Modeling Particle Precipitation in the Earth's Atmosphere

and how precise it is

10th European Space Weather Week, Antwerpen

Jan Maik Wissing

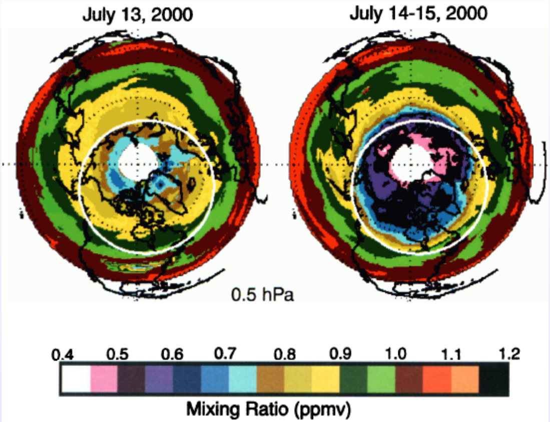
UNIVERSITÄT OSNABRÜCK

Department of Physics

e-mail: jawissin@uos.de

November 21, 2013

Motivation



[Jackman et al., 2001]

Why are we interested in precipitating particles?

Impacts:

- ionization
- chemical processes
- electric conductivity

Measurement of

1. input (needs in-situ particle measurements)
2. effects (TEC: radars, GPS or limp-sounding: MIPAS)

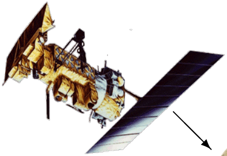
Outline

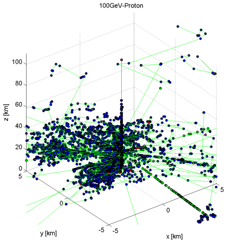
Outline

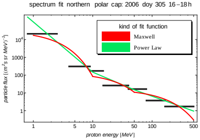
1. How do particle precipitation models work?
2. How precise are these models?
    - satellite data
    - model assumptions

How does an ionization model work?

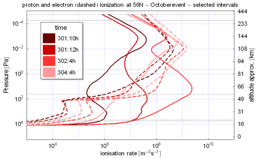
Scheme





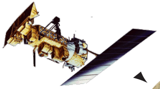


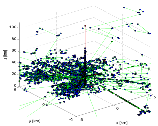
pitch angle assumption

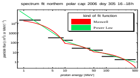


Assumptions and Limitations in Modeling atmospheric Ionization by precipitating Particles

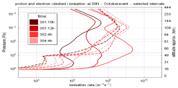
Which parts of ionization models affected by uncertainties? And how much?







pitch angle assumption



Particle Measurements

- degeneration, energy shift
- degeneration, noise effects
- crosstalk by out-of-field contributions
- crosstalk by different energies
- crosstalk by different species
- satellite selection

Remaining Problems

- non-isotropic pitch angle distribution
- SAA
- regional resolution

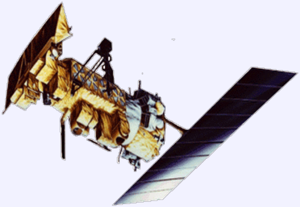
Spectrum Fit

- quality of fit (number of functions)
- selection of energy range
- fixed or variable intersections
- kind of fit function

Modeling Ionization

- atmospheric conditions
- kind of deposition algorithm
- statistics in e.g. Monte-Carlo
- transformation to ion pair production

Particle measurements



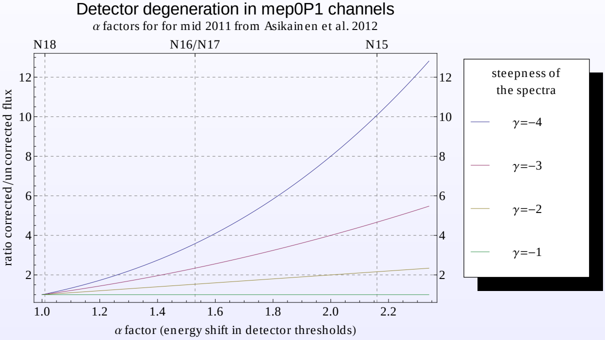
Detector degeneration - energy shift

Reason

impinging particles cause structure defects

Effect

shifts channel's energy thresholds to higher energies



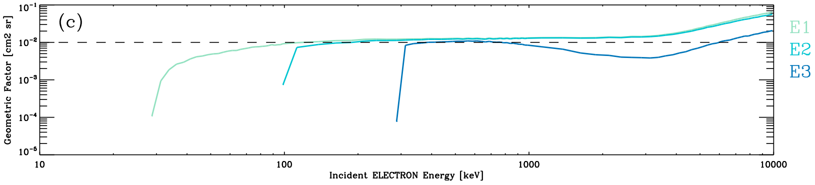
Solution

Using new satellites or applying correction factors [Asikainen et al., 2012] may improve data.

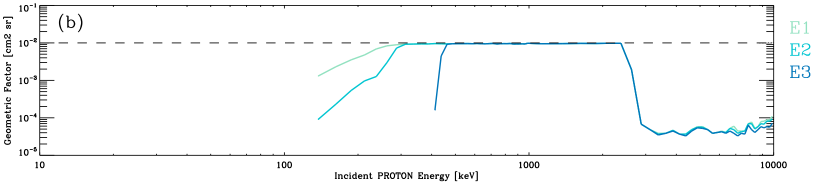
Crosstalk

e.g. in MEPED electron detectors [Yando et al., 2011]

Electron sensitivity:



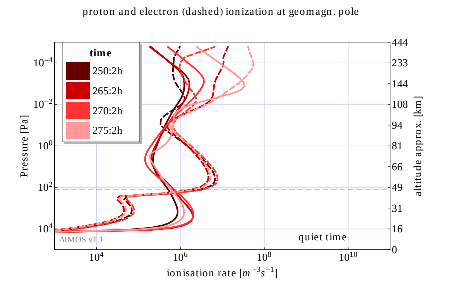
Sensitivity for proton contamination:



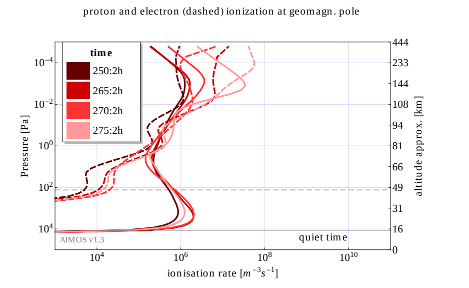
- contamination is confined to protons of energies 200–2700keV

Effect of crosstalk on quite day ionization profile (electrons)

mep0e3



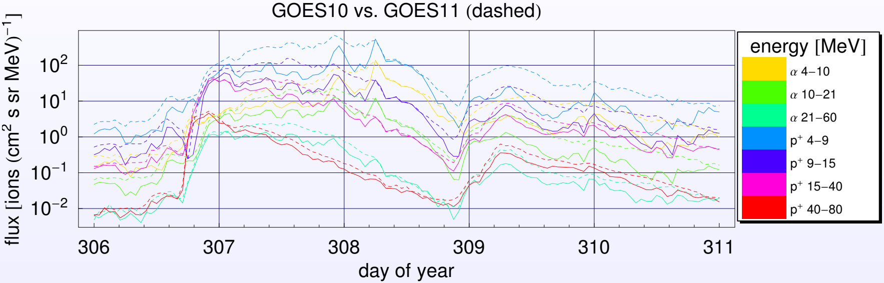
SOHO EPHIN



Solution

Probably solved/improved by new correction algorithms. [Janet Green]

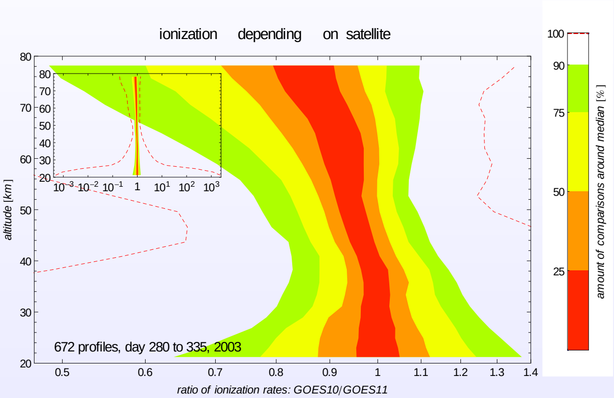
Variation among (same) satellites



measurements may differ because of

- different initial characteristics (construction)
- degradation, crosstalk
- local flux variations

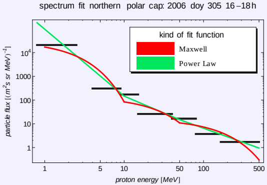
Variation among satellites



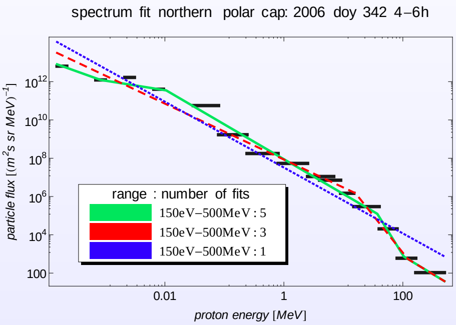
Solution

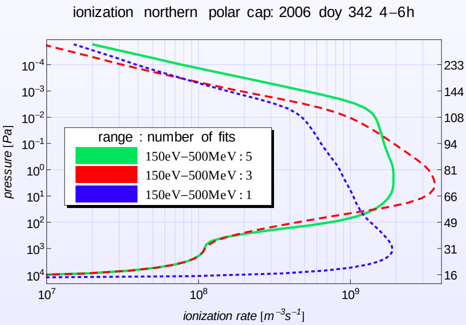
None

Spectrum fit



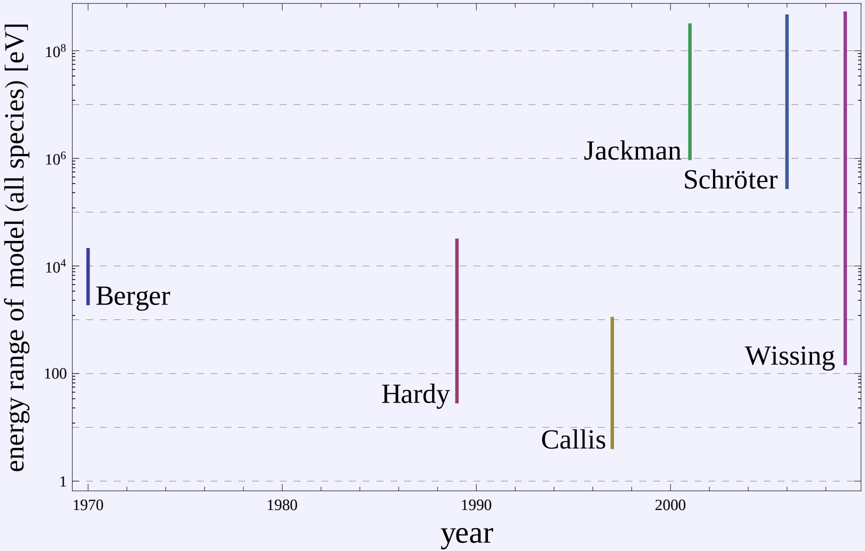
Quality of fit (number of functions)



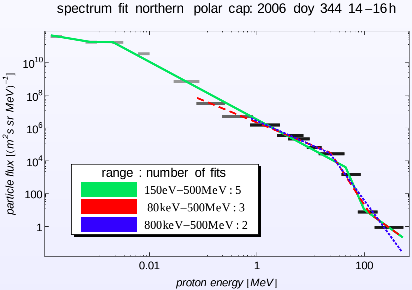


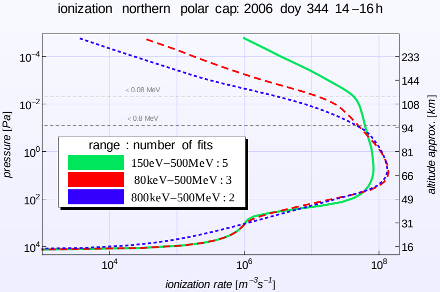
Different energy range of the model

History



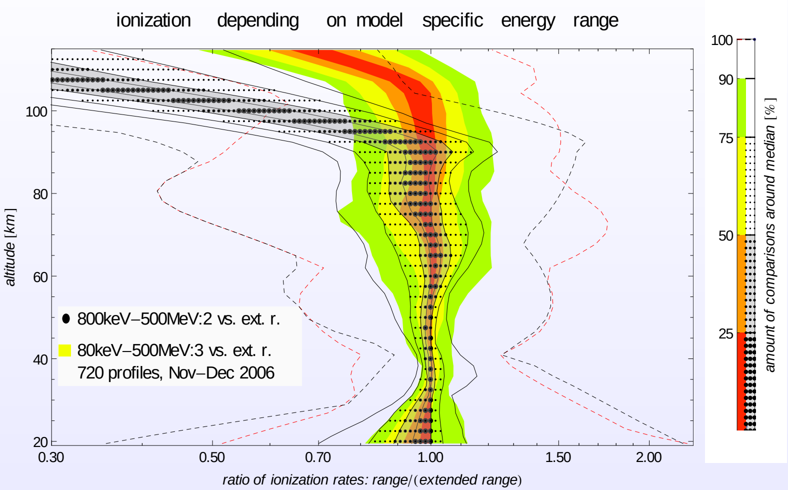
Different energy range of the model





The ratio of magnitudes in energy range divided by the number of fit function here is the same.

Different energy range - results for Nov–Dec 2006



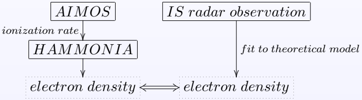
Solution

None

Summary of the uncertainties in modeling particle precipitation

reason	maximum expected error	possible improvements
degeneration, energy shift	depending on age and steepness of spectra up to 1000%	correction e.g. [Asikainen et al., 2012], or newer satellite
degeneration, noise effects	up to 1300% (NOAA-12, including energy shift)	correction e.g. [Asikainen et al., 2012], or newer satellite
crosstalk by out-of-field contrib.	10% contribution by out-of-view particles [Yando et al., 2011]	not needed
crosstalk by different energies	apart from degradation: negligible	not needed
crosstalk by different species	depending on channel, partly severe	different detector setup or coincidence correction needed
satellite selection	up to 300% proved - more possible, (but $>$90% are within a range of $\pm$50%)	-
quality of fit (number of functions)	orders of magnitude	limited by channels and theory
selection of energy range	$\pm$20% (in the center of the range significantly less)	-
fixed or variable intersections	up to 60%	use variable intersections
fit function	30%, 70% at end of energy range	theory suggestes power-law
atmospheric conditions	few %	without tropopause not needed
kind of deposition algorithm	some %	not needed
statistics in e.g. Monte-Carlo	$<$5%	not needed
transformation to ion pair prod.	$<$10%	not needed
non-isotropic pitch angle distrib.	-40% to +60%	needs new detector setup
SAA	?	proton crosstalk in e-channels may be corrected
regional resolution	strongly depending on model, but without regional resolution is not better	limited: a) temporal resolution vs. spatial resolution, b) more satellites needed

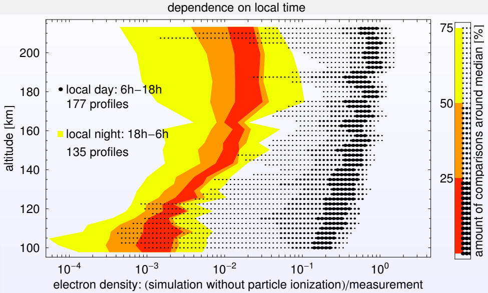
Regarding these uncertainties, should particle precipitation models be used?

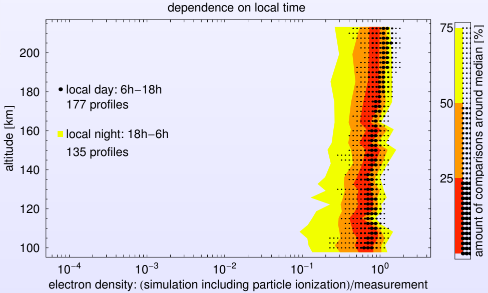


- 312 EISCAT profiles
- Oct 2003 – April 2004
- event & quiet

Yes!

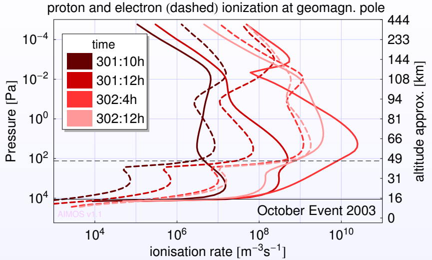
[Wissing et al., 2011]



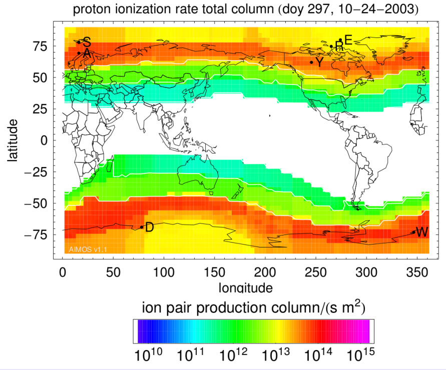


Outlook: *AIMOS Update v1.7*

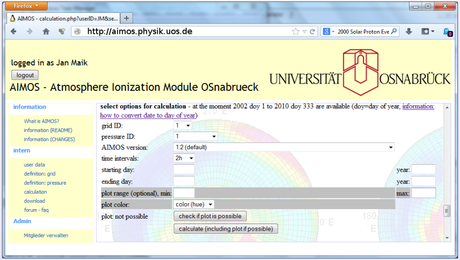
- removed proton contamination
- work in MLT rather than LT
- reduced impact of spikes
- improved spatial resolution in main precipitation regions
- current status: verification against AARDDVARK
- http://aimos.physik.uos.de



[Wi



[Wi



Agostinelli, S. et al., GEANT4-a simulation toolkit, *Nucl. Instr. Meth.* **506**, p. 250–303, 2003

Asikainen,T. , K. Mursula , V. Maliniemi, Correction of detector noise and recalibration of NOAA/MEPED energetic proton fluxes, submitted 2012 to JGR

Berger, M.J., S.M. Seltzer and K. Maeda, Energy deposition by auroral electrons in the atmosphere, *J. Atm. Solar-Terr. Phys.* **32**, p. 1015–1045, 1970

Callis, L.B., Odd nitrogen formed by energetic electron precipitation as calculated from TIROS data, *Geophys. Res. Letters*, vol 24, No 24, p. 3237–3240, 1997

Callis, L.B., M. Natarajan, D. S. Evans and J. D, Lambeth, Solar atmospheric coupling by electrons (SOLACE) 1. Effects of the May 12, 1997 solar event on the middle atmosphere, *J. Geophys. Res.* **103**, p. 28 405–28 419, 1998

Callis, L.B. and J. D, Lambeth, NO_y formed by precipitating electron events in 1991 and 1992: Descent into the stratosphere as observed by ISAMS, *Geophys. Res. Let.*, Vol. **25**, No. 11, p. 1875–1878, 1998.

Fang, X., M.W. Liemohn, J.U. Kozyra, D.S. Evans, A.D. DeJong and B.A. Emery, Global 30-240 keV proton precipitation in the 17-18 April 2002 geomagnetic storms: 1. Patterns, *J. Geophys. Res.*, **112**, A05301, doi:10.1029/2006JA011867, 2007

Funke, B., A. Baumgaertner, M. Calisto, T. Egorova, C.H. Jackman, J. Kieser, A. Krivolutsky, M. Lpez-Puertas, D.R. Marsh, T. Reddmann, E. Rozanov, S.-M. Salmi, M. Sinnhuber, G. P. Stiller, P. T. Verronen, S. Versick, T. von Clarmann, T. Y. Vyushkova, N. Wieters and J. M. Wissing, Composition changes after the "Halloween" solar proton event: the High-Energy Particle Precipitation in the Atmosphere (HEPPA) model versus MIPAS data inter-comparison study, *Atmospheric Chemistry and Physics*, **11**, p. 9089-9139, acp-2010-1001, 2011

Hardy, D.A., M.S. Gussenhoven and D. Brautigam, A statistical model of the auroral ion precipitation, *J. Geophys. Res.*, **94**, p. 370, 1989

Jackman, C.H., R.D. McPeters, G.J. Labow, E.L. Fleming, C.J. Praderas and J.M. Russell, Northern hemisphere atmospheric effects due to the July 2000 Solar Proton Event, *Geophys. Res. Lett.*, **28**(15), p. 2883–2886, 2001

Jackman, C.H., M.T. DeLand, G.J. Labow, E.L. Fleming, D.K. Weisenstein, M.K.W. Ko, M. Sinnhuber, and J.M. Russell, Neutral atmospheric influences of the solar proton events in October–November 2003, *J. Geophys. Res.*, **110**, A09S27, doi:10.1029/2004JA010888, 2005a

Roble, R.G. and E.C. Ridley, An auroral model for the NCAR thermospheric general circulation model (TGCM), *Ann. Geophys.*, **5A**, p. 369–382, 1987

Schröter J., B. Heber, F. Steinhilber and M.-B. Kallenrode, Energetic particles in the atmosphere: a Monte Carlo approach, *Adv. Space Res.* **37**, (8), p. 1597–1601, 2006.

Wissing, J.M., J.P. Bornebusch and M.-B. Kallenrode *Adv. Space Res.* 41, p. 1274–1278, 2008

Wissing, J.M. and M.-B. Kallenrode, Atmospheric Ionization Module OSnabrück (AIMOS) 1: A 3-D model to determine atmospheric ionization by energetic charged particles from different populations, *J. Geophys. Res.*, **114**, A06104, doi:10.1029/2008JA013884, 2009

Wissing, J.M., M.-B. Kallenrode, N. Wieters, H. Winkler and M. Sinnhuber, Atmospheric Ionization Module Osnabrück (AIMOS): 2. Total particle inventory in the October/November 2003 event and ozone, *J. Geophys. Res.*, **115**, A02308, doi:10.1029/2009JA014419, 2010

Wissing, J.M., M.-B. Kallenrode, J. Kieser, H. Schmidt, M.T. Rietveld, A. Strømme and P.J. Erickson, Atmospheric Ionization Module OSnabrück (AIMOS) 3: Comparison of electron density simulations by AIMOS/HAMMONIA and incoherent scatter radar measurements, *J. Geophys. Res.*, **116**, A08305, doi:10.1029/2010JA01630, 2011

K. Yando, R.M. Millan, J.C. Green and D.S. Evans: A Monte Carlo simulation of the NOAA POES Medium Energy Proton and Electron Detector instrument, JGR, vol. 116, A10231, doi:10.1029/2011JA015571, 2011