Two decades of long-term observations of polar mesospheric echoes at 69°N

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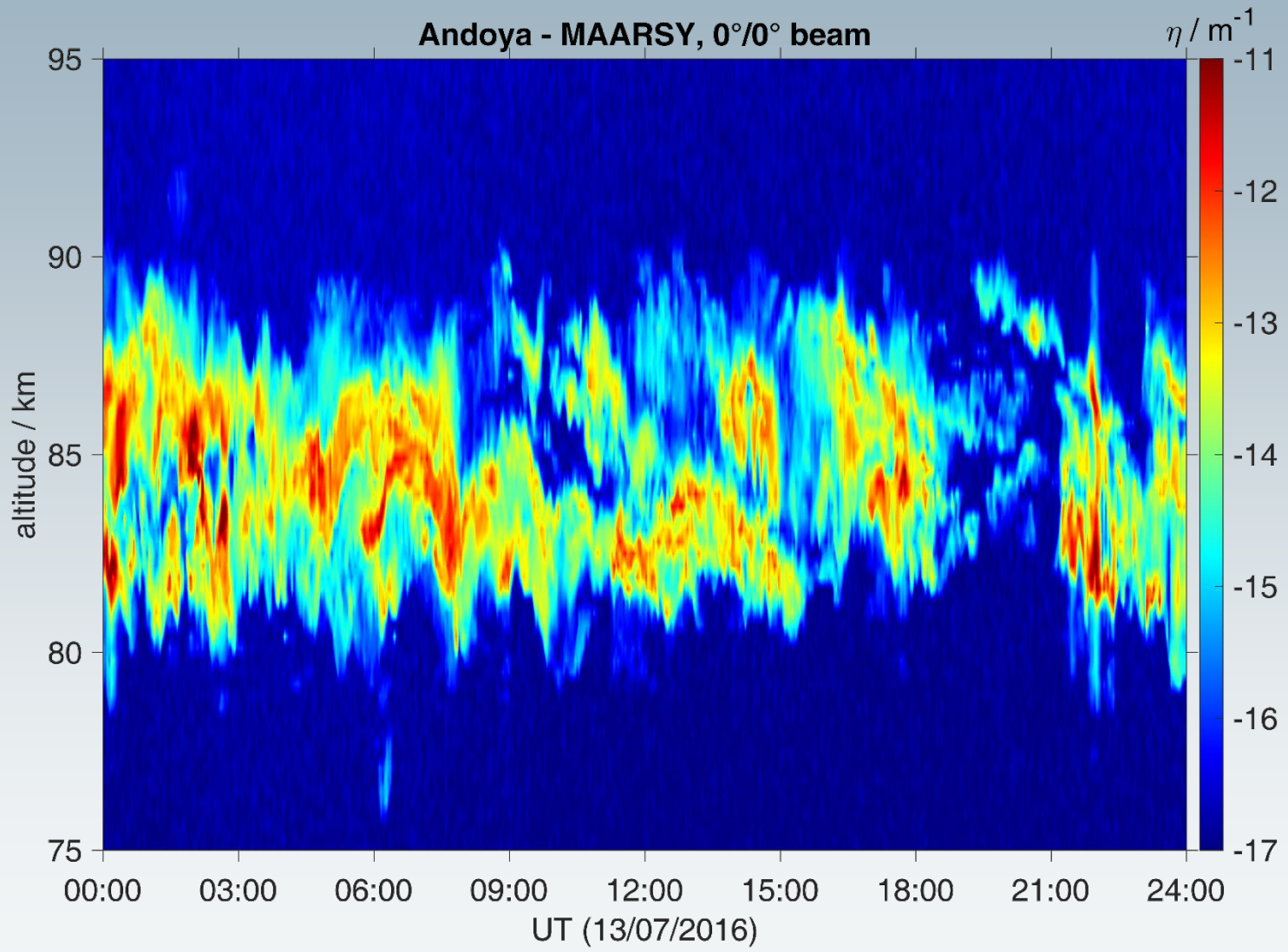
Polar **M**esosphere **S**ummer **E**choes



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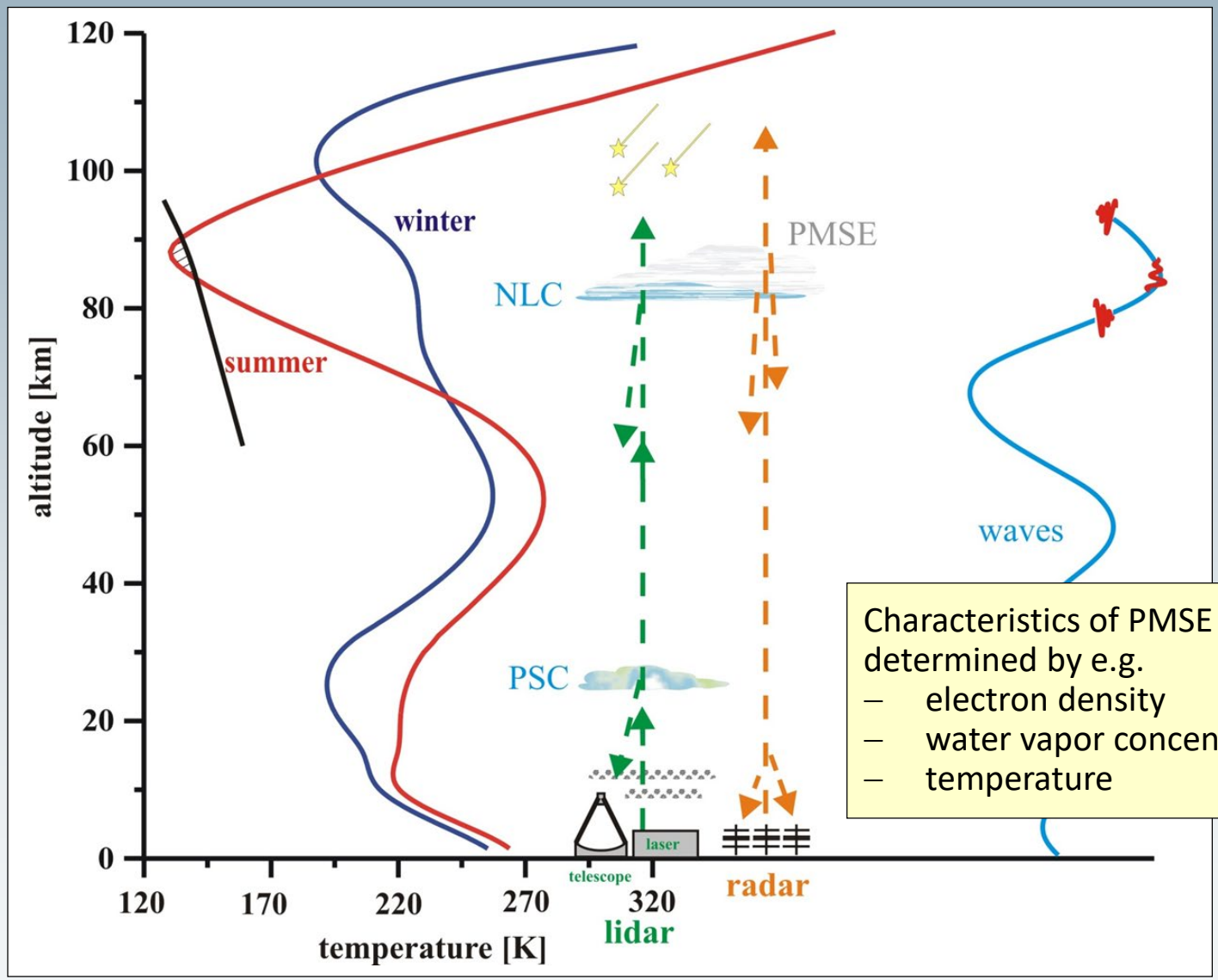
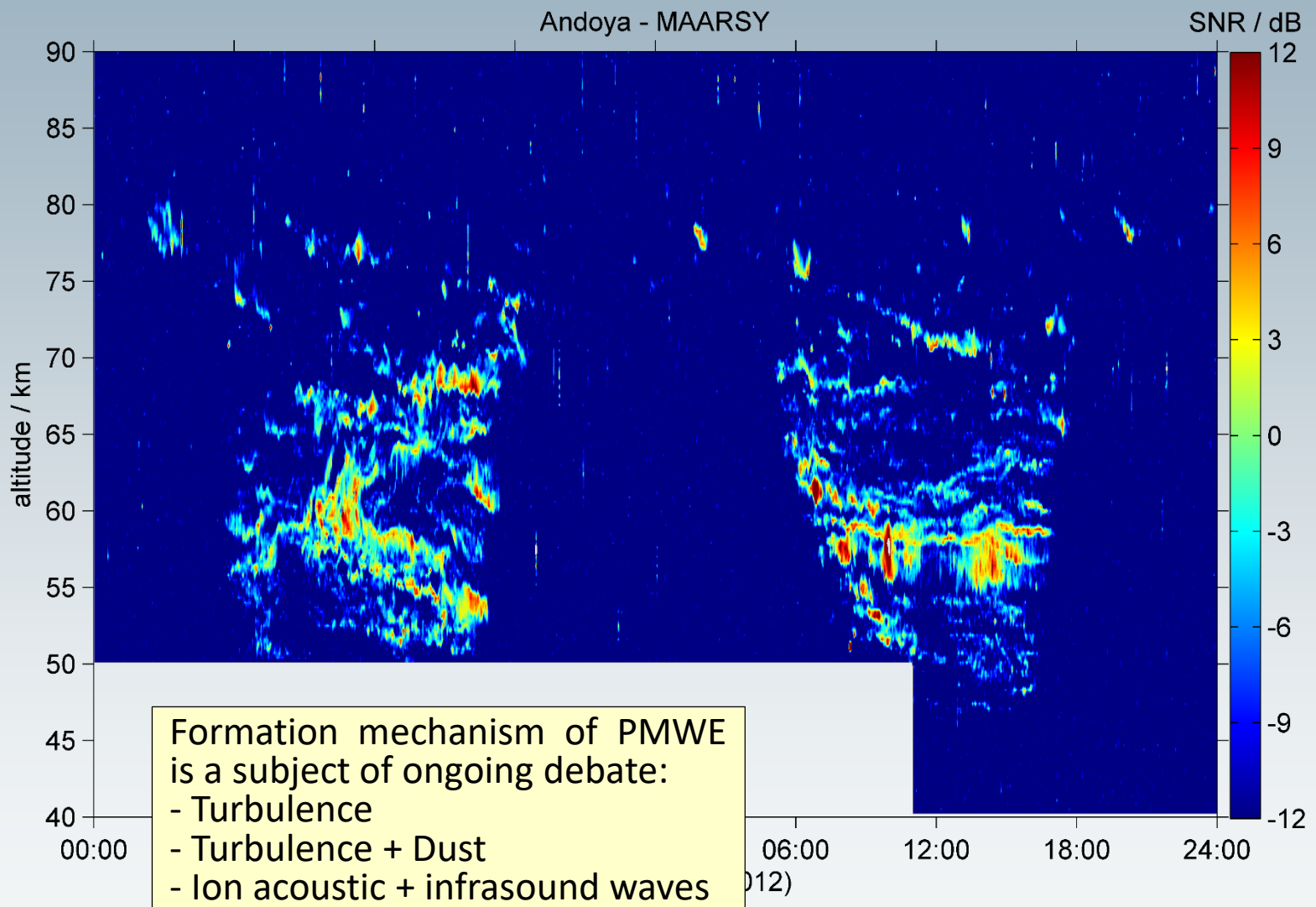


Characteristics of PMSE are determined by e.g.

- electron density
- water vapor concentration
- temperature

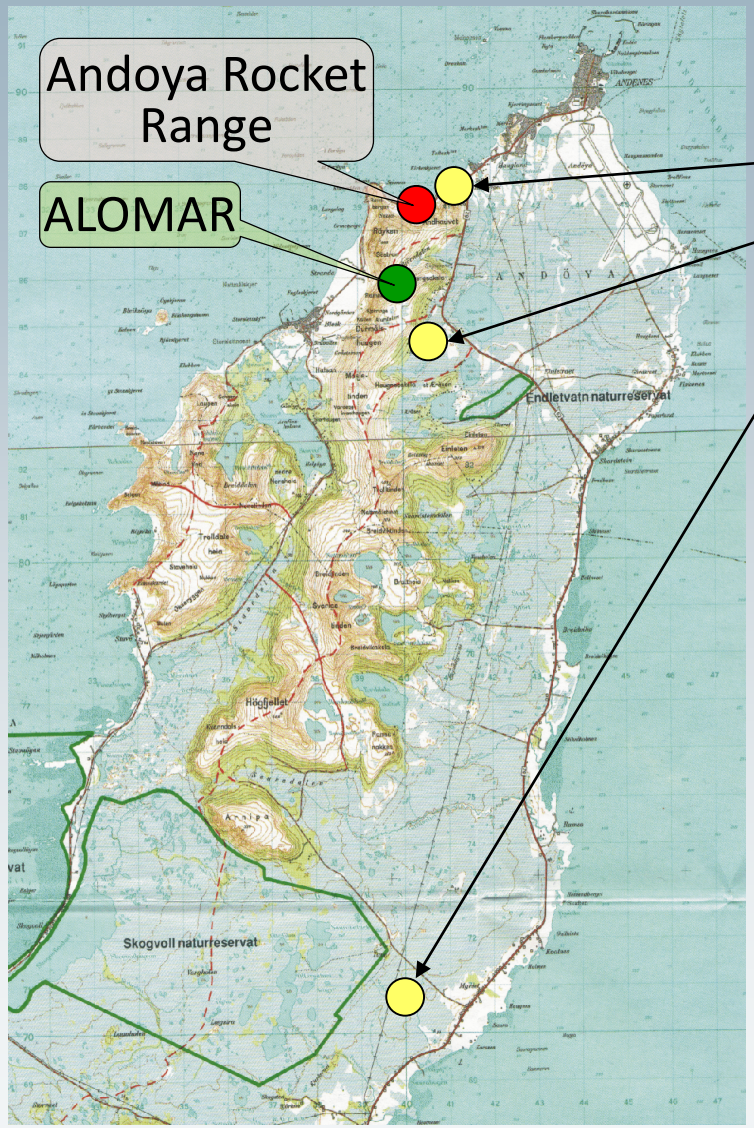
Polar Mesosphere Winter Echoes

PMWE after SPE in March 2012

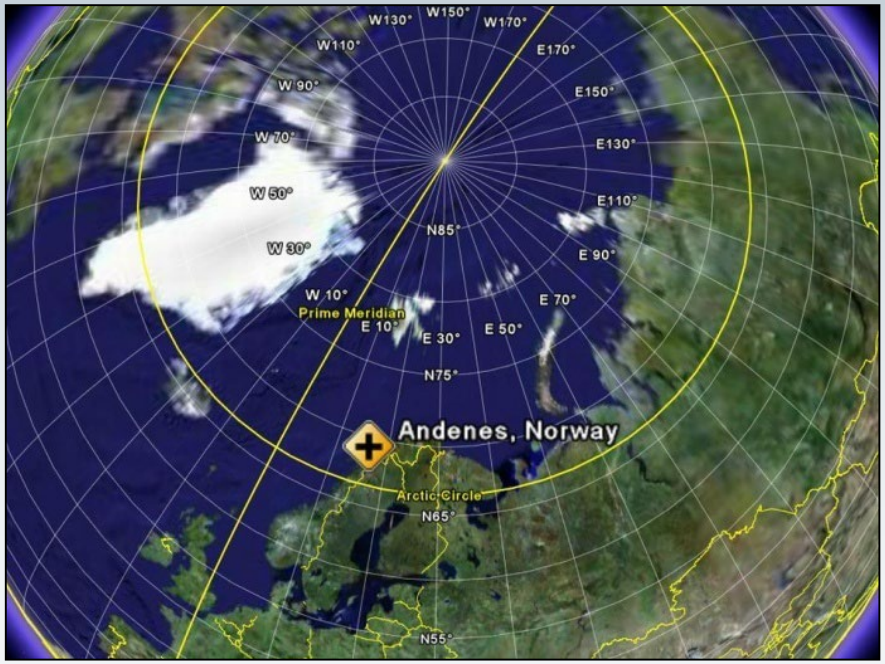


Formation mechanism of PMWE is a subject of ongoing debate:
- Turbulence
- Turbulence + Dust
- Ion acoustic + infrasound waves

Radar experiments on Andøya island (69°N)



- **VHF radar (53.5 MHz)**
- SIMONe meteor radar (32.55 MHz)
- Saura MF radar (3.17 MHz)



VHF radar site on Andøya

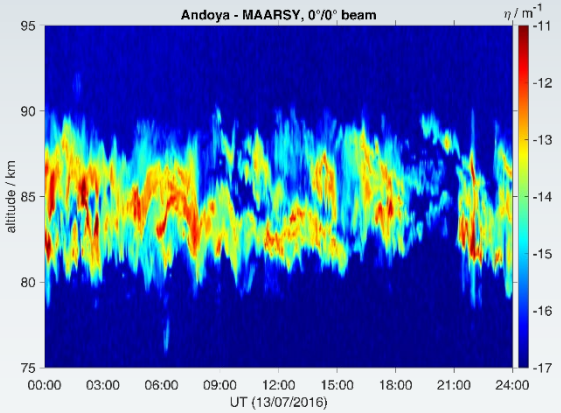
Middle **A**tmosphere **A**lomar **R**adar **Sy**stem

VHF radar site on Andøya

VHF radars operated at Andøya from 1994 until today

Parameters \ Radar	SOUSY 1994 – 1997	ALWIN 1999 – 2008	ALWIN64 2009	MAARSY 2010	MAARSY 2011 – today
Peak power P_t	150 kW	36 kW	36 kW	250 kW	736 kW
Number of transmitting antennas	148	144	6	147	433
Transmitting antenna gain G_t	29.0 dBi	28.3 dBi	15.6 dBi	29.0 dBi	33.5 dBi
Number of receiving antennas	148	24	64	7	7
Receiving antenna gain G_r	29.0 dBi	20.6 dBi	20.1 dBi	15.5 dBi	15.5 dBi
Two way beam width (HPHW)	2.3°	2.12°	4.41°	2.95°	1.79°
System losses e	0.8	0.58	0.58	0.54	0.54
Effective pulse width τ	2 µs	2 µs	2 µs	1.4 µs	1.4 µs
→ system factor c_{sys}	**7.6e-10**	**2.5e-08**	**2.3e-07**	**1.3e-08**	**4.3e-09**
Receiving path calibration factor c_s		**3.5e-19**	**1.1e-21**	**9.9e-21**	**6.2e-21**

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



Volume reflectivity distributions of Polar Mesopheric Echoes
observerd at Andøya from 1999 – 2019

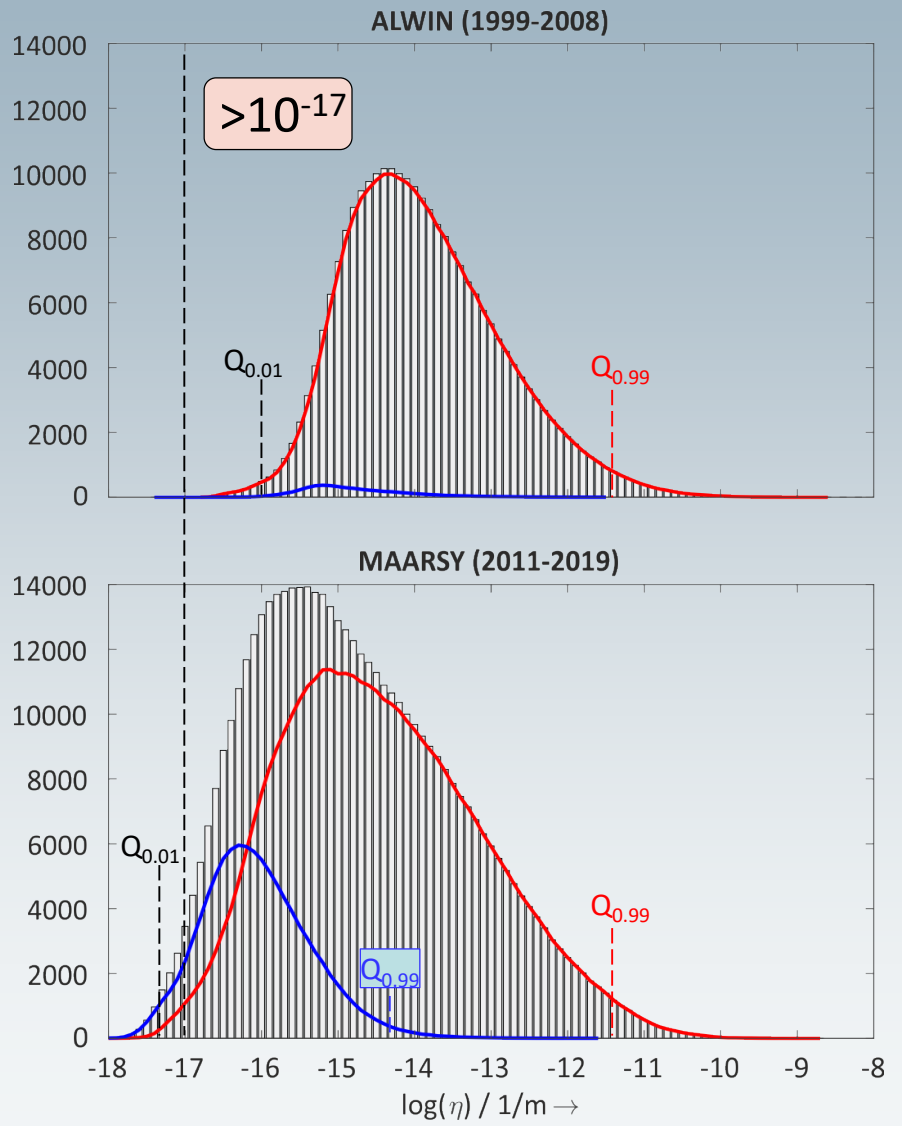
$$\eta_{radar}[m^{-1}] = \frac{P_r \cdot 128 \cdot \pi^2 \cdot 2 \cdot \ln(2) \cdot r^2}{P_t \cdot G_t \cdot G_r \cdot \lambda^2 \cdot e \cdot \Theta_{1/2}^2 \cdot c \cdot \tau}$$

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

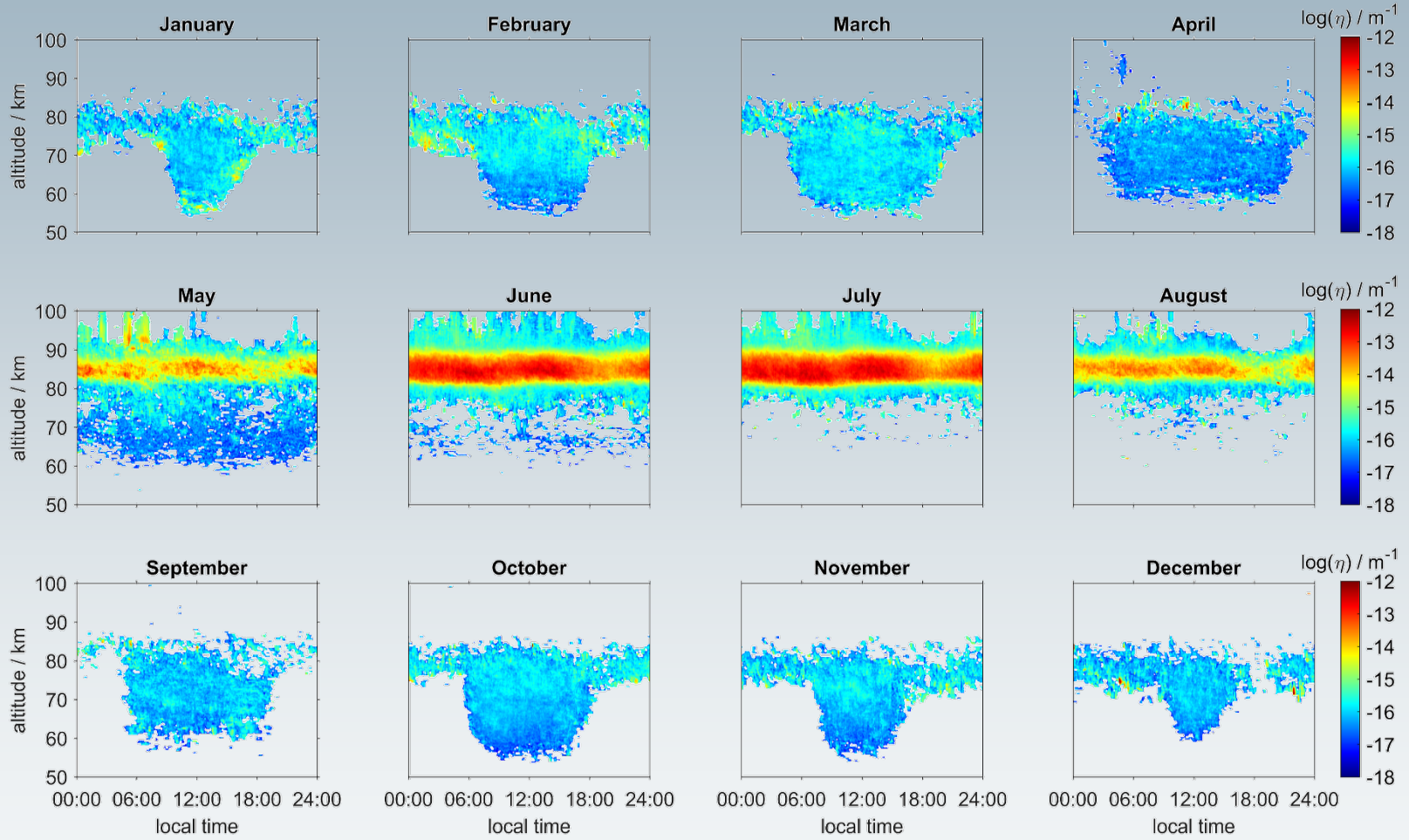
P_t	=	transmitted peak power [W]
P_r	=	received signal power [W]
G_t	=	gain of transmit antenna
G_r	=	gain of receive antenna
λ	=	radar wave length
e	=	efficiency
$\Theta_{1/2}$	=	half power half width of transmit antenna
r	=	range to volume center
$2\ ln(2)$	=	beam correction factor
c	=	speed of light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

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

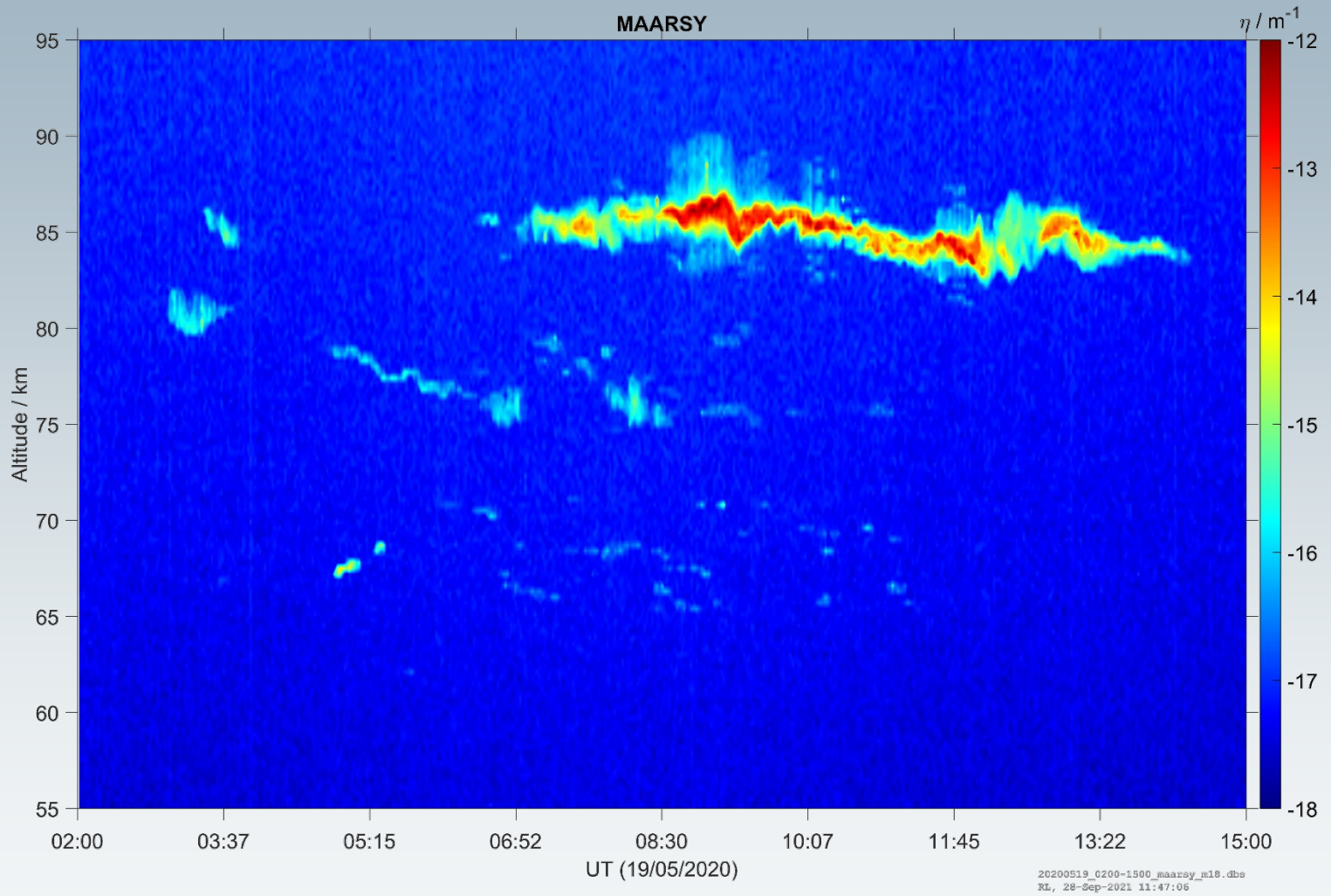
$$\eta_{radar} = P_r \cdot c_{sys} \cdot r^2$$



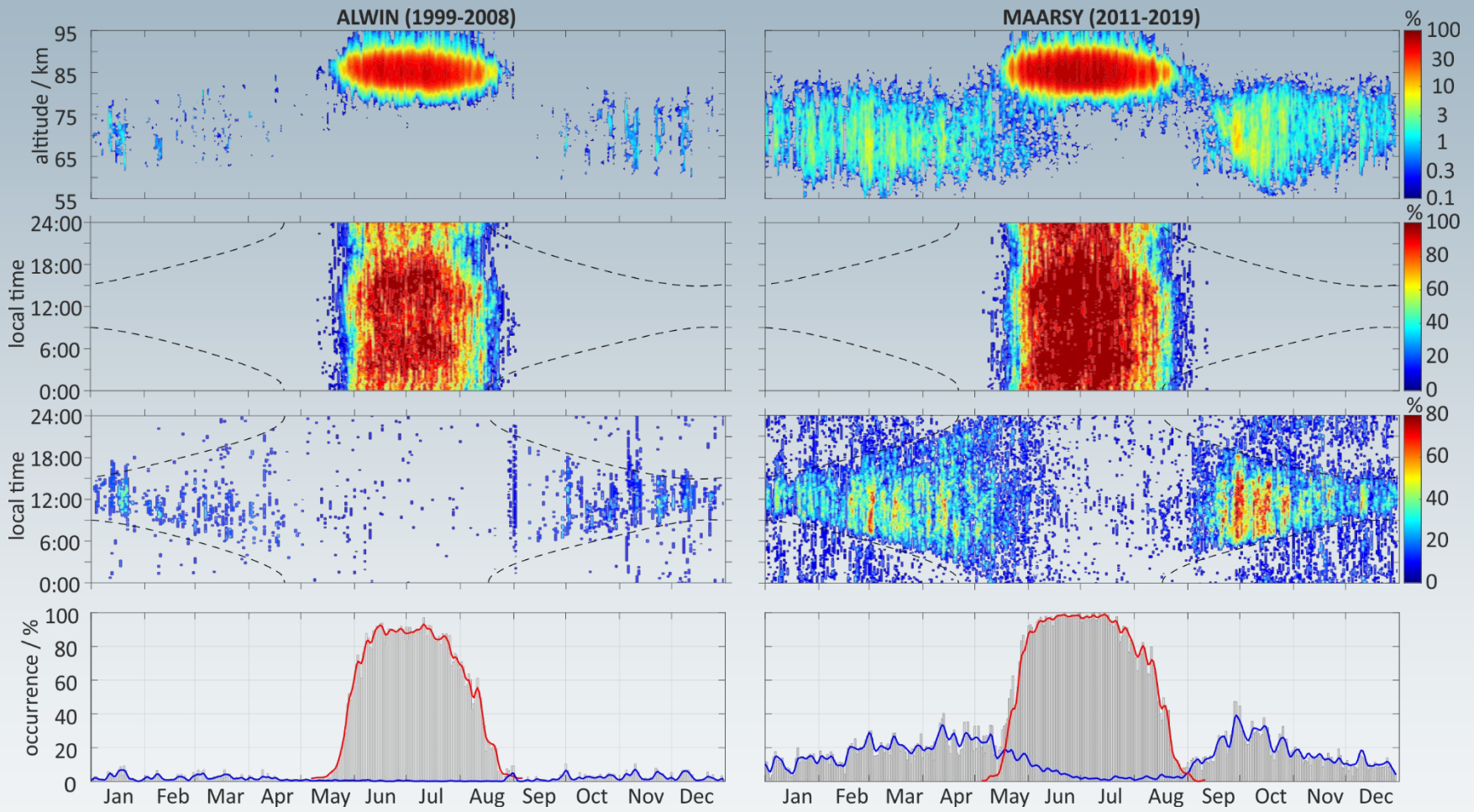
Volume reflectivity distributions of Polar Mesopheric Echoes
mean monthly values obtained by MAARSY (2011–2019)



Volume reflectivity of Polar Mesopheric Echoes
obtained by MAARSY on 19 May 2020



Seasonal mean values of the occurrence of mesospheric echoes
obtained by ALWIN (1999-2008) and MAARSY (2011–2019)



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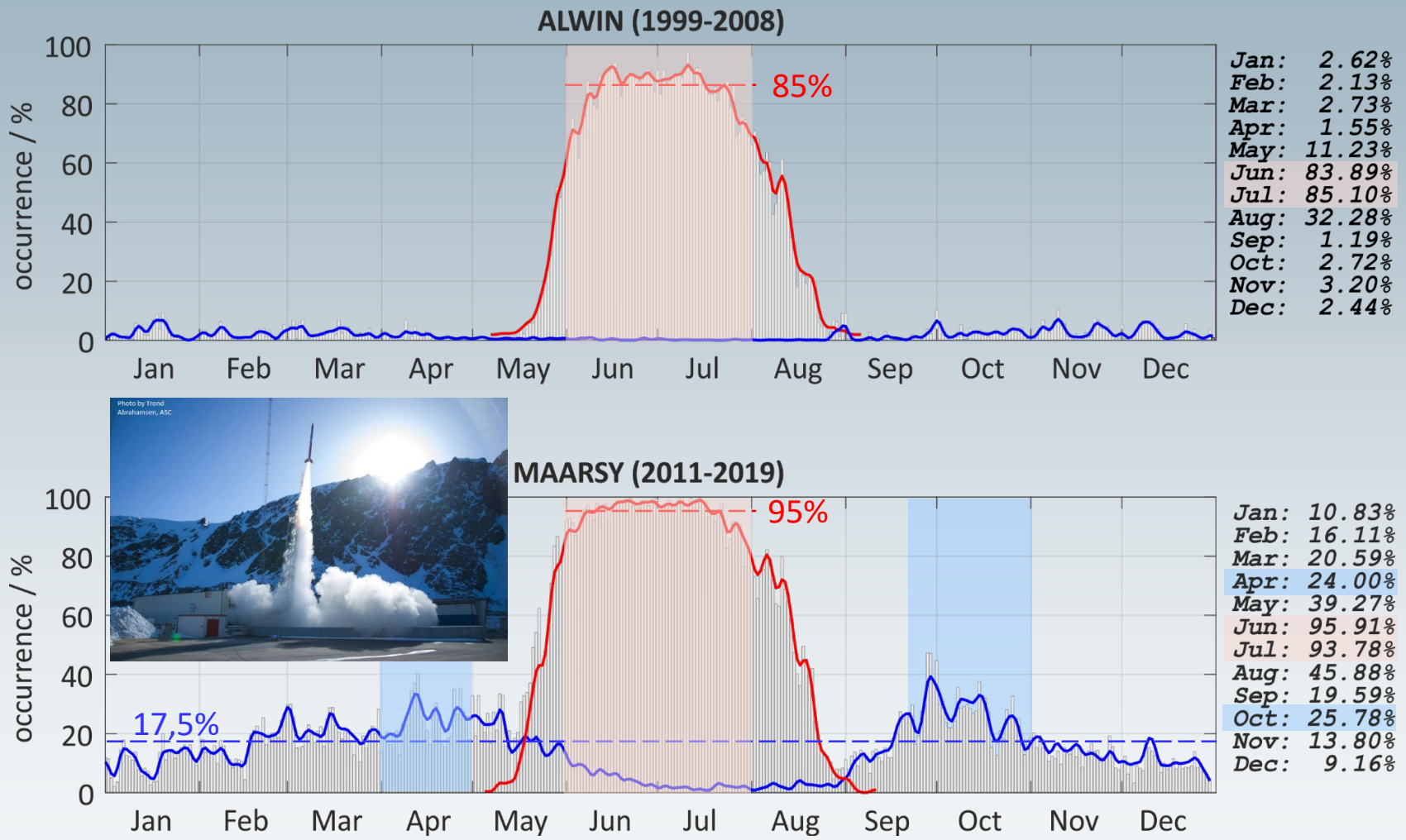

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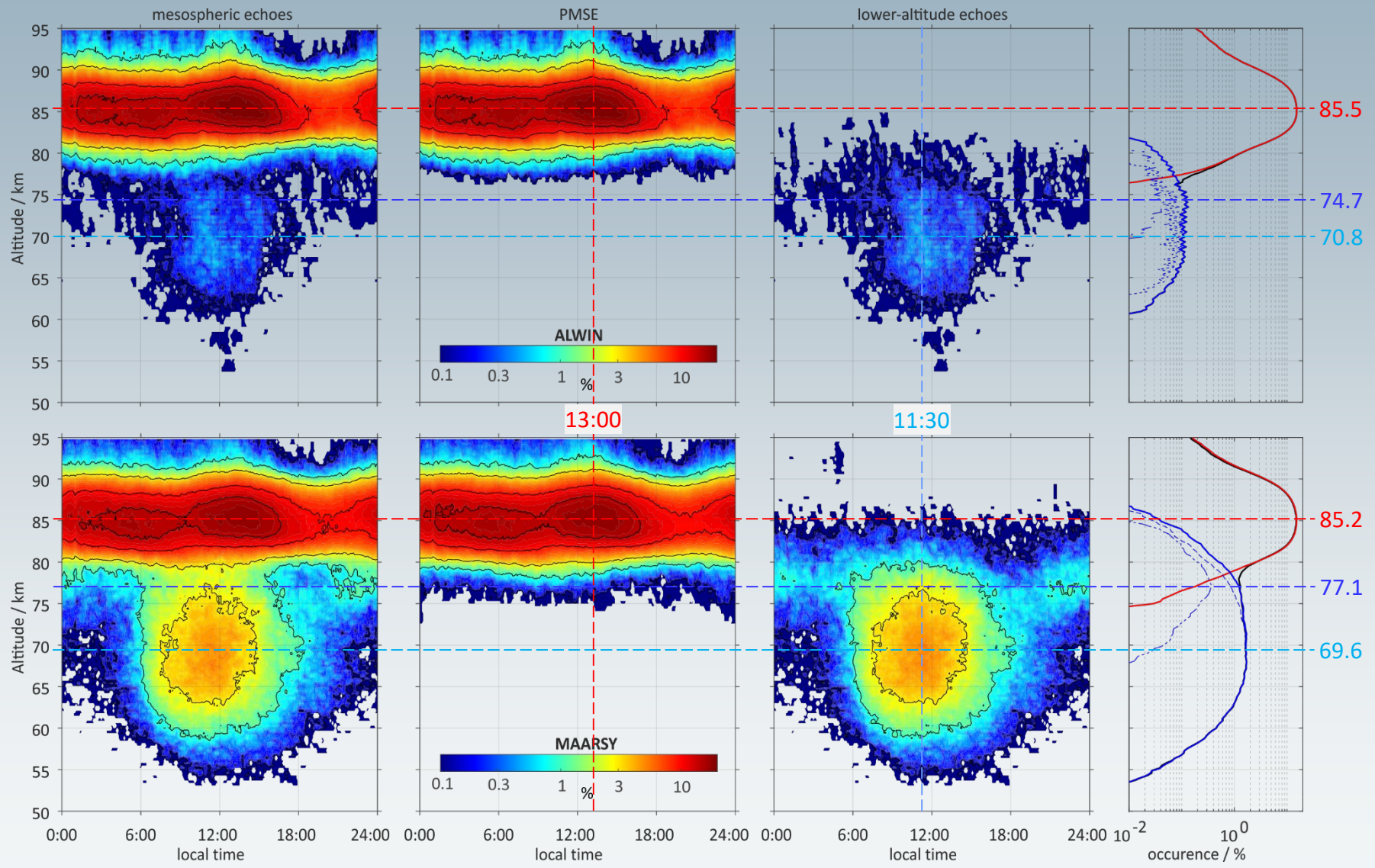
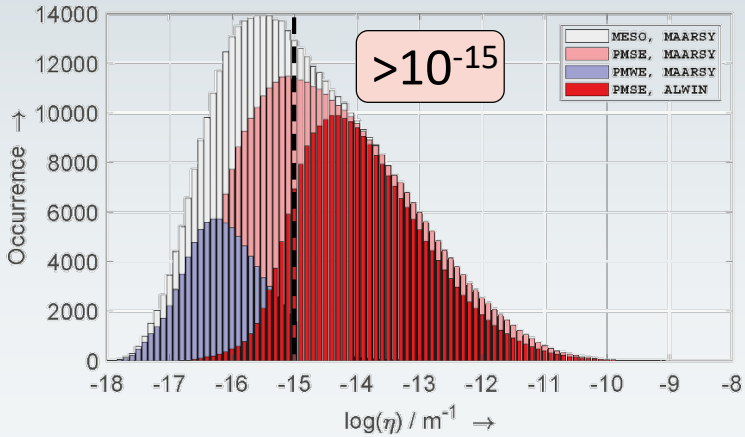
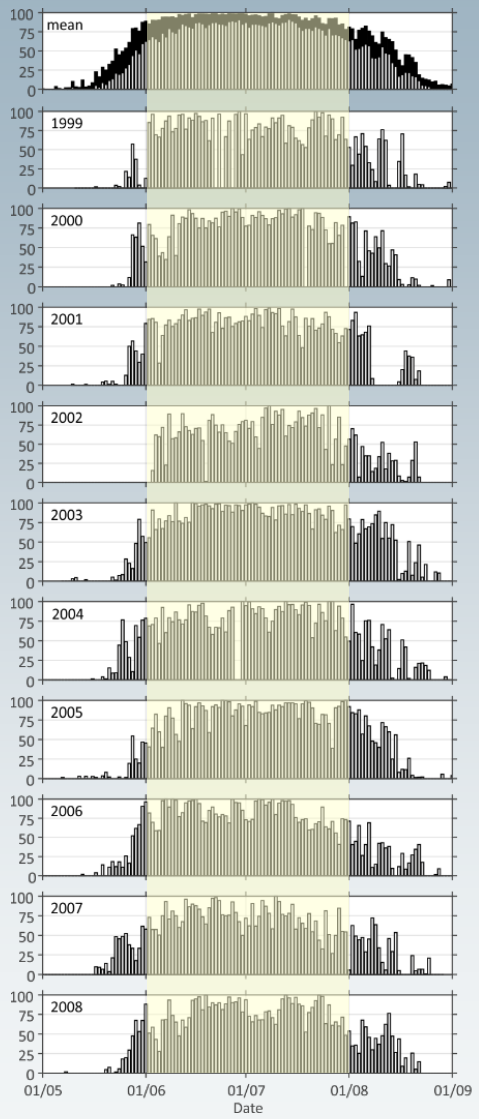


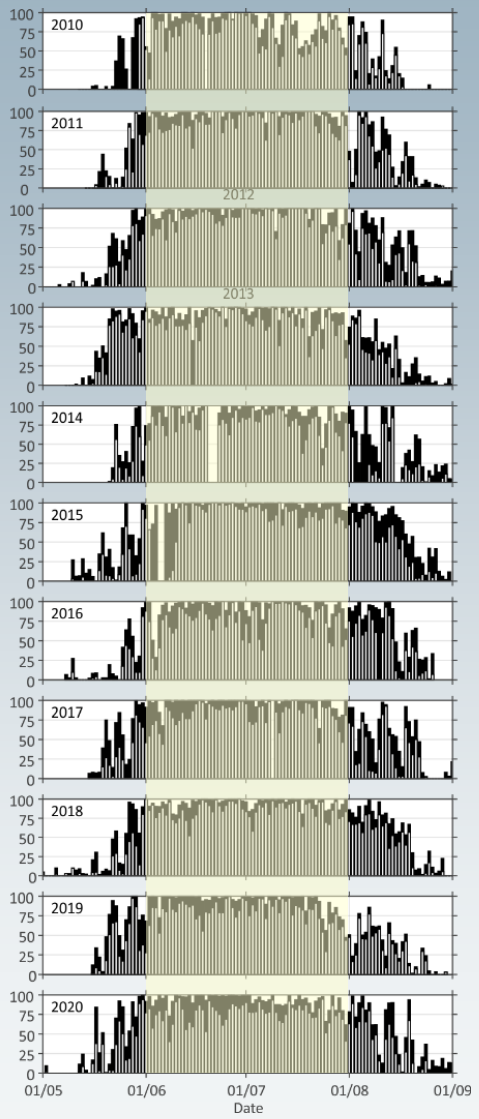
Long-term variation of PMSE occurrence rates
Seasonal variation of occurrence rates (1999 – 2020)

Previous studies

- 1994 – 2001: Bremer et al., 2003
- 1999 – 2005: Bremer et al., 2006
- 1999 – 2008: Bremer et al., 2009
- 1994 – 2012: Latteck and Bremer, 2013
- 1994 – 2016: Latteck and Bremer, 2017

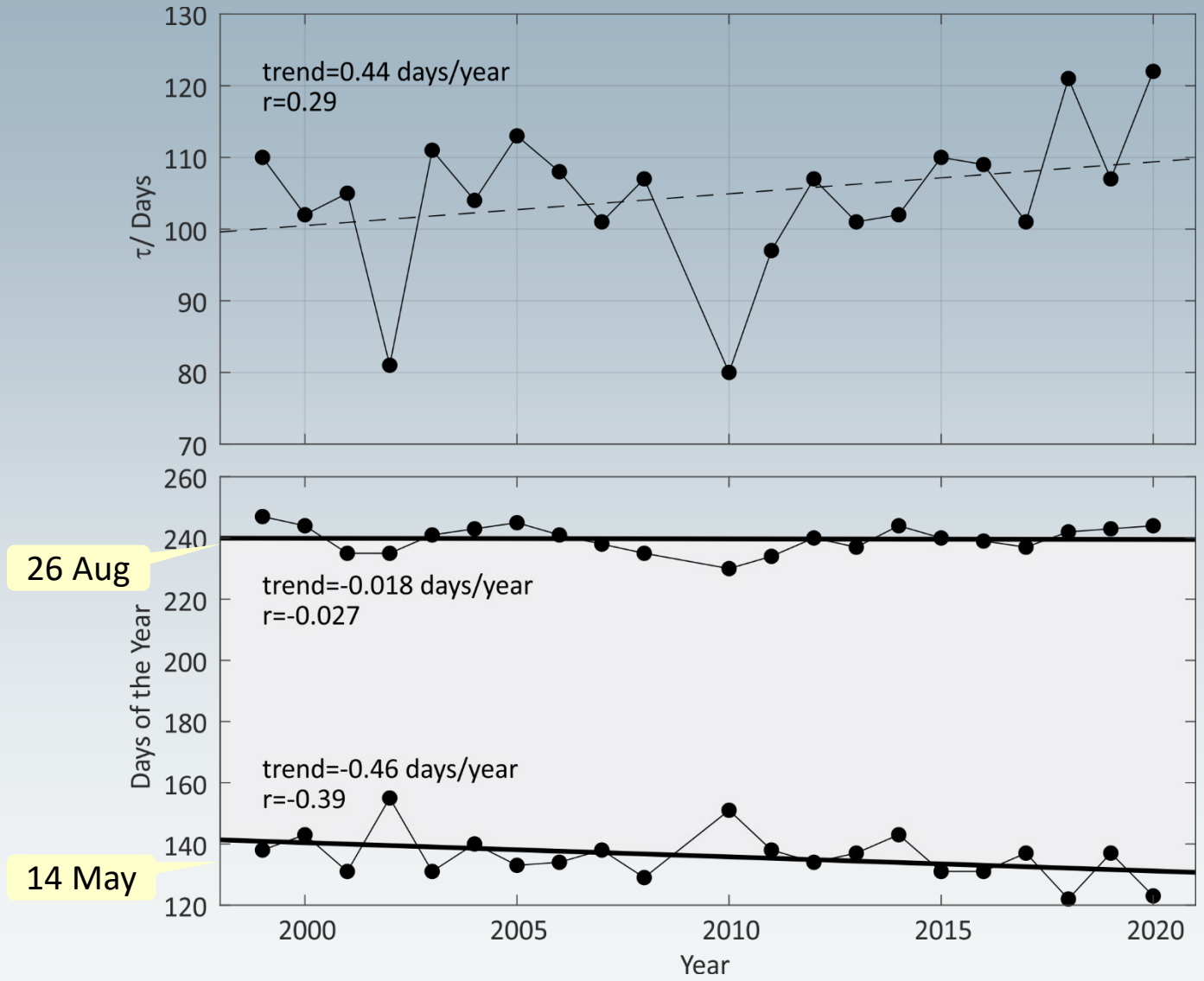




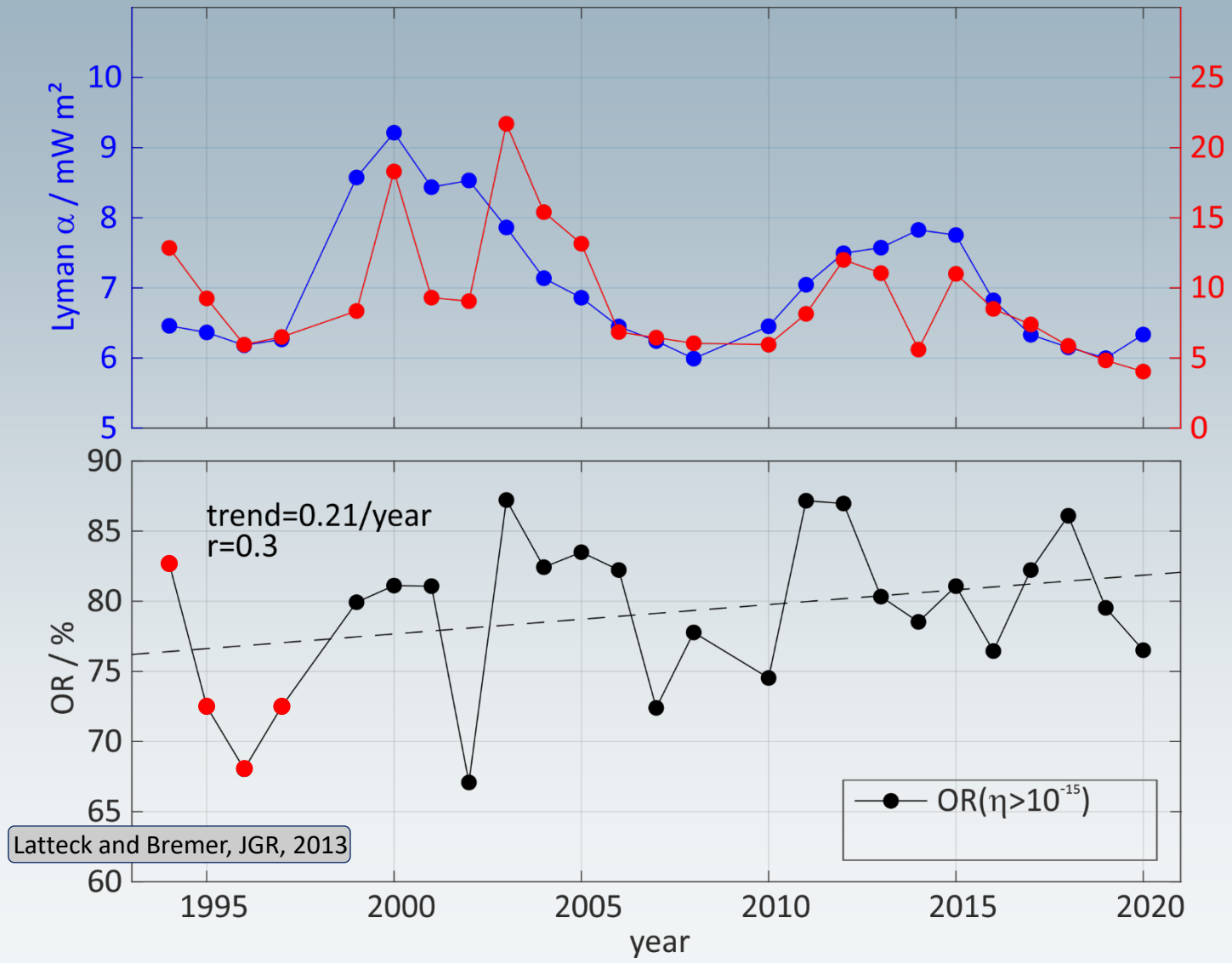


Long-term variation of PMSE occurrence rates

first and last detected PMSE in each season and duration τ of the PMSE season

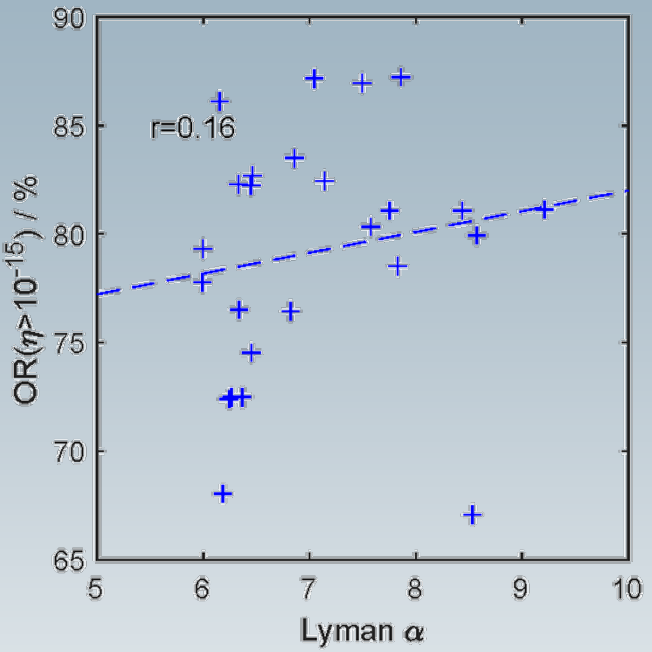


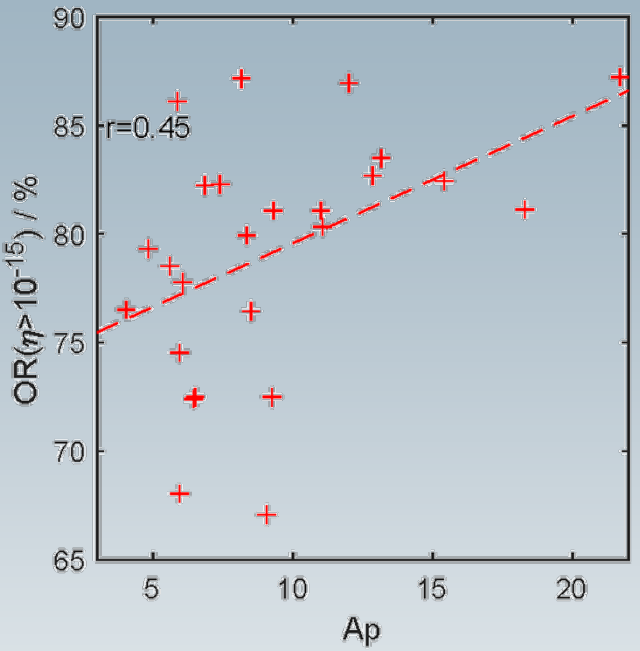
Seasonal mean values of PMSE occurrence
from 25 years of observation (1994 – 2020)



Latteck and Bremer, JGR, 2013

Dependence of the PMSE occurrence rates OR'$_{-15}$
on the solar Lyman α radiation and on geomagnetic Ap index





- slightly positive correlation
- r=0.16

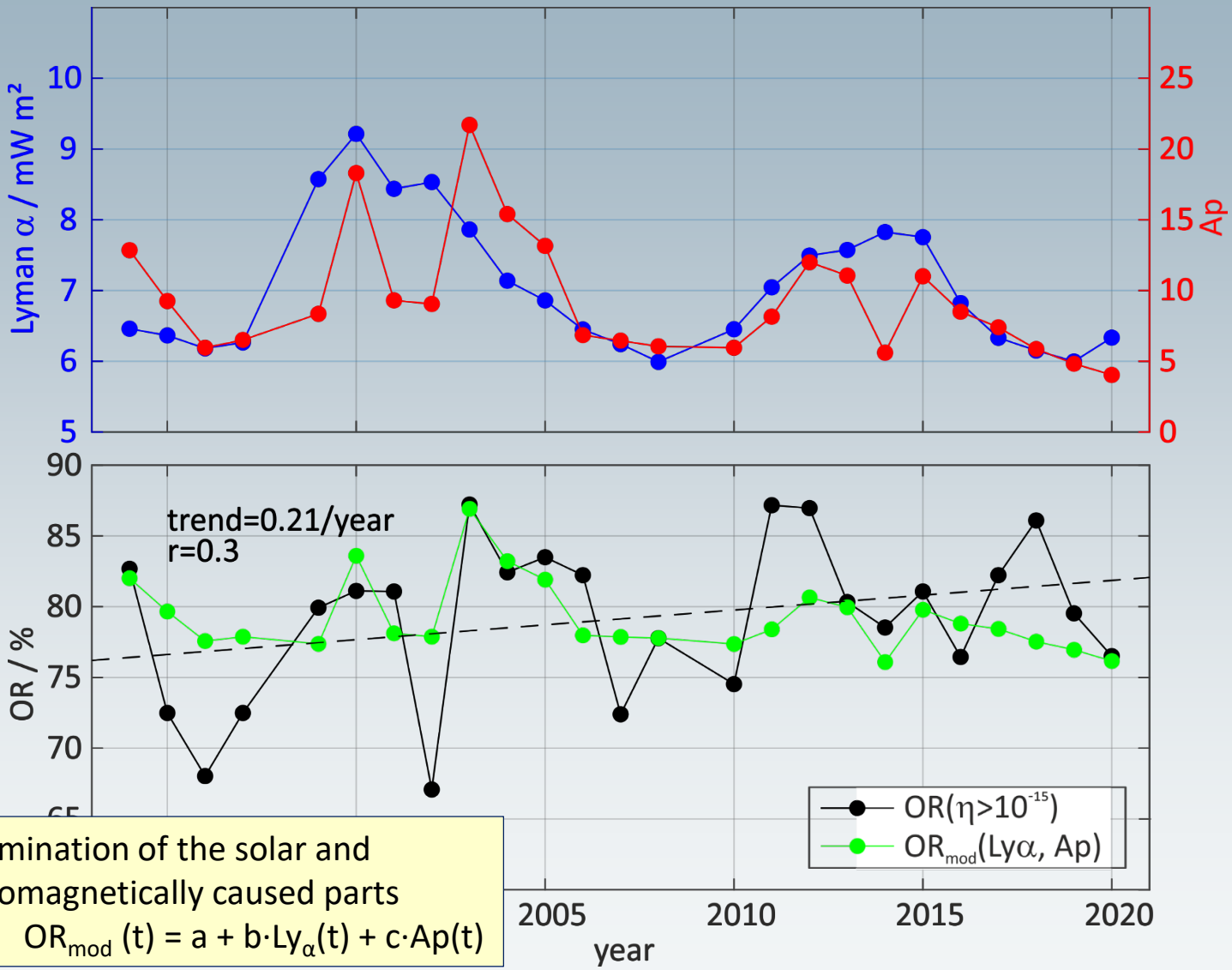
➢ small dependency of PMSE occurrence on solar activity

- more pronounced correlation
- r=0.45

➢ direct influence of precipitating fluxes of high energetic particles to the increase of Ne

➢ increase of PMSE

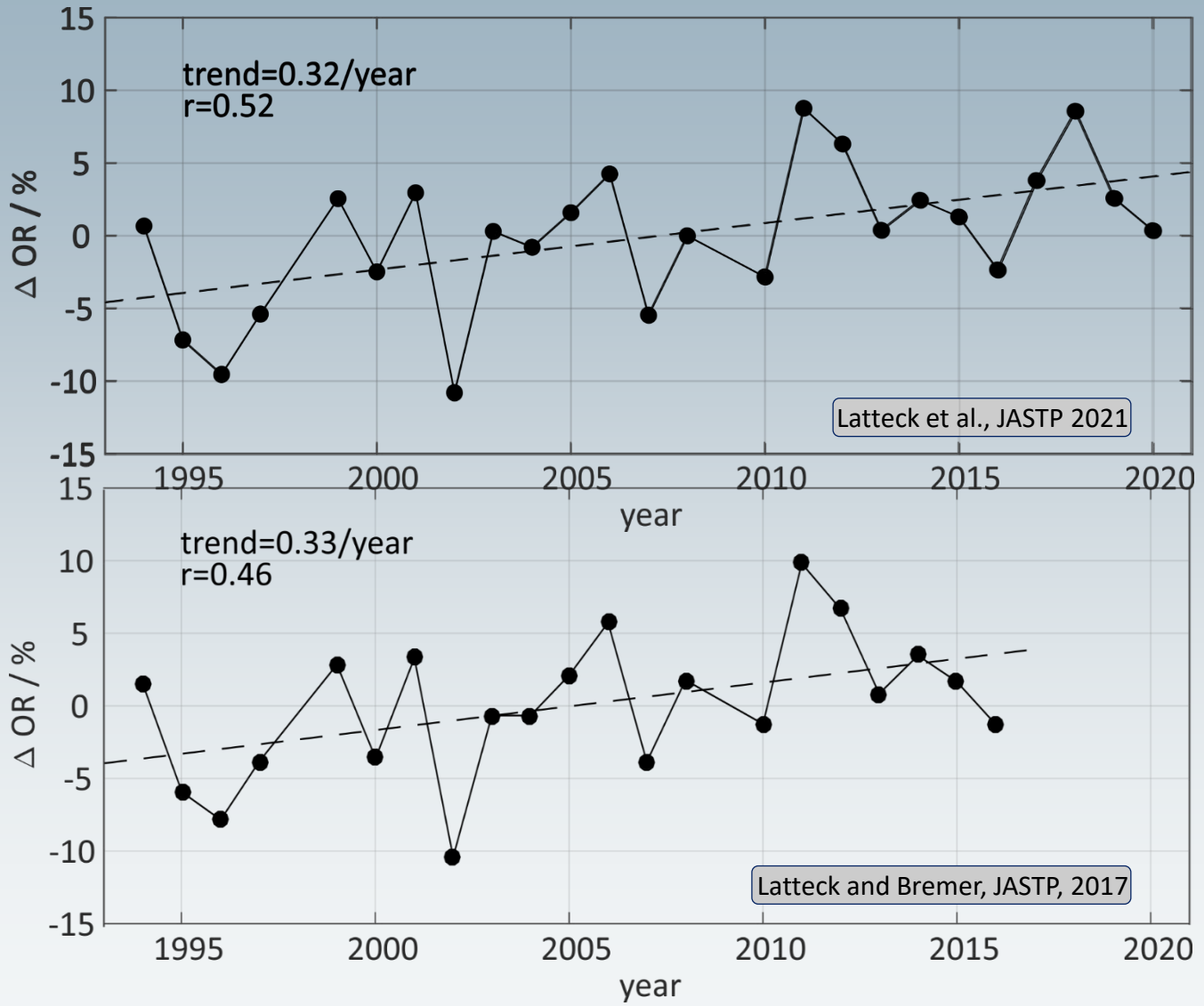
Seasonal mean values of PMSE occurrence
from 21 years of observation



elimination of the solar and geomagnetically caused parts

– $OR_{mod}(t) = a + b \cdot Ly_{\alpha}(t) + c \cdot Ap(t)$

Long-term variation of PMSE occurrence rates
(1994 – 2020) for volume reflectivity $\eta > 1 \cdot 10^{-15}$ m^{-1}



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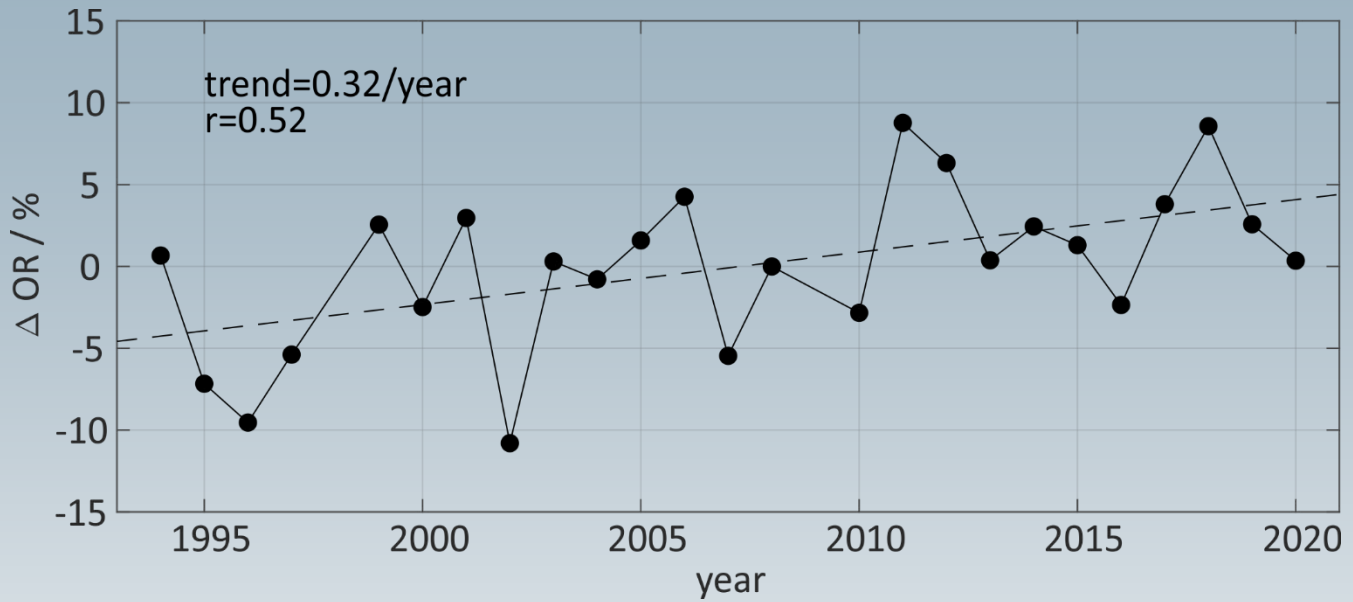

Method	Trend	Corr. Coeff.
OR	0.21	0.30
OR(Ap)	0.32	0.52
OR(Lya, Ap)	0.32	0.52
OR(Lya, Ap, t)	0.37	0.44

The PMSE occurrence rate has a **marked positive trend**

- increasing trend of the mesospheric water vapour
- decreasing temperature trend

Summary and conclusions

- Polar Mesospheric Echoes from 21 years of continuous VHF radar observations at Andøya (69°N) have been investigated for seasonal and diurnal variation and for signal strength:
  - The maximum signal strengths of PMSE and lower-altitude mesospheric echoes **differ by three orders of magnitude** with PMSE measured with maximum values up to $\eta_{max} = 2 \cdot 10^{-09} m^{-1}$ and lower-altitude mesospheric echoes with signal strengths up to $\eta_{max} = 4 \cdot 10^{-12} m^{-1}$
  - Lower-altitude mesospheric echoes occur mostly in an altitude range between **50 and 85 km** and with a maximum value of the altitude distribution at **68.7 km during daytime** and a peak altitude at **77.1 km during night time**.
  - Lower-altitude mesospheric echoes have been observed with MAARSY all year round with a mean seasonal occurrence frequency of about **14%**, but with differences in the monthly frequency rates from minimum values of 2% in July/August and **maxima of 22% and 26% in the months March/April and October**.
  - The mean PMSE season based on 21 years of ALWIN and MAARSY detections with signal strengths $\eta \geq 10^{-17} m^{-1}$ starts on **14 May, lasts 105 days and ends on 26 August** of that year. The average occurrence of PMSE in **June/July is 95%.** The mean diurnal occurrence of PMSE is characterized by an area of high abundance between 83 and 87 km and 22:00 LT and 18:00 LT, with a very pronounced maximum between 11:00 and 15:00 LT, **peaking at about 13:00 LT and 85 km** altitude and a strong minimum between 18:00 and 22:00 LT.

- PMSE occurrence rates from 1994 – 2020 were investigated for solar and geomagnetic control and for possible long-term changes:
  - PMSE occurrence at Andøya (69°N) is positively correlated with the solar Lyman a radiation (r = 0.16) and the geomagnetic activity (r = 0.45)
  - PMSE-trends based on 27 years of radar observations at Andøya are **positive** of about 0.3%/yr.
  - PMSE trend **may be caused by a negative temperature trend** and probably not by an increasing water vapour trend.

Thank you