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

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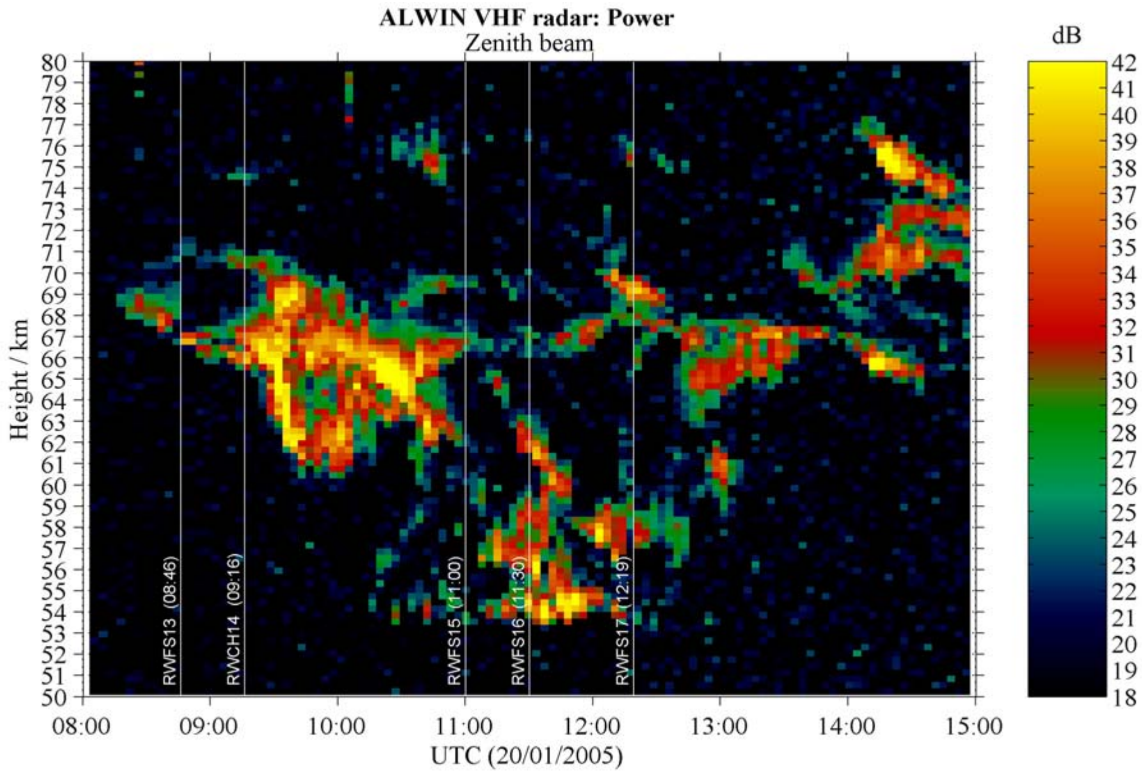
Outline

- 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
(**PMWE** ~ 3% occurrence rate ⇔ **PMSE** ~ 90% occurrence rate @ 69°N)



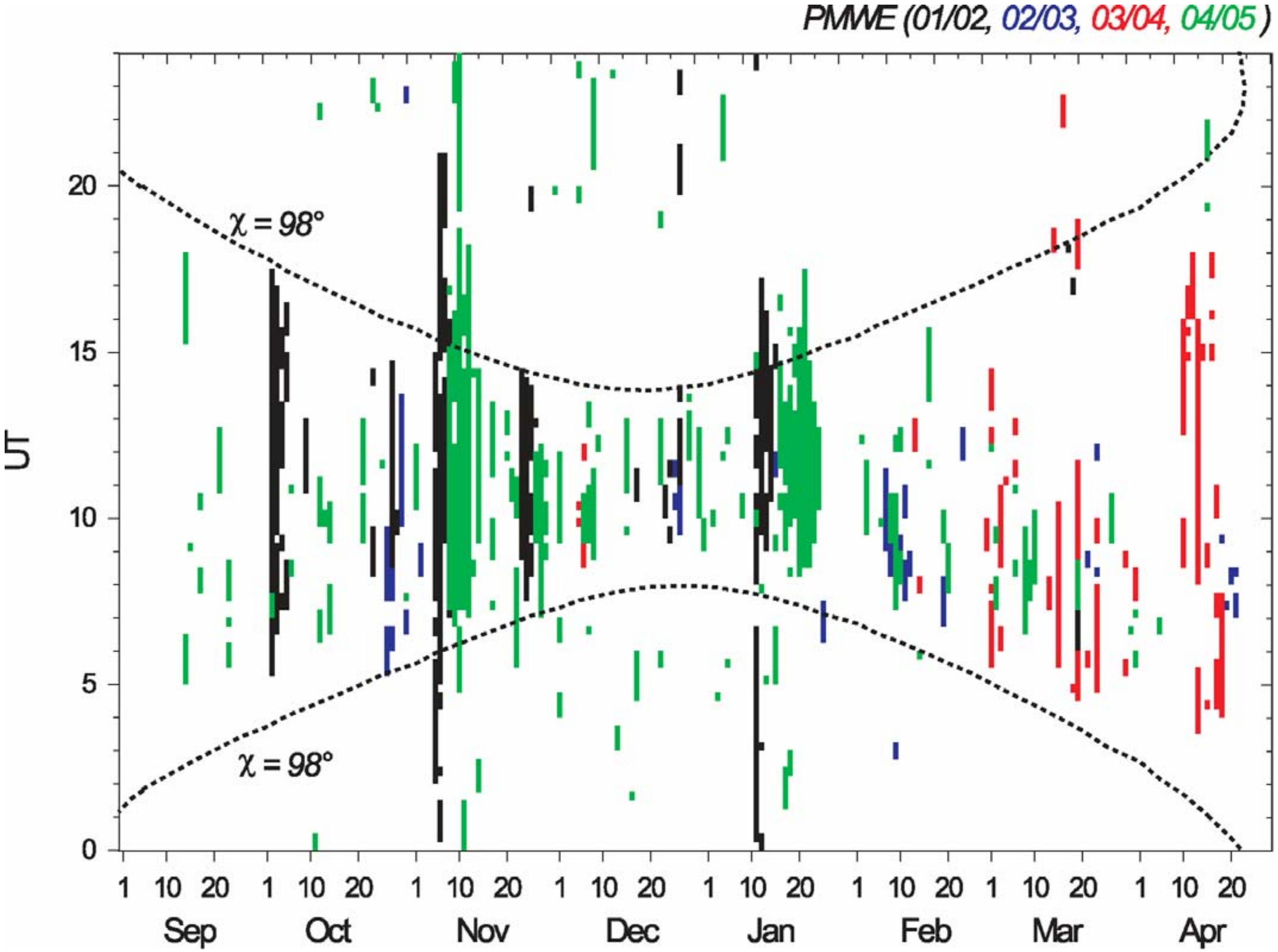
Proposed mechanisms:

● **turbulence**

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

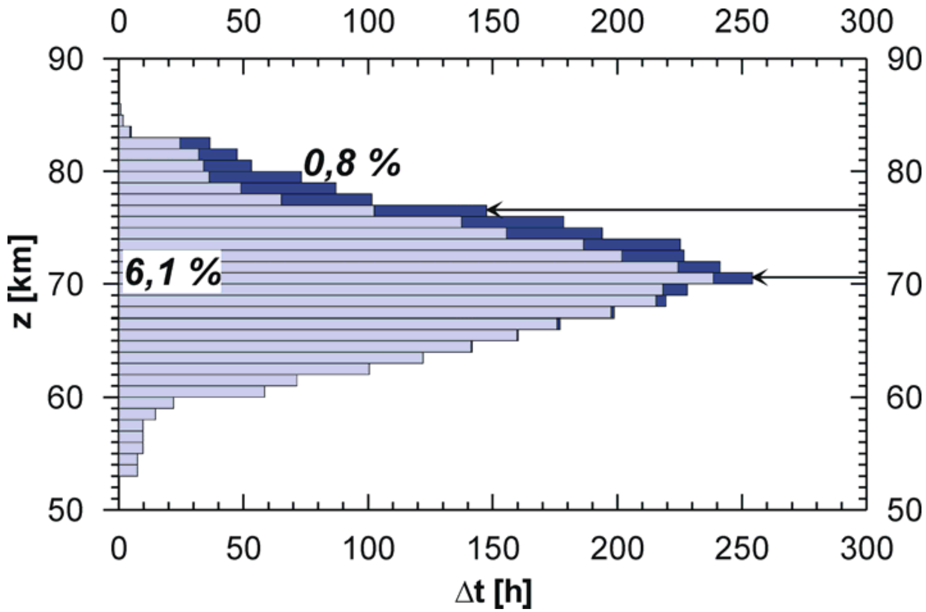
● aerosol particles

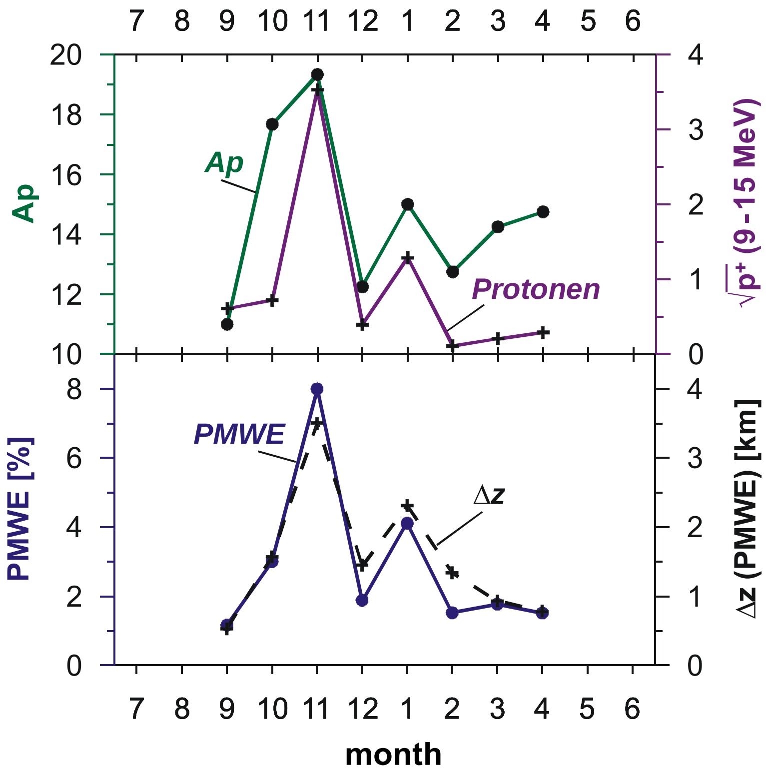
Seasonal variation of PMWE occurrence at 69°N, 2001 – 2005



Zeller et al., JASTP, 68, 1087-1104, 2006

Mean height distribution of PMWE for day and night time h_{peak}= 70.5 / 77.5 km



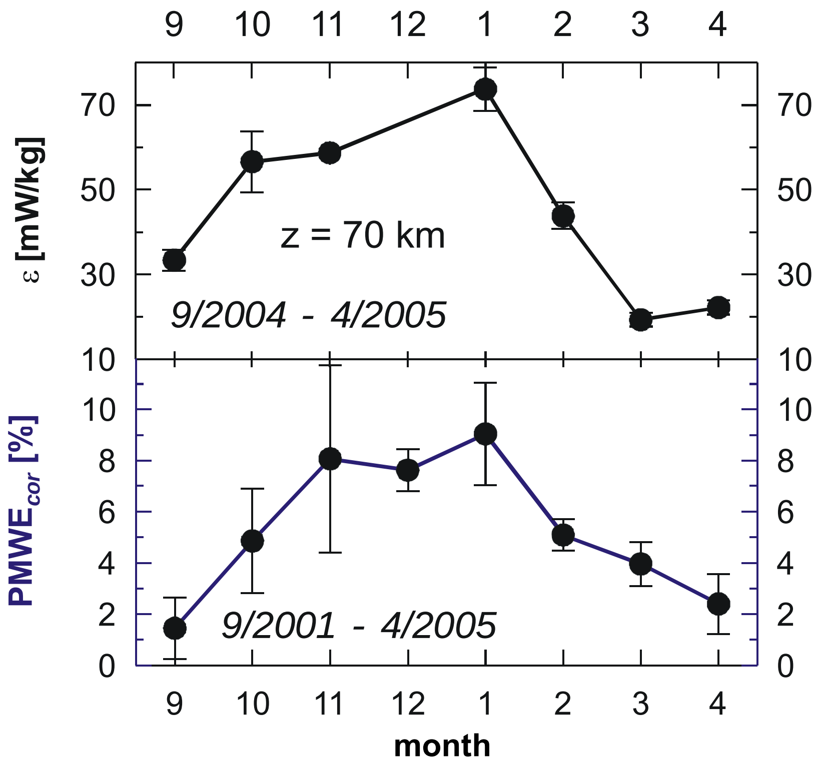


Seasonal variation of solar activity (proton flux 9 – 15 MeV) and geomagnetic activity (A_p)

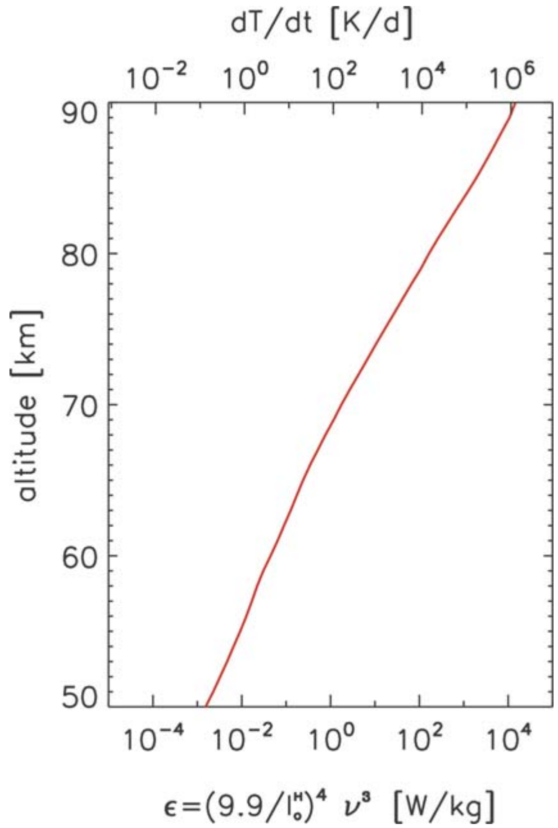
compared with

PMWE occurrence and layer width (Δz) 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 (!)

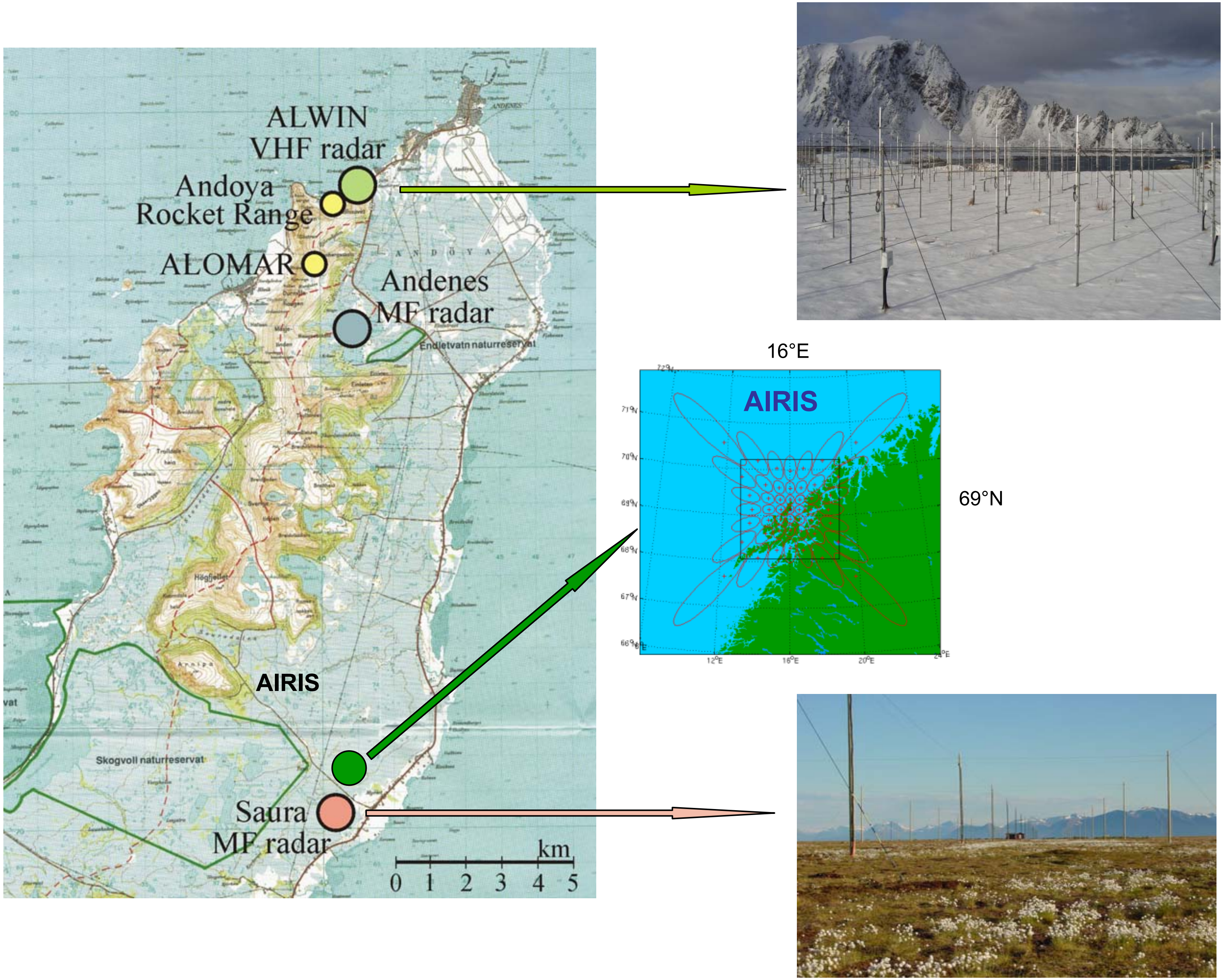
PMWE observations at Andenes (69.3°N, 16.0°E)

ALWIN VHF radar (53.5 MHz): vertical beam, Doppler & spaced antenna
Δh = 300 m, calibrated radar reflectivity

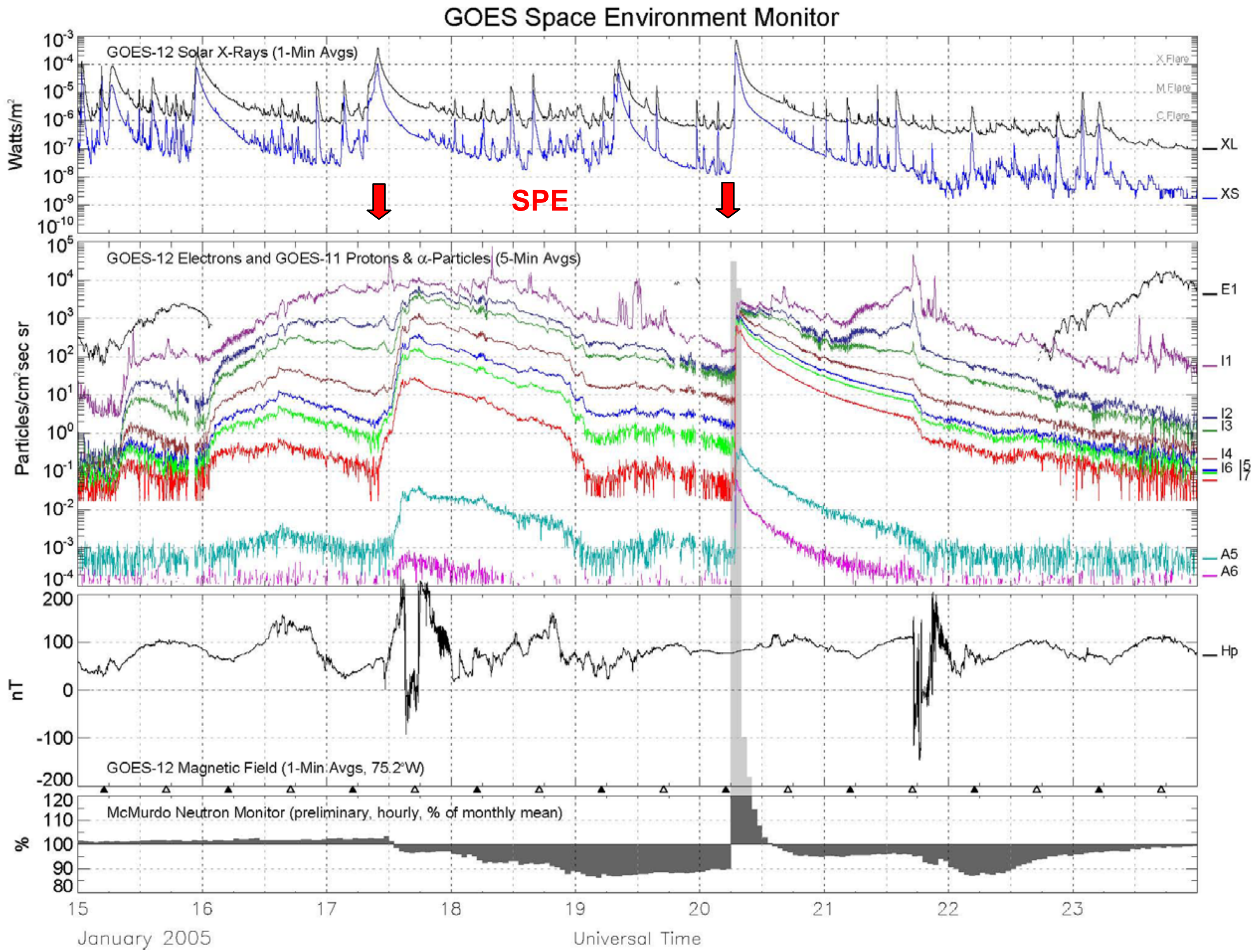
Saura MF radar (3.17 MHz): narrow beam Doppler radar
Δh ~ 1.5 km, beam width ~7° (FWHP)
Doppler winds, turbulence
electron density

AIRIS (imaging riometer 38.2 MHz): cosmic noise absorption

insitu measurements by meteorological & sounding rockets in January 2005

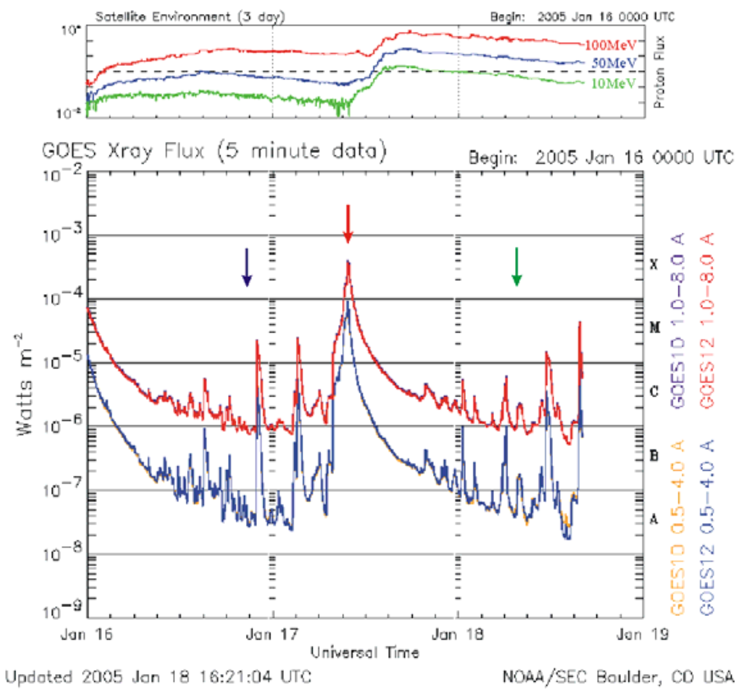

ALWIN
VHF radar
Andoya
Rocket Range
ALOMAR
Andenes
MF radar
Endletvatn naturreservat
AIRIS
Skogvoll naturreservat
Saura
MF radar
km
0 1 2 3 4 5
16°E
AIRIS
69°N

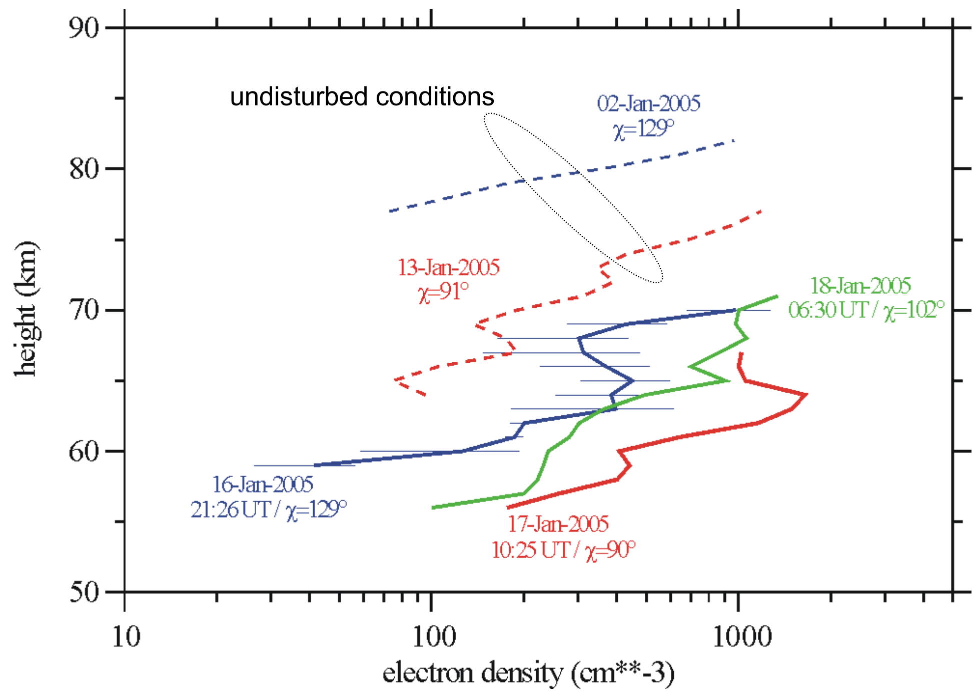
PMWE on January 17 - 21, 2005



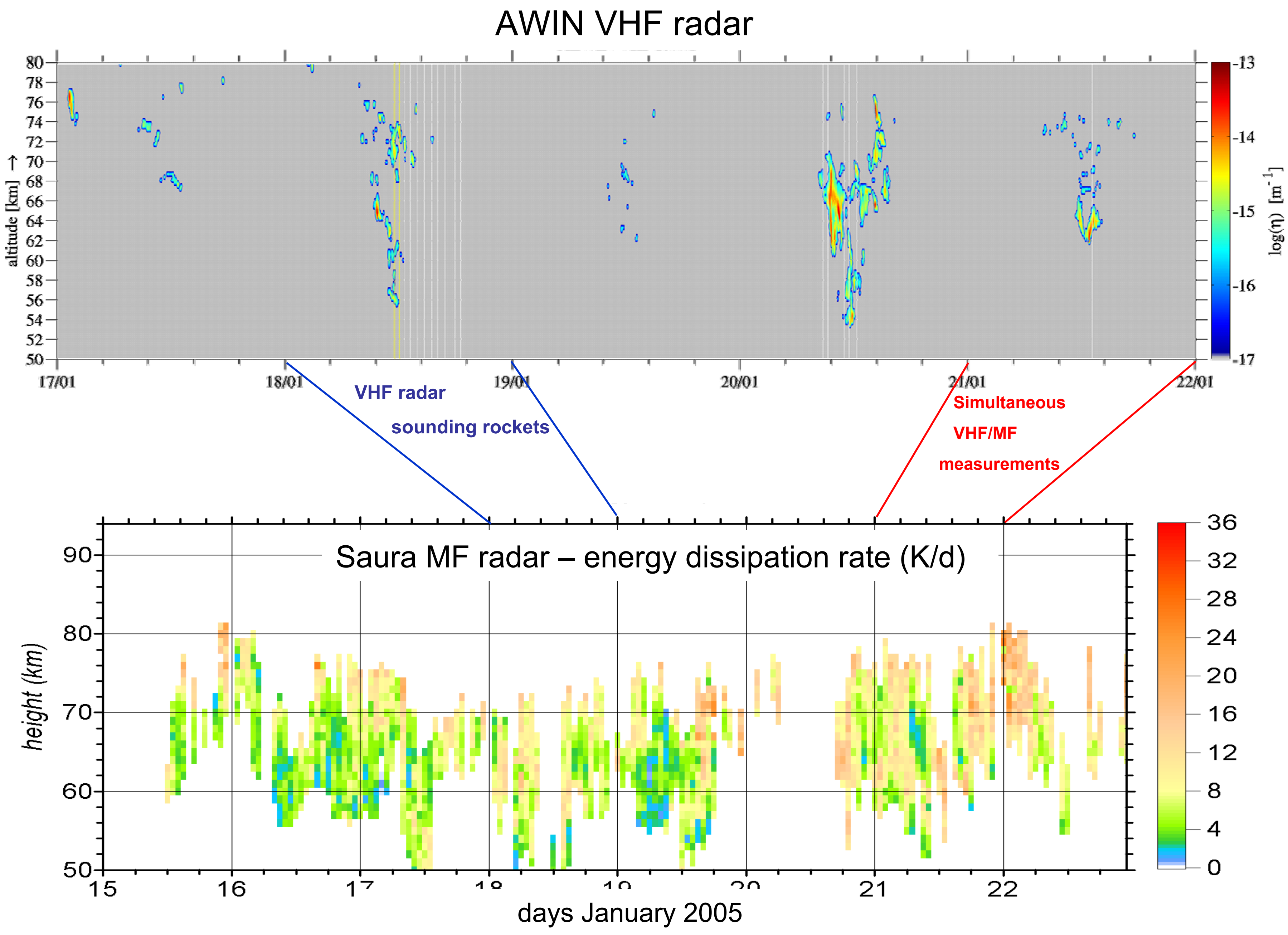
GOES Space Environment Monitor
GOES-12 Solar X-Rays (1-Min Avgs)
Watts/m^2
X Flare
M Flare
C Flare
XL
XS
SPE
GOES-12 Electrons and GOES-11 Protons & α-Particles (5-Min Avgs)
Particles/cm^2 sec sr
E1
I1
I2
I3
I4
I6
I5
I7
A5
A6
200
100
0
-100
-200
nT
Hp
GOES-12 Magnetic Field (1-Min Avgs, 75.2°W)
McMurdo Neutron Monitor (preliminary, hourly, % of monthly mean)
%
15
16
17
18
19
20
21
22
23
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

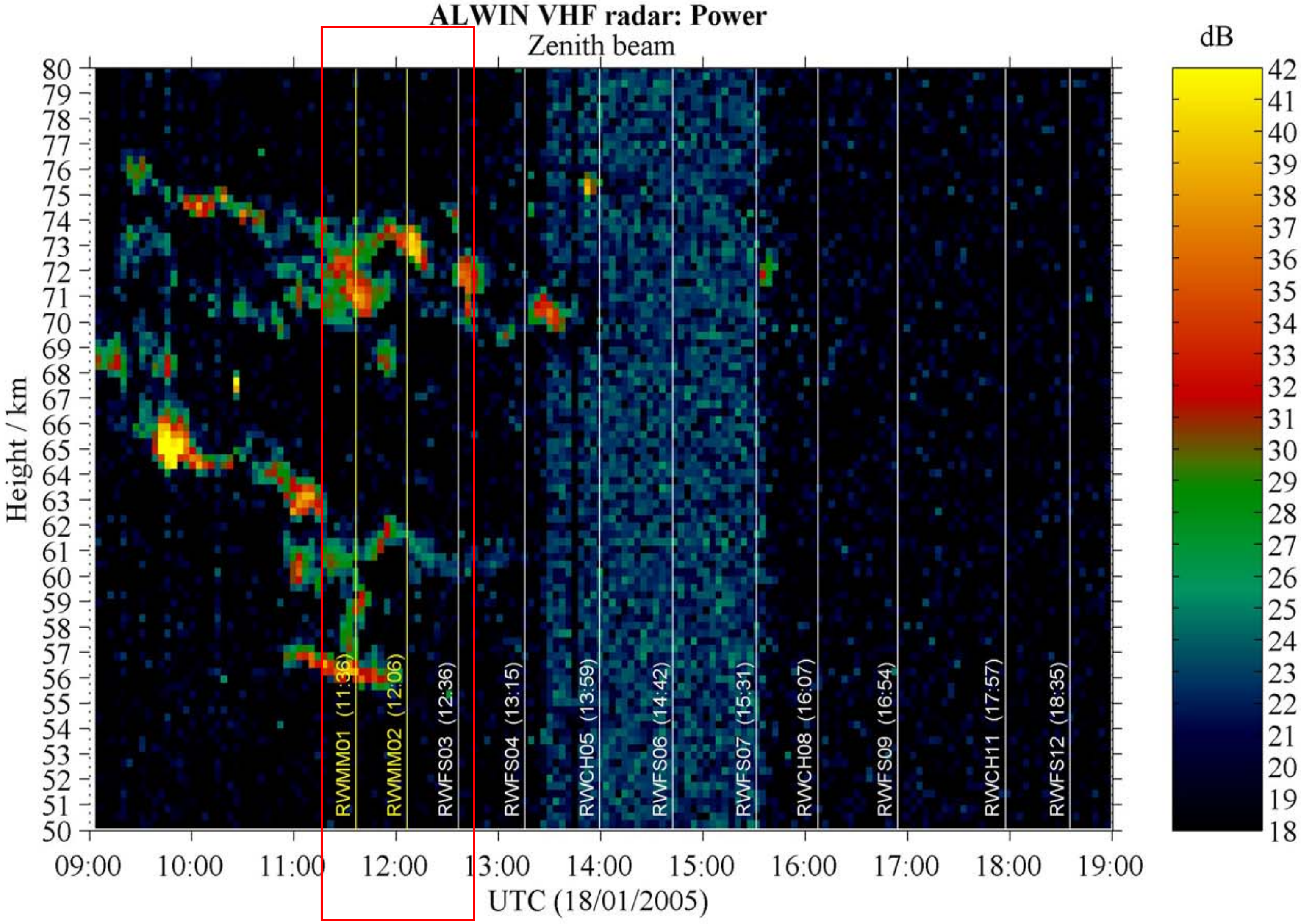




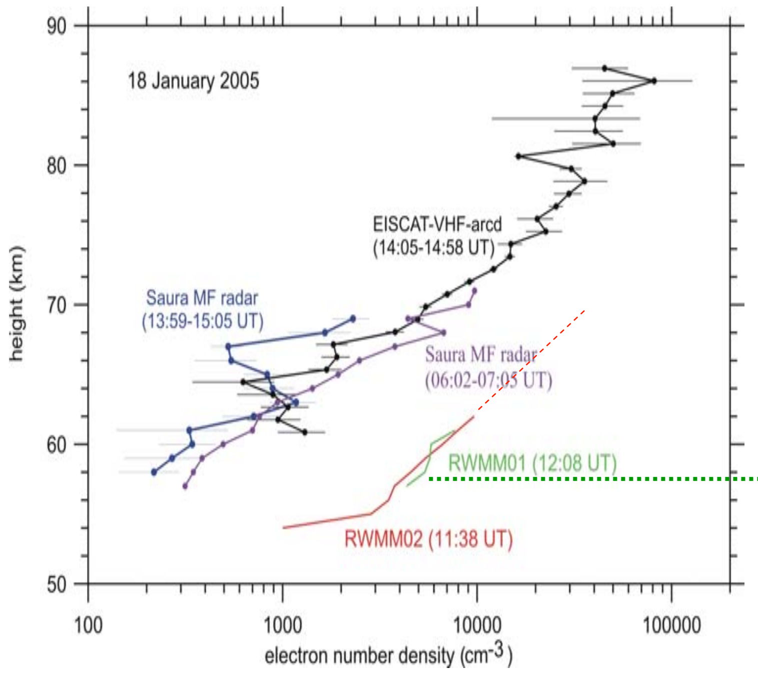
electron densities on **18 January** (06:30 UT) are still enhanced due to enhanced proton fluxes

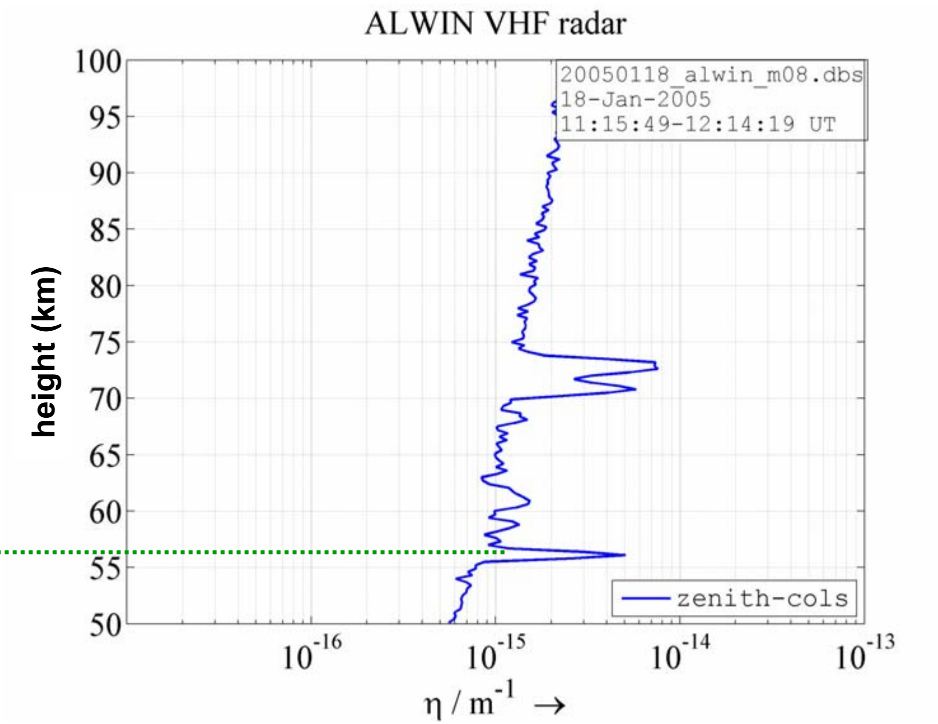


AWIN VHF radar
altitude [km]
log(η) [m^-1]
17/01
18/01
19/01
20/01
21/01
22/01
VHF radar
sounding rockets
Simultaneous
VHF/MF
measurements
Saura MF radar – energy dissipation rate (K/d)
height (km)
days January 2005


ALWIN VHF radar: Power
Zenith beam
Height / km
UTC (18/01/2005)
dB
RWMM01 (11:36)
RWMM02 (12:06)
RWFS03 (12:36)
RWFS04 (13:15)
RWCH05 (13:59)
RWFS06 (14:42)
RWFS07 (15:31)
RWCH08 (16:07)
RWFS09 (16:54)
RWCH11 (17:57)
RWFS12 (18:35)

Simultaneous measurements of radar reflectivity and insitu electron density

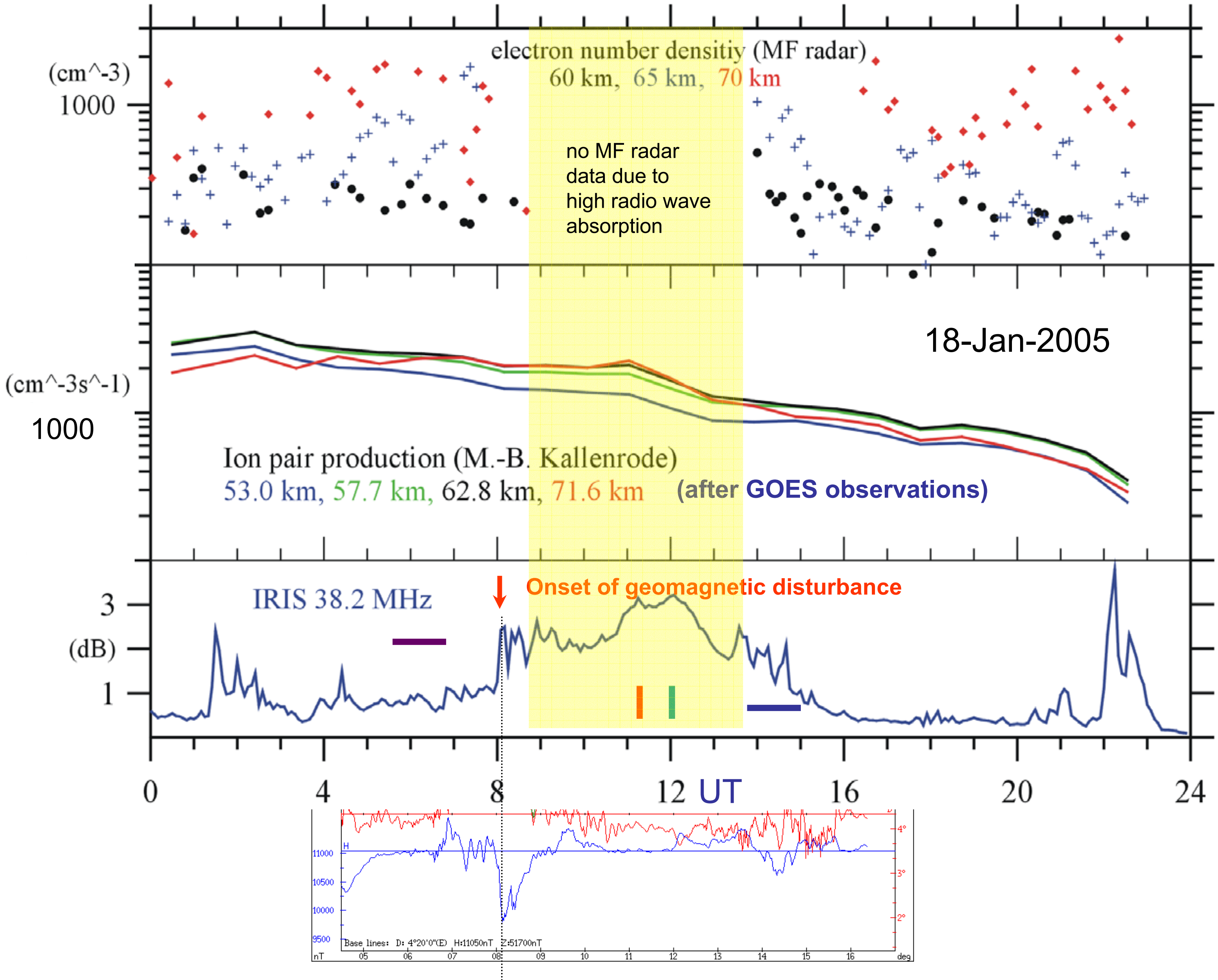




Insitu electron densities from radio wave propagation experiment increased by one order of magnitude at storm time

PMWE event with large vertical extension during a geomagnetic storm

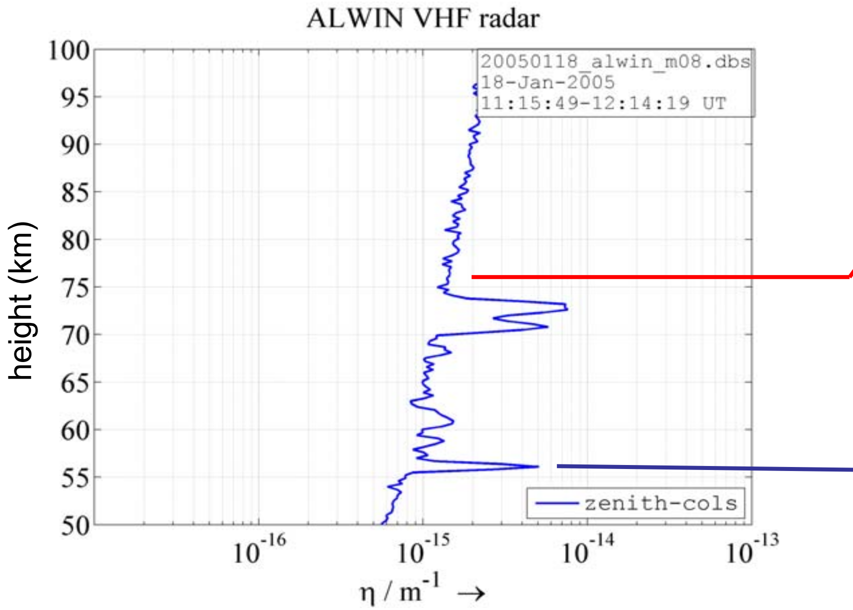
Geomagnetic storm on January 18, 2008

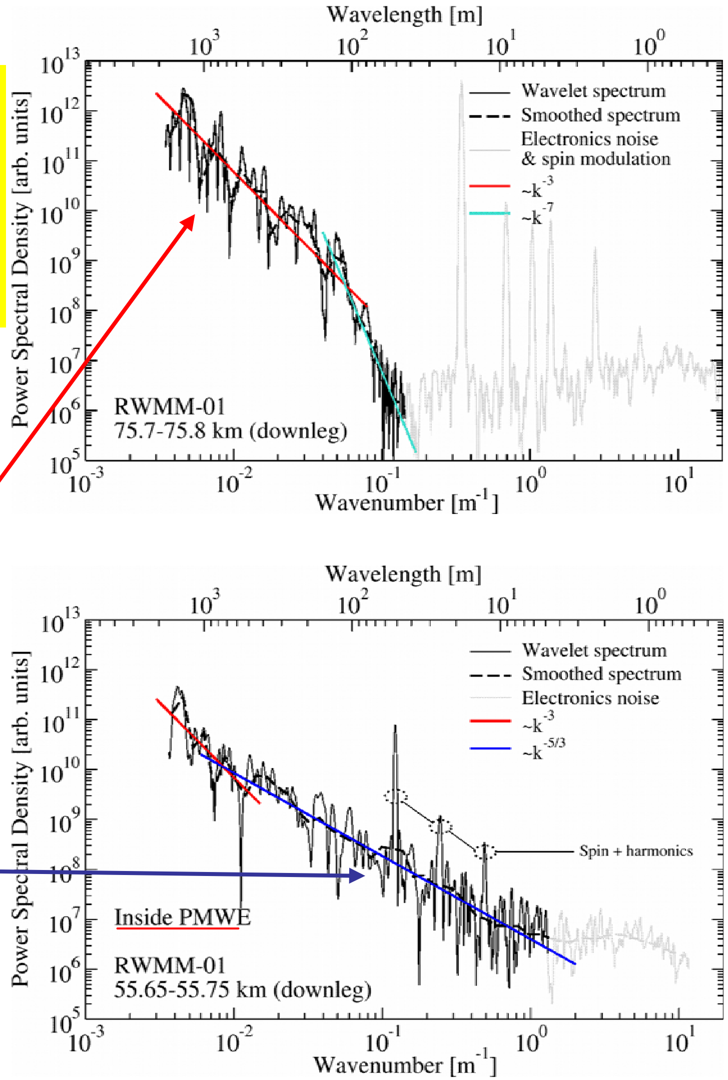


Insitu turbulence by PIP probe (ion fluctuations)

Brattli et al., ACP, 6, 5515-5524, 2006

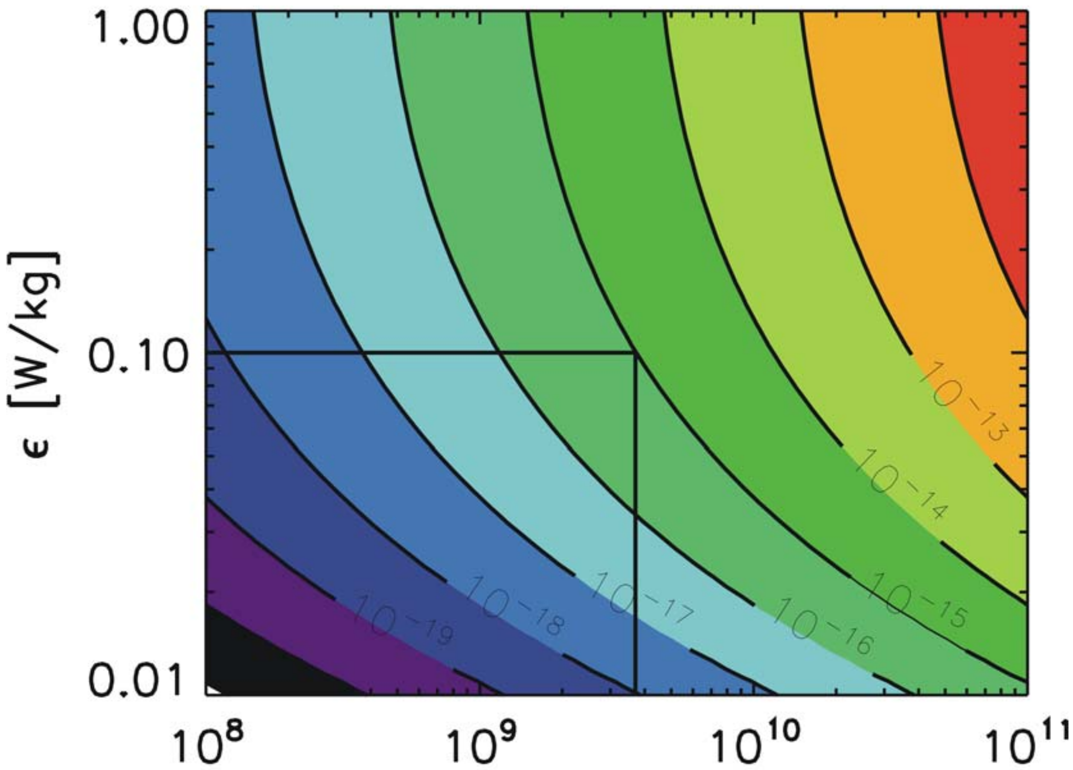
- non-turbulent spectrum outside the PMWE layer
- turbulent spectrum inside the PMWE layer





Theoretical values of radar reflectivity in dependence of turbulence and electron density

Insitu electron densities and observed PMWE radar reflectivities ($3 – 6 \cdot 10^{-15} m^{-1}$) result in realistic turbulence strengths.

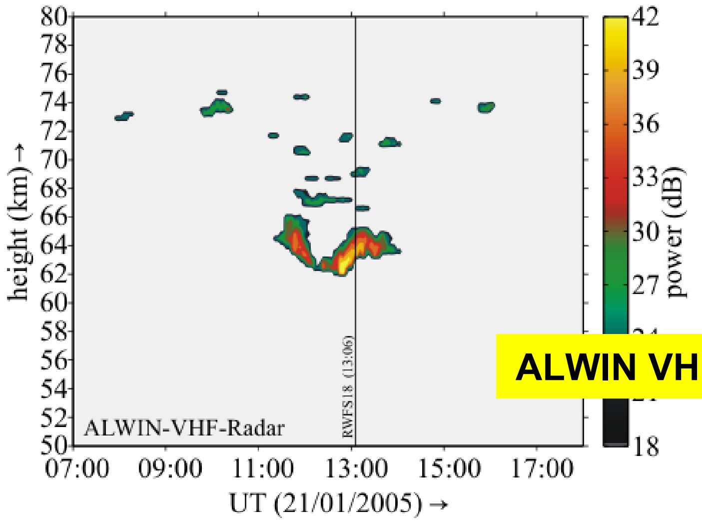


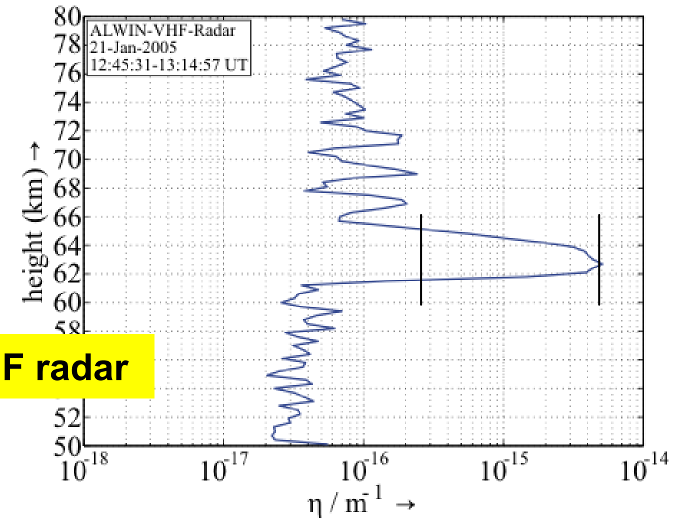
electron density (m^{-3})

PMWE on January 21, 2005

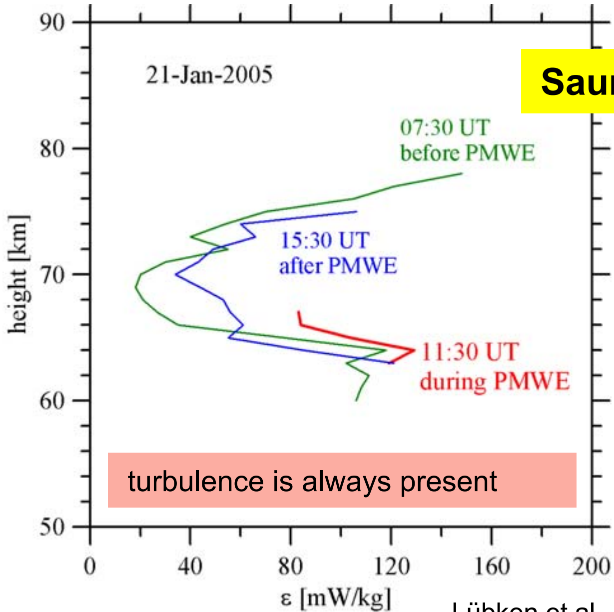
simultaneous observations of

- **radar reflectivity**
- **energy dissipation rates**
- **electron densities**

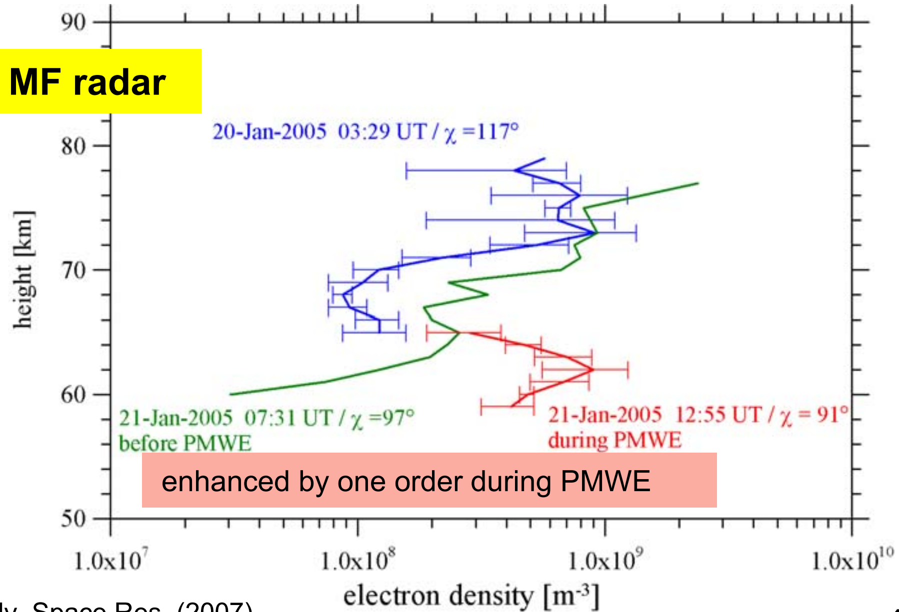




ALWIN VHF radar



Saura MF radar



turbulence is always present

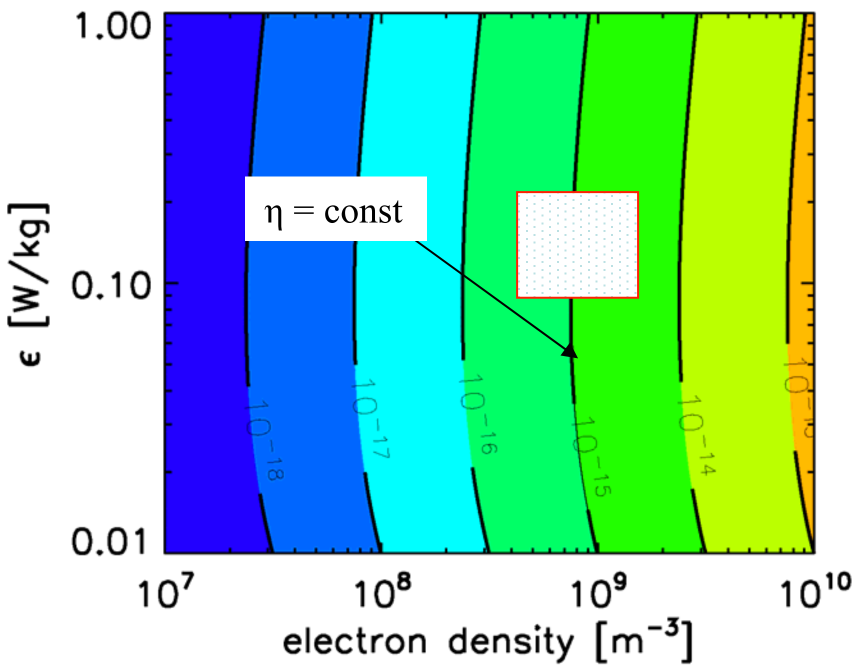
enhanced by one order during PMWE

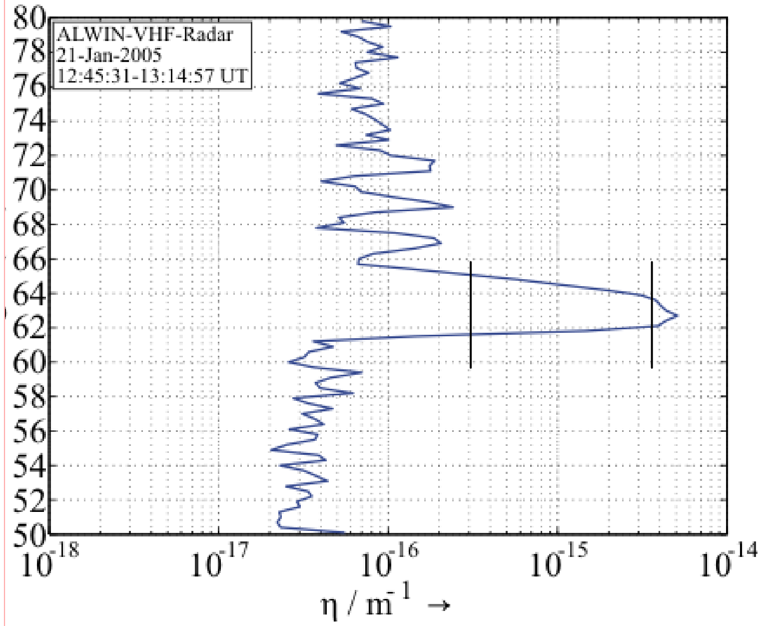
Lübken et al., Adv. Space Res. (2007)

model values of radar reflectivity η resulting from measured electron densities and turbulent energy dissipation rates ε with the Saura MF radar

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

ALWIN VHF radar: volume reflectivity

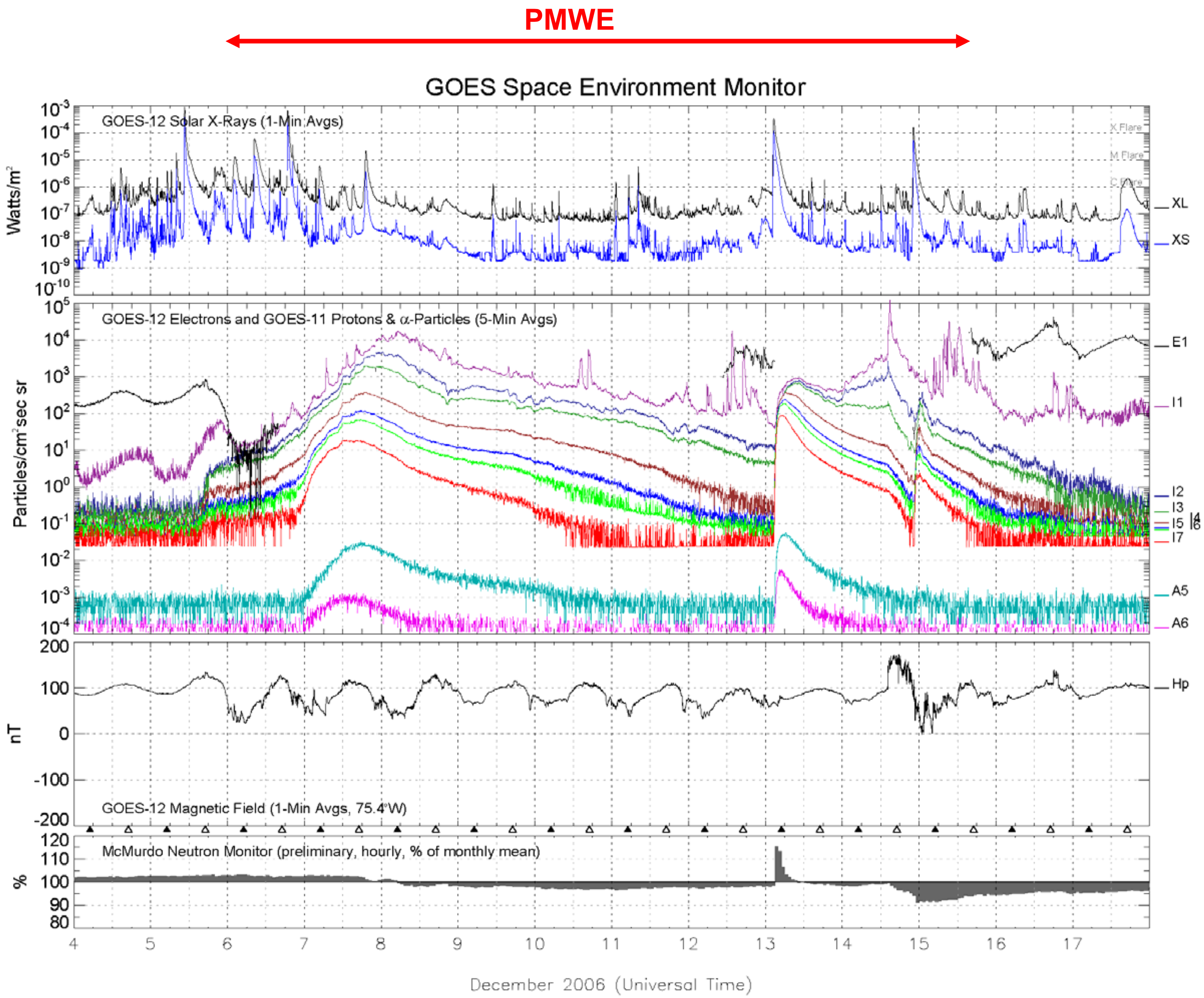




η (model) ~ η (ALWIN radar) ! ➔ PMWE is caused by turbulence

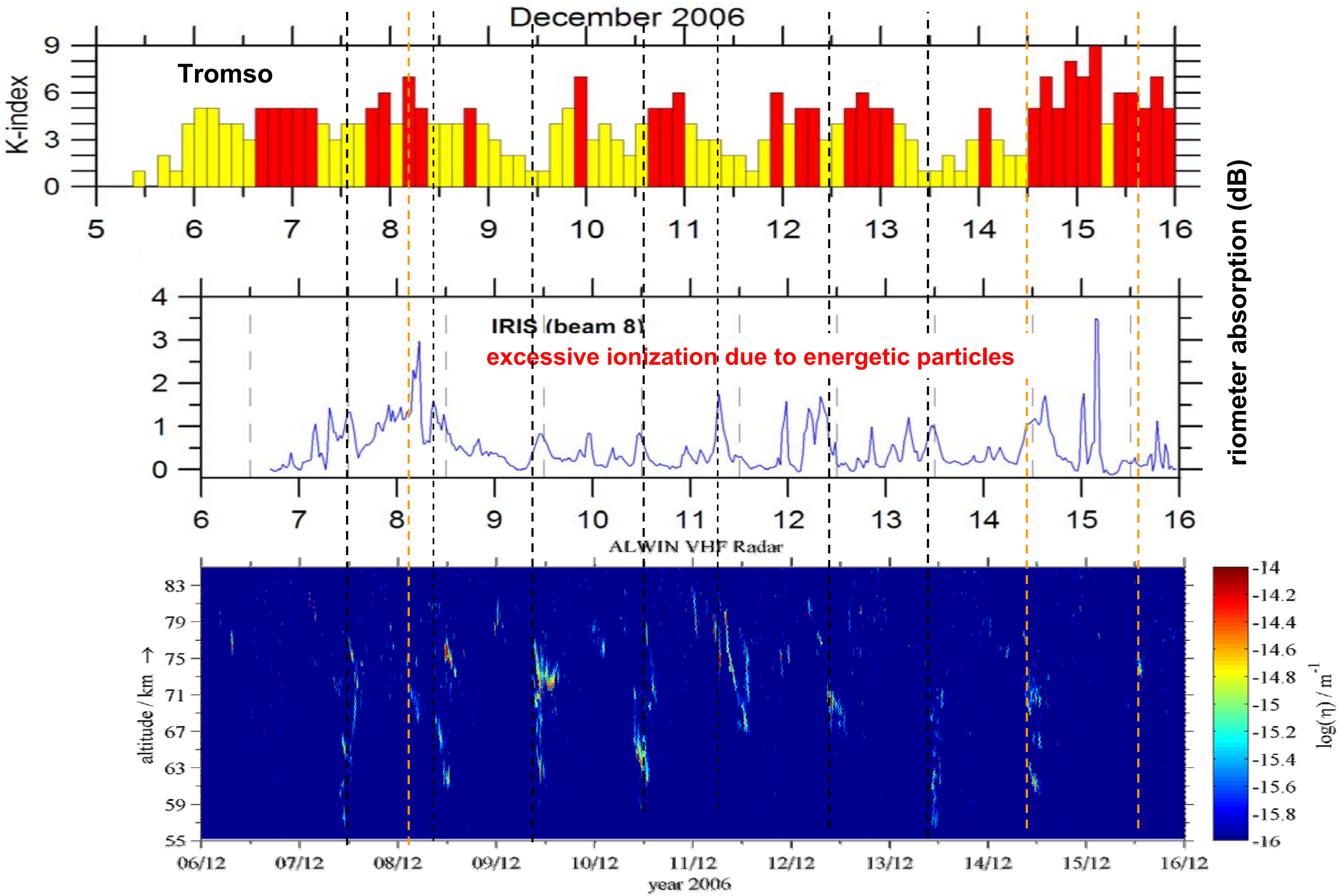
PMWE observations in 2006

December 6 - 15



PMWE
GOES Space Environment Monitor
GOES-12 Solar X-Rays (1-Min Avgs)
Watts/m²
X Flare
M Flare
C Flare
XL
XS
GOES-12 Electrons and GOES-11 Protons & α-Particles (5-Min Avgs)
Particles/cm²sec sr
E1
I1
I2
I3
I5
I7
I4
I6
A5
A6
Hp
nT
GOES-12 Magnetic Field (1-Min Avgs, 75.4°W)
McMurdo Neutron Monitor (preliminary, hourly, % of monthly mean)
%
December 2006 (Universal Time)

PMWE are highly correlated with enhanced riometer absorption

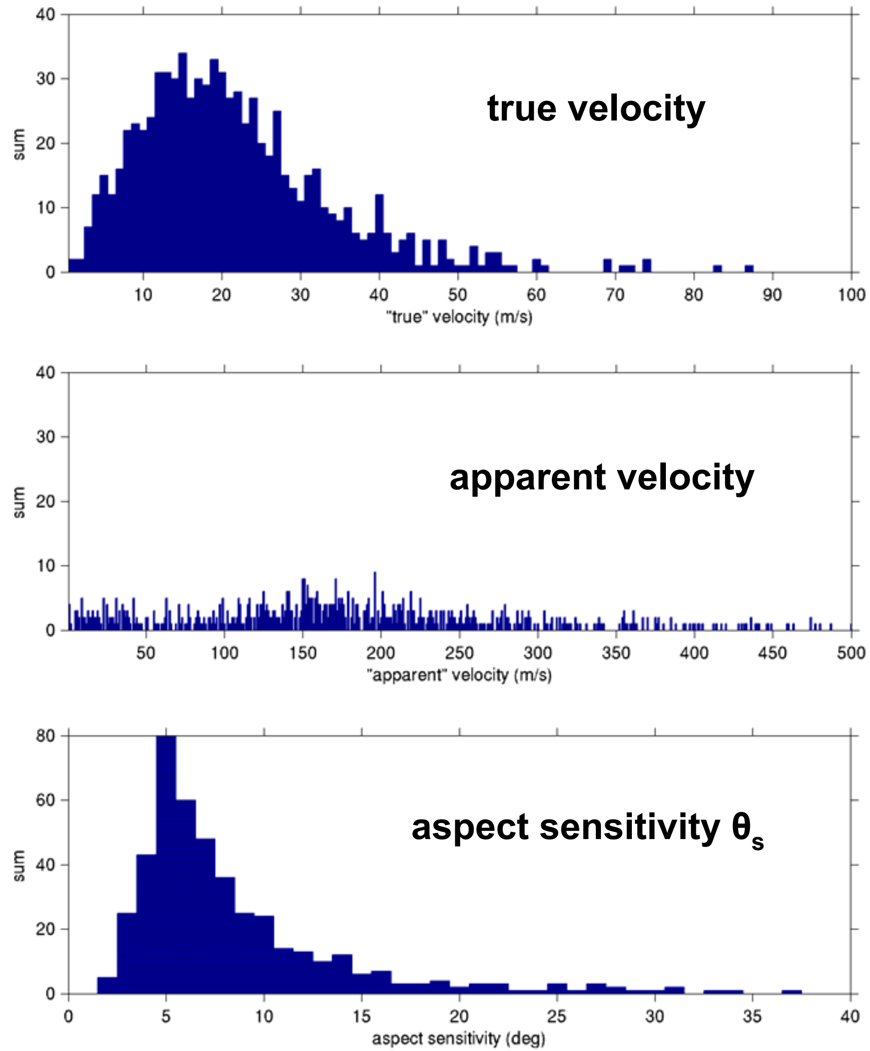


ALWIN VHF radar: no indications for specular reflections and extrem wind speeds

6 – 15 December 2006

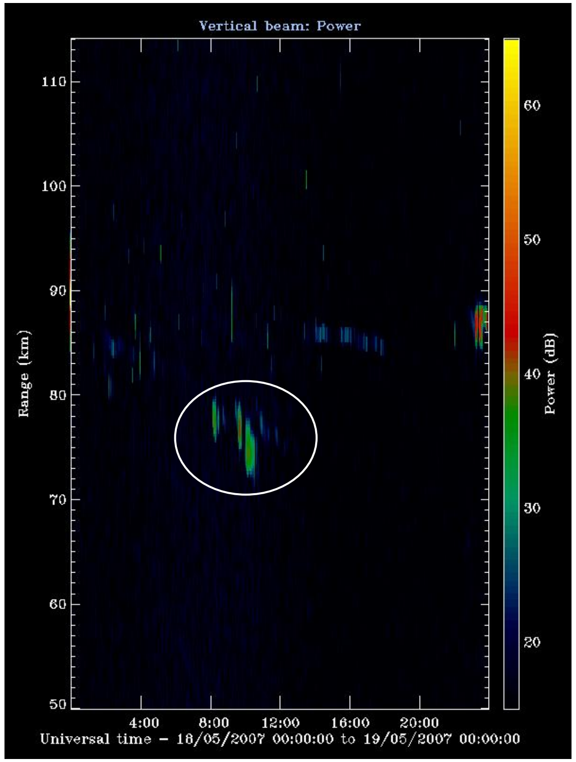
Spaced antenna observations:
Full Correlation Analysis (FCA),
without thresholds

no horizontal velocities > 100 m/s
no specular reflections $\theta_s < 3°$

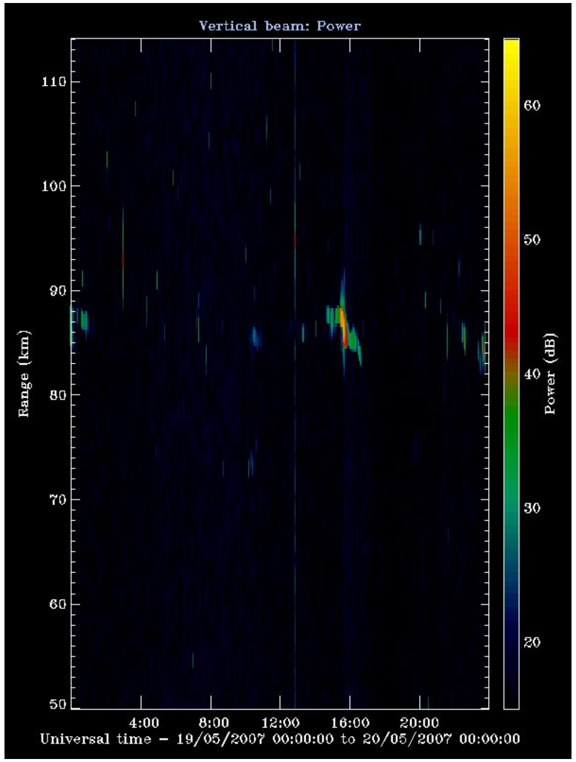


Simultaneous observations of PMWE/PMSE in May 2007

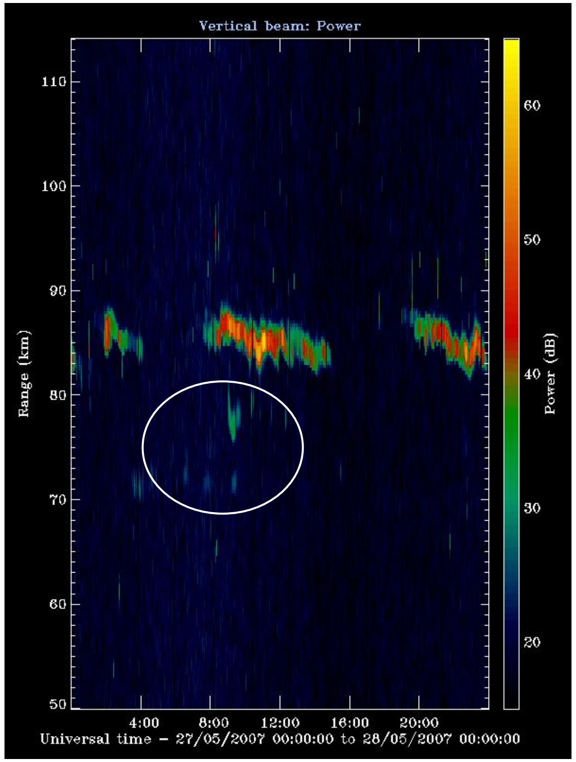
PMWE - 18 May



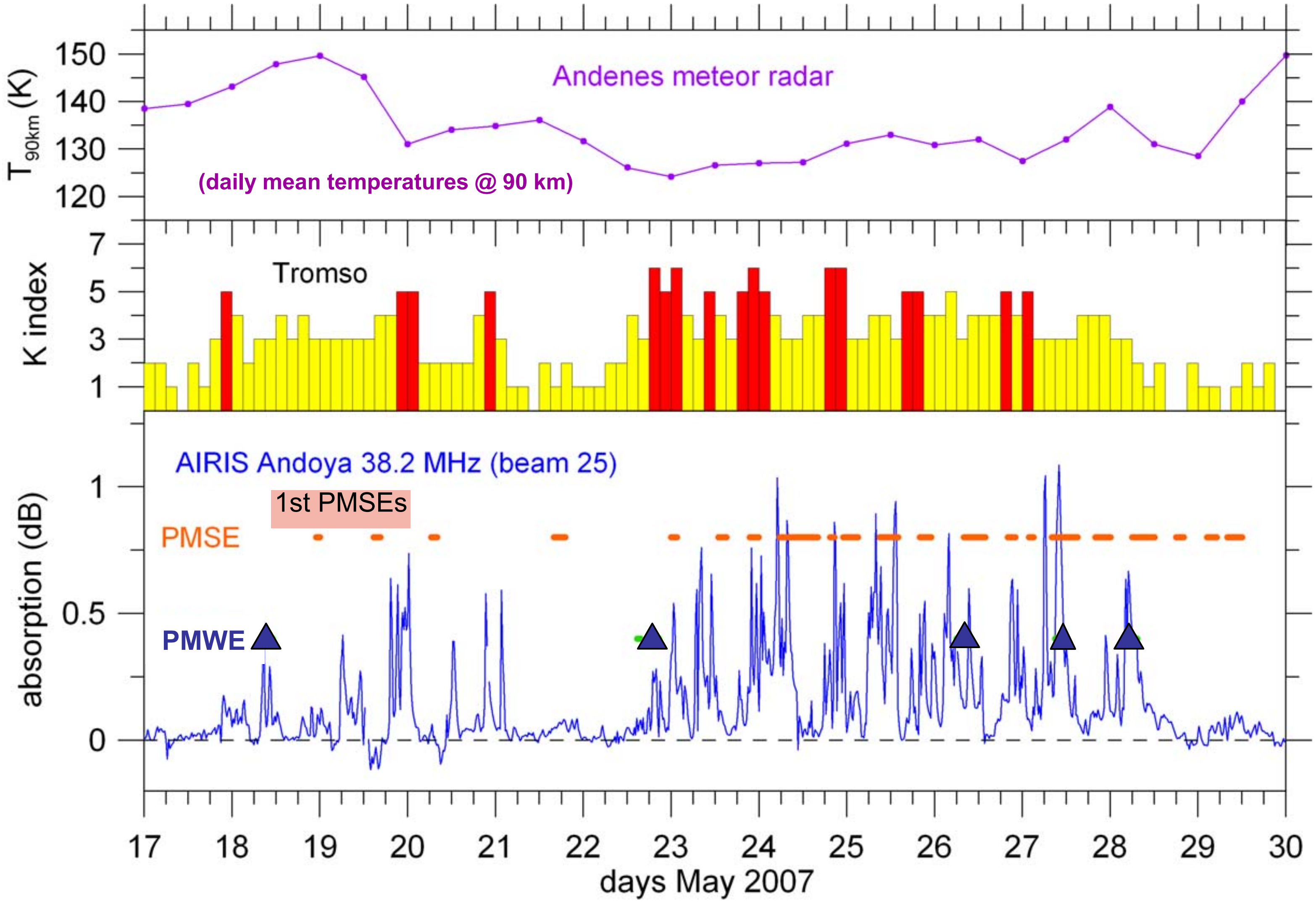
1st PMSE – 19 May



PMSE/PMWE – 27 May



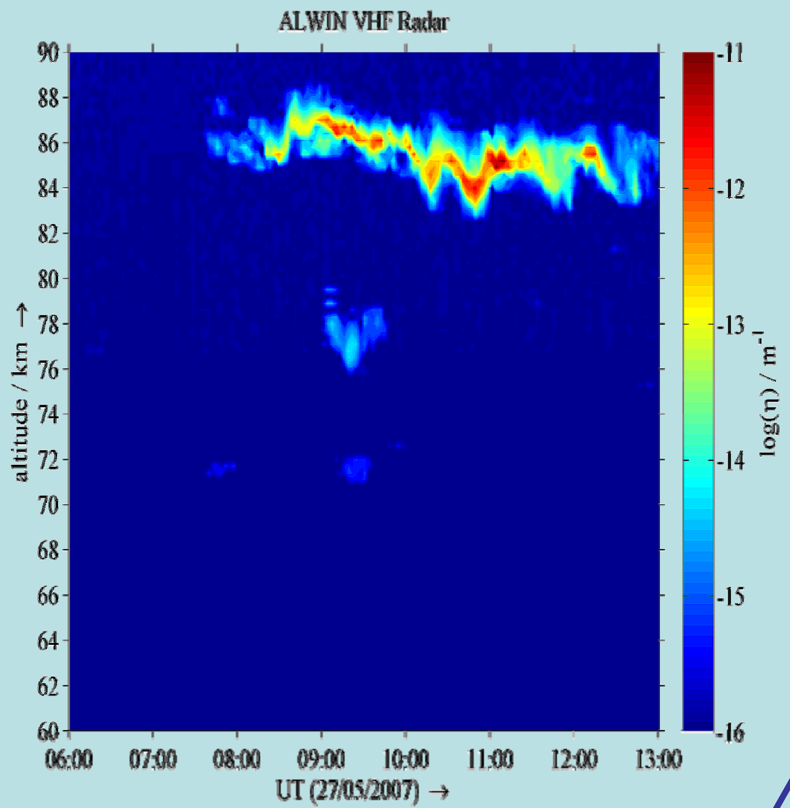
Occurrence of PMWE is well correlated with magnetically disturbed conditions (18-28 May) and enhanced riometer absorption



ALWIN VHF radar

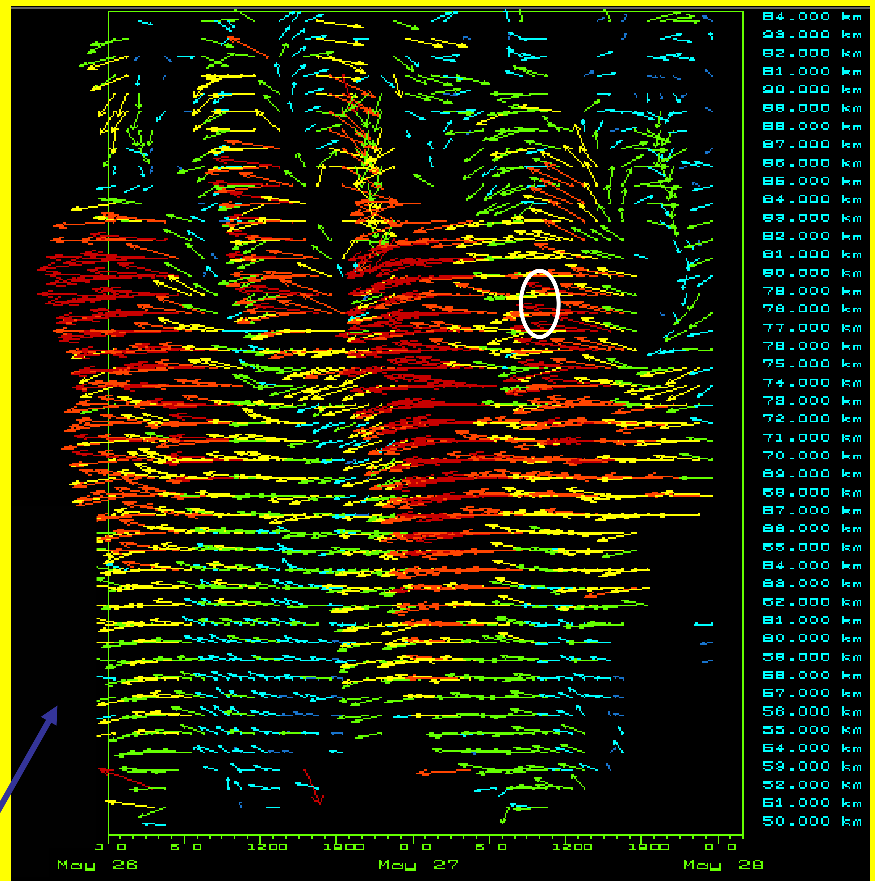
PMWE 27 May 09-10 UT

radar reflectivity



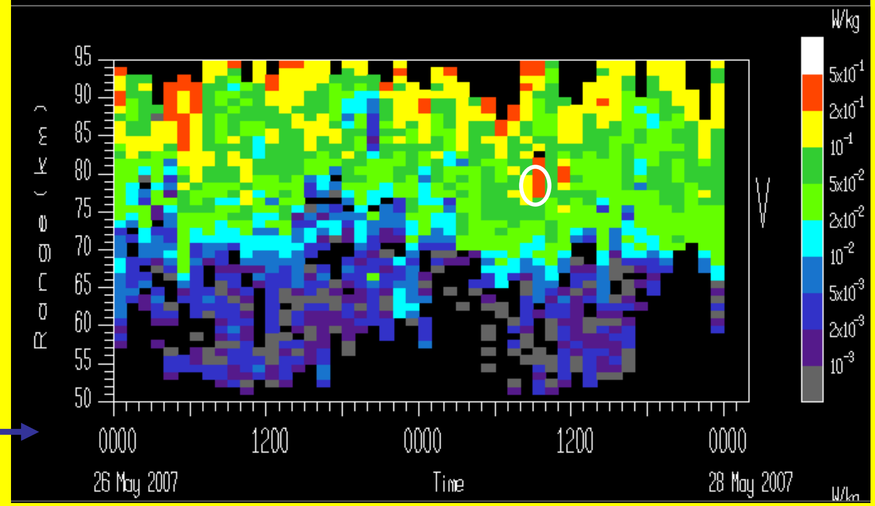
Saura MF radar

PMWE



horizontal winds

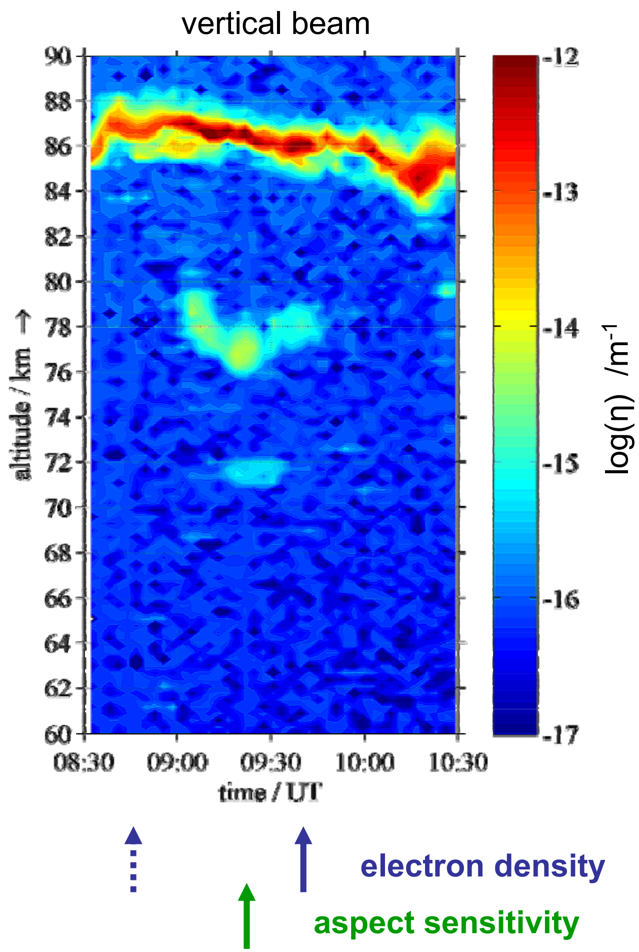
energy dissipation rates

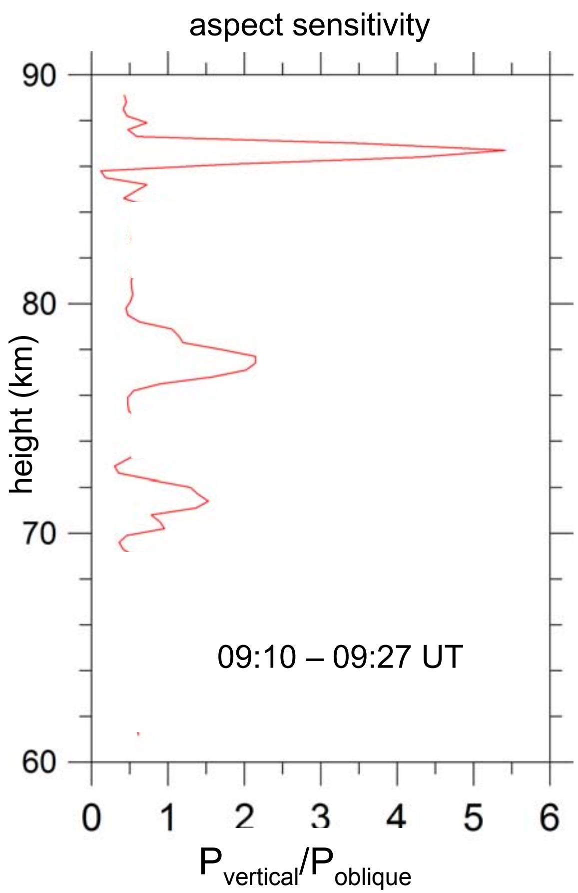


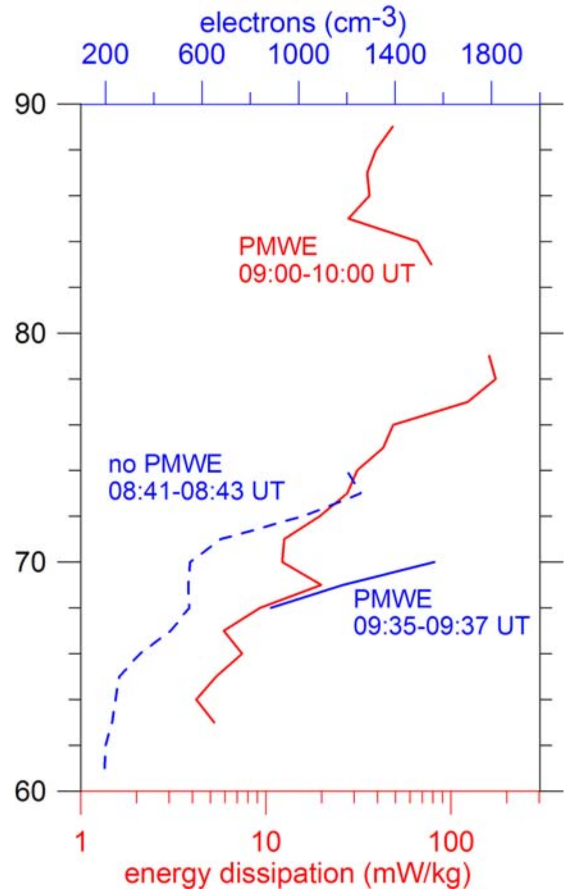
27 May 2007

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

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







Summary

PMWE - radar echoes below ~80 km

- radar reflectivities @ 53.5 MHz: $\sim 2 \cdot 10^{-16}$ - $\sim 8 \cdot 10^{-15}$ 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: $\sim 4 \cdot 10^{8}$ - 10^{9} electrons/m^{-3} ,increased by about one order of magnitude during solar activity storms and geomagnetic storms

Thank you!