Synergizing AI and Physical Models for TanDEM-X InSAR Forest Height Estimation: A Hybrid Approach over the Gabon

Islam Mansour, Ronny Hänsch,
Irena Hajnsek and Kostas Papathanassiou

TerraSAR-X/TanDEM-X Science Team Meeting 2023

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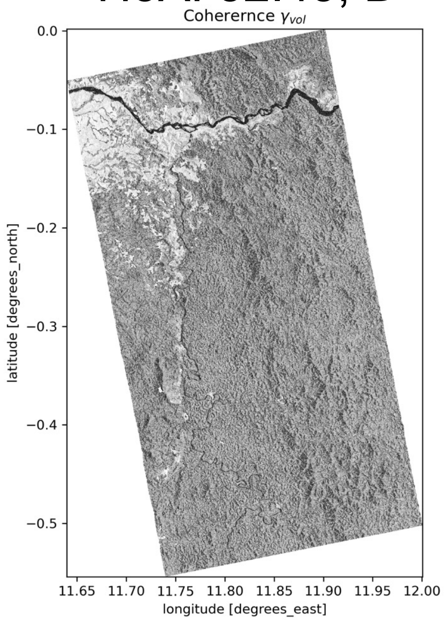
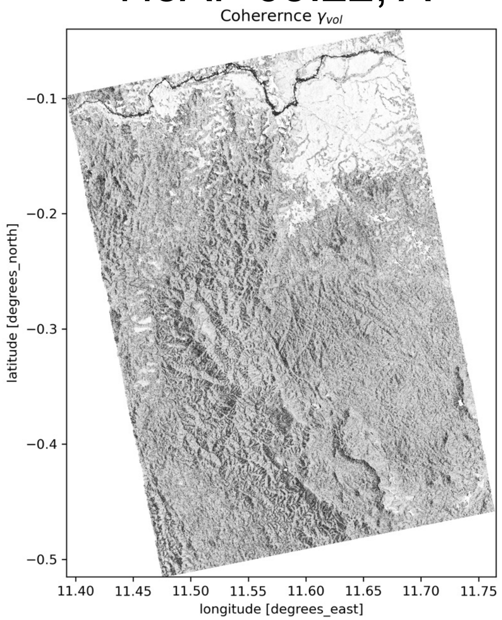
DLR

HoA: 52.45, D



HoA: -65.22, A



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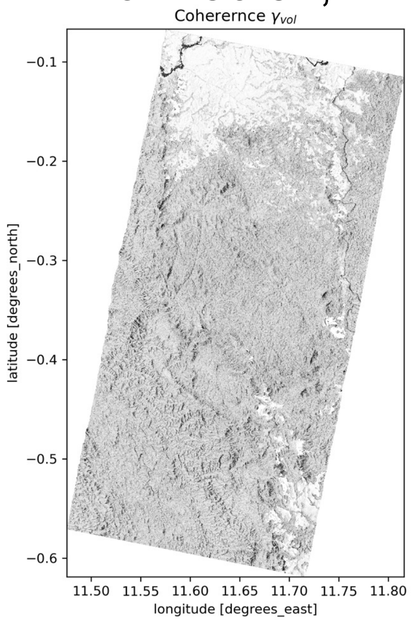
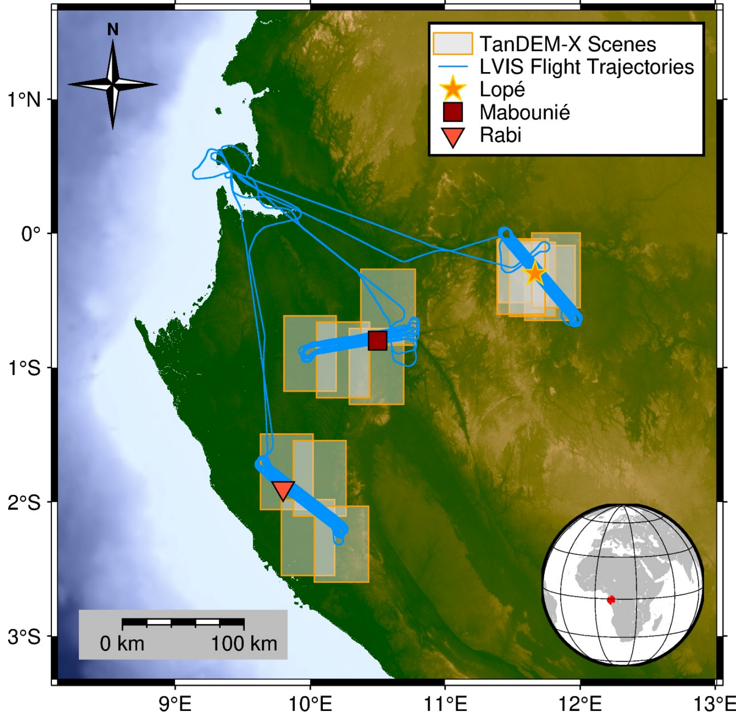
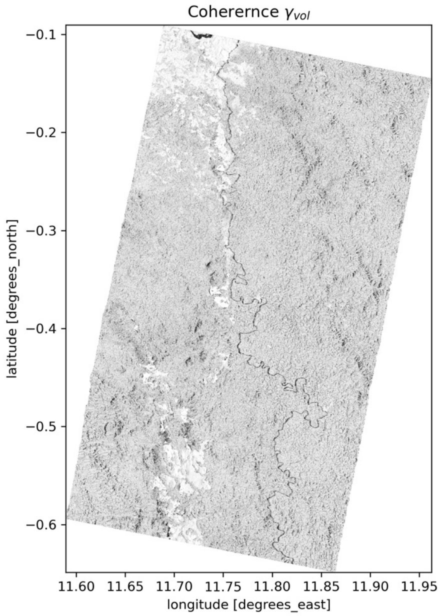
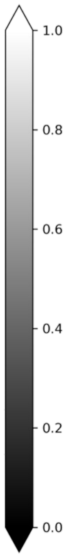


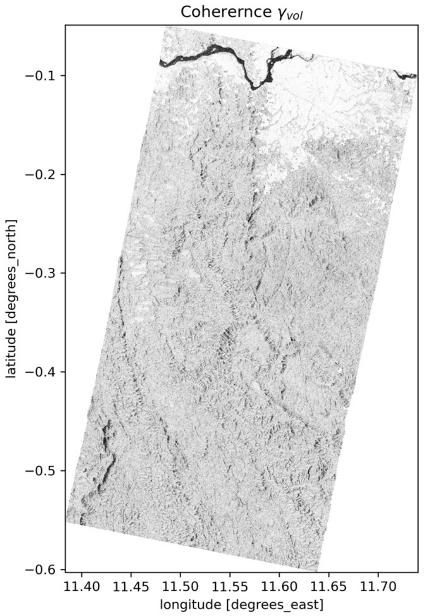


HoA: 94.89, D





HoA: 95.41, D



The interferometric coherence model:

$$\gamma_{vol} = \left| \frac{\int_0^{h_v} f(z) e^{i\kappa_z z} dz}{\int_0^{h_v} f(z) dz} \right|$$

$f(z)$ … vertical reflectivity function

κ_z … vertical wavenumber

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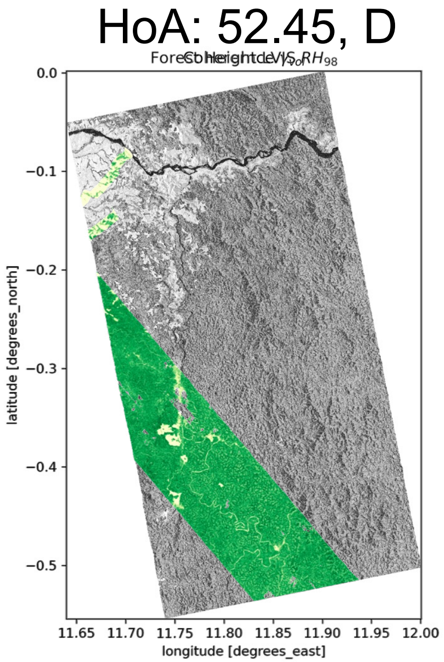

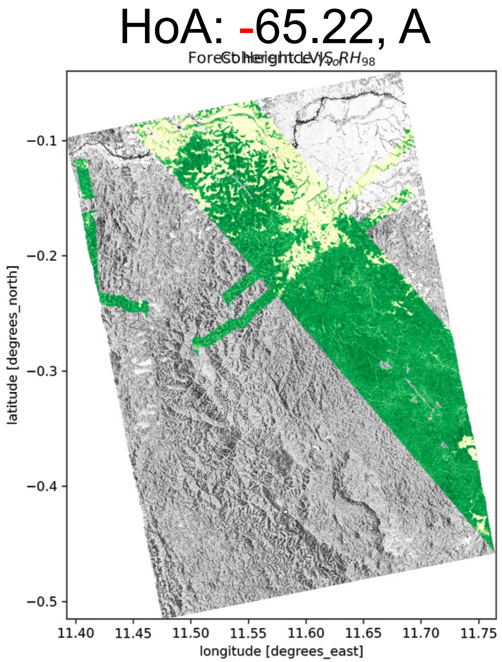

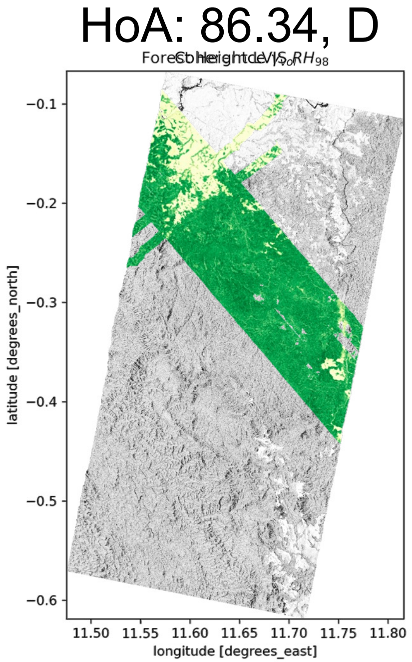

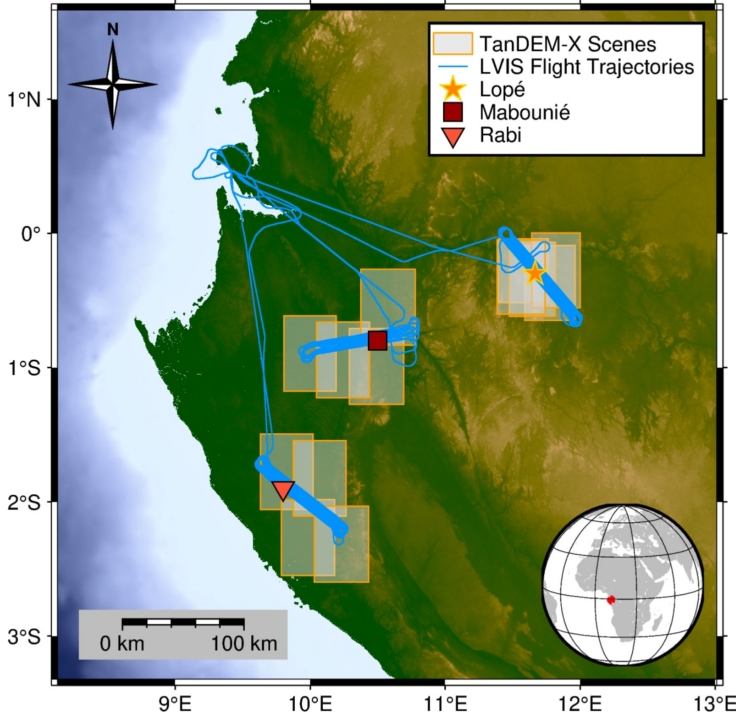

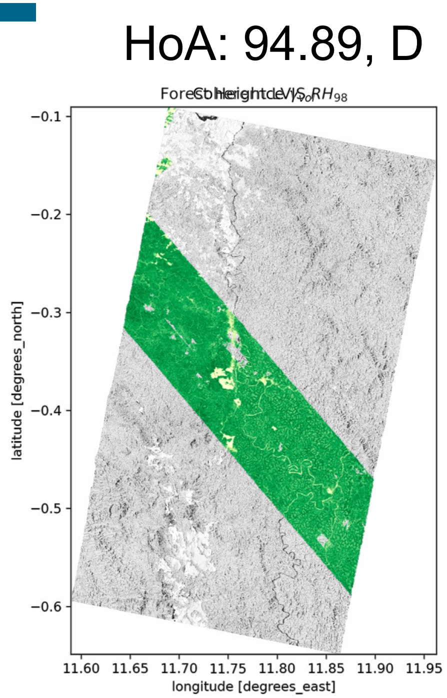

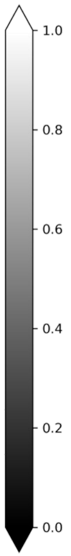

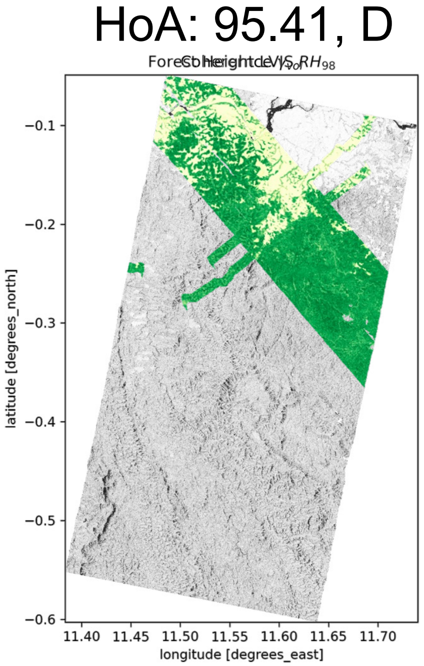

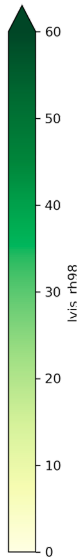

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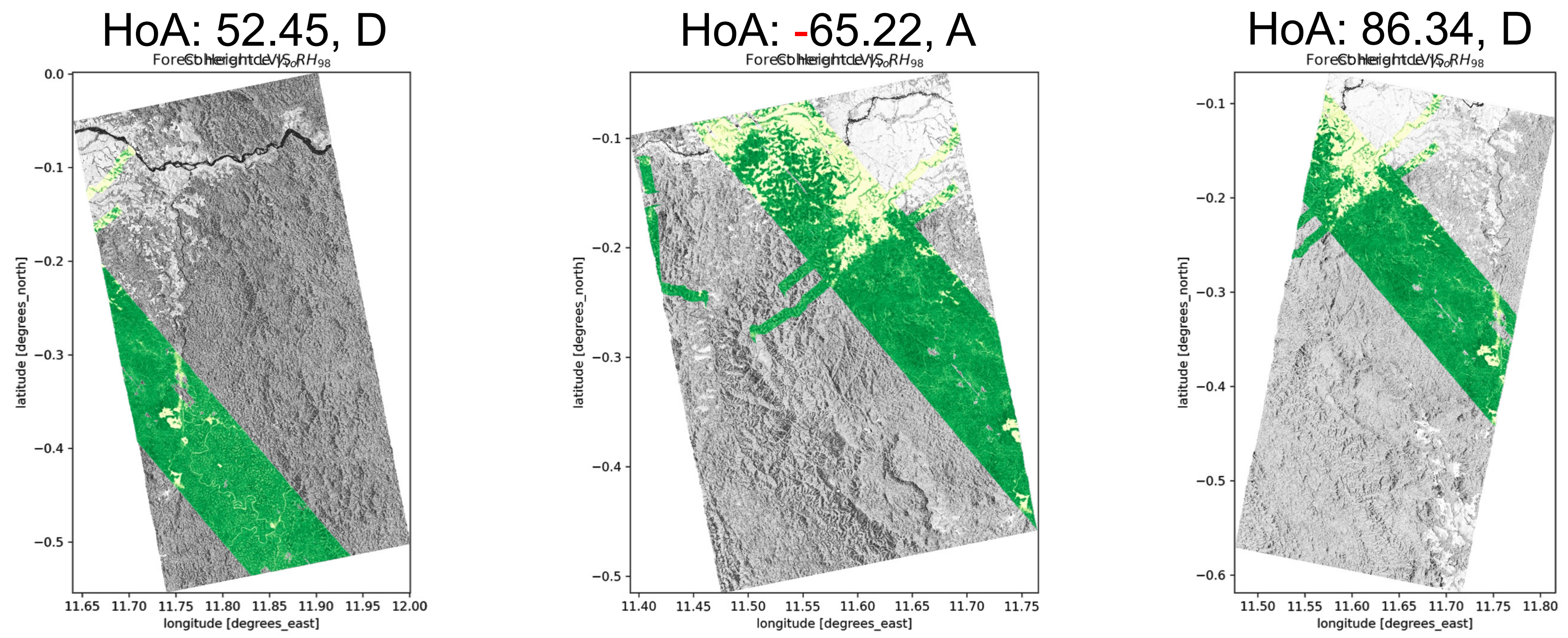

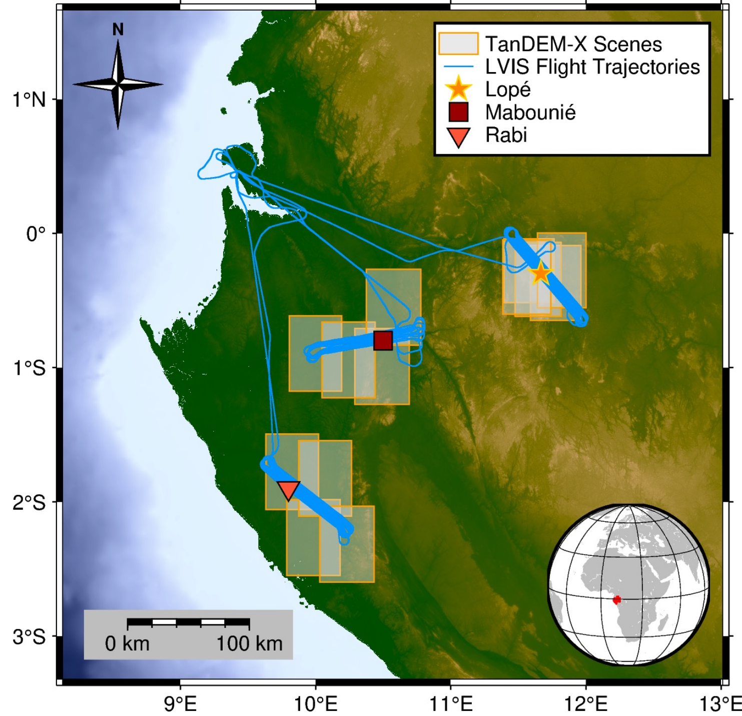

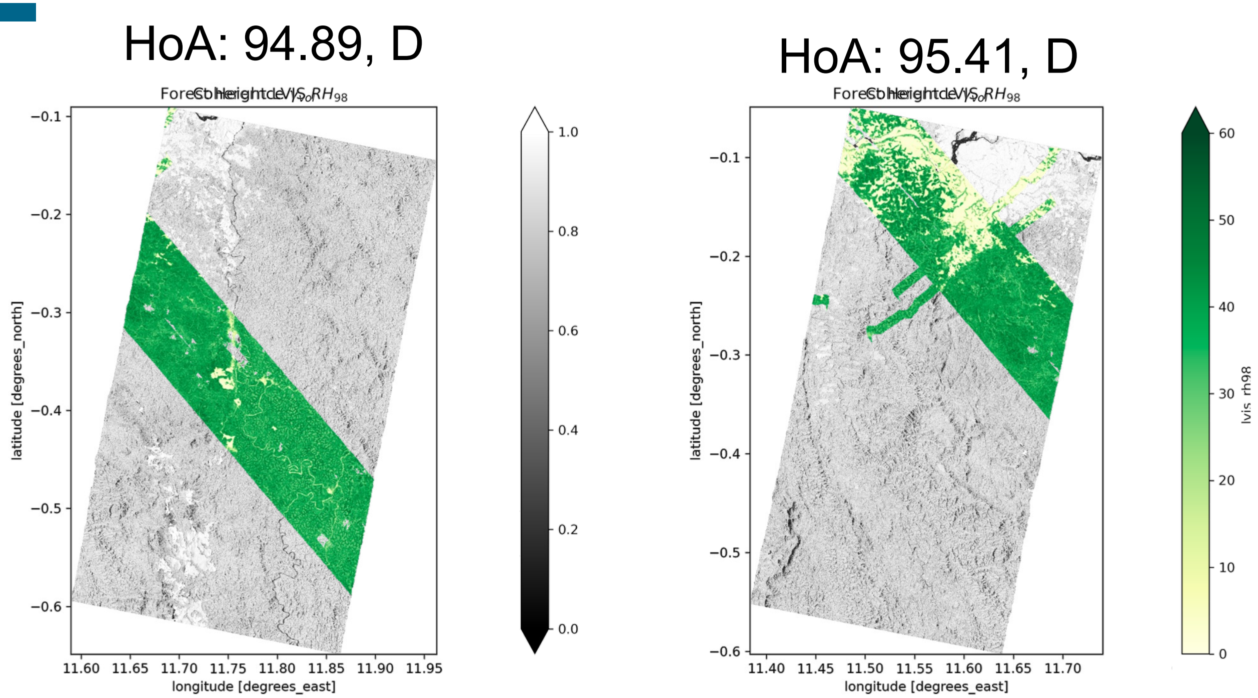

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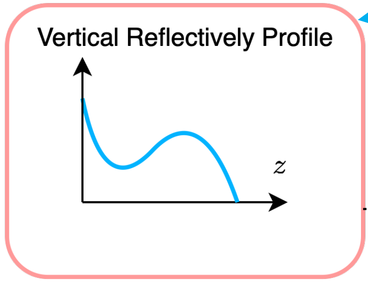

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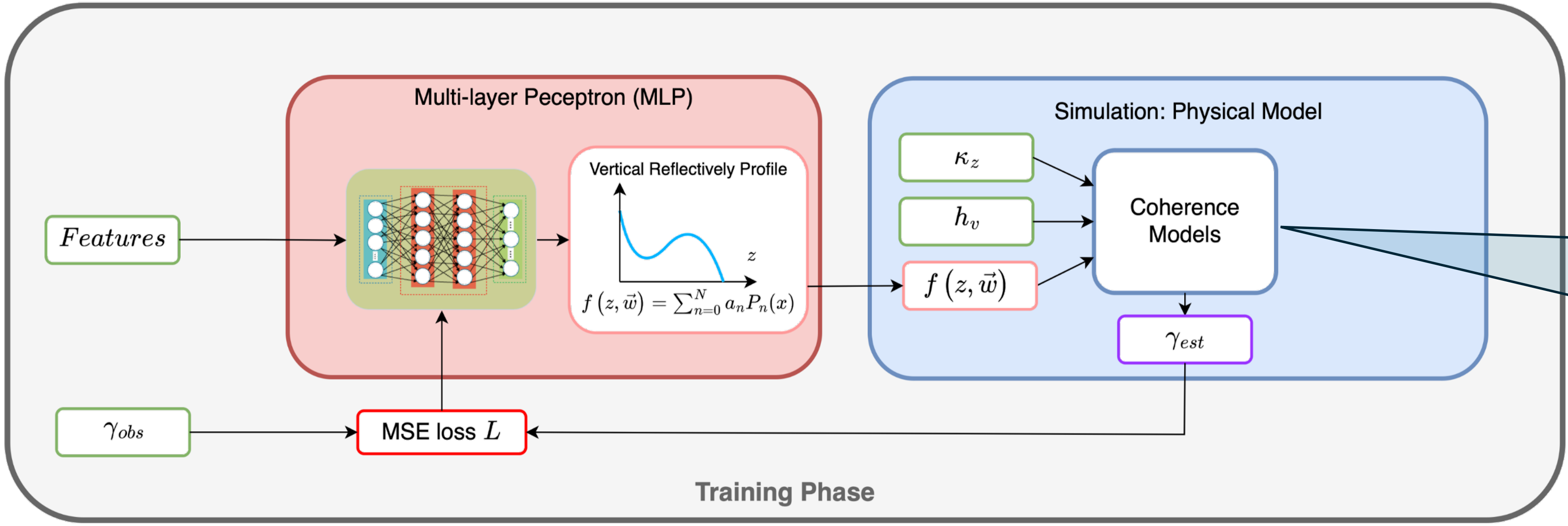
Integration of Machine Learning and Physical Models

Sequential Hybrid Model



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Assumptions Correction Model

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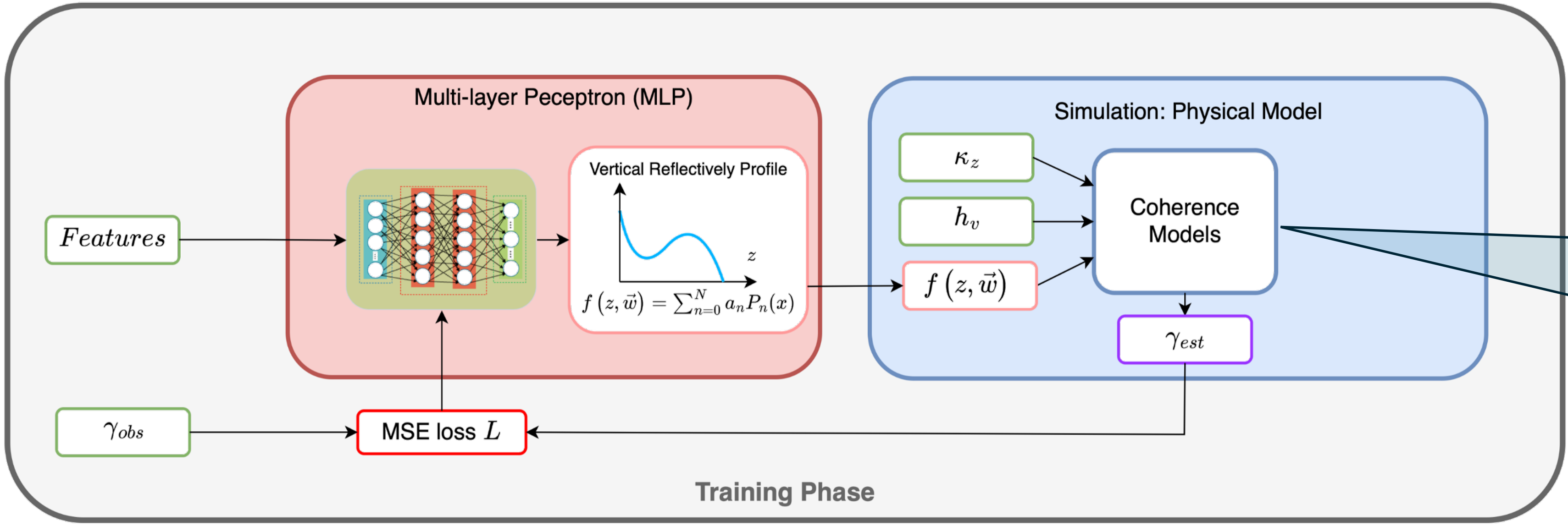

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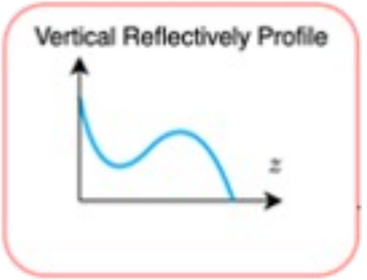

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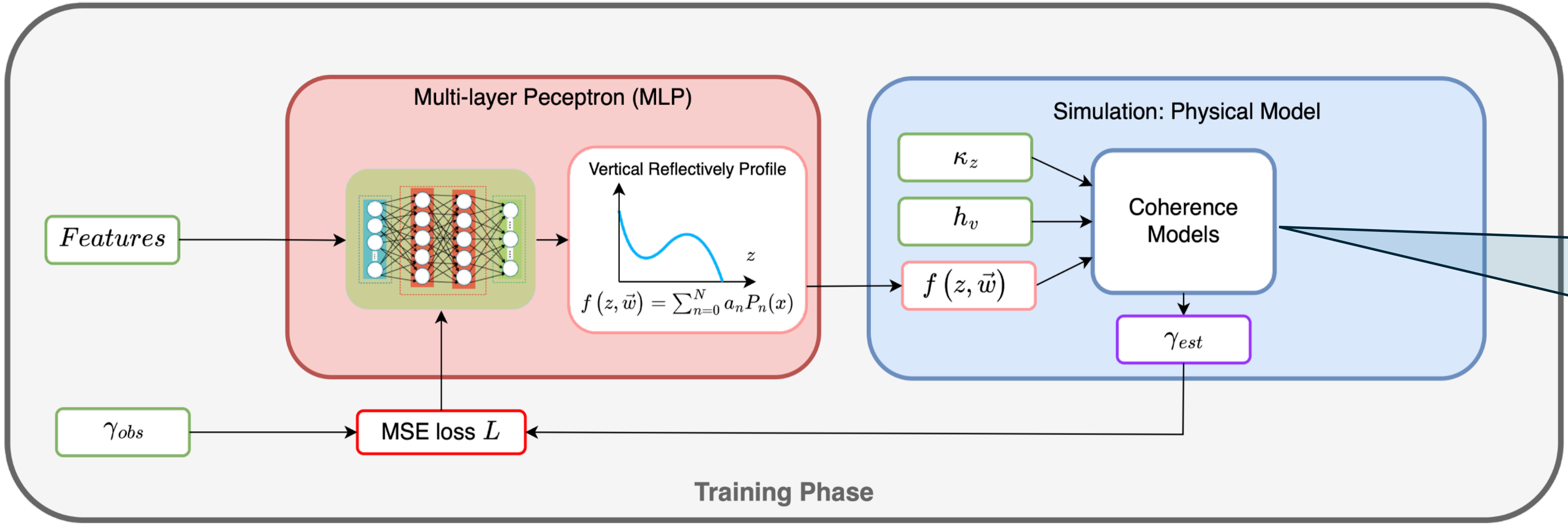

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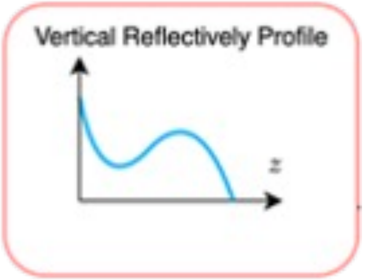

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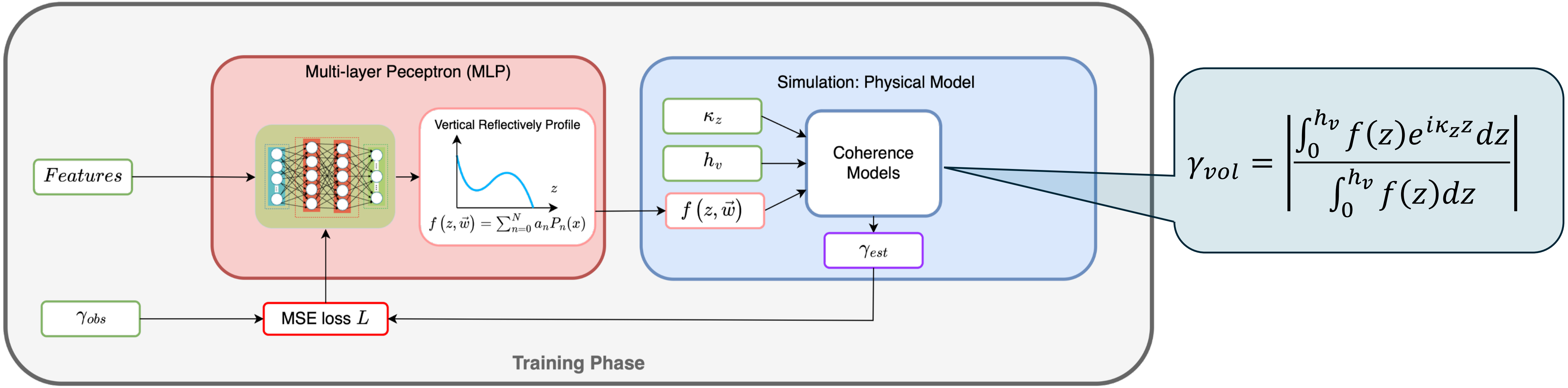

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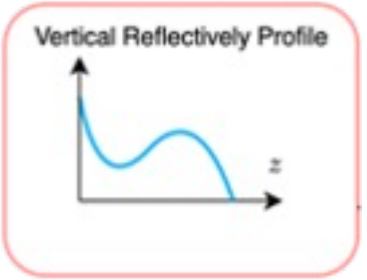

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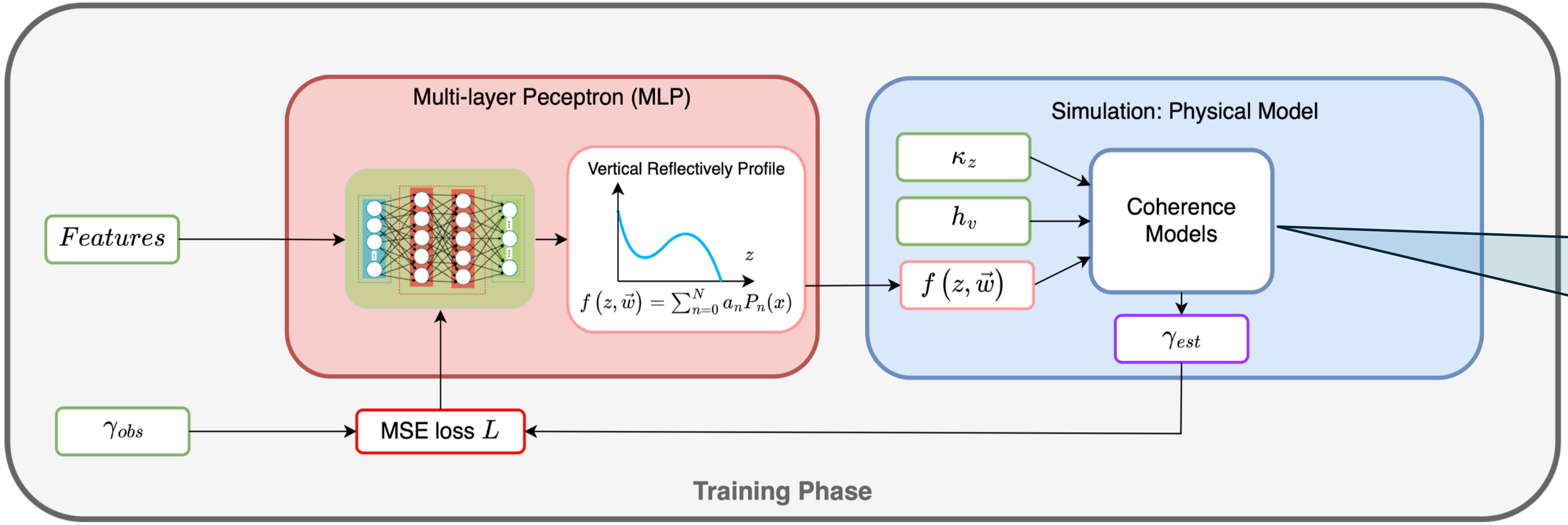

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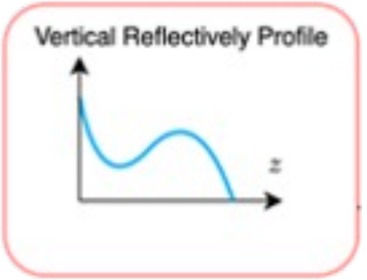

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where $P_n(z)$: Legendre Polynomials

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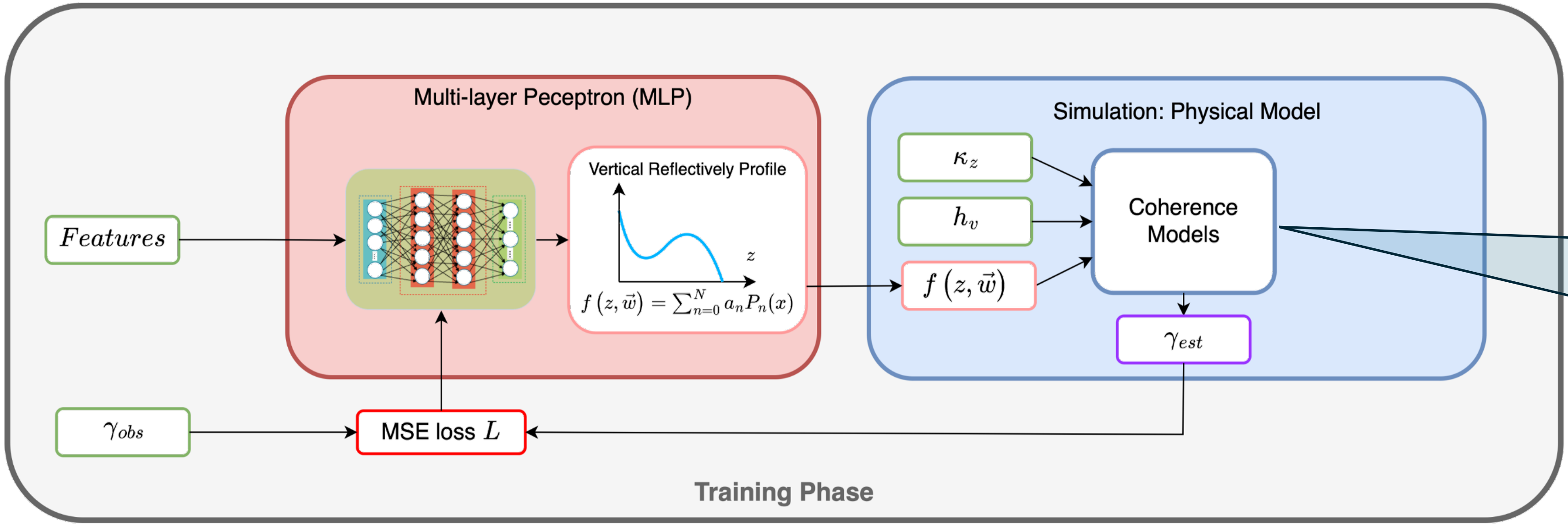

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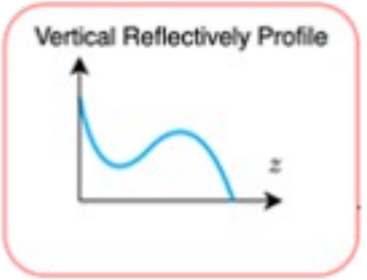

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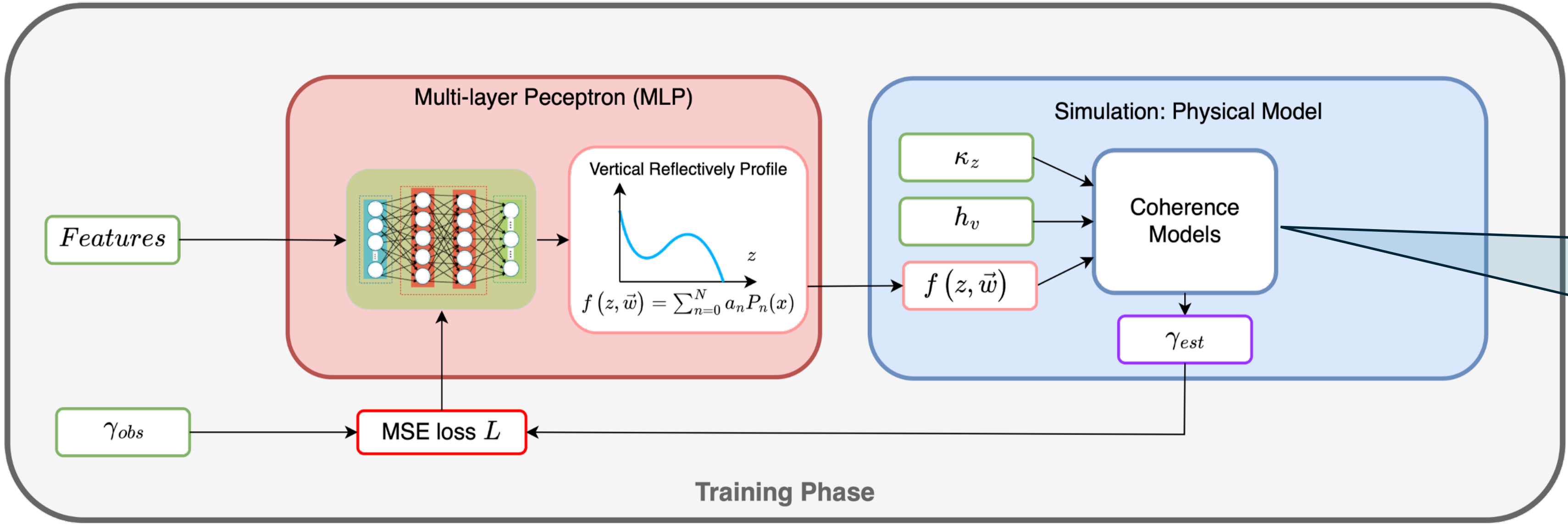

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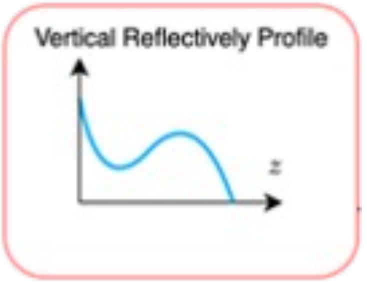

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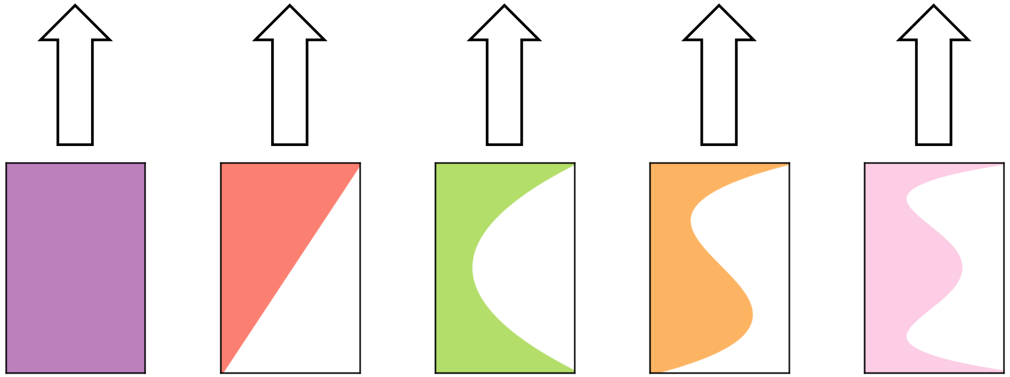

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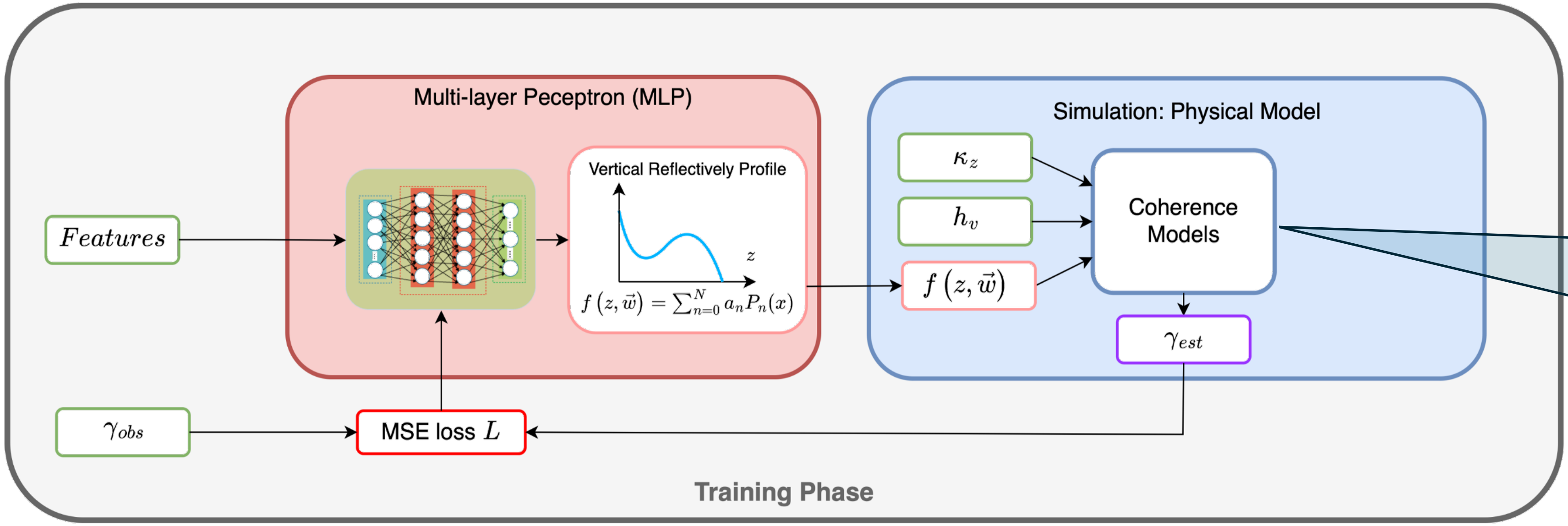

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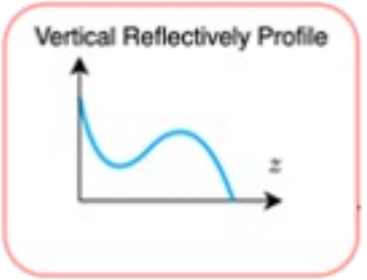

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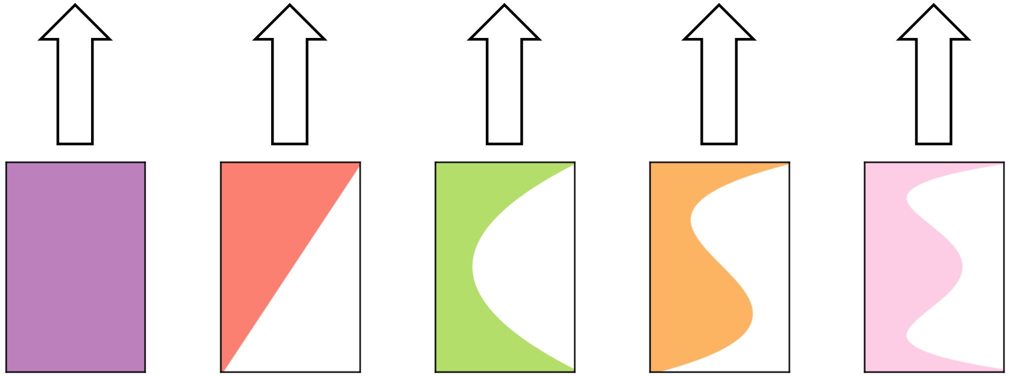

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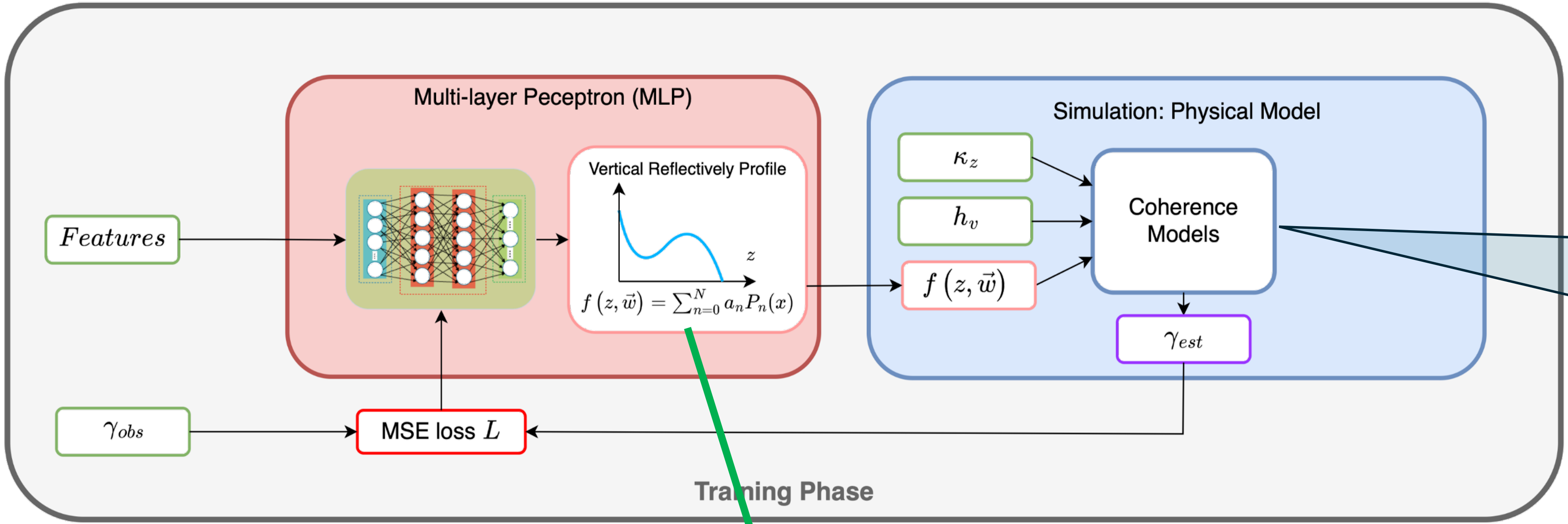

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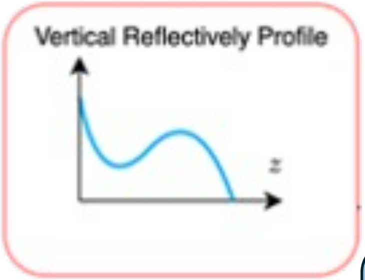

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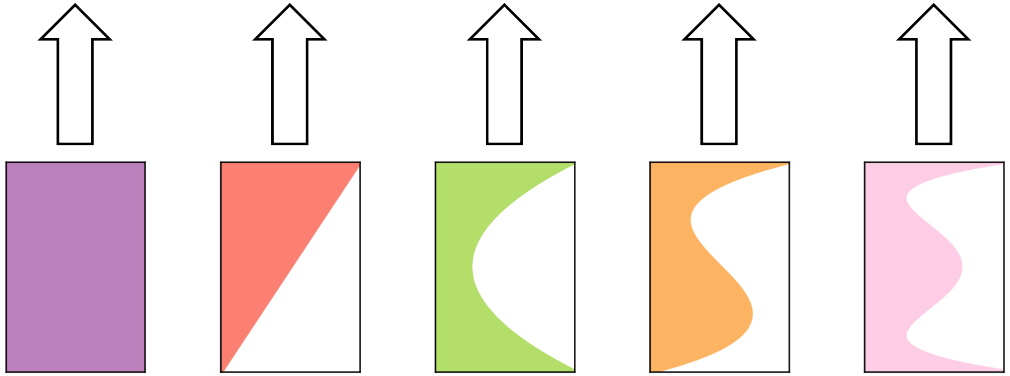
How many Legendre coefficients are required to approximate the function?

where $P_n(z)$: Legendre Polynomials



Experiments Setup

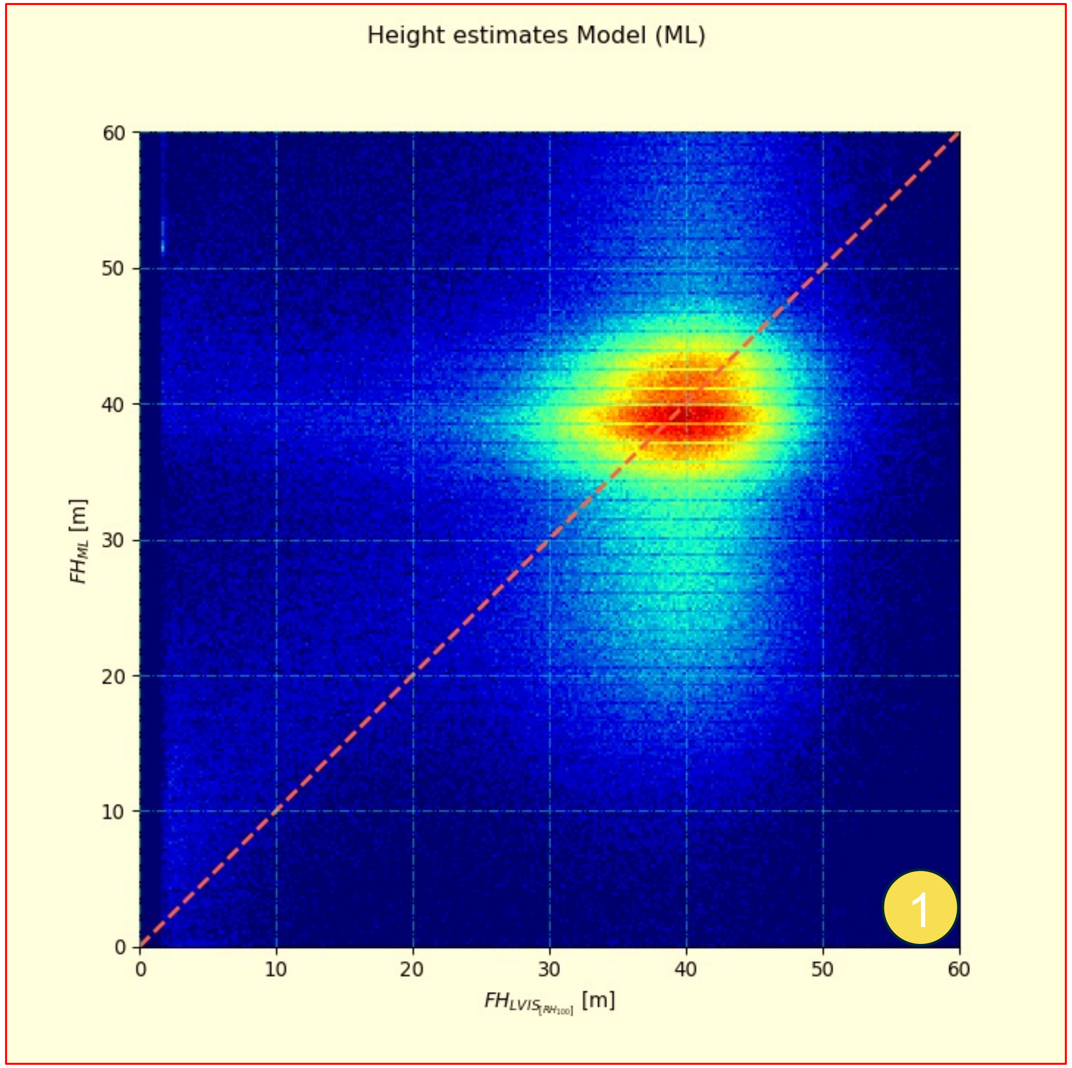
No.	Legendre coefficients (N)	HoA for Training	Features (Inputs – Parameters)
			TanDEM-X
1	3	$[-65.22]$	$\kappa_z, \tilde{\gamma}_{vol}, \cdots, \theta_o, \theta_T$
2	3	$[52.45, -65.22, 95.41]$	$\kappa_z, \tilde{\gamma}_{vol}, \cdots, \theta_o, \theta_T$
3	7	$[52.45, -65.22, 95.41]$	$\kappa_z, \tilde{\gamma}_{vol}, \cdots, \theta_o, \theta_T$

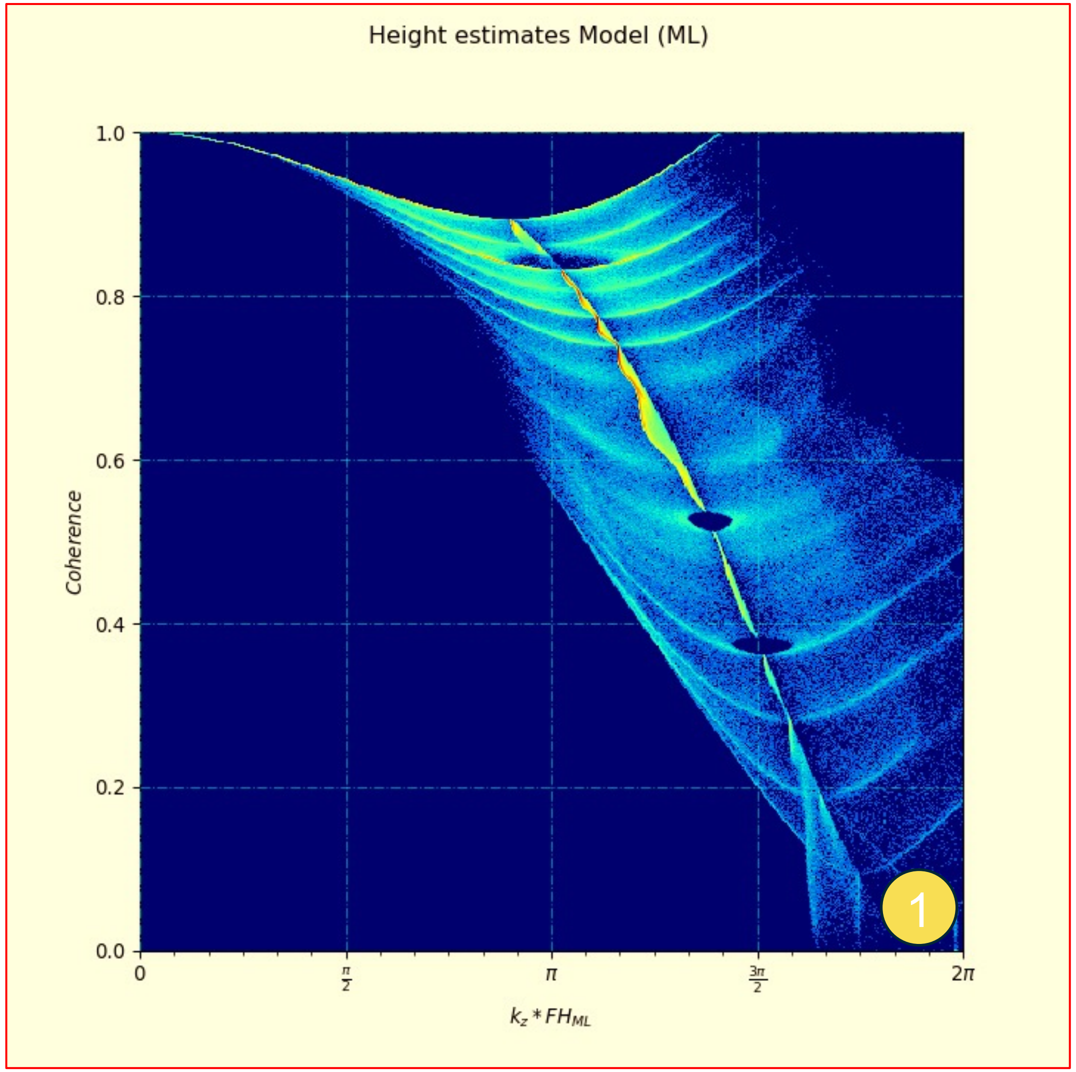
a) Data Selection: Selection of **HoA** for training

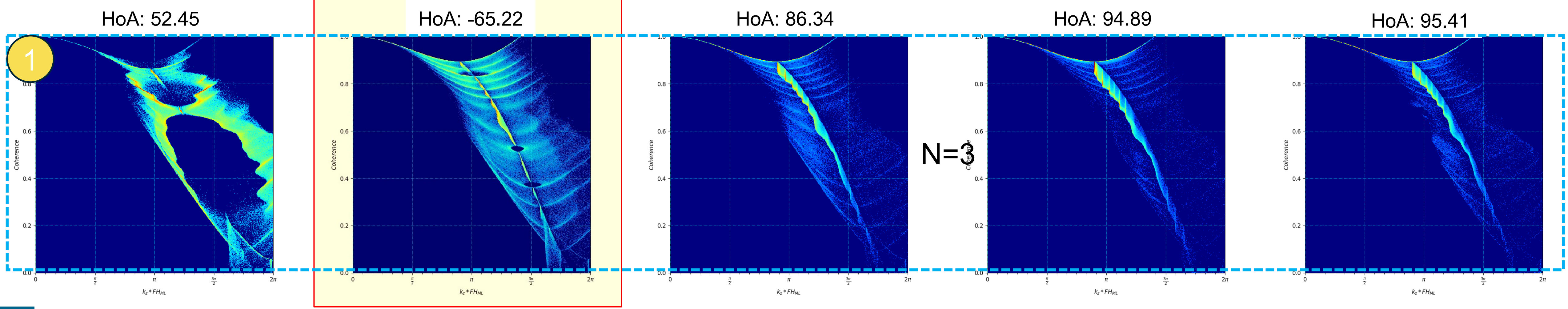
b) Coefficient Setup: A varying quantity (**N**) of Legendre coefficients

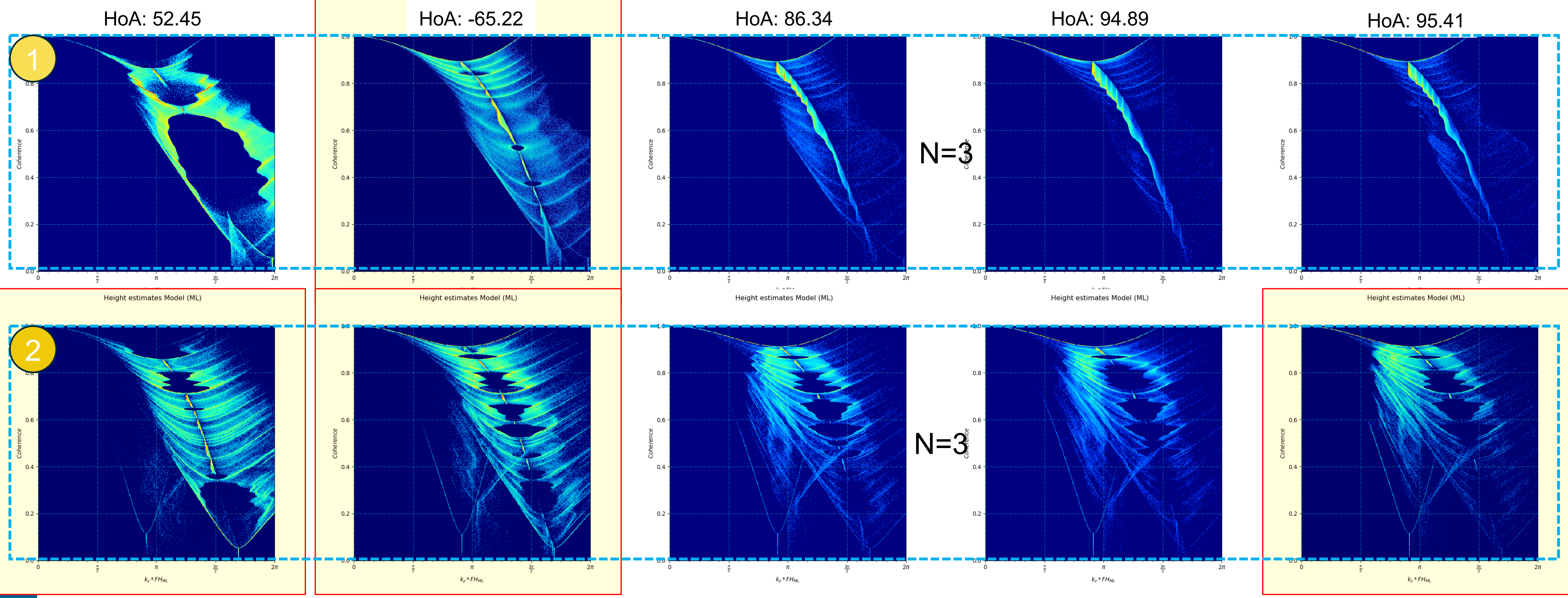
1 2 3

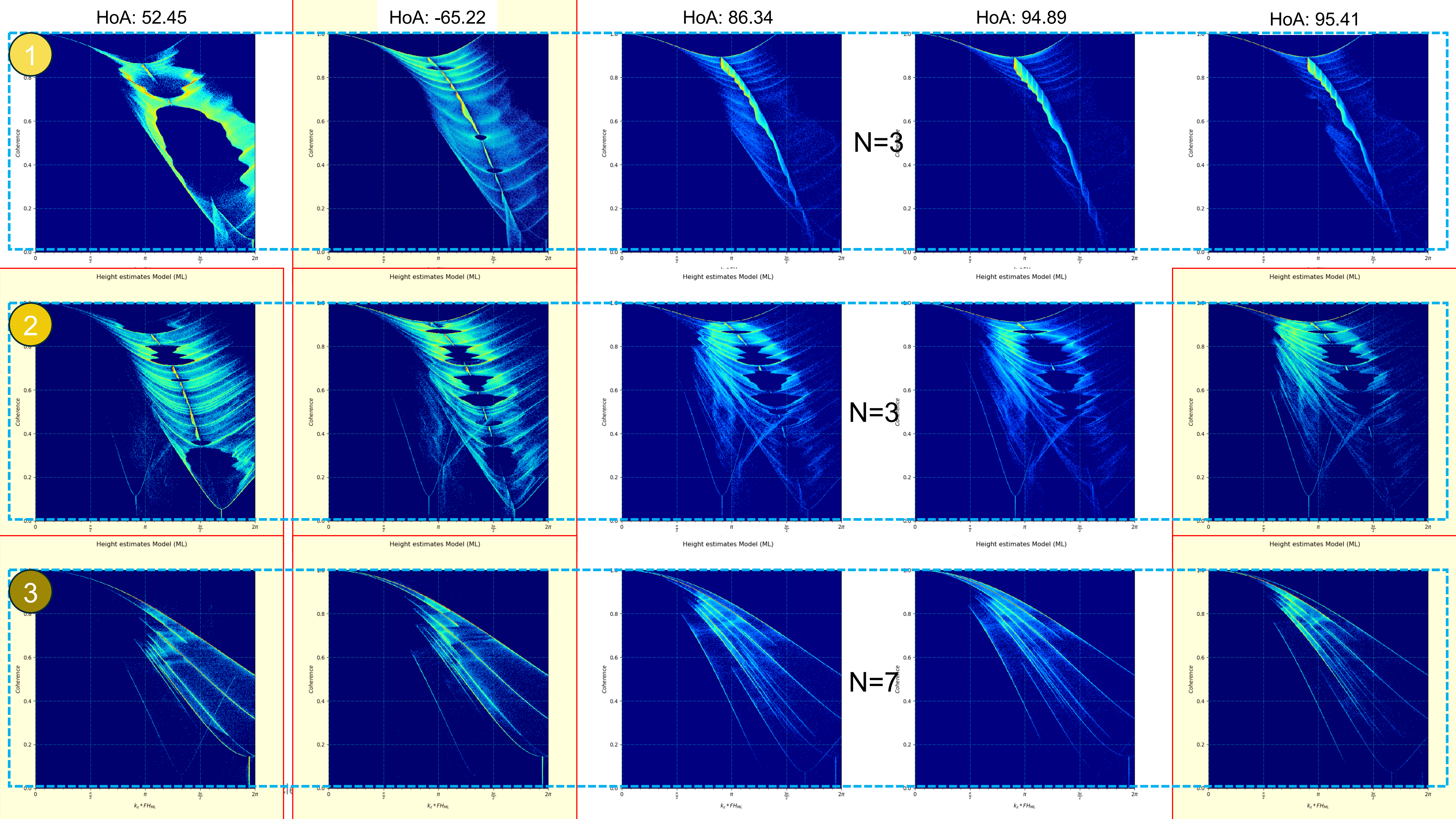
Results Explanation

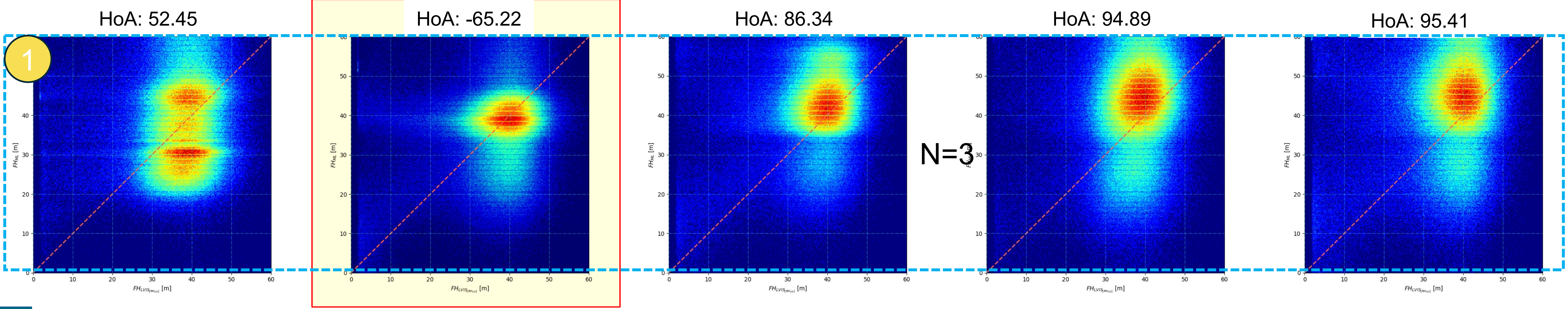





HoA: 52.45
HoA: -65.22
HoA: 86.34
HoA: 94.89
HoA: 95.41
1
N=3
Coherence
$k_z * FH_{ML}$


HoA: 52.45
HoA: -65.22
HoA: 86.34
HoA: 94.89
HoA: 95.41
1
2
N=3
N=3
Height estimates Model (ML)
Coherence
$k_z * FH_{ML}$


HoA: 52.45
HoA: -65.22
HoA: 86.34
HoA: 94.89
HoA: 95.41
1
2
3
N=3
N=3
N=7
Height estimates Model (ML)
Coherence
$k_z * FH_{ML}$
0
$\frac{\pi}{2}$
π
$\frac{3\pi}{2}$
2π
0.0
0.2
0.4
0.6
0.8
1.0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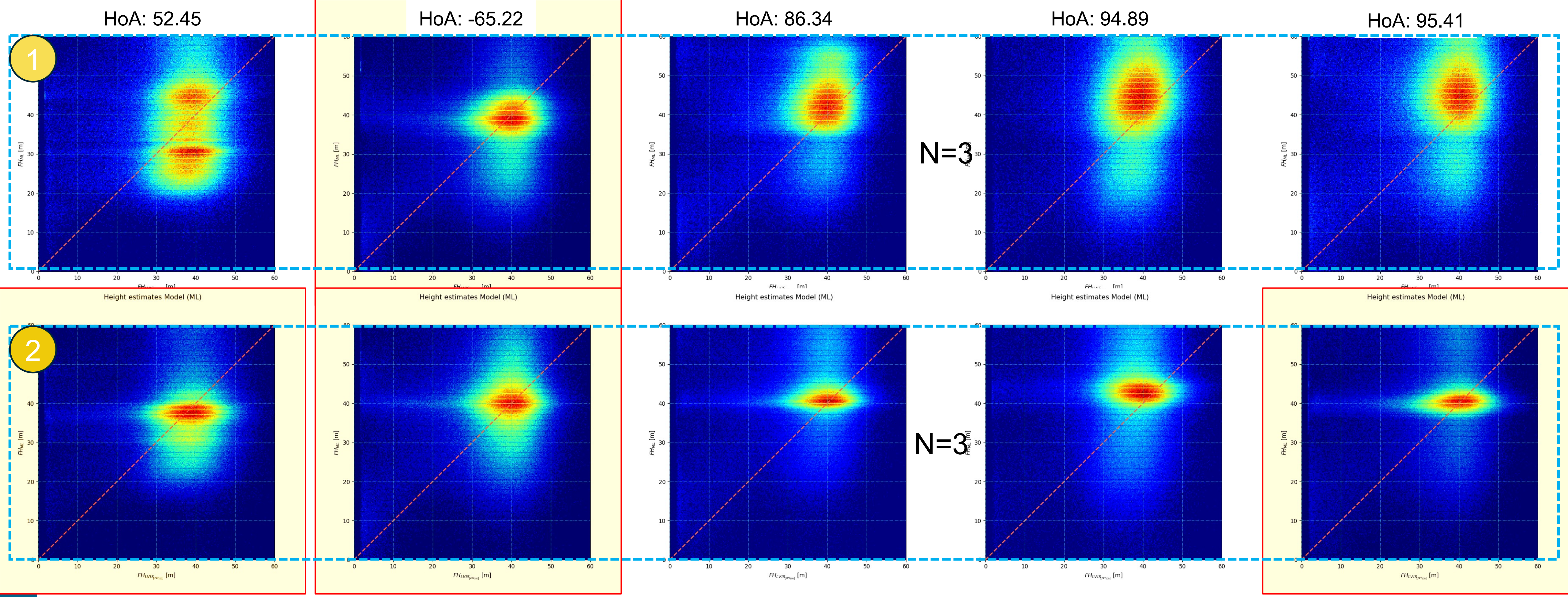
1
N=3



HoA: 52.45
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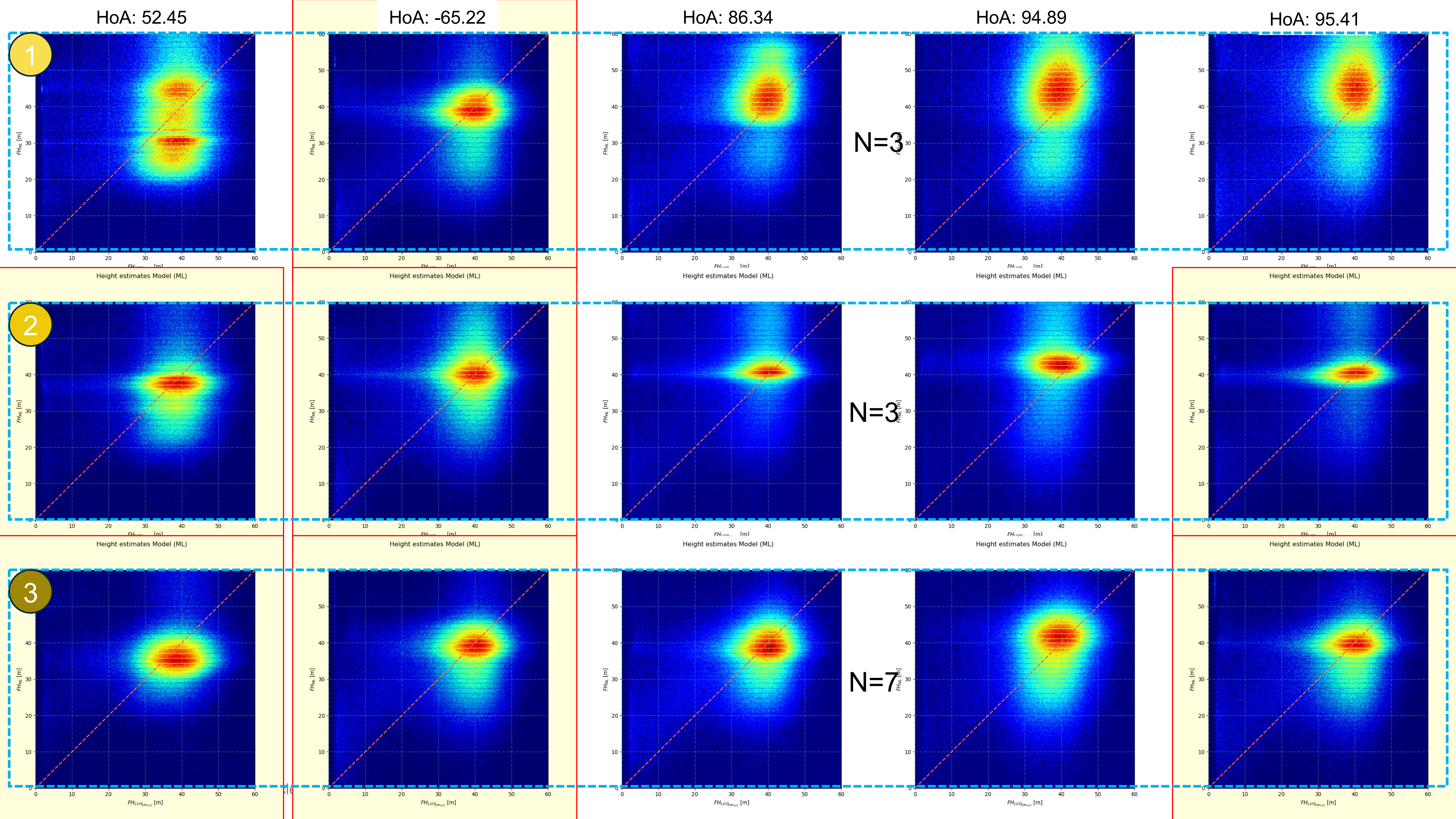
1
2
N=3
N=3
Height estimates Model (ML)



HoA: 52.45
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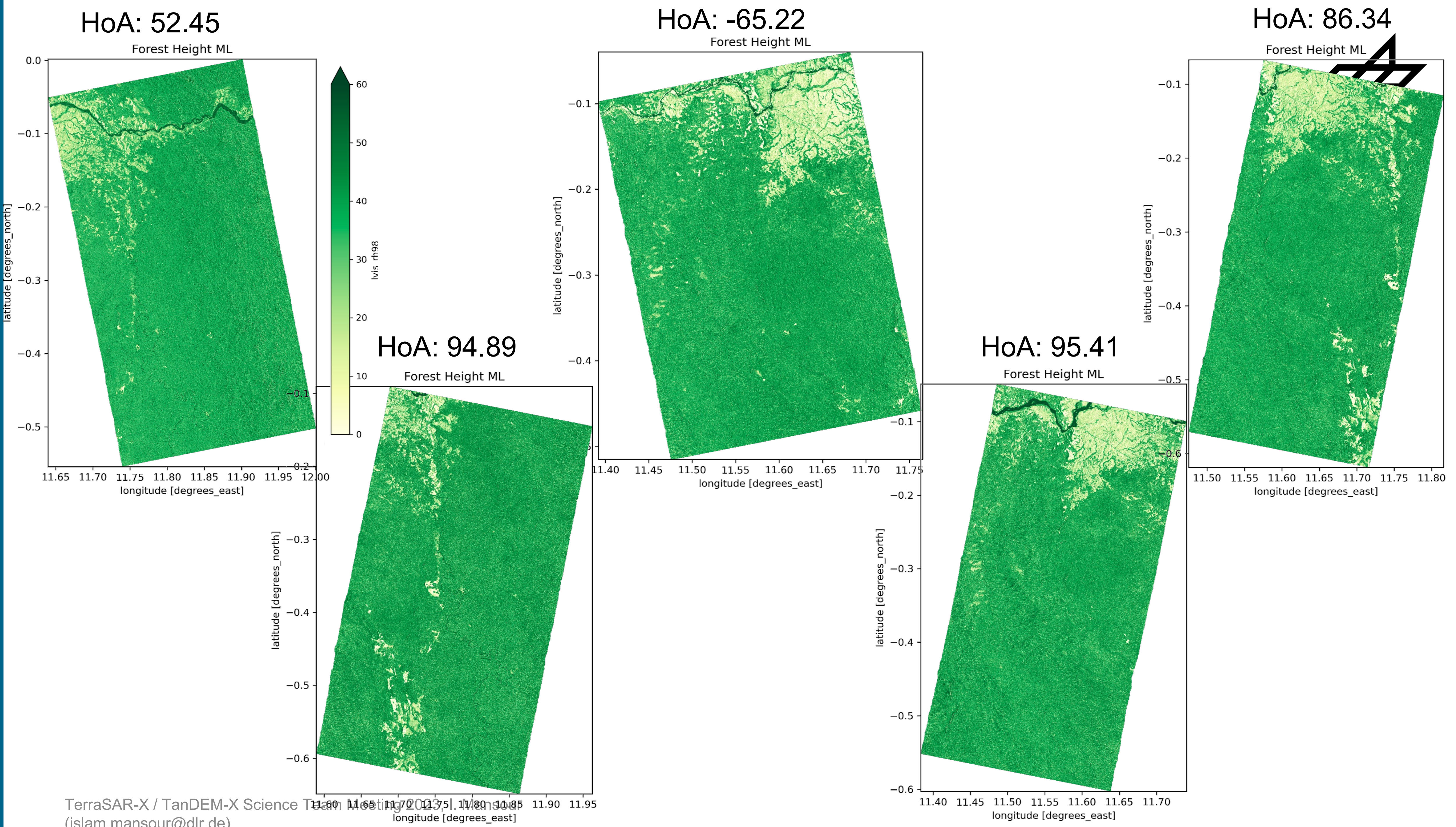
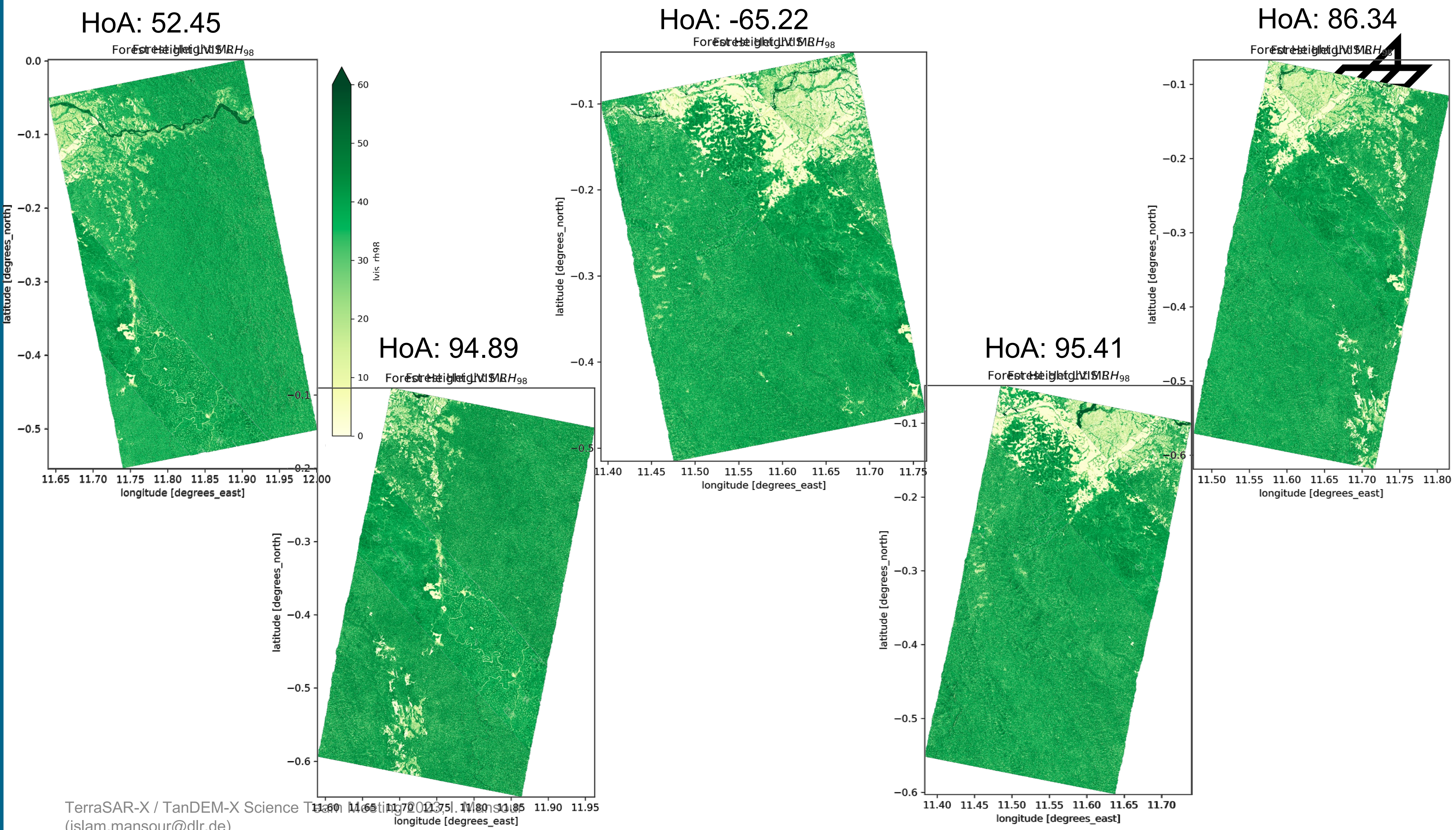
1
N=3
Height estimates Model (ML)
2
N=3
Height estimates Model (ML)
3
N=7



HoA: 52.45
Forest Height ML
latitude [degrees_north]
longitude [degrees_east]
lvis_rh98
HoA: 94.89
Forest Height ML
latitude [degrees_north]
longitude [degrees_east]
HoA: -65.22
Forest Height ML
latitude [degrees_north]
longitude [degrees_east]
HoA: 95.41
Forest Height ML
latitude [degrees_north]
longitude [degrees_east]
HoA: 86.34
Forest Height ML
latitude [degrees_north]
longitude [degrees_east]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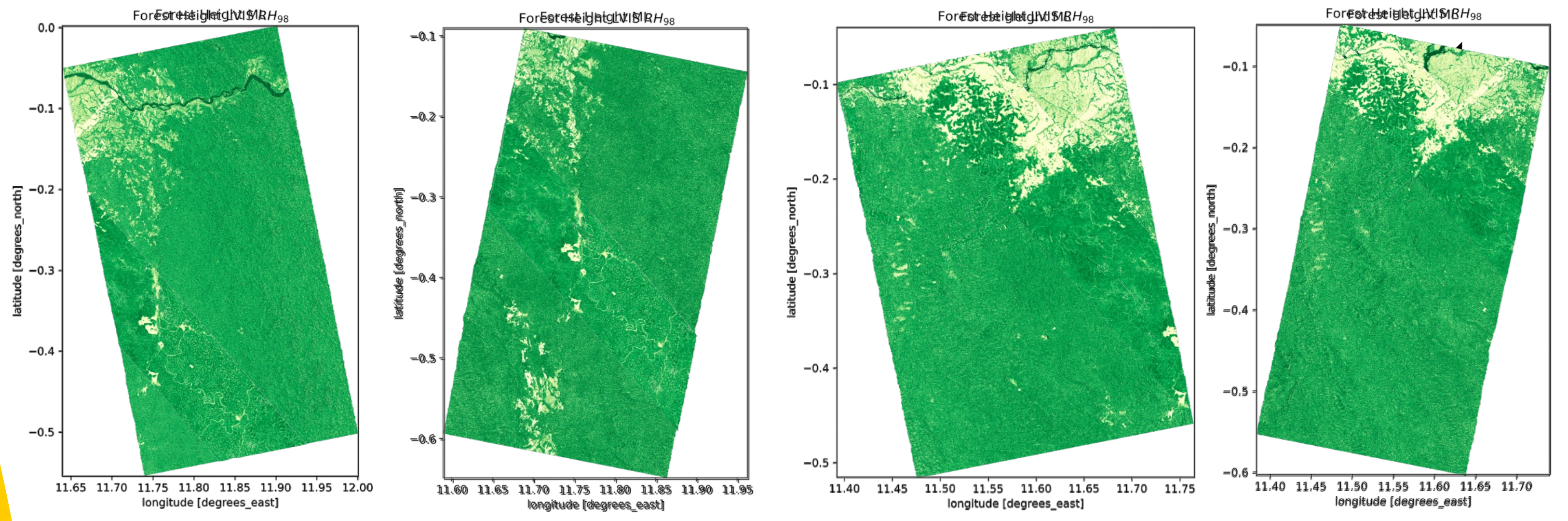
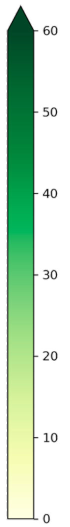
HoA: -65.22
HoA: 86.34
HoA: 94.89
HoA: 95.41
lvis rh98
latitude [degrees_north]
longitude [degrees_east]

Summary of Key Points and Implications

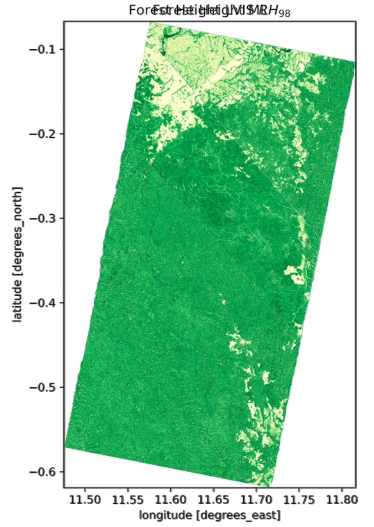
- **Hybrid Modeling Excellence:** Our novel hybrid modeling approach successfully integrates the domain-specific constraints of PM into ML. This enhances the model's robustness and generalizability while addressing the issue of explainability.
- **Importance of Legendre Coefficients:** The number (N) of Legendre coefficients is crucial for encapsulating the complexity of high-frequency components in the vertical reflectivity profile, thus playing a vital role in the model's performance.
- **Generalizability Enhancement:** To further improve the model's generalizability, the inclusion of diverse scenes with varying heights of ambiguity (vertical wavenumber) in the training dataset is imperative.
- **Multi-Sensor and Multi-Data:** This approach also enables the integration of multi-sensor and multi-data sources (e.g., multi-spectral images, LandSAT, ALOS) as features for the ML model, expanding its capabilities beyond traditional physical models.





Thank You!

Looking forward for your questions!



Thank you

Looking forward for your questions!