Simultaneous and co-located measurements of radar reflectivity, turbulence, winds, and electron density by VHF/MF radars during PMWE

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Outline

• Characteristics of PMWE

• VHF/MF radar observations at Andenes

• PMWE on January 17 - 21, 2005

• PMWE in December 2006

• PMWE/PMSE in May 2007

• Summary
Polar Mesosphere Winter Echoes (PMWE)

strongly enhanced VHF radar echoes from mesospheric heights of about 55 to 75 km

\( \text{PMWE} \sim 3\% \text{ occurrence rate} \quad \leftrightarrow \quad \text{PMSE} \sim 90\% \text{ occurrence rate} @ 69^\circ \text{N} \)

\[ \text{Proposed mechanisms:} \]

- turbulence

- scatter from evanescent ion-acoustic waves generated by partial reflection of infrasonic waves

- aerosol particles
Seasonal variation of PMWE occurrence at 69°N, 2001 – 2005

Zeller et al., JASTP, 68, 1087-1104, 2006
Mean height distribution of PMWE for day and night time $h_{\text{peak}} = 70.5 / 77.5$ km

Seasonal variation of solar activity (proton flux 9 – 15 MeV) and geomagnetic activity ($A_p$) compared with PMWE occurrence and layer width ($\Delta z$) for October 2001 – April 2005
Hints for PMWE generation by turbulence

Mean seasonal variation of turbulent energy dissipation rate and PMWE occurrence at 69°N

Minimum turbulence strength to generate radar echoes at a Bragg scale of 3 m

It increases by 6 orders of magnitude from 55 to 85 km (!)
PMWE observations at Andenes (69.3°N, 16.0°E)

**ALWIN VHF radar** (53.5 MHz): vertical beam, Doppler & spaced antenna
\[ \Delta h = 300 \text{ m}, \text{calibrated radar reflectivity} \]

**Saura MF radar** (3.17 MHz): narrow beam Doppler radar
\[ \Delta h \sim 1.5 \text{ km}, \text{beam width} \sim 7^\circ \text{ (FWHP)} \]
Doppler winds, turbulence
electron density

**AIRIS** (imaging riometer 38.2 MHz): cosmic noise absorption

**insitu measurements** by meteorological & sounding rockets in January 2005
PMWE on January 17 - 21, 2005
GOES Space Environment Monitor

GOES-12 Solar X-Rays (1-Min Avgs)

GOES-12 Electrons and GOES-11 Protons & α-Particles (5-Min Avgs)

GOES-12 Magnetic Field (1-Min Avgs, 75.2°W)

McMurdo Neutron Monitor (preliminary, hourly, % of monthly mean)

January 2005

Universal Time
Solar proton fluxes, X-ray fluxes and D-region electron densities before, around, and after the maximum of the solar activity event on January 17, 2005

Electron densities on **18 January (06:30 UT)** are still enhanced due to enhanced proton fluxes.
Simultaneous VHF/MF measurements

AWIN VHF radar

Saura MF radar – energy dissipation rate (K/d)

VHF radar
sounding rockets

Simultaneous VHF/MF measurements
Simultaneous measurements of radar reflectivity and insitu electron density

Insitu electron densities from radio wave propagation experiment increased by one order of magnitude at storm time

PMWE event with large vertical extension during a geomagnetic storm
Geomagnetic storm on January 18, 2005

Onset of geomagnetic disturbance (after GOES observations)

Ion pair production (M.-B. Kallenrode)
53.0 km, 57.7 km, 62.8 km, 71.6 km (after GOES observations)

IRIS 38.2 MHz
Onset of geomagnetic disturbance

No MF radar data due to high radio wave absorption
Insitu turbulence by PIP probe (ion fluctuations)
Brattli et al., ACP, 6, 5515-5524, 2006

• non-turbulent spectrum outside the PMWE layer
• turbulent spectrum inside the PMWE layer
Theoretical values of radar reflectivity in dependence of turbulence and electron density

Insitu electron densities and observed PMWE radar reflectivities ($3 - 6 \times 10^{-15} \text{m}^{-1}$) result in realistic turbulence strengths.
PMWE on January 21, 2005

simultaneous observations of

- radar reflectivity
- energy dissipation rates
- electron densities
Turbulence is always present and enhanced by one order during PMWE.
model values of radar reflectivity $\eta$ resulting from measured electron densities and turbulent energy dissipation rates $\varepsilon$ with the Saura MF radar

**Model:** radar reflectivity from coherent radar backscatter @ 65 km (Lübken et al., 2006)

**ALWIN VHF radar:** volume reflectivity

$\eta = \text{const}$

$\eta$ (model) $\sim$ $\eta$ (ALWIN radar) ! $\Rightarrow$ PMWE is caused by turbulence
PMWE observations in 2006

December 6 - 15
PMWE are highly correlated with enhanced riometer absorption
ALWIN VHF radar: no indications for specular reflections and extrem wind speeds

6 – 15 December 2006

Spaced antenna observations: Full Correlation Analysis (FCA), without thresholds

- no horizontal velocities > 100 m/s
- no specular reflections $\theta_s < 3^\circ$
Simultaneous observations of PMWE/PMSE in May 2007

PMWE - 18 May

1st PMSE – 19 May

PMSE/PMWE – 27 May
Occurrence of PMWE is well correlated with magnetically disturbed conditions (18-28 May) and enhanced riometer absorption.
ALWIN VHF radar
PMWE 27 May 09-10 UT
radar reflectivity

Saura MF radar
PMWE
horizontal winds
energy dissipation rates
27 May 2007

PMSE 08:30-10:30 UT $\eta_{\text{mean}} \sim 2 \cdot 10^{-13} \text{ m}^{-1}$

PMWE 09:00-09:45 UT $\eta_{\text{mean}} \sim 1.5-7 \cdot 10^{-16} \text{ m}^{-1}$
Summary

PMWE - radar echoes below ~80 km

- radar reflectivities @ 53.5 MHz: \(~2 \cdot 10^{-16} - 8 \cdot 10^{-15}\) m\(^{-1}\)

- observed echoes are generated by turbulence; other mechanisms can not be excluded but are unlikely

- charged ice particles are not necessary for PMWE but required for the generation of PMSE in the mesopause region above

- PMWE show no or only weak aspect sensitivity in contrast to PMSE

PMWE are observed with:
- energy dissipation rates: \(~40 – 120\) mW/kg;
- electron densities: \(~4 \cdot 10^8 - 10^9\) electrons/m\(^3\), increased by about one order of magnitude during solar activity storms and geomagnetic storms
Thank you!