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EARTH AND ENVIRONMENTAL SCIENCE
SUPPLEMENTARY-RESULT
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First observations of Polar Mesospheric Echoes at both 31 MHz and 53.5 MHz over Svalbard (78.2°N 15.1°E)

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Abstract
During summer 2020, observations of the mesosphere using a 53.5 MHz radar on Svalbard, at 78.2°N 15.1°E, revealed the well-known Polar Mesospheric Summer Echoes (PMSE). At the same time, a co-located meteor detection radar, operating at 31 MHz detected corresponding echoes very distinct from those associated with meteor trails. Comparing as many days as possible during 2020, incontestable evidence arose to demonstrate that the meteor detection radar was capable of observing PMSE, although not in the optimised fashion of the 53.5 MHz system. We present examples of results from both systems, supplementing the earlier findings of Swarnalingam et al. (2009), and simultaneously show very first results from this particular geographical location.

Keywords: Polar Mesospheric Summer Echoes (PMSE); high-latitude; multiple frequencies

Introduction

Strong coherent echoes occur when structures defined by discontinuities in refractive index are present with scales that match half the radar wavelength (Bragg condition, https://en.wikipedia.org/wiki/Bragg%27s_law). Such structures, simplistically envisaged as created by turbulent eddies, are present in the mesosphere and visible where the refractive index is governed by ionisation. The distribution of eddy sizes is determined by the inertial subrange of the Kolmogorov spectrum (Obukhov. 1941, and more accessibly, *e.g.*, Batchelor, 1953 and references therein) and this may be modified by charged dust and/or proton hydrates – a consequence of the particularly low temperatures at the high latitude mesopause – causing echoes at frequencies into the UHF (in the framework of these observations: Hall, 1993). Presence of echoes at frequencies lower than ~50 MHz, *i.e.* wavelengths greater than ~6 m, thus corresponding to eddies *larger* than ~3 m is surprisingly little investigated, one notable study being Swarnalingam et al. (2009). Here we have the opportunity to observe structures of ~5 m. We merely report the phenomenon, but otherwise the reader is referred to Batchelor (1953) for appreciation of the result in the framework of the fluid dynamics of the upper mesosphere.

The first observations of such particularly strong echoes – known as Polar Mesospheric Summer Echoes (PMSE) – are attributed to Czechowsky et al. (1979) and Ecklund and Balsley (1981), and thereafter, at 78.2°N 15.1°E by the 53.5 MHz "SOUSY" radar (Hall et al. 2009). A meteor wind radar operating at 31 MHz is co-located with SOUSY, and hereafter referred to as "NSMR" (Hall et al. 2002).

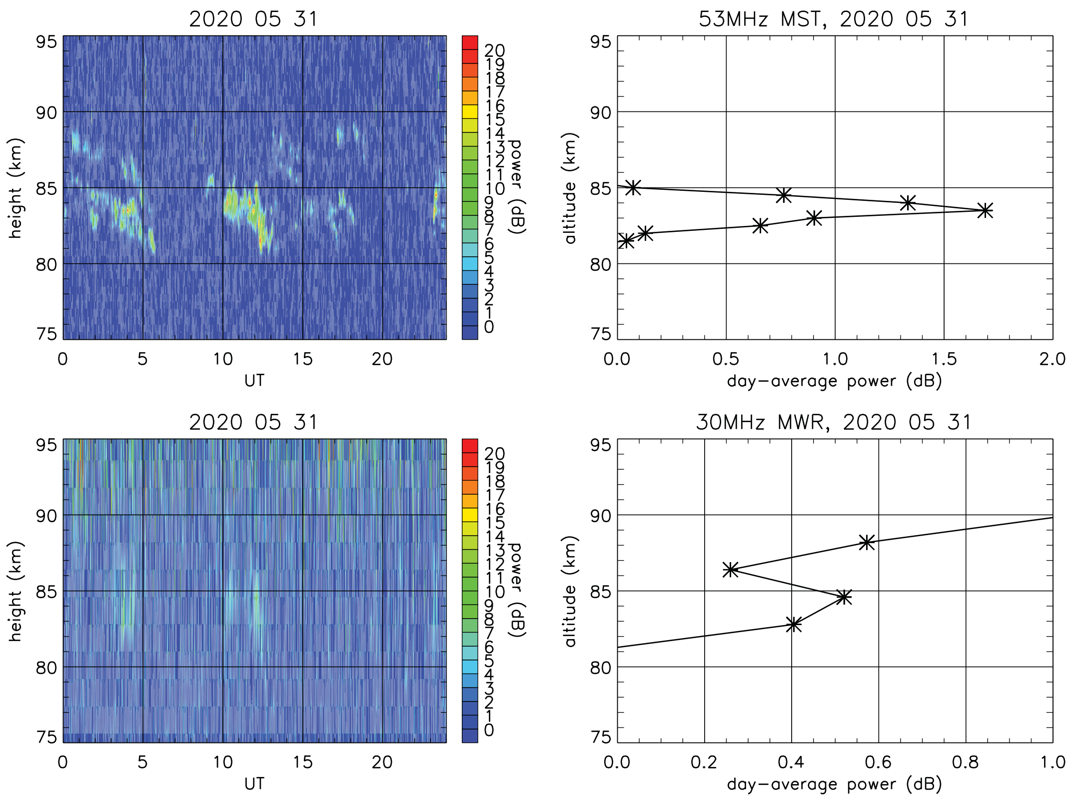

Figure 1. Echo power as a function of height and time, and as mean power for the two radars from 31st May 2020. Top row: the 53.5 MHz SOUSY radar; bottom row: the 31 MHz NSMR system; left column: power *vs.* height and time; right column: corresponding mean power *vs.* height for the day.

The systems were modernised in 2019 and therefore producing simultaneous observation of the upper mesosphere during the summer of 2020. PMSE are a known feature of the high-latitude mesosphere, normally observed by systems such as SOUSY, but here we present first results of PMSE detected by the meteor radar NSMR, demonstrating the echoes to be a feature at 31 MHz, supplementing the report by Swarnalingam et al. (2009), and furthermore over Svalbard.

Objective

To demonstrate that Polar Mesospheric Summer Echoes can be observed by a 31 MHz meteor detection radar, as well as by a 53.5 MHz radar optimised to such observations, and at 78.2°N 15.1°E.

Methods

The most up-to-date operating specifications of the two radars are fully described by Hall et al. (2002, 2009). The antenna patterns of the two systems are somewhat different and are fully described (including lucid illustrations) by Swarnalingam et al. (2009). Range resolutions are 1 km for SOUSY and 2 km for NSMR. These factors explain the marked superior definition of echoes from the (optimal) SOUSY system as compared to NSMR (optimised to meteor trail detection).

Results

As shown in Figure 1, we have compared mesospheric echo occurrences from two co-located radars operating at 53.5 and 31 MHz. When examining the figure, it must be reiterated that here the echo powers

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are not directly comparable. While Swarnalingam et al. (2009) determined consistent backscattered power from each instrument, this was outside the scope of our preliminary study. Since SOUSY is optimised to such observations, PMSE will be observed over longer intervals than by NSMR. Times and heights of peaks in occurrence can, however be compared with a good degree of confidence. The 31 MHz system is optimised to meteor trail observations, and these have a peak at around 90 km. Thus we focus on echoes near 85 km – the peak occurrence for PMSE and approximate location of the high latitude summer mesopause; a more advanced analysis and portrayal could hopefully filter out meteor trail signals. The effect is seen in the day-average height profiles: for the meteor radar, although the trail echoes begin to dominate immediately above the PMSE peak, whereas for 53.5 MHz (optimised to coherent echoes from abrupt changes in refraction coefficient *i.e.* Bragg scattering, explained earlier) there is a well-defined peak. The data presented here are, however, only an example of over two months of such observations, and the presence of echoes at 31 MHz corresponding to the PMSE observations at 53.5 MHz is undeniable.

Conclusions

We establish that a 31 MHz radar optimised to observing echoes from meteor trails occurring primarily between 85 and 95 km altitude, and over a wide field of view, is capable of detecting polar mesospheric summer echoes (PMSE) independently detected by a co-located 53.5 MHz system, specifically designed for PMSE observations. Although not the first such observation, it is in fact the first at 78.2°N 15.1°E over Svalbard, and that turbulent scales exist to at least 5 m.

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Author Contributions. The NSMR system is jointly operated by CH and MT, and the SOUSY system by CH. CA provides specialist data assimilation and delivery enabling direct comparisons of results.

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Data availability. Data from both radars are available from the Svalbard Integrated Arctic Earth Observing System portal (https://sios-svalbard.org/).

The Arctic University of Norway has repositories at:

http://radars.uit.no/sousy6/METADATA_DECODED.txt"(for SOUSY) and.

http://radars.uit.no/MWR/NSMR/METADATA.txt (for NSMR).

Conflict of Interest. The authors declare no conflicts of interest.

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Peer Reviews

Reviewing editor: Dr. Jacob Carley

NOAA Center for Weather and Climate Prediction, NCEP/Environmental Modeling Center, 5830 University Research Cour, College Park, Maryland, United States, 20740

This article has been accepted because it is deemed to be scientifically sound, has the correct controls, has appropriate methodology and is statistically valid, and has been sent for additional statistical evaluation and met required revisions.

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Review 1: First observations of Polar Mesospheric Echoes at both 31MHz and 53.5MHz over Svalbard (78.2°N 15.1°E)

Reviewer: Noora Partamies

Date of review: 11 September 2020

Conflict of interest statement. the reviewer declares no conflict of interest

Comments to the Author: The paper presents PMSE observations from both MST and meteor radars located on Svalbard. While the SOUSY radar is frequency-wise optimised for PMSE detection the NSMR is not. Being able to observe PMSEs with the meteor radar systems as well can significantly aid the future PMSE studies. As the authors point out, the meteor radar capabilities in the PMSE detection are very little investigated. One previous study is cited in this paper. The report would benefit from a little more detailing of this previous study by Swarnalingam et al. (2009), because it would allow emphasising the value of the presented Svalbard observations (frequency, latitude, co-location, length of data series…).

For the example day of data comparing SOUSY and NSMR measurements it would be helpful to include a grid in the mean power profile plots to guide the eye in reading the peak heights. Although clearly worth another more detailed study, it would make sense to point out the obvious differences in the PMSE echo strength and echo occurrence between the two radar systems.

Score Card

Presentation

5.0 /5

Is the article written in clear and proper English? (30%)	5/5
Is the data presented in the most useful manner? (40%)	5/5
Does the paper cite relevant and related articles appropriately? (30%)	5/5

Context

4.5 /5

Does the title suitably represent the article? (25%)	5/5
Does the abstract correctly embody the content of the article? (25%)	5/5
Does the introduction give appropriate context? (25%)	3/5
Is the objective of the experiment clearly defined? (25%)	5/5

Analysis

4.2 /5

Does the discussion adequately interpret the results presented? (40%)	3/5
Is the conclusion consistent with the results and discussion? (40%)	5/5
Are the limitations of the experiment as well as the contributions of the experiment clearly outlined? (20%)	5/5

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Review 2: First observations of Polar Mesospheric Echoes at both 31MHz and 53.5MHz over Svalbard (78.2°N 15.1°E)

Reviewer: Dr. Nimalan Swarnalingam

Date of review: 07 September 2020

Conflict of interest statement. Reviewer declares none.

Comments to the Author: The PMSE backscatter signals seem strong, and broad-beam meteor radar detects PMSE. It is an interesting result, in particular, observing PMSE using co-located SOUCY and NSMR radars. This would provide opportunities to study different scales of turbulent eddy structures, as well as the frequency dependence of PMSE.

Score Card

Presentation

4.6 /5

Is the article written in clear and proper English? (30%)	5/5
Is the data presented in the most useful manner? (40%)	4/5
Does the paper cite relevant and related articles appropriately? (30%)	5/5

Context

4.8 /5

Does the title suitably represent the article? (25%)	4/5
Does the abstract correctly embody the content of the article? (25%)	5/5
Does the introduction give appropriate context? (25%)	5/5
Is the objective of the experiment clearly defined? (25%)	5/5

Analysis

5.0 /5

Does the discussion adequately interpret the results presented? (40%)	5/5
Is the conclusion consistent with the results and discussion? (40%)	5/5
Are the limitations of the experiment as well as the contributions of the experiment clearly outlined? (20%)	5/5