
High spatiotemporal resolution radar imaging of atmospheric structures at the polar mesosphere during summer using MAARSY in a MIMO configuration

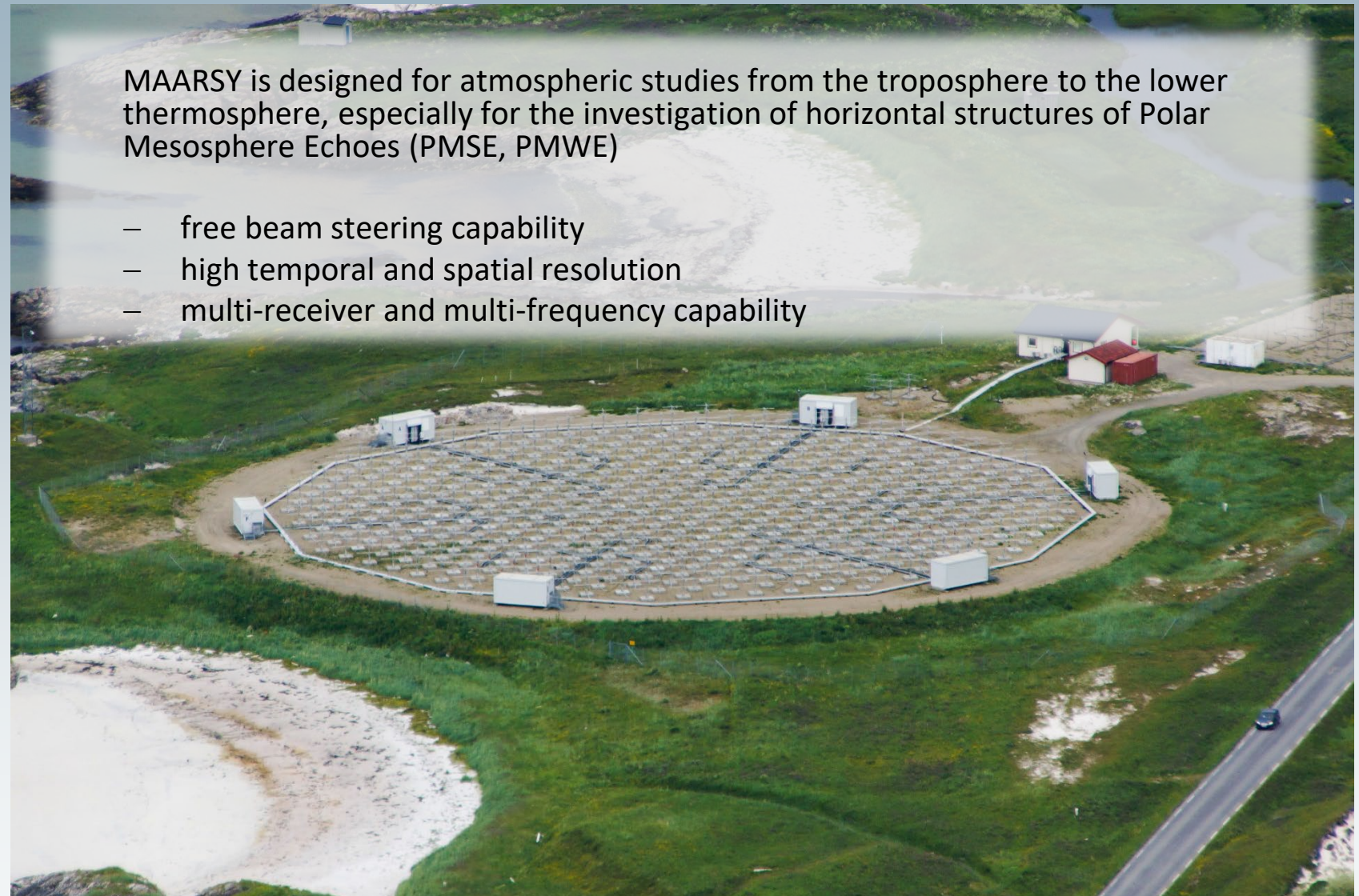
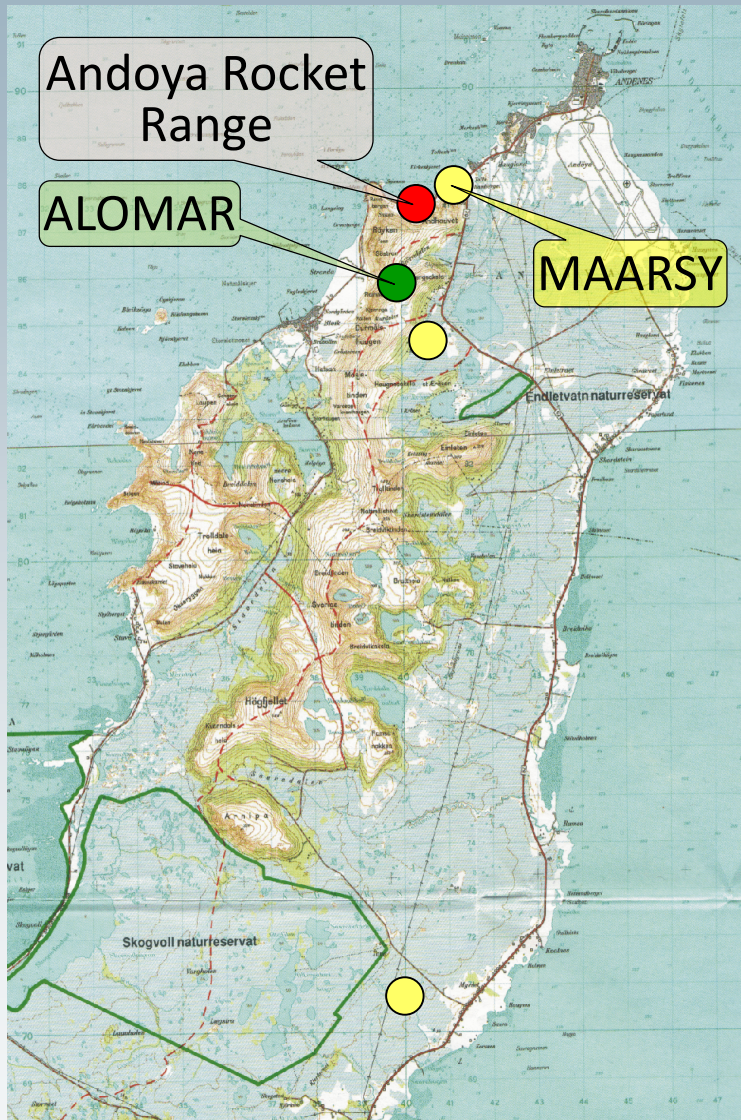
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MAARSY

Middle Atmosphere Alomar Radar System on Andøya island (69°N)

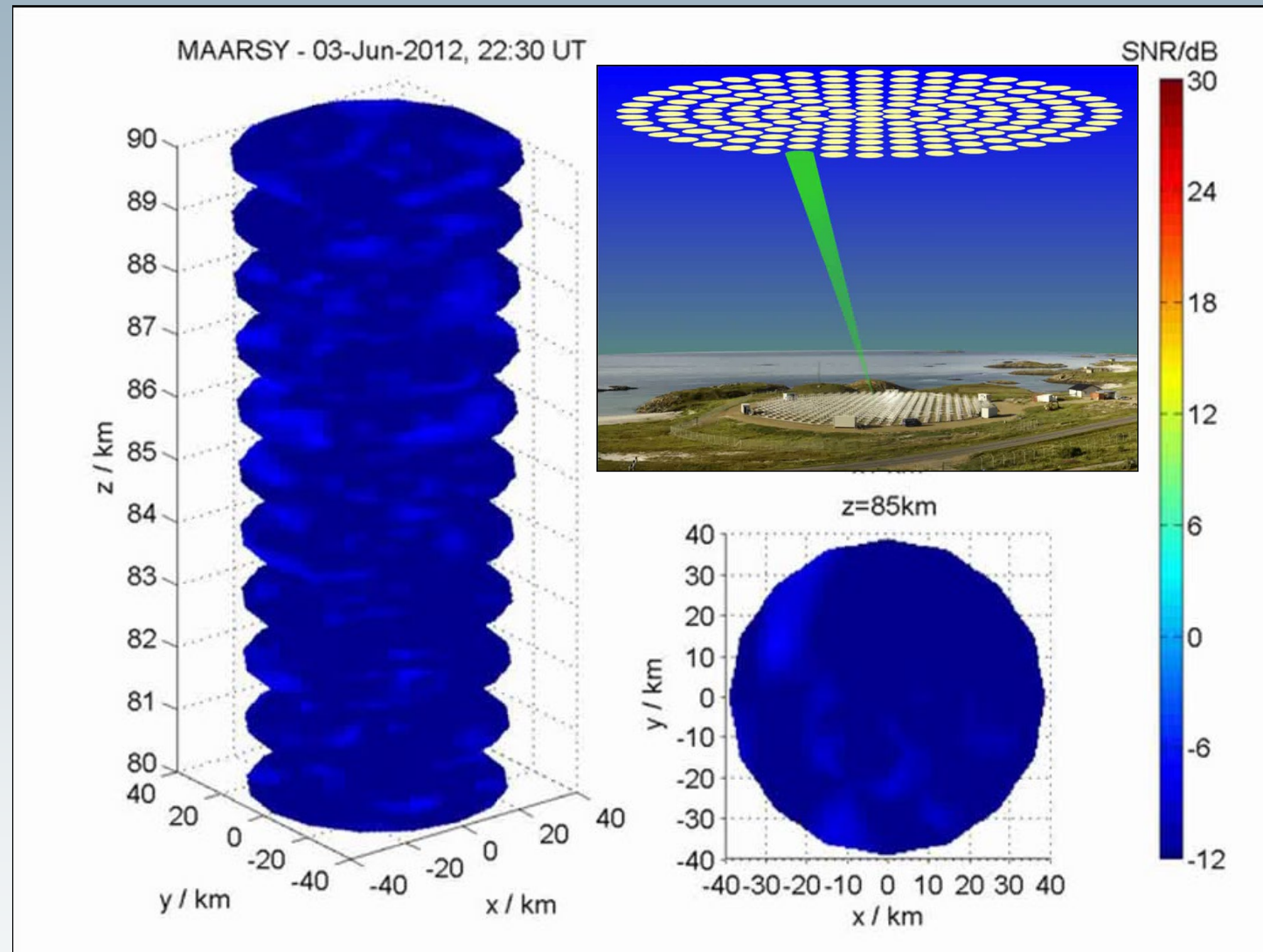


MAARSY is designed for atmospheric studies from the troposphere to the lower thermosphere, especially for the investigation of horizontal structures of Polar Mesosphere Echoes (PMSE, PMWE)

- free beam steering capability
- high temporal and spatial resolution
- multi-receiver and multi-frequency capability

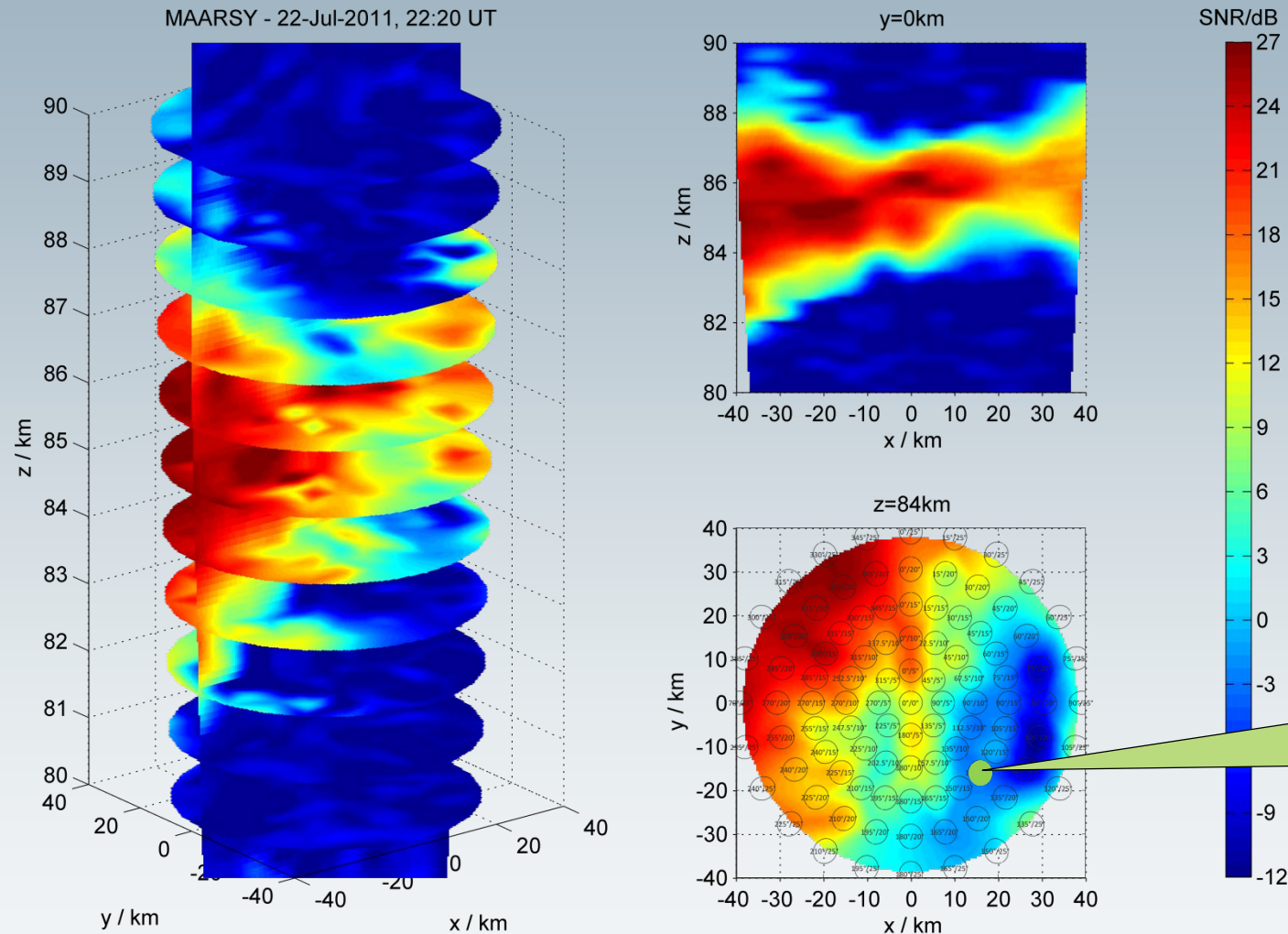
PMSE observation from Andøya

Vertical and horizontal structure of PMSE on June 3rd, 2012



PMSE observation from Andøya

Vertical and horizontal structure of PMSE on July 22nd, 2011

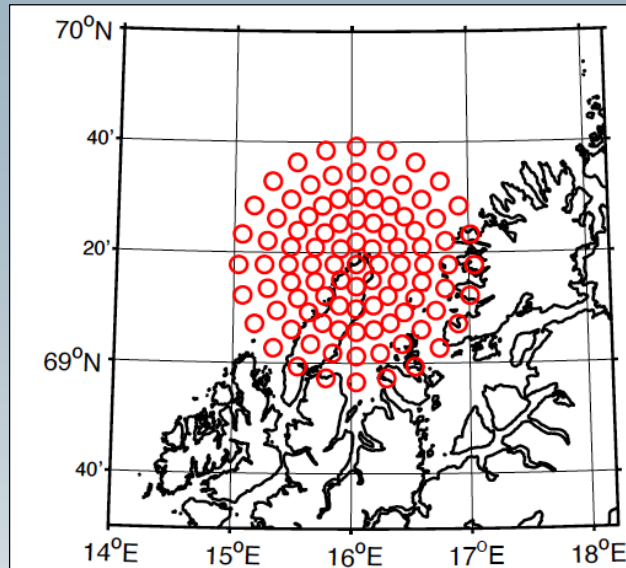


- **97 different beam positions**
- scheduled in 4 experiments with 25 beam positions each (24 oblique + vertical)
- a complete scan required 4 experiments runs a 21s

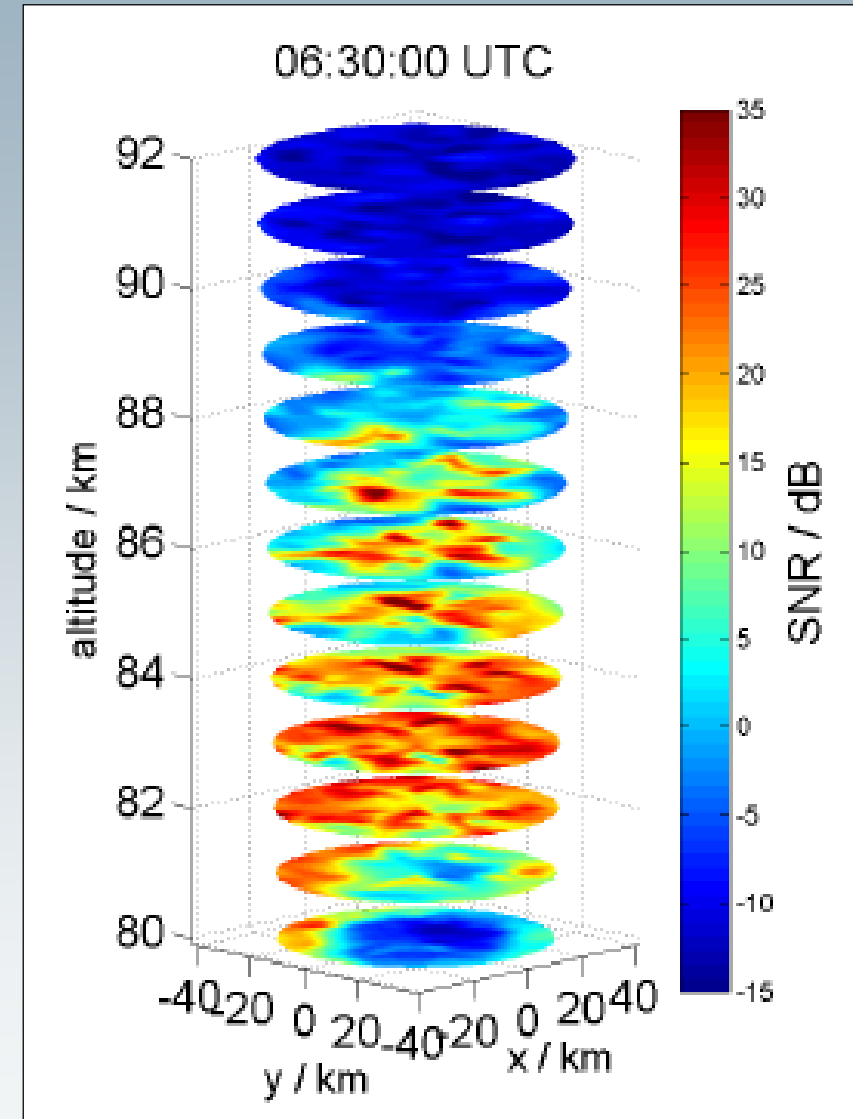
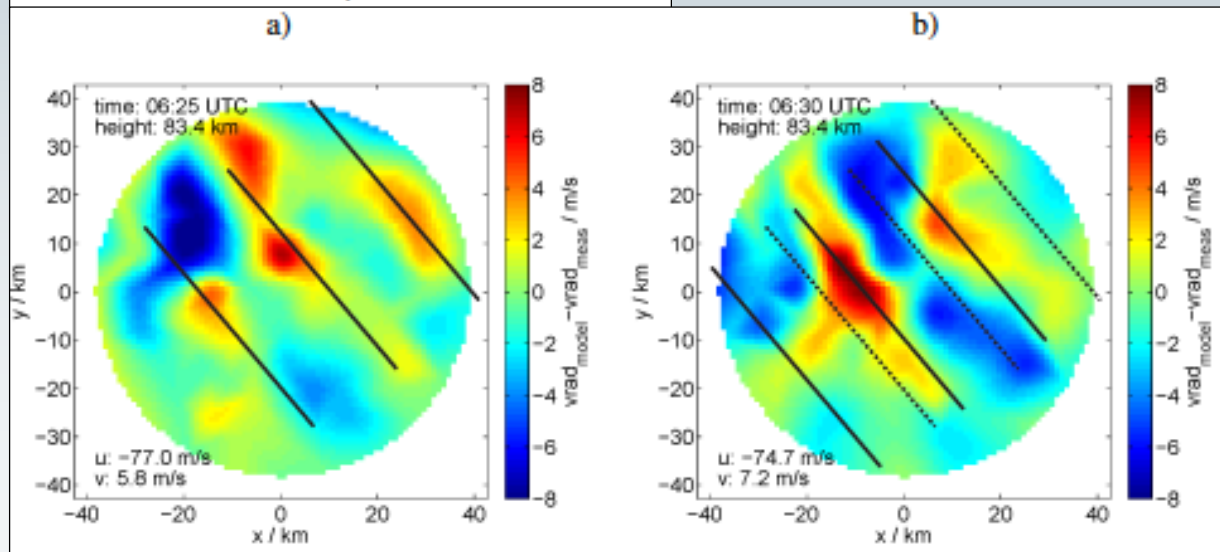
- large beam volume
- side lobe contributions

PMSE: Investigations of GWs from multi-beam observations

(from Stober et al, 2013)

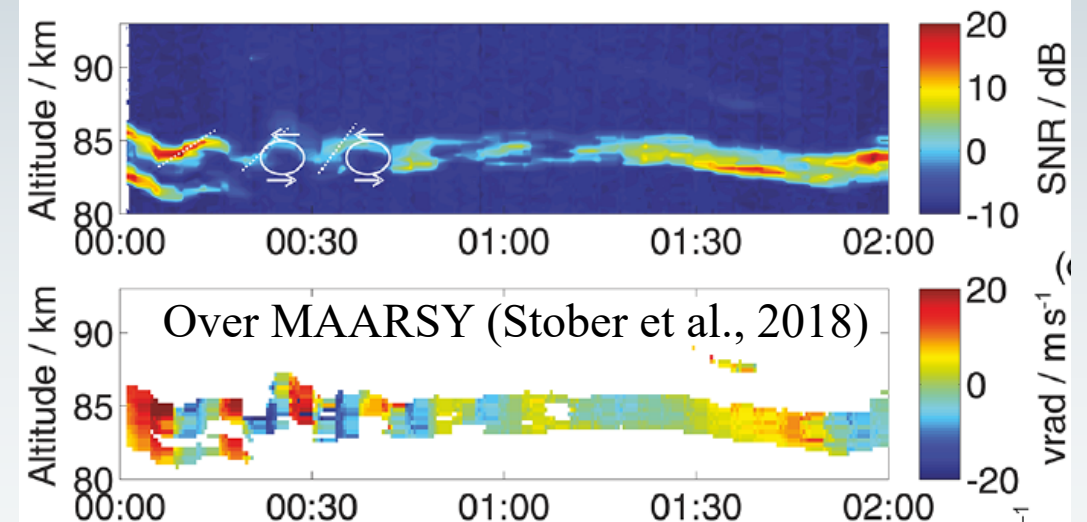
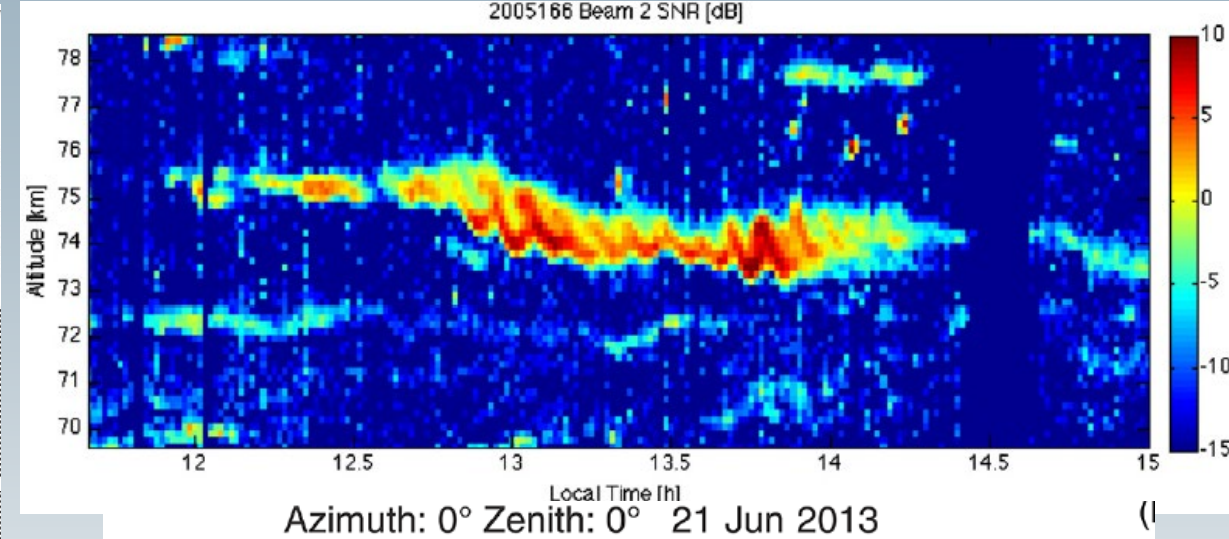
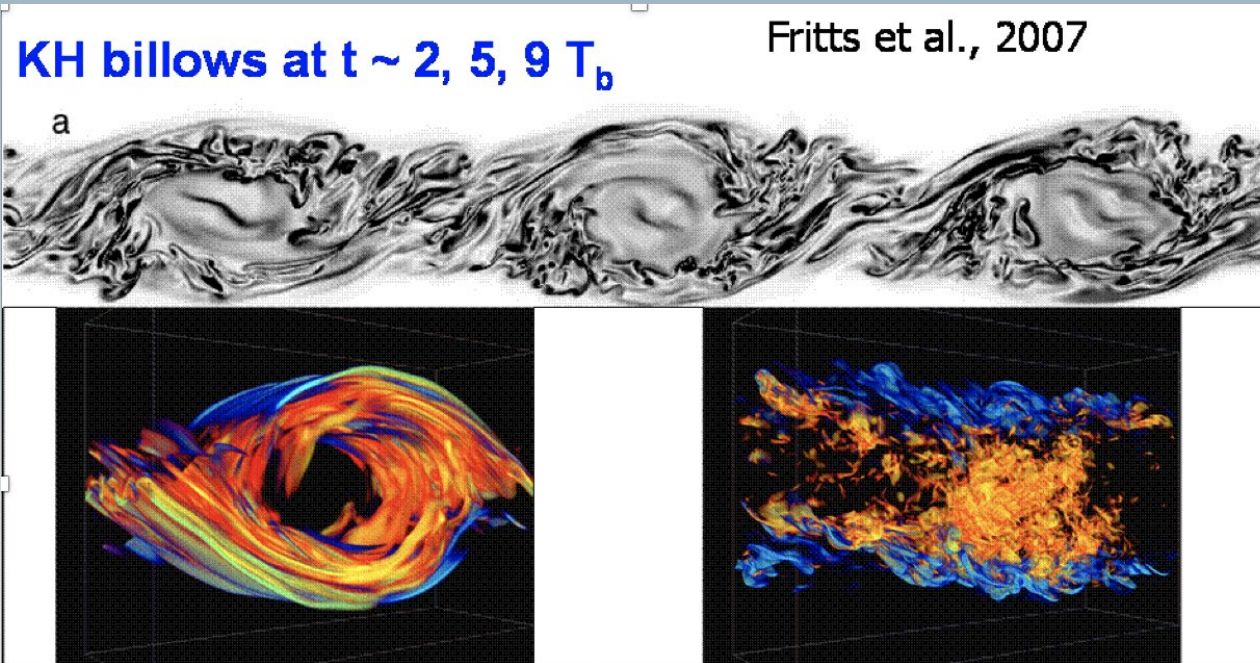


- Field of view 40 x 40 km²
- Frames every 5 minutes
- Wave parameters from Doppler maps:
 - ~15 min period
 - ~24 km wavelength
 - Duration 20 min



Mesospheric Kelvin Helmholtz Instabilities: Radar Observations

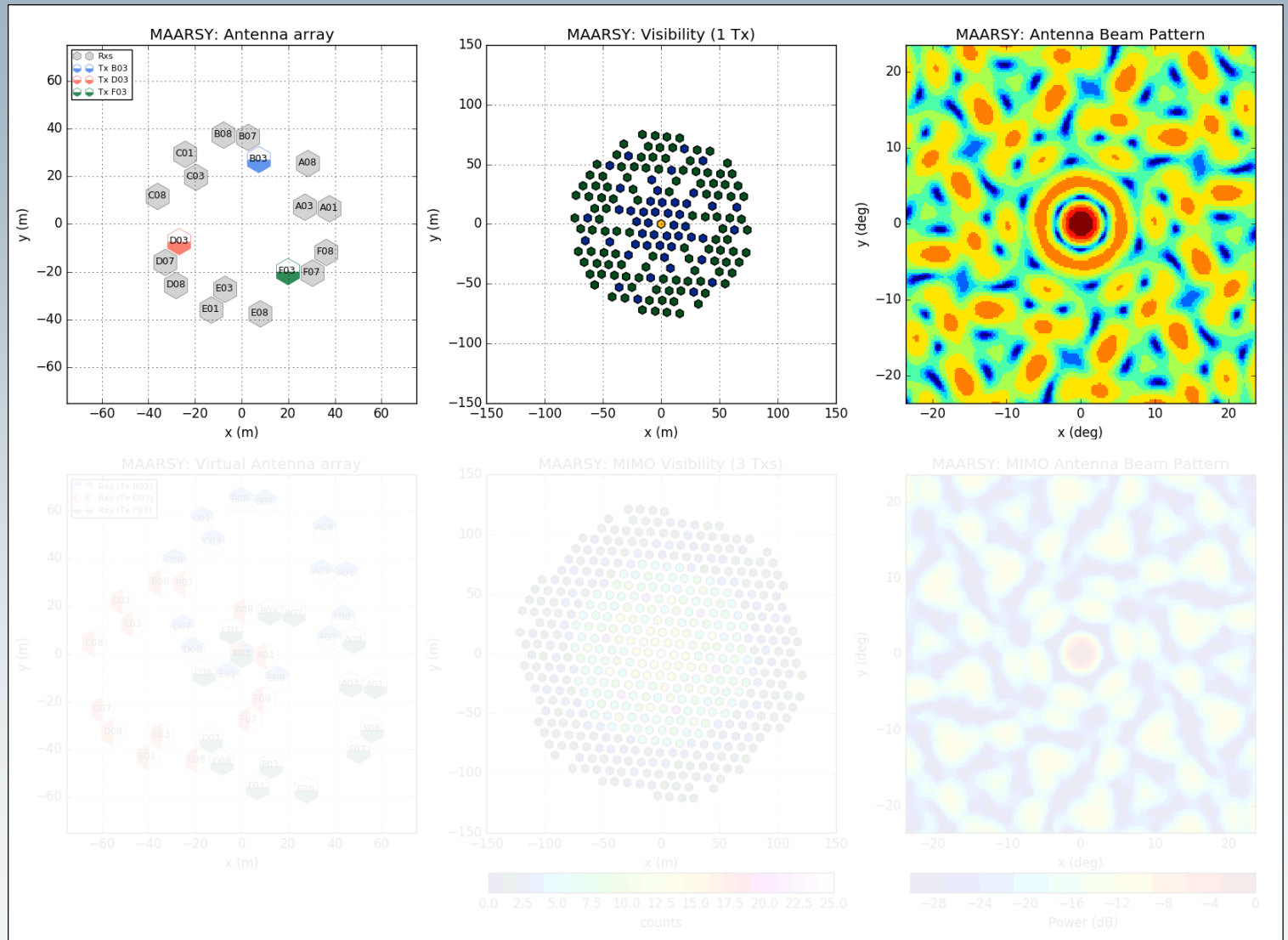
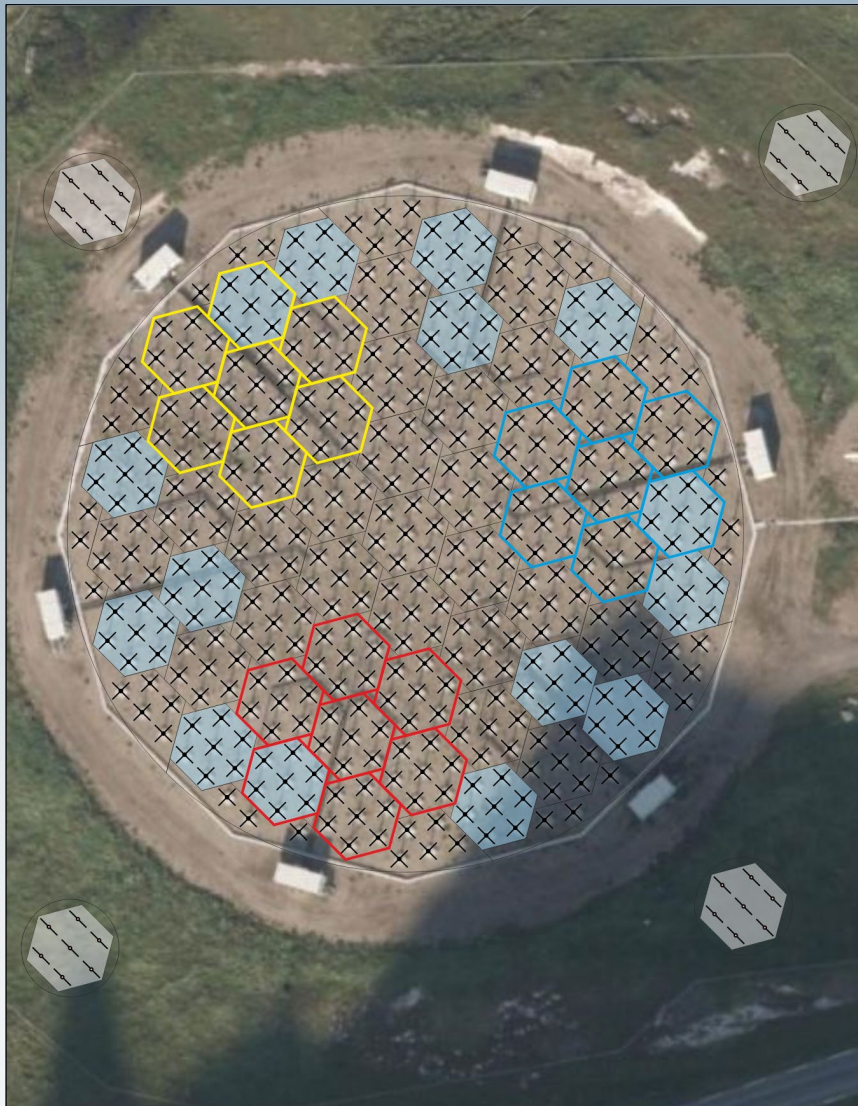
Over Jicamarca (Lehmacher et al., 2007)



Possible signatures in radar echoes (Gossard and Hooke, 1975)

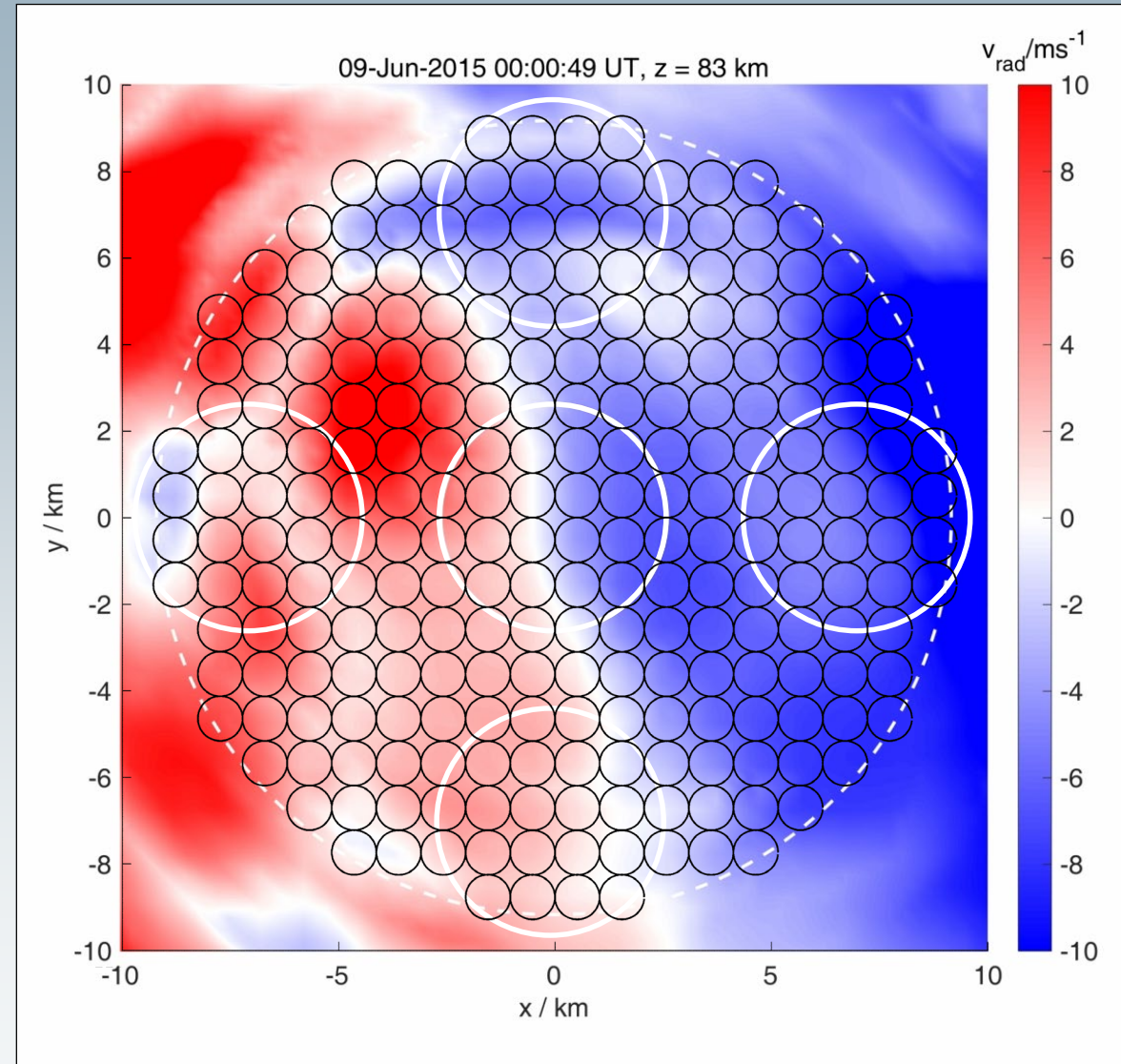
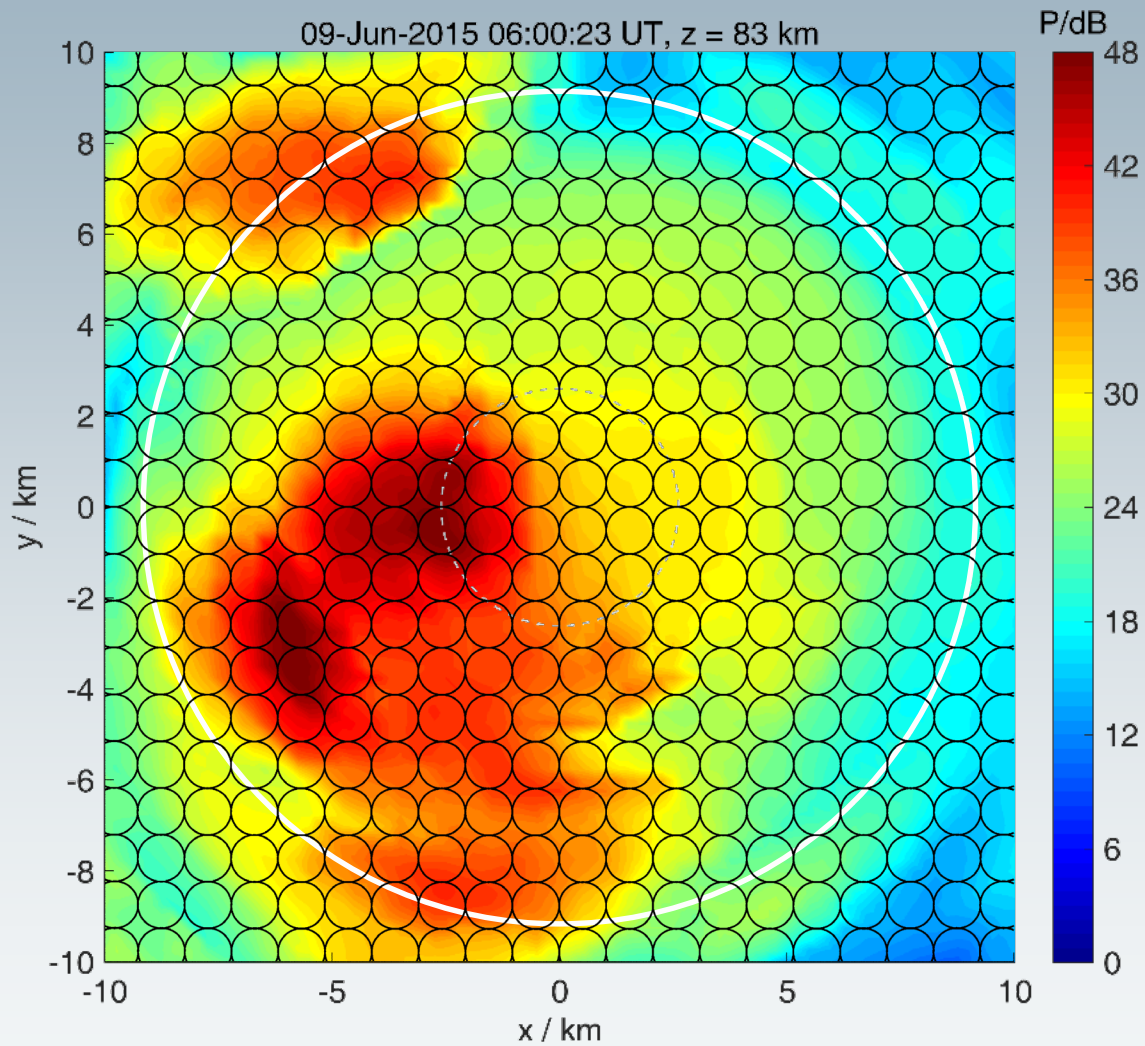
PMSE Radar Imaging-SIMO Experiment

(from Urco et al., 2019)



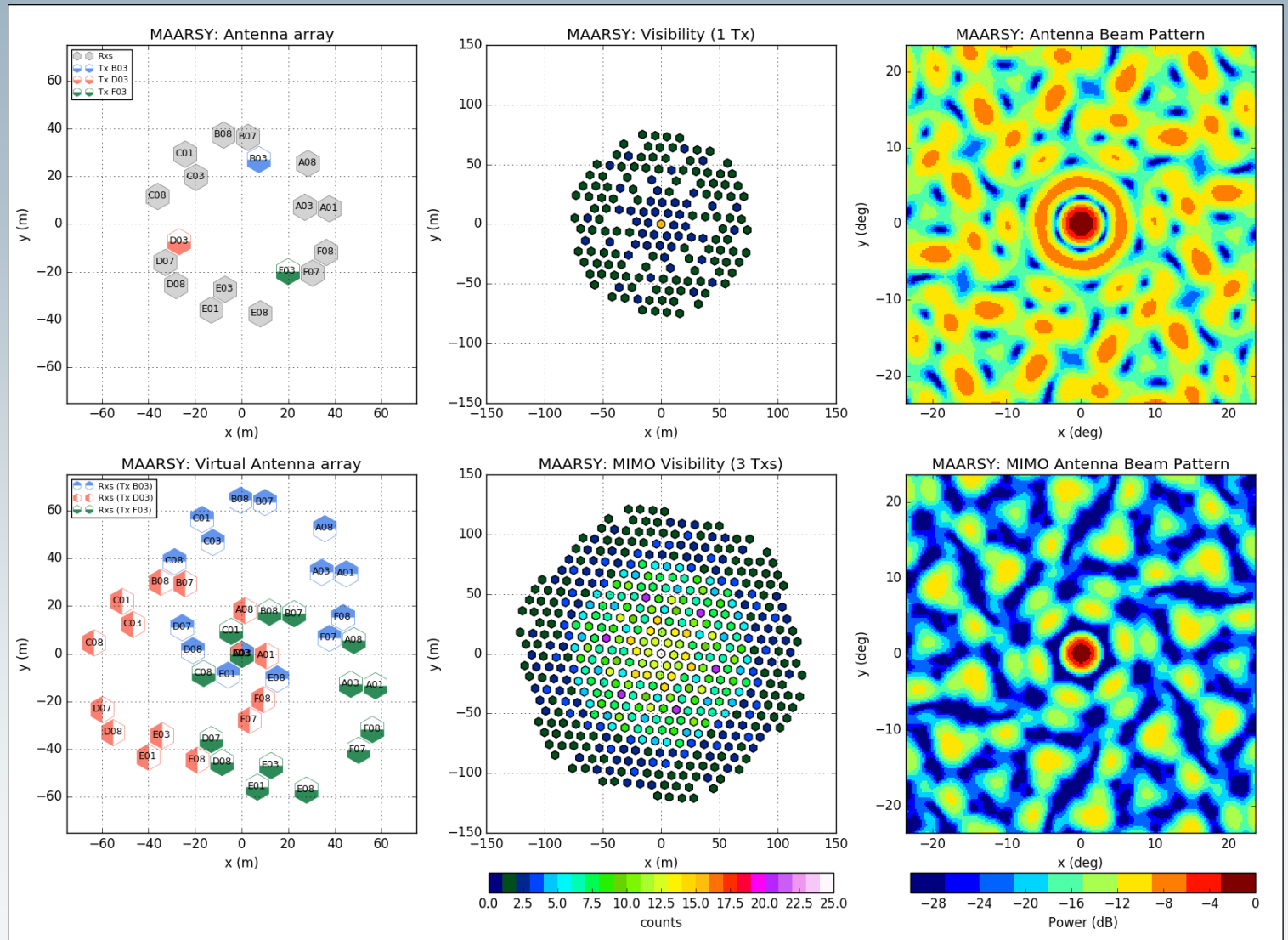
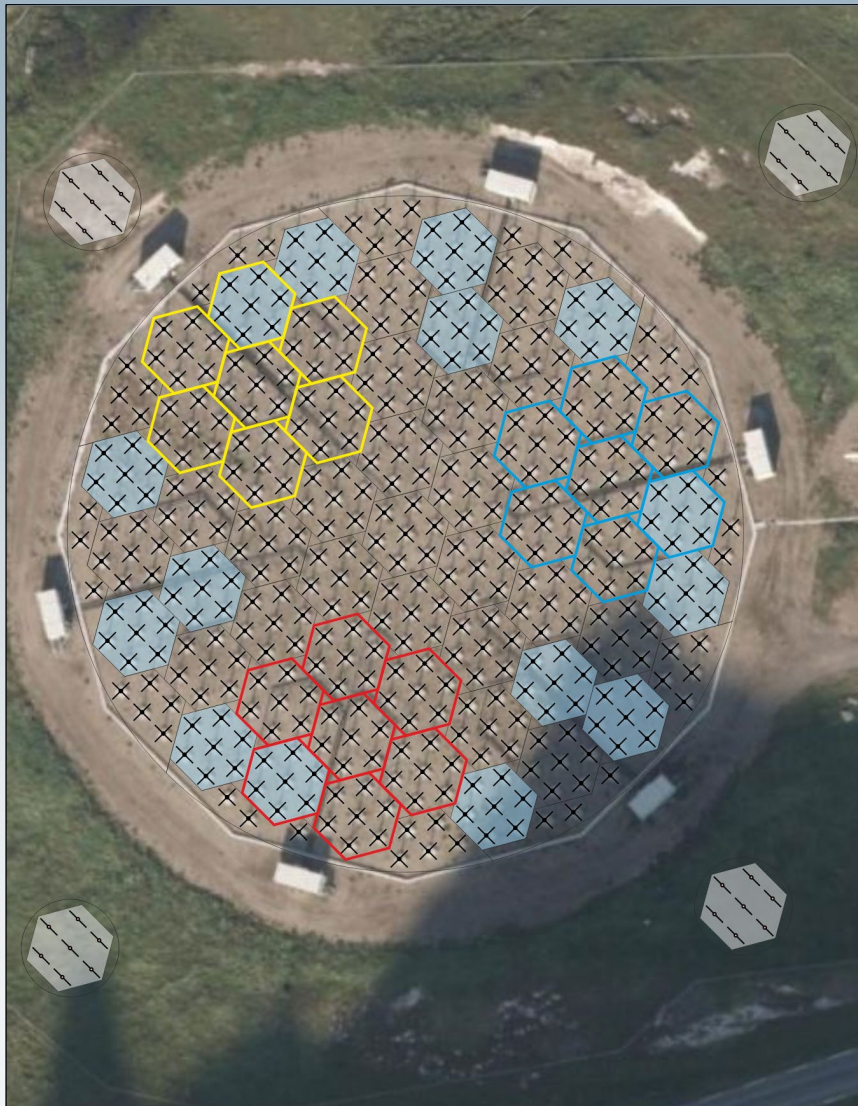
MAARSY coherent radar imaging (CRI)

signal power and v_{rad} from SIMO wide beams experiments using imaging

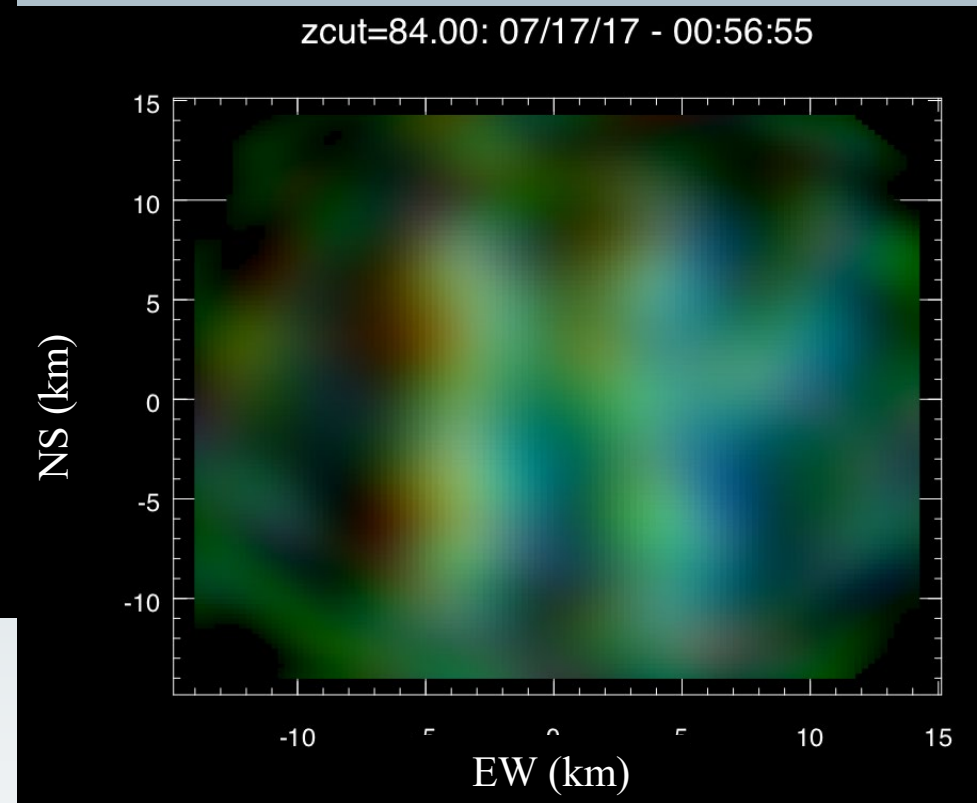
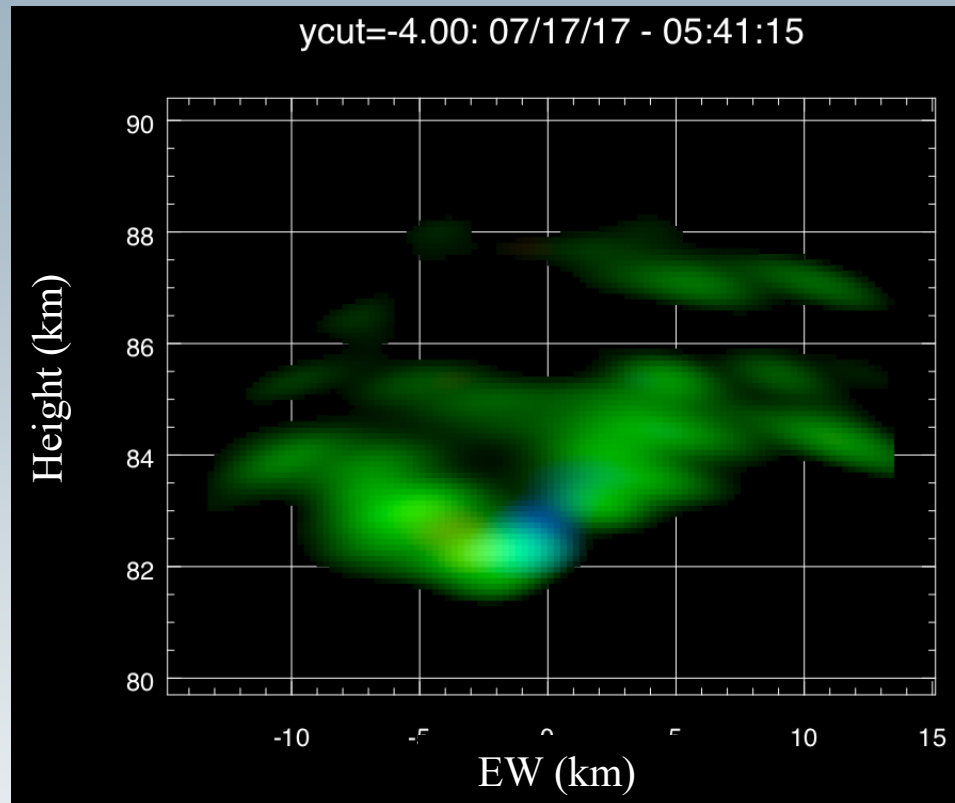


PMSE Radar Imaging - MIMO Experiment

(from Urco et al., 2019)

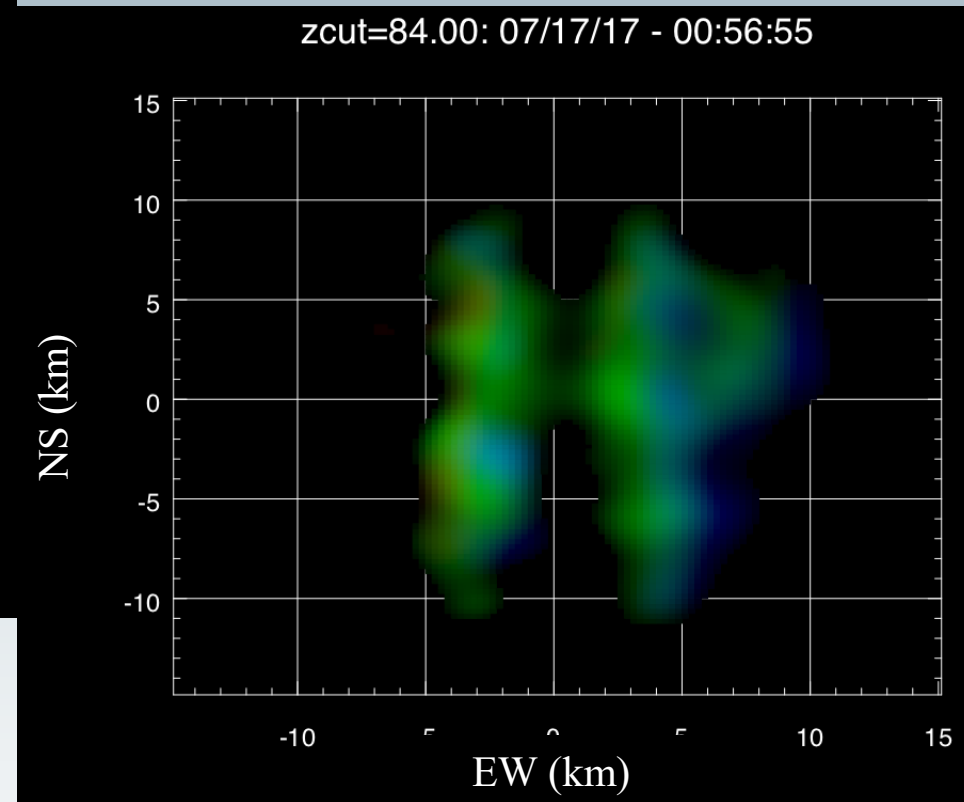
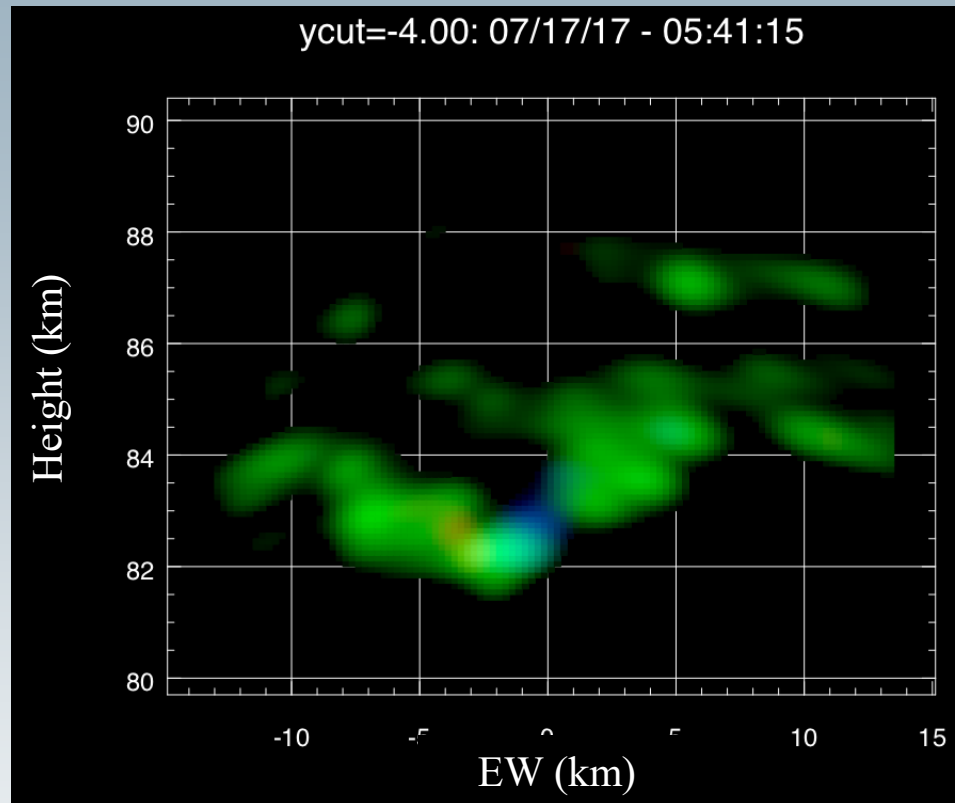


MaxEnt - SIMO

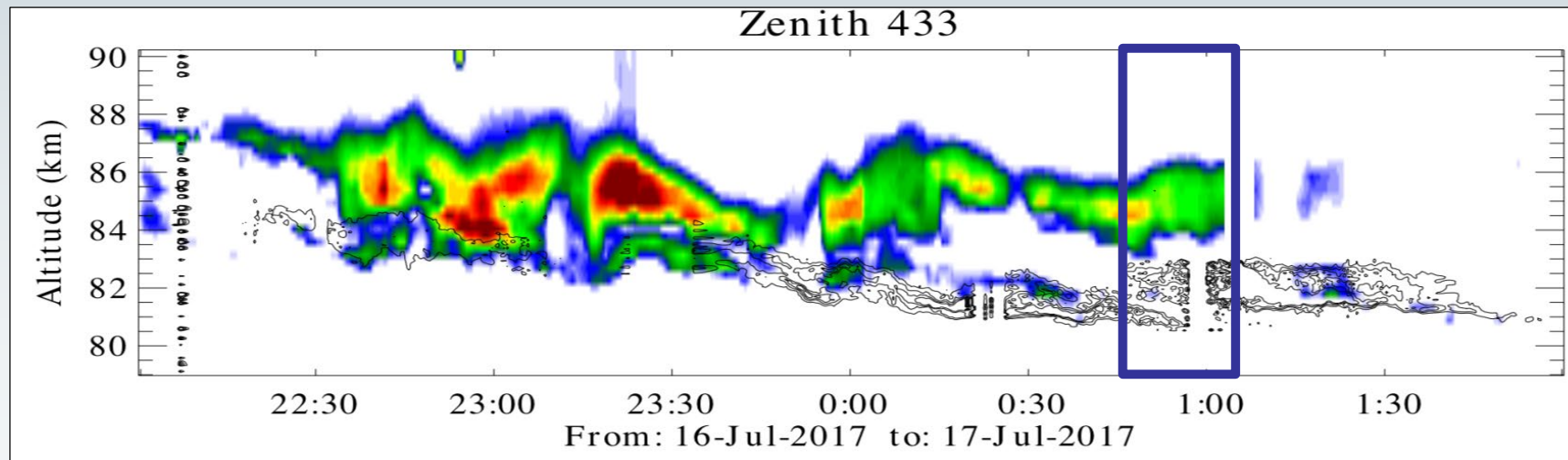
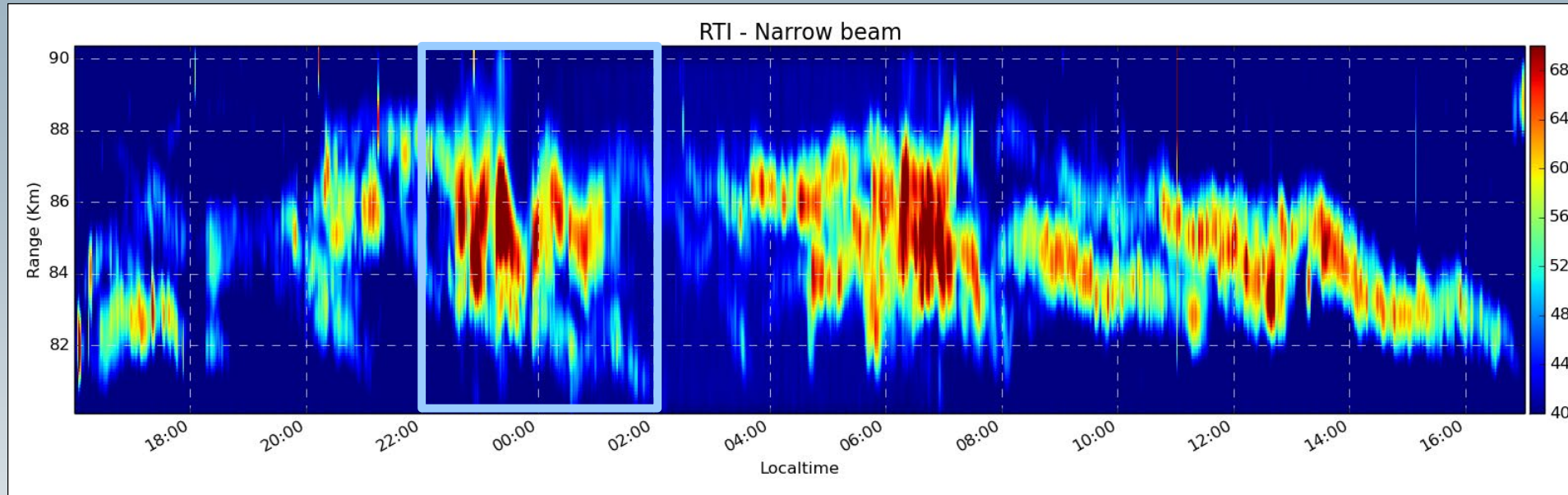


MaxEnt - MIMO

(from Urco et al., 2018)



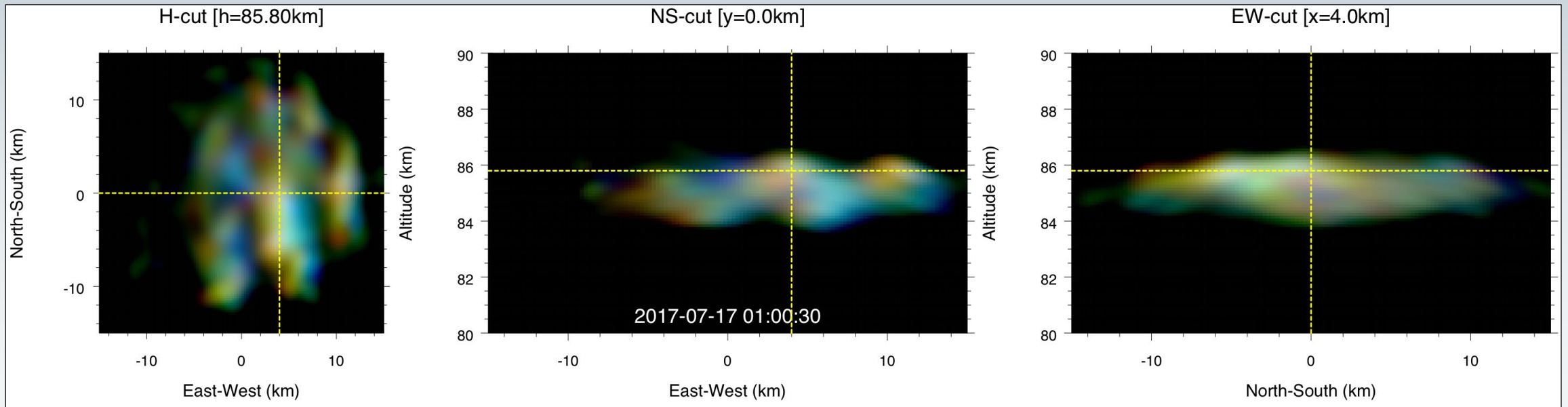
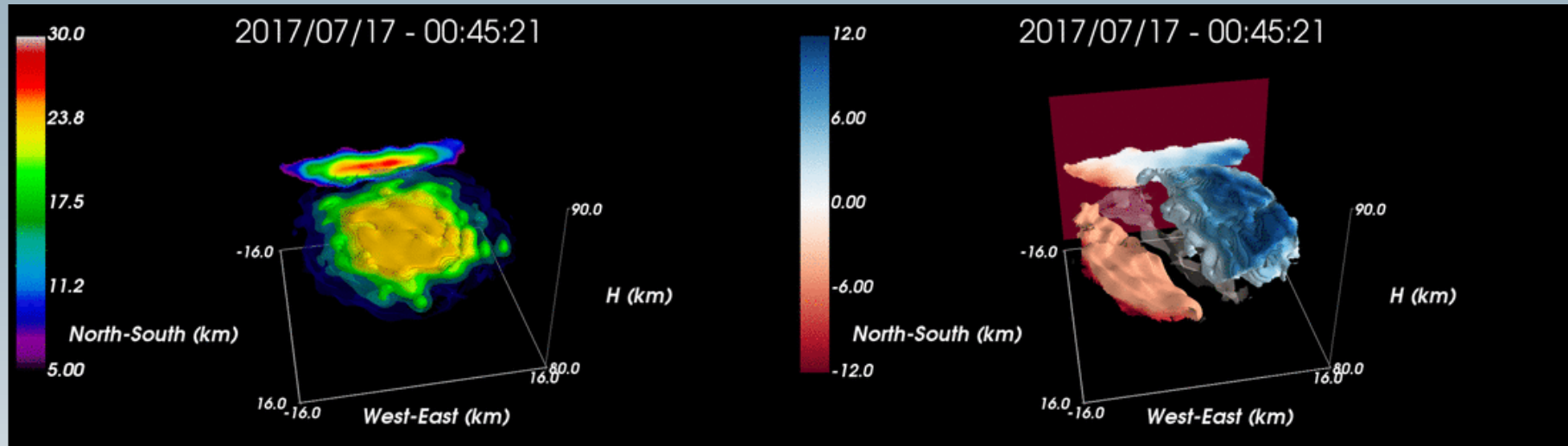
PMSE Observations: 16-17 July 2017



Considerations

- 3-m irregularities are good tracers of the background dynamics.
- Brightness changes are a combination of Schmidt number, Ne, temperature, turbulence, ...
- Magnetospheric/Io nospheric forcing do not modify the neutral dynamics, but they could modulate the echo brightness.

PMSE 4D visualization: Brightness, radial velocity, spectral width



Event 1: Ripples propagating drifting with neutral wind

Doppler velocity

- red: velocity from the radar
- blue: velocity to the radar
- green: velocity to zero.

SNR

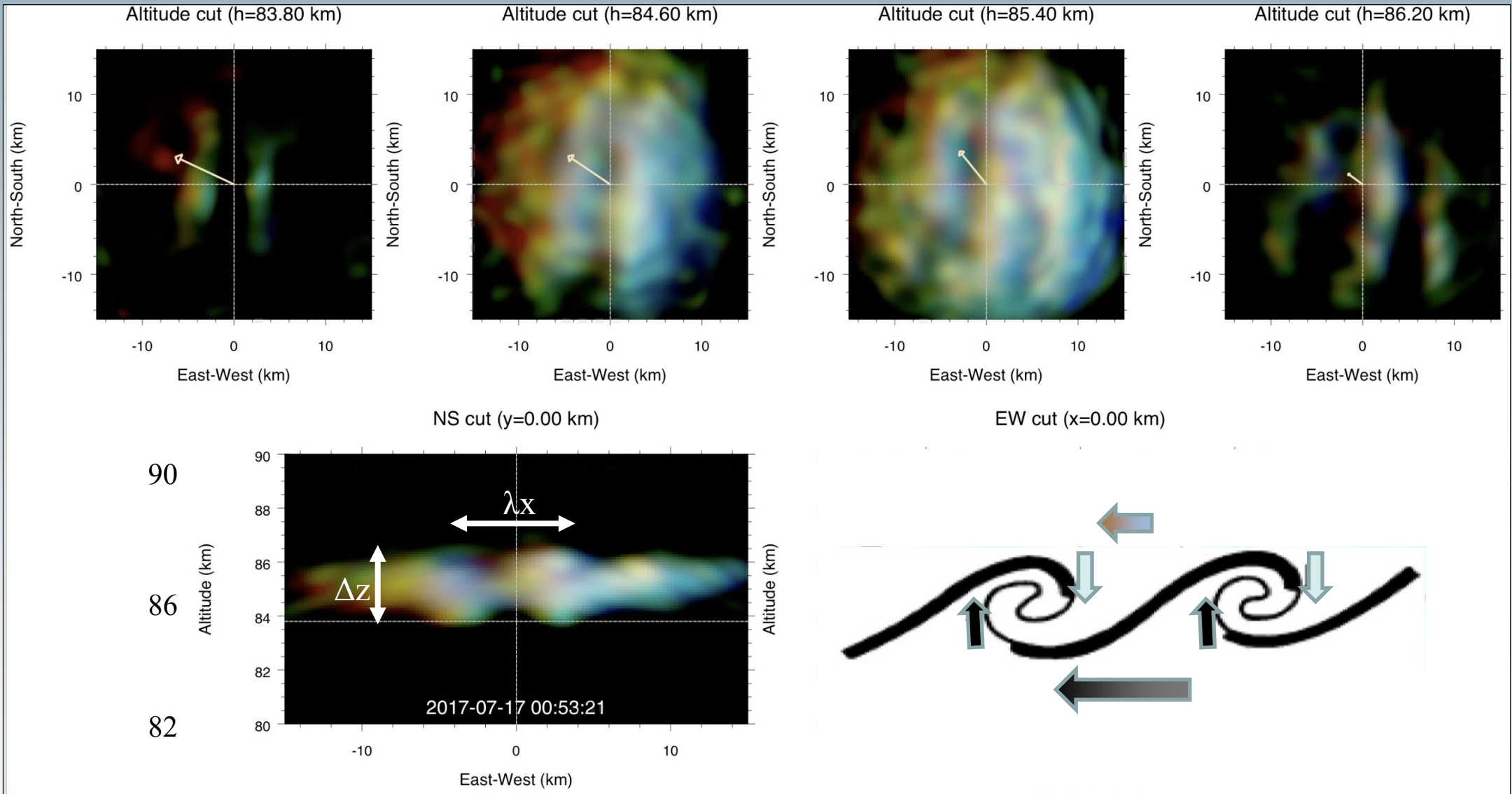
- intensity of the signal

Horizontal wind

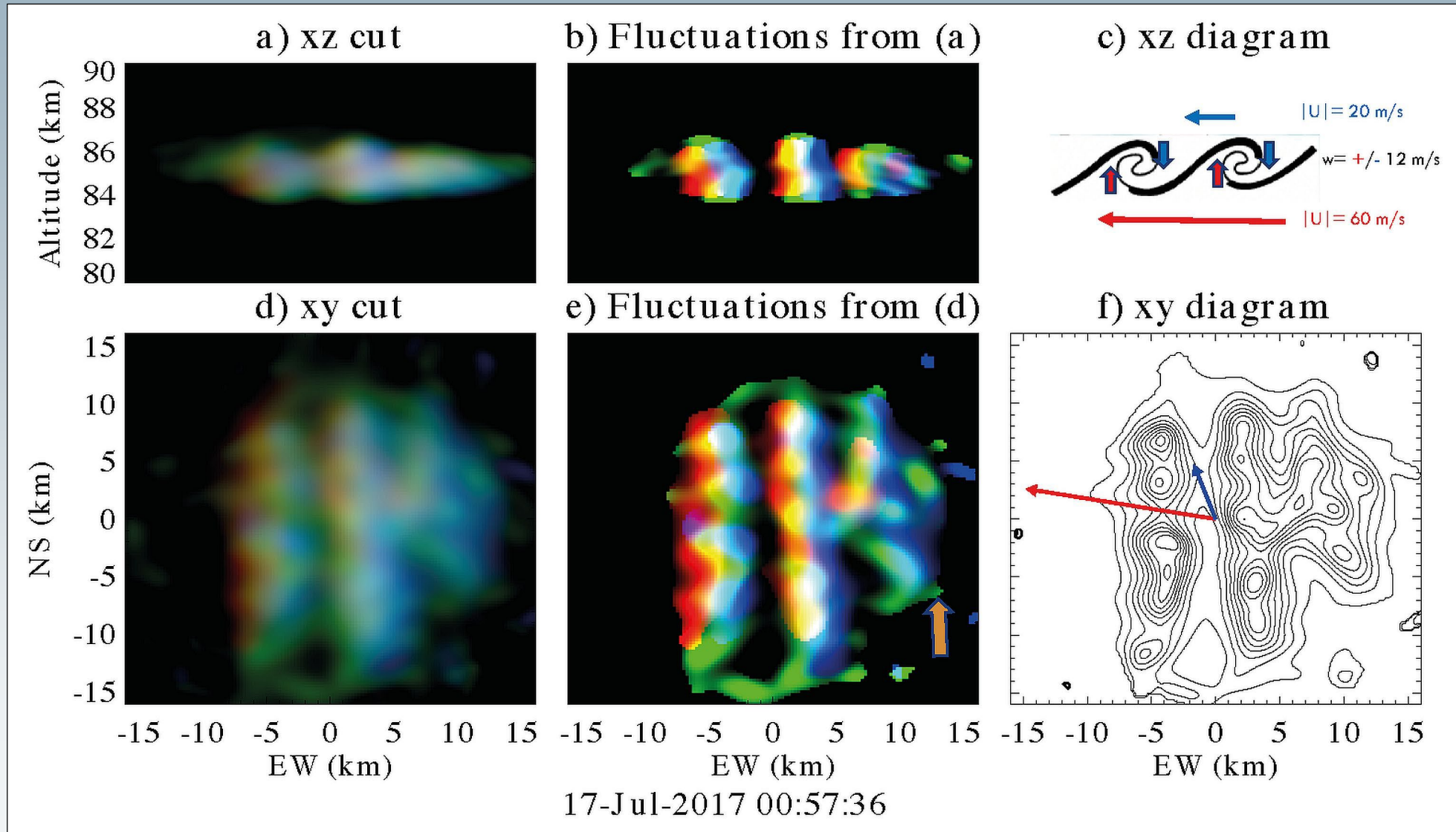
- yellow arrow: direction of the horizontal wind near-by space meteor radar



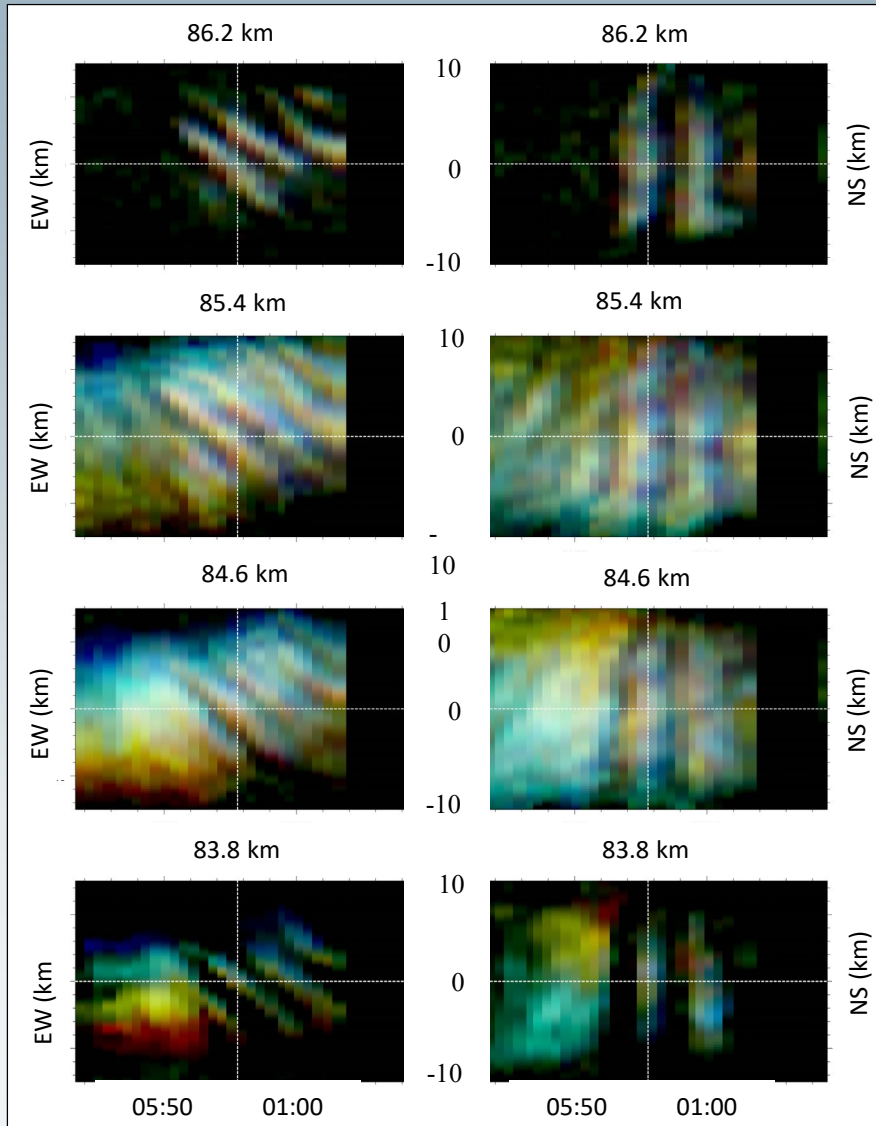
Event 1 @ 00:53:21UT



Event 1 @ 00:57:36 UT



Event 1: Summary of parameters



$\lambda_y = \text{large}$ (i.e., elongated along y)

$\Delta z = 1.8\text{-}2.1$ km

$\lambda_x = 6\text{-}8$ km

$\Delta t = 4\text{-}5$ min

$u = -28$ m/s

$v = 20$ m/s

BV period ~ 4 min

$$s = \Delta z / \lambda_x = 0.25\text{-}0.35$$

Assuming high Re

$$\text{Ri} = 0.08\text{-}0.13$$

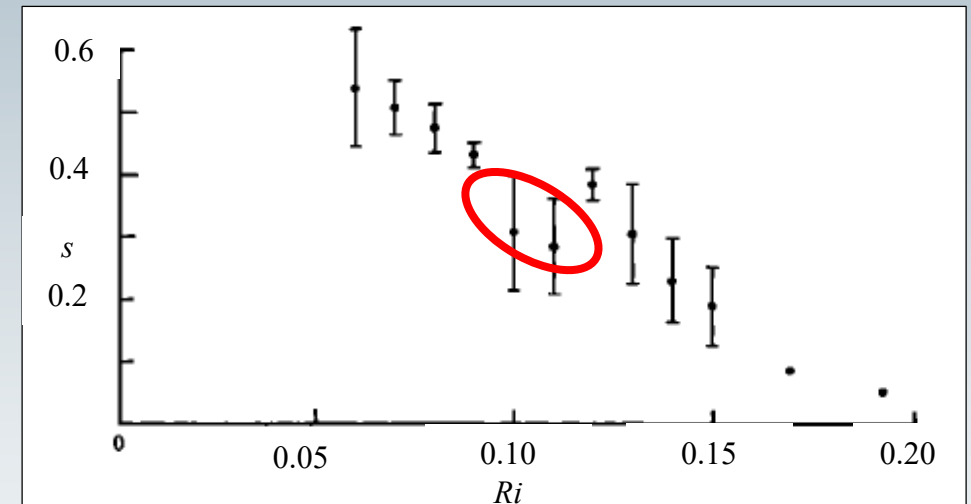
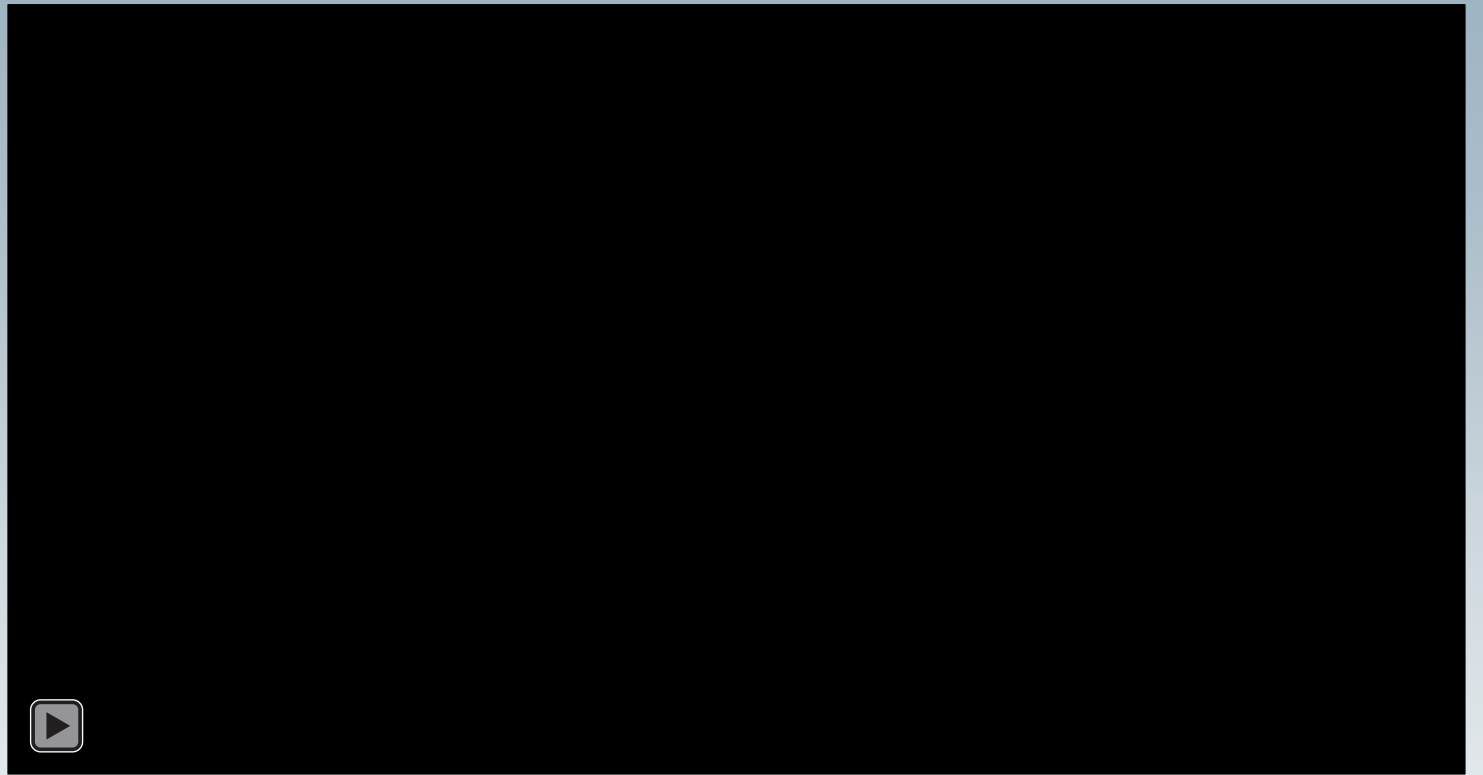
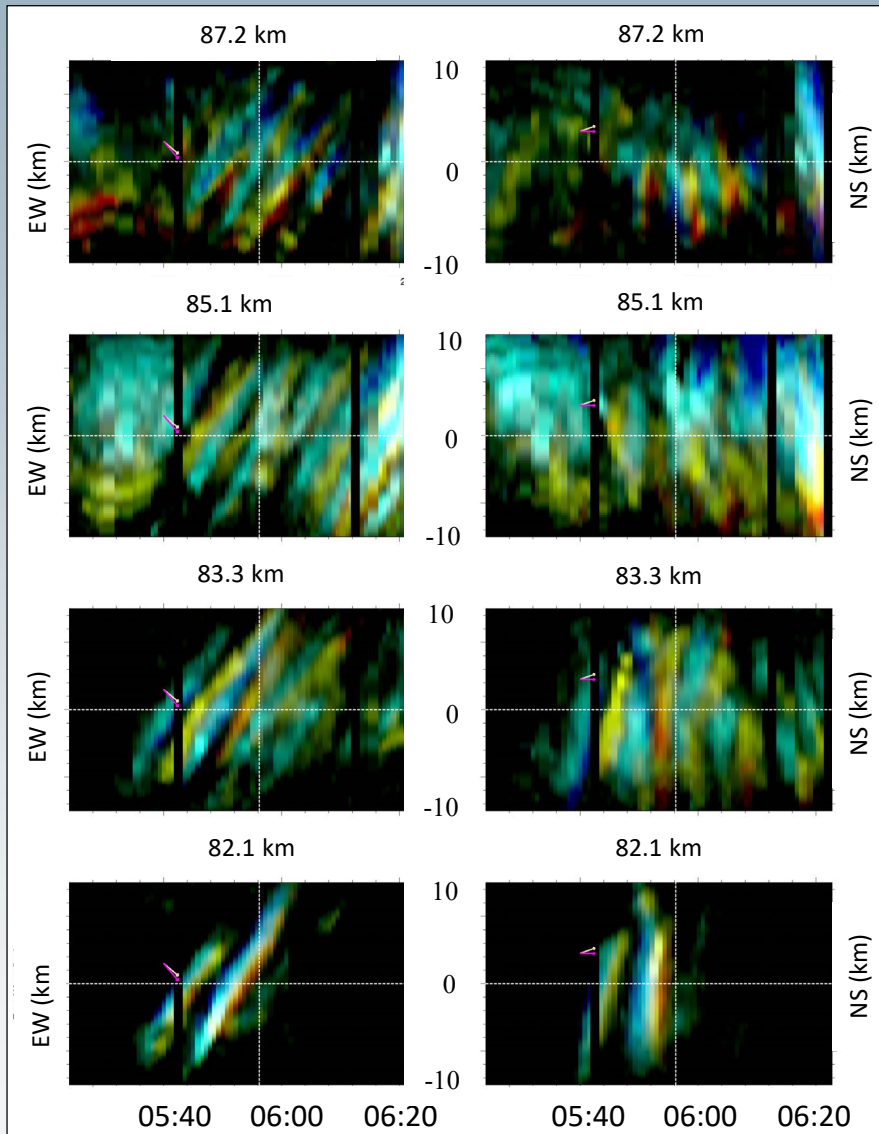


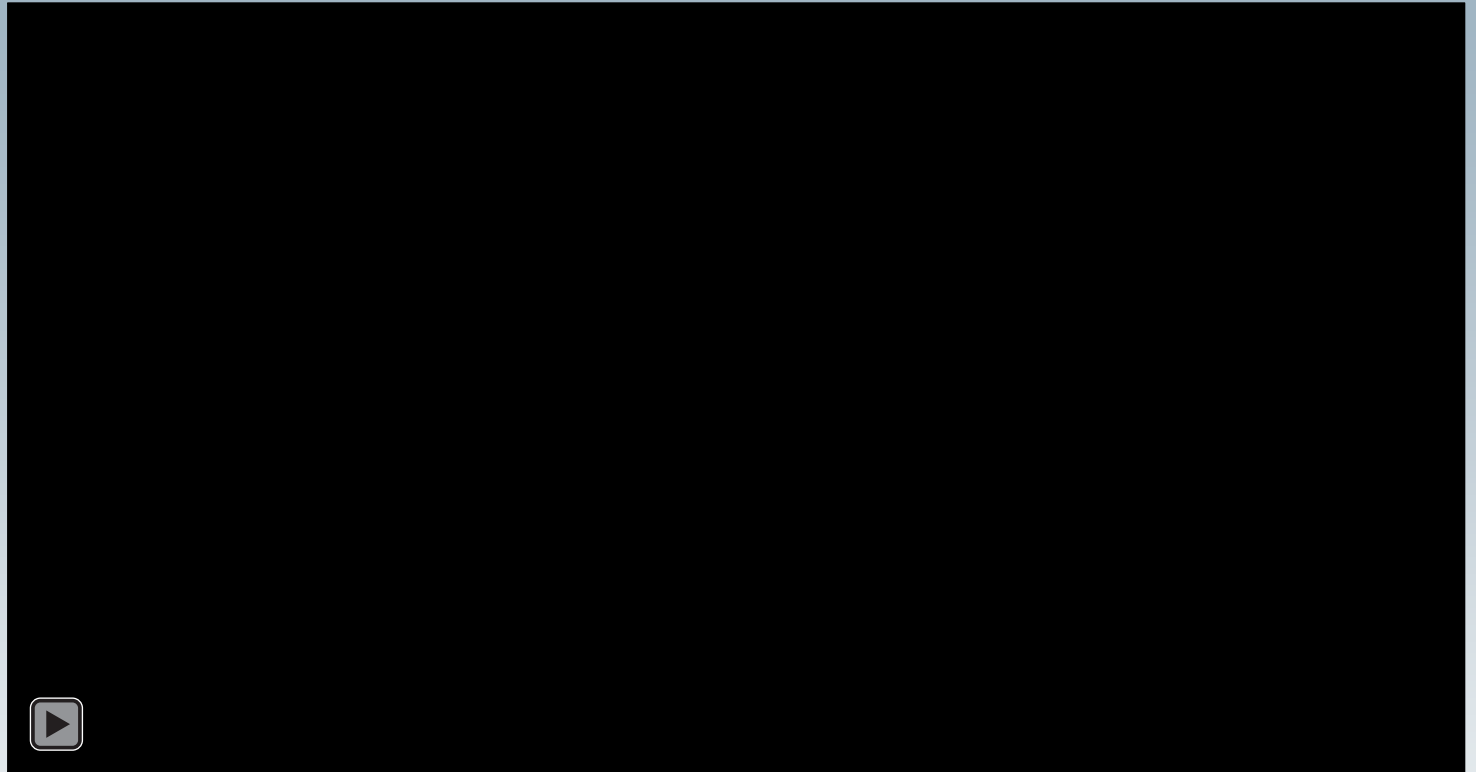
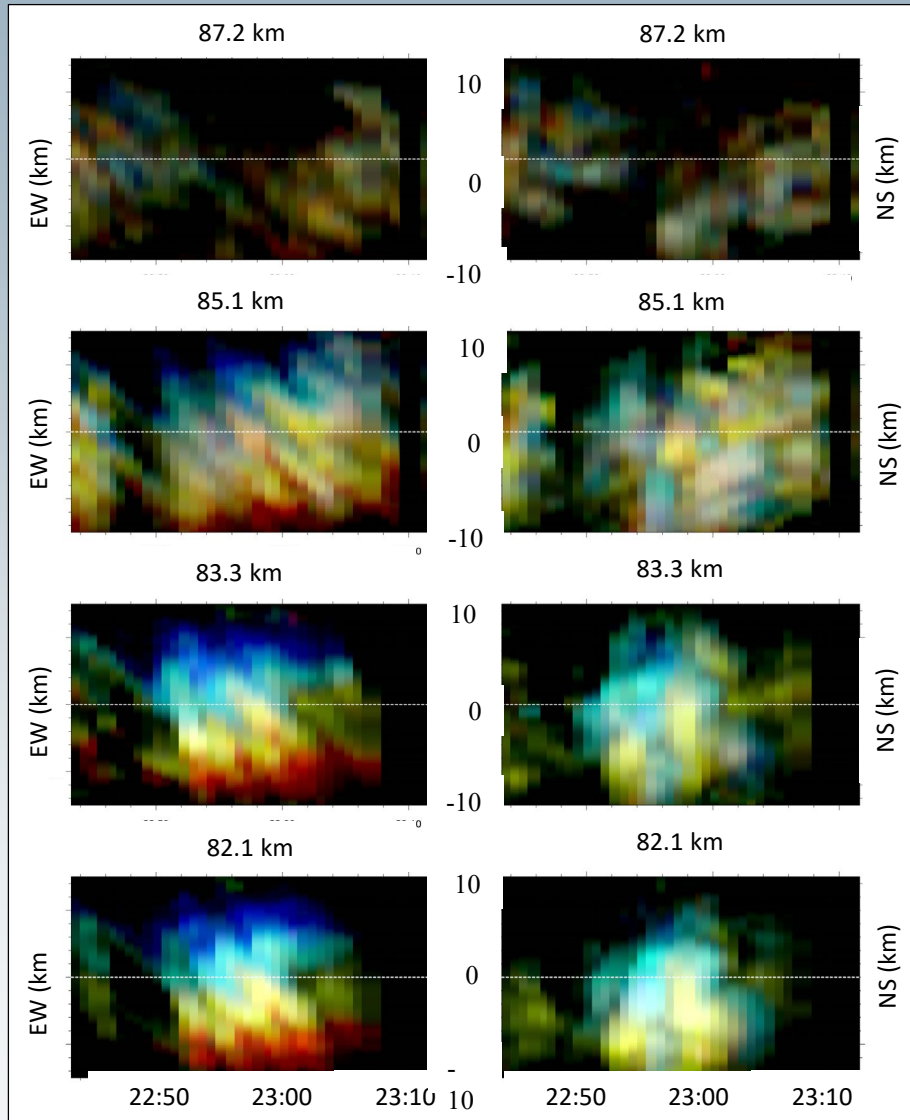
Fig. 3. Variation of s (billow height-to-wavelength ratio) with initial Richardson number [after Thorpe, 1973a]. Reynolds numbers were $Re \sim 10^3\text{-}10^4$. (Reprinted with permission of Cambridge University Press.)

(from Fritts and Rastogi, 1985)

Event 2: Propagating waves against the wind?

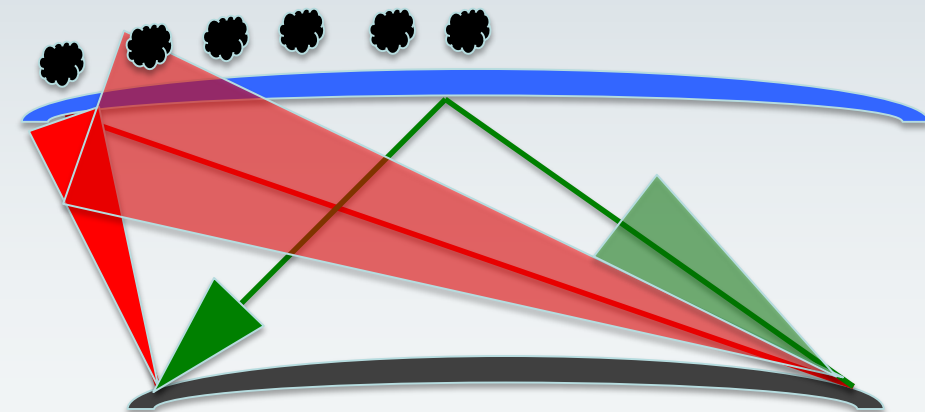
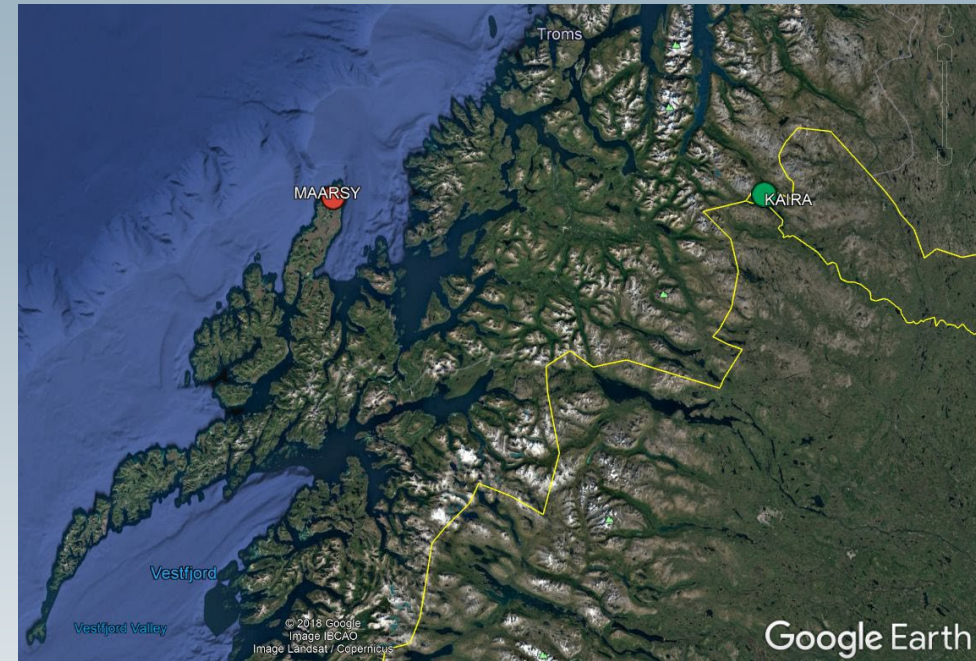
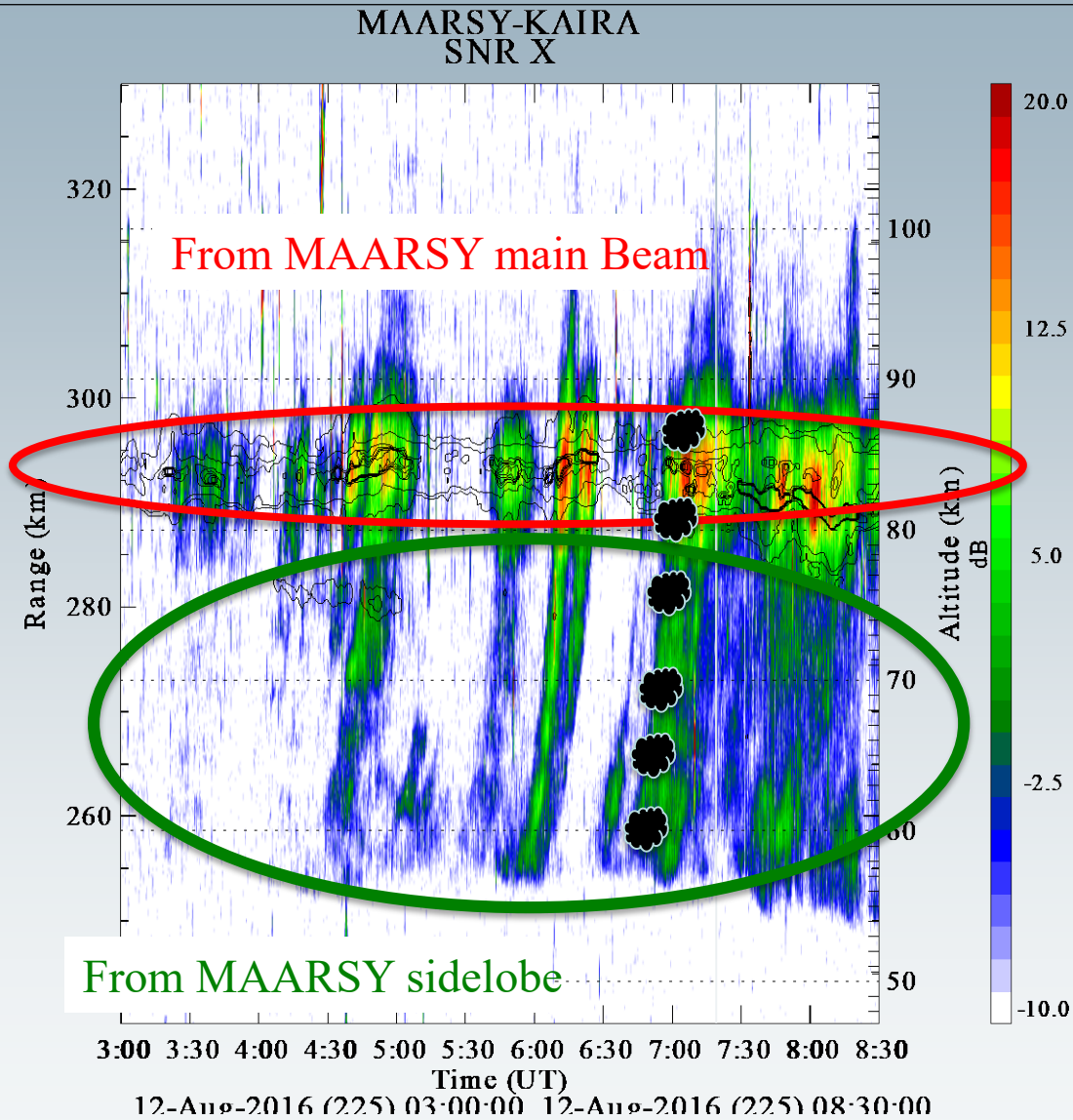


Event 3: ????



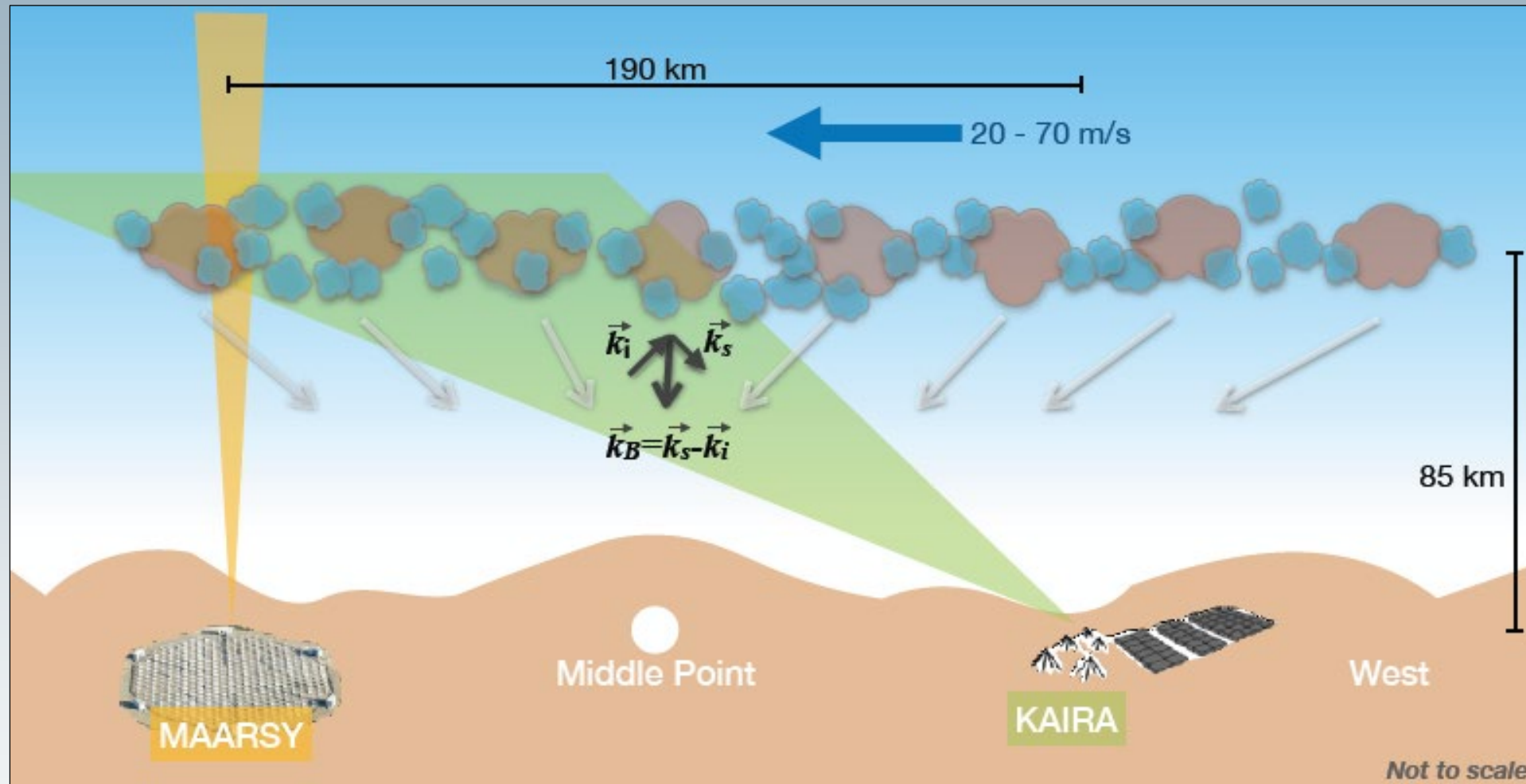
MAARSY-KAIRA Narrow Beam

(from Chau, McKay et al., 2018)



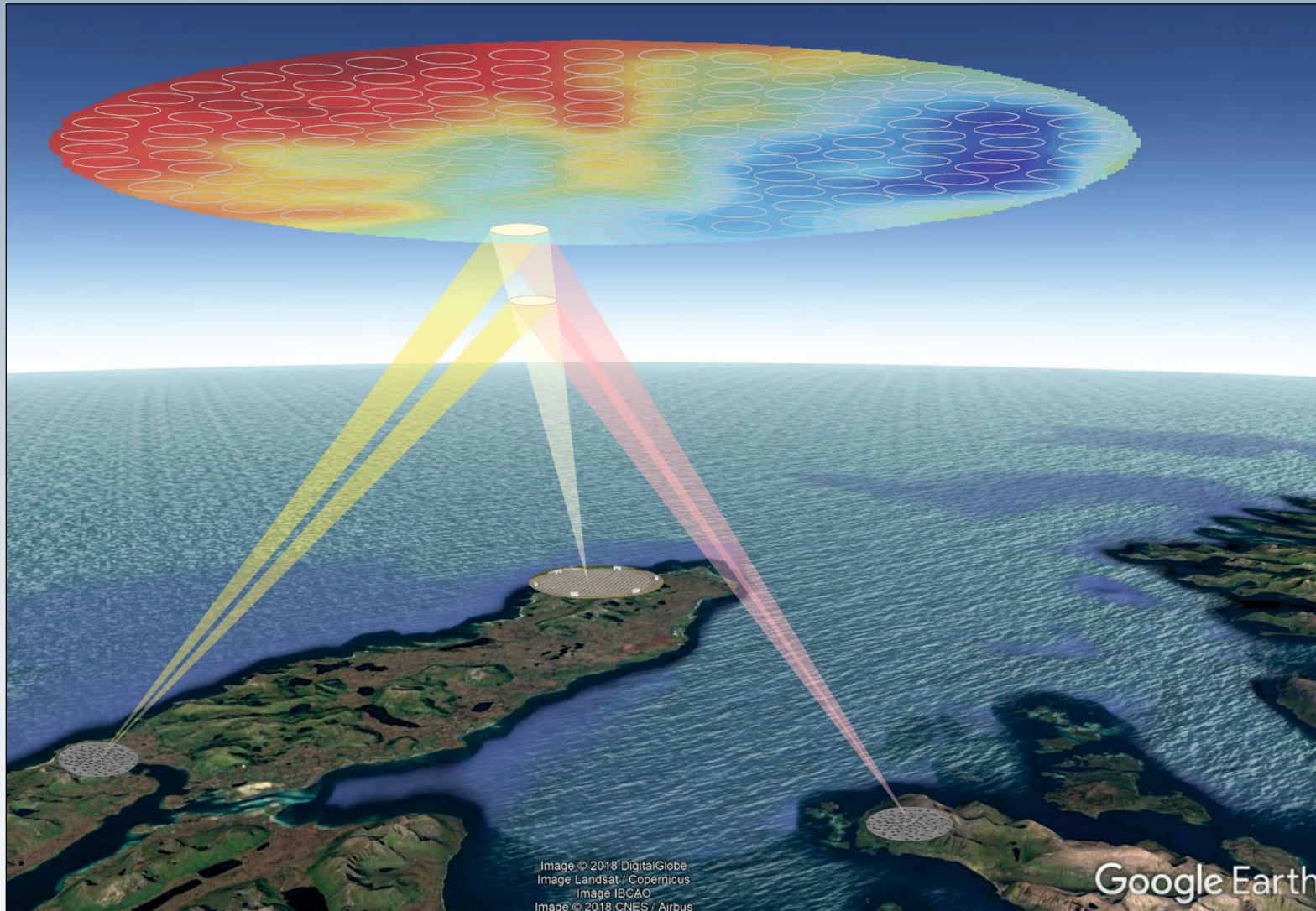
KAIRA-MAARSY PMSE observations

(from Chau, McKay et al., 2018)

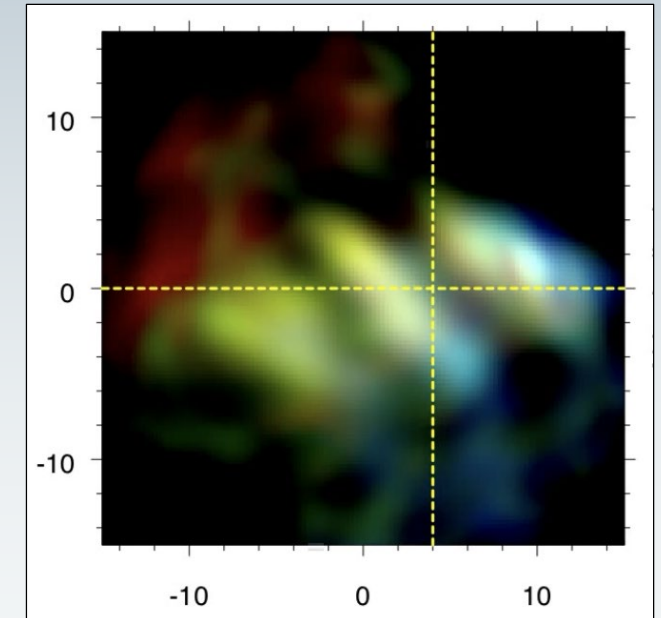


(courtesy K. Chau)

MAARSY 3D Sketch and Plans



- MAARSY Radar Imaging
 - ± 20 km
 - Scales less than 1 km
- MAARSY 3D
 - ± 60 km
 - Scales greater than 5 km
- EISCAT 3D



Summary

- Radar imaging (+MIMO) observations of PMSE allow exploring the polar mesospheric summer region with high spatio-temporal resolutions of: Brightness, Doppler, spectral width, whenever PMSE is strong enough!
- 4D measurements of PMSE, including altitude, are possible quasi continuously, independent of ground weather conditions.
- A text-book KHI event has been fully characterized. Other wave events, not limited to monochromatic waves, are waiting to be explored.

Thank you

