Cross-Continental Bayesian InSAR Forest Height Estimation

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Airborne LiDAR-derived Forest Height

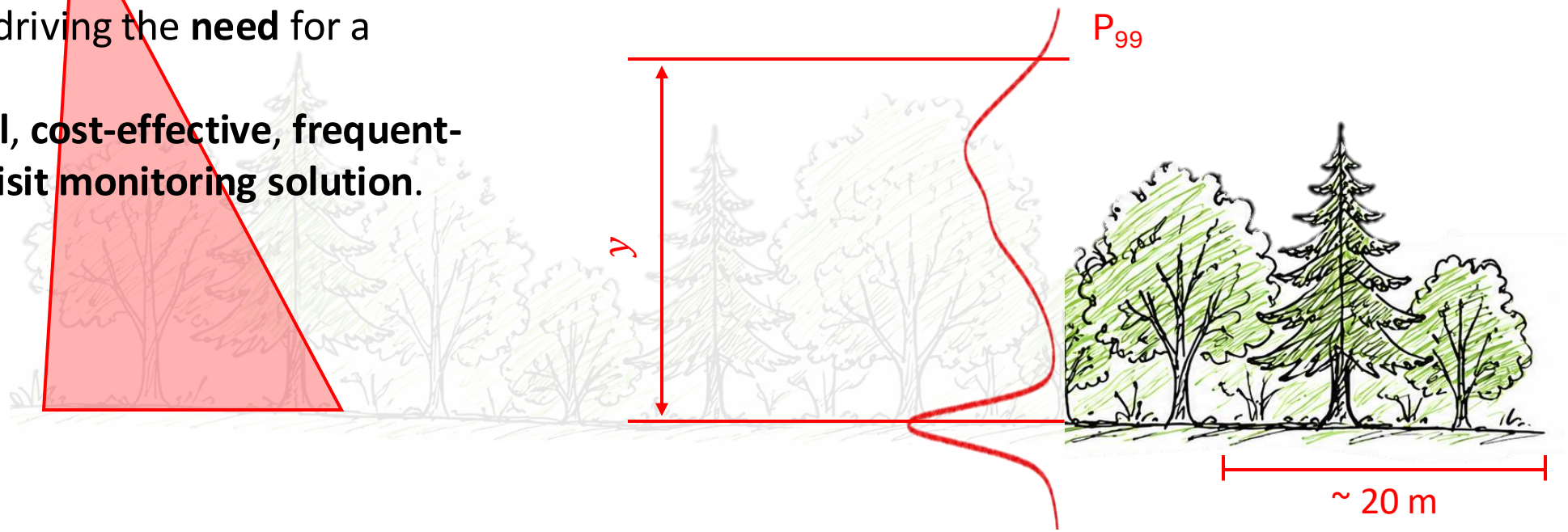
NASA LVIS

Forest height is an **ecological indicator** used to **support** sustainable **forest management**.

Forests change over time

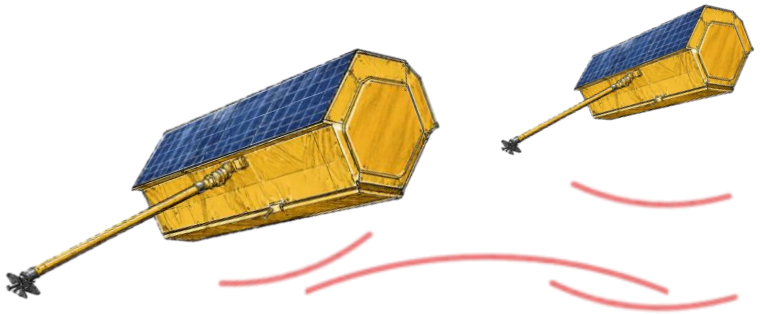
driving the **need** for a

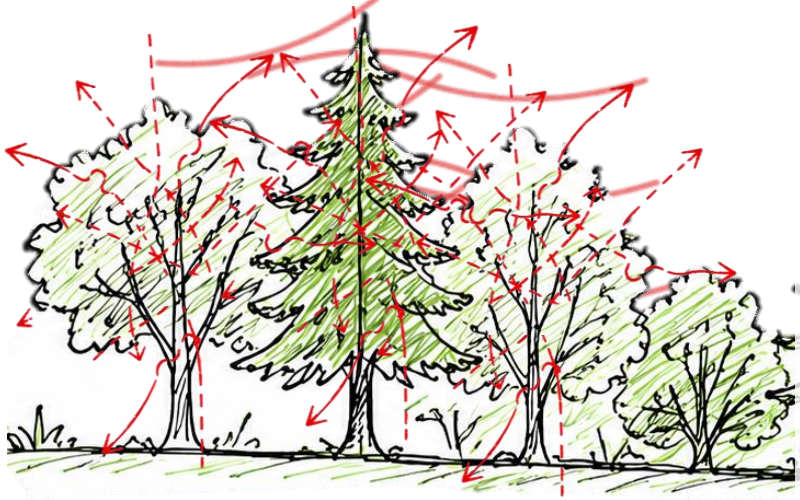
global, **cost-effective**, **frequent-revisit monitoring solution**.



SAR Satellites

TanDEM-X





- **Global coverage**
- **Short revisit time**
- **Weather-independent**
- **High-resolution**

- Microwave–tree **interaction** is **complex**
- **Physical models** require **simplifying assumptions**

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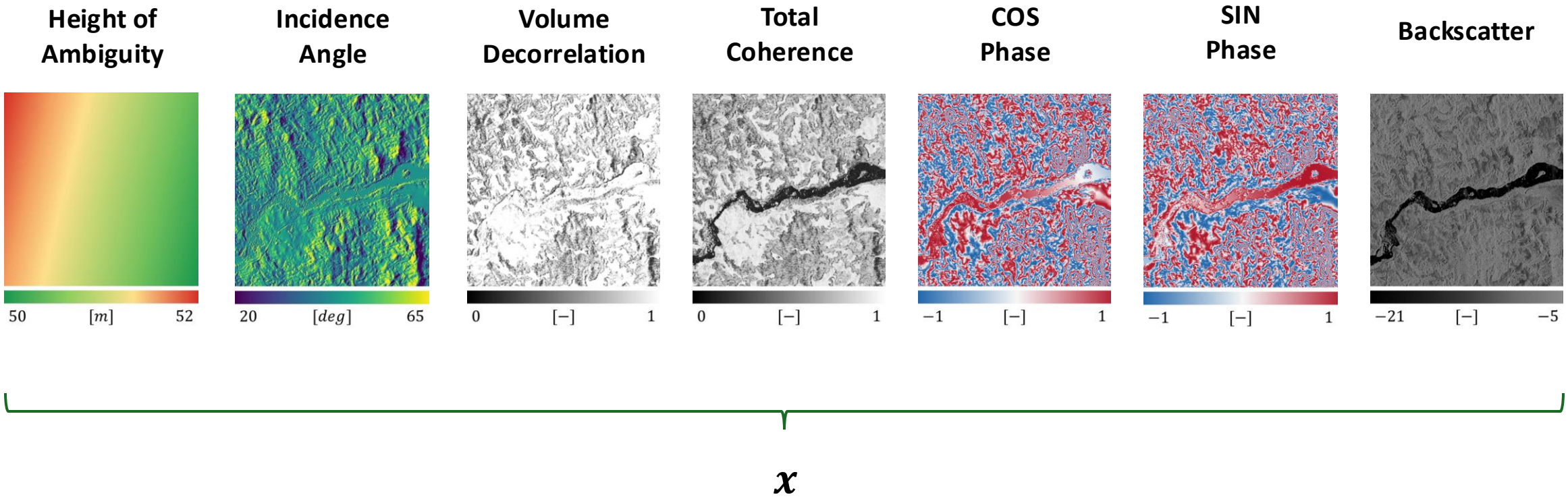
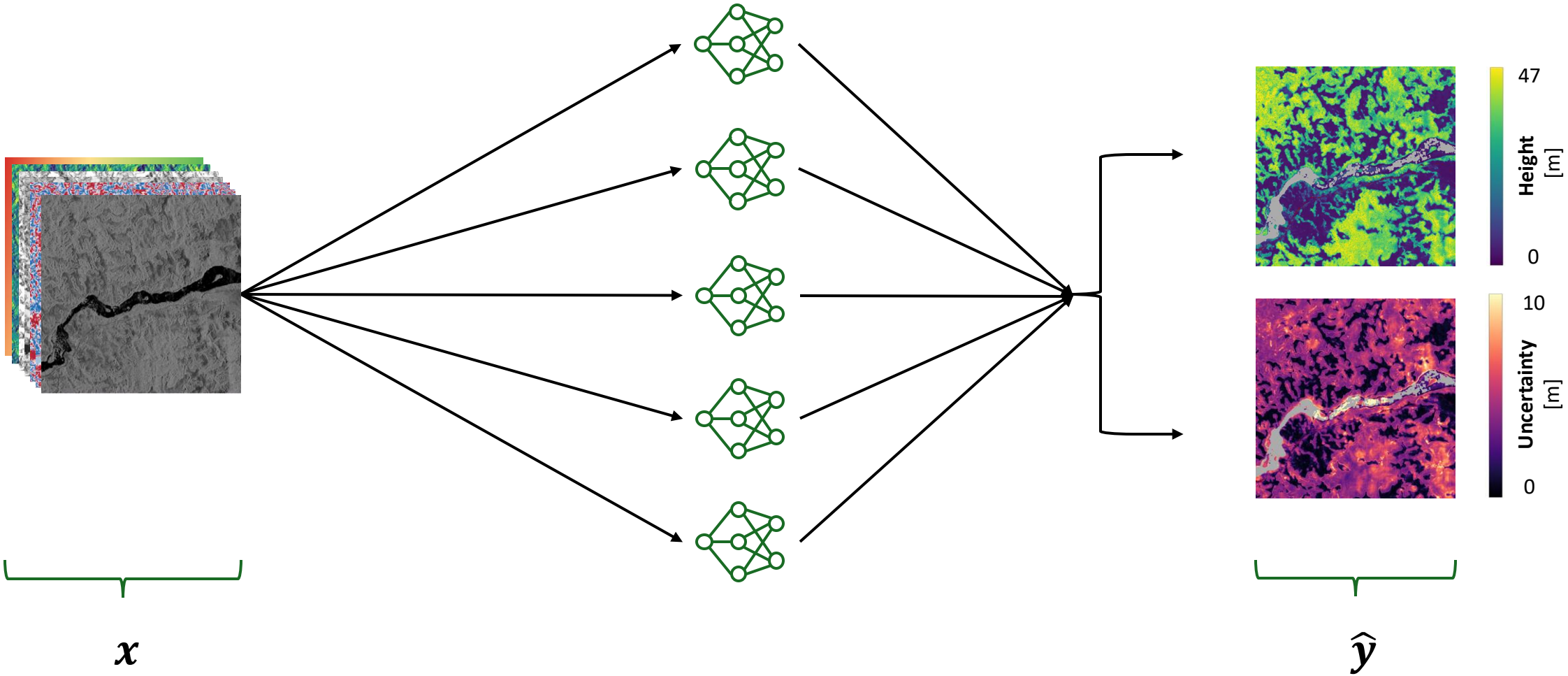
Deep Learning

TanDEM-X InSAR Data

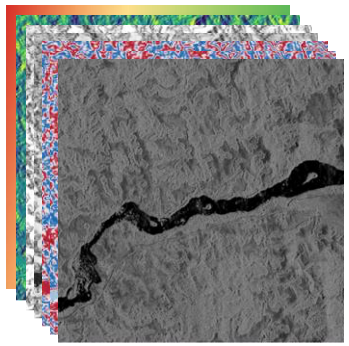
Boléko, Gabon @ 25m



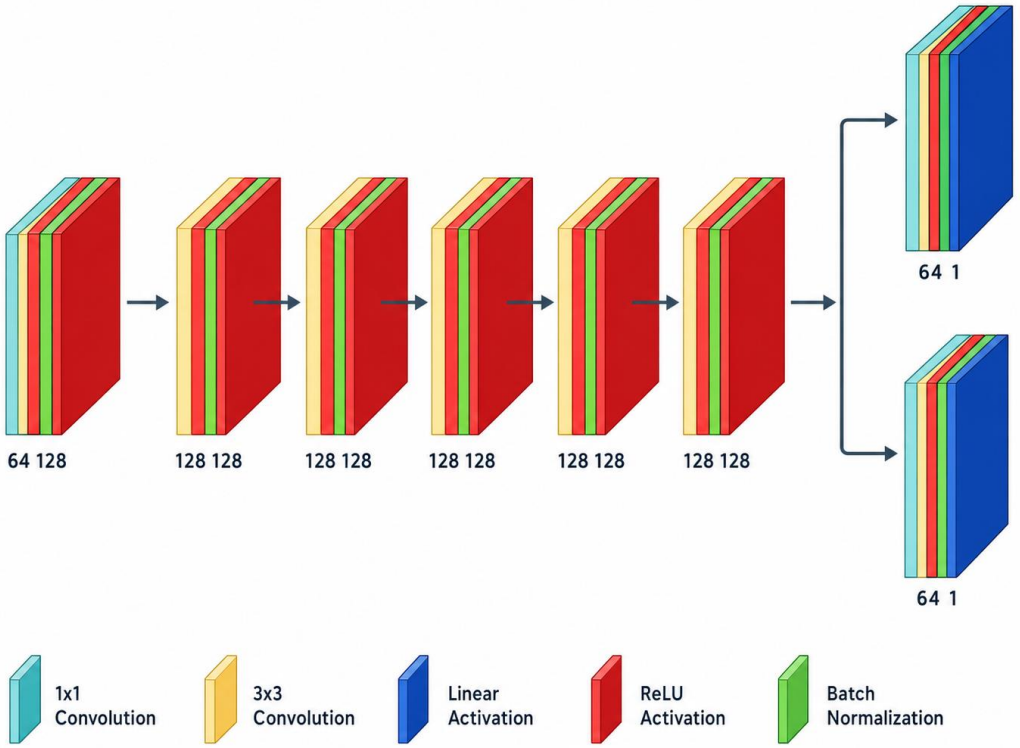
Bayesian Deep Learning

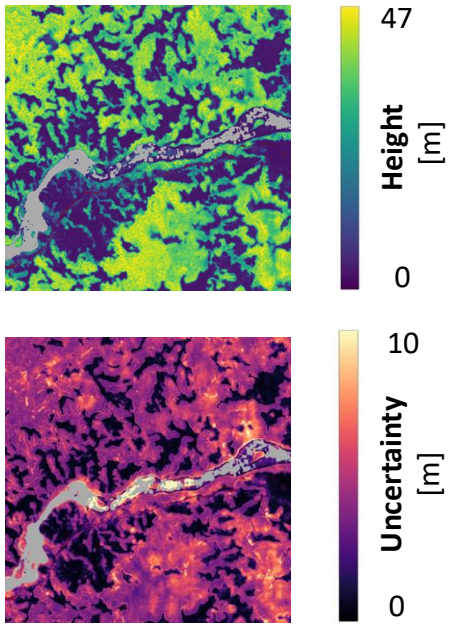


Bayesian Deep Learning



x

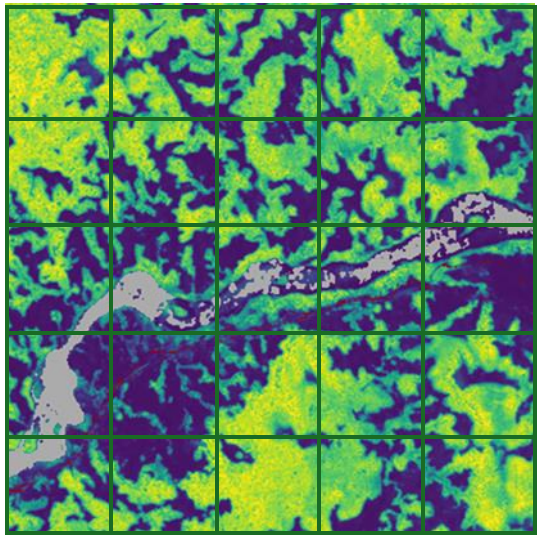




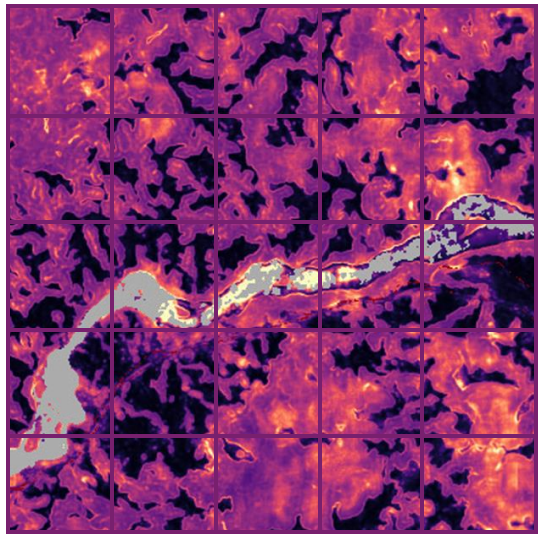
$\hat{y}$

Bayesian Deep Learning

Height Estimate
$(\hat{\mu})$

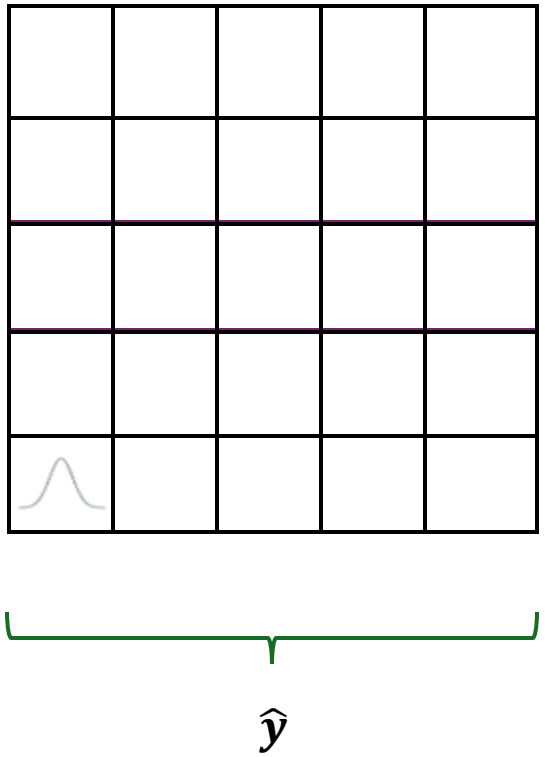


Uncertainty Estimate
$(\hat{\sigma})$

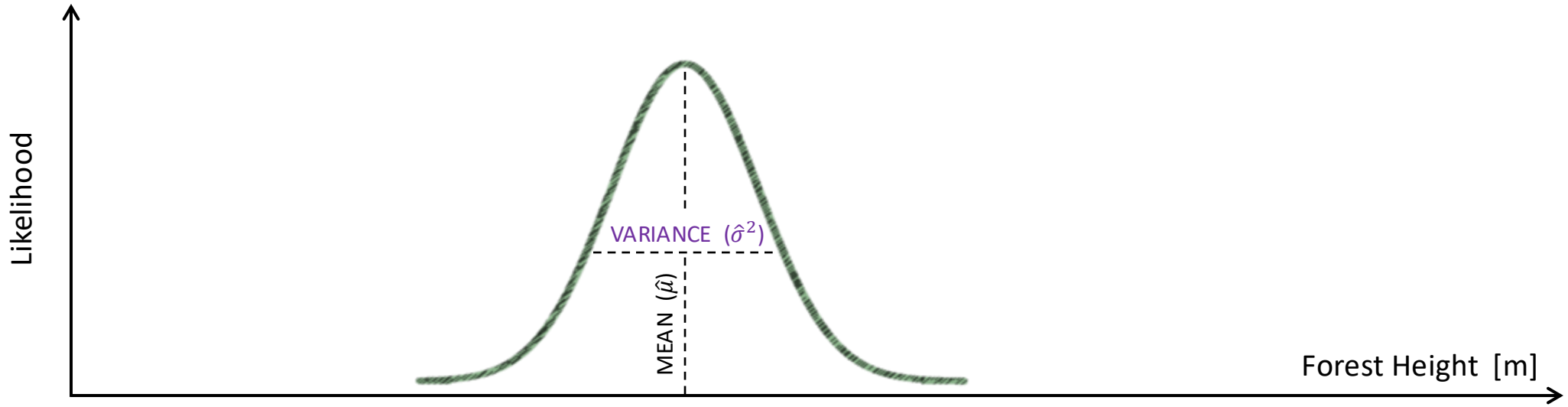


$\hat{y}$

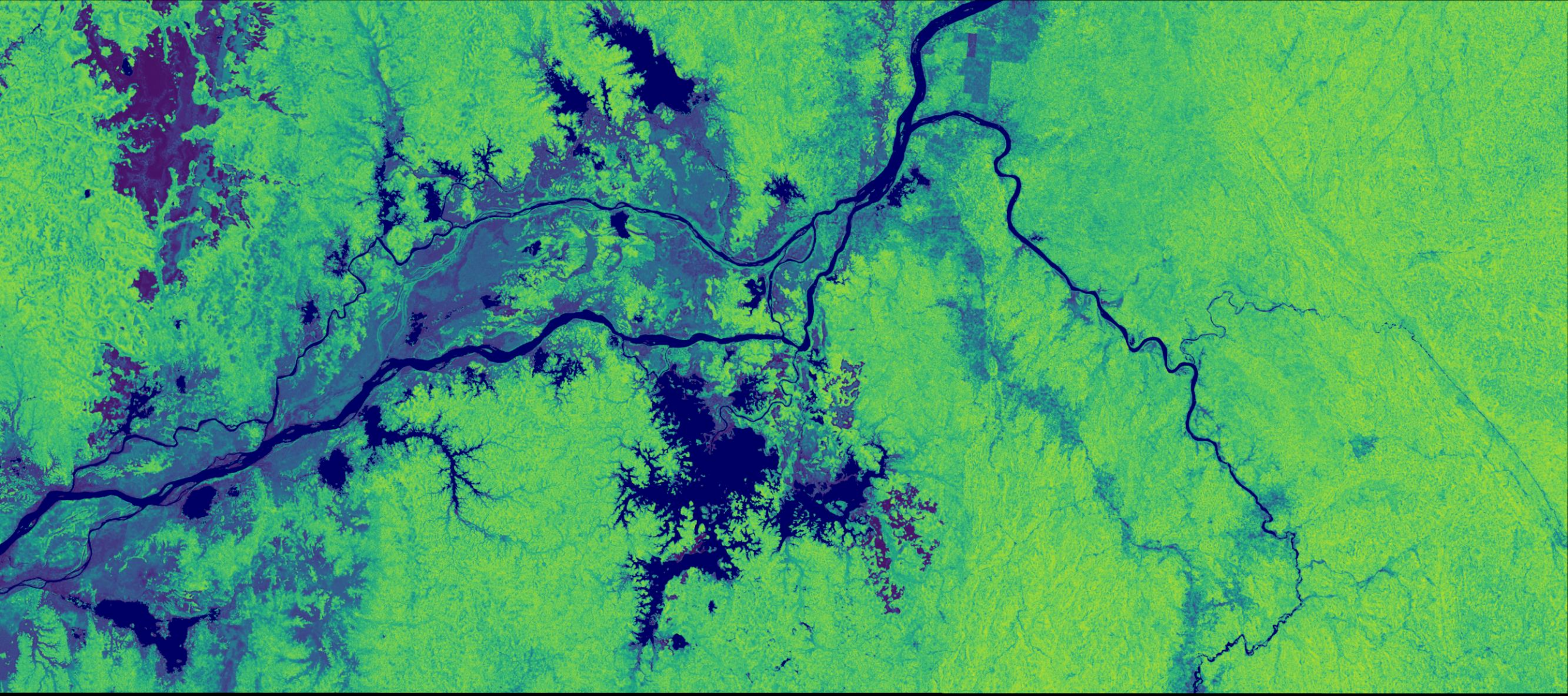
Bayesian Deep Learning



Bayesian Deep Learning

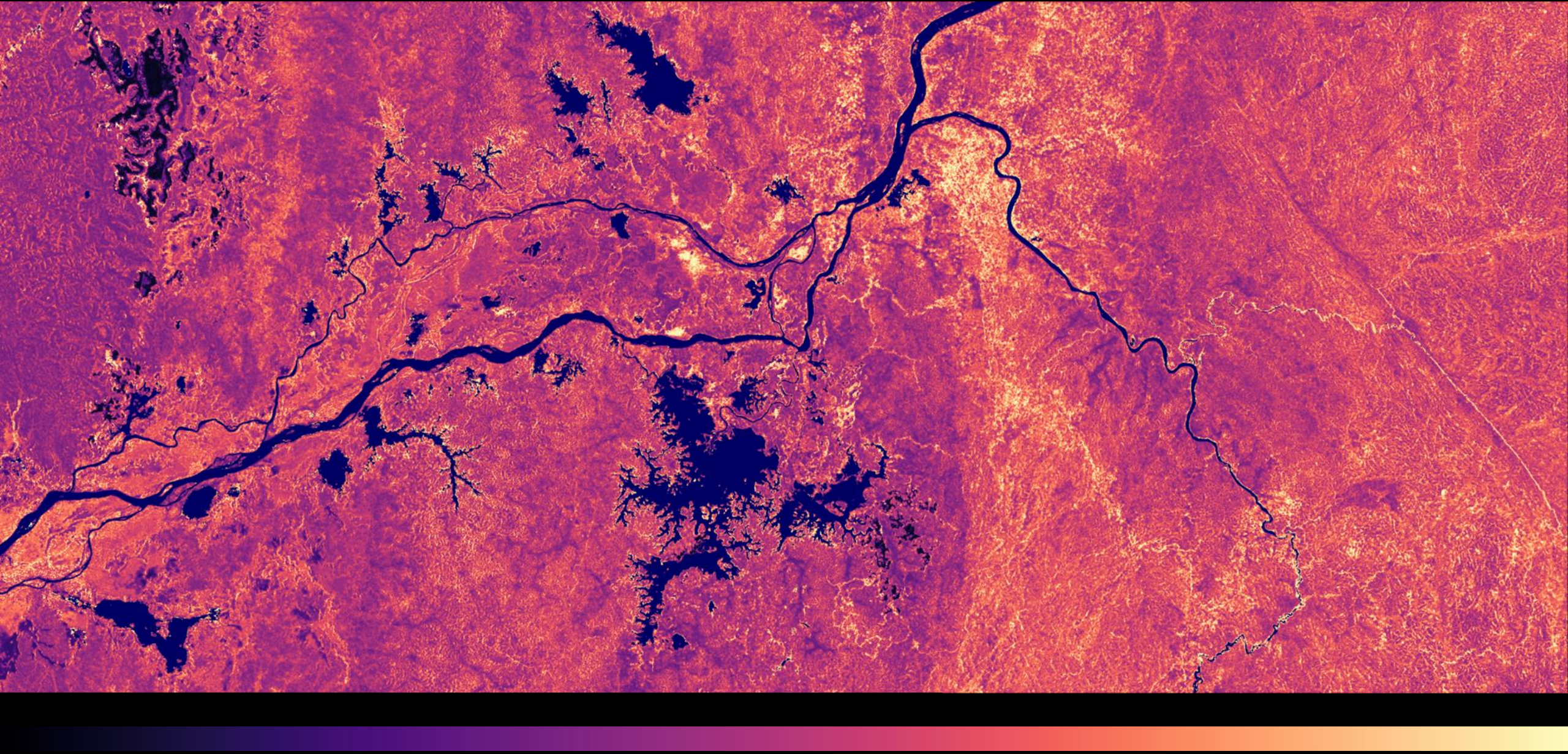


The **estimate** is a **distribution of height** possibilities,
with $\hat{\boldsymbol{\mu}}$ being the ***most likely*** value.



0 $[m]$ 70

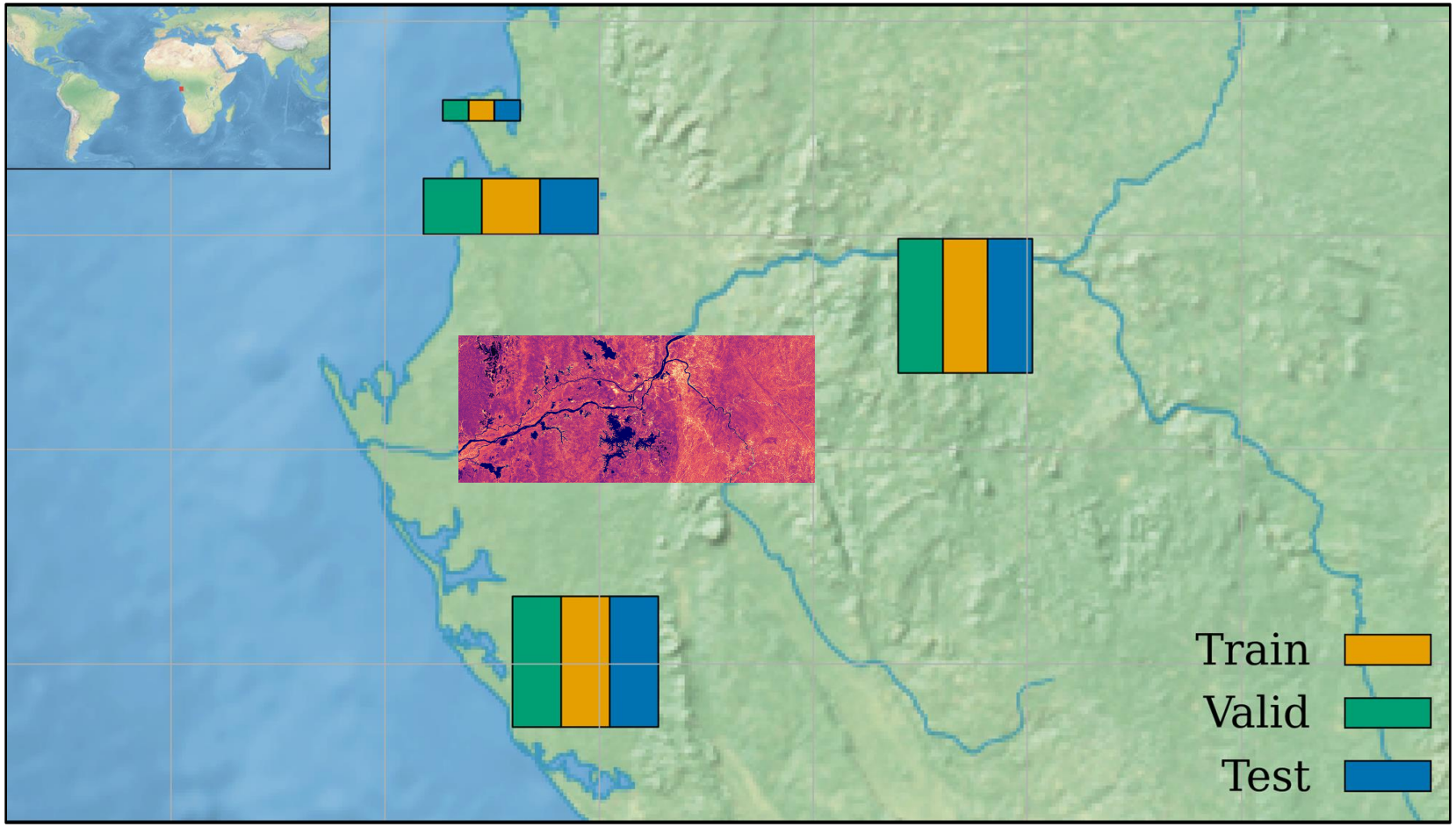
Moyen-Ogooué, Gabon



0 $[m]$ 8

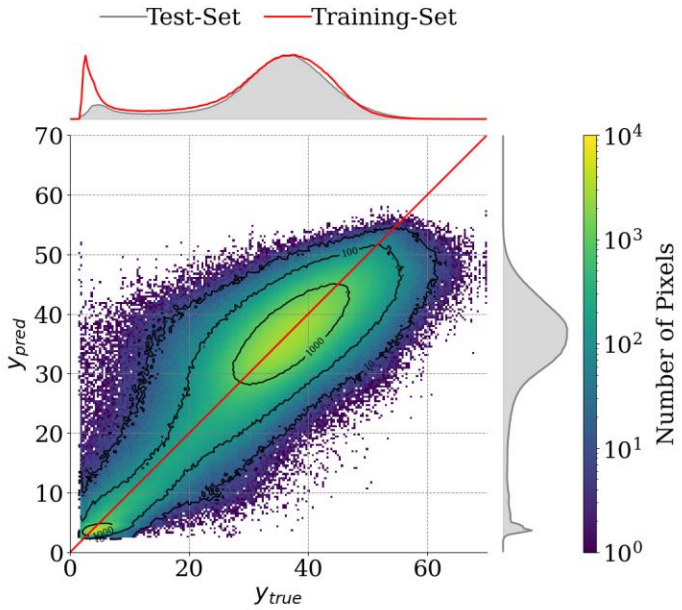
Moyen-Ogooué, Gabon

Test Scenarios



Gabon

Evaluation



GAB → GAB

ME	$RMSE$	R^2	$\frac{RMV}{RMSE}$	ECE
-0,39 m	4,64 m	0,82	1,01	0,15

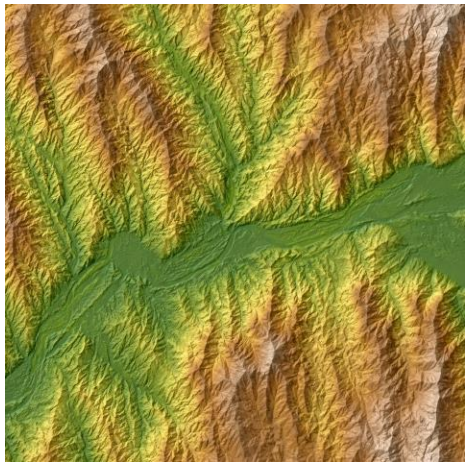
Scaling is not just adding more data

Why not only a global dataset?

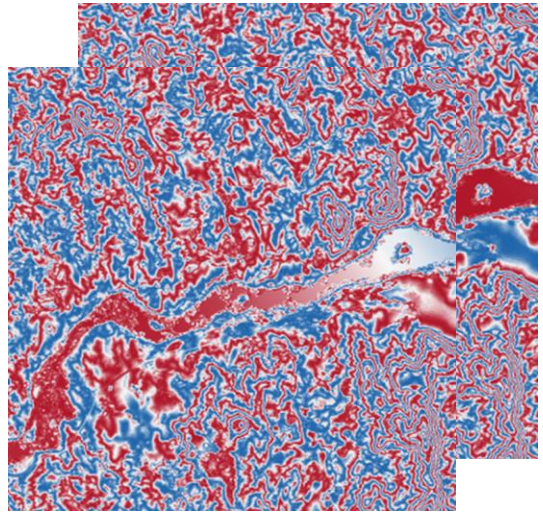
A global dataset sounds like the ***obvious*** *solution*. But the network mostly ***learns*** the ***dominant cases***. ***Rare*** domains become ***underrepresented***, and that is where robustness breaks.

Domain Generalization

Learn ***transferable features*** that remain ***robust*** across ***unseen*** regions, acquisition settings and environmental conditions.

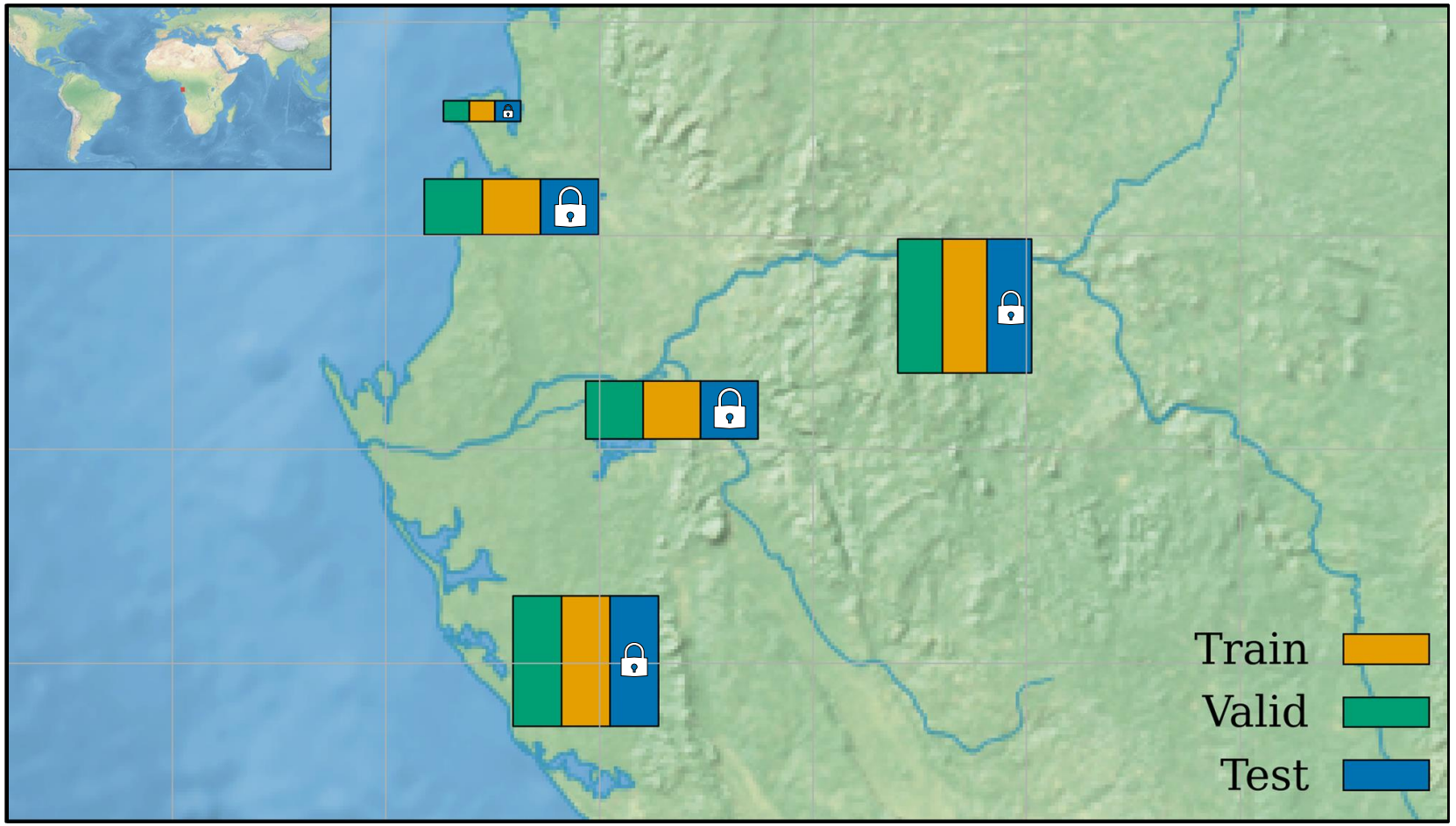


Digital Elevation Model



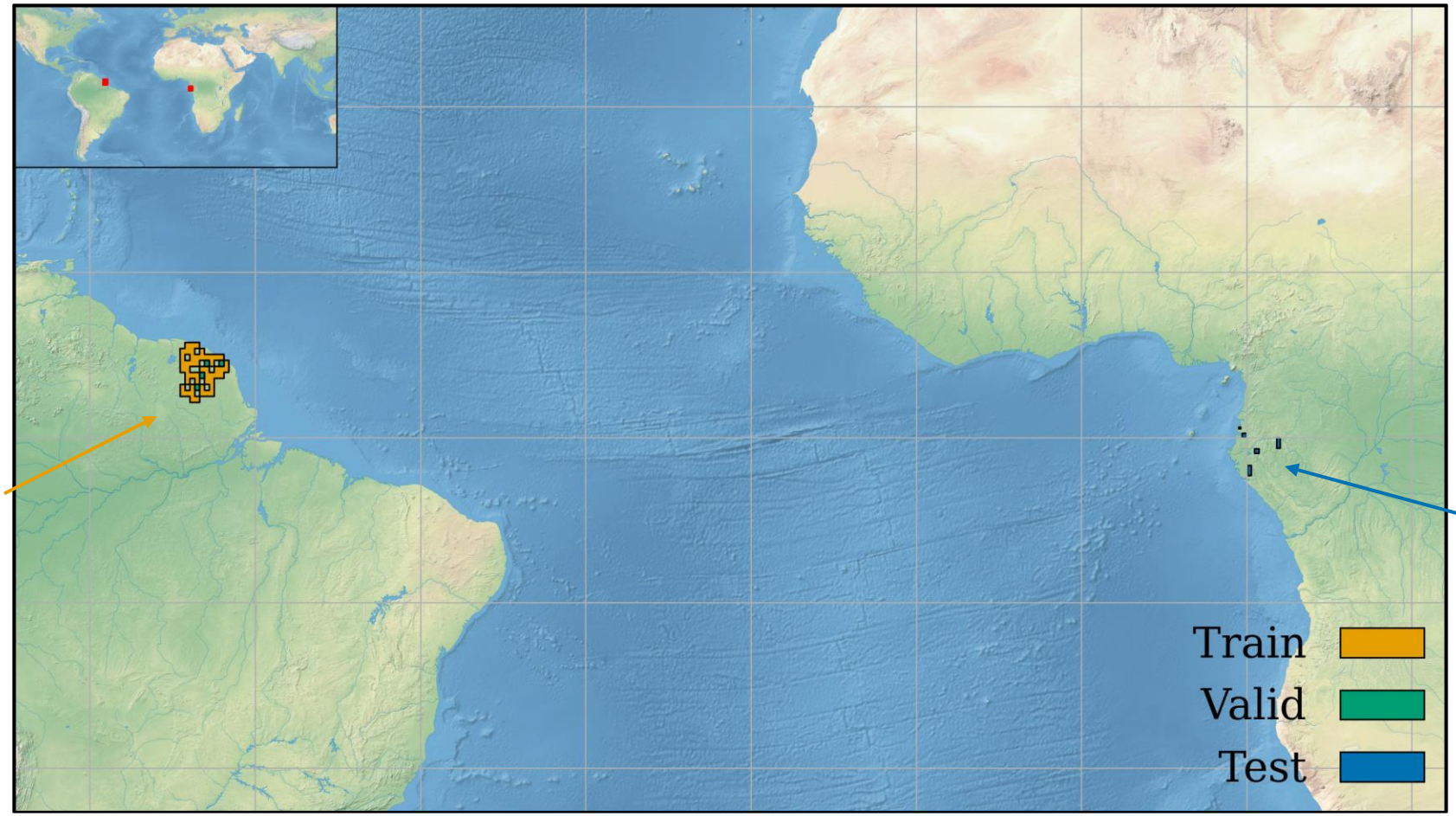
SIN & COS Phase

Test Scenarios

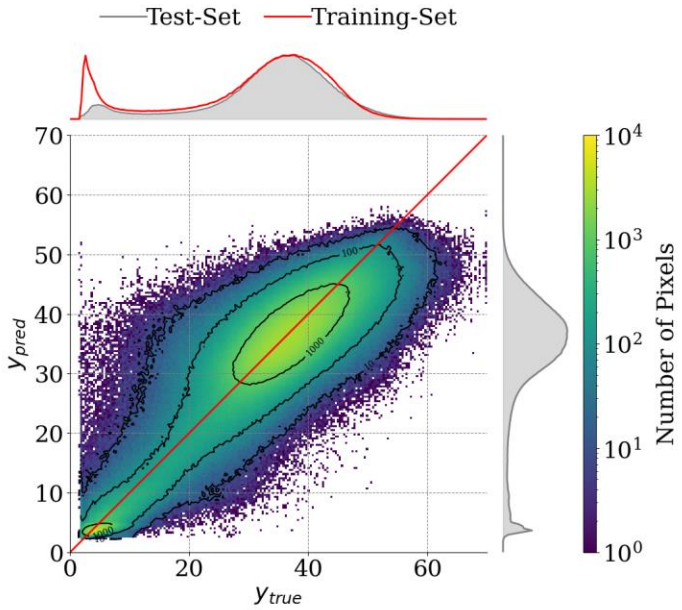


Gabon

Test Scenarios



Evaluation



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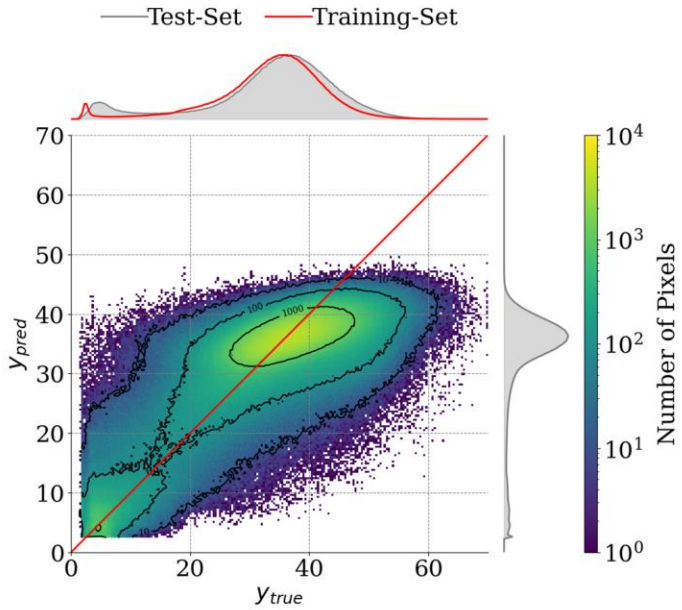


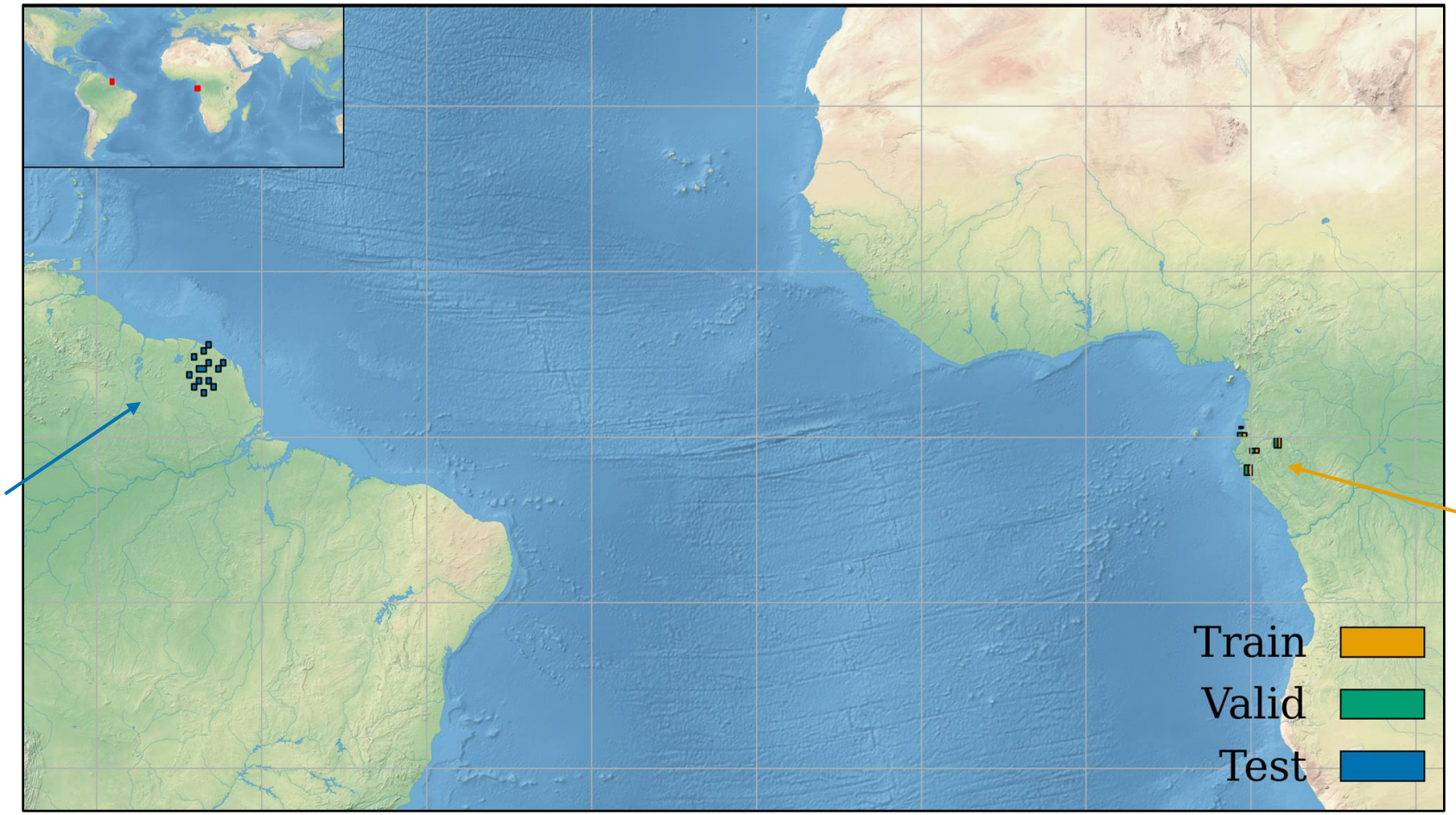
GUF → GAB

ME	$RMSE$	R^2	$\frac{RMV}{RMSE}$	ECE
-2,07 m	6,63 m	0,68	1,16	1,05
↓ 1,68 m	↑ 43%	↓ 17%	↑ 15%	↑ 0,90

w.r.t. GAB → GAB

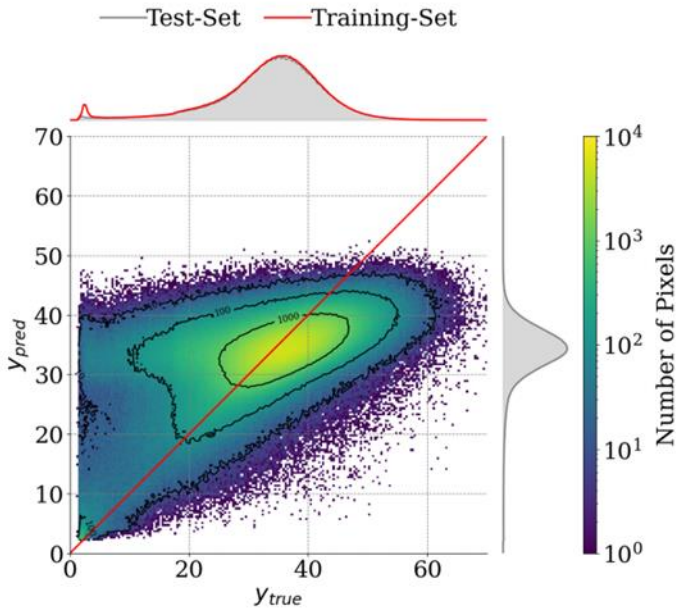
Test Scenarios

French Guiana



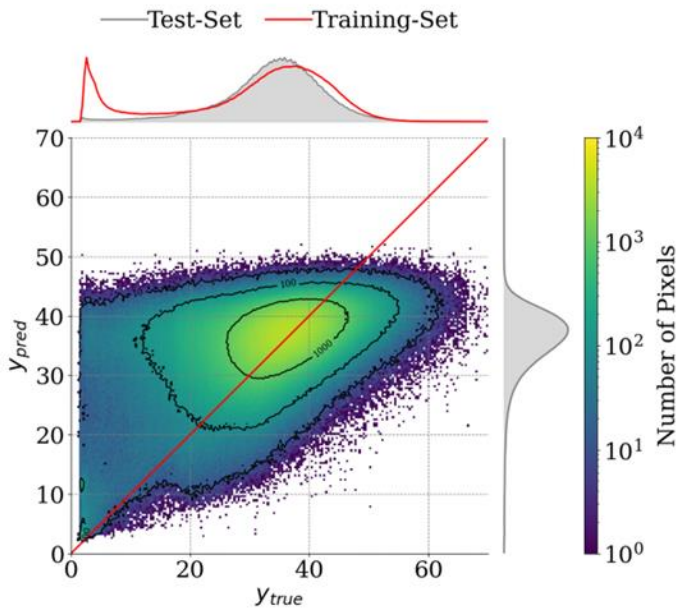
Gabon

Evaluation



GUF → GUF

ME	$RMSE$	R^2	$\frac{RMV}{RMSE}$	ECE
-0,20 m	6,88 m	0,35	0,99	0,10

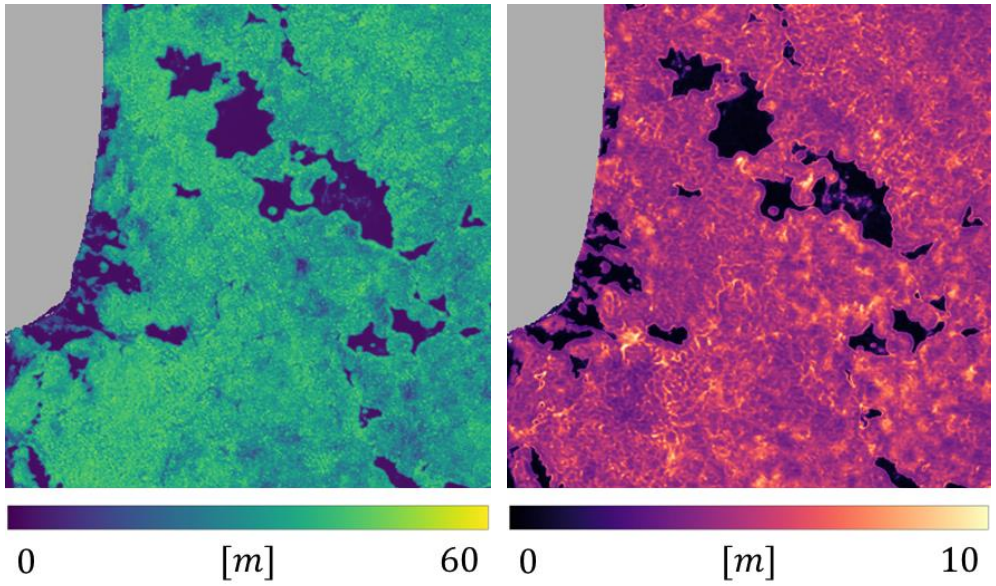


GAB → GUF

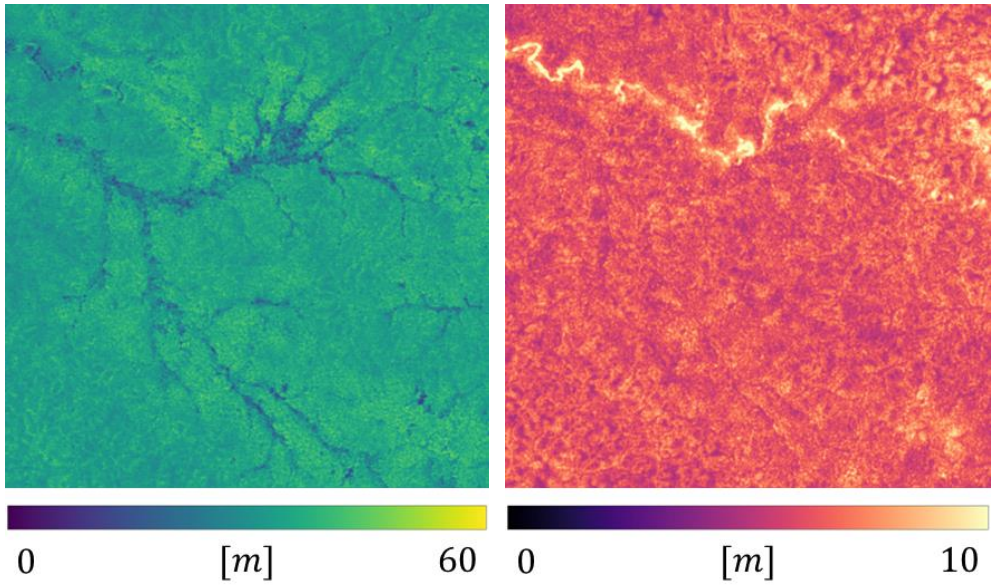
ME	$RMSE$	R^2	$\frac{RMV}{RMSE}$	ECE
1,73 m	7,81 m	0,16	0,74	2,09
↑ 1,53 m	↑ 14%	↓ 54%	↓ 25%	↑ 1,99

w.r.t. GUF → GUF

Some Insights on Performance



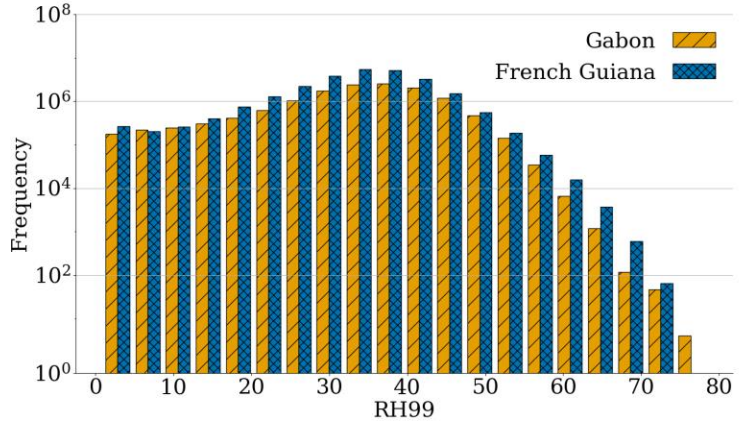
South of Pongara, Gabon



South-East of Mana, French Guiana

Some Insights on Performance

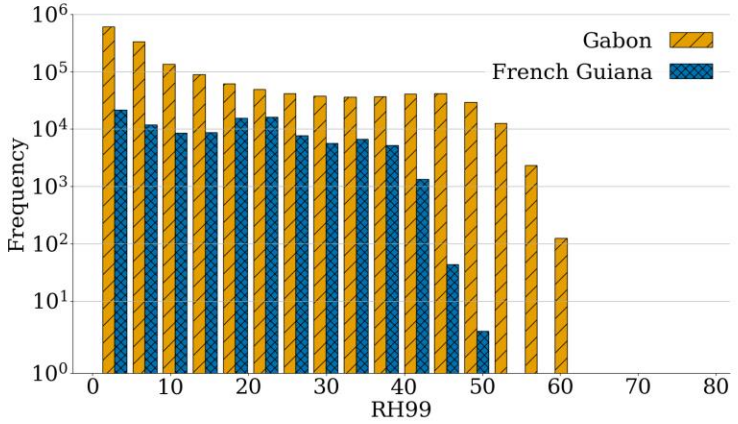
Inland Rainforest



GUF → GAB

ME	RMSE	R^2	$\frac{RMV}{RMSE}$	ECE
-1,54 m	5,85 m	0,48	1,28	1,72

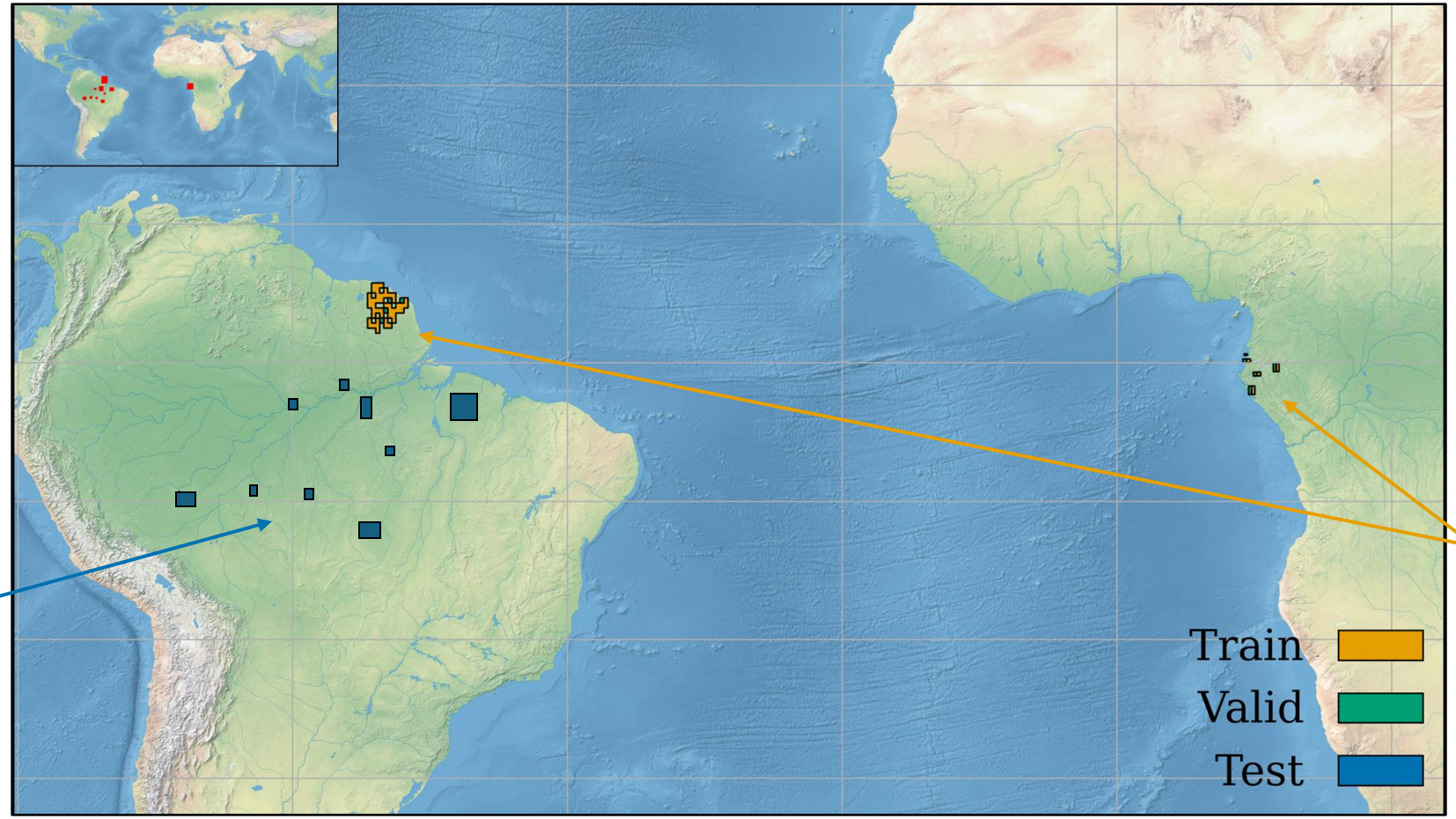
Mangrove



GUF → GAB

ME	RMSE	R^2	$\frac{RMV}{RMSE}$	ECE
-5,44 m	8,95 m	0,66	0,70	2,41

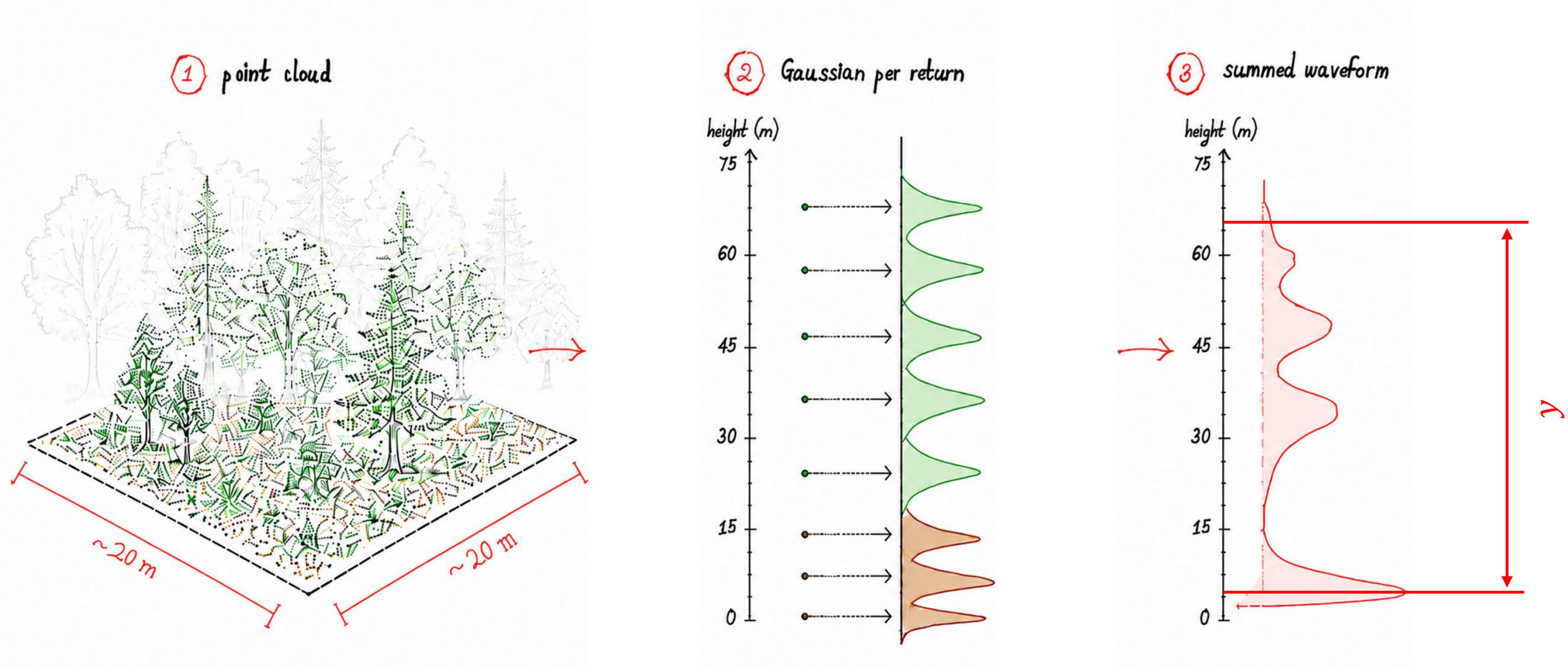
Test Scenarios



Amazon

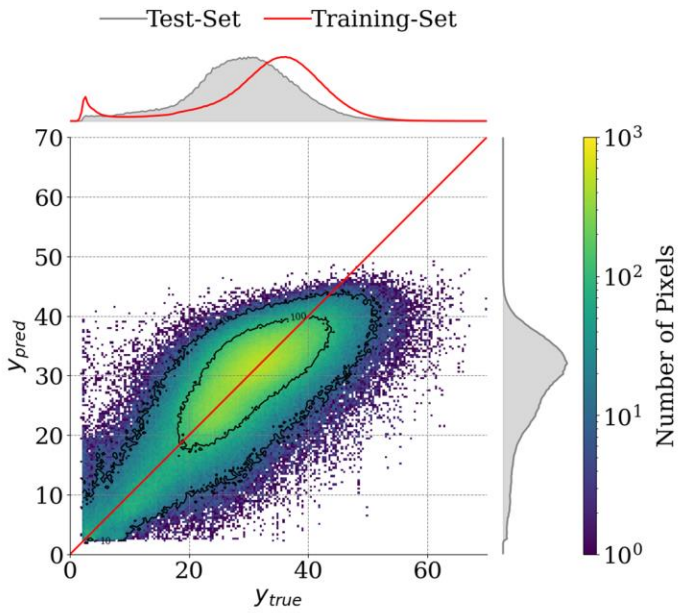
Gabon &
French Guiana

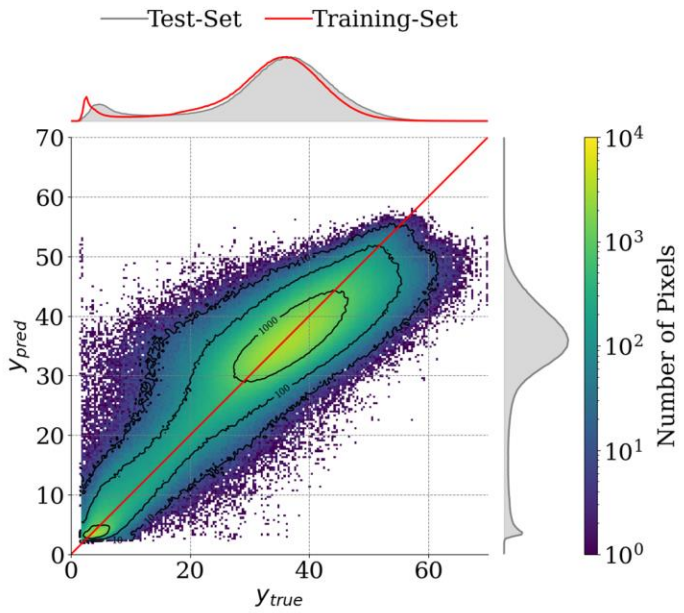
Where LVIS Did Not Acquire

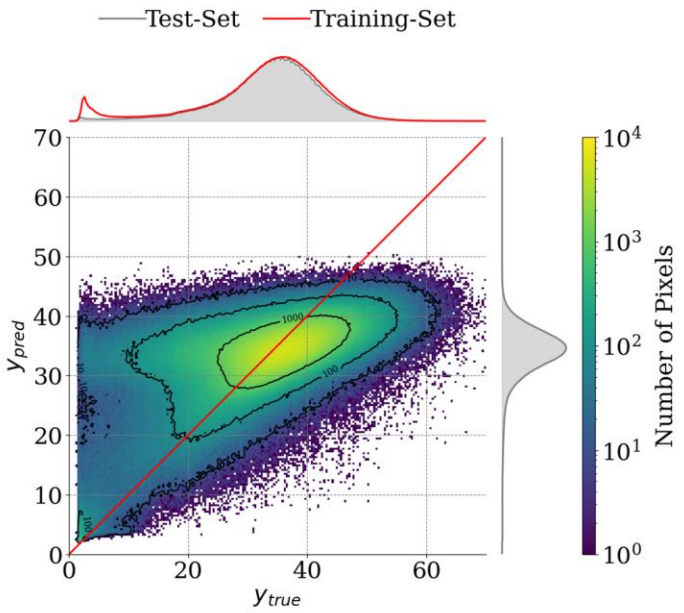


The **sensor** may **change**, the **target must not**: canopy height must be defined in the same way.

Evaluation







GAB + GUF → AMZ

ME	$RMSE$	R^2	$\frac{RMV}{RMSE}$	ECE
-0,69 m	5,61 m	0,59	1,03	0,53

GAB + GUF → GAB

ME	$RMSE$	R^2	$\frac{RMV}{RMSE}$	ECE
-0,27 m	4,53 m	0,84	1,11	0,49
↑ 0,12 m	↓ 2%	↑ 1%	↓ 9%	↓ 0,34

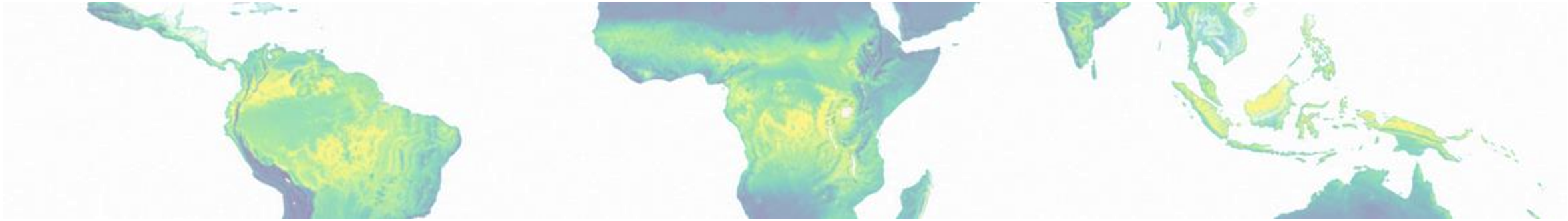
w.r.t. GAB → GAB

GAB + GUF → GUF

ME	$RMSE$	R^2	$\frac{RMV}{RMSE}$	ECE
-0,17 m	6,90 m	0,35	1,00	0,05
↑ 0,03 m	-	-	↑ 1%	↓ 0,05

w.r.t. GUF → GUF

Outlook



TanDEM-X Pantropical Canopy Height Map.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