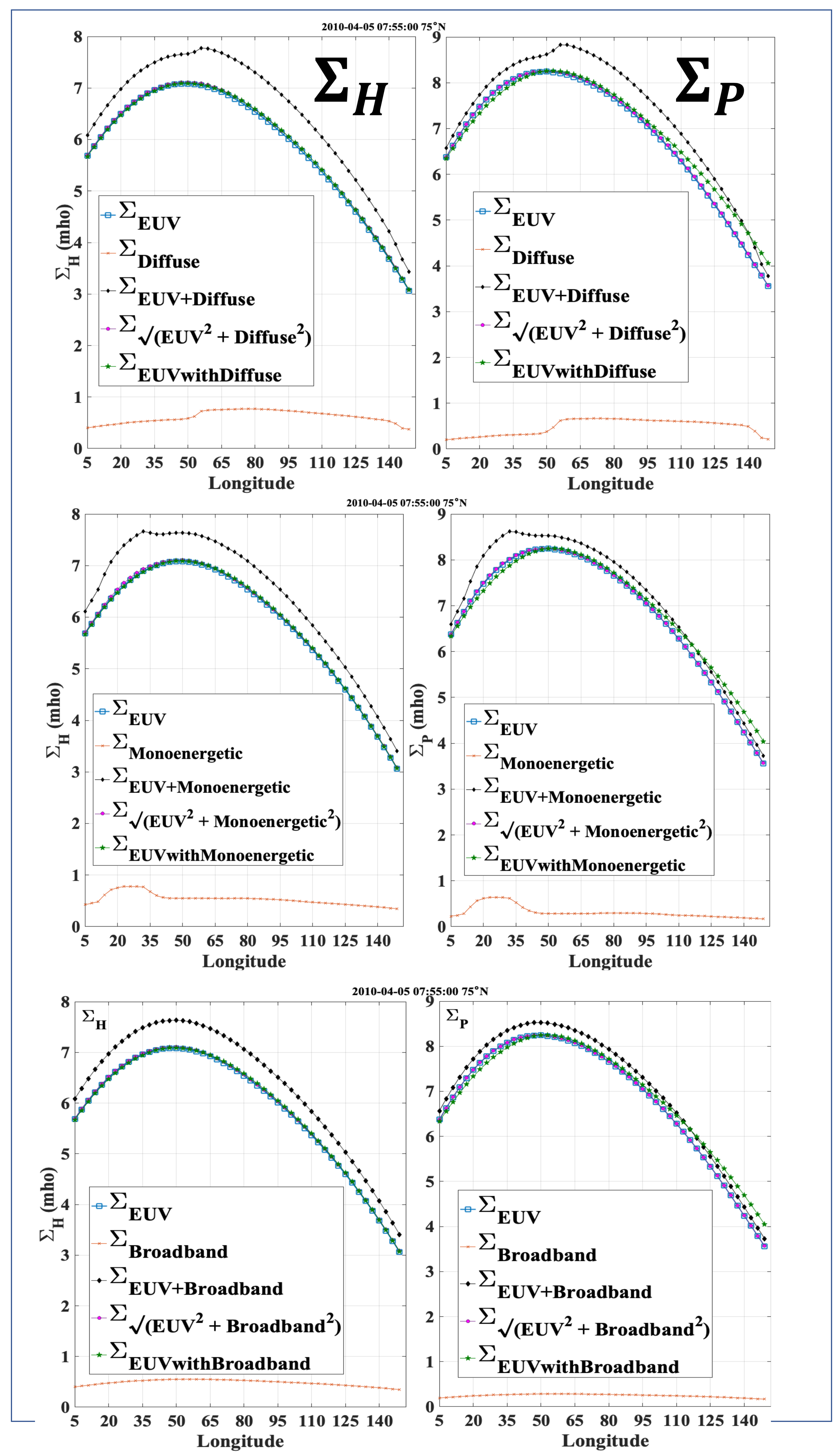
- Empirically, total ionospheric conductance (Hall and Pedersen) is found to be the root sum square of individual conductances
- Presence of less energetic broadband electron precipitation causes ionization in bottom-side F region
- But, can $\mathbf{\Sigma_{BB}}$ be linearly added to total conductance?

Global Ionosphere Thermosphere Model

- Solve ionosphere and thermosphere dynamics
- Physics-based Σ_H and Σ_P from Φ, ave. energy and E Flux

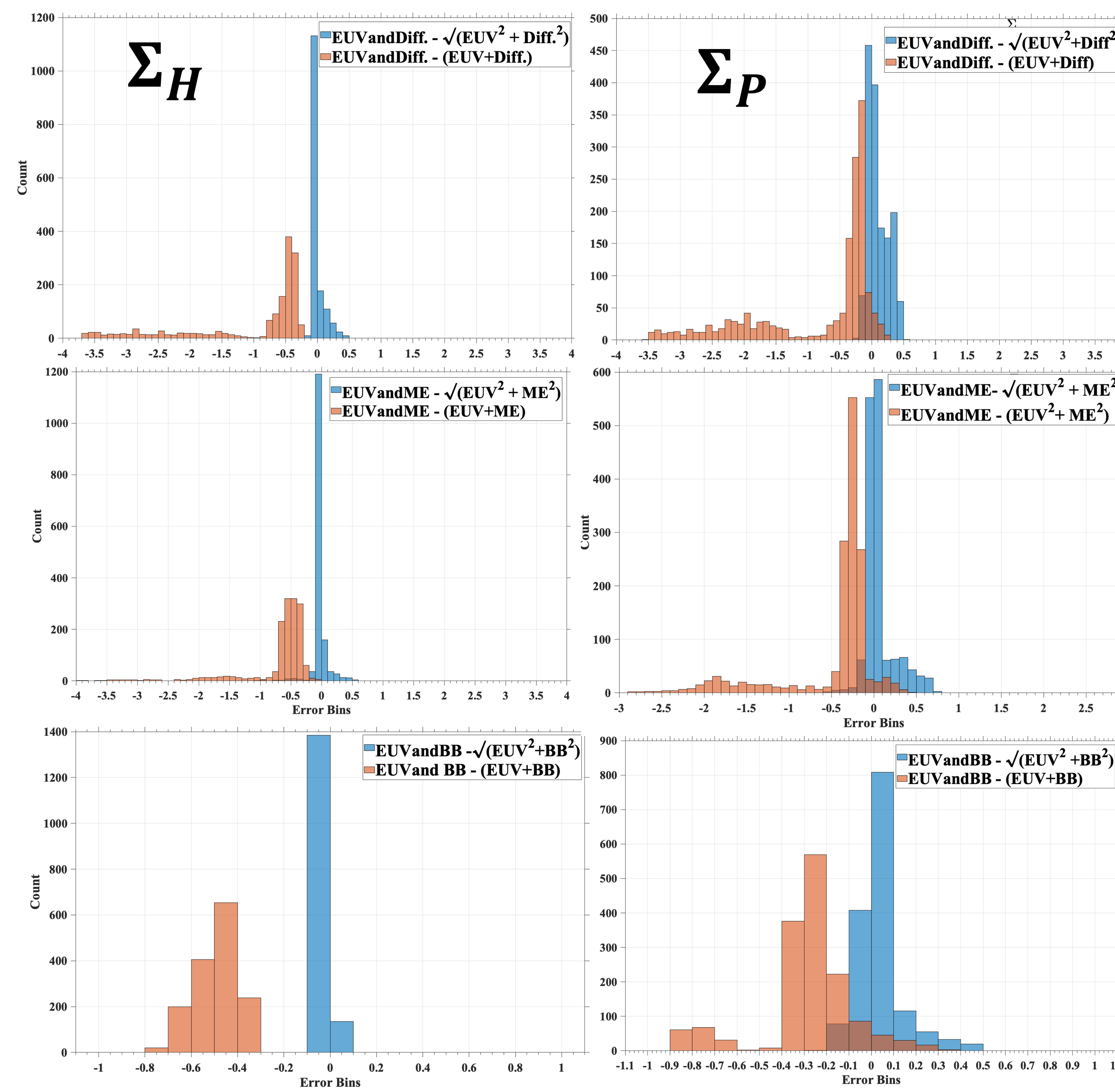
❑ GITM runs - 5 April 2010

1.EUV 2.Particle Precipitations 3.EUV&Diff. 4.EUV&ME 5.EUV&BB

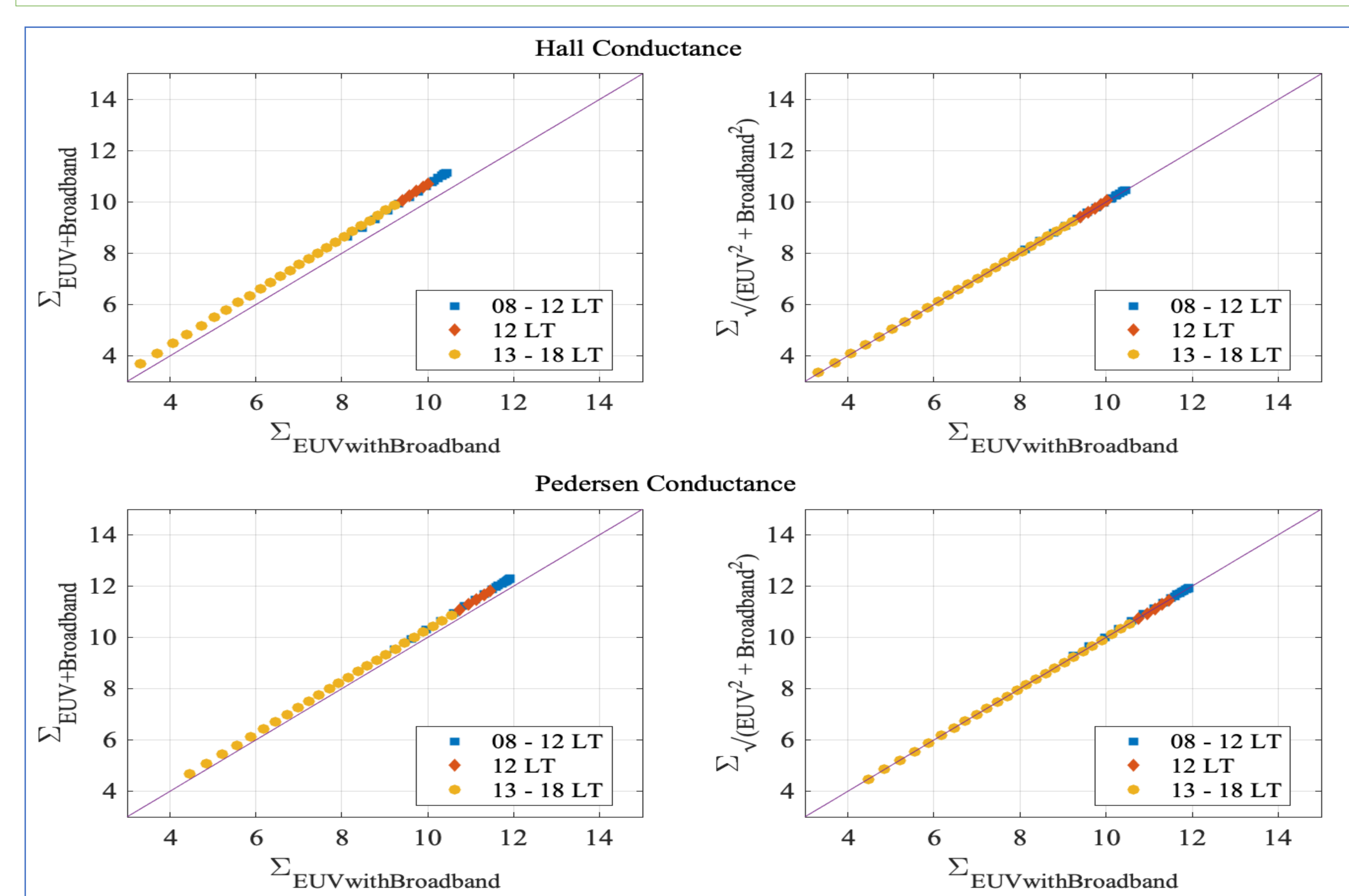


? Clearly, Σ_{Total} is not a linear sum.

? How well does the vector sum represent Σ_{Total}?



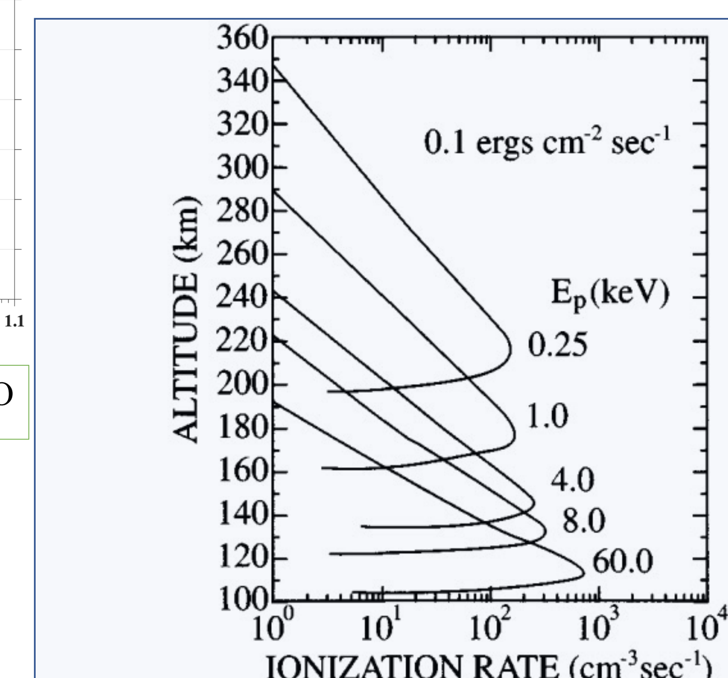
Histograms showing errors of both summations for all latitudes from 60-90^O



Linear and vector summation at 75^O N

Σ_H	Linear Sum			Vector Sum		
	Diff.	**ME**	**BB**	**Diff.**	**ME**	**BB**
RMSE	1.4495	0.9285	0.502	0.0897	0.1235	0.0259
ME	1.0510	0.7004	0.4921	-0.0098	0.0188	0.0220
$Std_{.Diff}$	0.7742	0.2360	0.0811	-0.0478	0.0049	0.0010
$Std_{.ratio}$	1.3476	1.1186	1.0410	0.9785	1.0025	1.0005
R	0.9702	0.9643	0.9998	0.9994	0.9981	1.0000
Fractional Error	23.59	15.635	8.5393	1.46	2.0792	0.4418

Σ_P	Linear Sum			Vector Sum		
	Diff.	**ME**	**BB**	**Diff.**	**ME**	**BB**
RMSE	1.2602	0.7377	0.3491	0.1866	0.1827	0.1076
ME	0.8066	0.4703	0.2810	-1.0751	-1.1113	-1.1019
$Std_{.Diff}$	0.7360	0.1277	0.0088	-0.0106	0.0170	0.0328
$Std_{.ratio}$	1.3263	1.0625	1.0043	0.9826	1.0083	1.0161
R	0.9706	0.9654	0.9949	0.9976	0.9965	0.9989
Fractional Error	17.48	10.4368	5.0007	2.5897	2.5853	1.5414



Calculated ionization rates due to precipitating, isotropic, monoenergetic proton fluxes with an energy flux of 0.1erg cm^{-2}s^{-1} (Schunk and Nagy, 2000)

Results

- Conductances resulting from different processes **do not add linearly**
- Vector sum shows lesser error
- Thus, $\mathbf{\Sigma_{Total}}$ **is the vector sum of ALL the sources.**

$$\Sigma_{Total} = \sqrt{(\Sigma^2_{\mathrm{EUV}} + \Sigma^2_{\mathrm{Diff.}} + \Sigma^2_{\mathrm{ME}} + \Sigma^2_{\mathrm{BB}})}$$

References:

Wallis&Budzinski, 1981; *Zhang et al.* JGR, 2015
Mukhopadyay et al., JGR 2022

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