Multi-radar studies of PMSE: implications for mesospheric large scale variability and microphysical processes

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Outline

1. Interhemispheric variation of mesospheric ice particles
   - PMSE observation at Andenes (69N) and Davis (69°S)
   - Modelling of NH/SH-temperature difference with LIMA

2. Deriving microphysical parameters from calibrated observations of PMSE
   - Measurements of η(PMSE) at three Bragg-scales
   - Particle parameters from 2-frequency observations

List of papers

- R. Latteck, W. Singer, R. J. Morris, W. K. Hocking, D. J. Murphy, D. A. Holdsworth und N. Swarnalingam, Similarities and differences in polar mesosphere summer echoes observed in the Arctic and Antarctica, *Ann. Geophys.*, 26, 2795-2806, 2008.
- F.-J. Lübken and U. Berger, Interhemispheric comparison of mesospheric ice layers from the LIMA model, *JASTP*, 69, 2292-2308, 2007.

- M. Rapp, I. Strelnikova, R. Latteck, P. Hoffmann, U.-P. Hoppe, I. Häggström, M.T. Rietveld, Polar mesosphere summer echoes (PMSE) studied at Bragg wavelengths of 2.8 m, 67 cm, and 16 cm, *JASTP*, 70 (7), 947-961, 2008.
- Q. Li, M. Rapp, J. Röttger, R. Latteck, M. Zecha, M. Hervig, C. Hall, Microphysical parameters of mesospheric ice clouds derived from calibrated observations of polar mesosphere summer echoes at Bragg wavelengths of 2.8 m and 30 cm, *submitted to JGR,* 2009.

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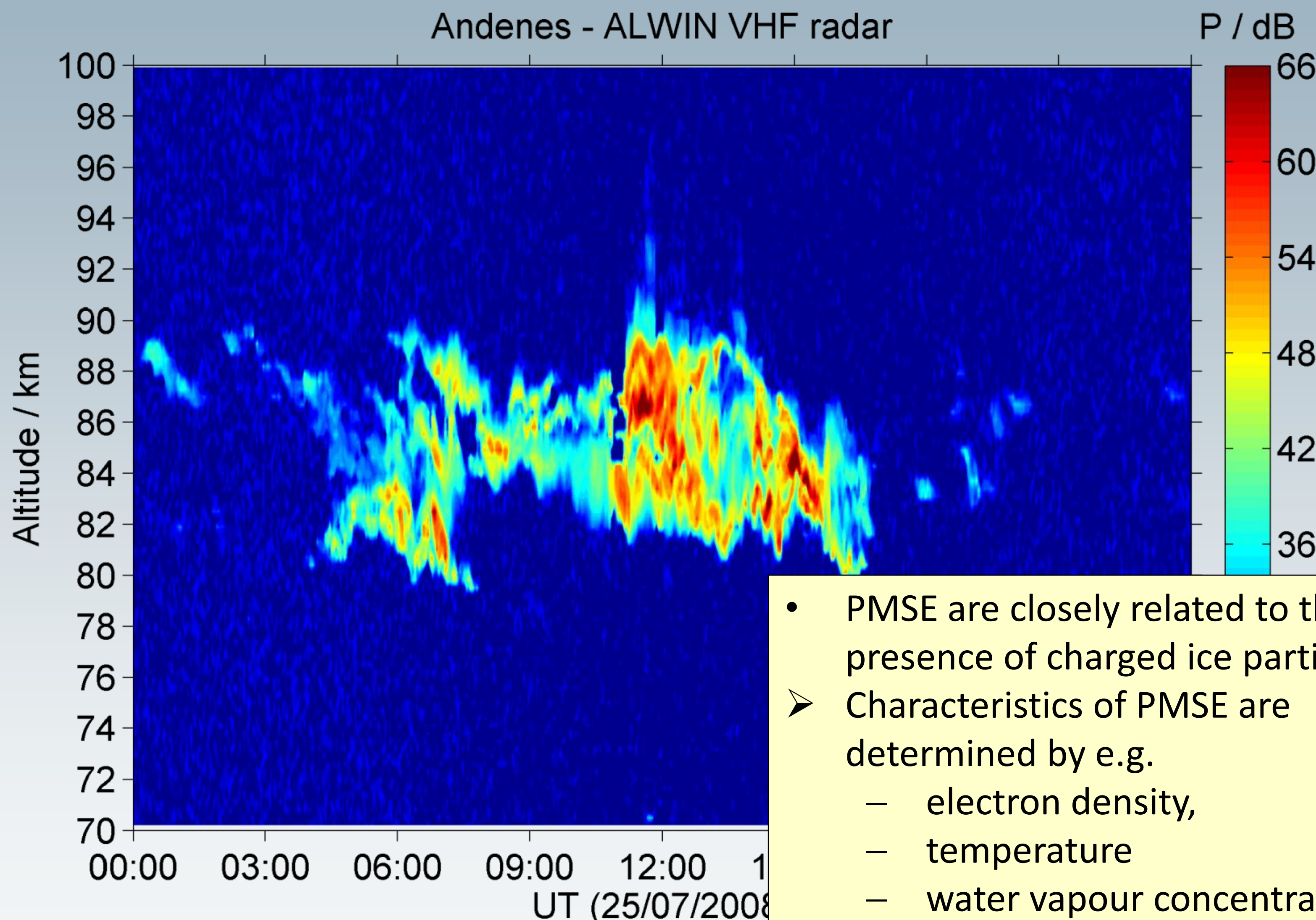
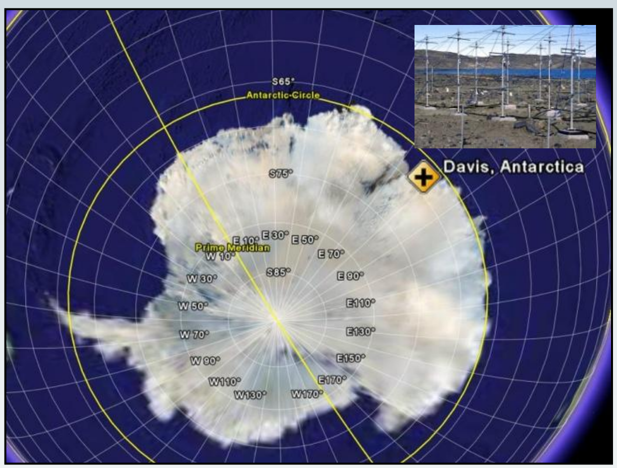
INTERHEMISPHERIC VARIATION OF MESOSPHERIC ICE PARTICLES

Polare **M**esosphere **S**ummer **E**choes



- PMSE are closely related to the presence of charged ice particles
- ➢ Characteristics of PMSE are determined by e.g.
  - – electron density,
  - – temperature
  - – water vapour concentration

Comparison of PMSE observations from 69°N and 69°S



Parameters \ Radar	ALWIN 69°N; 16°E	Davis-VHF-Radar 69°S; 78°E		
Installation / upgrade	1998	2003	2005	2006
Radar wavelength	5.6 m	5.5 m		
Peak power	36 kW	20 kW	36 kW	41 kW
Gain of Tx antenna array	28.3 dBi	28.9 dBi		
Half-power beam width	6°	6°		
Gain of SA receiving antenna array	20.6 dBi	21.0 dBi		
Efficiency	0.6	0.5		
Effective pulse width	300 m	600 m	450 m	
→ system factor c_{sys}	**2.1e-08**	**1.9e-08**	**1.4e-08**	**1.2e-08**
Experiment parameters				
Number of coherent integrations	32	116	104	
Number of code elements	16	1	8	
Receiver gain	101 dB	81 dB	81 dB	
Receiver bandwidth	500 kHz	368 kHz	280 kHz	
→ signal factor c_s	**3.5e-19**	**1.5e-21**	**1.5e-20**	

Volume reflectivity η

$$\eta_{radar}[m^{-1}] = \frac{P_r \cdot 128 \cdot \pi^2 \cdot 2 \cdot \ln(2) \cdot r^2}{P_t \cdot G_t \cdot G_r \cdot \lambda^2 \cdot e \cdot \Theta_{1/2}^2 \cdot c \cdot \tau}$$

$$\eta_{radar}[m^{-1}] = \sum_i \frac{\sigma_i}{1[m^{-3}]} = \frac{\sigma}{V}$$

P_t	=	transmitted peak power [W]
P_r	=	received signal power [W]
G_t	=	gain of transmit antenna
G_r	=	gain of receive antenna
λ	=	radar wave length
e	=	efficiency
$\Theta_{1/2}$	=	half power half width of transmit antenna
r	=	range to volume center
$2 \ln(2)$	=	beam correction factor
c	=	speed of light
τ	=	pulse width

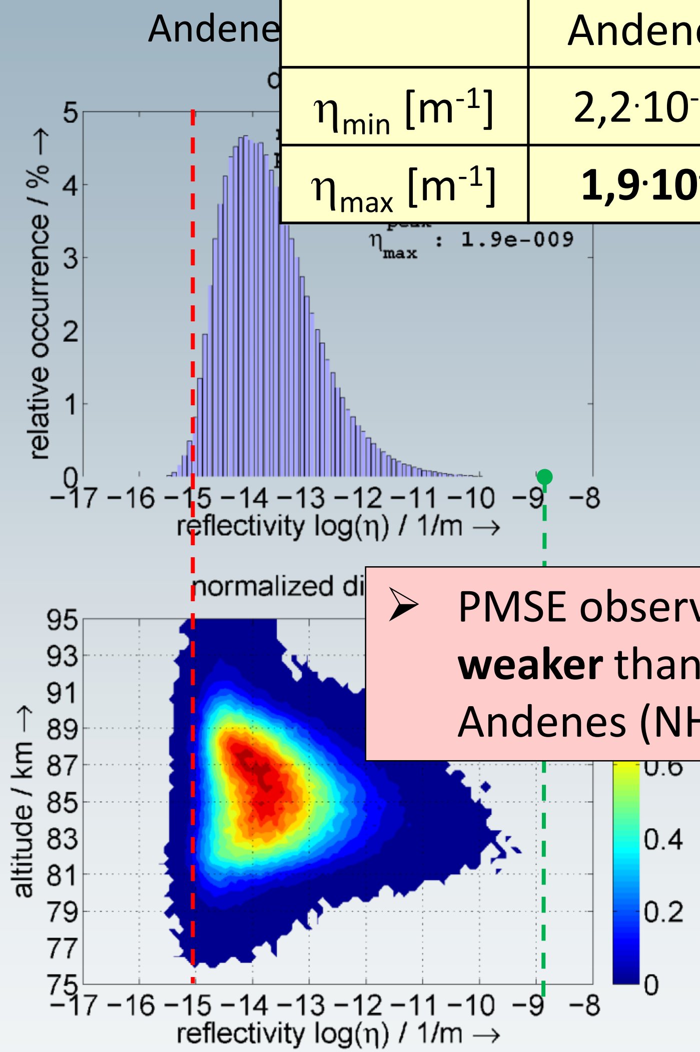
$$\Delta z = \frac{c \cdot \tau}{2}$$

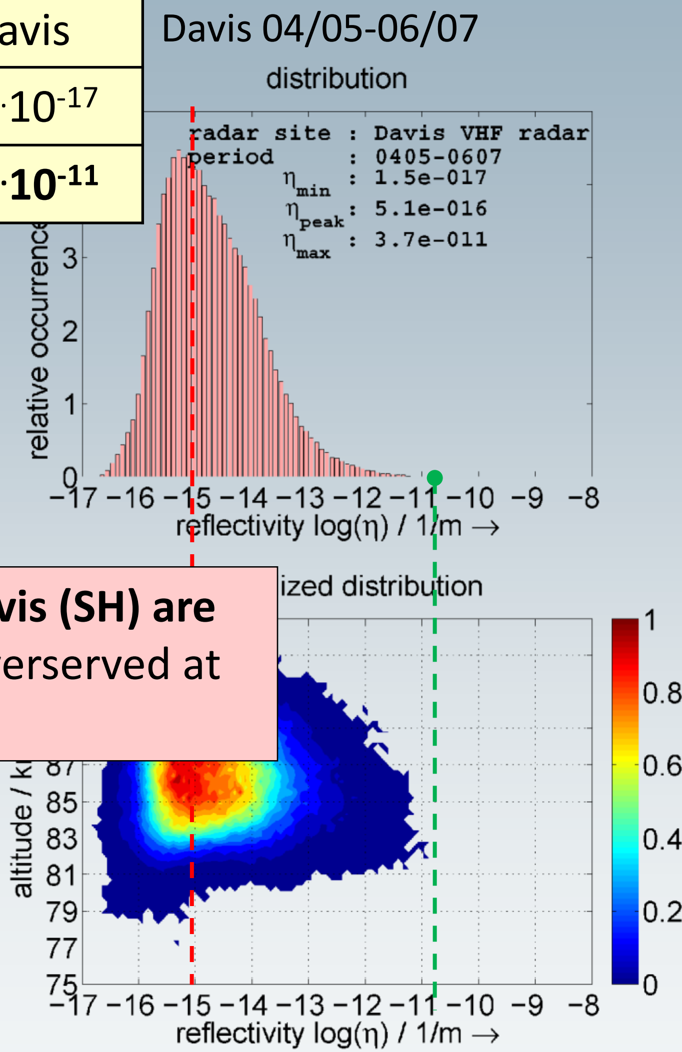
$$\eta_{radar} = P_r \cdot c_{sys} \cdot r^2$$

- volume reflectivity η
  (*Hocking and Röttger, RS, 1997*)
  - Sum of all backscatter cross sections σ_i per unit volume
  - includes all system parameters !
- determination of other physical parameters from absolute received power
  - Energy dissipations rates
- absolute calibration is required

Andenes (69N) – Davis (69°S)
distribution of PMSE volume reflectivity

	Andenes	Davis
η_{min} [m^{-1}]	$2{,}2 \cdot 10^{-16}$	$1{,}5 \cdot 10^{-17}$
η_{max} [m^{-1}]	**$1{,}9 \cdot 10^{-9}$**	**$3{,}7 \cdot 10^{-11}$**





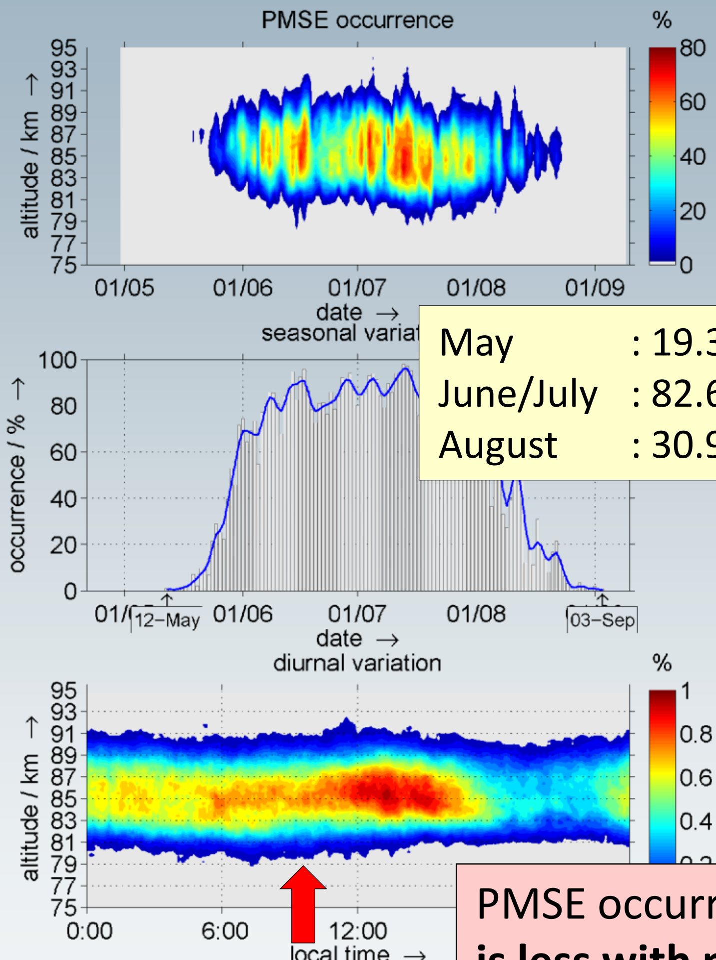
- PMSE observed **at Davis (SH) are weaker** than PMSE overserved at Andenes (NH)

Latteck et al., AnGeo, 2008

Andenes (69N) – Davis (69°S)

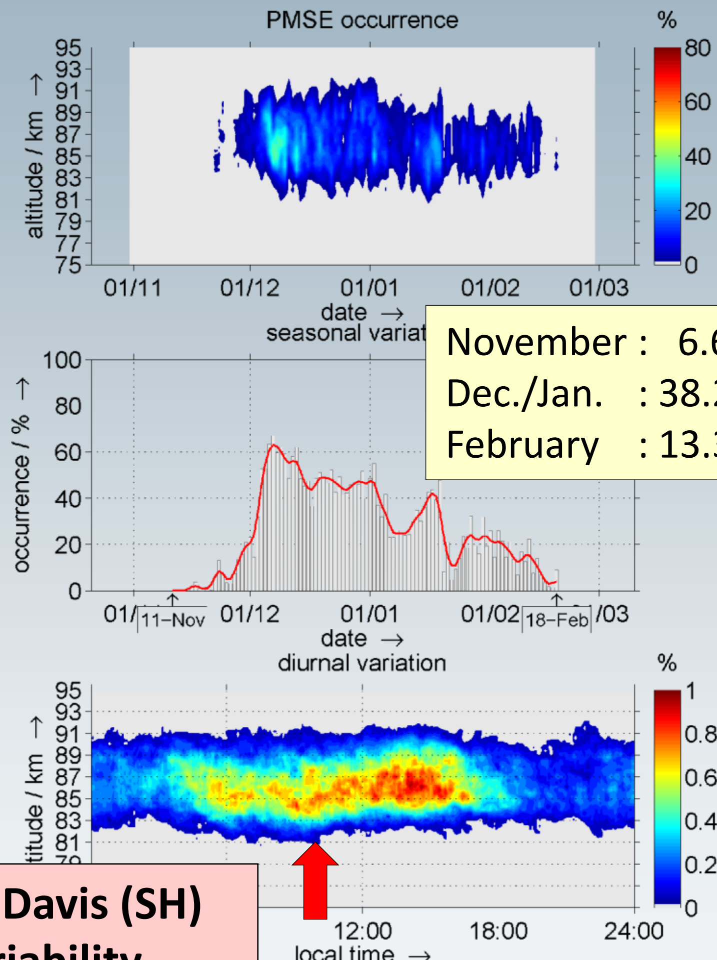
mean seasonal variation of PMSE occurrence for $\eta > 1 \cdot 10^{-15}\ m^{-1}$

Andenes 2000-2006



May	: 19.3 %
June/July	: 82.6 %
August	: 30.9 %

Davis 04/05-06/07



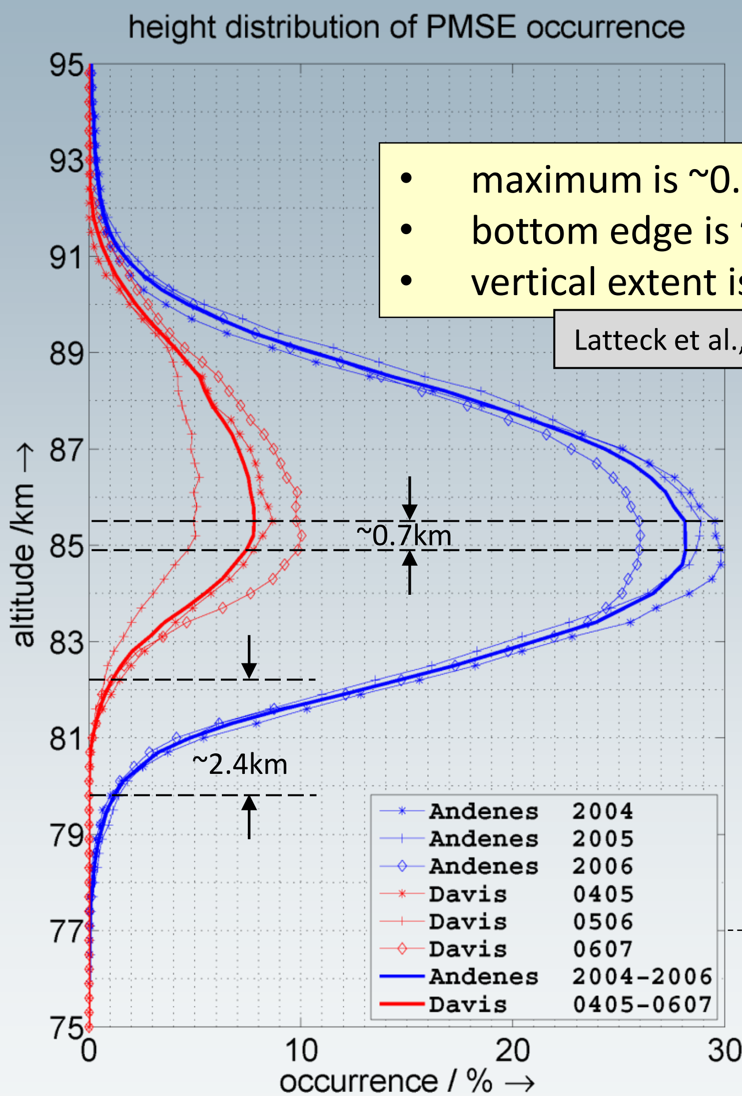
November	: 6.6 %
Dec./Jan.	: 38.2 %
February	: 13.3 %

PMSE occurrence **at Davis (SH) is less with more variability** than at Andenes (NH)

Latteck et al., AnGeo, 2008

Andenes (69N) – Davis (69°S)

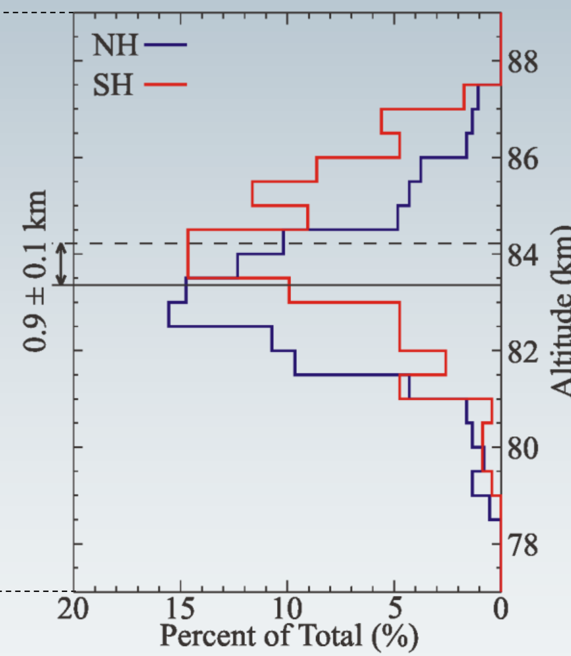
PMSE height distribution



The PMC altitude distribution as a percentage of the total number of PMCs observed by HALOE from 1991 to 2005 and latitudes between 55° and 70°

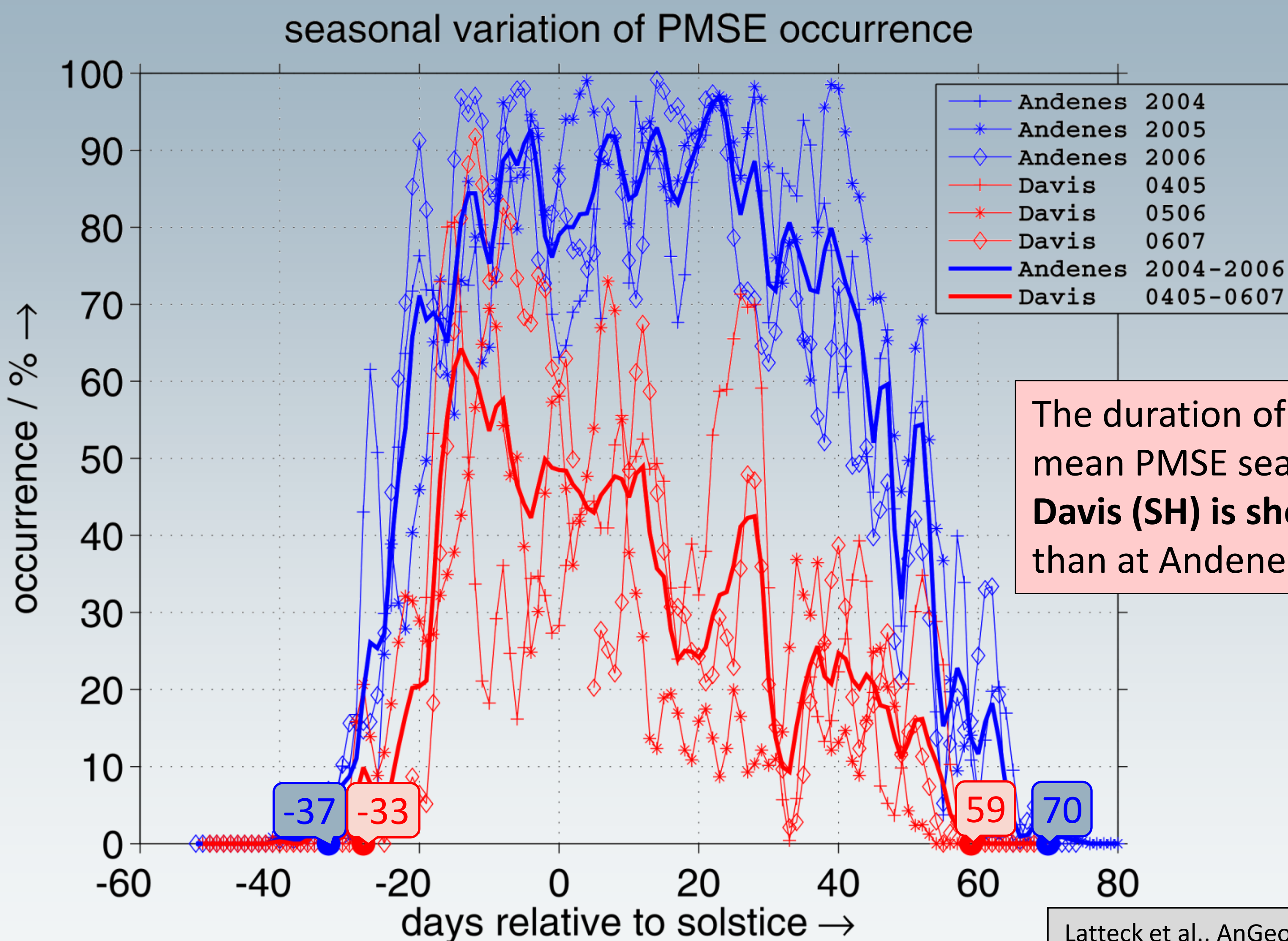
- maximum is ~0.7 km higher at Davis (SH) than at Andenes (NH)
- bottom edge is ~2.4 km higer at Davis than at Andenes
- vertical extent is ~ 3 km smaller at Daivs than at Andenes

Latteck et al., AnGeo, 2008



Wrotny et al., JASTP, 2006

Andenes (69N) – Davis (69°S)

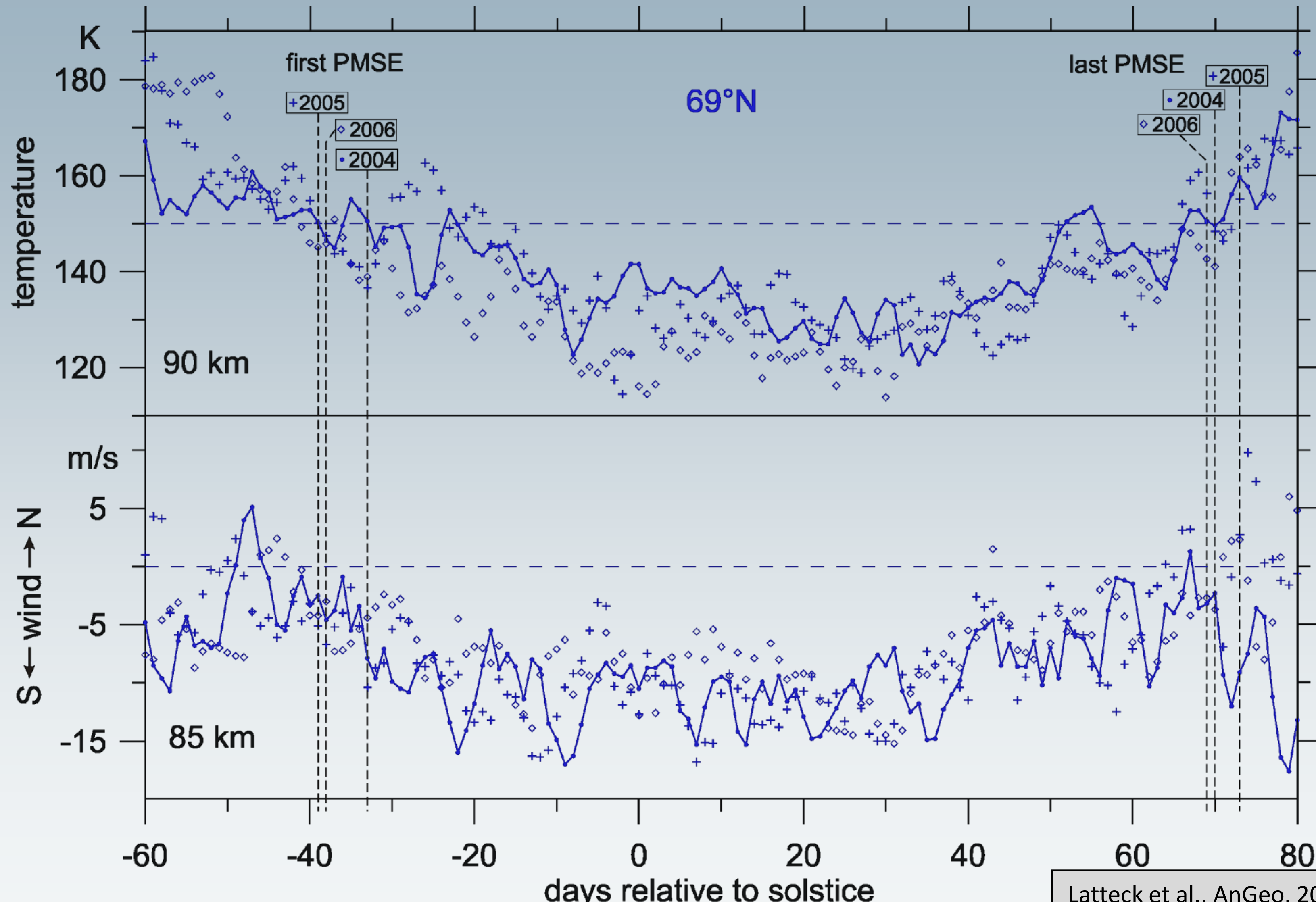


The duration of the mean PMSE season at **Davis (SH) is shorter** than at Andenes (NH)

Latteck et al., AnGeo, 2008

Comparison of PMSE observations from 69°N

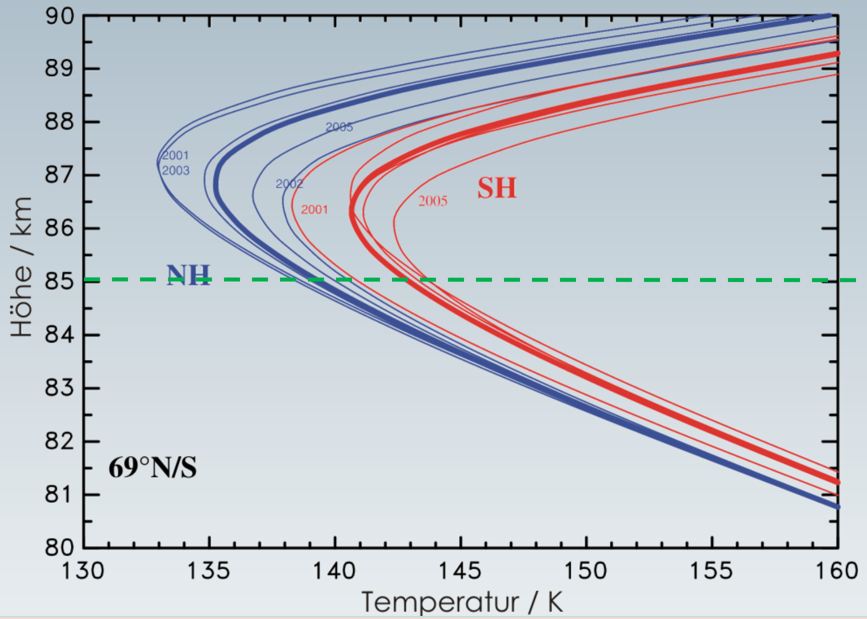
mean temperatures and mean meridional winds

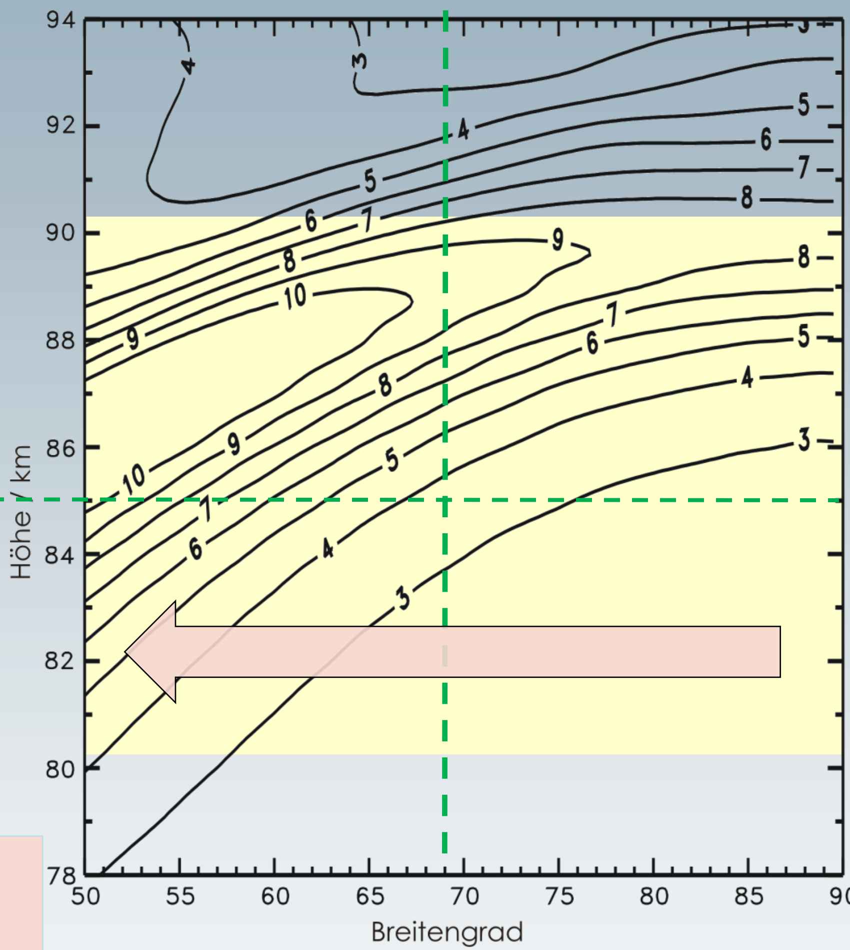


Latteck et al., AnGeo, 2008

Modelling of NH/SH temperature difference of the polare summer mesopause region using LIMA

- 3-D GCM for studying the interhemispheric similarities and differences in the background atmosphere between 0 and 150km
- Includes physical and chemical processes (dynamic, transport, chemistry, radiation





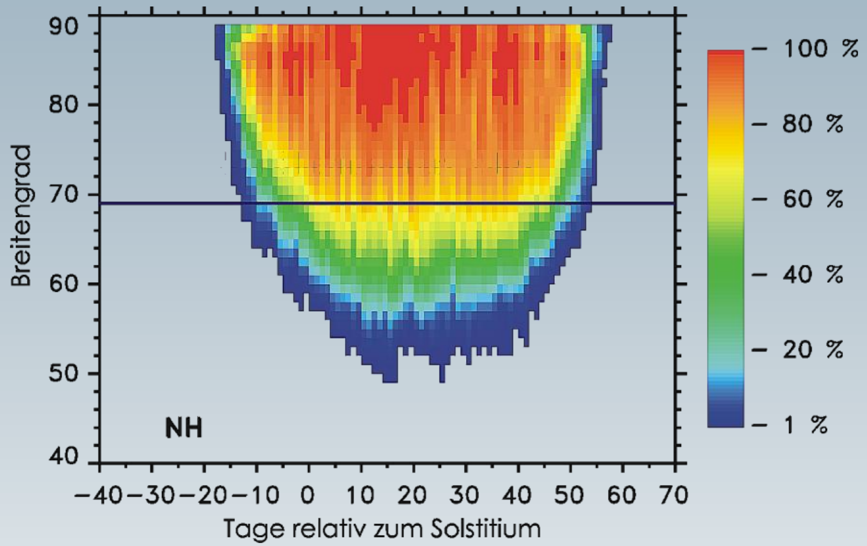
- In the altitude range of ice layers (80 - 90 km) the SH is warmer by 1-10K
- The difference is largest around the mesopause
- SH-NH temperature difference increases with decreasing geographical latitude

Lübken and Berger, JASTP, 2007

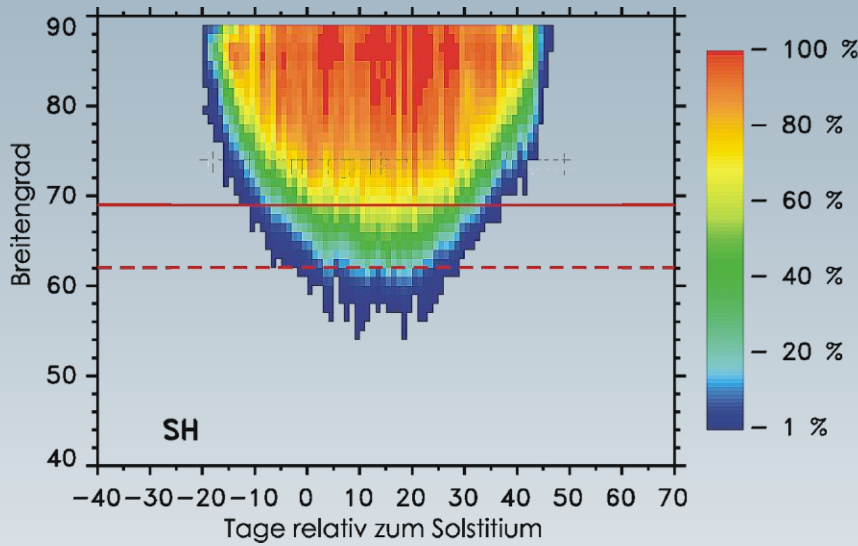
LIMA-ICE modelling

Seasonal variation of PMSE as function of geographic latitude

Northern hemisphere 2001



Southern hemisphere 2004/2005



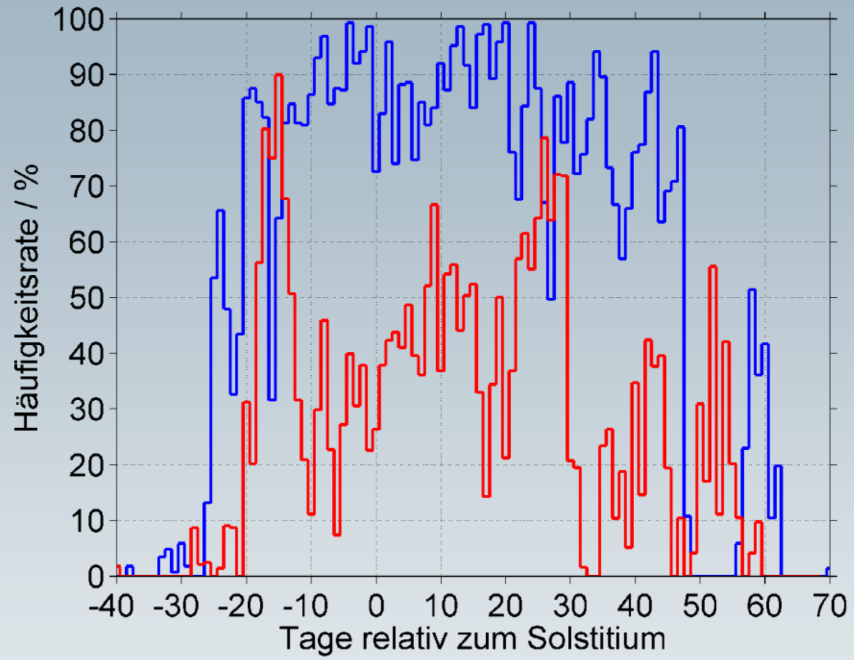
- PMSE occurrence increases towards polar latitudes in both hemispheres.
- PMSE are
  - practical present in both hemispheres from the pole to ~75°
  - basically disappear equator-ward of approximately 50°N and 60°S respectively
  - extend further equator-ward in the NH compared to SH

Lübken and Berger, JASTP, 2007

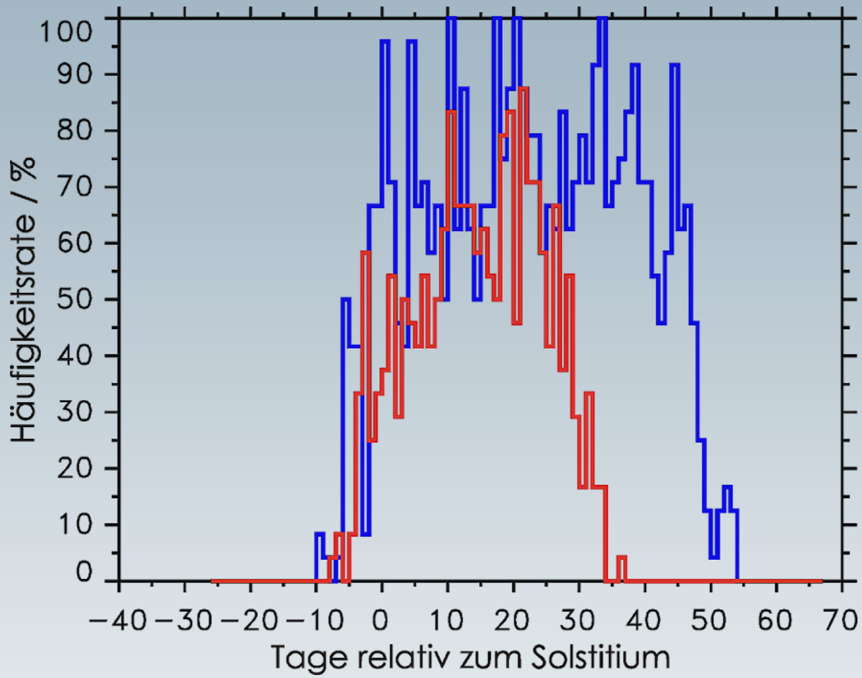
PMSE occurrences from observations and LIMA-ICE modelling

Andenes (69°N,16°O; 2001) and Davis (69°S,78°O; 2004/2005)

Radar observations



LIMA-ICE model results



- LIMA-ICE reproduces the main PMSE features as observed by various radars in the NH and SH
- ➢ **The NH/SH similarities and differences of PMSE are most likely determined by the thermal structure**

Lübken and Berger, JASTP, 2007

Summary part 1

- PMSE observed at Davis (69°S) have
  - a weaker volume reflectivity ($4 \cdot 10^{-11}\ m^{-1}$) than PMSE observed at Andenes (69°N, $2 \cdot 10^{-9}\ m^{-1}$)
  - a less seasonal occurrence but more seasonal variation than comparable observations at Andenes (69°N)
  - a peak in height distribution at ~86 km (85 km at Andenes)
  - The duration of the mean PMSE season at Davis (SH) is about 14 days shorter than at Andenes
- The LIMA-ICE model reproduces the main PMSE features as observed by various radars in the NH and SH

➢ **The NH/SH similarities and differences of PMSE are most likely determined by the thermal structure**

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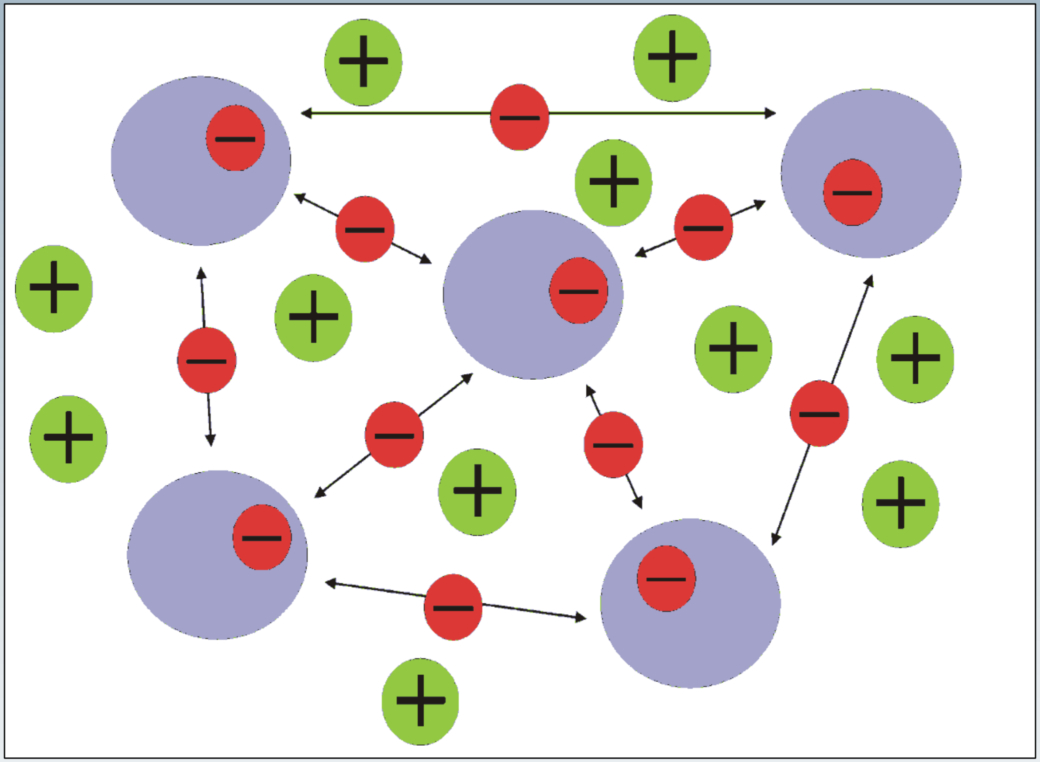
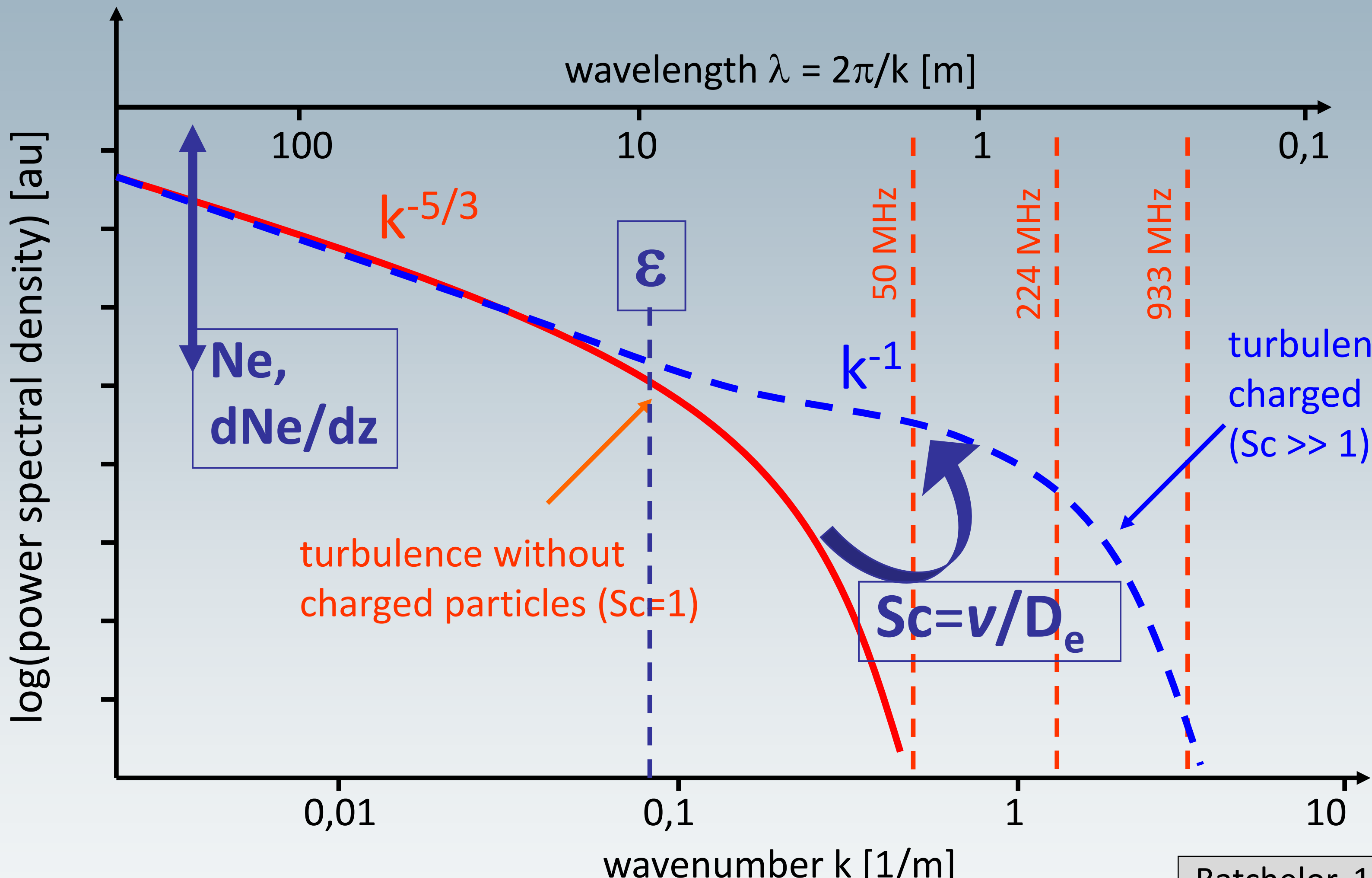
DERIVING MICROPHYSICAL PARAMETERS FROM CALIBRATED OBSERVATIONS OF PMSE

Effect of mesospheric aerosol particles on ambient plasma



- turbulent advection of charged heavy ice particles leads to the creation of small scale structures
- charged ice particles, electrons and positive ions form a coupled diffusion system
- the slowest component – the ice particles – define the diffusion time of the system
- ➢ **particles change also the electron diffusion D_e=f(radius)**
- ➢ small scale structures in the electron gas may well exist after the decay of neutral air turbulence and at smaller scales

PMSE: Turbulent scatter with charged ice particles



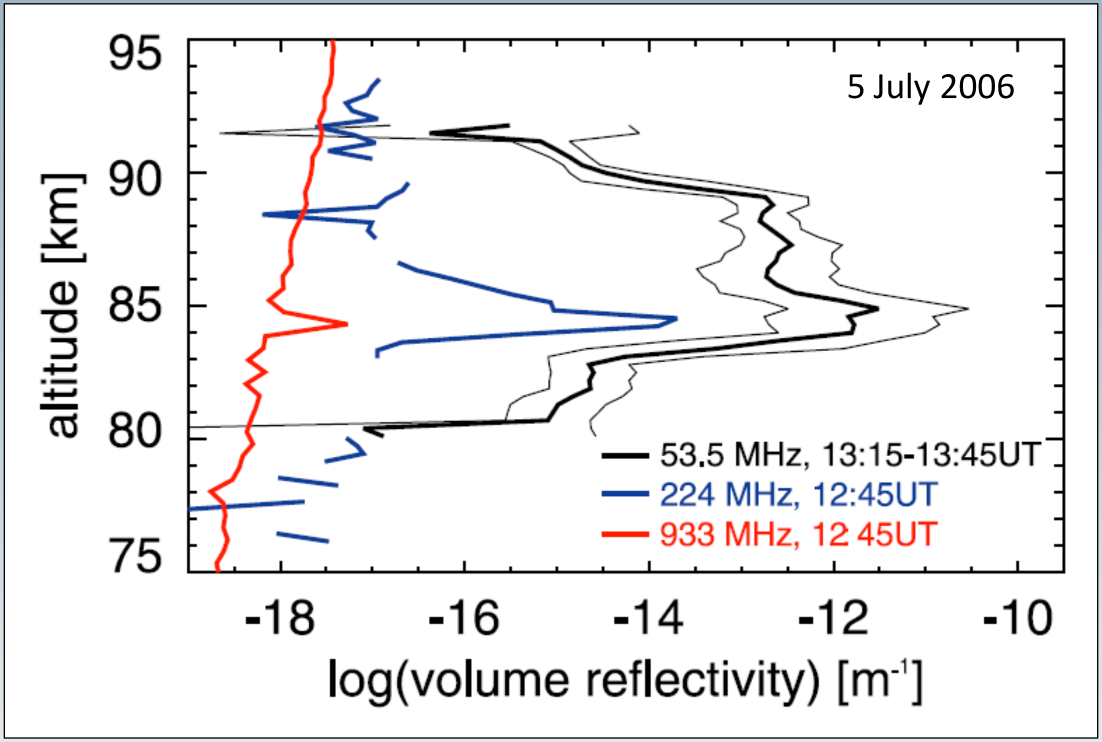
Batchelor, 1959
Kelley et al., 1987

Measurements of η(PMSE) at three Bragg-scales

Measurements of

- η(PMSE) at three Bragg-scales
- turbulente energy dissipation from spectral width (EISCAT)
- electron density from incoherent scatter (EISCAT UHF)

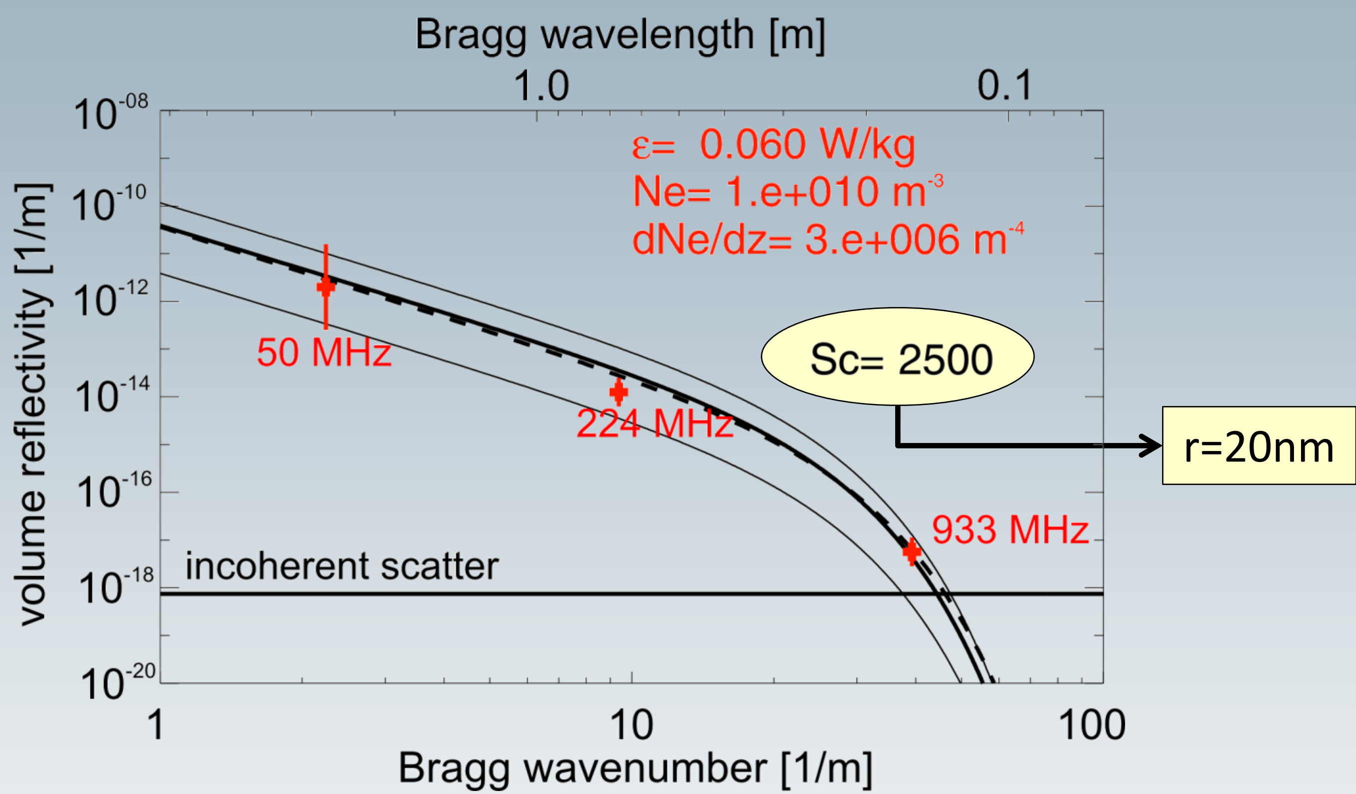
Observations
volume reflectivities measured at three frequencies



- Strong frequency dependency of PMSE
- from 53.5 MHz to 930 MHz η varies by as much as six orders of magnitude

Rapp et al., JASTP 2008

Comparison of experiment results with theory
turbulence with enhanced Schmidt number



- ε, Ne, dNe/dz from EISCAT VHF and UHF radar measurements
- thin lines indicate the uncertainty in the theoretical expression for η owing to uncertainties in the Richardson number and the turbulent Prandtl number

Rapp et al., JASTP 2008

Particle parameters from 2-f observations

Idea: Use calibrated observations at 2 frequencies to derive particle radii

$$\eta = 8\pi^3 \cdot \frac{f_\alpha \cdot q \cdot Ri}{\mathrm{Pr}^t} \cdot \frac{\sqrt{\varepsilon\upsilon}}{N^2} \cdot \tilde{M}_e^2 \cdot r_e^2 \cdot \frac{1}{k^3} \cdot \exp\left(-\frac{2\eta_K^2}{Sc} \cdot k^2\right)$$

identical for different frequencies

frequency-specific

Scattering cross section of PMSE based on the classical formulation for pure turbulent scatter by Hocking, Radio Sci., 1985

Rapp et al., JASTP 2008

$$Sc = \frac{2\eta_K^2\left(k_{ESR}^2 - k_{SSR}^2\right)}{\ln\left(\frac{\eta_{SSR}}{\eta_{ESR}} \cdot \frac{k_{ESR}^3}{k_{SSR}^3}\right)}$$

$$Sc = 6.5 \cdot r_A^2 [nm]$$

➢radius!

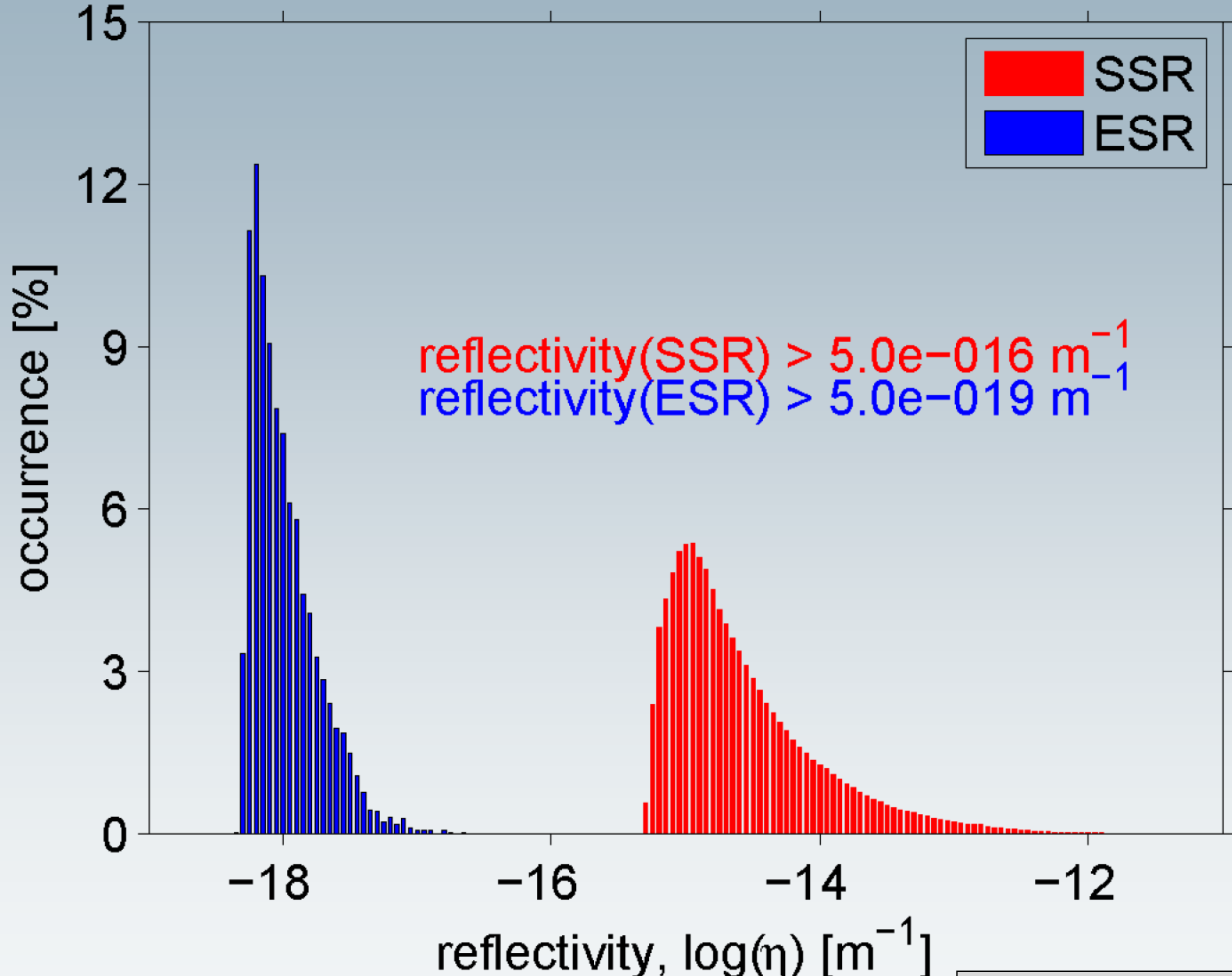
Li et al., submitted to JGR 2009

Li et al., **T1.11** in this workshop

η_K = Kolmogorow-microscale from ε estimations from spectral widths

2-frequency observations at Svalbard in June 2006

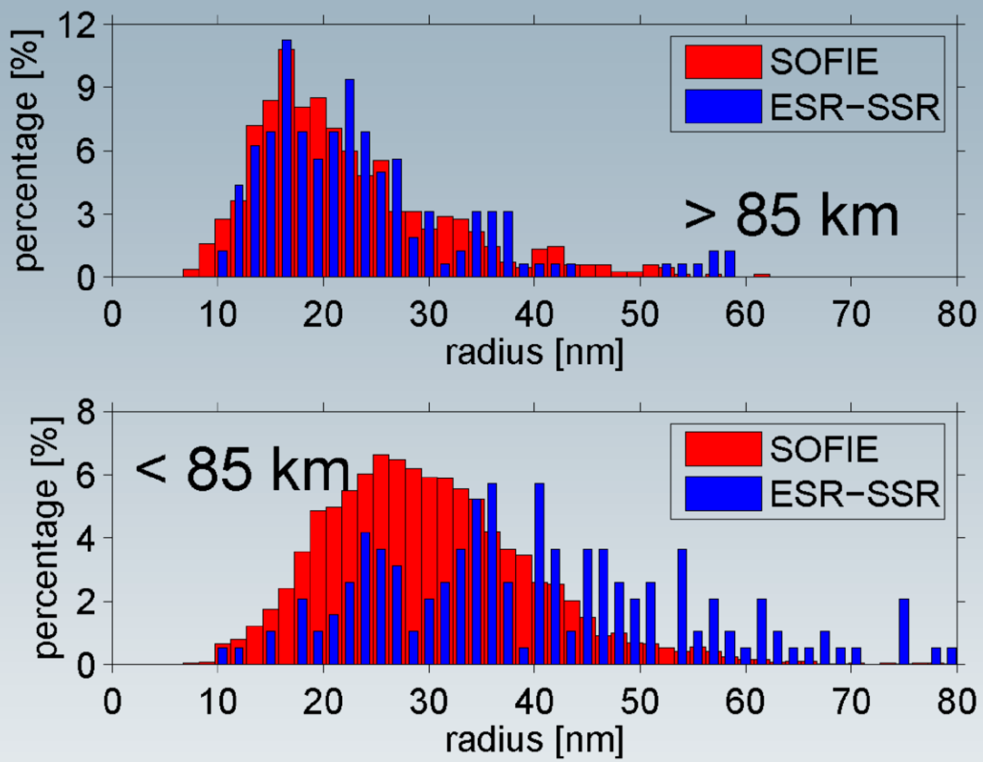
Histograms of absolute volume refectivities at 500 MHz and 53.5 MHz



Li et al., submitted to JGR 2009

Distribution of ice particle radii

derived from radar and optical observations from the SOFIE instrument



- radii are on average smaller above (mean value of 23 nm) and larger below 85 km (mean value of 40 nm).
- results are in full accord with expectations from microphysical models which predict particle nucleation close to the mesopause around 90 km and subsequent growth and sedimentation to lower altitudes.

Li et al., submitted to JGR 2009

Summary part 2

- Simultaneous observations of radar volume reflectivity in PMSE at three frequencies have been conducted in July 2006
- ➢ The current standard theory based on the assumption of turbulent scatter with large Schmidt number could be proofed

- common volume measurements of PMSE using the SSR (53,5 MHz) and ESR (500 MHz) have been performed in July 2006
  - turbulent energy dissipation rates with values between 5 and 200 mW/kg have been estimated from ESR spectral widths observations
  - absolute volume reflectivity has been derived from received signal power of both radars
  - the η-distributions vary from values of 5×10^{-19} m^{-1} to 1.2×10^{-17} m^{-1} for the ESR-echoes and from 5×10^{-16} m^{-1} to 6.3×10^{-12} m^{-1} for the SSR-echoes
- ➢ ice particle radii between 10-70 nm have been derived from η-ratio at the two Bragg wavelengths and turbulent energy dissipation rates.
- ➢ the results are in good agreement with independent satellite observations

List of papers

- R. Latteck, W. Singer, R. J. Morris, W. K. Hocking, D. J. Murphy, D. A. Holdsworth und N. Swarnalingam, Similarities and differences in polar mesosphere summer echoes observed in the Arctic and Antarctica, *Ann. Geophys.*, 26, 2795-2806, 2008.
- F.-J. Lübken and U. Berger, Interhemispheric comparison of mesospheric ice layers from the LIMA model, *JASTP*, 69, 2292-2308, 2007.

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- Q. Li, M. Rapp, J. Röttger, R. Latteck, M. Zecha, M. Hervig, C. Hall, Microphysical parameters of mesospheric ice clouds derived from calibrated observations of polar mesosphere summer echoes at Bragg wavelengths of 2.8 m and 30 cm, *submitted to JGR,* 2009.