Integrating radar and multi-spectral data to detect cocoa crops: a deep learning approach

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Philip van der Lugt

CO-READER
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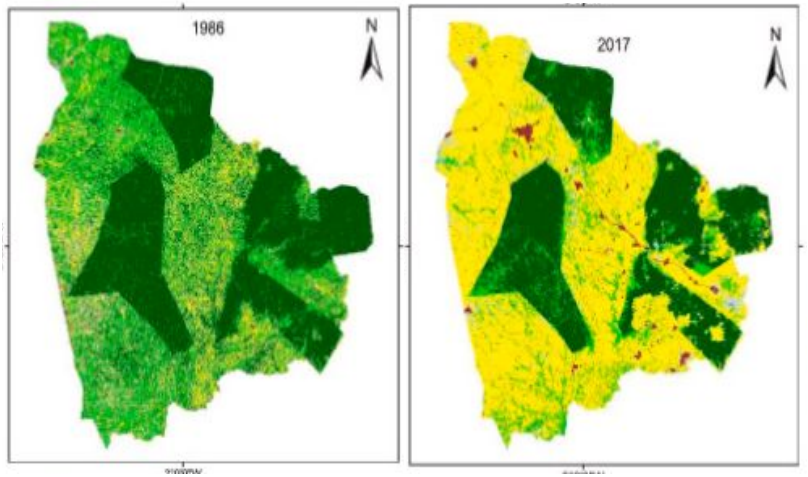
MERIDIA

MOTIVATION

DEFORESTATION



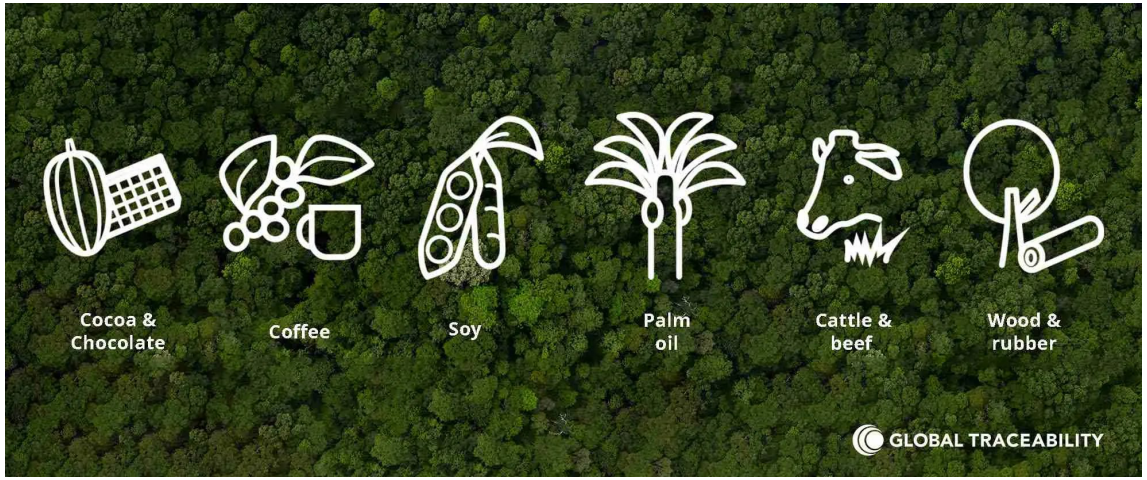
Adapted from Ashiagbor et al., 2022

7.54%
of EU-driven deforestation

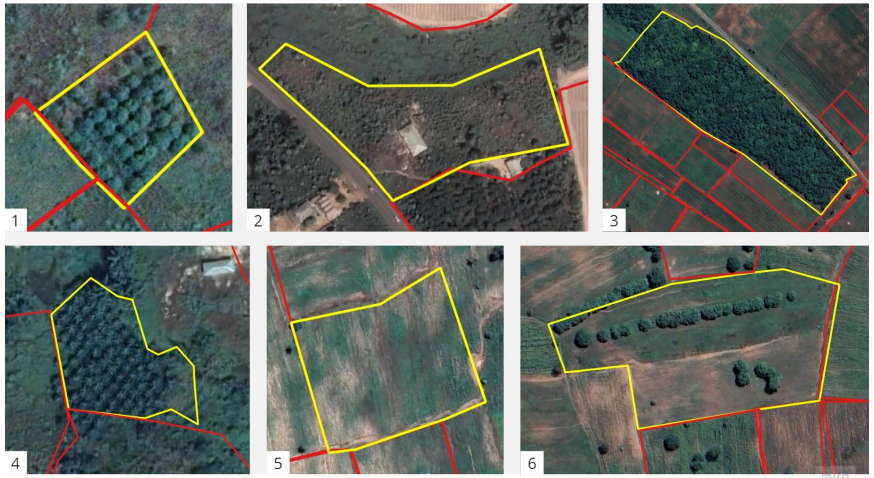
COCOA PRODUCTION

Meridia, 2020

EU DEFORESTATION REGULATION



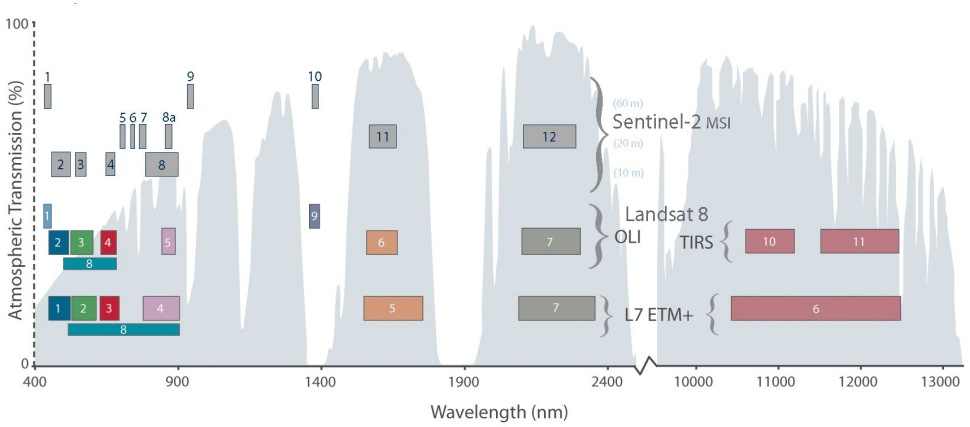
DETECTION CHALLENGES



Satellite data: Google Earth accessed via QGIS XYZ tiles layer connection | Polygon data: Meridia B.V.

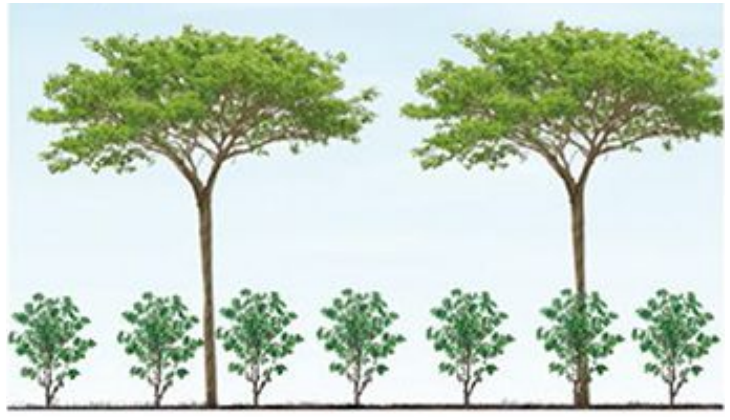
MULTISPECTRAL IMAGERY

MULTISPECTRAL IMAGERY



NASA 2015

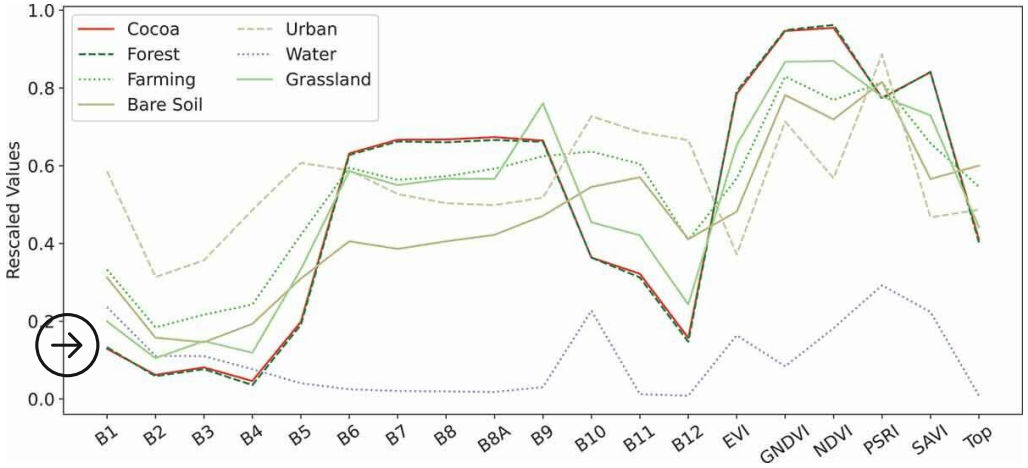
MONOCROP CANOPY



Adapted from Orozco-Aguilar et al., 2021

WEkEO, 2020

SPECTRAL SIMILARITY



Batista et al., 2022

VEGETATION SIMILARITY

Google Earth accessed via QGIS XYZ tiles layer connection

MULTISPECTRAL IMAGERY

INTERCROP FARMS

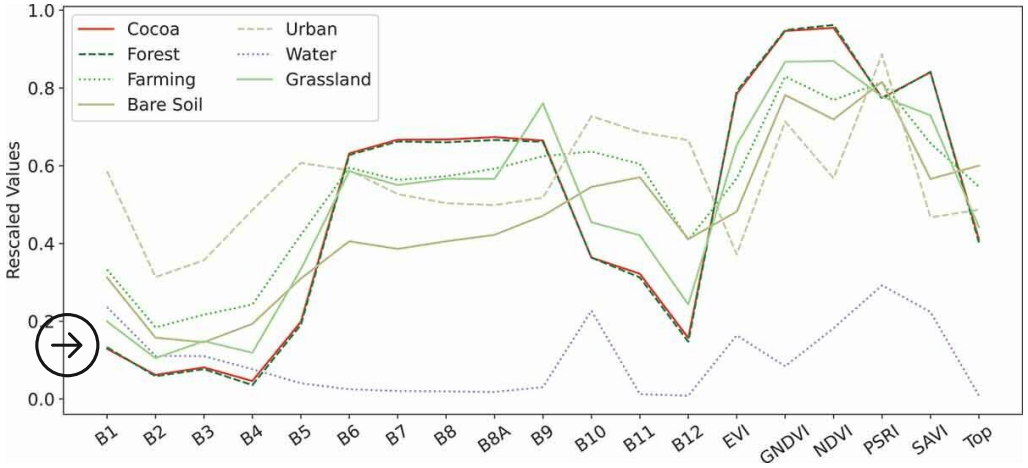
Google Earth accessed via QGIS XYZ tiles layer connection

AGROFORESTRY

MONOCROP CANOPY

Adapted from Orozco-Aguilar et al., 2021

SPECTRAL SIMILARITY



Batista et al., 2022

VEGETATION SIMILARITY

Google Earth accessed via QGIS XYZ tiles layer connection

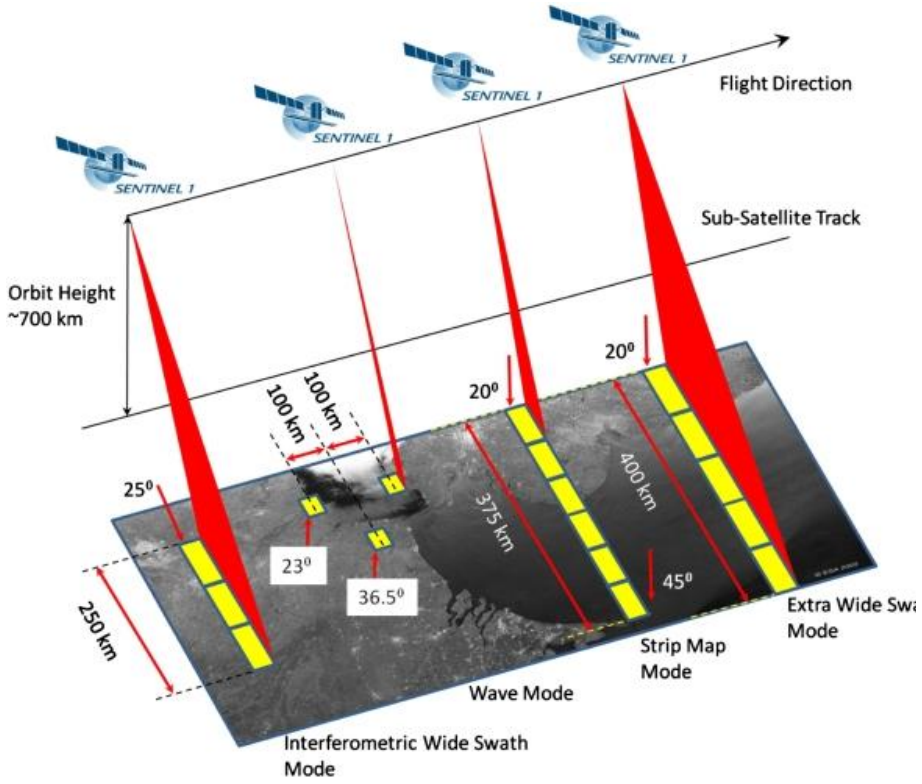
MULTISPECTRAL IMAGERY

CLOUD COVER

WEkEO, 2020

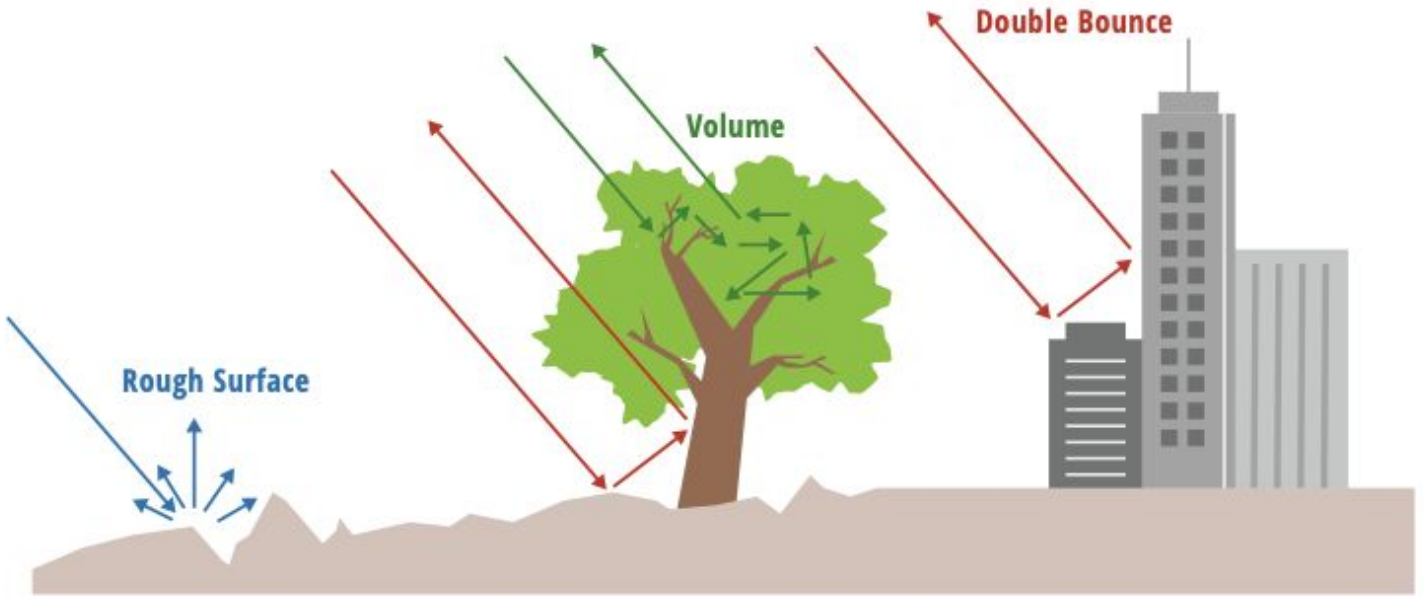
SYNTHETIC APERTURE RADAR

ACTIVE REMOTE SENSING



European Space Agency

BACKSCATTER



Alaska Satellite Facility

Co-polarized

VV

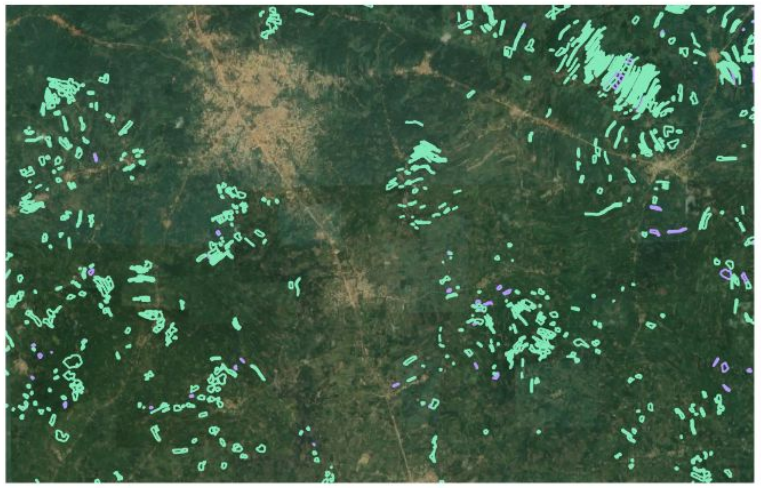
Cross-polarized

VH

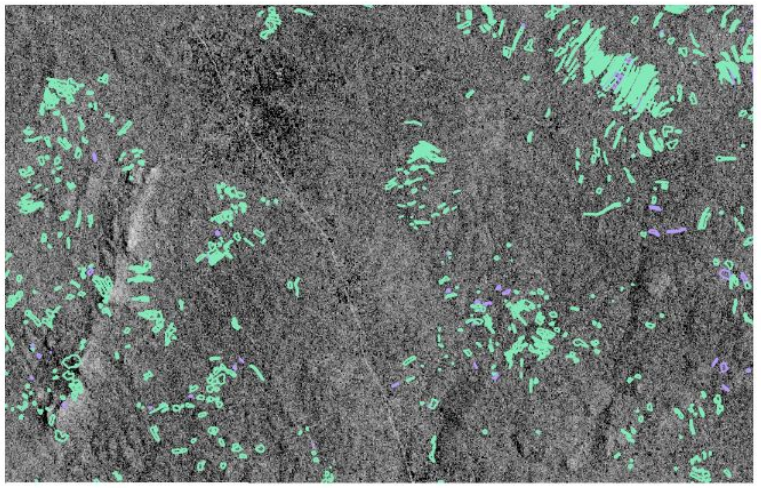
SYNTHETIC APERTURE RADAR

BACKSCATTER MAP

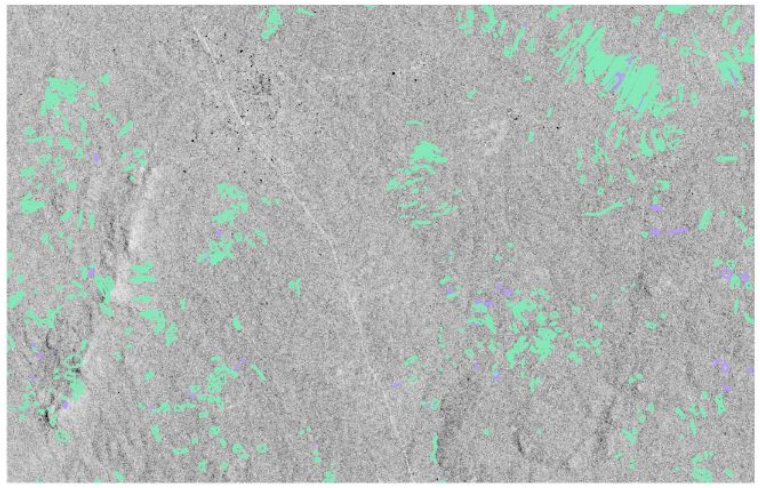
RGB
(Google Earth Satellite)



SAR - VV
(Sentinel 1)



SAR - VH
(Sentinel 1)



0 1 2 km

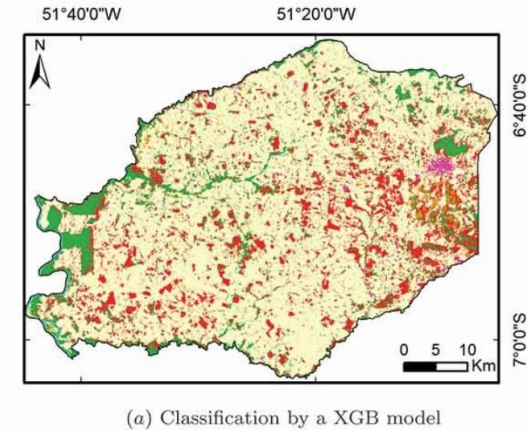
Monocrop cocoa

Backscatter

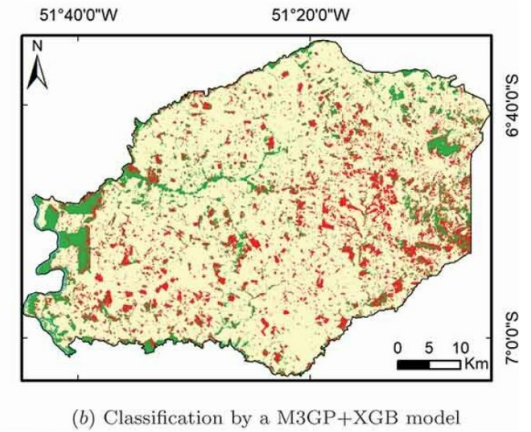
0 400

RELATED WORK

MSI



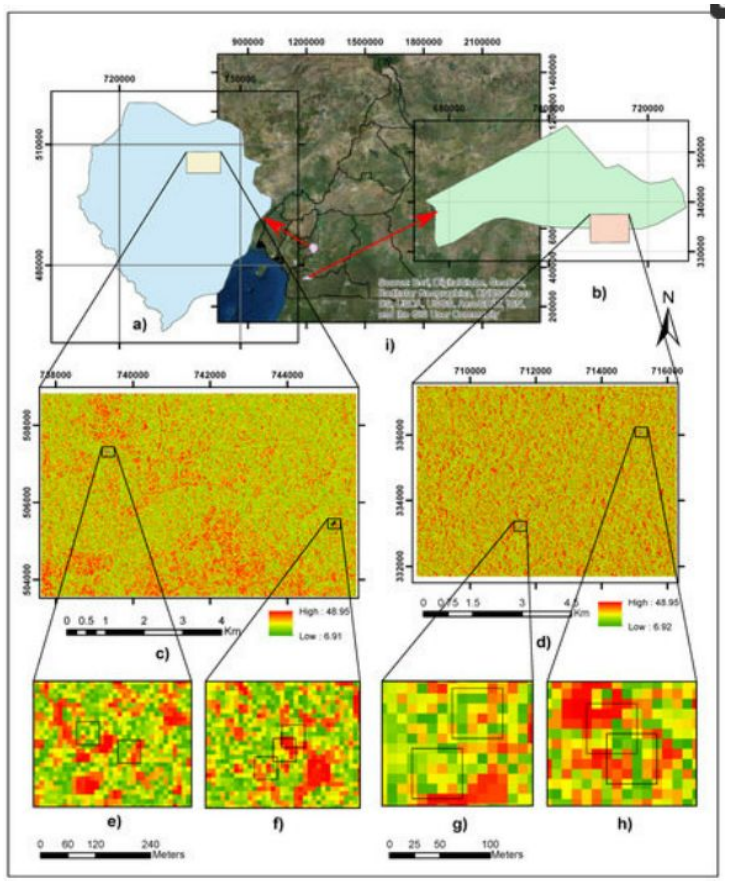
(a) Classification by a XGB model



(b) Classification by a M3GP+XGB model

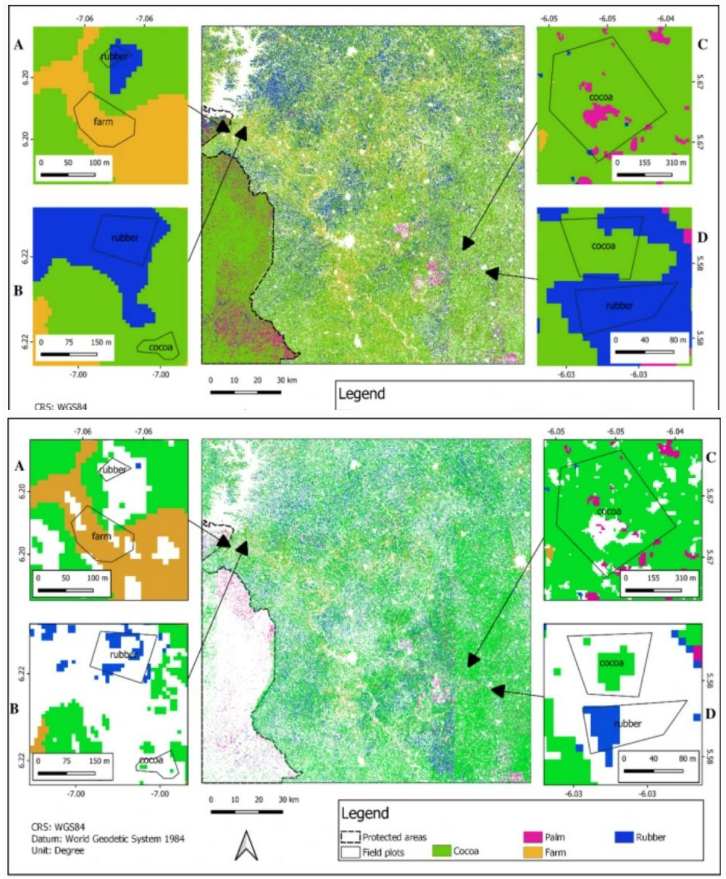
Batista et al., 2022

SAR



Numbisi & Van Coillie, 2020

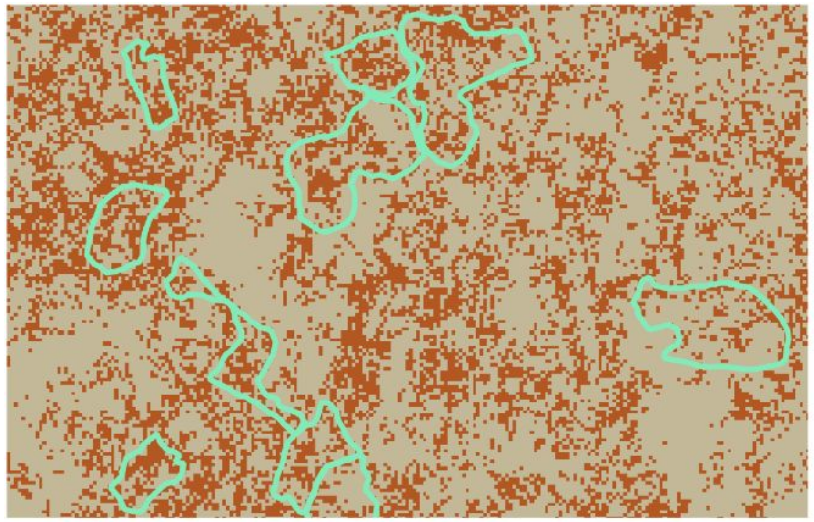
MSI + SAR



Kanmegne Tamga et al., 2022

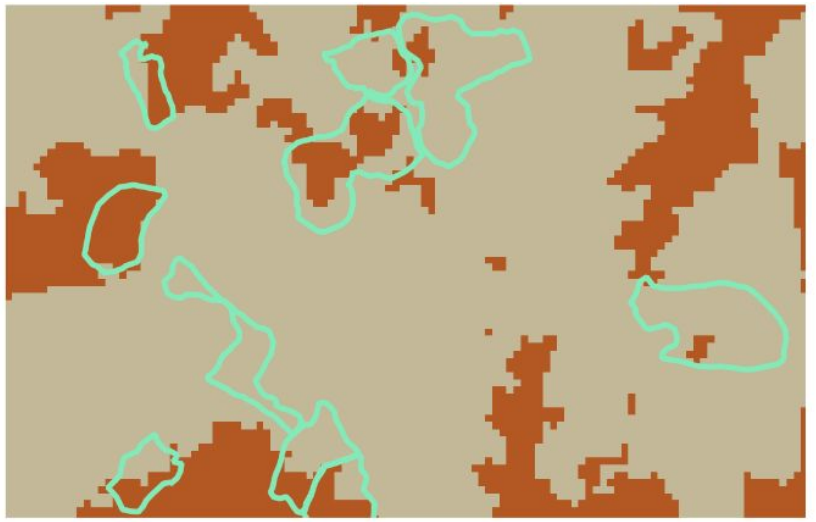
RELATED WORK

Pixel-based classification



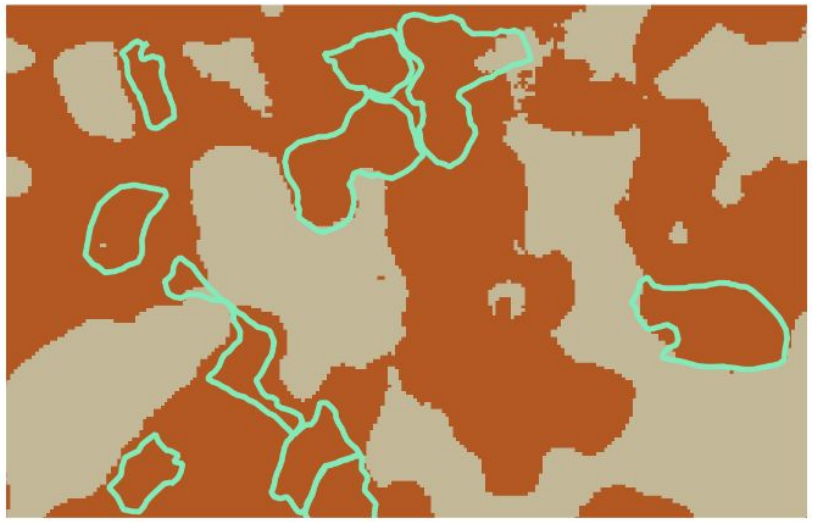
Adapted from
Abu et al., 2021

Object-based classification



Adapted from
Vivid Economics and RSAC, IMAGES, 2020

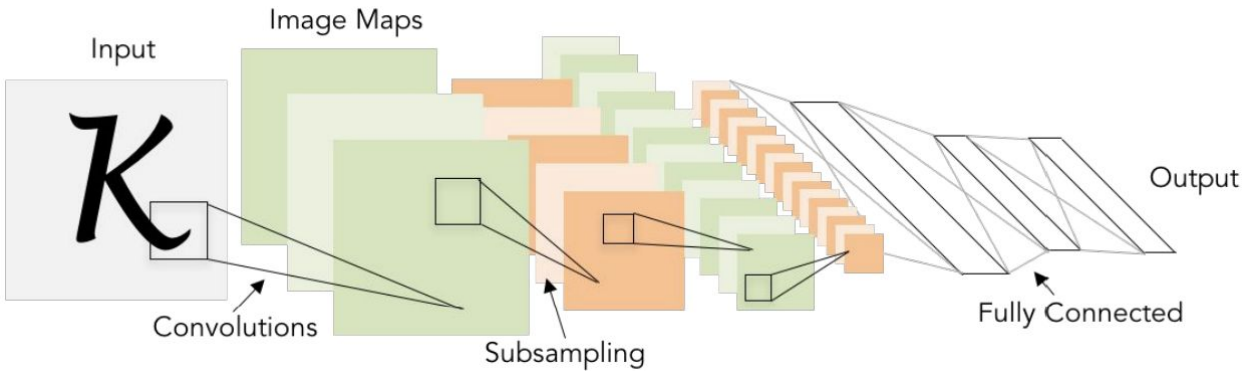
Semantic segmentation



Adapted from
Kalischek et al., 2022

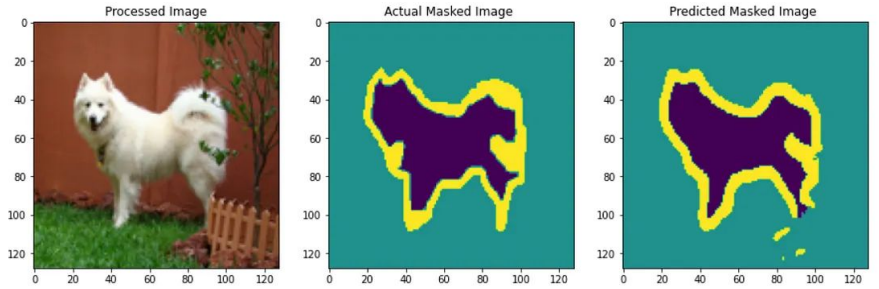
DEEP LEARNING

CONVOLUTIONAL NEURAL NETWORK



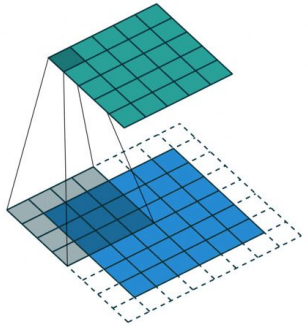
Fei-Kei et al., 2023

SEMANTIC SEGMENTATION



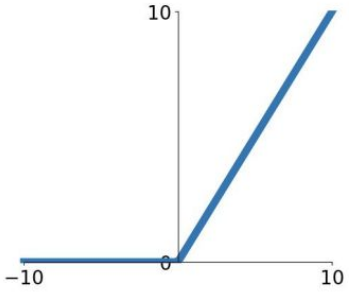
Bhatia, 2021

CONVOLUTIONAL LAYER



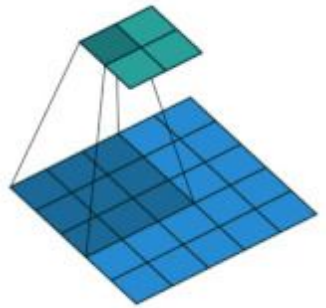
Dumoulin & Visin, 2016

ACTIVATION FUNCTION



Fei-Kei et al., 2023

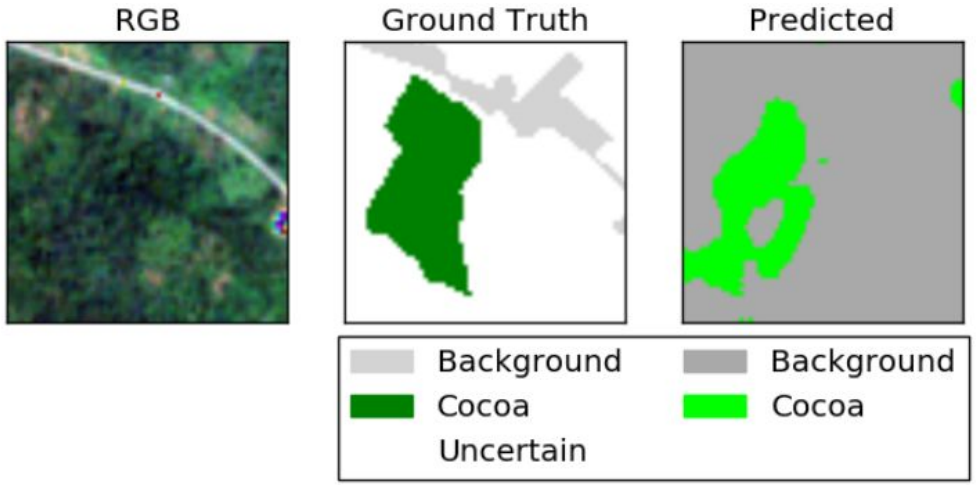
POOLING LAYER



Dumoulin & Visin, 2016

SEMANTIC SEGMENTATION

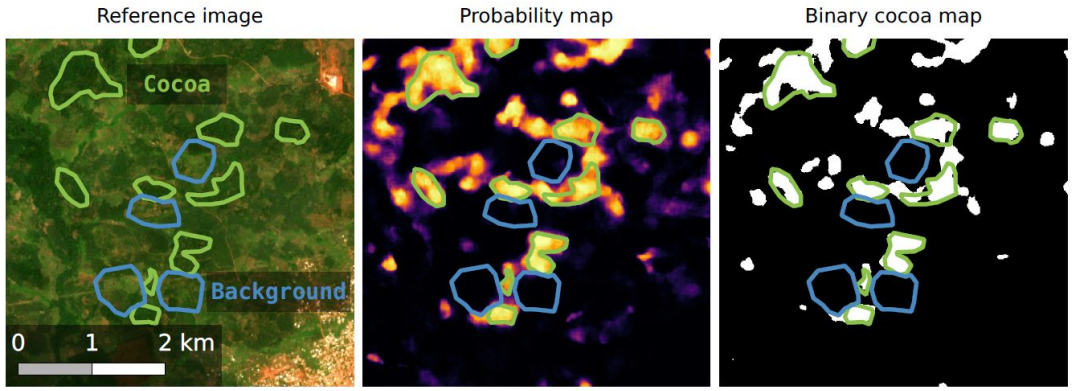
U-NET



Adapted from Bonet Filella, 2018

75% accuracy

XCEPTION

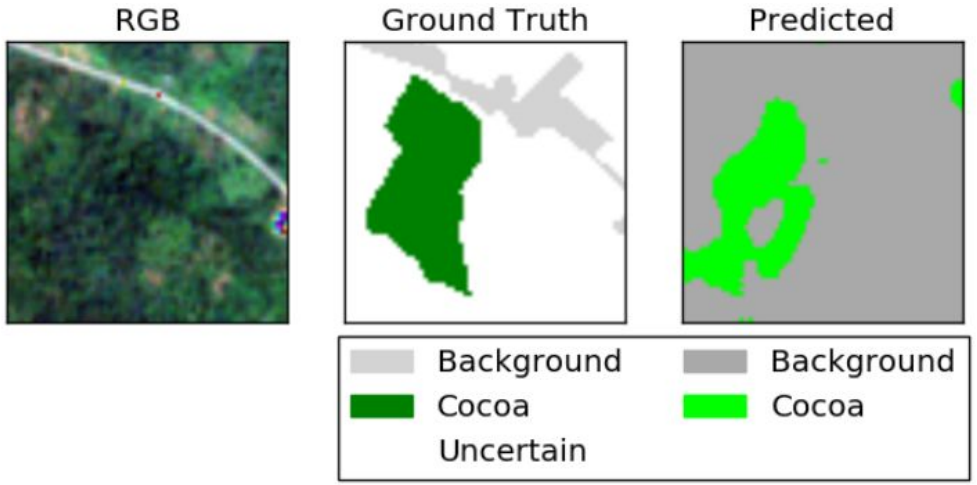


Adapted from Kalischek et al., 2022

85% accuracy

SEMANTIC SEGMENTATION

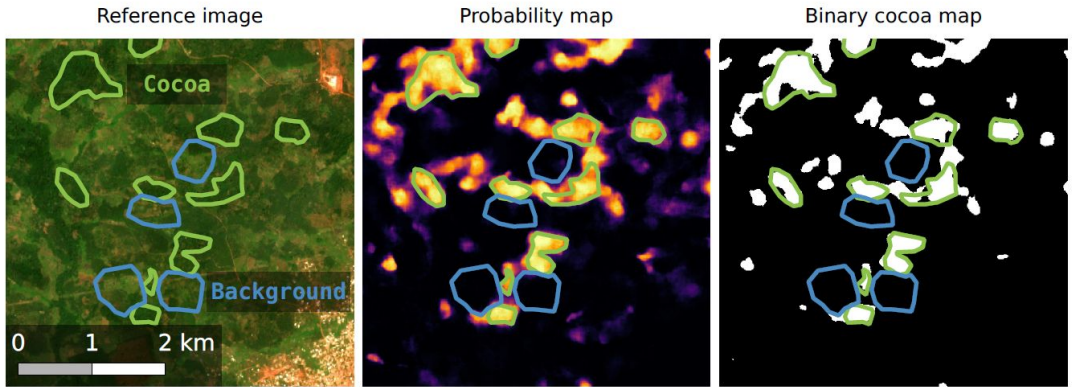
U-NET



Adapted from Bonet Filella, 2018

MSI

XCEPTION



Adapted from Kalischek et al., 2022

MSI
+ height prediction

RESEARCH QUESTIONS

To what extent can a Convolutional Neural Network (CNN) trained with multispectral imagery (MSI) **and** Synthetic Aperture Radar (SAR) datasets enable the automated detection of cocoa crops in Ghana?

1. How does the combination of MSI and SAR data affect the results of cocoa parcel segmentation trained with data from a *single day*?
2. How does the combination of MSI and SAR data affect the results of cocoa parcel segmentation trained with *temporal* datasets?
3. Why does the use of different *polarizations* (i.e. Vertical-Vertical (VV) or Vertical-Horizontal (VH)) affect the influence of SAR datasets on the cocoa segmentation results?
4. What is the impact of SAR and MSI training data on the detection of *intercrop* cocoa?

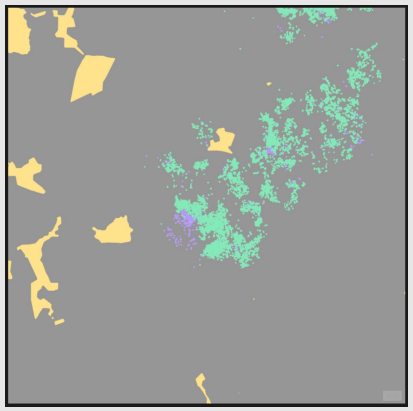
IMPLEMENTATION

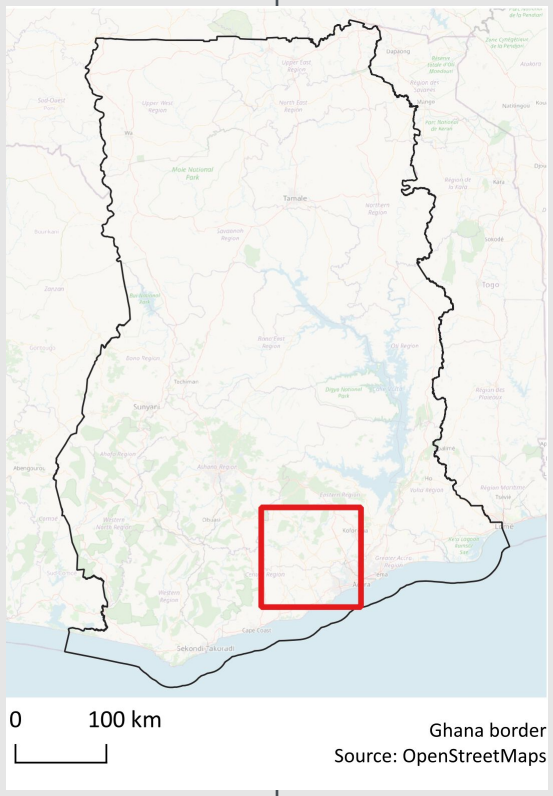
GROUND TRUTH POLYGONS

Monocrop cocoa

Intercrop cocoa

Forest reserves

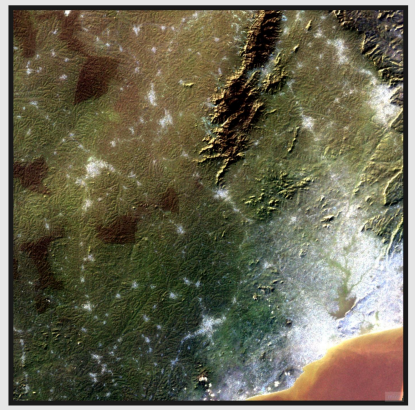




SATELLITE DATA

MSI

SAR



IMPLEMENTATION

GROUND TRUTH POLYGONS

Monocrop cocoa

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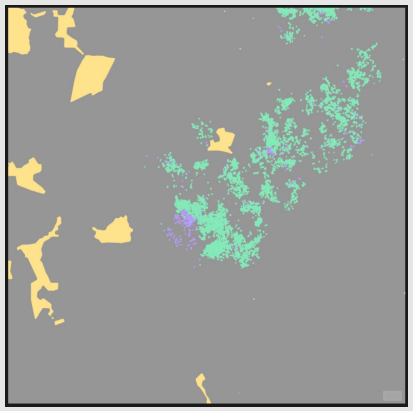
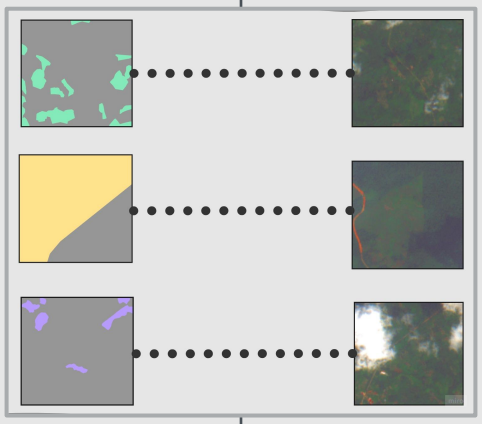
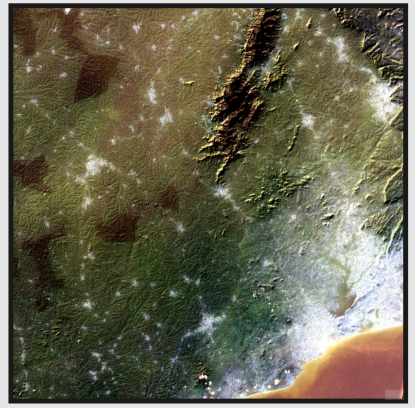




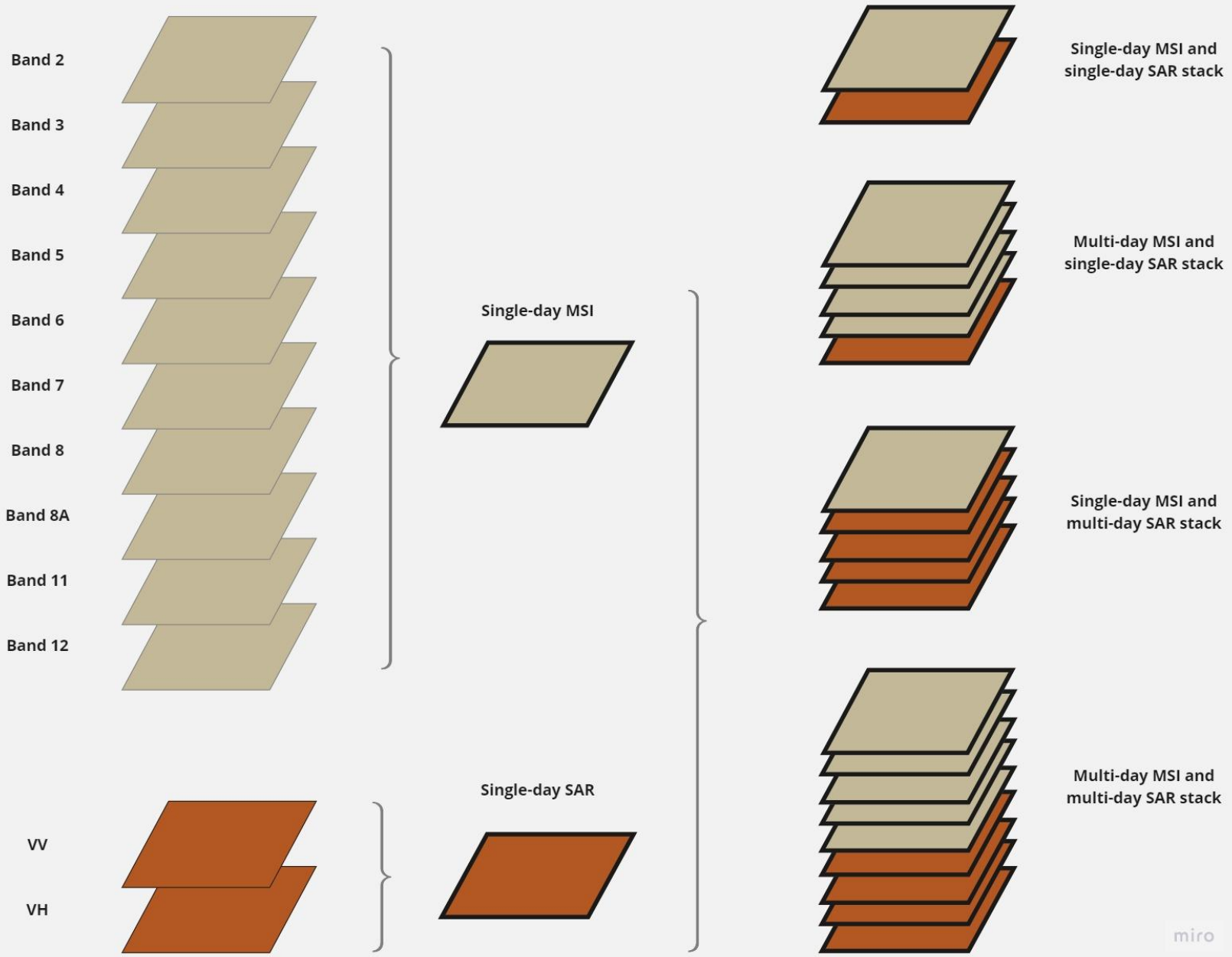
SATELLITE DATA

MSI

SAR

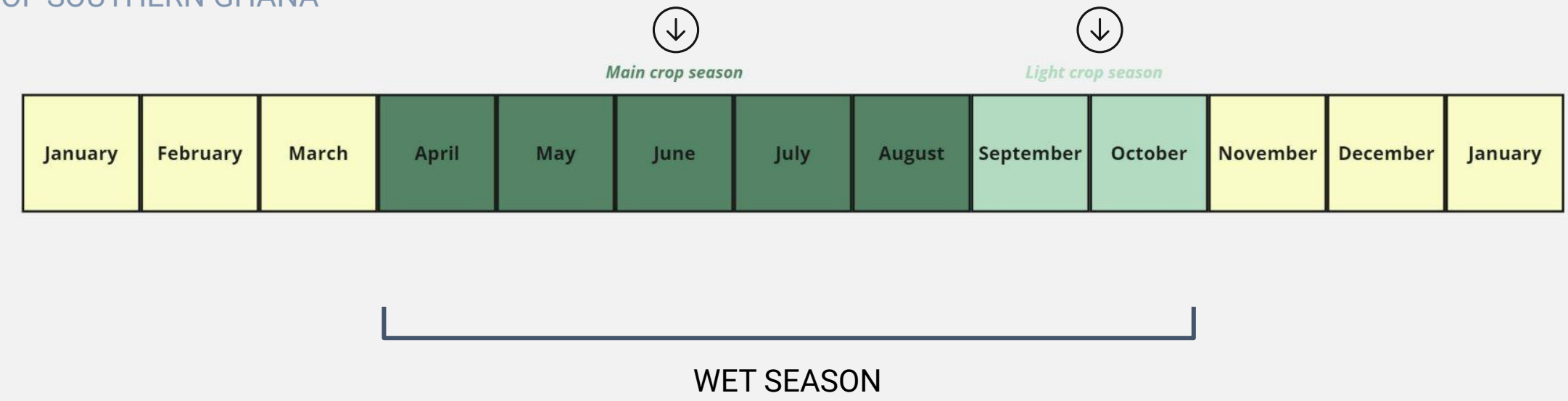


STACKING SATELLITE DATA



TEMPORAL DATA

SEASONS OF SOUTHERN GHANA

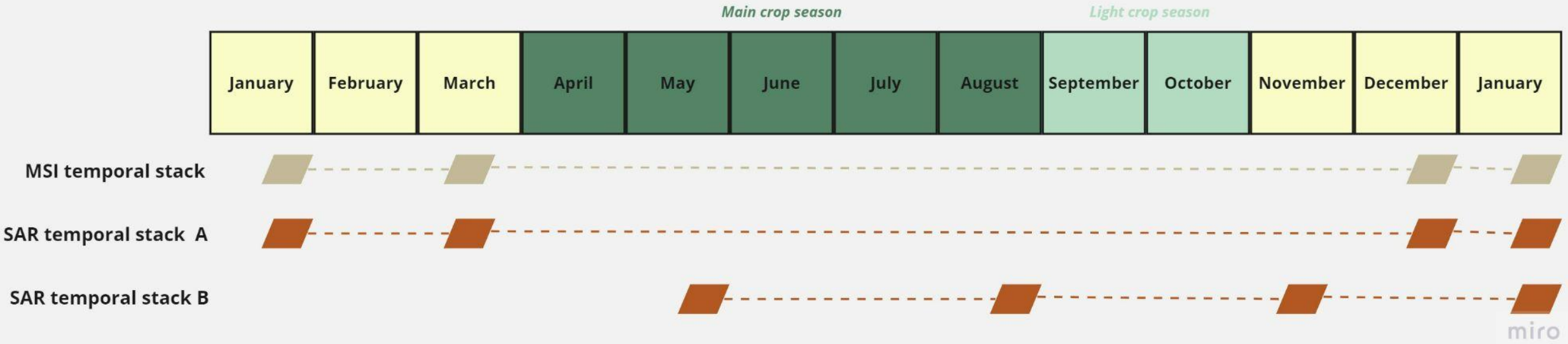


TEMPORAL DATA

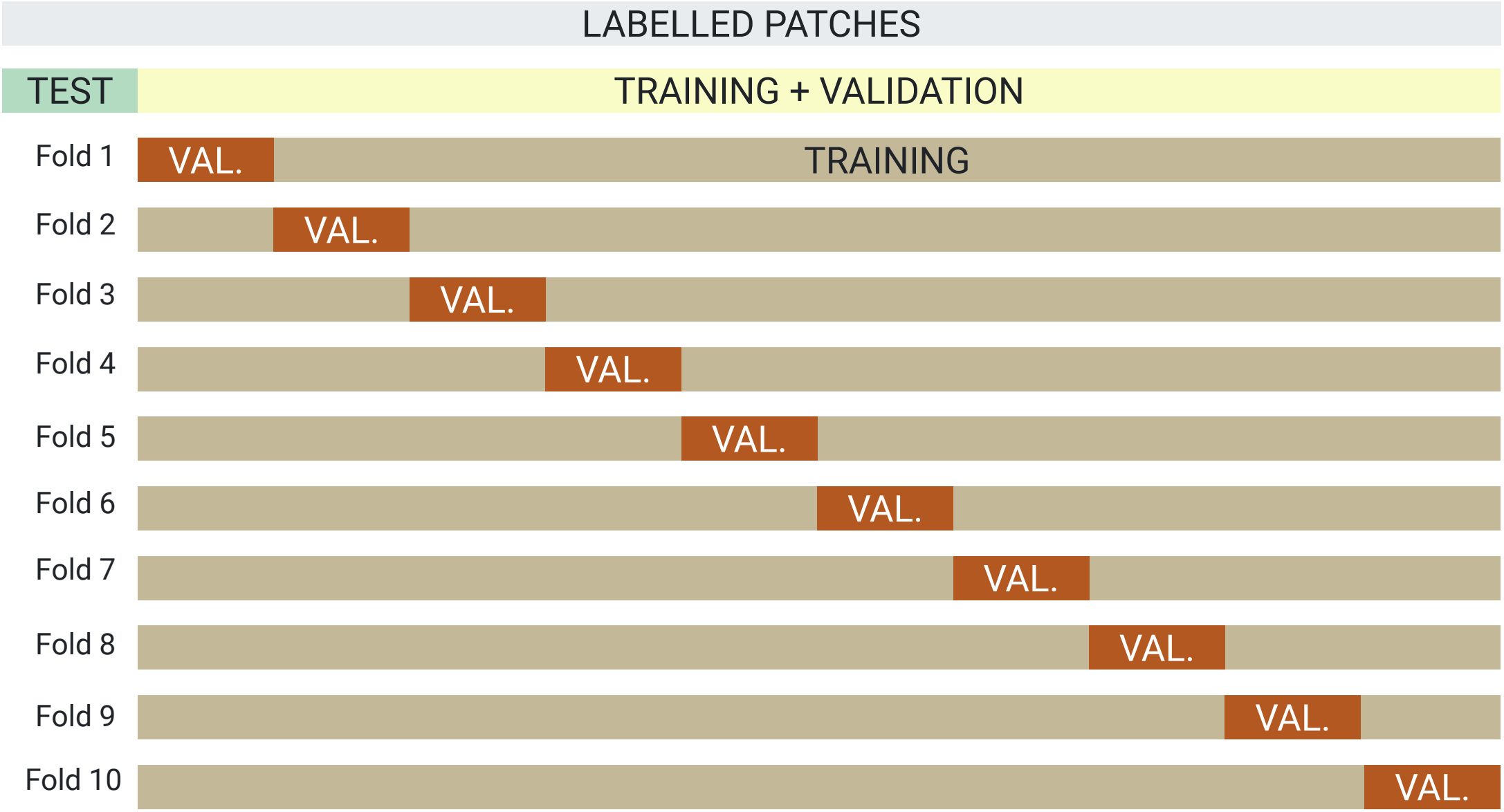
SEASONS OF SOUTHERN GHANA

TEMPORAL DATA

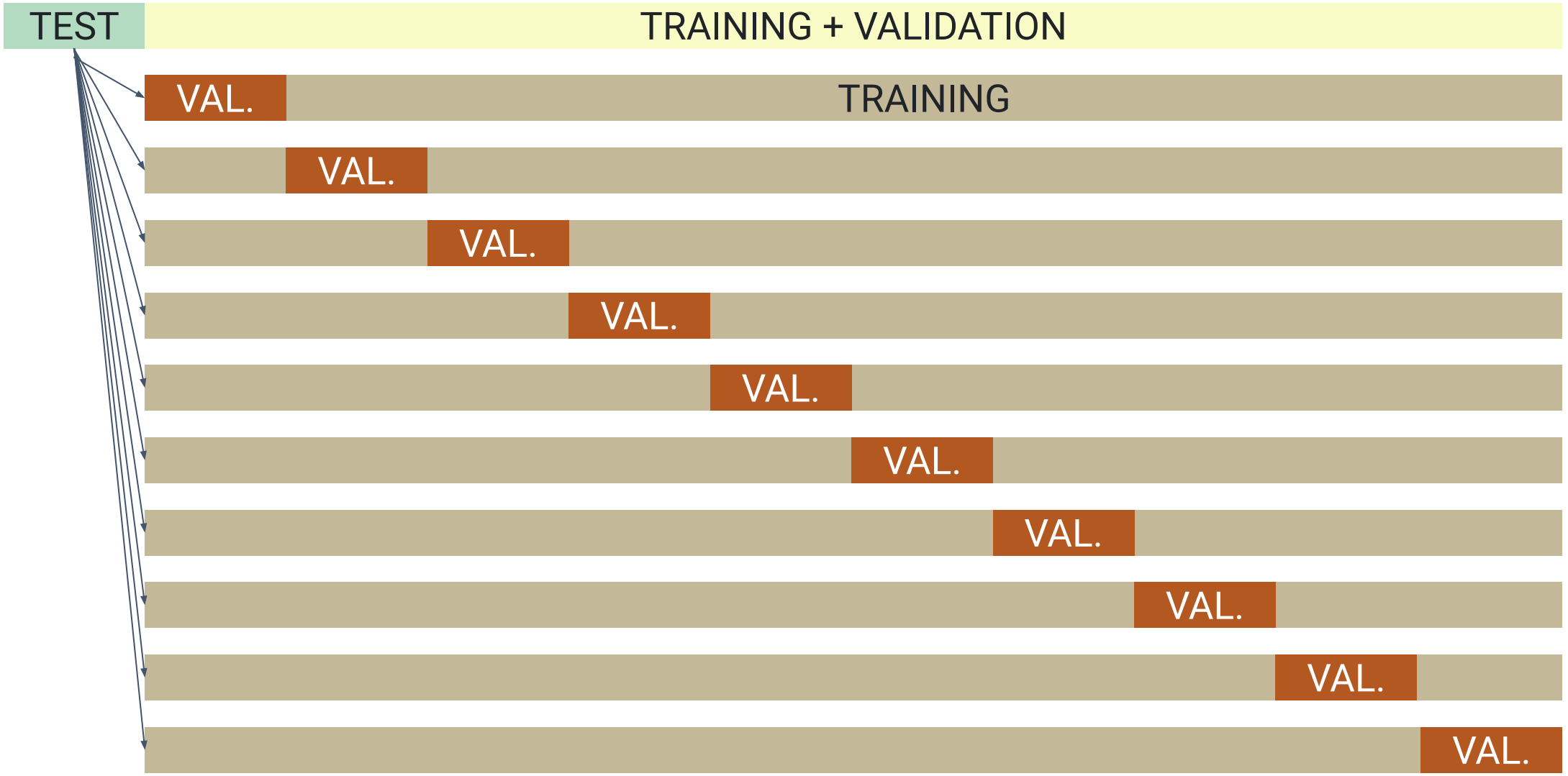
SEASONS OF SOUTHERN GHANA



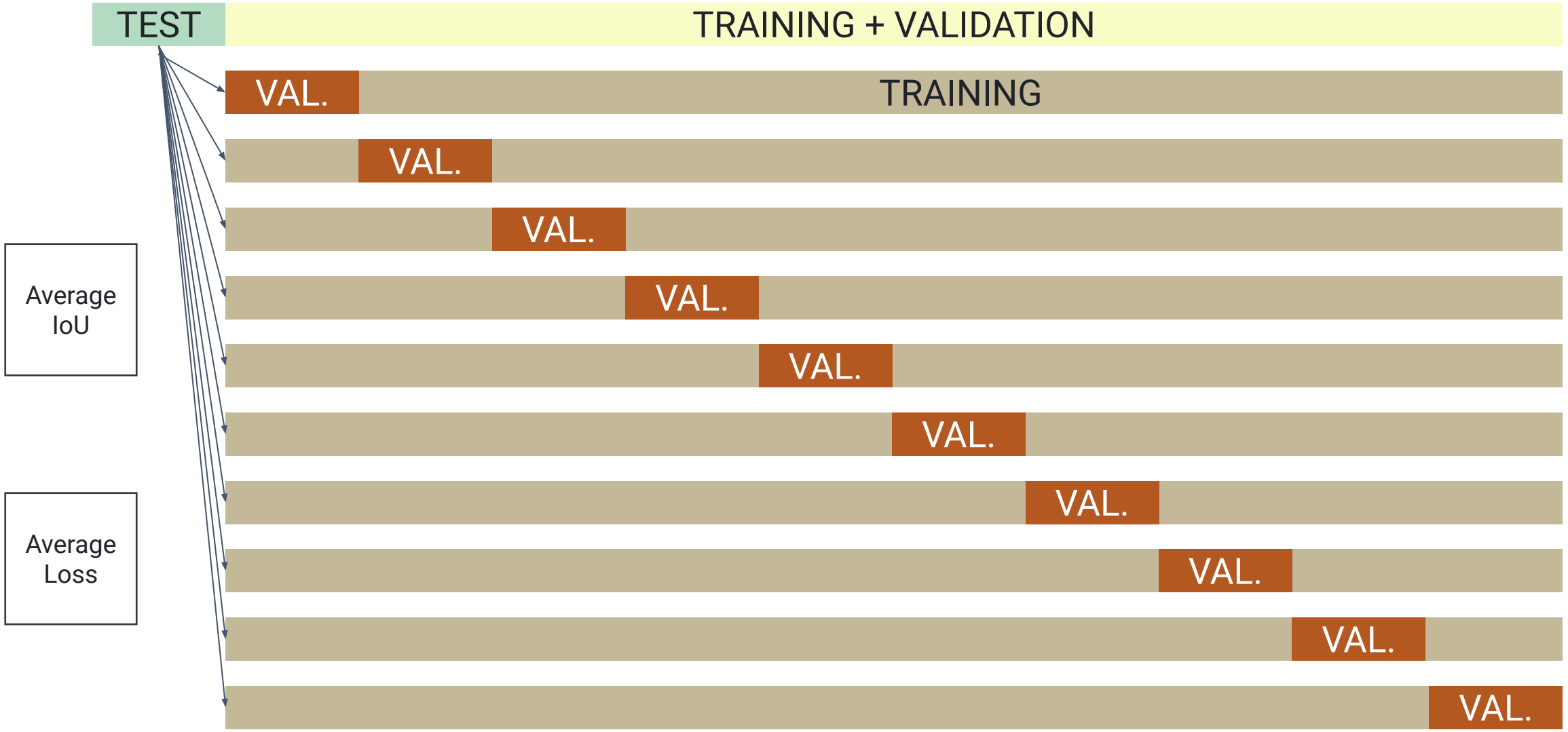
IMPLEMENTATION



IMPLEMENTATION

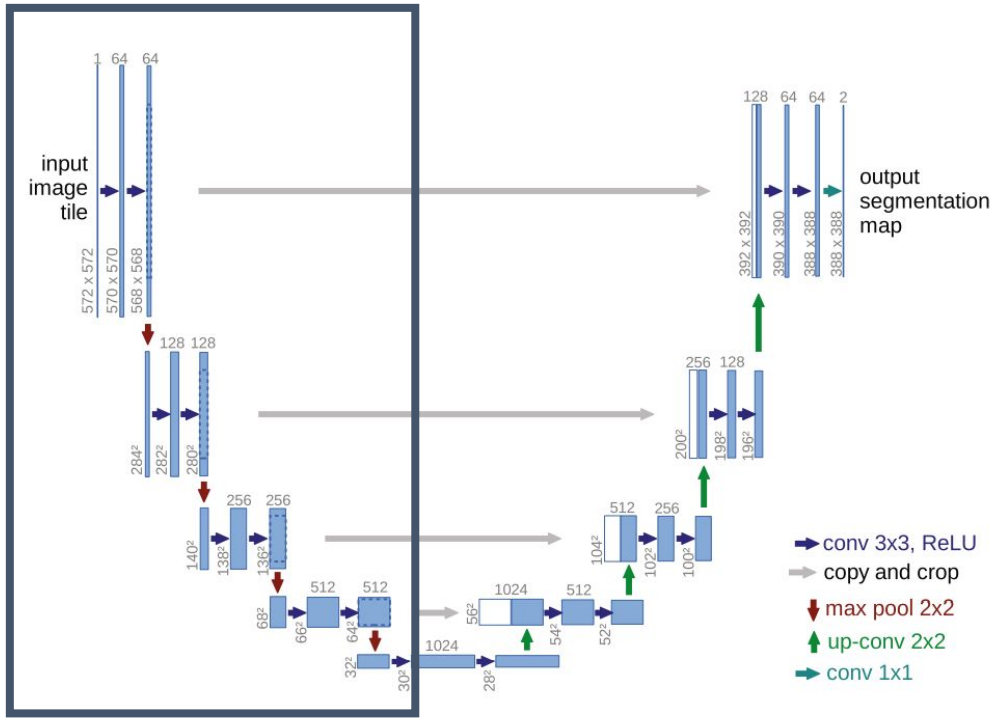


IMPLEMENTATION



IMPLEMENTATION

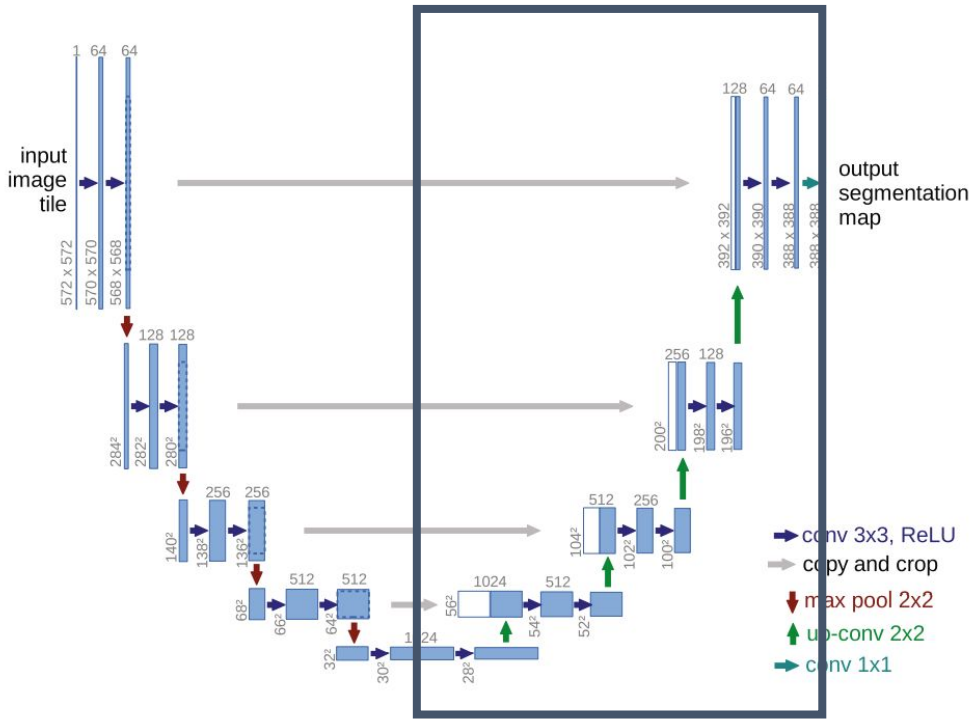
U-NET



(Source: Ronneberger, 2015)

IMPLEMENTATION

U-NET



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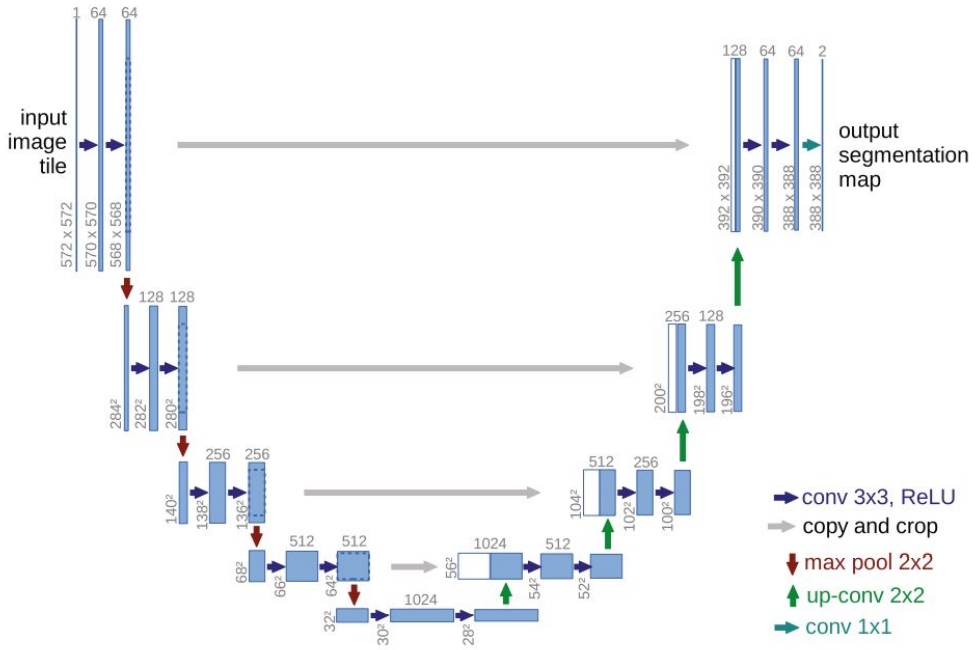
IMPLEMENTATION

U-NET



(Source: Ronneberger, 2015)

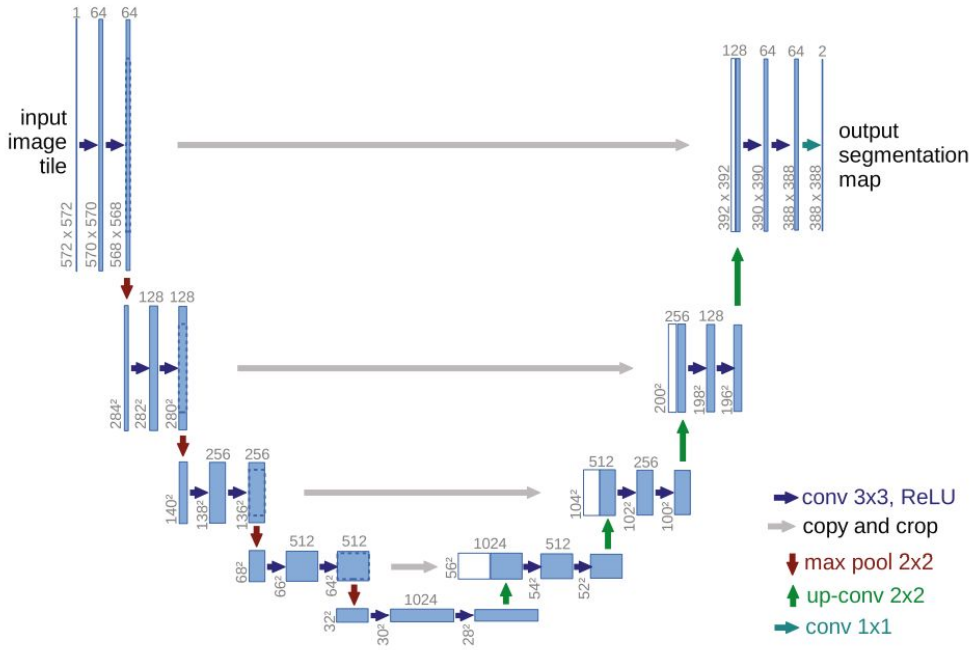
WEIGHTED LOSS

$$w_c = \frac{1}{\frac{n_c}{N}}$$

$$L_{cross-entropy}(\hat{y}, y) = -\frac{1}{N}\sum_{j}^{N}\sum_{c}^{M} w_c y_{c,j} \ln(\hat{y}_{c,j})$$

IMPLEMENTATION

U-NET

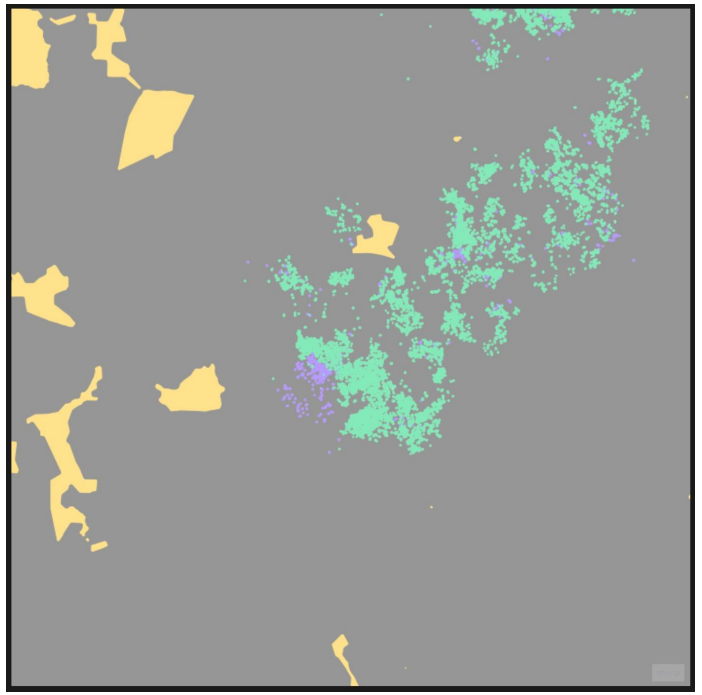


(Source: Ronneberger, 2015)

Forest weight –

Cocoa weight +

Unknown weight 0



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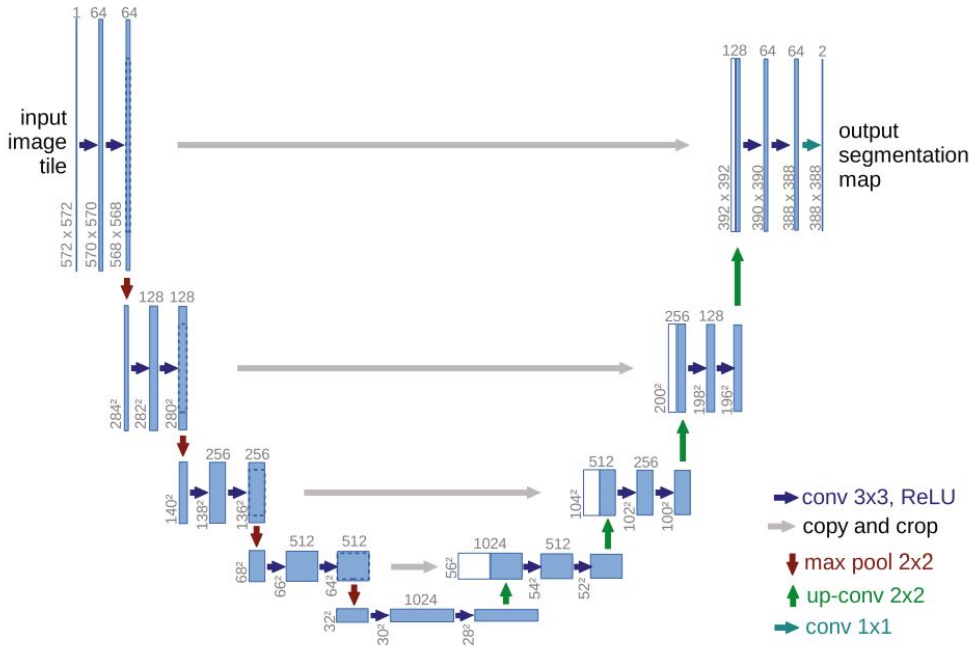
IMPLEMENTATION

U-NET



(Source: Ronneberger, 2015)

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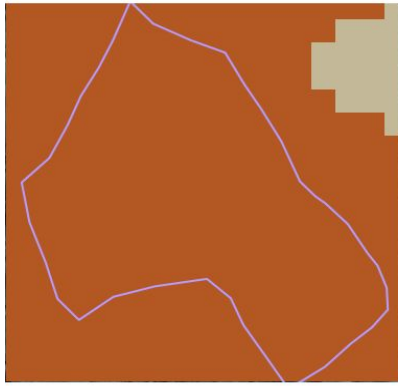
$$w_c = \frac{1}{\frac{n_c}{N}}$$

$$L_{cross-entropy}(\hat{y}, y) = -\frac{1}{N}\sum_{j}^{N}\sum_{c}^{M} w_c y_{c,j} \ln(\hat{y}_{c,j})$$

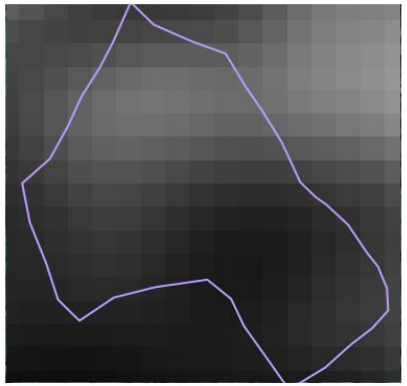
OUTPUT

Prediction map



Predictions:
- Cocoa
- Forest

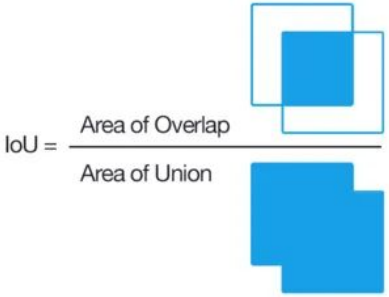
Cocoa probability map



Cocoa probability
1
0

METRICS

Intersection over Union **(Cocoa class)**



Loss value **(All classes)**

Lower is better

IMPLEMENTATION

Reference

EXPERIMENTS

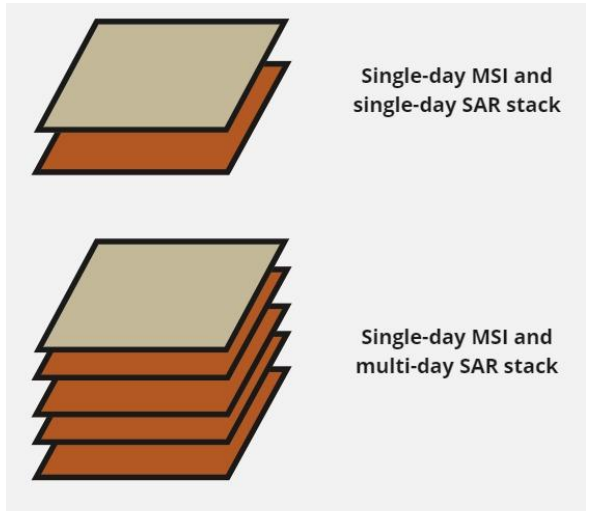
Set	#	MSI Data	SAR Data	Season
1	1	December	N/A	Dry
	2	March	N/A	Dry
	3	Jan, March, December, Jan	N/A	Dry
	4	N/A	May - VV	Wet
	5	N/A	May - VH	Wet
	6	N/A	May - VV VH	Wet
	7	N/A	Jan - VV	Dry
	8	N/A	Jan - VH	Dry
	9	N/A	Jan - VV VH	Dry
	10	N/A	Jan, March, December, Jan - VV	Dry
	11	N/A	Jan, March, December, Jan - VH	Dry
	12	N/A	Jan, March, December, Jan - VV VH	Dry
	13	N/A	May, August, November, Jan - VV	Multi
	14	N/A	May, August, November, Jan - VH	Multi
	15	N/A	May, August, November, Jan - VV VH	Multi
	16	December	Jan - VV	Dry
	17	December	Jan - VH	Dry
	18	December	Jan - VV VH	Dry
	19	December	May - VV	Multi
	20	December	May - VH	Multi
	21	December	May - VV VH	Multi
	22	December	May, August, November, Jan - VV	Multi
	23	December	May, August, November, Jan - VH	Multi
	24	December	May, August, November, Jan - VV VH	Multi
	25	Jan, March, December, Jan	May - VV	Multi
	26	Jan, March, December, Jan	May - VH	Multi
	27	Jan, March, December, Jan	May - VV VH	Multi
	28	Jan, March, December, Jan	May, August, November, Jan - VV	Multi
2	29	December (label change)	N/A	Dry
	30	December	May	Multi
	31	December	May, August, November, Jan	Multi
3	32	December (cloudless)	N/A	Dry
	33	December	May	Multi
	34	December	May, August, November, Jan	Multi

IMPLEMENTATION

EXPERIMENTS

Single-day MSI

Set	#	MSI Data	SAR Data	Season
1	1	December	N/A	Dry
	2	March	N/A	Dry
	3	Jan, March, December, Jan	N/A	Dry
	4	N/A	May - VV	Wet
	5	N/A	May - VH	Wet
	6	N/A	May - VV VH	Wet
	7	N/A	Jan - VV	Dry
	8	N/A	Jan - VH	Dry
	9	N/A	Jan - VV VH	Dry
	10	N/A	Jan, March, December, Jan - VV	Dry
	11	N/A	Jan, March, December, Jan - VH	Dry
	12	N/A	Jan, March, December, Jan - VV VH	Dry
	13	N/A	May, August, November, Jan - VV	Multi
	14	N/A	May, August, November, Jan - VH	Multi
	15	N/A	May, August, November, Jan - VV VH	Multi
	16	December	Jan - VV	Dry
	17	December	Jan - VH	Dry
	18	December	Jan - VV VH	Dry
	19	December	May - VV	Multi
	20	December	May - VH	Multi
	21	December	May - VV VH	Multi
	22	December	May, August, November, Jan - VV	Multi
	23	December	May, August, November, Jan - VH	Multi
	24	December	May, August, November, Jan - VV VH	Multi
	25	Jan, March, December, Jan	May - VV	Multi
	26	Jan, March, December, Jan	May - VH	Multi
	27	Jan, March, December, Jan	May - VV VH	Multi
	28	Jan, March, December, Jan	May, August, November, Jan - VV	Multi
2	29	December (label change)	N/A	Dry
	30	December	May	Multi
	31	December	May, August, November, Jan	Multi
3	32	December (cloudless)	N/A	Dry
	33	December	May	Multi
	34	December	May, August, November, Jan	Multi

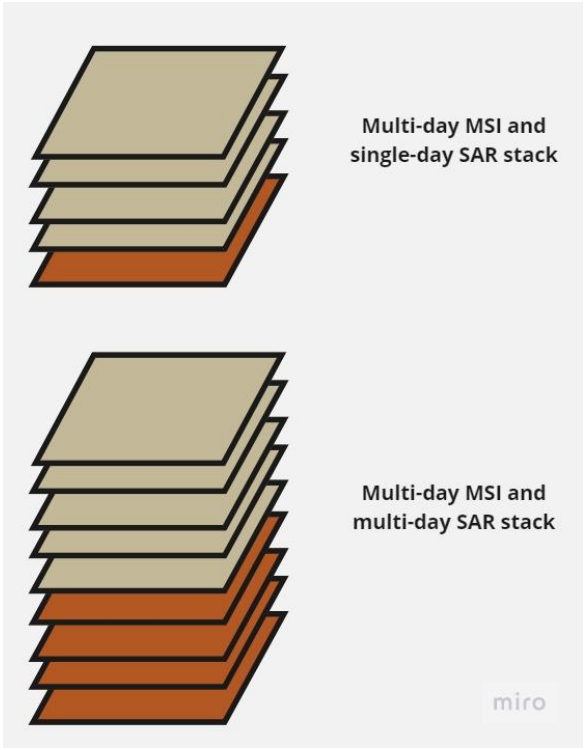


IMPLEMENTATION

EXPERIMENTS

Multi-day MSI

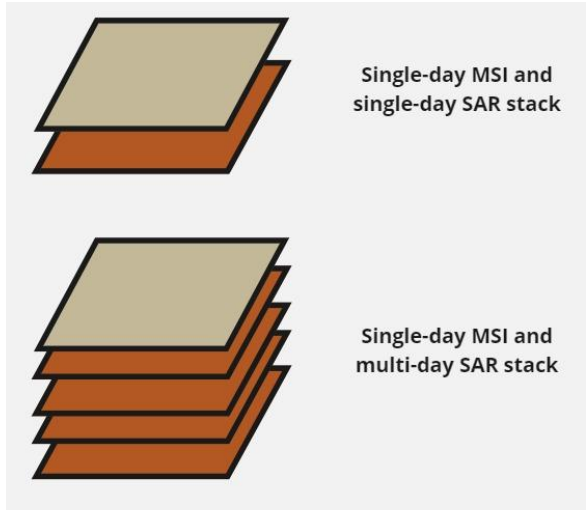
Set	#	MSI Data	SAR Data	Season
1	1	December	N/A	Dry
	2	March	N/A	Dry
	3	Jan, March, December, Jan	N/A	Dry
	4	N/A	May - VV	Wet
	5	N/A	May - VH	Wet
	6	N/A	May - VV VH	Wet
	7	N/A	Jan - VV	Dry
	8	N/A	Jan - VH	Dry
	9	N/A	Jan - VV VH	Dry
	10	N/A	Jan, March, December, Jan - VV	Dry
	11	N/A	Jan, March, December, Jan - VH	Dry
	12	N/A	Jan, March, December, Jan - VV VH	Dry
	13	N/A	May, August, November, Jan - VV	Multi
	14	N/A	May, August, November, Jan - VH	Multi
	15	N/A	May, August, November, Jan - VV VH	Multi
	16	December	Jan - VV	Dry
	17	December	Jan - VH	Dry
	18	December	Jan - VV VH	Dry
	19	December	May - VV	Multi
	20	December	May - VH	Multi
	21	December	May - VV VH	Multi
	22	December	May, August, November, Jan - VV	Multi
	23	December	May, August, November, Jan - VH	Multi
	24	December	May, August, November, Jan - VV VH	Multi
	25	Jan, March, December, Jan	May - VV	Multi
	26	Jan, March, December, Jan	May - VH	Multi
	27	Jan, March, December, Jan	May - VV VH	Multi
	28	Jan, March, December, Jan	May, August, November, Jan - VV	Multi
2	29	December (label change)	N/A	Dry
	30	December	May	Multi
	31	December	May, August, November, Jan	Multi
3	32	December (cloudless)	N/A	Dry
	33	December	May	Multi
	34	December	May, August, November, Jan	Multi



IMPLEMENTATION

EXPERIMENTS

Set	#	MSI Data	SAR Data	Season
1	1	December	N/A	Dry
	2	March	N/A	Dry
	3	Jan, March, December, Jan	N/A	Dry
	4	N/A	May - VV	Wet
	5	N/A	May - VH	Wet
	6	N/A	May - VV VH	Wet
	7	N/A	Jan - VV	Dry
	8	N/A	Jan - VH	Dry
	9	N/A	Jan - VV VH	Dry
	10	N/A	Jan, March, December, Jan - VV	Dry
	11	N/A	Jan, March, December, Jan - VH	Dry
	12	N/A	Jan, March, December, Jan - VV VH	Dry
	13	N/A	May, August, November, Jan - VV	Multi
	14	N/A	May, August, November, Jan - VH	Multi
	15	N/A	May, August, November, Jan - VV VH	Multi
	16	December	Jan - VV	Dry
	17	December	Jan - VH	Dry
	18	December	Jan - VV VH	Dry
	19	December	May - VV	Multi
	20	December	May - VH	Multi
	21	December	May - VV VH	Multi
	22	December	May, August, November, Jan - VV	Multi
	23	December	May, August, November, Jan - VH	Multi
	24	December	May, August, November, Jan - VV VH	Multi
	25	Jan, March, December, Jan	May - VV	Multi
	26	Jan, March, December, Jan	May - VH	Multi
	27	Jan, March, December, Jan	May - VV VH	Multi
	28	Jan, March, December, Jan	May, August, November, Jan - VV	Multi
2	29	December (label change)	N/A	Dry
	30	December	May	Multi
	31	December	May, August, November, Jan	Multi
3	32	December (cloudless)	N/A	Dry
	33	December	May	Multi
	34	December	May, August, November, Jan	Multi

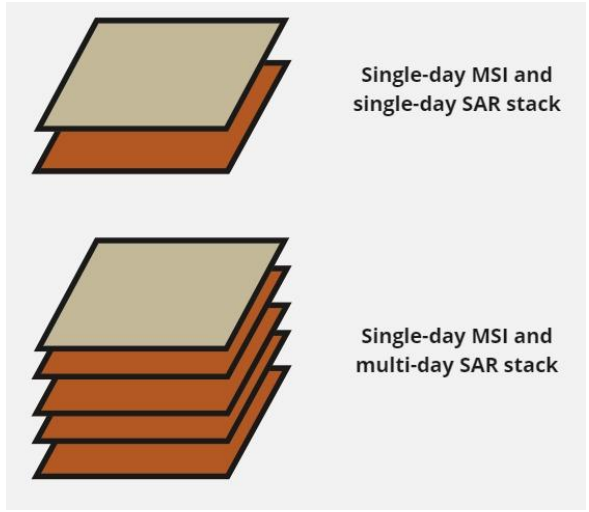


Expanded “Not Cocoa” class

IMPLEMENTATION

EXPERIMENTS

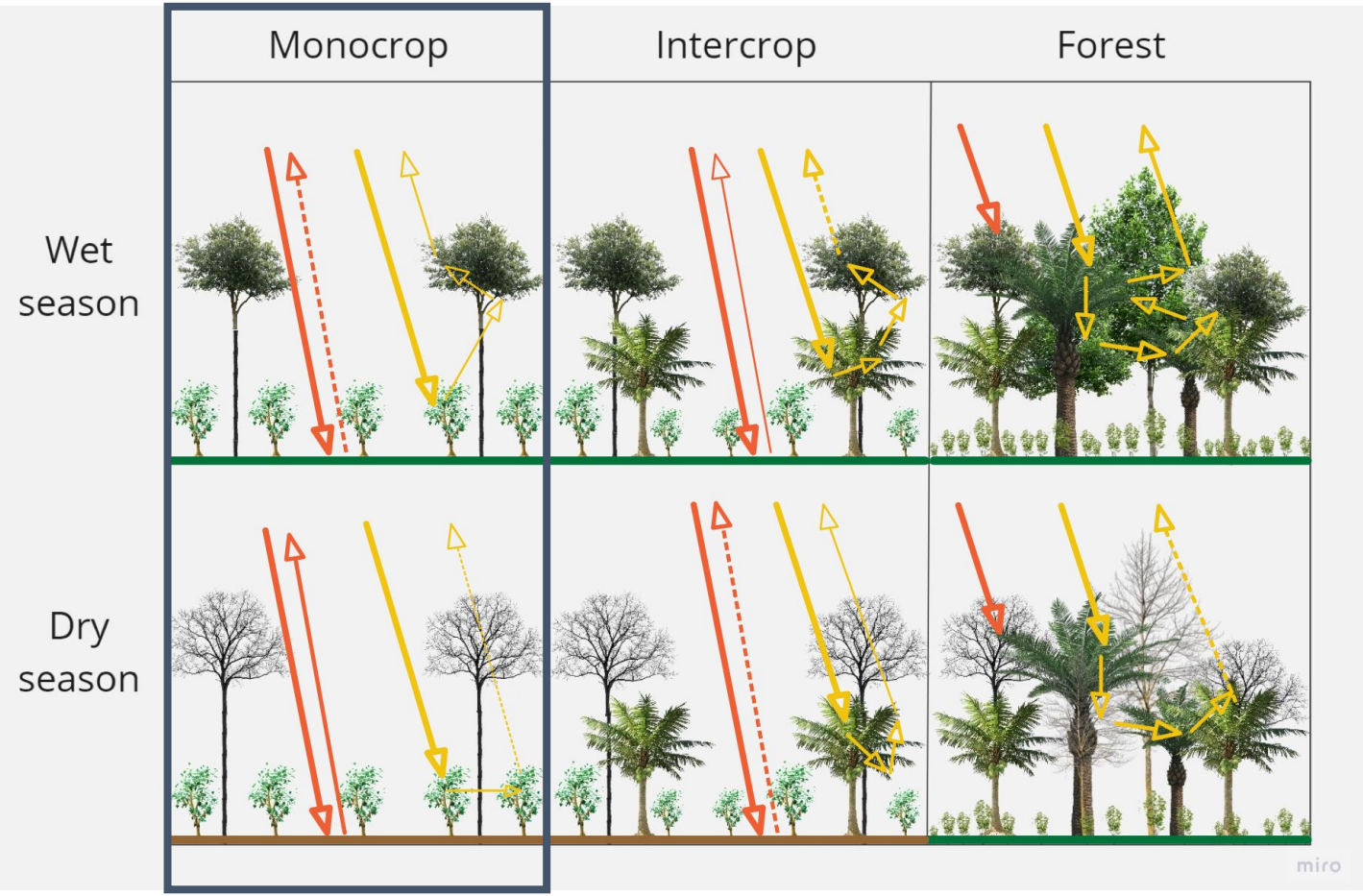
Set	#	MSI Data	SAR Data	Season
1	1	December	N/A	Dry
	2	March	N/A	Dry
	3	Jan, March, December, Jan	N/A	Dry
	4	N/A	May - VV	Wet
	5	N/A	May - VH	Wet
	6	N/A	May - VV VH	Wet
	7	N/A	Jan - VV	Dry
	8	N/A	Jan - VH	Dry
	9	N/A	Jan - VV VH	Dry
	10	N/A	Jan, March, December, Jan - VV	Dry
	11	N/A	Jan, March, December, Jan - VH	Dry
	12	N/A	Jan, March, December, Jan - VV VH	Dry
	13	N/A	May, August, November, Jan - VV	Multi
	14	N/A	May, August, November, Jan - VH	Multi
	15	N/A	May, August, November, Jan - VV VH	Multi
	16	December	Jan - VV	Dry
	17	December	Jan - VH	Dry
	18	December	Jan - VV VH	Dry
	19	December	May - VV	Multi
	20	December	May - VH	Multi
	21	December	May - VV VH	Multi
	22	December	May, August, November, Jan - VV	Multi
	23	December	May, August, November, Jan - VH	Multi
	24	December	May, August, November, Jan - VV VH	Multi
	25	Jan, March, December, Jan	May - VV	Multi
	26	Jan, March, December, Jan	May - VH	Multi
	27	Jan, March, December, Jan	May - VV VH	Multi
	28	Jan, March, December, Jan	May, August, November, Jan - VV	Multi
2	29	December (label change)	N/A	Dry
	30	December	May	Multi
	31	December	May, August, November, Jan	Multi
3	32	December (cloudless)	N/A	Dry
	33	December	May	Multi
	34	December	May, August, November, Jan	Multi



Clouds removed

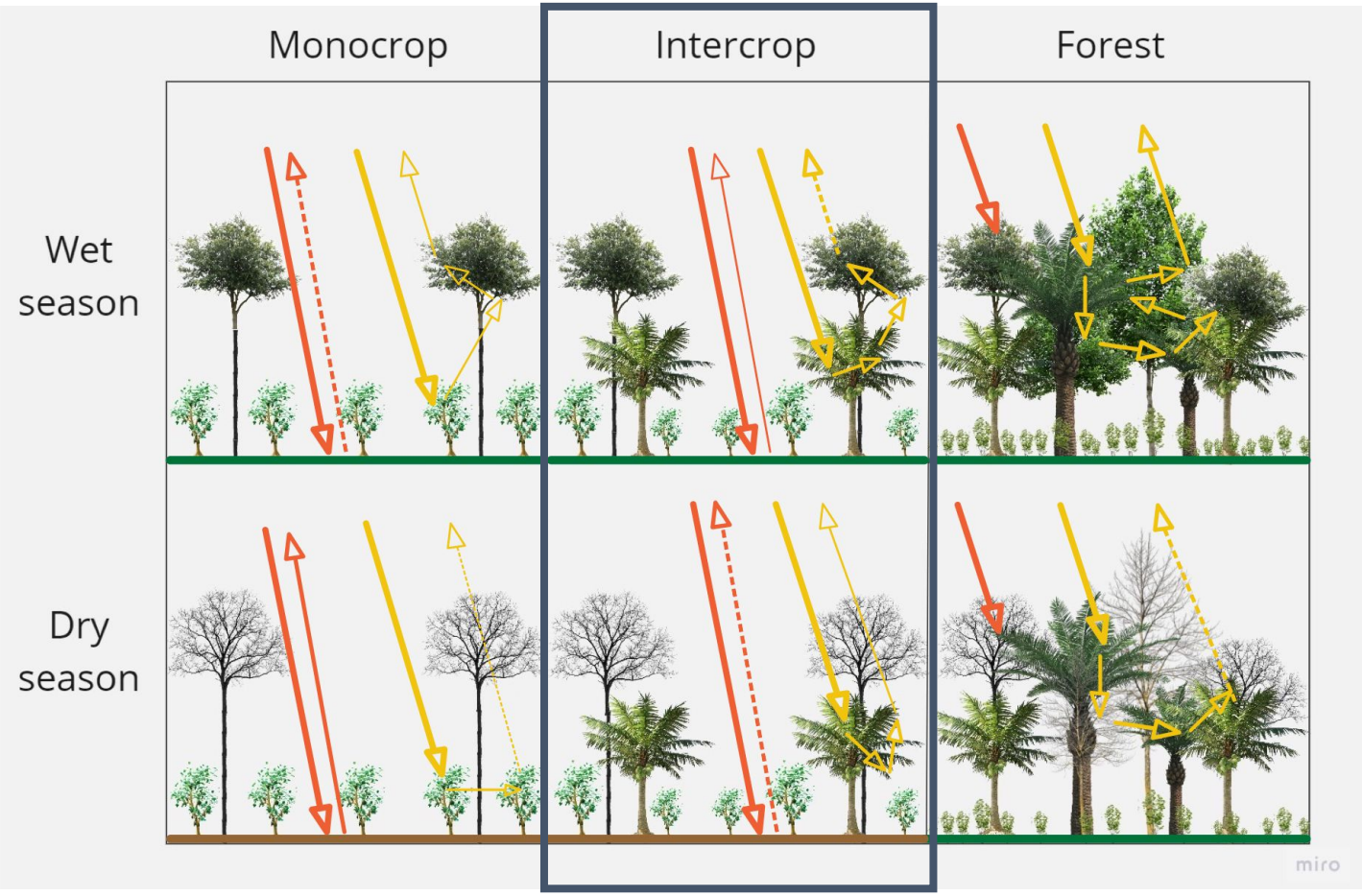
SYNTHETIC APERTURE RADAR

BACKSCATTER VARIATION



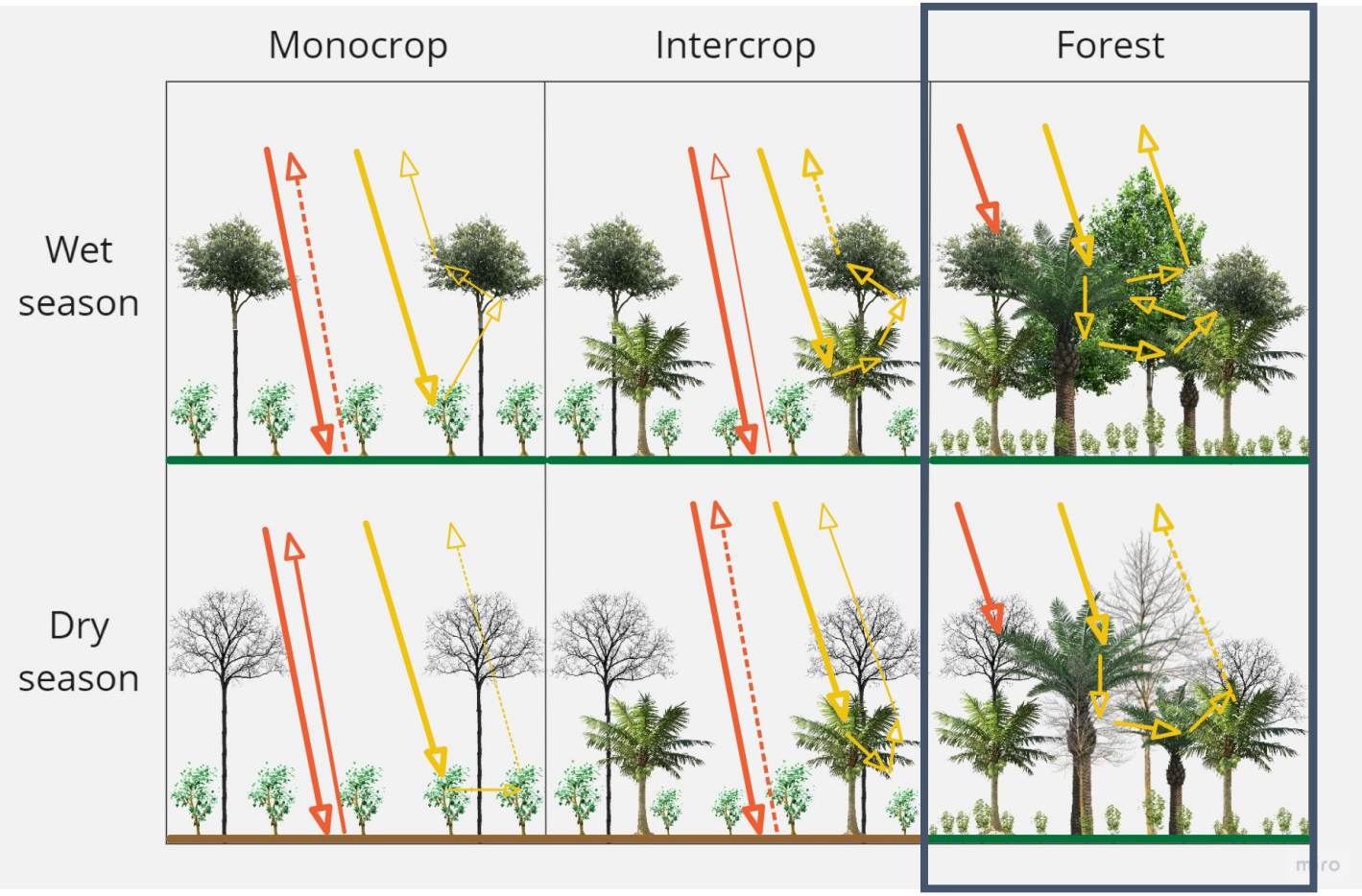
SYNTHETIC APERTURE RADAR

BACKSCATTER VARIATION

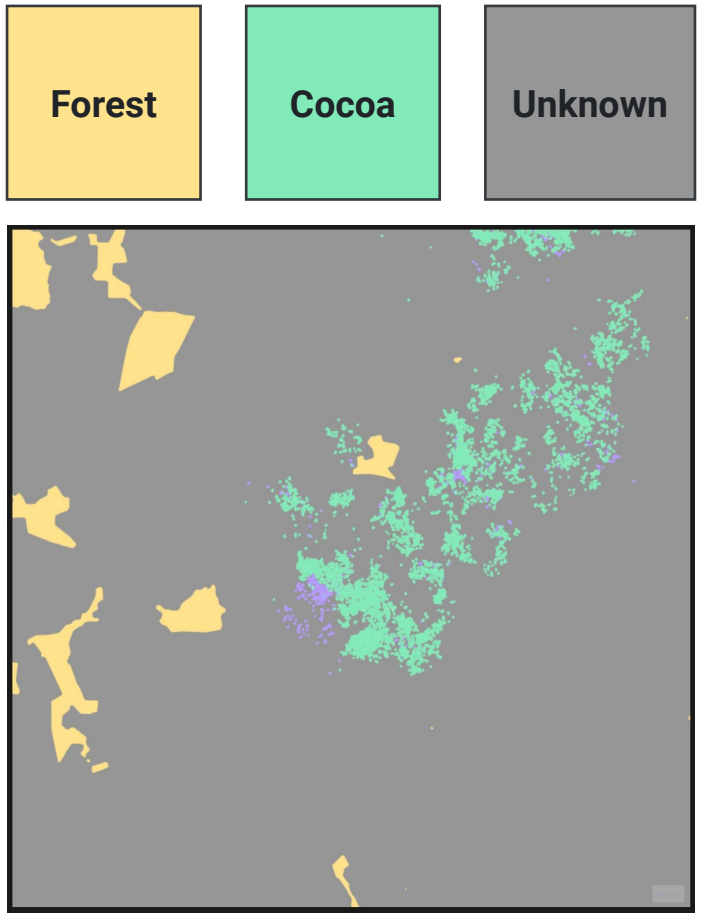


SYNTHETIC APERTURE RADAR

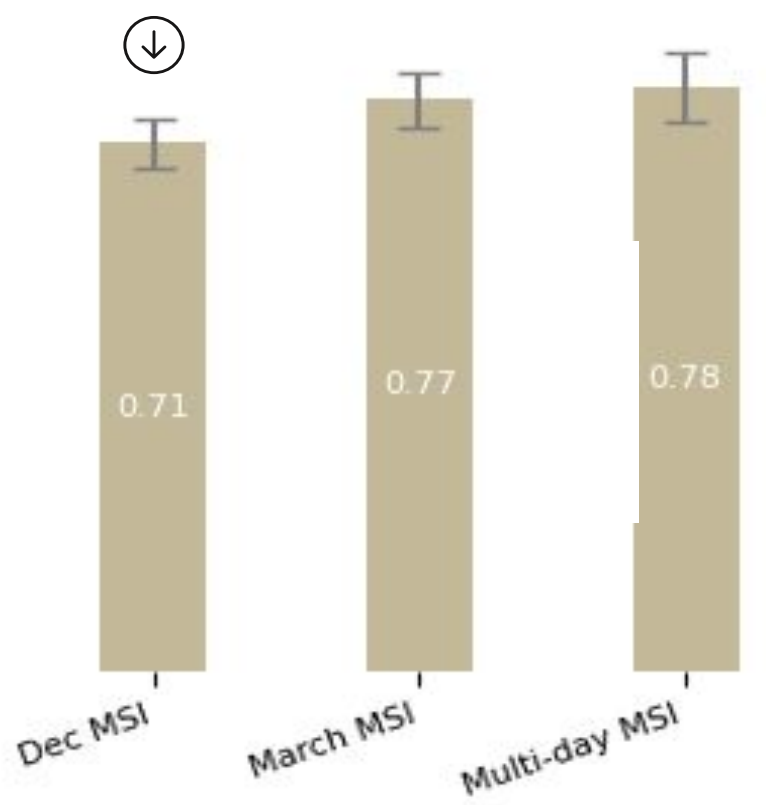
BACKSCATTER VARIATION



SET 1 RESULTS

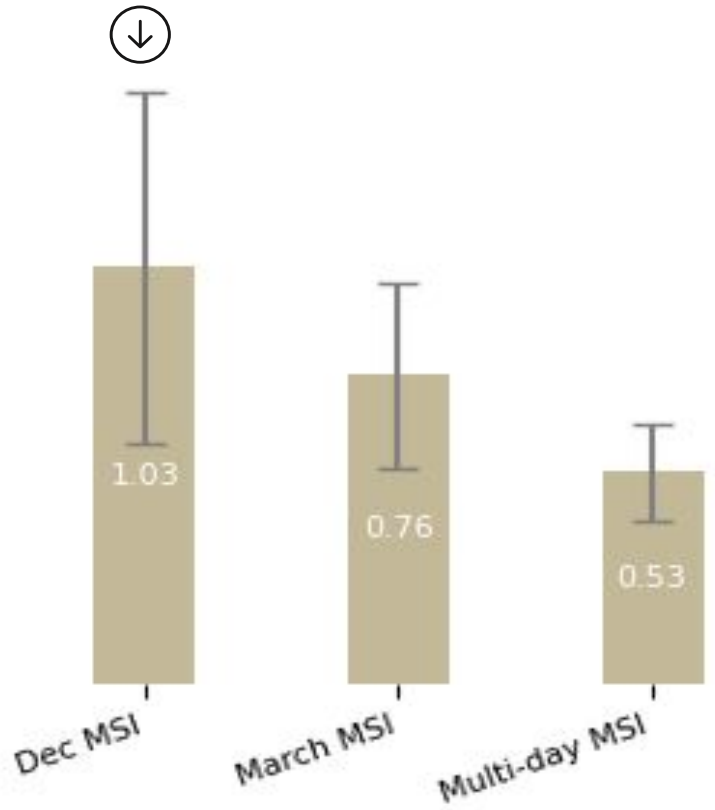


RESULTS - REFERENCE



Intersection over Union

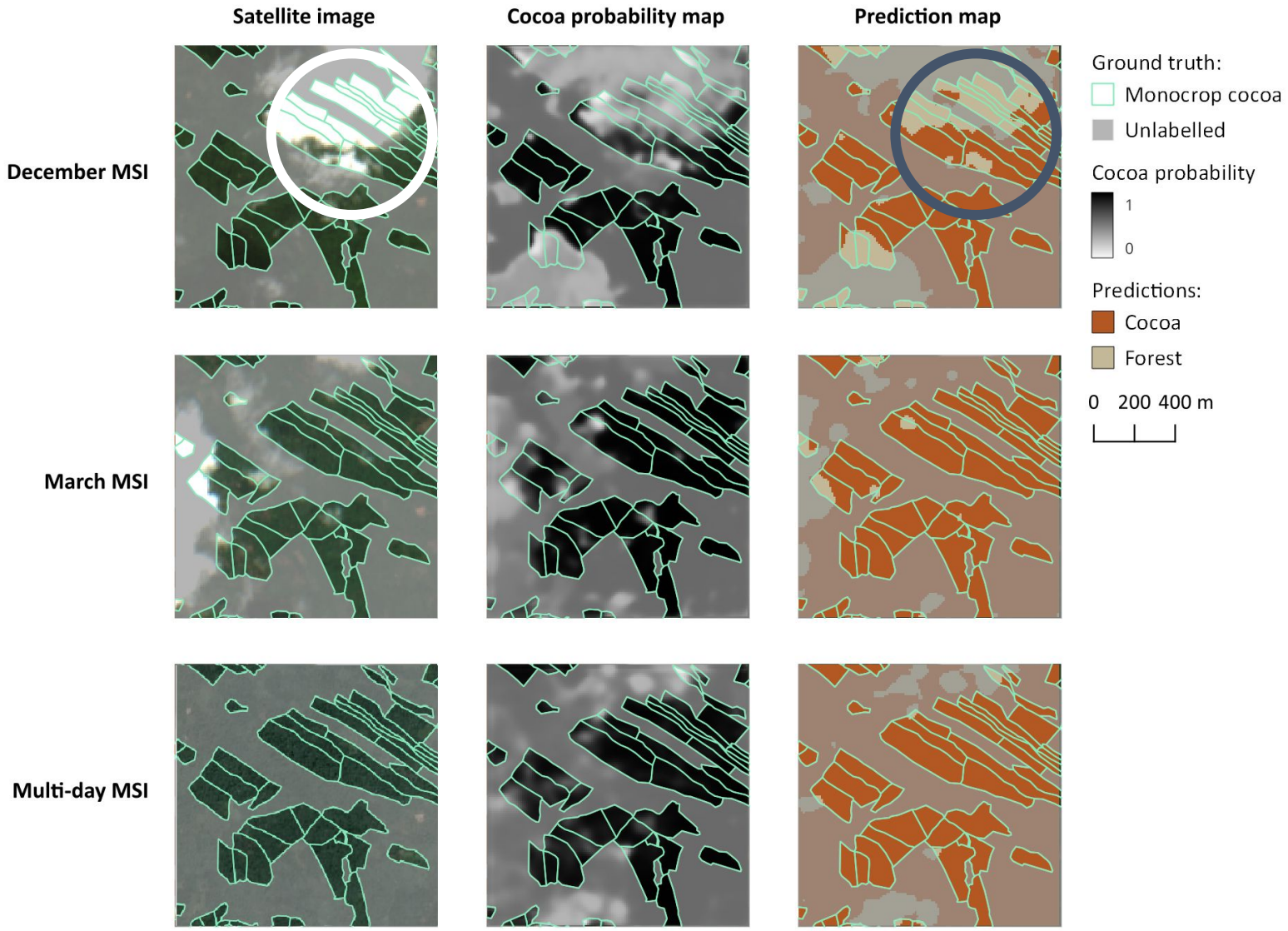
MSI only



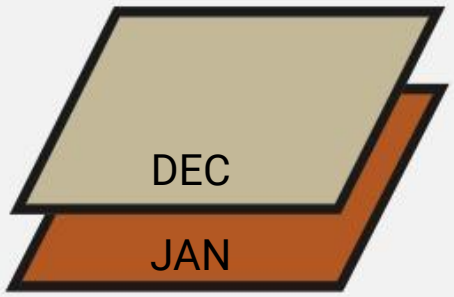
Loss

MSI only

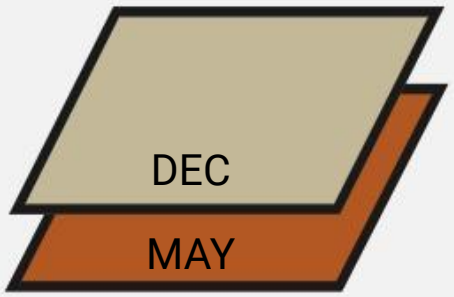
RESULTS - REFERENCE



SINGLE DAY MSI + SINGLE DAY SAR

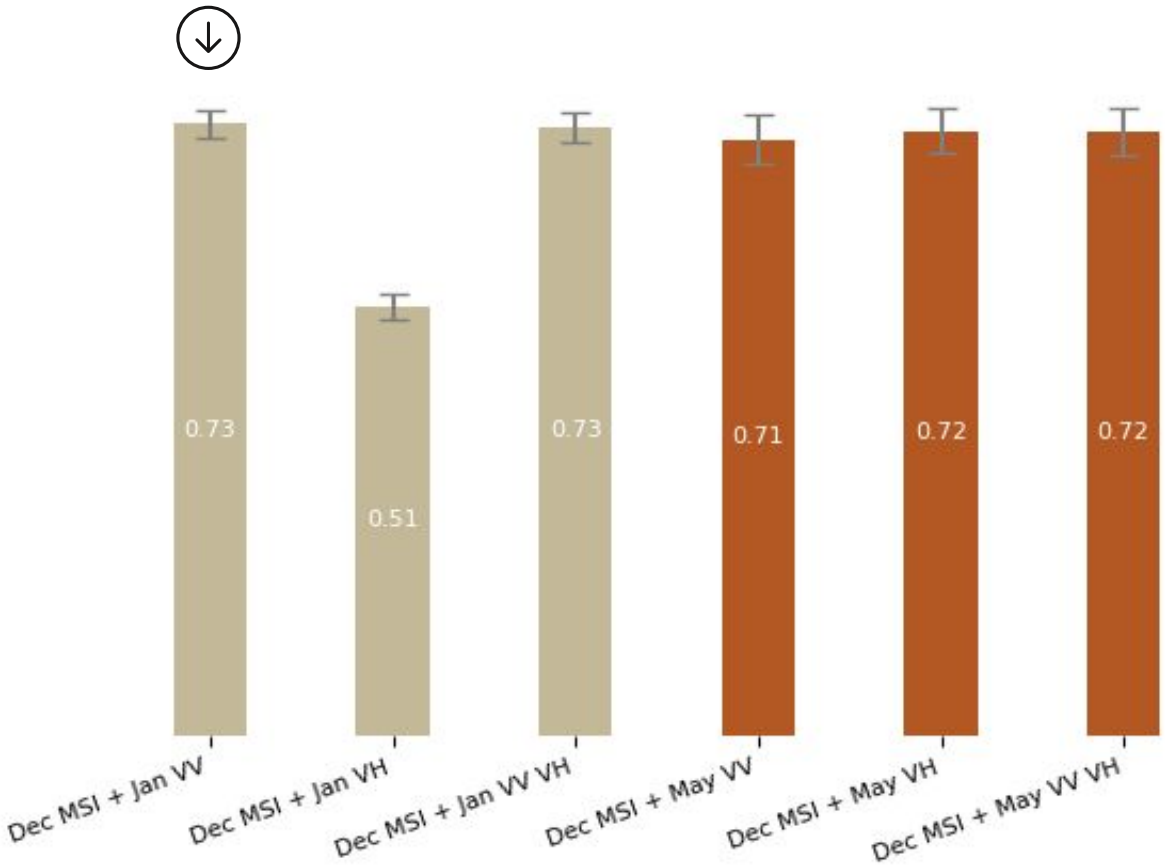


Single-day MSI and single-day SAR stack



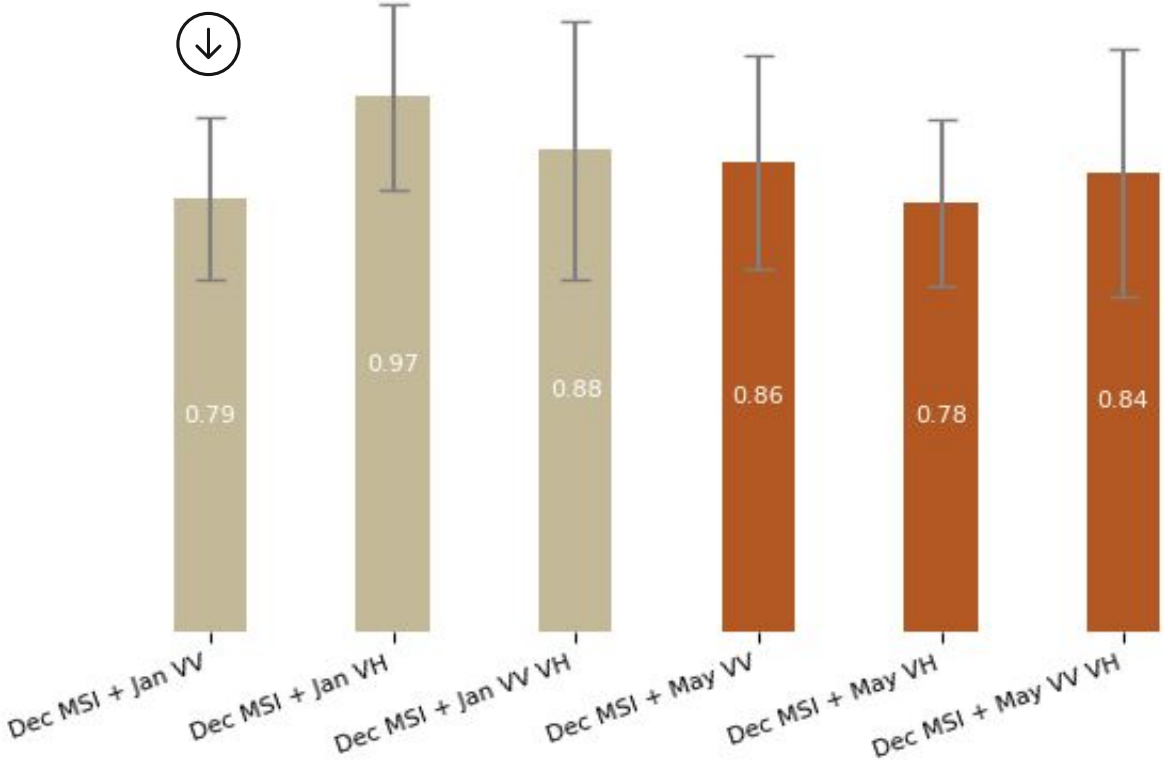
Single-day MSI and single-day SAR stack

SINGLE DAY MSI + SINGLE DAY SAR



Intersection over Union

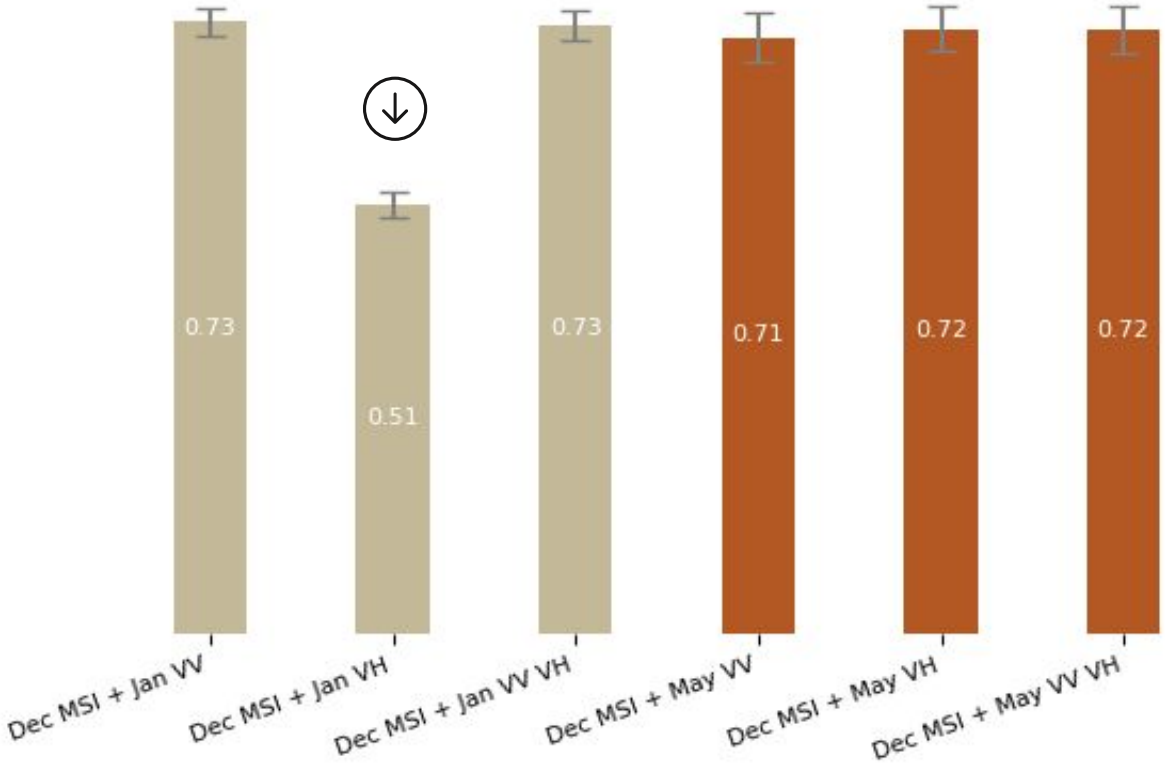
Single-day MSI + Single-day SAR



Loss

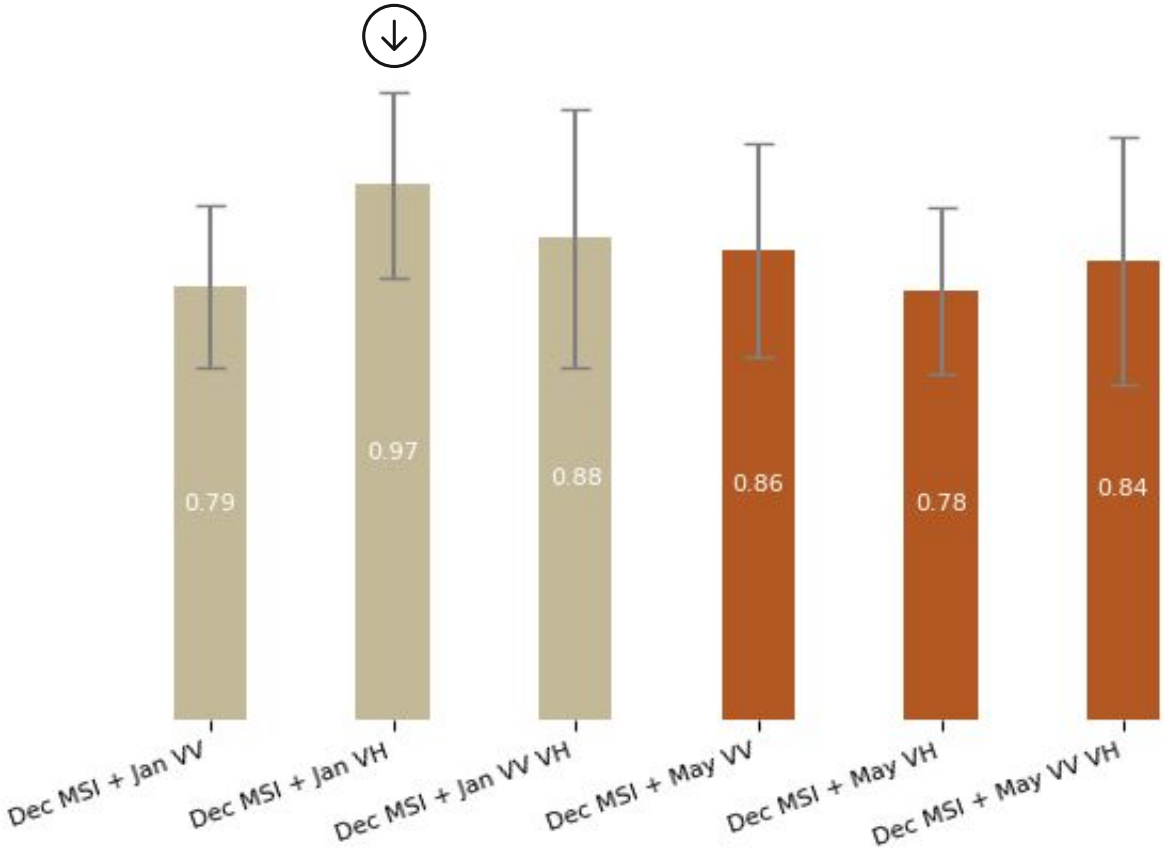
Single-day MSI + Single-day SAR

SINGLE DAY MSI + SINGLE DAY SAR



Intersection over Union

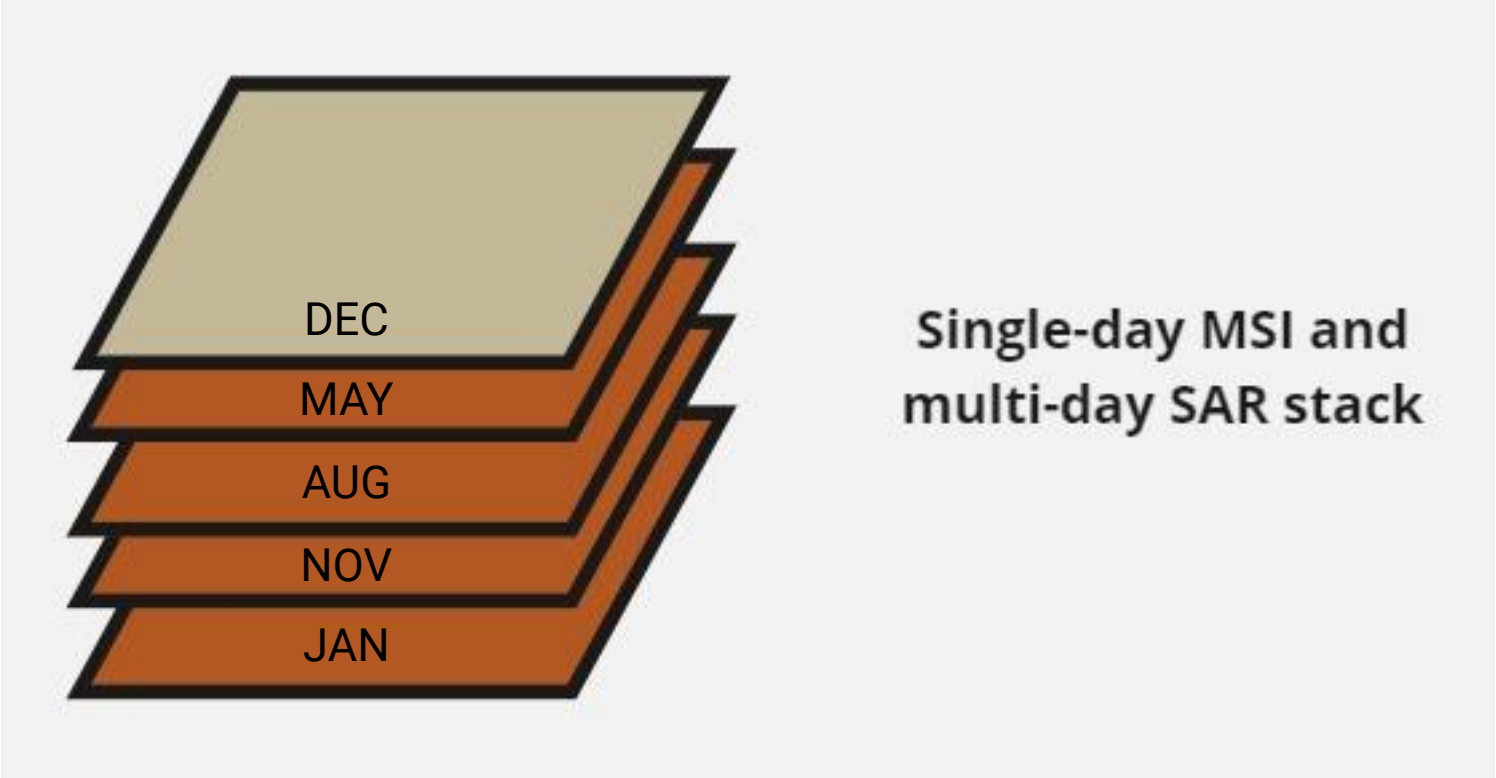
Single-day MSI + Single-day SAR



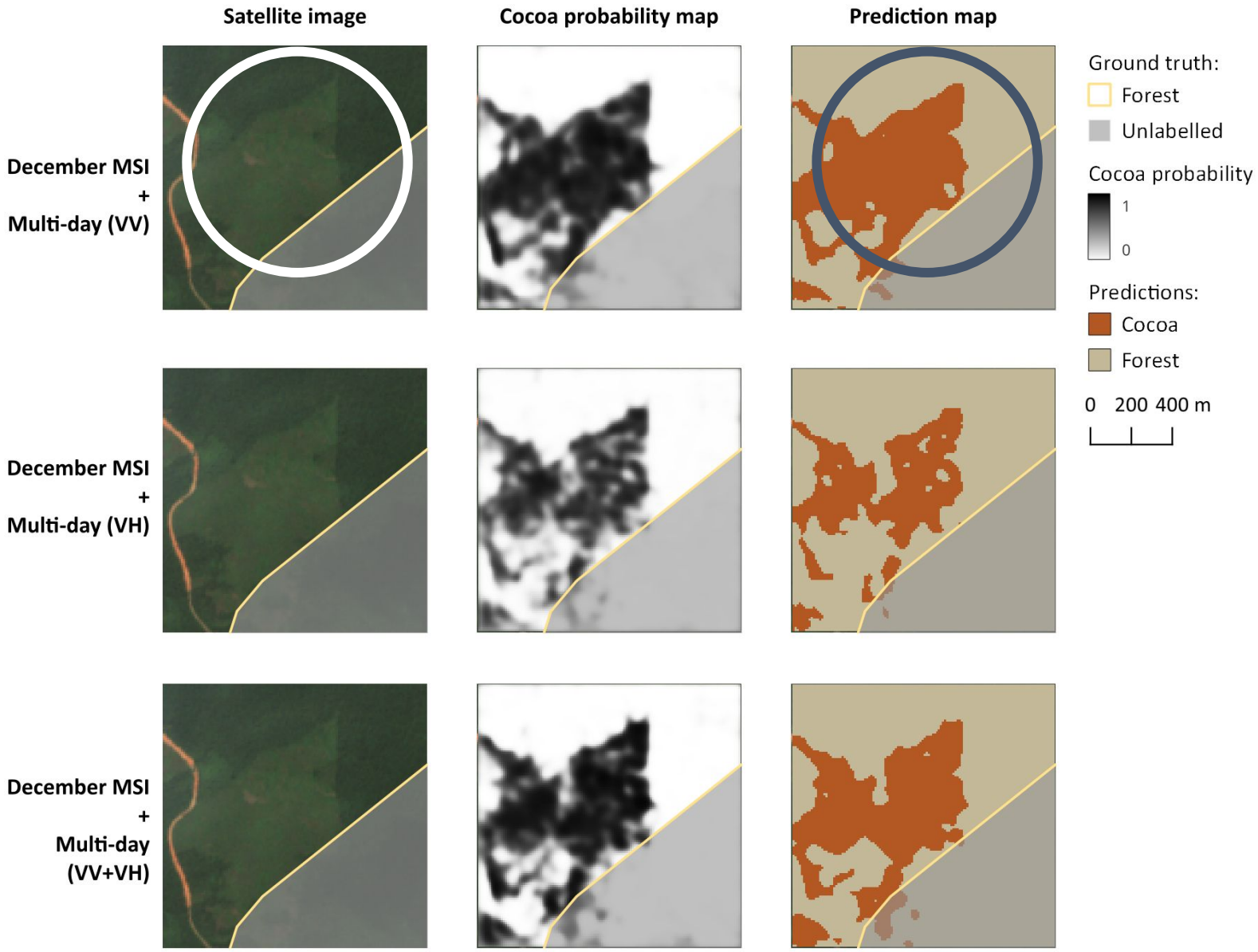
Loss

Single-day MSI + Single-day SAR

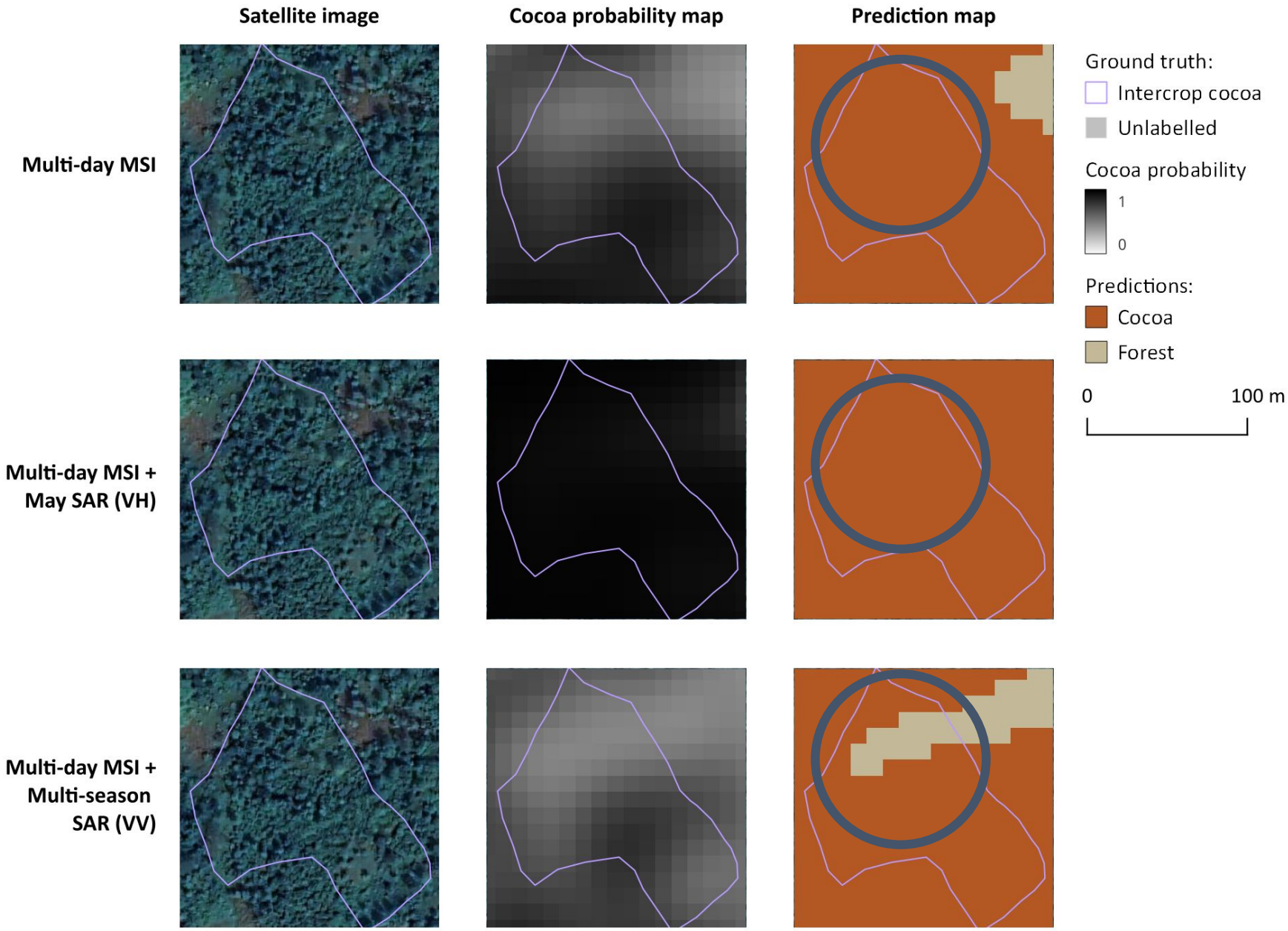
SINGLE DAY MSI + MULTI DAY SAR



RESULTS - SINGLE DAY MSI



RESULTS - INTERCROP

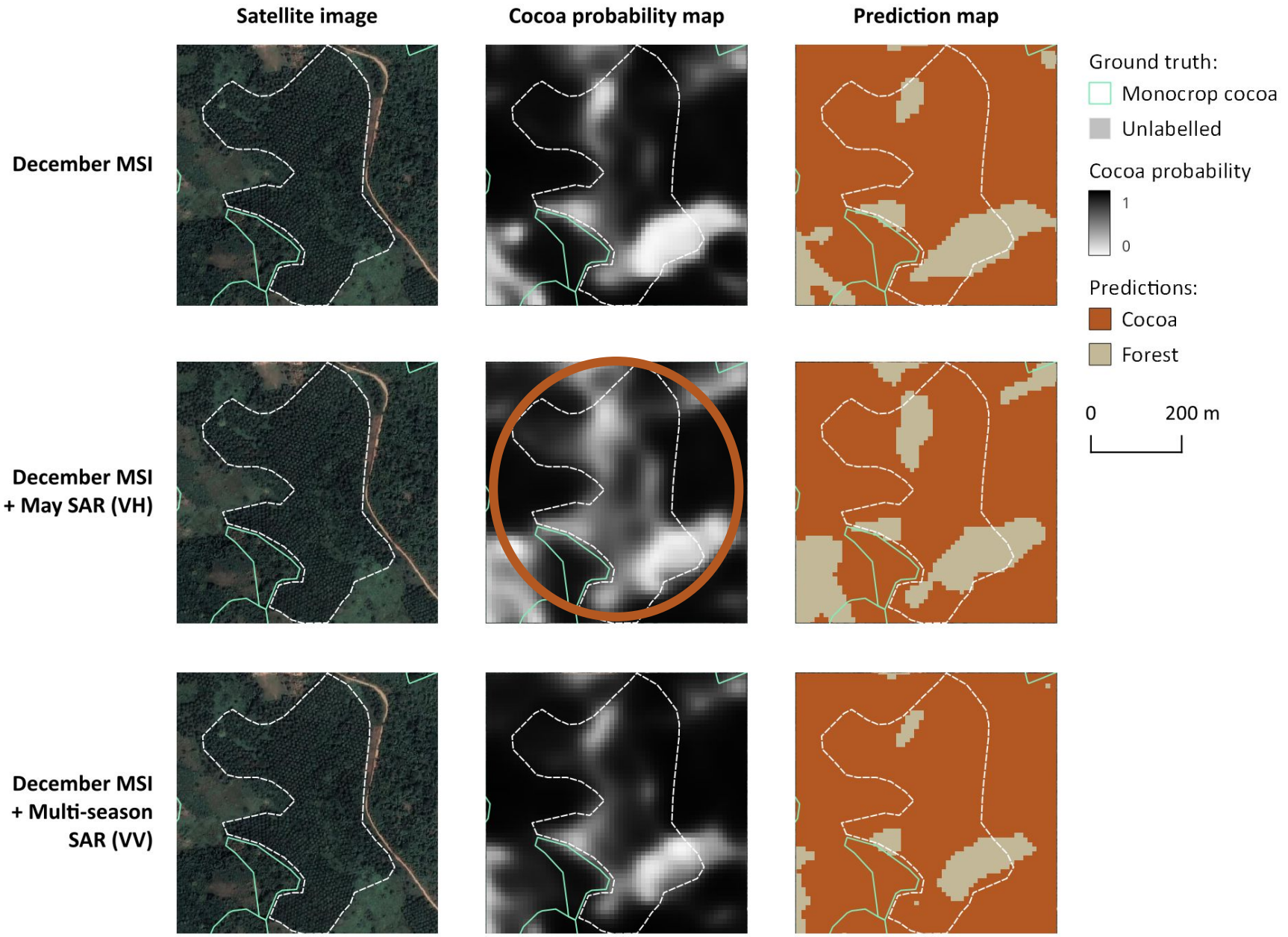


RESULTS - OTHER CROPS

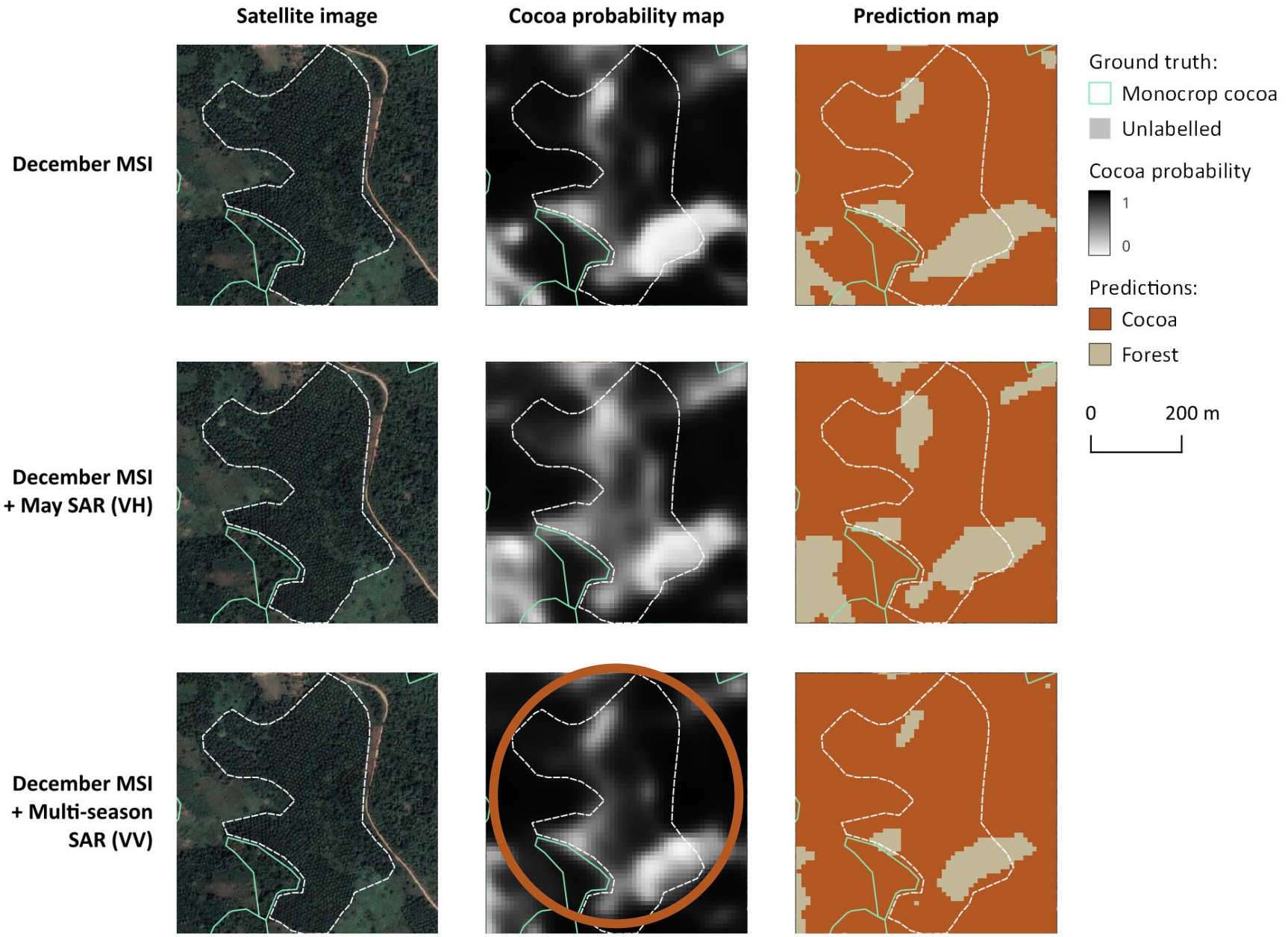
EOS Data Analytics

Google Earth Satellite

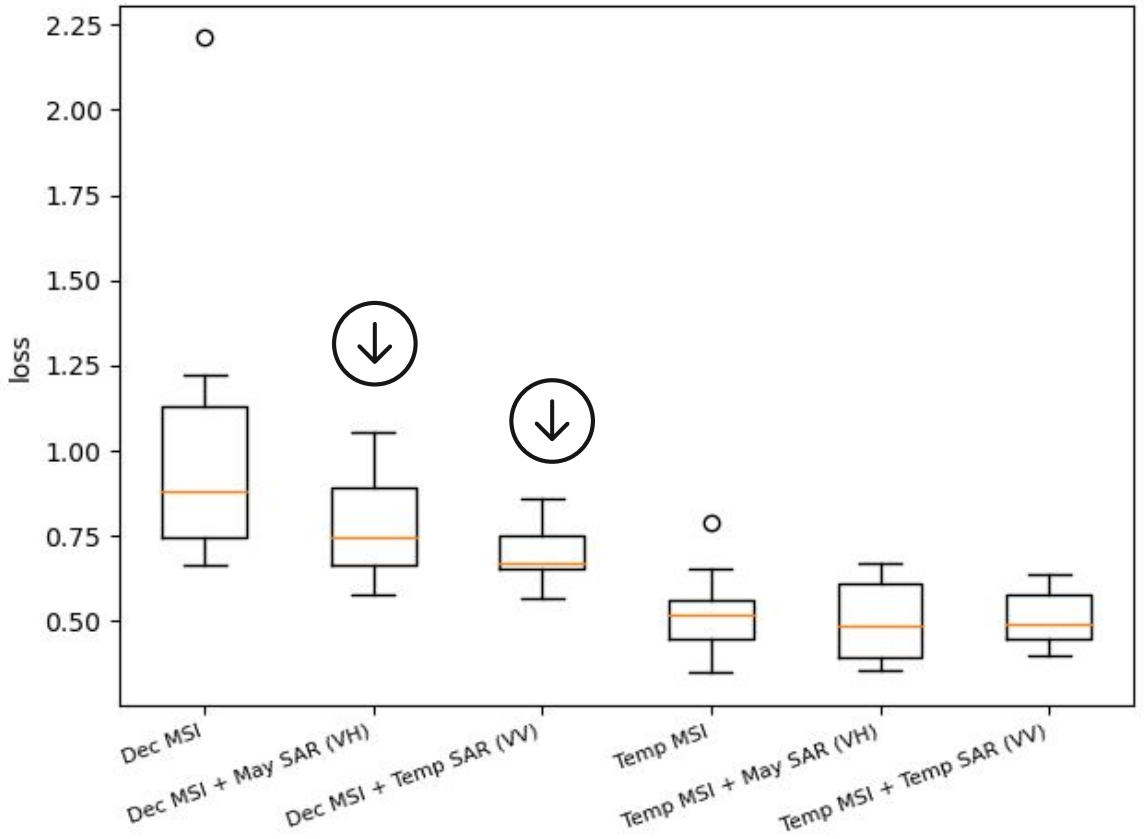
RESULTS - OTHER CROPS



RESULTS - OTHER CROPS



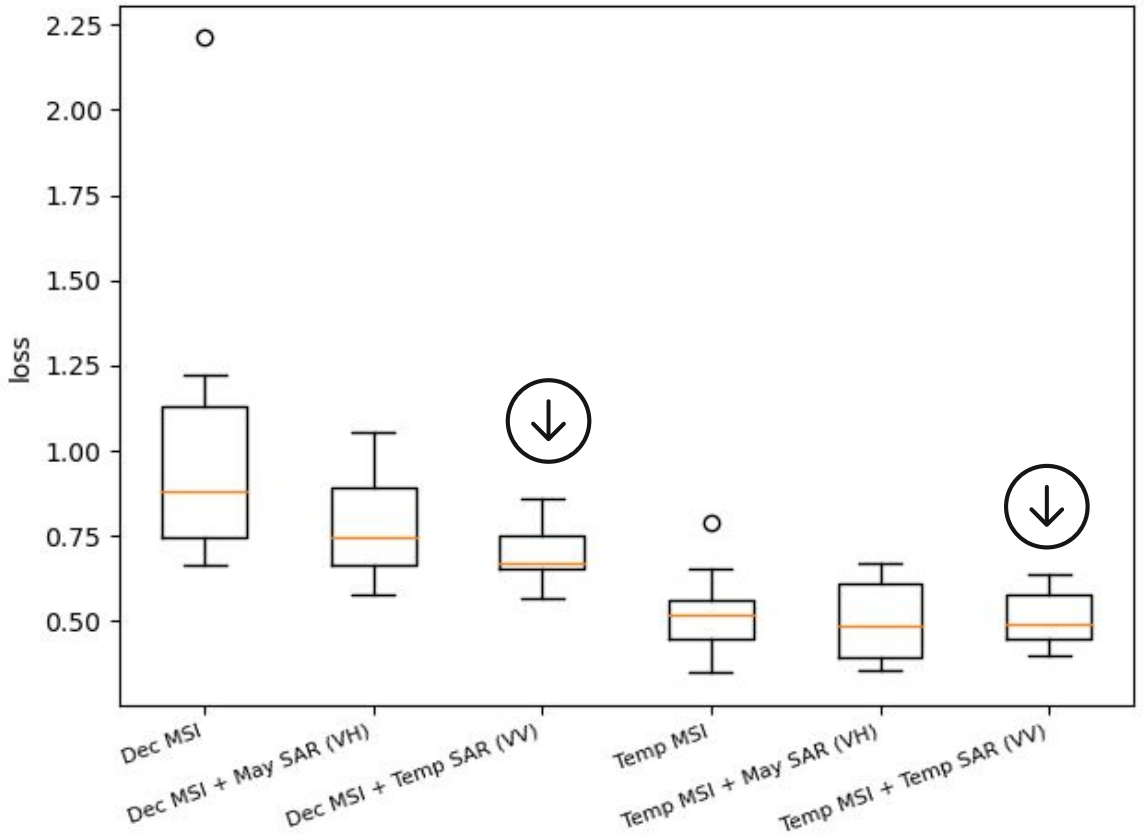
RESULTS - SUMMARY



Loss

MSI + SAR experiments

RESULTS - SUMMARY



Loss

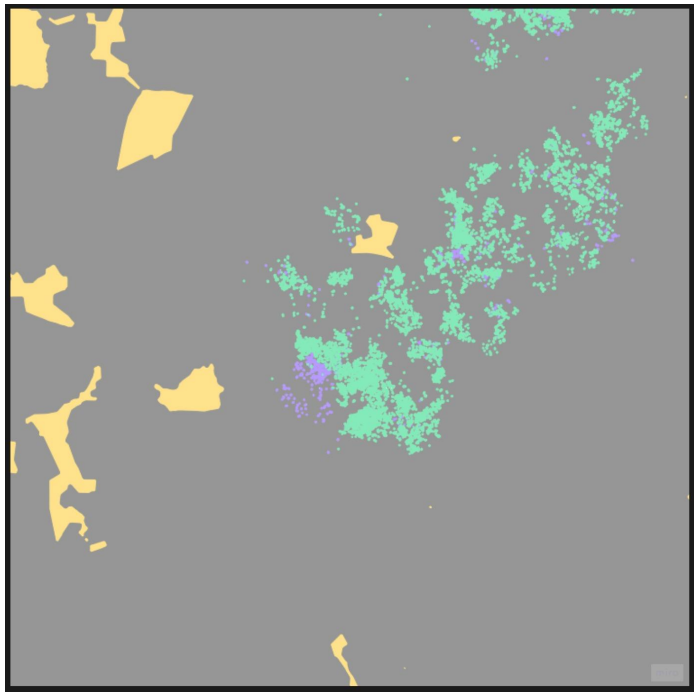
MSI + SAR experiments

SET 2 RESULTS

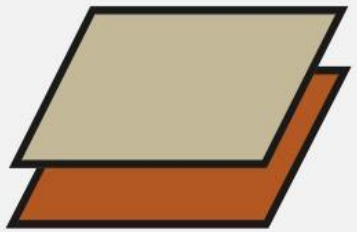
Forest + other crops

Cocoa

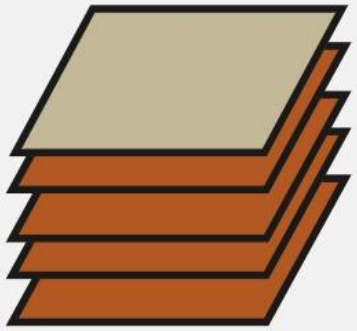
Unknown



Single-day MSI

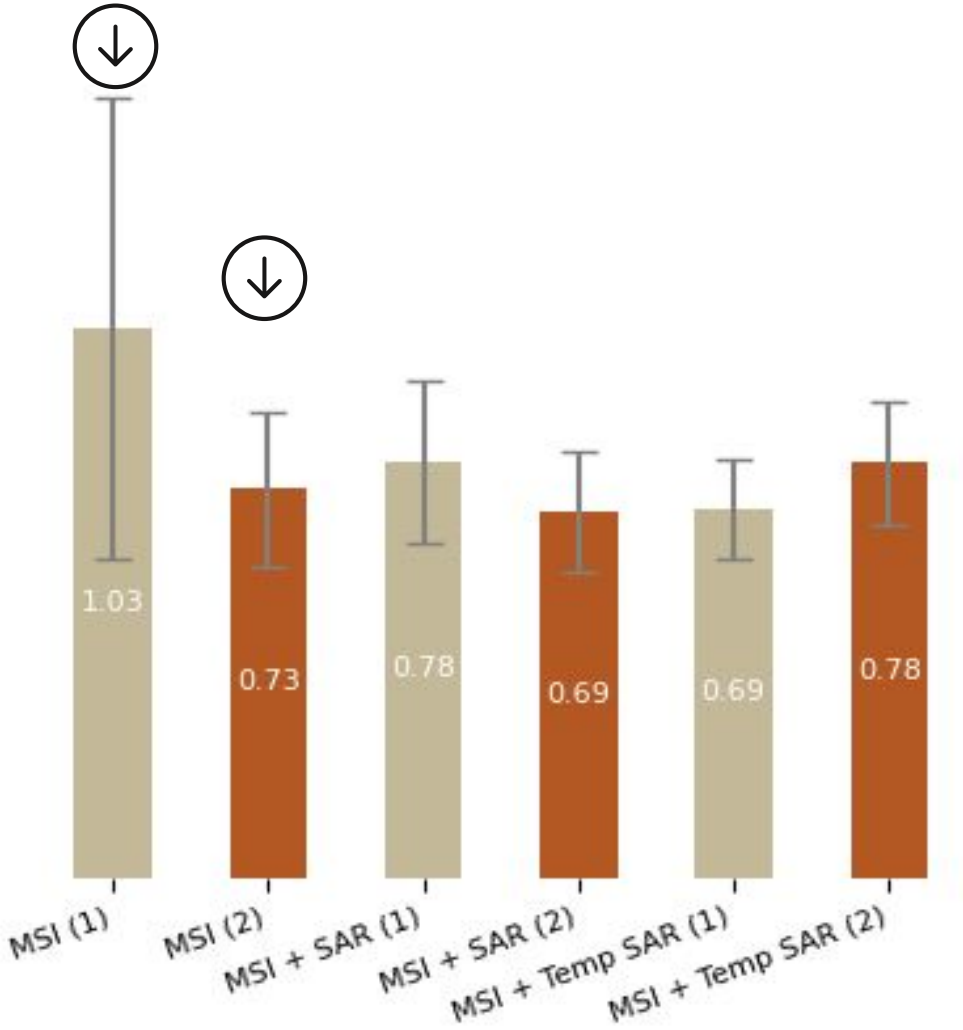


Single-day MSI and single-day SAR stack



Single-day MSI and multi-day SAR stack

RESULTS - SET 2



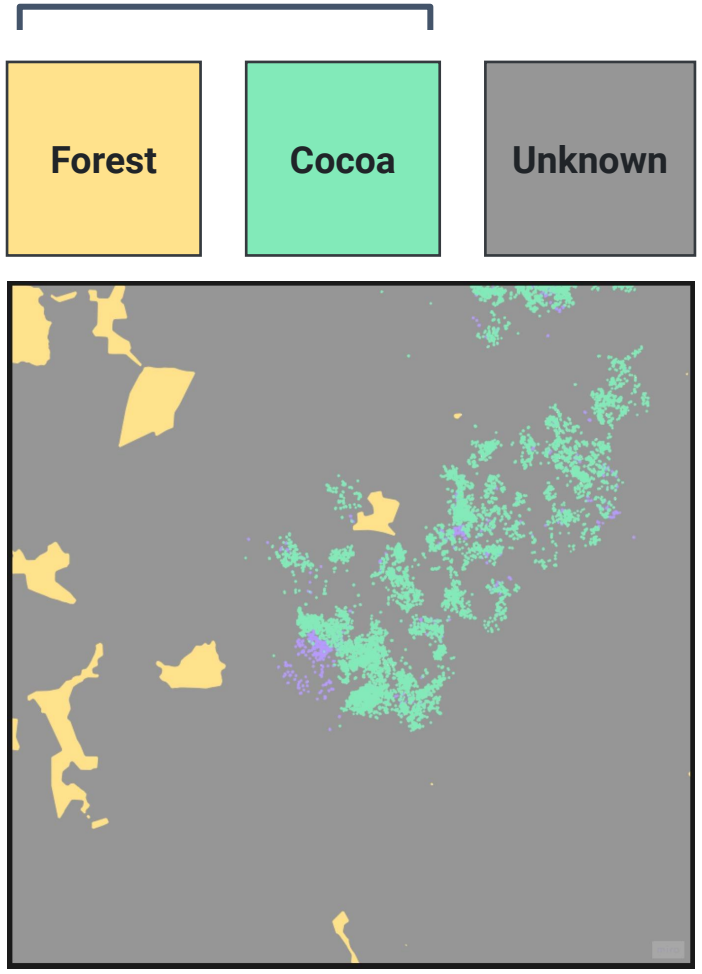
Loss

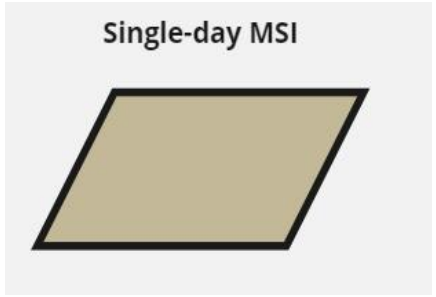
(1) Original experiments

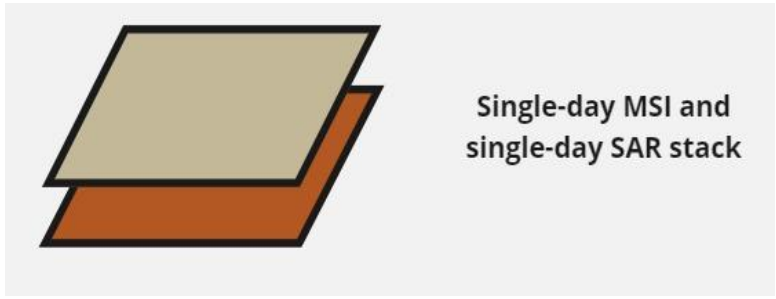
(2) Modified Labels

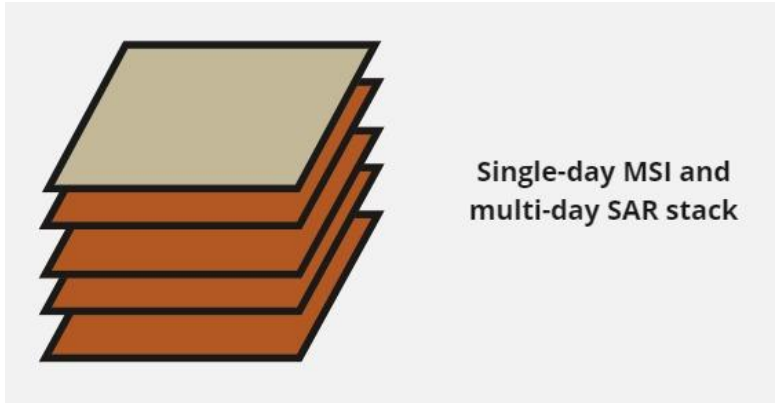
SET 3 RESULTS

Cloudy regions removed

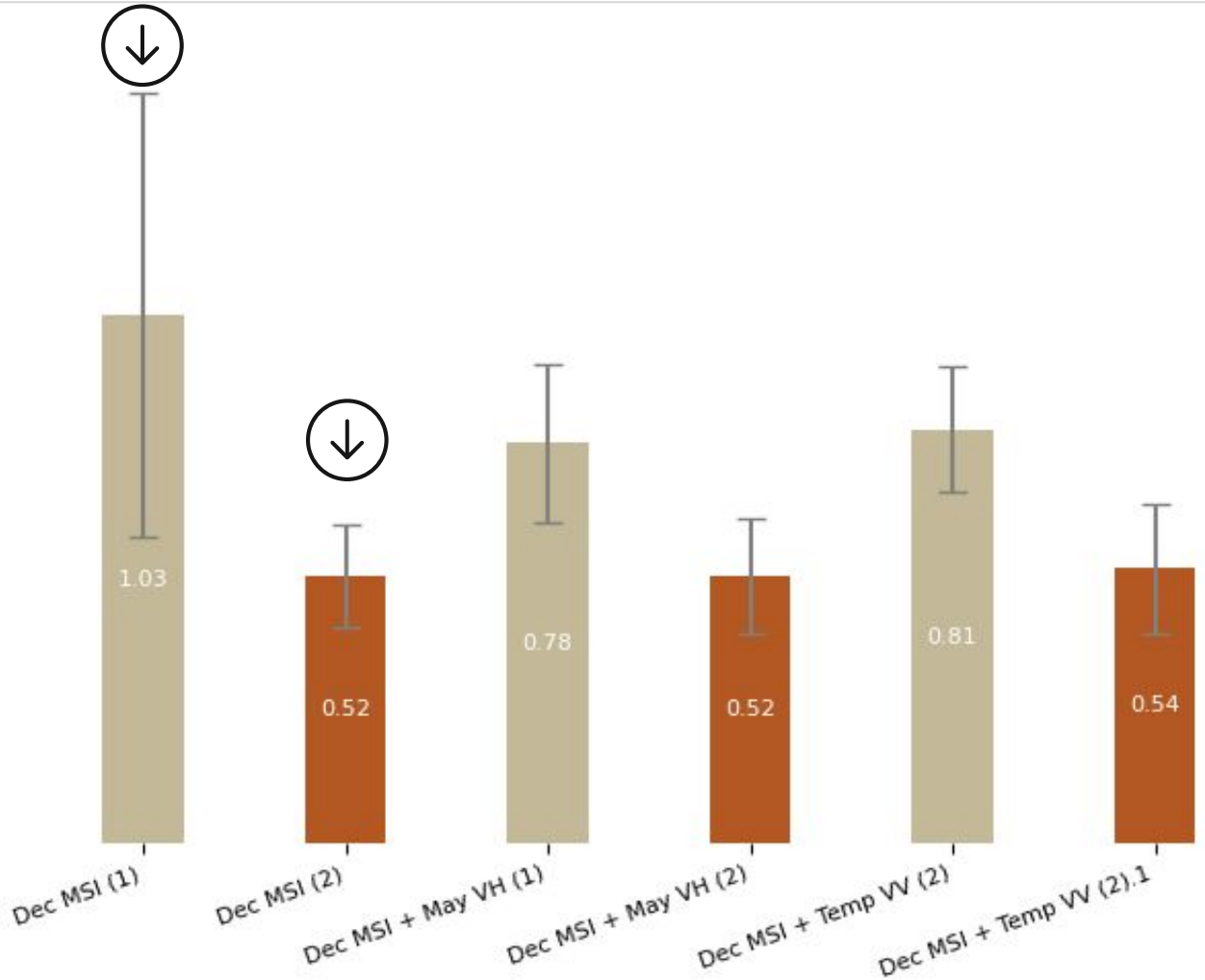








RESULTS - SET 3

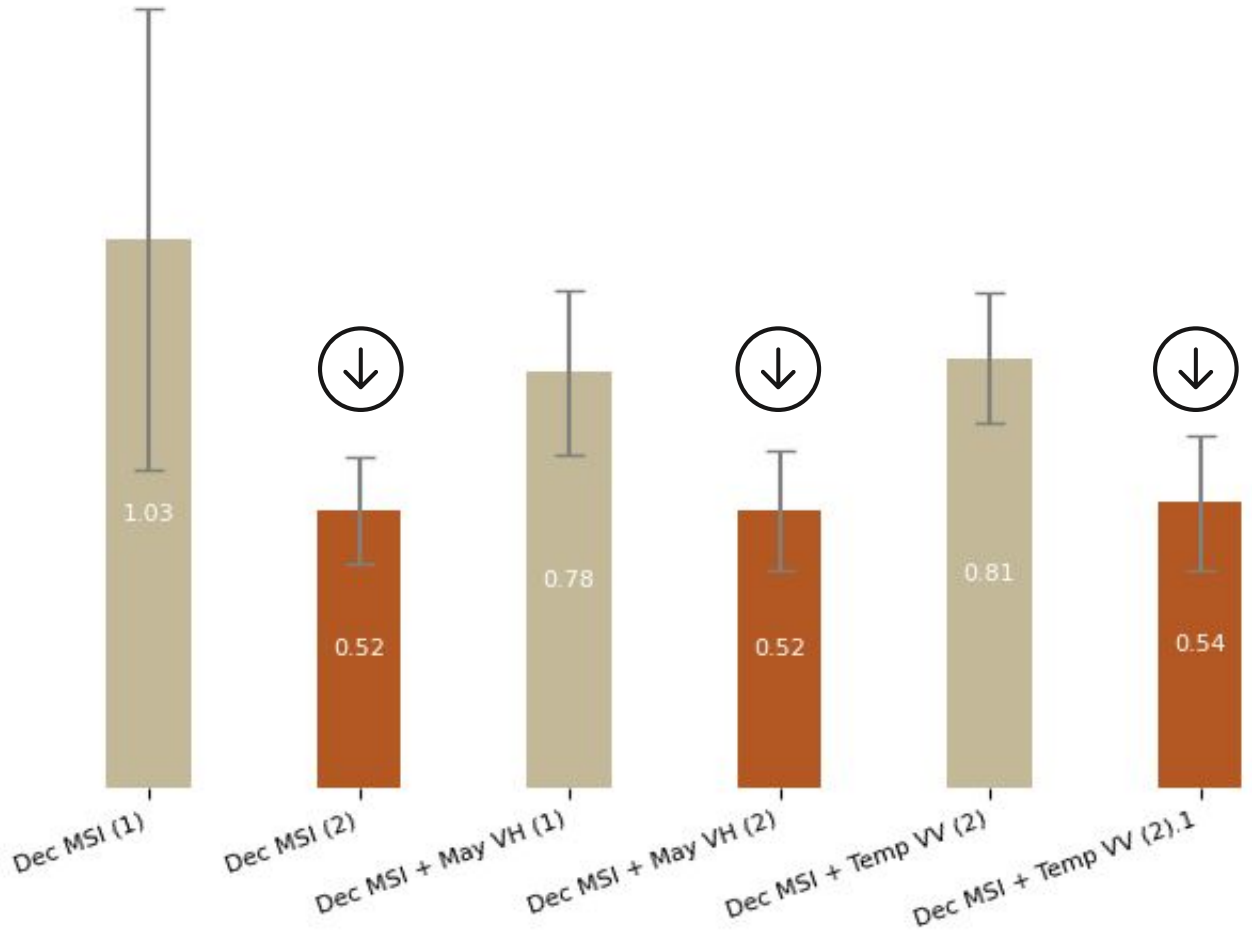


Loss

(1) Original experiments

(2) Clouds removed

RESULTS - SET 3



Loss

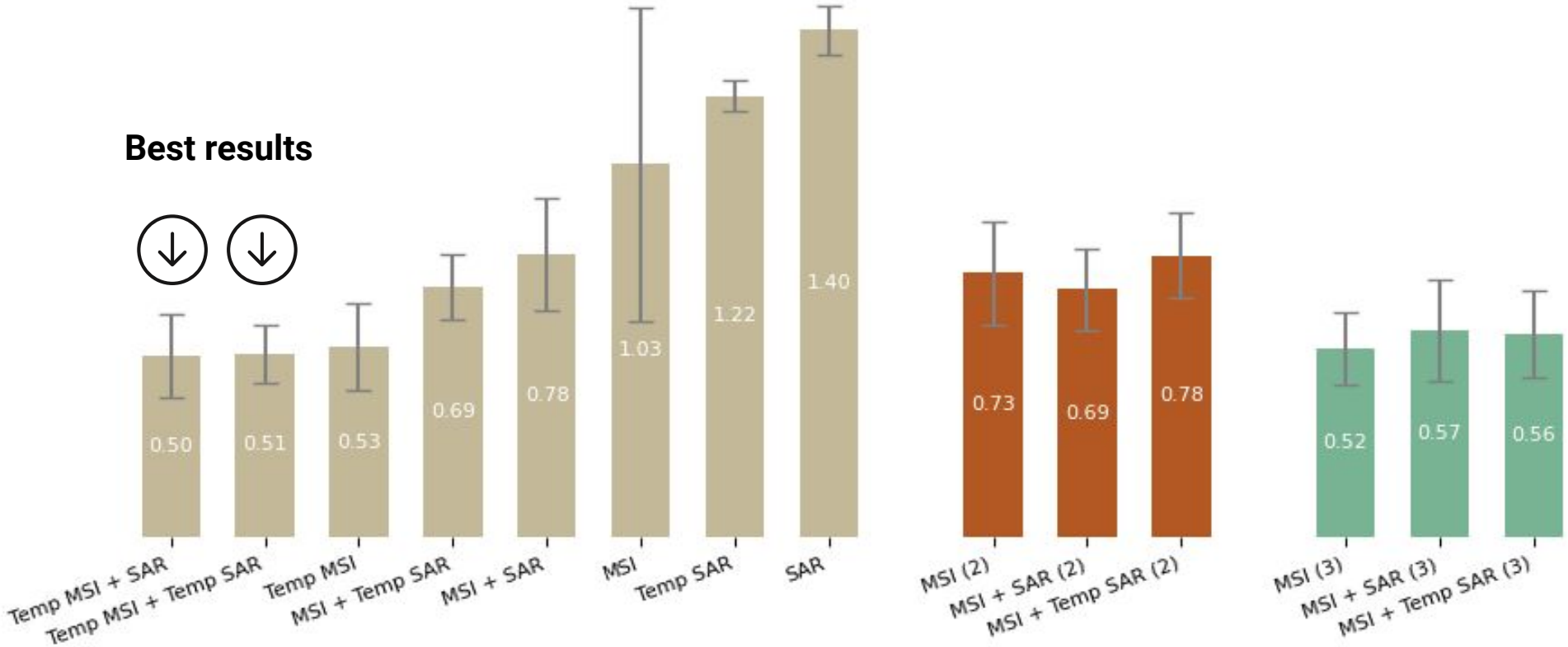
(1) Original experiments

(2) Clouds removed

RESULTS - SUMMARY

Loss values

Best results



Set 1

Forest + Cocoa

Set 2

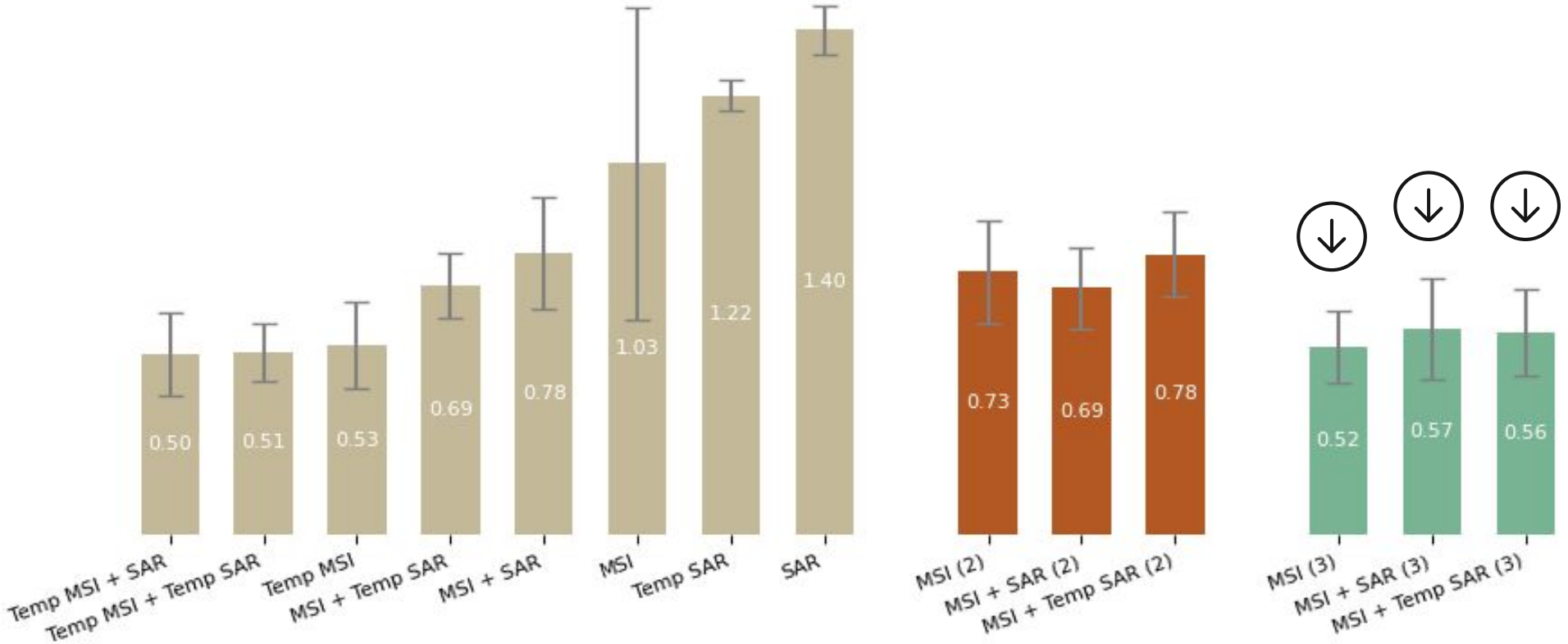
Forest/Non-cocoa crop + Cocoa

Set 3

Forest + Cocoa (Cloudless)

RESULTS - SUMMARY

Loss values



Set 1

Forest + Cocoa

Set 2

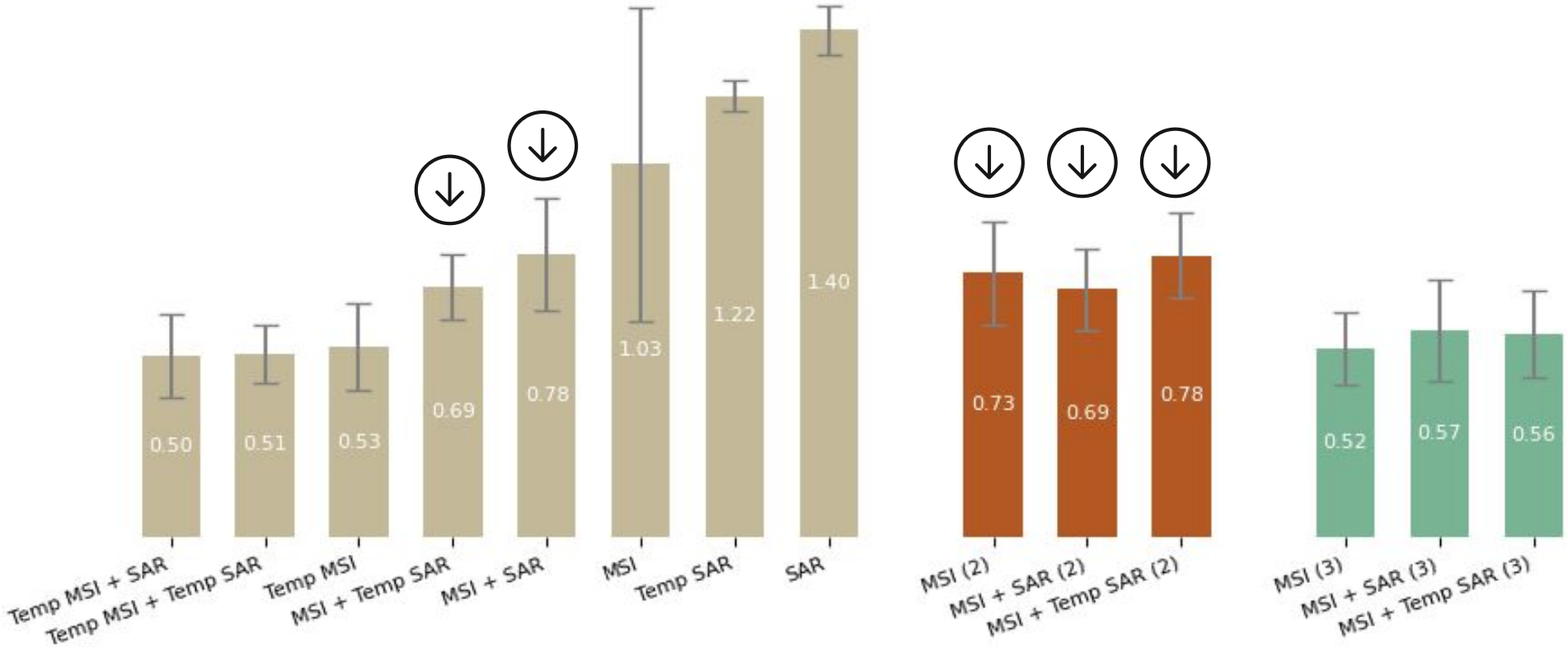
Forest/Non-cocoa crop + Cocoa

Set 3

Forest + Cocoa (Cloudless)

RESULTS - SUMMARY

Loss values



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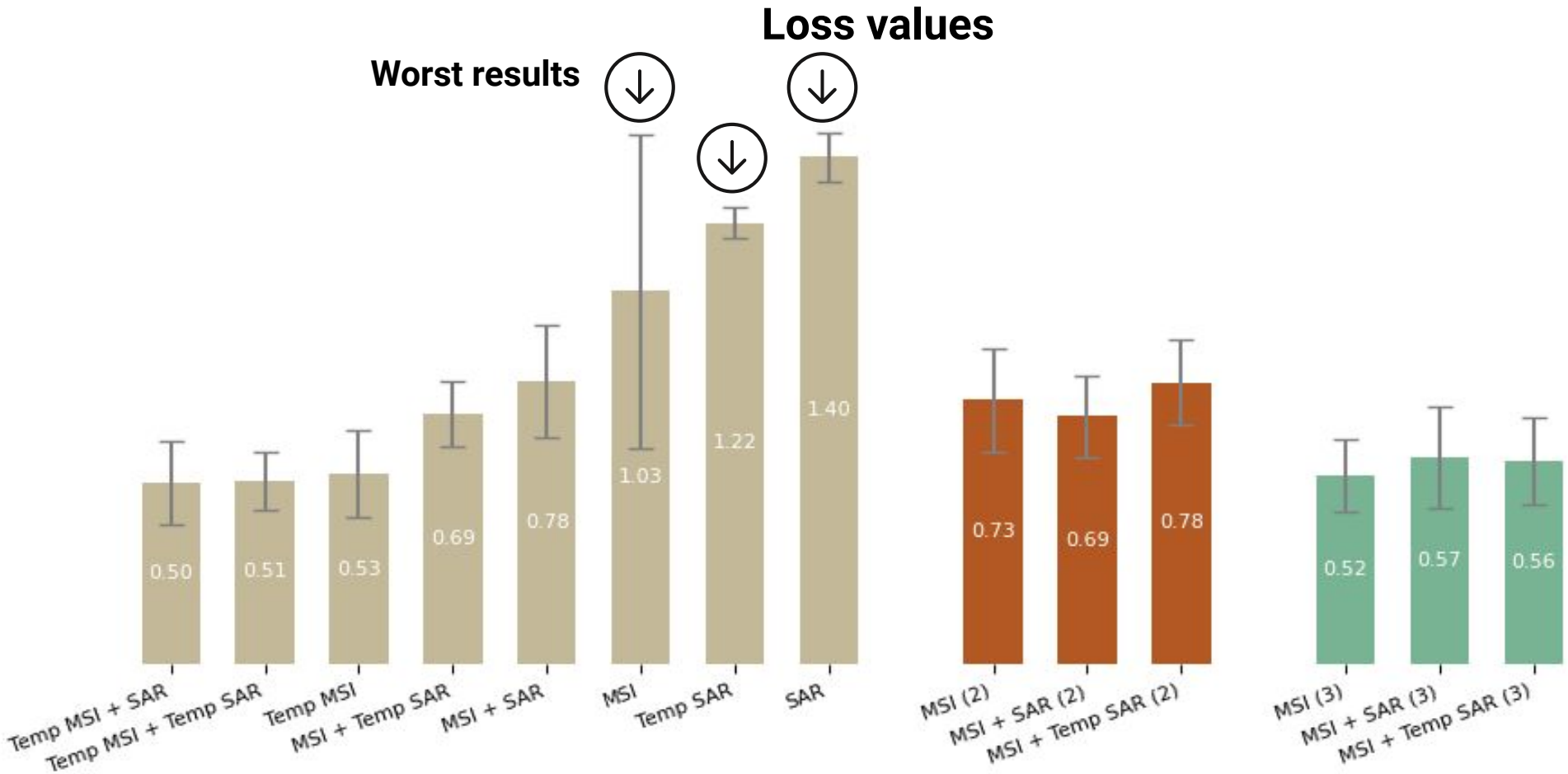
RESULTS - SUMMARY



Set 1

Forest + Cocoa

Set 2

Forest/Non-cocoa crop + Cocoa

Set 3

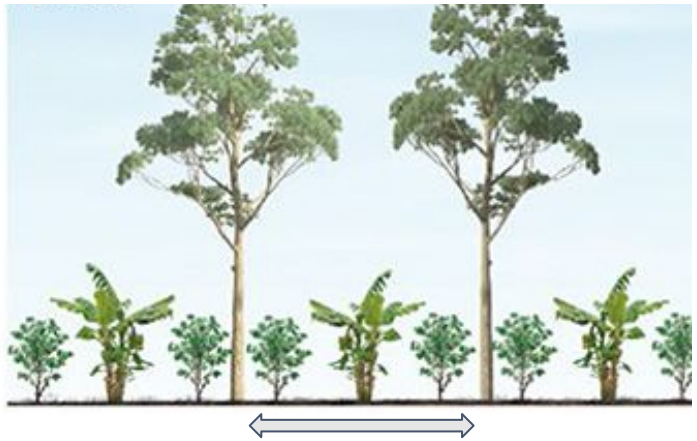
Forest + Cocoa (Cloudless)

LIMITATIONS

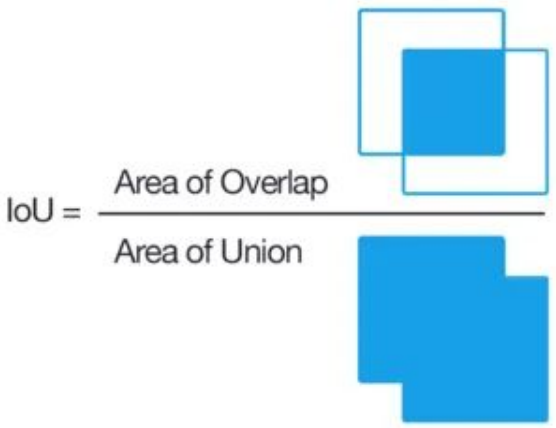
MISSING / UNCERTAIN GROUND TRUTH

Context and detail ommitted for confidentiality reasons.

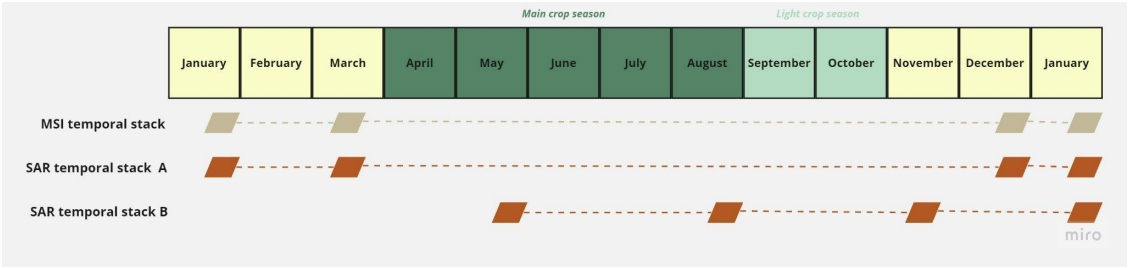
LOW SPATIAL RESOLUTION



METRICS



LOW TEMPORAL RESOLUTION



CONCLUSION

1 How does the combination of MSI and SAR data affect the results of cocoa parcel segmentation trained with data from a *single day*?

+ Single-day SAR

++ Multi-day SAR

2 How does the combination of MSI and SAR data affect the results of cocoa parcel segmentation trained with *temporal* datasets?

Not statistically significant

Possible improvement for non-vegetation land cover

CONCLUSION

3 Why does the use of different *polarizations* (i.e. Vertical-Vertical (VV) or Vertical-Horizontal (VH)) affect the influence of SAR datasets on the cocoa segmentation results?

+ Complementary data (relevant season and polarization)

- Noisy data or similar backscatter

4 What is the impact of SAR and MSI training data on the detection of *intercrop* cocoa?

Cannot draw quantitative conclusions

Possible increased sensitivity to vegetation types

CONCLUSION

To what extent can a Convolutional Neural Network (CNN) trained with multispectral imagery (MSI) **and** Synthetic Aperture Radar (SAR) datasets enable the automated detection of cocoa crops in Ghana?

- **SAR data can be combined with MSI in order to train a U-NET for cocoa detection.**

- **The influence of SAR data is highly sensitive to seasonality, polarization and ground truth label classes.**

- **Satellite datasets must be chosen carefully based on the application and available ground truth data.**

FUTURE WORK

EXTEND CURRENT MODEL

- Tuning U-NET hyperparameters
- Additional background land cover labels
- Higher temporal resolution satellite datasets
- Addition of height data
- Spectral / backscatter analysis

FEATURE EXTRACTION

- Vegetation indices (e.g. NDVI)
- Texture metrics (e.g. GLCM)
- Cross Ratio (VH/VV)

MODEL MODIFICATIONS

- Loss function (e.g. Lovasz, Dice)
- Architecture (e.g. Xception)

HIGHER PRECISION

- Longer SAR wavelengths (e.g. L, P-band)
- Higher resolution MSI
- Hyperspectral imagery

Thank you!

TU Delft MERIDIA