Observations of Mesosphere Summer Echoes with calibrated VHF radars at latitudes between 54°N and 69°N in summer 2004

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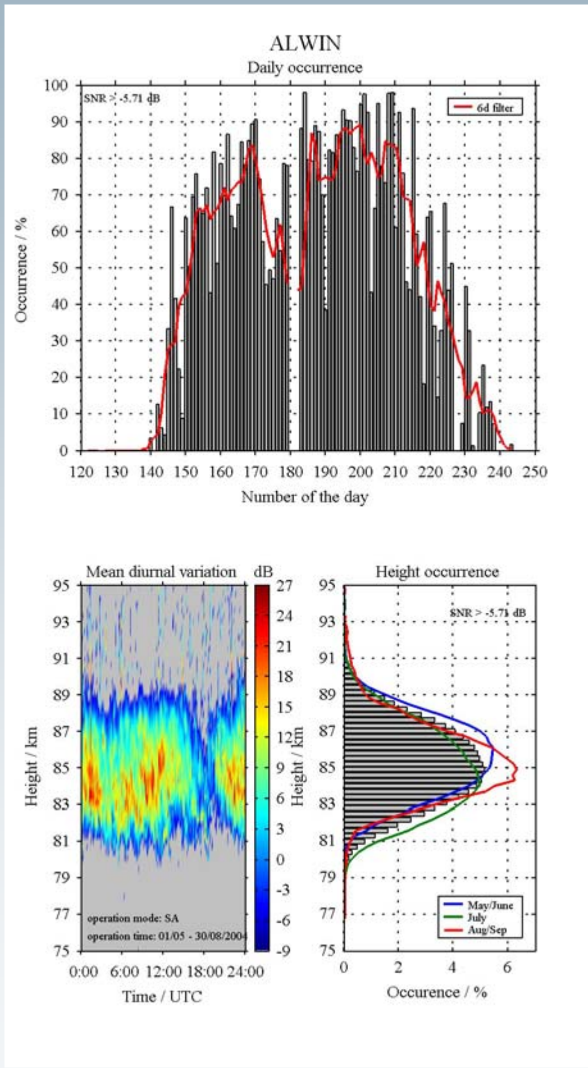
Outline

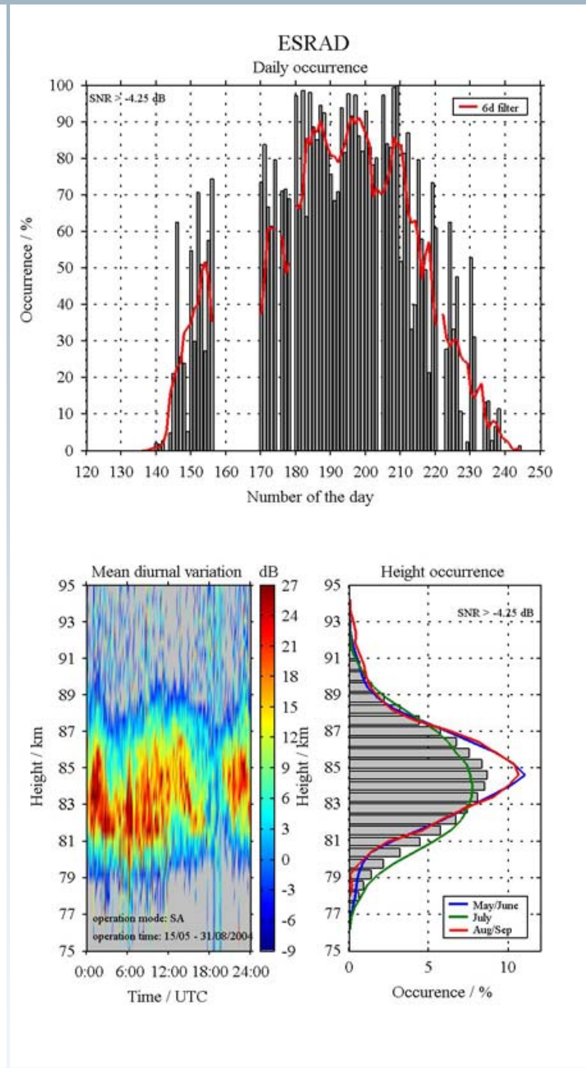
- Why absolute radar calibration?
- Two radar absolute calibration methods
- Results from three VHF radars
  ALWIN (69°N), ESRAD (68°N), OSWIN (54°N)

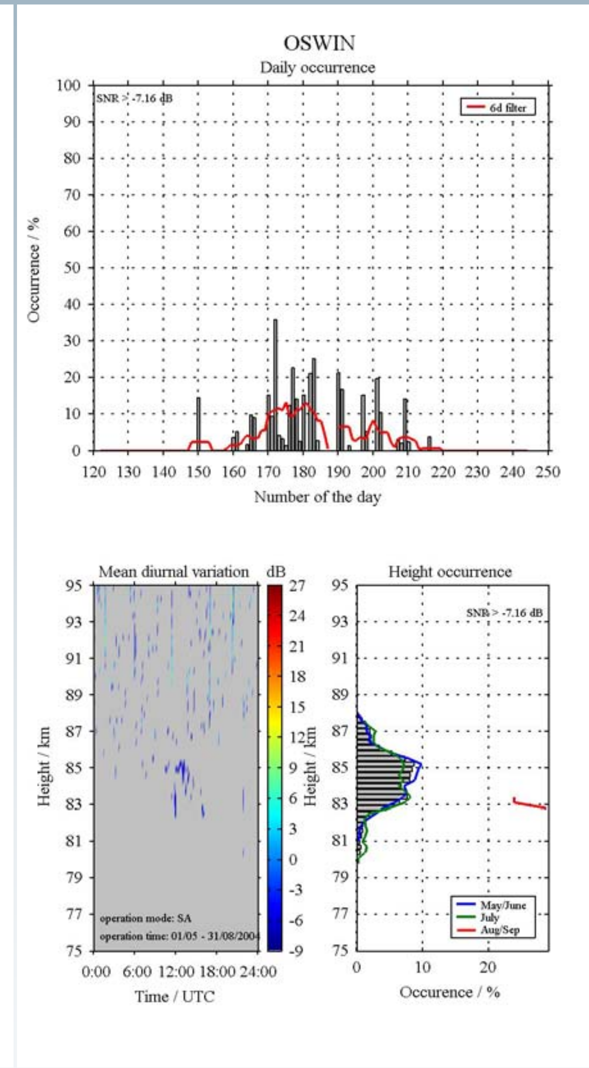
Why absolute radar calibration?

- Polar Mesosphere Summer Echoes (PMSE) have been observed with VHF radars around 50 MHz at various high-latitude locations for more than 20 years.
- A still open question is the inter-comparison of the various radar experiments as well as the latitudinal dependence of the strength of PMSE.
- Most of the observations are based on relative signal-to-noise ratios and not on absolute signal power → difficult to compare results from different radars.

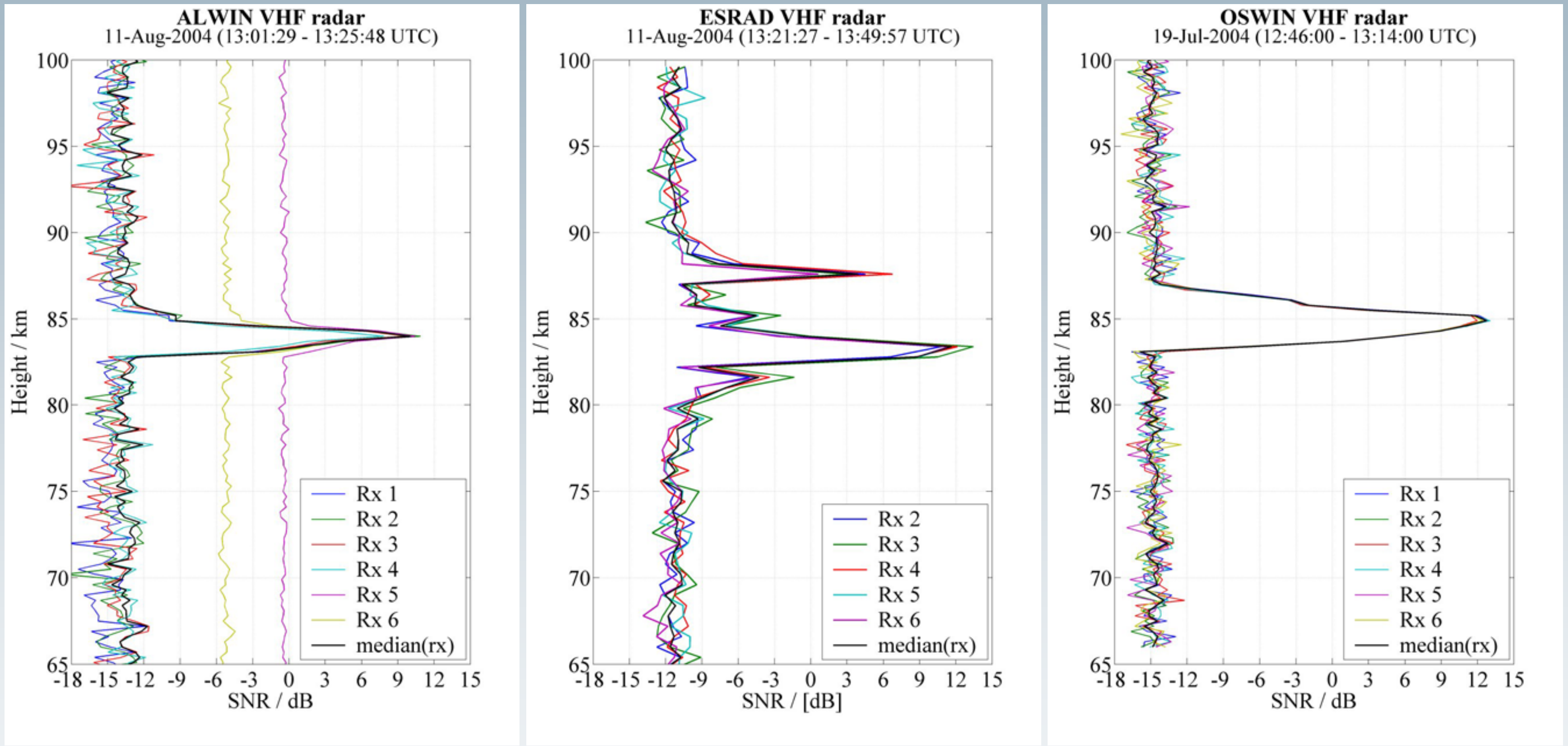
2004 PMSE statistics for ALWIN, ESRAD and OSWIN based on SNR with different min. values







PMSE with similar SNR observed by different radars



How comparable or how similiar are these echoes?

Why absolute radar calibration?

- Polar Mesosphere Summer Echoes (PMSE) have been observed with VHF radars around 50 MHz at various high-latitude locations for more than 20 years.
- A still open question is the inter-comparison of the various radar experiments as well as the latitudinal dependence of the strength of PMSE.
- Most of the observations are based on relative signal-to-noise ratios and not on absolute signal power → difficult to compare results from different radars.
- Absolute measurements allow also the estimation of further physical parameters (e.g. energy dissipation rate).

Radar reflectivity

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

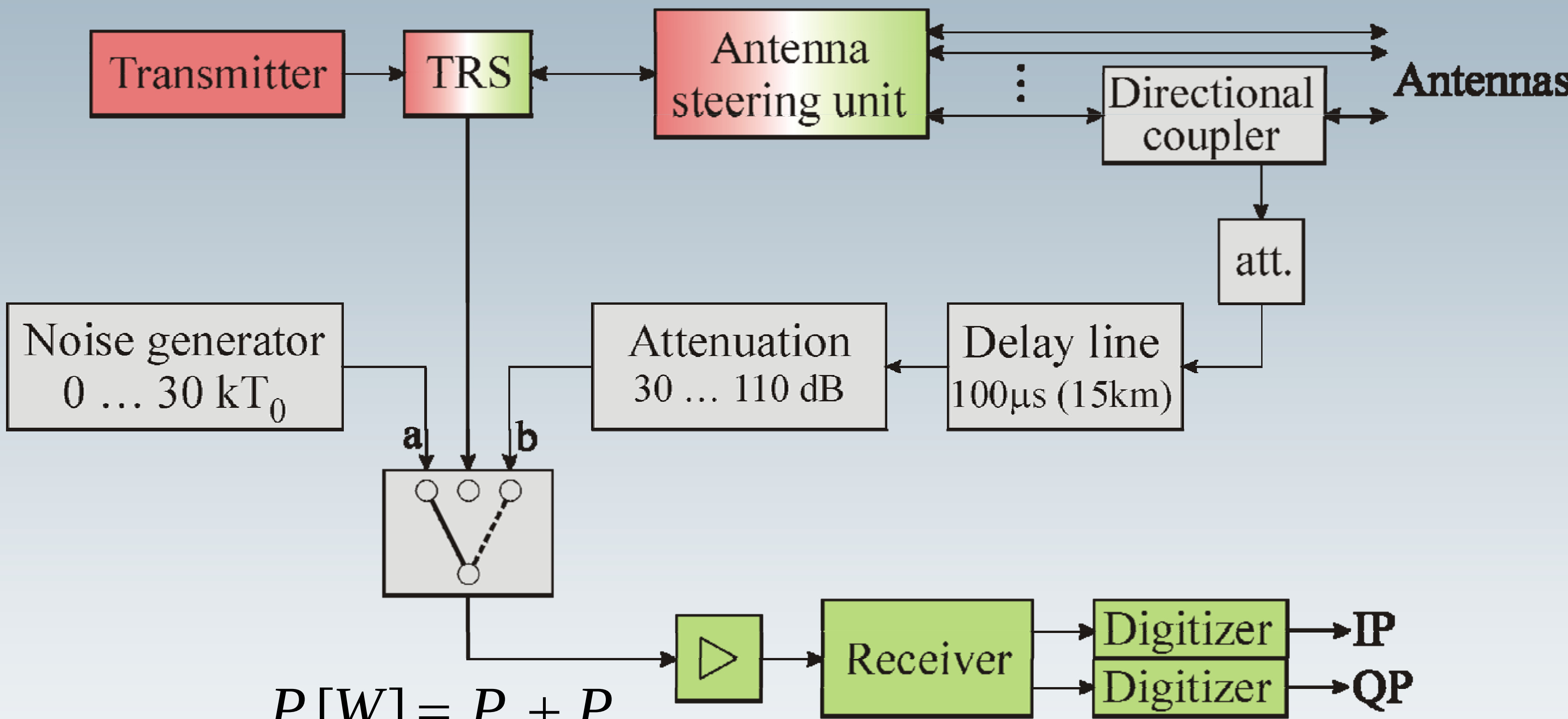
<u>Reference</u>

Hocking, W. K., Röttger, J., Studies of polar mesosphere summer echoes over EISCAT using calibrated signal strengths and statistical parameters, *Radio science*, vol. 32, no.4, pp. 1425-1444, 1997.

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

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

Two methods for absolute radar calibration



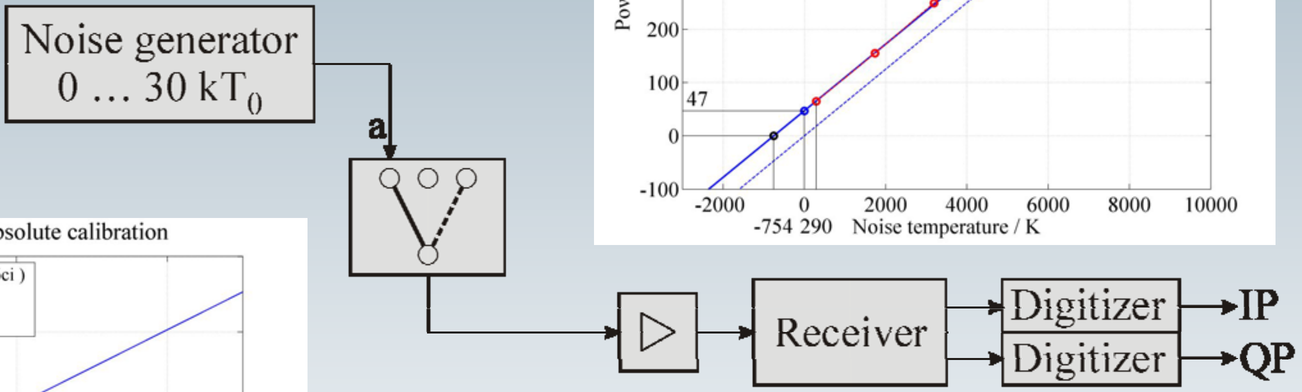
$$P_e[W] = P_r + P_n$$

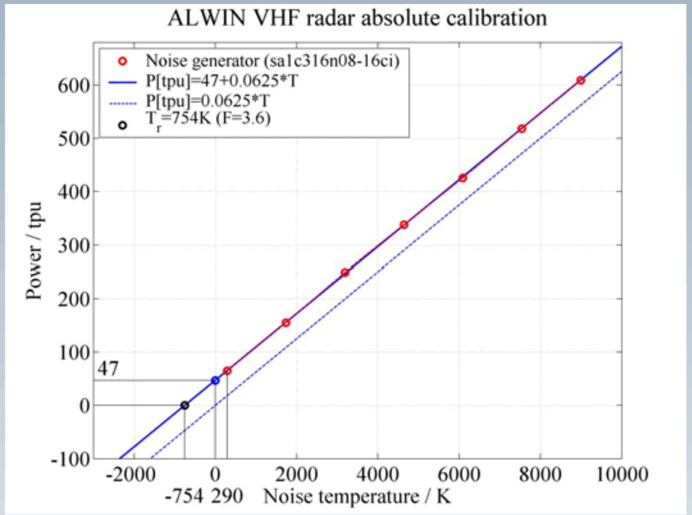
$$\frac{P_r[W]}{P_r[tpu]} = ?$$

$$P_r[tpu] = IP^2 + QP^2$$

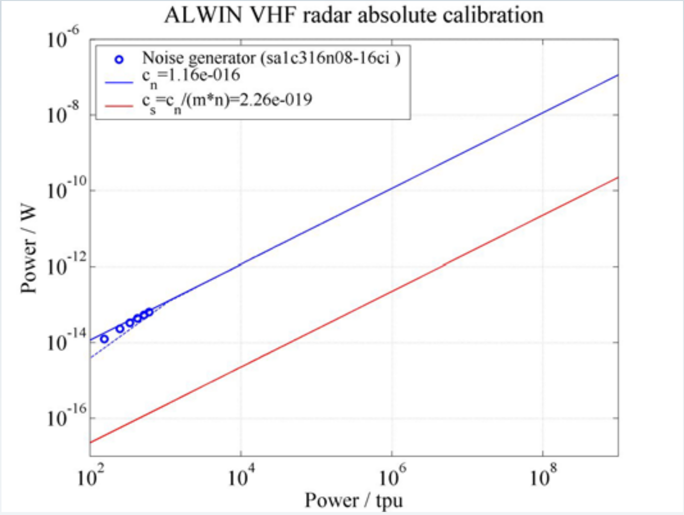
Radar calibration with noise source (1)

$$P_{inp.a}[W] = \Delta f \cdot k \cdot T = c \cdot T$$





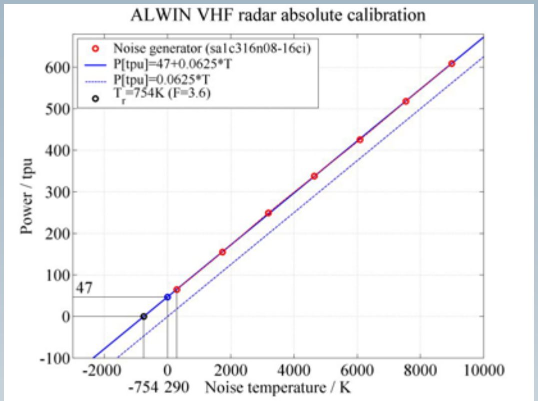
$$P_{out.a}[tpu] = a + b \cdot T$$

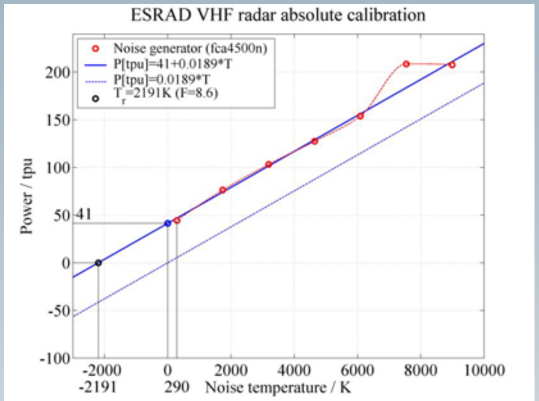


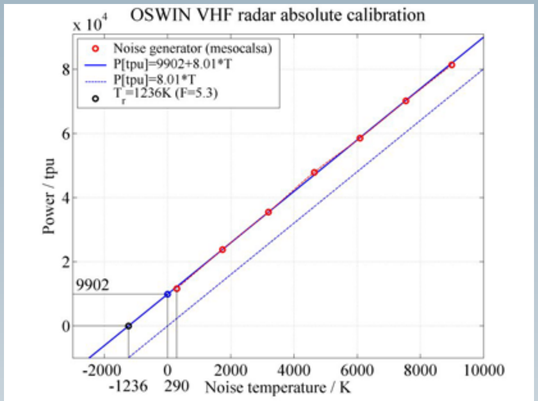
Calibration factor for noise signals:

$$c_n = \frac{P_{inp.a}[W]}{\left(P_{out.a}[tpu] - a\right)} = \frac{c}{b}$$

Radar calibration with noise source (2)

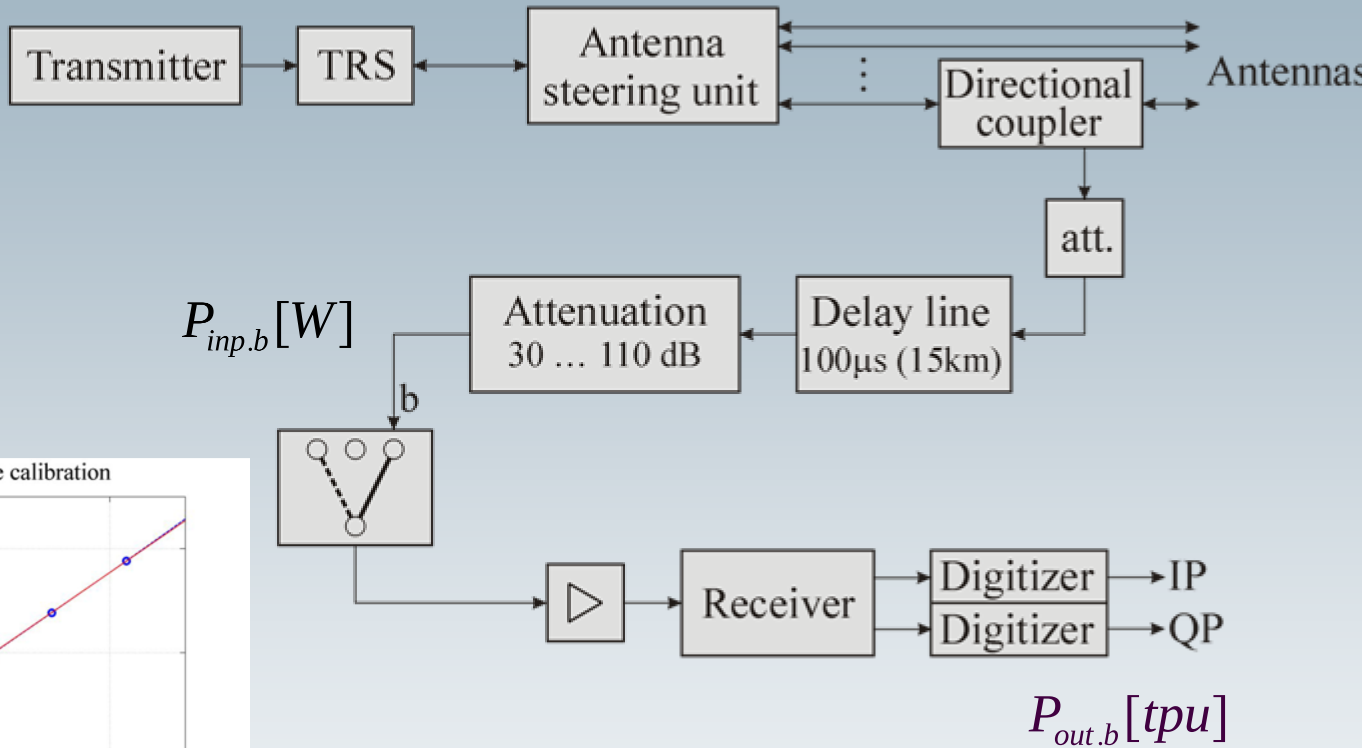


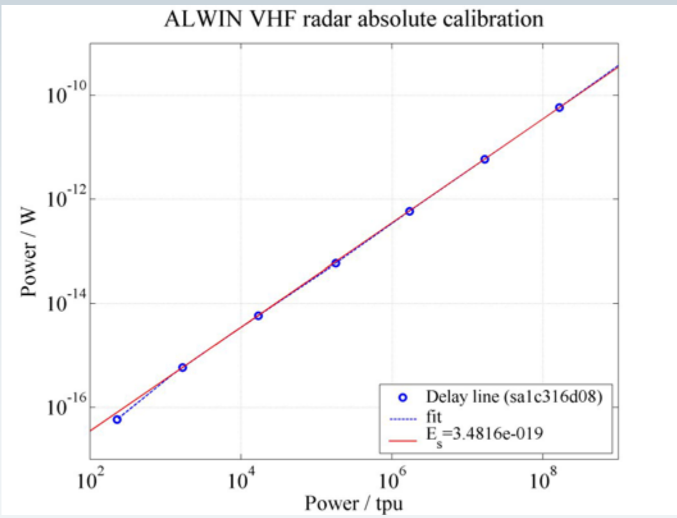




Parameter	ALWIN	ESRAD	OSWIN
Receiver bandwidth	500 kHz	500 kHz	506 kHz
Intersection $a = f(0)$	47	41	9902
Rising $b = \Delta P/\Delta T$	0.0625	0.0189	8.0116
Receiver noise temperature T_r	754 K	2191 K	1236 K
Noise figure	3.6	8.6	5.3
Calibration factor $\mathbf{c_n}$	$\mathbf{1.16 \cdot 10^{-16}}$	$\mathbf{1.92 \cdot 10^{-16}}$	$\mathbf{9.15 \cdot 10^{-19}}$

Radar calibration with delay line





Calibration factor for coherent detected signals:

$$c_s = \frac{P_{inp.b}[W]}{P_{out.b}[tpu]}$$

Calibration factors

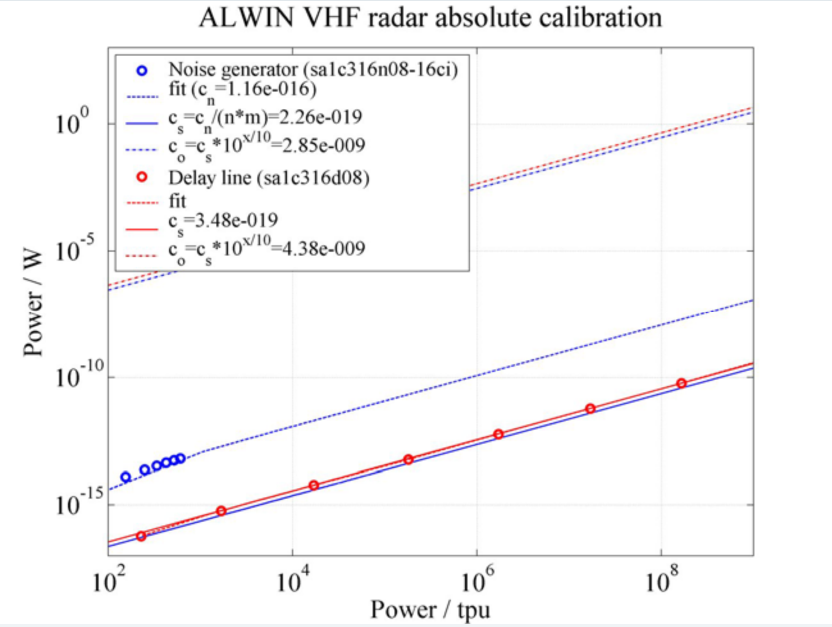
Noise signals

$$c_n = \frac{P_{inp.a}[W]}{\left(P_{out.a}[tpu] - a\right)} = \frac{c}{b}$$

Coherent detected signals

$$c_s = \frac{P_{inp.b}[W]}{P_{out.b}[tpu]}$$

$$c_n = (m \cdot n) \cdot c_s$$



m = total number of coherent integrations

n = code length

Calibration factor for received signal

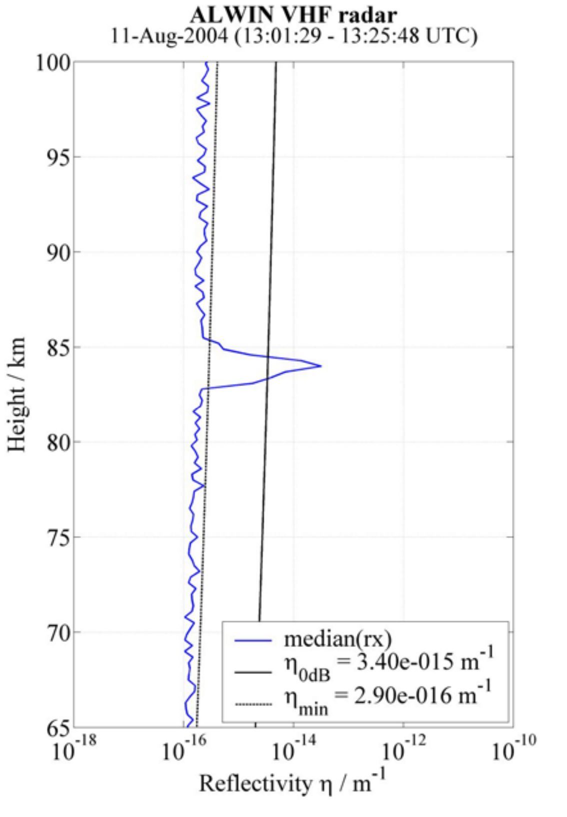
$$P_r[W] = c_s \cdot P_r[tpu]$$

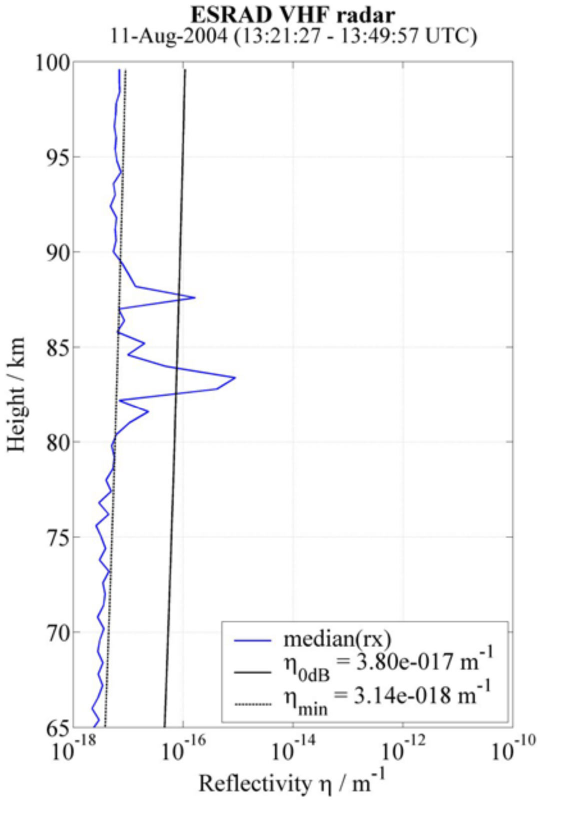
	Noise generator	Delay line
c_s	**$2.26 \cdot 10^{-19}$**	**$3.48 \cdot 10^{-19}$**

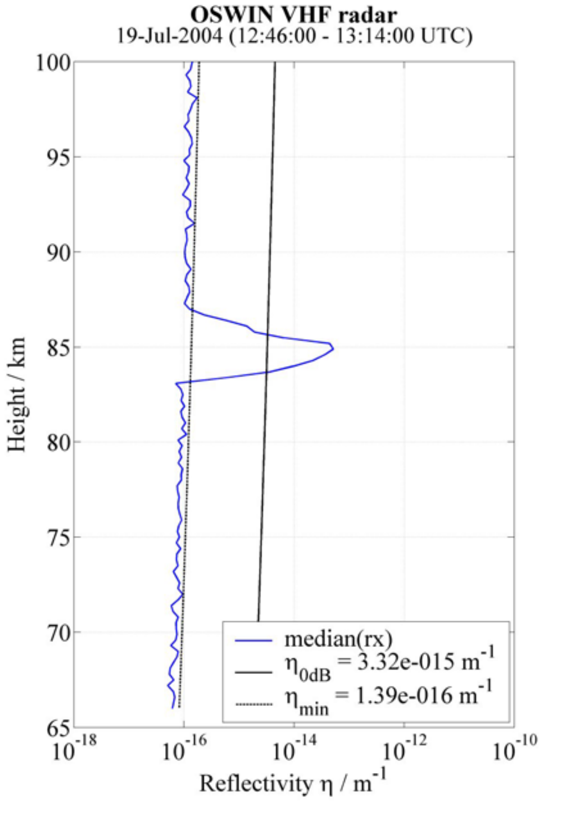
Basic radar system and experiment parameter

Parameter \ Radar	ALWIN (69°N; 16°E)	ESRAD (68°N; 21°E)	OSWIN (54°N; 11°E)
Radar wave length	5.6 m	5.8 m	5.6 m
Peak power	36 kW	72 kW	60 kW
Gain of Tx antenna	30.24 dBi	35.49 dBi	30.24 dBi
Half power half beam width	3°	2.12°	3°
Gain of Rx antenna	22.47 dBi	25.43 dBi	22.47 dBi
System efficiency	0.58	0.57	0.58
Sampling resolution	300 m	600 m	300 m
→ **System factor c_{sys}**	**8.69e-09**	**6.31e-10**	**5.22e-09**
Parameter \ Experiment	sa1c316m08	fca_4500	mesocal_sa
Number of coherent integrations	32	256	20
Code length	16	8	16
Receiver RF filter bandwidth	500 kHz	250 kHz	506 kHz
Noise calibration factor c_n	1.16e-16	1.92e-16	9.16e-19
→ **Signal calibration factor c_s**	**2.26e-19**	**9.37e-20**	**2.86e-21**

PMSE volume reflectivity for similar SNR observed by different radars







Minimum detectable reflectivity

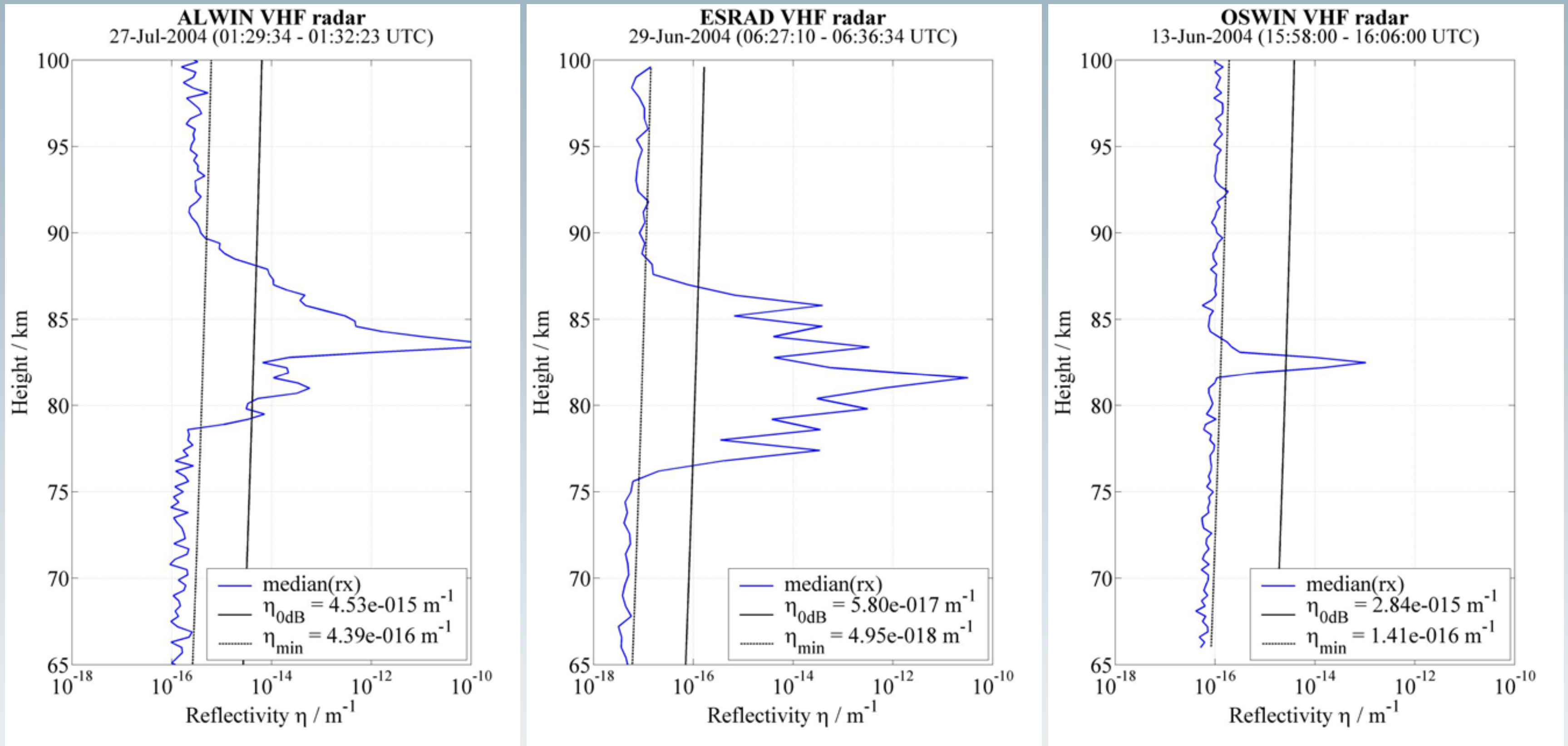
ALWIN (69°N): η_{min}= $\mathbf{4.45 \cdot 10^{-16}}$

ESRAD (68°N): η_{min}= $\mathbf{1.97 \cdot 10^{-17}}$

OSWIN (54°N): η_{min}= $\mathbf{3.17 \cdot 10^{-16}}$

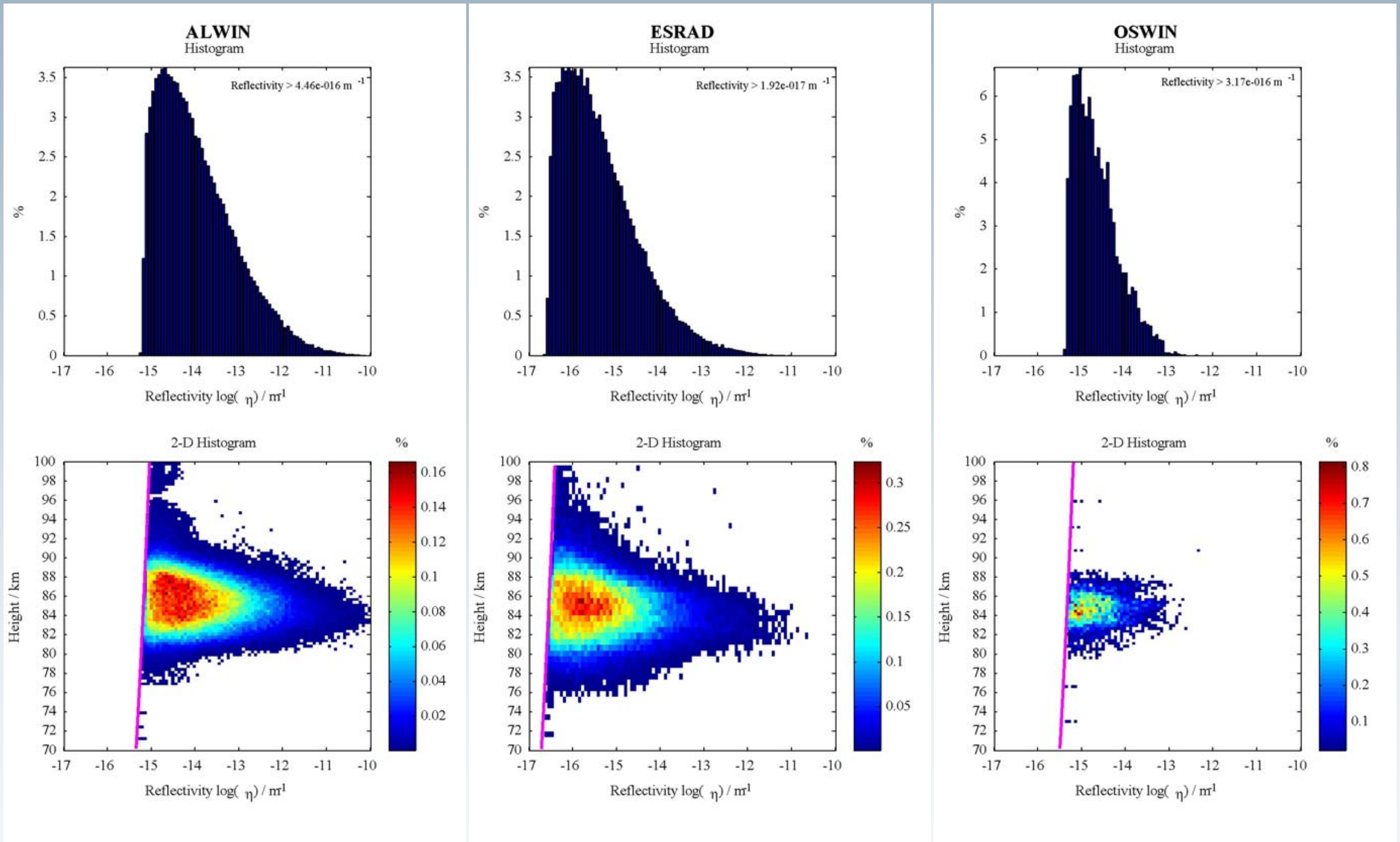
- ALWIN and OSWIN have a similar minimum detectable reflectivity
- ESRAD is more sensitive mainly due to the larger antenna array and peak power

Maximum volume reflectivity of PMSE observed in 2004 by different radars at different latitudes



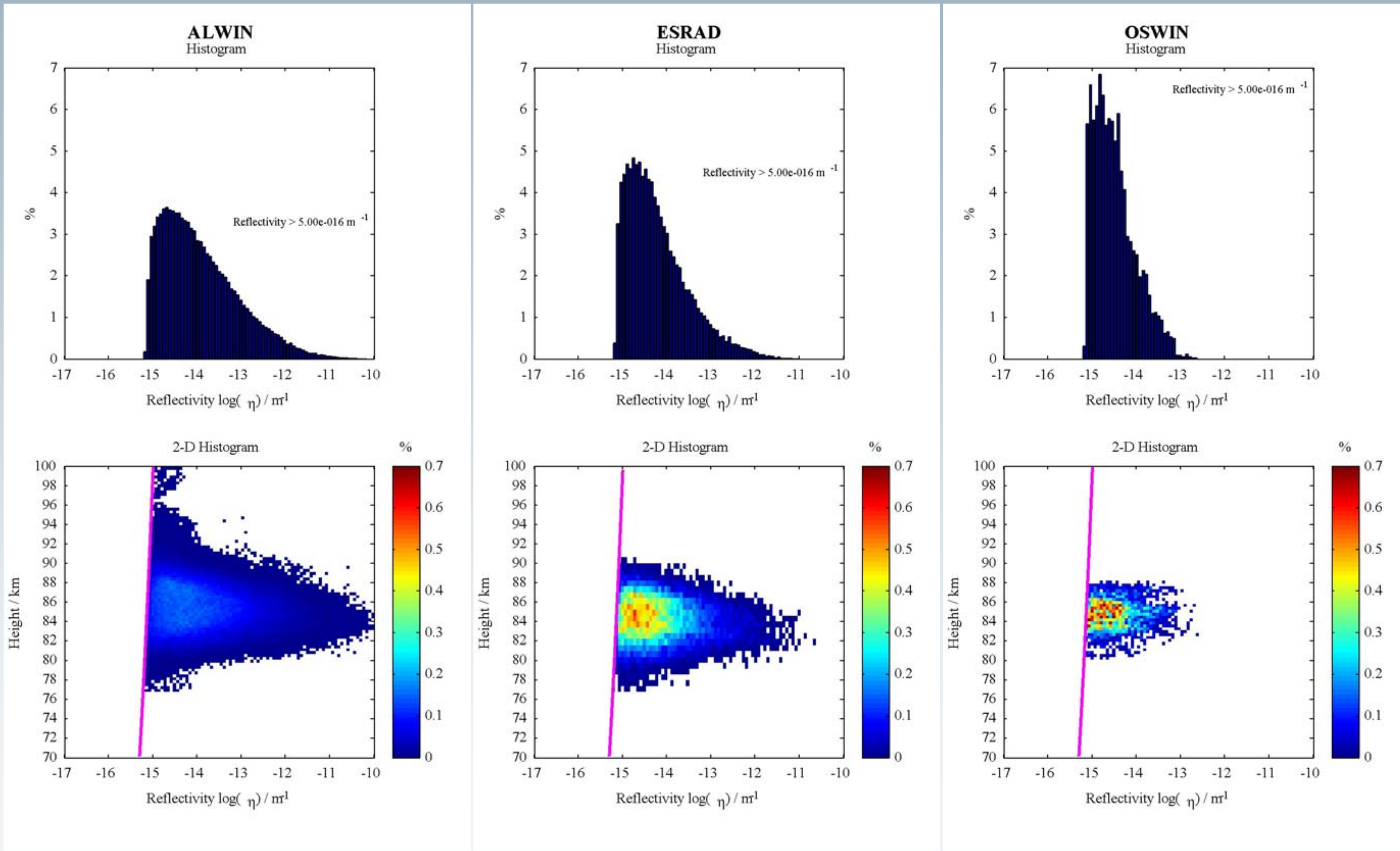
- ALWIN (69°N): η_{max}= **$2.84 \cdot 10^{-10}$** @ 27/07/2004 – 01:32 UT
- ESRAD (68°N): η_{max}= **$2.11 \cdot 10^{-11}$** @ 29/06/2004 – 06:32 UT
- OSWIN (54°N): η_{max}= **$2.36 \cdot 10^{-13}$** @ 13/06/2004 – 02:36 UT

PMSE season 2004
Reflectivity histograms for different min. values

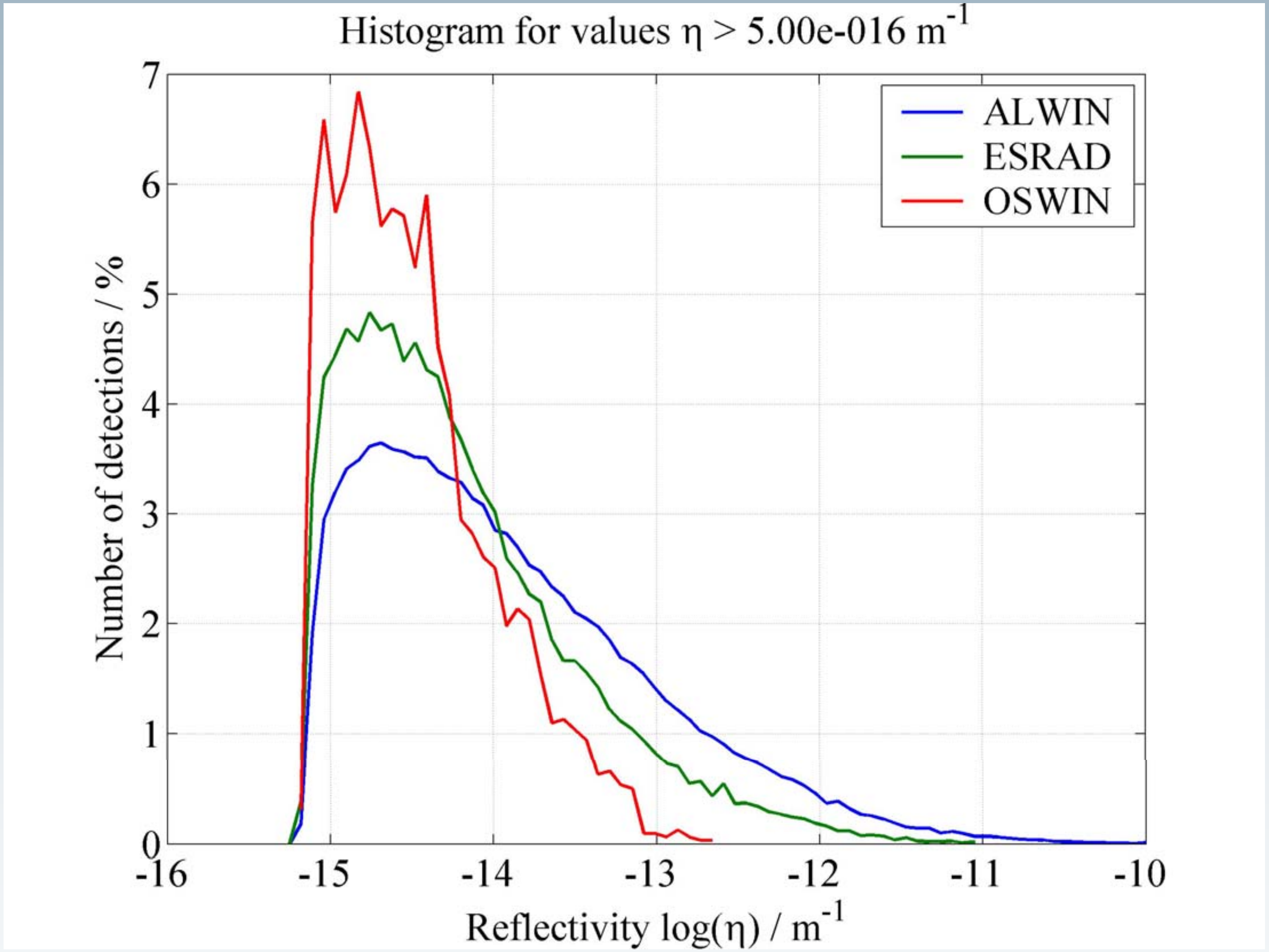


PMSE season 2004

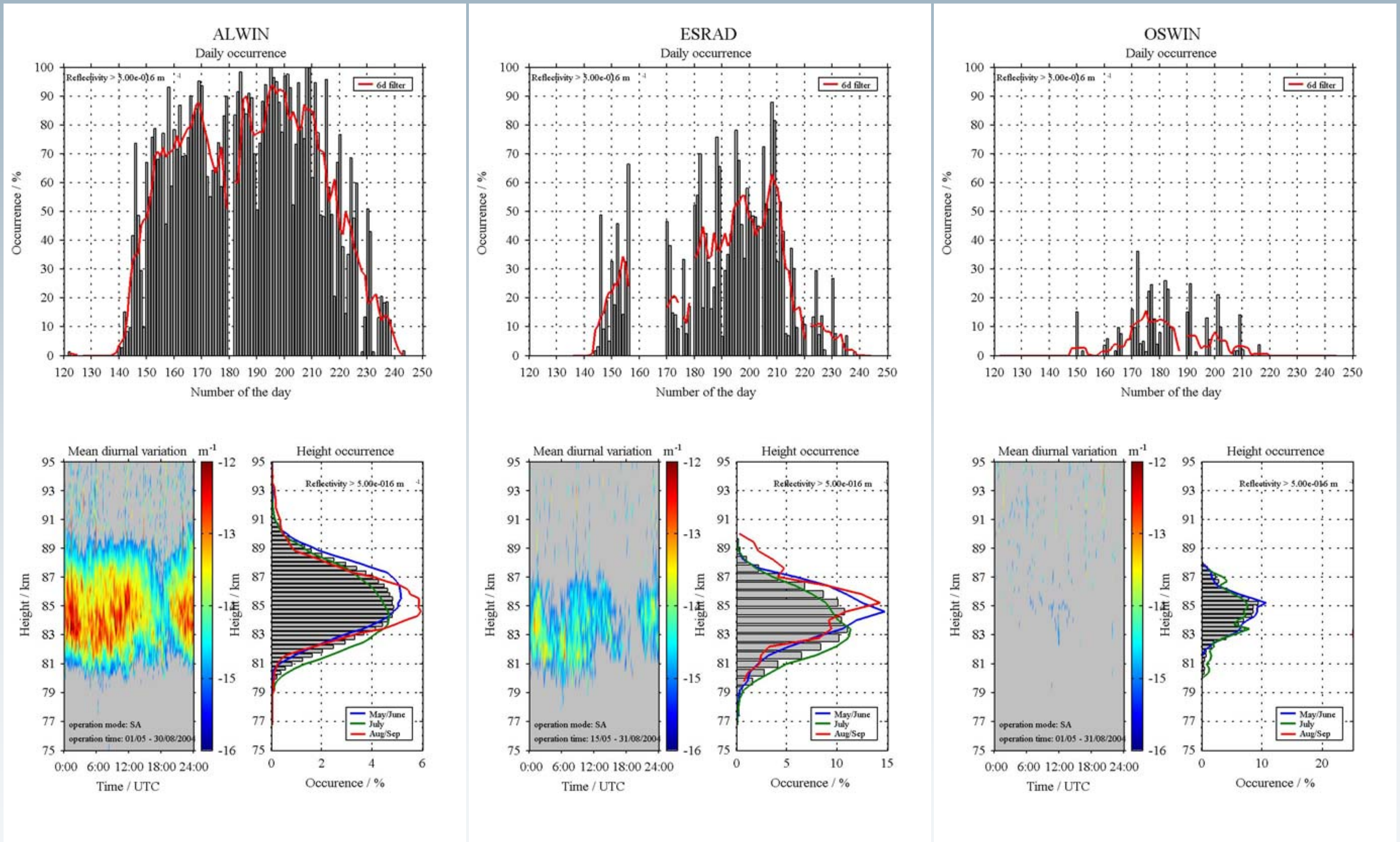
Reflectivity histograms $\eta > 5 \cdot 10^{-16}\ m^{-1}$



PMSE season 2004
Comparison of reflectivity histograms



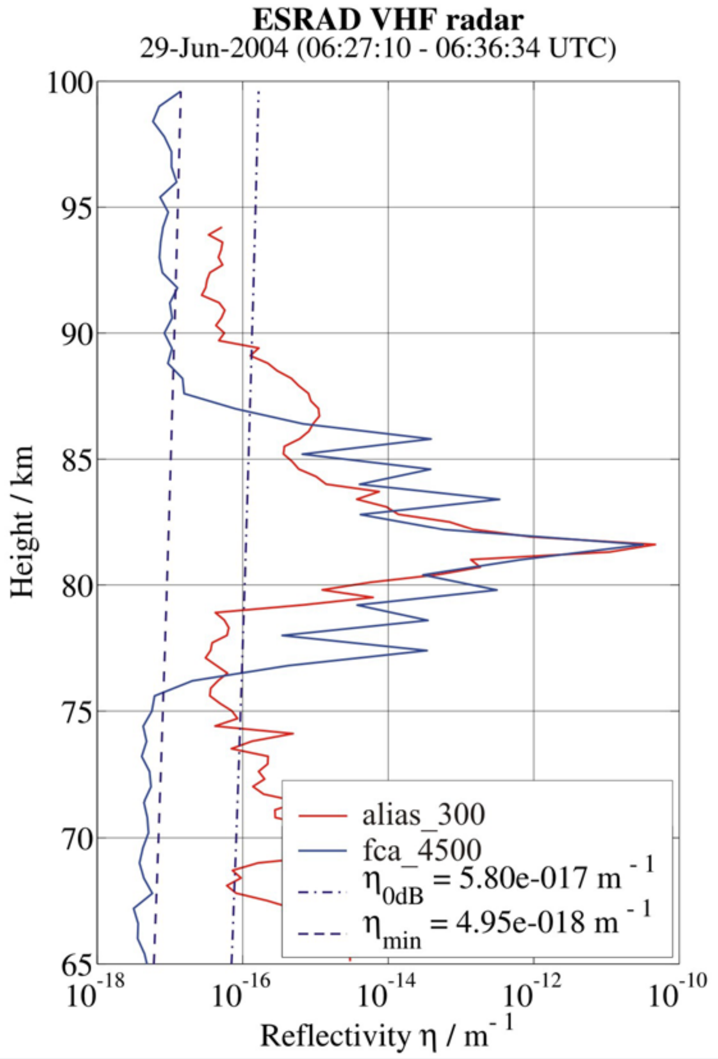
2004 PMSE statistics for ALWIN, ESRAD and OSWIN based on reflectivity $\eta > 5 \cdot 10^{-16}\ m^{-1}$



Summary

- Absolute calibration of VHF radars can be done using a calibrated noise source or a delayed transmitted signal
  → the results of both methods are convertible !
- ALWIN, ESRAD and OSWIN have been absolute calibrated using both methods.
- A minimum detectable radar reflectivity has been derived for all three radars → ESRAD is the most sensible system.
- (P)MSE radar reflectivity decreases with decreasing latitude (ALWIN 69°N – OSWIN 54°N)
- Differences in PMSE radar reflectivity have been found at nearly the same latitude (ALWIN 69°N, ESRAD 68°N) but at different sides of the Scandinavian ridge (???)

Comparison of results from different experiments carried out with ESRAD simultaneously



Parameter \ Experiment	**fca_4500**	**alias_300**
Pulse repetition frequency	1300 Hz	2520 Hz
Height range [km] → range alias [km]	2.4 – 34.8 61.8 – 94.2	4.8 – 99.6
Sampling resolution	600 m	300 m
Number of coherent integrations	128	256
Code length	8	8
Receiver RF filter bandwidth	250 Hz	500 Hz
Calibration factor c_s	9.37e-20	9.81e-20
Calibration factor ratio	**0.96**	

PMWE and PMSE