A Neural Network based algorithm for Multiple Scattering Onset identification in the INCUS reflectivity profiles

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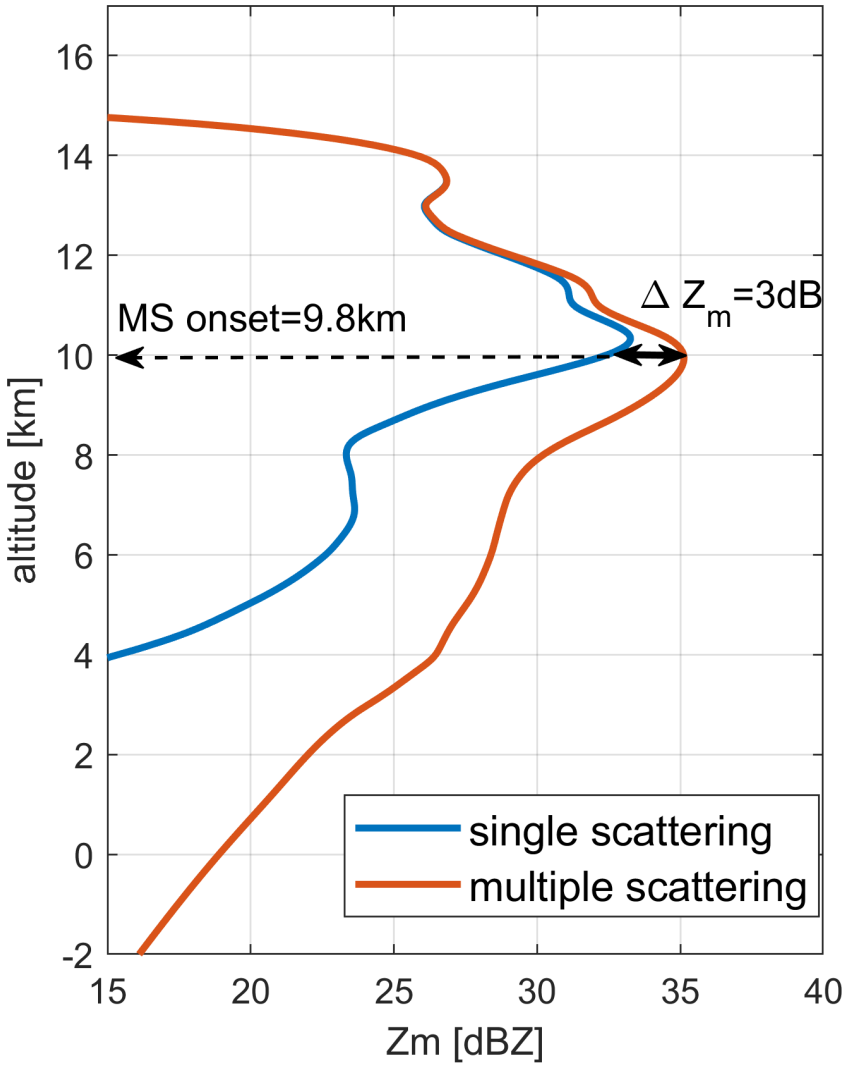
What is Multiple Scattering (MS)



Although MS is a well known and extensive studied phenomenon in the lidar community, it is considered to be a rare event in the radar field. The radar equation is based on the single scattering assumption. However, reflected received power can also come from radiation which has been scattered several times within the medium before returning back to the receiver. This typically occurs:

- at **high frequencies** (Ka, W-band) due to higher optical depth,
- at **larger footprints,**
- in presence of a large number of dense **ice particles**, e.g. in **deep convection**, due to their large $\mathbf{k_{ext}}$ and **single scattering albedo**

MS generates an **enhancement in reflectivity** at apparent ranges, that hides information originated from those contaminated range bins.
To determine which part of a Z-profile is contaminated by MS effects and therefore not usable for retrievals, knowledge of MS onset is required.

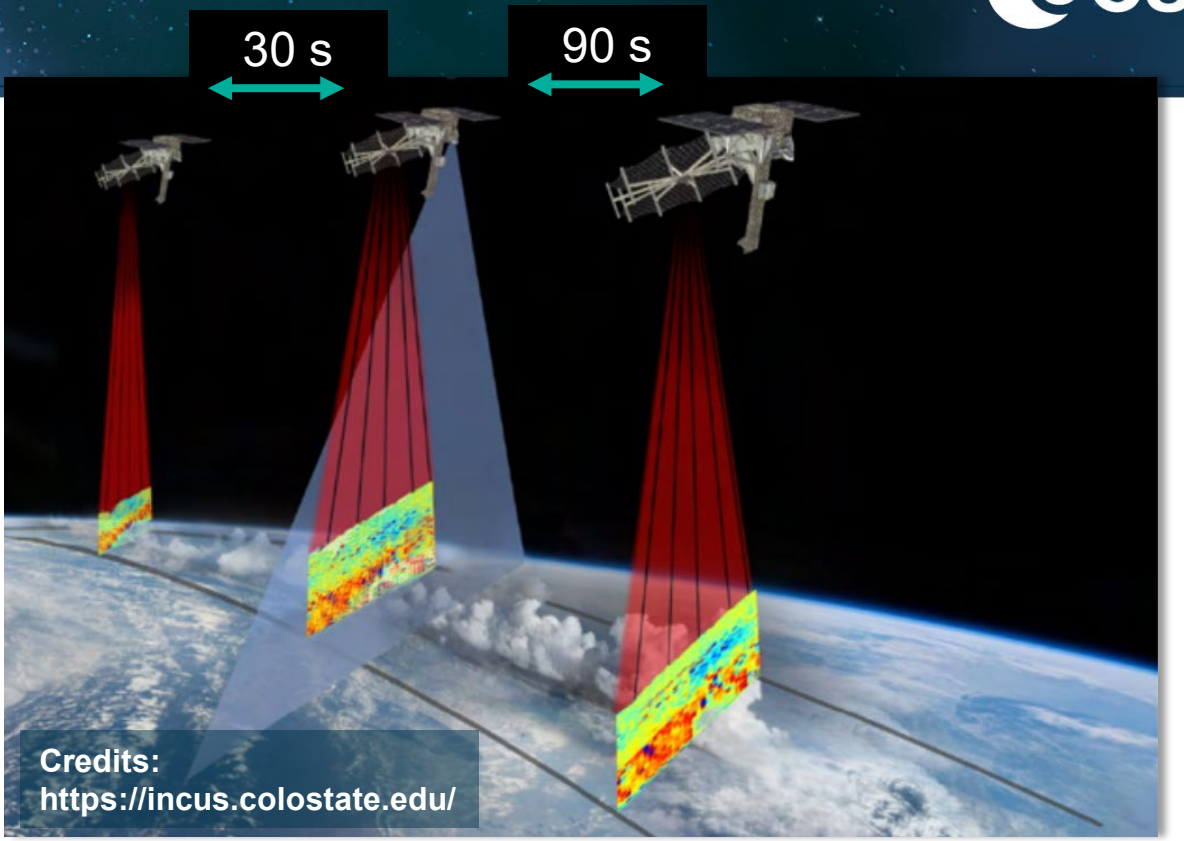
In this study, we used a 1D approximation (*Hogan and Battaglia, 2007*) to forward model multiple scattering.

NASA INCUS mission

General specs	
# of satellites	3
Altitude	~ 530 km
Inclination	~ 28°
Δt	0, 30, 120 s

Radar specs	
Radar frequency	35.75 GHz
Swath width	~ 9 km (pushbroom-like scanning)
Vertical resolution	~ 240 m
Horizontal resolution	~ 3.1 km (θ_{3dB} = 0.35°)
Sensitivity	~ 12 dBZ

Radiometer specs	
Channels	87, 165, 174, 178, 181 ± 0.5 GHz
Swath width	~ 1000 km (cross-track scanning
Horizontal resolution	~ 16 km



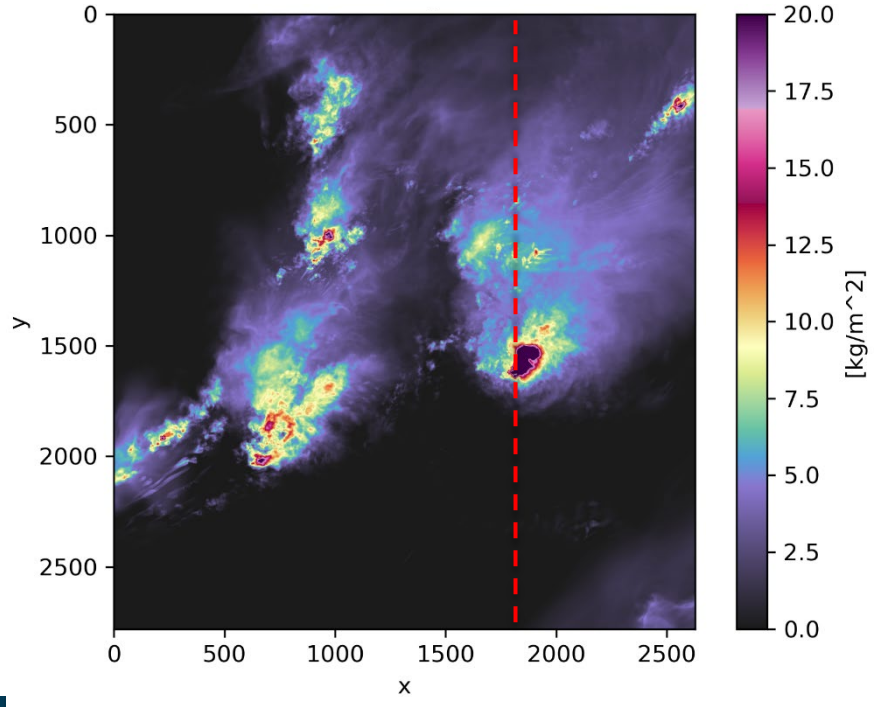
Principal Investigator: Susan van den Heever, Colorado State University
Project Manager: Yunkin Kim, NASA Jet Propulsion Laboratory
Project Scientist: Simone Tanelli, NASA Jet Propulsion Laboratory

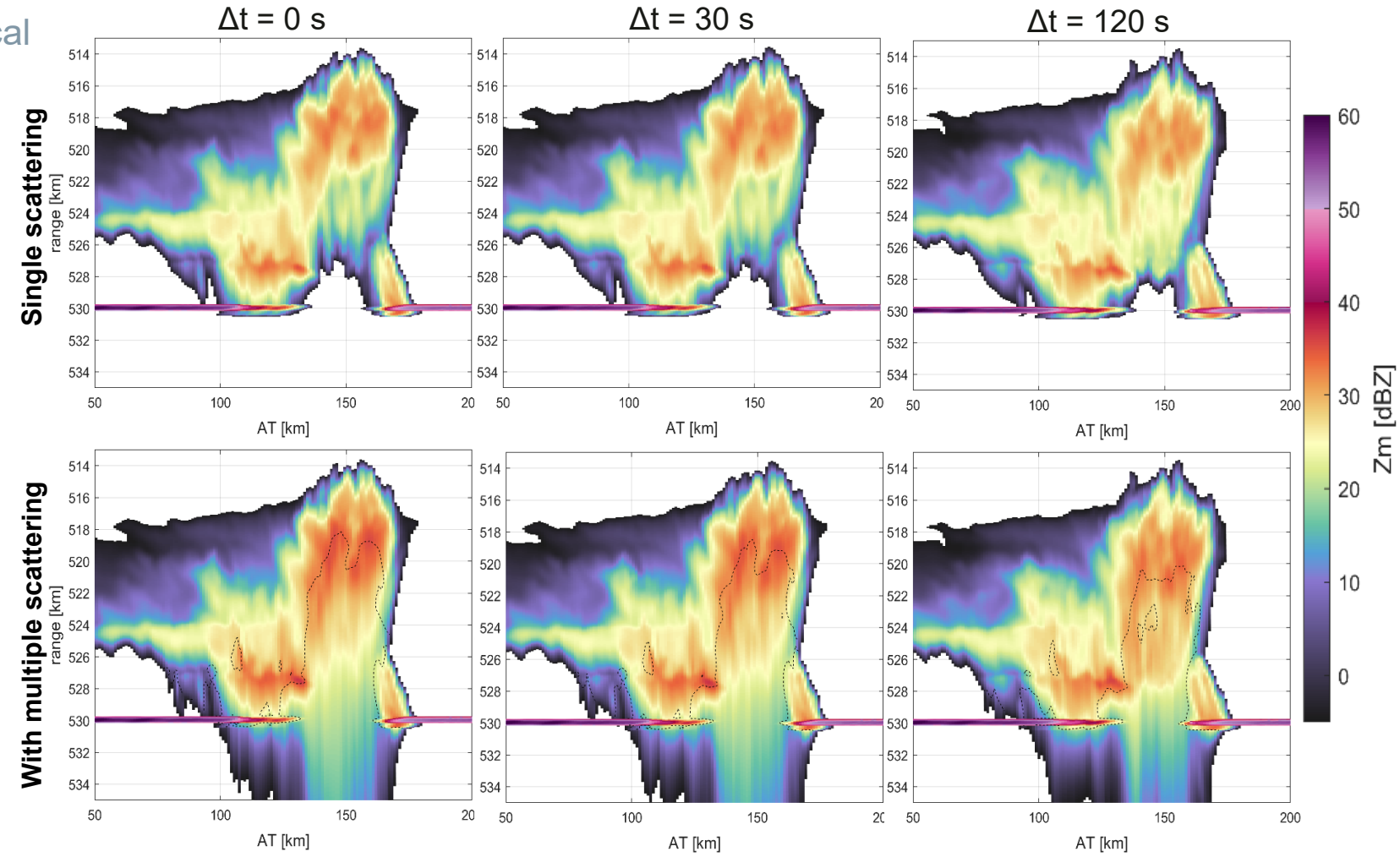
Flagship product:
profile of vertical mass flux of air and condensed-water estimated for every detected updraft [kg m^{-2} s^{-1}]

Dataset (1)

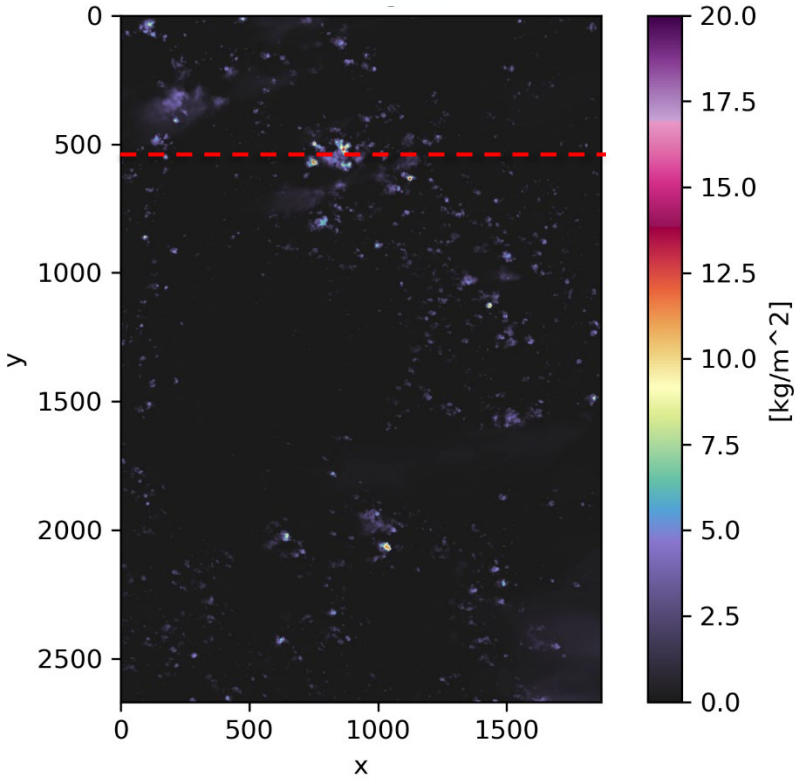
Regional Atmospheric Modeling System (**RAMS**, *Cotton et al., 2003; Saleeby and van den Heever, 2013*) outputs of tropical and subtropical convective systems at 100m grid spacing resolution (provided by CSU):

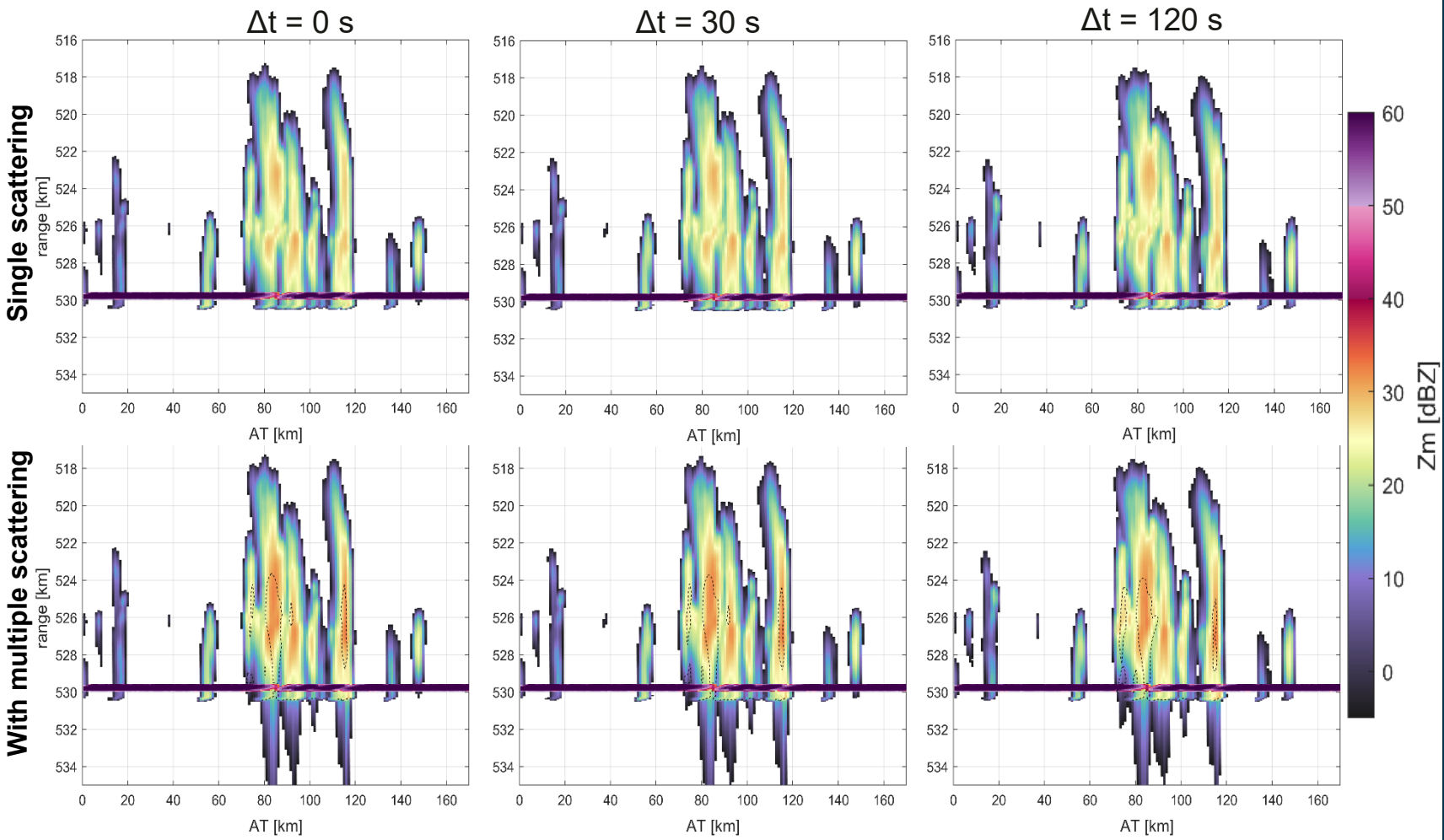
- Deep, shallow, organized, isolated, congestus, scattered, squall line, ...





Dataset (2)

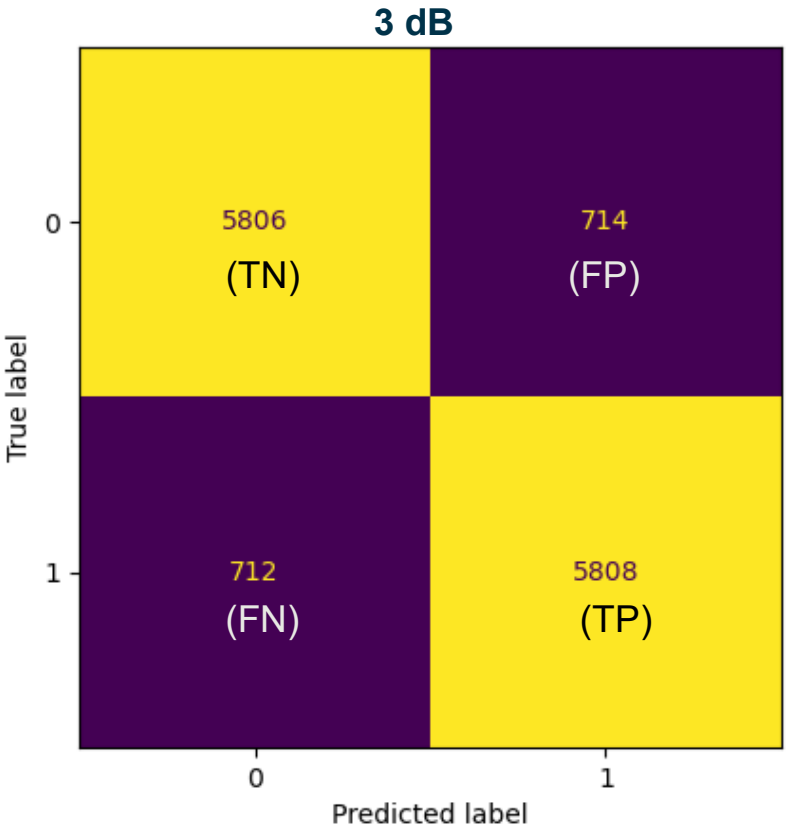

0
500
1000
1500
2000
2500
y
0
500
1000
1500
x
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
[kg/m^2]


Δt = 0 s
Δt = 30 s
Δt = 120 s
Single scattering
With multiple scattering
range [km]
AT [km]
Zm [dBZ]
60
50
40
30
20
10
0

Preliminary results: is a given Z-profile contaminated by MS?

Determining if a Z-profile is contaminated by MS or not: binary classification with CNN.

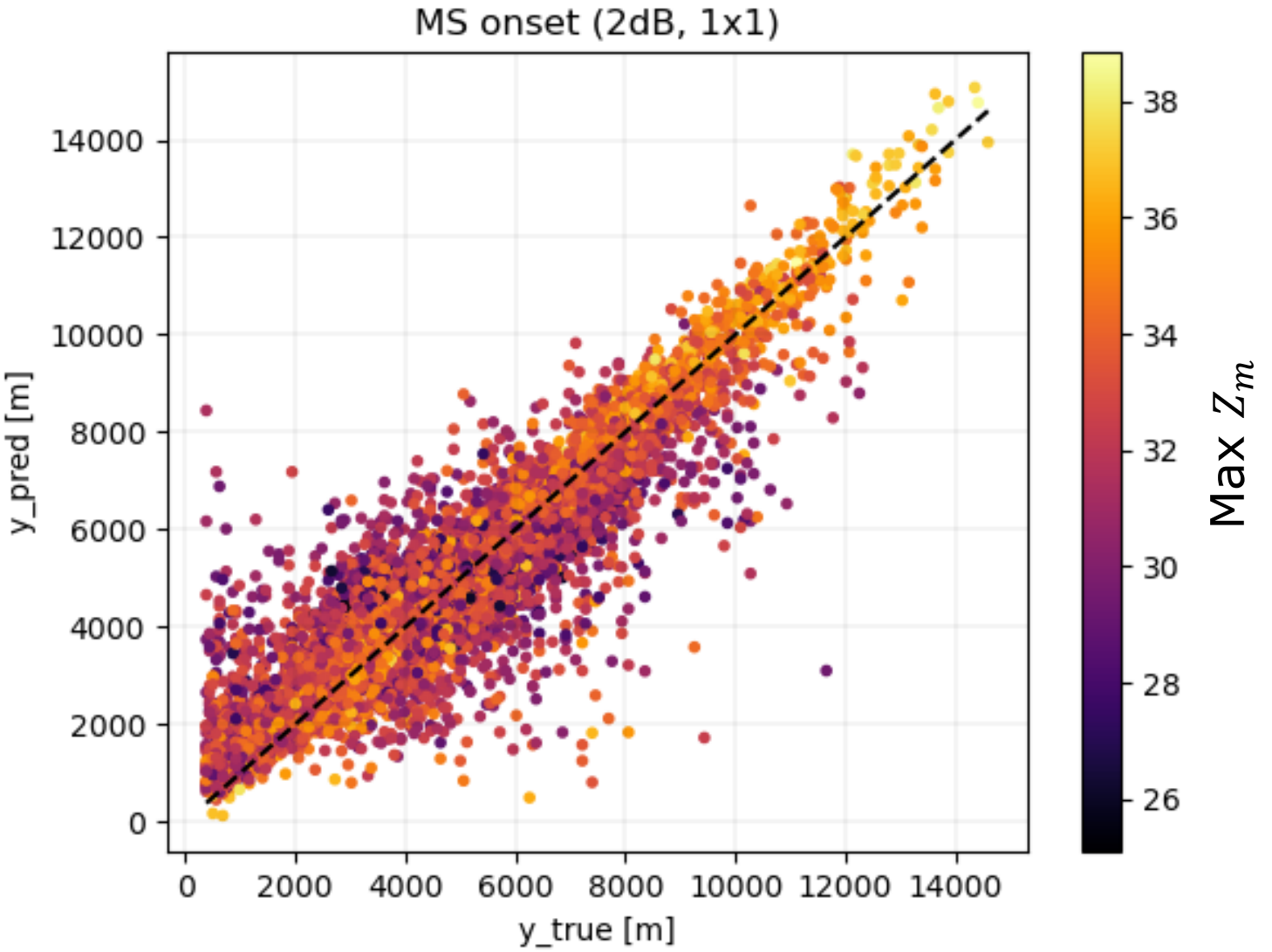
MS enhancement criterion [dB]	Accuracy $\frac{TP+TN}{TP+TN+FP+FN}$	False Positive Rate $\frac{FP}{TN+FP}$	False Negative Rate $\frac{FN}{FN+TP}$
0.5	0.87	0.12	0.16
1	0.88	0.10	0.14
2	0.89	0.13	0.11
3	0.89	0.11	0.11
5	0.91	0.10	0.08



Preliminary results: onset estimation

Given a Z-profile, which is contaminated by MS, determining the MS onset: regression with CNN.

MS enhancement criterion [dB]	RMSE [m]
0.5	1047
1	1042
2	1020
3	989
5	902



Conclusions and summary

Summary:

- The goal of INCUS is to observe the evolution of convective updrafts, which typically produce multiple scattering;
- The onset can be estimated with a RMSE of ~4 range gates;
- Larger errors produced by the model are for MS onsets below the freezing level.

Future developments:

- Improvement of forward modeling of multiple scattering, moving from 1D approximation to full 3D geometry: development of an importance sampling based MonteCarlo algorithm;
- Refine the NN model and include additional simulations in the datasets;
- Extend the algorithm to derive other MS metrics (e.g. MS enhancement at the surface, location of maximum MS enhancement);
- The methodology is applicable to many radar configurations (EarthCare CPR, GPM DPR, E11 WIVERN radar).