A fast, parameterized model of upper atmospheric ionization rates, chemistry, and conductivity

(JGR, DOI: 10.1002/2015JA021146)

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Overview

GLobal AirglOW (GLOW) model

- Basics/Additions

Parameterized GLOW model and validation

- Economies

Impact in the larger community

GLobal AirglOW (GLOW) model

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Solomon et al., [1988]

- Two-stream electron transport code to calculate energy redistribution in the upper atmosphere due to
  - ❖ incident solar radiation and
  - ❖ auroral electrons

Two-stream code based on work of *Nagy and Banks*, [1970]

- Computes altitude profiles of
  - ❖ ionization rates,
  - ❖ electron and primary ion constituent densities, and
  - ❖ temperature
- 80-200 km altitude range

GLobal AirglOW (GLOW) model

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Solomon et al., [1988]

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- 80-200 km altitude range

Hereafter referred to as **GLOWfull**

GLOWfull

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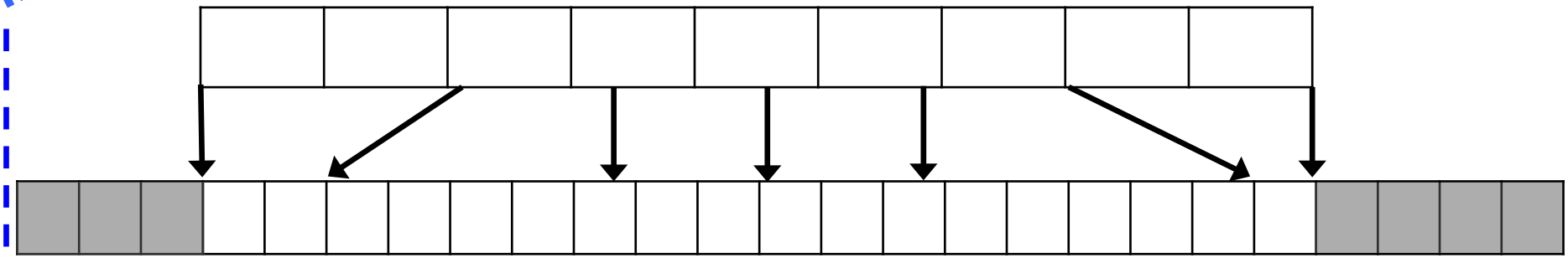
Boulder, Colorado

Input

Electron precipitation spectra



0.25 eV

48 keV

GLOWfull model energy grid

Two-stream transport code: elastic and inelastic collisions with O, N2, and O2; energy redistribution in 190-bin energy grid

+

3-D Nitric Oxide Empirical Model

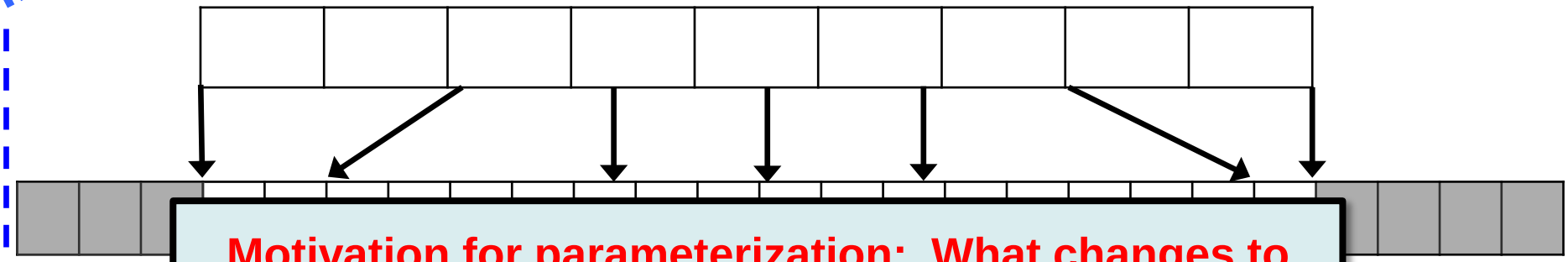
Output

Pedersen and Hall conductivities, electron impact and photoionization rates, ion/neutral/electron density profiles, temperature profiles

Input

Output

Electron precipitation spectra



Motivation for parameterization: What changes to this model would most directly benefit space weather research and the main consumers impacted by space weather?

Two-stream transport code: elastic and inelastic collisions with O, N2, and O2; energy redistribution in 190-bin energy grid

+

3-D Nitric Oxide Empirical Model

Pedersen and Hall conductivities, electron impact and photoionization rates, ion/neutral/electron density profiles, temperature profiles

Motivation

Desire:

Middle ground between GCMs and empirical models

- Computational efficiency
- High accuracy
- Complete specification of upper atmospheric ionization rates, chemistry, and conductivities

Facilitate analysis of large data sets

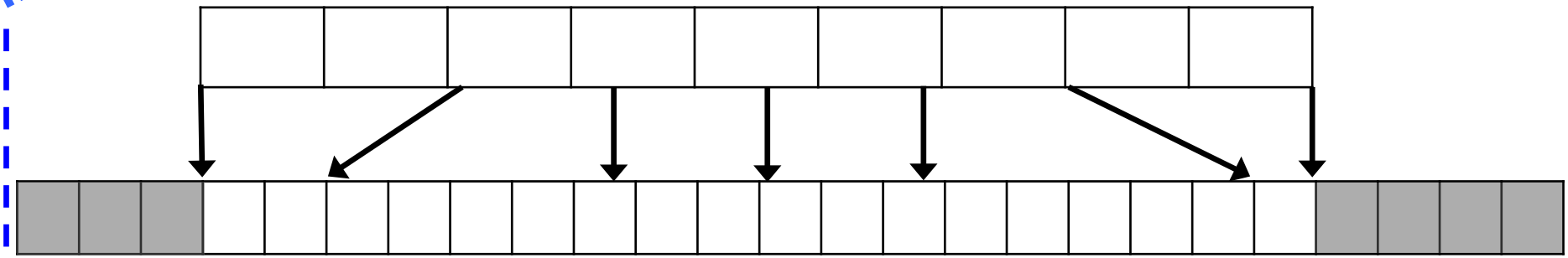
- COSMIC
- Forthcoming satellite missions (notably ICON and GOLD)

Parameterize Ionization!

Resulting model hereafter called **GLOWfast**

Input

Electron precipitation spectra



0.25 eV

48 keV

GLOWfast (with NOEM) model energy grid

Parameterizations:

Electron Impact Ionization -> *Fang et al.*, [2008, 2010]

Photoionization -> *Solomon and Qian.*, [2005]

Drastic computational improvement from parameterizing ionization calculation

Output

Pedersen and Hall conductivities, electron impact and photoionization rates, ion/neutral/electron density profiles, temperature profiles

Electron impact ionization parameterization

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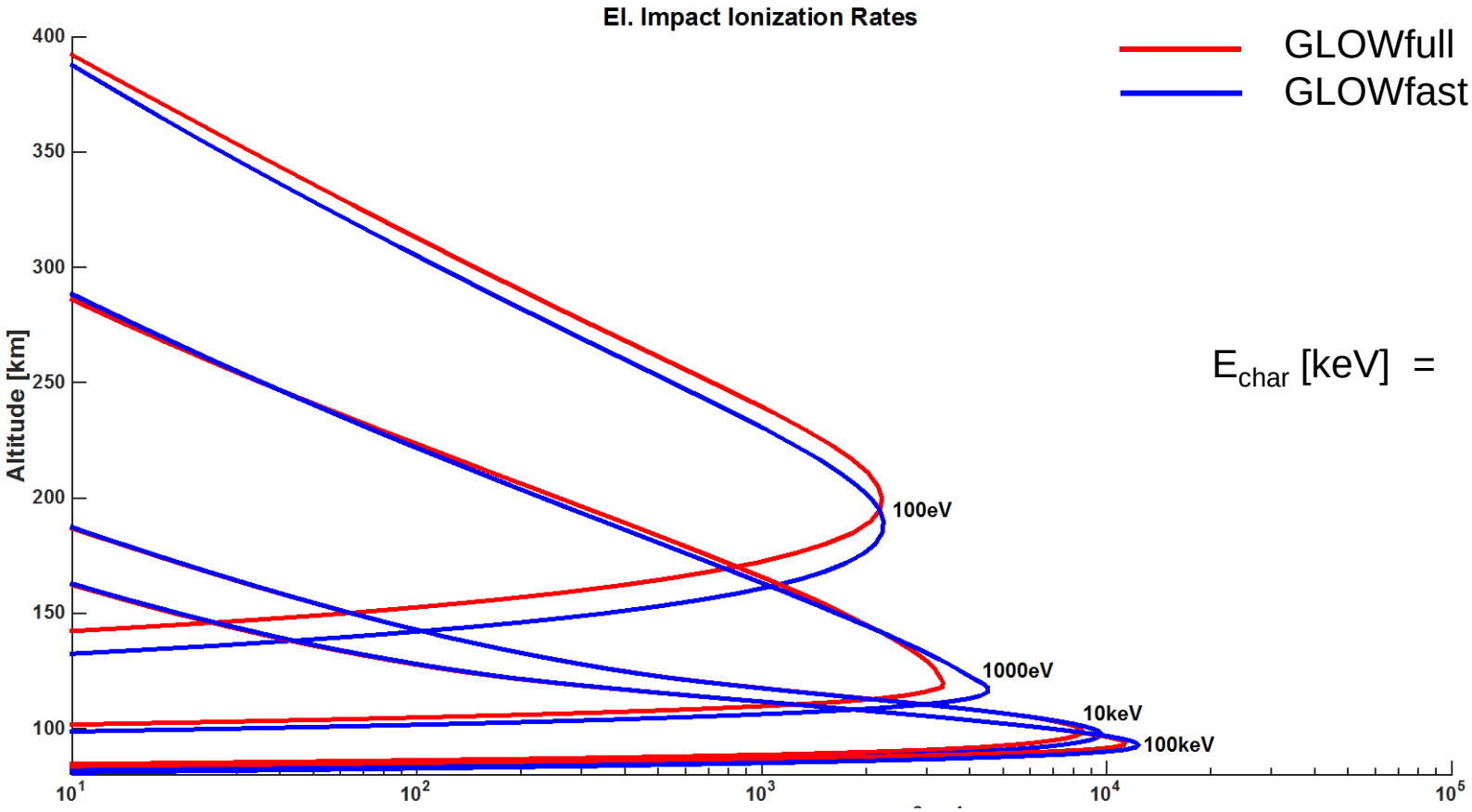
Boulder, Colorado



E_{char} [keV] = 0.1, 1, 10, 100

McGranaghan et al. [2015, JGR in press]

Photoionization parameterization

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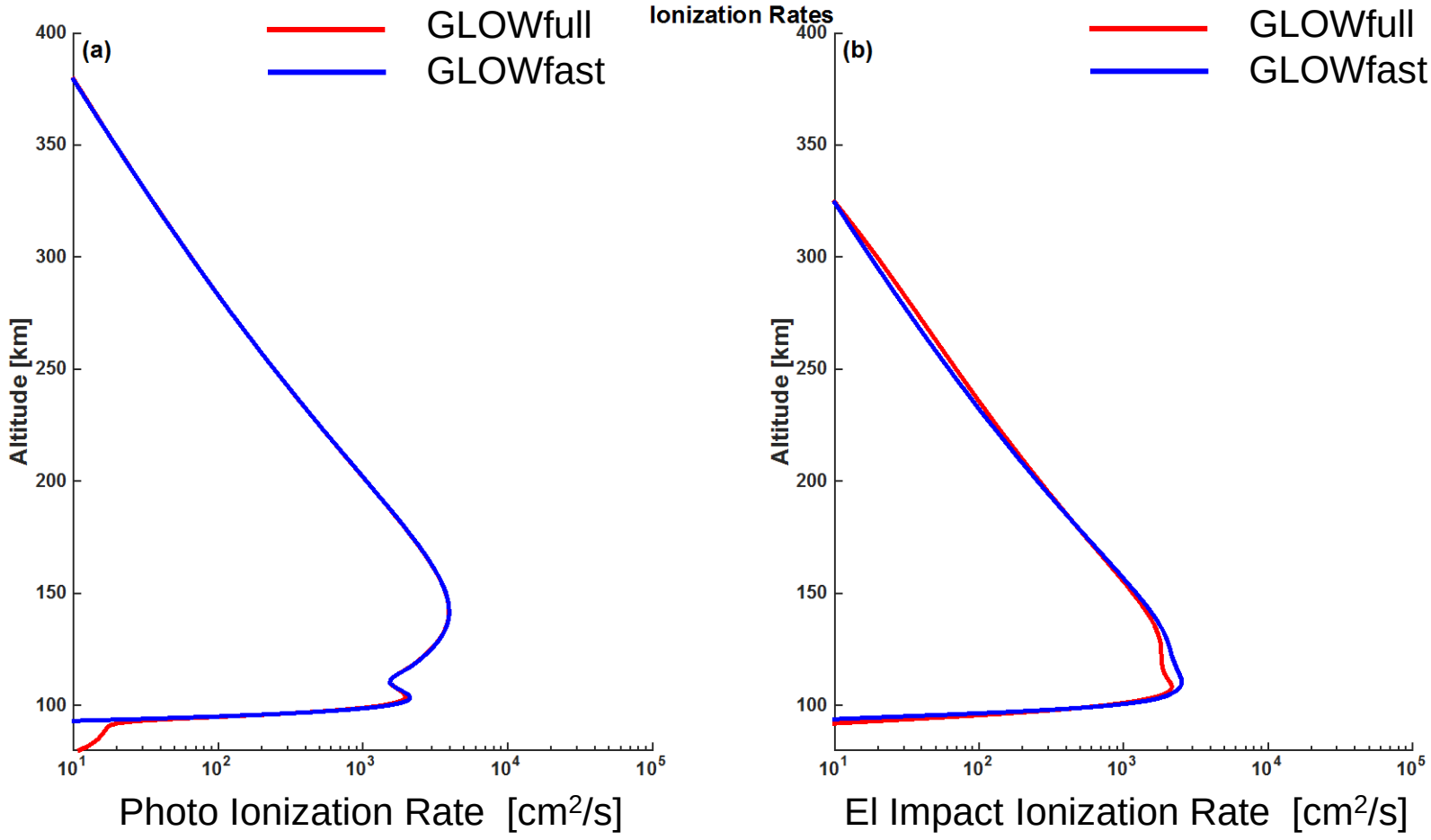
Boulder, Colorado



McGranaghan et al. [2015, JGR in press]

Variational Study (3024 Instances)

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		Comparison #		
		Auroral Ionization -Dominated	Solar Ionization -Dominated	Variational Study
Input Parameters	Units	1 (Figure 2)	2 (Figure 3)	3-3026 (Figures 4-7)
F10.7	sfu	50	70	[50 100 150]
Ap	nT	5	1	[5 20 40]
E_{char}	keV	variable	0	[0.5, 0.750, 1.0, 1.25, 1.50 1.75, 2.0, 3.0, 5.0, 7.50 10.0, 50.0, 75.0, 100.0]
Φ_0	erg $cm^{-2}s^{-1}$	1	1	1
Lat	deg	70	0	[60,70,80]
Long	deg	0	178	[0, 45, 90, 135, 180, 225, 270, 315]
SZA	deg	133.4	3.4	variable (determined indirectly by other inputs)

Electron impact ionization rate differences: 3024 test cases

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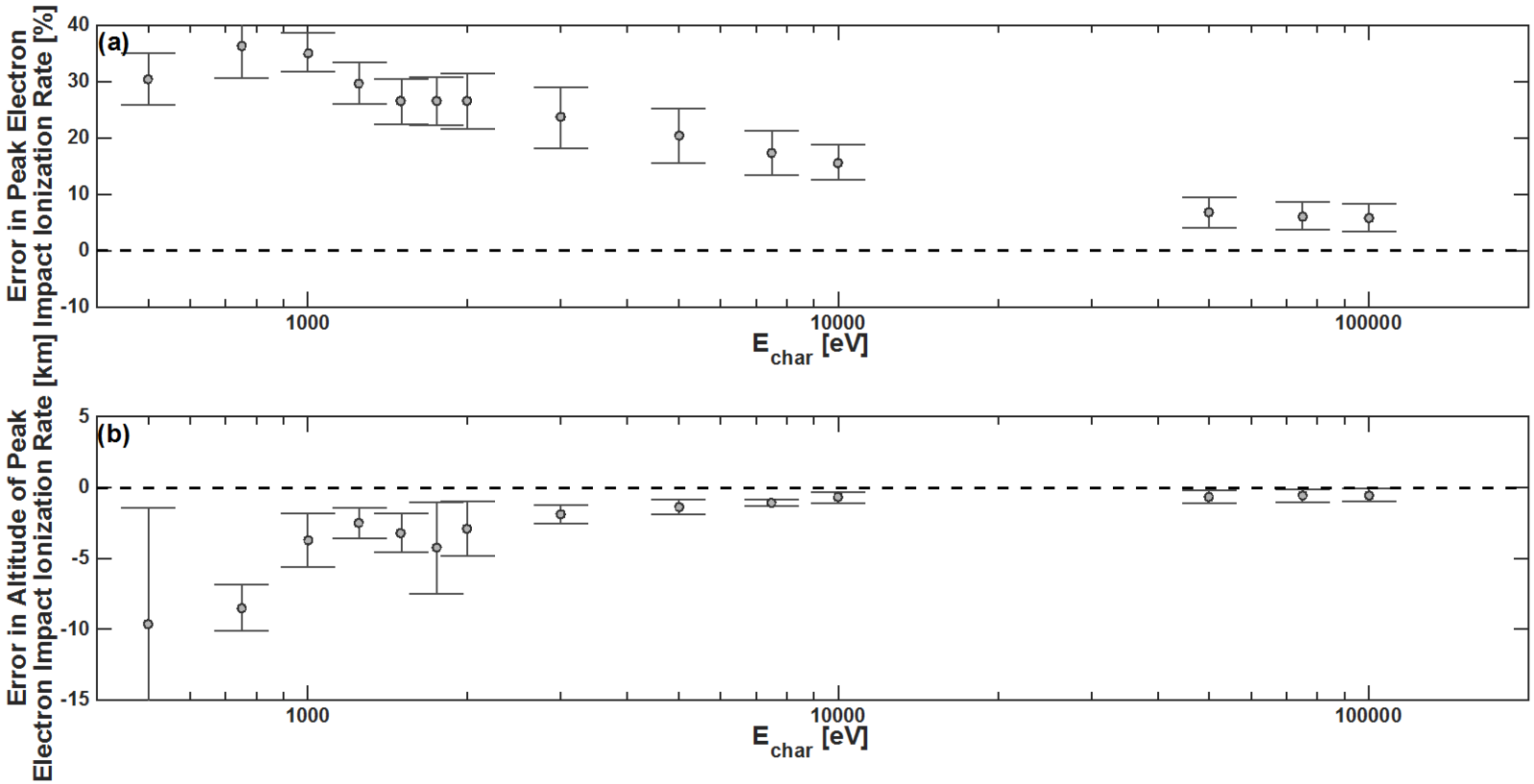
Boulder, Colorado

Percent Difference



McGranaghan et al. [2015, JGR in press]

Ion constituent densities differences: 3024 test cases

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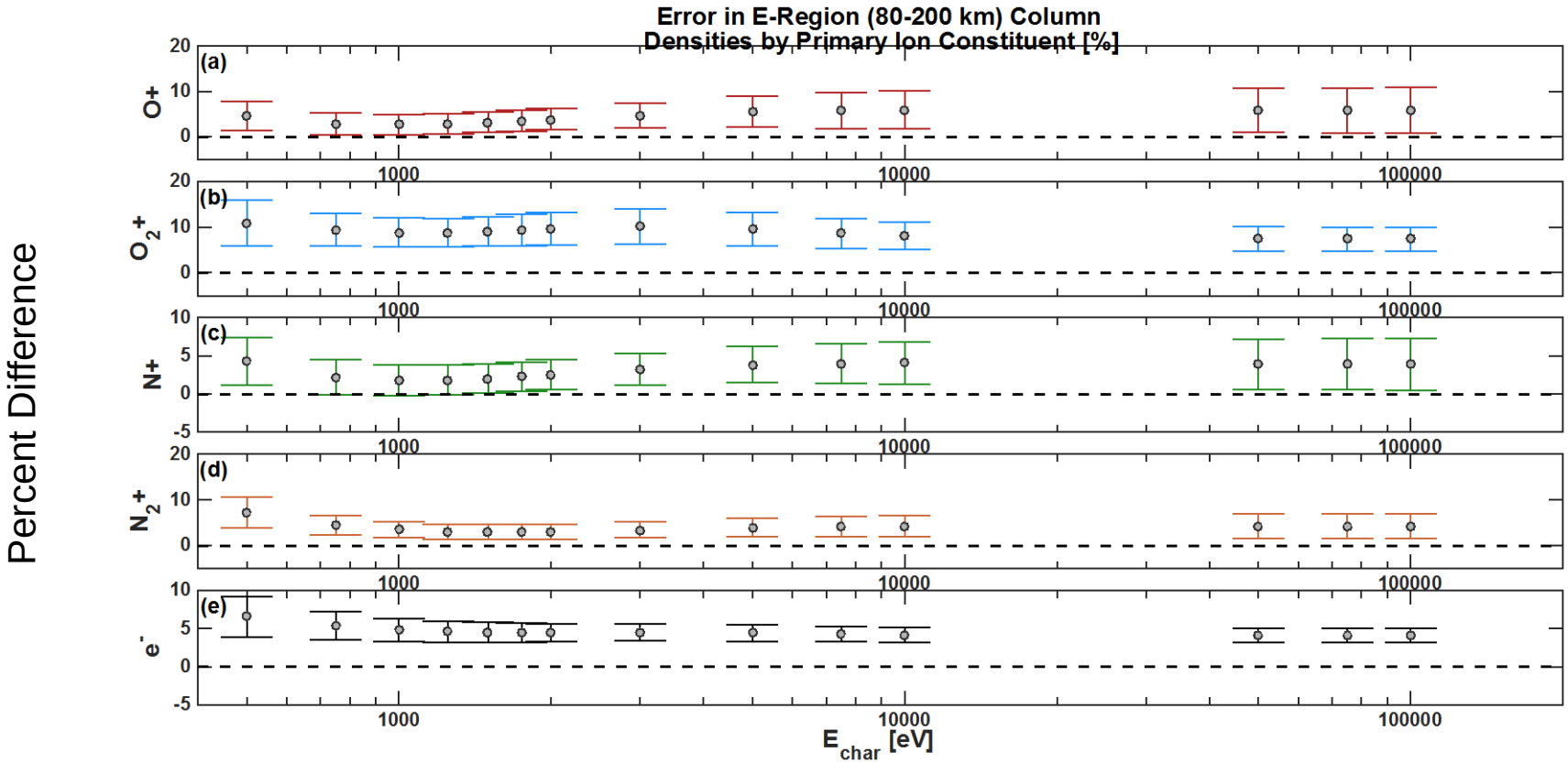

McGranaghan et al. [2015, JGR in press]

Conductance differences: 3024 test cases

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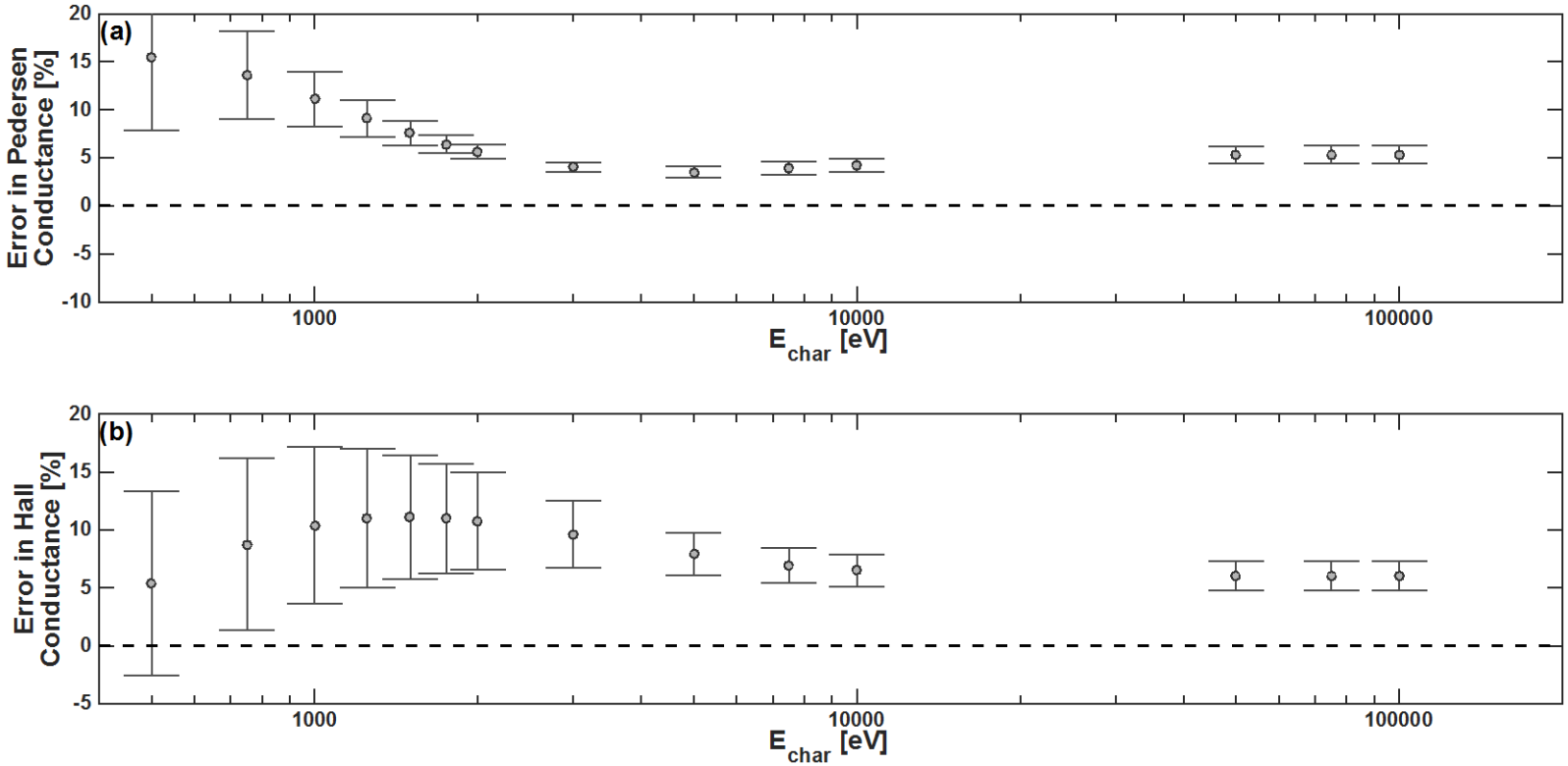
University of Colorado
Boulder, Colorado

Percent Difference



McGranaghan et al. [2015, JGR in press]

Photoionization rate differences: 3024 test cases

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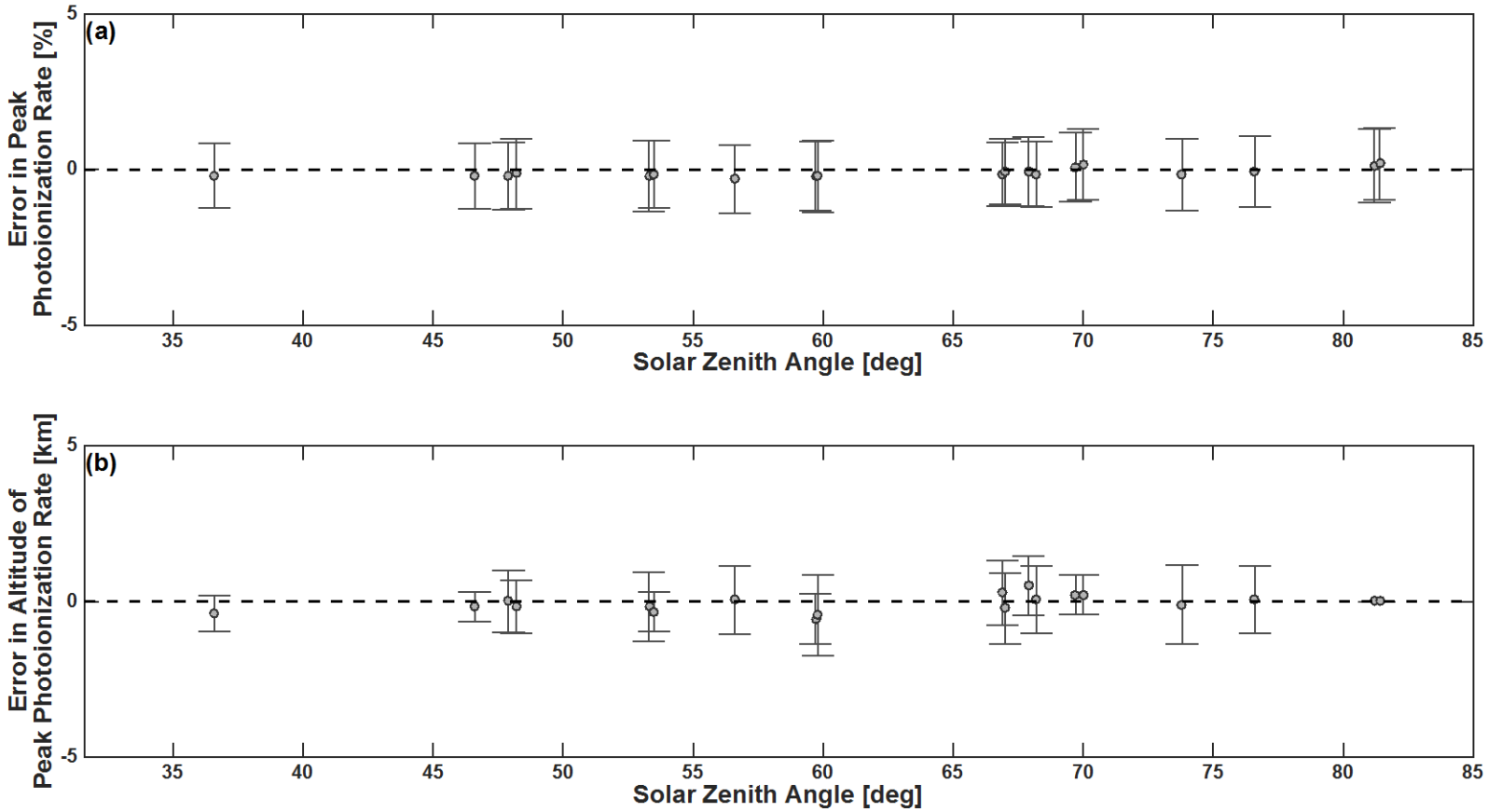
Percent Difference



McGranaghan et al. [2015, JGR in press]

COSMIC comparisons

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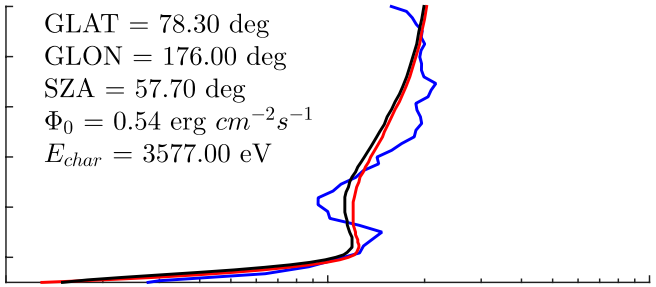
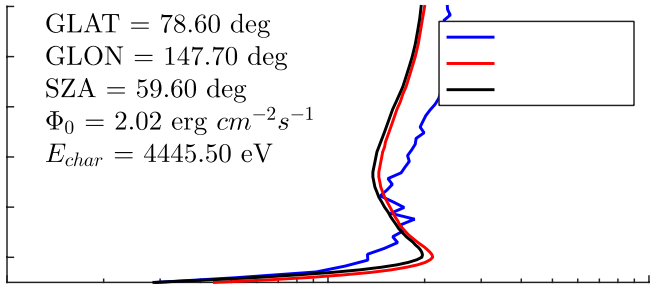
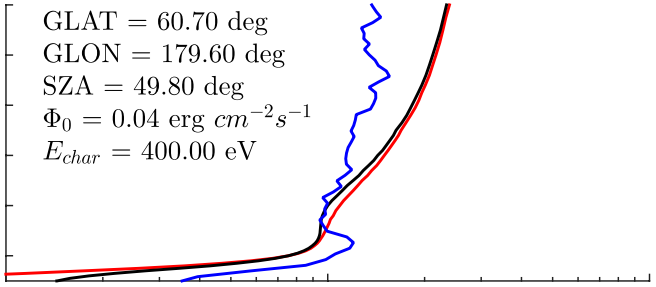
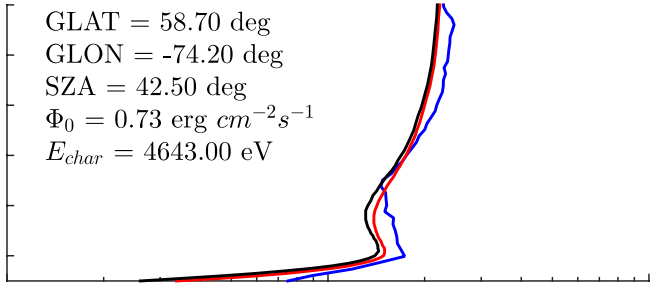
Boulder, Colorado









McGranaghan et al. [2015, JGR in press]

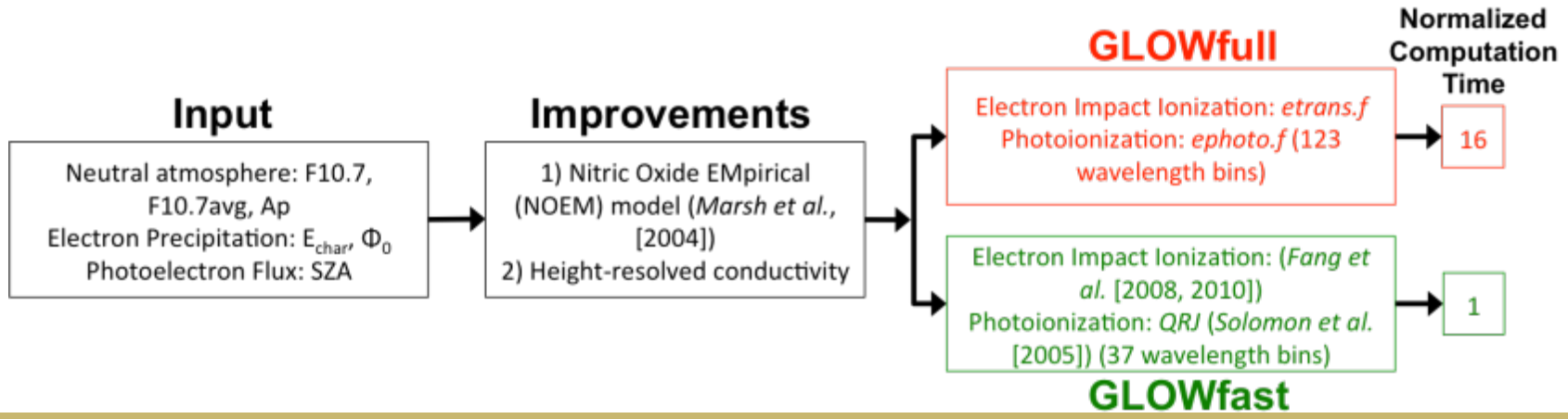
Result

Middle ground between GCMs and empirical models

- Computational efficiency
- High accuracy
- Complete specification of upper atmospheric ionization rates, chemistry, and conductivities

Facilitate analysis of large data sets

- COSMIC
- Forthcoming satellite missions (notably ICON and GOLD)



Significance

Addressing middle ground in upper atmospheric specification

Advancing ionospheric conductance/conductivity specification and pushing these improvements to the broader community

- GLOWfast freely available

Allowing the vast amounts of data available to be used effectively for upper atmospheric specification and forecasting

- COSMIC
- Forthcoming Earth-observing missions (ICON, GOLD, etc.)

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Acknowledgements: NSF Fellowship award DGE 1144083. NCAR is sponsored by the NSF.

GLOWfull

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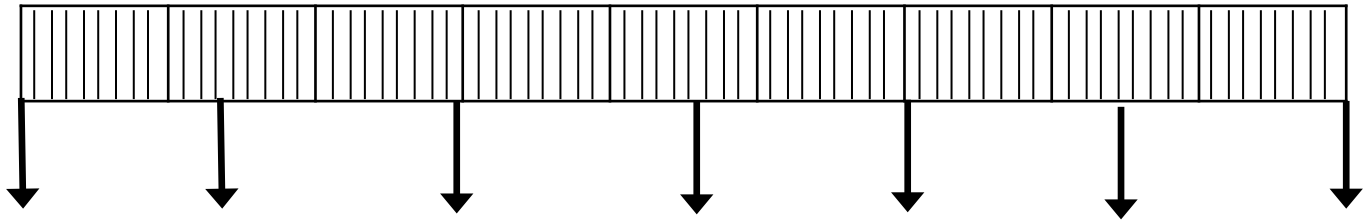
Input

Photon spectra



0.5 nm

GLOWfull model energy grid

175 nm

Photon and photoelectron spectra

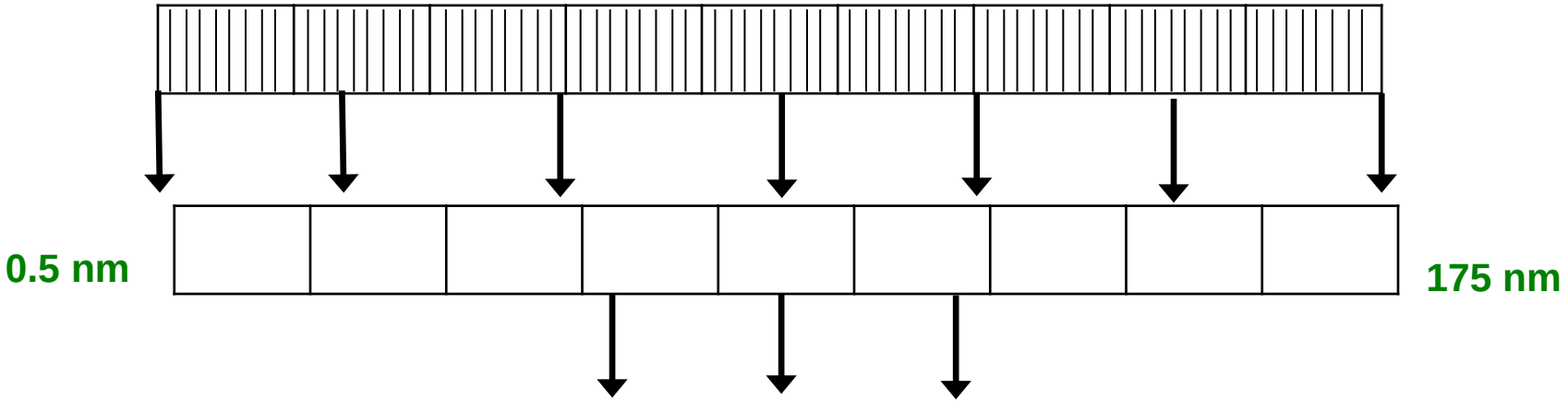
Two-stream transport code: elastic and inelastic collisions with O, N2, and O2; energy redistribution in 190-bin energy grid

Output

Pedersen and Hall conductivities, electron impact and photoionization rates, ion/neutral/electron density profiles, temperature profiles

Input

Photon spectra



Photon and photoelectron spectra

Parameterization via QRJ code (Solomon and Qian [2005])

Output

Pedersen and Hall conductivities, electron impact and photoionization rates, ion/neutral/electron density profiles, temperature profiles

Conductivities

$$\sigma_P = \frac{q_e}{B}\left[N_{O^+}\frac{r_{O^+}}{1+r_{O^+}^2} + N_{O_2^+}\frac{r_{O_2^+}}{1+r_{O_2^+}^2} + N_{NO^+}\frac{r_{NO^+}}{1+r_{NO^+}^2} + N_e\frac{r_e}{1+r_e^2}\right] \quad (1)$$

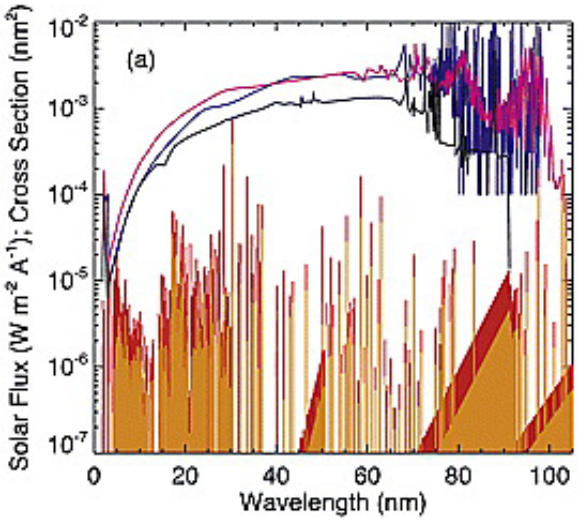
$$\sigma_H = \frac{q_e}{B}\left[-N_{O^+}\frac{1}{1+r_{O^+}^2} - N_{O_2^+}\frac{1}{1+r_{O_2^+}^2} - N_{NO^+}\frac{1}{1+r_{NO^+}^2} + N_e\frac{1}{1+r_e^2}\right], \quad (2)$$

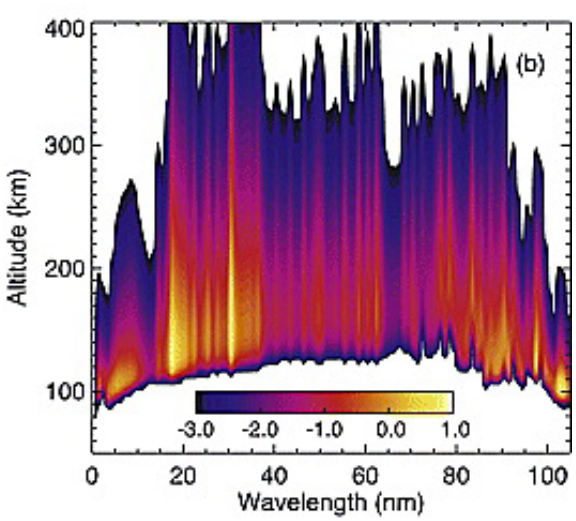
where:

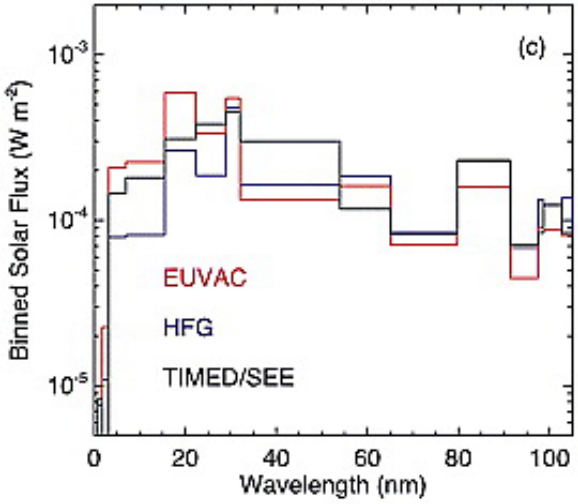
$$r_s = \frac{\text{collision frequency}}{\text{gyrofrequency}} = \frac{\nu_s}{\omega_s} \quad (3)$$

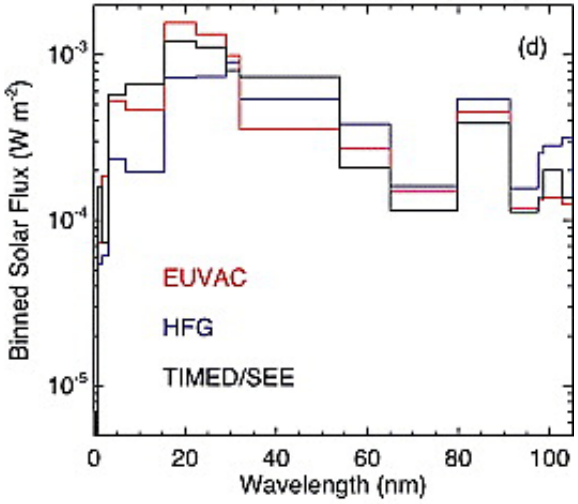
$$\omega_s = \frac{q_e B}{m_s}. \quad (4)$$

Solar extreme-ultraviolet irradiance for general circulation models









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