



# Pajala Fireball

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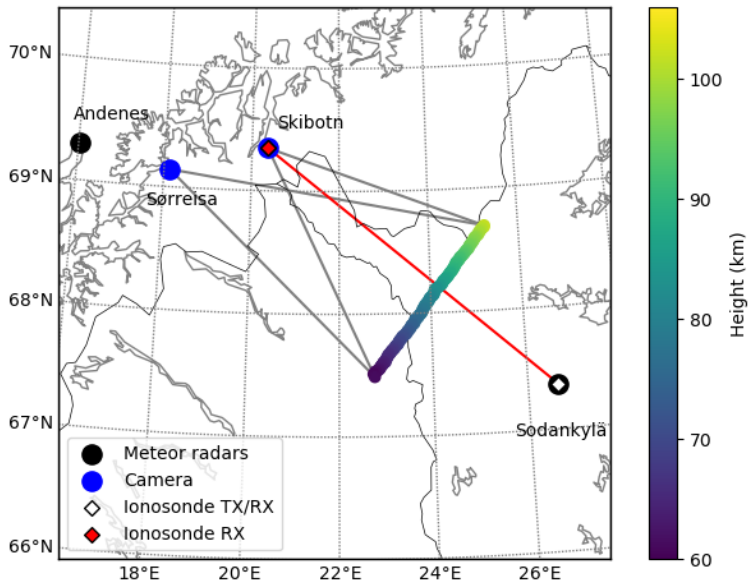
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# Overview

- ▶ Large daytime fireball observed on 2020-12-04T13:30:37Z
- ▶  $m_v \approx -13$ ,  $|v| = 28 \text{ km/s} \Rightarrow 1\text{-}100 \text{ kg}$  mass (needs to be improved!)
- ▶ Numerous eyewitness reports [13]
- ▶ Two stations of the Norwegian meteor network observed the full path (Skibotn and Sørreisa)
- ▶ Observations with two meteor radars and the Sodankylä ionosonde
- ▶ Long lasting trail echo, head echo, and sporadic E layer was observed.

# Observations



# Dual camera observations: 2020/12/04 13:30:37 UTC

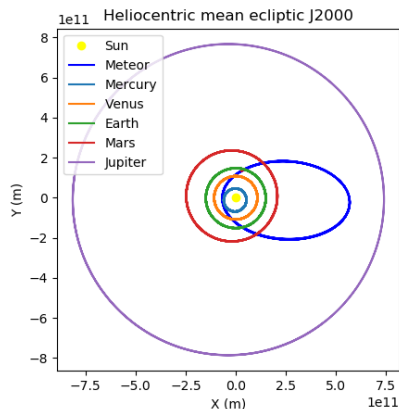


a) Skibotn and b) Sørreisa.

# Video

▶ Show video

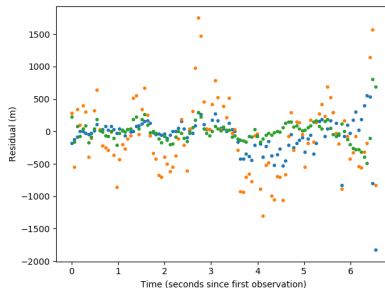
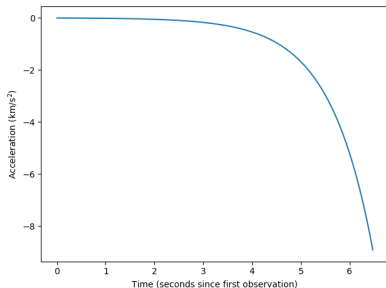
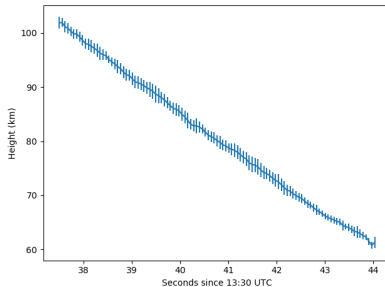
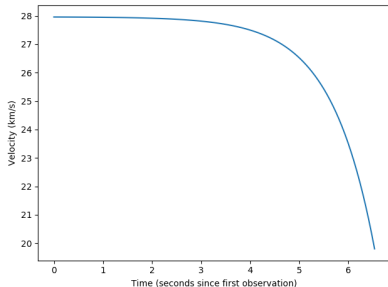
# Orbital parameters



Orbit propagated back 30 years  
using the Rebound  
propagator[17]

- ▶ Atmospheric drag removed
- ▶  $|v_0| = 27.96 \pm 0.02$  km/s.
- ▶ Radiant RA:  $76.13^\circ \pm 0.08$ ,  
Dec:  $30.04^\circ \pm 0.03$ .
- ▶ Earth's gravity removed
- ▶  $t_0 = 2019-12-04T13:30:37Z$ ,  
 $a = 2.12$  AU,  $e = 0.79$ ,  
 $i = 1.55^\circ$ ,  $\Omega = -107.4^\circ$ ,  
 $\omega = -75.4^\circ$ ,  $f = 189.75^\circ$
- ▶ Northern Taurids shower,  
Jupiter family. E.g., Comet  
Encke and Tunguska  
event[16, 8, 5, 1]

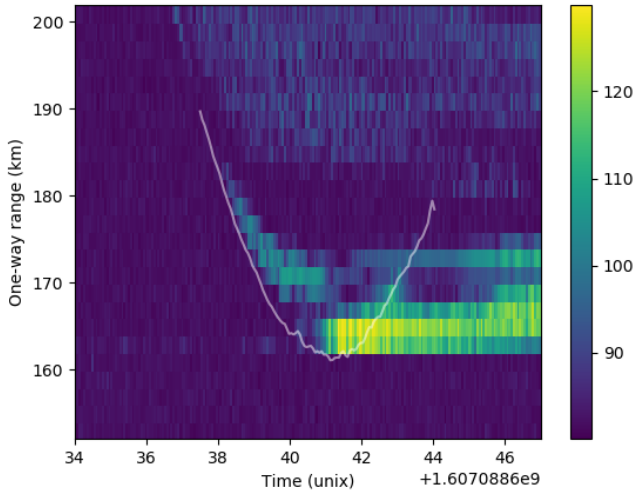
# Atmospheric deceleration



Atmospheric drag model:  $\vec{v}(t) = \hat{v}(|v_0| - |a_0|e^{-|a_1|t})$  (e.g., [20])

# Meteor radar “head” echo

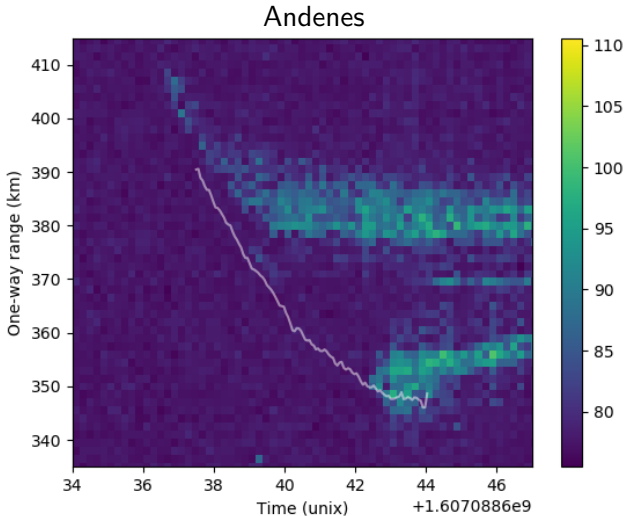
Sodankylä



Camera derived trajectory based range shown with white line.

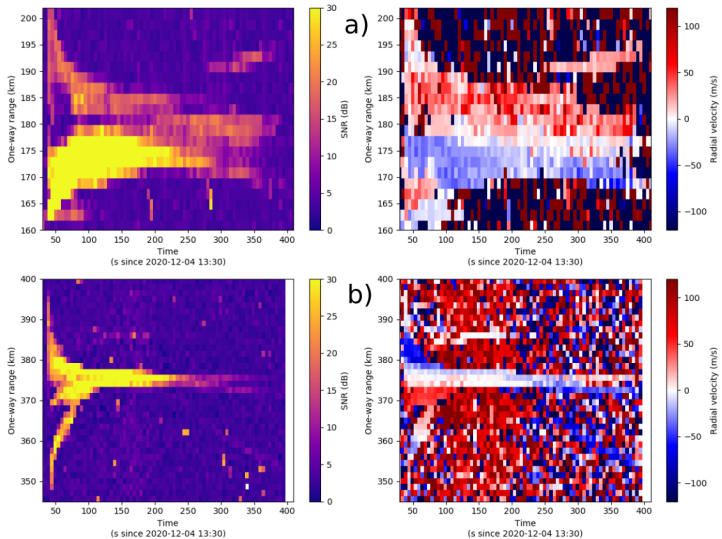


# Meteor radar “head” echo



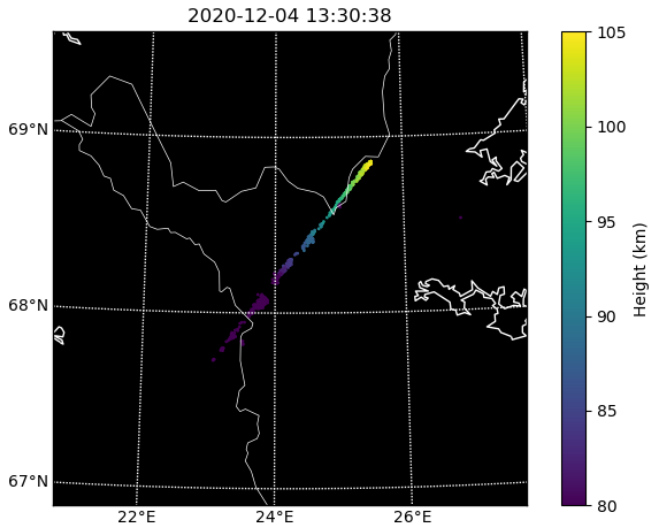
Camera derived trajectory based range shown with white line.

# Meteor radar trail echoes

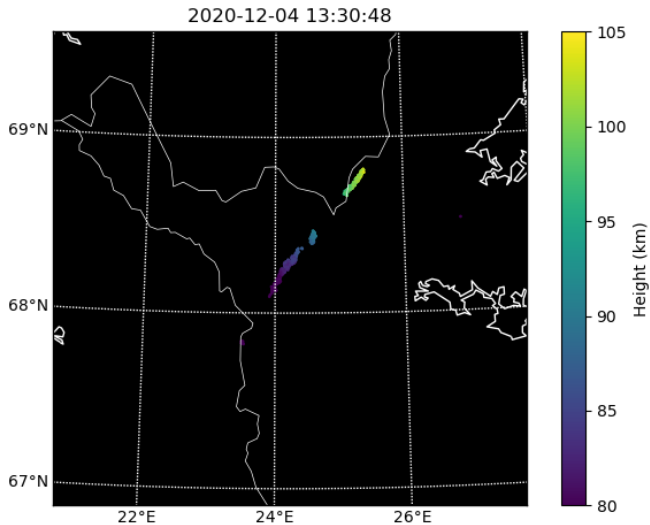


a) Sodankylä, b) Andenes. Positive velocity is away from radar.

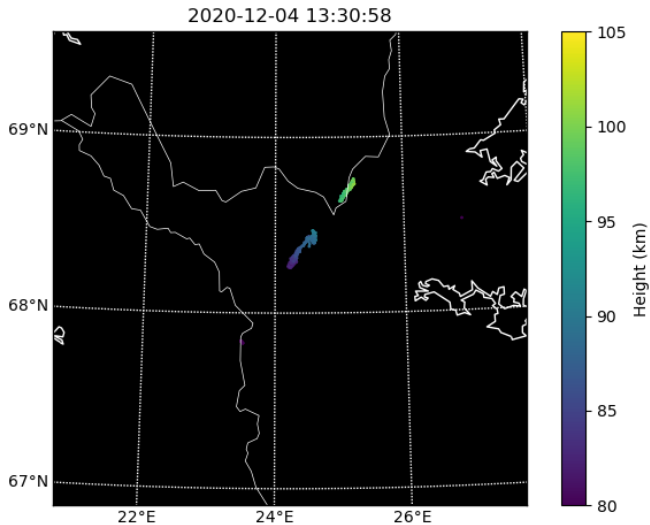
# Meteor radar trail echo interferometry



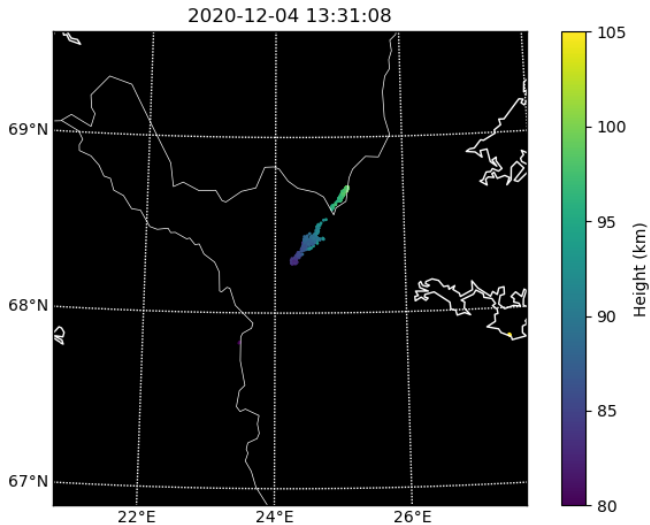
# Meteor radar trail echo interferometry



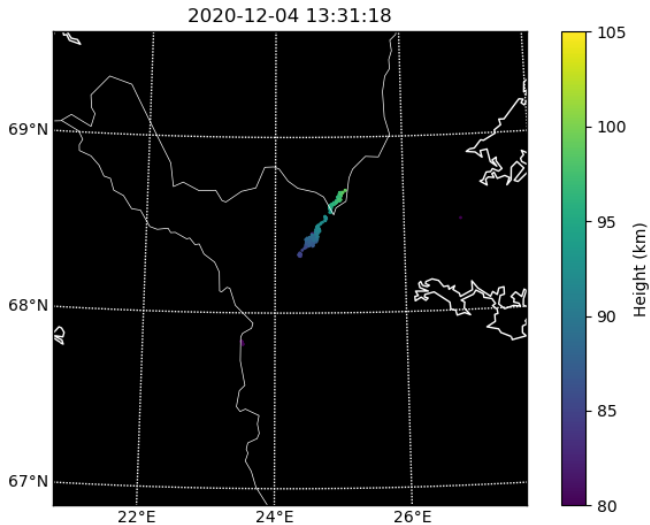
# Meteor radar trail echo interferometry



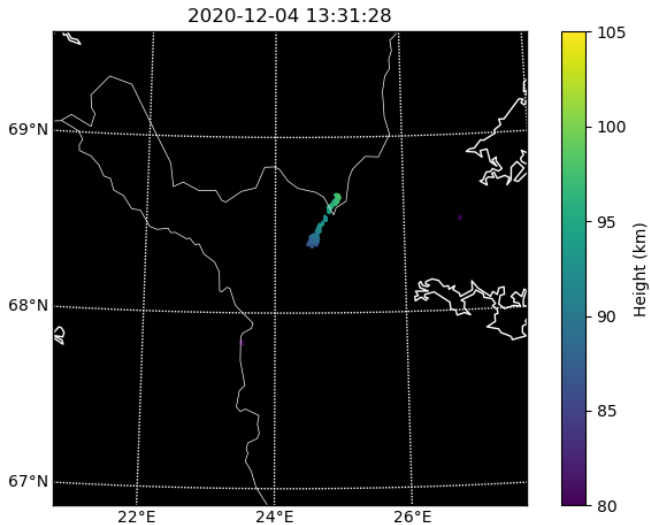
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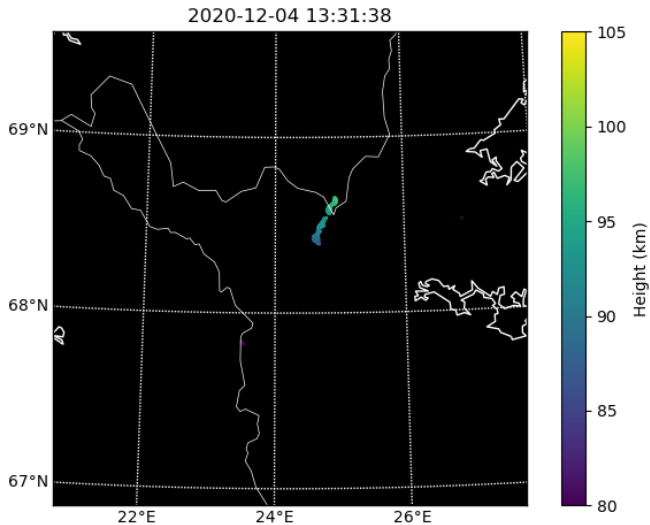


# Meteor radar trail echo interferometry

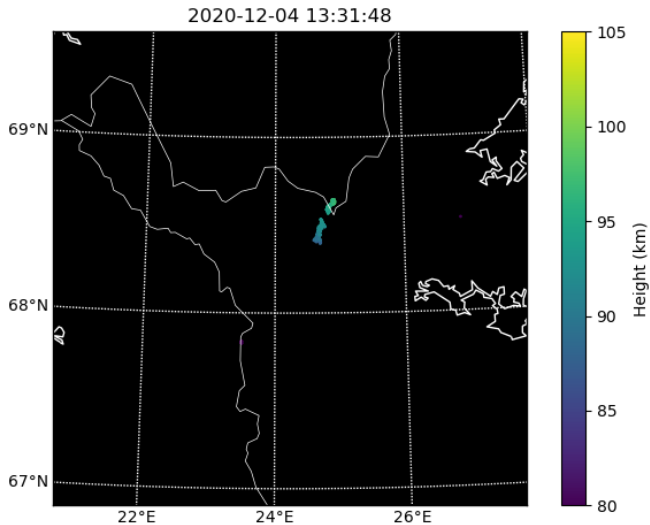




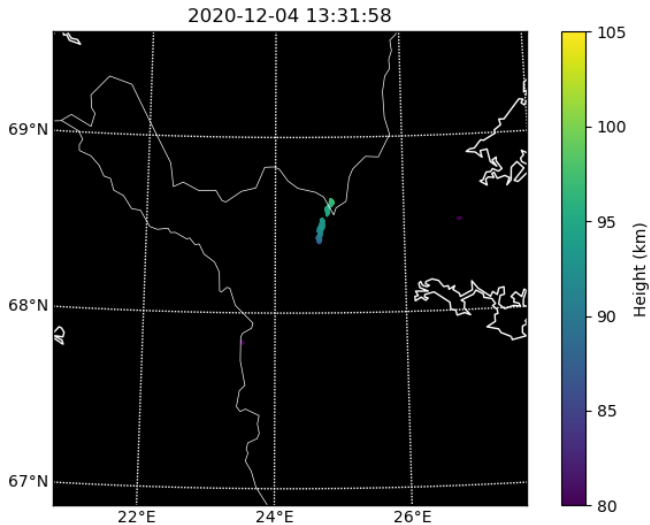
# Meteor radar trail echo interferometry



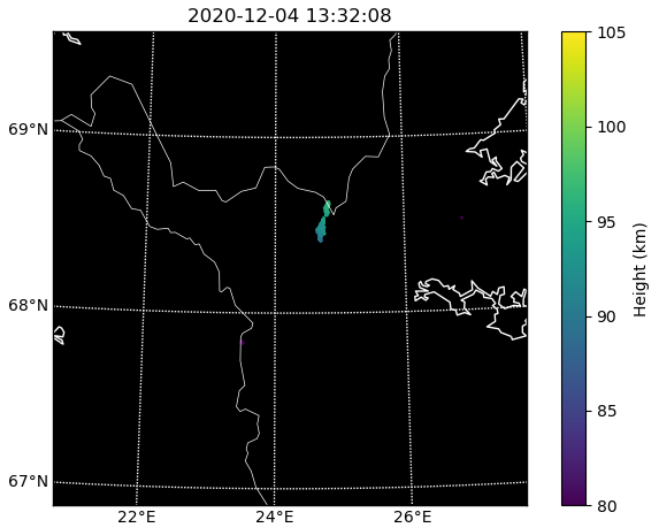
# Meteor radar trail echo interferometry



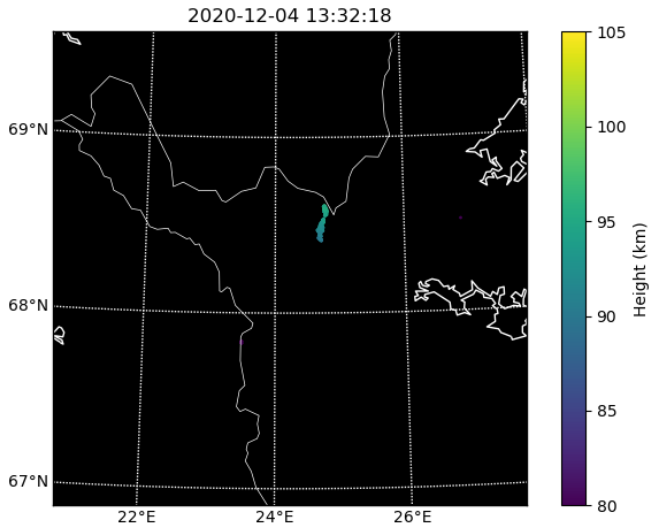
# Meteor radar trail echo interferometry



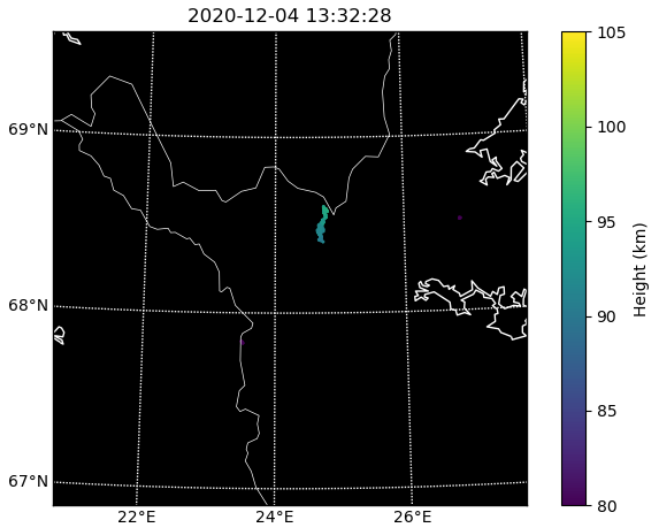
# Meteor radar trail echo interferometry



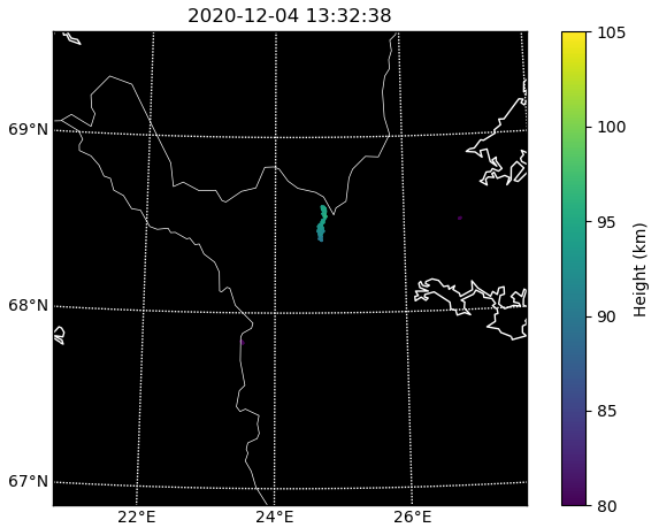
# Meteor radar trail echo interferometry



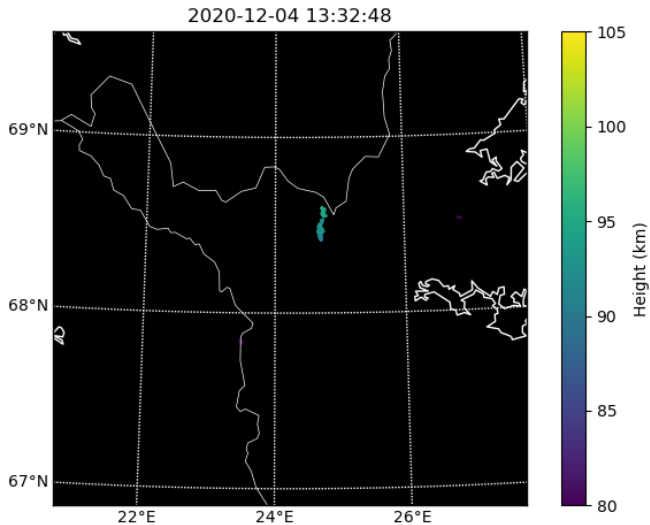
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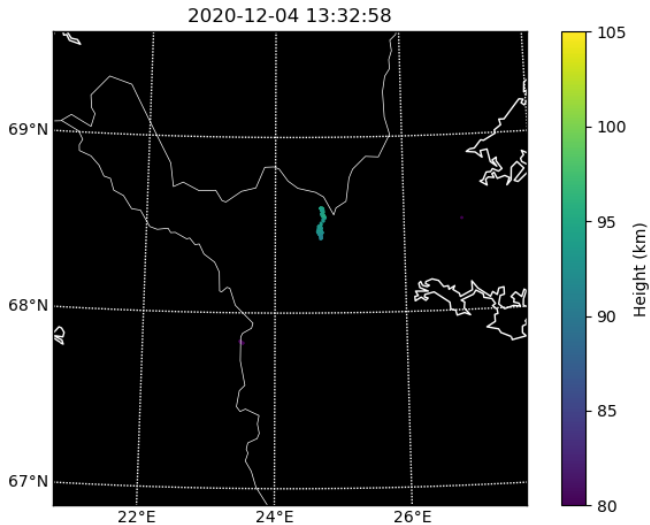


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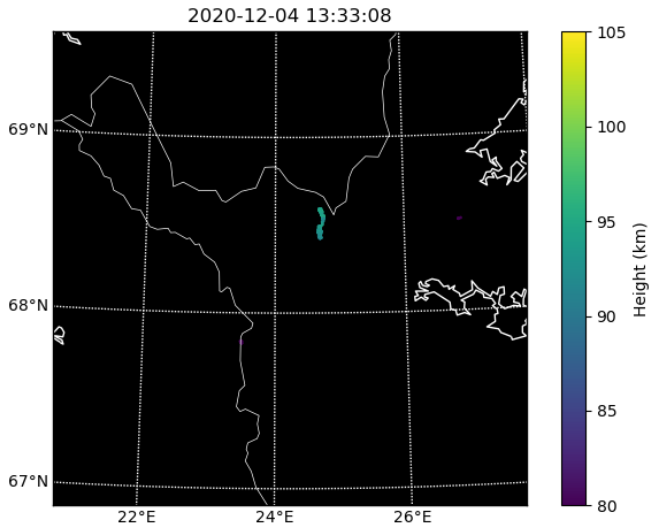




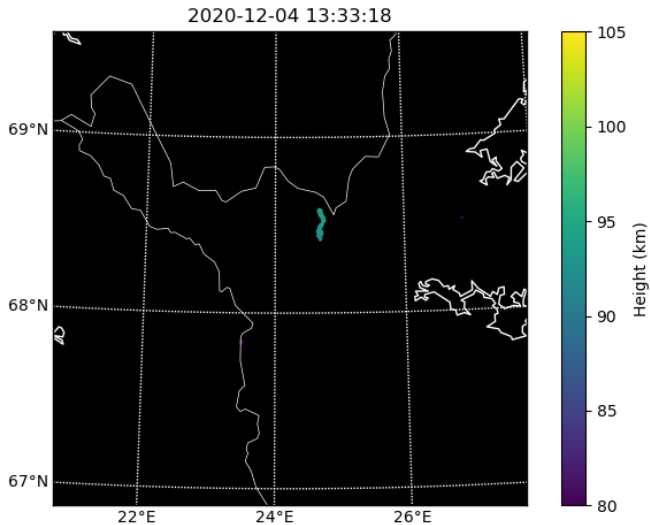
# Meteor radar trail echo interferometry



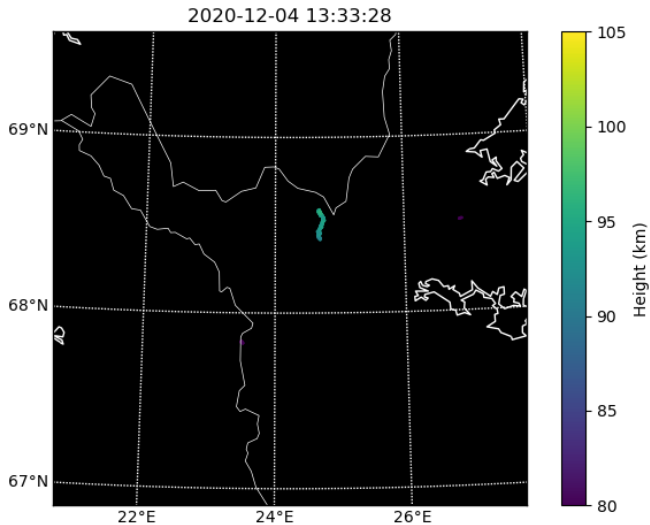
# Meteor radar trail echo interferometry



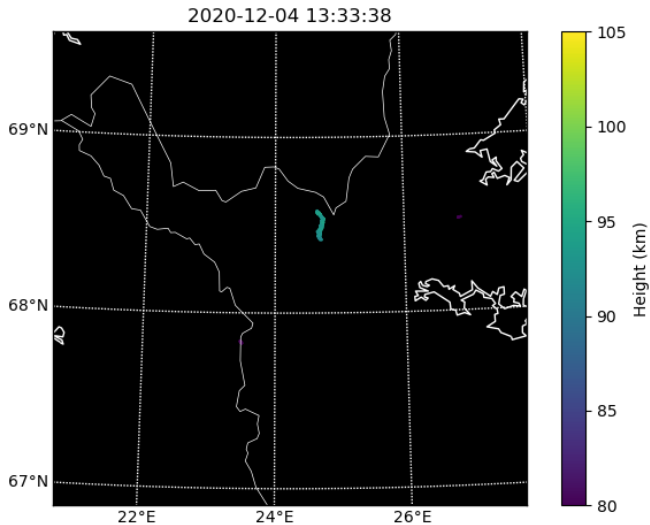
# Meteor radar trail echo interferometry



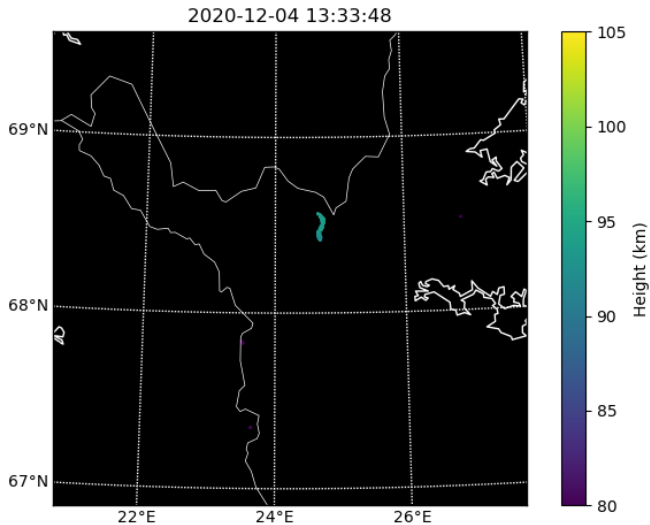
# Meteor radar trail echo interferometry



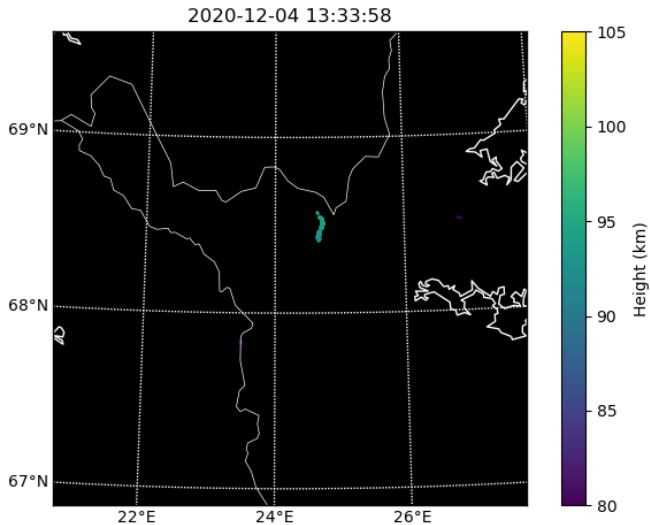
# Meteor radar trail echo interferometry



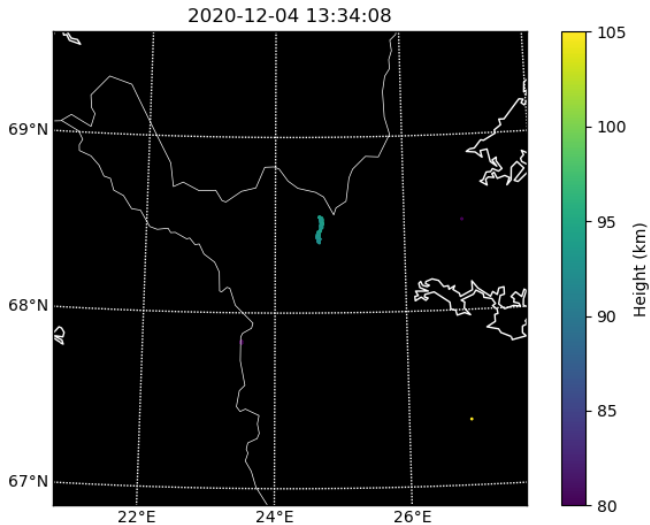
# Meteor radar trail echo interferometry



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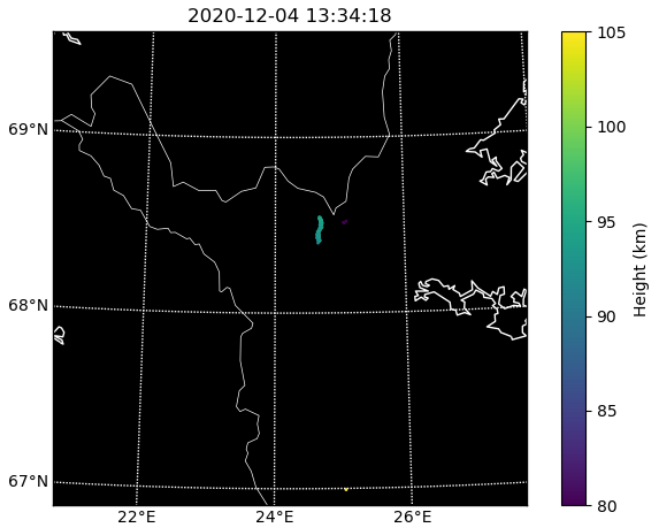


# Meteor radar trail echo interferometry

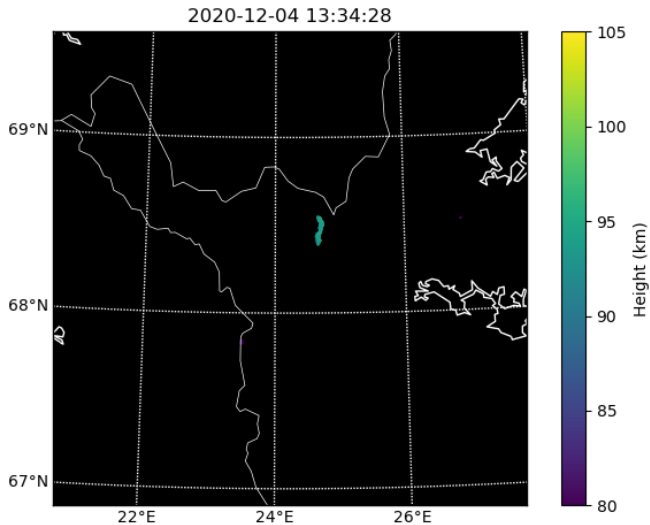




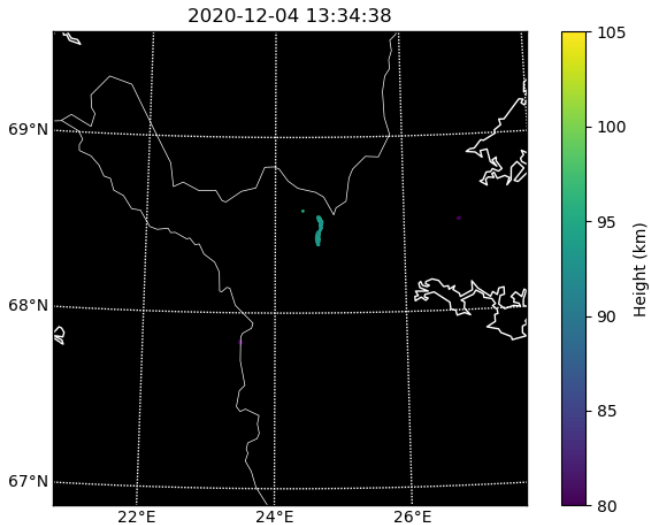
# Meteor radar trail echo interferometry



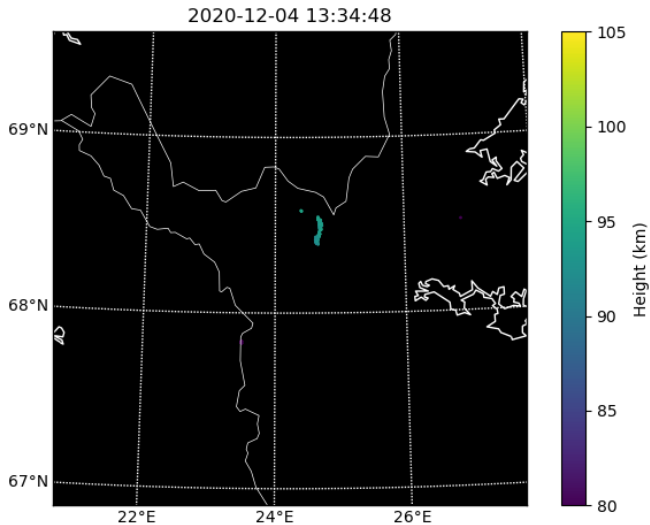
# Meteor radar trail echo interferometry



# Meteor radar trail echo interferometry

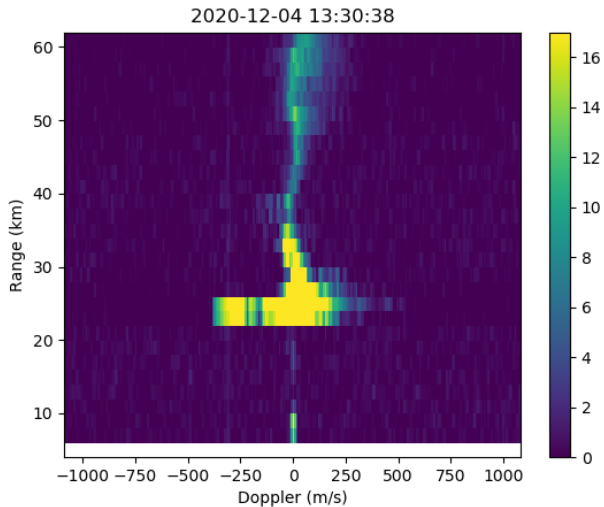


# Meteor radar trail echo interferometry

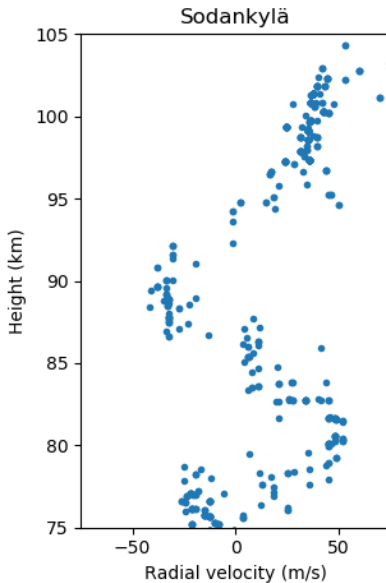
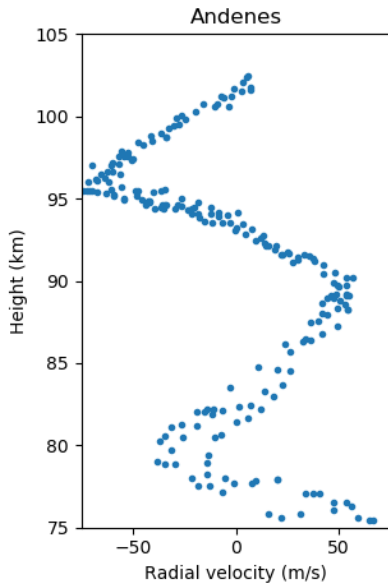


# Range-Doppler spectrum

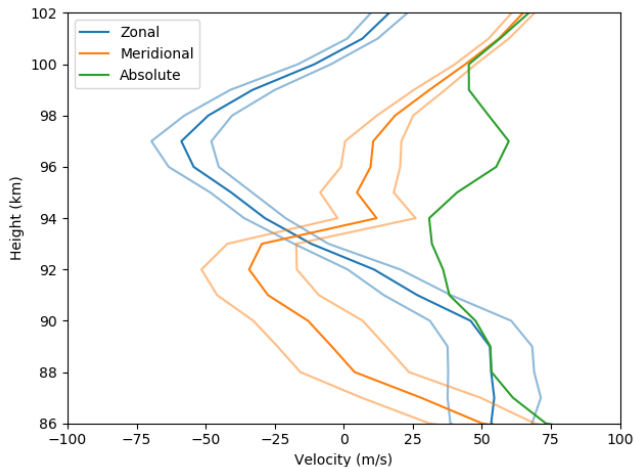
Sodankylä meteor radar



# Estimating horizontal wind

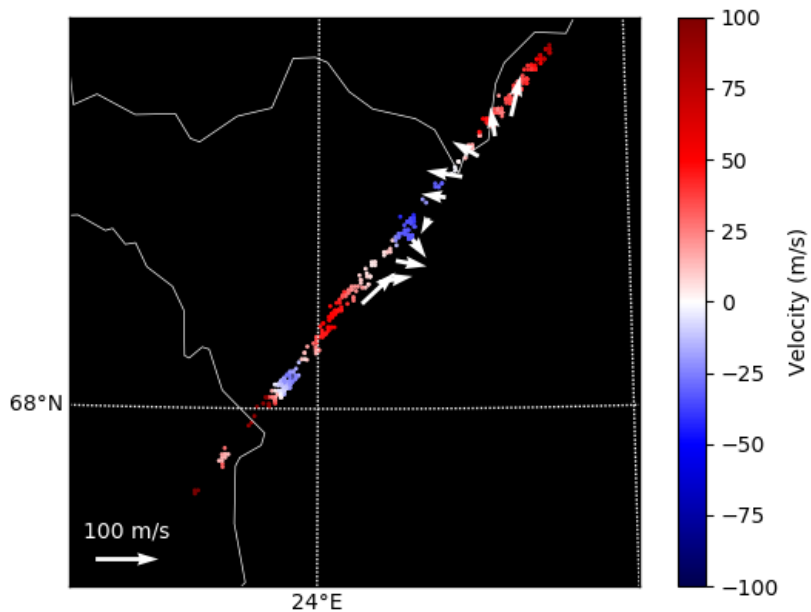


# Estimating horizontal wind



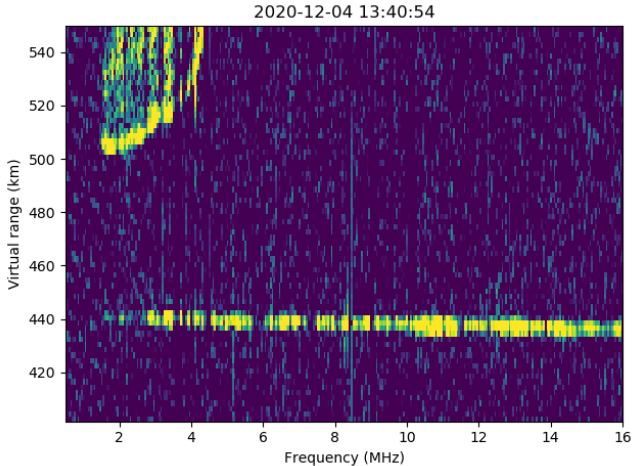
Positive is towards East and North.

## Horizontal wind estimated from trail





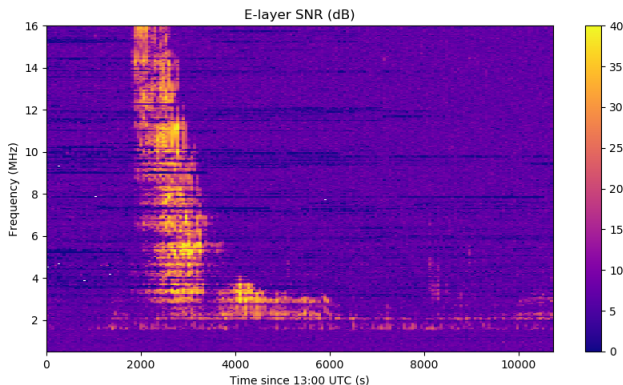
# Ionosonde observations



Sodankylä-Skibotn oblique path (Sodankylä-Sodankylä is similar)

# Ionosonde observations

## Sodankylä-Skibotn oblique path



Enhanced E-region echo lasts approximately one hour.  
(Sodankylä-Sodankylä is similar)

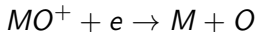
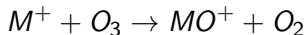
# Meteor radar trail echo properties (1/2)

## Properties:

- ▶ Long trail duration (400 s)
- ▶  $\mathbf{k} \not\perp \mathbf{B}$
- ▶  $\hat{\mathbf{v}} \not\perp \mathbf{k}$
- ▶ Delayed onset of trail echo
- ▶ The line of sight Doppler shift in agreement with background neutral wind
- ▶ The trail can be seen deforming due to neutral wind [4]
- ▶ Trail splits into three discernible components [4]

## Possible explanations:

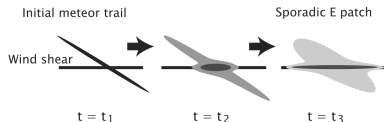
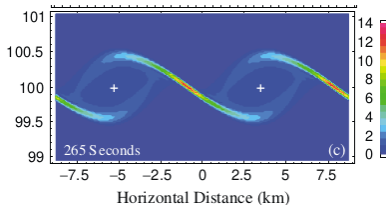
- ▶ Schmidt number increased due to meteoric aerosols  $\Rightarrow$  scattering from turbulent dusty plasma:  
$$\sigma = 4\pi r_e^2 \langle |\Delta N_e(\mathbf{k})|^2 \rangle \quad [9, 6]$$
- ▶ In situ  $O_3$  can be depleted, slowing down recombination of metallic ions [2, 15, 12]



- ▶ Hyperthermal shock wave may modify atmospheric chemistry [7, 19]

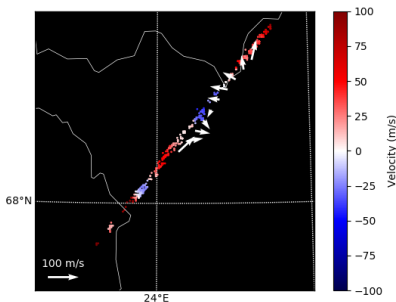
## Meteor radar trail echo properties (2/2)

- ▶ max trail duration at 93 km
- ▶ altitude where  $\partial_z v_h = 0$
- ▶ neutral wind westward above 93 km
- ▶ neutral wind eastward below 93 km
- ▶ zonal wind shear driven SpE ( $\mathbf{v}_n \times \mathbf{B}$ ) [3, 15, 12]
- ▶ Kelvin-Helmholtz Instability [3]



**Figure 11.** Formation of a sporadic *E* patch through the trapping of plasma by a wind shear.

zonal wind shear driven SpE (Maruyama et.al. 2003 [12])



## Summary

- ▶ The physics of atmospheric interactions of large fireball meteors not yet well understood (e.g., [19, 11]).
- ▶ Well instrumented multi-wavelength multi-k radar observation a large fireball that can be used to study atmospheric effects of large meteors [10, 19, 18, 15, 11]
- ▶ No radio emission was observed (Obenberger's radio afterglow [14]) using the KAIRA radio telescope. Signatures of strong forward scatter were observed.
- ▶ Long-duration range-spread trails of larger meteors can be used to estimate neutral wind and meteoroid radiant (they are not very rare [10])
- ▶ I propose a multi-static meteor shower campaign for studies of mesospheric dynamics (e.g., Perseids)
- ▶ Publication is in preparation

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