Atmospheric effects of Energetic Particle Precipitation (EPP)

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Introduction

- Observations of EPP effects on NOx and ozone
- Simulations of solar proton events and auroral EPP
- Summary and what we need

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Why study the atmospheric effects of EPP?
To what extent are EPP effects indicative of, and to what extent do they trigger, atmospheric coupling?
Changes in polar ozone result in changes in temperatures which change winds and wave filtering. 

Coupling via EPP
Energetic Particle Precipitation (EPP)

Adapted from Lean, 1994

- Solar EUV and X-rays
- Auroral Electrons
- Medium & High Energy Electrons
- Solar Protons
- Galactic Cosmic Rays

Altitude (km)

Ionization Rate (cm⁻³ s⁻¹)
Energetic Particle Precipitation (EPP)

↓↓↓

Ionization & Dissociation

↓↓↓

NO\textsubscript{x} and HO\textsubscript{x}

Direct Effect

thermosphere

mesosphere

stratosphere

troposphere

Indirect Effect
DIRECT EFFECT

- NO formed locally in stratosphere
- Requires highly energetic particles: **Sporadic**
  - **Thermosphere:** < 30 keV electrons
  - < 1 MeV protons
  - **Mesosphere:** 30-300 keV electrons (MEE)
  - 1-30 MeV protons
  - **Stratosphere:** > 300 keV electrons
  - > 30 MeV protons
- Immediately available to destroy ozone
INDIRECT EFFECT

- NO formed in MLT: Routine
- Descends during winter
- Ozone destroyed (~22-40 km)
INDIRECT EFFECT

- Requires efficient downward transport during polar night

- Odd nitrogen lifetime in sunlight:
  - 70-80 km: Days
  - 50-60 km: Weeks
  - <40 km: Months-Years

- Influenced by Dynamics
Pathways that link space weather variability to atmospheric coupling
**EPP Direct Effect**

NO$_x$ produced directly in stratosphere.

Occurs ~several times per solar cycle.

Stratospheric effects begin immediately & persist months-years.

Often followed by large EPP IE.

**EPP Indirect Effect**

NO$_x$ produced in MLT and descends to stratosphere.

Occurs routinely, but descent occurs in polar night.

Stratospheric effects begin ~months after production and persist months-years.

Often follows large EPP DE, but can occur anytime.
First satellite observations of EPP Indirect Effect from LIMS in NH, 1978-1979
Few observations of EPP-NO$_x$ from 1979 to 2003

Solar Occultation: SAGE, HALOE, POAM
- Sparse geographic coverage
- SAGE & POAM only measure NO$_2$, not NO
- No polar night

In 2003-2004 more NOx data became available
- GOMOS, MIPAS, SCIAMACHY, ACE-FTS
NH stratospheric NO$_x$ increase (4x) and ozone decrease (60%) *five* months after the 2003 Halloween Storms

Probably due to January 2004 EPP, not Halloween storms
Correlation of EPP NO$_x$ entering SH stratosphere with Ap and Solar f10.7 (Apr-Aug)

- Strong correlation with Ap
- Variability controlled by EPP-NO$_x$ production, not transport

Adapted from Randall et al., JGR 2007
Inferring causation requires a model

Community Earth System Model (CESM)

Whole Atmosphere Community Climate Model (WACCM4)
Whole Atmosphere Community Climate Model (Now v4)
A 3D coupled chemistry climate model
- 0 to ~145 km
- Comprehensive chemistry incl. heterogeneous rx
- Interactive Chemistry or Specified Meteorology
- 1-1.5 km vertical resolution in stratosphere
- 1.9° x 2.5° or 4 x 5° horizontal resolution
- Ref: Garcia et al., 2007
(Adapted from Rolando Garcia)
WACCM simulation of NOx in the SH polar vortex after July 2000 SPE agrees with

NOx in the SH polar vortex in Sept/Oct. (Jackman et al., 2008)
WACCM Simulations of Auroral EPP

Free-running, 40 years
Perpetual aurora with slightly elevated kp
With SPE WACCM NOx enhancement not even as large as was observed
O3 is depleted where NOx is most enhanced – but is this caused by transport?

Comparison with noEPP run will answer this.
What do we need?

**Measurements**
- NOx throughout the polar winter, stratosphere to thermosphere
- NOy and Cly
- Polar Mesospheric Clouds
- Winds in MLT
- Global ozone & temperature profiles
- Precipitating particles: energy spectrum and spatial distribution

**Models**
- Improved treatment of gravity waves in GCMs
- Incorporation of higher energy electrons in GCMs
High Energy Particle Precipitation in the Atmosphere
SOLAR Influences for SPARC
(Stratospheric Processes And their Role in Climate)

Boulder, Colorado
NCAR/HAO
9-12 October 2012

http://www2.acd.ucar.edu/heppasolaris
Thanks!
Extra Slides
Figure 1. Total ion production rate (left) for a Kp index of 4 and the difference between this and the rate for a Kp index of 2/3 (right) in the NH (top) and SH (bottom) at 4.4x10^-5 hPa (~112 km). The white contour shows the average vortex edge for the 40 years in the high aurora simulation at a potential temperature of 2000 K (~50 km, 0.74 hPa) for December, January, and February in the NH (top) and for June, July, and August in the SH (bottom).
Indirect Effect of EPP on the Stratosphere

The Polar Vortex

Stratospheric "Containment Vessel" over the South Pole

Subsiding Air

Isolation from other latitudes

From Turco, 1997

The Antarctic Ozone Hole: Dynamics

Subsiding Air

Cora Randall, LASP seminar, 10 April 2003

Descending Air

Isolation from other latitudes

Must understand interannual variability in NO production and SMLT dynamics
WACCM Parameterization of Precipitation Effects

**Aurora**
- Input = Kp
- Distribution = Auroral Oval
- Roble and Ridley, 1987

**SPEs**
- Input = GOES proton flux
- Distribution = polar cap
- Jackman et al., 2008

**Medium Energy Electrons**
(30 keV – 1 MeV)
- Input = MEPED electron flux
- Distribution = Codrescu patterns (JGR, 1997)
- Fang et al., 2008

(Adapted from Rolando Garcia)
Ionosphere-Thermosphere Processes