
Photo: John M. Oskal

Pajala Fireball

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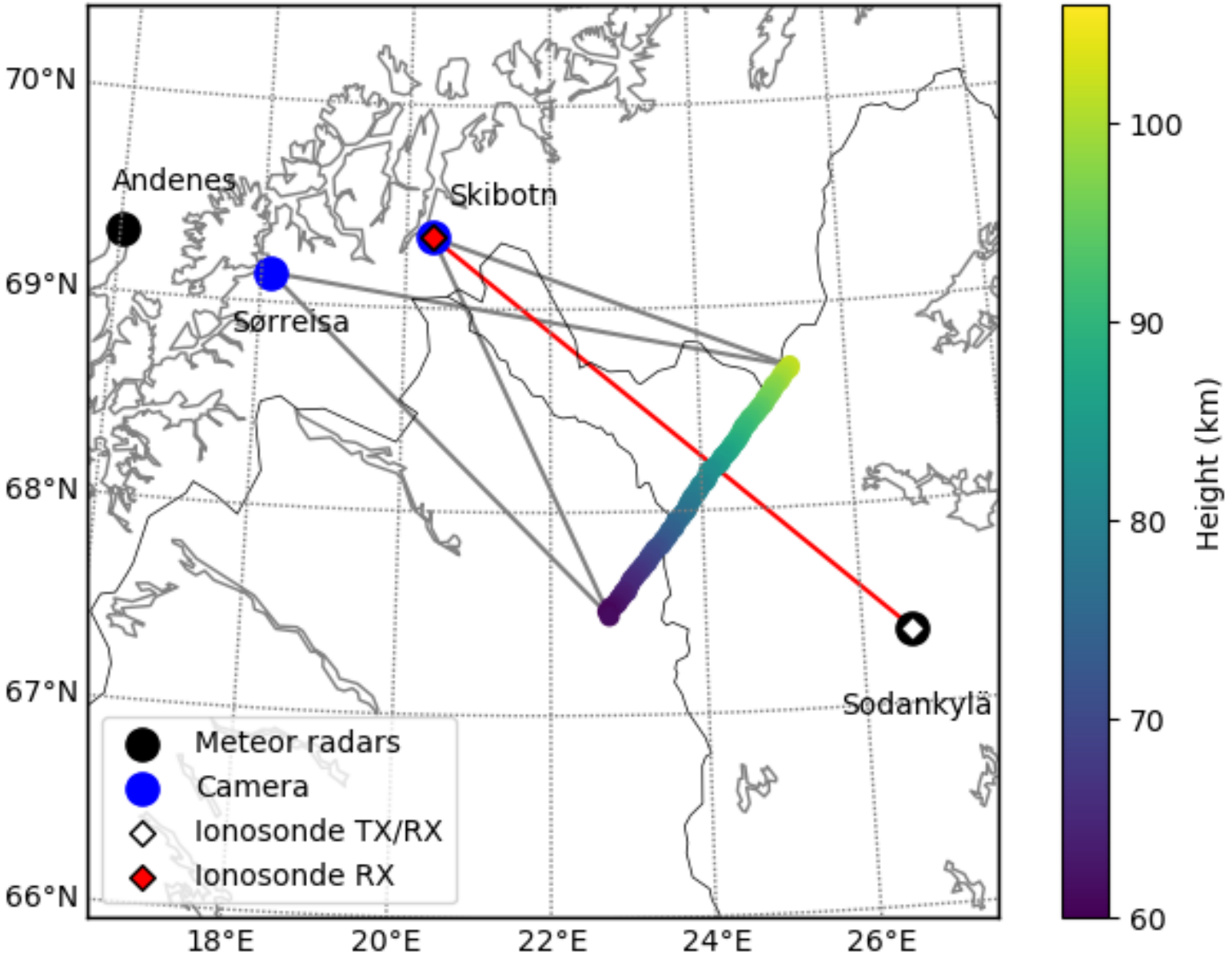
Overview

- Large daytime fireball observed on 2020-12-04T13:30:37Z
- $m_v \approx -13$, $|v| = 28$ km/s $\Rightarrow$ 1-100 kg mass (needs to be improved!)
- Numerous eyewitness reports [12]
- 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



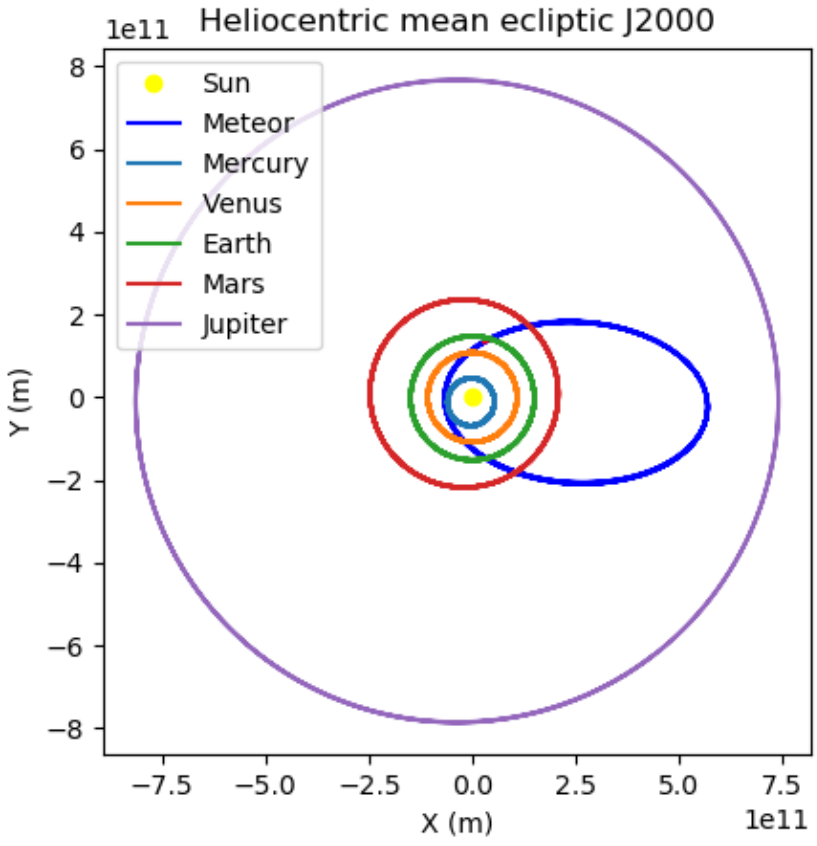
Dual camera observations: 2020/12/04 13:30:37 UTC

a) Skibotn and b) Sørreisa.

Video

- Show video

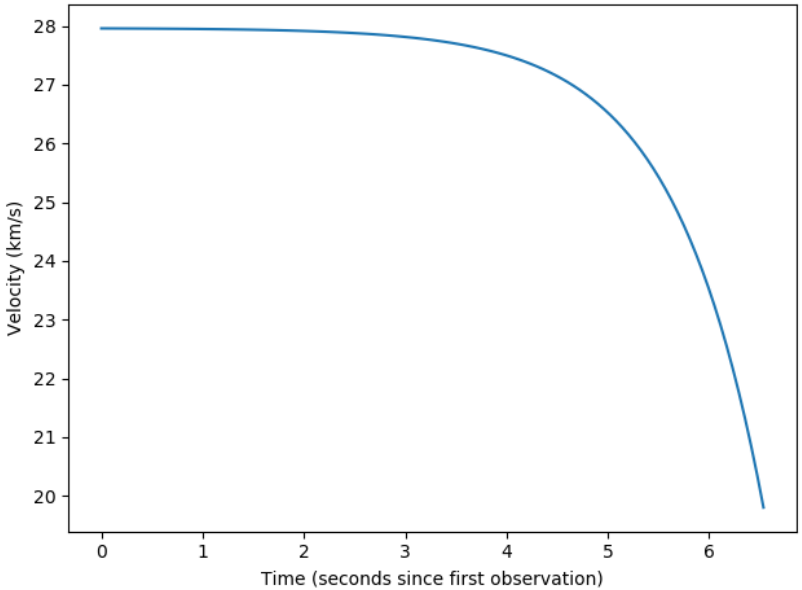
Orbital parameters

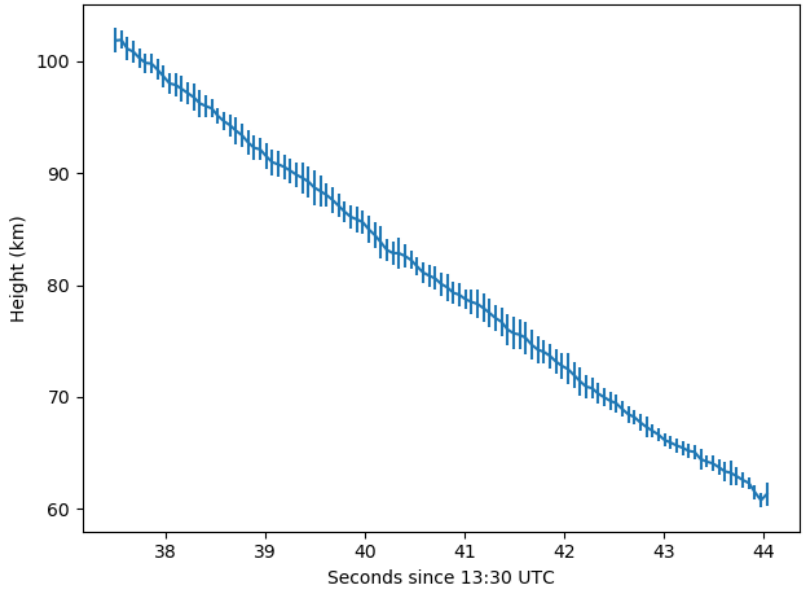


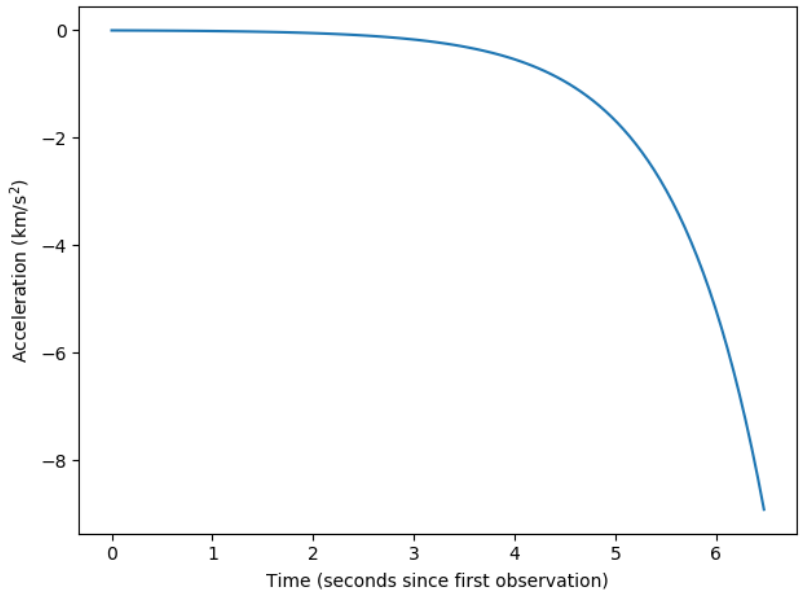
Orbit propagated back 30 years using the Rebound propagator[16]

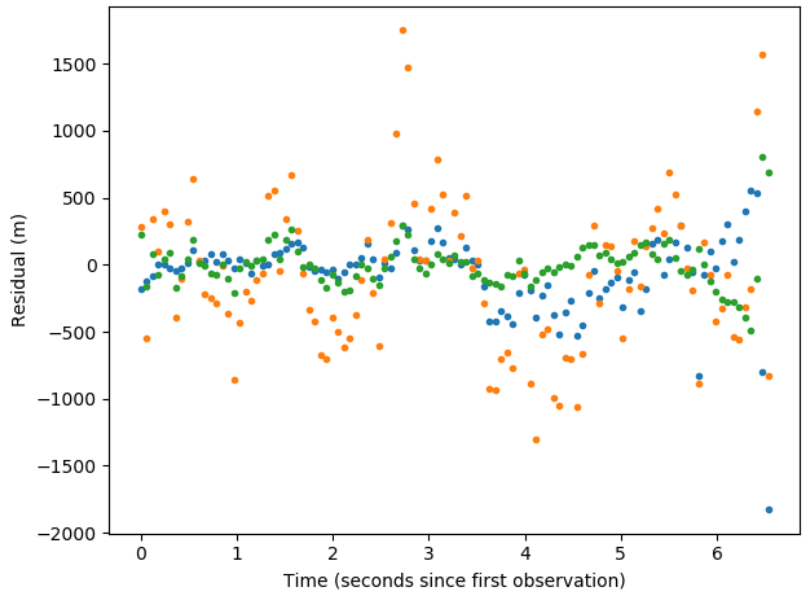
- Atmospheric drag removed
- $|v_0| = 27.96 \pm 0.02$ km/s.
- Radiant RA: $76.13° \pm 0.08$, Dec: $30.04° \pm 0.03$.
- Earth's gravity removed
- t_0 =2019-12-04T13:30:37Z, $a = 2.12$ AU, $e = 0.79$, $i = 1.55°$, $\Omega = -107.4°$, $\omega = -75.4°$, $f = 189.75°$
- Northern Taurids shower, Jupiter family. E.g., Comet Encke and Tunguska event[15, 7, 5, 1]

Atmospheric deceleration



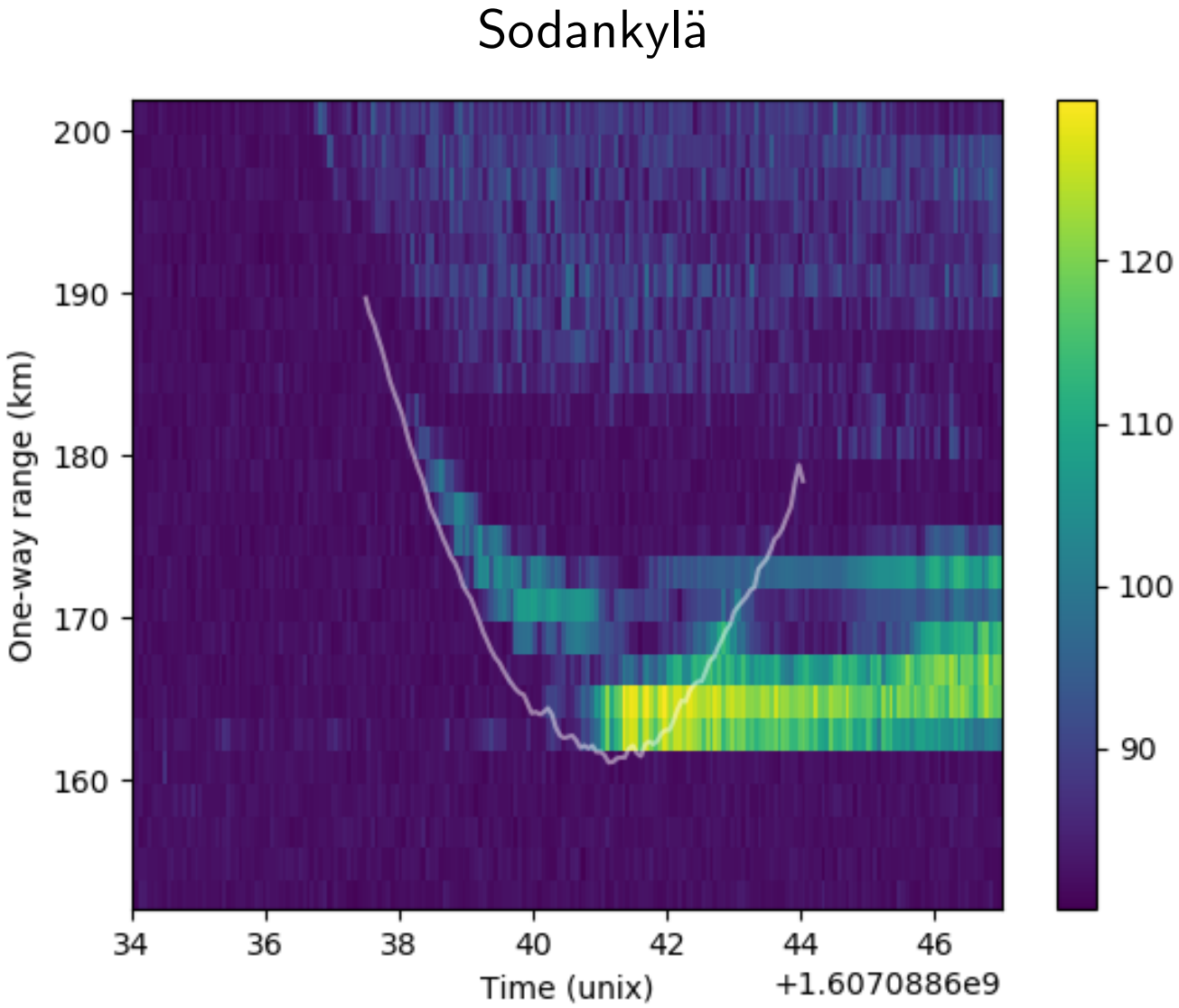






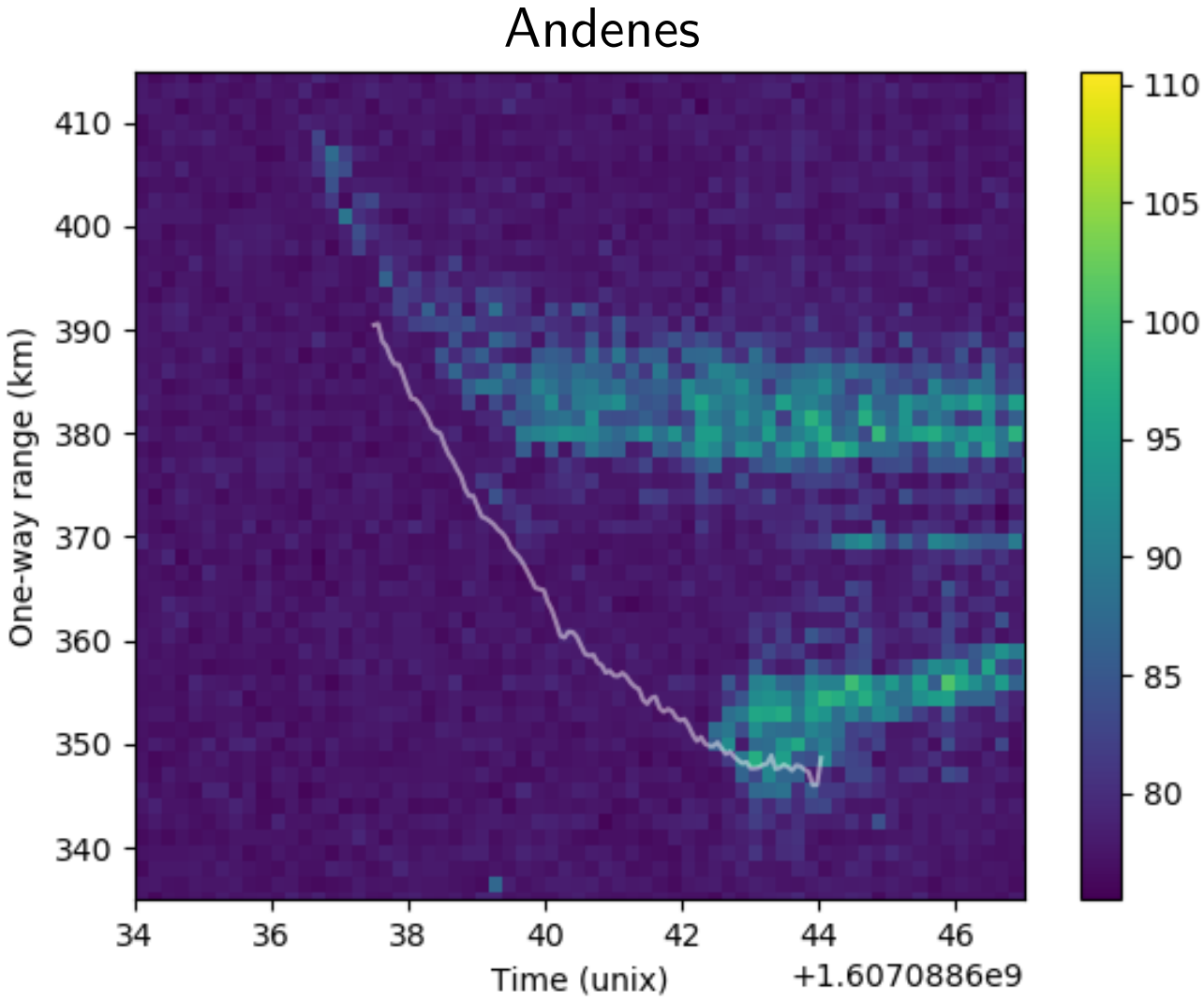
Atmospheric drag model: $\vec{v}(t) = \hat{v}(|v_0| - |a_0|e^{-|a_1|t})$ (e.g., [19])

Meteor radar "head" echo



Camera derived trajectory based range shown with white line.

Meteor radar "head" echo



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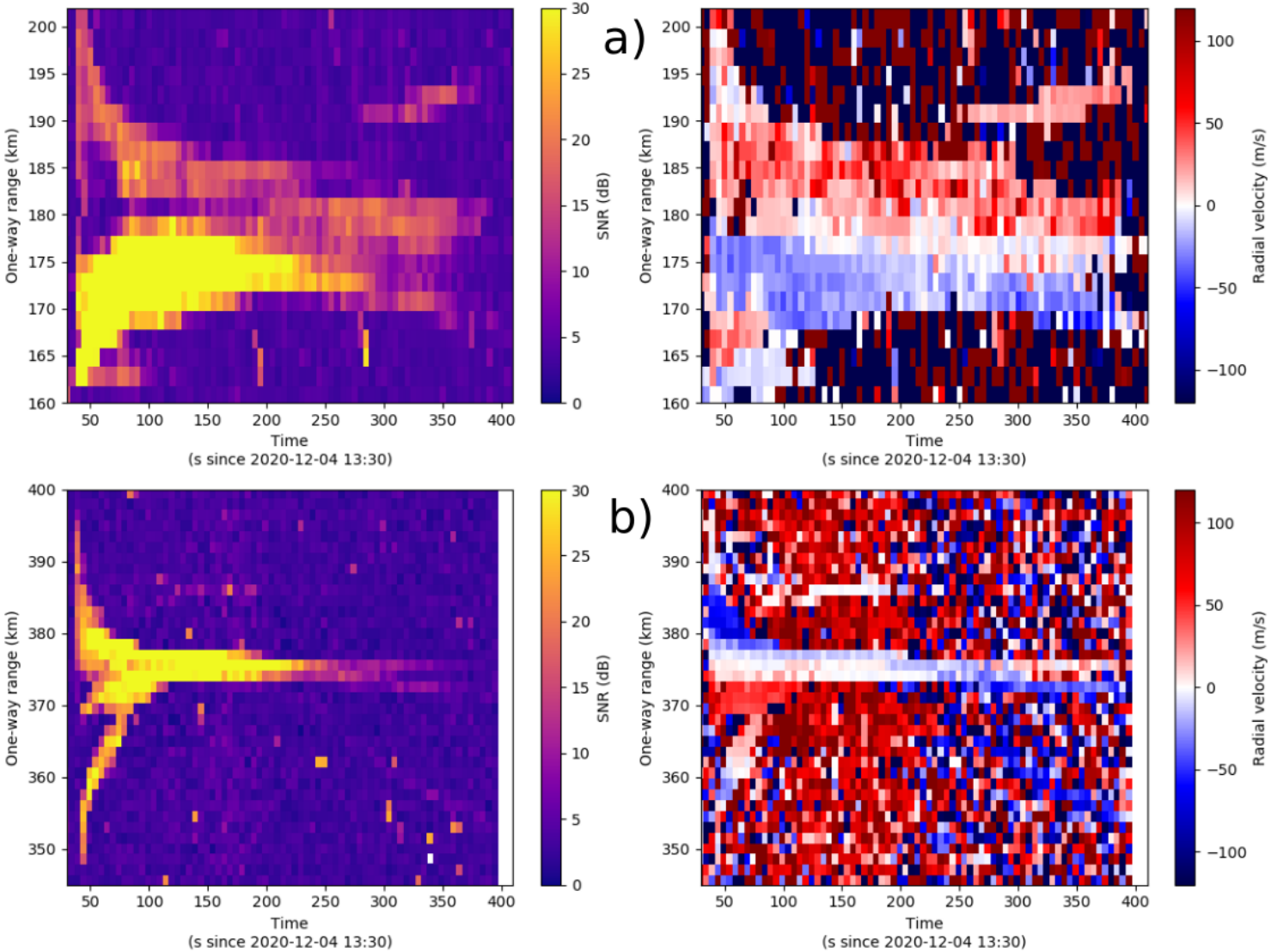
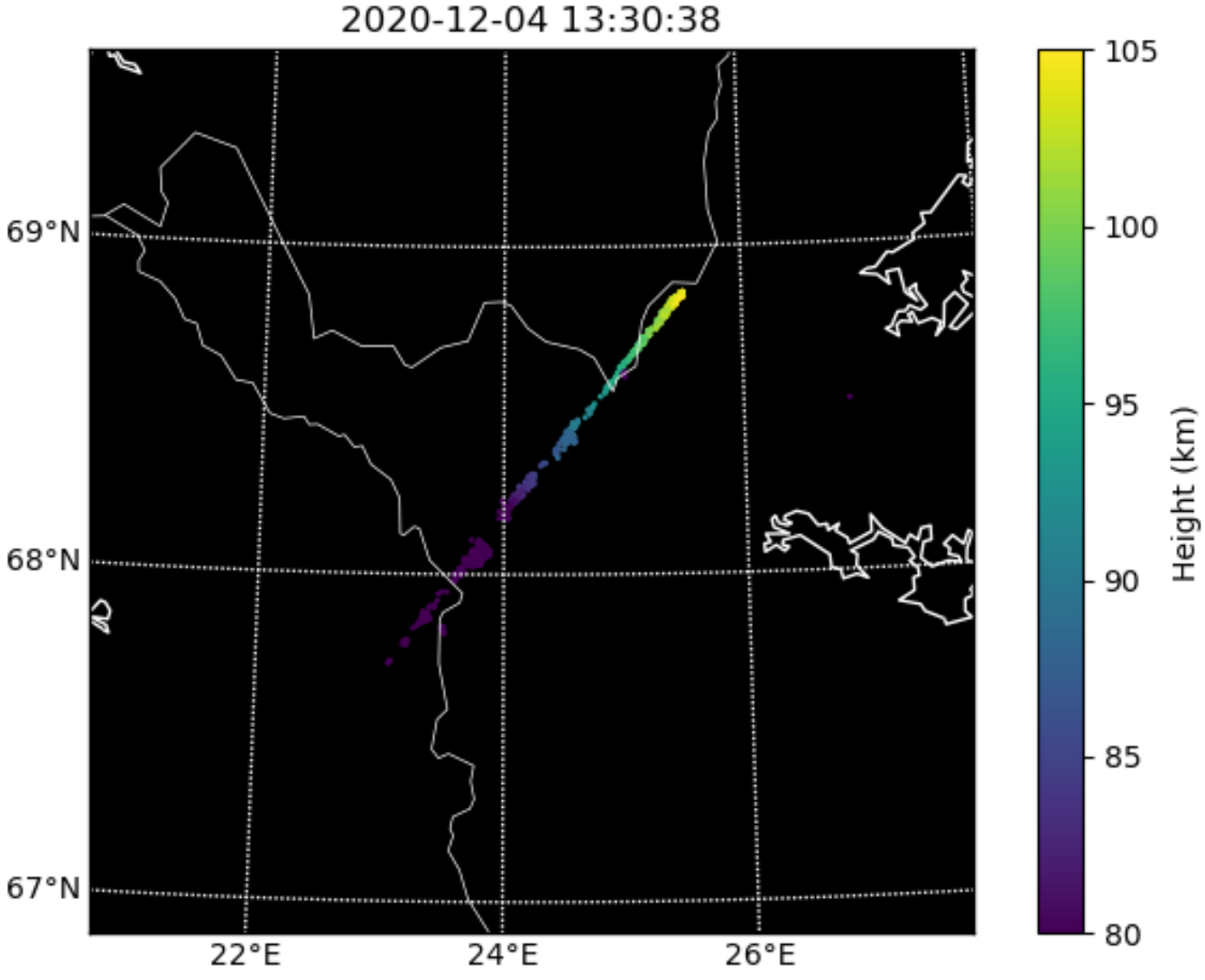
Meteor radar trail echoes



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

Meteor radar trail echo interferometry



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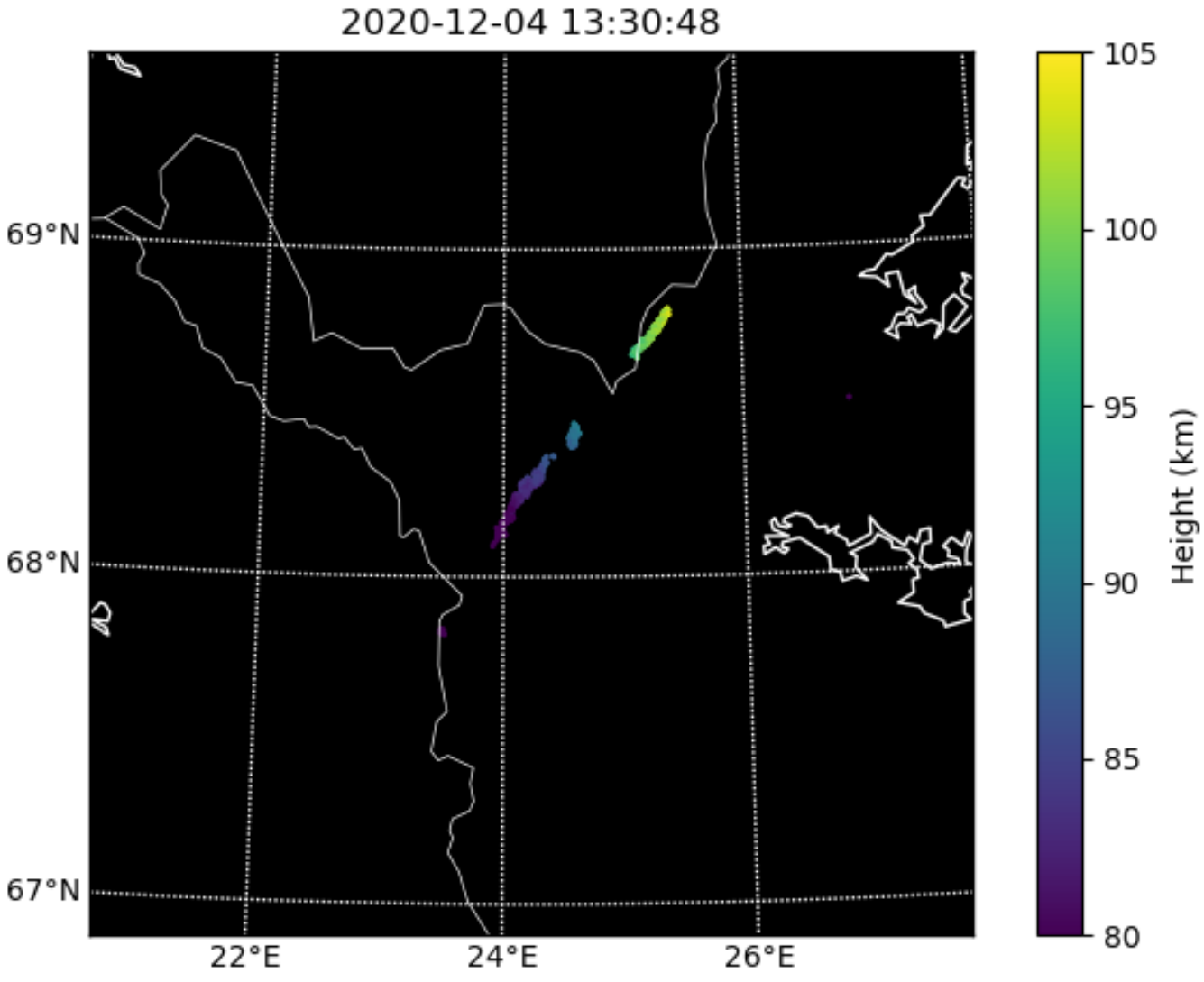

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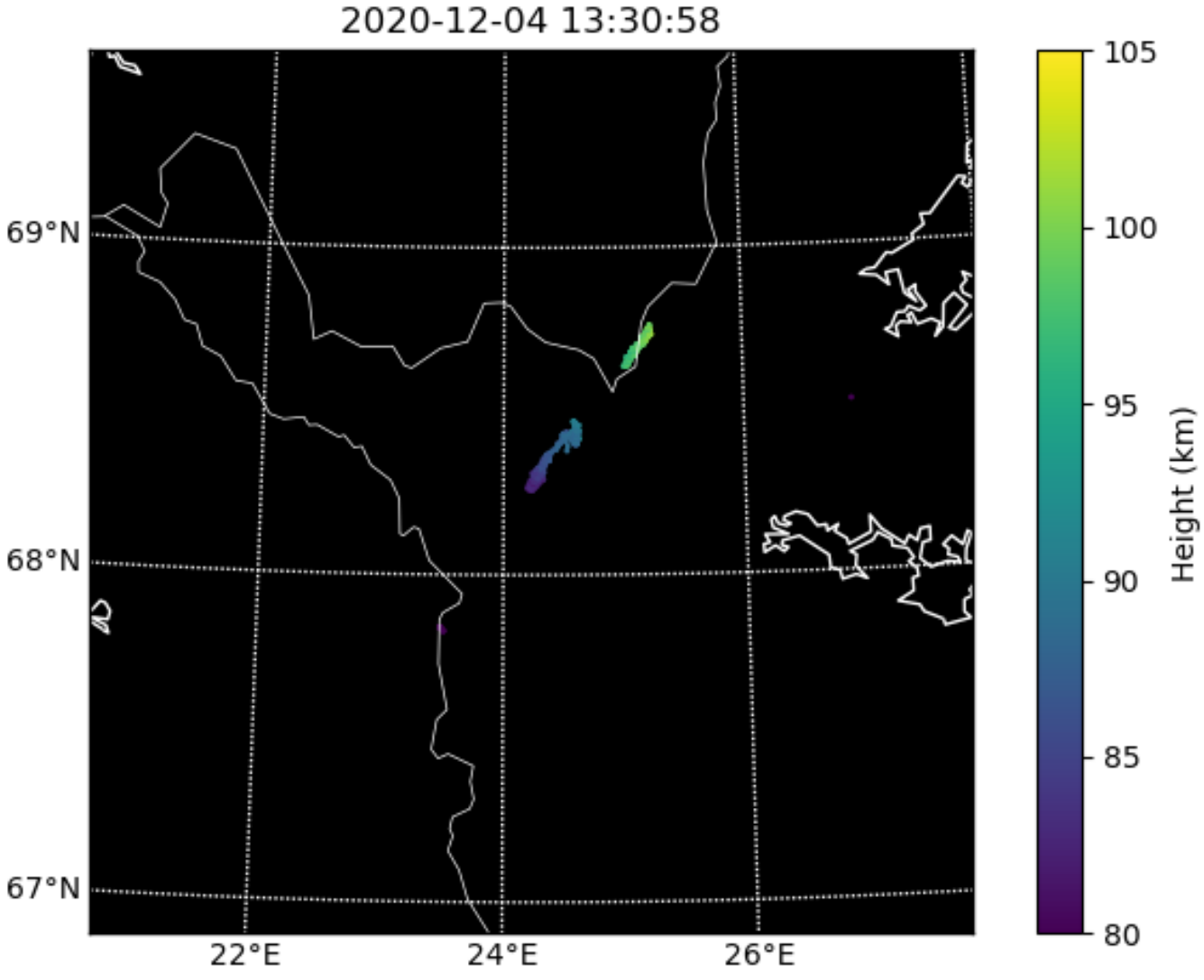

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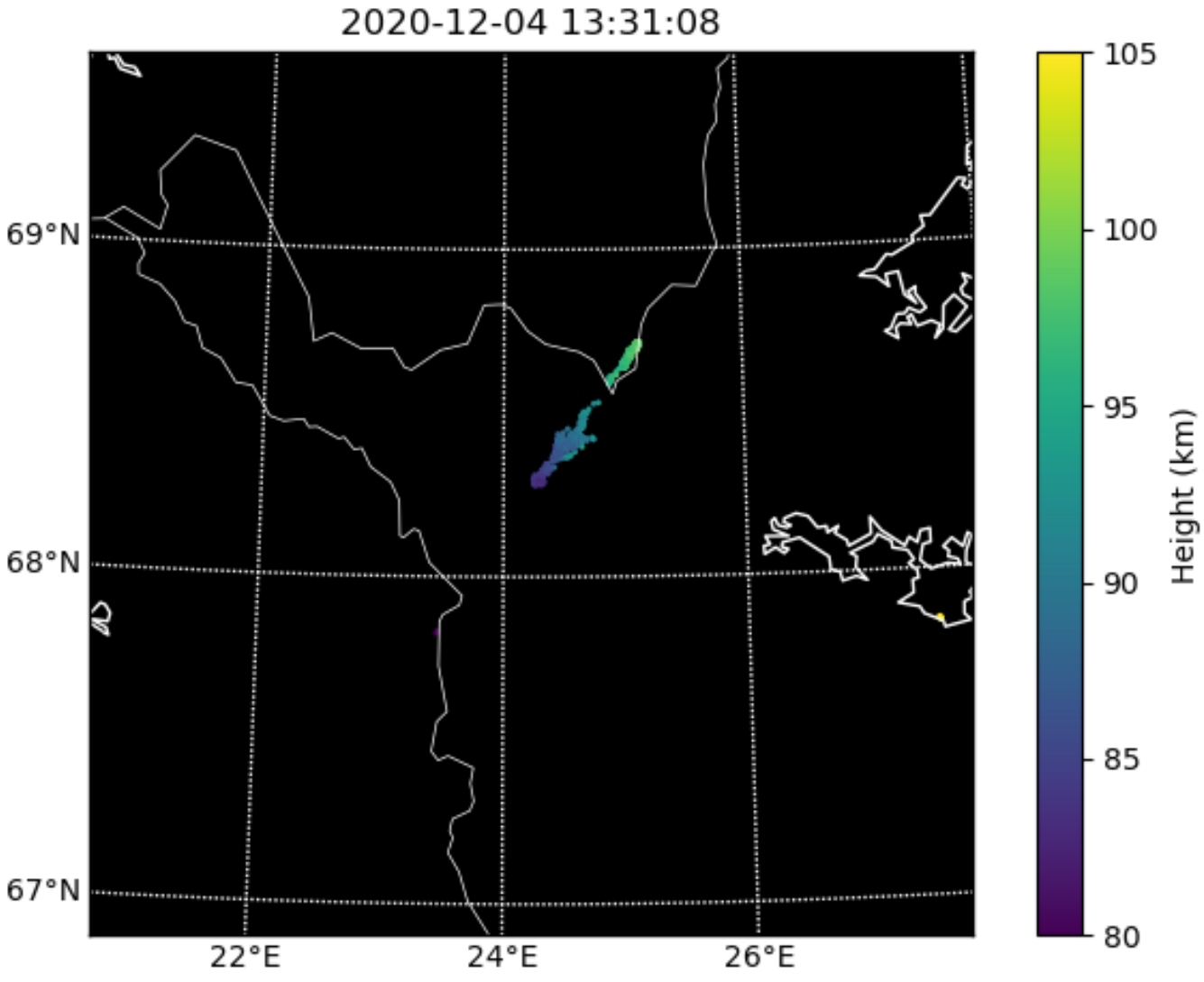

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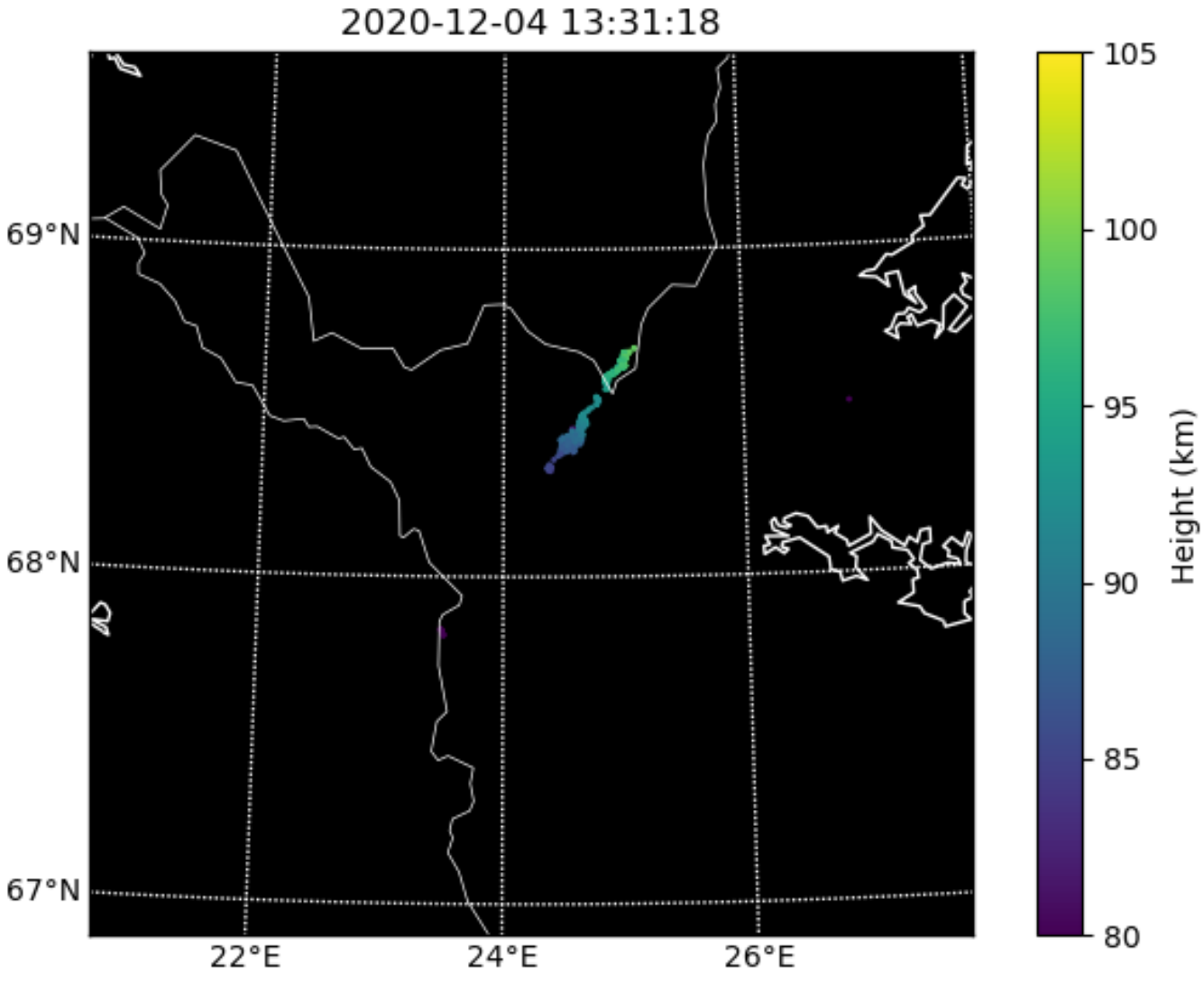
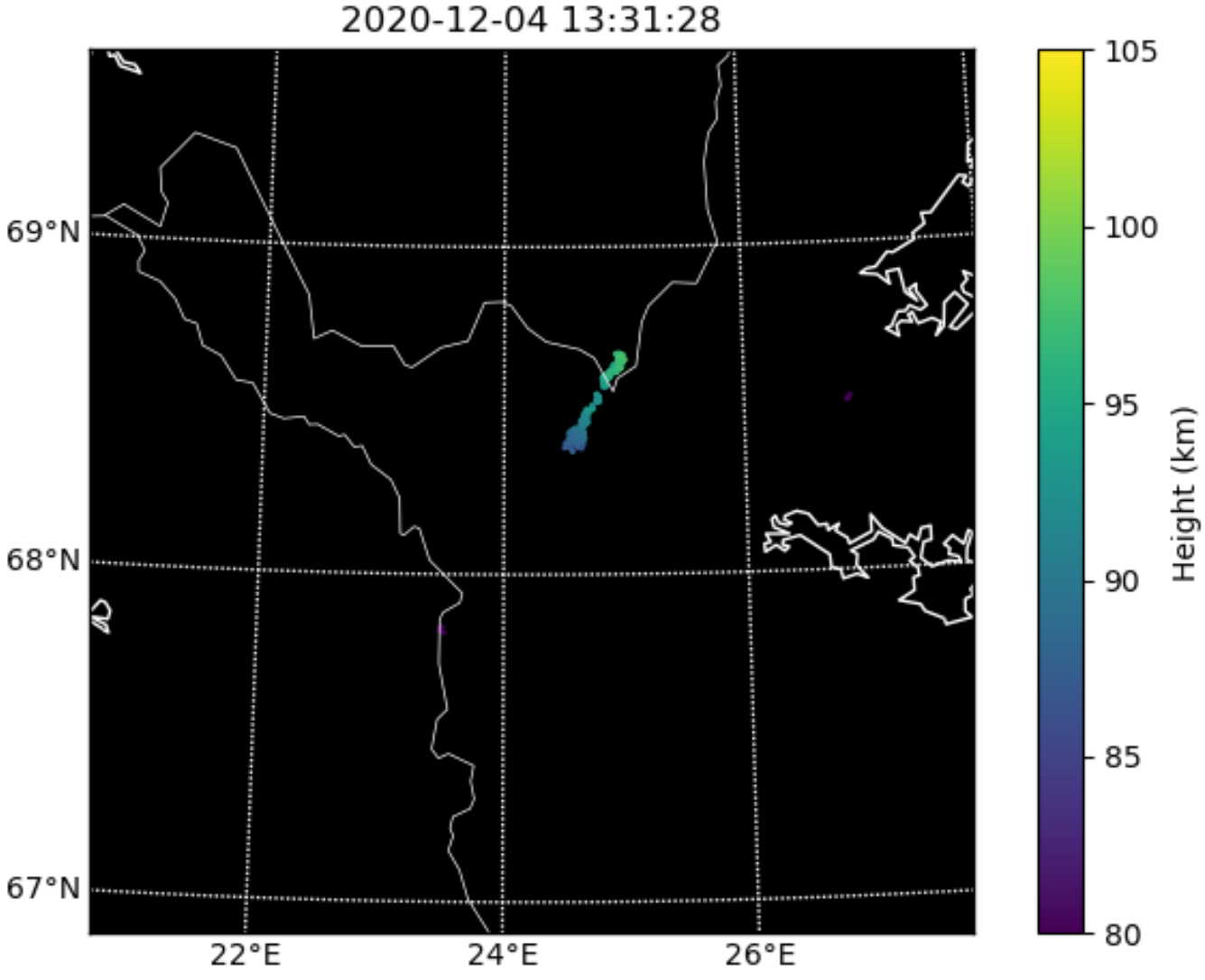


Meteor radar trail echo interferometry



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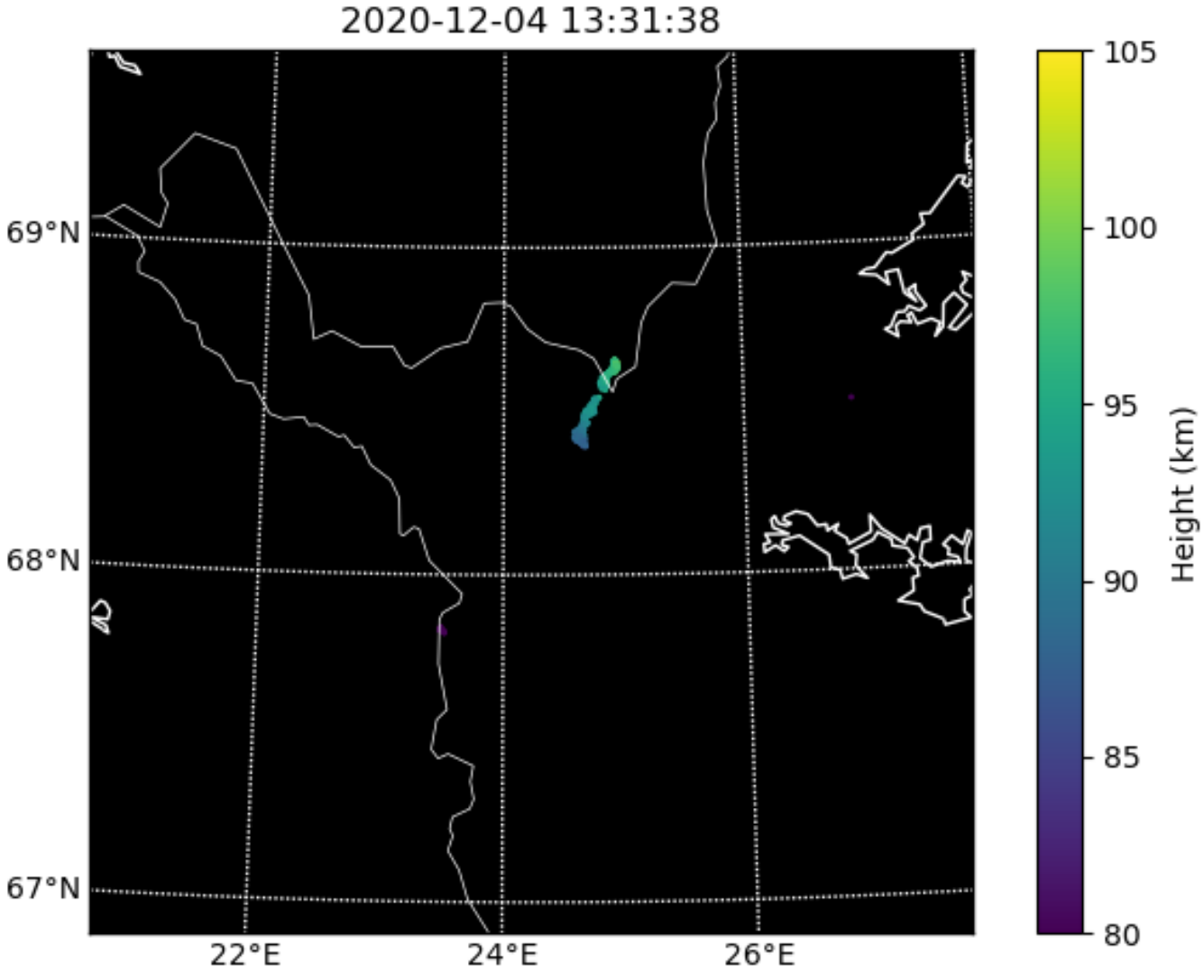

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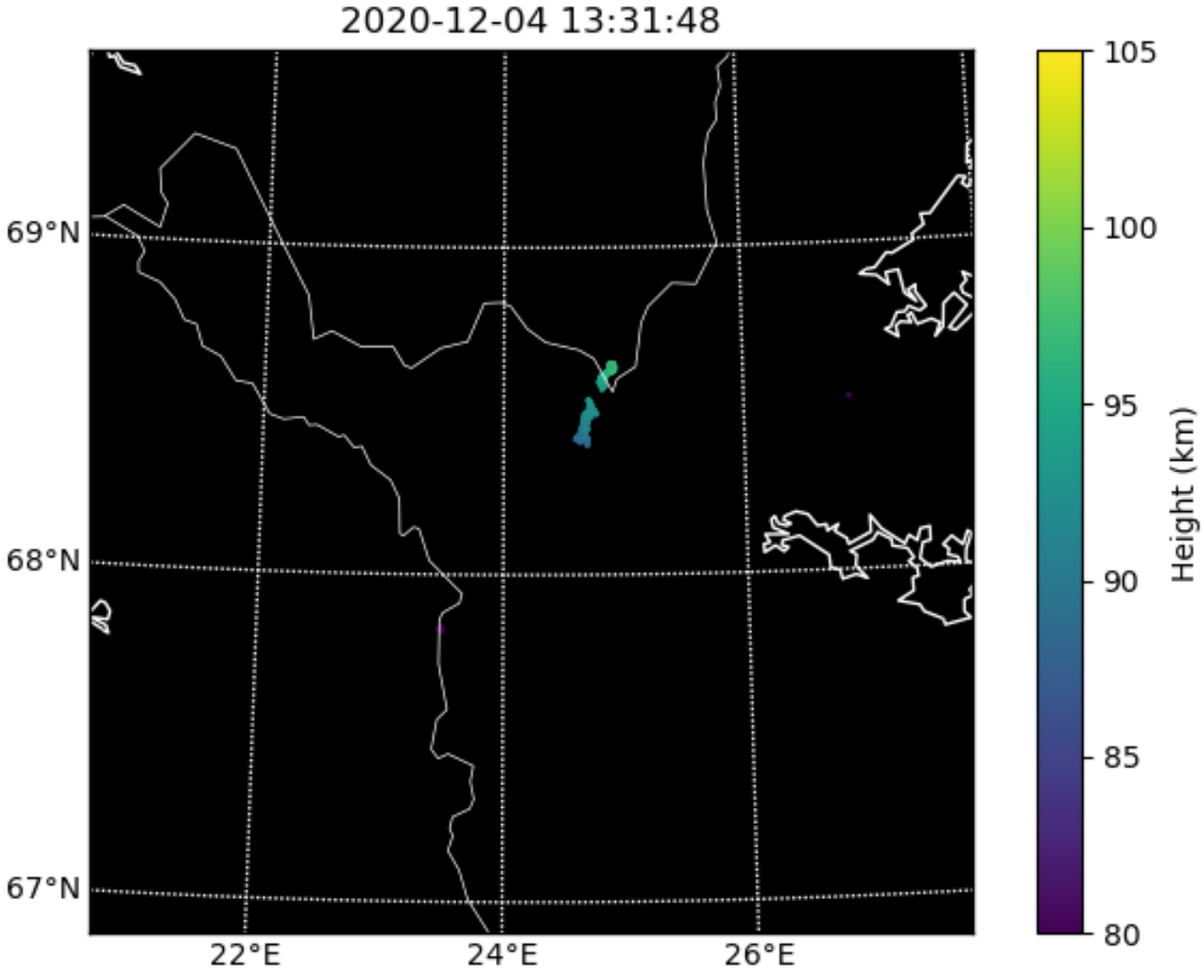
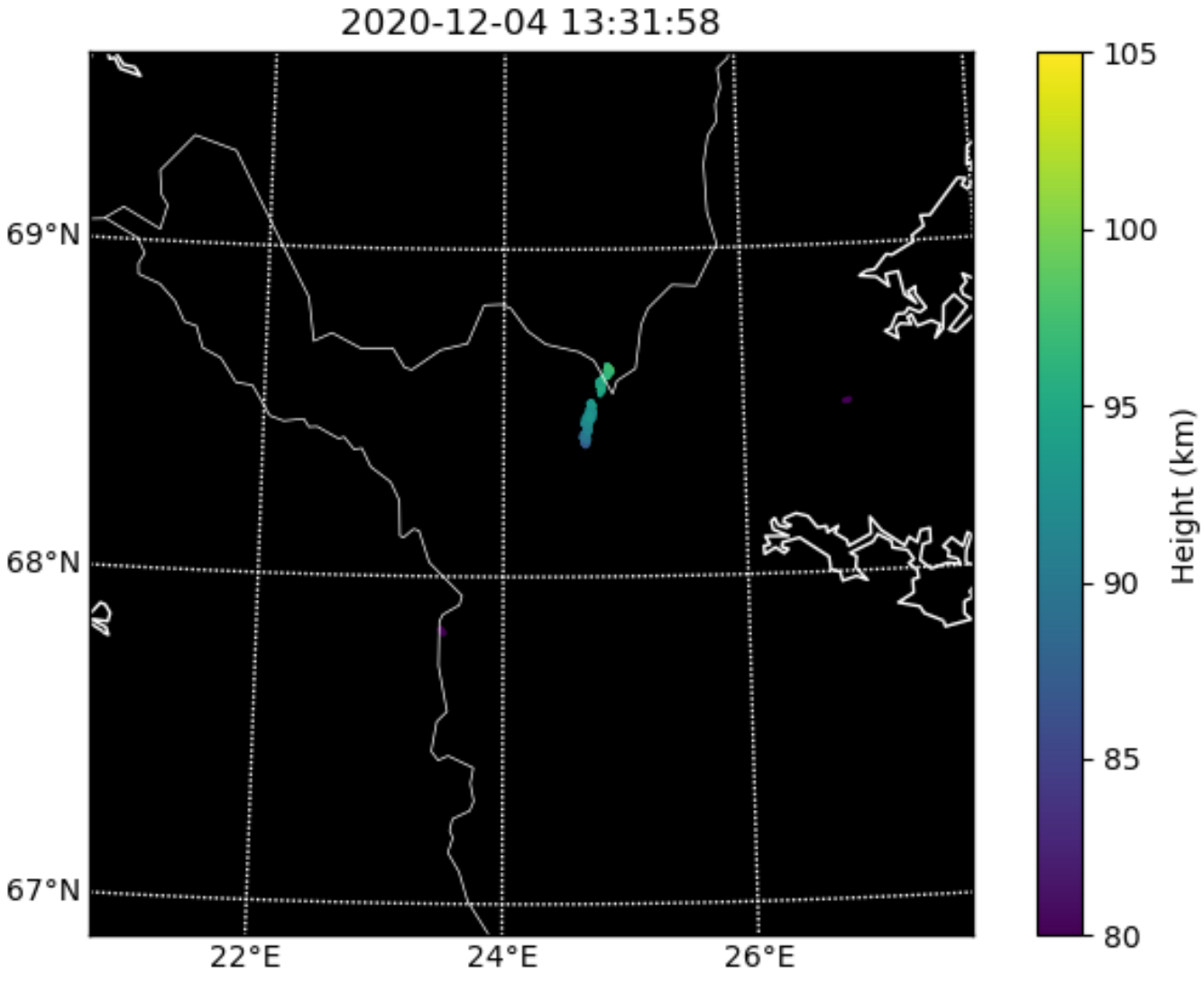
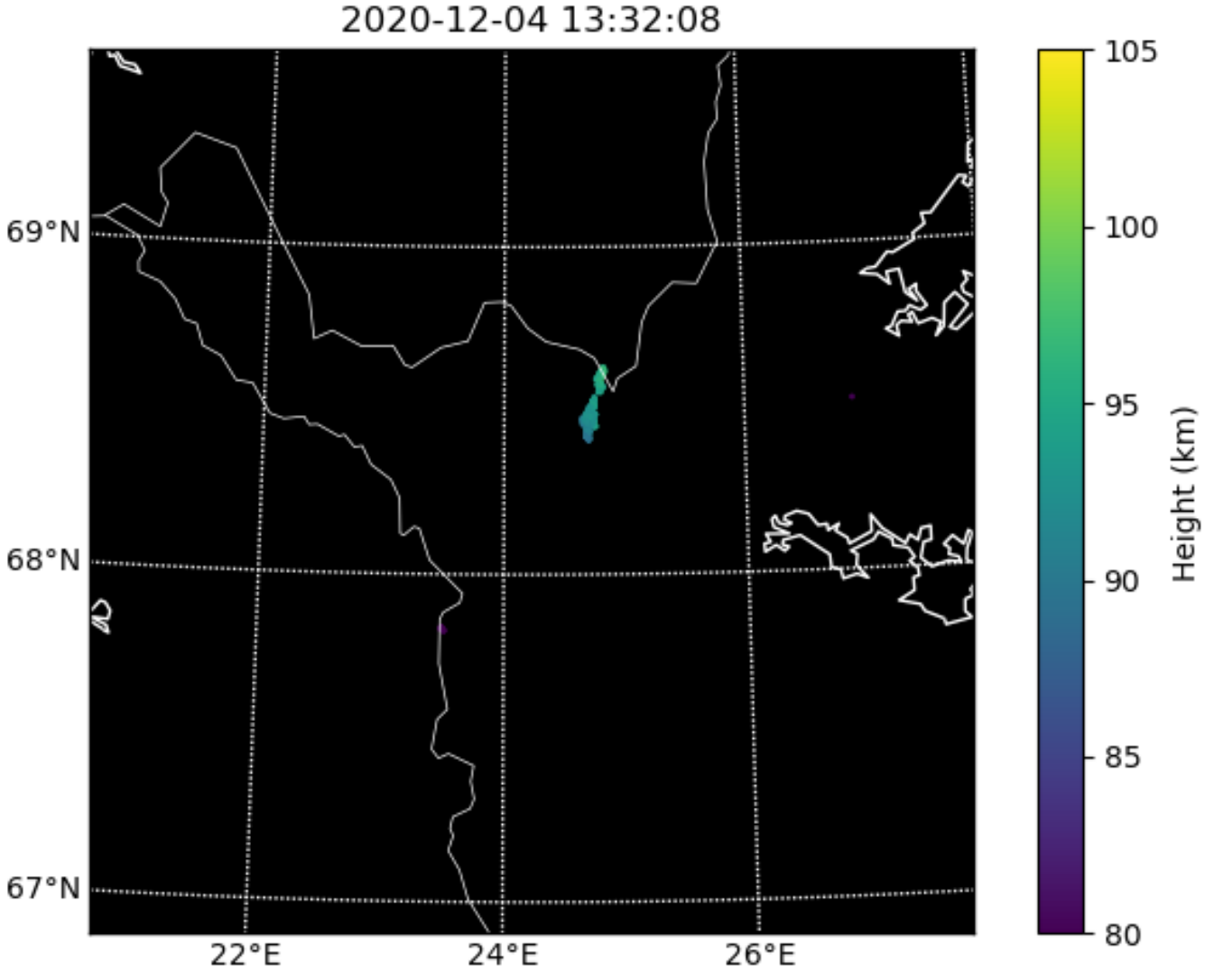


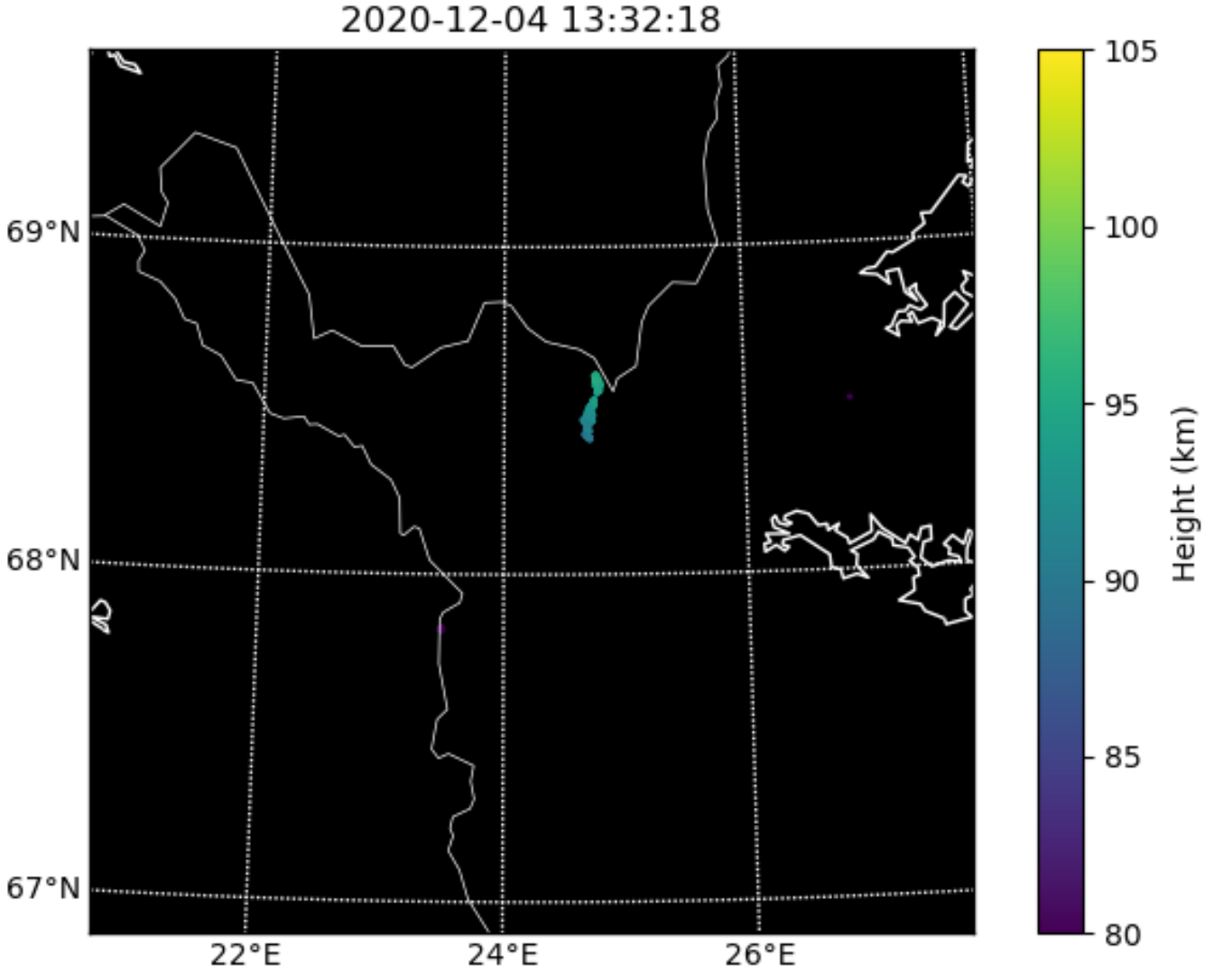
Meteor radar trail echo interferometry



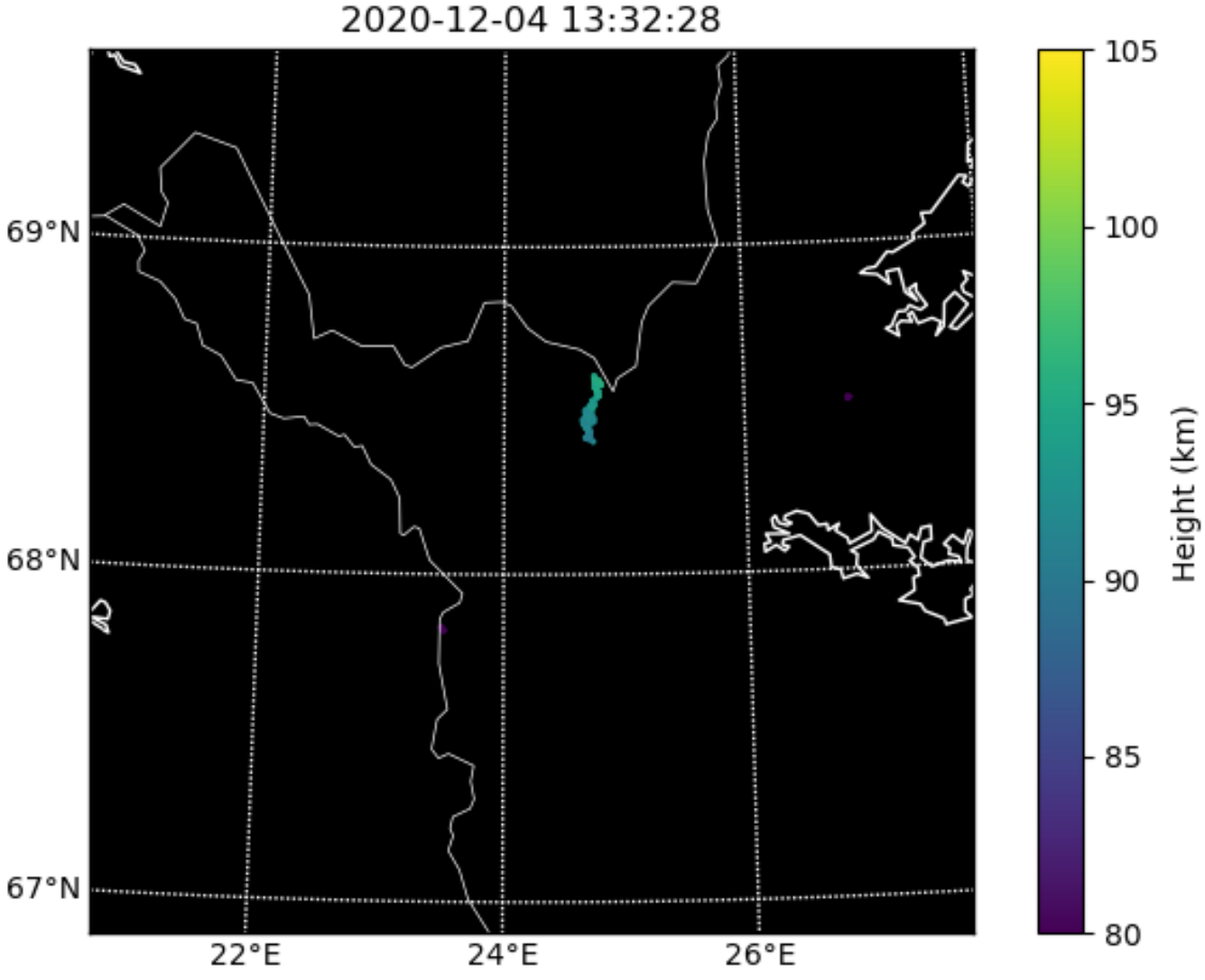
Meteor radar trail echo interferometry



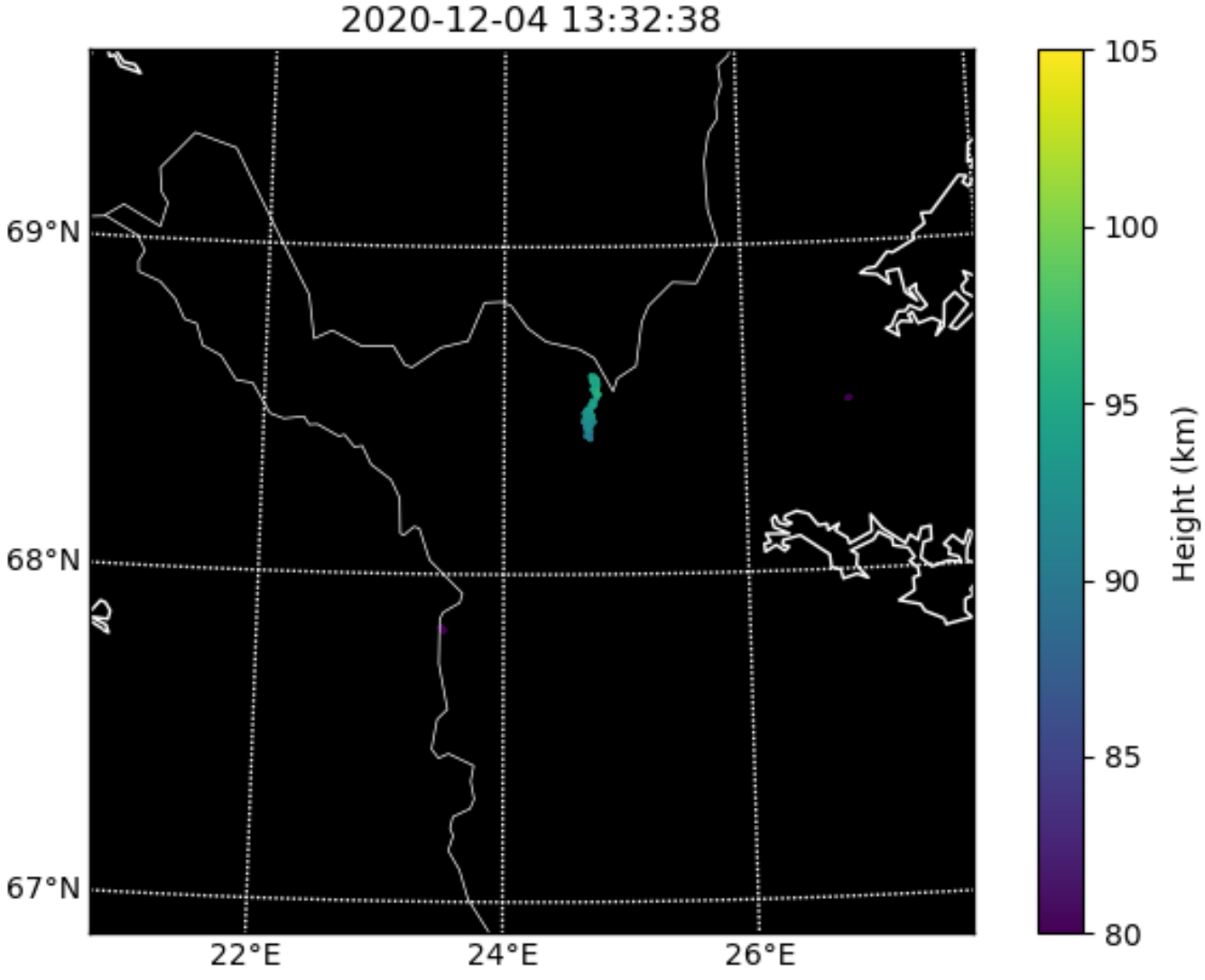
Meteor radar trail echo interferometry



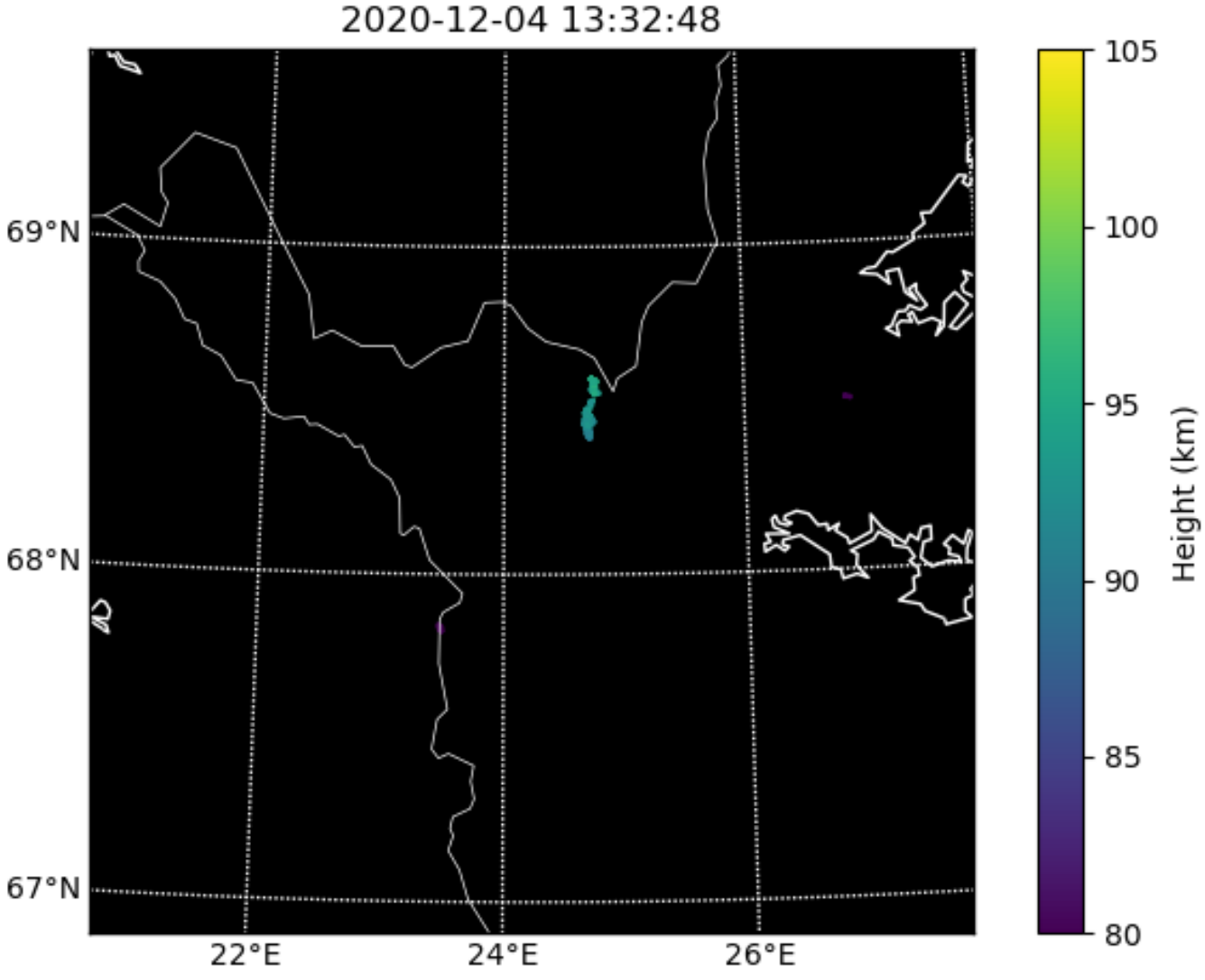
Meteor radar trail echo interferometry



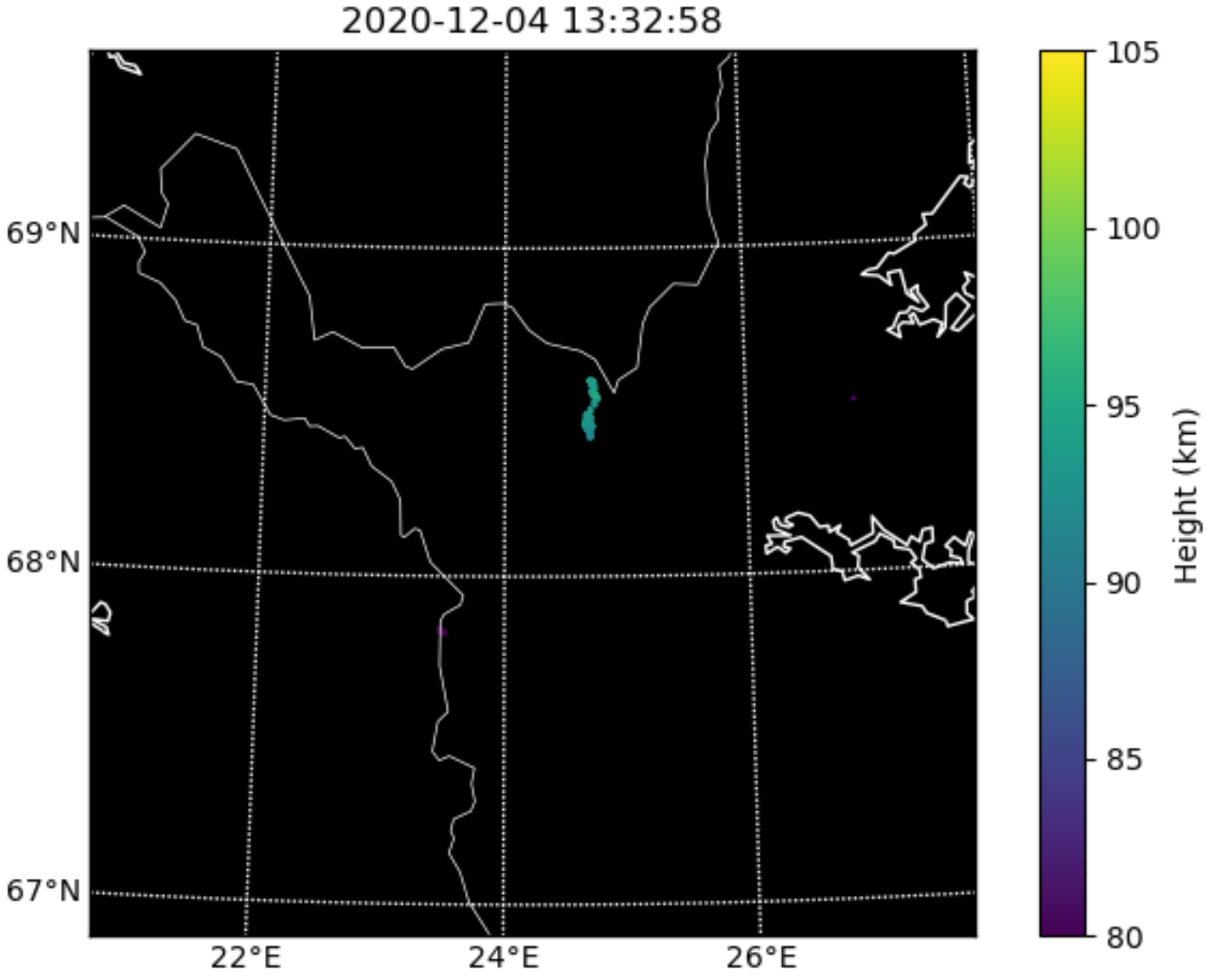
Meteor radar trail echo interferometry



Meteor radar trail echo interferometry



Meteor radar trail echo interferometry



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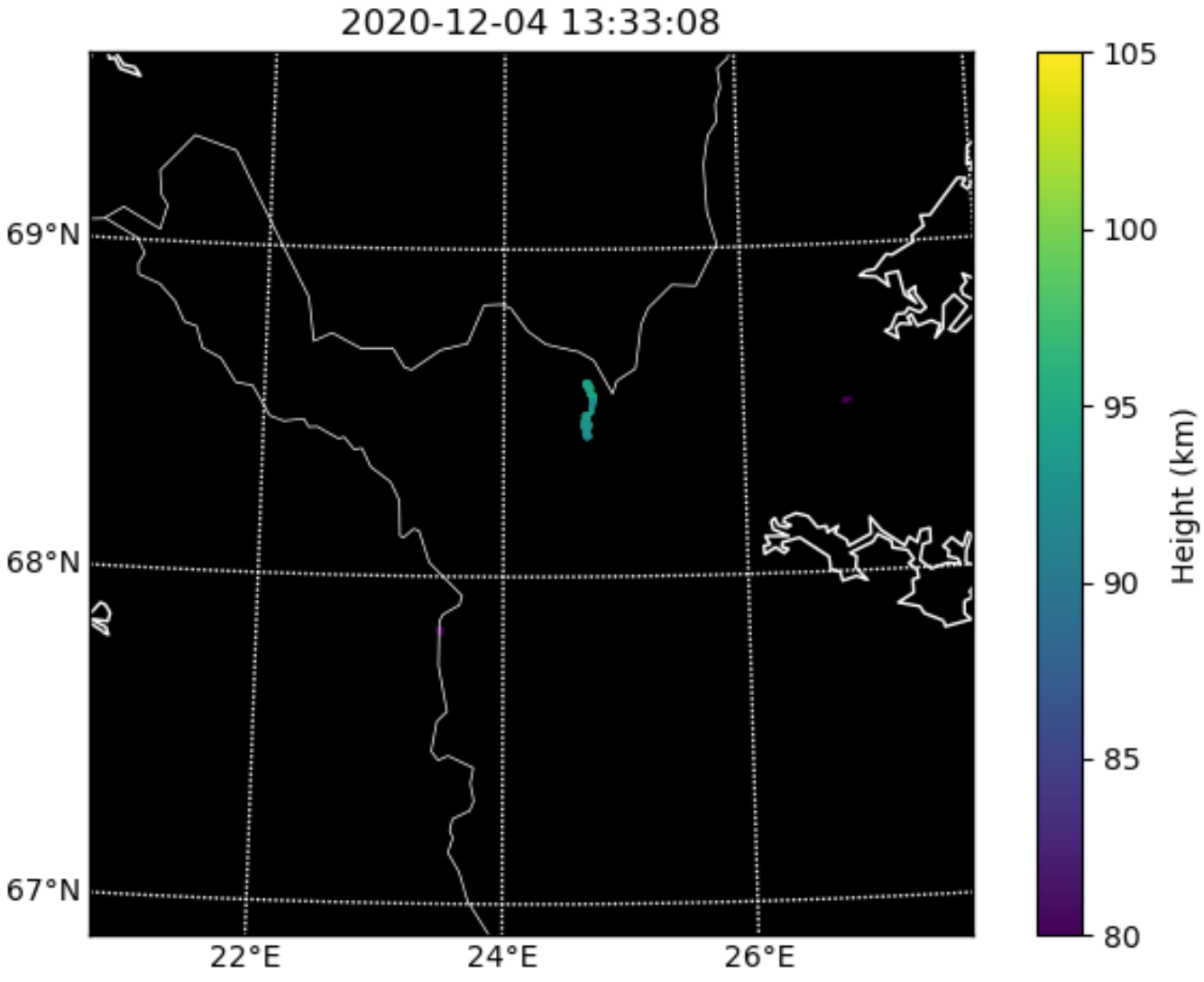
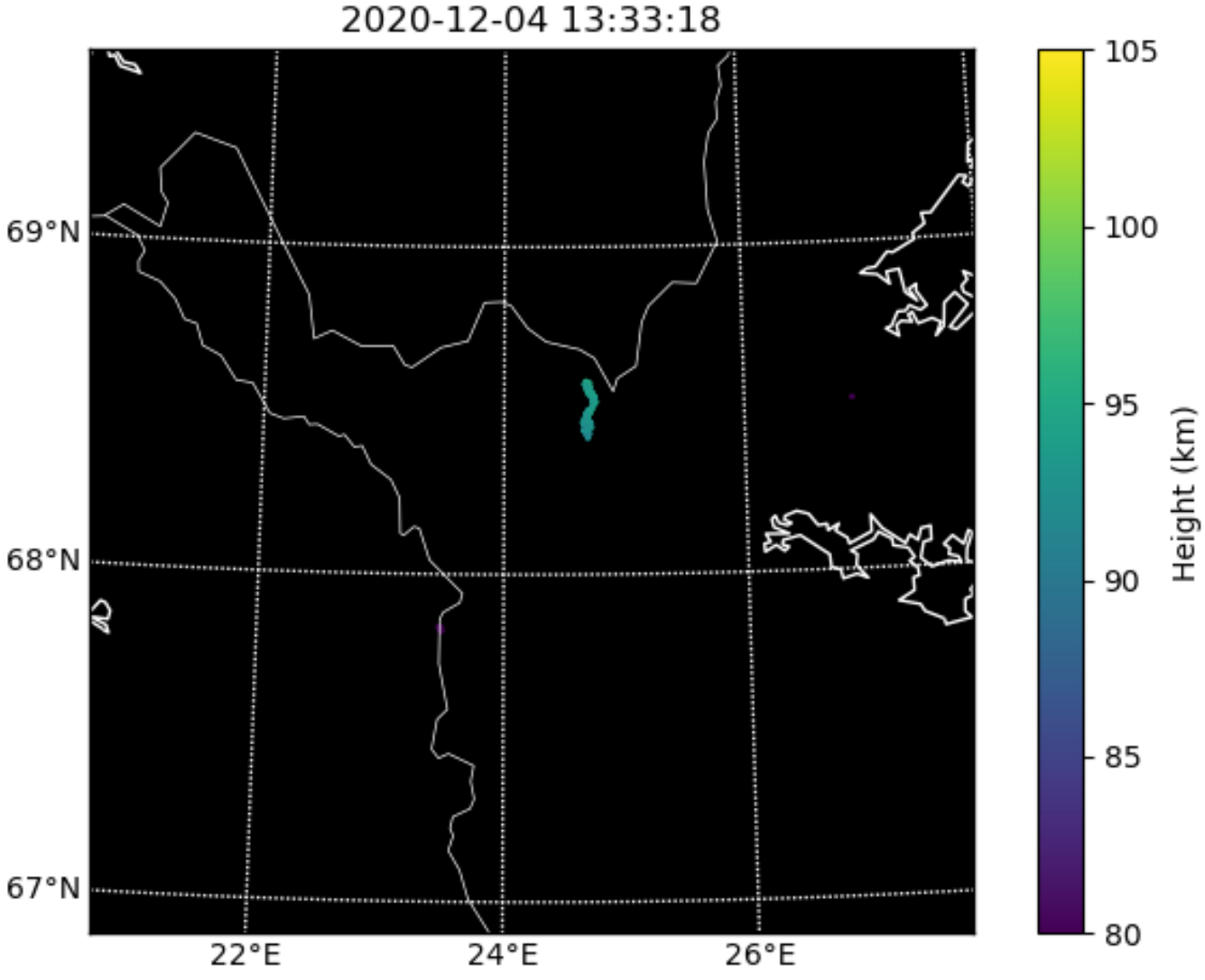
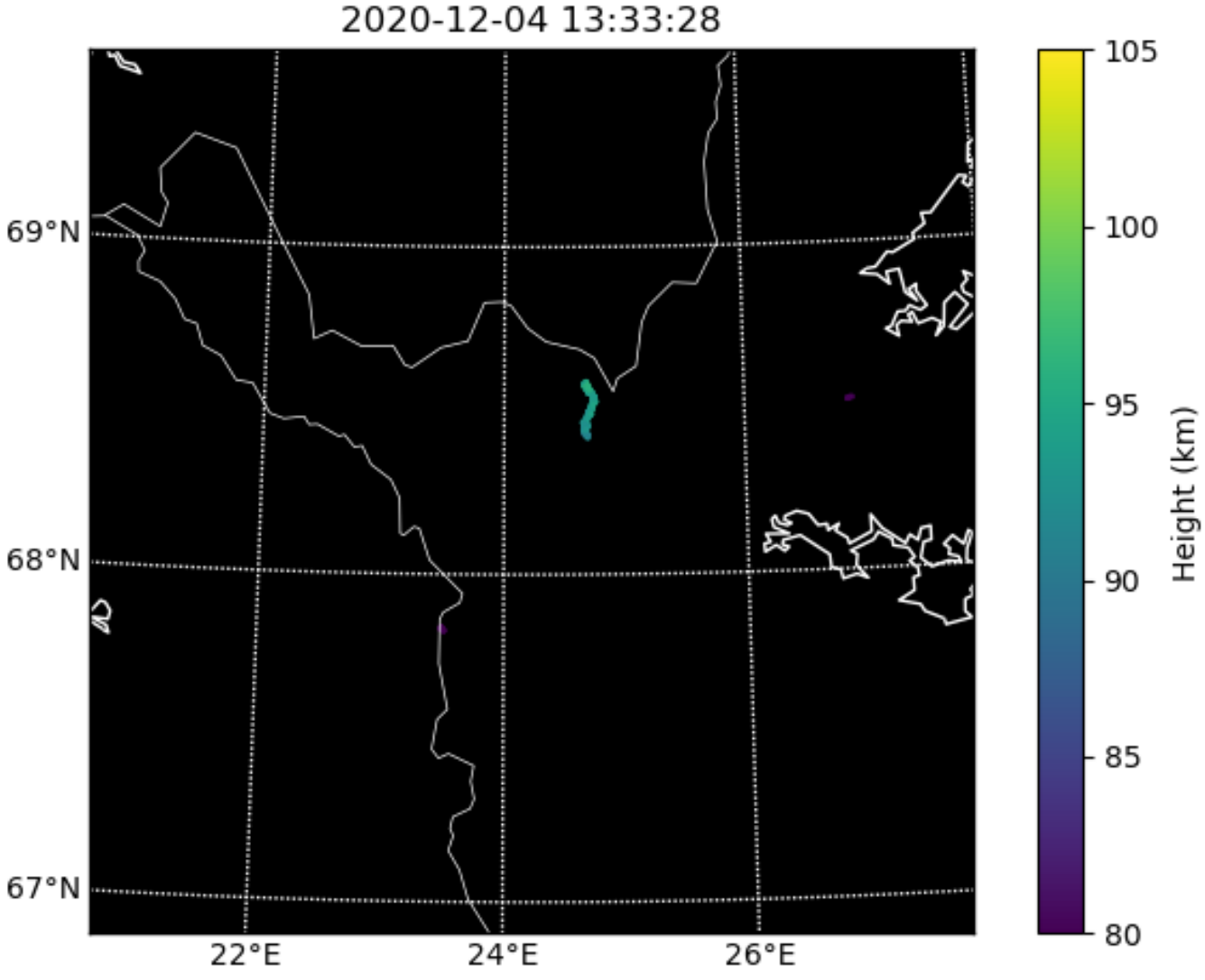


Meteor radar trail echo interferometry



Meteor radar trail echo interferometry



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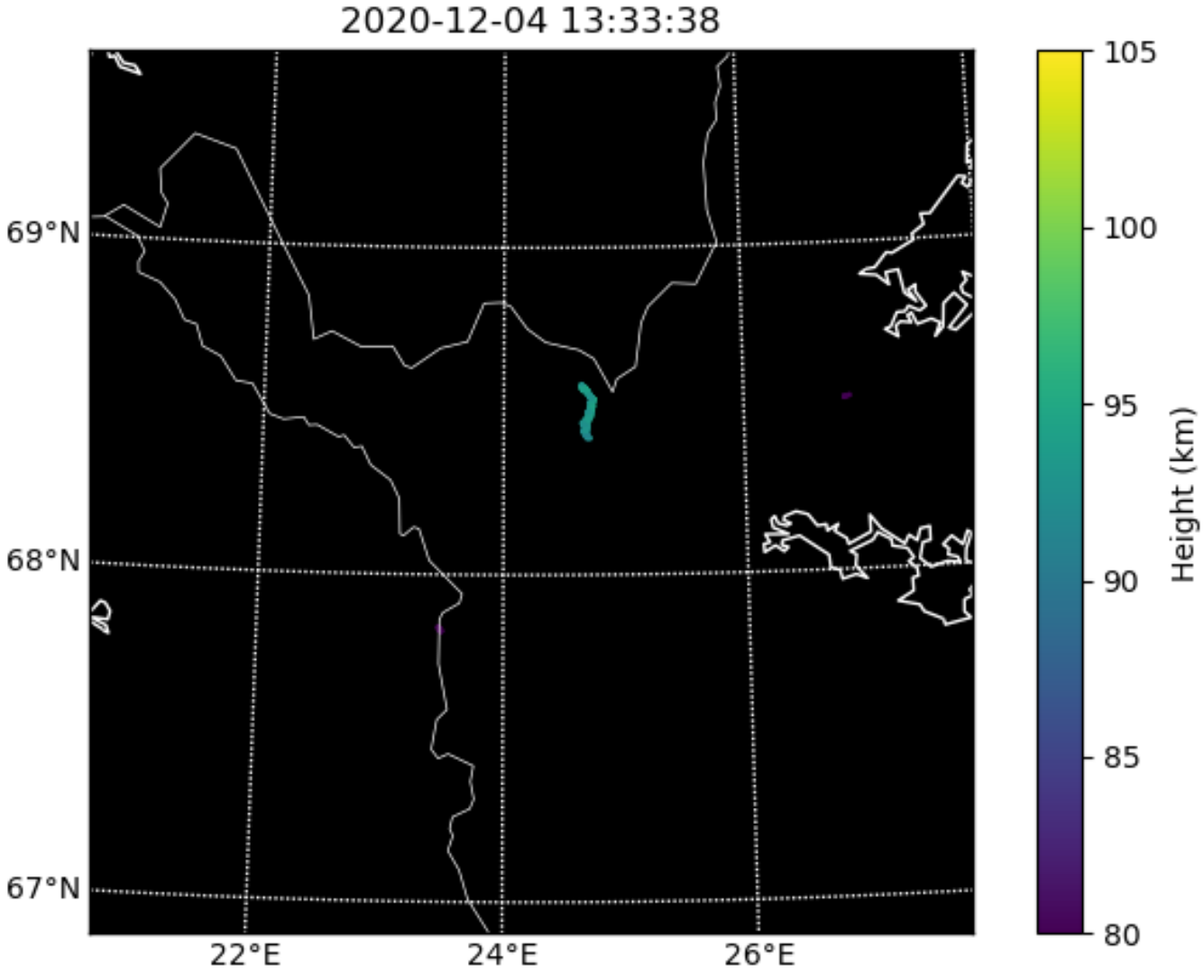

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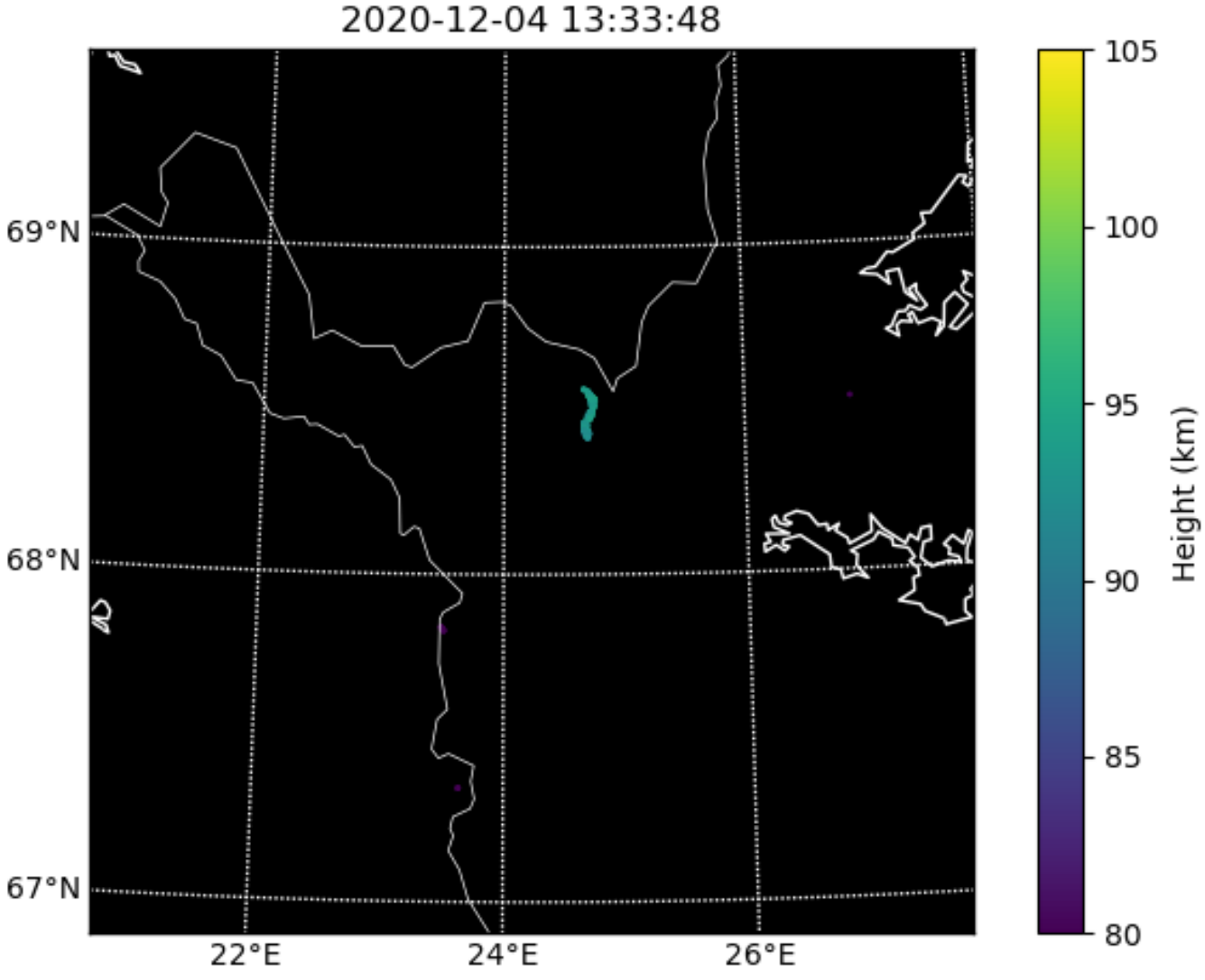

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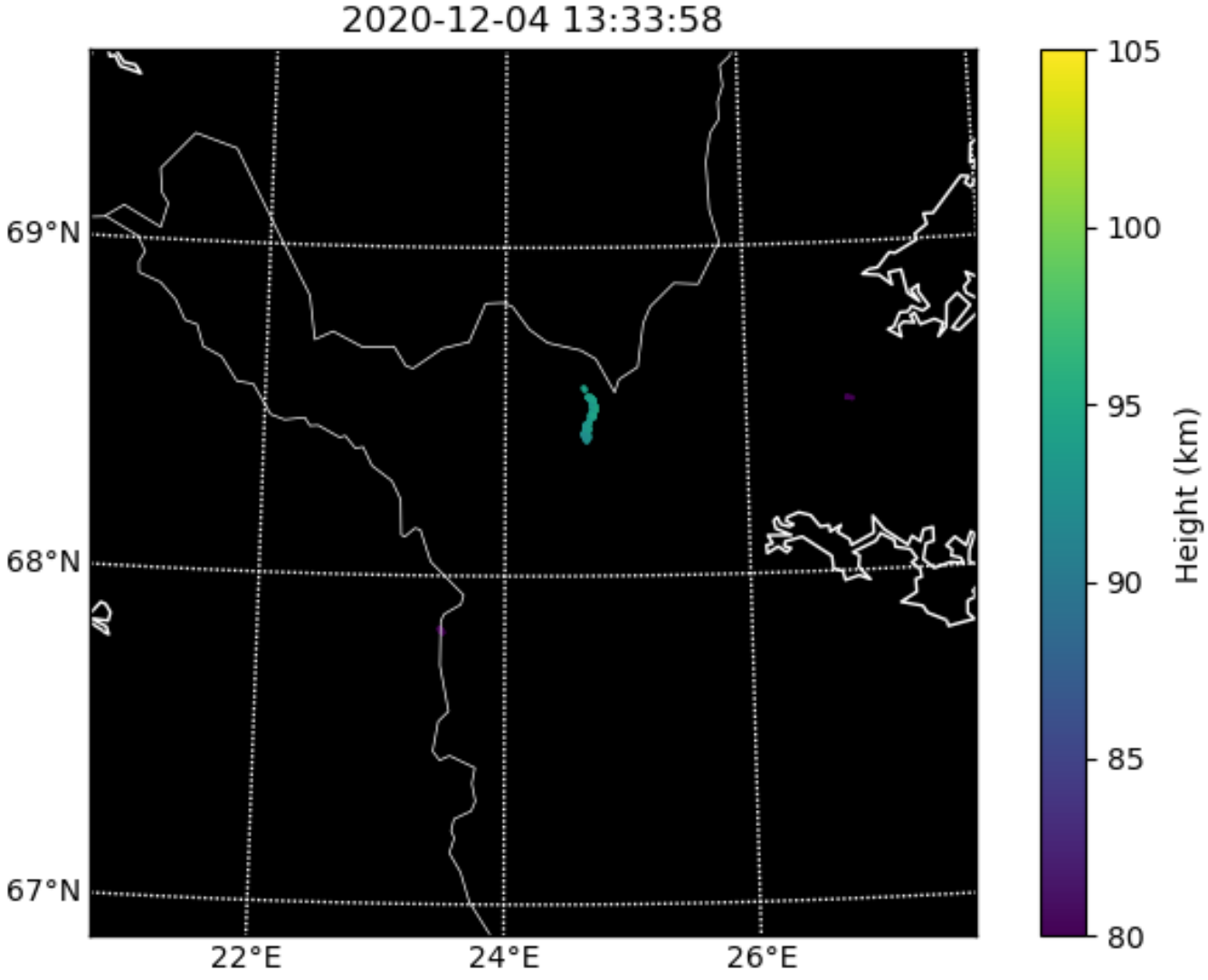
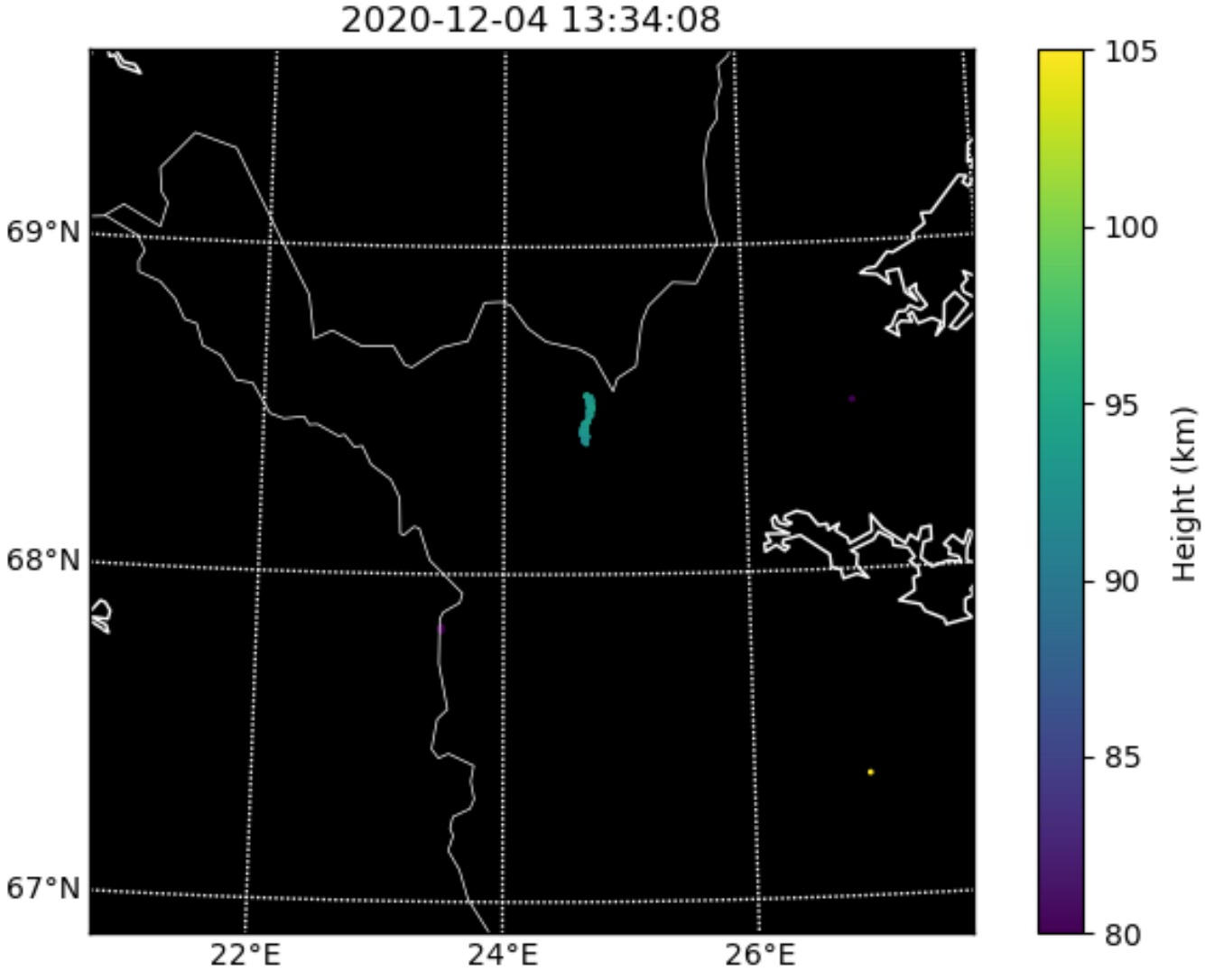
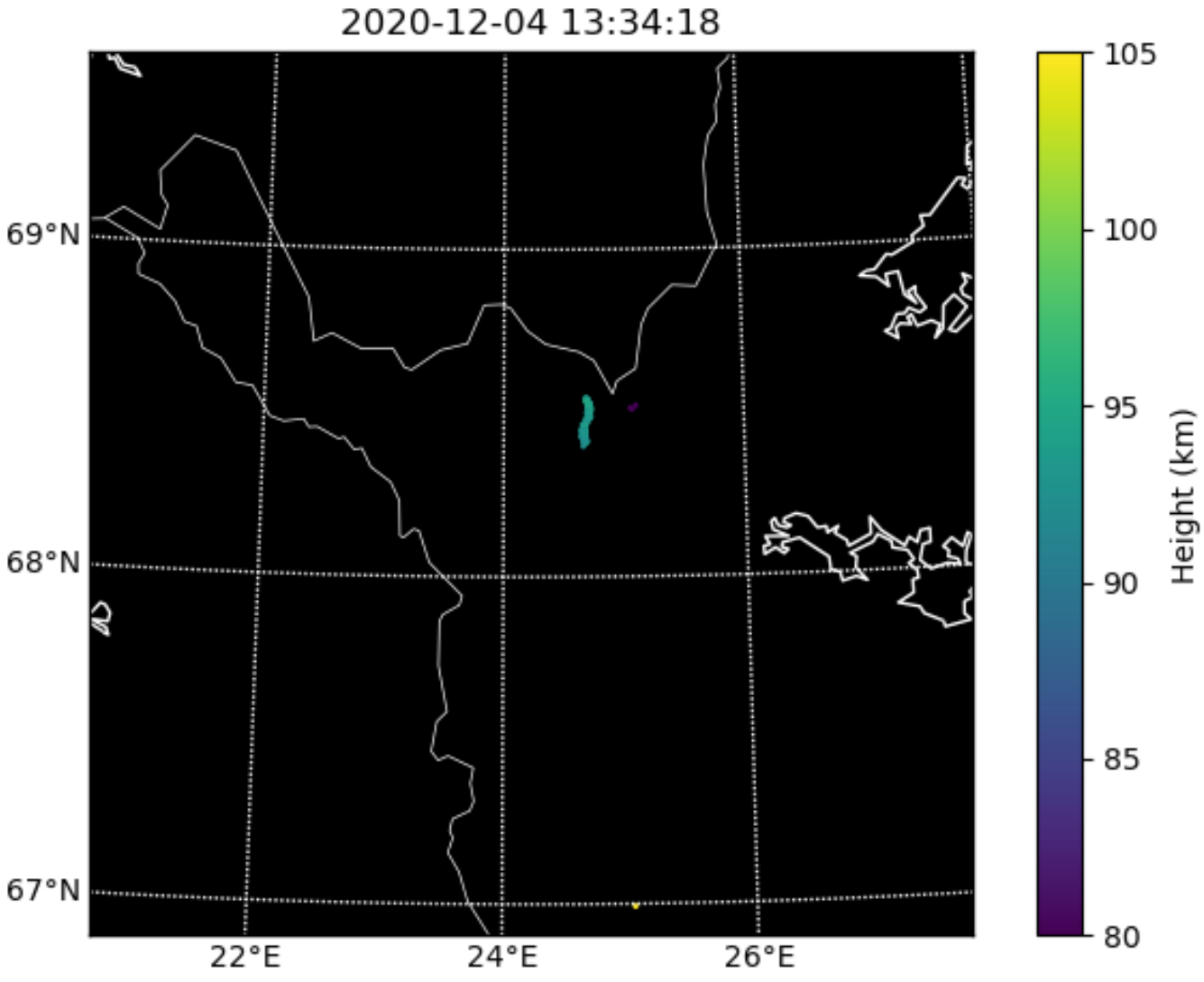


Meteor radar trail echo interferometry



Meteor radar trail echo interferometry



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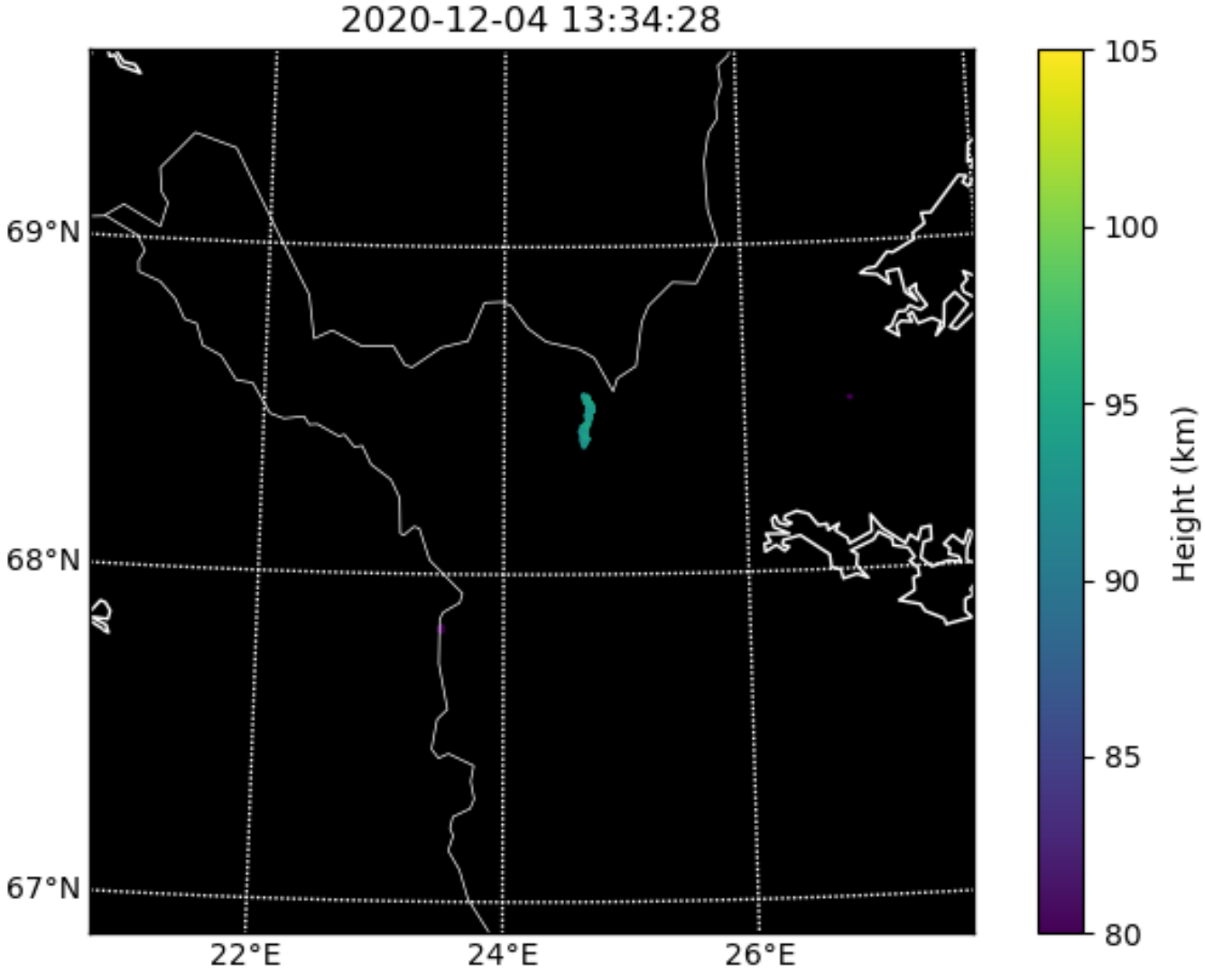

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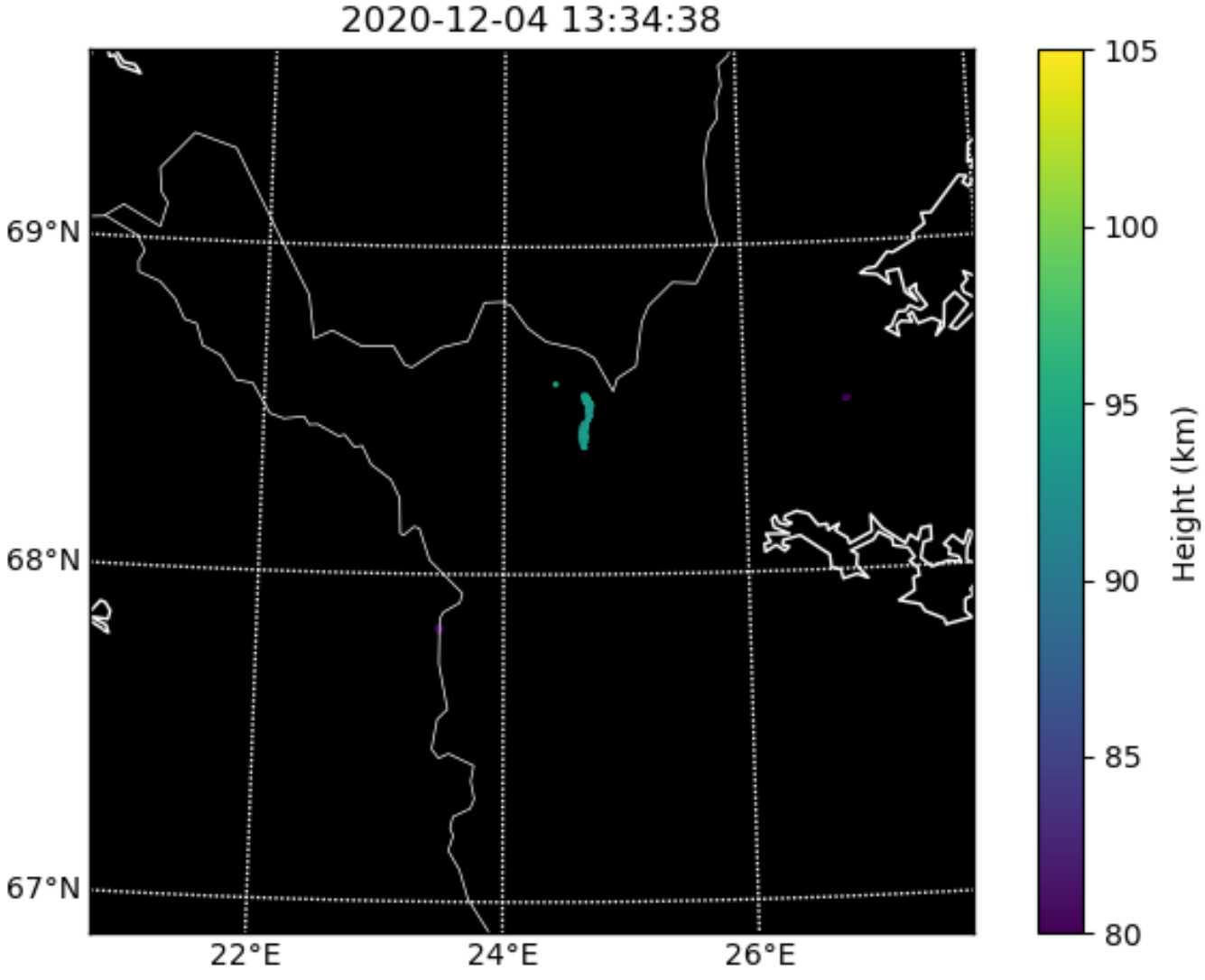

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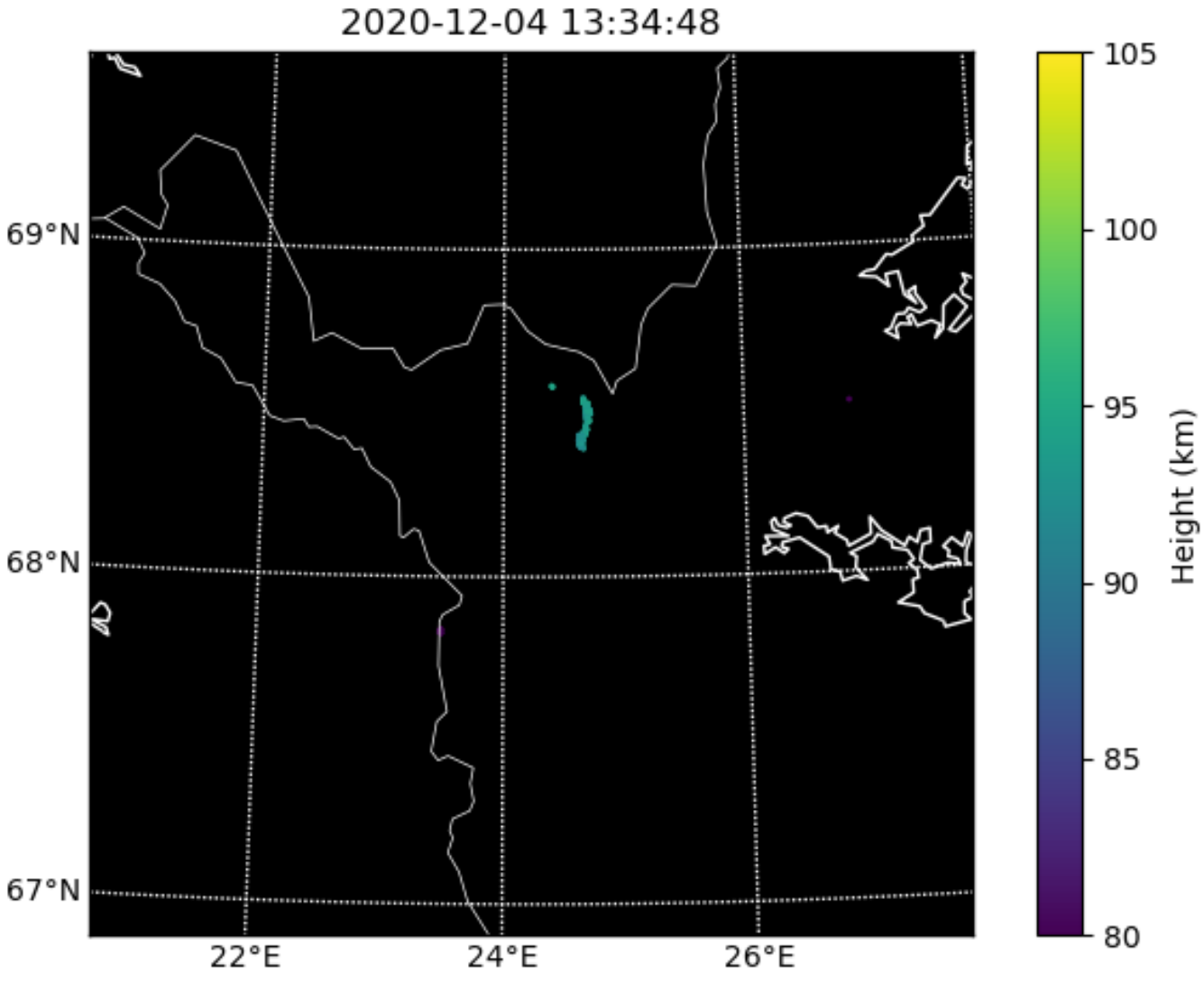
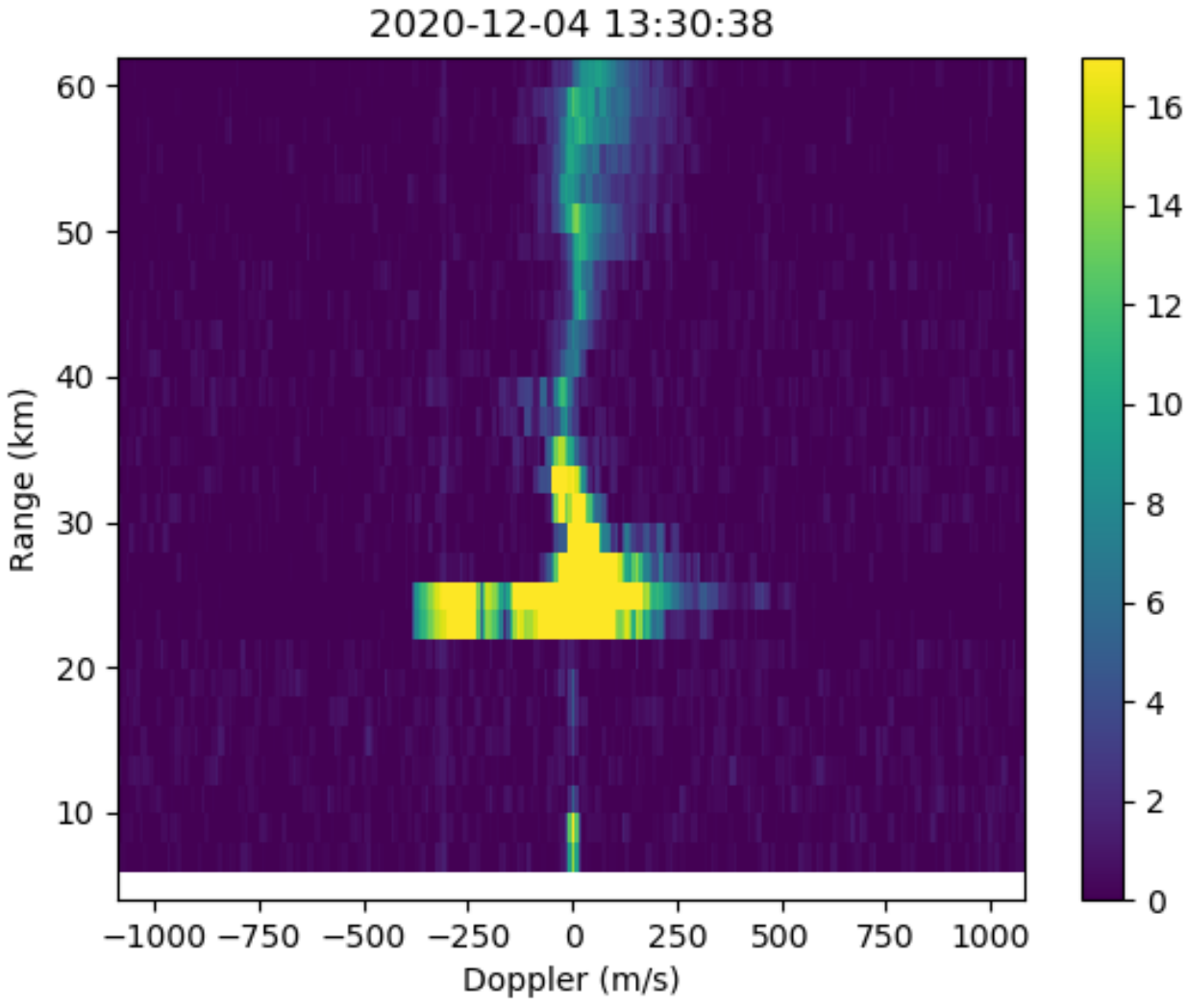
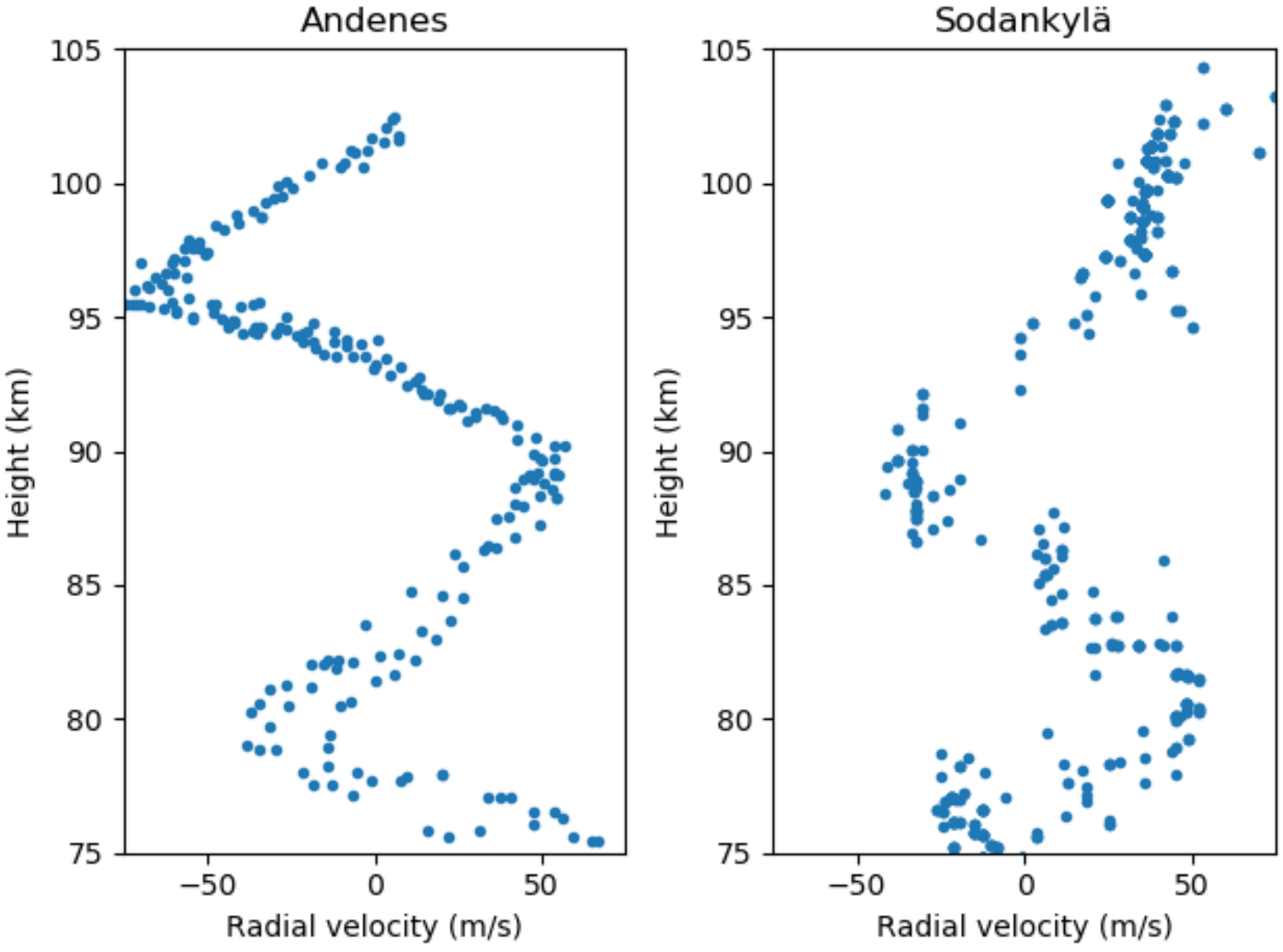


Range-Doppler spectrum



Neutral wind estimated from trail



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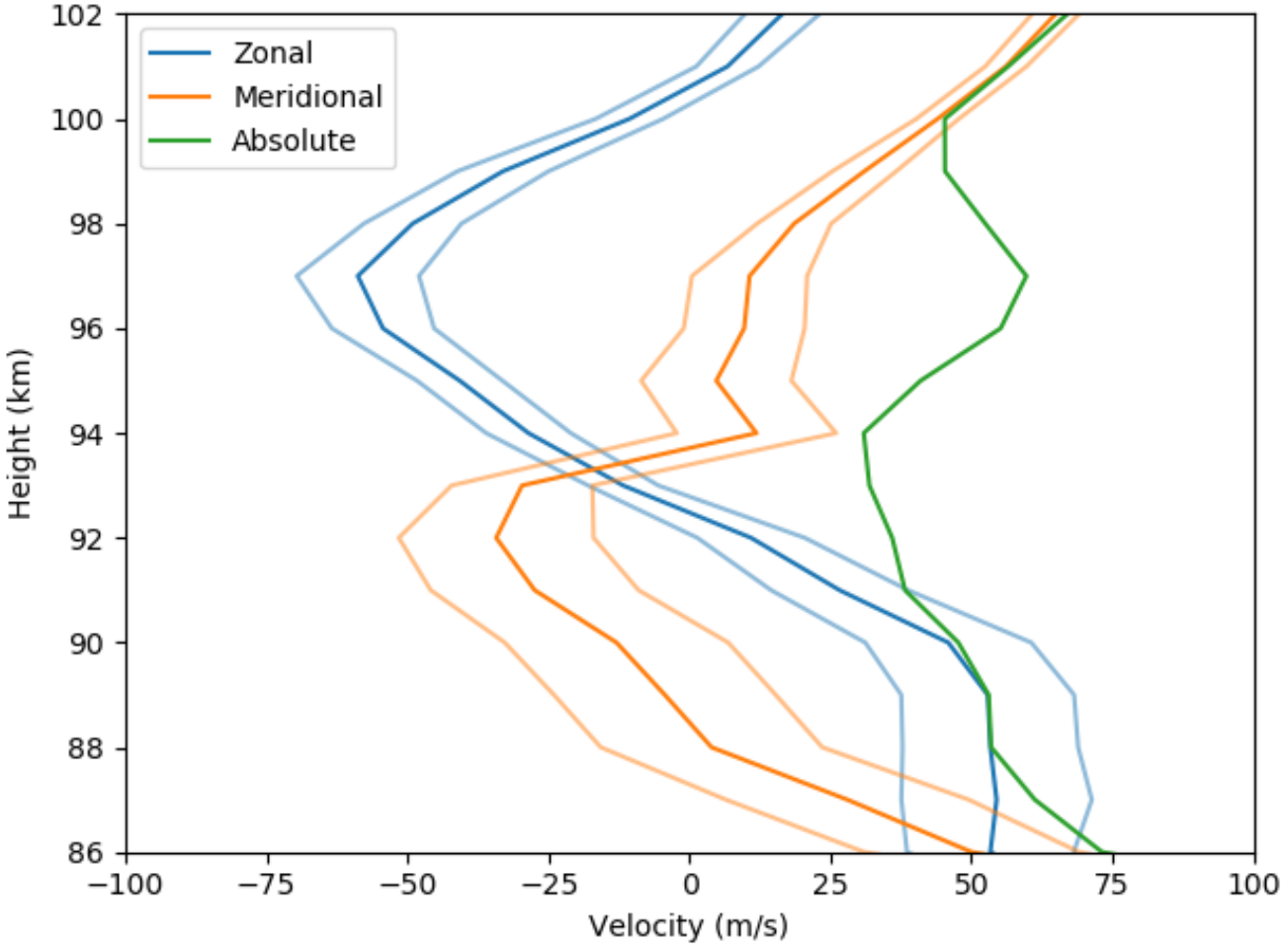
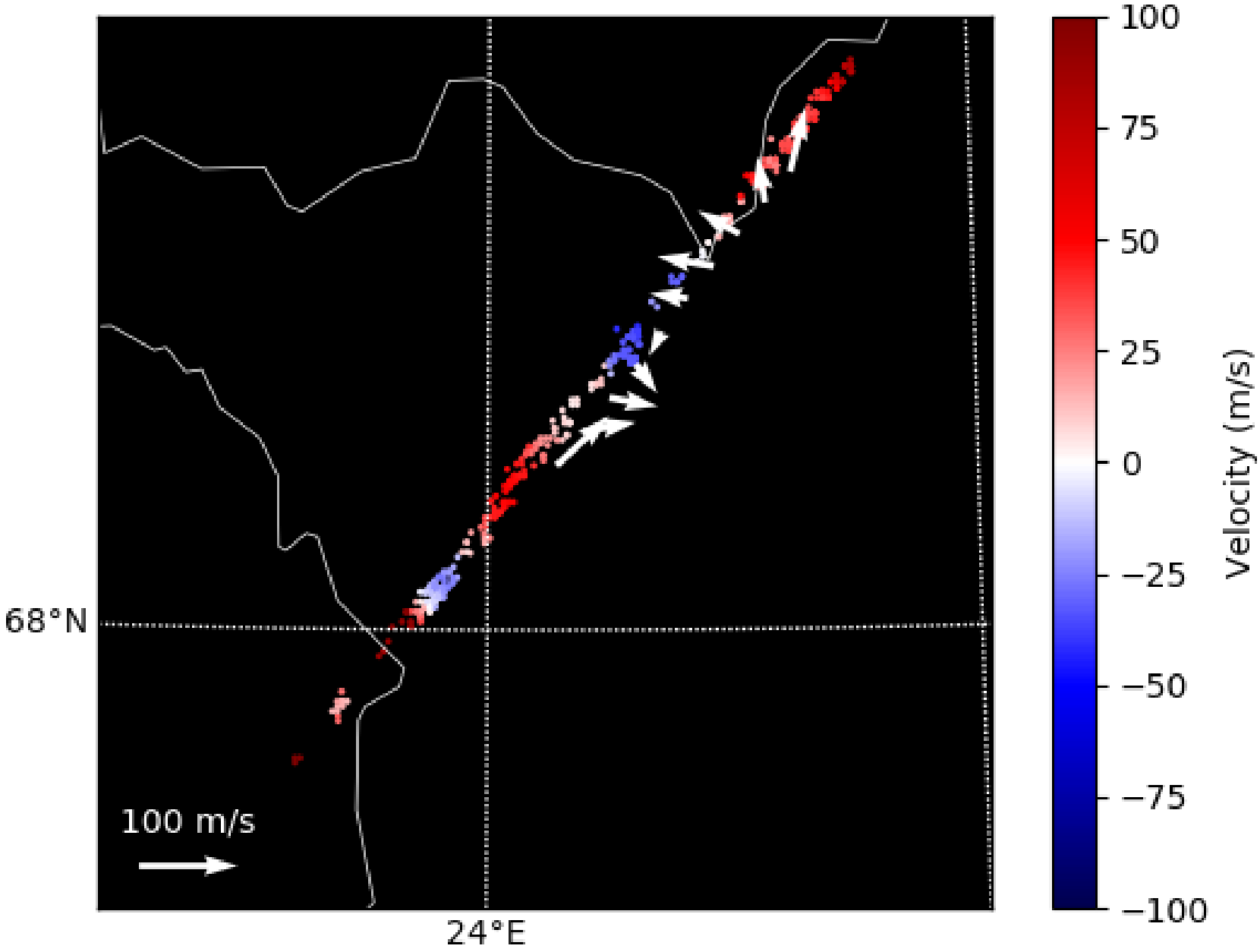
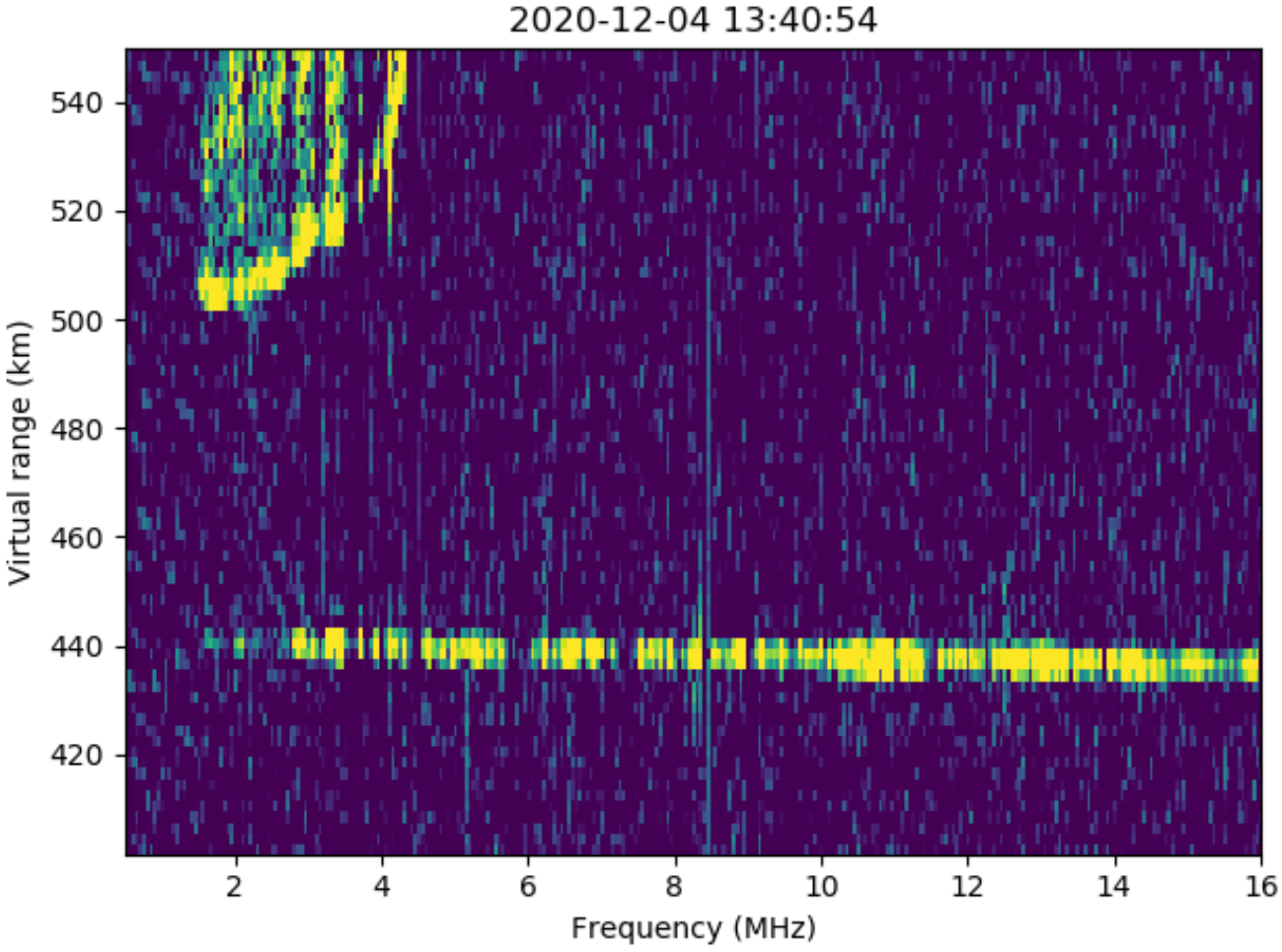


Positive is towards East and North.

Neutral wind estimated from trail



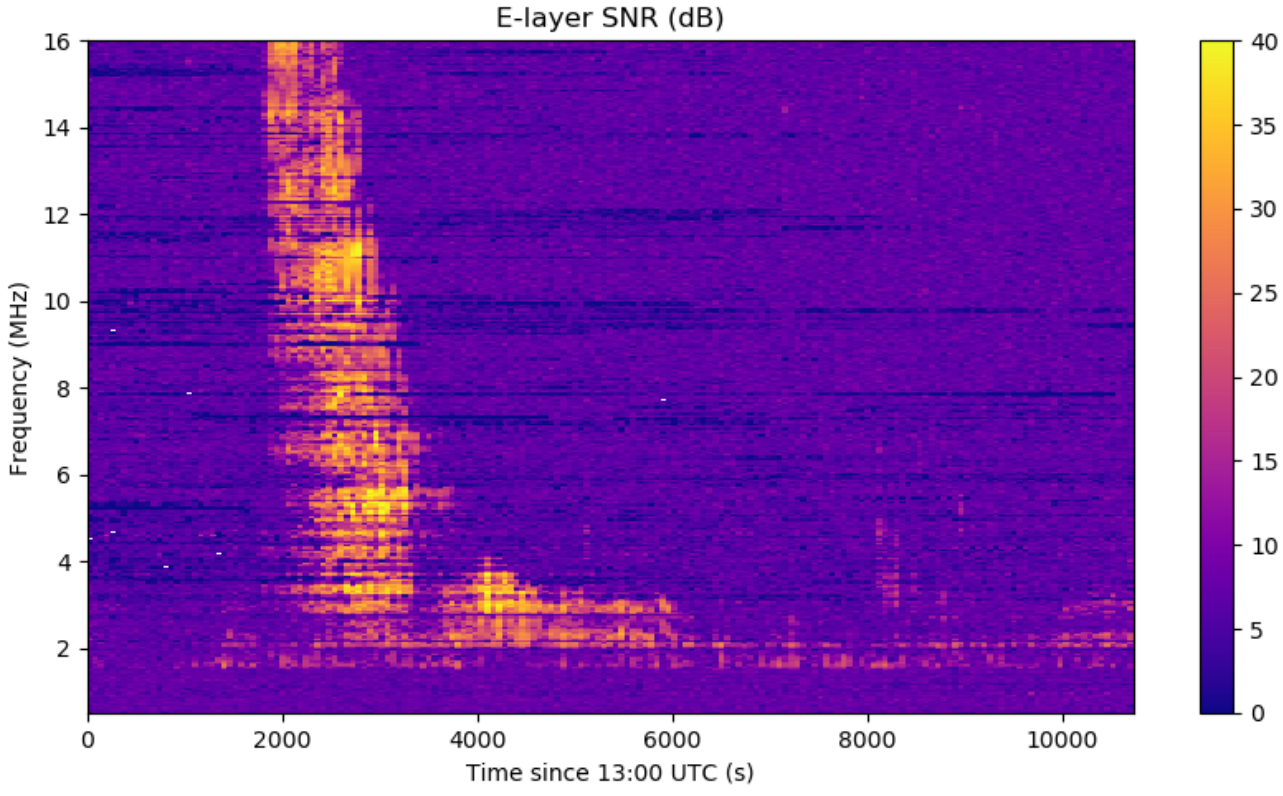
Ionosonde observations



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)
- $\boldsymbol{k} \not\perp \boldsymbol{B}$
- $\hat{\boldsymbol{v}} \not\perp \boldsymbol{k}$
- Delayed onset of trail echo
- The line of sight Doppler shift appears to reflect 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 presence of meteoric aerosols $\Rightarrow$ scattering from plasma turbulence: $\sigma = 4\pi r_e^2 \langle |\Delta N_e(\boldsymbol{k})|^2 \rangle$ [8, 6]
- In situ O_3 can be depleted, slowing down recombination of metallic ions [2, 14, 11]

$$M^+ + O_3 \rightarrow MO^+ + O_2$$
$$MO^+ + e \rightarrow M + O$$

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 $(\boldsymbol{v}_n \times \boldsymbol{B})$ [3, 14, 11]
- Kelvin-Helmholtz Instability [3]

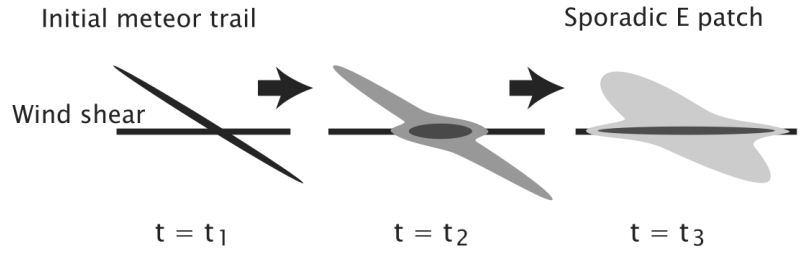
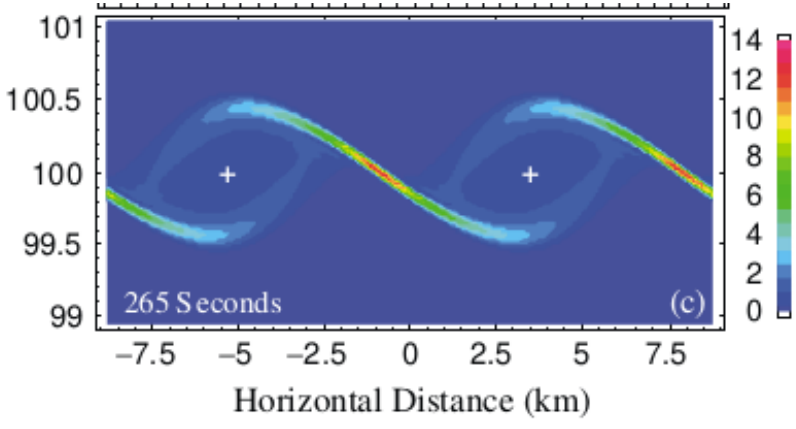
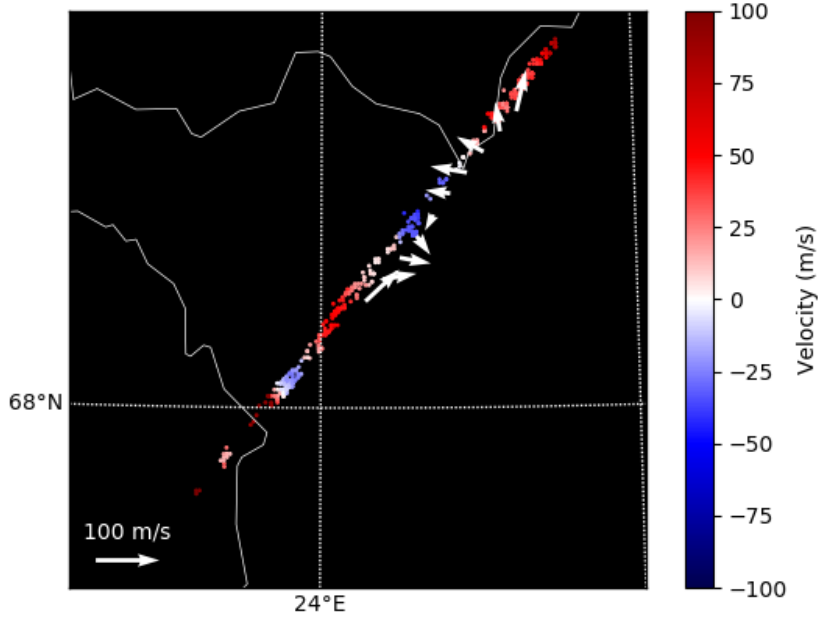


Figure 11. Formation of a sporadic E patch through the trapping of plasma by a wind shear.

(Maruyama et.al. 2003 [11])





Summary

- Well instrumented multi-wavelength multi-k radar observation a large fireball that can be used to study atmospheric effects of large meteors [9, 18, 17, 14, 10]
- The physics of radar scattering from long lasting trails not yet well understood (e.g., [10]).
- No radio emission was observed (Obenberger's radio afterglow [13]) 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 [9])
- A multi-static meteor shower campaign would be a promising idea for studies of mesospheric dynamics (e.g., Perseids)
- Publication is in preparation

References I

DJ Asher and DI Steel.
On the possible relation between the tunguska bolide and comet encke.
Planetary and space science, 46(2-3):205–211, 1998.

WJ Baggaley.
The de-ionizatton of dense meteor trains.
Planetary and Space Science, 26(10):979–981, 1978.

Paul A Bernhardt.
The modulation of sporadic-e layers by kelvin–helmholtz billows in the neutral atmosphere.
Journal of atmospheric and solar-terrestrial physics, 64(12-14):1487–1504, 2002.

References II


Alain Bourdillon, Christos Haldoupis, Christian Hanuise, Yvon Le Roux, and Jacky Ménard.
Long duration meteor echoes characterized by doppler spectrum bifurcation.
Geophysical research letters, 32(5), 2005.


P Brown, DK Wong, RJ Weryk, and P Wiegert.
A meteoroid stream survey using the canadian meteor orbit radar: Ii: Identification of minor showers using a 3d wavelet transform.
Icarus, 207(1):66–81, 2010.


JL Chau, I Strelnikova, C Schult, MM Oppenheim, MC Kelley, G Stober, and W Singer.
Nonspecular meteor trails from non-field-aligned irregularities: Can they be explained by presence of charged meteor dust?
Geophysical Research Letters, 41(10):3336–3343, 2014.

References III


P Jenniskens, Q Nénon, J Albers, PS Gural, B Haberman, D Holman, R Morales, BJ Grigsby, D Samuels, and C Johannink.
The established meteor showers as observed by cams.
Icarus, 266:331–354, 2016.


MC Kelley, C Alcala, and JYN Cho.
Detection of a meteor contrail and meteoric dust in the earth's upper mesosphere.
Journal of atmospheric and solar-terrestrial physics, 60(3):359–369, 1998.


A Kozlovsky, R Lukianova, and M Lester.
Occurrence and altitude of the long-lived nonspecular meteor trails during meteor showers at high latitudes.
Journal of Geophysical Research: Space Physics, 125(8):e2019JA027746, 2020.

References IV


A Kozlovsky, S Shalimov, J Kero, T Raita, and M Lester.
Multi-instrumental observations of nonunderdense meteor trails.
Journal of Geophysical Research: Space Physics, 123(7):5974–5989, 2018.


Takashi Maruyama, Hisao Kato, and Maho Nakamura.
Ionospheric effects of the leonid meteor shower in november 2001 as observed by rapid run ionosondes.
Journal of Geophysical Research: Space Physics, 108(A8), 2003.


Are Medby.
Slik reagerte nordlys-leserne på dagens store snakkis: «aldri sett noe lignende, fantastisk, tøft».
Nordlys, Dec 2020.

References V

KS Obenberger, JD Dowell, PJ Hancock, JM Holmes, TR Pedersen, FK Schinzel, and GB Taylor.
Rates, flux densities, and spectral indices of meteor radio afterglows.
Journal of Geophysical Research: Space Physics, 121(7):6808–6817, 2016.

John MC Plane.
Atmospheric chemistry of meteoric metals.
Chemical reviews, 103(12):4963–4984, 2003.

V Porubčan and L Kornoš.
The taurid meteor shower.
ESASP, 500:177–180, 2002.

References VI

Hanno Rein and S-F Liu.
Rebound: an open-source multi-purpose n-body code for collisional dynamics.
Astronomy & Astrophysics, 537:A128, 2012.

C Schult, G Stober, D Keuer, and W Singer.
Radar observations of the maribo fireball over juliusruh: revised trajectory and meteoroid mass estimation.
Monthly Notices of the Royal Astronomical Society, 450(2):1460–1464, 2015.

Elizabeth A Silber, Mark Boslough, Wayne K Hocking, Maria Gritsevich, and Rodney W Whitaker.
Physics of meteor generated shock waves in the earth's atmosphere–a review.
Advances in Space Research, 62(3):489–532, 2018.

References VII

Denis Vida, Peter S Gural, Peter G Brown, Margaret Campbell-Brown, and Paul Wiegert.
Estimating trajectories of meteors: an observational monte carlo approach–i. theory.
Monthly Notices of the Royal Astronomical Society, 491(2):2688–2705, 2020.